

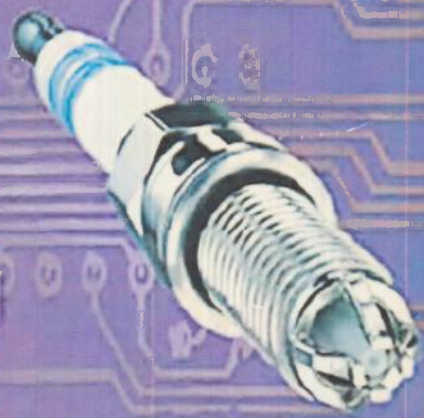


THIRD EDITION

AUTOMOBILE ELECTRICAL AND ELECTRONIC SYSTEMS

2

TOM DENTON



9.6.7 Electronic unit injection (EUI) – diesel fuel

The advantages of electronic unit injection are as follows.

Lower emissions

Through the use of higher injection pressures (up to 2000 bar), lower emissions of particulates and NO_x are achieved, together with a reduction in the levels of noise traditionally associated with diesel engines.

Electronic fuel quantity and timing control

Precise electronic control also assists in the reduction of emissions.

Shot to shot fuel adjustment

This feature also provides a very quick transient response, improving vehicle drivability.

Control of all engine functions

Through a series of sensors connected to the electronic control unit (ECU), the EUI system ensures that all the engine functions consistently operate at optimum performance.

Electronically controlled pilot injection

A new feature developed to meet tighter NO_x emissions standards, without loss of fuel consumption. Pilot injection also reduces combustion noise.

Communication with other systems

Linked to the ECU, the EUI system can communicate with other vehicle systems such as ABS, transmission and steering, making further systems development possible.

Cylinder cut-out

This is used as a diagnostic aid and offers potential for fuel economy at idling and low loads.

Reliability and durability

The EUI's reliability is proven under field conditions. Experience in the truck market indicates a service life of at least 800 000 km.

Full diagnostics capability

Fault codes can be stored and diagnostic equipment connected.

Further development potential

EUI technology is currently only at the beginning of its life cycle; it has significant further development potential which will enable the system to meet future tough emissions legislation.

In the EUI system, the fuel injection pump, the injector and a solenoid valve are combined in one, single unit; these unit injectors are located in the cylinder-head, above the combustion chamber. The EUI is driven by a rocker arm, which is in turn driven by the engine camshaft. This is the most efficient hydraulic and mechanical layout, giving the lowest parasitic losses. The fuel feed and spill pass through passages integrated in the cylinder-head.

The EUI uses sensors and an electronic control unit (ECU) to achieve precise injection timing and fuel quantities. Sensors located on the engine pass information to the ECU on all the relevant engine functions. This evaluates the information and compares it with optimum values stored in the ECU to decide on the exact injection timing and fuel quantity required to realize optimum performance. Signals are then sent to the unit injector's solenoid-actuated spill valve system to deliver fuel at the timing required to achieve this performance.

Injection is actuated by switching the integrated solenoid valve. The closing point of the valve marks the beginning of fuel delivery, and the duration of closing determines the fuel quantity. The operating principle is as follows.

Each plunger moves through a fixed stroke, actuated by the engine camshaft. On the upward (filling) stroke, fuel passes from the cylinder-head through a series of integrated passages and the open spill valve into a chamber below the plunger. The ECU then sends a signal to the solenoid stator, which results in the closure of the spill control valve. The plunger continues its downward stroke causing pressure to build in the high pressure passages. At a pre-set pressure the nozzle opens and fuel injection begins. When the solenoid stator is de-energized the spill control valve opens, causing the pressure to collapse, which allows the nozzle to close, resulting in a very rapid termination of injection.

Lucas electronic unit injectors (Figure 9.59) have been developed in a range of sizes to suit all engines, and can be fitted to light- and heavy-duty engines suitable for small cars and the largest premium trucks.

9.6.8 Lucas diesel common rail system (LDCR)

To meet the future stringent emissions requirements, and offering further improvements in fuel



Figure 9.59 Unit injector (Source: Bosch Press)

economy, the common rail fuel injection system is becoming popular.

Fuel injection equipment with the capability of operating at very high pressures is required to achieve the ultra low emissions and low noise demands of the future. The advantages of a system developed by Lucas are summarized below.

Compact design

The compact design of the injector outline enables the LDCR system to be used on 2 or 4 valves per cylinder engines.

Modular system

With one electronically driven injector per engine cylinder, the system is modular and can be used on 3, 4, 5 and 6 cylinder engines.

Low drive torque

As the pumping of the pressure rail is not phased with the injection, the common rail system requires a low drive torque from the engine.

Independent injection pressure

The injection pressure is independent of the engine speed and load, so enabling high injection pressures at low speed if required.

Lower NOx emissions

Injection sequences that include periods both pre and post the main injection can be utilized to reduce emissions, particularly NOx, enabling the system to meet the stringent emissions levels required by EURO-III and US-98 legislation and beyond.

Noise reduction and NOx control

The inclusion of pilot injection results in a significant reduction in engine noise.

Full electronic control

The common rail offers all the benefits of full electronic control for vehicles, including extremely accurate fuel metering and timing, as well as the option to interface with other vehicle functions.

The common rail can be easily adapted for different engines. The main components are as follows.

- Common pressure accumulator (the 'Rail')
- High pressure regulator.
- High pressure supply pump.
- Injectors.
- Electronic solenoids.
- Electronic Control Unit.
- Filter unit.

Figure 9.60 shows the layout of a common rail injection system. The system consists of a common pressure accumulator, called the 'rail', which is mounted along the engine block, and fed by a high pressure pump. The pressure level of the rail is electronically regulated by a combination of metering on the supply pump and fuel discharge by a high-pressure regulator. The pressure accumulator operates independently of engine speed or load, so that high injection pressure can be produced at low speeds if required. A series of injectors is connected to the rail, and each injector is opened and closed by a solenoid, driven by the Electronic Control Unit.

A feed pump delivers the fuel through a filter unit to the high-pressure pump. The high-pressure pump delivers fuel to the high pressure rail. The injectors inject fuel into the combustion chamber when the solenoid valve is actuated.

Because the injection pressure is independent of engine speed and load, the actual start of injection, the injection pressure, and the duration of injection can be freely chosen from a wide range. The introduction of pilot injection, which is adjusted depending on engine needs, results in significant engine noise reduction, together with a reduction in NOx emissions. The actuator controls the pressure in the system.

The Lucas system has been designed for use on future HSDI engines for passenger cars, which

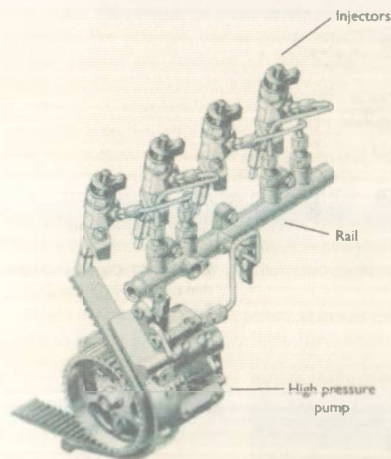


Figure 9.60 Diesel common rail injection

will be required to meet the EURO-III and US-98 emissions legislation and beyond.

9.6.9 Bosch diesel systems

The following information is adapted from a speech by Dr Ulrich Dohle, President of the Diesel Systems Division, Robert Bosch GmbH. It illustrates not only some of the interesting technology associated with diesel injection, but also how the developments are often led by legislation. Diesel cars are common in Europe and are likely to become more so in the USA in the near future.

Diesel-powered cars are more popular than ever before in Western Europe. Since the beginning of the 1990s, the proportion of newly registered diesel-powered cars has almost tripled – from less than 15% in 1991 to more than 40% today. In Austria, France and Belgium, for example, around two out of every three newly registered cars have diesel engines.

Bosch has had a decisive influence on the European diesel boom. Modern high-pressure injection systems have turned the heavy and dirty slowcoaches of former times into the sporty, fuel-efficient and clean cars of today. Since the beginning of the 1990s, Bosch's innovations have played a leading role in reducing the particulate emissions of diesel cars by 80%, and other emissions (carbon monoxide, nitrogen oxide and hydrocarbons) by at least 90%.

Observation of the Euro 4 norms will mean that particulate emissions are reduced by as much as

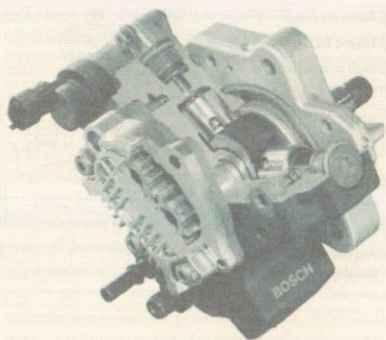


Figure 9.61 Cutaway view of a common rail high pressure pump (Source: Bosch Press)

90%, and the emission of carbon monoxide, nitrogen oxide and hydrocarbons by at least 95%. Diesel engines are also powerful; turbocharged automotive diesel engines are already capable of maximum specific torque levels of 170 Nm, and specific power ratings of more than 60 kW/litre of cylinder capacity. At the same time, the fuel consumption of diesel engines is very low. Diesel is the yardstick against which all other propulsion systems are measured in this respect.

Bosch is working hard to optimize the injection system in order to further reduce both fuel consumption and exhaust emissions, and improve engine performance. For example, Bosch has developed the third generation of the Common Rail (CR) system, which went into series production in May 2003. At the heart of the new injection system is the rapid-switch, compact inline injector with piezoelectric technology. In 2005 the company plans to introduce an improved variable injector nozzle, which will make engines even quieter and cleaner. Bosch is also working on solutions for exhaust emission treatment systems, which in future will be obligatory for some cars and commercial vehicles.

Third generation common rail with piezoelectric inline injectors

In Bosch's conventional Common Rail system a magnetic coil controls the injector. A piston rod transmits the hydraulic force required to open or close the injector to the nozzle needle. In May 2003 series production began of Bosch's third generation Common Rail, in which the injector actuators consist of piezo crystals. Piezo crystals have the property of expanding in an electrical field.

- ① Air mass meter
- ② Engine ECU
- ③ High pressure pump
- ④ Common rail
- ⑤ Injectors
- ⑥ Engine speed sensor
- ⑦ Coolant temp. sensor
- ⑧ Filter
- ⑨ Accelerator pedal sensor

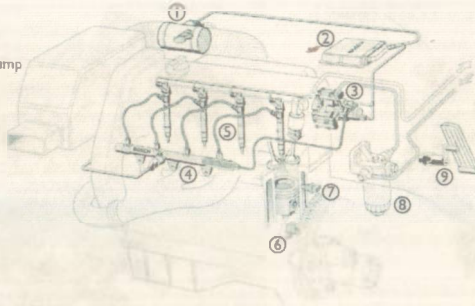


Figure 9.62 Common rail injection system components (Source: Bosch Press)

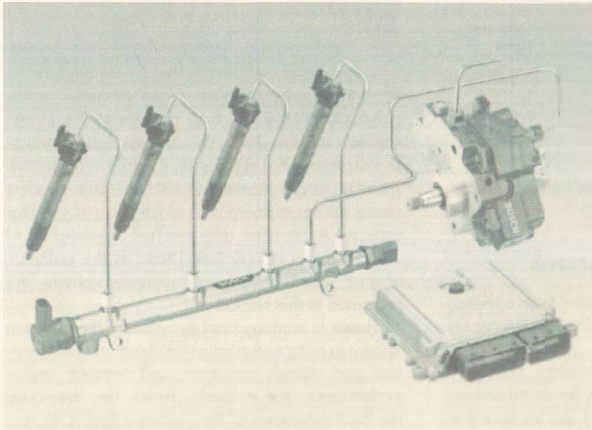


Figure 9.63 CR diesel rail, injectors, pump and ECU (Source: Bosch Press)

The piezoelectric actuator is a package of several hundred very small, thin crystals. The piezo actuator switches in less than ten thousandths of a second – less than half the time required by a magnetic switch. To exploit this property Bosch has integrated the actuator into the injector body. In the inline injector the movement of the piezo package is transferred to the rapid-switch nozzle needle without friction, as there are no mechanical components. The advantages over magnetic and existing conventional piezo injectors lie in a more precise dosing and an improved atomization of the injected fuel mixture within the combustion chamber.

The higher switching speed of the injector means that the intervals between the individual fuel injections can be reduced, giving a more flexible control of the injection process. The result is that diesel engines become even quieter, more fuel efficient, cleaner and more powerful. With the in-line

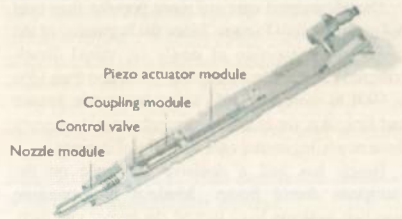


Figure 9.64 Piezo injector (Source: Bosch Press)

injector, the return flow of fuel not required for injection is very small. This allowed engineers to further reduce the delivery rate, and thus the energy requirement, of the high-pressure pump.

The low tolerances for the injection quantity and timing mean that the fuel dosage at the injector is

very exact. This results in lower levels of exhaust pollutants. For example, one or two pre-injections of fuel prevent the emission of white and blue smoke just after a cold start, and combustion noise is reduced. A supplementary injection following immediately on the main injection lowers the emission of soot particulates and a further injection can regenerate particulate filters, if fitted.

The Bosch third generation Common Rail system, with piezoelectric inline injectors, can reduce internal engine emissions by up to 20% compared with existing magnetic or piezoelectric systems currently in use.

Bosch has plans for another technical innovation in the Common Rail system in 2006. Ideas involving even higher injection pressures of over 2000 bar, and injectors with variable injection geometry are currently being explored.

Improvements to the Unit-Injector System

Bosch's Unit-Injector System (UIS) has the highest current injection pressure of any system at 2050 bar. At the moment this system is exclusively manufactured for passenger cars produced by VW. The very high injection pressures result, among other things, in low particulate emissions. This meant that some vehicles fitted with UIS were the first to meet the Euro 4 emission criteria. Bosch is presently working on a further development of the UIS. A Coaxial Variable Nozzle will make the engines both quieter and cleaner, and further increase available engine performance.

The variable nozzle differs from the conventional UIS injector in the number, arrangement, diameter

and shape of the injection apertures. A magnetic valve controls two coaxial nozzle needles and opens up two rows of jet apertures. The first row of apertures with a low rate of flow delivers small quantities of fuel at the start of the combustion process, producing a 'soft' combustion and a low level of combustion noise. In addition, under partial load conditions it improves the mixture quality, leading to significantly reduced emission levels.

Tests show particulate and nitrogen oxide reductions of between 25–40%. When the second row of jet apertures (with a higher flow rate) is opened, engine performance is enhanced without having to increase the injection pressure. Under ideal conditions, pre-injection can be dispensed with across a broad engine speed and load range, leading to lower particulate emissions.

Exhaust emission treatment

In Bosch's approach to the further lowering of diesel engine emissions, the focus is primarily on internal engine improvements; improved fuel combustion prevents, as far as possible, the formation of pollutants and also reduces fuel consumption. In this respect automobile manufacturers and their component suppliers have already achieved a great deal. A number of vehicles with a maximum permissible overall weight of between 1600–1800 kg, and in some cases more than this, will come within the Euro 4 thresholds even without any exhaust treatment system.

However, heavy passenger cars will not meet the Euro 4 standards without treatment systems. Bosch's EDC (Electronic Diesel Control) handles the management of particulate filters and nitrogen

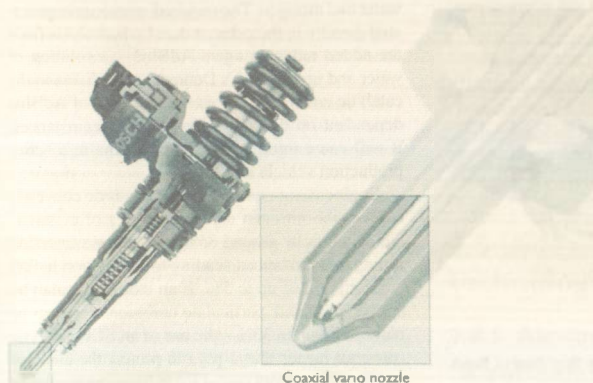


Figure 9.65 Variable nozzle unit injector (Source: Bosch Press)

oxide storage catalytic converters. It matches injection flexibly to the requirements of the exhaust emission treatment systems, for example by altering injection timing, quantity and process. EDC also matches the amount of combustion air fed to the engine to the respective demand. This is done by controlling the exhaust gas recirculation and determining the setting of the throttle valve and the operating pressure of the exhaust gas turbocharger. Sensors convey information to the EDC about the exhaust gas temperature, backpressure and composition. Engine management can, therefore, not only determine the condition of the particulate filter and the nitrogen oxide storage catalytic converter, but also improve the quality of combustion.

Diesel particulate filters

If the injection system and the particulate filter are working optimally together, exhaust emission values can be further improved. Bosch, therefore, is likely to begin mass production of diesel particulate filters from late 2005. A final decision on this project is pending. The particulate filter from Bosch is made of sintered metal and lasts considerably longer than current ceramic models, since its special structure offers a high storage capacity for oil and additive combustion residues. The filter is designed in such a way that the filtered particulates are very evenly deposited, allowing the condition of the filter to be identified more reliably and its regeneration controlled far better than with other solutions. The Bosch diesel particulate filter is designed to last as long as the vehicle itself.

Once the storage capacity of the particulate filter has been exhausted, the filter has to be regenerated by passing hot exhaust gases through it, which burn up the deposited particulates. In order to produce the necessary high exhaust gas temperatures,

the EDC alters the amount of air fed to the engine, as well as the amount of fuel injected and the timing of the injection. In addition, some unburnt fuel can be fed to the oxidizing catalytic converter by arranging for extra fuel to be injected during the expansion stroke. The fuel combusts in the oxidizing catalytic converter and raises the exhaust temperature even further. Engineers are currently developing a system for injecting fuel directly into the exhaust duct, supplementing the injection into the combustion chamber just referred to.

People often express the hope that particulate filters could be fitted retrospectively to diesel-powered vehicles. Such retro-fitting would require an enormous technical input, since not only would the engine have to be adjusted to the modified exhaust system, but the control unit and the control unit software would also have to be extensively modified.

Exhaust gas treatment for commercial vehicles

Commercial vehicles are only able to meet the current Euro 3 thresholds by using greatly improved injection systems, up-to-date combustion processes and intercooling. To meet the more stringent Euro 4 parameters, two options are possible:

- Exhaust gas recycling, if necessary in combination with the use of a particulate filter.
- Selective Catalytic Reduction (SCR). SCR, perhaps in combination with a particulate filter, will be the favoured solution for Euro 5 (to be introduced in 2008).

Bosch has developed the Denoxtronic dosage system for delivering the reducing agents for the SCR system. In the SCR process, the nitrogen oxide in the exhaust gases reacts with ammonia to produce water and nitrogen. The required ammonia is generated directly in the exhaust duct by hydrolysis from the added reducing agent AdBlue – a solution of water and urea. Bosch's Denoxtronic delivers to the catalytic converter the required amount of AdBlue dependent on the actual operating circumstances. It will come into use for the first time in a series production vehicle in 2004.

Engine design using an SCR catalytic converter reduces the nitrogen oxide emissions of commercial vehicles by around 85%. This allows injection timing to be advanced, leading to a reduction in fuel consumption of up to 5%. If an oxidizing catalytic converter is used, particulate emissions can also be reduced by up to 30% – the use of an SCR catalytic converter means that it pays to protect the environment, since the extra cost of the exhaust gas treatment

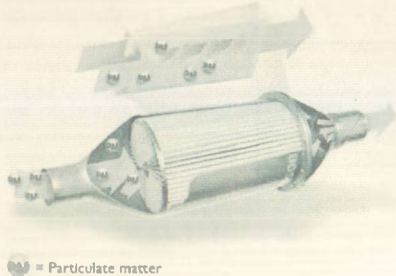


Figure 9.66 Diesel exhaust particulate filter (Source: Bosch Press)

system is soon outweighed by the savings in fuel consumption.¹

9.7 Diagnosing fuel control system faults

9.7.1 Introduction

As with all systems, the six stages of fault-finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 9.5 lists some common symptoms of a fuel system malfunction together with suggestions for the possible fault. Note that when diagnosing engine fuel system faults, the same symptoms may indicate an ignition problem.

9.7.2 Testing procedure

Caution/Achtung/Attention – Burning fuel can seriously damage your health!

The following procedure is generic and, with a little adaptation, can be applied to any fuel injection system. Refer to manufacturer's recommendations if in any doubt. It is assumed the ignition system is operating correctly. Most tests are carried out while cranking the engine.

1. Check battery state of charge (at least 70%).
2. Hand and eye checks (all fuel and electrical connections secure and clean).
3. Check fuel pressure supplied to rail (in multi-point systems it will be about 2.5 bar but check specifications).
4. If the pressure is *not* correct jump to stage 10.
5. Is injector operation OK? – continue if not (suitable spray pattern or dwell reading across injector supply).
6. Check supply circuits from main relay (battery volts minimum).
7. Continuity of injector wiring (0–0.2 Ω and note that many injectors are connected in parallel).

Table 9.5 Common symptoms of a fuel system malfunction and possible faults

Symptom	Possible fault
Engine rotates but does not start	<ul style="list-style-type: none"> ● No fuel in the tank! ● Air filter dirty or blocked. ● Fuel pump not running. ● No fuel being injected.
Difficult to start when cold	<ul style="list-style-type: none"> ● Air filter dirty or blocked. ● Fuel system wiring fault. ● Enrichment device not working (choke or injection circuit).
Difficult to start when hot	<ul style="list-style-type: none"> ● Air filter dirty or blocked. ● Fuel system wiring fault.
Engine starts but then stops immediately	<ul style="list-style-type: none"> ● Fuel system contamination. ● Fuel pump or circuit fault (relay). ● Intake system air leak.
Erratic idle	<ul style="list-style-type: none"> ● Air filter blocked. ● Inlet system air leak. ● Incorrect CO setting. ● Fuel injectors not spraying correctly.
Misfire through all speeds	<ul style="list-style-type: none"> ● Fuel filter blocked. ● Fuel pump delivery low. ● Fuel tank ventilation system blocked.
Engine stalls	<ul style="list-style-type: none"> ● Idle speed incorrect. ● CO setting incorrect. ● Fuel filter blocked. ● Air filter blocked. ● Intake air leak. ● Idle control system not working.
Lack of power	<ul style="list-style-type: none"> ● Fuel filter blocked. ● Air filter blocked. ● Low fuel pump delivery. ● Fuel injectors blocked.
Backfires	<ul style="list-style-type: none"> ● Fuel system fault (air flow sensor on some cars).

8. Sensor readings and continuity of wiring (0–0.2 Ω for the wiring sensors will vary with type).
9. If no fuel is being injected and all tests so far are OK, suspect ECU.
10. Fuel supply – from stage 4.
11. Supply voltage to pump (within 0.5 V battery – pump fault if supply is OK).
12. Check pump relay and circuit (note in most cases the ECU closes the relay but this may be bypassed on cranking).
13. Ensure all connections (electrical and fuel) are remade correctly.

9.8 Advanced fuel control technology

9.8.1 Air–fuel ratio calculations

The ideal ratio by mass of air to fuel for complete combustion is 14.7:1. This is given the lambda

¹ Dr Ulrich Dohle, President, Diesel Systems Division, Robert Bosch GmbH, June 2003, New Generations of Injection Systems: Piezoelectrics and more make diesel even cleaner and more fuel efficient. Speech at the 56th International Automotive Press Briefing, Boxberg

value 1, which is known as stoichiometry. This figure can be calculated by working out the exact number of oxygen atoms, that are required to oxidize completely the particular number of hydrogen and carbon atoms in the hydrocarbon fuel, then multiplying by the atomic mass of the respective elements.

Petrol consists of a number of ingredients, these are known as fractions and fall into three chemical series.

- Paraffins e.g. octane C_8H_{18}
- Napthenes e.g. cyclohexane C_6H_{12}
- Aromatics e.g. benzene C_6H_6

The ideal air-fuel ratio for each of these can be calculated from the balanced chemical equation and the atomic mass of each atom. The atomic masses of interest are:

- Carbon (C) = 12
- Hydrogen (H) = 1
- Oxygen (O) = 16

The balanced chemical equation for complete combustion of octane is as follows:



The molecular mass of $2C_8H_{18}$ is:

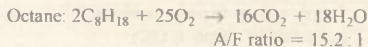
$$(2 \times 12 \times 8) + (2 \times 1 \times 18) = 228$$

The molecular mass of $25 O_2$ is:

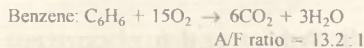
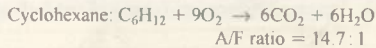
$$(25 \times 16 \times 2) = 800$$

Therefore the oxygen to octane ratio is 800 : 228 or 3.5 : 1, in other words 1 kg of fuel uses 3.5 kg of oxygen. Air contains 23% of oxygen by mass (21% by volume), which means 1 kg of air contains 0.23 kg of oxygen. Further, there is 1 kg of oxygen in 4.35 kg of air.

The ideal air-fuel (A/F) ratio for complete combustion of octane is $3.5 \times 4.35 = 15.2 : 1$.



If a similar calculation is carried out for cyclohexane and benzene, the results are as follows.



The above examples serve to explain how the air-fuel ratio is calculated and how petrol/gasoline, being a mixture of a number of fractions, has an ideal air-fuel ratio of 14.7 : 1.

This figure is, however, only the theoretical ideal and takes no account of pollutants produced

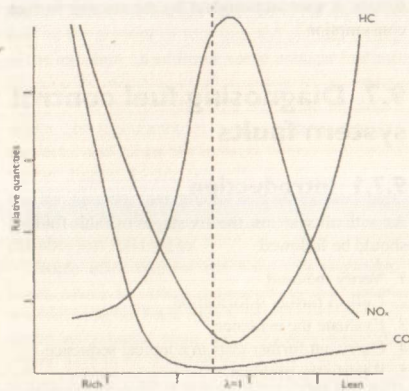


Figure 9.67 Influence of air-fuel ratio on the three main pollutants created from a spark ignition engine (no catalyst in use)

and the effect the air-fuel ratio has on engine performance. With modern engine fuel control systems it is possible to set the air-fuel ratio exactly at this stoichiometric ratio if desired. As usual though, a compromise must be sought as to the ideal setting. Figure 9.9 shows a graph comparing engine power output and fuel consumption, with changes in air-fuel ratio.

Figure 9.67 shows the influence of air-fuel ratio on the three main pollutants created from a spark ignition, internal combustion engine. A ratio slightly weaker than the lambda value of 1 (or about 15.5 : 1 ratio) is often an appropriate compromise.

9.9 New developments

9.9.1 Bosch lambda diesel

Lambda sensing is now also applicable to diesel engines. This new technology makes cars cleaner and more economical. Bosch is now also applying the lambda sensor in the closed loop control concept for diesel engines. The new system allows for a previously unreached fine tuning of injection and engine. This reduces fuel consumption and pollutant emission from diesel engines.

Different from the previous concept, the lambda-based control now optimizes the exhaust gas quality via exhaust gas recirculation, charge-air pressure and start of injection. These parameters decisively influence the emissions from diesel engines. A broad-band lambda sensor, with a wide working range, measures the oxygen content in the exhaust

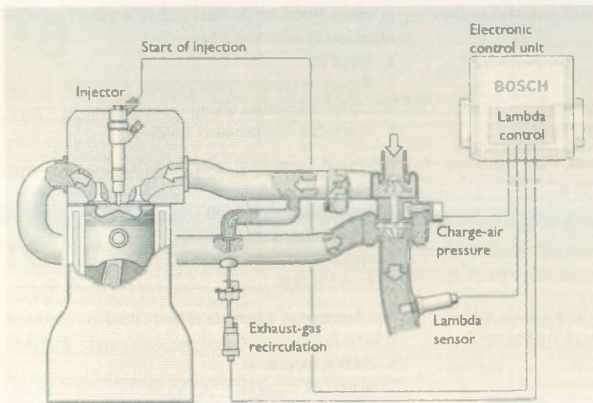


Figure 9.68 Lambda sensing on a diesel system (Source: Bosch Press)

gas and renders important information on the combustion processes in the engine, which can be utilized for the engine management.

Compared to the standard diesel engine management, the new Bosch system permits a stricter adherence to low emission values. Engines are better protected against defects. For example, the harmful combustion in cars running in overrun may be detected and corrected. In engines running under full load, the system offers more effective smoke suppression.

The lambda sensor will also monitor the NO_x accumulator catalytic converters (of future emission purification systems). The sensor supplies data for the management of the catalytic converter, which has to be cleaned at regular intervals in order to preserve its storage capability.

9.10 Self-assessment

9.10.1 Questions

1. Explain what is meant by a lambda (λ) value of 1.
2. State five advantages of fuel injection.
3. With reference to the combustion process, describe the effects of ignition timing.
4. With reference to the combustion process, describe the effects of mixture strength.
5. Draw a block diagram of a fuel injection system. Describe briefly the purpose of each component.
6. Explain the combustion process in a diesel engine.

7. Describe how electronic control of diesel fuel injection is achieved and state the advantages of EUI.
8. List all the main components of an electronic carburation control system and state the purpose of each component.
9. Make a clearly labelled sketch to show the operation of a fuel injector.
10. State six sources of emissions from a vehicle and describe briefly how manufacturers are tackling each of them.

9.10.2 Assignment

Draw an 8×8 look-up table (grid) for a digital fuel control system. The horizontal axis should represent engine speed from zero to 5000 rev/min, and the vertical axis engine load from zero to 100%. Fill in all the boxes with realistic figures and explain why you have chosen these figures. You should explain the trends and not each individual figure.

Download the 'Automotive Technology – Electronics' simulation program from my web site and see if your figures agree with those in the program. Discuss reasons why they may differ.

9.10.3 Multiple choice questions

The ratio, by mass, of air to fuel that ensures complete and clean combustion is:

1. 14.7 : 1
2. 10 : 1
3. 1 : 10
4. 1 : 14.7

Exhaust gas products that are NOT harmful to the environment are:

1. carbon dioxide and water
2. water and carbon monoxide
3. carbon monoxide and hydrocarbons
4. hydrocarbons and oxides of nitrogen

On an engine fitted with Electronic Fuel Injection, engine load may be determined by a:

1. MAP sensor
2. throttle position sensor
3. lambda sensor
4. vacuum capsule

The type of petrol injection system which makes use of a single injector that sprays fuel towards a throttle is termed a:

1. single point system
2. rotary system
3. multi-point system
4. in-line system

An injector pulse width, in milliseconds, is commonly:

1. 1.5-10
2. 1.0-30
3. 1.5-40
4. 2.0-30

Technician A says the speed of flame spread in a diesel engine is affected by the air charge temperature. Technician B says the speed of flame spread in a diesel engine is affected by atomization of the fuel. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

A valve fitted to the fuel rail in a petrol/gasoline injection system is used to:

1. bleed air
2. depressurize the system or test pressure
3. replace fuel after changing the filter
4. connect a compression tester

Increased nitrogen oxides are formed when combustion:

1. temperatures are high
2. temperatures are low
3. speed is slow
4. speed is fast

The function of a lambda sensor fitted in an exhaust system is to monitor:

1. carbon monoxide
2. oxides of nitrogen
3. carbon dioxide
4. oxygen

Technician A says reduction in CO, NOx and HC has been achieved by reducing lead in fuel. Technician B says reduction in CO, NOx and HC has been achieved by using engine management systems. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

10

Engine management

10.1 Combined ignition and fuel management

10.1.1 Introduction

As the requirements for lower and lower emissions continue, together with the need for better performance, other areas of engine control are constantly being investigated. This control is becoming even more important as the possibility of carbon dioxide emissions being included in future regulations increases. Some of the current and potential areas for further control of engine operation are included in this section. Although some of the common areas of 'control' have been covered in the previous two chapters, this chapter will cover some aspects in more detail and introduce further areas of engine control. Some of the main issues are:

- Ignition timing.
- Dwell angle.
- Fuel quantity.
- EGR (exhaust gas recirculation).
- Canister purge.
- Idle speed.

An engine management system can be represented by the standard three-stage model as shown in Figure 10.1. This representation shows closed loop feedback, which is a common feature, particularly related to:

- lambda control,
- knock,
- idle speed.

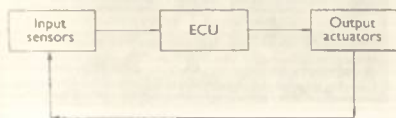


Figure 10.1 Representation of complete engine control as the standard functional system

The block diagram shown as Figure 10.2 can further represent an engine management system. This series of 'inputs' and 'outputs' is a good way of representing a complex system. This section continues with a look at some of the less common 'inputs and outputs'.

10.1.2 Variable inlet tract

For an engine to operate at its best, volumetric efficiency is not possible with fixed manifolds. This is because the length of the inlet tract determines the velocity of the intake air and, in particular, the propagation of the pressure waves set up by the pumping action of the cylinders. These standing waves can be used to improve the ram effect of the charge as it enters the cylinder but only if they coincide with the opening of the inlet valves. The length of the inlet tract has an effect on the frequency of these waves. One method of changing the length of the inlet tract is shown in Figure 10.3. The control valves move, which changes the effective length of the inlet.

Figure 10.4 shows how the design of the inlet manifold is a significant feature of the Volvo S80 engine.

10.1.3 Variable valve timing

With the widespread use of twin cam engines, one cam for the inlet valves and one for the exhaust

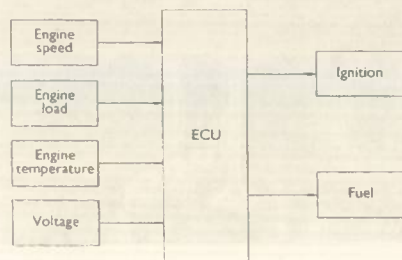


Figure 10.2 General block diagram of an ignition and fuel control system

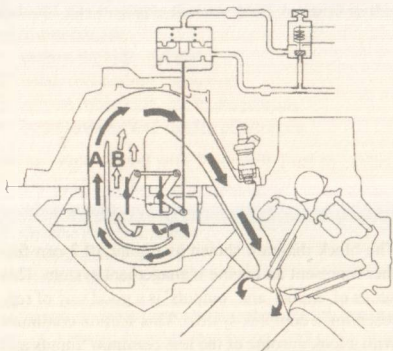


Figure 10.3 Variable length inlet manifold. A = long tract; B = short tract

valves, it is possible to vary the valve overlap while the engine is running. Honda has a system that noticeably improves the power and torque range by only opening both of the inlet valves at higher speed. This system is shown as Figure 10.5.

A system of valves using oil pressure to turn the cam with respect to its drive gear controls the cam positions on the BMW system shown in Figure 10.6. The position of the cams is determined from a suitable map held in ROM in the control unit.

A system that not only allows changes in valve timing but also valve open periods is also starting to be used. The system is known as active valve train (AVT) and was intended to be a development tool for the design of fixed camshafts. However, production versions are being developed. The opening of the inlet and exhaust valves will be by hydraulic

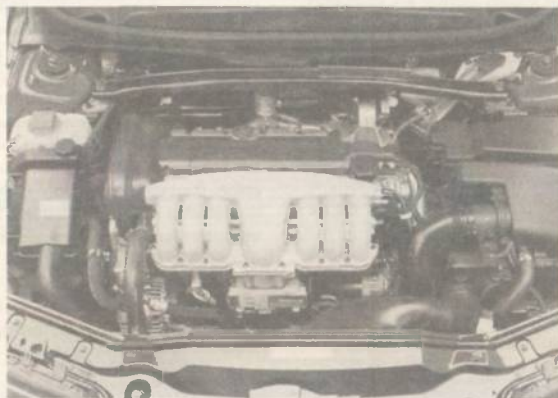


Figure 10.4 Volvo engine showing the feature of the inlet manifold design

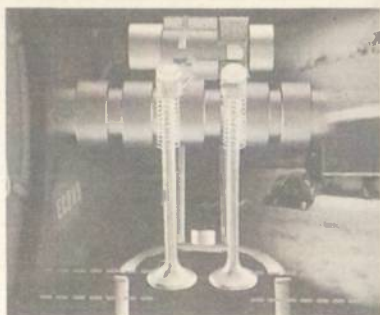
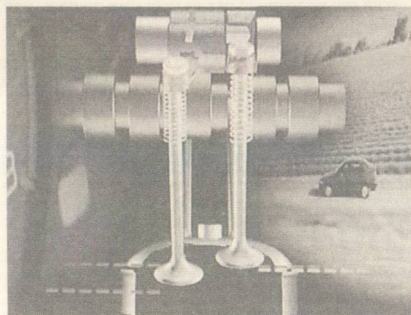


Figure 10.5 Honda's valve control system. At low revs the VTEC-E engine opens only one inlet valve per cylinder fully, so just 12 valves control the mixture and combustion of air and fuel. This delivers maximum efficiency with the lowest possible emissions. At higher engine speeds, hydraulic pins activate the extra valves to give 16 valve performance

actuators working at up to 200 bar with a high-speed servo valve controlling flow to the actuators.

10.1.4 Combustion flame and pressure sensing

Research is ongoing in the development of cost effective sensors for determining combustion pressure and combustion flame quality. These sensors are used during development but currently are prohibitively expensive for use in production. When available, these sensors will provide instantaneous closed loop feedback about the combustion process. This will be particularly important with lean burning engines.

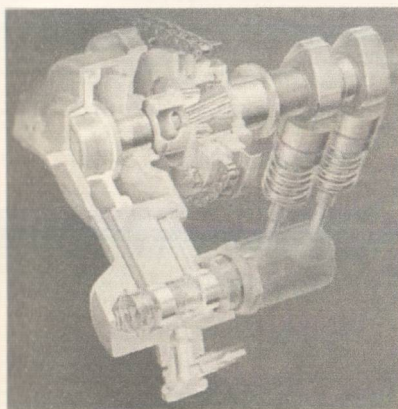


Figure 10.6 Variable valve timing from BMW

10.1.5 Wide range lambda sensors

Most lambda sensors provide excellent closed-control of the air-fuel ratio at or very near to stoichiometry (14.7:1). A sensor is now available that is able to provide a linear output between air-fuel ratios of 12:1 and about 24:1. This allows closed loop feedback over a much wider range of operating conditions.

10.1.6 Injectors with air shrouding

If high-speed air is introduced at the tip of an injector, the dispersal of the fuel is considerably improved. Droplet size can be reduced to below 50 μm during idle conditions. Figure 10.7 shows an injector with air shrouding.

Figure 10.8 shows the effect of this air shrouding as two photographs, one with the feature and

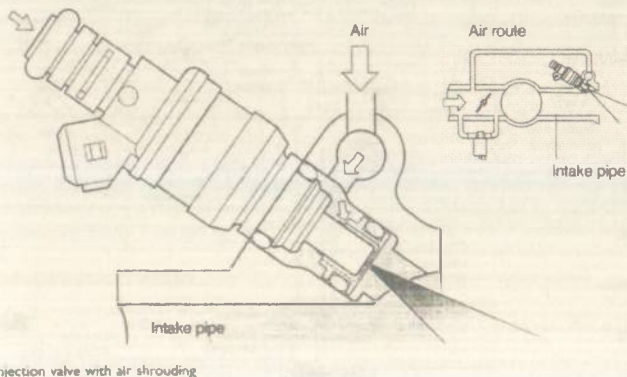


Figure 10.7 Injection valve with air shrouding

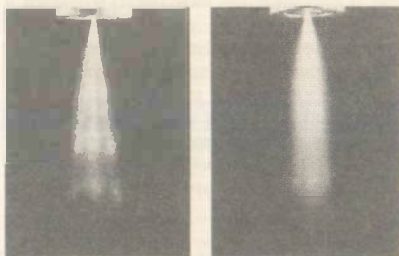


Figure 10.8 Better fuel preparation through injection with air shrouding. Left: injection valve without air shrouding. Right: injection valve with air shrouding

one without. The improved dispersal and droplet size is clear.

10.1.7 On-board diagnostics (OBD)

Figure 10.9 shows the Bosch Motronic M5 with the OBD 2 system. On-board diagnostics are becoming essential for the longer term operation of a system in order for it to produce a clean exhaust. Many countries now require a very comprehensive diagnosis of all components which affect the exhaust. Any fault detected will be indicated to the driver by a warning light. The OBD 2 system is intended to standardize the many varying methods used by different manufacturers. It is also thought that an extension to total vehicle diagnostics through a common interface is possible in the near future.

Digital electronics allow both sensors and actuators to be monitored. Allocating values to all operating states of the sensors and actuators achieves this. If a deviation from these figures is detected, it is stored in memory and can be output in the workshop to assist with fault-finding.

Monitoring of the ignition system is very important as misfiring not only produces more emissions of hydrocarbons, but the unburned fuel can enter the catalytic converter and burn there. This can cause higher than normal temperatures and may damage the catalytic converter.

An accurate crankshaft speed sensor is used to monitor ignition and combustion in the cylinders. Misfiring alters the torque of the crankshaft for an instant, which causes irregular rotation. This can be monitored, thus allowing a misfire to be recognized instantly.

A number of further sensors are required for the functions of the OBD 2 system. Another lambda sensor, placed after the catalytic converter, monitors the operation of the OBD 2. An intake pressure sensor and a valve are needed to control the activated charcoal filter to reduce and monitor evaporative emissions from the fuel tank. A differential pressure sensor also monitors the fuel tank permeability. As well as the driver's fault lamp a considerable increase in the electronics is required in the control unit in order to operate an OBD system. A better integral-monitoring system will have a superior effect in reducing vehicle emissions than tighter MOT regulations.

The diagnostic socket used by systems conforming to OBD 2 standards should have the following pin configuration.

1. Manufacturer's discretion.
2. Bus + Line, SAE J1850.
3. Manufacturer's discretion.
4. Chassis ground.
5. Signal ground.
6. Manufacturer's discretion.
7. K Line, ISO 9141.

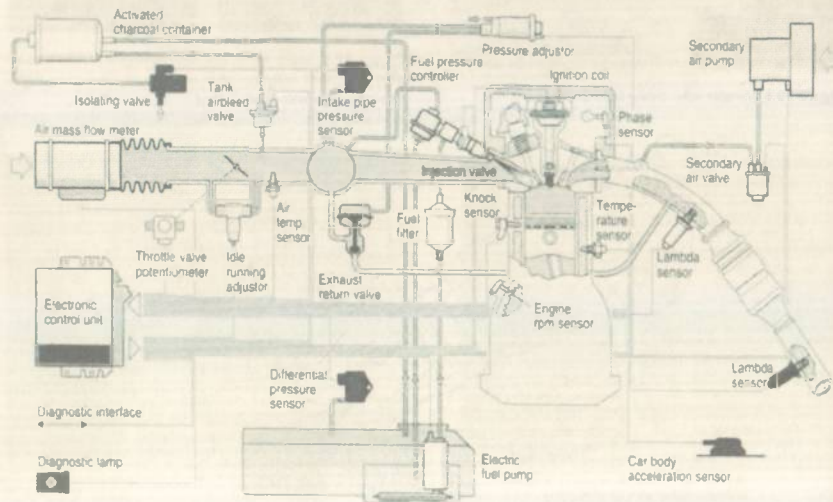


Figure 10.9 Motronic M5 with OBD 2

8. Manufacturer's discretion.
9. Manufacturer's discretion.
10. Bus - Line, SAE J1850.
11. Manufacturer's discretion.
12. Manufacturer's discretion.
13. Manufacturer's discretion.
14. Manufacturer's discretion.
15. 1. line, ISO 9141
16. Vehicle battery positive.

It is hoped that with future standards and goals set it will be beneficial for vehicle manufacturers to begin implementation of at least the common connector in the near term. Many diagnostic system manufacturers would welcome this move.

If the current lack of standardization continues, it will become counter-productive for all concerned.

10.2 Exhaust emission control

10.2.1 Engine design

Many design details of an engine have a marked effect on the production of pollutant emissions. With this in mind, it will be clear that the final design of an engine is a compromise between conflicting interests. The major areas of interest are as discussed in the following sections.

10.2.2 Combustion chamber design

The main source of hydrocarbon emissions is unburnt fuel that is in contact with the combustion chamber walls. For this reason the surface area of the walls should be kept as small as possible and with the least complicated shape. A theoretical ideal is a sphere but this is far from practical. Good swirl of the cylinder charge is important, as this facilitates better and more rapid burning. Perhaps more important is to ensure a good swirl in the area of the spark plug. This ensures a mixture quality that is easier to ignite. The spark plug is best positioned in the centre of the combustion chamber as this reduces the likelihood of combustion knock by reducing the distance the flame front has to travel.

10.2.3 Compression ratio

The higher the compression ratio, the higher, in general, the thermal efficiency of the engine and therefore the better the performance and fuel consumption. The two main drawbacks to higher compression ratios are the increased emissions and the

increased tendency to knock. The problem with emissions is due to the high temperature, which in turn causes greater production of NO_x. The increase in temperature makes the fuel and air mixture more likely to self-ignite, causing a higher risk of combustion knock. Countries which have had stringent emission regulations for some time, such as the USA and Japan, have tended to develop lower compression engines. However, with the changes in combustion chamber design and the more widespread introduction of four valves per cylinder, together with greater electronic control and other methods of dealing with emissions, compression ratios have increased over the years.

10.2.4 Valve timing

The effect of valve timing on exhaust emissions can be quite considerable. One of the main factors is the amount of valve overlap. This is the time during which the inlet valve has opened but the exhaust valve has not yet closed. The duration of this phase determines the amount of exhaust gas left in the cylinder when the exhaust valve finally closes. This has a significant effect on the reaction temperature (the more exhaust gas the lower the temperature), and hence has an effect on the emissions of NO_x. The main conflict is that, at higher speeds, a longer inlet open period increases the power developed. The down-side is that this causes a greater valve overlap and, at idle, this can greatly increase emissions of hydrocarbons. This has led to the successful introduction of electronically controlled valve timing.

10.2.5 Manifold designs

Gas flow within the inlet and exhaust manifolds is a very complex subject. The main cause of this complexity is the transient changes in flow that are due not only to changes in engine speed but also to the pumping action of the cylinders. This pumping action causes pressure fluctuations in the manifolds. If the manifolds and both induction and exhaust systems are designed to reflect the pressure wave back at just the right time, great improvements in volumetric efficiency can be attained. Many vehicles are now fitted with adjustable length induction tracts. Longer tracts are used at lower engine speeds and shorter tracts at higher speed.

10.2.6 Charge stratification

If the charge mixture can be inducted into the cylinder in such a way that a richer mixture is in the proximity of the spark plug, then overall the cylinder

charge can be much weaker. This can bring great advantages in fuel consumption, but the production of NO_x can still be a problem. The later section on direct mixture injection development is a good example of the use of this technique. Many lean-burn engines use a form of stratification to reduce the chances of misfire and rough running.

10.2.7 Warm up time

A significant quantity of emissions produced by an average vehicle is created during the warm-up phase. Suitable materials and care in the design of the cooling system can reduce this problem. Some engine management systems even run the ignition timing slightly retarded during the warm-up phase to heat the engine more quickly.

10.2.8 Exhaust gas recirculation

This technique is used primarily to reduce peak combustion temperatures and hence the production of nitrogen oxides (NO_x). Exhaust gas recirculation (EGR) can be either internal as mentioned above, due to valve overlap, or external via a simple arrangement of pipes and a valve (Figure 10.10). A proportion of exhaust gas is simply returned to the inlet side of the engine.

This EGR is controlled electronically as determined by a ROM in the ECU. This ensures that drivability is not affected and also that the rate of EGR is controlled. If the rate is too high, then the production of hydrocarbons increases. Figure 10.11 shows the effect of various rates of EGR.

One drawback of EGR systems is that they can become restricted by exhaust residue over a period of time, thus changing the actual percentage of recirculation. However, valves are now available that reduce this particular problem.

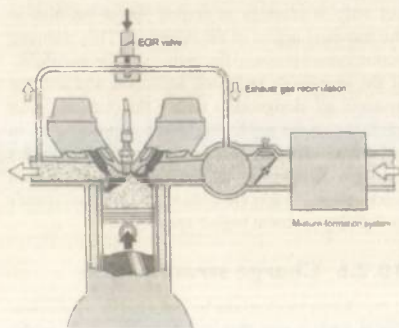


Figure 10.10 Exhaust-gas recirculation system

10.2.9 Ignition system

The ignition system can affect exhaust emissions in two ways; first, by the quality of the spark produced, and secondly, the timing of the spark. The quality of a spark will determine its ability to ignite the mixture. The duration of the spark in particular is significant when igniting weaker mixtures. The stronger the spark the less the likelihood of a misfire, which can cause massive increases in the production of hydrocarbons.

The timing of a spark is clearly critical but, as ever, is a compromise with power, drivability, consumption and emissions. Figure 10.12 is a graph showing the influence of ignition timing on emissions and fuel consumption. The production of carbon monoxide is dependent almost only on fuel

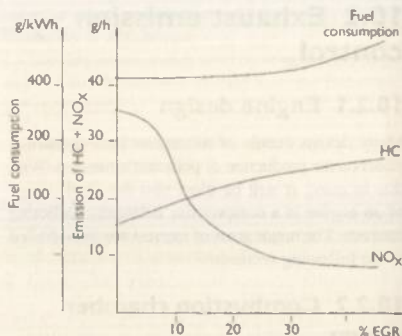


Figure 10.11 Effect of various rates of EGR

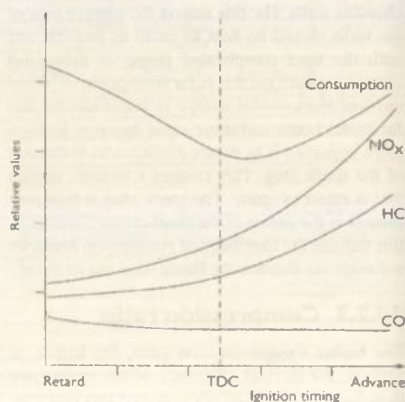


Figure 10.12 Influence of ignition timing on emissions and fuel consumption

mixture and is not significantly affected by changes in ignition timing. Electronic and programmed ignition systems have made significant improvements to the emission levels of today's engines.

10.2.10 Thermal after-burning

Prior to the more widespread use of catalytic converters, thermal after-burning was used to reduce the production of hydrocarbons. In fact, hydrocarbons do continue to burn in the exhaust manifold and recent research has shown that the type of manifold used, such as cast iron or pressed steel, can have a noticeable effect on the reduction of HC. At temperatures of about 600 °C, HC and CO are burnt or oxidized into H₂O and CO₂. If air is injected into the exhaust manifold just after the valves, then the after-burning process can be encouraged.

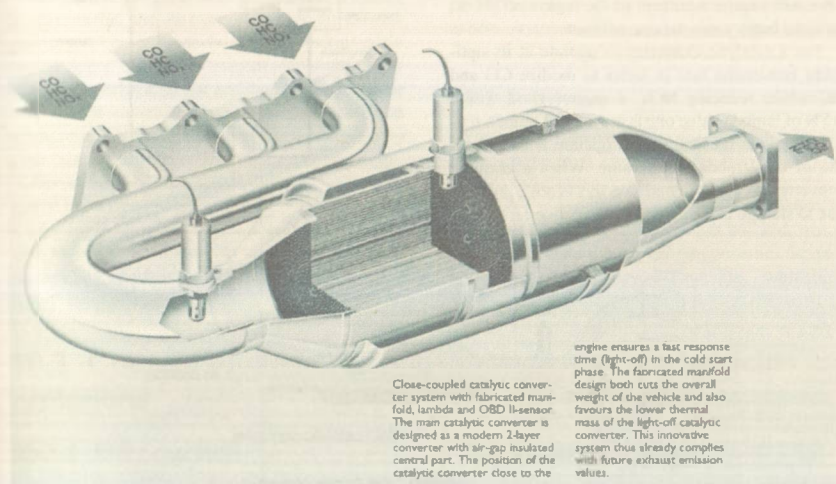
10.2.11 Catalytic converters

Stringent regulations in most parts of the world have made the use of a catalytic converter almost indispensable. The three-way catalyst (TWC) is used to great effect by most manufacturers. It is a very simple device and looks similar to a standard exhaust box. Note that, in order to operate correctly, however, the engine must be run at – or very near to – stoichiometry. This is to ensure that the right 'ingredients' are available for the catalyst to perform its function.

Figure 10.13 shows a view of the inside of a catalytic converter. There are many types of hydrocarbons but the following example illustrates the main reaction. Note that the reactions rely on some CO being produced by the engine in order to reduce the NO_x. This is one of the reasons that manufacturers have been forced to run engines at stoichiometry. This legislation has tended to stifle the development of lean-burn techniques. The fine details of the emission regulations can in fact, have a very marked effect on the type of reduction techniques used. The main reactions in the 'cat' are as follows:

- $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$
- $2\text{C}_2\text{H}_6 + 2\text{CO} \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}$
- $2\text{NO} + 2\text{CO} \rightarrow \text{N}_2 + 2\text{CO}_2$

The ceramic monolith type of base, when used as the catalyst material, is a magnesium aluminium silicate and, due to the several thousand very small channels, provides a large surface area. This area is coated with a wash coat of aluminium oxide, which further increases its effective surface area by a factor of about seven thousand. Noble metals are used for the catalysts. Platinum promotes the oxidation of HC and CO, and rhodium helps the reduction of NO_x. The converter shown is the latest metal substrate type with a built-in manifold. The whole three-way catalytic converter only contains about 3–4 g of the precious metals.



Close-coupled catalytic converter system with fabricated manifold, lambda and OBD II-sensor. The main catalytic converter is designed as a modern 2-layer converter with air-gap insulated central part. The position of the catalytic converter close to the

engine ensures a fast response time (light-off) in the cold start phase. The fabricated manifold design both cuts the overall weight of the vehicle and also favours the lower thermal mass of the light-off catalytic converter. This innovative system thus already complies with future exhaust emission values.

Figure 10.13 Catalytic converter

The ideal operating temperature range is from about 400 to 800 °C. A serious problem to counter is the delay in the catalyst reaching this temperature. This is known as the 'catalyst light-off time'. Various methods have been used to reduce this time as significant emissions are produced before 'light-off' occurs. Electrical heating is one solution, as is a form of burner, which involves lighting fuel inside the converter. Another possibility is positioning the converter as part of the exhaust manifold and down pipe assembly. This greatly reduces light-off time but gas flow problems, vibration and excessive temperature variations can be problems that reduce the potential life of the unit.

Catalytic converters can be damaged in two ways. The first is by the use of leaded fuel, which causes lead compounds to be deposited on the active surfaces, thus reducing the effective area, and, secondly, by engine misfire, which can cause the catalytic converter to overheat due to burning inside the unit. BMW, for example, uses a system on some vehicles where a sensor monitors the output of the ignition HT system and, if the spark is not present, will not allow fuel to be injected.

A further possible technique to reduce emissions during the warm-up time of the catalyst is to use a small electrically heated pre-converter as shown in Figure 10.14. Initial tests of this system show that the emissions of hydrocarbons during the warm-up phase can be reduced significantly. The problem yet to be solved is that about 30 kW of heat is required during the first 30 s to warm up the pre-converter. This will require a current in the region of 250 A; an extra battery may be one solution.

For a catalytic converter to operate at its optimum conversion rate in order to oxidize CO and HC whilst reducing NO_x, a narrow band within 0.5% of lambda value one is essential. Lambda sensors in use at present tend to operate within about 3% of the lambda mean value. When a catalytic converter is in prime condition this is not a problem due to storage capacity within the converter for CO

and O₂. Damaged converters, however, cannot store a sufficient quantity of these gases and hence become less efficient. The damage, as suggested earlier in this section, can be due to overheating or 'poisoning' due to lead or even silicon. If the control can be kept within 0.5% of lambda the converter will continue to be effective even if damaged to some extent. Sensors are becoming available that can work to this tolerance. A second sensor fitted after the converter can be used to ensure ideal operation.

10.2.12 Closed loop lambda control

Current regulations have almost made mandatory closed loop control of the air-fuel mixture in conjunction with a three-way catalytic converter. It was under discussion that a lambda value of 1 should become compulsory for all operating conditions, but this was not agreed.

Lambda control is a closed loop feedback system in that the signal from a lambda sensor in the exhaust can directly affect the fuel quantity injected. The lambda sensor is described in more detail in Chapter 2. Figure 10.15 shows a block diagram of the lambda control system.

A graph to show the effect of lambda control and a three-way catalyst (TWC) is shown in Figure 10.16.

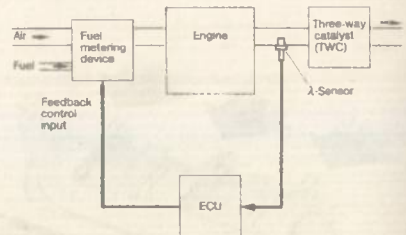


Figure 10.15 Fuel metering with closed loop control

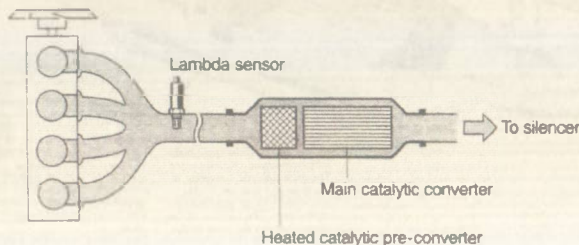


Figure 10.14 Electrically heated catalytic pre-converter

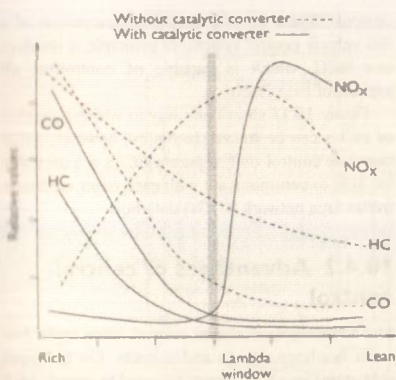


Figure 10.16 The effect of lambda control and a three-way catalyst (TWC)

The principle of operation is as follows: the lambda sensor produces a voltage that is proportional to the oxygen content of the exhaust, which is in turn proportional to the air-fuel ratio. At the ideal setting, this voltage is about 450 mV. If the voltage received by the ECU is below this value (weak mixture) the quantity of fuel injected is increased slightly. If the signal voltage is above the threshold (rich mixture) the fuel quantity is reduced. This alteration in the air-fuel ratio must not be too sudden as it could cause the engine to back. To prevent this, the ECU contains an integrator, which changes the mixture over a period of time.

A delay also exists between the mixture formation in the manifold and the measurement of the exhaust gas oxygen. This is due to the engine's working cycle and the speed of the inlet mixture, the time for the exhaust to reach the sensor and the sensor's response time. This is sometimes known as 'dead time' and can be as much as one second at idle speed but only a few hundred milliseconds at higher engine speeds.

Due to the dead time the mixture cannot be controlled to an exact value of $\lambda = 1$. If the integrator is adjusted to allow for engine speed then it is possible to keep the mixture in the lambda window (0.97–1.03), which is the region in which the TWC is at its most efficient.

10.3 Control of diesel emissions

10.3.1 Introduction

Exhaust emissions from diesel engines have been reduced considerably by changes in the design of

combustion chambers and injection techniques. More accurate control of start of injection and spill timing has allowed further improvements to be made. Electronic control has also made a significant contribution. A number of further techniques can be employed to control emissions.

10.3.2 Exhaust gas recirculation

In much the same way as with petrol engines, exhaust gas recirculation (EGR) is employed primarily to reduce NO_x emissions by reducing the reaction temperature in the combustion chamber. However, if the percentage of EGR is too high, increased hydrocarbons and soot are produced.

10.3.3 Intake air temperature

This is appropriate to turbocharged engines such that if the air is passed through an intercooler and there are improvements in volumetric efficiency, lower temperature will again reduce the production of NO_x. The intercooler is fitted in the same area as the cooling system radiator.

10.3.4 Catalytic converter

On a diesel engine, a catalyst can be used to reduce the emission of hydrocarbons but will have less effect on nitrogen oxides. This is because diesel engines are always run with excess air to ensure better and more efficient burning of the fuel. A normal catalyst therefore will not strip the oxygen off the NO_x to oxidize the hydrocarbons because the excess oxygen will be used instead. Special NO_x converters are becoming available.

10.3.5 Filters

To reduce the emission of particulate matter (soot), filters can be used. These can vary from a fine grid design made from a ceramic material, to centrifugal filters and water trap techniques. The problem to overcome is that the filters can get blocked, which adversely affects the overall performance. Several techniques are employed, including centrifugal filters.

10.4 Complete vehicle control systems

10.4.1 Introduction

The possibility of a complete vehicle control system has been around since the first use of digital

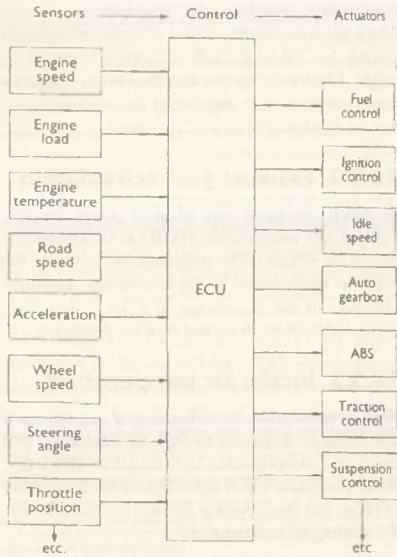


Figure 10.17 Representation of a full vehicle control system

control. Figure 10.17 shows a representation of a full vehicle control system. In principle, it involves one ECU, which is capable of controlling all aspects of the vehicle.

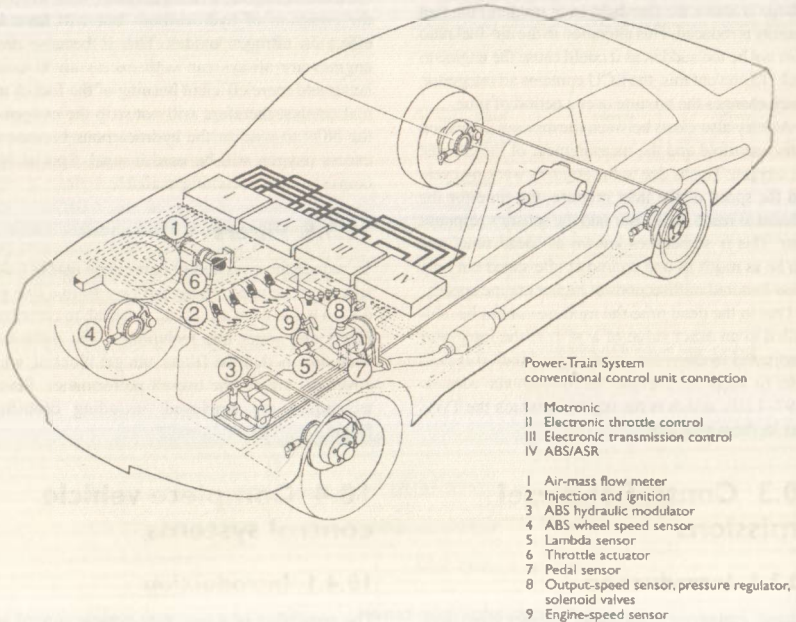
Figure 10.18 shows one way in which a number of ECUs can be linked. In reality, however, rather than one control unit, separate ECUs are used that are able to communicate with each other via a controller area network (CAN) data bus.

10.4.2 Advantages of central control

The advantages of central control come under two main headings, inputs and outputs. On the input side, consider all the inputs required to operate each of the following:

- Ignition system.
- Fuel system.
- Transmission system.

It will be apparent that there are many common requirements even with just three possible areas of vehicle control. Having one central control system can potentially decrease the complexity of the



Power-Train System
conventional control unit connection

- I Motronic
 - II Electronic throttle control
 - III Electronic transmission control
 - IV ABS/ASR
- 1 Air-mass flow meter
 - 2 Injection and ignition
 - 3 ABS hydraulic modulator
 - 4 ABS wheel speed sensor
 - 5 Lambda sensor
 - 6 Throttle actuator
 - 7 Pedal sensor
 - 8 Output-speed sensor, pressure regulator, solenoid valves
 - 9 Engine-speed sensor

Figure 10.18 Linking ECUs

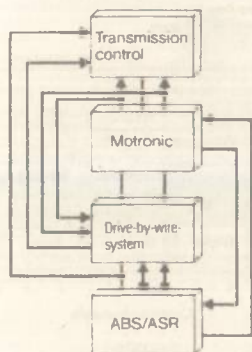
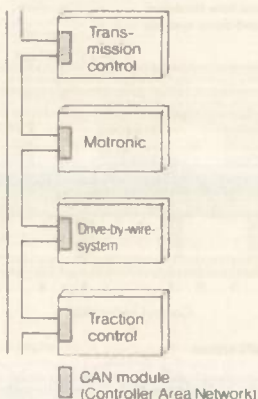
Via cable harness**Via data bus**

Figure 10.19 System link

wiring whilst increasing the possibilities for control. This is, in fact, the advantage of the 'outputs'. Consider the common operating condition for a vehicle of a sudden and hard acceleration and the possible responses from each of the systems listed.

System	Possible action
Ignition	Retard the timing
Fuel	Inject extra fuel
Transmission	Change down a gear

If each system is operating in its own right, it is possible that each, to some extent, will not react in the best way with respect to the others. For example, the timing and fuel quantity may be set but then the transmission ECU decides to change down a gear thus increasing engine speed. This, in turn, will require a change in fuel and timing. During the transition stage, a decrease in efficiency and an increase in emissions are likely.

With a single control unit, or at least communication between them, the ideal actions could all take place at the most appropriate time. The complexity of the programming, however, requires much increased computing power. This is particularly important if other vehicle systems are considered, such as traction control, ABS, active suspension and steering. These systems are discussed individually in other sections of this book.

10.4.3 Bosch Cartronic system

The complexity of combining systems as suggested above is increasing. Bosch has a system involving a hierarchy of vehicle electronics. Improvements in performance, emissions, driver safety and comfort require increased interconnection of various electronic systems. In the previous section, a simple example highlighted the need for separate electronic systems to communicate with each other. Bosch uses a hierarchical signal structure to solve this problem. Figure 10.19 shows two ways in which the systems can be linked. The first using conventional wiring and the second using a Controller Area Network (CAN).

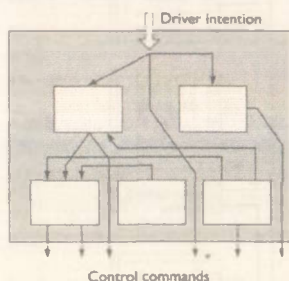
Figure 10.20 shows the difference between the data flow in a stand-alone system and the data flow in a hierarchical system. The Cartronic system works on the principle that each system can only be controlled by a system placed above it in the hierarchy. As an example, the integrated transmission control systems of engine control and gearbox control do not communicate directly but via the hierarchically superior transmission control system.

10.4.4 Summary

Research is continuing into complete control systems for vehicles. As more and more systems are integrated then the cost of the electronics necessary will reduce. The computing power required for these types of developments is increasing, and 32- (or even 64-) bit high-speed microcontrollers

Distribution and interconnection of functions

Data flow between stand-alone systems



Data flow in hierarchical system

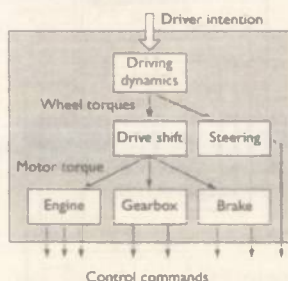


Figure 10.20 Cartronic system

will soon become the norm. The down-side of using a single ECU to control the entire vehicle is the replacement cost of the unit. At present prices, even a single system ECU can cost a significant amount. Overall though, the cost of vehicle manufacture may be less.

Full central control has other possible advantages such as allowing the expansion of onboard diagnostics (OBD) to cover the whole vehicle, potentially saving repair time and running costs.

10.5 Case study – Mitsubishi GDI

10.5.1 Introduction

I am grateful to Mitsubishi for the information in this section.

For many years, innovative engine technology has been a development priority of Mitsubishi Motors. In particular, Mitsubishi has sought to improve engine efficiency in an endeavour to meet growing environmental demands – such as those for energy conservation and the reduction of CO₂ emissions in order to limit the negative impact of the greenhouse effect.

In Mitsubishi's endeavour to design and build ever more efficient engines, it has devoted significant resources to developing a gasoline direct injection engine. For years, automotive engineers have believed this type of engine has the greatest potential to optimize fuel supply and combustion, which in turn can deliver better performance and lower fuel consumption. Until now, however, no one has successfully designed an in-cylinder direct injection

engine for use on production vehicles. A result of Mitsubishi's engine development capabilities, Mitsubishi's advanced Gasoline Direct Injection 'GDI' engine is the realization of an engineering dream.

For the fuel supply, conventional engines use a fuel injection system which replaced the carburation system. MPI or Multi-Point Injection, where the fuel is injected to each intake port, is currently one of the most widely used systems. However, even in MPI engines there are limits to the fuel supply response and the combustion control because the fuel mixes with air before entering the cylinder. Mitsubishi set out to push these limits by developing an engine where gasoline is directly injected into the cylinder as in a diesel engine, and, moreover, where injection timings are precisely controlled to match load conditions. The GDI engine achieved the following outstanding characteristics.

- Extremely precise control of fuel supply to achieve fuel efficiency that exceeds that of diesel engines by enabling combustion of an ultra-lean mixture supply.
- A very efficient intake and a relatively high compression ratio unique to the GDI engine deliver both high performance and a response that surpass those of conventional MPI engines.

Figure 10.21 shows the progress towards higher output and efficiency. For Mitsubishi, the technology realized for this GDI engine will form the cornerstone of the next generation of high efficiency engines and, in its view, the technology will continue to develop in this direction.

Figure 10.22 shows the transition of the fuel supply system.

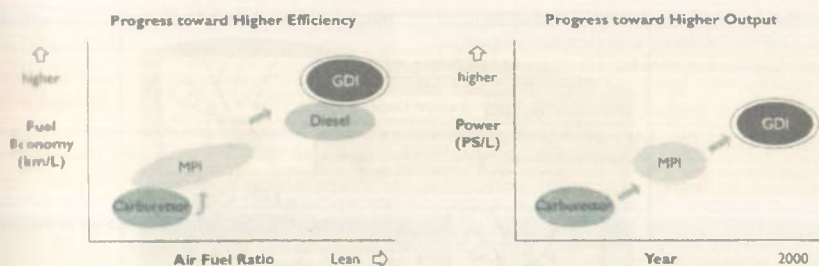


Figure 10.21 Progress towards higher output and efficiency

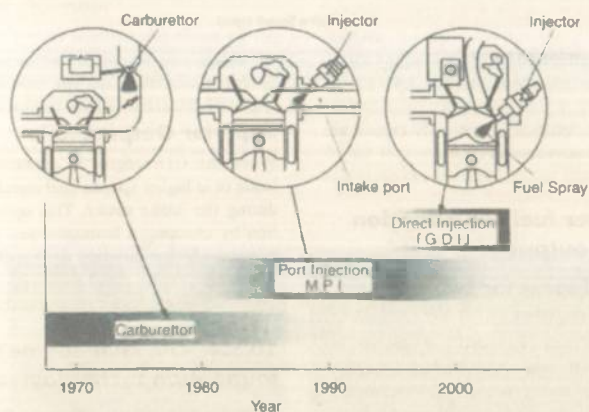


Figure 10.22 Transition of fuel supply system

Figure 10.23 is the Mitsubishi Gasoline Direct Injection (GDI) engine.

10.5.2 Major objectives of the GDI engine

- Ultra-low fuel consumption that is even better than that of diesel engines.
- Superior power to conventional MPI engines.

Technical features

- Upright straight intake ports for optimal air flow control in the cylinder.
- Curved-top pistons for better combustion.
- High-pressure fuel pump to feed pressurized fuel into the injectors.
- High-pressure swirl injectors for optimum air-fuel mixture.

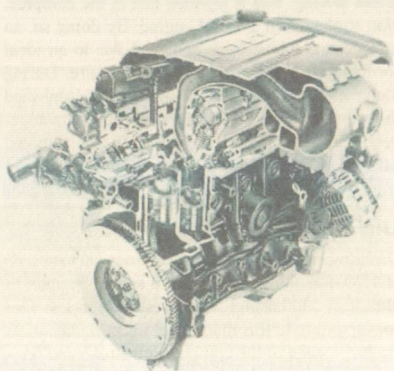


Figure 10.23 Mitsubishi gasoline direct injection 'GDI' engine

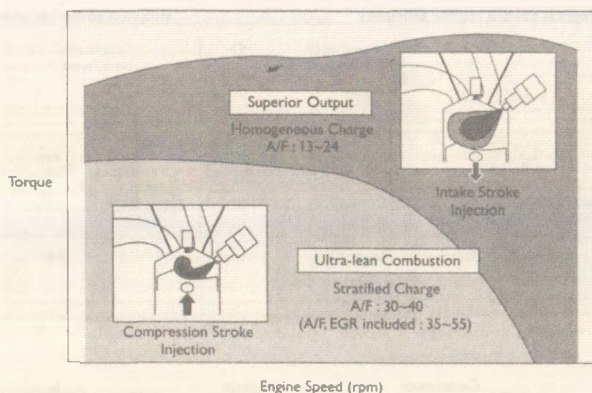


Figure 10.24 Two combustion modes

The major characteristics of the GDI engine are considered in the next few sections.

10.5.3 Lower fuel consumption and higher output

Optimal fuel spray for two combustion modes

Using methods and technologies unique to Mitsubishi, the GDI engine provides both lower fuel consumption and higher output. This seemingly contradictory and difficult feat is achieved with the use of two combustion modes. Put another way, injection timings change to match engine load.

For the load conditions required in average urban driving, fuel is injected late in the compression stroke, as in a diesel engine. By doing so, an ultra-lean combustion is achieved due to an ideal formation of a stratified air-fuel mixture. During high performance driving conditions, fuel is injected during the intake stroke. This enables a homogeneous air-fuel mixture, like that in conventional MPI engines, to deliver a higher output.

Ultra-lean combustion mode

Under most normal driving conditions, up to speeds of 120 km/h, the Mitsubishi GDI engine operates in ultra-lean combustion mode, resulting in less fuel consumption. In this mode, fuel injection occurs at the latter stage of the compression stroke and ignition occurs at an ultra-lean air-fuel ratio of 30:40 (35:55, including EGR).

Superior Output Mode

When the GDI engine is operating with higher loads or at higher speeds, fuel injection takes place during the intake stroke. This optimizes combustion by ensuring a homogeneous, cooler air-fuel mixture which minimizes the possibility of engine knocking.

These two modes are represented in Figure 10.24.

10.5.4 The GDI engine's foundation technologies

There are four technical features that make up the foundation technology. The 'upright straight intake port' supplies optimal air flow into the cylinder. The 'curved top piston' controls combustion by helping to shape the air-fuel mixture. The 'high-pressure fuel pump' supplies the high-pressure needed for direct in-cylinder injection. In addition, the 'high-pressure swirl injector' controls the vaporization and dispersion of the fuel spray.

These fundamental technologies, combined with other unique fuel control technologies, enabled Mitsubishi to achieve both development objectives - fuel consumption lower than that of diesel engines and output higher than that of conventional MPI engines. The methods are shown below.

In-cylinder air flow

The GDI engine has upright straight intake ports rather than the horizontal intake ports used in conventional engines. The upright straight intake ports efficiently direct the air flow down at the curved-top piston, which redirects the air flow into a strong

reverse tumble for optimal fuel injection, as shown in Figure 10.25.

Fuel spray

Newly developed high-pressure swirl injectors provide the ideal spray pattern to match each engine's operational modes. This is shown as Figure 10.26. At the same time, by applying highly swirling motion to the entire fuel spray, the injectors enable sufficient fuel atomization that is mandatory for the GDI even with a relatively low fuel pressure of 50 kg/cm.

Optimized configuration of the combustion chamber

The curved-top piston controls the shape of the air-fuel mixture as well as the air flow inside the combustion chamber and has an important role in maintaining a compact air-fuel mixture. The mixture, which is injected late in the compression stroke, is carried towards the spark plug before it can disperse.

Mitsubishi's advanced in-cylinder observation techniques, including laser-methods, have been utilized to determine the optimum piston shape shown in Figure 10.27.

10.5.5 Realization of lower fuel consumption

Basic concept

In conventional gasoline engines, dispersion of an air-fuel mixture with the ideal density around the spark plug was very difficult. However, this is possible in the GDI engine. Furthermore, extremely low fuel consumption is achieved because ideal stratification enables fuel injected late in the compression stroke to maintain an ultra-lean air-fuel mixture.

An engine for analysis purposes has proved that an air-fuel mixture with the optimum density gathers around the spark plug in a stratified charge. This is also borne out by analysing the behaviour of the fuel spray immediately before ignition and analysing the air-fuel mixture itself.

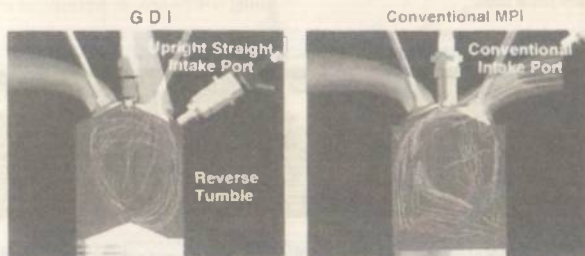


Figure 10.25 Upright straight intake ports

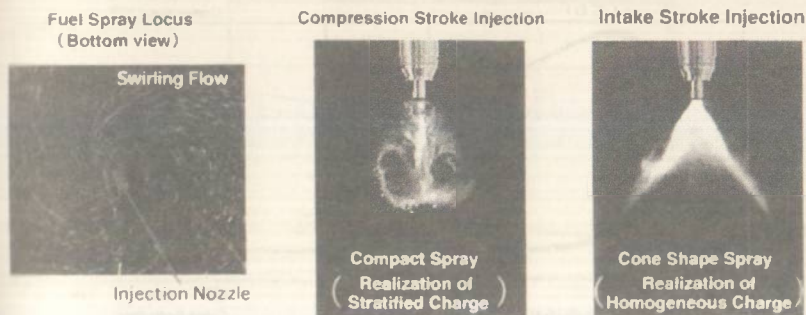


Figure 10.26 Swirl injectors

As a result, extremely stable combustion of an ultra-lean mixture with an air-fuel ratio of 40 (55, EGR included) is achieved as shown in Figure 10.28.



Figure 10.27 Optimum piston shape

Combustion of ultra-lean mixture

In conventional MPI engines, there were limits to the mixture's leanness due to large changes in combustion characteristics. However, the stratified mixture of the GDI enabled greatly decreasing the air-fuel ratio without leading to poorer combustion. For example, during idling, when combustion is most inactive and unstable, the GDI engine maintains a stable and fast combustion even with an extremely lean mixture of 40:1 air-fuel ratio (55:1, EGR included). Figure 10.29 shows a comparison between GDI and a conventional multipoint system.

Vehicle fuel consumption

Fuel consumption is considered under idling, cruising and city driving conditions.

Fuel consumption during idling

The GDI engine maintains stable combustion even at low idle speeds. Moreover, it offers greater flexibility in setting the idle speed. Compared with conventional engines, its fuel consumption during idling is 40% less, as represented in Figure 10.30.



Figure 10.28 Behaviour of fuel spray (injection in compression stroke) - Schlieren photo method

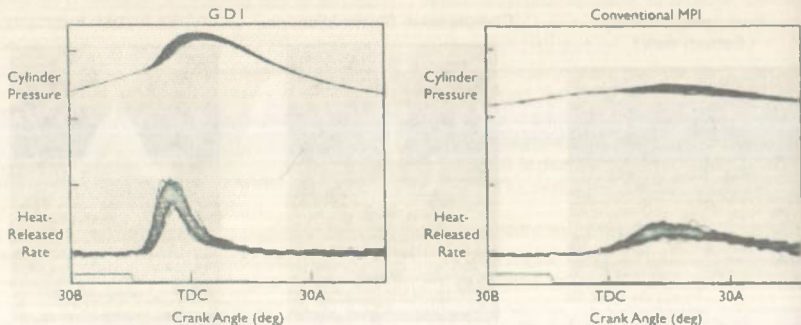


Figure 10.29 Comparison between GDI and a conventional multipoint system

Fuel consumption during cruising

At 40 km/h, the GDI engine uses 35% less fuel than a comparably sized conventional engine (Figure 10.31).

Fuel consumption in city driving

In Japanese 10.15 mode tests (representative of Japanese urban driving), the GDI engine used 35% less fuel than comparably sized conventional gasoline engines. Moreover, these results indicate that the GDI engine uses less fuel than even diesel engines (Figure 10.32).

Emission control

Previous efforts to burn a lean air-fuel mixture have resulted in difficulty in controlling NOx emissions.

However, for the GDI engine, 97% NOx reduction is achieved by utilizing a high-rate EGR (Exhaust Gas Recirculation) such as 30%, which is allowed by the stable combustion unique to the GDI, as well as by the use of a newly developed lean-NOx catalyst. Figure 10.33 shows a graph of NOx emissions. Figure 10.34 is a newly developed lean-NOx catalyst.

10.5.6 Realization of superior output

Basic concept

To achieve power superior to conventional MPI engines, the GDI engine has a high compression

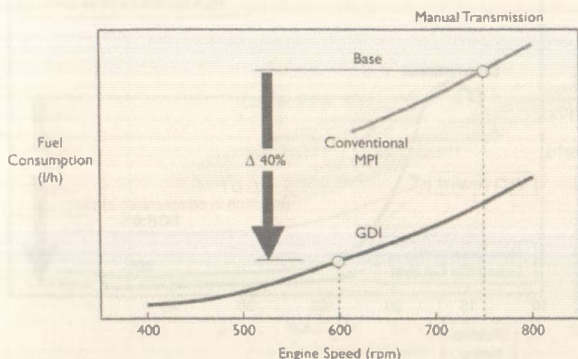


Figure 10.30 Fuel consumption during idling

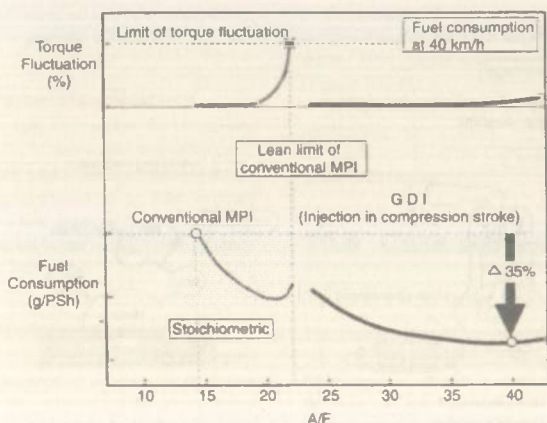


Figure 10.31 Fuel consumption during cruising

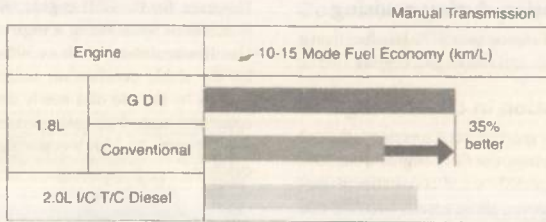


Figure 10.32 Fuel consumption in city driving

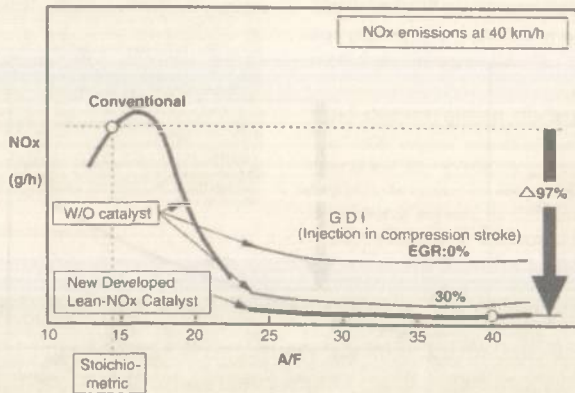


Figure 10.33 NOx emissions

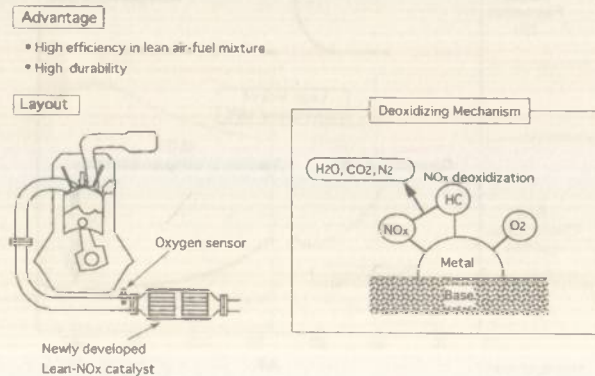


Figure 10.34 Newly developed lean NOx catalyst (HC selective deoxidization type)

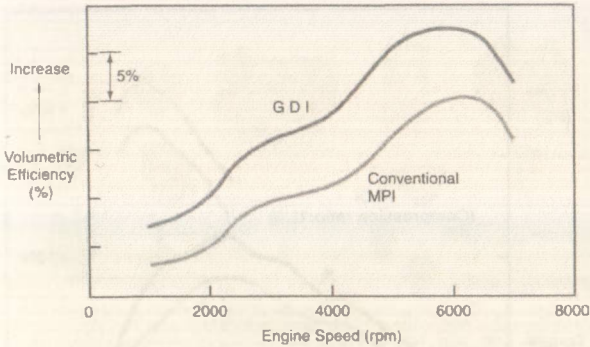


Figure 10.35 Improved volumetric efficiency

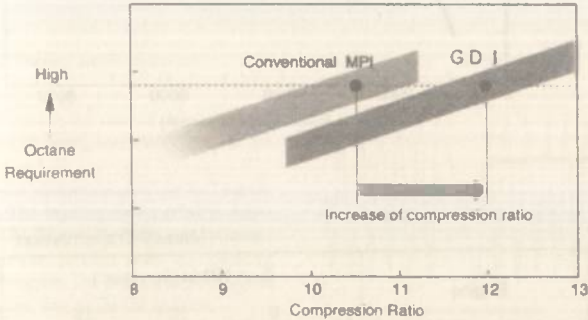


Figure 10.36 Increased compression ratio

ratio and a highly efficient air intake system, which result in improved volumetric efficiency.

Improved volumetric efficiency

Compared with conventional engines, the Mitsubishi GDI engine provides better volumetric efficiency. The upright straight intake ports enable smoother air intake. The vaporization of fuel, which occurs in the cylinder at a late stage of the compression stroke, cools the air for better volumetric efficiency (Figure 10.35).

Increased compression ratio

The cooling of air inside the cylinder by the vaporization of fuel has another benefit to minimize engine knocking. This allows a high compression ratio of 12, and thus improved combustion efficiency (Figure 10.36).

Compared with conventional MPI engines of a comparable size, the GDI engine provides approximately 10% greater output and torque at all speeds (Figure 10.37).

In high-output mode, the GDI engine provides outstanding acceleration. Figure 10.38 compares the performance of the GDI engine with a conventional MPI engine.

10.6 Case studies – Bosch

10.6.1 Motronic M3

The combination of ignition and injection control has several advantages. The information received from various sensors is used for computing both fuelling and ignition requirements. Perhaps more importantly, ignition and injection are closely linked. The influence they have on each other can

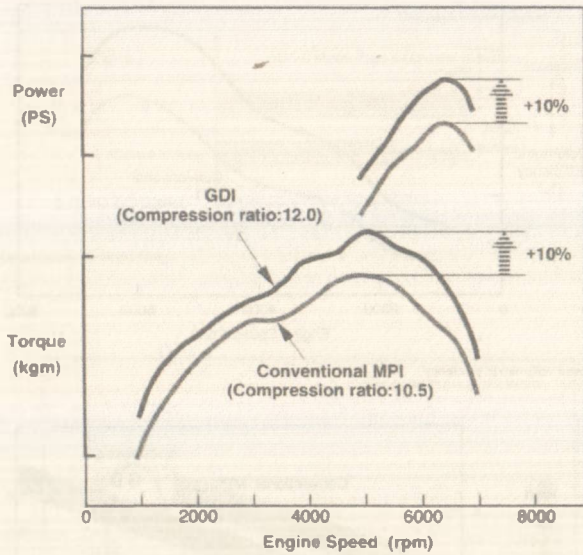


Figure 10.37 Engine performance

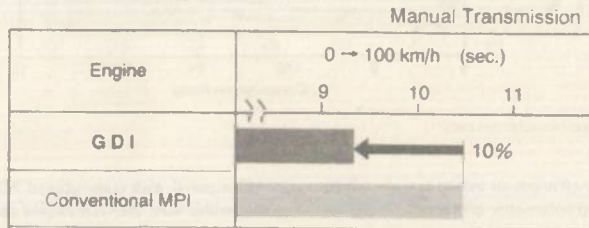


Figure 10.38 Vehicle acceleration

easily be taken into account to ensure that the engine is working at its optimum, under all operation conditions.

Overall, this type of system is less complicated than separate fuel and ignition systems and, in many cases, the ECU is able to work in an emergency mode by substituting missing information from sensors with pre-programmed values. This will allow limited but continued operation in the event of certain system failures.

The ignition system is integrated and is operated without a high tension distributor. The ignition process is controlled digitally by the ECU. The data for the ideal characteristics are stored in ROM from

information gathered during both prototyping and development of the engine. The main parameters for ignition advance are engine speed and load, but greater accuracy can be achieved by taking further parameters into account, such as engine temperature. This provides both optimum output and close control of anti-pollution levels. Performance and pollution level control means that the actual ignition point must, in many cases, be a trade-off between the two.

The injection system is multipoint and, as is the case for all fuel systems, the amount of fuel delivered is primarily determined by the amount of air drawn into the engine. The method for measuring

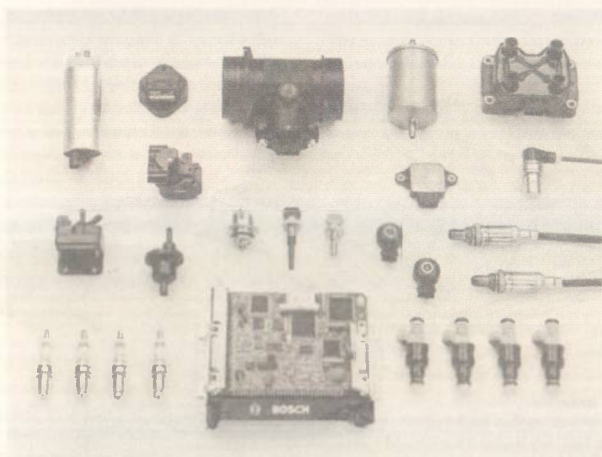


Figure 10.39 Bosch Motronic system components

these data is indirect in the case of this system as a pressure sensor is being used to determine the air quantity.

Electromagnetic injectors control the fuel supply into the engine. The injector open period is determined by the ECU. This will obtain very accurate control of the air-fuel mixture under all operating conditions of the engine. The data for this are stored in ROM in the same way as for the ignition.

Figure 10.39 shows the components of this system.

Ignition system operation

The main source of reference for the ignition system is from the crankshaft position sensor. This is a magnetic inductive pick-up sensor positioned next to a flywheel ring containing 58 teeth. Each tooth takes up a 6° angle of the flywheel with one 12° gap positioned 114° before top dead centre (TDC) for the number one cylinder.

Typical resistance of the sensor coil is 800Ω . The air gap between the sensor and flywheel ring is about 1 mm. The signal produced by the flywheel sensor is shown in Figure 10.40. It is essentially a sine wave with one cycle missing, which corresponds to the gap in the teeth of the reluctor plate.

The information provided to the ECU is engine speed from the frequency of the signal, and engine position from the number of pulses before or after the missed pulses.

The block diagram in Figure 10.41 shows a block diagram layout of how the ignition system is

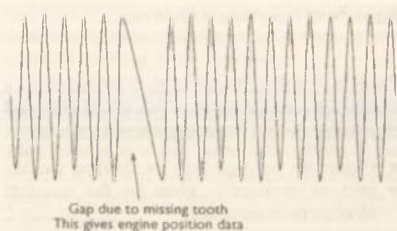


Figure 10.40 Crankshaft sensor signal

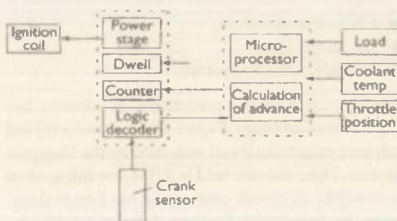


Figure 10.41 Simplified layout of the control of the ignition system

controlled. At ignition system level the ECU must be able to:

- Determine and create advance curves.
- Establish constant energy.
- Transmit the ignition signal direct to the ignition coil.

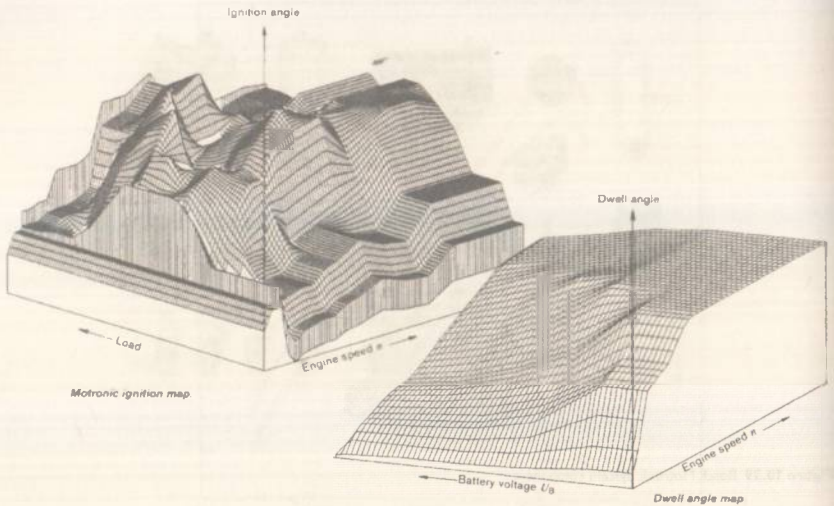


Figure 10.42 Engine timing and dwell maps

The basic ignition advance angle is obtained from a memorized cartographic map. This is held in a ROM chip within the ECU. The parameters for this are:

- Engine rev/min – given by the flywheel sensor.
- Inlet air pressure – given by the manifold absolute pressure sensor.

The above two parameters (speed and load) give the basic setting but to ensure optimum advance angle the timing is corrected by:

- Coolant temperature.
- Air temperature.
- Throttle butterfly position.

The ignition is set to a predetermined advance during the starting phase. Figure 10.42 shows a typical advance map and a dwell map used by the Motronic system. These data are held in ROM. For full ignition control, the electronic control unit has first to determine the basic timing for three different conditions.

- Under idling conditions, ignition timing is often moved very quickly by the ECU in order to control idle speed. When timing is advanced, engine speed will increase within certain limits.
- Full load conditions require careful control of ignition timing to prevent combustion knock. When a full load signal is sensed by the ECU (high manifold pressure) the ignition advance angle is reduced.

- Partial throttle is the main area of control and, as already stated, the basic timing is set initially by a programme as a function of engine speed and manifold pressure.

Corrections are added according to:

- Operational strategy.
- Knock protection.
- Phase correction.

The ECU will also control ignition timing variation during overrun fuel cut-off and reinstatement and also ensure anti-jerk control. When starting, the ignition timing plan is replaced by a specific starting strategy. Phase correction is when the ECU adjusts the timing to take into account the time taken for the HT pulse to reach the spark plugs. To ensure good drivability the ECU can limit the variations between the two ignition systems to a maximum value, which varies according to engine speed and the basic injection period.

The anti-jerk function operates when the basic injection period is less than 2.5 ms and the engine speed is between 720 and 3200 rev/min. This function operates to correct the programmed ignition timing in relation to the instantaneous engine speed and a set filtered speed; this is done to stabilize the engine rotational characteristics as much as possible.

In order to maintain constant high tension (HT) energy, the dwell period must increase in line with

engine speed. To ensure the ignition primary current reaches its maximum at the point of ignition, the ECU controls the dwell by the use of another memory map, which takes battery voltage into account.

The signal from the flywheel sensor is virtually a sinusoid created as the teeth pass the winding. The zero value of this signal occurs as the sensor 'sees' the apex of each tooth. A circuit within the ECU (a Schmitt trigger) converts the signal into a square wave. The passage of the missing teeth gives a longer duration signal. The ECU detects the gap in the teeth and, from this, can determine the first TDC. The second TDC in the cycle is determined by counting 29 teeth, which is half a revolution. The ECU, having determined the ignition angle then controls the coil every half engine revolution. Using the reference signal, the ECU switches the coil on at a point determined by a number of teeth corresponding to the dwell, before the point determined by timing value, where the coil is switched off.

The ignition module is only used as a simple switch to control the coil primary windings. It consists of a Darlington-type amplifier. This switching function is carried out within the ECU on some systems, this choice very much depends on the location of the ECU compared with the ignition coil. Also, the heat generated by the switching of heavy current may be better separate from the main ECU. A final consideration is whether the interference caused by the switching could cause problems within the ECU.

The 'distributorless' ignition coil is made up of two primary windings and two secondary windings. The primary windings have a common 12 V supply and are switched to earth in turn in the normal manner. The primary resistance is of the order

of 0.5Ω and the secondary resistance is $14.5 \text{ k}\Omega$. The system works on the lost spark principle in that cylinders 1 and 4 fire together as do 2 and 3. The disadvantage of this system is that one cylinder of each pair has the spark jumping from the plug earth electrode to the centre. However, owing to the very high energy available for the spark, this has no significant effect on performance.

The HT cables used are resistive. Spark plugs used for this system are standard but vary between types of engine. A gap of around 0.8 mm is the norm.

Fuel supply

Fuel is collected from the tank by a pump either immersed in it or outside, but near the tank. The immersed type is quieter in operation has better cooling and no internal leaks. The fuel is directed forwards to the fuel rail or manifold, via a paper filter. Figure 10.43 shows the fuel supply system.

Fuel pressure is maintained at about 2.5 bar above manifold pressure by a regulator mounted on the fuel rail. Excess fuel is returned to the tank. The fuel is usually picked up via a swirl pot in the tank to prevent aeration of the fuel. Each of the four inlet manifold tracts has its own injector.

The fuel pump is a high-pressure type and is a two-stage device. A low-pressure stage, created by a turbine, draws fuel from the tank and a high-pressure stage, created by a gear pump, delivers fuel to the filter. It is powered by a 12 V supply from the fuel pump relay, which is controlled by the ECU as a safety measure.

The fuel pump characteristics are:

- Delivery – 120 litres per hour at 3 bars.
- Resistance – 0.8Ω (static).

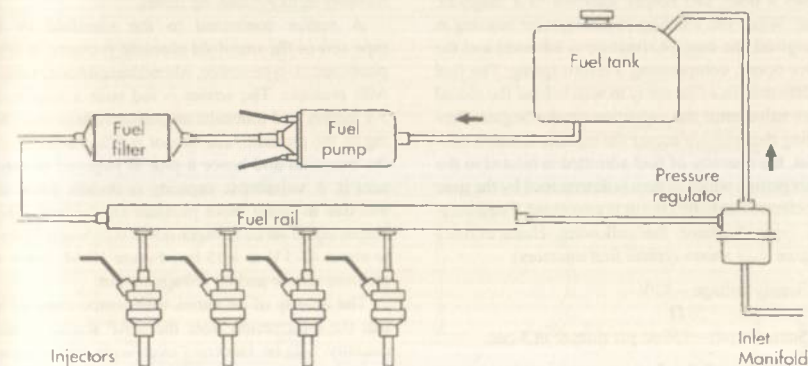


Figure 10.43 The main components in the fuel supply system

- Voltage – 12 V.
- Current – 10.5 A.

The rotation of the turbine draws fuel in via the inlet. The fuel passes through the turbine and enters the pump housing where it is pressurized by rotation of the pump and the reduction of the volume in the gear chambers. This pressure opens a residual valve and fuel passes to the filter. When the pump stops, pressure is maintained by this valve, which prevents the fuel returning. If, due to a faulty regulator or a blockage in the line, fuel pressure rises above 7 bar an over-pressure valve will open, releasing fuel back to the tank. Figure 9.30 shows this type of pump.

The fuel filter is placed between the fuel pump and the fuel rail. It is fitted to ensure that the outlet screen traps any paper particles from the filter element. The filter will stop contamination down to between 8 and 10 μm . Replacement of the filter varies between manufacturers but 80 000 km (50 000 miles) is often recommended.

The fuel rail, in addition to providing a uniform supply to the injectors, acts as an accumulator. Depending on the size of the fuel rail some systems also use an extra accumulator. The volume of the fuel rail is large enough to act as a pressure fluctuation damper, ensuring that all injectors are supplied with fuel at a constant pressure.

Injectors and associated components

One injector is used for each cylinder although very high performance vehicles may use two. The injectors are connected to the fuel rail by a rubber seal. The injector is an electrically operated valve manufactured to a very high precision. The injector comprises a body and needle attached to a magnetic core. When the winding in the injector housing is energized, the core or armature is attracted and the valve opens, compressing a return spring. The fuel is delivered in a fine spray to wait behind the closed inlet valve until the induction stroke begins. Providing the pressure across the injector remains constant, the quantity of fuel admitted is related to the open period, which in turn is determined by the time the electromagnetic circuit is energized. The injectors typically have the following characteristics (Figure 9.29 shows typical fuel injectors):

- Supply voltage – 12 V.
- Resistance – 16 Ω .
- Static output – 150 cc per minute at 3 bar.

The purpose of the fuel pressure regulator is to maintain differential pressure across the injectors at

a pre-determined constant. This means the regulator must adjust the fuel pressure in response to changes in manifold pressure. It is made of two compressed cases containing a diaphragm, spring and a valve. Figure 9.31 is a fuel pressure regulator similar to those used on this and many other injection systems.

The calibration of the regulator valve is determined by the spring tension. Changes in manifold pressure vary the basic setting. When the fuel pressure is sufficient to move the diaphragm, the valve opens and allows fuel to return to the tank. The decrease in pressure in the manifold, also acting on the diaphragm for example, idle speed, will allow the valve to open more easily, hence maintaining a constant differential pressure between the fuel rail and the inlet manifold. This is a constant across the injectors and hence the quantity of fuel injected is determined only by the open time of the injectors. The differential pressure is maintained at about 2.5 bar.

The air supply circuit will vary considerably between manufacturers but an individual manifold from a collector housing, into which the air is fed via a simple butterfly valve, essentially supplies each cylinder. The air is supplied from a suitable filter. A supplementary air circuit is utilized during the warm-up period after a cold start and to control idle speed.

Fuel mixture calculation

The quantity of fuel to be injected is determined primarily by the quantity of air drawn into the engine. This is dependent on two factors:

- Engine rpm.
- Inlet manifold pressure.

This speed load characteristic is held in the ECU memory in ROM look-up tables.

A sensor connected to the manifold by a pipe senses the manifold absolute pressure. It is a piezoelectric-type sensor, where the resistance varies with pressure. The sensor is fed with a stabilized 5 V supply and transmits an output voltage according to the pressure. The sensor is fitted away from the manifold and hence a pipe is required to connect it. A volumetric capacity is usually fitted in this line to damp down pressure fluctuations. The output signal varies between about 0.25 V at 0.17 bar to about 4.75 V at 1.05 bar. Figure 10.44 shows a pressure sensor and its voltage output.

The density of air varies with temperature such that the information from the MAP sensor on air quantity will be incorrect over wide temperature variations. An air temperature sensor is used to inform the ECU of the inlet air temperature such

that the ECU may correct the quantity of fuel injected. As the temperature of air decreases its density increases and hence the quantity of fuel injected must also be increased.

The sensor is a negative temperature coefficient (NTC) resistor. The resistance value decreases as temperature increases and vice versa. The output characteristic of this sensor is non-linear. Further details about this type of sensor and one solution to the non-linear response problem are examined in Chapter 2.

In order to operate the injectors, the ECU needs to know – in addition to air pressure – the engine speed to determine the injection quantity. The same flywheel sensor used by the ignition system provides this information. All four injectors operate simultaneously, once per engine revolution, injecting half of the required fuel. This helps to ensure balanced combustion. The start of injection varies according to ignition timing.

A basic open period for the injectors is determined by using the ROM information relating to

manifold pressure and engine speed. Two corrections are then made, one relative to air temperature and another depending on whether the engine is idling, at full or partial load.

The ECU then carries out another group of corrections, if applicable:

- after-start enrichment,
- operational enrichment,
- acceleration enrichment,
- weakening on deceleration,
- cut-off on overrun,
- reinstatement of injection after cut-off,
- correction for battery voltage variation.

Under starting conditions, the injection period is calculated differently. This is determined mostly from a set figure, which is varied as a function of temperature.

The coolant temperature sensor is a thermistor and is used to provide a signal to the ECU relating to engine coolant temperature. The ECU can then calculate any corrections to fuel injection and ignition timing. The operation of this sensor is the same as the air temperature sensor.

The throttle potentiometer is fixed on the throttle butterfly spindle and informs the ECU of the throttle position and rate of change of throttle position. The sensor provides information on acceleration, deceleration and whether the throttle is in the full load or idle position. Figure 10.45 shows the throttle potentiometer and its electrical circuit. It comprises a variable resistance and a fixed resistance. As is common with many sensors, a fixed supply of 5 V is provided and the return signal will

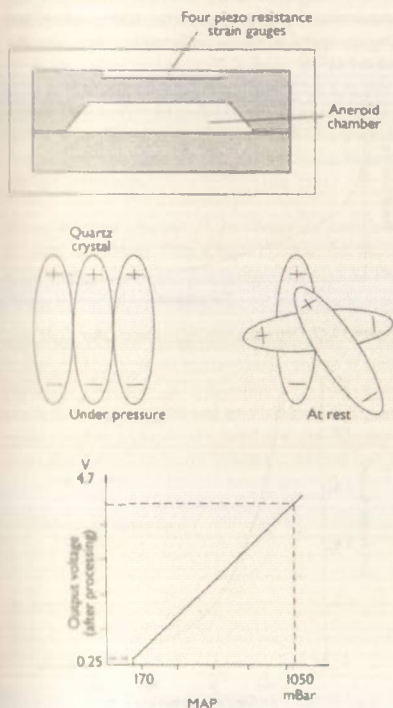


Figure 10.44 Pressure sensor and its voltage output

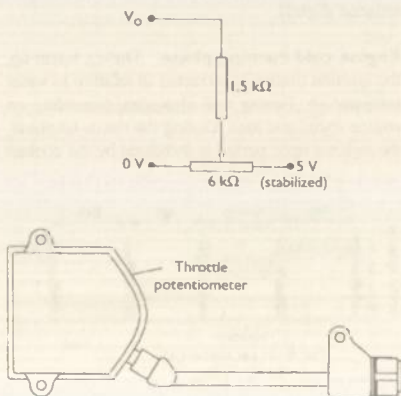


Figure 10.45 Throttle potentiometer and its electrical circuit

vary approximately between 0 and 5 V. The voltage increases as the throttle is opened.

Operating functions The operation functions employed by this system can be examined under a number of headings or phases, as follows.

Starting phase Entry to the starting phase occurs as soon as the ECU receives a signal from the flywheel sensor. The ignition advance is determined relative to the engine speed and the water temperature. The ECU operates the injectors four times per engine cycle (twice per crankshaft revolution) in order to obtain the most uniform mixture and to avoid wetting the plugs during the starting phase. Figure 10.46 shows the injection and ignition timing relative to engine position. Injection ceases 24° after the flywheel TDC signal. The ECU sets an appropriate injection period, corrected in relation to water temperature if starting from cold and air temperature if starting from hot. Exit from this starting phase is when the engine speed passes a threshold determined by water temperature.

After-start enrichment phase Enrichment is necessary to avoid stalling after starting. The amount of enrichment is determined by water and air temperature and decreases under control of the ECU. If the engine is cold or an intermediate temperature, the initial mixture is a function of water temperature. If the engine is hot, the initial mixture is a function of air and water temperature. Figure 10.47 is a representation of the decreasing mixture enrichment after a cold start. The next post-start enrichment will be reduced slightly.

Engine cold running phase During warm up, the ignition timing is corrected in relation to engine temperature. Timing will also alter depending on engine speed and load. During the warm-up phase, the injector open period is increased by the coolant

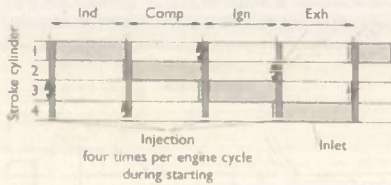


Figure 10.46 Injection and ignition timing relative to engine position

temperature signal to make up for fuel losses and to prevent the engine speed dropping. The enrichment factor is reduced as the resistance of the temperature sensor falls, finally ceasing at 80°C. Figure 10.48 shows the enrichment factor during warm up. The enrichment factor is determined by engine speed and temperature at idle and at other times by the programmed injection period relative to engine speed as well as the water temperature. To overcome the frictional resistance of a cold engine it is important to increase the mixture supply. This is achieved by using a supplementary air control device, which allows air to bypass the throttle butterfly.

Idling phase Air required for idling bypasses the throttle butterfly by a passage in the throttle housing. A volume screw is fitted for adjustment of idle speed. Idle mixture adjustment is carried out electronically in response to the adjusting of a potentiometer, either on the ECU or as a separate unit. The ignition and injection functions for idle condition are set using information from the throttle potentiometer that the throttle is at the idle position, and engine speed is set by information from the flywheel sensor.

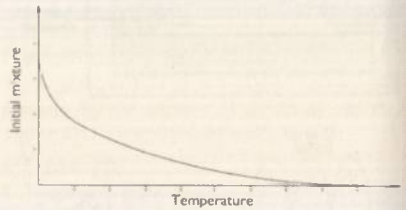


Figure 10.47 Decreasing mixture enrichment after a cold start

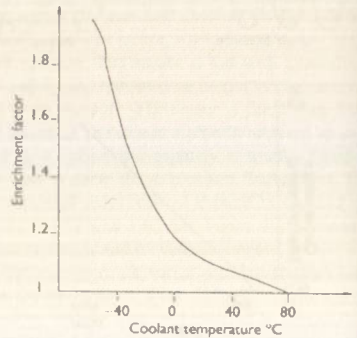


Figure 10.48 Enrichment factor during warm up

Full load phase Under full load conditions the ignition timing is related to engine speed and full load information from the throttle potentiometer. The injection function in order to achieve maximum power must be set such that the mixture ratio is increased to 1 : 1. The information from the throttle potentiometer triggers a programme in the ECU to enrich the mixture in relation to engine speed in order to ensure maximum power over the speed range but also to minimize the risk of knocking. It is also important not to increase fuel consumption unnecessarily and not to allow significant increases in exhaust emissions.

Acceleration phase When a rapid acceleration is detected by the ECU from the rate of change of the throttle potentiometer signal, enrichment occurs over a certain number of ignitions. The enrichment value is determined from water temperature and pressure variations in the inlet manifold. The enrichment then decreases over a number of ignitions. Figure 10.49 shows the acceleration enrichment phase. The enrichment is applied for the calibrated number of ignitions and then reduced at a fixed rate until it is non-existent. Acceleration enrichment will not occur if the engine speed is above 5000 rev/min or at idle. Under very strong acceleration it is possible to have unsynchronized injection. This is determined from the water temperature, a ROM map of throttle position against engine speed and a battery voltage correction.

Deceleration phase If the change in manifold pressure is greater than about 30 mbar the ECU enriches the mixture to be weakened relative to the detected pressure change.

Injection cut-off on deceleration phase This is designed to improve fuel economy and to reduce particular emissions of hydrocarbons. It will occur when the throttle is closed and when the engine speed is above a threshold related to water temperature (about 1500 rev/min). When the engine speed

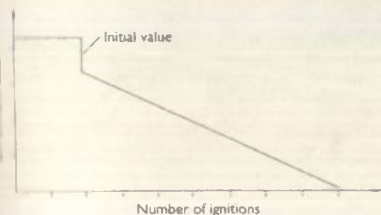


Figure 10.49 Acceleration enrichment phase

falls to about 1000 rev/min, injection recommences with the period rising to the value associated with the current engine speed and load. Figure 10.50 shows the strategy used to control injection cut-out and reinstatement.

Knock protection phase Ignition timing is also controlled to reduce jerking and possible knocking during cut-off and reinstatement. The calculated advance is reduced to keep the ignition just under the knock limit. The advance correction against knock is a programme relating to injection period, engine speed and water/air temperature.

Engine speed limitation Injection is cut-off when the engine speed rises above 6900 rev/min and is reinstated below this figure. This is simply to afford some protection against over-revving of the engine and the damage that may be caused.

Battery voltage correction This is a correction in addition to all other functions in order to compensate for changes in system voltage. The voltage is converted every TDC and the correction is then applied to all injection period calculations. On account of the time taken for full current to flow in the injector winding and the time taken for the current to cease, a variation exists depending on applied voltage. Figure 10.51 shows how this delay can occur, if S_1 is greater than S_2 a correction is

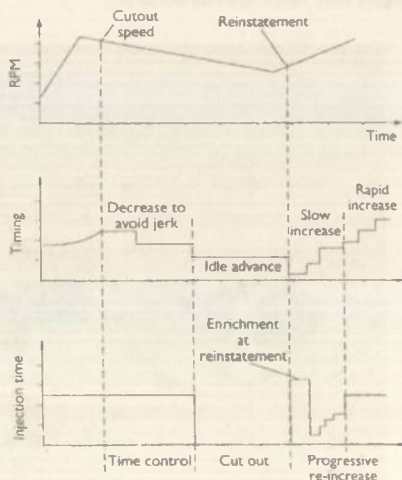


Figure 10.50 Strategy used to control injection cut-out and reinstatement

required. $S_1 - S_2 = S$ where S represents the time delay due to the inductance of the injector winding.

10.6.2 Motronic Gasoline Direct Injection (GDI)

Introduction

Bosch's high-pressure injection system for gasoline engines is based on a pressure reservoir and a fuel rail, which a high-pressure pump charges to a regulated pressure of up to 120 bar. The fuel can therefore

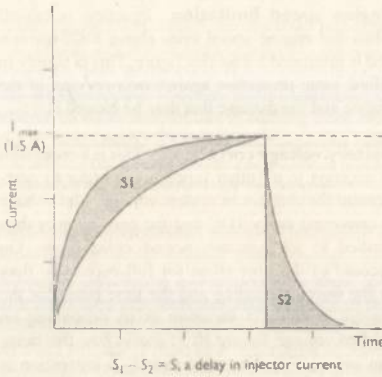


Figure 10.51 Injector operation time curve

be injected directly into the combustion chamber via electro-magnetic injectors. This system achieves reduced emissions and improved fuel consumption.

The air mass drawn in can be adjusted through the electronically controlled throttle valve (gas-by-wire) and is measured with the help of an air mass meter. For mixture control, a wide-band oxygen sensor is used in the exhaust. It is positioned before the catalytic converters. This sensor can measure a range between $\lambda = 0.8$ and infinity. The electronic engine control unit regulates the operating modes of the engine with gasoline direct injection in three ways:

- Stratified charge operation – with λ values greater than 1.
- Homogenous operation – at $\lambda = 1$.
- Rich homogenous operation – with $\lambda = 0.8$.

Compared to the traditional manifold injection system, the entire fuel amount must be injected in full-load operation in a quarter of the time. The available time is significantly shorter during stratified charge operation in part load. Especially at idle, injection times of less than 0.5 ms are required due to the lower fuel consumption. This is only one-fifth of the available time for manifold injection.

The fuel must be atomized very finely in order to create an optimal mixture in the brief moment between injection and ignition. The fuel droplets for direct injection are on average smaller than 20 μm . This is only one-fifth of the droplet size reached with the traditional manifold injection and one-third

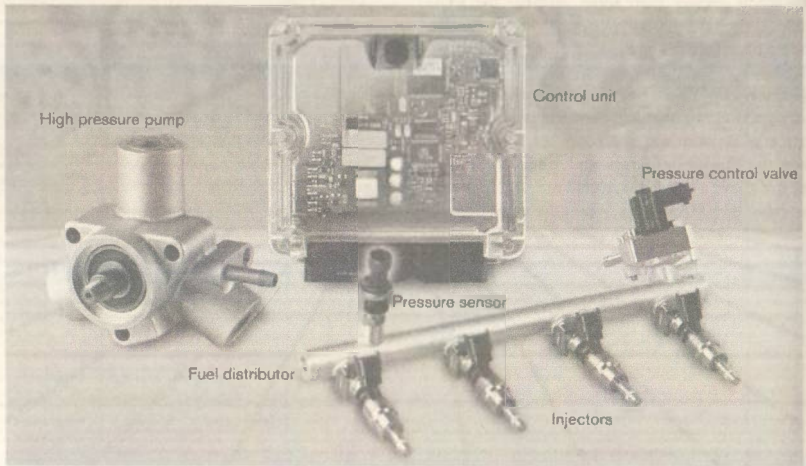


Figure 10.52 Injector used by gasoline direct injection (Source: Bosch Press)

of the diameter of a single human hair. This improves efficiency considerably. However, even more important than fine atomization is an even fuel distribution in the injection beam. This is done to achieve fast and uniform combustion.

Conventional spark ignition engines have a homogenous air/fuel mixture at a 14.7:1 ratio, corresponding to a value of $\lambda = 1$. Direct injection engines, however, operate according to the stratified charge concept in the part load range and function with high excess air. In return, very low fuel consumption is achieved.

With retarded fuel injection, a combustion chamber split into two parts is an ideal condition, with fuel injection just before the ignition point and injection directly into the combustion chamber. The result is a combustible air/fuel mixture cloud on the spark plug. This is cushioned in a thermally insulating layer, which is composed of air and residual exhaust gas. The engine operates with an almost completely opened throttle valve, which reduces pumping losses.

With stratified charge operation, the λ value in the combustion chamber is between about 1.5 and 3. In the part load range, gasoline direct injection achieves the greatest fuel savings with up to 40% at idle compared to conventional fuel injection.

With increasing engine load, and therefore increasing injection quantities, the stratified charge cloud becomes even richer and emission characteristics become worse. Like diesel engine combustion, soot

may form. In order to prevent this, the DI-Motronic engine control converts to a homogenous cylinder charge at a pre-defined engine load. The system injects very early during the intake process in order to achieve a good air/fuel mixture at a value of $\lambda = 1$.

As is the case for conventional manifold injection systems, the amount of air drawn in at all operating modes is adjusted through the throttle valve according to the desired torque specified by the driver. The Motronic ECU calculates the amount of fuel to be injected from the drawn-in air mass and performs an additional correction via λ control. In this mode of operation, a torque increase of up to 5% is possible. Both the thermodynamic cooling effect of the fuel vaporizing directly in the combustion chamber and the higher compression of the engine with gasoline direct injection play a role in this.

For these different operating modes two central demands are raised for engine control:

- The injection point must be adjustable between 'late' (during the compression phase) and 'early' (during the intake phase) depending on the operating point.
- The adjustment for the drawn-in air mass must be detached from the throttle pedal position in order to permit unthrottled engine operation in the lower load range. However, throttle control in the upper load range must also be permitted.

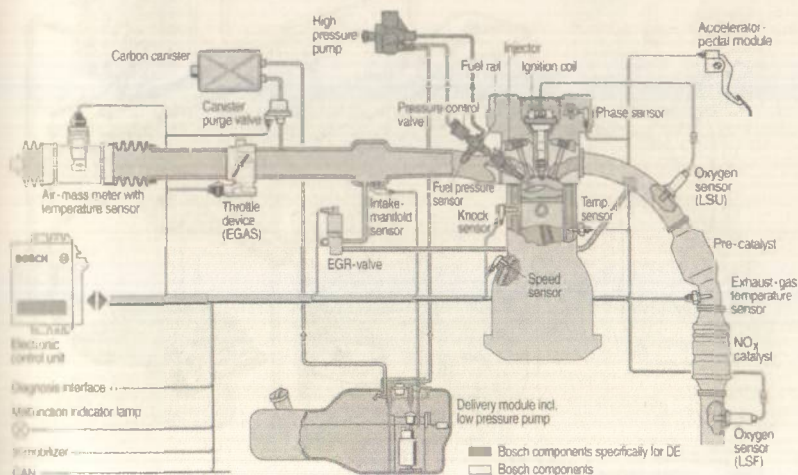


Figure 10.53 Bosch Gasoline Direct Injection DI-Motronic (Source: Bosch Press)

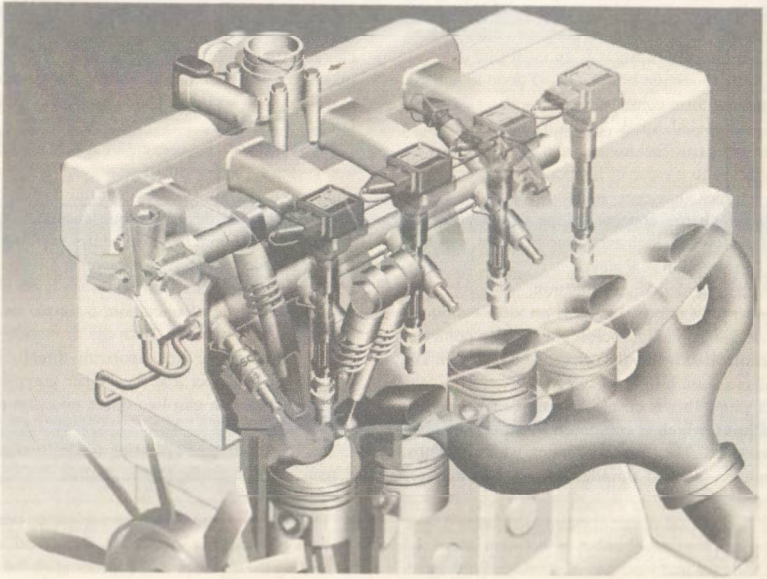


Figure 10.54 Cutaway engine showing the GDI system operating (Source: Bosch Press)

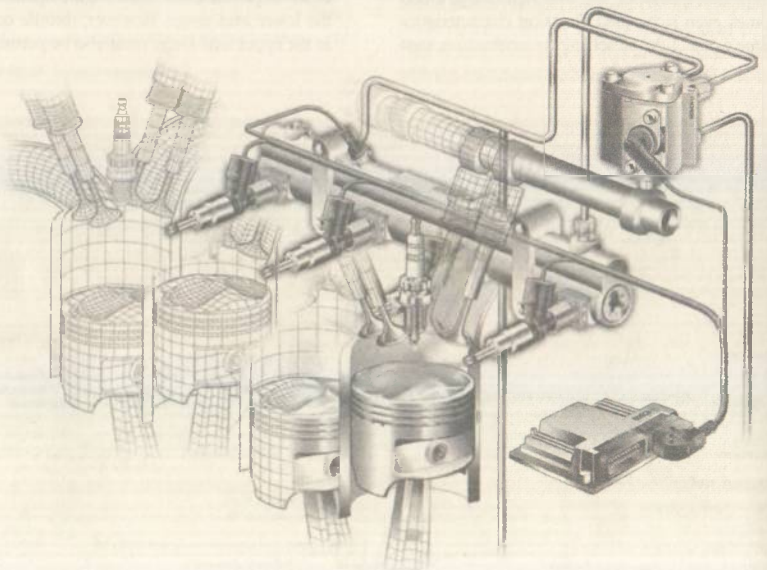


Figure 10.55 System components showing fuel and electrical connections (Source: Bosch Press)

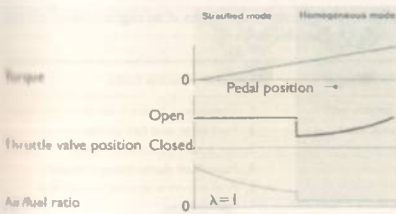


Figure 10.56 Switching between operating modes depending on engine load (Source: Bosch Press)

With optimal use of the advantages, the average fuel saving is up to 15%.

In stratified charge operation the nitrogen oxide (NOx) segments in the very lean exhaust cannot be reduced by a conventional, three-way catalytic converter. The NOx can be reduced by approximately 70% through exhaust returns before the catalytic converter. However, this is not enough to fulfil the ambitious emission limits of the future. Therefore, emissions containing NOx must undergo special treatment. Engine designers are using an additional NOx accumulator catalytic converter in the exhaust

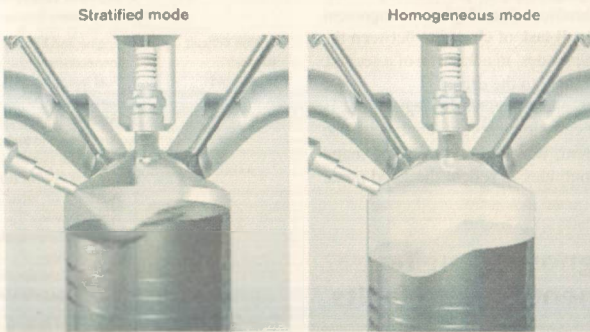


Figure 10.57 Operating modes (Source: Bosch Press)

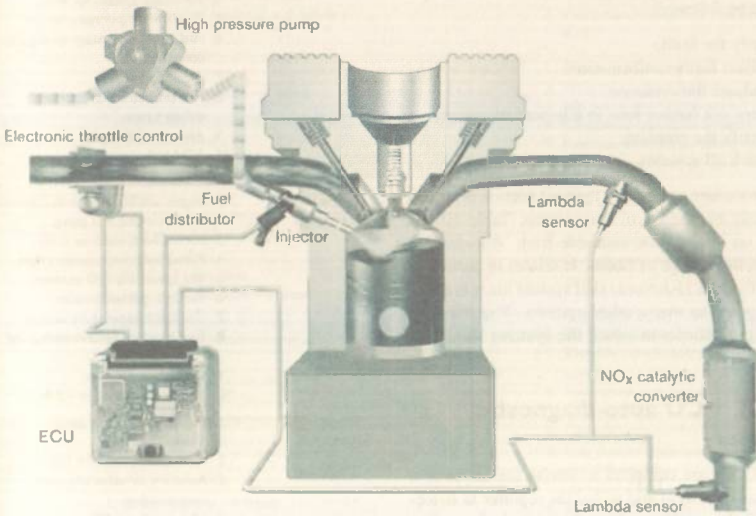


Figure 10.58

system. The NO_x is deposited in the form of nitrates (HNO₃) on the converter surface, with the oxygen still contained in the lean exhaust.

The capacity of the NO_x accumulator catalytic converter is limited. Therefore, as soon as it is exhausted the catalytic converter must be regenerated. In order to remove the deposited nitrates, the DI-Motronic briefly changes over to its third operating mode (rich homogenous operation with lambda values of about 0.8). The nitrate, together with the carbon monoxide, is reduced in the exhaust to non-harmful nitrogen and oxygen. When the engine operates in this range, the engine torque is adjusted according to the driver's pedal position by opening the throttle valve. Engine management achieves the difficult task of changing between the different operating modes, in a fraction of a second, in a way not noticeable to the driver.

The continuing challenge, set by legislation, is to reduce vehicle emissions to very low levels. The DI-Motronic system, which is now used by many manufacturers, continues to reflect the good name of Bosch.

10.7 Diagnosing engine management system faults

10.7.1 Introduction

As with all systems the six stages of fault finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 10.1 is based on information available from 'Autodata' in its excellent range of books. It relates in particular to the Bosch LH-Jetronic fuel system but it is also a good guide to many other systems. The numbers relate to the order in which the systems should be checked.

10.7.2 ECU auto-diagnostic function

Most ECUs are equipped to advise the driver of a fault in the system and to aid the repairer in detection of the problem. The detected fault is first notified to the driver by a dashboard warning light.

Table 10.1 Common symptoms of an engine malfunction and checks for possible faults

Symptoms	Check for possible faults
Engine will not start	<ol style="list-style-type: none"> 1. Engine and battery earth connections 2. Fuel filter and fuel pump. 3. Air intake system for leaks. 4. Fuses/fuel pump/system relays. 5. Fuel injection system wiring and connections. 6. Coolant temperature sensor. 7. Auxiliary air valve/idle speed control valve. 8. Fuel pressure regulator and delivery rate. 9. ECU and connector. 10. Limp home function – if fitted.
Engine difficult to start when cold	<ol style="list-style-type: none"> 1. Engine and battery earth connections. 2. Fuel injection system wiring and connections. 3. Fuses/fuel pump/system relays. 4. Fuel filter and fuel pump. 5. Air intake system for leaks. 6. Coolant temperature sensor. 7. Auxiliary air valve/idle speed control valve. 8. Fuel pressure regulator and delivery rate. 9. ECU and connector. 10. Limp home function – if fitted.
Engine difficult to start when warm	<ol style="list-style-type: none"> 1. Engine and battery earth connections. 2. Fuses/fuel pump/system relays. 3. Fuel filter and fuel pump. 4. Air intake system for leaks. 5. Coolant temperature sensor. 6. Fuel injection system wiring and connections. 7. Air mass meter. 8. Fuel pressure regulator and delivery rate. 9. Air sensor filter. 10. ECU and connector. 11. Knock control – if fitted.
Engine starts then stops	<ol style="list-style-type: none"> 1. Engine and battery earth connections 2. Fuel filter and fuel pump. 3. Air intake system for leaks. 4. Fuses/fuel pump/system relays. 5. Idle speed and CO content. 6. Throttle potentiometer. 7. Coolant temperature sensor. 8. Fuel injection system wiring and connections. 9. ECU and connector. 10. Limp home function – if fitted.
Erratic idling speed	<ol style="list-style-type: none"> 1. Engine and battery earth connections. 2. Air intake system for leaks. 3. Auxiliary air valve/idle speed control valve. 4. Idle speed and CO content.

(Continued)

Table 10.1 (Continued)

Symptoms	Check for possible faults	Symptoms	Check for possible faults
	<ol style="list-style-type: none"> Fuel injection system wiring and connections. Coolant temperature sensor. Knock control – if fitted. Air mass meter. Fuel pressure regulator and delivery rate. ECU and connector. Limp home function – if fitted. 		<ol style="list-style-type: none"> Air mass meter. ECU and connector.
Incorrect idle speed	<ol style="list-style-type: none"> Air intake system for leaks. Vacuum hoses for leaks. Auxiliary air valve/idle speed control valve. Idle speed and CO content. Coolant temperature sensor. 	Poor engine response	<ol style="list-style-type: none"> Engine and battery earth connections. Air intake system for leaks. Fuel injection system wiring and connections. Throttle linkage. Coolant temperature sensor. Fuel pressure regulator and delivery rate. Air mass meter. ECU and connector. Limp home function – if fitted.
High or low idle speed	<ol style="list-style-type: none"> Engine and battery earth connections. Air intake system for leaks. Fuel injection system wiring and connections. Coolant temperature sensor. Fuel pressure regulator and delivery rate. Air mass meter. Fuses/fuel pump/system relays. 	Excessive fuel consumption	<ol style="list-style-type: none"> Engine and battery earth connections. Idle speed and CO content. Throttle potentiometer. Throttle valve/housing/sticking/initial position. Fuel pressure regulator and delivery rate. Coolant temperature sensor. Air mass meter. Limp home function – if fitted.
High or low constant speed	<ol style="list-style-type: none"> Air flow sensor. 	CO level too high	<ol style="list-style-type: none"> Limp home function – if fitted. ECU and connector. Emission control and EGR valve – if fitted. Fuel injection system wiring and connections. Air intake system for leaks. Coolant temperature sensor. Fuel pressure regulator and delivery rate.
Hesitation when accelerating	<ol style="list-style-type: none"> Engine and battery earth connections. Air intake system for leaks. Fuel injection system wiring and connections. Vacuum hoses for leaks. Coolant temperature sensor. Fuel pressure regulator and delivery rate. Air mass meter. ECU and connector. Limp home function – if fitted. 	CO level too low	<ol style="list-style-type: none"> Engine and battery earth connections. Air intake system for leaks. Idle speed and CO content. Coolant temperature sensor. Fuel injection system wiring and connections. Injector valves. ECU and connector. Limp home function – if fitted. Air mass meter. Fuel pressure regulator and delivery rate.
Hesitation at constant speed	<ol style="list-style-type: none"> Engine and battery earth connections. Throttle linkage. Vacuum hoses for leaks. Auxiliary air valve/idle speed control valve. Fuel lines for blockage. Fuel filter and fuel pump. Injector valves. ECU and connector. Limp home function – if fitted. 	Poor performance	<ol style="list-style-type: none"> Engine and battery earth connections. Air intake system for leaks. Throttle valve/housing/sticking/initial position. Fuel injection system wiring and connections. Coolant temperature sensor. Fuel pressure regulator/fuel pressure and delivery rate. Air mass meter. ECU and connector. Limp home function – if fitted.
Hesitation on overrun	<ol style="list-style-type: none"> Air intake system for leaks. Fuel injection system wiring and connections. Coolant temperature sensor. Throttle potentiometer. Fuses/fuel pump/system relays. Air sensor filter. Injector valves. Air mass meter. 		
Knock during acceleration	<ol style="list-style-type: none"> Knock control – if fitted. Fuel injection system wiring and connections. 		

A code giving the details is held in RAM within the ECU. The repairer can read this fault code as an aid to fault-finding.

Each fault detected is memorized as a numerical code and can only be erased by a voluntary action. Often, if the fault is not detected again for 50 starts of the engine, the ECU erases the code automatically. Only serious faults will light the lamp but minor faults are still recorded in memory. The faults are memorized in the order of occurrence. Certain major faults will cause the ECU to switch over to an emergency mode. In this mode, the ECU substitutes alternative values in place of the faulty signal. This is called a 'limp home facility'.

Faults can be read as two digit numbers from the flashing warning light by shorting the diagnostic wire to earth for more than 2.5 s but less than 10 s. Earthing this wire for more than 10 s will erase the fault memory, as does removing the ECU constant battery supply. Earthing a wire to read fault codes should only be carried out in accordance with the manufacturer's recommendations. The same coded signals can be more easily read on many after-sales service testers. On some systems it is not possible to read the fault codes without a code reader.

10.7.3 Testing procedure

Caution/Achtung/Attention – Burning fuel can seriously damage your health!

Caution/Achtung/Attention – High voltages can seriously damage your health!

The following procedure is very generic but with a little adaptation can be applied to any fuel injection system. Refer to the manufacturer's recommendations if in any doubt.

1. Check battery state of charge (at least 70%).
2. Hand and eye checks (all fuel and electrical connections secure and clean).
3. Check for spark at plug lead (if poor or no spark jump to stage 15).
4. Check fuel pressure supplied to rail (for multi-point systems it will be about 2.5 bar but check specifications).
5. If the pressure is NOT correct jump to stage 11.
6. Is injector operation OK? – continue if NOT (suitable spray pattern or dwell reading across injector supply).
7. Check supply circuits from main relay (battery volts minimum).
8. Continuity of injector wiring (0–0.2 Ω and note that many injectors are connected in parallel).
9. Sensor readings and continuity of wiring (0–0.2 Ω for the wiring sensors will vary with type).
10. If no fuel is being injected and all tests so far are OK (suspect ECU).
11. Fuel supply – from stage 5.
12. Supply voltage to pump (within 0.5 V of battery – pump fault if supply is OK).
13. Check pump relay and circuit (note that, in most cases, the ECU closes the relay but this may be bypassed on cranking).
14. Ensure all connections (electrical and fuel) are remade correctly.
15. Ignition section (if appropriate).
16. Check supply to ignition coil (within 0.5 V of battery).
17. Spark from coil via known good HT lead (jumps about 10 mm, but do not try more).
18. If good spark then check HT system for tracking and open circuits. Check plug condition (leads should be a maximum resistance of about 30 k Ω /m per lead) – stop here in this procedure.
19. If no spark, or it will only jump a short distance, continue with this procedure (colour of spark is not relevant).
20. Check continuity of coil windings (primary 0.5–3 Ω , secondary several k Ω).
21. Supply and earth to 'module' (12 V minimum supply, earth drop 0.5 V maximum).
22. Supply to pulse generator if appropriate (10–12 V).
23. Output of pulse generator (inductive about 1 V AC when cranking, Hall-type switches 0–8 V DC).
24. Continuity of LT wires (0–0.1 Ω).
25. Suspect ECU but only if all of the above tests are satisfactory.

10.7.4 Injection duration signals

Figure 10.59 shows typical injector signals as would be shown on an oscilloscope during a test procedure. These will vary depending on the particular system but, in principle, are the same. The most important parts of the traces are marked. These are the open time or dwell, current limiting phase and the back EMF produced when the injector is switched off. The traces showing variations in the dwell represent how the quantity of fuel injected is varied. The difference in how the dwell is varied is due to the method of injector switching. If a simple on/off technique is used then the trace will be as shown in the first two sketches; if current limiting is used then the trace will be slightly different, as shown by the lower two sketches.

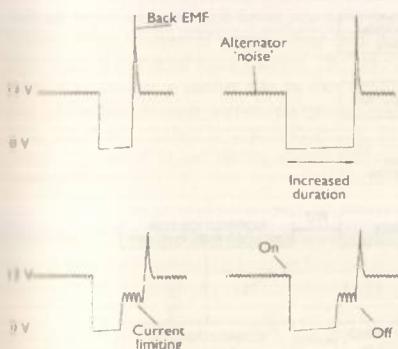


Figure 10.59 Injector signals as would be shown on an oscilloscope during a test procedure

These traces are very useful for diagnosing faults – it is possible to see how the trace changes under the engine operating conditions, for example:

- Does the trace width extend under acceleration?
- Does the trace cut off on overrun?
- Does the trace width reduce as the engine warms up?

10.8 Advanced engine management technology

10.8.1 Speed density and fuel calculations

Engine management systems that do not use an air flow sensor rely on the speed-density method for determining the required fuel quantity. Accurate measurement of the manifold absolute pressure (MAP) and intake air temperature are essential with this technique.

The volume flow rate of air taken into an engine at a given speed can be calculated by:

$$A_v = \left[\left(\frac{RPM}{60} \right) \left(\frac{D}{2} \right) V_c \right] - EGR_v$$

where A_v = air volume flow rate (litres/s); EGR_v = exhaust gas recirculation volume (litres/s); D = displacement of the engine (litres); and V_c = volumetric efficiency (as a percentage from look-up tables).

The density of air in the inlet manifold is related to its temperature and pressure. If these are measured

accurately then density can be calculated. A basic gas law states that, in a fixed volume:

$$d_a = d_o \left(\frac{P_i}{P_o} \times \frac{T_o}{T_i} \right)$$

where d_a = density; P_i = intake pressure; and T_i = intake temperature.

P_o , d_o and T_o are known values relating to pressure, density and temperature under 'sea level standard day' (SLSD) conditions.

The mass of the air can be calculated by:

$$M_a = d_a \times V$$

where M_a = mass of air (kg); d_a = density of the air (kg/litre); and V = volume of air (litres).

The mass flow rate can now be calculated by:

$$A_m = d_a \times A_v$$

where A_m = air mass flow rate (kg/s).

Finally, by substitution and simplification, air mass flow can be calculated by:

$$A_m = d_a \left[\left(\frac{RPM \cdot D \cdot V_c}{120} \right) - EGR_v \right]$$

Further to this calculation, the basic fuel quantity can be determined as follows:

$$F = \frac{A_m}{AFR}$$

where F = fuel quantity (kg) and AFR = desired air-fuel ratio.

To inject the required quantity of fuel, the final calculation is that of the injector pulse width:

$$T = \frac{F}{R_f}$$

where T = time and R_f = fuel injector(s) delivery rate.

Note that the actual injection period will also depend on a number of other factors such as temperature and throttle position. The total fuel quantity may also be injected in two halves.

10.8.2 Ignition timing calculation

Data relating to the ideal ignition timing for a particular engine are collected from dynamometer tests and operational tests in the vehicle. These data are stored in the form of look-up tables in ROM. These look-up tables hold data relative to the speed and load of the engine. The number of look-up values is determined by the computing power of the microcontroller, in other words the number of bits,

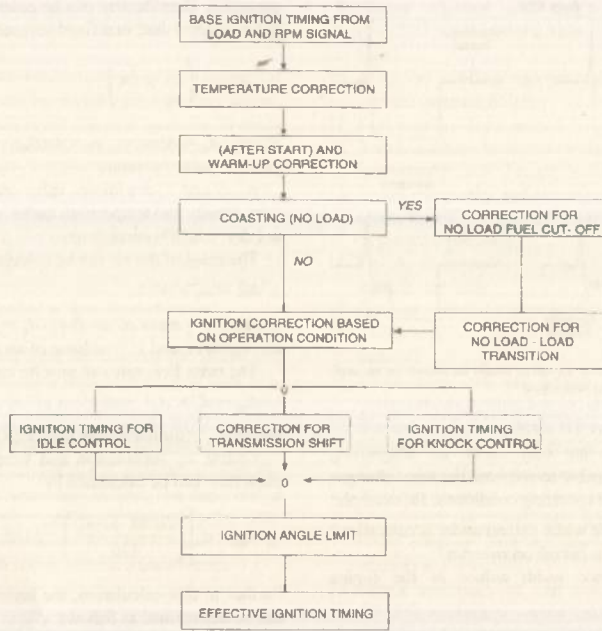


Figure 10.60 Determination of effective ignition timing

as this determines the size of memory that can be addressed.

Inputs from speed and load sensors are converted to digital numbers and these form the reference to find the ideal timing value. A value can also be looked up for the temperature correction. These two digital numbers are now added to give a final figure. Further corrections can be added in this way for conditions such as overrun and even barometric pressure if required.

This 'timing number' is used to set the point at which the coil is switched off; that is, the actual ignition point. The ECU receives a timing pulse from the 'missing flywheel tooth' and starts a 'down counter'. The coil is fired (switched off) when the counter reaches the 'timing number'. The computing of the actual 'timing number' is represented by Figure 10.60.

To prevent engine damage caused by detonation or combustion knock, but still allow the timing to be set as far advanced as possible, a knock sensor is used. The knock sensor (accelerometer) detects the onset of combustion knock, but the detection process only takes place in a 'knock window'. This

window is just a few degrees of crankshaft rotation either side of top dead centre compression for each cylinder. This window is the only time knock can occur and is also a quiet time as far as valve opening and closing is concerned. The sensor is tuned to respond to a particular frequency range of about 5–10 kHz, which also helps to eliminate erroneous signals. The resonant frequency of this type of accelerometer is greater than about 25 kHz.

The signal from the knock sensor is filtered and integrated in the ECU. A detection circuit determines a yes/no answer to whether the engine knocked or not. When knock is detected on a particular cylinder, the timing for that cylinder is retarded by a set figure, often 2°, each time the cylinder fires, until the knocking stops. The timing is then advanced more slowly back towards the look-up value. Figure 10.61 represents this process in more detail.

10.8.3 Dwell calculation

In order for an ignition system to produce constant energy the dwell angle must increase as the engine speed increases. Ideal dwell values are held in a

lookup table; engine speed forms one axis, and battery voltage the other. If battery voltage falls, the dwell angle is increased to compensate. The 'dwell number' is used in a similar way to the 'timing number' in the previous section except that this time, the 'dwell number' is used to determine the switch-on point of the coil during operation of the down counter.

10.8.4 Injection duration calculation

The main criteria for the quantity of fuel required for injection are engine speed and load. Further corrections are then added. Figure 10.62 represents the process carried out in a digital electronic control unit to calculate injection duration. The process

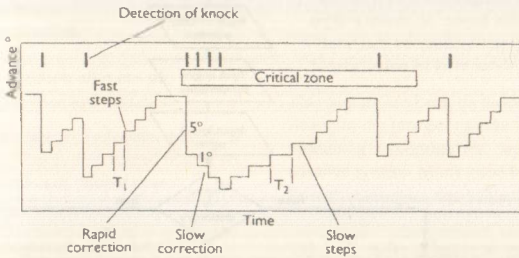


Figure 10.61 How timing is varied in response to combustion knock

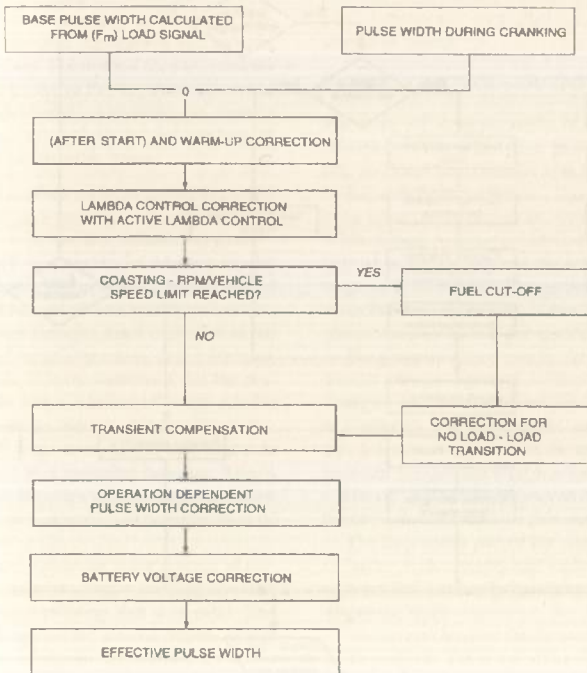


Figure 10.62a Determination of effective injector pulse width

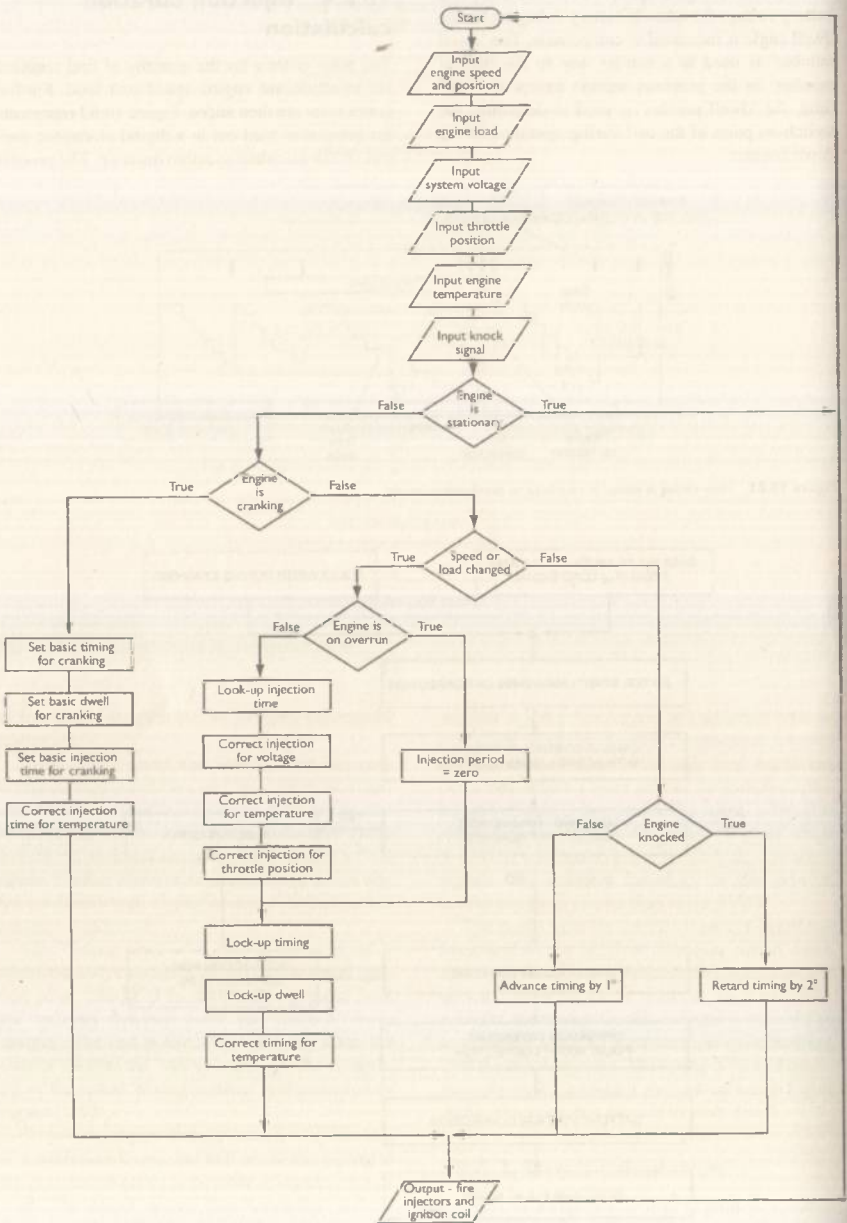


Figure 10.62b Engine management fuel and ignition calculation flow diagram

of injection duration calculation is summarized as follows.

- A basic open period for the injectors is determined from the ROM information relating to engine speed and load.
- Corrections for air and engine temperature.
- Idling, full or partial load corrections.
- After-start enrichment.
- Operational enrichment.
- Acceleration enrichment.
- Weakening on deceleration.
- Cut-off on over-run.
- Reinstatement of injection after cut-off.
- Correction for battery voltage variation.

Under starting conditions the injection period is calculated differently. This is determined from a set figure varied as a function of temperature.

10.8.5 Developing and testing software

There is, of course, more than one way of producing a 'computer' program. Most programs used in the electronic control unit of a vehicle digital control system are specialist applications and, as such, are one-off creations. The method used to create the final program is known as the 'top down structured programming technique'. Following on from a 'need' for the final product, the process can be seen to pass through six definable stages.

1. Requirement analysis seeks to answer the question as to whether a computerized approach is the best solution. It is, in effect, a feasibility study.
2. Task definition is a process of deciding exactly what the software will perform. The outcome of this stage will be a set of functional specifications.
3. Program design becomes more important as the complexity of the task increases. This is because, where possible, it is recommended that the program be split into a number of much smaller tasks, each with its own detailed specification.
4. Coding is the stage at which the task begins to be represented by a computer language. This is when the task becomes more difficult to follow as the language now used is to be understood by the 'computer'.
5. Debugging and validation is the process of correcting any errors or a bug in the program code and then finally ensuring that it is valid. This means checking that the desired outputs appear in response to appropriate inputs. In other words, does it work? (As a slight aside, did you know that the original computer bug was actually a

moth trapped between the contacts of a relay?) Note that it is very important to get the program right at this stage as it is likely to be incorporated into tens of thousands of specially produced microcontrollers. A serious error can be very expensive to rectify.

6. Operation and maintenance is the stage when the program is actually in use. Occasionally slight errors do not come to light until this stage, such as a slight hesitation during acceleration at high altitude or some other obscure problem. These can be rectified by program maintenance for inclusion in later models.

This section has been included with the intention of filling in the broader picture of what is involved in producing a program for, say, an electronic spark advance system. Many good books are available for further reading on this subject.

10.8.6 Simulation program

Automotive Technology (AT) is a training and diagnostic software program. It works in conjunction with this textbook and on-line learning. All complex electronically controlled systems can be considered as having:

INPUTS - CONTROL - OUTPUTS

The main 'AT' program works in the same way but also incorporates diagnostics. In other words, it will help you learn how complex systems work and how to diagnose faults with them. The program concentrates on engine management, starting and charging. A MultiScope program is included that allows actual tests to be carried out and the results viewed on a scope or a multimeter. The software is fully functional but runs out of fuel! It should be registered if you continue to use it to prevent the tank leaking...

The program allows you to 'drive' the vehicle or directly change inputs to systems such as engine management. The computer (just like the computer in a vehicle), will calculate the outputs of the system. Engine management is the main area covered but other systems are available for use. The system can be set to provide telemetry to the MultiScope as the car is driven round the Silverstone circuit!

The diagnostics part of the program is designed to assist with diagnosing faults in automotive systems. It is ideal to help with the development of diagnostic skills.

The comprehensive diagnostic routines are part of the program. These can also be printed for use in the workshop. A step by step process helps you track down any fault. The MultiScope program is

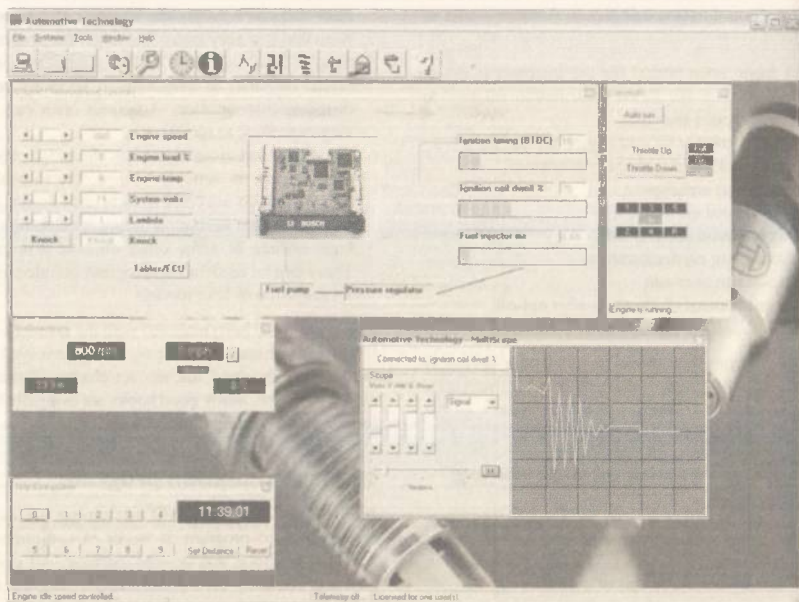


Figure 10.63

used to test the operation of sensors and actuators. Faults can be set to allow practice of diagnostic techniques.

The program (as well as other useful resources) can be downloaded from: www.automotive-technology.co.uk

10.8.7 Hot chipping!

Hot chipping is the name often given to the fitting of new processors/memory to improve the performance of a vehicle. It should be noted that the improvements are at the expense of economy, emissions and engine life! Fitting a 'Power Processor', which is a programmable computer specifically designed for high performance engines, is the first step. The fuel map, engine ignition timing map, acceleration fuel and all parameters for fuel management are programmable using an IBM compatible PC or laptop computer. Note that a new ECU is needed in most cases but this does allow improvement of other features.

The software even allows changes to be made while you are driving the vehicle. This system is appropriate for virtually any fuel injected engine. A basic calibration is used to get the engine started and running. The user then performs fine tuning.

The systems are capable of closed or open loop operation. Some systems even feature control of nitrous injection with automatic engagement based on throttle position and rev/min. Ignition timing is automatically retarded with pre-set parameters.

CalMap Software is a well respected system for developing custom calibrations for high performance engines. The software allows 'online' and 'offline' adjustments to be made to the 'ACCEL Digital Fuel Injection Power Processors' (contact information is available in Chapter 18). The software kit comes with an interface cable, a user manual and a floppy disk, which contains the software. The software is user friendly and arguably should be considered a must for all modern performance shops. Setting and adjusting the spark curve for your distributor from a laptop computer in the vehicle is possible – as you are driving down the road. Snapshots can be taken using the software. For example, you could record a set distance run and review the engine performance in order to determine how the engine is running.

Tuning a fuel-injected engine requires experience, time and patience. One mistake with the laptop keyboard and your engine can easily be turned into a pile of junk from detonation or a lean condition!

When determining the size of the base fuel map's rev/min resolution, the cell widths should be as small as possible. This gives the most tuning set points in the operating range of the engine. If the map is configured to 5000 rev/min, any resolution above that figure would be lost, but resolution would be gained where the engine spends its most time, i.e. below 5000 rev/min.

If the fuel map is calibrated to 5000 rev/min and the calibrated pulse width at that speed is 12 ms, the ECU will keep issuing pulses of 12 ms at any speed above this value. It is beneficial to use as many of the 256 (16×16 look-up table or 2^8 relating to 8 bits) set points as possible during tuning. This is established by setting the rev/min between cells. The largest fuel commands should be at the peak torque and, as the engine speed escalates above peak torque, the pulse width reduces. Most values from the ECU's inputs and outputs will be available 'on-screen', as if from the serial data link on a production ECU.

Most systems use 'interpolative' software, meaning the cells surrounding the actual chosen cell in the fuel map will affect the issued pulse width. Getting the fuel calculations as near to the stoichiometric set point as possible and using very little, if any, oxygen sensor trim is a good technique. This is the approach that the original equipment manufacturers use. While working on the base fuel map, note that with injector pulse widths below 2 ms, you are entering an unstable range. Work with all of the cells around the chosen idle cell because the surrounding cell values are used for interpolation. Large variations in matrix values around the idle cell can lead to surging.

The resolution of the ignition map is referenced from the fuel table and is scaled at a rate of 1.5 to the fuel table. The same theory applies to the spark table, as to the fuel table, in regard to keeping the same timing command beyond its rev/min resolution. The amount of retardation required to stop detonation once it is started in the combustion chamber is greater than the amount that would be needed never to allow detonation to start. A trial and error method is required for the best results. The amount of spark advance is affected by engine criteria such as:

- Cylinder-head combustion chamber design.
- Mixture movement.
- Piston design.
- Intake manifold length and material.
- Compression ratio.
- Available fuel.
- Thermal transfer from the cylinder-head to the cooling system.

10.8.8 Artificial Intelligence

Artificial intelligence (AI) is the ability of an artificial mechanism to exhibit intelligent behaviour. The term invites speculation about what constitutes the mind or intelligence. Such questions can be considered separately, but the endeavour to construct and understand increasingly sophisticated mechanisms continues.

AI has shown great promise in the area of expert systems, or knowledge-based expert programs, which, although powerful when answering questions within a specific domain, are nevertheless incapable of any type of adaptable, or truly intelligent, reasoning.

No generally accepted theories have yet emerged within the field of AI, due in part to AI being a new science. However, it is assumed that on the highest level, an AI system must receive input from its environment, determine an action or response and deliver an output to its environment. This requires techniques of expert reasoning, common sense reasoning, problem solving, planning, signal interpretation and learning. Finally, the system must construct a response that will be effective in its environment.

The possibilities for AI in vehicle use are unlimited. In fact, it becomes more a question of how much control the driver would be willing to hand over to the car. If, for example, the vehicle radar detects that you tend to follow the car in front too closely, should it cause the brakes to be applied? The answer would probably be no, but if the question was, as the engine seems to surge at idle should the idle speed be increased slightly, then the answer would most likely be yes.

It is not just the taking in of information and then applying a response as this is carried out by all electronic systems to some extent, but in being able to adapt and change. For example, if the engine was noticed to surge when the idle speed was set to 600 rev/min, then the ECU would increase the speed to, say, 700 rev/min. The adaptability, or a very simple form of AI, comes in deciding to set the idle speed at 700 rev/min on future occasions. This principle of modifying the response is the key. Many systems use a variation of this idea to control idle speed and also to adapt air-fuel ratios in response to a lambda sensor signal.

An adaptive ignition system has the ability to adapt the ignition point to the prevailing conditions. Programmed ignition has precise values stored in the memory appropriate for a particular engine. However, due to manufacturing tolerances, engine wear with age and road conditions means that the

ideal timing does not always correspond to that held in the ECU memory.

The adaptive ignition ECU has a three-dimensional memory map as normal for looking up the basic timing setting, but it also has the ability to alter the spark timing rapidly, either retarding or advancing, and to assess the effect this has on engine torque. The ECU monitors engine speed by the crankshaft sensor, and if it sees an increase in speed after a timing alteration, it can assume better combustion. If this is the case, the appropriate speed load site on the memory map is updated. The increase in speed detected is for one cylinder at a time; therefore, normal engine speed changes due to the throttle operation do not affect the setting.

The operation of the adaptive ignition system is such as to try and achieve a certain slope on the timing versus torque curve as shown by Figure 10.64. Often the slope is zero (point A) for maximum

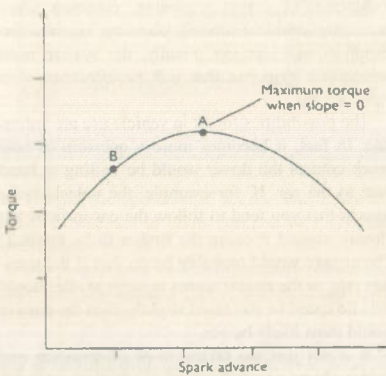


Figure 10.64 Timing versus torque curve

economy but is sometimes non-zero (point B), to avoid detonation and reduce emissions.

Figure 10.65 shows the adaptive ignition block diagram. The fixed spark timing map produces a 'non-adapted' timing setting. A variation is then added or subtracted from this point and the variation is also sent to the slope detector. The slope detector determines whether the engine torque was increased or decreased from the measure of the slope on the torque/timing curve compared with data from the slope map. The difference is used to update the timing correction map. The correction map can be updated every time a spark variation occurs, allowing very fast adaptation even during rapid changes in engine operation. The slope map can be used to aim for either maximum torque or minimum emissions.

10.8.9 Neural computing

The technology behind neural computing is relatively new and is expanding rapidly. The exciting aspect is that neural networks have the capacity to learn rather than having to be programmed. This form of artificial intelligence does not require specific instructions on how a problem can be solved. The user allows the computer to adapt itself during a training period, based on examples of similar problems. After training, the computer is able to relate the problem to the solution, inputs to outputs, and thus offer a viable answer to the 'question'.

The main part of a neural computer is the neural network, a schematic representation of which is shown in Figure 10.66. In this representation the circles represent neurons and the lines represent links between them. A neuron is a simple processor, which takes one or more inputs and produces an output. Each input has an associated 'weight', which determines its intensity or strength. The neuron simply has to determine the weight of its

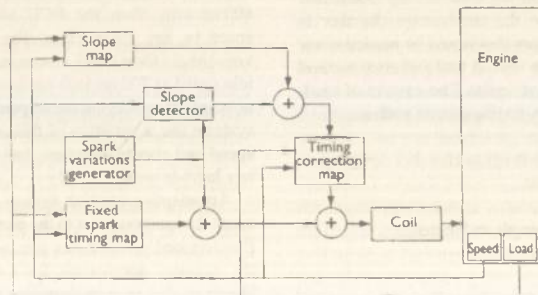


Figure 10.65 Adaptive ignition block diagram

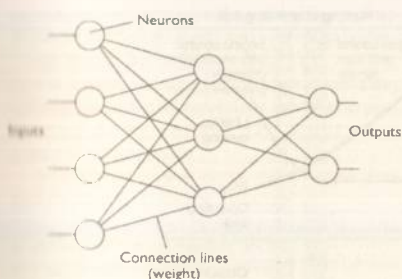


Figure 10.66 Neural network

inputs and produce a suitably weighted output. The number of neurons in a network can range from tens to many thousands.

The way the system learns is by comparing its actual output with an expected output. This produces an error value, which in turn changes the relative weights of the links back through the whole network. This eventually results in an ideal solution, as connections leading to the correct answer are strengthened. This, in principle, is similar to the way a human brain works. The neural computing system has a number of advantages over the conventional method.

- Very fast operation due to 'parallel processing'.
- Reduced development time.
- Ability to find solutions to problems that are difficult to define.
- Flexible approach to a solution, which can be adapted to changing circumstances.
- More robust, as it can handle 'fuzzy' data or unexpected situations. An adaptive fuzzy system acts like a human expert. It learns from experience and uses new data to fine-tune its knowledge.

The advantages outlined make the use of neural nets on automobile systems almost inevitable. Some are even starting to be used in such a way that the engine control system is able to learn the driver's technique and anticipate the next most likely action. It can then set appropriate system parameters before the action even happens!

10.9 New developments in engine management

10.9.1 Introduction

Research is going on all the time into different ways of reducing emissions in order to keep within the current and expected regulations. In a way, the

European market has an advantage as the emission laws in the USA and, in particular, the State of California, are very stringent and set to become more so. It is reasonable to expect that EC regulations will broadly follow the same route. The one potential difference is if CO₂ is included in the legislation. This will, in effect, make fuel consumption as big an issue as noxious emissions. Some of the current areas of development are briefly mentioned below. It is becoming clear that nitrogen oxides are the most difficult gases to reduce in line with future legislation. The technology for a NO_x reducing catalyst has just started to reach production stage.

10.9.2 Lean burn engines

Any engine running at a lambda value greater than one is a form of lean burn. In other words, the combustion takes place with an excess of air. Fuel consumption is improved and CO₂ emissions are lower than with a conventional 'lambda equals one and catalyst system'. However, with the same comparison, NO_x emissions are higher. This is due to the excess air factor. Rough running can also be a problem with lean burn (Figure 10.67), due to the problems encountered lighting lean mixtures. A form of charge stratification is a way of improving this. Note also the case studies in this and the previous chapters.

10.9.3 Direct mixture injection

A new technique called DMI, or direct mixture injection, shows a potential 30% saving in fuel. This system involves loading a small mixing chamber above the cylinder-head with a suitable quantity of fuel during the compression stroke and start of combustion. This may be by a normal injector. The heat of the chamber ensures total fuel evaporation.

During an appropriate point in the next cycle the mixture is injected into the combustion chamber. This is one of the key advances because it is injected in such a way that the charge is in the immediate vicinity of the spark plug. This stratification is controlled by the mixture injection valve opening, the in-cylinder pressure and the mixing chamber pressure. Figure 10.68 shows the layout of a DMI system. The lambda values possible with this system range from 8 to 10 at idle and from 0.9 to 1 at full load. Compare this with the lean limits of a homogeneous mixture, which is typically $\lambda = 1.6-1.8$.

10.9.4 Two-stroke engines

The two-stroke engine could be the answer to emission problems, but experts have differing views.

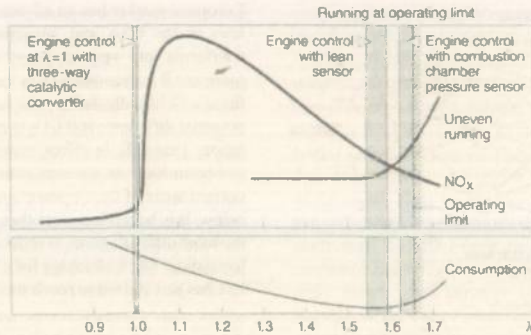


Figure 10.67 Lean-burn engine

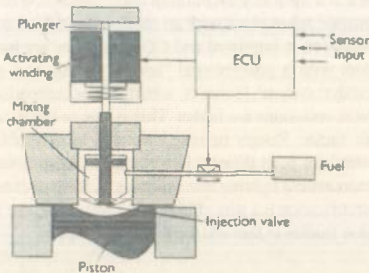


Figure 10.68 Layout of a direct mixture injection system

The main reason for this is that the potential improvements for the four-stroke system have by no means been exhausted. The claimed advantages of the two-stroke engine are lower weight, lower fuel consumption and higher power density. These, however, differ depending on engine design. The major disadvantages are less smooth running, shorter life and higher NO_x emissions. An Australian company, Orbital, have made a considerable contribution to two-stroke technology. A simple shutter control is used in their system and, in a published paper, a one-litre two-stroke engine was compared with a one-litre four-stroke engine. The two-stroke engine weighs 30% less, has lower consumption and low NO_x levels while being comparable in all other ways. The engine can use direct injection to stratify the charge.

10.9.5 Alternative fuels

Engines using alcohol (e.g. ethanol) do not require major design changes. The fuel supply components

would need to withstand corrosion and slightly different cold start strategies are needed. Other than this, changes to the engine 'maps' are all that is required. If an alcohol sensor is used in the fuel tank, the management system could adapt to changes in the percentage of alcohol used, if mixed with petrol. Some advantages in emissions are apparent with ethanol-petrol mixtures. It is said that the use of alcohol fuels is a political, not a technical issue.

Gas powered engines have been used for some time but storage of suitable quantities is a problem. These engines, however, do produce lower CO, HC and CO₂ emissions. Hydrogen powered vehicles offer the potential to exceed the ultra low emission vehicle (ULEV) limits, but are still in the early stages. Many manufacturers do, however, have prototypes. Electric powered vehicles, which meet the zero emission vehicle (ZEV) limits, are discussed in Chapter 17.

When all alternatives are considered it is clear that the petrol/gasoline and diesel engines are not easily replaceable. Indeed there are still many possible areas for further improvements.

10.9.6 Delphi's 'building block' approach to advanced engine management systems

This section is included as an example of how the 'current thinking' is going with regard to engine management systems in general. Delphi is a well respected company in this area.

The following is taken from a Press Release - Delphi Energy & Engine Management Systems, Presentation to the SAE, 1998.

'Engine management is the science of equipping and calibrating an engine to achieve the cleanest

possible exhaust stream while maintaining top performance and fuel economy, and continuously diagnosing system faults. However, the focus on those priorities often varies around the world, reflecting differing governmental regulations, customer expectations and driving conditions and a host of vehicle types and content levels.

Typically, an engine management system integrates numerous elements, including:

- An engine control module (ECM).
- Control and diagnostics software.
- An air induction and control subsystem.
- A fuel handling module.
- A fuel injection module.
- An ignition subsystem.
- A catalytic converter.
- A subsystem to handle evaporative emissions.
- A variety of sensors and solenoids.

Delphi states the following: 'We don't start at ground zero with each customer, in each market, with each vehicle. We use modular systems architecture, rapid calibration development tools and controls based on real world models. We use off-the-shelf interchangeable hardware whenever possible and software that will work in most systems and most processors. We use "plug and play" tools, like auto-code generation, so we do not have to reconfigure the whole system when we modify a piece of it.

Highlighted advanced engine management systems include the following:

- Modular systems architecture.
- Delphi's building block approach to engine management selects from sets of "commonized", interchangeable software and electronics in the engine or powertrain control modules.
- Allowing OEMs to custom-build systems for widely differing markets.
- Software has expansion/deletion capabilities.
- Systems are designed with a minimum number of basic electronic controllers, which can be expanded if desired.
- Component hardware is interchangeable among systems.
- Software can be used across a variety of systems.
- Rapid Calibration Development Tools (RapidCal).
- Rapid prototyping permits immediate evaluation of the performance of new systems developments.
- Results can be benchmarked against plant/control models and rapid prototypes to verify correct implementation.
- Model-Based Controls (MBC).

- Control algorithms are redesigned around physically based models or mathematical representations of "the real world".
- Piece changes only require changing the calibration data for that single piece, rather than changing the whole system.
- MBC technologies include pneumatic and thermal estimators, model-based transient fuel control and individual cylinder fuel control.

Benefits of the building block approach include the following:

- Saves development costs.
- Offers flexibility to manufacturers.
- Adapts easily to the needs of a variety of customers, from emerging markets to high-end applications.
- Allows use of off-the-shelf components with minimal recalibration after modification.
- Enables compliance with varying emissions regulations over a wide range of driving conditions, driving habits, customer expectations and vehicle types.
- Saves fuel, reduces emissions.
- Reduces time-to-market for vehicle manufacturers.'

10.9.7 Video link diagnostics

Some manufacturers have introduced hand-held video cameras to aid with diagnosing faults. This is relevant to all areas of the vehicle as well as engine management systems.

The camera is linked via an Internet/modem line from the dealers to the manufacturers. The technician is therefore able to show what tests have been done as well as describe the problem to the engineer/specialist.

10.9.8 Saab combustion control system

Introduction

The Saab Combustion Control (SCC) system has been developed to reduce fuel consumption and significantly reduce exhaust emissions. However, engine performance is not affected. The key to the operation of the SCC is the use of exhaust gases.

By circulating a significant proportion of exhaust gas back into the combustion process, the fuel consumption can be reduced by up to 10%. The exhaust emissions can also be reduced to a value below the American Ultra Low Emission Vehicle 2 (ULEV2) and the European Euro 4 requirements. This technology almost halved the carbon monoxide and

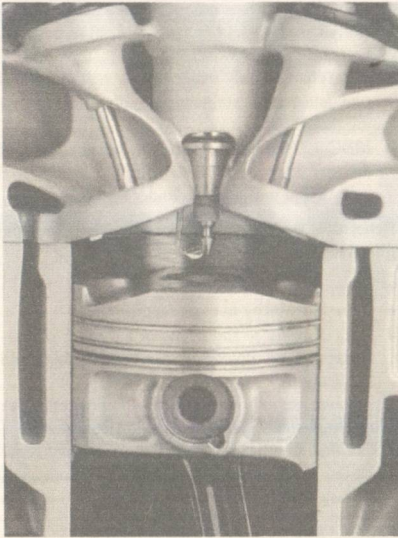


Figure 10.69 Combustion control spark plug injector
(Source: Saab)

hydrocarbon emissions, and cut the nitrogen oxide emissions by 75%.

Unlike standard direct injection systems, the SCC system reaps benefits without disturbing the ideal air-to-fuel ratio (14.7:1). This ratio is necessary for a conventional three-way catalytic converter to work properly. The most important aspects of the SCC system are:

- Air-assisted fuel injection with turbulence generator – the injector unit and spark plug are combined into one unit known as the spark plug injector (SPI). Fuel is injected directly into the cylinder with the help of compressed air and another blast of air creates turbulence in the cylinder just before the fuel is ignited. This assists combustion and shortens the combustion time.
- Variable valve timing – variable cams are used so that the SCC system can vary the opening and closing of the inlet and exhaust valves. This allows exhaust gases to be mixed into the combustion air in the cylinder. This is the key aspect that gets the benefits of direct injection while keeping $\lambda = 1$ under most operating conditions. The exact recirculation percentage depends on the operating conditions, but up to 70% of the cylinder contents during combustion can consist of exhaust gases.

- Variable spark plug gap with high spark energy – the spark plug gap is variable from 1–3.5 mm. The spark is created from the centre electrode of the SPI to a fixed earth electrode, with a 3.5 mm gap, or to an earth electrode actually on the piston. Very high spark energy (about 80 mJ) is necessary to ignite an air/fuel mixture that is mixed with 70% of exhaust gases.

The best way to understand the SCC process is to start with the expansion or power stroke (the following numbers refer to Figure 10.70).

1. The power stroke operates in the normal way – air/fuel mixture burns, increases the pressure, and this forces the piston down.
2. As the piston reaches the end of the power stroke, the exhaust valves open and most of the exhaust is discharged through the exhaust ports. Remaining exhaust gases are discharging as the piston rises on the exhaust stroke.
3. Fuel is injected into the cylinder via the SPI just before the piston reaches TDC. The inlet valves open at the same time. Exhaust, mixed with fuel, is discharged through both the exhaust and inlet ports.
4. At the start of the inlet stroke, the exhaust and inlet valves open and the mixture of exhaust and fuel is drawn back from the exhaust manifold into the cylinder. A significant proportion of the exhaust/fuel mixture now flows up into the inlet ports.
5. As the piston continues to move down, the exhaust valves close but the inlet valves stay open. The exhaust/fuel mixture that flowed into the inlet manifold is now drawn back into the cylinder.
6. As the piston nears BDC, all the exhaust/fuel mixture is drawn back into the cylinder. Towards the end of the inlet stroke, only air is drawn in.
7. As the piston moves upwards during the compression stroke, the inlet valves close and the mixture of exhaust, air and fuel is compressed. About half way up the compression stroke, the SPI delivers a blast of air into the cylinder. This creates turbulence that facilitates combustion and therefore shortens the combustion time.
8. Just before the piston reaches TDC, a spark from the electrode of the SPI ignites the mixture (a) and the next expansion stroke begins (b).

The three-way catalytic converter is still the most important exhaust emission control element. This is because it can catalyse up to 99% of the harmful components in the exhaust gases. However, the catalytic converter has no influence on the carbon dioxide (CO_2) emissions, which are directly proportional to the fuel consumption.

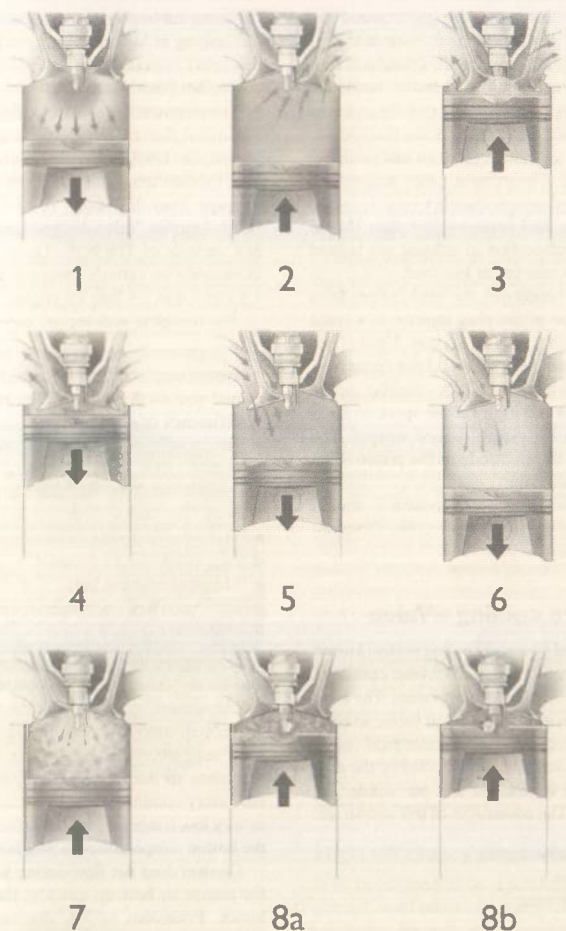


Figure 10.70 Stages of combustion control (Source: Saab)

Direct injection of petrol is a good way of lowering fuel consumption. Because a precise amount of fuel is injected directly into the cylinder, the consumption can be controlled more accurately. However, only the area around the plug is ignitable because the remainder of the cylinder is filled with air. With standard direct injection systems, this reduces fuel consumption but results in higher nitrogen oxide emissions. The resulting exhaust gases are not ideally suited to a conventional three-way catalytic converter. For this reason, a special catalytic converter with a 'nitrogen oxide trap' has to

be used. These are more expensive because they have higher levels of precious metals. In addition, they are more temperature-sensitive and need cooling when under heavy load. This is often achieved by injecting extra fuel. To regenerate the NO_x trap when it is 'full up', the engine also has to be run briefly on a richer fuel/air mixture.

The SCC system also contributes towards reducing pumping losses. These usually occur when an engine is running at low load with the throttle almost closed. Under these conditions, the piston in the cylinder operates under a partial vacuum during the

induction stroke. The extra energy required for pulling down the piston results in increased fuel consumption. In an SCC engine the cylinder is supplied with just the amount of fuel and air needed at any particular time. The remainder of the cylinder is filled with exhaust gases. This means that the piston does not need to draw in extra air and pumping losses are reduced. The exhaust gases account for 60–70% of the combustion chamber volume, while 29–39% is air; the fuel occupies less than 1%. In general, a higher proportion of exhaust gas is used when the engine is running at low load.

Under low load conditions, the spark is fired from the centre electrode of the plug injector to a fixed earth electrode with a gap of 3.5 mm. Under high load conditions, the spark is fired later (retarded). The gas density in the combustion chamber, under these conditions, is too high for the spark to jump 3.5 mm. A pin on the piston is used instead. The spark will jump to the electrode on the piston when the gap is less than 3.5 mm.

The Saab combustion control system is now in use and is proving to be very effective. Developments are continuing.

10.9.9 Active cooling – Valeo

Valeo has developed an active cooling system known as THEMIS. This system uses electronic control to manage and optimize engine temperature. The main system components are an electronic valve, an electronically controlled fan and an electrical water pump. Engine temperature is controlled by the efficient management of coolant and air within and around the engine. The advantages of this system are:

- Reduced fuel consumption.
- Lower emissions.
- Reduced engine wear.

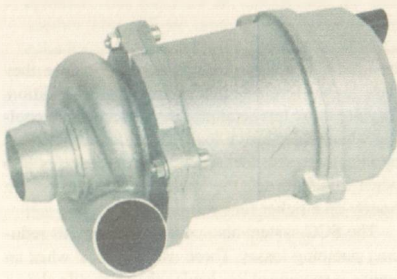


Figure 10.71 Pumptronic® – electric cooling pump (Source: Valeo)

Better cabin comfort is achieved by boosting of the heating at lower engine speeds, and heating in the cabin is maintained in cold weather after the engine has been switched off.

Development of Valeo's fully electronically controlled thermal management system, THEMIS, started in 1995, to work towards satisfying the Euro IV and Euro V emission levels and the Corporate Average Fuel Economy (CAFE) regulation for North America. Valeo designed and prototyped several variants of THEMIS. These have been tested extensively on various European and US cars from 1.4 litre L4 to 3.8 litre V6 engines.

The complete architecture consists of:

- Pumptronic® or electronic water pump. This system uses brushless motor technology, wet-rotor and rare earth magnets. This results in a global efficiency of over 55%.
- Fantronic® or continuous variable speed fan system. This uses an embedded pulse width modulation driver in the motor, which is cooled by the fan blades themselves.
- Multi-way proportional electronic valve.
- Engine temperature sensor.
- Electronic control unit.
- Optimized heat exchangers (coolant radiators and heater cores).

In addition to improved fuel efficiency, reduced emission levels, enhanced cabin comfort and improved engine reliability, it is possible to have fail-safe modes, self diagnosis options and servicing diagnosis. Fuel consumption and emissions were tested according to the European and US test cycles in laboratory conditions. Field testing was carried out at very low temperatures in Northern Europe and at the hottest temperatures in Southern Europe.

Coolant does not flow during warm up, to allow the engine to heat up quickly; this limits thermal losses. Emissions of HC decrease by 10% and CO by 0–20% during the test cycles. NOx remains unchanged. A higher coolant temperature (110/115°C vs 95°C) is possible on low and medium loads. This results in more efficient combustion, a 2–5% fuel economy and proportionate reduction of CO₂ emissions. The following benefits are also evident:

- Boosting water flow in cold weather provides 30 minutes of heating even after the engine has stopped.
- When cabin heating is not required, there is no water flow in the heater core to optimize climate control systems.
- Knocking and local boiling in the cylinder head are reduced. At high engine load, the ECU

lowers engine temperature to an average 90 °C for maximum performance.

- No thermal shocks or heat peak when the engine stops. The electric water pump boosts water flow to ensure a steady reduction of temperature when necessary.
- Potential trouble can be anticipated. In the case of a rapid rise of temperature, the controller boosts the water flow and/or the fan system.

The Valeo THEMIS system tunes and controls the operation of the various components continuously. If one component is not working correctly, the system can compensate by over-boosting another component. This is known as a fail-safe mode and the driver is informed via a warning light. Overall, this

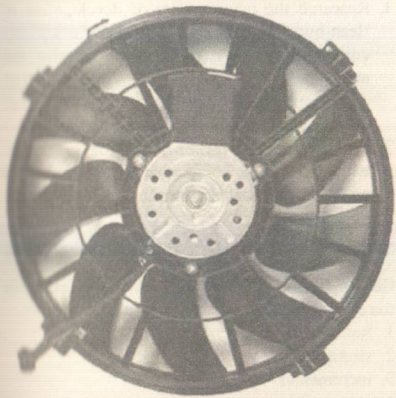


Figure 10.72 Fantronic® – electrically operated cooling fan (Source: Valeo)

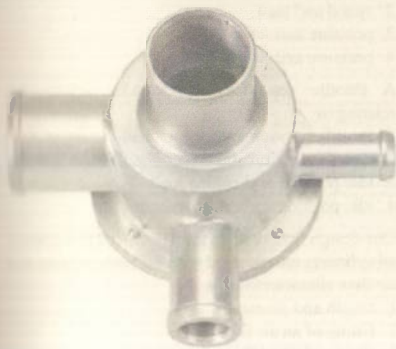


Figure 10.73 Electronic control valve (Source: Valeo)

active cooling system also reduces the power consumed by the water pump. The first applications are expected in 2005.

10.9.10 Engine trends – spark ignition

Recently in Europe (late 2003), vehicles with compression ignition (CI) engines have started to out-sell the spark ignition (SI) versions. However, because of this competition, as well as that from alternative fuel vehicles, engineers are making more developments to the SI engine. More power, reduced consumption and emissions, together with more efficient packaging are the key challenges being met. Some of the innovations under development and/or in use are considered briefly here.

Variable compression ratios

A higher compression ratio results in greater thermal efficiency. However, it also makes the engine run hotter and the components are under greater stress. Being able to vary the compression ratio to achieve improvements under certain speed and load conditions is an innovative approach. Saab has done considerable work in this area.

Electromechanical valve train

Full control of valve operation means engine management can take greater control. However, operating valves independently is difficult – so the camshaft will be with us for some time yet. Lotus engineers have made significant advancements using hydraulic operating mechanisms.

High efficiency superchargers

New developments in supercharging mean that the charger itself takes less energy from the engine. Of particular interest are electrically driven superchargers because they allow full electronic control.

Cylinder deactivation

This technique has been tried on and off for a number of years. The capacity of, say, a 3-litre V8 is reduced when used around town, with the consequent reduction in consumption and emissions. GM uses this system on their XV8 engine. It is called displacement on demand.

High pressure direct injection

Gasoline direct injection is now becoming commonplace. However, work is ongoing to increase the fuel pressure, as this results in more possibilities for

controlling the cylinder charge. Needless to say, Bosch are working in this area!

Reduced-current draw-fuel pumps

A simple but effective technique, which can result in lower emissions and consumption, is to reduce the electrical current consumed. A fuel pump has been developed by Visteon, which can increase fuel economy by up to 0.2 mpg.

Intelligent valve control

Honda have produced an engine for the RSX that uses intelligent valve control. The valve lift and phase can be controlled electronically. The result is impressive economy and low emissions.

Gas-by-wire

This concept has been in use by BMW for some time. The idea is that the driver's instructions, via the throttle pedal, are interpreted and the throttle is moved to achieve optimum performance. For example, for full acceleration the driver 'floors' the pedal – which opens the throttle fully on a traditional system – but opens the throttle more progressively on a gas-by-wire system.

Air-assisted direct fuel injection

One important aspect of direct fuel injection is that the charge in the cylinder can be stratified. In other words, the region around the plug is at the ideal ratio, but a large part of the cylinder is then made up of air or, better, recirculated exhaust gases. Ford now have an engine that can run as lean as 60:1.

'W' engine configuration

An interesting cylinder configuration, quite appropriately developed by VW, is the 'double V' or 'W' concept. This allows a W12 engine to be as compact as a V8. The result is very smooth operation and a relatively low mass which, as with any reduction in mass, improves efficiency.

Some of the areas outlined above are discussed in more detail in other parts of this book. The overall implication, however, is that there is a lot of life left in the SI engine yet ...

10.10 Self-assessment

10.10.1 Questions

1. Describe what is meant by 'Engine management'.
2. State what the term 'light off' refers to in connection with catalytic converters.
3. Explain the stages of calculating 'fuel quantity' that take place in an ECU.

4. Make a clearly labelled sketch to show an exhaust gas recirculation system.
5. Draw a block diagram of an engine management system showing all the main inputs and outputs.
6. Describe the purpose of on-board diagnostics (OBD).
7. Make a simple sketch to show a variable length inlet manifold system.
8. State the information provided by a throttle potentiometer.
9. State four methods of reducing diesel engine emissions.
10. Explain the operation of a gasoline direct injection (GDI) system.

10.10.2 Assignment

1. Research the current state of development of 'lean-burn' technology. Produce an essay discussing current progress. Consider also the advantages and disadvantages of this method of engine operation. Make a reasoned prediction of the way in which this technology will develop.
2. Compare the early version of the Motronic system with the Motronic M5 or other systems and report on where, and why, changes have been made.

10.10.3 Multiple choice questions

Gasoline direct injection systems allow mixture in the cylinder to be:

1. homogenous
2. stratified
3. incremental
4. strong

The main ECU 'input' parameters for calculating ignition timing and injector duration are:

1. speed and temperature
2. speed and load
3. pressure and temperature
4. pressure and load

A throttle potentiometer provides information relating to:

1. throttle position and engine load
2. throttle position and driver intention
3. idle position and engine load
4. idle position and driver intention

One design feature of an inlet manifold that ensures all cylinders are supplied with the same volume and air flow characteristics is the:

1. length and diameter
2. fitting of an air flow meter
3. fitting of a MAP sensor
4. material it is made from

Atomization and distribution of fuel is generally improved if the air:

1. speed is reduced
2. pressure is reduced
3. is heated
4. is cooled

A catalytic converter is fitted close to the exhaust manifold because:

1. it is the furthest point from the expansion box
2. it is protected from vibration
3. exhaust heat aids chemical reactions
4. exhaust gas speed is low at this point

Measurement of exhaust emissions, just after starting the engine from cold, gives a higher than specification reading. The reason for this is:

1. the temperature of the catalyst is low
2. the catalyst is faulty
3. combustion temperature is always higher after start-up
4. compression pressures are higher after start-up

A function that switches off the injectors during certain conditions is known as:

1. over-run fuel cut-off
2. deceleration reduction
3. under-run fuel cut-off
4. acceleration reduction

An EGR system usually operates during:

1. cold starts
2. high vacuum conditions
3. fast accelerations
4. engine decelerations

A correctly functioning lambda sensor will give readings between:

1. 0.002–0.008 volts
2. 0.02–0.08 volts
3. 0.2–0.8 volts
4. 2–8 volts

11

Lighting

11.1 Lighting fundamentals

11.1.1 Introduction

Vehicle lighting systems are very important, particularly where road safety is concerned. If headlights were suddenly to fail at night and at high speed, the result could be catastrophic. Many techniques have been used, ranging from automatic changeover circuits to thermal circuit breakers, which pulse the lights rather than putting them out as a blown fuse would. Modern wiring systems fuse each bulb filament separately and even if the main supply to the headlights failed, it is likely that dim-dip would still work.

We have come a long way since lights such as the Lucas 'King of the road' were in use. These were acetylene lamps! A key point to remember with vehicle lights is that they must allow the driver to:

- See in the dark.
- Be seen in the dark (or conditions of poor visibility).

Sidelights, tail lights, brake lights and others are relatively straightforward. Headlights present the most problems, namely that, on dipped beam they must provide adequate light for the driver but without dazzling other road users. Many techniques have been tried over the years and great advances have been made, but the conflict between seeing and dazzling is very difficult to overcome. One of the latest developments, ultra-violet (UV) lighting, which is discussed later, shows some promise.

11.1.2 Bulbs

Joseph Swan in the UK demonstrated the first light bulb in 1878. Much incremental development has taken place since that time. The number, shape and size of bulbs used on vehicles is increasing all the time. Figure 11.1 shows a common selection. Most bulbs for vehicle lighting are generally either conventional tungsten filament bulbs or tungsten halogen.

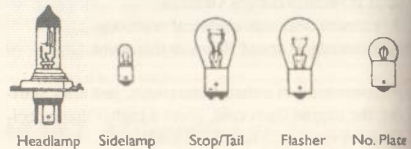


Figure 11.1 Selection of bulbs

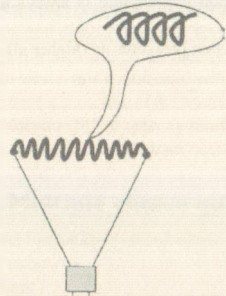


Figure 11.2 A bulb filament is like a spiralled spiral

In the conventional bulb the tungsten filament is heated to incandescence by an electric current. In a vacuum the temperature is about 2300°C . Tungsten is a heavy metallic element and has the symbol W, its atomic number is 74, and its atomic weight 2.85. The pure metal is steel grey to tin white in colour. Its physical properties include the highest melting point of all metals: 3410°C . Pure tungsten is easily forged, spun, drawn and extruded, whereas in an impure state it is brittle and can be fabricated only with difficulty. Tungsten oxidizes in air, especially at higher temperatures, but it is resistant to corrosion and is only slightly attacked by most mineral acids. Tungsten or its alloys are therefore ideal for use as filaments for electric light bulbs. The filament is normally wound into a 'spiralled spiral' to allow a suitable length of thin wire in a small space and to provide some mechanical strength. Figure 11.2 shows a typical bulb filament.

If the temperature mentioned above is exceeded even in a vacuum, then the filament will become

very volatile and break. This is why the voltage at which a bulb is operated must be kept within tight limits. The vacuum in a bulb prevents the conduction of heat from the filament but limits the operating temperature.

Gas-filled bulbs are more usual, where the glass bulb is filled with an inert gas such as argon under pressure. This allows the filament to work at a higher temperature without failing and therefore produce a whiter light. These bulbs will produce about 17 lm/W compared with a vacuum bulb, which will produce about 11 lm/W.

Almost all vehicles now use tungsten halogen bulbs for their headlights as these are able to produce about 24 lm/W (more for some modern designs). The bulb has a long life and will not blacken over a period of time like other bulbs. This is because in normal gas bulbs, over a period of time, about 10% of the filament metal evaporates and is deposited on the bulb wall. The gas in halogen bulbs is mostly iodine. The name halogen is used because there are four elements within group VIIA of the periodic table, known collectively as the halogens. The name, derived from the Greek *hal-* and *-gen*, means 'salt-producing'. The four halogens are bromine, chlorine, fluorine and iodine. They are highly reactive and are not found free in nature. The gas is filled to a pressure of several bar.

The glass envelope used for the tungsten halogen bulb is made from fused silicon or quartz. The tungsten filament still evaporates but, on its way to the bulb wall, the tungsten atom combines with two or more halogen atoms forming a tungsten halide. This will not be deposited on to the bulb because of its temperature. The convection currents will cause the halide to move back towards the filament at some point and it then splits up, returning the tungsten to the filament and releasing the halogen. Because of this the bulb will not become blackened, the light output will therefore remain constant throughout its life. The envelope can also be made smaller as can the filament, thus allowing better focusing. Figure 11.3 shows a tungsten halogen headlight bulb.

Next, some common bulbs are discussed further.

Pestoon

The glass envelope has a tubular shape, with the filament stretched between brass caps cemented to the tube ends. This bulb was commonly used for number-plate and interior roof lighting.

Miniature centre contact (MCC)

This bulb has a bayonet cap consisting of two locating pins projecting from either side of the cylindrical

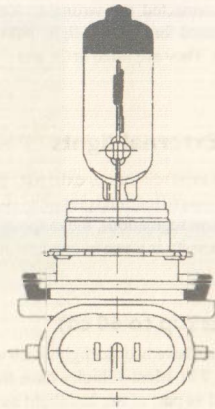


Figure 11.3 Halogen bulb

cap. The diameter of the cap is about 9 mm. It has a single central contact (SCC), with the metal cap body forming the second contact, often the earth connection. It is made with various power ratings ranging from 1 to 5 W.

Capless bulb

These bulbs have a semi-tubular glass envelope with a flattened end, which provides the support for the terminal wires, which are bent over to form the two contacts. The power rating is up to 5 W, and these bulbs are used for panel lights, sidelights and parking. They are now very popular due to the low cost of manufacture.

Single contact, small bayonet cap (SBC)

These bulbs have a bayonet cap with a diameter of about 15 mm with a spherical glass envelope enclosing a single filament. A single central contact (SCC) uses the metal cap body to form the second contact. The size or wattage of the bulb is normally 5 W or 21 W. The small 5 W bulb, is used for side or tail lights and the larger 21 W bulb is used for indicators, hazard, reversing and rear fog-lights.

Double contact, small bayonet cap

Similar in shape and size to the large SCC 15 mm SBC bulb, as described above. It has two filaments, one end of each being connected to an end contact, and both of the other ends are joined to the cap body forming a third contact, which is usually the earth. These caps have offset bayonet pins so that the two filaments, which are of different wattage,

cannot be connected the wrong way around. One filament is used for the stop light and the other for the tail light. They are rated at 21 and 5 W (21/5 W) respectively.

11.1.3 External lights

Regulations exist relating to external lights, the following is a simplified interpretation and amalgamation of current regulations, the range of permissible luminous intensity is given in brackets after each sub heading.

Sidelights (up to 60 cd)

A vehicle must have two sidelights each with wattage of less than 7 W. Most vehicles have the sidelights incorporated as part of the headlight assembly.

Rear lights (up to 60 cd)

Again, two must be fitted each with wattage not less than 5 W. Lights used in Europe must be 'E' marked and show a diffused light. Their position must be within 400 mm from the vehicle edge and over 500 mm apart, and between 350 and 1500 mm above the ground.

Brake lights (40–100 cd)

These two lights are often combined with the rear lights. They must be between 15 and 36 W each, with diffused light and must operate when any form of first line brake is applied. Brake lights must be between 350 and 1500 mm above the ground and at least 500 mm apart in a symmetrical position. High-level brake lights are now allowed and, if fitted, must operate with the primary brake lights.

Reversing lights (300–600 cd)

No more than two lights may be fitted with a maximum wattage each of 24 W. The light must not dazzle and either be switched automatically from the gearbox or with a switch incorporating a warning light. Safety reversing 'beepers' are now often fitted in conjunction with this circuit, particularly on larger vehicles.

Day running lights (800 cd max)

Volvo use day running lights as these are in fact required in Sweden and Finland. These lights come on with the ignition and must only work in conjunction with the rear lights. Their function is to indicate that the vehicle is moving or about to move. They switch off when parking or headlights are selected.

Rear fog lights (150–300 cd)

One or two may be fitted but, if only one, then it must be on the offside or centre line of the vehicle. They must be between 250 and 1000 mm above the ground and over 100 mm from any brake light. The wattage is normally 21 W and they must only operate when either the sidelights, headlights or front fog lights are in use.

Front spot and fog lights

If front spot lights are fitted (auxiliary driving lights), they must be between 500 and 1200 mm above the ground and more than 400 mm from the side of the vehicle. If the lights are non-dipping then they must only operate when the headlights are on main beam. Front fog lamps are fitted below 500 mm from the ground and may only be used in fog or falling snow. Spot lamps are designed to produce a long beam of light to illuminate the road in the distance. Fog lights are designed to produce a sharp cut off line such as to illuminate the road just in front of the vehicle but without reflecting back or causing glare.

Figure 11.4 shows a selection of vehicle light designs and some of the groupings used.

11.1.4 Headlight reflectors

Light from a source, such as the filament of a bulb, can be projected in the form of a beam of varying patterns by using a suitable reflector and a lens. Reflectors used for headlights are usually parabolic, bifocal or homifocal. Lenses, which are also used as the headlight cover glass, are used to direct the light to the side of the road and in a downward direction. Figure 11.5 shows how lenses and reflectors can be used to direct the light.

The object of the headlight reflector is to direct the random light rays produced by the bulb into a beam of concentrated light by applying the laws of reflection. Bulb filament position relative to the reflector is important, if the desired beam direction and shape are to be obtained. This is demonstrated in Figure 11.5(a). First, the light source (the light filament) is at the focal point, so the reflected beam will be parallel to the principal axis. If the filament is between the focal point and the reflector, the reflected beam will diverge – that is, spread outwards along the principal axis. Alternatively, if the filament is positioned in front of the focal point the reflected beam will converge towards the principal axis.

A reflector is basically a layer of silver, chrome or aluminium deposited on a smooth and polished



(a)



(b)

surface such as brass or glass. Consider a mirror reflector that 'caves in' – this is called a concave reflector. The centre point on the reflector is called the pole, and a line drawn perpendicular to the surface from the pole is known as the principal axis. If a light source is moved along this line, a point will be found where the radiating light produces a reflected beam parallel to the principal axis. This point is known as the focal point, and its distance from the pole is known as the focal length.

Parabolic reflector

A parabola is a curve similar in shape to the curved path of a stone thrown forward in the air. A parabolic reflector (Figure 11.5(a)) has the property of reflecting rays parallel to the principal axis when a light source is placed at its focal point, no matter where the rays fall on the reflector. It therefore

produces a bright parallel reflected beam of constant light intensity. With a parabolic reflector, most of the light rays from the light-bulb are reflected and only a small amount of direct rays disperses as stray light.

The intensity of reflected light is strongest near the beam axis, except for light cut-off by the bulb itself. The intensity drops off towards the outer edges of the beam. A common type of reflector and bulb arrangement is shown in Figure 11.6 where the dip filament is shielded. This gives a nice sharp cut-off line when on dip beam and is used mostly with asymmetric headlights.

Bifocal reflector

The bifocal reflector (Figure 11.5(c)) as its name suggests has two reflector sections with different focal points. This helps to take advantage of the



Figure 11.4 Vehicle lighting designs. (a) Ford Mustang (b) Jaguar S-Type; (c) Mercedes-Benz S-class; (d) the Hyundai XG

light striking the lower reflector area. The parabolic section in the lower area is designed to reflect light down to improve the near field area just in front of the vehicle. This technique is not suitable for twin filament bulbs, it is therefore only used on vehicles with a four-headlight system. With the aid of powerful CAD programs, variable focus reflectors can be made with non-parabolic sections to produce a smooth transition between each area.

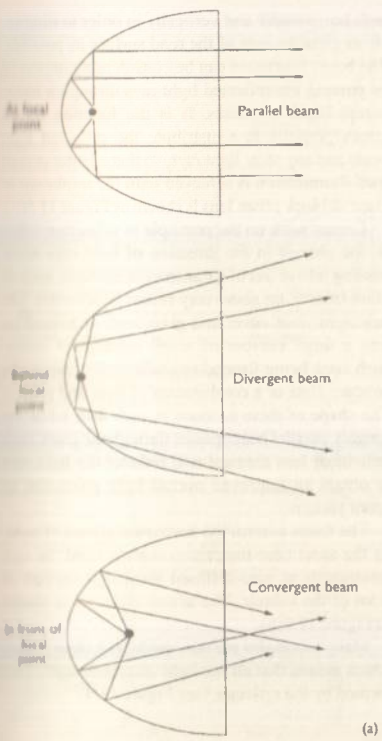
Homifocal reflector

A homifocal reflector (Figure 11.5(d)) is made up of a number of sections each with a common focal point. This design allows a shorter focal length and hence, overall, the light unit will have less depth.

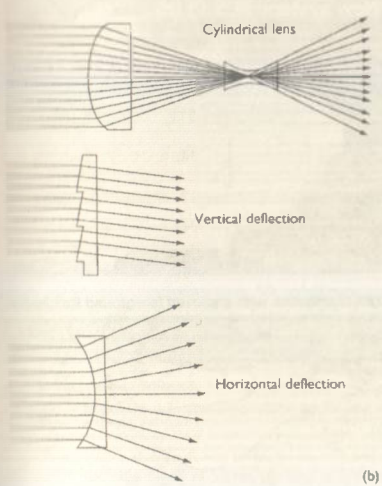
The effective luminous flux is also increased. It can be used with a twin filament bulb to provide dip and main beam. The light from the main reflector section provides the normal long range lighting and the auxiliary reflectors improve near field and lateral lighting.

Poly-ellipsoidal headlight system (PES)

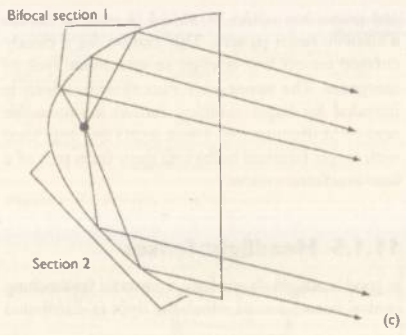
The poly-ellipsoidal system (PES) as shown in Figure 11.7 was introduced by Bosch in 1983. It allows the light produced to be as good, or in some cases better than conventional lights, but with a light-opening area of less than 30 cm^2 . This is achieved by using a CAD designed elliptical reflector



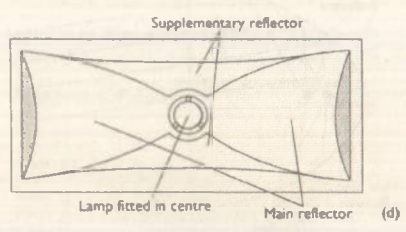
(a)



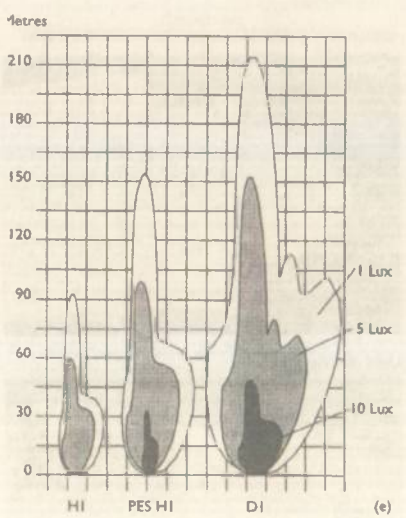
(b)



(c)



(d)



(e)

Figure 11.5 Headlight patterns are produced by careful use of lenses and reflectors

and projection optics. A shield is used to ensure a suitable beam pattern. This can be for a clearly defined cut-off line or even an intentional lack of sharpness. The newer PES Plus system, which is intended for larger vehicles, further improves the near-field illumination. These lights are only used with single filament bulbs and must form part of a four-headlamp system.

11.1.5 Headlight lenses

A good headlight should have a powerful far-reaching central beam, around which the light is distributed

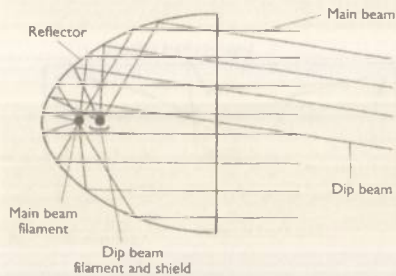
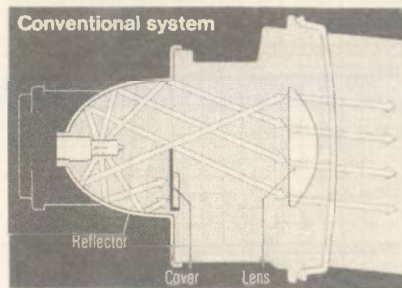


Figure 11.6 Creating a dip beam with a twin filament shielded bulb



Light distribution

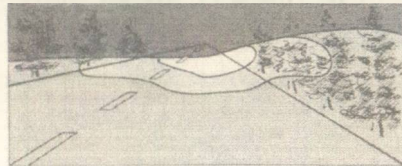


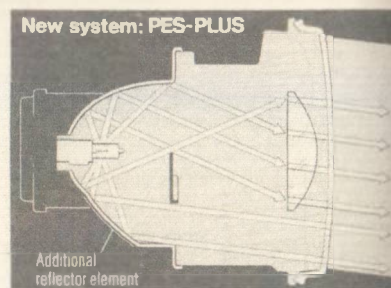
Figure 11.7 Improved poly-ellipsoid low beam

both horizontally and vertically in order to illuminate as great an area of the road surface as possible. The beam formation can be considerably improved by passing the reflected light rays through a transparent block of lenses. It is the function of the lenses partially to redistribute the reflected light beam and any stray light rays, so that a better overall road illumination is achieved with the minimum of glare. A block prism lens is shown as Figure 11.5(b).

Lenses work on the principle of refraction – that is, the change in the direction of light rays when passing into or out of a transparent medium, such as glass (plastic on some very recent headlights). The headlight front cover and glass lens, is divided up into a large number of small rectangular zones, each zone being formed optically in the shape of a concave flute or a combination of flute and prisms. The shape of these sections is such that, when the roughly parallel beam passes through the glass, each individual lens element will redirect the light rays to obtain an improved overall light projection or beam pattern.

The flutes control the horizontal spread of light. At the same time the prisms sharply bend the rays downwards to give diffused local lighting just in front of the vehicle. The action of lenses is shown as Figure 11.5(b).

Many headlights are now made with clear lenses, which means that all the light directionality is performed by the reflector (see Figure 11.4).



Light distribution with improved foreground illumination

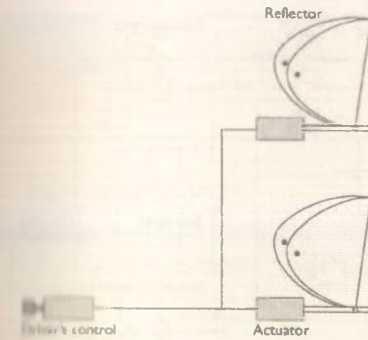
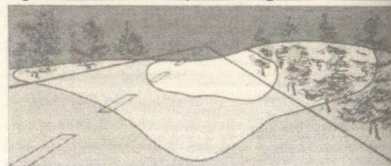


Figure 11.8 Manual headlight levelling

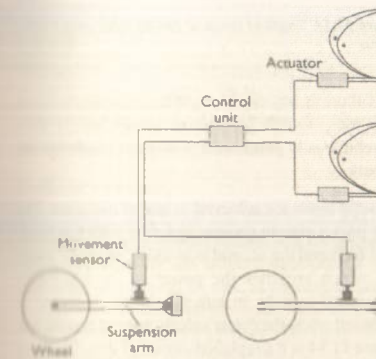


Figure 11.9 Automatic headlight adjustment

11.1.6 Headlight levelling

The principle of headlight levelling is very simple, the position of the lights must change depending on the load in the vehicle. Figure 11.8 shows a simple manual aiming device operated by the driver.

An automatic system can be operated from sensors positioned on the vehicle suspension. This will allow automatic compensation for whatever the load distribution on the vehicle. Figure 11.9 shows the layout of this system. The actuators, which actually move the lights, can vary from hydraulic devices to stepper motors.

The practicality of headlight aiming is represented by Figure 11.10. Adjustment is by moving two screws positioned on the headlights, such that one will cause the light to move up and down the other will cause side-to-side movement.

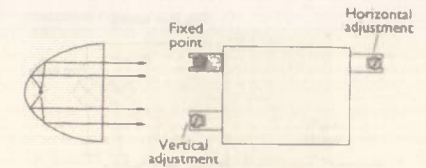


Figure 11.10 Principle of headlight aiming

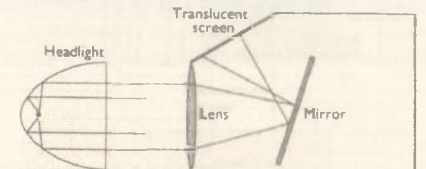


Figure 11.11 Beam setter principle

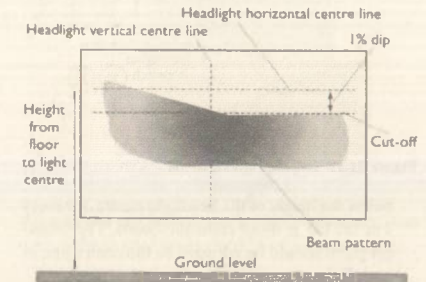


Figure 11.12 Headlight aiming board

11.1.7 Headlight beam setting

Many types of beam-setting equipment are available and most work on the same principle, which is represented in Figure 11.11. The method is the same as using an aiming board but is more convenient and accurate due to easier working and less room being required.

To set the headlights of a car using an aiming board the following procedure should be adopted.

1. Park the car on level ground, square on to a vertical aiming board at a distance of 10 m if possible. The car should be unladen except for the driver.
2. Mark out the aiming board as shown in Figure 11.12.
3. Bounce the suspension to ensure it is level.
4. With the lights set on dip beam, adjust the cut-off line to the horizontal mark, which will be 1 cm*

* or whatever the manufacturer recommends

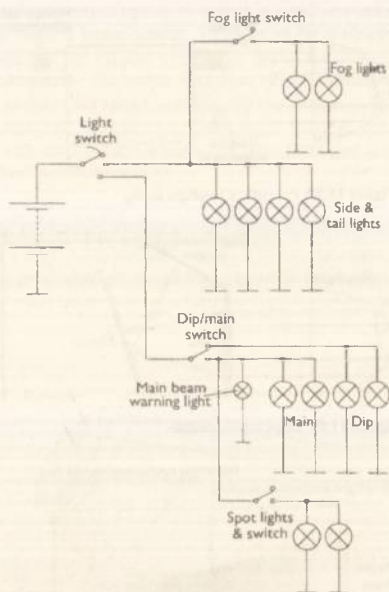


Figure 11.13 Simplified lighting circuit

below the height of the headlight centre, for every 1 m the car is away from the board. The break-off point should be adjusted to the centre line of each light in turn.

11.2 Lighting circuits

11.2.1 Basic lighting circuit

Figure 11.13 shows a simple lighting circuit. Whilst this representation helps to demonstrate the way in which a lighting circuit operates, it is not now used in this simple form. The circuit does, however, help to show in a simple way how various lights in and around the vehicle operate with respect to each other. For example, fog lights can be wired to work only when the sidelights are on. Another example is how the headlights cannot be operated without the sidelights first being switched on.

11.2.2 Dim-dip circuit

Dim-dip headlights are an attempt to stop drivers just using sidelights in semi-dark or poor visibility conditions. The circuit is such that when sidelights and ignition are on together, then the headlights will come on automatically at about one-sixth of normal power.

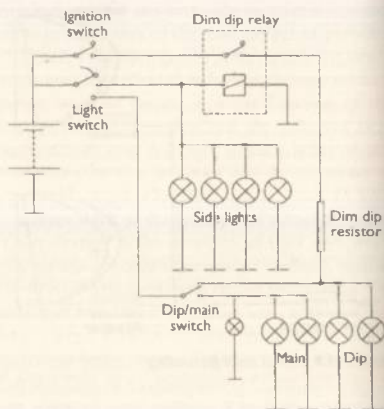


Figure 11.14 Simplified circuit of dim-dip lights using a series resistor

If there is any doubt as to the visibility or conditions, switch on dipped headlights. If your vehicle is in good order it will not discharge the battery.

Dim-dip lights are achieved in one of two ways. The first uses a simple resistor in series with the headlight bulb and the second is to use a 'chopper' module, which switches the power to the headlights on and off rapidly. In either case the 'dimmer' is bypassed when the driver selects normal headlights. Figure 11.14 is a simplified circuit of dim-dip lights using a series resistor. This is the most cost-effective method but has the problem that the resistor (about $1\ \Omega$) gets quite hot and hence has to be positioned appropriately.

11.3 Gas discharge and LED lighting

11.3.1 Gas discharge lamps

Gas discharge headlamps (GDL) are now being fitted to vehicles. They have the potential to provide more effective illumination and new design possibilities for the front of a vehicle. The conflict between aerodynamic styling and suitable lighting positions is an economy/safety tradeoff, which is undesirable. The new headlamps make a significant contribution towards improving this situation because they can be relatively small. The GDL system consists of three main components.

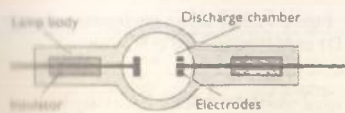


Figure 11.15 Operating principle of a gas discharge bulb

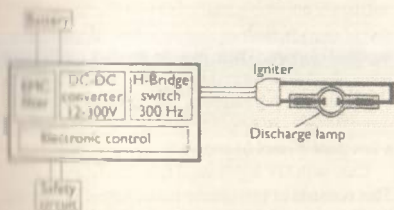


Figure 11.16 Ballast system to control a GDL

Lamp

This operates in a very different way from conventional incandescent bulbs. A much higher voltage is needed. Figure 11.15 illustrates the operating principle of a GD bulb.

Ballast system

This contains an ignition and control unit and converts the electrical system voltage into the operating voltage required by the lamp. It controls the ignition stage and run up as well as regulating during normal use and finally monitors operation as a safety aspect. Figure 11.16 shows the lamp circuit and components.

Headlamp

The design of the headlamp is broadly similar to conventional units. However, in order to meet the limits set for dazzle, a more accurate finish is needed, hence more production costs are involved.

The source of light in the gas discharge lamp is an electric arc, and the actual discharge bulb is only about 10 mm across. Two electrodes extend into the bulb, which is made from quartz glass. The gap between these electrodes is 4 mm. The distance between the end of the electrode and the bulb contact surface is 25 mm – this corresponds to the dimensions of the standardized H1 bulb.

At room temperature, the bulb contains a mixture of mercury, various metal salts and xenon under pressure. When the light is switched on, the xenon illuminates at once and evaporates the mercury and metal salts. The high luminous efficiency is due to the metal vapour mixture. The mercury generates most of the light and the metal salts affect the colour

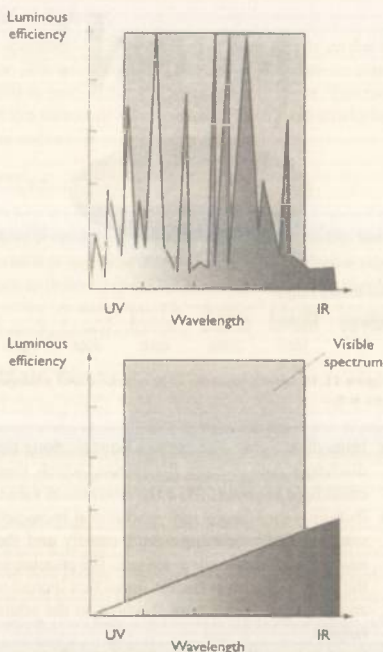


Figure 11.17 Spectrum of light produced by the GDL (top) compared with that from a halogen HI bulb

Table 11.1 Comparison of HI and DI bulbs

Bulb	Light (%)	Heat (%)	UV radiation (%)
HI	8	92	<1
DI	28	58	14

spectrum. Figure 11.17 shows the spectrum of light produced by the GDL compared with that from a halogen HI bulb. Table 11.1 highlights the difference in output between the DI and HI bulbs (the figures are approximate and for comparison only).

The high output of UV radiation from the GDL means that for reasons of safety, special filters are required. Figure 11.18 shows the luminance of the GDL again compared with an H1 bulb. The average output of the GDL is three times greater.

To start the DI lamp, the following four stages are run through in sequence.

- Ignition – a high voltage pulse causes a spark to jump between the electrodes, which ionizes the gap. This creates a tubular discharge path.

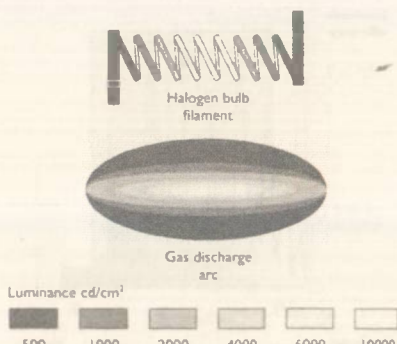


Figure 11.18 Luminance of the GDL compared with a halogen light bulb

- Immediate light – the current flowing along the discharge path excites the xenon, which then emits light at about 20% of its continuous value.
- Run-up – the lamp is now operated at increased wattage, the temperature rises rapidly and the mercury and metal salts evaporate. The pressure in the lamp increases as the luminous flux increases and the light shifts from the blue to the white range.
- Continuous – the lamp is now operated at a stabilized power rating of 35 W. This ensures that the arc remains still and the output does not flicker. The luminous flux (28 000 lm) and the colour temperature (4500 K) are reached.

In order to control the above stages of operation, a ballast system is required. A high voltage, which can be as much as 20 kV, is generated to start the arc. During run-up, the ballast system limits the current and then also limits voltage. This wattage control allows the light to build up very quickly but prevents overshoot, which would reduce the life of the bulb. The ballast unit also contains radio suppression and safety circuits.

The complete headlamp can be designed in a different way, as the D1 bulb produces 2.5 times the light flux and at less than half the temperature of the conventional H1 bulb. This allows far greater variation in the styling of the headlamp and hence the front end of the vehicle.

If the GDL system is used as a dip beam, the self-levelling lights are required because of the high luminous intensities. However, use as a main beam may be a problem because of the on/off nature. A GDL system for dip beam, which stays on all the time and is supplemented by a conventional main beam (four-headlamp system), may be the most appropriate

use. Figure 11.5(e) shows the light distribution of the D1 and H1 bulbs used in headlamps.

11.3.2 Ultraviolet headlights

The GDL can be used to produce ultraviolet (UV) lights. Since UV radiation is virtually invisible it will not dazzle oncoming traffic but will illuminate fluorescent objects such as specially treated road markings and clothing. These glow in the dark much like a white shirt under some disco lights. The UV light will also penetrate fog and mist, as the light reflected by water droplets is invisible. It will even pass through a few centimetres of snow.

Cars with UV lights use a four-headlamp system. This consists of two conventional halogen main/dip lights and two UV lights. The UV lights come on at the same time as the dipped beams, effectively doubling their range but without dazzling.

Two-stage blue filters are used to eliminate visible light. Precise control of the filter colour is needed to ensure UVB and UVC are filtered out, as these can cause eye damage and skin cancer. This leaves UVA, which is just beyond the visible spectrum and is used, for example, in suntan lamps. However, some danger still exists; for example, if a child were to look directly and at close range into the faint blue glow of the lights. To prevent this, the lights will only operate when the vehicle is moving. This is a very promising contribution to road safety.

11.3.3 LED lighting

Light emitting diode (LED) displays were first produced commercially in 1968. Almost from this time there has been speculation as to possible vehicle applications. Such LEDs have certainly found applications in the interior vehicle, particularly in dashboard displays. However, until recently, legislation has prevented the use of LEDs for exterior lighting. A simple change in the legislative language from 'incandescent lamp' to 'light source', has at last made it possible to use lighting devices other than filament bulbs. Figure 11.19 shows a light unit containing LEDs.

The advantages of LED lighting are clear, the greatest being reliability. LEDs have a typical rated life of over 50 000 hours, compared with just a few thousand for incandescent lamps. The environment in which vehicle lights have to survive is hostile to say the least. Extreme variations in temperature and humidity as well as serious shocks and vibration have to be endured.

LEDs are more expensive than bulbs but the potential savings in design costs due to sealed units

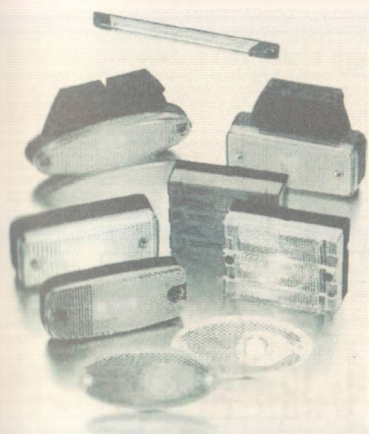


Figure 11.19 Light units with LEDs

being used and the greater freedom of design could outweigh the extra expense. A further advantage is that they turn on quicker than ordinary bulbs. This turn-on time is important; the times are about 130 ms for the LEDs, and 200 ms for bulbs. If this is related to a vehicle brake light at motorway speeds, then the increased reaction time equates to about a car length. This is also potentially a major contribution to road safety.

Most of the major manufacturers are undertaking research into the use of LED lighting. Much time is being spent looking at the use of LEDs as high-level brake lights. This is because of their shock resistance, which will allow them to be mounted on the boot lid. In convertible cars, which have no rear screen as such, this application is ideal. Many manufacturers are designing rear spoilers with lights built in, and this is a good development as a safety aspect.

Heavy vehicle side marker lights are an area of use where LEDs have proved popular. Many lighting manufacturers are already producing lights for the after-market. Being able to use sealed units will greatly increase the life expectancy. Side indicator repeaters are a similar issue due to the harsh environmental conditions.

11.4 Case studies

11.4.1 Rover lighting circuit

The circuit shown in Figure 11.20 is the complete lighting system of a Rover vehicle. Operation of the main parts of this circuit is as follows.

Sidelights

Operation of the switch allows the supply on the N or N/S wire (colour codes are discussed on page 85) to pass to fuses 7 and 8 on an R wire. The two fuses then supply left sidelights and right sidelights as well as the number plate light.

Dipped beam

When the dip beam is selected, a supply is passed to fuse 9 on a U wire and then to the dim-dip unit, which is now de-energized. This then allows a supply to fuses 10 and 11 on the O/U wire. This supply is then passed to the left light on a U/K wire and the right light on a U/B wire.

Main beam

Selecting main beam allows a supply on the U/W wire to the main/dip relay, thus energizing it. A supply is therefore placed on fuses 21 and 22 and hence to each of the headlight main beam bulbs.

Dim-dip

When sidelights are on there is a supply to the dim-dip unit on the R/B wire. If the ignition supplies a second feed on the G wire then the unit will allow a supply from fuse 5 to the dim-dip resistor on an N/S wire and then on to the dim-dip unit on an N/G wire. The unit then links this supply to fuses 10 and 11 (dip beam fuses).

11.4.2 Generic lighting circuit – Bosch

Figure 11.21 shows a typical lighting circuit using the 'flow diagram' or schematic technique. The identifiers are listed in the Table 11.2. Note that, when following this circuit, the wires do not pass directly through the 'lamp check module' from top to bottom. There is a connection to the appropriate lamp but this will be through for example, a sensing coil.

Also, note how codes are used to show connections from some components to others rather than a line representing the wire. This is to reduce the number of wires in general but also to reduce cross-over points.

11.4.3 Xenon lighting – Hella

The risk of being injured or killed in a traffic accident on the roads is much higher at night than during the day, in spite of the smaller volumes of traffic. Although only about 33% of accidents occur at dusk or in the dark, the number of persons seriously injured increases by 50%, and the number of deaths

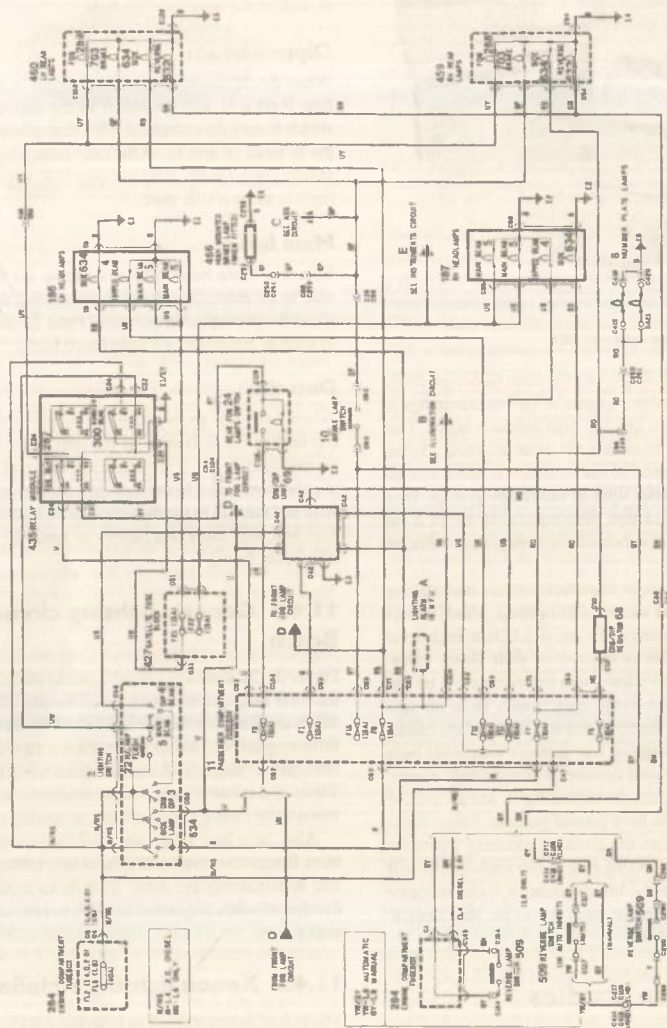


Figure 11.20 Complete vehicle lighting circuit

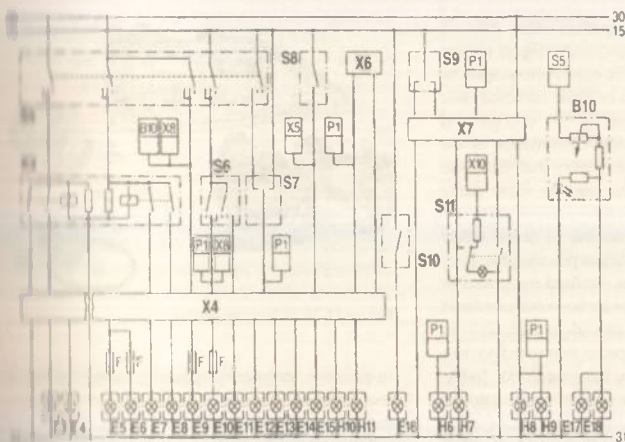


Figure 11.21 Lighting circuit flow diagram

Table 11.2 Identifiers for Figure 11.21

Identifier	Device
B10	Dimmer for instrument lighting
E2, E	Fog warning lamps
E3, E	Main beam headlamps
E10	Fog lamps
E9, E	Dip beam headlamps
E11, E	Side-marker lamps
E1	Number plate lamp
E14, E	Tail lamps
E16	Reverse lamp
E17, E	Instrument lighting
E6, E, E	Indicator lamps
X3	Lighting relay
S5	Headlamp switch
S6	Fog lamp switch
S7	Dip switch
S8	Stop lamp switch
S9	Turn signal switch
S10	Back-up lamp switch
S11	Hazard warning switch
X4	Plug, lamp check module
X5	Plug, check control
X7	Socket, hazard warning relay

by 10% compared with accidents that occur during the day.

Alongside factors such as self-dazzling caused by wet road surfaces, higher speeds because of the reduced traffic density and a reduction of about 25% of the distance maintained to the vehicle in front, factors relating to eye physiology play a very important role.

The eyes age faster than any other sensory organ, and the human eye's powers of vision begin to

deteriorate noticeably from as early an age as 30! The consequence of this – a reduction in visual acuity and contrast sensitivity when the light begins to fade – is a situation that is very rarely noticed by the motorist, as these functional deficits develop only slowly.

However, the vision – even of a person with healthy eyes – is considerably reduced at night. The associated risk factors include delayed adjustment to changes between light and dark, impaired colour vision and the slow transition from day to night, which, through the habituation effect, can lull the motorist into a false sense of security.

Hella – for the past 100 years a forerunner in the development and production of innovative head-lamp and lighting systems – is therefore giving increasing backing to xenon technology, the only system that offers more light than conventional tungsten bulbs – and that is daylight quality.

However, a good xenon headlamp alone is not enough to translate the additional light quantity and quality into increased safety. In order, for example, to avoid the hazard of being dazzled by oncoming traffic, the legally required range of additional equipment includes such items as headlamp cleaning equipment and automatic beam levellers. Only the system as whole is able to provide the clear advantage of higher safety for all road-users, even under the most adverse weather conditions. This means that even in rain, fog and snow, spatial vision is improved and the motorist's orientation abilities are less restricted.

Already today, according to a survey, 94% of xenon headlamp users are convinced of their positive

benefits. Night vision is improved claim 85% of users – in the case of the over-50s this figure is even increased to 90%. Visibility in rain is also judged by 80% to be better, while 75% of those surveyed have perceived an increase in safety for cyclists and pedestrians owing to the wider illumination of the road. The same percentage maintains that, thanks to xenon light, obstacles on the road are more easily recognized.

In order to make this increase in active safety available to as many road users as possible, the automobile industry – whether as standard equipment or as an optional accessory – is laying more emphasis on xenon headlamps. The annual requirement for xenon headlamps in Europe is estimated to rise to over two million units by the year 2000. Today, more than 600 000 cars have already been equipped with xenon headlamps.

The xenon bulb is a micro-discharge bulb filled with a mixture of noble gases including xenon. The bulb has no filament, as is the case with a halogen bulb, but the light arc is created between two electrodes. As is the case with other gas discharge bulbs, the xenon bulb has an electronic starter for quick ignition, and requires an electronic ballast to function properly.

The xenon bulb provides more than twice the amount of light of a halogen bulb, while only consuming half the power. Therefore, the driver can see more clearly, and the car has more power for other functions. Moreover, it is environmentally friendly, as less power means less fuel consumption. The clear white light produced by the xenon bulb is similar to daylight. Research has shown that this enables drivers to concentrate better. Furthermore, this particular light colour reflects the road markings and signs better than conventional lighting. The xenon bulb also delivers a marked contribution to road safety in the event of limited visibility due to weather conditions. In practical terms, the life span of the bulb is equal to that of the car, which means that the bulb need only be replaced in exceptional cases.

The light produced by a xenon bulb is, in fact, not blue but white, falling well within the international specifications for white light – the light only appears blue in comparison to the warmer 'yellow' light produced by halogen. However, it clearly appears white in comparison to daylight. Technically speaking, it is possible to adapt the light colour produced, but this would lead to a substantial loss of intensity, thereby cancelling out the particular advantages.

The international regulations governing light distribution and intensity on the road are very strict. Xenon light falls well within these boundaries.

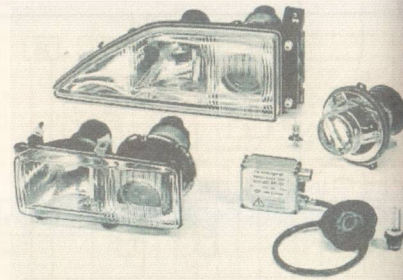


Figure 11.22 Hella xenon lighting

In addition, technically speaking, xenon lighting is less irritating than conventional light. As the light-darkness borders are much more clearly defined, less light is reflected into the eyes of oncoming drivers. The increased amount (double) of light produced is mainly used to achieve higher intensity and better distribution of light on the road. Moreover, the verges are also better lit. There are three conditions that must be met. These are contained in the international regulations concerning the use of xenon light: the headlamps must be aligned according to regulations; the vehicle must be fitted with an automatic headlamp levelling system, so that when the load is increased the headlight beams are automatically adjusted; the headlamp must be fitted with an automatic cleaning system, as dirt deposits on the lens act as a diffuser, thereby projecting the light beyond the prescribed range. These three conditions together with the extensive life span of the xenon bulb greatly reduce the risk of incorrectly aligned headlamps. The use of halogen bulbs entails a much higher risk.

Xenon light sometimes appears to irritate oncoming drivers. In normal circumstances drivers look straight ahead; however, due to the conspicuous colour of xenon light, drivers are more inclined to look into the headlamps. The same phenomenon was experienced during the introduction of halogen headlamps in the 1960s. In those days people also spoke of 'that irritating white light'. The introduction of xenon headlamps will therefore entail a period in which everybody will become accustomed. Figure 11.22 shows the xenon lamp from Hella.

11.4.4 Blue lights!

Philips 'BlueVision' white light stimulates driver concentration and makes night-time driving less tiring and reflects much better on road markings and signs. The new headlight and sidelight bulbs meet

all the European safety legislation. The bulbs are directly interchangeable with existing bulbs.

With the introduction of BlueVision, Philips Automotive Lighting is illuminating the way ahead in the future of enhanced headlamp performance. The future is ... white light BlueVision. For the simple reason that the Blue Vision lamps reproduce the light type light ... in night-time conditions!

Using the UV cut quartz developed by Philips for halogen lamps means that BlueVision can safely be used for all headlamps. However, it should be noted that halogen technology is not comparable to the xenon discharge technology, fitted as original equipment to more and more of the world's cars.

11.4.5 New signalling and lighting technologies

Valer Lighting Systems has developed new signal lighting technologies to provide more variety and innovation to signal lamp concepts, which are a key styling feature on cars.

Jewel aspect signal lamps

Jewel aspect signal lamps are based on the complex shape technology widely used in headlamps. Beam pattern is no longer completely controlled by the lens but by the reflector which, in some cases, may be in conjunction with an intermediary filter. Conventional lens optics using prisms is minimized, giving the impression of greater depth and brightness.

Mono-colour signal lamps

With mono-colour technology, in addition to the traditional red functions (stop, tail lamp and fog), the reverse and turn signal functions appear red when not in use, but emit white and amber light respectively when functioning. Several technologies make this possible. In the case of subtractive synthesis lamps, coloured screens are placed in front of the bulb. Their colours are selected so that, in conjunction with the red of the external lens, they colour the light emitted by the lamp in line with the regulations: white for reverse, amber for the turn signal. Complementary colour technology uses a two-colour external lens, which combines red (dominant) and its complementary colour (yellow for the turn signal, blue for reverse). The combination of these two lights – red and yellow for the turn signal, red and blue for reverse – produces the colour of light (white or amber) stipulated by the regulations.

Linear lighting

Linear tail lamps can easily be harmonized with the design of the vehicle by introducing the aspect of very elongated lamps. Each function light is narrow, (35 mm), and can be up to 400 mm long. The lamps use optical intermediary screens, which are so precise that they not only fulfil legal photometric requirements but also create a harmonious overall aspect and very distinct separations between the function lights. This new technology is particularly well suited for the rear of mini-vans and light trucks.

New light sources for signal lamps

LED (light emitting diode) and neon combination lamps are a unique way to combine style and safety. Innovative style: thanks to their compactness, LED and neon offer enhanced design flexibility, notably for highlighting the lines of the vehicle and illuminating the bumper. Their homogeneous or pointillist appearance accentuates the differentiation and high-tech aspect of these signal lamps. Increased safety: the response time of these new sources, approximately 0.2 s faster than incandescent bulbs, allows danger to be anticipated as it provides the equivalent of 5 m extra braking distance for a vehicle travelling behind at 120 km/h.

Centre high mounted stop lamps (CHMSLs)

An LED CHMSL illuminates 0.2 s faster than conventional incandescent lamps, improving driver response time and providing extra braking distance of 5 m at 120 km/h. Owing to their low height and reduced depth, LED CHMSLs can be easily harmonized with all vehicle designs, whether they are mounted inside or integrated into the exterior body or spoiler. The lifetime of an LED CHMSL is greater than 2000 hours, exceeding the average use of the light during the life of the vehicle. Each new LED generation feature enhances photometric performance and allows a reduction in the number of LEDs required for the CHMSL function. This number has already decreased from 16 to 12 in some configurations and should decrease even further over the next few years.

Neon technology

As with LED technology, neon lamps have an almost instantaneous response time (increased safety), take up little space (design flexibility) and last more than 2000 hours, thus exceeding the average use of a CHMSL during the life of the vehicle. Moreover, the neon CHMSL is very homogeneous in appearance and offers unmatched lateral visibility.

11.4.6 Electric headlamp levelling actuators

The primary function of a levelling actuator is to adjust the low beam in accordance with the load carried by the car and thereby avoid dazzling oncoming traffic. Manual electric levelling actuators are connected up to a control knob on the dashboard so allowing the driver to adjust beam height.

In addition to its range of manual electric headlamp levelling actuators, Valeo now also offers a new range of automatic actuators. As their name implies, these products do not require any driver adjustment. They are of two types.

- Automatic static actuators adjust beam height to the optimum position in line with vehicle load conditions. The system includes two sensors (front and rear) which measure the attitude of the vehicle. An electronic module converts data from the sensors and drives two electric gear motors (or actuators) located at the rear of the headlamps, which are mechanically attached to the reflectors. Beam height is adjusted every 10–30 s.
- Automatic dynamic adjusters have two sensors, an electronic module and two actuators. The sensors are the same as in the static system but the electronic module is more sophisticated in that it includes electronics that control rapid response actuator stepper motors. Response time to changes in vehicle attitude due to acceleration or deceleration is measured in tenths of a second. Corrective action is continuous and provides enhanced driving comfort, as the beam aim is optimized. In line with regulations, automatic dynamic levelling actuators are mandatory on all vehicles equipped with high intensity discharge (HID) lighting systems.

11.4.7 Baroptic styling concept

The Baroptic concept provides flexibility in the front-end styling of vehicles for the year 2000 and beyond while optimizing aerodynamics. The Baroptic lighting system's volume is significantly reduced as compared with complex shape technology. The volume benefits allow enhanced management of 'under hood' packaging. The product is a breakthrough both in terms of volume and shape. The futuristic elongated appearance of Baroptic headlamps, illuminated or not, sets them apart from conventional headlamps which tend to be oval or circular-shaped.

The Baroptic uses a new optical concept. Traditionally, the luminous flux emitted by the source is reflected by the surface of the reflector (parabolic

or complex shape) and the beam is spread by a striated outer lens or refocused by the inner lenses (elliptical reflector), which then projects this flux onto the road.

In the Baroptic system, the luminous flux generated either by a halogen or a HID lamp is projected into an optical guide with reflecting facets. It is then focused through lenses and, positioned along the optical guide, which defines, in conjunction with shields, the desired beam characteristics: spread width, length, cut-off and homogeneity.

The benefit of this total reflection system is that photometric performance is similar to normal-sized headlamps. The spread of light is also optimized which serves to enhance visual comfort when driving at night. The Baroptic system is currently under development.

11.4.8 Complex shape reflectors

The surface of the reflector is calculated through advanced computer analysis using a minimum of 50 000 individual points, each specific to the headlamp model under design. The third generation of complex shape reflectors (SC3) combines the benefits of the first two developments and controls both beam cut-off and pattern as well as homogeneity. SC3 headlamp lenses can be perfectly clear or with striations purely for decorative purposes. The lens is there to enhance aesthetic appeal and aerodynamics. Figure 11.23 shows a headlamp using this technique together with some other lighting components.

11.4.9 Infrared lights

Thermal-imaging technology promises to make night driving less hazardous. Infrared thermal-imaging systems are going to be fitted to cars. The Cadillac division of General Motors is now offering a system called 'Night Vision' as an option. After 'Night Vision' is switched on, 'hot' objects, including animals and people show up as white in the thermal image, as shown in Figure 11.24.

The infrared end of the light spectrum was discovered as long ago as 1800 by William Herschel. When investigating light passing through a prism, Herschel found heat was being emitted by rays he could not see. This part of the spectrum is called infrared (from the Latin *infra*, meaning 'below') because the rays are below the frequency of red light. The infrared spectrum begins at a wavelength of about 0.75 μm and extends up to 1 mm. Every object at a temperature above absolute zero (-273°C) emits some kind of infrared radiation.

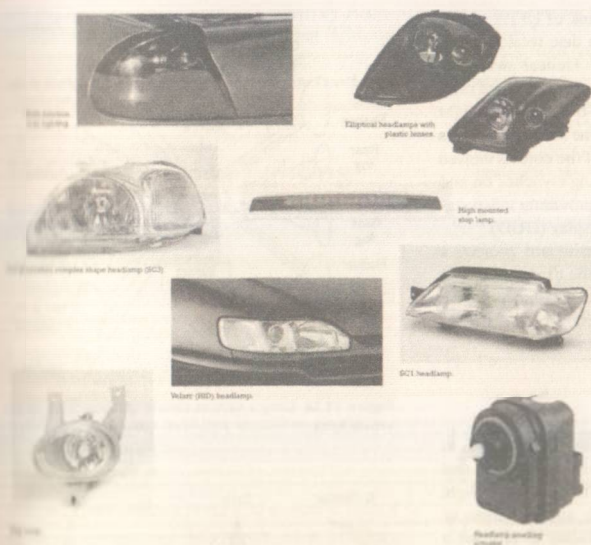


Figure 11.23 SC3 and other lighting products from Valeo

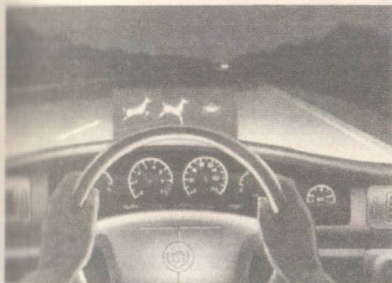


Figure 11.24 Night vision system in use



Figure 11.25 Night vision system range

On the vehicle system a camera unit sits on headlamp-type mountings in the centre of the car, behind the front grille. Its aim is adjusted just like that of headlamps. The mid-grille position was chosen because most front collisions involve offset rather than full head-on impacts. However, the sensor is claimed to be tough enough to withstand 9 mph (14.5 kph) bumper impacts anyway. The sensor is focused 125 m ahead of the car as shown in Figure 11.25.

The outer lens of the sensor is coated with silicon to protect it against scratching. Behind this are two lenses made of black glass called tecalgenite. This is a composite material that transmits

infrared easily but visible light will not pass through it.

The device looks a bit like a conventional camera, but instead of film it houses a bank of ferroelectric barium-strontium-titanate (BST) sensor elements; 76 800 of them can be packed onto a substrate measuring 25 mm square. Each element is a temperature dependent capacitor, the capacitance of which changes in direct proportion to how much infrared radiation it senses. This is termed an uncooled focal plane array (UFPA). An electrically-heated element maintains a temperature of 10 °C inside the UFPA, enabling it to operate between ambient temperatures of -40 and +85 °C.

Between the lens and the bank of UFPA sensor elements there is a thin silicon disc rotated by an electric motor at 1800 rev/min. Helical swirls are etched on some segments of the disc. Infrared radiation is blocked by the swirls but passes straight through the plain segments. The UFPA elements respond to the thermal energy of the objects viewed by the lens. Each sensor's reading switches on and off every 1/30 of a second, thus providing video signals for the system's head-up display (HUD).

The display, built into the dashboard, projects a black-and-white image, which the driver sees near the front edge of the car's bonnet. Objects in the image are the same size as viewed by the UFPA, helping the driver judge distances to them.

11.4.10 RGB lights

The reliability of the LED is allowing designers to integrate lights into the vehicle body in ways that have so far not been possible. The colour of light emitted by LEDs is red, orange, amber, yellow or green. Developments are progressing to produce a blue LED which, when combined with red and green, will allow white light from a solid state device. Red, green and blue are the primary colours of light and can be mixed to produce any other colour. This is how the combinations of pixels (RGB), on a colour monitor or television screen operate.

The possibilities as the technology develops are very wide. The type of lights used and the possible position of the lights on the vehicle are limitless. Rear lights in particular could be changed depending on what the requirements were. For example, when travelling normally, the rear lights would be red but when reversing all of the light could be white.

11.4.11 Single light-source lighting

It is now possible to use a gas discharge lamp (GDL) as a central source for vehicle lighting. Development of this new headlamp system allows a reduction in headlamp dimensions for the same output or improved lighting with the same dimensions. Using a GDL as a central light source for all the vehicle lights is shown in Figure 11.26.

The principle is that light from the 'super light source', is distributed to the headlamps and other lamps by a light-guide or fibre-optic link. The light from the GDL enters the fibre-optics via special lenses and leaves the light-guide in a similar manner as shown in Figure 11.27. A patterned covered lens provides the required light distribution. Shields can

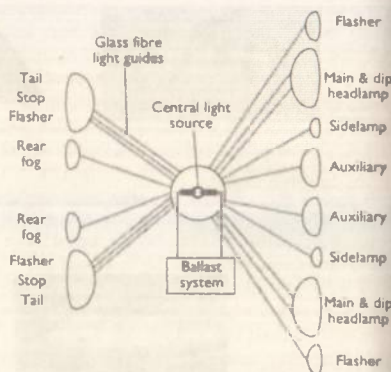


Figure 11.26 Using a GDL as central light source for all the vehicle lights

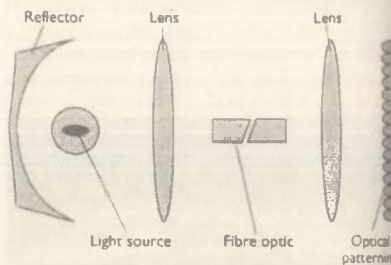


Figure 11.27 The light from the gas discharge lamp (GDL) enters and leaves the light guide via a special lens

provide functions such as indicators, or electrochromatic switches may even become available.

Heat build-up can be a problem in the fibre-optics but an infrared permeable coating on the reflector will help to alleviate this issue. The light-guide system has a very low photometric efficiency (10–20% at best), but the very efficient light source still makes this technique feasible. One of the main advantages is being able to improve the light distribution of the main headlamp. Due to the legal limits with regard to dazzle, conventional lights do not intensely illuminate the area just under the cut-off line. Consequently, several glass fibre bundles can be used to direct the light in an even distribution onto the desired areas of the road.

The central light source can be placed anywhere in the vehicle. Only one source is required but it is thought that a second would be used for safety reasons. A vehicle at present uses some 30 to 40 bulbs.

and this number could be reduced markedly. A single light source could be utilized for rear lights on the vehicle, which would allow rear lights with an overall depth of only about 15 mm. This could be supplied with light from a single conventional bulb.

11.5 Diagnosing lighting system faults

11.5.1 Introduction

As with all systems the six stages of faultfinding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 11.3 lists some common symptoms of a lighting system malfunction together with suggestions for the possible fault. The faults are very generic but will serve as a good reminder.

11.5.2 Testing procedure

The process of checking a lighting system circuit is broadly as follows:

1. Hand and eye checks (loose wires, loose switches and other obvious faults) – all connections clean and tight.

Table 11.3 Common symptoms and possible faults of a lighting system malfunction

Symptom	Possible fault
Lights dim	<ul style="list-style-type: none"> • High resistance in the circuit • Low alternator output • Discoloured lenses or reflectors
Headlights out of adjustment	<ul style="list-style-type: none"> • Suspension fault • Loose fittings • Damage to body panels • Adjustment incorrect
Lights do not work	<ul style="list-style-type: none"> • Bulbs blown • Fuse blown • Loose or broken wiring/connections/fuse • Relay not working • Corrosion in light units • Switch not making contact

2. Check battery (see Chapter 5) – must be 70% charged.
3. Check bulb(s) – visual check or test with ohmmeter.
4. Fuse continuity – (do not trust your eyes) voltage at both sides with a meter or a test lamp.
5. If used, does the relay click (if yes, jump to stage 8) – this means the relay has operated, it is not necessarily making contact.
6. Supply to switch – battery volts.
7. Supply from the switch – battery volts.
8. Supplies to relay – battery volts.
9. Feed out of the relay – battery volts.
10. Voltage supply to the light – within 0.5 V of the battery.
11. Earth circuit (continuity or voltage) – 0 Ω or 0 V.

11.6 Advanced lighting technology

11.6.1 Lighting terms and definitions

Many unusual terms are used when relating to lighting, this section aims to give a simplified description of those used when dealing with vehicle lighting. First, terms associated with the light itself are given, and then terms relating more particularly to vehicle lights. The definitions given are generally related to the construction and use of headlights.

Luminous flux (ϕ)

The unit of luminous flux is the lumen (lm). Luminous flux is defined as the amount of light passing through an area in one second. The lumen is defined as the light falling on a unit area at a unit distance from a light source, which has a luminous intensity of one candela.

Luminous intensity I

This is the power to produce illumination at a distance. The unit is the candela (cd); it is a measure of the brightness of the light rather than the amount of light falling on an object.

Illumination intensity E

This can be defined on a surface as the luminous flux reaching it per unit area. The luminous intensity of a surface such as the road will be reduced if the light rays are at an angle. The unit is the lux (lx), it is equivalent to one lumen per square metre or to

the illuminance of a surface one metre from a point source of light of one candela. In simple terms it depends on the brightness, distance from, and angle to, a light source.

Brightness or luminance L

This should not be confused with illumination. For example when driving at night the illumination from the vehicle lights will remain constant. The brightness or luminance of the road will vary depending on its surface colour. Luminance therefore depends not just on the illumination but also on the light reflected back from the surface.

Range of a headlight

The distance at which the headlight beam still has a specified luminous intensity.

Geometric range

This is the distance to the cut-off line on the road surface when the dip beam is set at an inclination below the horizontal.

Visual range

This is affected by many factors so cannot be expressed in units but it is defined broadly as the distance within the luminous field of vision, at which an object can still be seen.

Signal identification range

The distance at which a light signal can be seen under poor conditions.

Glare or dazzle

This is again difficult to express, as different people will perceive it in different ways. A figure is used, however, and that is if the luminous intensity is 1 lx at a distance of 25 m, in front of a dipped headlight at the height of the light centre, then the light is said not to glare or dazzle. The old British method stated that the lights must not dazzle a person on the same horizontal plane as the vehicle at a distance over 25 feet, whose eye level is more than 3 ft 6 in above the plane (I presume s/he is sitting down.) In general, headlights when on dipped beam must fall below a horizontal line by 1% (1.2% or more in some cases) or 1 cm/m.

11.6.2 Expert Lighting Systems

The Expert Lighting System is a new Valeo technology developed to adapt the headlamp beam to various road and traffic conditions. The low beam

is adapted to curves and the high beam to the vehicle's speed. These lighting functions provide drivers with:

- enhanced comfort due to the increased quantity of light and quality of the beam.
- improved safety, particularly in difficult driving conditions such as winding mountain roads.

This function is achieved by additional moving reflectors, which rotate according to the position of the steering wheel (in line with the direction of the driver's sight). The additional beam illuminates the area beyond or at the curve that is not normally illuminated by a traditional low beam function.

High beam adaptation to speed is based on the translation of 'additional mirrors' within the high beam reflector. The high beam is automatically adapted for beam width and range according to vehicle speed. This function is not subject to the introduction of new regulations.

11.6.3 Intelligent front lighting – Hella

The lighting of modern vehicles has improved continually in the past few decades. The halogen technology developed by Hella in particular set new standards after it was introduced early in the 1970s, as has xenon technology in the 1990s. The advantages of these systems were, and still are, their high lighting performance and their precise light distribution. The intelligent lighting systems of the future, however, will have to offer even more than this in order to make driving safer and more enjoyable.

In cooperation with the motor industry, Hella is masterminding a project for the development of an intelligent front lighting system for future generations of motor vehicles. Market research surveys conducted all over Europe first enabled an analysis to be made of the requirements drivers make on their vehicle lighting.

European drivers, according to this study, would like the front lighting to respond to the various different light conditions they encounter such as daylight, twilight, night-time, and driving in and out of tunnels, and to such weather situations as rain, fog, or falling snow. They would also like better illumination on bends. Drivers would also like better light on motorways. Their list of requirements also includes better light along the edge of the road, and additional light for parking in a narrow space and when reversing.

For Hella's lighting experts, turning these requirements into an intelligent front lighting system means comprehensive detail work and the development of totally new lighting technologies that can respond in various different ways to all these different situations, some of which call for contradictory patterns of light distribution.

For instance, direct lighting of the area immediately in front of the car is desirable when the roadway is dry, but can dazzle oncoming traffic if the road is wet. Light emitted above the cut-off line in fog dazzles the driver him/herself. And a long-range, narrow pattern of light distribution for high-speed driving is unsuitable on twisting country roads, where the need is for a broad illumination in front of the car, possibly augmented by special headlights for bends or a 'dynamic' long-range lighting system. Despite the wide diversity of all these light-distribution patterns, none must be allowed to dazzle oncoming drivers.

Another theme is the idea of lights that switch on automatically. Unlit vehicles keep turning up at night, for instance in city-centre traffic, because the street lighting is so good that some drivers fail to notice that they are driving without lights. The same phenomenon can be seen where cars drive through tunnels. In both cases, the unlit vehicles represent a major safety risk because other road users can hardly see them.

With the aid of the sensors that are already installed on some vehicles, an intelligent lighting system can recognize the ever-changing light situation and give the appropriate assistance to the driver. For instance, the sunlight sensors that already exist for controlling air-conditioning systems, or speed sensing devices, could also deliver data to an intelligent lighting system.

Additional sensors for ambient light and light density in the field of vision, for identifying a dry or wet road, fog, and whether the road ahead is straight or curved, could also deliver important data. In modern vehicles with digital electronic systems and bus interfaces, these data will not only be useful to the lighting systems but also to the other electronically controlled systems, such as ABS or ASR, and give the driver vital assistance particularly in the most difficult driving situations.

The data transmitted by the various sensors on a vehicle can only be put to use if the vehicle has a 'dynamic' headlamp system that is capable of producing various different light-distribution patterns. This could begin with an automatic, dynamic height-adjustment and headlamps that automatically swivel sideways and could even include variable reflectors providing a whole range of light-distribution patterns.

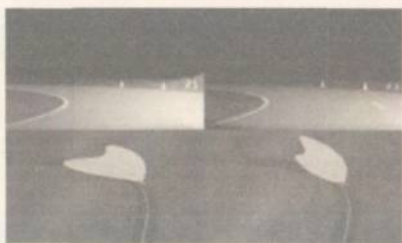


Figure 11.28 Dynamic bending light and normal lighting (Source: Valeo)

11.7 New developments in lighting systems

11.7.1 Light duties

Bending Light

Valeo is developing a headlight technology it calls 'Bending Light'.¹ This technique automatically directs light into road bends to optimize forward visibility at night. The technology makes a significant contribution to comfort and convenience by reducing driver fatigue.

The Bending Light system consists of a bi-xenon projector, or reflector headlamp, that can rotate up from its normal position. An additional projector, or reflector, or a combination of the two can be used to deliver more light into a road bend. The actuation of the motorized lighting unit, within each headlamp assembly, is controlled by an electronic control unit, which employs signals from the steering wheel and wheel-speed sensors. A link to a satellite navigation system (GPS) can also be used if required.

Bending Light is the first of a new generation of adaptive front lighting systems to be launched by Valeo following an extensive R&D program. The range includes three distinct lighting types:

- Motorway Lighting – typically above 80 km/h (50 mph), the low-beam function of the headlamp is raised using a signal received from the wheel-speed sensor to actuate a self-levelling system, which increases driver visibility at high speeds
- Adverse Weather Lighting – provides, under reduced-visibility conditions in fog, rain and snow, additional illumination to help keep track

¹Valeo, 2002/3, Adaptive Front Lighting Systems – Bending Light

Manual adjustment

Vertical rotation axis

Large frame

Stepper-motor

Bi-Xenon projector

Small frame

Stepper-motor

Horizontal rotation axis



Figure 11.29 Mechanical design of the AFS (Source: Visteon)

of road edges, while light is removed from the foreground to reduce reflection from the wet road

- Town Lighting – in well-illuminated urban areas the light beam is lowered and lateral light is increased, improving pedestrian and cyclist identification at crossings as well as reducing dazzle.

Bending Light is an intelligent headlamp system that optimizes the night-time illumination of road curves by directional control of vehicle headlamps. To turn an increased quantity of light into road bends automatically, Bending Light systems adopt several flexible design approaches. Dynamic Bending Light (DBL) uses a Bi-Xenon lamp (projector or reflector type) housed in each headlamp unit, together with an electronic actuator and an electronic control unit. This design facilitates the horizontal rotation of the Bi-Xenon lamp by up to 15° from the normal 'straight-ahead' position. This function is controlled by a microcontroller linked to the vehicle's data network with real-time inputs from both the steering angle and speed sensors. Fixed Bending Light (FBL) employs an additional projector or reflector type lamp integrated into the headlamp unit at a 45° angle.

Advanced Frontlighting System (AFS)

Visteon's Advanced Frontlighting System² incorporates innovative electronic controls to adjust headlight output so that the beam pattern is directed for specific driving conditions, such as speed and vehicle direction. The driver automatically experiences the optimized light distribution according to



Figure 11.30 Situation where AFS improves target detection (Source: Visteon)

the individual driving situation, thus enhancing visibility and safety for drivers at night.

Advanced Frontlighting Systems included:

Basic function:

- Electronic control module.
- Swivel low beam headlamp.
- Halogen in low beam.

Expanded function – provides additional features above the basic function:

- Electronic control module.
- Beam pattern will adjust up at high speeds and down and outward at low speeds.
- 42 V compatible.
- Ability to shift the low beam up when the high beam is activated.
- Longer and narrower light distribution to increase visibility at greater distances.

²Visteon, June 17, 2002, Innovations: Advanced Front Lighting Systems

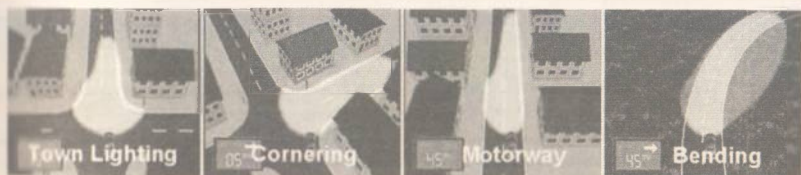


Figure 11.31 Four functions of AFS (Source: Visteon)

- Shorter and wider light distribution to increase visibility at closer distances.
- Driver flexibility to activate/deactivate the system.

Each system is equipped with sensors, that detect changing conditions, a driver-controlled switch, an electronic control unit, which processes data from the sensors, and electronic mechanisms that reposition the headlights. Each system is controlled by a Visteon proprietary algorithm that controls headlight actuation. A central processor receives data from a steering wheel sensor (to measure steering angle), a speed sensor and axle sensors to direct the headlights in real time.

When a vehicle turns a corner, for instance, the outer headlight maintains a straight beam pattern while the inner headlight beam illuminates the upcoming turn. AFS responds to vehicle speed, adjusting for higher and lower speeds. Additionally, at times when high beams are activated, the system adjusts the low beam upwards to further extend the range of vision.

One fundamental differentiator of these systems is Visteon's ability to scale them to the manufacturer's needs. This system can use cost-effective Halogen bulbs. Visteon's internal surveys revealed that while vehicle buyers know and understand the benefits of Xenon technology, the higher cost of Xenon bulbs could act as a potential deterrent to consumers. Depending on manufacturer needs, Advanced Frontlighting Systems can be modified to recognize and respond to a variety of road conditions, and can also be implemented on vehicles with 14 or 42 V electrical systems.

Visteon's Advanced Frontlighting Systems also offer a great degree of design flexibility for vehicle designers. These systems, well suited to the recent trend towards projector-style headlights, can be easily packaged as an articulated assembly in reflector-style headlamps.

Other lighting developments

Two other continuing areas of lighting developments are the use of light emitting diodes (LEDs) and gas discharge lighting (GDL).

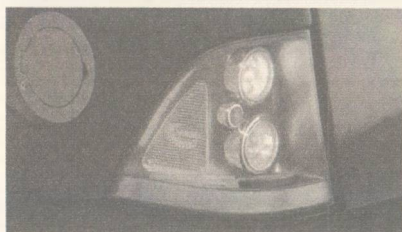


Figure 11.32 LED lighting (Source: Visteon)

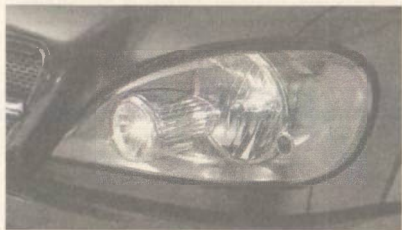


Figure 11.33 Xenon lighting (Source: Visteon)

LEDs have a typical rated life often 25 times that of incandescent lamps. Extreme variations in temperature and humidity, as well as serious shocks and vibration, have to be endured. LEDs are more suited to this type of environment. LEDs are more expensive than bulbs, but the potential savings in design costs, due to sealed units being used and greater freedom of design, could outweigh the extra expense. A further advantage is that they turn on quicker than ordinary bulbs – important when used as stoplights.

The benefit of Xenon lighting is that it emits more than twice the amount of light of a halogen bulb, while only consuming half the power. Therefore, the driver can see more clearly and the car has more power for other functions.

The clear white light produced by the xenon bulb is similar to daylight, and research has shown that this enables drivers to concentrate better. In practical terms, the life span of the bulb is equal to

that of the car, which means that the bulb need only be replaced in exceptional cases.

11.7.2 LEDs

LED displays have been used for many years in dashboards and other instrument-type applications. However, until recently, LEDs were not expected to be used for replacing bulbs in lighting applications. LEDs provide much higher reliability and lower power consumption, as well as requiring less maintenance.

Recent advances in brightness and colour availability are leading to the use of LEDs in place of incandescent lamps. It currently takes a cluster of LEDs to match the light output of an ordinary bulb, but the LED cluster only consumes about 15% of the power for the same light output. Incandescent lamps need replacing after about 1000 hours whereas LEDs will last up to 100 000 hours.

Recently, due to the advent of gallium nitride (GaN) and indium doped gallium nitride (InGaN), 'super-bright' LEDs are starting to replace incandescent bulbs. Blue is a key issue – or at least a key colour. In addition to adding another colour to the 'instrument palate', blue is key in working within a matrix of red and green. In other words, when combined it will produce white or any other colour of light. However, while white light can be created by the 'RGB' method, coating an 'InGaN' blue LED with phosphor directly produces a white light output by a process commonly called the phosphor down-conversion method.

A number of manufacturers have focussed on production or purchase of InGaN LEDs. InGaN LEDs have fallen in price by over 50% recently and are expected to do the same again in the near future. LEDs will continue to become more popular for less traditional uses.

11.8 Self-assessment

11.8.1 Questions

- Describe briefly the reasons for fitting vehicle lights.
- State four methods of converting electrical energy into light energy.
- Explain the reason why headlights are fused independently.
- Draw a simplified circuit of a lighting system showing the side- and headlight bulbs, light switch, dip switch and main beam warning light.
- Make a clearly labelled sketch to show the 'aiming board' method of setting headlight alignment.
- Describe the operation of a gas discharge lamp.
- List the advantages and disadvantages of gas discharge lamps.
- Explain the operation of infrared lighting and sketch a block diagram of the system components.
- Define the term 'Expert or Intelligent lighting'.
- Draw a typical dim-dip circuit and state the reason why it is used.

11.8.2 Assignment

Design a vehicle lighting system using technology described in this chapter. Decide which techniques you are going to use and justify your choices. For example, you may choose to use a single light source for all lights or you may decide to use neon lights for the rear and gas discharge for the front. Whatever the choice, it should be justified with sound reasons such as cost, safety, aerodynamics, styling, reliability and so on.

Make sketches to show exterior views. Circuit diagrams are not necessary but you should note where components would be located. State whether the vehicle is standard or 'top of the range' etc.

11.8.3 Multiple choice questions

In a conventional incandescent bulb the filament is made from:

- halogen
- tungsten
- quartz
- non-resistive wire

In a headlamp the bulb's filament position relative to the reflector ensures:

- the correct beam direction
- reduced electrical resistance
- the correct beam colour
- increased electrical resistance

An asymmetric headlight gives a:

- whiter light
- dim-dip facility
- diverging beam pattern
- sharp cut-off line when on dip

Technician A says dim-dip lighting is achieved with a simple series resistor. Technician B says dim-dip

lighting is achieved by switching on and off fast.

Who is right?

- 1 A only
- 2 B only
- 3 Both A and B
- 4 Neither A nor B

The main advantage of using light emitting diodes (LEDs) in vehicle lighting is:

- 1 the variety of colours available
- 2 that they produce whiter light
- 3 their long life
- 4 all of the above

The wattage of a stoplight bulb is normally:

- 1 3 W
- 2 6 W
- 3 17 W
- 4 31 W

The safety hazard associated with gas discharge lamps is related to the:

- 1 use of high voltages
- 2 use of kryptonite gas
- 3 length of time to cool down
- 4 length of time to discharge

The headlights of a vehicle fail to illuminate when switched on. An initial visual check shows the wiring to be OK and the relay 'clicks'. Technician A says the fault is poor relay earth connection. Technician B says check the relay output. Who is right?

- 1 A only
- 2 B only
- 3 Both A and B
- 4 Neither A nor B

Correct headlamp beam alignment is necessary because:

- 1 it is a legal requirement
- 2 it ensures efficient operation
- 3 road safety is improved
- 4 all of the above

Checking the stoplight switch can be done by removing the wires and:

- 1 bridging them with a jumper wire
- 2 bridging the switch terminals with a test lamp
- 3 bridging them with a voltmeter
- 4 bridging the switch terminals with an ammeter

12

Auxiliaries

12.1 Windscreen washers and wipers

12.1.1 Functional requirements

The requirements of the wiper system are simple. The windscreen must be clean enough to provide suitable visibility at all times. To do this, the wiper system must meet the following requirements.

- Efficient removal of water and snow.
- Efficient removal of dirt.
- Operate at temperatures from -30 to 80°C .
- Pass the stall and snow load test.
- Service life in the region of 1500 000 wipe cycles.
- Resistant to corrosion from acid, alkali and ozone.

In order to meet the above criteria, components of good quality are required for both the wiper and washer system. The actual method used by the blades in cleaning the screen can vary, providing the legally prescribed area of the screen is cleaned. Figure 12.1 shows five such techniques.

Figure 12.2 shows how the front screen is split into 'zones' and how a 'non-circular wiping' technique is applied.

12.1.2 Wiper blades

The wiper blades are made of a rubber compound and are held on to the screen by a spring in the wiper arm. The aerodynamic properties of the wiper blades have become increasingly important due to the design of the vehicle as different air currents flow on and around the screen area. The strip on top of the rubber element is often perforated to reduce air drag. A good quality blade will have a contact width of about 0.1 mm. The lip wipes the surface of the screen at an angle of about 45° . The pressure of the blade on the screen is also important as the coefficient of friction between the rubber and glass can vary from 0.8 to 2.5 when dry and 0.1 to 0.6 when wet. Temperature and velocity will also affect these figures.

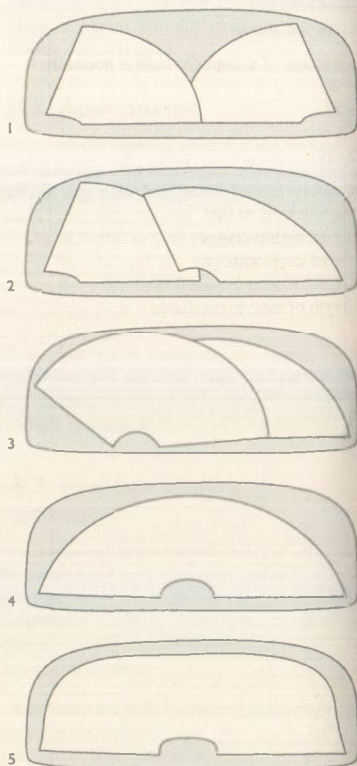


Figure 12.1 Five techniques of moving wiper blades on the screen

12.1.3 Wiper linkages

Most wiper linkages consist of series or parallel mechanisms. Some older types use a flexible rack and wheel boxes similar to the operating mechanism of many sunroofs. One of the main considerations for the design of a wiper linkage is the point at

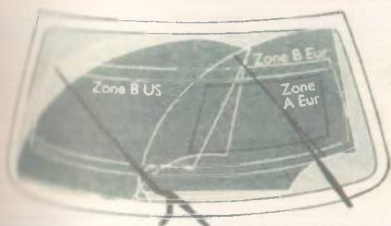


Figure 12.3 Non-circular wiping

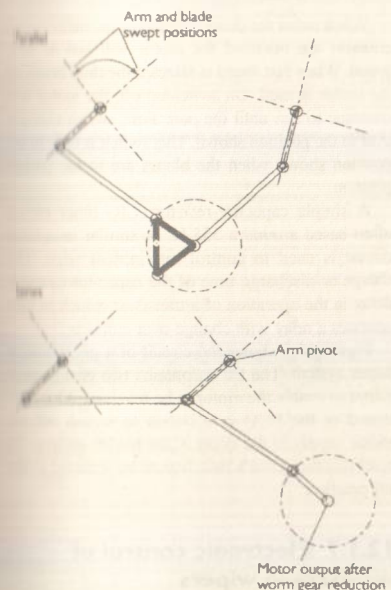


Figure 12.3 Two typical wiper linkage layouts

which the blades must reverse. This is because of the high forces on the motor and linkage at this time. If the reverse point is set so that the linkage is at its maximum force transmission angle then the reverse action of the blades puts less strain on the system. This also ensures smoother operation. Figure 12.3 shows two typical wiper linkage layouts, the first figure is shown at the reverse point. Note that the position of the rotary link and the angles of the rods are designed to reduce the loading on the motor at this point.

Figure 12.4 shows one method used on some vehicles together with the cam linkage, which allows off-screen parking.

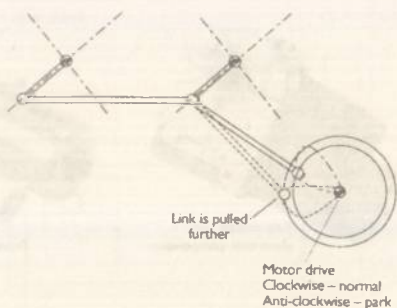


Figure 12.4 Wiper linkage used on some vehicles, together with the cam link which allows off-screen reverse parking

12.1.4 Wiper motors

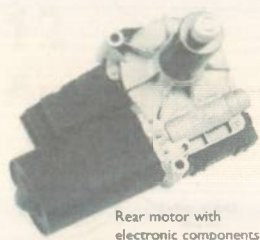
Most, if not all, wiper motors now in use are the permanent magnet motors. The drive is taken via a worm gear to increase torque and reduce speed. Three brushes may be used to allow two-speed operation. The normal speed operates through two-brushes placed in the usual positions opposite to each other. For a fast speed, the third brush is placed closer to the earth brush. This reduces the number of armature windings between them, which reduces resistance and hence increases current and therefore speed. Figure 12.5 shows two typical wiper motors. Typical specifications for wiper motor speed and hence wipe frequency are 45 rev/min at normal speed and 65 rev/min at fast speed. The motor must be able to overcome the starting friction of each blade at a minimum speed of 5 rev/min.

The characteristics of a typical car wiper motor are shown in Figure 12.6. The two sets of curves indicate fast and slow speed.

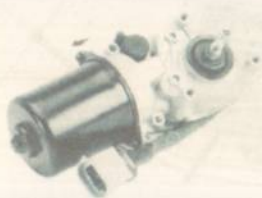
Wiper motors, or the associated circuit, often have some kind of short circuit protection. This is to protect the motor in the event of stalling, if frozen to the screen for example. A thermal trip of some type is often used or a current sensing circuit in the wiper ECU, if fitted. The maximum time a motor can withstand stalled current is normally specified. This is usually in the region of about 15 minutes.

12.1.5 Windscreen washers

The windscreen washer system usually consists of a simple DC permanent magnet motor driving a centrifugal water pump. The water, preferably with a cleaning additive, is directed onto an appropriate part of the screen by two or more jets. A non-return valve is often fitted in the line to the jets to prevent



Rear motor with electronic components



Front wiper motor

Figure 12.5 Wiper motors

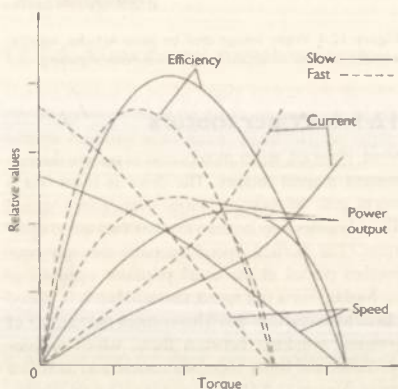


Figure 12.6 Characteristics of a wiper motor; the two sets of curves indicate fast and slow speed

water siphoning back to the reservoir. This also allows 'instant' operation when the washer button is pressed. The washer circuit is normally linked to the wiper circuit such that when the washers are operated the wipers start automatically and will continue for several more sweeps after the washers have stopped. The circuit is shown in the next section.

12.1.6 Washer and wiper circuits

Figure 12.7 shows a circuit for fast, slow and intermittent wiper control. The switches are shown in the off position and the motor is stopped and in its park position. Note that the two main brushes of the motor are connected together via the limit switch, delay unit contacts and the wiper switch. This causes regenerative braking because of the current generated by the motor due to its momentum after the power is switched off. Being connected to a very low resistance loads up the 'generator' and it stops instantly when the park limit switch closes.

When either the delay contacts or the main switch contacts are operated the motor will run at slow speed. When fast speed is selected the third brush on the motor is used. On switching off, the motor will continue to run until the park limit switch changes over to the position shown. This switch is only in the position shown when the blades are in the parked position.

A simple capacitor-resistor (CR) timer circuit, often based around a 555 IC or similar integrated circuit is used to control intermittent wipe. The charge or discharge time of the capacitor causes a delay in the operation of a transistor, which in turn operates a relay with change-over contacts.

Figure 12.8 shows the circuit of a programmed wiper system. The ECU contains two change-over relays to enable the motor to be reversed. Also contained in the ECU is a circuit to switch off the motor supply in the event of the blades stalling. To reset this the driver's switch must be returned to the off position.

12.1.7 Electronic control of windscreen wipers

Further control of wipers other than just delay is possible with appropriate electronic control. Manufacturers have used programmed electronic control of the windscreen wipers for a number of years now. One system consists of a two-speed motor with two limit switches, one for the park position and one that operates at the top limit of the sweep. A column switch is utilized that has positions for wash/wipe, fast speed, slow speed, flick wipe and delay, and which has several settings. The heart of this system is the programmed wiper control unit. An innovative feature is that the wiper blades may be parked below the screen. This is achieved by utilizing the top limit switch to signal the ECU to reverse the motor for parking. The switch is normally closed and switches open circuit when the blades reach the 'A' post. Due to the design of the linkage, the arms move further

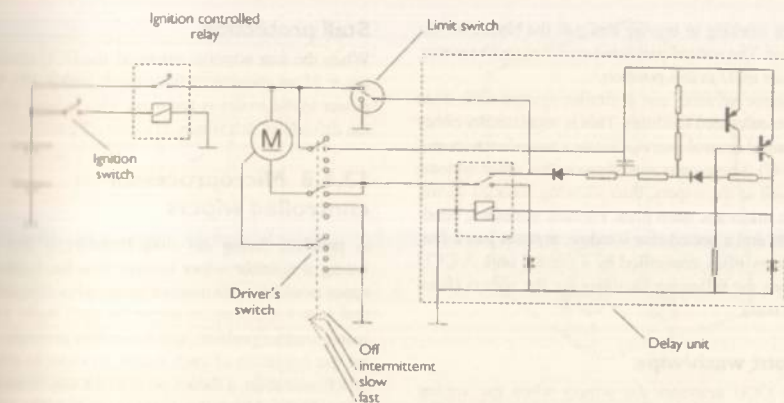


Figure 12.7 Wiper circuit with intermittent/delay operation as well as slow and fast speed

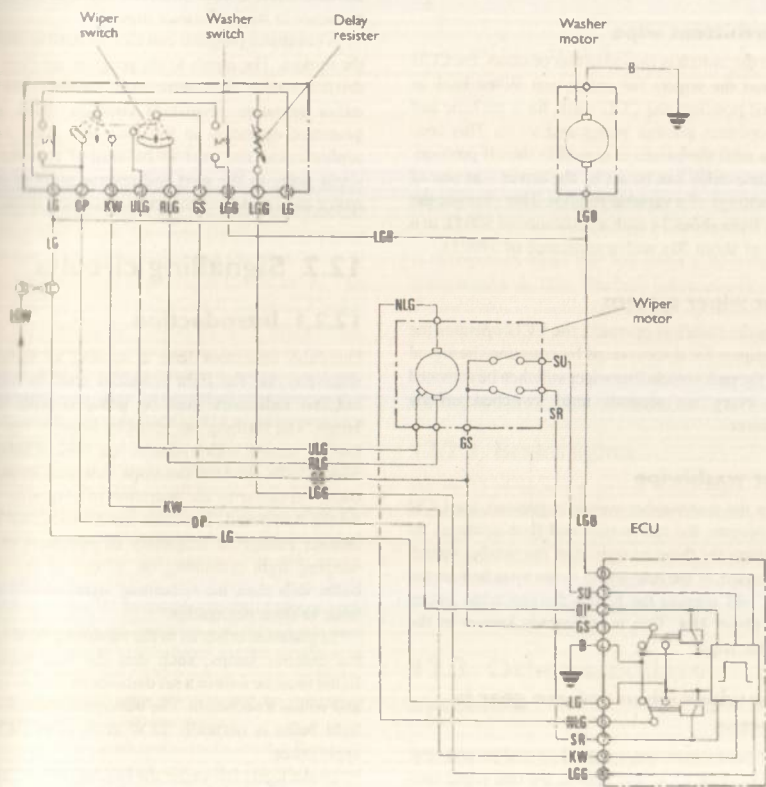


Figure 12.8 Programmed washer wipe and variable intermittent wipe circuit

when working in reverse and pull the blades off the screen. The normal park limit switch stops the motor, via the ECU in this position.

Some vehicles use a similar system with even more enhanced facilities. This is regulated by either a central control unit (CCU) or a multifunction unit (MFU). These units can often control other systems as well as the wipers, thus allowing reduced wiring bulk under the dash area. Electric windows, headlights and a heated rear window, to name just a few, are now often controlled by a central unit. A CCU allows the following facilities for the wipers (front and rear).

Front wash/wipe

The CCU activates the wipers when the washer switch is pressed and keeps them going for a further six seconds when the switch is released.

Intermittent wipe

When the switch is moved to this position, the CCU operates the wipers for one sweep. When back in the rest position, the CCU waits for a set time and then operates another sweep and so on. This continues until the switch is moved to the off position. The time delay can be set by the driver—as one of five settings of a variable resistor. This changes the delay from about 3 s with a resistance of 500 Ω , to a delay of about 20 s with a resistance of 5400 Ω .

Rear wiper system

When the switch is operated, the CCU operates the rear wipers for three sweeps by counting the signal from the park switch. The wiper will then be activated once every six seconds until switched off by the driver.

Rear wash/wipe

When the rear washer switch is pressed, the CCU will operate the rear wiper and then continue its operation for three sweeps after the washer switch is released. If the rear wiper is not switched on the CCU will operate the blades for one more sweep after about 18 s. This is commonly known as the 'dribble wipe'!

Rear wiper when reverse gear is selected

If the front wipers are switched on and reverse gear is selected the CCU will operate the rear wiper continuously. This will stop when either the front wipers are switched off or reverse gear is deselected.

Stall protection

When the rear wiper is operated, the CCU starts a timer. If no movement is detected within 15 s the power to the motor is removed. This is reset when the driver's switch is moved to the off position.

12.1.8 Microprocessor controlled wipers

A problem facing car manufacturers is that of fitting a suitable wiper linkage into the minimal space available with modern body styles. One solution is to use a separate motor for each blade. This leaves another problem, and that is how to synchronize the operation of each motor. In order to allow synchronization, a datum point and a way of measuring distance from this point is needed. The solution to this is to utilize a normal park limit switch as the datum and to count the revolutions of the motor armature to imply distance moved.

A computer program can then be used to control the motors. The inputs to the program are from the driver's switch, the motor limit switches and the motor armature revolution counters. Fully programmed operation in this way will allow more sophisticated facilities to be used if required. A slight delay in the start and reverse point of each motor can be used to reduce high current draw.

12.2 Signalling circuits

12.2.1 Introduction

Direction indicators have a number of statutory requirements. The light produced must be amber but the indicators may be grouped with other lamps. The flashing rate must be between one and two per second with a relative 'on' time of between 30 and 57%. If a fault develops, this must be apparent to the driver by the operation of a warning light on the dashboard. The fault can be indicated by a distinct change in frequency of operation or the warning light remaining on. If one of the main bulbs fails then the remaining lights should continue to flash perceptibly.

Legislation exists as to the mounting position of the exterior lamps, such that the rear indicator lights must be within a set distance of the tail lights and within a set height. The wattage of the indicator light bulbs is normally 21 W at 6, 12 or 24 V as appropriate.

Brake lights fall under the heading of auxiliaries or 'signalling'. A circuit is examined later in this section.

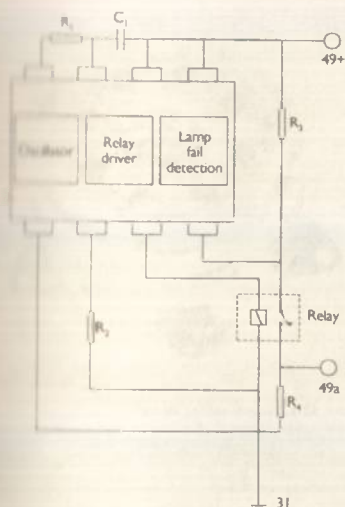


Figure 12.9 Circuit diagram of an electronic flasher unit

12.2.2 Flasher units

Figure 12.9 shows the internal circuit of an electronic flasher unit. The operation of this unit is based around an integrated circuit. The type shown can operate at most four 21 W bulbs (front and rear) and two 5 W side repeaters when operating in hazard mode. This will continue for several hours if required. Flasher units are rated by the number of bulbs they are capable of operating. When towing a trailer or caravan the unit must be able to operate at a higher wattage. Most units use a relay for the actual switching as this is not susceptible to voltage spikes and also provides an audible signal.

The electronic circuit is constructed together with the relay, on a printed circuit board. Very few components are used as the integrated circuit is specially designed for use as an indicator timer. The integrated circuit itself has three main sections. The relay driver, oscillator and a bulb failure circuit. A Zener diode is built in to the IC to ensure constant voltage such that the frequency of operation will remain constant in the range 10–15 V. The timer for the oscillator is controlled by R_1 and C . The values are normally set to give an on-off ratio of 50% and an operating frequency of 1.5 Hz (90 per minute).

The on-off signals produced by the oscillator are passed to a driver circuit, which is a Darlington pair with a diode connected to protect it from back-EMF as the relay coil is switched on and off. Bulb failure

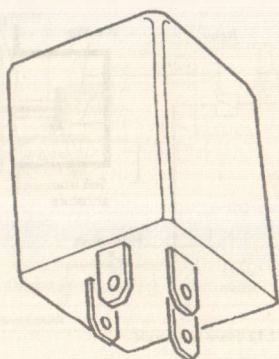


Figure 12.10 Electronic flasher unit

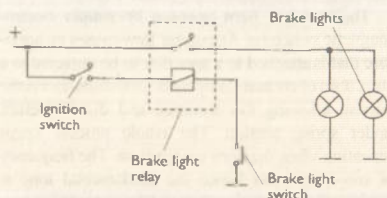


Figure 12.11 Typical brake light circuit

is recognized when the volt drop across the low value resistor R_2 falls. The bulb failure circuit causes the oscillator to double the speed of operation. Extra capacitors can be used for added protection against transient voltages and for interference suppression. Figure 12.10 shows the normal 'packaging' for a flasher unit.

12.2.3 Brake lights

Figure 12.11 shows a typical brake light circuit. Most incorporate a relay to switch the lights, which is in turn operated by a spring-loaded switch on the brake pedal. Links from this circuit to cruise control may be found. This is to cause the cruise control to switch off as the brakes are operated.

12.3 Other auxiliary systems

12.3.1 Electric horns

Regulations in most countries state that the horn (or audible warning device) should produce a uniform

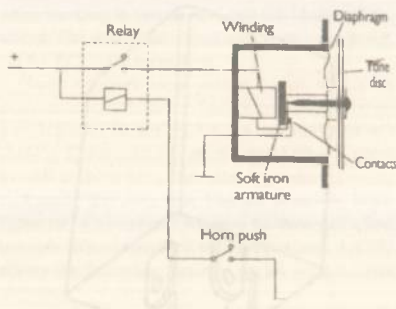


Figure 12.12 Horn and circuit

sound. This consequently makes sirens and melody-type fanfare horns illegal! Most horns draw a large current, so are switched by a suitable relay.

The standard horn operates by simple electro-magnetic switching. As current flow causes an armature that is attached to a tone disc to be attracted to a stop, a set of contacts is opened. This disconnects the current allowing the armature and disc to return under spring tension. The whole process keeps repeating when the horn switch is on. The frequency of movement and hence the fundamental tone is arranged to lie between 1.8 and 3.5 kHz. This gives good penetration through traffic noise. Twin horn systems, which have a high and low tone horn, are often used. This produces a more pleasing sound but is still very audible in both town and higher speed conditions. Figure 12.12 shows a typical horn together with its associated circuit.

12.3.2 Engine cooling fan motors

Most engine cooling fan motors (radiator cooling) are simple permanent magnet types. Figure 12.13 shows a typical example. The fans used often have the blades placed asymmetrically (balanced but not in a regular pattern) to reduce noise when operating.

When twin cooling fans and motors are fitted, they can be run in series or parallel. This is often the case when air conditioning is used as the condenser is usually placed in front of the radiator and extra cooling air speed may be needed.

A circuit for series or parallel operation of cooling fans is shown in Figure 12.14.

12.3.3 Headlight wipers and washers

There are two ways in which headlights are cleaned, first by high pressure jets, and secondly by small wiper blades with low pressure water supply. The

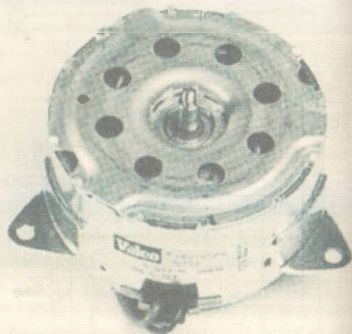
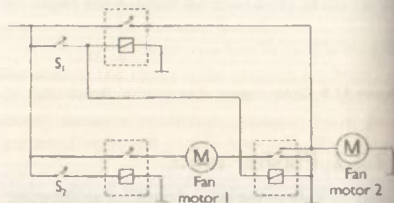


Figure 12.13 Engine cooling motor



S_1 for series – slow speed
 S_1 and S_2 for parallel – full speed

Figure 12.14 Circuit for series or parallel operation of cooling fans

second method is, in fact, much the same as windscreen cleaning but on a smaller scale. The high pressure system tends to be favoured but can suffer in very cold conditions due to the fluid freezing. It is expected that the wash system should be capable of about 50 operations before refilling of the reservoir is necessary. Figure 12.15 shows the pressure wash technique.

Headlight cleaners are often combined with the windscreen washers. They operate each time the windscreen washers are activated, if the headlights are also switched on.

A retractable nozzle for headlight cleaners is often used. When the water pressure is pumped to the nozzle it pushes the nozzle from its retracted position flush with the bodywork. When the washing is completed the jet is retracted back into the housing.

Some minor vehicle electrical systems, which are not covered elsewhere, are shown in Figure 12.16. Cigar lighter, clock, rotating beacon and electric aerial are all circuits that could be used by many other systems.



Figure 12.15 Headlight washers in action

12.4 Case studies

12.4.1 Indicators and hazard circuit – Rover

The circuit diagram shown in Figure 12.17 is part of the circuit from a Rover car and shows the full layout of the indicator and hazard lights wiring. Note how the hazard switch, when operated, disconnects the ignition supply from the flasher unit and replaces it with a constant supply. The hazard system will therefore operate at any time but the indicators will only work when the ignition is switched on. When the indicator switch is operated left or right, the front, rear and repeater bulbs are connected to the output terminal of the flasher unit, which then operates and causes the bulbs to flash.

When the hazard switch is operated, five sets of contacts are moved. Two sets connect left and right circuits to the output of the flasher unit. One set disconnects the ignition supply and another set connects the battery supply to the unit. The final set of contacts causes a hazard warning light to be operated. On this and most vehicles the hazard switch is illuminated when the sidelights are switched on.

When operating in hazard mode the bulbs would draw 7.8 A (94 W/12 V).

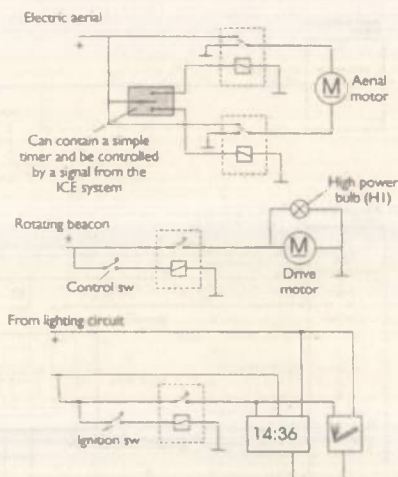


Figure 12.16 Electric aerial, rotating beacon, cigar lighter and clock circuit

However, this current will peak much higher due to the cold resistance of the bulbs. In the circuit shown, the top fuse is direct from the battery and the other is ignition controlled.

With the ignition switched on, fuse 1 in the passenger compartment fusebox provides a feed to the hazard warning switch on the G wire. Provided the hazard warning switch is in the off position the feed crosses the switch and supplies the flasher unit on the LG/K wire. When the switch control is moved for a right turn, the switch makes contact when the LG/N wire from the flasher unit is connected to the G/W wire, allowing a supply to pass the right-hand front and rear indicator lights and then to earth on the B wire. When the switch control is moved for a left turn, the switch makes contact with the G/R wire, which allows the supply to pass to the left-hand front and rear indicator lights and then to earth on the B wire. The action of the flasher unit causes the circuit to 'make and break'.

By pressing the hazard warning switch a battery supply on the N/O from fuse 3 (1.4, 2.0 and diesel models) or 4 (1.6 models) in the engine bay fusebox crosses the switch and supplies the flasher unit on the LG/K wire. At the same time contacts are closed to connect the hazard warning light and the flasher unit to both the G/W and GIR wires, the right-hand and left-hand indicators and the warning light flash alternately.

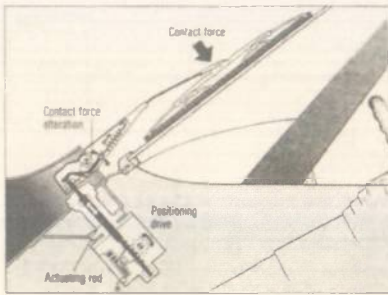


Figure 12.19 Wiper blade pressure control system

sources of noise are the wiper blade (particularly when it turns over at the end of each movement) and the wiper motor.

Valeo has produced a new rear wiper module offering an original solution to these problems in the form of a specific, integrated electronics control system. This system is designed around an H-bridge power stage, which has no relays. This eliminates all switching noise. The control algorithm provides pinpoint management of wiper speed; it slows the blades at the end of each cycle, thus cutting out turning noise.

Note: an H-bridge uses four power devices that are connected to reverse the voltage across both terminals of a load. This is used to control the direction of a motor.

Current wiper systems that are based on an alternative rotary movement cover a wipe area of between 50 and 60% of the total surface area of the rear window. This limit is due to the height/width ratio and the curve of the window. Valeo's linear rear wiper concept ensures optimum visual comfort as it covers over 80% of the rear window surface; this is a visibility gain for the driver exceeding 60%.

This increase in the driver's field of vision enhances safety, especially during low-speed manoeuvres such as reversing or parking. The linear rear wiper concept is in keeping with the trend towards narrower, highly convex rear windows and can be



Figure 12.20 Linear wiper system

fully integrated into vehicle design. Figure 12.20 shows this technique.

The Silencio windshield wiper offers two major innovations to enhance passenger comfort and safety:

- A new extended-life rubber coating called 'Skin'.
- A wear indicator that tells the driver when to change the wiper.

External wear factors such as UV, ozone, pollution, windshield wiper fluid, etc. damage the rubber blade and affect wiping quality. 'Skin' is a new coating that protects the blade.

This surface coating, composed of a slipping agent, a polymer bonding agent and an 'impermeability' agent, can be applied to natural or synthetic rubber. An innovative polymerization process ensures long-lasting adhesion to the blade. By protecting the blade from wear, 'Skin' maintains initial wiping quality longer and also eliminates rubber squeaking and friction noise on dry glass.

Silencio is also fitted with a wear indicator that tells the driver the state of wear of the wiper blade. The indicator – a round tab fixed to the wiper – degrades at the same speed as the rubber blade. External wear factors such as UV, ozone and pollution activate chemicals in the indicator which then gradually changes colour, going from black to yellow, as the wiper wears out.

12.4.5 Electronic fan system control

The electronic control of the fan system is a further step in the drive to improve engine cooling management. Besides reducing electrical consumption, one of the main benefits of Valeo's concept is the reduction in noise levels thanks to continuous

the speed regulation, adjusted to the minimum flow required for engine cooling and A/C management.

Wides is due to start producing these variable speed motor units in 2000. They have the following technical features.

- Electrical consumption reduced by half for an average usage profile.
- Noise level reduced by 15 dBA at half speed.
- Soft start of the fan, which removes peak starting currents and provides a better subjective sound level.

Electronic functions designed to improve the safety of the fan are possible; speed can be adapted to the minimum required, diagnostic functions are possible and self-protection in case of fan lock due to contamination is built in.

The fan electronic management unit can be easily installed in different places in the engine compartment to meet all types of customer specifications, even the most demanding ones in terms of high temperature. Wides is currently developing a new concept that has a

compact pulse width modulation (PWM) module integrated into the motor.

12.5 Diagnosing auxiliary system faults

12.5.1 Introduction

As with all systems the six stages of fault-finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 12.1 lists some common symptoms of an auxiliary system malfunction together with suggestions for the

Table 12.1 Common symptoms and possible faults of an auxiliary system malfunction

Symptom	Possible fault
Fan not working or poor sound quality	<ul style="list-style-type: none"> • Loose or broken wiring/connections/fuse. • Corrosion in horn connections. • Switch not making contact. • High resistance contact on switch or wiring. • Relay not working.
Wipers not working or poor operation	<ul style="list-style-type: none"> • Loose or broken wiring/connections/fuse. • Corrosion in wiper connections. • Switch not making contact. • High resistance contact on switch or wiring. • Relay/timer not working. • Motor brushes or slip ring connections worn. • Limit switch contacts open circuit or high resistance.
Washers not working or poor operation	<ul style="list-style-type: none"> • Blades and/or arm springs in poor condition. • Loose or broken wiring/connections/fuse. • Corrosion in washer motor connections. • Switch not making contact. • Pump motor poor or not working. • Blocked pipes or jets. • Incorrect fluid additive used.
Indicators not working or incorrect operating speed	<ul style="list-style-type: none"> • Bulb(s) blown. • Loose or broken wiring/connections/fuse. • Corrosion in horn connections. • Switch not making contact. • High resistance contact on switch or wiring. • Relay not working.
Heater blower not working or poor operation	<ul style="list-style-type: none"> • Loose or broken wiring/connections/fuse. • Switch not making contact. • Motor brushes worn. • Speed selection resistors open circuit.

possible fault. The faults are very generic but will serve as a good reminder.

12.5.2 Testing procedure

The process of checking an auxiliary system circuit is broadly as follows.

1. Hand and eye checks (loose wires, loose switches and other obvious faults) – all connections clean and tight.
2. Check battery (see Chapter 5) – must be 70% charged.
3. Check motor linkage/bulbs – visual check.
4. Fuse continuity – (do not trust your eyes) voltage at both sides with a meter or a test lamp.
5. If used does the relay click (if yes, jump to stage 8) – this means the relay has operated, but it is not necessarily making contact.
6. Supply to switch – battery volts.
7. Supply from the switch – battery volts.
8. Supplies to relay – battery volts.
9. Feed out of the relay – battery volts.
10. Voltage supply to the motor – within 0.5 V of the battery.
11. Earth circuit (continuity or voltage) – 0 Ω or 0 V.

12.6 Advanced auxiliary systems technology

12.6.1 Wiper motor torque calculations

The torque required to overcome starting friction of each wiper blade can be calculated as follows:

$$T = F \mu_{\max} f_s f_t f \left(\frac{w_a}{w_m} \right) \left(\frac{1}{e} \right) \left(\frac{R_h}{R_c} \right)$$

where

- T = torque to move one wiper arm;
 F = force of one blade onto the screen;
 μ_{\max} = maximum dry coefficient of friction (e.g. 2.5);
 f_s = multiplier for joint friction (e.g. 1.15);
 f_t = tolerance factor (e.g. 1.12);
 l = wiper arm length;
 w_a = maximum angular velocity of arm;
 w_m = mean angular velocity of motor crank;
 e = efficiency of the motor gear unit (e.g. 0.8);
 R_h = motor winding resistance – hot;
 R_c = motor winding resistance – cold.

12.6.2 PM Motor – electronic speed control

The automotive industry uses permanent magnet (PM) motors because they are economical to produce and provide good performance. A simple current limiting resistor or a voltage regulator can vary the motor's speed. This simple method is often used for motors requiring variable speed control. However, to control the speed of a motor that draws 20 A at full speed and about 10 A at half speed is a problem.

At full speed, the overall motor control system's efficiency is around 80%. If the speed is reduced to half the system's, then efficiency drops to 40%. This is because there would be a heat loss of 70 W in the series resistor and 14 W lost in the motor. A more efficient speed control system is therefore needed.

One way is to interrupt the motor's voltage at a variable duty cycle using a switching power supply. A system known as pulse width modulation (PWM) has been developed. An introduction to this technique follows.

Because the armature of the PM motor acts as a flywheel, the voltage interruption rate can be 1 kHz or slower, without causing the motor's speed to pulsate. A problem at this or other audible frequencies is the noise generated from within the motor. At higher frequencies, 16 kHz for example, the audible noise is minimized. A further noise problem is significant EMR (electromagnetic radiation). This is generated by the fast switching speeds. This can be improved by slowing down the switching edge of the operating signal. A compromise has to be made between the edge speeds and power device heat loss.

When the EMR problems are safely contained the stalled motor condition must be considered. The motor's copper windings have a positive temperature coefficient of 0.00393 Ω/°C. Therefore, a 0.25 Ω motor resistance value at 25°C would be about 0.18 Ω at -40°C. Using a typical 20 A motor as the load, the maximum stalled or locked rotor current can be calculated to be about 77 A as shown:

$$I_{\max} = \frac{E_{\max}}{R_{\text{mtr}}}$$

where E_{\max} = maximum power supply voltage (14.4 V) and R_{mtr} = minimum motor resistance (0.18 Ω).

When the maximum motor current has been calculated, the specifications of the power transistor

can be determined. In this case, the device needs an average current rating of at least 77 A. However, a further consideration for reliable power transistor operation is its worst case heat dissipation.

The worst case includes maximum values for the supply voltage, ambient temperature and motor current. A junction temperature of 150°C for the power transistors is used as a maximum point. The following equation calculates the transistor's maximum allowable heat dissipation for use in an 85°C environment using a 2.7°C/W heat sink and a 1°C/W junction to case power FET thermal resistance.

$$P_{D_{max}} = \frac{T_{J_{max}} - T_{A_{max}}}{R_{\theta JC} + R_{\theta CS} + R_{\theta SA}}$$

where $T_{J_{max}}$ = maximum allowable junction temperature (150°C); $T_{A_{max}}$ = maximum ambient temperature (85°C); $R_{\theta JC}$ = junction to case thermal resistance (1°C/W); $R_{\theta CS}$ = case to heat sink interface thermal resistance (0.1°C/W); $R_{\theta SA}$ = heat sink to ambient thermal resistance (1°C/W).

Using the given figure results in a value of about 114 W. This is considerably better than using a dissipating resistor, but to achieve this, several power transistors would have to be connected in parallel. Significant heat sinking is also necessary.

This technique may become popular because of its significant improvement in efficiency over conventional methods and the possibilities for greater control over the speed of a PM motor.

12.7 New developments in auxiliary systems

12.7.1 Electronic wiper control

The first electronically controlled reversing twin-motor wiper system was fitted to the 2002 Volkswagen Phaeton. The two main advantages are that the twin motor system does not use much space and also results in excellent visibility in any situation. Traditional wiper systems have two wiper arms connected to a single motor via an appropriate linkage. With this new system, the wiper arms are synchronized electronically and do not share a mechanical link. The motors reverse, under electronic control, at the end of the wipe area. The motors decelerate before reversing to reduce shock loading. This also reduces the reversing noise and increases the service life of the wiper blades.

The electronic wiper system reduces the impact of headwind and rain intensity on the wiping frequency, and the size of the wipe pattern. In this way, the electronic system always provides the maximum field of view at a constant sweep rate. When the wipers are turned off, the blades and arms park under the screen. This improves aerodynamics and reduces the risk of injuries during collisions with pedestrians. The wiper system can be made to operate automatically if it is combined with a rain and light sensor.

The two drives of the wiper arms are adjustable to suit specific features of the vehicle and a linkage is not used. This means that manufacturers gain

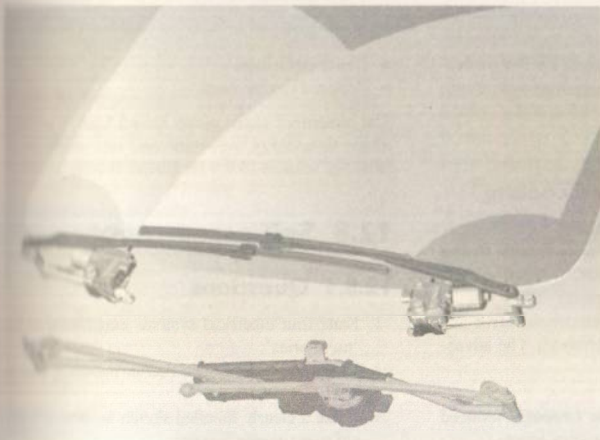


Figure 12.21 Comparison of single- and twin-motor wiper systems (Source: Bosch Press)

Enlarged wipe field

- ① Extended reversing position
- ② Extended park position

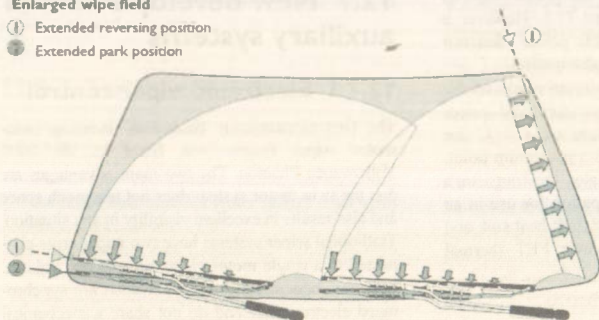


Figure 12.22 Electronically controlled wiper system (Source: Bosch Press)



Figure 12.23 Twin-motor wiper in position (Source: Bosch Press)

significant installation advantages. This is particularly so in vehicles with contrary-motion systems. The system is adjustable to match specific vehicle construction details.

12.7.2 Electric engine cooling

Using an electric motor in place of the coolant or water pump means that power consumption can be reduced and engine cooling can be electronically controlled or enhanced. The pump shown here is used in conjunction with an electronic valve and fan. The valve replaces the thermostat. The advantages of this technique are:

- Reduced fuel consumption (through reduced power usage, as well as efficiency gains).

- Lower emissions.
- Reduced engine wear.

The electronic water pump shown uses brushless motor technology, wet-rotor and rare earth magnets. See section 10.9.9 for further details.

12.8 Self-assessment

12.8.1 Questions

1. State four electrical systems considered to be 'auxiliaries'.
2. Describe briefly how a flasher/indicator unit is rated.
3. Make a clearly labelled sketch to show a typical wiper motor linkage.

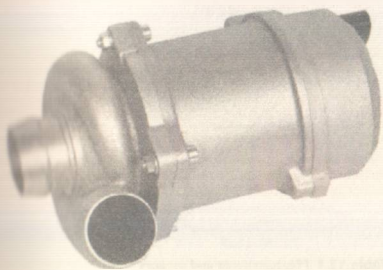


Figure 12.24 Electric cooling pump (Source: Valeo)

4. Draw a circuit diagram of an indicator circuit, and label each part.
5. List five requirements of a wiper system.
6. Explain how off-screen parking is achieved by some wiper systems.
7. Describe what is meant by the term 'stall protection' in relation to wiper motors.
8. Draw a clearly labelled brake light circuit. Include three 21 W bulbs, a relay and fuse as well as the brake light switch.
9. Calculate the rating of the fuse required in Question 8.
10. Explain with the aid of a sketch what is meant by 'windscreen zones'.

12.8.2 Assignment

Investigate a modern vehicle and produce a report of the efficiency and operation of the washer and wiper systems (front and rear).

Make a reasoned list of suggestions as to how improvements could be made. Consider for the purposes of lateral thinking that, in this case, money is not an issue!

12.8.3 Multiple choice questions

When checking the operation of a relay, an audible click is heard when the switch is operated. If there is no supply out from the relay this indicates:

1. that the relay is faulty
2. an open circuit supply
3. a faulty switch
4. all of these

The operating frequency of an electronic flasher unit is:

1. 0.5 Hz
2. 1.5 Hz

3. 2.5 Hz
4. 3.5 Hz

The wattage of an indicator bulb is normally:

1. 5 W
2. 6 W
3. 12 W
4. 21 W

A wiper motor may use three brushes in order to:

1. increase torque
2. allow two speed operation
3. allow three speed operation
4. provide intermittent operation

A thermal trip may be incorporated in a wiper motor in order to:

1. park the blades
2. protect the motor
3. provide intermittent operation
4. slow the blades in heavy rain

When the two main brushes of a wiper motor are connected together via the limit switch, delay unit contacts and the wiper switch, this causes:

1. fast speed operation
2. slow speed operation
3. regenerative braking
4. none of the above

Off-screen parking of wiper blades reduces:

1. current draw
2. voltage drop
3. aerodynamic drag
4. aerodynamic drop

The delay time in a wiper control unit is set by a resistor and:

1. an inductor
2. a transistor
3. a diode
4. a capacitor

A front screen wiper system can have:

1. only one motor
2. two motors
3. no motors
4. all of the above

A vehicle horn produces sound because a tone disc is made to vibrate by:

1. electrostatics
2. electroplating
3. electrocuting
4. electromagnetism

13

Instrumentation

13.1 Gauges and sensors

13.1.1 Introduction

The topic of instrumentation has now reached such a level as to have become a subject in its own right. This chapter covers some of the basic principles of the science, with examples as to how it relates to automobile systems. By definition, an instrumentation system can be said to convert a 'variable', into a readable or usable display. For example, a fuel level instrument system will display, often by an analogue gauge, a representation of the fuel in the tank.

Instrumentation is not always associated with a gauge or a read-out type display. In many cases the whole system can be used just to operate a warning light. However, the system must still work to certain standards, for example if a low outside temperature warning light did not illuminate at the correct time, a dangerous situation could develop.

This chapter will cover vehicle instrumentation systems in use and examine in more detail the issues involved in choosing or designing an instrumentation system. Chapter 2 contains many details associated with sensors, an integral part of an instrumentation system, and it may be appropriate to refer back for some information related to this chapter.

13.1.2 Sensors

In order to put some limit on the size of this section, only electrical sensors associated with vehicle use will be considered. Sensors are used in vehicle applications for many purposes; for example, the coolant temperature thermistor is used to provide data to the engine management system as well as to the driver via a display. For the purpose of providing information to the driver, Table 13.1 gives a list of measurands (things that are measured) together with typical sensors, which is representative of today's vehicles.

Figure 13.1 shows some of the sensors listed in Table 13.1.

Table 13.1 Measurements and sensors

Measurement required	Sensor example
Fuel level	Variable resistor
Temperatures	Thermistor
Bulb failure	Reed relay
Road speed	Inductive pulse generator
Engine speed	Hall effect
Fluid levels	Float and reed switch
Oil pressure	Diaphragm switch
Brake pad wear	Embedded contact wire
Lights in operation	Bulb and simple circuit
Battery charge rate	Bulb circuit/voltage monitor

13.1.3 Thermal-type gauges

Thermal gauges, which are ideal for fuel and engine temperature indication, have been in use for many years. This will continue because of their simple design and inherent 'thermal' damping. The gauge works by utilizing the heating effect of electricity and the benefit of the widely adopted bimetal strip. As a current flows through a simple heating coil wound on a bimetal strip, heat causes the strip to bend. The bimetal strip is connected to a pointer on a suitable scale. The amount of bend is proportional to the heat, which in turn is proportional to the current flowing. Providing the sensor can vary its resistance in proportion to the measurand (e.g. fuel level), the gauge will indicate a suitable representation providing it has been calibrated for the particular task. Figure 13.2 shows a representation of a typical thermal gauge.

The inherent damping is due to the slow thermal effect on the bimetal strip. This causes the needle to move very slowly to its final position. It can be said to have a large time constant. This is a particular advantage for displaying fuel level, as the variable resistor in the tank will move, as the fuel moves, due to vehicle movement! If the gauge were able to react quickly it would be constantly moving. The movement of the fuel however is, in effect, averaged out and a relatively accurate display can be obtained. Some electronically driven thermal fuel gauges are damped even more by the control system.

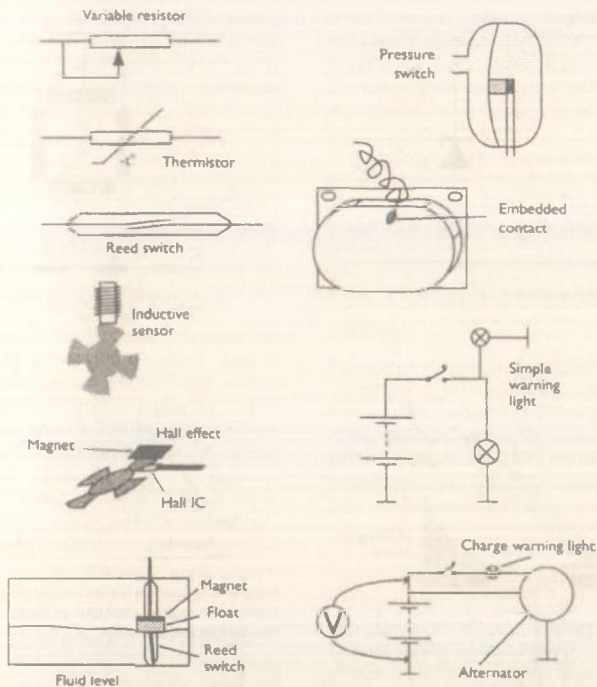


Figure 13.1 Sensors used for instrumentation

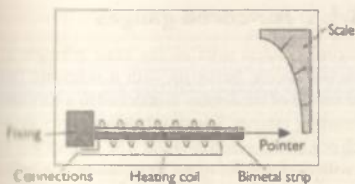


Figure 13.2 Bimetal strip operation in a thermal-type gauge

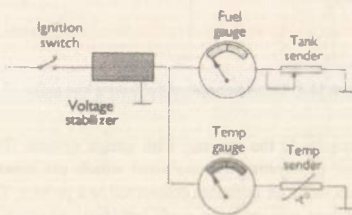


Figure 13.3 Bimetal fuel and temperature gauge circuit

Thermal-type gauges are used with a variable resistor and float in a fuel tank or with a thermistor in the engine water jacket. Figure 13.3 shows the circuit of these two together. The resistance of the fuel tank sender can be made non-linear to counteract any non-linear response of the gauge. The sender resistance is at a maximum when the tank is empty.

A constant voltage supply is required to prevent changes in the vehicle system voltage affecting the reading. This is because, if the system voltage increased, the current flowing would increase and

hence the gauges would read higher. Most voltage stabilizers are simple Zener diode circuits, as shown in Figure 13.4.

13.1.4 Moving iron gauges

The moving iron gauge was in use earlier than the thermal type but is now gaining popularity for some applications. Figure 13.5 shows the circuit and

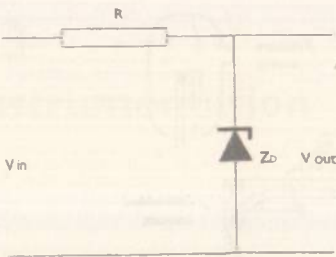


Figure 13.4 A voltage stabilizer

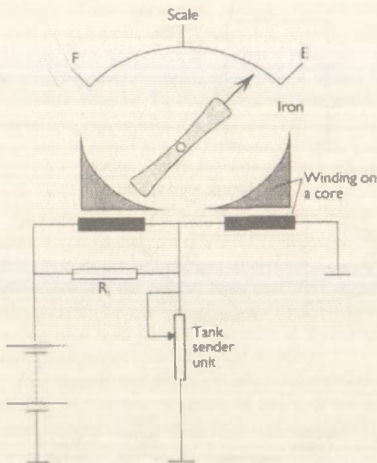


Figure 13.5 Circuit/principle of the moving iron gauge

principle of the moving iron gauge system. Two small electromagnets are used which act upon a small soft iron armature connected to a pointer. The armature will position itself between the cores of the electromagnets depending on the magnetic strength of each. The ratio of magnetism in each core is changed as the linear variable resistance sender changes and hence the needle is moved. This type of gauge reacts very quickly (it has a small time constant) and is prone to swing about with movement of the vehicle. Some form of external damping can be used to improve this problem. Resistor R_1 is used to balance out the resistance of the tank sender. A good way to visualize the operation of the circuit is to note that when the tank is half full, the resistance of the sender will be the same as the resistance of R_1 . This makes the circuit

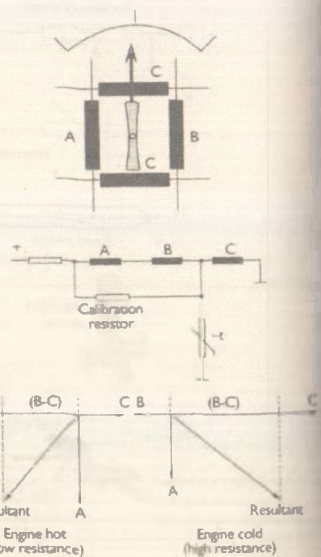


Figure 13.6 Principle of the air-cored gauge together with the circuit when used as a fuel level or temperature indicator and the resultant magnetic fields

balanced and the gauge will read half full. The sender resistance is at a maximum when the tank is full.

13.1.5 Air-cored gauges

Air-cored gauges work on the same principle as a compass needle lining up with a magnetic field. The needle of the display is attached to a very small permanent magnet. Three coils of wire are used and each produces a magnetic field. The magnet will line up with the resultant of the three fields. The current flowing and the number of turns (ampere-turns) determine the strength of the magnetic flux produced by each coil. As the number of turns remains constant the current is the key factor. Figure 13.6 shows the principle of the air-cored gauge together with the circuit for use as a temperature indicator. The ballast resistor on the left is used to limit maximum current and the calibration resistor is used for calibration. The thermistor is the temperature sender. As the thermistor resistance is increased, the current in all three coils will change. Current through C will be increased but the current in coils A and B will decrease. The resultant magnetic fields are shown in Figure 13.6. This moves the magnetic armature accordingly.

The air-cored gauge has a number of advantages. It has almost instant response and, as the needle is held in a magnetic field, it will not move as the vehicle changes position. The gauge can be arranged to continue to register the last position even when switched off or, if a small 'pull off' magnet is used, it will return to its zero position. As a system voltage change would affect the current flowing in all these coils variations are cancelled out, negating the need for voltage stabilization. Note that the operation is similar to the moving iron gauge.

13.1.6 Other types of gauges

A variation of any of the above types of gauge can be used to display other required outputs, such as voltage or oil pressure. Gauges to display road or engine speed, however, need to react very quickly to changes. Many systems now use stepper motors for this purpose although some retain the conventional cable driven speedometers.

Figure 13.7 shows a block diagram of a speedometer, which uses an ammeter as the gauge. This system uses a quenched oscillator sensor that will produce a constant amplitude signal even at very low speed. The frequency of the signal is proportional to road speed. The sensor is driven from the gearbox or a final drive output. The electronic control or signal conditioning circuit consists firstly of a Schmitt trigger, which shapes the signal and suppresses any noise picked up in the wiring. The monostable is used to produce uniform signals in proportion to those from the pulse generator. The sensing coil gauge will read an average of the pulses. This average value is dependent on the frequency of the input signal, which in turn is dependent on vehicle speed. The odometer is driven by a stepper

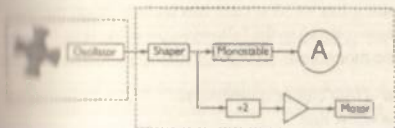


Figure 13.7 Block diagram of a speedometer system which uses a simple ammeter as the gauge

motor, which is driven by the output of a divider and a power amplifier. The divider is to calibrate the action of the stepper motor to the distance covered. The actual speedometer gauge can be calibrated to any vehicle by changing the time delay of the monostable (see Chapter 2).

A system for driving a tachometer is similar to the speedometer system. Pulses from the ignition primary circuit are often used to drive this gauge. Figure 13.8 shows the block diagram of a typical system.

13.1.7 A digital instrumentation system

Figure 13.9 shows a typical digital instrumentation system. All signal conditioning and logic functions are carried out in the ECU. This will often form part of the dashboard assembly. Standard sensors provide information to the ECU, which in turn will drive suitable displays. The ECU contains a ROM section, which allows it to be programmed to a specific

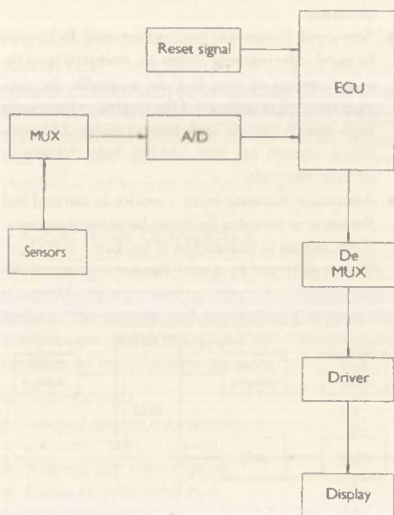


Figure 13.9 Digital instrumentation system



Figure 13.8 Block diagram of a tachometer which uses signals from the ignition coil

vehicle. The gauges used are as described in the above sections. Some of the extra functions available with this system are described briefly as follows.

- Low fuel warning light – can be made to illuminate at a particular resistance reading from the fuel tank sender unit.
- High engine temperature warning light – can be made to operate at a set resistance of the thermistor.
- Steady reading of the temperature gauge – to prevent the gauge fluctuating as the cooling system thermostat operates, the gauge can be made to read only at, say, five set figures. For example, if the input resistance varies from 240 to 200 Ω as the thermostat operates, the ECU will output just one reading, corresponding to 'normal' on the gauge. If the resistance is much higher or lower the gauge will read to one of the five higher or lower positions. This gives a low resolution but high readability for the driver.
- Oil pressure or other warning lights can be made to flash – this is more likely to catch the driver's attention.
- Service or inspection interval warning lights can be used – the warning lights are operated broadly as a function of time but, for example, the service interval is reduced if the engine experiences high speeds and/or high temperatures. Oil condition sensors are also used to help determine service intervals.
- Alternator warning light – works as normal but the same or an extra light can be made to operate if the output is reduced or if the drive belt slips. This is achieved by a wire from one phase of the

alternator providing a pulsed signal, which is compared to a pulsed signal from the ignition. If the ratio of the pulses changed this would indicate a slipping belt.

As an example of how some of this system works consider the high temperature and low fuel warning lights as examples. Figure 13.10 shows a block diagram of just this part of the overall system.

The analogue to digital converter is time division multiplexed to various sensors. The signals from the temperature and fuel level sensors will produce a certain digital representation of a numerical value when they reach say 180 Ω (about 105 °C) and 200 Ω (10 litres left), respectively. These figures (assigned to variables 'temp_input' and 'fuel_input') can then be compared with those pre-programmed into memory, variables 'high_temp' and 'low_fuel'. The following simplified lines of computer program indicate the logical result.

```
IF temp_input > high_temp THEN
  high_temp_light = on
```

```
IF fuel_input > low_fuel THEN
  low_fuel_light = on
```

A whole program is built up which can be made suitable for any particular vehicle requirements.

13.2 Driver information

13.2.1 Vehicle condition monitoring

VCM or vehicle condition monitoring is a form of instrumentation. It has now become difficult to separate it from the more normal instrumentation system discussed in the first part of this chapter. The complete VCM system can include driver information relating to the following list of systems that can be monitored.

- High engine temperature.
- Low fuel.
- Low brake fluid.
- Worn brake pads.
- Low coolant level.
- Low oil level.
- Low screen washer fluid.
- Low outside temperature.
- Bulb failure.
- Doors, bonnet or boot open warning.

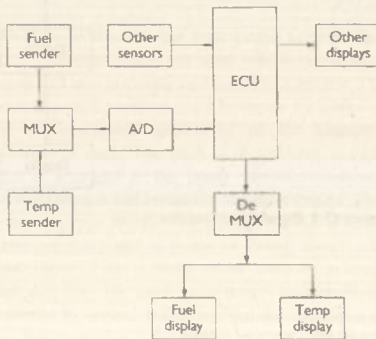


Figure 13.10 Block diagram of high temperature and low fuel warning lights. The A/D converter is time division multiplexed to various sensors

Figure 13.11 shows a trip computer display, which also incorporates the vehicle map (see next section)

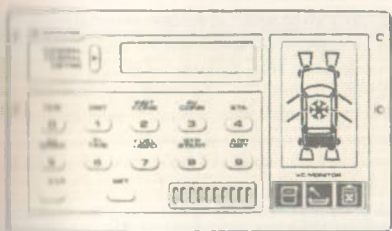


Figure 13.11 Trip computer display and a vehicle 'map'

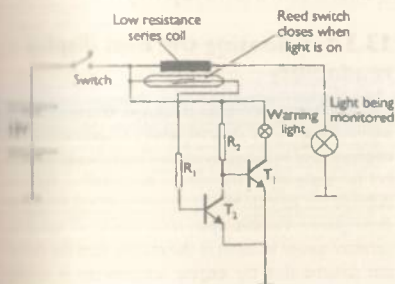


Figure 13.12 Bulb failure warning circuit

The circuit shown in Figure 13.12 can be used to operate bulb failure warning lights for whatever particular circuit it is monitoring. The simple principle is that the reed relay is only operated when the bulb being monitored is drawing current. The fluid and temperature level monitoring systems work in a similar way to the systems described earlier but in some cases the level of a fluid is monitored by a float and switch.

Oil level can be monitored by measuring the resistance of a heated wire on the end of the dipstick. A small current is passed through the wire to heat it. How much of the wire is covered by oil will determine its temperature and therefore its resistance.

Many of the circuits monitored use a dual resistance system so that the circuit itself is also checked. Figure 13.13 shows the equivalent circuit for this technique. In effect, it will produce one of three possible outputs: high resistance, low resistance or an out-of-range reading. The high or low resistance readings are used to indicate say correct fluid level and low fluid level. A figure outside these limits would indicate a circuit fault of either a short or open circuit connection.

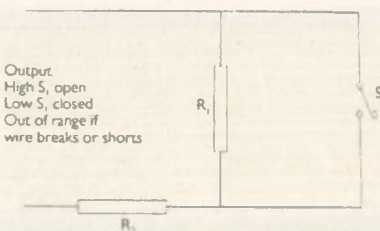


Figure 13.13 Equivalent circuit of a dual resistance self-testing system

Table 13.2 Input to the system

Input	Source
Clock signal	Crystal oscillator
Vehicle speed	Speed sensor or instruments ECU
Fuel being used	Injector open time or flow meter
Fuel in the tank	Tank sender unit
Mode/Set/Clear	Data input by the driver

The display is often just a collection of LEDs or a back lit LCD. These are arranged into suitable patterns and shapes such as to represent the circuit or system being monitored. An open door will illuminate a symbol that looks like the door of the vehicle map (plan view of the car) is open. Low outside temperature or ice warning is often a large snowflake.

13.2.2 Trip computer

The trip computer used on many top range vehicles is arguably an expensive novelty, but is popular nonetheless. The display and keypad of a typical trip computer are shown in Figure 13.11. The functions available on most systems are:

- Time and date.
- Elapsed time or a stop watch.
- Estimated time of arrival.
- Average fuel consumption.
- Range on remaining fuel.
- Trip distance.

The above details can usually be displayed in imperial, US or metric units as required. In order to calculate the above outputs the inputs to the system shown in Table 13.2 are required.

Figure 13.14 shows a block diagram of a trip computer system. Note that several systems use the same inputs and that several systems 'communicate' with each other. This makes the overall wiring very bulky – if not complicated. This type of interaction

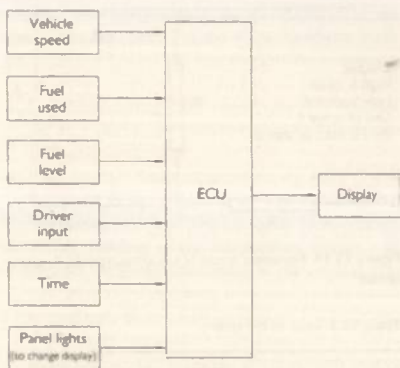


Figure 13.14 Display of a typical trip computer

and commonality between systems has been one of the reasons for the development of multiplexed wiring techniques (see Chapter 3).

13.2.3 Traffic information

Over 25 years have passed since we first watched James Bond use a tracking device, which showed a moving blip across a screen on the dashboard of his Aston Martin. Advances in computer technology and GPS systems have turned this into reality.

In California, many motor vehicles have been equipped with a gadget called the Navigator, which helps drivers get to a destination by displaying their vehicle's location on a glowing green map. The Navigator, introduced by a company known as Etak, is an electronic road map that calculates position by means of dead reckoning. Data from a solid-state compass installed in the vehicle's roof and from sensors mounted on its wheels are processed by a computer and displayed on a dashboard screen. The car's position is represented as a fixed triangle on a map, which scrolls down as the car moves forward and rotates sideways when it turns.

Toyota already offers a computerized dash-board map on an expensive model sold only in Japan, but many manufacturers are considering fitting these devices in the near future. Jaguar, as part of a project called 'Prometheus', in conjunction with other manufacturers, has developed a computerized system that picks up information from static transmitters. This system gives directions and advanced warning of road junctions, signposts and speed limits.

Other forms of driver information systems are being considered, such as one being developed in

USA. 'DriverGuide' is the electronic equivalent of winding down a window and asking for directions. By choosing from a variety of screen menus, the driver can specify where he or she wants to go. Twenty seconds later a printed sheet of driving instructions constructed from a cartographic database will be printed. Computerized route finding software is already very popular. Its one problem is that the data on disk is out of date instantly due to roadworks and other restrictions. Transmitting live data to the vehicle is the answer.

13.3 Visual displays

13.3.1 Choosing the best display – readability

The function of any visual display is to communicate information to the desired level of accuracy. Most displays used in the vehicle must provide instant data but the accuracy is not always important. Analogue displays can provide almost instant feedback from one short glance. For example, if the needle of the temperature gauge is about in the middle then the driver can assume that the engine temperature is within suitable limits. A digital read-out of temperature such as 98°C would not be as easy to interpret. This is a good example as to why even when digital processing and display techniques are used, the actual read-out will still be in analogue form. Figure 13.15 shows a display using analogue gauges.

Figure 13.16 shows an instrument display using digital representation. Numerical and other forms of display are, however, used for many applications. Some of these are as follows:

- Vehicle map.
- Trip computer.
- Clock.
- Radio displays.
- Route finding displays.
- General instruments.

These displays can be created in a number of ways, the following sections examine each of these in more detail. To drive individual segments or parts of a complete display, a technique called *time division multiplexing* is often used.

13.3.2 Light-emitting diode displays

If the PN junction of a diode is manufactured from gallium arsenide phosphide (GaAsP), light will be emitted from the junction when a current is made to



Figure 13.15 Analogue display



Figure 13.16 A display using LEDs

pass in the forward-biased direction. This is a light-emitting diode (LED) and will produce red, yellow or green light with slight changes in the manufacturing process. LEDs are used extensively as indicators on electronic equipment and in digital displays. They last for a very long time (50 000 hours) and draw only a small current.

LED displays are tending to be replaced for automobile use by the liquid crystal type display, which can be backlit to make it easier to read in the daylight. However, LEDs are still popular for many applications.

The actual display will normally consist of a number of LEDs arranged into a suitable pattern for the required output. This can range from the standard seven-segment display to show numbers, to a custom-designed speedometer display. A small number of LED displays are shown in Figure 13.17.

13.3.3 Liquid crystal displays

Liquid crystals are substances that do not melt directly from a solid to the liquid phase, but first pass through a paracrystalline stage in which the molecules are partially ordered. In this stage, a liquid crystal is a cloudy or translucent fluid but still has some of the optical properties of a solid crystal.

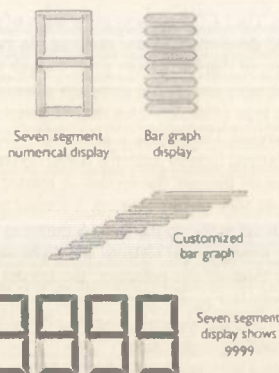


Figure 13.17 LED displays

The three main types of liquid crystals are smectic, nematic and cholesteric (twisted nematic), which are differentiated by the alignments of the rod-shaped molecules. Smectic liquid crystals have molecules parallel to one another, forming a layer, but within the layer no pattern exists. Nematic types have the rod-like molecules oriented parallel to one another but have no layer structure. The cholesteric types have parallel molecules, and the layers are arranged in a helical, or spiral, fashion.

Mechanical stress, electric and magnetic fields, pressure and temperature can alter the molecular structure of liquid crystals. A liquid crystal also scatters light that shines on it. Because of these properties, liquid crystals are used to display letters and numbers on calculators, digital watches and automobile instrument displays. LCDs are also used for portable computer screens and even television

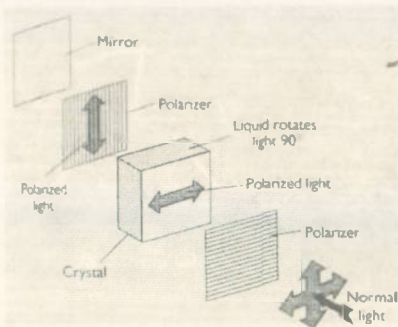


Figure 13.18 Principle of a liquid crystal display

screens. The LCD has many more areas of potential use and developments are ongoing. In particular, this type of display is now good enough to reproduce pictures and text on computer screens.

One type of display uses the cholesteric type of liquid crystal. This display is achieved by only allowing polarized light to enter the liquid crystal which, as it passes through the crystal, is rotated by 90° . The light then passes through a second polarizer, which is set at 90° to the first. A mirror at the back of the arrangement reflects the light so that it returns through the polarizer, the crystal and the front polarizer again. The net result is that light is simply reflected, but only when the liquid crystal is in this one particular state.

When a voltage of about 10 V at 50 Hz is applied to the crystal, it becomes disorganized and the light passing through it is no longer twisted by 90° . This means that the light polarized by the first polarizer will not pass through the second, and will therefore not be reflected. This will show as a dark area on the display.

These areas are constructed into suitable segments in much the same way as with LEDs to provide whatever type of display is required. The size of each individual area can be very small, such as to form one pixel of a TV or computer screen if appropriate. Figure 13.18 shows a representation of how this liquid crystal display works.

LCDs use very low power but do require a source of light to operate. To be able to read the display in the dark some form of lighting for the display is required. Instead of using a reflecting mirror at the back of the display a source of light known as backlighting can be used. A condition known as DC electroluminescence is an ideal phenomenon. This uses a zinc-sulphide based compound, which is placed between two electrodes in much the same way as the

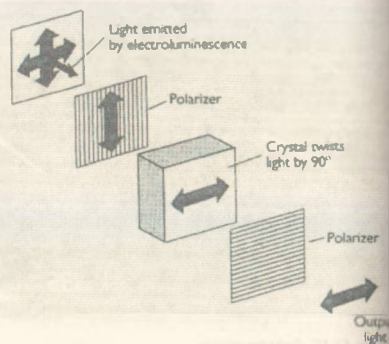


Figure 13.19 Backlighting effect can be used to good effect for display purposes

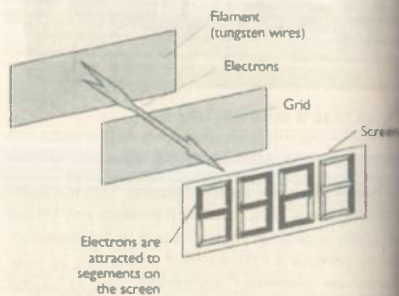


Figure 13.20 Vacuum fluorescent display

liquid crystal, but it emits light when a voltage is applied. Figure 13.19 shows how this backlighting effect can be used to good effect for display purposes.

13.3.4 Vacuum fluorescent displays

A vacuum fluorescent display (VFD) works in much the same way as a television tube and screen. It is becoming increasingly popular for vehicle use because it produces a bright light (which is adjustable) and a wider choice of colours than LED or LCD displays. Figure 13.20 shows that the VFD system consists of three main components. These are the filament, the grid and the screen with segments placed appropriately for the intended use of the display. The filament forms the cathode and the segments the anode of the main circuit. The control

grid is used to control brightness as the voltage is altered.

When a current is passed through the tungsten filaments they become red hot (several hundred degrees centigrade) and emit electrons. The whole tube is made to contain a good vacuum so that the electrons are not affected by any outside influence. The segments are coated with a fluorescent substance and connected to a control wire. The segments are given a positive potential to attract the electrons. When electrons strike the segments they fluoresce, emitting a yellow-green or a blue-green light depending on the type of phosphor used to coat the segments. If the potential of the grid is changed, the number of electrons striking the segments can be changed, thus affecting the brightness. If no segments are connected to a supply (often only about 15V), then all the electrons emitted are stopped at the grid. The grid is also important in that it tends to organize the movement of electrons.

Figure 13.21 shows a circuit used to control a VFD. Note how the potential of the segments when activated is above that of the grid. The driver circuit for this system is much the same, in principle, as any other display, i.e. the electronic control will connect one or more of the appropriate segments to a supply to produce the desired output.

The glass front of the display can be coloured to improve the readability and aesthetic value. This type of display has many advantages but the main problem for automobile use is its susceptibility to shock and vibration. This can be overcome, however, with suitable mountings.

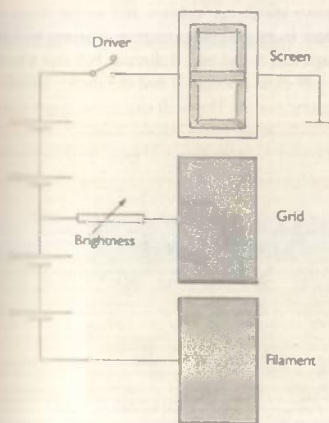


Figure 13.21 Circuit which could be used to control a VFD

13.3.5 Head-up displays

One of the main problems to solve with any automobile instrument or monitoring display is that the driver has to look away from the road to see the information. Also, in many cases, the driver does not actually need to look at the display, and hence could miss an important warning such as low oil pressure. Many techniques can be used such as warning beepers or placing the instruments almost in view, but one of the most innovative is the head-up display (HUD). This was originally developed by the aircraft industry for fighter pilots; aircraft designers had similar problems in displaying up to 100 different warning devices in an aircraft cockpit. Figure 13.22 shows the principle of a head-up display. Information from a display device, which could be a CRT (cathode ray tube), is directed onto a partially reflecting mirror. The information displayed on the CRT would therefore have to be reversed for this system. Under normal circumstances the driver would be able to see the road through the mirror. The brightness of the display would, of course, have to be adjusted to suit ambient lighting conditions. A great deal of data could be presented when this system is computer controlled.

A problem, however, is which information to provide in this way. The speedometer could form part of a lower level display and a low oil pressure could cause a flash right in front of the driver. A visual warning could also be displayed when a forward facing radar detects an impending collision. Current HUD systems are for straight-ahead vision, but liquid crystal rear view mirrors, used to dim and cut headlight glare automatically, can be used as an effective display screen for rear facing, blind spot detecting radar.

One of the most interesting studies is to determine exactly where the driver is looking at any point in time, which could be used to determine where the head-up display would be projected at any particular

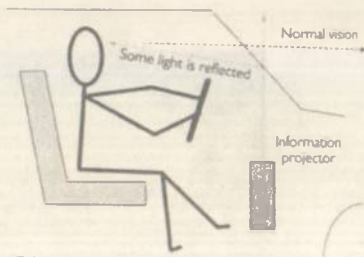


Figure 13.22 Head-up display

time. The technique involves tiny video cameras, coupled to a laser beam that reflects from the cornea of the driver's eye and can measure exactly where he or she is looking. Apart from its use in research, the eye motion detector is one of a series of tools used in bio-mechanical research that can directly monitor the physical well-being of the driver. Some of these tools could eventually be used actively to control the car or to wake up a driver who is at risk of falling asleep.

13.3.6 Display techniques summary

Most of the discussion in previous sections has been related to the activation of an individual display device. The techniques used for – and the layout of – dashboard or display panels are very important. To a great extent this again comes back to readability. When so many techniques are available to the designer it is tempting to use the most technologically advanced. This, however, is not always the best. It is prudent to ask the one simple question: what is the most appropriate display technique for this application? Figure 13.23 shows a display that combines some of the devices discussed previously.

Many of the decisions regarding the display are going to be according to the preference of the designer. I find numerical display of vehicle speed

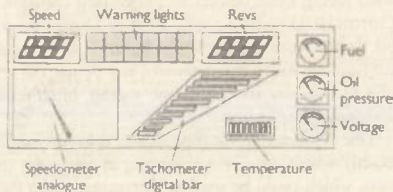


Figure 13.23 Displays which combine some of the devices discussed



Figure 13.24 An instrument panel and other readout displays

or engine rev/min irritating. Even the bar graph displays are not as good as simple analogue needles (this, however, is only my opinion).

The layout and the way that instruments are combined is an area in which much research has been carried out. This relates to the time it takes the driver to gain the information required when looking away from the road to glance at the instrument panel. Figure 13.24 shows an instrument panel and other readout displays. Note how compact it is so that the information can be absorbed almost without the driver having to scan to each readout in turn. The aesthetic looks of the dashboard are an important selling point for a vehicle. This could be at odds with the best readability on some occasions.

13.4 Case studies

13.4.1 Air-cored temperature gauge – Rover

Figure 13.25 shows the system used on some Rover vehicles for the temperature gauge. It is an air-cored device with fluid damping. The temperature gauge is fitted with a spiral pull off spring to make the gauge read 'cold' when the ignition is switched off. The fuel gauge is very similar but retains its position when the ignition is off.

When the system receives a supply from the ignition the resistance of the thermistor determines the current flowing through the coils. When engine coolant temperature is low, the resistance of the sender will be high. This will cause the voltage at point X to be higher than that at point Y. This will be above the Zener voltage and so the diode will conduct in its reverse direction. Current will flow through coil A and coil B directly but also a further path will exist through R and the diode, effectively bypassing coil A. This will cause the magnetism of coil B to be greater than coil A, deflecting the magnet and pointer towards the cold side. As the resistance

of the sender falls with increasing temperature, the voltage at X will fall, reducing the current through coil B, allowing the needle to rise.

At normal operating temperature, the voltage at X will be just under the Zener diode breakdown voltage. Current through each coil will now be the same and the gauge will read in the centre. If coolant temperature increases further, then current will flow through the diode in its forward direction, thus increasing the current through coil A, which will cause the needle to move to the hot side. Operation of the fuel gauge is similar but a resistor is used in place of the

Zener diode. The diode is used to stabilize the gauge when reading 'normal' to reduce fluctuations due to thermostat operation.

13.4.2 Car navigation system – Alpine Electronics

The 'Alpine' navigation system is one of the most advanced systems in current use. It features very accurate maps, is easy to use and even offers some voice guidance. The system consists of the base unit, a monitor, an antenna, a remote control and CD-ROM discs. Figure 13.26 shows the system in a vehicle. The following features are highlighted by 'Alpine'.

One easy setting and you're on your way. You can input and have the system search for your destination in a variety of ways: by address, street name, category or memory point. Destinations can be set by quick alphabetical input or you can switch directly to common destinations like airports or hotels. Popup menus allow you to choose spellings of destinations, memory inputs, etc. by using the remote control cursor.

Once inputting is done, the system calculates the best route to your destination according to your instructions. You can choose whether to go via motorway or normal streets, and also include local-points (like restaurants or fuel stations) or exclude avoid-points, which you set. If traffic flow is obstructed, use 'Alternate Route Setting' instantly to get a new route. Cross-border routes can also be specified.

Alpine gives 'Voice Guidance' to the destination, as well as a wide selection of display options. The 'Basic Direction Mode' displays only the most essential information, so as not to distract you from driving. It clearly shows the car's direction, distance

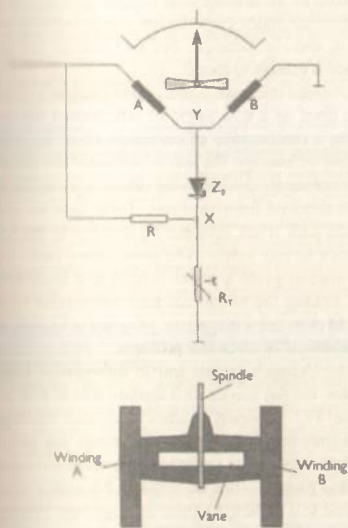


Figure 13.25 Air-cored gauge with fluid damping



Figure 13.26 'Alpine' navigation system mounted in a vehicle

to next junction, and time remaining to destination. The direction at the next junction is also shown – a big advantage in heavy traffic. 'Intersection Zoom' is a facility allowing a closer look, and any of several display modes, such as north-up or heading-up, are available. Figure 13.27 shows two screenshots from the system.

Intersection Zoom is an interesting feature of the Alpine system and the key to its easy to understand guidance. As you approach an intersection, the upcoming junction is enlarged so you know exactly what turns are required to stay on your route. If a junction is missed, the 'Auto Reroute' function calculates a new route within seconds. It works so smoothly and quickly you may not even realize you have missed your original way!

Alpine has become the most successful navigation system in the world. This has been achieved by meeting present demands and also by anticipating future needs. For instance, if you change from summer to winter tyres, the system may have to be calibrated. The Alpine system auto-calibrates during the first few miles and software updates are easily downloaded from CD into the flash memory.

13.4.3 Telematics

The information provided here is taken from information provided by the Automobile Association (AA), a well-respected organization, in the UK. Similar developments are taking place across the world. It was difficult to know whether 'Telematics' should be included in the instrumentation section or elsewhere – but here it is anyway.

The car is a necessary component of our lives. Over the last 50 years the number of vehicles has grown 10-fold and, by 2030, traffic is expected to have increased by a further 60%. The cost of personal transport is high; we should be acting now to ease congestion, save fuel and protect the environment. The technology to create some of the solutions is already available.

First-generation telematics services are already available, or under development. They include:

- Voice based roadside assistance, emergency dispatch, traffic information services and route advice.
- Travel guidance, points of interest, touring and travel information.
- Stolen vehicle tracking by satellite.
- Radio Data System (RDS) built into most car radios and the recent launch of RDS-TMC (Traffic Message Channel).

A fifth of all driving time is spent getting lost on unfamiliar roads even though it is possible to pinpoint specific locations like fuel stations and then guide a vehicle to them.

A small telematics control unit fitted in a vehicle can open up a new world of information services, using a combination of communications and computing technology. The unit is connected to a receiver that constantly calculates the vehicle's position using data received from satellites. These data are combined with other information and fed to the telematics service centre. The information could then be used to guide a patrol vehicle to a breakdown. By linking the telematics unit, the service centre could even use a diagnostic program to identify the mechanical or electrical problem.

As Europe's largest traffic information broadcaster, the AA has taken a leading role in nine separate EC transport studies and has developed real-time traffic management systems that provide instant information about road problems and uncongested routes. When an onboard telematics unit is linked to a vehicle's engine management system it will be able to monitor vehicle performance and give advance warning of mechanical problems. In the near future, a wide range of vital new services may be on offer.

- Traffic information. To give drivers the best and quickest route destination given the road conditions at the time.

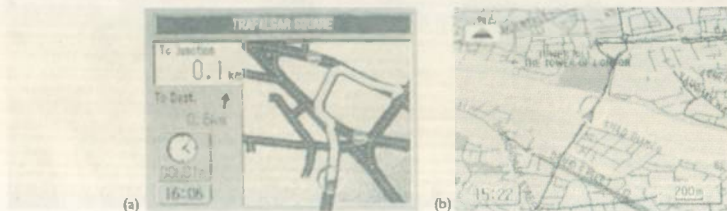


Figure 13.27 Screenshots from 'Alpine' showing (a) intersection zoom and (b) automatic rerouting

- **Route guidance.** The service centre will be able to calculate the best route to a nominated destination, taking into account traffic conditions along the way, and relay it to a visual and audible display in the vehicle.
- **Radio Data System Traffic Message Channel (RDS-TMC).** This is coded traffic information, broadcast continuously as a sub-carrier on a national radio channel, with updates made every 10 seconds. A driver can choose precisely when he or she receives the information, and can even specify particular roads that are relevant to their own journey.
- **Vehicle tracking.** This is tracking technology that can trace a stolen vehicle and identify its location.
- **Remote services.** To lock, unlock or immobilize a vehicle remotely. The operator will even be able to flash the vehicle's lights to help you locate it in a car park.
- **Emergency dispatch.** An in-vehicle emergency button that will be able to alert the emergency services to an incident and give its location. Alternatively, the services could be alerted automatically by a vehicle sensor, triggered by an event such as a deployed airbag.
- **Remote vehicle diagnostics.** Telematics will predict when your vehicle is about to break down, and arrange for a patrol to meet you at a convenient nearby location.
- **Floating car data.** Every vehicle fitted with a telematics unit could eventually help to keep traffic moving by automatically and continuously providing the service centre with details of traffic flow in its immediate location. That traffic condition data can then be assessed and fed back out to other drivers who may be approaching the same area and possible congestion.

(Data from Automobile Association, 1998)

Table 13.3 Common symptoms and possible faults of an instrumentation system malfunction

Symptom	Possible fault
Fuel and temperature gauges both read high or low	● Voltage stabilizer.
Gauges read full/hot or empty/cold all the time	● Short/open circuit sensors.
Instrumentations do not work	● Short or open circuit wiring.
	● Loose or broken wiring/connections/fuse.
	● Inoperative instrument voltage stabilizer.
	● Sender units (sensor) faulty.
	● Gauge unit fault (not very common).

13.5 Diagnosing instrumentation system faults

13.5.1 Introduction

As with all systems the six stages of fault-finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 13.3 lists some common symptoms of an instrumentation system malfunction together with suggestions for the possible fault. The faults are very generic but will serve as a good reminder.

13.5.2 Testing procedure

The process of checking a thermal gauge fuel or temperature instrument system is broadly as follows.

1. Hand and eye checks (loose wires, loose switches and other obvious faults) – all connections clean and tight.
2. *Either* fit a known good 200 Ω resistor in place of the temperature sender – gauge should read full.
3. *Or* short fuel tank sender wire to earth – gauge should read full.
4. Check continuity of wire from gauge to sender – 0 to 0.5 Ω .
5. Check supply voltage to gauge (pulsed 0–12 V on old systems) – 10 V stabilized on most.
6. If all above tests are OK the gauge head is at fault.

13.6 Advanced instrumentation technology

13.6.1 Multiplexed displays

In order to drive even a simple seven-segment display, at least eight wiring connections are required. This would be one supply and seven earths (one for each segment). This does not include auxiliary lines

required for other purposes, such as backlighting or brightness. To display three seven-segment units, up to about 30 wires and connections would be needed.

To reduce the wiring, time division multiplexing is used. This means that the individual display unit will only be lit during its own small time slot. From Figure 13.28 it can be seen that, if the bottom connection is made at the same time as the appropriate data is present on the seven input lines, only one seven-segment display will be activated. This is carried out for each in turn, thousands of times a second and the human eye does not perceive a flicker.

The technique of multiplexing is taken a stage further by some systems, in that one digital controller carries out the whole of the data or signal processing. Figure 13.29 shows this in block diagram form. The technique is known as data sampling. The electronic control unit samples each input in turn in its own time slot, and outputs to the appropriate display again in a form suitable for the display device used. The electronics will contain a number of A/D and D/A converters and these will also be multiplexed where possible.

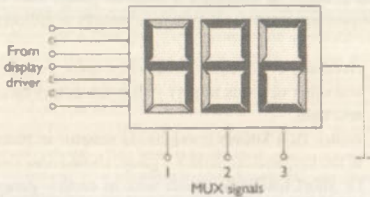


Figure 13.28 Time divisions multiplexing is used so the individual display unit will only be lit during its own small time slot

13.6.2 Quantization

When analogue signals are converted to digital a process called quantization takes place. This could be described as digital encoding. Digital encoding breaks down all data into elementary binary digits (bits), which enable it to be processed, stored, transmitted and decoded as required by computer technologies.

The value of an analogue signal changes smoothly between zero and a maximum. This infinitely varying quantity is converted to a series of discrete values of 0 or 1 by a process known as quantization. The range of values from zero to the maximum possible is divided into a discrete number of steps or quantization levels. The number of steps possible depends on the bit size of the word the digital processors can deal with. For an 8-bit word, the range can be divided into 256 steps (2^8), i.e. from 00000000, to 11111111. These digital 'samples' should always be taken at more than twice the frequency of the analogue signal to ensure accurate reproduction.

Quantization introduces an error into the process as each value is 'rounded' to the nearest quantization level. The greater the number of quantization levels the more accurate the process will be, but obviously increased accuracy involves more bits being used to define the increased number of levels.

13.6.3 Holography

A holographic image is a three-dimensional representation of the original subject. It can be created by splitting a laser beam into object and reference beams. These beams produce an interference pattern, which can be stored on a plate or projected on to a special screen. Some research is currently ongoing towards using holography to improve night driving safety. Information from infrared cameras

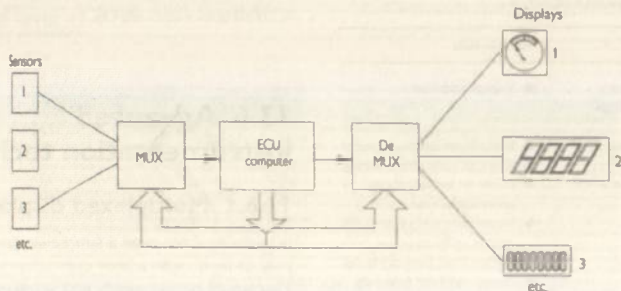


Figure 13.29 Block diagram showing how multiplexing is taken a stage further by some systems

can be processed, and then an enhanced holographic image can be projected onto a vehicle windscreen.

13.7 New developments in instrumentation systems

13.7.1 Global positioning system (GPS)

From 1974 to 1979 a trial using six satellites allowed navigation in North America for just four hours per day. This trial was extended worldwide by using eleven satellites until 1982, at which time it was decided that the system would be extended to twenty-four satellites, in six orbits, with four operating in each. These orbits are not symmetrical and they can be varied. They are set at a height of about 21 000 km (13 000 miles) and take approximately twelve hours to orbit the Earth.

The system was developed by the American Department of Defence. Using an encrypted code allows a ground location to be positioned to within a few centimetres. The signal employed for civilian use is artificially reduced in quality so that positioning accuracy is in the region of 50 m.

The GPS satellites send out synchronized information fifty times a second. Data on orbit position, time and identification signals are transmitted. The navigation computer, in the vehicle or elsewhere, receives signals from up to eight satellites. The times taken for the signals to reach the vehicle are calculated at the same time. From this information the computer can calculate the distance from each satellite. The current vehicle position can then be determined using three coordinates. Imagine the three satellites forming a triangle – the position of the vehicle within that triangle can be determined if the distance from each corner (satellite) is known.

The satellites each have very accurate atomic clocks (four of them) that are synchronized by a communication link between satellites. Navigation computers also have clocks and, to eliminate the difference between satellite time and computer time, an additional measurement to a more distant satellite is taken.

The main components of a 'sat-nav' system are shown in Figure 13.31. Maps of towns and cities as well as names of towns, cities and roads are stored on CD-ROM in the main unit. Information on main routes and menu sound/text is also held. The unit is mounted in the boot or under the passenger seat.

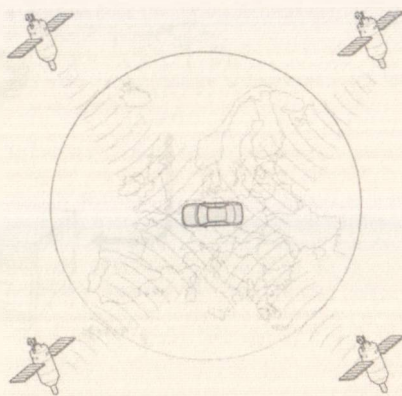


Figure 13.30 Satellites used to determine vehicle position (Source: Ford)

In addition to the GPS, the operating unit also controls the ICE system.

The navigation unit processes the following input signals:

- Magnetic field sensor OR turn angle sensor (depending on version).
- ABS wheel speed sensor signals.
- GPS positioning information.
- Data from the CD-ROM.
- Reverse light switch.

The wheel speed sensors provide information on distance covered. The sensors on the non-driven wheels are used because the driven wheels slip when accelerating. On some versions turn angle is calculated by comparing left and right hand signals. This is not necessary when a turn angle sensor is used.

The reverse light switch is used because the signals from the wheel speed sensors do not indicate if the vehicle is travelling forwards or in reverse. The GPS antenna receives the satellite signals and also amplifies them. It is mounted under the panel in front of the windscreen or a similar position.

The magnetic field sensor (if used) is usually located at the top of the rear window in a sealed housing. The compass determines direction of travel in relation to the Earth's magnetic field. It also senses the changes in direction when driving round a corner or a bend.

The two crossed measuring coils sense changes in the Earth's magnetic field because it has a different effect in each of them. The direction of the Earth's field can be calculated from the polarity and voltage produced by these two coils. The smaller

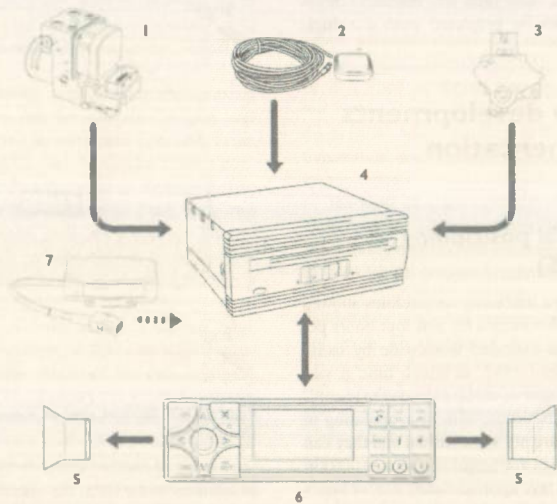


Figure 13.31 Radio navigation system (Source: Ford). 1. ABS module (distance information calculated from wheel speed sensors). 2. GPS antenna. 3. Reverse light switch. 4. Main computer including CD-ROM drive. 5. Speakers. 6. Display and operating unit. 7. Magnetic field sensor (not used if the main unit contains a turn angle sensor).

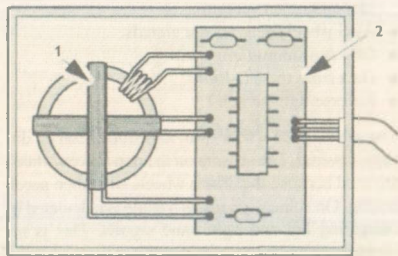


Figure 13.32 Magnetic field sensor or compass (Source: Ford). 1. Sensor element. 2. Evaluation circuit.

excitation coil produces a signal that causes the ferri-te core to oscillate. The direction of the Earth's magnetic field causes the signals from the measuring coils to change depending on the direction of the vehicle. One problem with this type of sensor is that it is also affected by other magnetic fields such as that produced by the heated rear window. Allowance must therefore be made for this in the configuration.

The turn angle sensor allows the navigation computer to follow a digital map, in conjunction with other sensor signals, because it provides accurate information about the turning of the vehicle around its vertical axis. It is mounted in the main

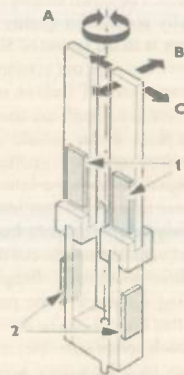


Figure 13.33 Turn angle sensor (Source: Ford). Piezo electric element (picks up acceleration in the twisting direction A around the vertical axis of the vehicle A). 2. Piezo electric element (causes vibration in direction C).

unit and supersedes the magnetic compass. The sensor is like a tiny tuning fork that is made to vibrate in the kilohertz range, by the two lower Piezo electric elements. The upper elements sense the acceleration when the vehicle changes direction; this is because the twisting of the Piezo element causes an electrical charge. This signal is processed

converted into a voltage that corresponds to vehicle heading movement, and sent on to the main computer. The advantage of this type of sensor is that it is not sensitive to magnetic effects.

The operation method and functions available will vary with manufacturers and are also under constant development. However, Figure 13.34 is a typical example as used by Ford. A later display and control unit version is shown in Figure 13.35; the functions have been developed but are similar.

Text and speech output in a number of languages is normally available. When English is selected as the language, a choice of metric and imperial measurements is also available.

When the NAV function is selected, a menu appears that shows options such as:

- Address book (for pre-set destinations).
- Points of interest.
- Last destination.
- System setup (includes a diagnostic mode on some systems).

To use the system, the destination address is entered using the cursor keys. The systems 'predict' the possible destination as letters are entered, so it is not usually necessary to enter the complete address. Once the destination is set the unit will calculate the route. Options may be given for the shortest or quickest routes at this stage. Driving instructions, relating to the route to be followed, are given visually on the display and audibly through the speakers.

● Address entry.

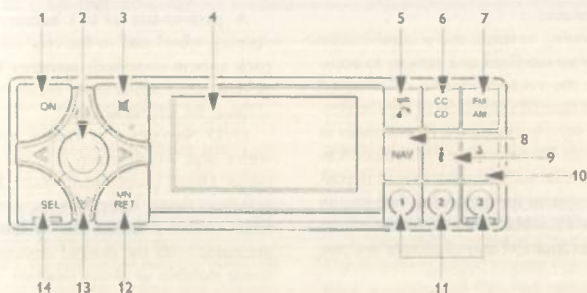


Figure 13.34 Typical operating unit display (Source: Ford). 1. On/off switch. 2. Volume, bass, fade and balance (selected by SEL). 3. Mute button. 4. Display area. 5. Tape control. 6. Tape/CD. 7. Wavebands. 8. Navigation system on/off. 9. Info. 10. Detour function. 11. Pre-set stations. 12. Menu/return. 13. Cursor control. 14. Select audio function.



Figure 13.35 Telematics display (Source: Ford)

Even though the satellite information only provides a positional accuracy of about 50 m, using dead-reckoning the intelligent software system can still get the driver to their destination with an accuracy of about 5 m. Dead-reckoning means that the vehicle position is determined from speed sensor and turn angle signals. The computer can update the vehicle position given by the GPS data by using the possible positions on the stored digital map. For example, when the vehicle approaches and then makes a right turn, the combination of GPS data and dead-reckoning allows its position to be determined more accurately. This is because in many places on the map only one particular position is possible – it is assumed that short cuts across fields are not taken! Dead-reckoning even allows navigation when satellite signals are disrupted. However, the starting position of a journey would also need to be entered.

Global positioning systems use a combination of information from satellites and sensors to accurately determine the vehicle position on a digital map. A route can then be calculated to a given destination. Like all vehicle systems, GPS continues to develop and will do for some time yet as more features are added to the software. Already it is possible to 'ask' the system for the nearest fuel station or restaurant, for example. Work is continuing as more vehicle entertainment and telematics systems converge.

13.7.2 Advanced telematics and communications systems – Jaguar

The following description, supplied by Jaguar, relates to the 2004 Jaguar XJ and is a good illustration of how telematics and communication systems are progressing:

JaguarVoice, an industry-first for Jaguar in 1999, provides drivers and rear passengers with access to voice-activated control of compatible systems, including primary audio functions, teletext, telephone, climate control, navigation systems and in-vehicle displays. Jaguar has made voice activation – a technology to reduce distraction when driving – an ongoing research priority. All vehicles are pre-wired for installation of the desired language mode. The system will be available in English, French, and Spanish.

A push-to-talk (PTT) button located on the steering wheel and in the rear multimedia switch pack (where specified) activates the JaguarVoice system, and automatically mutes the audio system volume, for telephone use.

DVD Navigation, a Denso navigation system with a large 7-inch screen, is available across the XJ range. Using exceptionally fast DVD technology to deliver timely mapping information to the clear, touch-sensitive screen, the system is easily programmed with the desired destination, such as a house number or street junction. Alternatively, a



Figure 13.36 Jaguar DVD/Navigation touch screen (Source: Ford)



Figure 13.37 BMW HUD – a clear information source – albeit in German here! (Source: Siemens)

post zip code can be entered into the system, which then calculates a route and instructs the driver via visual and voice guidance. If the driver strays off the route, the system recalculates a revised routing to the desired destination and guides accordingly. DVD technology allows complete mapping of, for example, the whole of the USA on one disc.

Along the route, the system can indicate 'points of interest', including restaurants, hotels, fuel stations, parking areas and Jaguar dealers, and can even be linked with the fuel gauge to automatically display nearby fuel stations when the fuel level indicated low.

The navigation system receives signals from global positioning satellites (GPS) that allow its electronic control unit (ECU) to calculate the vehicle's exact location, along with its speed and direction, using inputs from ABS system sensors and a gyroscopic sensor. The navigation system's crystal clear screen is also used for touch-screen programming of vehicle systems. Navigation is optional across the range.

The new rear seat multimedia system allows rear seat passengers to access the audio and video systems independently of the driver and front seat passenger. The front passenger could be listening to a CD while one of the rear seat passengers is viewing a film on DVD and the other rear seat passenger plays a video game.

Two 16 cm (6.5-inch) colour display screens are mounted in the rear of the front seat head restraints for video and TV viewing. Rear seat passengers use headphones to listen to the audio output in comfort.

The rear multimedia switch pack controls audio and video signals and has an open architecture to accept all types of inputs from devices. Sockets for two accessory headphones are also located in the switch pack. The rear multimedia system is optional on XJR and Vanden Plas versions.

A high quality sound system comes as standard. The 8-speaker sound system fitted to the XJ8 features a single-slot CD and radio with RDS, and automatic volume control. The system is pre-wired for a six-disc CD auto-changer. A 320 watt Jaguar Premium sound system with 12 speakers, digital sound processing, power amplifier, subwoofers, as well as the remote six-disc CD auto-changer and single-slot CD/radio is fitted as standard on XJR and Vanden Plas and optional on the XJ8.

(It is interesting to note that, as with many developments, telematics is converging with other systems. This is particularly so with the multimedia systems.)

13.7.3 Siemens cockpit display system

Some one hundred years after the invention of the speedometer, modern cockpits have advanced well beyond the primitive instrumentation of the first cars and trucks. Although round instruments with pointers and scales are still in evidence, ever larger displays, screens and dazzling illumination technologies optimize a growing driver information load. "Siemens VDO Automotive AG" (Siemens) is at work

on exciting new developments such as the coloured head-up display, which will change information management behind the steering wheel dramatically. Although vehicles today generate more data, commands and messages that have to be transmitted, the driver is informed much faster and far more efficiently than in the past.

Currently, it is taken as a given that our vehicles will keep drivers informed about the important things, such as a low oil level or the proper road exit to take. Instruments are now more or less fully programmable and offer the ideal medium for the exchange of information. Modern instrumentation, going well beyond the conventional requirements of speed, rpm and fuel consumption, provide in-depth analysis of mechanical problems, or project information, from the on-board computer directly into the driver's line of sight. What's more, navigation instructions and controls for the audio system and telephone are increasingly being shifted out of the centre console and into the instrument cluster.

Instrumentation technology has developed quickly. While the first screen displays in the mid-1980s were small monochrome screens, they have given way to large full-colour monitors. The latest instruments can even create three-dimensional graphics on a high-resolution TFT (thin film transistor) monitor. For navigation purposes, megabyte-scale image data are programmed into systems today, offering the driver a variety of scenarios composed from more than 300 individual images. In addition, navigation controls make use of several hundred pictograms and, in some cases, moving animations. Mechanical warnings may be viewed on the instrument cluster – with supplementary information in several languages. Powerful computing is naturally required for this enormous graphics capability. For this reason Siemens is one of the first suppliers to use 32-bit processors that guarantee particularly high computing speeds.

Siemens designs instrumentation to make the best use of the limited space behind the steering wheel. Where a miniaturization of printed circuit boards, controllers and movements is not sufficient alone, displays are completely integrated into the round dashboard instrument – as in the BMW 7 Series or in the E-Class from Mercedes-Benz. Here, Siemens developers place the pointer either through the middle of the dot matrix display or on an invisible ring around the outside of the instrument scale. This prevents, for example, a telephone directory display from being obscured. And, so that the circular segment display for the autonomous cruise control does not interfere with navigation instructions, several displays are often layered. In light of these

developments, the instrument cluster display has a great future. In the near term, it will even be possible to display the pointer and dial of a fully reconfigurable instrument cluster as a digital computer animation. Farther out, the digital cluster may even displace other elements from the instrument panel.

To maintain effective eye contact between driver and vehicle, the illumination has to be right. For this reason Siemens has consistently forged new ground with the development of many high-tech lighting technologies. In the beginning instruments were floodlit from the outside using a bulb, and later illuminated from the rear through a partially transparent dial. Since 1995 light-emitting diodes (LED) have offered perfect colour saturation, uniform illumination and maintenance-free operation. These extremely bright light sources are available in practically the entire colour spectrum, including the white LED. A novel solution helped eliminate the annoying halo that surrounded the speedometer pointer shaft in some devices. Today the pointer is irradiated with invisible ultraviolet LED light which becomes visible only in a tip made of luminescent material. Many of these new technologies, of course, require new electronics. In order to save space on the printed circuit board, Siemens is employing a unique solution that is now on the speedometer dial of the Mercedes-Benz E-Class – a white electroluminescent film. Parallel to this work is also being done on a projection display in which the surface of the cockpit is used as a projector screen. This affords new freedom for the designer because even curved surfaces could be used for the display in the future. Another interesting design twist: when the car is parked, the instrument cluster is completely invisible.

In the near future the classic dashboard instrument will be getting additional support. Siemens will soon bring the first programmable colour head-up display into production. The HUD will significantly expand the display area of the instrument panel. Important information on speed, vehicle condition and navigation can be projected in colour onto the windscreen with a powerful light source and mirror. In the direct field of view the driver can immediately receive information without taking his eyes off the road. Tests have already shown that driver concentration is maintained for longer periods with the head-up display. The eyes adapt very quickly to the information projected on the windshield; there is also less time lag between the appearance of the information and the driver's reaction.

That time saving means safer driving.¹

¹Siemens, Nov. 7, 2002, Frankfurt, www.siemens.com

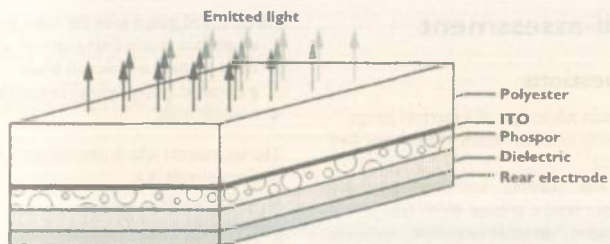


Figure 13.38 Construction of an EL lamp (Source: Durel)

13.7.4 Electroluminescent instrument lighting – Durel

Electroluminescent backlighting is an enticing technology for the automotive industry because of its very uniform lighting characteristics. Durel Corporation has done significant development work in this area.³ Electroluminescent (EL) lamps provide a range of exciting opportunities for instrument designers.

An EL lamp is similar to a capacitor. It consists of a dielectric layer and a light-emitting phosphor layer between two conductive plates. The device needs to be protected from high voltages but the dielectric layer achieves this because it is an insulator. Alternating current (AC) is needed to operate an EL lamp. The AC generates an electric field across the phosphor and dielectric layers. The phosphor electrons are excited by the electric field which causes them to move to a higher energy orbit. When these electrons fall back to a lower orbit, energy is released in the form of light.

Polyethylene terephthalate (PET) is used as the base material for many EL lamps. The front electrode is made of indium tin oxide (ITO). The phosphor, dielectric and rear electrode are screen printed onto the ITO side of the polyester, which results in a source of light that is thin and flat.

There are a number of clear benefits to EL lighting:

- Uniformity.
- Durability.
- Flexibility (thin and lightweight).
- Easy to make into different shapes.
- Low power consumption and low heat generation.
- Simple to design.

The other options for instrument lighting are bulbs, light emitting diodes and cold-cathode fluorescent

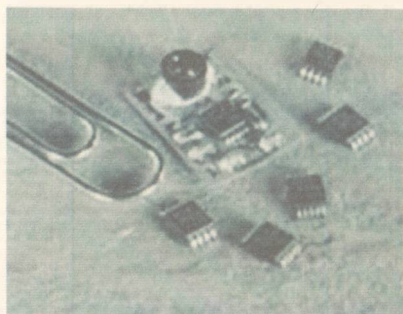


Figure 13.39 IC inverter for an EL system (Source: Durel)

lamps (sometimes known as vacuum fluorescent displays). EL lamps are often superior to these other types, particularly when instruments are considered as a complete system.

A wide range of colours can be created using the EL method. This is achieved by blending combinations of phosphors before screen printing. It is also possible to print selected areas with different phosphors, thus creating a multi-coloured lamp. Typical colours are blue-green, green, yellow-green, white, blue and orange-red.

Because EL lamps need AC to emit light, it is necessary to use an inverter. Typically, the signal used for EL operation is 60 to 150 V_{rms} at a frequency of 300 to 500 Hz. The current draw of the inverter and lit area is only about 1 to 2 mA/cm². EL lamps can operate for over 20 000 hours, which usually exceeds the life of the vehicle.

For final assembly purposes the EL lamp is essentially a 2.5 mm-thick film that is sandwiched between a backplate and the graphic overlay.

The future for EL instrument lighting is bright! The reduced costs and uniform lighting characteristics make the technology desirable to designers. With further development of brighter EL lamps, daytime lighting and 'tell-tale' lighting will also become possible

³JJ McFarren, CL Baker and RT Eckersley, 2002, Durel Corp. IEE paper 2002-01-1039

13.8 Self-assessment

13.8.1 Questions

1. State the main advantage of a thermal gauge.
2. Make a clearly labelled sketch of a thermal fuel gauge circuit.
3. Describe why moving iron and air-cored gauges do not need a voltage stabilizer.
4. Define the term, 'driver information'.
5. Explain why digital displays are multiplexed.
6. Draw the circuit of a bulb failure system and describe its operation.
7. List five typical outputs of a trip computer and the inputs required to calculate each of them.
8. Describe with the aid of a sketch how a head-up display (HUD) operates.
9. Explain the operation of an air-cored fuel gauge system.
10. Describe what is meant by 'Telematics'.

13.8.2 Assignment

Design an instrument display for a car. Choose whatever type of display techniques you want, but make a report justifying your choices. Some key issues to consider are readability, accuracy, cost and aesthetic appeal.

13.8.3 Multiple choice questions

When checking an NTC type temperature sensor, Technician A says remember resistance increases as temperature increases. Technician B says remember resistance decreases as temperature increases. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

One characteristic of a thermal type fuel gauge is its:

1. slow moving needle
2. almost instantaneous response
3. need for a reed switch type sensor
4. ability to be used for oil pressure measurement

The component which prevents changes in the system voltage affecting a gauge reading is called a:

1. moving iron resistor
2. variable resistor
3. current regulator
4. voltage stabilizer

An air-cored gauge uses the same principle as:

1. a compass needle lining up with a magnetic field
2. wind pushing a windmill blade
3. a bi-metal strip moving the needle when heated
4. none of these

The instrument which uses pulses from the ignition primary circuit is a:

1. speedometer
2. tachometer
3. ammeter
4. odometer

A vehicle condition monitoring system can monitor:

1. bulb operation by monitoring current drawn by the lights
2. door position by signals from switches
3. brake pad wear by contact wires in the friction material
4. all of the above

One reason for using a dual resistance system is:

1. if one resistor breaks down the other will still operate
2. so that the circuit itself is checked
3. it reduces the operating temperature of the resistors
4. so the current flow in the circuit is increased

The basic functions available on a trip computer include:

1. average fuel consumption, trip distance, elapsed time
2. trip distance, elapsed time, fuel remaining
3. elapsed time, fuel remaining, estimated time of arrival
4. fuel remaining, estimated time of arrival, date and time

Technician A says advantages of LEDs are that they last a very long time and only draw a small current. Technician B says a disadvantage of LEDs is that they only produce red, yellow or green light. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

Backlighting of a liquid crystal display (LCD) is used in order to:

1. be able to read the display
2. prevent DC electroluminescence
3. display the light in a forward biased direction
4. increase vacuum fluorescence

14

Air conditioning

14.1 Conventional heating and ventilation

14.1.1 Introduction

The earliest electrical heating I have come across was a pair of gloves with heating elements woven into the material (c. 1920). These were then connected to the vehicle electrical system and worked like little electric fires. The thought of what happened in the case of a short circuit is a little worrying!

The development of interior vehicle heating has been an incremental process and will continue to be so — the introduction of air conditioning being the latest step. The comfort we now take for granted had some very cold beginnings, but the technology in this area of the vehicle electrical system is still evolving. Systems now range from basic hot/cold air blowers to complex automatic temperature and climate control systems.

Any heating and ventilation system has a simple set of requirements, which are met to varying standards. These can be summarized as follows.

- Adjustable temperature in the vehicle cabin.
- Heat must be available as soon as possible.
- Distribute heat to various parts of the vehicle.
- Ventilate with fresh air with minimum noise.
- Facilitate the demisting of all windows.
- Ease of control operation.

The above list, whilst by no means definitive, gives an indication of what is required from a heating and ventilation system. As usual, the more complex the system the more the requirements are fulfilled. This is directly related to cost.

Some solutions to the above requirements are discussed below, starting with simple ventilation and leading on to full automatic temperature control. Figure 14.1 shows a representation of the perceived comfortable temperature in the vehicle compared with the outside temperature.

14.1.2 Ventilation

To allow fresh air from outside the vehicle to be circulated inside the cabin, a pressure difference must

be created. This is achieved by using a plenum chamber. A plenum chamber by definition holds a gas (in this case air), at a pressure higher than the ambient pressure. The plenum chamber on a vehicle is usually situated just below the windscreen, behind the bonnet hood. When the vehicle is moving the air flow over the vehicle will cause a higher pressure in this area. Figure 14.2 shows an illustration of the plenum chamber effect. Suitable flaps and drains are utilized to prevent water entering the car through this opening.

By means of distribution trunking, control flaps and suitable 'nozzles', the air can be directed as required. This system is enhanced with the addition of a variable speed blower motor. Figure 14.3 shows a typical ventilation and heating system layout.

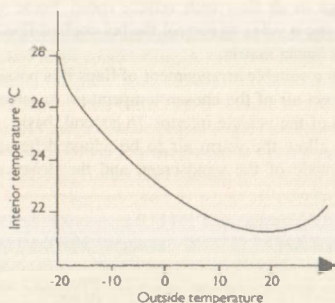


Figure 14.1 Representation of comfortable temperature

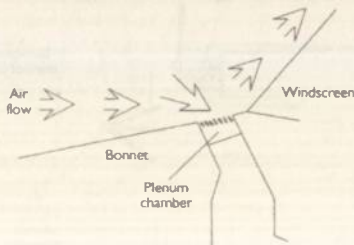


Figure 14.2 Plenum chamber effect

When extra air is forced into a vehicle cabin the interior pressure would increase if no outlet was available. Most passenger cars have the outlet grilles on each side of the vehicle above or near the rear quarter panels or doors.

14.1.3 Heating system – water-cooled engine

Heat from the engine is utilized to increase the temperature of the car interior. This is achieved by use of a heat exchanger, called the heater matrix. Due to the action of the thermostat in the engine cooling system the water temperature remains broadly constant. This allows for the air being passed over the heater matrix to be heated by a set amount depending on the outside air temperature and the rate of air flow. A source of hot air is therefore available for heating the vehicle interior. However, some form of control is required over how much heat (if any), is required. The method used on most modern vehicles is the blending technique. This is simply a control flap, which determines how much of the air being passed into the vehicle is directed over the heater matrix. The main drawback of this system is the change in air flow with vehicle speed. Some systems use a valve to control the hot coolant flowing to the heater matrix.

By a suitable arrangement of flaps it is possible to direct air of the chosen temperature to selected areas of the vehicle interior. In general, basic systems allow the warm air to be adjusted between the inside of the windscreen and the driver and

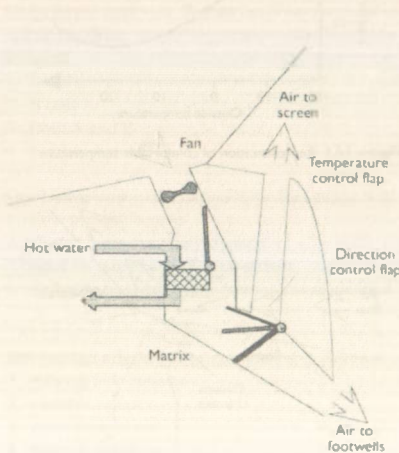


Figure 14.3 Ventilation and heating system

passenger foot wells. Most vehicles also have small vents directing warm air at the drivers and front passenger's side windows. Fresh cool air outlets with directional nozzles are also fitted.

One final facility, which is available on many vehicles, is the choice between fresh or recirculated air. The main reason for this is to decrease the time it takes to demist or defrost the vehicle windows, and simply to heat the car interior more quickly to a higher temperature. The other reason is that, for example, in heavy congested traffic, the outside air may not be very clean.

14.1.4 Heater blower motors

The motors used to increase air flow are simple permanent magnet two-brush motors. The blower fan is often the centrifugal type and in many cases, the blades are positioned asymmetrically to reduce resonant noise. Figure 14.4 shows a typical motor and fan arrangement. Varying the voltage supplied controls motor speed. This is achieved by using dropping resistors. The speed in some cases is made 'infinitely' variable by the use of a variable resistor. In most cases the motor is controlled in three or four set speeds.

Figure 14.5 shows a circuit diagram typical of a three-speed control system. The resistors are usually wire wound and are placed in the air stream to prevent overheating. These resistors will have low values in the region of $1\ \Omega$ or less.

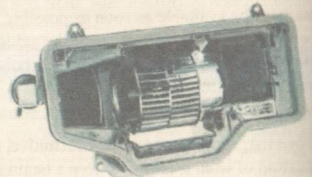


Figure 14.4 HVAC motor mounted in spiral housing

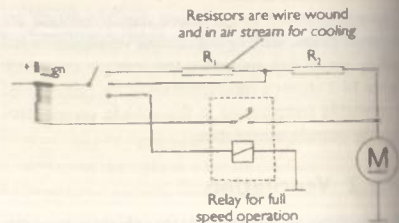


Figure 14.5 Circuit diagram of a three-speed control system

14.1.5 Electronic heating control

Most vehicles that have electronic control of the heating system also include air conditioning, which is covered in the next section. However, a short description at this stage will help to lead into the more complex systems. Figure 14.6 shows a block diagram representing an electronically controlled vehicle heating system.

This system requires control of the blower motor, blend flap, direction flaps and the fresh or recirculated air flap. The technique involves one or a number of temperature sensors suitably positioned in the vehicle interior, to provide information for the ECU. The ECU responds to information received from these sensors and sets the controls to their optimum positions. The whole arrangement is, in fact, a simple closed loop feedback system with the air temperature closing the loop. The ECU has to compare the position of the temperature control switch with the information that is supplied by the sensors and either cool or heat the car interior as required.

14.2 Air conditioning

14.2.1 Introduction

A vehicle fitted with air conditioning allows the temperature of the cabin to be controlled to the ideal or most comfortable value determined by the ambient conditions. The system as a whole still utilizes the standard heating and ventilation components, but with the important addition of an evaporator, which both cools and dehumidifies the air.

Air conditioning can be manually controlled or, as is now often the case, combined with some form of electronic control. The system as a whole can be thought of as a type of refrigerator or heat exchanger. Heat is removed from the car interior and dispersed to the outside air.

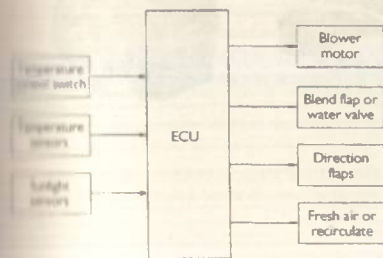


Figure 14.6 An electronically controlled vehicle heating system

14.2.2 Principle of refrigeration

To understand the principle of refrigeration the following terms and definitions will be useful.

- Heat is a form of energy.
- Temperature means the degree of heat of an object.
- Heat will only flow from a higher to a lower temperature.
- Heat quantity is measured in 'calories' (more often kcal).
- 1 kcal heat quantity, changes the temperature of 1 kg of liquid water by 1 °C.
- Change of state, is a term used to describe the changing of a solid to a liquid, a liquid to a gas, a gas to a liquid or a liquid to a solid.
- Evaporation is used to describe the change of state from a liquid to a gas.
- Condensation is used to describe the change of state from gas to liquid.
- Latent heat describes the energy required to evaporate a liquid without changing its temperature (breaking of molecular bonds), or the amount of heat given off when a gas condenses back into a liquid without changing temperature (making of molecular bonds).

Latent heat in the change of state of a refrigerant is the key to air conditioning. A simple example of this is that if you put a liquid such as methylated spirits on your hand it feels cold. This is because it evaporates and the change of state (liquid to gas) uses heat from your body. This is why the process is often thought of as 'unheating' rather than cooling.

The refrigerant used in many air conditioning systems is known as R134A. This substance changes state from liquid to gas at -26.3°C . R134A is hydrofluorocarbon (HFC) rather than chlorofluorocarbon (CFC) based, due to the problems with atmospheric ozone depletion associated with CFC-based refrigerants. Note that this type of refrigerant is *not* compatible with older systems.

A key to understanding refrigeration is to remember that a low-pressure refrigerant will have low temperature, and a high-pressure refrigerant will have a high temperature.

Figure 14.7 shows the basic principle of an air conditioning or refrigeration system. The basic components are the evaporator, condenser and pump or compressor. The evaporator is situated in the car; the condenser outside the car, usually in the air stream. The compressor is driven by the engine.

As the pump operates it will cause the pressure on its intake side to fall, which will allow the refrigerant in the evaporator to evaporate and draw heat

from the vehicle interior. The high pressure or output of the pump is connected to the condenser. The pressure causes the refrigerant to condense (in the condenser); thus giving off heat outside the vehicle as it changes state.

Several further components are needed for efficient operation; these are explained over the next few sections. Figure 14.8 shows some typical components of an air conditioning system.

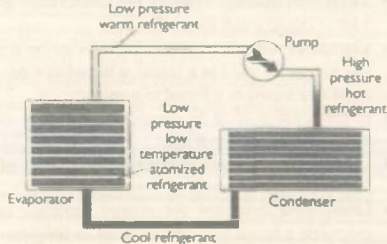


Figure 14.7 Basic principle of an air conditioning or refrigeration system

14.2.3 Air conditioning overview

The operation of the system is a continuous cycle. The compressor pumps low pressure but heat laden vapour from the evaporator, compresses it and pumps it as a super-heated vapour under high pressure to the condenser. The temperature of the refrigerant at this stage is much higher than the outside air temperature, hence it gives up its heat via the fins on the condenser as it changes state back to a liquid.

This high-pressure liquid is then passed to the receiver-drier where any vapour which has not yet turned back to a liquid is stored, and a desiccant bar removes any moisture (water) that is contaminating the refrigerant. The high-pressure liquid is now passed through the thermostatic expansion valve and is converted back to a low-pressure liquid as it passes through a restriction in the valve into the evaporator. This valve is the element of the system that controls the refrigerant flow and hence the amount of cooling provided. As the liquid changes state to a gas in the evaporator, it takes up heat from its surroundings, thus cooling or 'unheating' the air that is forced over the fins. The low pressure vapour leaves the evaporator returning to the pump.

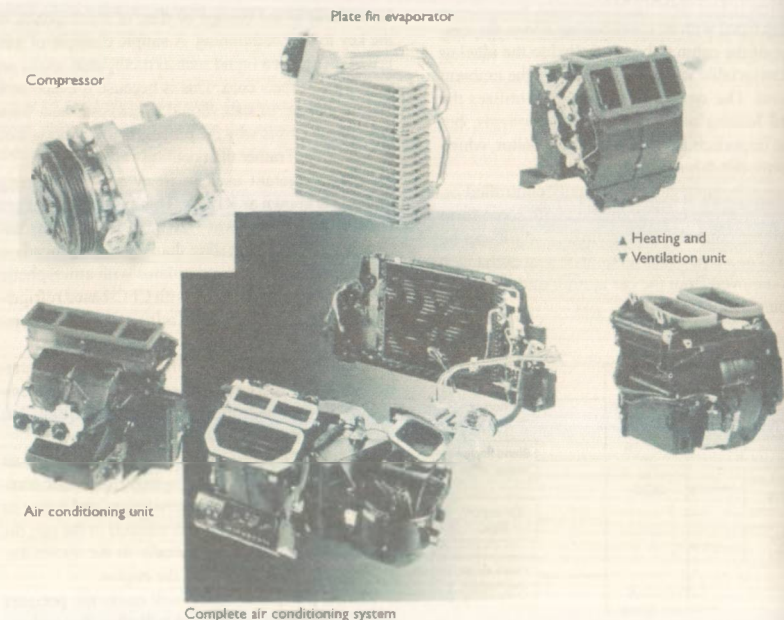


Figure 14.8 Heating ventilation and air conditioning (HVAC) components

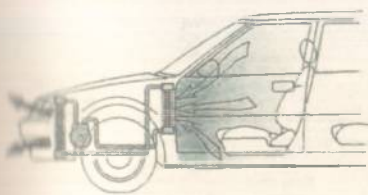


Figure 14.9 Air conditioning operation

thus completing the cycle. The cycle is represented in Figure 14.9.

If the temperature of the refrigerant increases beyond certain limits, condenser cooling fans can be switched in to supplement the ram air effect.

A safety switch is fitted in the high-pressure side of most systems. It is often known as a high–low pressure switch, as it will switch off the compressor if the pressure is too high due to a component fault, or if the pressure is too low due to a leakage, thus protecting the compressor.

14.2.4 Automatic temperature control

Full temperature control systems provide a comfortable interior temperature in line with the passenger controlled input. The electronic control unit has full control of fan speed, air distribution, air temperature, fresh or recirculated air and the air conditioning pump. These systems will soon be able to control automatic demist or defrost, when reliable sensors are available. A single button will currently set the system to full defrost or demist.

A number of sensors are used to provide input to the ECU.

- An ambient temperature sensor mounted outside the vehicle will allow compensation for extreme temperature variations. This device is usually a thermistor.
- A solar light sensor can be mounted on the fascia panel. This device is a photodiode and allows a measurement of direct sunlight from which the ECU can determine whether to increase the air to the face vents.
- The in-car temperature sensors are simple thermistors but, to allow for an accurate reading, a small motor and fan can be used to take a sample of interior air and direct it over the sensing elements.
- A coolant temperature sensor is used to monitor the temperature of the coolant supplied to the heater matrix. This sensor is used to prevent

operation of the system until coolant temperature is high enough to heat the vehicle interior.

- Driver input control switches.

The ECU takes information from all of the above sources and will set the system in the most appropriate manner as determined by the software. Control of the flaps can be either by solenoid controlled vacuum actuators or by small motors. The main blower motor is controlled by a heavy duty power transistor and is constantly variable. These systems are able to provide a comfortable interior temperature when exterior conditions range from -10 to $+35^{\circ}\text{C}$ even in extreme sunlight.

14.3 Other heating systems

14.3.1 Seat heating

The concept of seat heating is very simple. A heating element is placed in the seat, together with an on-off switch and a control to regulate the heat. However, the design of these heaters is more complex than first appears.

The heater must meet the following criteria.

- The heater must only supply the heat loss experienced by the person's body.
- Heat to be supplied only at the major contact points.
- Leather and fabric seats require different systems due to their different thermal properties.
- Heating elements must fit the design of the seat.
- The elements must pass the same rigorous tests as the seat, such as squirm, jounce and bump tests.

Figure 14.10 shows a seat containing heating elements.

In order for the passengers (including the driver) to be comfortable, rigorous tests have been carried out to find the optimum heat settings and the best position for the heating elements. Many tests are carried out on new designs, using a manikin with sensors attached, to measure the temperature and heat flow.

The cable used for most heating elements is known as a Sine Cable and consists of multi-strand alloyed copper. This cable may be coated with tin or insulated as the application demands. The heating element is laminated and bonded between layers of polyurethane foam.

The traditional method of control is a simple thermostat switch. Recent developments, however, tend to favour electronic control combined with a thermistor. A major supplier of seat heaters,

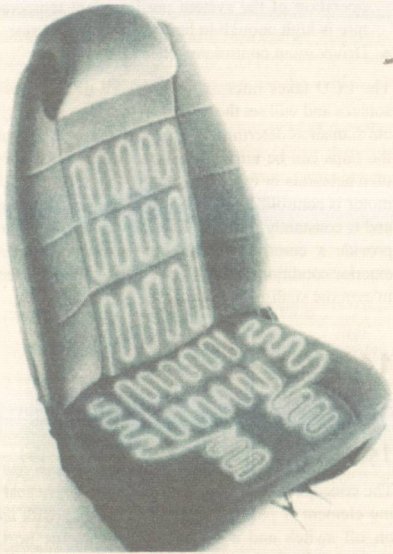


Figure 14.10 Seat containing heating element

Scandnec Ltd, supplies an electronic system that includes push button switches, potentiometers, timer function, short and open circuit detection. This is in addition to accurate control of the chosen temperature setting. These seat heaters will heat up to provide an initial sensation in 1 minute and to full regulated temperature in 3 minutes.

14.3.2 Screen heating

Heating of the rear screen involves a very simple circuit as shown in Figure 14.11. The heating elements consist of a thin metallic strip bonded to the glass. When a current is passed through the elements, heat is generated and the window will defrost or demist. This circuit can draw high current, 10–15 A being typical. Because of this, the circuit often contains a timer relay to prevent the heater being left on too long. The timer will switch off after 10–15 minutes. The elements are usually positioned to defrost the main area of the screen and the rest position of the rear wiper blade if fitted.

Front windscreen heating is being introduced on some vehicles. This of course presents more problems than the rear screen, as vision must not be obscured. The technology, drawn from the aircraft industry, involves very thin wires cast into the glass. As with the heated rear window, this device can consume a large current and is operated by a timer relay.

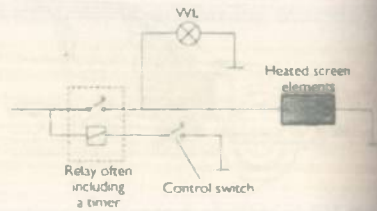


Figure 14.11 Screen heating circuit.

14.4 Case studies

14.4.1 Air conditioning – Rover

Figure 14.12 is the air conditioning system layout showing all the main components.

The compressor shown in Figure 14.13 is belt driven from the engine crankshaft and it acts as a pump circulating refrigerant through the system. The compressor shown is a piston and reed valve type. As the refrigerant is drawn into the cylinder due to the action of the piston, the outlet valve is closed due to the pressure. When the piston begins its compression stroke the inlet reed valve closes and the outlet opens. This compressor is controlled by an electromagnetic clutch, which may be either under manual control or electronic control depending on the type of system.

Figure 14.14 shows the condenser fitted in front of the vehicle radiator. It is very similar in construction to the radiator and fulfils a similar role. The heat is conducted through the aluminium pipes and fins to the surrounding air and then, by a process of convection, is dispersed by the air movement. The air movement is caused by the ram effect, which is supplemented by fans as required.

Figure 14.15 is the receiver-drier assembly. It is connected in the high-pressure line between the condenser and the thermostatic expansion valve. This component has four features.

- A reservoir to hold refrigerant until a greater flow is required.
- A filter to prevent contaminants circulating through the system.
- Vapour is retained in this unit until it finally converts back to a liquid.
- A drying agent removes any moisture from the system. The substance used in R134A systems is Zeolite. Some manufacturers recommend that this unit should be replaced if the system has been open to the atmosphere.

A sight glass is fitted to some receiver-driers to give an indication of refrigerant condition and system

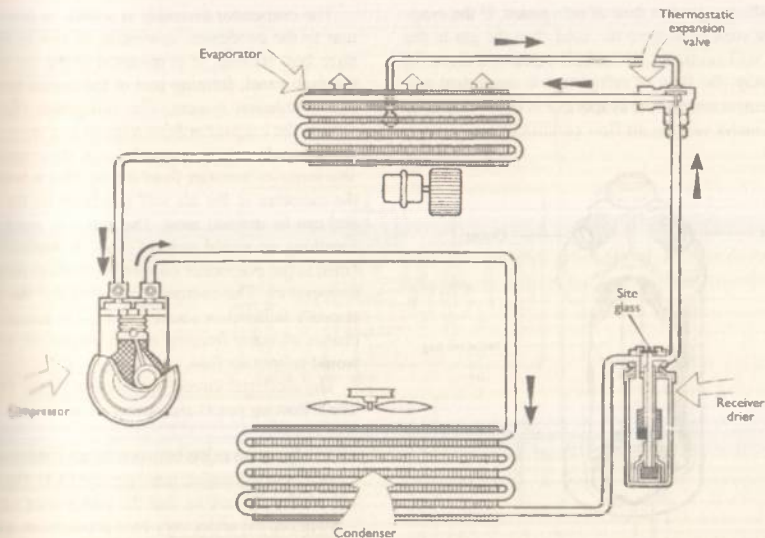


Figure 14.12 Air conditioning system layout

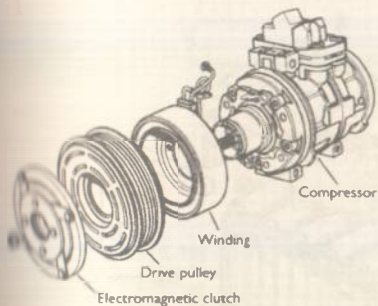


Figure 14.13 Air conditioning compressor

operation. The refrigerant generally appears clear if the system is in order.

The thermostatic expansion valve is shown as part of Figure 14.16 together with the evaporator assembly. It has two functions to fulfil:

- Control the flow of refrigerant as demanded by the system.
- Reduce refrigerant pressure in the evaporator.

The thermostatic expansion valve is a simple spring controlled ball valve, which has a diaphragm attached to a spring. A temperature sensitive gas such as carbon dioxide acts upon the diaphragm.

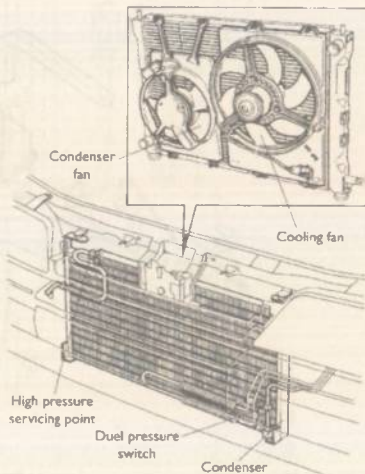


Figure 14.14 Air conditioning condenser

The gas is in a closed system including a capillary tube and a sensing bulb. This sensing bulb is secured on the evaporator. If the temperature of the evaporator rises, the gas in the bulb expands and acts on the diaphragm such as to open the ball valve

and allow a greater flow of refrigerant. If the evaporator were to become too cold, then the gas in the bulb will contract and the ball valve will close. In this way, the flow of refrigerant is controlled and the temperature of the evaporator is held fairly constant under varying air flow conditions.

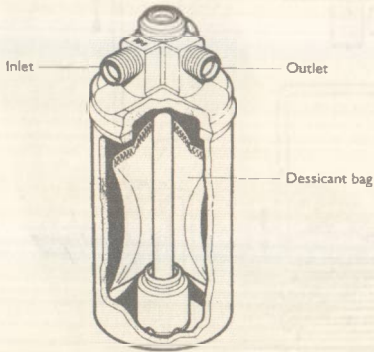


Figure 14.15 Receiver-drier

The evaporator assembly is similar in construction to the condenser, consisting of fins to maximize heat transfer. It is mounted in the car under the dash panel, forming part of the overall heating and ventilation system. The refrigerant changes state in the evaporator from a liquid to a vapour. As well as cooling the air passed over it, the evaporator also removes moisture from the air. This is because the moisture in the air will condense on the fins and can be drained away. The action is much like breathing on a cold pane of glass. A thermistor is fitted to the evaporator on some systems to monitor temperature. The compressor is cycled if the temperature falls below about 3 or 4 °C to prevent the chance of water freezing on the evaporator, which would restrict air flow.

The electrical circuit is shown in Figure 14.17. The following points are worthy of note.

- A connection exists between the air conditioning ECU and the engine management ECU. The reasons for this are so that the compressor can be switched off under very hard acceleration and to enable better control of engine idle.

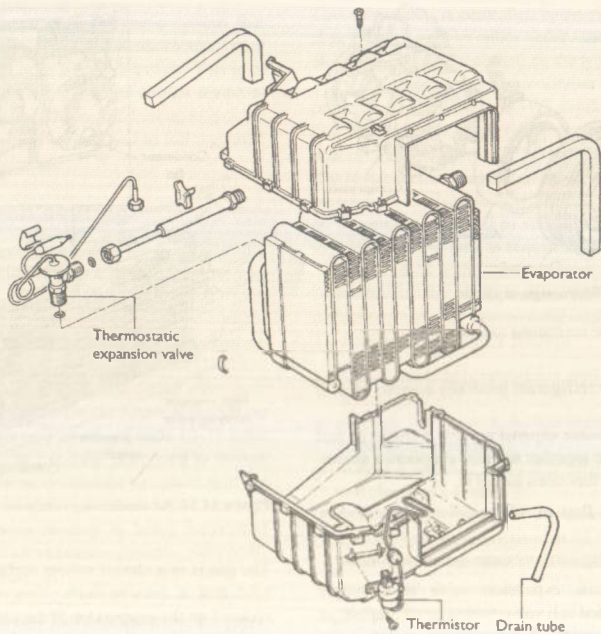


Figure 14.16 Evaporator and thermostatic expansion valve

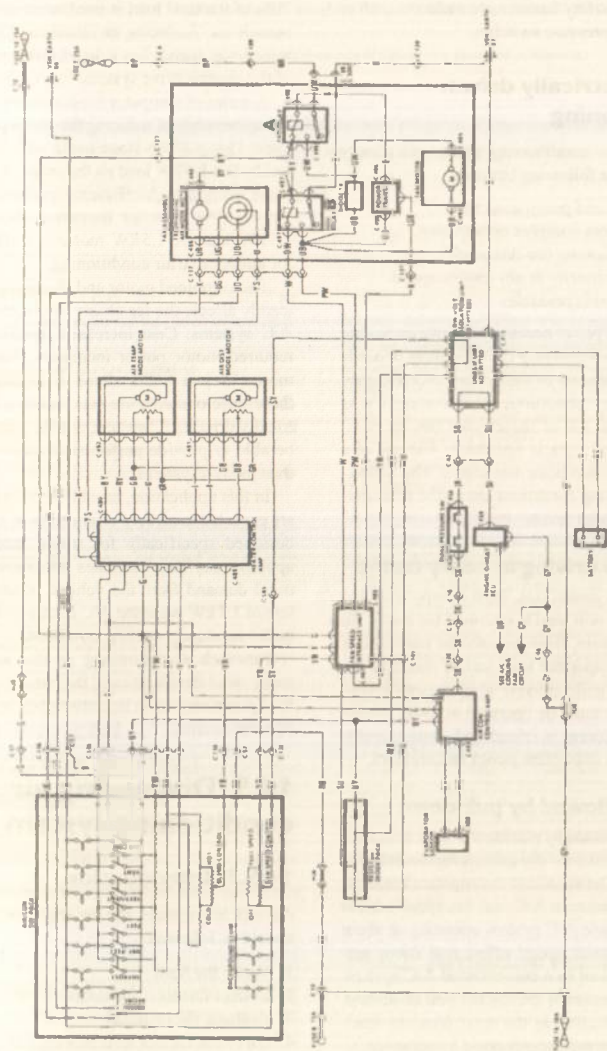


Figure 14.17 Air conditioning electrical circuit

- Twin cooling fans are used to cool the condenser. These can be run at two speeds using relays to connect them in series for slow operation, or in parallel for full speed.
- A number of safety features are included such as the high/low pressure switches.

14.4.2 Electrically driven air conditioning

To drive the air conditioning pump electrically could provide the following benefits:

- Sealed motor and pump assembly.
- Smaller and less complex compressor.
- Flexible positioning (no drive belt).
- Full cooling capacity at any engine speed.
- Greater control is possible.

The motor output power necessary to drive an electric automotive air conditioning (A/C) system depends on the cooling capacity of the system, its efficiency and the boundary conditions (temperatures) it is operating against. All of these quantities are variable under normal vehicle operation. The use of a 'brushless' motor has been considered. The following 'standard' rating conditions are useful in assessing maximum power levels.

Stop-and-go driving in heavy traffic

Under these test conditions, high compressor discharge pressures will tend to overload the motor. To prevent this problem, fresh air must be restricted at idle to reduce evaporator load and, if possible, the condenser fan should operate at overspeed conditions. The motor must be operated at lower speeds during idle to prevent overload and, consequently, will not reach its maximum power requirement.

Hot soak followed by pull down

This test is established by placing the vehicle in a hot sunny environment until the cabin temperature rises to about 65°C. The vehicle is then operated at about 50 km/h with maximum A/C and fan speed control settings. An electric A/C system operating at about half of its maximum speed offers pull down performance equivalent to a conventional A/C system. If operated at maximum during the pull down test, a significant reduction in the time taken to reach acceptable cabin temperatures could be achieved.

Cruising with full fresh air intake

This operating condition requires the A/C system to maintain comfortable cabin temperatures while processing significant quantities of outside air.

This establishes a maximum capacity level, which in turn sets the size of the motor and its drive electronics. For conventional A/C systems, a 3.75 kW motor is a reasonable estimate for this condition. About 70% of the total load is used to condition the fresh outside air. Reducing or eliminating fresh air load at highway speeds has a direct influence on the size of the electric drive system.

A series of computer simulations was conducted to explore ways of reducing the motor power requirement. Using a two-stage cycle with 25% fresh air results in a 1.5 kW load on the motor. A conventional cycle using a high-efficiency compressor coupled with a 20% fresh air limitation also results in a 1.5 kW load. A 1.5 kW motor is a realistic option for automotive air conditioning.

The combined motor and electronics cost significantly affects the feasibility of electric automotive A/C systems. Cost increases cycle with 25% fresh air as the required motor power increases. Development of more efficient A/C systems is ongoing. Assuming these developments are successful, a 1.5 kW electrically driven A/C system will be possible and will be able to provide performance equal to or better than today's systems.

In this application, brushless DC motor systems are expected to achieve efficiencies of 85–90% when designed specifically for sealed automotive A/C applications. This translates into a maximum electrical demand from the vehicle power supply system of 1.7 kW when the A/C electrical drive operates under maximum cooling conditions.

Research is continuing in this area but, like many other developments, the current extra costs of the system may soon be outweighed by the benefits of extra control.

14.5 Diagnosing air conditioning system faults

14.5.1 Introduction

As with all systems, the six stages of fault-finding should be followed

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

Table 14.1 lists some common symptoms of an air conditioning system malfunction together with suggestions for the possible fault. The faults are gener-

Table 14.1 Symptoms and faults of an air conditioning system

Symptom	Possible fault
After stopping the compressor, pressure falls quickly to about 195 kPa and then falls gradually	Air in the system or, if no bubbles are seen in the sight glass as the condenser is cooled with water, excessive refrigerant may be the fault.
Discharge pressure low	Fault with the compressor or, if bubbles are seen, low refrigerant.
Discharge temperature is lower than normal	Frozen evaporator.
Suction pressure too high	High pressure valve fault, excessive refrigerant or expansion valve open too long.
Suction and discharge pressure too high	Excessive refrigerant in the system or condenser not working due to fan fault or clogged fins.
Suction and discharge pressure too low	Clogged or kinked pipes.
Refrigerant loss	Oil marks (from the lubricant in the refrigerant) near joints or seals indicate leaks.

but will serve as a good reminder. It is assumed an appropriate pressure gauge set has been connected.

14.5.2 Testing procedure

Do not work on the refrigerant side of air conditioning systems unless you have been trained and have access to suitable equipment.

The process of checking an air conditioning system is broadly as follows.

1. Hand and eye checks (loose wires, loose switches and other obvious faults) – all connections clean and tight.
2. Check system pressures.
3. Check discharge temperature.
4. Inspect receiver–drier sight glass.
5. Refer to the previous table.

14.6 Advanced temperature control technology

14.6.1 Heat transfer

Here is a reminder of the key terms associated with heat transfer.

Convection

Heat energy transfer that involves the movement of a fluid (gas or liquid). Fluid in contact with the source of heat expands and tends to rise within the bulk of the fluid. Cooler fluid sinks to take its place, setting up a convection current.

Conduction

Flow of heat energy through a material without the movement of any part of the material itself. Heat

energy is present in all materials in the form of the kinetic energy of their vibrating molecules, and may be conducted from one molecule to the next in the form of this mechanical vibration. In the case of metals, which are particularly good conductors of heat, the free electrons within the material carry heat around very quickly.

Radiation

In physics, radiation is the emission of radiant energy as particles or waves; for example, heat, light, alpha particles and beta particles.

When designing a heating or air conditioning system, calculations can be used to determine the heating or cooling effect required. The following is the main heat current equation and can be used, for example, to help determine the heat loss through the windows.

$$\frac{\Delta Q}{\Delta t} = -kA \frac{\Delta T}{\Delta x} = -\frac{\Delta T}{\Delta x / kA}$$

where ΔQ = heat energy, ΔT = temperature, Δx = thickness/distance of material, Δt = time, k = thermal conductivity of the material ($\text{W m}^{-1} \text{K}^{-1}$), A = cross-sectional area, $\Delta Q/\Delta t$ can be thought of as 'heat current'.

14.6.2 Armature reaction

Most heater motors, like many other motors, are unidirectional due to the positioning of the brushes. When a motor is running it also acts as a generator producing a back EMF. The brushes of a motor (or generator) must be placed around the commutator in such a way that, as the armature rotates and the brushes effectively short one commutator segment to the next, no EMF must be present in that associated armature winding.

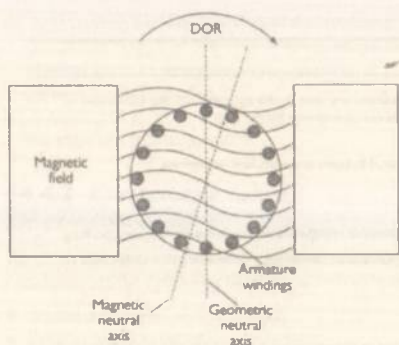


Figure 14.18 Field warp which causes armature reaction

If an EMF is present, then current will flow when the short is made. This creates sparks at the brushes and is known as armature reaction. To overcome this problem, the brushes are moved from the geometric neutral axis to the magnetic neutral axis of the motor fields. This is because, as armature current flows, the magnetism created around the armature windings interacts with the main magnetic field causing it to warp. Figure 14.18 shows this field warp diagrammatically. This phenomenon was used in some very early generators as a way of controlling output.

14.7 New developments in temperature control systems

14.7.1 Heating is cool

Two interesting developments by Valco show how heating systems can actually be quite cool! These are:

- Pollution sensor.
- Photo-catalyst.

The pollution sensor provides improved cabin air quality for enhanced comfort of vehicle passengers. The sensor detects the principal noxious atmospheric pollutants (carbon monoxide and nitrogen dioxides) present in the environment. It fits into the air inlets of the heating and AC system. By electronic control, the sensor automatically activates the air recirculation mode, sealing off the cabin from harmful air pollution. The flaps can be closed in as little as 1.8 seconds. This results in a 20% decrease in pollution concentration and a 40% decrease in passengers noticing the odours.

Using a photo-catalyst means that air in the cabin can be improved because pollutant gases are eliminated. These gases can be destroyed by the UV action of a photo-catalyst. Volatile organic compounds, nitrogen and sulphur oxides are the main culprits. Bacteria can also be eliminated because they are killed on the filter. The photo-catalyst, which is made of titanium oxide (TiO_2), is self-regenerating to ensure long life. The system is 70% efficient on toluene after 6 minutes in recirculation mode. It can also be made to start automatically in association with the pollution sensor.

14.7.2 Electric heating and air conditioning

The increased demand for electrical power in general has made the move to 42 V a certainty. This change also allows other options to be considered in the ever present pursuit of improved comfort with reduced consumption and emissions. Climate control devices will play an important role in this respect. Some small air conditioning (AC) components used on 42 V systems may remain at 14 V. However, the two major existing components in terms of power consumption will switch to 42 V. These are:

- Blower motor.
- PTC-R (positive temperature coefficient resistance) heater.

The maximum power of a blower motor can reach 400 W, which at 14 V means a current draw of about 30 A. If a 14 V alternator is not used, the required 42/14 V Dc/Dc converter and wiring will need to be particularly robust. The power consumed by electric heaters is between 500 and 1500 W. It is therefore crucial to convert to 42 V. For similar reasons, electrically driven AC compressors are only practical at 42 V. PTC-R electric heaters (small electric fires!) mean that heat is not taken from the engine cooling system. Overall, the clear solution is to change the components directly to 42 V.

The use of pulse width modulation control for the blower motor is one way to increase the speed range. The current draw of the 42 V motor will be a third of that for a 14 V type. This also results in improved efficiency in the vehicle system's electronic components. The other major component is the AC compressor.

Manufacturers have already improved mechanical compressors. However, using an electrical compressor will allow further improvements in efficiency and control. Electrical compressors consume about 3–4 kW so 14 V is not practical. Further, when compared with the low efficiency of 14 V alternators (about 50%), the 42 V machines are much better and

work at about 80%. The change to 42 V also means the maximum current to the electrical compressor will be under 100 A.

The electrically driven compressor is clearly a key element for overall efficiency of the electrical AC systems. The electrical air conditioning (E-AC) compressor will be a combination of two main technologies:

- Scroll design – which leads to a high refrigerant distribution and volumetric efficiency.
- Brushless motor – with high electrical efficiency.

These two technologies mean that the system is able to adapt the thermodynamic cycle to changing external conditions very quickly. There are four key operational and/or environmental benefits that result from this. These are:

- Stop and go functionality.
- Battery temperature control.
- Efficiency improvements.
- Refrigerant leakage reduction/elimination.

The main fuel consumption reduction in 42 V vehicles is the result of using regenerative braking and the 'stop and go' function. This is particularly noticeable in city driving because braking and stops are frequent. This has little or no effect on comfort if the ambient temperature is moderate. However, in hot, cold, or damp conditions conventional HVAC components could cause problems. This is because using heat energy from the engine and mechanical energy via the belt drive to the compressor – which are both required to maintain cabin comfort – can have a significant effect on engine operation. End users will, of course, also expect a fuel-consumption decrease, especially in view of the higher price for EV powertrains. For these reasons, electrical heating and air conditioning is an essential step in the development process.

For the 'stop and go' function the use of an electrical compressor is the only choice for maintaining comfort levels during engine stops. A further advantage for end users is that poor cooling performance in idle will be avoided. This is because compressor speed will be independent from engine speed. E-AC will also result in more efficient dehumidification. This results in better visibility from the beginning of a journey. In conventional cars, a slow warm-up can prevent efficient de-misting after a cold start.

The new electrical HVAC devices will use regenerative braking energy, as well as alternator-generated energy that will be stored in batteries. New batteries such as nickel metal hydride (NiMH), or lithium-ion units, are very efficient, but require thermal control to guarantee adequate performance. NiMH

batteries work best at temperatures above 10 °C (50 °F) – they are also sensitive to corrosion, which increases significantly above 35 °C (95 °F). To keep battery temperature in the ideal range, electrical heating and air conditioning become essential. This is because the heating/cooling system will still operate when the vehicle is stopped or parked.

The efficiency of mechanical AC systems has been improved by techniques that allow their capacity to be varied and adjusted. This minimizes and optimizes evaporation pressure, which, overall, results in a better balance between required and produced cooling powers.

It is often assumed that a conventional AC system must be refilled every 3 or 4 years. This is because of refrigerant leakage. There are three identified sources of leakage (other than obvious faults):

- Imperfect connections.
- Permeable flexible hoses.
- Compressor lip seal.

Because an electrical compressor does not use a lip seal, the total leakage is reduced by about 30%. Also, because the electrical compressor will not be fitted to the engine, more aluminium pipes will be used instead of flexible hoses. AC system maintenance could, therefore, be almost eliminated if improved double-seal connections are used.

The improved operation of the system in relation to efficiency and comfort levels means that E-AC is a technology that will become standard – in the not too distant future.

14.8 Self-assessment

14.8.1 Questions

1. State the meaning of 'plenum chamber'.
2. Make a clearly labelled sketch to show the main components of an air conditioning system.
3. Explain the principle of refrigeration.
4. Draw a circuit showing how 'dropping' resistors are used to control motor speed.
5. Describe the operation of an air conditioning system.
6. State three potential benefits of an electrically driven air conditioning compressor.
7. Define: heat flow, radiation, convection and conduction.
8. Describe the reason for *and* the operation of a thermostatic expansion valve.
9. Draw a circuit of a screen heater that includes a timer relay.
10. List four functional requirements of a seat heater.

Chrysler cooling module

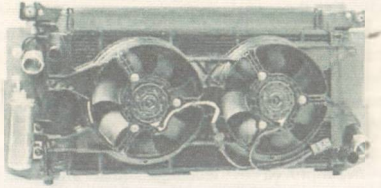


Figure 14.19 Chrysler cooling module

14.8.2 Assignment

- In relation to heating and air conditioning systems, discuss why the temperature and climate settings in a vehicle may need to be changed under different external conditions to achieve the same 'perceived or ideal' feeling of comfort. Draw a block diagram of the system and add appropriate comments as to how this 'ideal' effect could be achieved.
- Figure 14.19 shows a cooling module for a Chrysler. Design a suitable electrical circuit to run the motors at two speeds.
- Produce a report, following the standard format, about the operation of an air conditioning system fitted to a vehicle.

14.8.3 Multiple choice questions

The function of a plenum chamber in a ventilation system is to:

- circulate air inside the cabin
- exhaust air from the cabin
- hold air at a pressure higher than ambient pressure
- hold air at a pressure lower than ambient pressure

One reason for using recirculated air in a heating system is because it

- decreases warm up time
- increases warm up time
- reduces pollution
- reduces traffic congestion

Technician A says the heater motor speed is controlled by using dropping resistors. Technician B says the heater motor speed is controlled by using a variable resistor. Who is right?

- A only
- B only

- Both A and B
- Neither A nor B

The requirements of a seat heater system will include:

- that the heater must supply more than the heat loss experienced by the person's body
- that heat must be supplied only at the major contact points
- that heating elements must be of a universal design to fit all seats
- all of the above

The refrigerant used in many air conditioning systems is known as:

- CFC
- Ozone
- R134A
- 26.3C

The most likely position of a condenser on a car is

- outside the car in the air stream
- inside the car, behind the dashboard
- bolted to the engine
- none of the above

The change of state that takes place in the evaporator is:

- solid to liquid
- liquid to gas
- gas to liquid
- liquid to solid

Which of the following is a true statement:

- an air conditioning compressor is controlled by an electromagnetic clutch
- an air conditioning compressor is permanently driven
- the compressor is always mechanically controlled
- the compressor is always manually controlled

The component that controls the flow of refrigerant as demanded by the system is called the:

- compressor
- condenser
- evaporator
- expansion valve

The current drawn by a blower motor running at full speed is likely to be about:

- 0.15 amps
- 1.5 amps
- 15 amps
- 150 amps

Chassis electrical systems

15.1 Anti-lock brakes

15.1.1 Introduction

The reason for the development of anti-lock brakes (ABS) is very simple. Under braking conditions, if one or more of the vehicle wheels locks (begins to skid), there are a number of consequences.

- Braking distance increases.
- Steering control is lost.
- Abnormal tyre wear.

The obvious result is that an accident is far more likely to occur. The maximum deceleration of a vehicle is achieved when maximum energy conversion is taking place in the brake system. This is the conversion of kinetic energy to heat energy at the discs and brake drums. The potential for this conversion process between a tyre skidding, even on a dry road, is far less. A good driver can pump the brakes on and off to prevent locking but electronic control can achieve even better results.

ABS is becoming more common on lower price vehicles, which should be a significant contribution to safety. It is important to remember, however, that for normal use, the system is not intended to allow faster driving and shorter braking distances. It should be viewed as operating in an emergency only. Figure 15.1 shows how ABS can help to maintain steering control even under very heavy braking conditions.

15.1.2 Requirements of ABS

A good way of considering the operation of a complex system is to ask: 'what must the system be able to do?' In other words, what are the requirements? These can be considered for ABS under the following headings.

Fail-safe system

In the event of the ABS system failing the conventional brakes must still operate to their full potential. In addition, a warning must be given to the

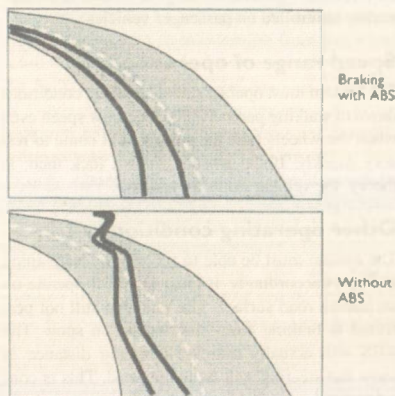


Figure 15.1 ABS can help maintain steering control

driver. This is normally in the form of a simple warning light.

Manoeuvrability must be maintained

Good steering and road holding must continue when the ABS system is operating. This is arguably the key issue, as being able to swerve around a hazard whilst still braking hard is often the best course of action.

Immediate response must be available

Even over a short distance the system must react such as to make use of the best grip on the road. The response must be appropriate whether the driver applies the brakes gently or slams them on hard.

Operational influences

Normal driving and manoeuvring should produce no reaction on the brake pedal. The stability and steering must be retained under all road conditions. The system must also adapt to braking hysteresis when the brakes are applied, released and then re-applied.

Even if the wheels on one side are on dry tarmac and the other side on ice, the yaw (rotation about the vertical axis of the vehicle) of the vehicle must be kept to a minimum and only increase slowly in order to allow the driver to compensate.

Controlled wheels

In its basic form, at least one wheel on each side of the vehicle should be controlled on a separate circuit. It is now general for all four wheels to be separately controlled on passenger vehicles.

Speed range of operation

The system must operate under all speed conditions down to walking pace. At this very slow speed even when the wheels lock the vehicle will come to rest very quickly. If the wheels did not lock then, in theory, the vehicle would never stop!

Other operating conditions

The system must be able to recognize aquaplaning and react accordingly. It must also still operate on an uneven road surface. The one area still not perfected is braking from slow speed on snow. The ABS will actually increase stopping distance in snow but steering will be maintained. This is considered to be a suitable trade-off.

A number of different types of anti-lock brake systems are in use, but all try to achieve the requirements as set out above.

15.1.3 General system description

As with other systems, ABS can be considered as a central control unit with a series of inputs and outputs. An ABS system is represented by the closed loop system block diagram shown in Figure 15.2. The most important of the inputs are the wheel speed sensors, and the main output is some form of brake system pressure control.

The task of the control unit is to compare signals from each wheel sensor to measure the acceleration or deceleration of an individual wheel. From these data and pre-programmed look-up tables, brake pressure to one or more of the wheels can be regulated. Brake pressure can be reduced, held constant or allowed to increase. The maximum pressure is determined by the driver's pressure on the brake pedal.

A number of variables are sensed, used or controlled by this system.

Pedal pressure

Determined by the driver.

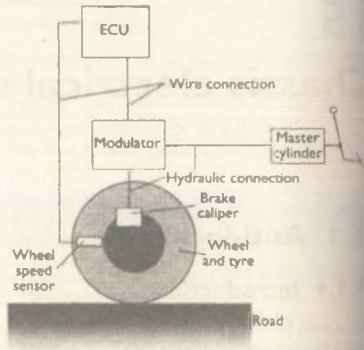


Figure 15.2 Anti-lock brake system

Brake pressure

Under normal braking this is proportional to pedal pressure but under control of the ABS it can be reduced, held or allowed to increase.

Controlled variable

This is the actual result of changes in brake pressure in other words the wheel speed, which then allows acceleration, deceleration and slip to be determined.

Road/vehicle conditions

Disturbances such as the vehicle load, the state of the road, tyre condition and brake system condition.

From the wheel speed sensors the ECU calculates the following.

Vehicle reference speed

Determined from the combination of two diagonal wheel sensor signals. After the start of braking the ECU uses this value as its reference.

Wheel acceleration or deceleration

This is a live measurement that is constantly changing.

Brake slip

Although this cannot be measured directly, a value can be calculated from the vehicle reference speed. This figure is then used to determine when/if ABS should take control of the brake pressure.

Vehicle deceleration

During brake pressure control, the ECU uses vehicle reference speed as the starting point and decreases it in a linear manner. The rate of deceleration

is determined by the evaluation of all signals received from the wheel sensors.

Driven and non-driven wheels on the vehicle must be treated in different ways as they behave differently when braking.

A logical combination of wheel deceleration/acceleration and slip is used as the controlled variable. The actual strategy used for ABS control varies with the operating conditions.

10.1.4 ABS components

There are a few variations between manufacturers involving a number of different components. For the majority of systems, however, there are three main components.

- 1 Wheel speed sensors.
- 2 Electronic control unit.
- 3 Hydraulic modulator.

Wheel speed sensors

Most of these devices are simple inductance sensors and work in conjunction with a toothed wheel. They consist of a permanent magnet and a soft iron rod around which is wound a coil of wire. As the toothed

wheel rotates, the changes in inductance of the magnetic circuit generate a signal; the frequency and voltage of which are proportional to wheel speed. The frequency is the signal used by the electronic control unit. The coil resistance is of the order of $1\text{ k}\Omega$. Coaxial cable is used to prevent interference affecting the signal. Some systems now use 'Hall effect' sensors, as described in Chapter 2.

Electronic control unit

The function of the ECU (Figure 15.3 shows part of an ECU) is to take in information from the wheel sensors and calculate the best course of action for the hydraulic modulator. The heart of a modern ECU consists of two microprocessors such as the Motorola 68HC11, which run the same program independently of each other. This ensures greater security against any fault, which could adversely affect braking performance because the operation of each processor should be identical. If a fault is detected, the ABS disconnects itself and operates a warning light. Both processors have non-volatile memory into which fault codes can be written for later service and diagnostic access. The ECU also has suitable input signal processing stages and output or driver stages for actuator control.

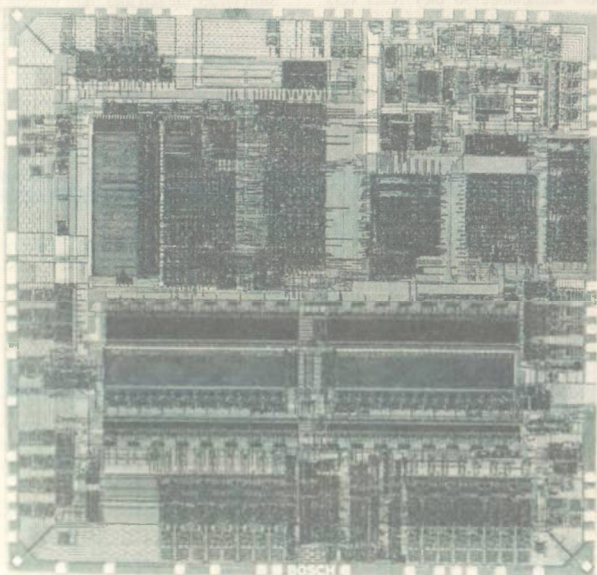


Figure 15.3 A microprocessor as used in an ABS ECU

The ECU performs a self-test after the ignition is switched on. A failure will result in disconnection of the system. The following list forms the self-test procedure.

- Current supply.
- Exterior and interior interfaces.
- Transmission of data.
- Communication between the two micro-processors.
- Operation of valves and relays.
- Operation of fault memory control.
- Reading and writing functions of the internal memory.

All this takes about 300 ms.

Hydraulic modulator

The hydraulic modulator as shown in Figure 15.4 has three operating positions.

- Pressure build-up – brake line open to the master cylinder.
- Pressure reducing – brake line open to the accumulator.
- Pressure holding – brake line closed.

The valves are controlled by electrical solenoids, which have a low inductance so they react very quickly. The motor only runs when ABS is activated.

15.1.5 Anti-lock brake system control

The control of ABS can be summarized under a number of headings as given below.

Brake pressure control commencement

The start of ABS engagement is known as 'first control cycle smoothing'. This smoothing stage is necessary in order not to react to minor disturbances such as an uneven road surface, which can cause changes in the wheel sensor signals. The threshold of engagement is critical as, if it were too soon, it would be distracting to the driver and cause unnecessary component wear; too late and steering/stability could be lost on the first control cycle.

Even road surface regulation

Under these ideal circumstances adhesion is almost constant. ABS works at its best under these conditions, regulation frequency is relatively low with small changes in brake pressure.

Vehicle yaw (twist about the vertical axis, swerving moment)

When braking on a road surface with different adhesion under the left and right wheels, the vehicle will yaw or start to spin. The driver can control this with

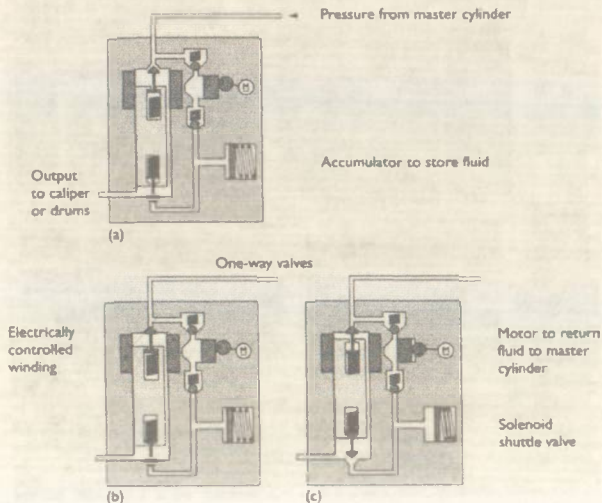


Figure 15.4 ABS hydraulic modulator. (a) Normal pressure build-up; (b) holding phase; (c) reducing

the steering if time is available. This can be achieved if when the front wheel with poor adhesion becomes unstable, the pressure to the other front wheel is reduced. This acts to reduce the vehicle yaw, which is particularly important, when the vehicle is cornering.

Axle vibration

Wheel speed instability occurs frequently and at random on rough roads. Due to this instability, brake pressure tends to be reduced more than it is increased, during ABS operation. This could lead to loss of braking under certain conditions. Adaptation to these conditions is therefore necessary to overcome this problem. An increase in brake pressure is made soon during hard re-acceleration of the wheel after an unstable instant. With modern soft suspension systems the axle may be subject to vibration. This can cause superimposed signals on the wheel speed sensors. The indicated accelerations can be the same as for actual unstable braking conditions. A slight delay in the reaction of the ABS due to the delay in signal smoothing – the time taken to move control valves and a time lag in the brake lines – helps to reduce the effect of axle vibration. The regular frequency of the vibrations can be recognized by the ECU. A constant brake pressure is introduced when axle vibrations are recognized.

10.1.6 Control strategy

The strategy of the anti-lock brake system can be summarized as follows.

- Rapid brake pressure reduction during wheel speed instability so the wheel will re-accelerate fast without too much pressure reduction, which will avoid under braking.
- Rapid rise in brake pressure during and after a re-acceleration to a value just less than the instability pressure.
- Discrete increase in brake pressure in the event of increased adhesion.
- Sensitivity suited to the prevalent conditions.
- Anti-lock braking must not be initiated during axle vibration.

The application of these five main requirements leads to the need for compromise between them. Common programming and prototype testing can reduce the level of compromise but some disadvantages have to be accepted. The best example of this is braking on uneven ground in deep snow, as deceleration is less effective unless the wheels are locked up. In this example, priority is given to stability over than stopping distance, as directional control is favoured in these circumstances.

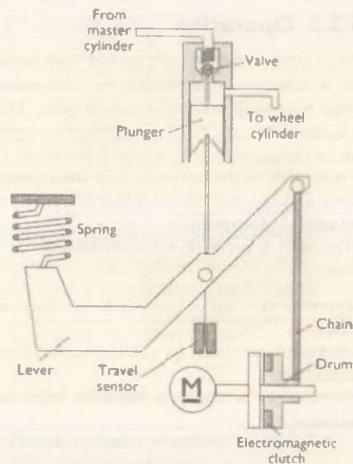


Figure 15.5 Motor and spring anti-lock brake system

15.1.7 Variations of ABS

A novel approach to ABS has been developed which uses springs and a motor to produce the brake pressure conditions of reducing, holding or increasing. The potential advantage of this technique is that the response is smooth rather than pulsed. Figure 15.5 shows the layout of the motor and spring system.

15.2 Active suspension

15.2.1 Introduction

Active suspension, like many other innovations, was developed in the Grand Prix world. It is now slowly becoming more popular on production vehicles. It is interesting to note that just as some Formula 1 teams perfected it, the rules changed (1993–94) to prevent its use!

Conventional suspension systems are always a compromise between soft springs for comfort and harder springing for better cornering ability. A suspension system has to fulfil four main functions.

- Absorb bumps.
- Manage nose dive when braking.
- Prevent roll when cornering.
- Control body movement.

This means that some functions have to be compromised in order to fulfil others to a greater extent.

15.2.2 Operation

Active suspension allows the best of both worlds. This is achieved by replacing the conventional springs with double-acting hydraulic units. These are controlled by an ECU, which receives signals from various sensors. Oil pressure in excess of 150 bar is supplied to the hydraulic units from a pump. A servo valve controls the oil, which is arguably the most critical component.

The main benefits of active suspension are as follows.

- Improvements in ride comfort, handling and safety.
- Predictable control of the vehicle under different conditions.
- No change in handling between laden and unladen.

15.2.3 Sensors, actuators and system operation

To control the hydraulic units to the best advantage, the ECU needs to 'know' certain information. This is determined from sensor readings from various parts of the vehicle. A number of sensors are used to provide information to the suspension ECU.

Load sensor

A load cell used to determine whether actual load is positioned on each hydraulic ram.

Displacement and vertical acceleration

This sensor can take a number of forms, as simple as a variable resistor or a more accurate and sensitive linear sensor such as the LVDT (see Chapter 2).

Lateral and longitudinal acceleration

Acceleration can be determined from a pendulum-type sensor using strain gauges linked to a mass, or devices similar to an engine knock sensor.

Yaw transducer

Yaw can be determined from lateral acceleration if the sensor is mounted at the front or rear of the vehicle.

Steering position

As well as steering position, rate of change of position is determined from a rotary position sensor. This device can be a light beam and detector type or

similar. If the rate of change of steering position is beyond a threshold the system will switch to a harder suspension setting.

Vehicle speed

The speed of the vehicle is taken from a standard type sensor as used for operating the speedometer.

Throttle position

Similar to the existing throttle potentiometers, this gives data on the driver's intention to accelerate or decelerate allowing the suspension to switch to a harder setting when appropriate.

Driver mode selection

A switch is provided allowing the driver to choose soft or hard settings. Even if the soft setting is selected, the system will switch to hard, under certain operational conditions.

The layout of the suspension system also shows a simplified view of the hydraulic unit. This is, in effect, a hydraulic ram and can have oil under very high pressure fed to the upper or lower chamber. The actual operation of the whole system is as follows. As a wheel meets a bump in the road there is increased upward acceleration and vertical load. This information is fed to the ECU, which calculates the ideal wheel displacement. A control signal is now sent to the servo valve(s), which control the position of the main hydraulic units. As this process can occur hundreds of times per second, the wheel can follow the contour of the road surface. This cushions the vehicle body from unwanted forces.

By considering information from other sensors, such as the lateral acceleration sensor, which gives data relating to cornering, and the longitudinal sensor, which gives data relating to braking or acceleration forwards, the actuators can be moved to provide maximum stability at all times.

Active suspension looks set to have an easy ride in the future. The benefits are considerable and, as component prices reduce, the system will become available on more vehicles. It is expected that even off-road vehicles may be fitted with active suspension in the near future. A representation of an electronically controlled suspension system is shown in Figure 15.6.

15.3 Traction control

15.3.1 Introduction

The steerability of a vehicle is not only lost when the wheels lock up on braking; the same effect arises

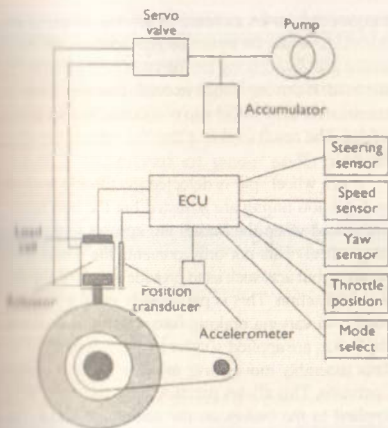


Figure 15.6 Sensors used to provide information to suspension ECU and general layout of an active suspension system

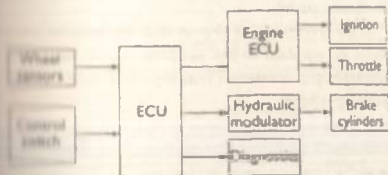


Figure 15.7 Traction control system

If the wheels spin when driving off under severe acceleration. Electronic traction control has been developed as a supplement to ABS. This control system prevents the wheels from spinning when moving off or when accelerating sharply while on the drive. In this way, an individual wheel, which is spinning is braked in a controlled manner. If both or all of the wheels are spinning, the drive torque is reduced by means of an engine control function. Traction control has become known as ASR or TCR.

Traction control is not normally available as an independent system, but in combination with ABS. This is because many of the components required are the same as for the ABS. Traction control only requires a change in logic control in the ECU and a few extra control elements such as control of the throttle. Figure 15.7 shows a block diagram of a traction control system. Note the links with ABS and the engine control system.

Traction control will intervene to achieve the following:

- Maintain stability.
- Reduction of yawing moment reactions.

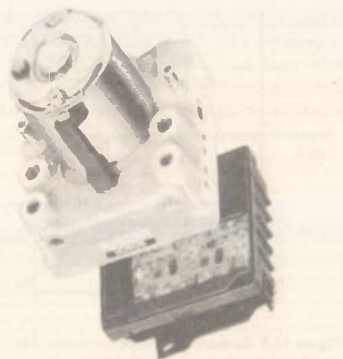


Figure 15.8 ABS and traction control ECU on the modulator

- Provide optimum propulsion at all speeds.
- Reduce driver workload.

The following list of advantages can be claimed for a good traction control system.

- Improved tractive force.
- Better safety and stability on poor surfaces.
- Less driver stress.
- Longer tyre life.
- No wheel spin on turning and cornering.

An automatic control system can intervene in many cases more quickly and precisely than the driver of the vehicle. This allows stability to be maintained at time when the driver might not have been able to cope with the situation. Figure 15.8 shows an ABS and traction control modulator, complete with an ECU.

15.3.2 Control functions

Control of tractive force can be by a number of methods. Figure 15.9 shows a comparison of three techniques used to prevent wheel spin, throttle, ignition and brake control.

Throttle control

This can be via an actuator, which can move the throttle cable, or if the vehicle employs a drive-by-wire accelerator, then control will be in conjunction with the engine management ECU. This throttle control will be independent of the driver's throttle pedal position. This method alone is relatively slow to control engine torque.

Ignition control

If ignition is retarded, the engine torque can be reduced by up to 50% in a very short space of time.

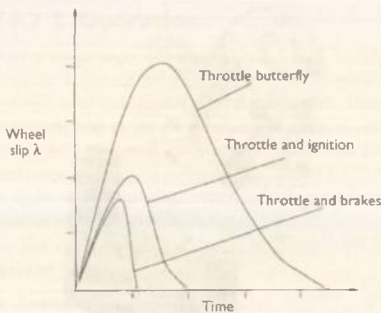


Figure 15.9 Comparison of three techniques used to prevent wheel spin: throttle, ignition and brake control

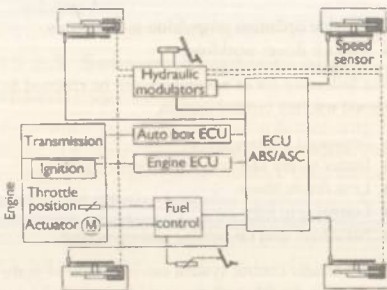


Figure 15.10 Layout of a traction control system which includes links with other vehicle control systems

The timing is adjusted by a set ramp from the ignition map value.

Braking effect

If the spinning wheel is restricted by brake pressure, the reduction in torque at the affected wheel is very fast. Maximum brake pressure is not used, to ensure passenger comfort is maintained.

15.3.3 System operation

The layout of a traction control system, which includes links with other vehicle control systems, is shown in Figure 15.10. The description that follows is for a vehicle with an electronic (drive-by-wire) accelerator.

A simple sensor determines the position of the accelerator and, taking into account other variables such as engine temperature and speed for example, the throttle is set at the optimum position by a servo motor. When accelerating, the increase in engine

torque leads to an increase in driving torque at the wheels. In order for optimum acceleration, the maximum possible driving torque must be transferred to the road. If driving torque exceeds that which can be transferred, then wheel slip will occur, at least at one wheel. The result of this is that the vehicle becomes unstable.

When wheel spin is detected the throttle position and ignition timing are adjusted but the best results are gained when the brakes are applied to the spinning wheel. This not only prevents the wheel from spinning but acts such as to provide a limited slip differential action. This is particularly good when on a road with varying braking force coefficients. When the brakes are applied, a valve in the hydraulic modulator assembly moves over to allow traction control operation. This allows pressure from the pump to be applied to the brakes on the offending wheel. The valves – in the same way as with ABS – can provide pressure build-up, pressure hold and pressure reduction. This all takes place without the driver touching the brake pedal.

The summary of this is that the braking force must be applied to the slipping wheel, such as to equalize the combined braking coefficient for each driving wheel.

15.4 Automatic transmission

15.4.1 Introduction

The main aim of electronically controlled automatic transmission (ECAT) is to improve conventional automatic transmission in the following ways.

- Gear changes should be smoother and quieter
- Improved performance.
- Reduced fuel consumption.
- Reduction of characteristic changes over system life.
- Increased reliability.

The actual operation of an automatic gearbox is beyond the scope of this book. However, the important points to remember are that gear changes and lock-up of the torque converter are controlled by hydraulic pressure. In an ECAT system, electrically controlled solenoid valves can influence the hydraulic pressure. Figure 15.11 is a block diagram of an ECAT system.

Most ECAT systems now have a transmission ECU that is in communication with the engine control ECU (by a CAN – controller area network – databus

in many cases). The system as a whole consists of a number of sensors providing data to the ECU, which in turn is able to control a number of actuators or output devices. Figure 15.12 shows a modern automatic gearbox as used by the Porsche Carrera.

15.4.2 Control of gear shift and torque converter

With an ECAT system, the actual point of gear shift is determined from pre-programmed memory

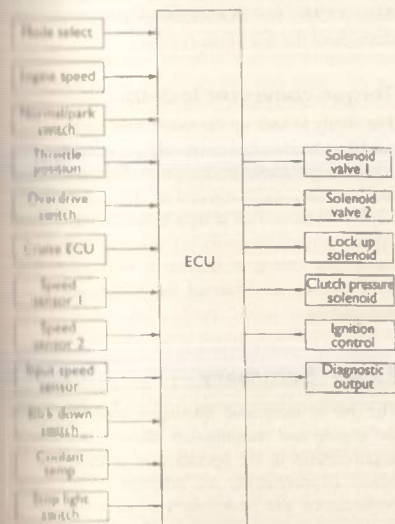


Figure 15.11 Block diagram of an ECAT system

within the ECU. Data from the sensors are used to reference a look-up table mainly as a function of engine speed and vehicle speed. Data from other sensors are also taken into consideration. Actual gear shifts are initiated by changes in hydraulic pressure, which is controlled by solenoid valves.

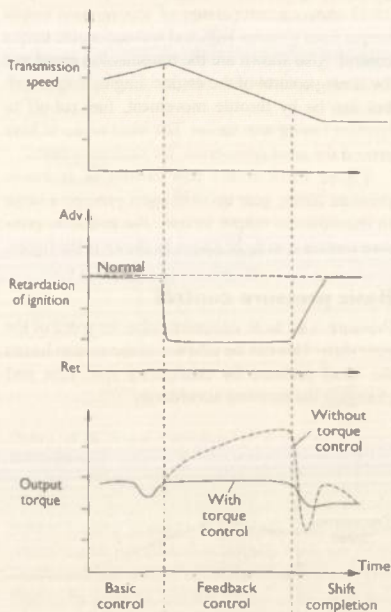


Figure 15.13 Transmission output torque from systems with and without engine torque control

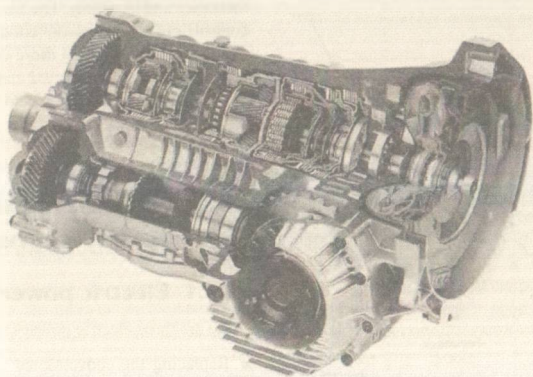


Figure 15.12 Automatic gearbox as used in the Porsche Carrera

The two main control functions of this system are hydraulic pressure and engine torque. The temporary reduction in engine torque during gear shifting (about 200 ms) allows smooth operation. This is because the peaks of gearbox output torque are suppressed, which causes the characteristic surge as the gears change on conventional automatics. Figure 15.13 shows a comparison of transmission output torque from systems with and without engine torque control. Also shown are the transmission speed and the timing control of the engine. Engine torque control can be by throttle movement, fuel cut-off or ignition timing retardation. The latter seems to have proved the most appropriate for modern systems.

Figure 15.14 shows how control of hydraulic pressure during gear up-shift again prevents a surge in transmission output torque. The hydraulic pressure control is in three stages as shown in the figure.

Basic pressure control

Pressure is set to an optimum value for speed of the gear shift. This can be adapted as the system learns the ideal pressure by monitoring shift time and changing the pressure accordingly.

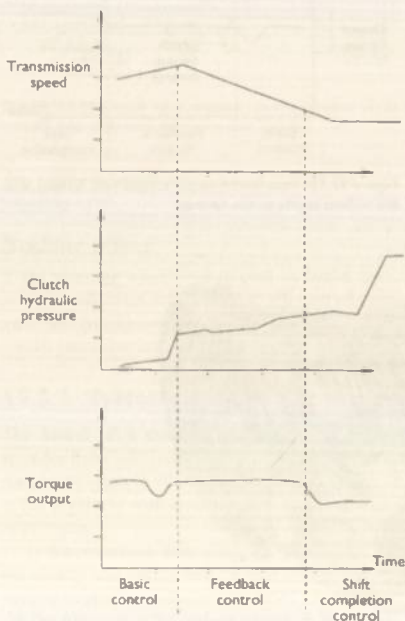


Figure 15.14 Control of hydraulic pressure

Feedback control

The ECU detects the deviation of the rotational speed of the input shaft from a target value and adjusts pressure to maintain fine control.

Completion control

Torque converter hydraulic pressure is reduced momentarily so that as the engine torque output control is released, the potential surge is prevented. Because of these control functions, smooth gear shifts are possible and, due to the learning ability of some ECUs, the characteristics remain constant throughout the life of the system.

Torque converter lock-up

The ability to lock up the torque converter has been used for some time, even on vehicles with more conventional automatic transmission. This gives better fuel economy, quietness and improved driveability. Lock-up is carried out using a hydraulic valve, which can be operated gradually to produce a smooth transition. The timing of lock-up is determined from ECU memory in terms of the vehicle speed and acceleration.

15.4.3 Summary

The use of integrated intelligent control of both the engine and transmission allows considerable improvements to the operation of automatic gearboxes. Improvements are possible to efficiency, performance and smoothness of operation. Extra facilities become available to the driver such as being able to select the desired mode of operation. This can be a choice between, for example, performance and economy. The tie up between engine control and transmission control helps to illustrate how it is becoming more difficult to consider vehicle systems as isolated units and how more consideration must be given to the overlap of the system boundaries.

15.5 Other chassis electrical systems

15.5.1 Electric power steering

There are three electric power steering techniques

- Replacing the conventional system pump with an electric motor whilst the ram remains much the same.

- drive motor, which directly assists with the steering and has no hydraulic components.
- Active steering in which the steering wheel is replaced with a joystick.

The first of these systems is popular, as the pump will only run when needed. This gives some savings in fuel consumption and also allows the drive shaft arrangement at the front of the engine to be simplified.

The second system listed is now becoming the most common. An electric motor acts directly on the steering via an epicyclic gear train. This completely replaces the hydraulic pump and servo cylinder. It eliminates the fuel penalty of the conventional pump and greatly simplifies the drive arrangements. It also allows the power steering to be operated at low speeds. The torque sensor is also eliminated. An optical torque sensor is used to measure driver effort on the steering wheel. The sensor works by measuring light from an LED, which is shining through holes that are aligned in discs at either end of a 50 mm torsion bar fitted into the steering column. This system occupies little engine bay space (something which is at a premium these days), and the 400 W motor only averages about 2 A under urban driving conditions. The benefits over conventional hydraulic methods are considerable.

'Active steering' is the name given to a system developed by Saab from its experience in the aircraft industry. The technique is known as drive-by-wire. A joystick is used in place of the steering wheel and an array of sensors determines the required output and, via the control unit, operates two electro-hydraulic control valves. The ECU filters out spurious data from the sensors and provides a feedback to the joystick in order to maintain driver feel. As a safety feature, electronic circuits have built-in self-test facilities and backup modules. Hydraulic fluid pressure is also held in reserve in an accumulator. Figure 15.15 shows an overview of the active steering system. Great benefit could be gained using this technique due to the removal of the steering column – although some opposition is expected to this radical approach! Disabled drivers, however, may consider this to be a major improvement.

15.5.2 Electronic clutch

The electronic clutch was developed for racing vehicles to improve the getaway performance. For production vehicles, a strategy has been developed to interpret the driver's intention. With greater throttle openings, the strategy changes to prevent abuse and drive line damage. Electrical control of the clutch

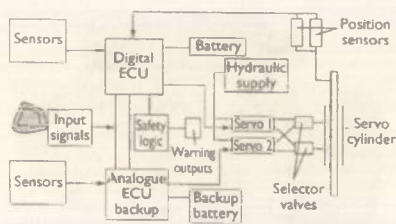


Figure 15.15 Overview of active steering system

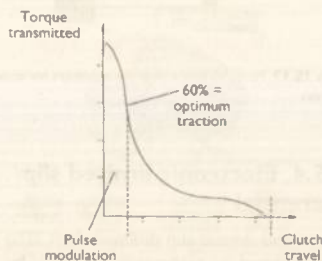


Figure 15.16 Torque transmitted curve for an electronic clutch system

release bearing position is by a solenoid actuator, which can be modulated by signals from the ECU. This allows the time to reach the ideal take-off position to be reduced and the ability of the clutch to transmit torque to be improved. The efficiency of the whole system can therefore be increased. Figure 15.16 shows the torque transmitted curve for an electronic clutch system. A switch could be provided to change between performance or economy mode.

15.5.3 Active roll reduction

The conventional anti-roll bar, as fitted to many vehicles, is replaced with a bar containing a rotary actuator. The actuators are hydraulically operated from a dedicated pump. Lateral acceleration is calculated by the ECU from steering angle and road speed. Hydraulic pressure is then regulated as required to the front and rear actuators such as to provide a force on the roll bar preventing the body of the vehicle from tilting. A good use for this system is on larger panel vans although it is being offered as an option to a range of vehicles. Figure 15.17 shows the positioning of one of the actuators for active roll reduction.

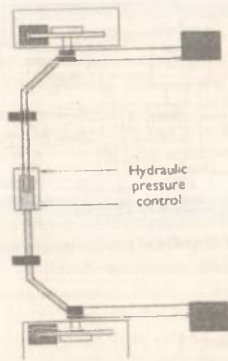


Figure 15.17 Positioning of one of the actuators for active roll reduction

15.5.4 Electronic limited slip differential

Conventional limited slip differentials (LSDs) cannot be designed for optimum performance because of the effect on the vehicle when cornering. Their characteristics cannot be changed when driving. Front-wheel drive vehicles have even more problems due to the adverse effect on the steering. These issues have prompted the development of electronic control for the LSD.

The slip limiting action is controlled by a multi-disc clutch positioned between the crown wheel and the differential housing. It is able, if required, to lock the axle fully. The pressure on the clutch plates is controlled by hydraulic pressure, which in turn is controlled by a solenoid valve under the influence of an ECU. Data are provided to the ECU from standard ABS-type wheel sensors. Figure 15.18 shows a block diagram of a final drive and differential unit with electronic control.

15.5.5 Brake assist systems

Brake assist systems may be developed because of evidence showing that drivers are not realizing the full benefit of anti-lock braking systems (ABSs). The introduction of ABS has not resulted in the reduction of accidents that had been hoped for. The reason for this is debatable; one view is that many drivers do not push hard enough on the brake pedal during an emergency stop, therefore the tyres do not slip sufficiently to engage the antilock system.

To counteract this problem, companies are developing brake assist systems that apply more

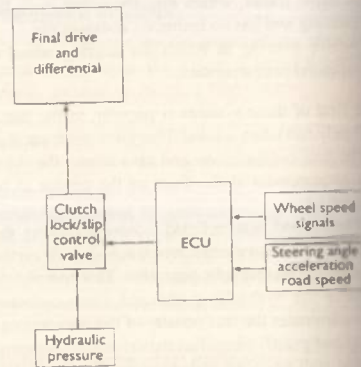


Figure 15.18 Final drive and differential unit electrical control

hydraulic pressure than normal if an emergency condition is sensed. The system's ability to discern whether a braking operation is an emergency, or not, is critical. Pedal force sensors only, as well as pedal force sensors in conjunction with apply sensors, are under development, as are the control strategies. If field tests produce satisfactory results, brake assist systems could be introduced relatively quickly into mass production.

Electric actuators may even begin to take the place of conventional wheel cylinders. Precisely controlled DC motors operating on drum brakes have the potential advantages of lower total system weight and cost. Developments are occurring in the area of magnetic braking, which has the potential to remove all wearing components from the vehicle.

15.5.6 Total vehicle dynamics

Throughout this chapter on chassis electronic systems, and in previous chapters on engine control, it may have become apparent that more and more electronic systems are required to be in communication to achieve optimum results. This is one of the driving forces behind data bus communications (Chapter 1), because many of the sensors used by various systems are common. Data are used by each in a slightly different way but many systems have an effect on others.

Systems, which are now quite common, that lend themselves to combined control, are as follows:

- Anti-lock brakes.
- Traction control.
- Active suspension.
- Four-wheel steering.

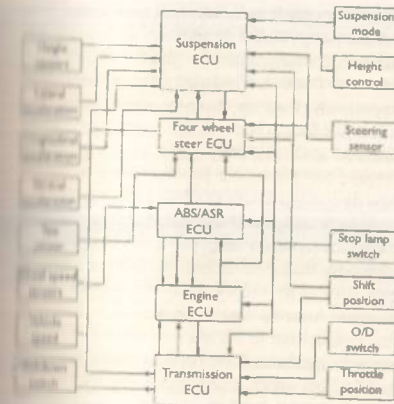


Figure 15.19 How several systems could be linked together: anti-lock brakes; traction control; active suspension; four-wheel steering; engine management; automatic transmission

- Engine management.
- Automatic transmission.

Figure 15.19 is a block diagram showing how these systems could be linked together. When these systems are working together, significant improvements in the operation of each can be produced. Research is still to be carried out in this area and further significant benefits are still possible in the future.

15.6.7 Automatic clutch

Valeo's Compact Automatic Clutch (CAC) eliminates the need for a clutch pedal. Cars equipped with Valeo's CAC are therefore more comfortable and fun to drive as the driver is freed from the strenuous effort of depressing and releasing the clutch pedal every time he or she changes gear. The gear lever remains, however, leaving active control of the car with the driver.

The Valeo CAC is an add-on system, which can be fitted to conventional manual transmissions. It consists of a clutch actuator, a powerful CPU and various sensors driven by dedicated software that is optimized for each vehicle type. Figure 15.20 shows the clutch actuator.

The Valeo CAC uses electromechanical actuators, which are therefore more compact, weigh less and are less noisy compared with hydraulic systems. Its internal compensation spring allows for very fast response time (declutching time: 70–100 ms)

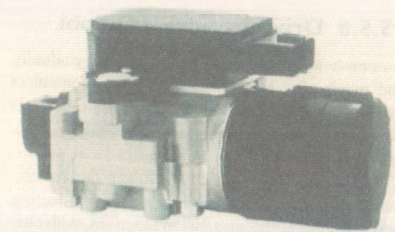


Figure 15.20 Compact automatic clutch actuator

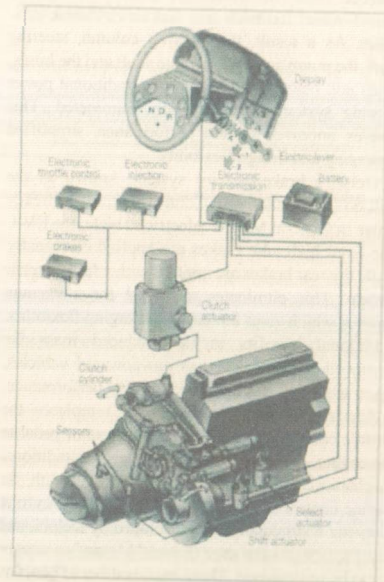


Figure 15.21 Robotized manual gearbox

combined with low electrical consumption (20 W). Its 16-bit electronic control unit and power electronics were developed and produced by Valeo Electronics.

Valeo has developed high performance computer simulation tools to design operating software that can make the car respond exactly in line with vehicle manufacturers' requirements.

The Valeo CAC is also designed to provide maximum safety and includes fault modes to minimize the impact of potential component failure. Figure 15.21 shows a 'robotized' manual gearbox.

15.5.8 Drive-by-wire – Delphi

Automotive technology has advanced gradually, and much of it has simply been a refinement of existing systems. Drive-by-wire technologies will change everything we know about designing, manufacturing and driving cars.

Drive-by-wire technology involves the replacement of traditional mechanical systems for steering, braking, throttle and suspension functions, with electronic controllers, actuators and sensors. For example, in Delphi's steer-by-wire system, the mechanical links between the steering wheel and the front wheels are replaced with two motorized assist mechanisms, a hand-wheel feedback unit and an electronic controller. As a result, the steering column, steering shaft, the pump and intermediate shaft and the hoses, fluids and belts associated with a traditional power steering system are completely eliminated. This enables improved system performance, simplified packaging and design flexibility.

Delphi's brake-by-wire system, known as the Galileo Intelligent Brake Control System, is already in use in General Motors' electric vehicle, the EV-1. The front hydraulic brakes are applied electrically, while the rear brakes are applied with a fully electric system. This eliminates the need for a vacuum booster, which gives increased packaging flexibility. Additional benefits include reduced mass for improved fuel efficiency in gas-powered vehicles, easier assembly and improved braking performance.

Electronic throttle control (ETC) replaces the throttle cables that run from the accelerator pedal to the engine. An electronic link replaces the traditional mechanical link, which communicates with an engine control module (ECM). The 1997 Chevrolet Corvette featured an ETC, developed by Delphi, and was the first gas-powered General Motors' passenger car to be so equipped. There are a number of benefits associated with ETC, including reduced mass, lower emissions, and increased throttle response.

Other drive-by-wire systems under development include damping by wire and roll by wire, where actuators and controllers replace conventional dampers and roll bars. Sensors measure vehicle yaw and levelling, as well as vehicle speed. Utilizing these data, a signal is sent to the proper actuators to damp the suspension actively. It is an infinitely variable system that can even compensate for the emptying of the fuel tank. Such a suspension reduces mass, which helps improve fuel economy, while improving ride and handling. It also reduces assembly time due to fewer parts and a simpler design.

Taken as a whole, these drive-by-wire systems allow for greatly increased modularity, which

simplifies vehicle assembly, with the resultant, lower vehicle cost potential. In addition, they are environmentally friendly, since the number of hoses, pulleys and fluids are reduced or eliminated. More importantly, however, drive-by-wire systems bring a new freedom to how vehicles are designed, manufactured and ultimately used by the consumer. Prepare for a dramatic paradigm shift as entirely new design and assembly philosophies evolve.

Vehicle design will take different forms, allowing manufacturers to do things previously thought impossible with traditional technology and manufacturing processes. The vehicle's steering wheel is one example. Steer-by-wire technology will allow eventual replacement of the steering wheel and column since the mechanical link between the steering wheel and the front wheels is no longer necessary. The space will be available for designers to do something completely different, such as incorporating new energy-absorbing systems in the body structure.

From an assembly standpoint, the entire system for steering, damping and braking can be contained in one module, which will arrive at the assembly point as a fully tested unit that is simply plugged into the vehicle. The simplicity of this module approach will greatly reduce assembly time, while at the same time increasing quality, since it will arrive fully tested. Manufacturers will find cost savings in a variety of areas.

15.6 Case studies

15.6.1 Tiptronic S – Porsche

Developed by Porsche, Tiptronic S is a fully 'intelligent' multi-programme automatic transmission with additional fingertip control. The dual-function, 5-speed, automatic transmission, with active shift driving programmes is controlled by the 'Porsche Tiptronic' control system. As an alternative, and in addition to, the automatic mode, it is also possible to shift manually with fingertip controls.

Tiptronic first appeared in 1990 with technology directly descended from F1 and the 'Le Mans Porsche 962s, which went on to win the 1994 'Le Mans 24 Hrs'. The Tiptronic S system features manual shift control integrated into the steering wheel. With two rocker switches in the spokes of the steering wheel, Tiptronic S offers an impressive and unique driving experience.

Once in manual mode, a driver can shift manually by pushing one of the two rocker switches. Slight pressure of the thumb is all it takes to shift up – tipping it downward will produce a downshift

The location and design of the rocker switches, as well as the distinctly perceptible pressure points, in combination with electronic transmission management, rule out any shift errors. The chosen gear is always indicated via a read-out located on the speedometer.

The quick responses of the transmission triggered by just a thumb push generate an absolutely spontaneous driving impression, gear changes being twice as quick as a manual gear-box. Since the hands remain at the wheel, Porsche, with its Tiptronic S, has extended levels of primary safety.

The Tiptronic S system 'learns' about a particular driving style by monitoring eight sensors around the car, which include throttle speed and position, road speed, engine speed and temperature, lateral acceleration and deceleration. Redline-controlled protective programmes in the system prevent engine damage due to shift errors.

The shift patterns range from an economic variant to smooth motoring to dynamic motoring with the engine revving to maximum torque and power in the respective gears before changing, and downshifting appropriately from relatively high engine speeds. Rapid movements of the accelerator pedal, as well as hard acceleration, result in a graduated change of shift maps, right up to the most extreme variant. In addition, the system is intelligent enough to react to other driving conditions and, for example, to downshift when braking before corners, which obviously reflects driving style with manual gearboxes.

This 'intelligent shift program' - ISP for short - of the Porsche Tiptronic S is characterized by the following special features in addition to the five automatic electronic shift maps.

- 1. A warm-up program, which suppresses early up-shifting to ensure a rapid rise to the engine operating temperature to ensure clean emissions.
- 2. Active shifting - when the accelerator pedal is depressed and released rapidly, the most 'dynamic' shift map is available instantaneously.
- 3. Suppression of the overrun up-shift on a sudden lifting of the throttle - e.g. no gear change mid-bend.
- 4. Brake-initiated downshift to the next lower gear for more efficient engine braking.
- 5. Holding onto a gear in curves - i.e. no gear change whilst in mid-bend.
- 6. Graduated up-shifting from lower gears to prevent immediate change over to the top gear, especially after active downshifting.
- 7. Identification of uphill stretches to stay in the lower gears as long as possible when driving up or downhill.

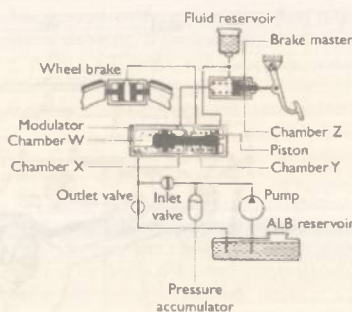


Figure 15.22 Honda ABS

- Slip-induced up-shifting initiated by inertia forces when braking on slippery surfaces (rain, snow) to improve lateral guidance of the driving wheels and consequently driving stability.

15.6.2 Honda anti-lock brakes

A Honda anti-lock brake system is based on the plunger principle. Figure 15.22 shows the schematic diagram. When anti-lock is not operating, the chamber labelled W is connected to the reservoir via the outlet valve. The chamber is held at atmospheric pressure because the inlet valve blocks the line from the pressure accumulator. During braking, pressure is created in the master cylinder and fluid flows from chamber Z into chamber X, moving the piston and increasing pressure in chamber Y.

If a wheel threatens to lock, the outlet valve closes, pressure in chamber W rises and prevents further movement of the piston thus *holding* the pressure. If the risk of lock-up continues the inlet valve opens and allows fluid to flow from the accumulator into chamber W. This pressure moves the piston back, thus reducing the pressure to the wheel cylinder. When the risk of lockup has gone, the inlet valve closes and the *hold* phase is restored.

The Honda system is a relatively simple ABS and has just two control channels. The front wheel which has the *higher* coefficient of friction determines the brake pressure for both front wheels. The result is that one front wheel may lock during extreme braking. The rear wheel with the *lower* coefficient of friction determines the rear brake pressure.

15.6.3 ABS - Chevrolet Corvette

The anti-lock braking system (ABS) was introduced on the Corvette in 1986 and is designed to maintain vehicle control even under severe braking

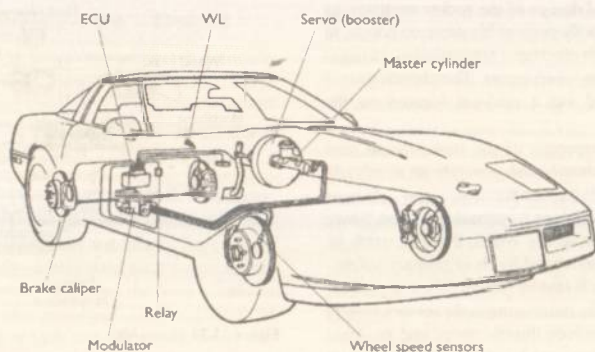


Figure 15.23 Chevrolet Corvette ABS components

conditions. The system does this by monitoring the speed of each wheel and then controlling the brake line pressure to prevent the wheels from locking.

Every time the vehicle is started, the anti-lock warning light illuminates for a short time and then goes out to indicate that the system is operating correctly. A test, which actually runs the modulator valve, ensures that the system is fully functional. This test occurs when the vehicle is first started and when it reaches about 7 km/h (4 miles/h). During vehicle operation, the control module constantly monitors the system. If a fault occurs in any part of the system, the dashboard warning light will illuminate. If a fault in the ABS system occurs, the conventional brake system will remain fully functional.

The modulator valve is located in the compartment behind the driver's seat. The purpose of the modulator valve is to maintain or reduce the brake fluid pressure to the wheel calipers. It cannot increase the pressure above that transmitted to the master cylinder, and can never apply the brakes by itself! The modulator valve receives all its instructions from the control unit.

The control module is also located in the rear storage compartment behind the driver's seat. The function of the control module is to read and process information received from the wheel speed sensors. Acceleration, deceleration and slip values are calculated to produce control instructions for the modulator valve.

The lateral acceleration switch is located on the floor, just under the air conditioning control head. This switch is used to detect if the vehicle is cornering faster than a given curve speed. If so, a signal is sent to the control module indicating this hard cornering situation.

The wheel speed sensors are located at each wheel and send an electric signal to the control module indicating rotational speed. They are fitted in the knuckles and have toothed rings pressed onto the front hub and bearing assemblies, and the rear drive spindles. Figure 15.23 shows the location of the main ABS components.

15.6.4 'Jatco' automatic transmission

The 'Jatco SFPO' is the first electronically controlled automatic transmission (ECAT) fitted to a Rover Group vehicle. The new ECAT is part of a new series of transmissions with a stand alone diagnostics system. It has five-speed adaptive control and is European on-board diagnostics (EOBD) compliant. Gear change and torque converter lock-up are determined by the throttle angle and the vehicle speed. Torque converter lock-up is available in third, fourth and fifth gears. Lock-up of the torque converter transmits maximum power from the engine to the wheels of the vehicle without slip occurring. The automatic transmission control unit (ATCU) is located in the passenger footwell.

Like all automatic transmission vehicles, the engine will only start in Park or Neutral. The EWS-3 (Elektronische Wegfahrsperr) immobilizer monitors the gear selector position transmitted by the gear selector position transmitted by the ATCU on the Controller Area Network Bus (CAN-Bus). The start inhibitor switch is also hard-wired from the transmission to the WES-3. Starting is allowed when the EWS-3 immobilizer receives a closed inhibitor switch signal or an appropriate CAN message transmitted from the ATCU. A further safety feature of the

transmission system is 'reverse inhibition'. When the vehicle speed exceeds 10 km/h in the forward direction, the ATCU switches a solenoid, which drains the oil from the reverse clutch, thus preventing reverse selection and subsequent transmission damage.

The inhibitor switch consists of seven sets of contacts; the ATCU monitors these switches to determine the position of the gear range selector and choose the best shift pattern. It also transmits a signal relating to the selected gear on to the CAN-Bus. This CAN signal is used to illuminate the corresponding part of the 'PRND432' display on the instrument pack. A display also informs the driver which mode has been selected.

- 'D' means the transmission is in normal drive mode
- 'S' means sport mode.
- A snowflake symbol indicates winter/snow mode.
- 'F' means the ATCU has entered a fail-safe mode. Fault(s) are stored in the ATCU non-volatile memory.

Solenoid actuators that are controlled by the ATCU cause the automatic transmission gear changes. This is achieved using nine solenoids, which regulate the control valve operation.

The solenoid valve block is located inside the transmission system. The three shift solenoids, which engage the various gear ratios within the transmission, are called A, B and C in the block diagram of Figure 15.24 and there is a given combination of these solenoid states for the selection of each gear. Figure 15.24 is a block diagram of the system showing where the solenoids are used.

The pressure of the transmission fluid must be regulated correctly. If pressure becomes too high, gear shifting will occur at high speeds, which is uncomfortable for passengers and can damage the transmission. If the line pressure becomes too low, gear shifting will take longer to complete and can shorten the life of the various clutches within the transmission. One solenoid control valve – called the line pressure duty solenoid (PL) – regulates line pressure. The required pressure is calculated by the ATCU from current engine speed, vehicle speed, current engine torque and throttle angle signals.

Being electronically controlled means it is possible to vary the characteristics of the shift maps. The shift maps can be selected manually by the driver mode options.

- Snow mode.
- Sport mode.
- Normal drive mode, 4, 3, 2.

Automatic intervention by the ATCU will occur if demanded by prevailing driving conditions. The shift map adaptations are called strategies; on power-up of the vehicle, the ATCU will default to normal drive mode. The system supports, and can automatically initiate, the following strategies.

1. Hill/trailer mode engagement. This is an adaptive mode with which the ATCU detects steep gradients and automatically enters this mode. ATCU detection is by monitoring of engine torque values, throttle angle and engine speed. Pulling a trailer has a similar effect on a vehicle in terms of torque requirements as a vehicle

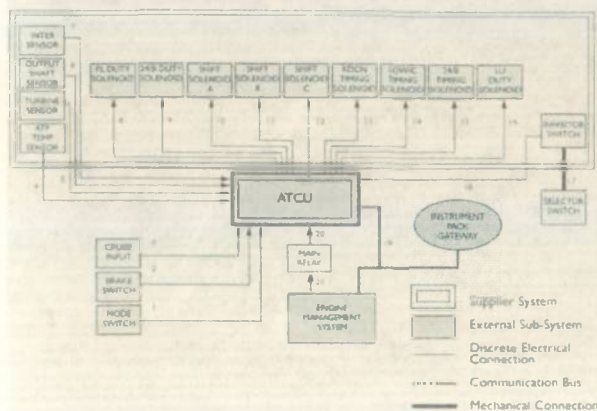


Figure 15.24 Jatco system fitted to a Rover car

climbing a hill. This mode helps to prevent the gears shifting up and down in response to frequent throttle pedal adjustments that the driving conditions may require.

- Downhill recognition. This strategy decreases the need for the application of the brakes when driving downhill. The system recognizes the decrease in throttle angle and the increase in speed as a slope. When the brakes are applied, the transmission changes down a gear. It stays in this mode until application of the throttle.
- Cooling strategy engagement. Torque converter lock-up will not usually occur in second gear, and under high loading conditions the transmission can generate excessive heat. Locking the torque converter or changing gear can reduce the amount of heat generated. The ATCU recognizes that a low gear has been selected and that engine speed, engine torque and throttle angles are all high and it will engage the cooling strategy.
- Cold start/climate strategy. This strategy holds onto the gears for longer than usual. It also prevents lock-up until the oil has reached a set temperature. This warms up the power-train of the vehicle and it reaches its optimum performing temperature earlier. An improvement in vehicle emissions, fuel economy and driveability is the result.

The above strategies are controlled automatically by the ATCU. The driver can select various shift maps by choosing the sport mode or the snow/winter mode from the driver mode switch on the centre console.

The transmission defaults to normal/drive mode on vehicle start up. In sport mode, the ATCU will hold on to the gears for longer than usual, improving acceleration performance, and will downshift more readily giving faster overall vehicle responsiveness. When snow/winter mode is selected, the ATCU limits the amount of wheel slip when the transmission is shifting between the gears by shifting power to reduced engine torque loads. This mode is designed for use in icy and wet conditions.

15.6.5 Power steering – ZF Servoelectric

The ZF Servoelectric system is one of the most user-friendly Electric Power-Steering Systems available to date. It offers extensive economic and environmental improvements over hydraulic steering systems for a wide range of cars. In addition, ZF's new electric system is much easier to install by the original equipment (OE) vehicle manufacturer. Instead of a complex range of parts, ZF Servoelectric is offered as a modular kit, ensuring universal and cost-effective applications. Figure 15.25 shows a ZF steering system. The kit is available in three versions.

For small passenger cars

A Servoelectric system with an integral servo unit incorporated in the steering column. This is primarily suitable for small passenger cars with restrictions in engine compartment space. Maximum steering wheel load is 600 kg.

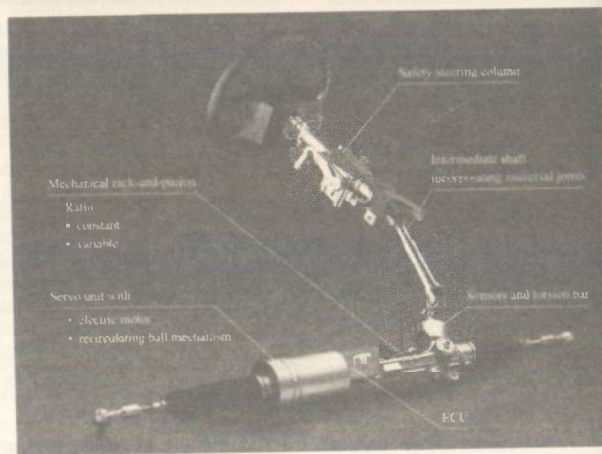


Figure 15.25 Electric power steering system

For mid-range cars

A Servoelectric system designed for mid-range cars with the servo unit working on the pinion. Maximum steering load is 900 kg.

For upper mid-range cars

A Servoelectric system designed for upper mid-range passenger cars and light duty commercial vehicles where the steering rack itself is driven by an electric motor.

A reduction in energy consumption of up to 80% over hydraulic systems is possible. The average mid-range car fitted with the Servoelectric system would experience reductions in fuel consumption of around 0.5 litres per 100 km. This is possible because the electric motor is operating only whilst the vehicle is being steered, unlike a continuously operating oil pump which is neither economical nor environmentally friendly. Electric steering also offers considerable benefits to vehicle manufacturers since the system is easier – not to mention a lot quicker – to install. An in-built ECU offers OE manufacturers the opportunity to adapt the steering system to their specific requirements, for instance, to the precise vehicle steering parameters, or to offer road-speed related steering assistance. Integrated sensors housed in the steering system can transmit information about steering angles and speeds to chassis control units, or even to the navigated driver information systems.

The Servoelectric system offers steering comfort both equal to conventional hydraulic steering systems. In addition, driving on uneven road surfaces is

made effortless, due to the system's programmable damping. There are many factors to bear in mind when selecting a steering system; these include performance, safety, strength, installation conditions and, of course, costs. ZF can now offer a wide range of possibilities for a particular solution from its range of hydraulic, electric or even electric-hydraulic power steering solutions – the latter supplies pressure by means of an electrically-driven oil pump. Estimates have shown that, by the year 2000, one-third of all power-steering systems manufactured in Western Europe will have electrical assistance. Furthermore, it has been predicted that eventually, the electric solution will completely replace hydraulic systems.

15.6.6 Porsche stability management

The new 911 Carrera 4 is the first Porsche to feature Porsche Stability Management (PSM), which is a combination of four-wheel drive designed for sports motoring and electronic suspension control, carefully geared to the character of the car. The result is not only a high standard of driving safety, but also that very special driving pleasure Porsche drivers have learnt to appreciate so much over the last 50 years. Figure 15.26 shows the layout of the PSM system.

This objective calls for control and suspension management features different from those to be found in other cars incorporating similar systems. A Porsche will retain its agile, sporting and dynamic driving behaviour all the way to the most extreme

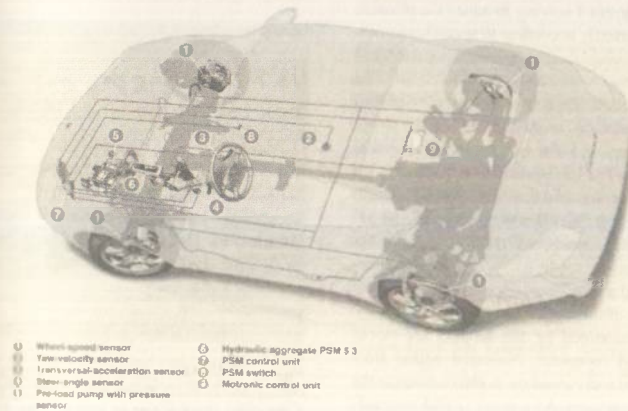


Figure 15.26 Porsche stability management system

limit. In addition, thanks to the high standard of safety reserves offered by the suspension, the driver only has to intervene in the car's behaviour on dry roads when driving under near-racing conditions. At the same time, PSM discreetly and almost unnoticeably corrects any minor deviations in directional stability attributable to load change or application of the brakes in a bend.

Porsche's engineers allow PSM to intervene more energetically at an even earlier point on wet or slippery roads and, in particular, on road surfaces with varying frictional coefficients. It is here, too, that PSM makes stopping distances much shorter while keeping the car stable and firmly on course when applying the brakes.

In its operation, PSM follows two fundamental control strategies. First, it offers the well-known concept of longitudinal control with ABS anti-lock brakes, anti-spin control and the Automatic Brake Differential, keeping the car smoothly on course when accelerating and applying the brakes on a straight or in bends.

Second, PSM also offers lateral or transverse control keeping the car reliably on course even when subject to substantial lateral forces in a bend. The corrections required for this purpose are provided by the specific, carefully controlled application of the brakes.

Any tendency to oversteer with the rear end of the car swerving around is counteracted by the exact, perfectly metered application of the brake on the outer front wheel in a bend. Under-steering, in turn, is prevented by applying the brake on the rear inner wheel. Lengthwise dynamic control also comes in here to provide a supportive effect, with E-Gas technology in the Carrera 4 serving to adjust the position of the throttle butterfly according to specific requirements. On the road, this means much easier and smoother steering.

To ensure precise function at all times, PSM features a whole number of monitoring units. The wheel speed sensors introduced for the first time together with ABS not only provide information on the speed of the car, acceleration and deceleration, but are also able, by considering the difference in speed from left to right, to 'detect' bends and their radius. Further units are the steering angle sensor, a lateral acceleration sensor and a yaw sensor serving to detect any drift inclination of the car.

All data determined by the sensors are stored within the PSM computer, evaluated within fractions of a second and passed on as instructions to the E-Gas or brake system. As a result, PSM responds a lot faster in threatening situations than even the most experienced driver.

Really enthusiastic drivers wishing to try out the 'natural' dynamic behaviour of their Carrera 4 on the race track are able to deactivate the lateral dynamic control provided by Porsche Stability Management simply by flipping a switch on the instrument panel. Even then the risk involved when taking the car into a power slide is reasonably limited, since all the driver has to do when the angle of the car becomes excessive is to step on the brakes in order to reactivate the dynamic control function. Consequently under circumstances like this, PSM is able to 'bend', slightly but of course never fully overrule the laws of physics.

15.6.7 Twenty-five years of the Bosch ABS

A core component of driving safety for motor vehicles has celebrated its twenty-fifth anniversary: the ABS anti-lock braking system. It took a large number of engineers many years to develop and test this brake control system. Before ABS was introduced, control of steering under emergency braking was not possible, and tyres suffered enormously. The anti-lock system, first produced by Bosch in 1978, prevents the wheels from locking, leaving the vehicle under control and allowing the driver to steer around obstacles. Braking distance is also reduced in most cases. The increasing use of ABS in motor vehicles is a major contribution to safety on the roads.

People had been wondering how to prevent wheels from locking since the beginning of the twentieth century – not only on cars, but also on railway vehicles and even on airplanes. As early as



Figure 15.27 ABS makes vehicles steerable even during braking (Source: Bosch Press). A short lapse of attention while driving ABS can support you in steering the car safely around obstacles even in critical situations

In 1966 Bosch had registered a patent for a 'mechanism to prevent locking of the wheels of a motor vehicle'. All the earlier designs shared the same faults: they were too complicated and therefore too prone to failure, and they worked too slowly. It was not until digital technology became available in the 1970s that a reliable ABS system could be developed. Bosch subsidiary Teldix started working on the project in 1964 and within two years development engineers had already managed to reduce the braking distance on test vehicles. Steering and cornering stability were also retained.

Based on these early models, the engineers were able to design a system which for the very first time was controlled entirely by electronics. The basic principle of this new design – named ABS 1 – is still to be found in nearly all ABS systems. But the reliability and durability of the electronic control unit, with its roughly 1000 analogue components and the safety switches then used, were not yet good enough for volume production – both of these had to be improved. The advent of digital technology and integrated control circuits finally allowed the number of electronic components to be reduced to 140 in total.

After 14 long years of development, everything was finally in place in 1978: the second generation of Bosch's ABS – ABS 2 – began to be fitted as optional equipment, at first in Mercedes-Benz's C-class cars and shortly afterwards in BMW's E-series limousines.

Then, as now, the hydraulic unit remained the central component of an ABS system. Each of the four wheels has a speed sensor, which measures the rotational speed of the wheel. This information is

monitored by an electronic control unit, which opens and closes the magnetic valves at the right time. If a wheel is about to lock under heavy braking, the system continues to reduce the hydraulic pressure on that wheel alone until the threat of locking is past. Once the wheel is turning freely again, the hydraulic pressure is increased. This increase and release of pressure continues until the driver reduces the force on the brake pedal or until the tendency to lock is overcome – if there is more grip on the road surface, for instance. Depending on the particular system, there is a certain amount of feedback movement at the brake pedal.

During the succeeding years developers concentrated on simplifying the system. In 1989 Bosch's engineers succeeded in attaching a hybrid control unit directly to the hydraulic modulator. This allowed them to dispense with both the wiring harness (linking the control unit and the hydraulic modulator) and the vulnerable plug-in connectors, thus significantly reducing the overall weight of this ABS 2E generation. Using new solenoid valves Bosch engineers created generation 5.0 in 1993, and in subsequent years versions 5.3 and 5.7. The main features were once again a significantly reduced weight and additional functions such as electronically distributed brake pressure, which replaced the mechanical brake pressure reduction mechanism on the rear axle.

ABS 8 – the current generation – first appeared in 2001. It has a modular design, which allows the various degrees of complexity of the brake control system – ABS, TCS and ESP – to be manufactured in very similar ways. This makes it possible to optimize synergies in development and manufacture. All the systems currently produced by Bosch are



Figure 15.28 Progress in ABS wheel speed sensors (Source: Bosch Press). The ABS wheel speed sensors have become increasingly smaller and more efficient in the course of time. Recent models not only measure the speed and direction of rotation but can be integrated into the wheel bearing as well

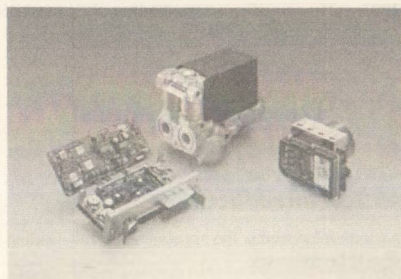


Figure 15.29 ABS 2 and ABS 8 (Source: Bosch Press). The direct comparison of hydraulics aggregate and the ABS control unit from 1978 (left) and the ABS of the latest generation show how the latter is clearly more compact. ABS of the latest generation is much smaller and more lightweight than it used to be at the start of mass production

manufactured to the same quality standards, regardless of where in the world they are actually produced. The majority of ABS systems are manufactured as close as possible to the customer being supplied – no matter whether that is in Germany, France, the USA, Korea or Japan. With increasing technical progress, the range and number of functions also increases. In 1987, for example, Bosch began series production for passenger cars of the ABS-based TCS traction control system which prevents wheel spin. TCS helps to improve acceleration on smooth or slippery surfaces, and also increases stability by reducing engine power when corners are taken too fast.

The ESP Electronic Stability Program – the most advanced brake control system in the world – was launched by Bosch in 1995 as a world first. It improves stability not only under braking and acceleration, but in every driving situation. If there

is a risk of the vehicle going into a skid, ESP reduces engine power and simultaneously provides braking pressure to individual wheels – offering a significant increase in driving safety. ABS – from ‘optional extra’ to ‘fitted as standard’ The successive technical improvements have meant that ABS has been providing greater safety in more and more vehicles since the start of production. Through the 1980s, annual sales of ABS grew slowly. In 1988 Bosch delivered its millionth ABS system to its customers. During the 1990s ABS finally began to be fitted to medium-sized and compact cars.

Sales figures grew from year to year: by 1996 Bosch alone had sold a cumulative total of 50 million systems. Soon – at least in Europe – every new car will have ABS: according to a self-commitment of the European car manufacturers’ association every car sold in Europe from mid-2004 onwards will be fitted as standard with the ABS safety system.

Milestones of development

- 1936 Bosch registers a patent for a ‘mechanism to prevent locking of the wheels of a motor vehicle’.
- 1970 ABS 1 models perform all required functions; but reliability of the control unit is not yet adequate.
- 1978 First fitting of ABS 2 as option at Mercedes-Benz and shortly thereafter at BMW.
- 1981 100 000th ABS system supplied; ABS now also in commercial vehicles.
- 1985 Bosch ABS fitted for the first time in US vehicles.
- 1986 One million Bosch ABS delivered.
- 1987 Production of TCS traction control system for passenger cars’ starts.
- 1989 With the ABS 2E the control unit is attached directly to the hydraulic unit.
- 1992 10 million ABS systems from Bosch.
- 1993 Start of production of ABS 5.0 from Bosch.
- 1995 Production of Bosch ABS 5.3 starts; also start of the Electronic Stability Program (ESP).
- 1998 Bosch begins volume production of ABS 5.7.
- 1999 50 million Bosch ABS systems.
- 2001 Bosch ABS version 8 launched.
- 2003 25 years of series production of Bosch ABS.

15.7 Diagnosing chassis electrical system faults

15.7.1 Introduction

As with all systems, the six stages of fault-finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

Table 15.1 lists some common symptoms of chassis electrical system malfunctions together with suggestions for the possible fault. The faults are generic but will serve as a good reminder. It is assumed an appropriate pressure gauge set has been connected.

15.7.2 Testing procedure – black box technique

‘Chassis electrical systems’ covers a large area of the vehicle. The generic fault-finding lists presented in other chapters may be relevant but the technique that will be covered here is known as ‘black box fault-finding’. This is an excellent technique and

Table 15.1 Common symptoms and possible faults of a chassis electrical system malfunction

Symptom	Possible fault
ABS not working and/or warning light on	<ul style="list-style-type: none"> ● Wheel sensor or associated wiring open circuit/high resistance. ● Wheel sensor air gap incorrect. ● Power supply/earth to ECU low or not present. ● Connections to modulator open circuit. ● No supply/earth connection to pump motor. ● Modulator windings open circuit or high resistance.
Throttle control inoperative	<ul style="list-style-type: none"> ● Wheel sensor or associated wiring open circuit/high resistance. ● Wheel sensor air gap incorrect. ● Power supply/earth to ECU low or not present. ● ABS system fault. ● Throttle actuator inoperative or open circuit connections.
ECU system reduced performance or not working	<ul style="list-style-type: none"> ● Communication link between engine and transmission ECUs open circuit. ● Power supply/earth to ECU low or not present. ● Transmission mechanical fault. ● Gear selector switch open/short circuit. ● Speed sensor inoperative.
Power steering assistance low or not working	<ul style="list-style-type: none"> ● Power supply/earth to ECU low or not present. ● Mechanical fault. ● Power supply/earth to drive motor low or not present. ● Steering sensor inoperative.

can be applied to many vehicle systems from engine management and ABS to cruise control and instrumentation.

As most systems now revolve around an ECU, the ECU is considered to be a 'black box', in other words we know what it should do but how it does it is irrelevant! 'Any colour, so long as it's black,' said Henry Ford in the 1920s. I doubt that he was referring to ECUs though.

Figure 15.30 shows a block diagram that could be used to represent any number of automobile electrical or electronic systems. In reality the arrows from the 'inputs' to the ECU and from the ECU to the 'outputs' are wires. Treating the ECU as a 'black box' allows us to ignore its complexity. The theory is that if all the sensors and associated wiring to the 'black box' are OK, all the output actuators and their wiring are OK and the supply/earth connections are OK, then the fault must be the 'black box'. Most ECUs are very reliable, however, and it is far more likely that the fault will be found in the inputs or outputs.

Normal fault-finding or testing techniques can be applied to the sensors and actuators. For example, if an ABS system uses four inductive-type wheel speed sensors, then an easy test is to measure their resistance. Even if the correct value were not known, it would be very unlikely for all four to be wrong at the same time, so a comparison can be made. If the same resistance reading is obtained on the end of the sensor wires at the ECU, almost all of the 'inputs' have been tested with just a few ohmmeter readings.

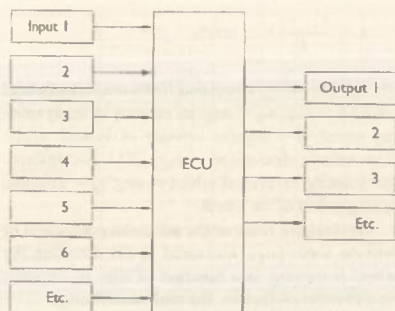


Figure 15.30 Block diagram representing many electrical systems

The same technique will often work with 'outputs'. If the resistance of all the operating windings in, say, a hydraulic modulator were the same, then it would be reasonable to assume the figure was correct.

Sometimes, however, it is almost an advantage *not* to know the manufacturer's recommended readings. If the 'book' says the value should be between 800 and 900 Ω , what do you do when your ohmmeter reads 915 Ω ? Answers on a postcard please ...

Finally, don't forget that no matter how complex the electronics in an ECU, they will not work without a good power supply and an earth.

15.8 Advanced chassis systems technology

15.8.1 Road surface and tyre friction

The friction between the tyre and the road surface is a key issue when considering anti-lock brakes. Frictional forces must be transferred between the tyre contact patch and the road surface when the vehicle is accelerating or braking. The normal rules for friction between solid bodies have to be adapted because of the springy nature of rubber tyres. To get around this complicated problem, which involves molecular theory, the term 'slip' is used to describe the action of tyre and road.

Slip occurs when braking effort is applied to a rotating wheel. This can be defined as follows:

$$\lambda = \frac{\omega_0 - \omega}{\omega_0} \times 100\%$$

or

$$\lambda = \frac{V_v - V_r}{V_v} \times 100\%$$

0% is a free rolling wheel and 100% is a locked wheel where λ = slip; ω_0 = angular velocity of freely rotating wheel; ω = angular velocity of braked wheel; V_v = vehicle road speed = $\omega_0 r_d$; V_r = circumferential velocity of braked wheel = ωr_d ; r_d = dynamic rolling radius of the wheel.

The braking force or the adhesion coefficient of braking force (μ_F), measured in the direction the wheel is turning, is a function of slip. μ_F depends on a number of factors, the main ones being:

- Road surface material/condition.
- Tyre material, inflation pressure, tread depth, tread pattern and construction.
- Contact weight.

Figure 15.31 shows the relationship between the adhesion coefficient of braking effort and the amount of slip. Note that the graph is divided into two areas, stable and unstable. In the stable zone a balance exists between the braking effort applied and the adhesion of the road surface. Non-slip braking is therefore possible. In the unstable zone when the critical slip (λ_c) is passed, no balance exists and the wheel will lock unless the braking force is reduced.

The value of critical slip (λ_c) can vary between about 8 and 30% depending on the tyres and the road surface conditions. Figure 15.32 shows the difference between road surface conditions. This

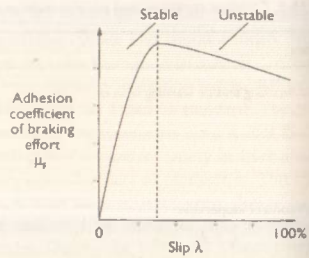


Figure 15.31 Relationship between adhesion coefficient of braking effort and amount of slip

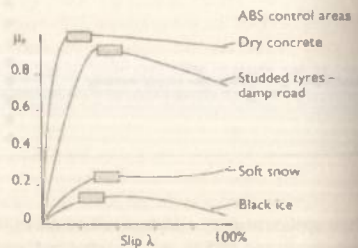


Figure 15.32 Difference between road surface conditions

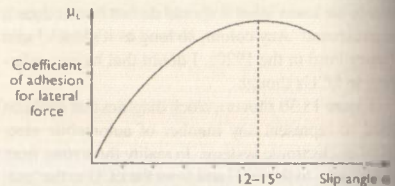


Figure 15.33 Graph of the coefficient of adhesion for lateral force μ_L against slip angle (α)

serves to highlight that a fixed slip threshold as a reference point, for when ABS should operate, would not make the best use of the available adhesion coefficient.

Lateral slip of the vehicle wheels must also be considered. This occurs when the wheel centre-line forms an angle of drift with the intended path of the wheel centre. The directional movement of the vehicle is defined as the correlation between the slip angle and the lateral force. This is shown in Figure 15.33, which is a graph of the coefficient of adhesion for lateral force, designated as μ_L , against slip angle (α). The critical slip angle (α_c) lies, in general, between 12 and 15°.

To regulate braking, it is essential that braking force and lateral guidance forces be considered. Figure 15.34 shows the combination of adhesion coefficient (μ_F), and the lateral adhesion coefficient (μ_L) against braking slip (λ). The slip angle is shown at 2° and 10° and the test is on a dry road. Note the considerable reduction in lateral adhesion (μ_L) when the braking slip (λ) increases. When $\lambda = 28$, the value of μ_L is as a result of the steered angle of the wheel. This can be calculated as:

$$\mu_L(\min) = \mu_F \sin \alpha$$

This serves to demonstrate how a locked wheel provides little steering effect. From Figure 15.33 it can be seen that ABS control must be extended for larger slip angles. If full braking occurs when the vehicle is experiencing high lateral acceleration (larger α) then ABS must intervene early and progressively allow greater slip as the vehicle speed decreases. These data are stored in lookup tables in a read only memory in the electronic control unit.

15.8.2 ABS control cycles

Figure 15.35 shows the braking control cycle for a high adhesion road (good grip). Figure 15.36 shows

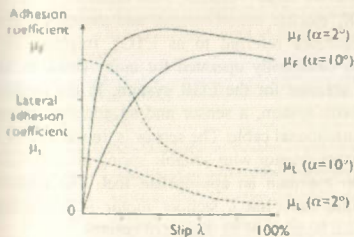
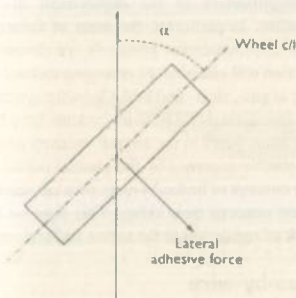


Figure 15.34 The combination of adhesion coefficient (μ_F) and lateral adhesion coefficient (μ_L) against braking (λ)

control cycles for a low adhesion surface (slippery). Each figure is split into eight phases, which are described as follows.

High adhesion

1. Initial braking, ABS not yet activated.
2. Wheel speed exceeds the threshold calculated from the vehicle reference speed and brake pressure is held at a constant value.
3. Wheel deceleration falls below a threshold ($-a$) and brake pressure is reduced.
4. Brake pressure holding is now occurring and wheel speed will increase.
5. Wheel acceleration exceeds the upper limit ($+A$) so brake pressure is now allowed to increase.
6. Pressure is again held constant as the limit ($+a$) is exceeded.
7. Brake pressure is now increased in stages until wheel speed threshold ($-a$) is exceeded.
8. Brake pressure is decreased again and then held constant when ($-a$) is reached.

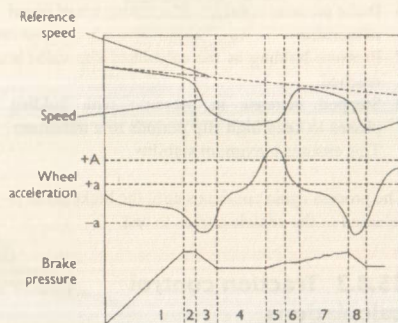


Figure 15.35 Braking control cycle for a high-adhesion surface

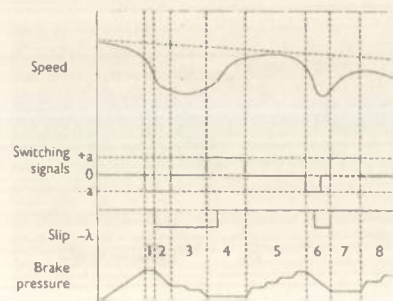


Figure 15.36 Braking control cycles for a low-adhesion surface

The process as above continues until the brake pedal is released or the vehicle speed is less than a set minimum, at which time the wheels will lock to bring the vehicle finally to rest.

Low adhesion

1. Initial braking, ABS not yet activated.
2. Wheel speed exceeds the threshold calculated from the vehicle reference speed and brake pressure is held at a constant value.
3. During this phase a short holding time is followed by a reduction in brake pressure. The wheel speed is compared with, and found to be less than, the calculated slip threshold so pressure is reduced again followed by a second holding time. A second comparison takes place and the pressure is reduced again.
4. A brake pressure holding phase allows the wheel speed to increase.
5. There is a gradual introduction of increased brake pressure and holding pressure in steps until the wheel again slips.
6. Brake pressure is decreased allowing wheel speed to increase.
7. Pressure holding as the calculated slip value is reached.
8. Stepped increase in pressure with holding phases to keep high slip periods to a minimum. This ensures maximum stability.

The process again continues until the brake pedal is released or the vehicle comes to rest.

15.8.3 Traction control calculations

Figure 15.37 shows the forces acting on the wheels of a vehicle when accelerating on a non-homogeneous road surface.

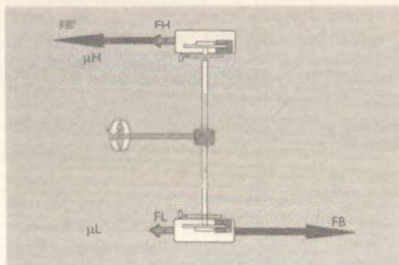


Figure 15.37 Forces acting on wheels of a vehicle when accelerating on a non-homogeneous road surface

road surface. The maximum propulsion force can be calculated:

$$F = FH + FL = 2FL + FB$$

where F = total propulsion force; FH = force transmitted to μ_H part of road; FL = force transmitted to μ_L part of road; FB = braking force; μ_H = high braking force coefficient; μ_L = low braking force coefficient.

15.9 New developments in chassis electrical systems

15.9.1 X-by-Wire

Introduction

The term 'X-by-wire' is used to represent any mechanical technology on the vehicle that is operated electrically. In some areas this has been used for many years. 'Window lift-by-wire' would be a good example. However, the term tends to be used now to represent systems that have not, traditionally, been electrically operated: brake-by-wire and steer-by-wire are two such areas. The industry is going through a development stage that will lead to some level of standardization in the deployment of X-by-wire systems. In particular, the areas of failure tolerance and communication protocols are developing. This section will examine the emerging technologies relating to gas-, steer- and brake-by-wire systems.

Interestingly, X-by-wire systems have been in use for many years in the aircraft industry and appear to be readily accepted by the general public. However, the concept of brake-by-wire on a car seems to cause great concern over safety. This may be due to the lack of regulation in the repair and service industry.

Gas-by-wire

The concept of gas-by-wire is already accepted and in use on many vehicles. This includes injection, EGR, electric supercharging and throttle-by-wire (sometimes referred to as ETC). Injectors have been electrically operated for many years, as has the actuator for the EGR system. In the throttle-by-wire system, a sensor and an actuator replace the traditional cable. The sensor is, in most cases, a variable resistor with suitable spring pressure built in to maintain an appropriate feel. The actuator designs vary but a stepper motor is a common choice because of its degree of control.

Electric supercharging is an interesting development; it is particularly useful for gasoline direct injection engines where it improves performance

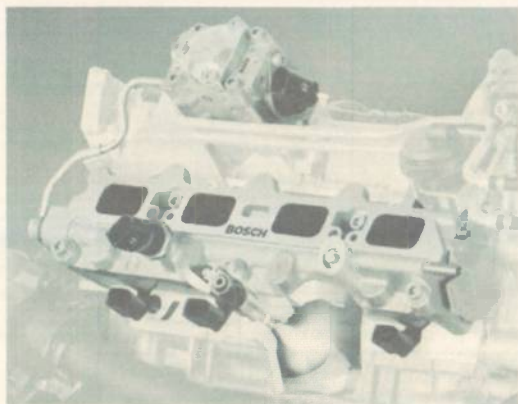


Figure 15.38 Gas-by-wire GDI components (Source: Bosch Press)

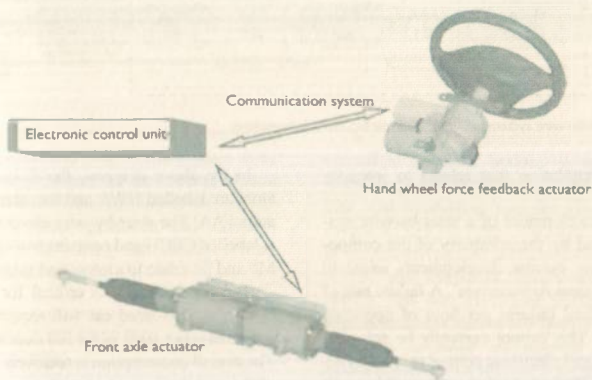


Figure 15.39 Fault-tolerant steer-by-wire system layout (Source: TRW Automotive)

generally but also prevents 'turbo lag'. The development of gas-by-wire systems will continue because of the pressure to reduce CO₂ emissions. This is leading to the development of smaller, more efficient engines.

Steer-by-wire

Currently all series production power steering systems maintain a mechanical connection between the vehicle's front wheels and the steering wheel. If the assistance system, be it electric or hydraulic were to fail, the mechanical link still works as a back up. Furthermore, current regulations require this mechanical connection to be in place. However,

the rigid mechanical connection is a major drawback as far as the system's functional features are concerned. Issues such as noise, vibration and harshness (NVH) and crashworthiness are also drawbacks of the rigid system.

Advances in mechatronic systems mean that the rigid link may soon be replaced – with wires. Steer-by-wire vehicles transfer the rotation of the steering wheel to front wheel movement by using sensors, and use an electronically controlled actuator in place of the conventional steering rack. Feedback, an important characteristic of a steering system, is generated for the driver by a force feedback actuator behind the steering wheel. A change to the regulations relating to the rigid link are being

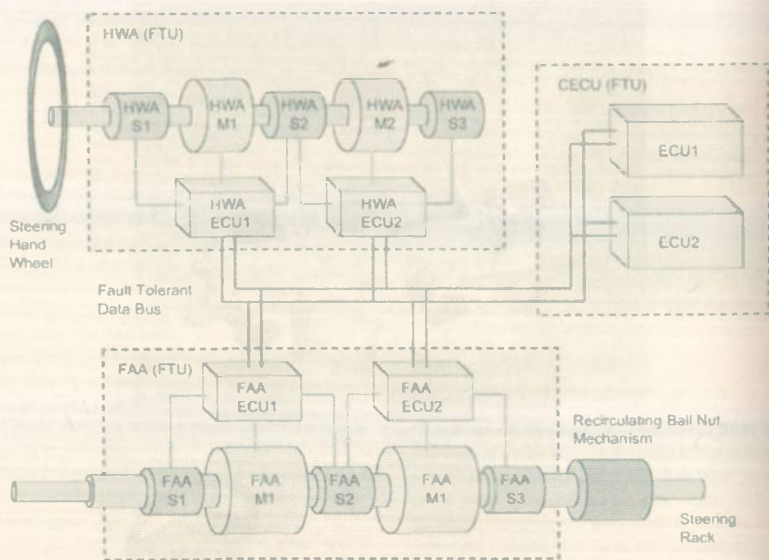


Figure 15.40 Steer-by-wire system architecture (Source: TRW Automotive)

replaced by a regulation that relates to integrity requirements.

Clearly the development of a steer-by-wire system is determined by the reliability of the components used. Many current developments relate to 'fault-tolerant system Architecture'. A failure rate of less than 10^{-7} fatal failures per hour of operating time is the aim. This cannot currently be achieved using single-channel electronic control units (ECUs). To achieve an integrity value comparable with mechanical link systems, steer-by-wire must be able to tolerate single electrical or electronic faults in any of its sub-systems. It must also include a method of detecting these faults. This tolerance would therefore exclude the possibility of sudden fatal failure. Appropriate fault handling may involve a limit to vehicle speed, or in critical conditions would prevent the vehicle from being driven.

The force feedback to the steering wheel is often considered to be less safety-critical. However, for high speed passenger vehicle use the response time of the driver may be critical. For this reason the feedback actuator must also be part of the fault-tolerant system. The overall architecture of a fault-tolerant steer-by-wire system must include significant redundancy. In simple terms, almost all components are duplicated and must include a fault-tolerant power supply.

In the above diagram, the force-feedback actuators are labelled HWA and the 'steering rack' actuators FAA. The steer-by-wire electronic control unit is labelled CECU and contains two ECUs. The labels M# and S# relate to motors and sensors respectively.

The power supply is critical for any X-by-wire system. A mid-sized car will require a peak power output of about 1000 W for full steering performance. The overall consumption is relatively low but because of the peak loading, most systems are designed for a 42 V supply. The ECUs can be operated by 14 V if necessary. The scenario at present is that the electronic drive units will require a dual redundant 42 V supply and the ECUs a dual redundant 42/14 V supply.

The many advantages that steer-by-wire will bring tend to suggest that it will soon be available. TRW Automotive, a well-known and respected OEM, say that steer-by-wire will be ready for production by 2007.¹

Brake-by-wire

Many aspects of the brake-by-wire field are already quite advanced. However, it is becoming clear that

¹ Dr Heinz-Dieter Heitzer, TRW, 2003. Development of a Fault Tolerant Steer-By-Wire Steering System, AutoTechnology Aug. 2003

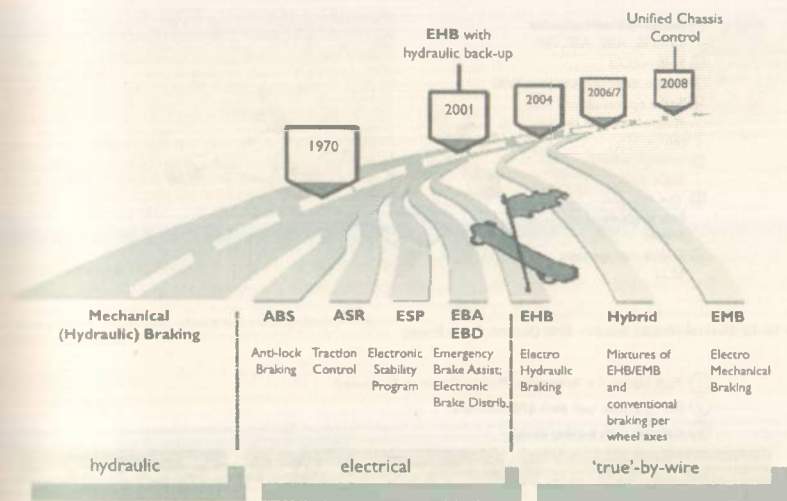


Figure 15.41 Evolution of electric braking systems (Source: Infineon)

Full electrical operation of the brakes, i.e. removal of the hydraulic/mechanical link, is some years away yet. However, the functions of the braking system are undergoing a smooth and continuous evolution.²

There are significant operational and constructional advantages to having full brake-by-wire. Some of these are as follows:

- Safety – improved reaction time of just 0.5 s could decrease death from front end collisions by between 30–50%.
- Environment – hydraulic brake fluid is poisonous and requires changing during the vehicle lifetime.
- Control – a consistent and integrated approach will enhance other functions such as adaptive cruise control and stability control.
- Comfort – lower and adjustable pedal force, as well as features such as ‘hill-holding’, enhance the driver experience.

The need for a fault-tolerant electrical system and the additional cost, means that all current developments have retained the hydraulic system. Figure 15.41 shows the evolution and future projection for brake system developments.

In 1978 Bosch³ launched the first electronically controlled anti-lock braking system (ABS); nine years later came the traction control system (TCS). The next innovation was the Electronic Stability Program (ESP) in 1995. The most advanced system in current production is the electro-hydraulic brake (EHB), also known as Sensoronic Brake Control (SBC). This was developed jointly by Bosch and Mercedes and is shown in Figure 15.42.

Bosch seriously investigated the full brake-by-wire system, but shelved it for technical reasons. Until there is a fully redundant, i.e. duplicated, 42 V wiring circuit in a car there is little probability of this technology being introduced as standard.

Bosch is pursuing the idea of a scalable product range based on ESP, i.e. a product range whose features and performance specifications can be expanded. In contrast to the existing technical concept for the electro-hydraulic brake, this new arrangement is based on a conventional braking system. However, it can perform all the driver-related additional functions by electro-hydraulic means (by wire), without requiring complex and expensive changes to the vehicle’s electrical system. A range of

² Hans A. Kelling and Patrick Leteinturier, 2003. Infineon Technologies AG, X-by-wire: Opportunities, Challenges and Trends, SAE Paper

³ Günther Plapp, Jean Dufour, Robert Bosch GmbH, 2003. New functions for brake control systems, Automotive Press Briefing, Boxberg

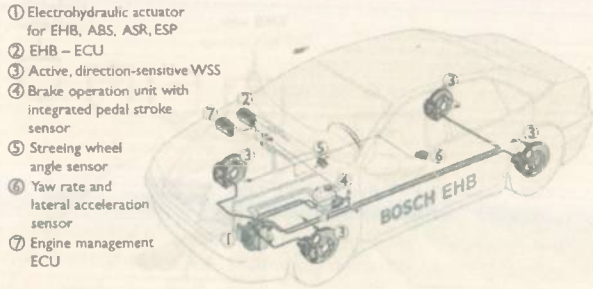


Figure 15.42 Electrohydraulic brakes – EHB (Source: Bosch Press)

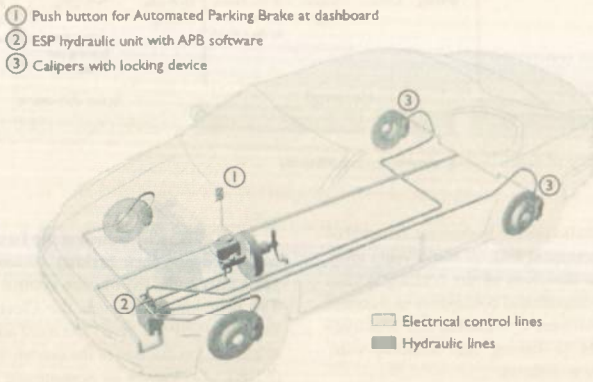


Figure 15.43 Automatic parking brake system (Source: Bosch Press)

new safety and/or convenience features is under development:

- **Electronic Brake Prefill** – if the driver lifts their foot suddenly off the accelerator, the brake system will deduce that there is a potential emergency. The brake pads are immediately moved into contact with the brake discs, so that there is no delay in slowing the vehicle down if emergency braking is undertaken.
- **Brake Disc Wiping** – in heavy rain a film of moisture forms on the brake discs. The brake pads are made to touch the discs briefly on a regular basis, removing the film of water and helping the brakes to bite more quickly.
- **Soft-Stop** – this facilitates smooth, jerk-free stopping by reducing braking pressure shortly before the vehicle comes to rest.
- **Hill Hold Control** – this prevents unintentional rolling backwards on hill starts. The brake system

automatically maintains the braking pressure and stops the vehicle rolling backwards until the driver presses the accelerator again.

- **Stop & Go** – this expands the Adaptive Cruise Control (ACC) distance control system. Using data from distance sensors, this function can automatically bring the vehicle to a complete halt and then move it forward again when traffic allows, without the driver needing to do anything.

An automatic parking brake (APB) is another attractive function offering the driver increased comfort and convenience. Since the handbrake lever is dispensed with, car manufacturers have more freedom of choice as to where they site the operating parts within the car. The technical principle involved can be compared with that of a ball-point pen, where the ink cartridge is pushed out by finger pressure and then held in position with a locking mechanism until the button is pressed once again.

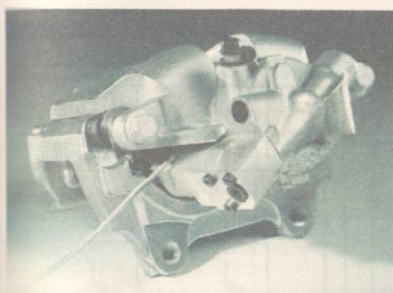


Figure 15.44 Electrically operated parking brake caliper (Source: Bosch Press)



Figure 15.45 MagneRide strut (Source: Delphi)

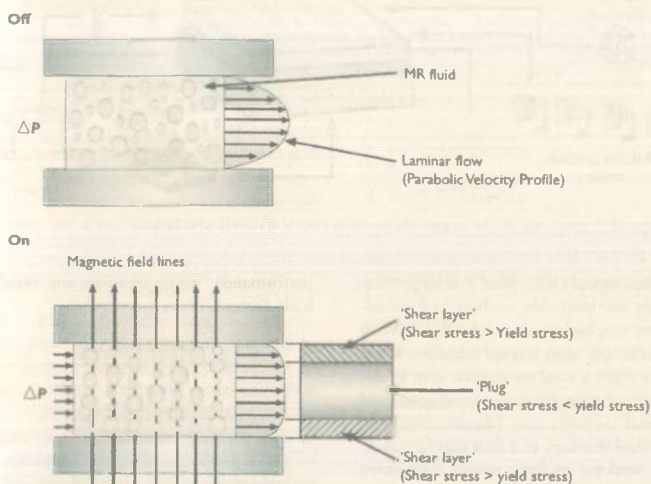


Figure 15.46 MR fluid activation (Source: Delphi)

When the driver presses the switch to activate the parking brake, the ESP unit automatically generates pressure in the braking system and presses the brake pads against the disc. The calipers are then locked in position – an electrically controlled magnetic valve built into the caliper operates the locking mechanism hydraulically. The caliper then remains locked without any hydraulic pressure. To release the brake, the ESP briefly generates pressure again, slightly more than was needed to lock the caliper.

Development of brake-by-wire will not stop – because it has the potential to improve significantly the way in which the vehicle will stop!

15.9.2 Delphi MagneRide

The MagneRide™ system produced by Delphi provides the industry's first semi-active suspension technology, with no electro-mechanical valves and no small moving parts. The MagneRide magneto-rheological (MR) fluid-based semi-active suspension system consists of MR fluid-based monotube struts, monotube shock absorbers, a sensor set and on-board controller.¹

¹Delphi, 2002, MagneRide press information, www.delphi.com

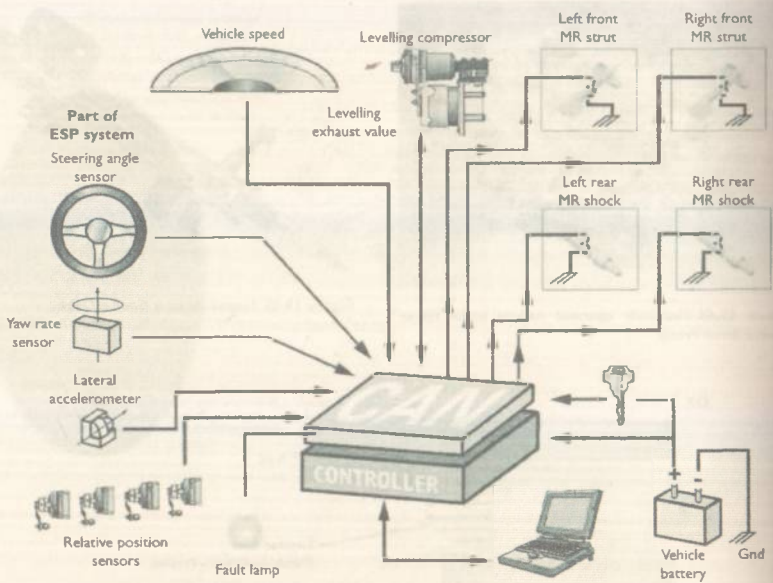


Figure 15.47 MagneRide struts and 'shocks' as part of a complete control system (Source: Delphi)

Magneto-rheological (MR) fluid is a suspension of magnetically soft particles, such as iron microspheres, in synthetic hydrocarbon base fluid. When MR fluid is in the 'off' state it is not magnetized and the particles exhibit a random pattern. But in the 'on', or magnetized state, the applied magnetic field aligns the metal particles into fibrous structures, changing the fluid rheology to a near plastic state.

Used as a working medium within fluid-based struts and shocks, MR fluid performs a critical active ride and handling function for the MagneRide system. By controlling the current to an electromagnetic coil inside the piston of the damper, the MR fluid's shear strength can be changed, which varies the resistance to fluid flow. Fine tuning of the magnetic current allows for any state between the low forces of 'off' to the high forces of 'on' to be achieved in the damper. The result is continuously variable real time damping.

MagneRide isolates and smoothes out the action of each wheel. On gravel and slippery surfaces, MagneRide integrates with traction control to assure maximum stability. MagneRide works with ABS brakes to help keep the automobile poised and balanced for positive stopping power.

With MagneRide as an integral part of a ride and handling system, the driver can expect increased

performance, safety, comfort and reliability. The main features of the system are:

- Simple monotube design with no electro-mechanical valves or small moving parts.
- Improved performance and reliability over valve-based competitive systems.
- Full software tuneable damping characteristics which provide excellent low frequency body control without excessive harshness at high velocities.
- Excellent roll control during transient steering and evasive manoeuvres.
- Wide range of force control and high bandwidth for fast response.
- Low power requirements (20 W per damper max).

15.10 Self-assessment

15.10.1 Questions

1. Describe the three main control phases of an ABS system.
2. Describe what is meant by 'black box fault-finding'.
3. Explain with the aid of a labelled sketch the operation of a wheel speed sensor.

4. State four advantage of electric power steering.
5. Draw a graph to show the effectiveness of traction control when only the throttle is controlled.
6. Make a simple sketch of a block diagram for an electronically controlled automatic transmission (ECAT) system and state the purpose of each part.
7. List eight chassis systems that can be controlled by electronics.
8. Define: 'Total vehicle dynamics'.
9. Describe the operation of an active suspension system.
10. State three possible disadvantages of an ABS system.

15.10.2 Assignment

Investigate the possibilities of producing a vehicle with a central control unit (CCU) that is able to control *all* operations of the vehicle from engine management to instrumentation and stability control.

Produce a report for the board of a major vehicle manufacturer showing the possible advantages and disadvantages of this approach. Make a clear recommendation to the board as to whether they should make this idea into a reality – or not. Justify your decision.

15.10.3 Multiple choice questions

Technician A says an anti-lock braking system must recognize poor road conditions, such as when a vehicle is aquaplaning and react accordingly. Technician B says an anti-lock braking system can increase the stopping distance when on poor road conditions, such as loose gravel or snow. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

The task of an ABS control module is to compare signals from wheel speed sensors by determining wheel:

1. speed
2. deceleration
3. linear speed
4. percentage slip

When a wheel locks during the braking of a vehicle fitted with ABS, the modulator action will be:

1. release, hold, build-up
2. hold, build-up, release
3. build-up, release, hold
4. none of the above

An oscilloscope connected to a wheel speed sensor should show a:

1. sine wave pattern
2. cosine wave pattern
3. high resistance
4. low resistance

On most vehicles, disconnecting the ABS fuse for 10 seconds will:

1. disable the ABS
2. de-activate the ABS
3. reset the ABS fault memory
4. test the ABS sensors

Electronically controlled automatic transmissions can prevent surging by controlling:

1. hydraulic vacuum
2. hydraulic pressure
3. feedback vacuum
4. feedback pressure

Electric power steering that does not have a mechanical connection between the steering wheel and the front wheels is known as:

1. a crazy idea
2. a good idea
3. steer-by-wire
4. scare-by-wire

A system that improves the grip of driven wheels when accelerating is known as:

1. ABS
2. ECU
3. TCR
4. ECAT

Brake assist systems help to apply the brakes under:

1. all conditions
2. inclement conditions
3. anti-lock conditions
4. emergency conditions

An electronically controlled clutch:

1. reduces wear and improves performance
2. reduces wear but reduces performance
3. increases wear but improves performance
4. increases wear and reduces performance

16

Comfort and safety

16.1 Seats, mirrors and sun-roofs

16.1.1 Introduction

Electrical movement of seats, mirrors and the sun-roof are included in one chapter as the operation of each system is quite similar. The operation of electric windows and central door locking is also much the same.

Fundamentally, all the above mentioned systems operate using one or several permanent magnet motors, together with a supply reversing circuit. A typical motor reverse circuit is shown in Figure 16.1. When the switch is moved, one of the relays will operate and this changes the polarity of the supply to *one* side of the motor. If the switch is moved the other way, then the polarity of the other side of the motor is changed. When at rest, both sides of the motor are at the same potential. This has the effect of regenerative braking so that when the motor stops it will do so instantly.

Further refinements are used to enhance the operation of these systems. Limit switches, position memories and force limitations are the most common.

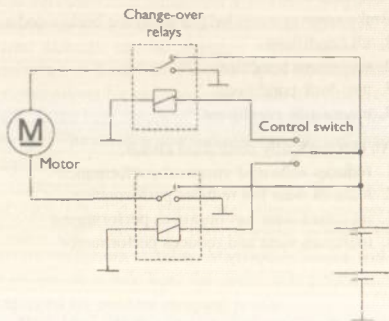


Figure 16.1 Typical motor reverse circuit

16.1.2 Electric seat adjustment

Adjustment of the seat is achieved by using a number of motors to allow positioning of different parts of the seat. Movement is possible in the following ways.

- Front to rear.
- Cushion height rear.
- Cushion height front.
- Backrest tilt.
- Headrest height.
- Lumber support.

Figure 16.2 shows a typical electrically controlled seat. This system uses four positioning motors and one smaller motor to operate a pump, which controls the lumbar support bag. Each motor can be considered to operate by a simple rocker-type switch that controls two relays as described above. Nine relays are required for this, two for each motor and one to control the main supply.

When the seat position is set, some vehicles have set position memories to allow automatic re-positioning if the seat has been moved. This is often combined with electric mirror adjustment. Figure 16.3 shows how the circuit is constructed to allow position memory. As the seat is moved a variable

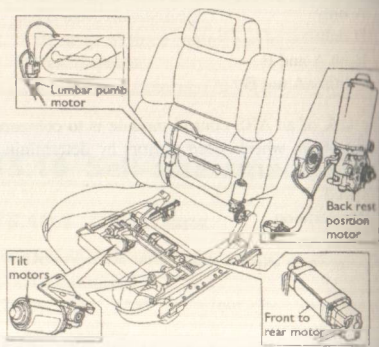


Figure 16.2 Electrically controlled seat

resistor, mechanically linked to the motor, is also moved. The resistance value provides feedback to an electronic control unit. This can be 'remembered' in a number of ways; the best technique is to supply the resistor with a fixed voltage such that the output relative to the seat position is proportional to position. This voltage can then be 'analogue-to-digital' converted, which produces a simple 'number' to store in a digital memory. When the driver presses a memory recall switch, the motor relays are activated by the ECU until the number in memory and the number fed back from the seat are equal. This facility is often isolated when the engine is running to prevent the seat moving into a dangerous position as the car is being driven. The position of the seats can still be adjusted by operating the switches as normal.

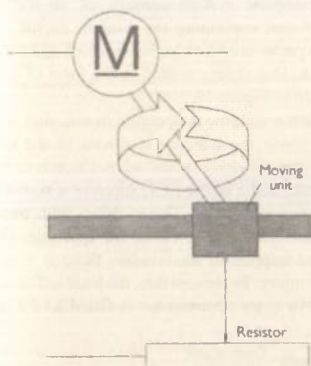


Figure 16.3 Position memory for electric seats

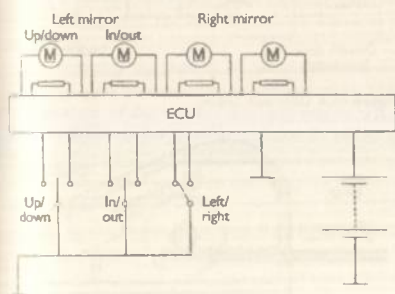


Figure 16.4 Feedback resistors for positional memory and the circuit

16.1.3 Electric mirrors

Many vehicles have electric adjustment of mirrors, particularly on the passenger side. The system used is much the same as has been discussed above in relation to seat movement. Two small motors are used to move the mirror vertically or horizontally. Many mirrors also contain a small heating element on the rear of the glass. This is operated for a few minutes when the ignition is first switched on and can also be linked to the heated rear window circuit. Figure 16.4 shows an electrically operated mirror circuit, which includes feedback resistors for positional memory.

16.1.4 Electric sun-roof operation

The operation of an electric sun-roof is similar to the motor reverse circuit discussed earlier in this chapter. However, further components and circuitry are needed to allow the roof to slide, tilt and stop in the closed position. The extra components used are a micro switch and a latching relay. A latching relay works in much the same way as a normal relay except that it locks into position each time it is energized. The mechanism used to achieve this is much like that used in ball-point pens that use a button on top.

The micro switch is mechanically positioned such as to operate when the roof is in its closed position. A rocker switch allows the driver to adjust the roof. The circuit for an electrically operated sun-roof is shown in Figure 16.5. The switch provides the supply to the motor to run it in the chosen direction. The roof will be caused to open or tilt. When the switch is operated to close the roof, the motor is run

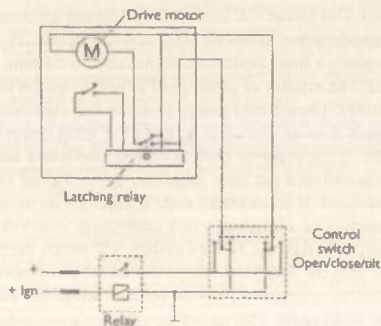


Figure 16.5 Sun-roof circuit

in the appropriate direction until the micro switch closes when the roof is in its closed position. This causes the latching relay to change over, which stops the motor. The control switch has now to be released. If the switch is pressed again, the latching relay will once more change over and the motor will be allowed to run.

16.2 Central locking and electric windows

16.2.1 Door locking circuit

When the key is turned in the driver's door lock, all the other doors on the vehicle should also lock. Motors or solenoids in each door achieve this. If the system can only be operated from the driver's door key, then an actuator is not required in this door. If the system can be operated from either front door or by remote control, then all the doors need an actuator. Vehicles with sophisticated alarm systems often lock all the doors as the alarm is set.

Figure 16.6 shows a door locking circuit. The main control unit contains two change-over relays (as in Figure 16.1), which are actuated by either the door lock switch or, if fitted, the remote infrared key. The motors for each door lock are simply wired in parallel and all operate at the same time.

Most door actuators are now small motors which, via suitable gear reduction, operate a linear rod in either direction to lock or unlock the doors. A simple motor reverse circuit is used to achieve the required action. Figure 16.7 shows a typical door lock actuator.

Infrared central door locking is controlled by a small hand-held transmitter and an infrared sensor receiver unit as well as a decoder in the main control unit. This layout will vary slightly between different manufacturers. When the infrared key is operated by pressing a small switch, a complex code is transmitted. The number of codes used is well in excess of 50 000. The infrared sensor picks up this code and sends it in an electrical form to the main control unit. If the received code is correct, the relays are triggered and the door locks are either locked or unlocked. If an incorrect code is received on three consecutive occasions when attempting to unlock the doors, then the infrared system will switch itself off until the door is opened by the key. This will also reset the system and allow the correct code to operate the locks again. This technique prevents a scanning type transmitter unit from being used to open the doors. Figure 16.8 shows a flow diagram representing

the operation of a system that uses a 'rolling code' (MAC stands for Message Authentication Code).

16.2.2 Electric window operation

The basic form of electric window operation is similar to many of the systems discussed so far in this chapter, that is, a motor reversing system that is operated either by relays or directly by a switch.

More sophisticated systems are now becoming more popular for reasons of safety as well as improved comfort. The following features are now available from many manufacturers:

- One shot up or down.
- Inch up or down.
- Lazy lock.
- Back-off.

The complete system consists of an electronic control unit containing the window motor relay, switch packs and a link to the door lock and sun-roof circuits. This is represented in the form of a block diagram in Figure 16.9.

When a window is operated in one-shot or one-touch mode the window is driven in the chosen direction until either the switch position is reversed, the motor stalls or the ECU receives a signal from the door lock circuit. The problem with one-shot operation is that if a child, for example, should become trapped in the window there is a serious risk of injury. To prevent this, the back-off feature is used. An extra commutator is fitted to the motor

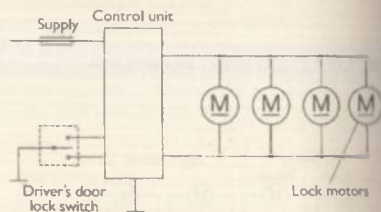


Figure 16.6 Door lock circuit

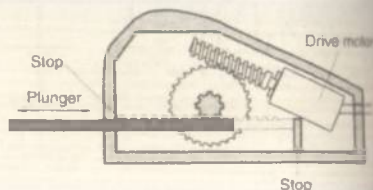


Figure 16.7 Door lock actuator

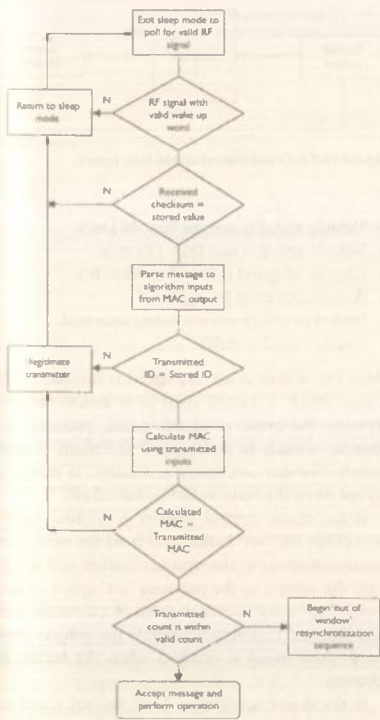


Figure 16.8 Flow diagram representing the 'Rolling code' system

armature and produces a signal via two brushes, proportional to the motor speed. If the rate of change of speed of the motor is detected as being below a certain threshold when closing, then the ECU will reverse the motor until the window is fully open.

By counting the number of pulses received, the ECU can also determine the window position. This is important, as the window must not reverse when it stalls in the closed position. In order for the ECU to know the window position it must be initialized. This is often done simply by operating the motor to drive the window first fully open, and then fully closed. If this is not done then the one-shot close will not operate.

On some systems, Hall effect sensors are used to detect motor speed. Other systems sense the current being drawn by the motor and use this as an indication of speed.

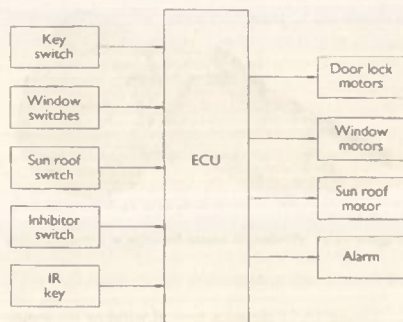


Figure 16.9 Block diagram showing links between door locks, windows and sun-roof - controlled by an infrared key

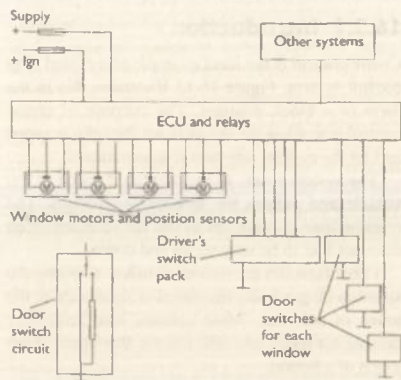


Figure 16.10 Electric window control circuit

The lazy lock feature allows the car to be fully secured by one operation of a remote infrared key. This is done by the link between the door lock ECU and the window and sun-roof ECUs. A signal is supplied and causes all the windows to close in turn, then the sun-roof, and finally it locks the doors. The alarm will also be set if required. The windows close in turn to prevent the excessive current demand that would occur if they all tried to operate at the same time.

A circuit for electric windows is shown in Figure 16.10. Note the connections to other systems such as door locking and the rear window isolation switch. This is commonly fitted to allow the driver to prevent rear window operation for child safety, for example.

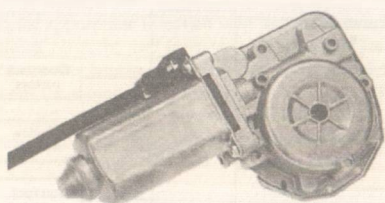


Figure 16.11 Window lift motor for cable or arm-lift systems

Figure 16.11 shows a typical window lift motor used for cable or arm-lift systems.

16.3 Cruise control

16.3.1 Introduction

Cruise control is the ideal example of a closed loop control system. Figure 16.12 illustrates this in the form of a block diagram. The purpose of cruise control is to allow the driver to set the vehicle speed and let the system maintain it automatically.

The system reacts to the measured speed of the vehicle and adjusts the throttle accordingly. The reaction time is important so that the vehicle's speed does not feel to be surging up and down.

Other facilities are included such as allowing the speed to be gradually increased or decreased at the touch of a button. Most systems also remember the last set speed and will resume this again at the touch of a button.

To summarize and to add further refinements, the following is the list of functional requirements for a good cruise control system.

- Hold the vehicle speed at the selected value.
- Hold the speed with minimum surging.
- Allow the vehicle to change speed.
- Relinquish control immediately the brakes are applied.
- Store the last set speed.
- Contain built in safety features.

16.3.2 System description

The main switch turns on the cruise control, this in turn is ignition controlled. Most systems do not retain the speed setting in memory when the main switch has been turned off. Operating the 'set' switch programs the memory but this normally will only work if conditions similar to the following are met.

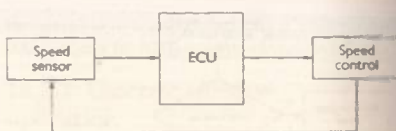


Figure 16.12 Cruise control closed loop system

- Vehicle speed is greater than 40 km/h.
- Vehicle speed is less than 12 km/h.
- Change of speed is less than 8 km/h/s.
- Automatics must be in 'drive'.
- Brakes or clutch are not being operated.
- Engine speed is stable.

Once the system is set, the speed is maintained to within about 3–4 km/h until it is deactivated by pressing the brake or clutch pedal, pressing the 'resume' switch or turning off the main control switch. The last 'set' speed is retained in memory except when the main switch is turned off.

If the cruise control system is required again then either the 'set' button will hold the vehicle at its current speed or the 'resume' button will accelerate the vehicle to the previous 'set' speed. When cruising at a set speed, the driver can press and hold the 'set' button to accelerate the vehicle until the desired speed is reached when the button is released.

If the driver accelerates from the set speed to overtake, for example, then when the throttle is released, the vehicle will slow down until it reaches the last set position.

16.3.3 Components

The main components of a typical cruise control system are as follows.

Actuator

A number of methods are used to control the throttle position. Vehicles fitted with driven-by-wire systems allow the cruise control to operate the same actuator. A motor can be used to control the throttle cable or, in many cases, a vacuum-operated diaphragm is used which is controlled by three simple valves. This technique is shown in Figure 16.13. When the speed needs to be increased, valve 'x' is opened allowing low pressure from the inlet manifold to one side of the diaphragm. The atmospheric pressure on the other side will move the diaphragm and hence the throttle. To move the other way, valve 'x' is closed and valve 'y' is opened allowing

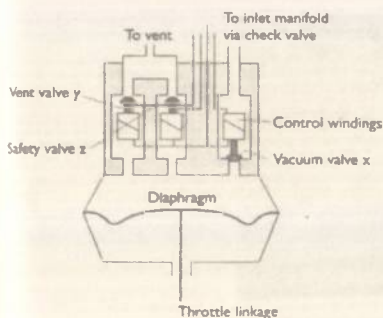


Figure 16.13 Cruise control 'vacuum' actuator

atmospheric pressure to enter the chamber. The spring moves the diaphragm back. If both valves are closed then the throttle position is held. Valve 'x' is normally closed and valve 'y' normally open; thus, in the event of electrical failure cruise control will not remain engaged and the manifold vacuum is not disturbed. Valve 'z' provides extra safety and is controlled by the brake and clutch pedals.

Main switch and warning lamp

This is a simple on/off switch located within easy reach of the driver on the dashboard. The warning lamp can be part of this switch or part of the main instrument display as long as it is in the driver's field of vision.

Set and resume switches

These are fitted either on the steering wheel or on a stalk from the steering column. When the switches are part of the steering wheel, slip rings are needed to transfer the connection. The 'set' button programs the speed into memory and can also be used to increase the vehicle and memory speed. The 'resume' button allows the vehicle to reach its last set speed or temporarily to deactivate the control.

Brake switch

This switch is very important, as it would be dangerous braking if the cruise control system was trying to maintain the vehicle speed. This switch is normally of superior quality and is fitted in place or as a supplement to the brake light switch activated by the brake pedal. Adjustment of this switch is important.

Clutch or automatic gearbox switch

The clutch switch is fitted in a similar manner to the brake switch. It deactivates the cruise system to

prevent the engine speed increasing if the clutch is pressed. The automatic gearbox switch will only allow the cruise to be engaged when it is in the 'drive' position. This is again to prevent the engine over-speeding if the cruise control tried to accelerate to a high road speed with the gear selector in the '1' or '2' position. The gearbox will still change gear if accelerating back up to a set speed as long as it 'knows' top gear is available.

Speed sensor

This will often be the same sensor that is used for the speedometer. If not, several types are available – the most common produces a pulsed signal, the frequency of which is proportional to the vehicle speed.

16.3.4 Adaptive cruise control

Conventional cruise control has now developed to a high degree of quality. It is, however, not always very practical on many European roads as the speed of the general traffic varies constantly and traffic is often very heavy. The driver has to take over from the cruise control system on many occasions to speed up or slow down. Adaptive cruise control can automatically adjust the vehicle speed to the current traffic situation. Figure 16.14 shows the operation of the system. The system has three main aims.

- Maintain a speed as set by the driver.
- Adapt this speed and maintain a safe distance from the vehicles in front.
- Provide a warning if there is a risk of collision.

The main components of basic and more complex adaptive cruise systems are shown in Figure 16.15. Note the main extra components are the 'headway' sensor and the steering angle sensor, the first of these is clearly the most important. Information on steering angle is used to enhance further the data from the headway sensor by allowing greater discrimination between hazards and spurious signals. Two types of the headway sensor are in use, the *radar* and the *lidar*. Both contain transmitter and receiver units. The radar system uses microwave signals at about 35GHz, and the reflection time of these gives the distance to the object in front. Lidar uses a laser diode to produce infrared light signals, the reflections of which are detected by a photodiode.

These two types of sensors have advantages and disadvantages. The radar system is not affected by rain and fog but the lidar can be more selective by recognizing the standard reflectors on the rear of the vehicle in front. Radar can produce strong reflections from bridges, trees, posts and other normal

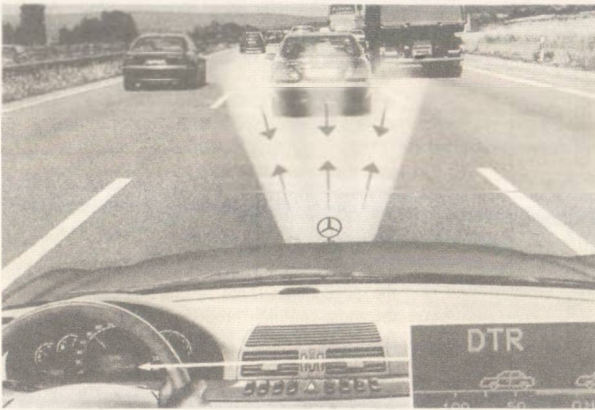


Figure 16.14 Adaptive cruise control operation

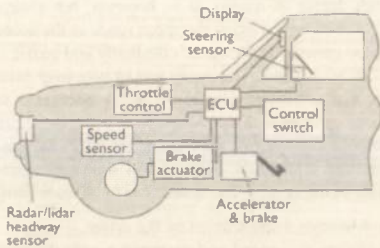


Figure 16.15 Adaptive cruise control

roadside items. It can also suffer loss of signal return due to multipath reflections. Under ideal weather conditions, the lidar system appears to be the best but it becomes very unreliable when the weather changes. A beam divergence of about 2.5° vertically and horizontally has been found to be the most suitable whatever headway sensor is used. An important consideration is that signals from other vehicles fitted with this system must not produce erroneous results. Figure 16.16 shows a typical headway sensor. Fundamentally, the operation of an adaptive cruise system is the same as a conventional system except when a signal from the headway sensor detects an obstruction, in which case the vehicle speed is decreased. If the optimum stopping distance cannot be achieved by just backing off the throttle, a warning is supplied to the driver. A more complex system can also take control of the vehicle transmission and brakes but this, while very promising, is further behind in development. It is

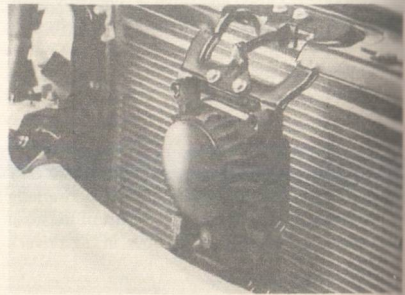


Figure 16.16 Headway sensor fitted at the front of a vehicle

important to note that adaptive cruise control is designed to relieve the burden on the driver, not take full control of the vehicle!

16.4 In-car multimedia

16.4.1 Introduction

These days it would be almost unthinkable not to have at least a radio cassette player in our vehicles. It does not seem too long ago, however, that these were an optional extra. Looking back just a little further, the in-car record player must have been interesting to operate – it was evidently quite successful in large American cars in the US but left a bit to be desired in British vehicles and on British roads. Figure 16.17 shows a typical high quality in-car entertainment (ICE) system with a multi-CD changer.

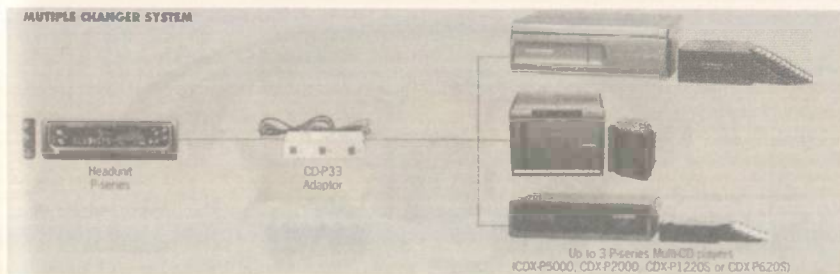


Figure 16.17 ICE system

We now have ICE systems fitted to standard production cars, which are of good hi-fi quality. Facilities such as compact disc players and multiple compact disc changers together with automatic station search and re-tune are popular.

We have seen the rise and fall of the CB radio and the first car telephones – which were so large the main unit had to be fitted in the car boot. 'Hands-free' car telephones, which allow both hands to be kept free to control the car, are in common use and voice activation of other systems is developing.

The 'In-car PC' or the 'Auto PC' is an emerging technology that will soon become the 'norm'. The 'digital' automobile is here!

16.4.2 Speakers

Good ICE systems include at least six speakers, two larger speakers in the rear parcel shelf to produce good low frequency reproduction, two front door speakers for the mid-range and two front door tweeters for high frequency notes. Figure 16.18 shows a Pioneer sub-woofer speaker.

Speakers are a very important part of a sound system. No matter how good the receiver or CD player is, the sound quality will be reduced if inferior speakers are used. Equally, if the speakers are of a lower power output rating than the set, distortion will result at best, and damage to the speakers at worst. Speakers generally fall into the following categories.

- Tweeters – high frequency reproduction.
- Mid-range – middle range frequency reproduction (treble).
- Woofers – low frequency reproduction (bass).
- Sub-woofers – very low frequency reproduction.

Figure 16.19 shows the construction of a speaker.



Figure 16.18 Pioneer sub-woofer

16.4.3 ICE

Controls on most ICE sets will include volume, treble, bass, balance and fade. Cassette tape options will include Dolby filters to reduce hiss and other tape selections such as chrome or metal. A digital display, of course, will provide a visual output of the operating condition. This is also linked into the vehicle lighting to prevent glare at night. Track selection and programming for one or several compact discs is possible.

Many ICE systems are coded to deter theft. The code is activated if the main supply is disconnected and will not allow the set to work until the correct code has been re-entered. Some systems now include a plug-in electronic 'key card', which makes the set worthless when removed.

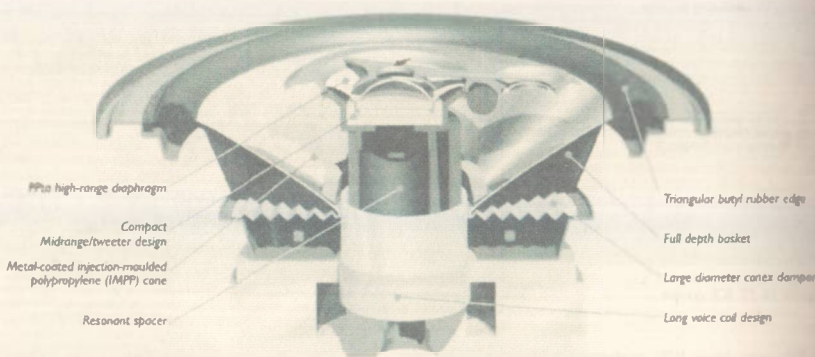


Figure 16.19 Speaker construction

16.4.4 Radio data system (RDS)

RDS has become a standard on many radio sets. It is an extra inaudible digital signal, which is sent with FM broadcasts in a similar way to how teletext is sent with TV signals. RDS provides information so a receiver can appear to act intelligently. The possibilities available when RDS is used are as follows.

- The station name can be displayed in place of the frequency.
- Automatic tuning is possible to the best available signal for the chosen radio station. For example, in the UK, a journey from the south of England to Scotland would mean the radio would have to be re-tuned up to ten times. RDS will do this without the driver even knowing.
- Traffic information broadcasts can be identified and a setting made so that whatever you are listening to at the time can be interrupted.

RDS has six main features, which are listed here with a brief explanation.

1. Programme identification to allow the re-tune facility to follow the correct broadcasts.
2. Alternative frequencies, again to allow the receiver to try other signals for re-tuning as required.
3. Programme service name for displaying the name of the station on the radio set.
4. Traffic information, which provides for two codes to work in conjunction with route finding equipment.
5. Traffic programme, which allows the set to indicate that the station broadcasts traffic information.

6. A traffic announcement is transmitted when an announcement is being broadcast. This allows the receiver either to adjust the volume, switch over from the cassette during the announcement, lift an audio mute or, of course, if the driver wishes it, to do nothing.

16.4.5 Radio reception

There are two main types of radio signal transmitted; these are amplitude modulation (AM) and frequency modulation (FM). Figure 16.20 shows the difference between AM and FM signals.

Amplitude modulation is a technique for varying the height, or amplitude, of a wave in order to transmit information. Some radio broadcasts still use amplitude modulation. A convenient and efficient means of transmitting information is by the propagation of waves of electromagnetic radiation. Sound waves in the audible range, such as speech and music, have a frequency that is too low for efficient transmission through the air for significant distances. By the process of modulation, however, this low frequency audio information can be impressed on a carrier wave that has a much higher frequency and can propagate through space for great distances. The transmitter at a radio station generates a carrier wave having constant characteristics, such as amplitude and frequency. The signal containing the desired information is then used to modulate the carrier.

This new wave, called the modulated wave, will contain the information of the signal. In AM, it is the amplitude of the carrier wave that is made to vary so that it will contain the information of the signal. When the modulated wave reaches a radio

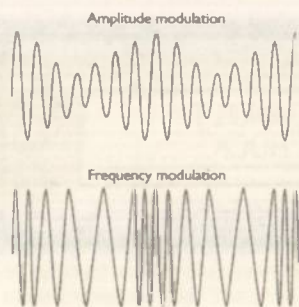


Figure 16.20 Difference between AM and FM signals

receiver tuned to the proper frequency, it is demodulated, which is essentially the opposite of modulation. The set can then reproduce the desired sound via an amplifier and the loudspeakers. AM radio is still a popular form of radio broadcasting, but it does have a number of disadvantages. The quality of reproduction is relatively poor because of inherent limitations in the technique and because of interference from other stations and other electrical signals, such as those produced by lightning or by electronic devices – of which the car has more than its fair share. Some of these drawbacks can be overcome by using FM.

Frequency modulation is a method of modulation in which the frequency of a wave is varied in response to a modulating wave. The wave in which frequency is varied is called the carrier, and the modulating wave is called the signal. Frequency modulation requires a higher-frequency carrier wave and a more complex method for transmitting information than does AM; however, FM has an important advantage in that it has constant amplitude; it is therefore much less susceptible to interference from both natural and artificial sources. Such sources cause static in an amplitude-modulated radio.

Both types of modulation, however, are used in radio broadcasting. FM radio is generally a far better source of high fidelity music. This is because the quality of AM reception, as well as the problems outlined above, is limited by the narrow bandwidth of the signal. During the winter months, reception of AM signals becomes worse due to changes in the atmosphere. FM does, however, present problems with reception when mobile. As most vehicles use a rod aerial, which is omni-directional, it will receive signals from all directions. Because of this, reflections from buildings, hills and other vehicles can reach the set all at the same time. This

can distort the signal and is heard as a series of clicks or signal flutter as the signal is constantly enhanced or reduced. The best FM reception is considered to be line-of-sight from the transmitter. In general, the coverage or footprint of FM transmitters is quite extensive and, especially with the advent of RDS, the reception when mobile is quite acceptable.

16.4.6 Radio broadcast data system (RBDS)

The Radio Broadcast Data System is an extension of the Radio Data System (RDS), which has been in use in Europe since 1984. The system allows the broadcaster to transmit text information at the rate of about 1200 bits per second. The information is transmitted on a 57 kHz suppressed sub-carrier as part of the FM multiplexed (MPX) signal.

RBDS was developed for the North American market by the National Radio Systems Committee (NRSC), a joint committee composed of the Electronic Industries Association (EIA) and the National Association of Broadcasters (NAB). The applications for the transmission of text to the vehicle are interesting.

- Song title and artist.
- Traffic, accident and road hazard information.
- Stock information.
- Weather.

In emergency situations, the audio system can be enabled to interrupt the cassette, CD or normal radio broadcast to alert the user.

16.4.7 Digital audio broadcast (DAB)

Digital Audio Broadcasting is designed to provide high-quality, multiservice digital radio broadcasting for reception by stationary and mobile receivers. It is being designed to operate at any frequency up to 3 GHz. A system is being demonstrated and extensively tested in Europe, Canada and the United States. It is a rugged and also a very efficient sound and data broadcasting system.

The system uses digital techniques to remove redundancy and perceptually irrelevant information from the audio source signal. It then applies closely controlled redundancy to the transmitted signal for error correction. All transmitted information is then spread in both the frequency and the time domains (multiplexed) so a high quality signal is obtained in the receiver, even under poor conditions.

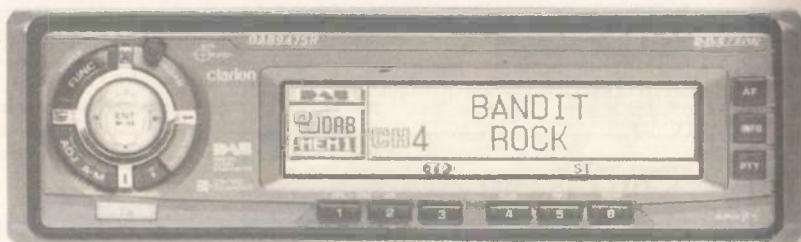


Figure 16.21 Clarion DAB receiver

Frequency reallocation will permit broadcasters to extend services, virtually without limit, using additional transmitters, all operating on the same radiated frequency. A common worldwide frequency in the L band (around 1.5 GHz) is being considered, but some disagreement still exists. The possibilities make the implementation of DAB inevitable. Figure 16.21 shows the front panel of the Clarion system, capable of receiving digital broadcast signals.

16.4.8 Interference suppression

The process of interference suppression on a vehicle is aimed at reducing the amount of unwanted noise produced from the speakers of an ICE system. This, however, can be quite difficult. To aid the discussion, it is necessary first to understand the different types of interference. Figure 16.22 shows two signals, one clean and the other suffering from interference. The amount of interference can be stated as a signal-to-noise ratio. This is the useful field strength compared with the interference field strength at the receiver. This should be as high as possible but a value in excess of 22.1 for radio reception is accepted as a working figure. Interference is an electromagnetic compatibility (EMC) issue and further details can be found in Chapter 4.

There are two overall issues to be considered relating to suppression of interference on a vehicle. These are as follows.

1. Short range – the effect of interference on the vehicle's radio system.
2. Long range – the effect of the vehicle on external receivers such as domestic televisions. This is covered by legislation making it illegal to cause disturbance to radios or televisions when using a vehicle.

Interference can propagate in one of four ways.

- Line borne, conducted through the wires.
- Air borne, radiated through the air to the aerial.

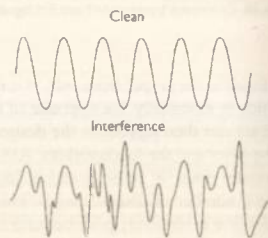


Figure 16.22 Two signals, one clean and the other suffering from interference

- Capacitive coupling by an electric field.
- Inductive coupling magnetic linking.

The sources of interference in the motor vehicle can be summarized quite simply as any circuit, which is switched or interrupted suddenly. This includes the action of a switch and the commutation process in a motor, both of which produce rapidly increasing signals. The secret of suppression is to slow down this increase. Interference is produced from four main areas of the vehicle.

- Ignition system.
- Charging system.
- Motors and switches.
- Static discharges.

The ignition system of a vehicle is the largest source of interference, particularly the high tension side. Voltages up to 30 kV are now common and the peak current for a fraction of a second when the spark plug fires can peak in excess of 100 A. The interference caused by the ignition system is mostly above 30 MHz and the energy can peak, for fractions of a second, of the order of 500 kW.

The charging system produces noise because of the sparking at the brushes. Electronic regulators produce little problems but regulators with vibrating contacts can cause trouble.

Any motor or switch, including relays, is likely to produce some interference. The most popular sources are the wiper motor and heater motor. The starter is not considered due to its short usage time.

The build-up of static electricity is due to friction between the vehicle and the air, and the tyres and the road. If the static on, say, the bonnet builds up more than the wing then a spark can be discharged. Using bonding straps to ensure all panels stay at the same potential easily prevents this. Due to the action of the tyres, a potential can build up between the wheel rims and the chassis unless suitable bonding straps are fitted. The arc to ground can be as much as 10 kV.

There are five main techniques for suppressing radio interference.

- Resistors.
- Bonding.
- Screening.
- Capacitors.
- Inductors.

Resistance is used exclusively in the ignition HT circuit, up to a maximum of about 20 k Ω per lead. This has the effect of limiting the peak current, which in turn limits the peak electromagnetic radiation. Providing excessive resistance is not used, the spark quality is not affected. These resistors effectively damp down the interference waves.

Bonding has been mentioned earlier, it is simply to ensure all parts of the vehicle are at the same electrical potential to prevent sparking due to the build-up of static.

Screening is generally only used for specialist applications such as emergency services and the military. It involves completely enclosing the ignition system and other major sources of noise, in a conductive screen, which is connected to the vehicle's chassis earth. This prevents interference waves escaping; it is a very effective technique but expensive. Often, a limited amount of screening – metal covers on the plugs for example – can be used to good effect.

Capacitors and inductors are used to act as filters. This is achieved by using the changing value of 'resistance' to alternating signals as the frequency increases. The correct term for this resistance is either capacitive or inductive reactance.

By choosing suitable values of a capacitor in parallel and or an inductor in series it is possible to filter out unwanted signals of certain frequencies.

The aerial is worth a mention at this stage. Several types are in use; the most popular still being the rod aerial, which is often telescopic. The advantage of a rod aerial is that it extends beyond

the interference field of the vehicle. For reception in the AM bands the aerial represents a capacitance of 80 pF with a shunt resistance of about 1 M Ω . The set will often incorporate a trimmer to ensure the aerial is matched to the set. Contact resistance between all parts of the aerial should be less than 20 m Ω . This is particularly important for the earth connection.

When receiving in the FM range, the length of the aerial is very important. The ideal length of a rod aerial for FM reception is one quarter of the wavelength. In the middle of the FM band (94 MHz) this is about 80 cm. Due to the magnetic and electrical field of the vehicle and the effect of the coaxial cable, the most practical length is about 1 m. Some smaller aerials are available but whilst these may be more practical the signal strength is reduced. Aerials embedded into the vehicle windows or using the heated rear window element are good from the damage prevention aspect and insensitivity to moisture, but produce a weaker signal, often requiring an aerial amplifier to be included. Note that this will also amplify interference. Some top-range vehicles use a rod aerial and a screen aerial, the set being able to detect and use the strongest signal. This reduces the effect of reflected signals and causes less flutter.

Consideration must be given to the position of an external aerial. This has to be a compromise taking into account the following factors.

- Rod length – 1 m if possible.
- Coaxial cable length – longer cable reduces the signal strength.
- Position – as far away as reasonably possible from the ignition system.
- Potential for vandalism – out of easy reach.
- Aesthetic appearance – does it fit with the style of the vehicle?
- Angle of fitting – vertical is best for AM, horizontal for FM.

Most quality sets also include a system known as interference absorption. This is a circuit built into the set consisting of high quality filters.

Figure 16.23 shows a circuit of a typical ICE system. An electric aerial is included and also the connection to a multi compact disc unit via a data bus.

16.4.9 Mobile communications

If the success of the cellular industry is any indication of how much use we can make of the telephone, the future promises an even greater expansion. Cellular technology started to become

useful in the 1980s and has continued to develop from then – very quickly!

The need and desire we perceive to keep in touch with each other is so great that an increasing number of business people now have up to five telephone numbers: home, office, pager, fax and cellular. But within the foreseeable future, high-tech digital radio technology and sophisticated telecommunications systems will enable all communications to be processed through a single number.

With personal numbering, a person carrying a pocket-size phone will need only one phone number. Instead of people calling places, people will call people – we will not be tied to any particular place. Personal numbering will make business people more productive because they will be able to reach, and be reached by, colleagues and clients, anywhere and anytime, indoors or outdoors. When travelling from home to office or from one meeting

to the next, it will be possible to communicate with anyone, whenever the need arises.

But where does this leave communication systems relating to the vehicle? It is my opinion that 'in-vehicle' communication equipment for normal business and personal use will be by the simple pocket sized mobile phone and that there is no further market for the car telephone. Hands-free conversions will still be important.

CB radios and short-range two-way systems such as used by taxi firms and service industries will still have a place for the time being. However, even these may decline as the cellular network becomes cheaper and more convenient to use.

16.4.10 Auto PC

A revolution in the use of information technology in vehicles is taking place! Advanced computing, communications and positioning developments are being introduced in even the most basic vehicles. Figure 16.24 shows an Auto PC/Car Multimedia system. However, there were several barriers to the widespread use of such new technology.

- Not robust enough.
- Too costly.
- Difficult to install.
- Lack of common standards.
- Difficult to operate.

Most of these problems either have been resolved or are about to be, and other developments are also beneficial:

- Computers have become smaller.
- Prices have reduced.

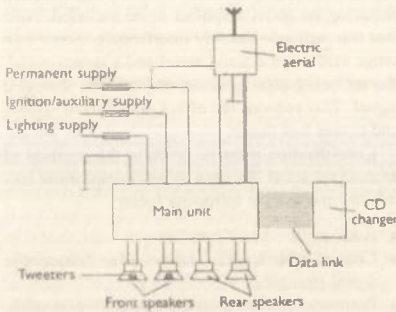


Figure 16.23 ICE system wiring



Figure 16.24 Car multimedia

- Performance has improved.
- Standards are being agreed.

Many leading computer companies, including Microsoft, IBM, and Intel have identified the vehicle as their next big market place. Plans have been announced for in-vehicle computers with a range of integrated functions. Microsoft's Auto PC, for example, uses the Windows CE operating system, a cut-down version of Windows 95/98/2000.

Many suppliers of Windows programs are now committed to offering Windows CE versions of their programs for use in car computers and hand-held personal computers (PCs). Just like a desktop PC, the car computer supports a range of programs. A car computer that will give the driver spoken directions while passengers browse the Internet or watch football will be a reality.

The Auto PC will be able to run familiar desk-top programs whilst also offering the following.

- Spoken turn-by-turn navigation.
- Digital map database of useful sites, such as filling stations and cinemas.
- Voice memo system.
- Vehicle diagnostics program.
- Vehicle security and tracking system.
- Emergency roadside assistance service.

The unit could also be a high-performance stereo system capable of playing CDs and receiving FM radio. An optional communications interface will enable cellular phones to be controlled by spoken instructions, and traffic news received over a pager or cellular service. Intel, the largest computer chip manufacturer, envisages a car computer that is even more highly specified than Microsoft's Auto PC.

The Intel Connected Car PC has a full Windows operating system. As well as providing the driver with similar functions to the Auto PC, this also gives passengers access to a monitor for browsing the Internet or watching television programmes. IBM is working with car manufacturers to help them create networking capabilities in their vehicles.

Whether car computers ultimately succeed or not, there is little doubt that there will be much greater integration of all electronic systems in cars in the future. Efforts are underway in Europe, Japan and the United States to develop a standard database system linking and powering non-safety related electronic systems in vehicles, such as CD players, positioning systems, air conditioning and electric windows. Adding electronic systems later would be by what is described as 'plug and play'.

Tying the computer in with the mobile communication system opens up even more possibilities.

Cellular phone systems can provide an excellent means of tracking vehicles. Phone operators divide the country into separate cells and monitor phones as they move between them to ensure that each phone communicates through the best transmitter. Mobile communication systems will have a profound impact on how vehicles are used. Development work is underway on the exchange of information between vehicles and the road infrastructure.

(See also the section on 'Telematics' in Chapter 13.)

16.5 Security

16.5.1 Introduction

Stolen cars and theft from cars account for about a quarter of all reported crime. A huge number of cars are reported missing each year and over 20% are never recovered. Even when returned many are damaged. Most car thieves are opportunists, so even a basic alarm system can serve as a deterrent.

Car and alarm manufacturers are constantly fighting to improve security. Building the alarm system as an integral part of the vehicle electronics has made significant improvements. Even so, retro-fit systems can still be very effective. Three main types of intruder alarm are used.

- Switch operated on all entry points.
- Battery voltage sensed.
- Volumetric sensing.

There are three main ways to disable the vehicle.

- Ignition circuit cut off.
- Starter circuit cut off.
- Engine ECU code lock.

A separate switch or IR transmitter can be used to set an alarm system. Often, they are set automatically when the doors are locked.

16.5.2 Basic security

To help introduce the principles of a vehicle alarm, this section will describe a very simple system, which can be built as a DIY retro-fit. First, the requirements of this particular alarm system.

- It must activate when a door is opened.
- The ignition to be disabled.
- The existing horn is used as the warning.
- Once triggered, the horn must continue even when the door is closed.
- It must reset after 15 seconds.

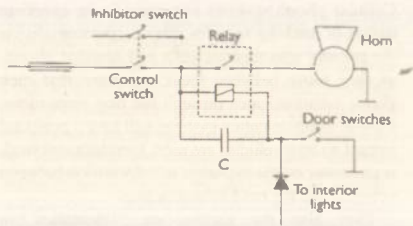


Figure 16.25 Simple alarm circuit the entry delay is made by using a CR circuit

The design will be based around a simple relay circuit. When a door is opened, the switches make an earth connection. This will be used to trigger the relay, which in turn will operate the horn. The delay must be built in using a capacitor, which will keep the relay energized even after the door closes, for a further 15 seconds. An external key switch is to be used to arm and disarm whilst isolating the ignition supply. Figure 16.25 shows a simple alarm circuit, which should achieve some of the aims. The delay is achieved by using a CR circuit; the 'R' is the resistance of the relay coil. Using the following data the capacitor value can be calculated.

- Time delay = 15 s.
- Relay coil = 120 Ω .
- Supply voltage = 12 V.
- Relay drop out = 8 V.

A capacitor will discharge to about 66% of its full value in CR seconds. The supply voltage is 12 V, so 66% of this is 8 V.

Therefore, if $CR = 15$, then, $C = 15/120$

$$C = 125 \text{ mF}$$

This seems an ideal simple solution – but it is not. As an assignment, find the problem and design a simple electronic circuit using a transistor, resistor and capacitor.

16.5.3 Top of the range security

The following is an overview of the good alarm systems now available either as a retro-fit or factory fitted. Most are made for 12 V, negative earth vehicles. They have electronic sirens and give an audible signal when arming and disarming. They are all triggered when the car door opens and will automatically reset after a period of time, often 1 or 2 minutes. The alarms are triggered instantly when an entry point is breached. Most systems can be considered as two pieces, with a separate control

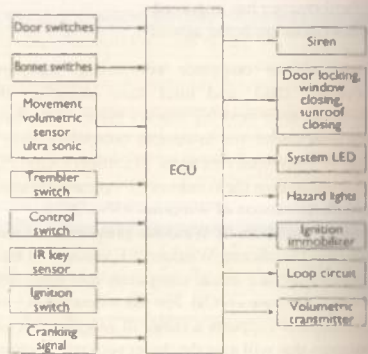


Figure 16.26 Block diagram of a complex alarm system

unit and siren; most will have the control unit in the passenger compartment and the siren under the bonnet.

Most systems now come with two infrared remote 'keys' that use small button-type batteries and have an LED that shows when the signal is being sent. They operate with one vehicle only. Intrusion sensors such as car movement and volumetric sensing can be adjusted for sensitivity.

When operating with flashing lights most systems draw about 5 A. Without flashing lights (siren only) the current drawn is less than 1 A. The siren produce a sound level of about 95 dB, when measured 2 m in front of the vehicle.

Figure 16.26 shows a block diagram of a complex alarm system. The system, as is usual, can be considered as a series of inputs and outputs.

Inputs

- Ignition supply.
- Engine crank signal.
- Volumetric sensor.
- Bonnet switch.
- Trembler switch.
- IR/RF remote (Figure 16.27).
- Doors switches.
- Control switch.

Outputs

- Volumetric transmitter.
- System LED.
- Horn or siren.
- Hazard lights.
- Ignition immobilizer.
- Loop circuit.
- Electric windows, sun-roof and door locks.

Some factory fitted alarms are combined with the central door locking system. This allows the facility mentioned in a previous section known as lazy lock. Pressing the button on the remote unit, and as well as setting the alarm, the windows and sun-roof close, and the doors lock.

16.5.4 Security coded ECUs

A security code in the engine electronic control unit is a powerful deterrent. This can only be 'unlocked' to allow the engine to start when it receives a coded signal. Ford and other manufacturers use a special ignition key that is programmed with the required information. Even the correct 'cut' key will not start the engine. Citroën, for example, have used a similar idea but the code has to be entered via a numerical keypad.

Of course nothing will stop the car being lifted on to a lorry and driven away, but this technique will mean a new engine control ECU will be needed by the thieves. The cost will be high and also questions may be asked as to why a new ECU is required.

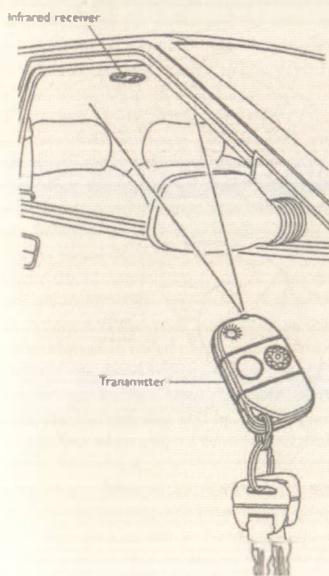


Figure 16.27 Alarm system with remote control

16.6 Airbags and belt tensioners

16.6.1 Introduction

A seat-belt, seat-belt tensioner and an airbag are, at present, the most effective restraint system in the event of a serious accident. At speeds in excess of 40 km/h the seat-belt alone is no longer adequate. Research after a number of accidents has determined that in 68% of cases an airbag provides a significant improvement. It is suggested that if all cars in the world were fitted with an airbag then the number of fatalities annually would be reduced by well over 50 000. Some airbag safety issues have been apparent in the USA where airbags are larger and more powerful. This is because in many areas the wearing of seat-belts is less frequent.

The method becoming most popular for an airbag system is that of building most of the required components into one unit. This reduces the amount of wiring and connections, thus improving reliability. An important aspect is that some form of system monitoring must be built-in, as the operation cannot be tested – it only ever works once. Figure 16.28 shows the airbags operating in a Peugeot.

16.6.2 Operation of the system

The sequence of events in the case of a frontal impact at about 35 km/h, as shown in Figure 16.29, is as follows.

1. The driver is in the normal seating position prior to impact. About 15 ms after the impact the

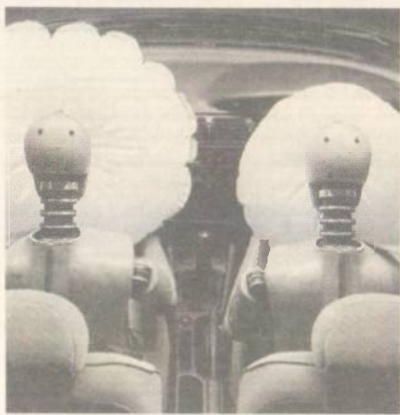


Figure 16.28 Don't be a crash test dummy!

- vehicle is strongly decelerated and the threshold for triggering the airbag is reached. The igniter ignites the fuel tablets in the inflator.
2. After about 30 ms the airbag unfolds and the driver will have moved forwards as the vehicle's crumple zones collapse. The seat-belt will have locked or been tensioned depending on the system.
 3. At 40 ms after impact the airbag will be fully inflated and the driver's momentum will be absorbed by the airbag.
 4. About 120 ms after impact the driver will be moved back into the seat and the airbag will have almost deflated through the side vents, allowing driver visibility.

Passenger airbag events are similar to the above description. A number of arrangements are used with the mounting of all components in the steering wheel centre becoming the most popular. Nonetheless, the basic principle of operation is the same.

16.6.3 Components and circuit

The main components of a basic airbag system are as follows.

- Driver and passenger airbags.
- Warning light.

- Passenger seat switches.
- Pyrotechnic inflator.
- Igniter.
- Crash sensor(s).
- Electronic control unit.

The airbag is made of a nylon fabric with a coating on the inside. Prior to inflation the airbag is folded up under suitable padding that has specially designed break lines built-in. Holes are provided in the side of the airbag to allow rapid deflation after deployment. The driver's air has a volume of about 60 litres and the passenger airbag about 160 litres.

A warning light is used as part of the system monitoring circuit. This gives an indication of a potential malfunction and is an important part of the circuit. Some manufacturers use two bulbs for added reliability.

Consideration is being given to the use of a seat switch on the passenger side to prevent deployment when not occupied. This may be more appropriate to side-impact airbags mentioned in the next section.

The pyrotechnic inflator and the igniter can be considered together. The inflator in the case of the driver is located in the centre of the steering wheel. It contains a number of fuel tablets in a combustion chamber. The igniter consists of charged capacitors.

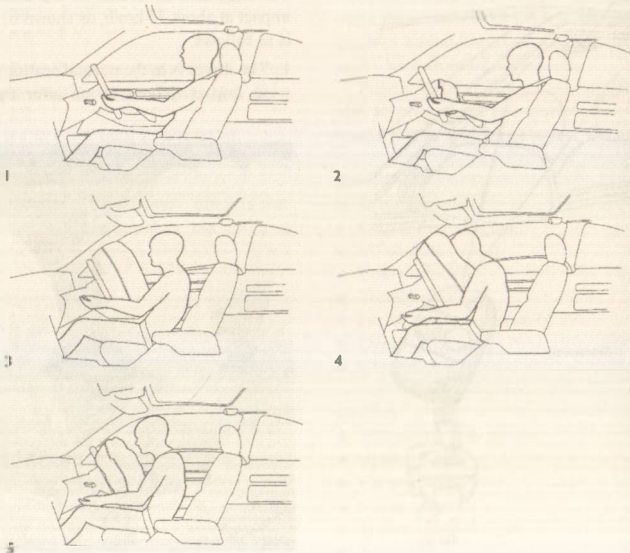


Figure 16.29 Airbag in action

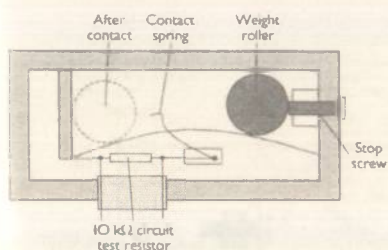


Figure 16.30 The mechanical impact sensor works by a spring holding a roller

which produce the ignition spark. The fuel tablets burn very rapidly and produce a given quantity of nitrogen gas at a given pressure. This gas is forced into the airbag through a filter and the bag inflates breaking through the padding in the wheel centre. After deployment, a small amount of sodium hydroxide will be present in the airbag and vehicle interior. Personal protection equipment must be used when removing the old system and cleaning the vehicle interior.

The crash sensor can take a number of forms; these can be described as mechanical or electronic. The mechanical system (Figure 16.30) works by a spring holding a roller in a set position until an impact above a predetermined limit, provides enough force to overcome the spring and the roller moves, triggering a micro switch. The switch is normally open with a resistor in parallel to allow the system to be monitored. Two switches similar to this may be used to ensure the bag is deployed only in the case of sufficient frontal impact. Note that the airbag is not deployed in the event of a roll over.

The other main type of crash sensor can be described as an accelerometer. This will sense deceleration, which is negative acceleration. Figure 16.31 is a sensor based on strain gauges.

Figure 16.32 shows two types of piezoelectric crystal accelerometers, one much like an engine knock sensor and the other using spring elements. A severe change in speed of the vehicle will cause an output from these sensors as the seismic mass moves or the springs bend. Suitable electronic circuits can monitor this and be pre-programmed to react further when a signal beyond a set threshold is reached. The advantage of this technique is that the sensors do not have to be designed for specific vehicles, as the changes can be software-based.

The final component to be considered is the electronic control unit or diagnostic control unit. When a mechanical-type crash sensor is used, in theory no electronic unit would be required. A

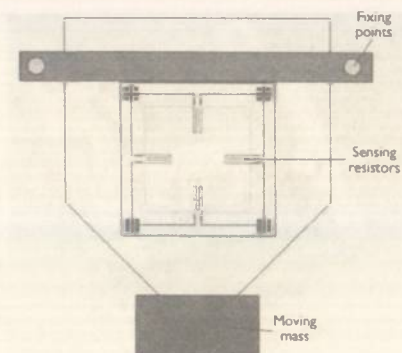


Figure 16.31 Strain gauges accelerometer

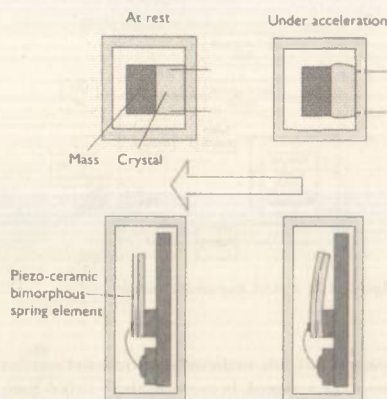


Figure 16.32 Piezoelectric crystal accelerometer

simple circuit could be used to deploy the airbag when the sensor switch was operated. However, it is the system monitoring or diagnostic part of the ECU, that is most important. If a failure is detected in any part of the circuit then the warning light will be operated. Up to five or more faults can be stored in the ECU memory, which can be accessed by blink code or serial fault readers. Conventional testing of the system with a multimeter and jump wires is not to be recommended as it might cause the airbag to deploy! Figure 16.33 shows an airbag ECU.

A block diagram of an airbag circuit is shown in Figure 16.34. Note the 'safing' circuit, which is a crash sensor that prevents deployment in the event of a faulty main sensor. A digital-based system using electronic sensors has about 10 ms at a vehicle

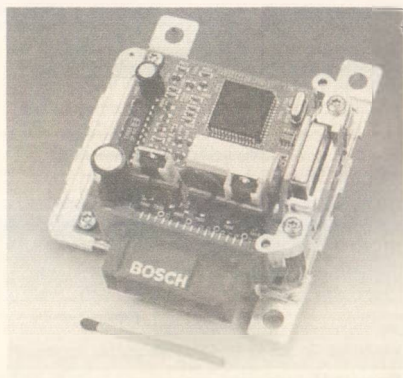


Figure 16.33 Airbag ECU

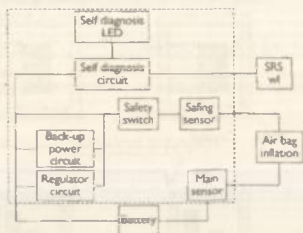


Figure 16.34 A block diagram of an airbag circuit

speed of 50 km/h, to decide if the restraint systems should be activated. In this time about 10 000 computing operations are necessary. Data for the development of these algorithms are based on computer simulations but digital systems can also remember the events during a crash, allowing real data to be collected.

16.6.4 Seat-belt tensioners

Taking the 'slack' out of a seat-belt in the event of an impact is a good contribution to vehicle passenger safety. The decision to take this action is the same as for the airbag inflation. The two main types of tensioners are:

- Spring tension.
- Pyrotechnic.

The mechanism used by one type of seat-belt tensioner is shown in Figure 16.35. When the explosive charge is fired, the cable pulls a lever on the seat-belt reel, which in turn tightens the belt. The

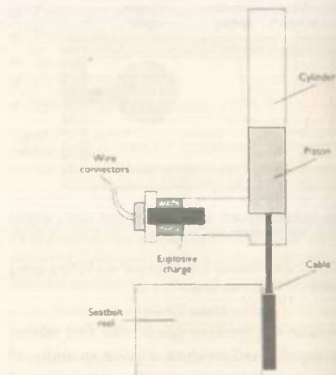


Figure 16.35 The mechanism used by one type of seat-belt tensioner

unit must be replaced once deployed. This feature is sometimes described as anti-submarining.

16.6.5 Side airbags

Airbags working on the same techniques to those described previously are being used to protect against side impacts. In some cases bags are stowed in the door pillars or the edge of the roof. Figure 16.36 shows this system.

Figure 16.37 shows a full seat-belt and airbag system used by Ford.

16.7 Other safety and comfort systems

16.7.1 Obstacle avoidance radar

This system, sometimes called collision avoidance radar, can be looked at in two ways. First, as an aid to reversing, which gives the driver some indication as to how much space is behind the car. Second, collision avoidance radar can be used as a vision enhancement system.

The principle of radar as a reversing aid is illustrated in Figure 16.38. This technique is, in effect, a range-finding system. The output can be audio or visual, the latter being perhaps most appropriate, as the driver is likely to be looking backwards. The audible signal is a 'pip pip pip' type sound, the repetition frequency of which increases as the car comes nearer to the obstruction, and becomes almost continuous as impact is imminent.

- ① Central airbag unit
- ② Side airbag sensor
- ③ Upfront sensor

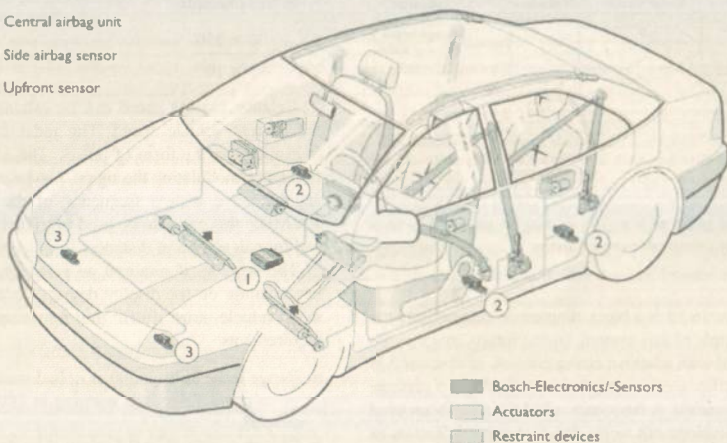


Figure 16.36 Optimized airbag control (Source: Bosch Press)

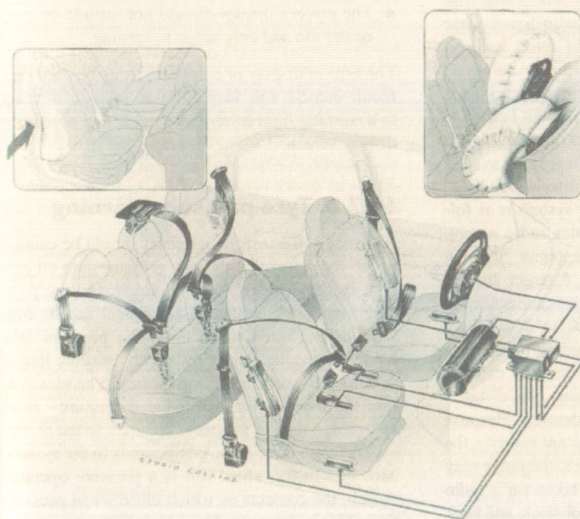


Figure 16.37 Seat-belt and airbag operation

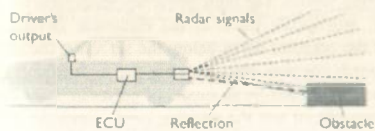


Figure 16.38 Obstacle avoidance radar

The technique is relatively simple as the level of discrimination required is fairly low and the radar only has to operate over short distances. The main problem is to ensure the whole width of the vehicle is protected.

Obstacle avoidance radar, when used as a vision enhancement system, is somewhat different.

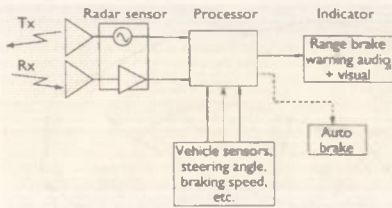


Figure 16.39 Block diagram of obstacle avoidance radar when used as a vision enhancement system

Figure 16.39 is a block diagram to demonstrate the principle of this system. In the future, this may be linked with adaptive cruise control, as discussed in an earlier section, but at this stage the two systems are separate. A frequency of 94 GHz has been used for development work; this frequency is known as millimetre waves.

A short look at the history and principle of radar at this stage will help with an overall understanding. Radar was the name given during World War II to an electronic system by which radio waves were bounced off an aircraft in order to detect its presence and locate its position. The term is an acronym, made from the fuller term 'radio detection and ranging'. A large number of researchers helped to develop the devices and techniques of radar, but the development of the earliest practical radar system is usually credited to Sir Robert Watson-Watt.

The operation of a basic radar system is as follows: a radio transmitter generates radio waves, which are then radiated from an antenna, 'lighting up' the airspace with radio waves. A target, such as another vehicle that is in this space, scatters a small portion of the radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed, often on a cathode ray tube. To determine its position, the distance (range) and bearing must be measured. Because radio waves travel at a known constant velocity, the speed of light, which is 3×10^8 m/s, the range may be found by measuring the time taken for a radio wave to travel from transmitter to obstacle and back to the receiver.

For example, if the range were 150 m, the time for the round trip would be:

$$t = \frac{2d}{C}$$

where t = time, d = distance to object, and C = speed of light.

In this example:

$$t = \frac{2 \times 150}{3 \times 10^8}$$

Relative closing speed can be calculated from the current vehicle speed. The radar is actually transmitted in the form of pulses. This is done by frequency modulating the signal, maybe using a triangular wave with a frequency of the order of 100 MHz; this can also be used to trigger a display and for calculation of distance.

The bearing, if required, is given by the relative position on the display device. Radar for use in a vehicle must fulfil the following general requirements.

- Range to be at least 300 m in bad weather. This gives about 7 seconds warning at 160 k/h (100 mile/h).
- Objects greater than 0.1 m² must be detected.
- Data update greater than one per second.
- Beam spread of about 15° horizontal and vertical.
- The driver's display should not intrude on concentration and only act as a warning.

The type of display or output that may be used on a motor vehicle will vary from an audible warning to a warning light or series of lights and possibly a display screen.

16.7.2 Tyre pressure warning

A glance at the instrument panel should be enough to tell the driver that the tyre pressures are all correct. Bosch has developed an electronic tyre pressure monitoring system. Each wheel has its own pilot lamp, which lights up if the pressure falls below a set value. Poorly inflated tyres cause loss of control and worse fuel consumption. The idea is to give the driver warning of reduced pressure – as an instant deflation is generally apparent to the driver!

There are three basic components to the system. Mounted in the wheel rim is a pressure operated switch, the contacts of which close when pressure falls. This is recognized by a high frequency sender which the switch passes but does not contact as the wheel rotates. The high frequency sender transmits an appropriate pulse to the electronic evaluator. If the pressure drops below the set value then the switch contacts open, causing the high frequency sender to interrupt its stream of pulses to the evaluation circuit and the warning lamp comes on. The system measures the tyre pressure with an accuracy of ± 50 mbar. The design of the switch is such that

changes in temperature of the air in the tyre will not cause false readings.

If the tyre pressure warning system is used in conjunction with wheels fitted with 'limp-home' tyres, it will provide a reminder that the limp-home mode is in use.

Bosch is also developing another tyre pressure warning system using active analogue sensors in the tyre and wireless transmission of the signal from the wheel to the body. The advantage is that absolute values of pressure and temperature are measured continuously, even when the car is at rest. Values such as vehicle speed and load are also included in the calculation.

16.7.3 Noise control

The principle of adaptive noise control is that of using sound, which is identical and 180° out of phase, or in anti-phase, to cancel out the original source of noise. Figure 16.40 shows three signals, the original noise, the anti-phase cancelling waveform and the residual noise.

A microphone picks up the original noise. It is then inverted and amplified, and then replayed by a suitably positioned speaker. This effectively cancels out the noise. Whilst the theory is relatively simple, until recently it has not been particularly suitable for motor vehicle use. This is due to the wide range of noise frequencies produced, and the fast response time, which is needed to give acceptable results. Low frequency noise (<200 Hz), causes 'boom' in a vehicle, this is very difficult to reduce by conventional methods.

Much development time and money has been spent on reducing cabin noise levels. This can range from simple sound-deadening material to a special design of engine mountings, exhaust systems and using balance shafts on the engine. Even so, the demand still exists to reduce noise further and this is becoming ever more expensive.

Most vehicles today are susceptible to some low frequency boom in the passenger compartment,

even when a large amount of sound deadening is used. The trend to produce lighter vehicles using thinner grade metal further exacerbates the problem. Conventional techniques solve the problem at certain frequencies, not all across the range.

To apply the adaptive noise control system to a car required the development of high-speed digital signal processors as well as a detailed understanding of noise generation dynamics in the vehicle. A typical four-cylinder engine running between 600 and 6000 rev/min has a firing frequency of about 20–200 Hz. There are several critical speeds at which the vehicle will display unpleasant boom. Low-profile tyres and harder suspension also generate considerable low frequency noise.

Lotus Engineering has developed a system which uses eight microphones embedded in the vehicle headlining to sample the noise. A digital signal processor measures the average sound pressure energy across the cabin and adjusts the phase and amplitude of the anti-noise signals. These are played through the in-car speaker system until, by measuring the error signal from the microphones, a minimum noise is achieved. The maximum active noise control can be achieved in about 70 ms. A quality loudspeaker system is needed which must be able to produce up to 40 W RMS per channel. This is not uncommon on many ICE systems. Figure 16.41 shows a typical layout of an adaptive noise control system. The greatest improvements are gained in

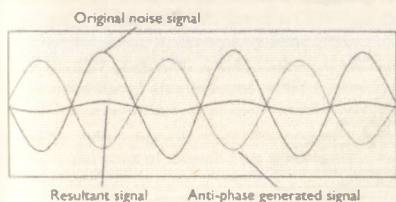


Figure 16.40 Three signals; the original noise, the anti-phase cancelling waveform and the residual noise

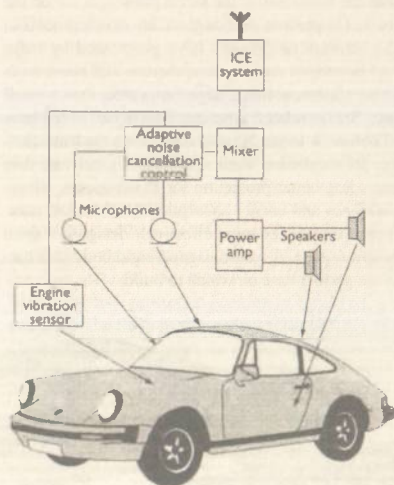


Figure 16.41 Layout of an adaptive noise control system and how it could be fitted

small vehicles where the perceived reduction is as much as 80%.

16.8 Case studies

16.8.1 Volvo safety

The following information is extracted from information relating to features on the Volvo S80. It shows the clear commitment of manufacturers in general, and perhaps Volvo in particular, to safety developments.

Safety is very much part of Volvo's soul and, as a result, it is always present (claims the company). It is an integral part of the first design work and a vital part at every stage of the development process. Active safety can be summarized as active accident avoidance, passive safety can be summed up in three words: passenger protection priority. One of Volvo's prerequisites is that every new Volvo has to be safer than the previous one. Figure 16.42 shows the Volvo S80 airbags.

When it comes to the Volvo S80, this is very much the case. One of the objectives when designing the Volvo S80 was to strengthen further Volvo's position as the world leader in the field of passenger protection. This aim has been realized. With two new and important technical features, the level of passenger protection has taken yet another step forward. It would perhaps be no exaggeration to say that the Volvo S80 is the safest passenger car on the market at present. Although safety developments in the automotive industry have progressed by leaps and bounds in recent years, there is still some truth in the statement that a large car is safer than a small one. Size is related to safety. This is part of the laws of nature. A larger, heavier car suffers the least damage in a collision with a smaller, lighter car, thus providing better protection for its occupants. Crumple zones and energy absorption are two vital parameters that can be more effectively designed if there is more space. A well-designed, rigid body structure is the perfect base on which to build.

Volvo has always claimed that the most important protective feature in a car is the seat-belt. The Volvo S80 has three-point belts on all five seating positions; all equipped with pyrotechnical pretensioners. The pretensioners automatically tighten the belts in a crash, eliminating the slack, which is normal in a belt. The front seat-belts are also equipped with force limiters, which control and regulate the roll speed of the belt webbing and provide more gentle restraint. The front seat-belts also have automatic belt height adjusters for optimum belt geometry. The belt system has been integrated with the airbag systems as these systems interact.

The passenger airbag is invisibly stored under the upper part of the dashboard and is designed to activate in a 'friendly' way in order to protect the passenger rather than being a risk. A belt sensor indicates whether or not the front seat passenger is wearing a seat-belt and adapts the airbag trigger level accordingly. This means that more crash energy is needed to trigger the bag when the passenger is wearing a seat-belt than when he is not.

In 1997, the Volvo Car Corporation presented the Whiplash Protection Study, WHIPS, which was an R&D project designed to produce a seat that would reduce the risk of whiplash injuries in rear-end collisions (Figure 16.43). Although they are most frequently caused at low speeds in relatively minor accidents, whiplash injuries are extremely painful, both physically and mentally, for the people who incur them, as well as being difficult to detect and define. They are also perhaps the single most expensive injury in insurance terms.

Since rear-end collisions often occur in city traffic, the WHIPS system is optimized to be most effective at speeds ranging from 15 to 30 km/h. The system consists of two elements. The first element of the WHIPS system is a brand new device that adjusts the angle between the seat cushion and the backrest. The system is activated in two phases.

1. The backrest of the seat is allowed to move backwards together with the occupant, reducing G-forces.



Figure 16.42 Volvo S80 airbags

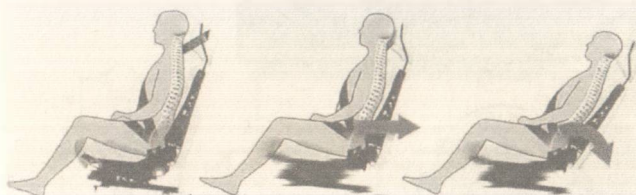


Figure 16.43 Volvo S80 'WHIPS'



Figure 16.44 Volvo new SIPS airbag

2. The angle of the backrest folds backwards by up to 15° , effectively catching the body and preventing a catapault effect.

The second element of WHIPS are six modified springs in the backrest with limiters that provide even support of the spine when pressed into the seat. The fixed head restraint, which remains close to the head, minimizes head movement and reduces forces on the neck. Consequently, the entire back is pressed against the backrest in a controlled manner. Tests conducted by Volvo during the development of the system reveal that the WHIPS system can reduce the acceleration forces in the neck by some 50%.

Passenger protection in side impacts is perhaps the most difficult area in terms of safety development, because of the lack of space and the minimal crumple zone, only 25–30 cm. Passengers sit very close to the point of impact. This must therefore be compensated for one way or another. The Side Impact Protection System (SIPS) structure has been extensively upgraded and its interacting components consist of the energy-absorbing elements in bottom rails,

pillars, cross-members, roof and seats, plus energy-absorbing materials in the doors. This has been supplemented with more, further improved, padding in all the roof pillars and along the edges of the headliner. This material feels hard when it is touched, but it yields in a 'friendly' manner and absorbs energy when it is hit in an impact. The second step in the continued development of the SIPS system was the introduction of the SIPS bags in 1994 – now a standard item on all Volvo cars.

The Volvo side airbag (Figure 16.44) is located in the outer part of the backrest and is therefore always in the optimum protective position in relation to the occupant. The SIPS further reduces the risk of severe chest and pelvic injuries, as its function is to keep the occupant away from the side of the car. The side airbags are triggered by electronic sensors, one in the B pillar and one behind the rear door. Their position makes the reaction time from moment of impact to triggering the bag very short – a factor that is of vital importance in side impacts. However, padding and side airbags cannot completely make up for what can happen to the head when the car is hit from the side.

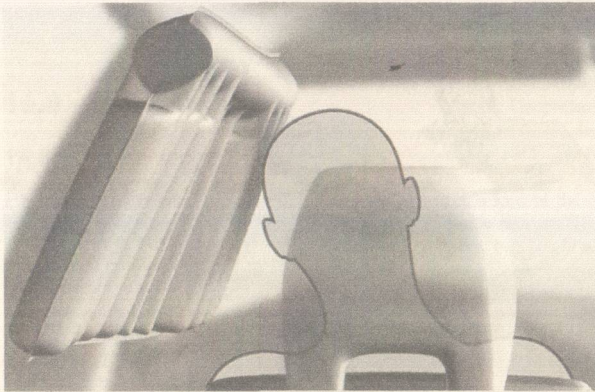


Figure 16.45 Volvo S80 inflatable curtain

The Inflatable Curtain (IC) was presented together with WHIPS as an R&D project in 1997, and is claimed to be the first technical system for this type of protection. The purpose of the system (Figure 16.45) is to reduce further injuries in a side impact by protecting the head and neck of the occupants both in the front and rear seats. The curtains, one on each side, are woven in one piece and hidden inside the roof lining. They cover the upper part of the interior, from the 'A' pillar to the rear side pillar. The same sensors as used with the SIPS bags activate the IC. They are 'slave' sensors to a central sensor, which determines where the impact is and which bag should be triggered in order to protect the occupants.

If only the rear sensor is affected, the IC is activated but not the SIPS bag. The curtain is filled within 2.5 ms and stays inflated about three seconds in order to provide maximum protection in complicated collisions. The ducts do not cover the entire surface of the curtain. Instead, they are concentrated in the areas that are most likely to be hit by the occupants' heads. As a result, the need for gas is limited and the activation time is minimal. The ducts act as controlled head restraints and prevent the head from hitting the inside of the car. The curtain also prevents the head from impacting on collision obstacles, such as lampposts and similar objects. The size of the curtain also provides support, keeping the passengers inside the car instead of being partially thrown out of the side windows.

The protective capacity of the IC remains the same, regardless of whether the window is open or closed. When the curtain is activated, it hardly touches the side window but expands inwards, moving closer to the heads of the occupants.

In order to permit the installation of a rear-facing child seat in the front passenger position, the passenger airbag can be switched on and off using a switch. This switch, which can be fitted only by a Volvo dealer, works via the ignition key. When the ignition is turned on, an indicator lamp on the switch comes on and shows whether or not the passenger airbag is activated. If the switch suffers electronic failure, the supplementary restraint system (SRS) lamp comes on, just as it does if any other defect occurs in the SRS system.

16.8.2 Rover electric windows

The circuit of the electric window system used by some Rover vehicles is shown in Figure 16.46. The windows will only operate when the ignition is switched on. When the ignition is switched on, the window lift relay is energized by the supply from fuse 18 in the passenger compartment fuse-box on the LG wire, which passes to earth on a B wire. With the relay energized, the battery supply from fusible link 4 on the N wire feeds the four window lift fuses on an N/U wire.

The driver's window can only be operated from the switchblock on the driver's door, which is supplied from fuse 30 in satellite fuse block 2, on an S/G wire. When the 'up' switch is pressed, the feed from the fuse crosses the window lift switch and provides a feed to the control unit on a B/Y wire. The control unit will now provide a positive supply to the window lift motor on a R/U wire and an earth path on an R/Y wire. The window will now move upwards until the switch is released or it reaches the end of its travel.

When the 'down' switch is pressed the supply from fuse 30 in satellite fuse block 2 provides a

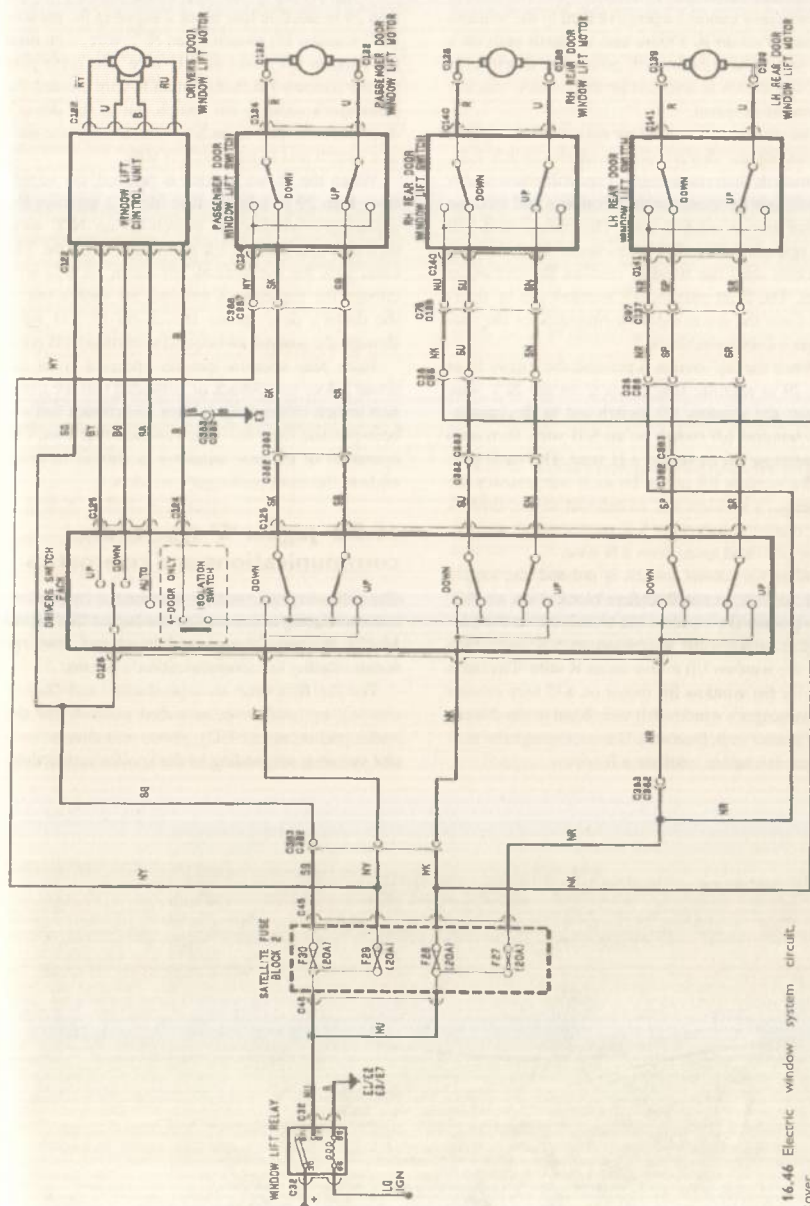


Figure 16.46 Electric window system circuit, used by Rover

feed to the control unit on an S/G wire. The control unit will now connect a positive feed to the window lift motor on an R/Y wire and an earth path on a R/U wire. The window will now move downwards until the switch is released or the window reaches the end of its travel.

The driver's door window may be fully opened by moving the driver's door window switch fully downwards then releasing it. This will allow a supply to cross the closed switch contacts and feed the control unit on an S/B wire. The control unit will now operate the window lift motor in the downward direction until the window reaches the end of its travel. The front passenger's window can be operated from the driver's door switchback or the passenger's door switchback.

When the 'up' switch is pressed, the supply from fuse 29 in satellite fuse block 2 on the N/Y wire crosses the window lift switch out to the passenger's window lift switch on an S/B wire, then onto the window lift motor on a U wire. The earth path for the window lift motor on an R wire crosses the passenger's window lift switch out to the driver's door master switch on an S/K wire, through the isolator switch and to earth on a B wire.

When the 'down' switch is pressed, the supply from fuse 29 in satellite fuse block 2 on an N/Y wire crosses the window lift switch out to the passenger's window lift switch on an S/K wire, then onto the window lift motor on an R wire. The earth path for the window lift motor on a U wire crosses the passenger's window lift switch out to the driver's door master switch on an S/B wire, through the isolator switch and to earth on a B wire.

When the 'up' switch is pressed, the supply from fuse 29 in satellite fuse block 2 supplies the passenger's window lift switch on an N/Y wire, then onto the window lift motor on a U wire. The earth path for the window lift motor on an R wire crosses the passenger's window lift switch out to the driver's door master switch on an S/K wire, through the isolator switch and to earth on a B wire.

When the 'down' switch is pressed, the supply from fuse 29 in satellite fuse block 2 supplies the passenger's window lift switch on an N/Y wire, then onto the window lift motor on an R wire. The earth path for the window lift motor on a U wire crosses the passenger's window lift switch out to the driver's door master switch on an S/B wire, through the isolator switch and to earth on a B wire.

Each rear window can be operated from the driver's door switchback or, provided that the isolation switch in the driver's door switchback has not been pressed, from the switch on each rear door. The operation of the rear windows is similar in operation to the front passenger's window.

16.8.3 Jaguar 'S' type audio, communications and telematics

The following information is extracted from information relating to features on the Jaguar 'S' (Figure 16.47). It shows the general trend and developments relating to 'communication' systems.

For the first time on a production car (Jaguar claims), optional voice-activated controls for the audio (radio/cassette/CD), phone and climate control systems, responding to the spoken instructions



Figure 16.47 Jaguar S-type

of the driver, provide safe, hands-free operation. The system responds to a wide diversity of English and North American accents, but also provides for training to recognize a specific voice.

A first for Jaguar is the optional, fully integrated on-board satellite navigation system using multi-lingual, digitized map data on CD-ROM. The system can point out useful landmarks and points of interest and links with the UK's Trafficmaster system to provide real-time data on traffic delays.

The 175 W, 12-speaker, premium sound system, features two active 'centre fill' speakers, an active sub-woofer enclosure and 6-disc CD auto-changer. Digital sound processing, working with Dolby, provides special audio effects and compensates for the number of vehicle occupants.

The premium specification Motorola portable GSM phone is a factory fit option, combining the advantages of vehicle integration, safety, convenience and performance with the versatility of a pocket phone.

16.8.4 Noise control developments

A hydraulic engine mount, which is electronically controlled in response to the engine vibration, can significantly reduce noise. Some manufacturers, however, are now using a much simpler version, which can switch between hard and soft settings. A system developed by Lotus is claimed to be as effective as about 45 kg of sound deadening material.

An exhaust company, 'Walker', has developed an active muffler for reducing exhaust noise. The

heart of this system is a digital processor. Two inputs are used, a microphone to measure the noise from the tailpipe and an engine speed sensor. The system calculates the correct anti-noise and delivers this by means of special speaker drivers mounted on the exhaust system. The residual noise is measured and adjustments can be made. Because the system is self-learning it will adapt to the changing noises of an ageing engine.

The active muffler allows straight gas flow from the exhaust after the catalytic converter. This allows improved engine performance that can mean less fuel is used. An average reduction in fuel consumption of 5% is possible. Future EC directives are expected relating to exhaust noise, which are currently set at 77 dB (A) in Germany. Larger mufflers will be needed to comply, which means this system may well become quite popular.

16.8.5 Alarming developments!

Professional car thieves will always find ways around the latest alarm systems. However, the vehicle manufacturers strive to stay one jump ahead. Tracking devices can be built-in to an unknown part of the vehicle's chassis. This can be activated in the event of the car being stolen, allowing the police to trace the vehicle. A system popular in the UK is 'Tracker' and this works as follows.

1. The car is stolen.
2. Depending on the product, the owner tells 'Tracker' or 'Tracker' tell the customer.



Figure 16.48 Since 1993 'Tracker' has helped police forces throughout the UK recover more than £35 million worth of stolen vehicles

3. The 'Tracker' unit in the car is activated by powerful transmitters.
4. Police with tracking computers detect the silent homing signal.
5. The police recover the car.

The 'Tracker' unit is a radio transponder. When the vehicle is reported stolen the police are informed and the 'Tracker' unit is activated. The unit then broadcasts a unique reply code, which can be detected and decoded by police tracking computers, which are fitted in police cars, helicopters and fixed land sites. The police then track the vehicle, taking appropriate action. Figure 16.48 shows a stolen car recovery in action.

A 'Tracker' unit can be fitted to any self-propelled road vehicle that has a suitable location where the unit can be hidden. The system currently only operates in mainland Great Britain. It constantly draws power from the main vehicle battery but if this is disconnected, a re-chargeable back-up battery provides power for up to 2 days. The presence of the unit is not disclosed to the thief, which means there is a greater likelihood of rapid recovery and minimal damage. The unit is not transferable from one vehicle to another but the new owner need only pay for the network subscription. Most insurance companies offer additional discounts of up to 20% if this system is fitted.

16.8.6 ICE warning

The following is a description of a Blaupunkt 'New York RDA 127' ICE system.

This is a purely high-end system thanks to DSA, which is an automatic calibration program for linear frequency response in the car and the 'psycho-acoustic masking' of driving noises (DNC). An integrated high-end CD drive is included with an optional opto-changer.

The 'Sub-Out' and the many equalizer functions demonstrate its serious claim of sophistication among the high-end car hi-fi systems of today. The whole spectrum of new car audio technology is covered along with some fascinating options:

- FM, MW, LW
- TIM (Traffic Memo)
- Dual-tuner RDS
- RDS-EON-PTY
- Radiotext
- Travelstore
- CD 1 bit/8 × Over-sampling
- Disc Management System (DMS)
- Digital Signal Adaptation (DSA)
- Dynamic Noise Covering (DNC)

- Self-adjusting equalizer
- 4 × 23 watts RMS power
- 4 × 35 watts maximum power
- Digital-in
- Four-channel pre-amp output
- Sub-Out

This type of mobile multimedia seems to have everything! In spite of high-end performance, it all remains uncomplicated. Good sized, easily readable displays, menu-controlled operator prompting and an ergonomic, award-winning design make an important contribution to driving pleasure.

High-end sound technology automatically perfects the acoustics in the vehicle interior, masks undesirable driving noises and uses incredible dynamics and 'spatiality' to make listening to the audio system on the road a real experience.

16.8.7 Intelligent airbag sensing system

Bosch has developed an 'Intelligent Airbag Sensing System' which can determine the right reaction for a specific accident situation. The system can control a one- or two-stage airbag inflation process via a two-stage gas generator. Acting on signals from vehicle acceleration and belt buckle sensors, which vary according to the severity of the accident, the gas generator receives different control pulses. Firing off one airbag stage (de-powering), both stages (full inflation), or staged inflation with a time interval.

Future developments will lead to capabilities for multistage inflation or a controllable sequence of inflation following a pattern determined by the type of accident and the position of the vehicle occupants. The introduction of an automotive occupancy sensing (AOS) unit that uses ultrasonic and infrared sensors will provide further enhancements. This additional module will detect seat and child occupancy and will be capable of assessing whether a passenger is in a particular position, such as feet on the dashboard!

Bosch hopes that the latest radar technology will assist the design of a pre-crash sensor capable of detecting an estimated impact speed prior to collision, and activating individual restraint systems, such as seat-belt pre-tensioners. Or, if necessary, all available restraint systems. Figure 16.49 shows a representation of this system.

16.8.8 ICE system – digital recordable radio

The Woodstock DAB 53 digital car radio from Blaupunkt contains some interesting features. Digital

audio broadcasting (DAB) is now fully available. Compared to the paths of transmission used up to now, DAB provides considerably improved reception characteristics in terms of quality. It effectively eliminates the interference caused by multi-path reception or fluctuating signal strength.

The unit is equipped with an impressive new feature: while driving, the driver can record DAB programs at the touch of a button and play them back again. Blaupunkt selected the multimedia card (MMC), one of the smallest, most modern storage mediums currently available in the world, as the most

suitable medium for the innovative new 'Recordable' feature. In addition, the multimedia card and the integrated CD audio/MP3 drive make it possible to play music in the MP3 format. This provides up to twelve hours of sounds from a single CD-ROM.

The set is fully digital and can be installed in the standard radio compartment of any vehicle. It is able to process all the audio signals of the DAB transmission system digitally and has been equipped to receive radio stations on the FM, MW and LW wavebands. For FM reception the digital tuner concept provides excellent sound quality and RDS (Radio Data System) makes sure that the radio always tunes into the best available frequency.

The Woodstock DAB 53 has been equipped with a 4 × 45 W output stage and a 4-channel preamp out. The radio can also be connected to a hands-free telephone system and is able to operate a CD changer. The front panel folds down to reveal the CD and MMC slots. As effective theft protection, the operating panel can be removed.

16.8.9 Reverse sensing/ parking aid

A Reverse Sensing System is a reverse only parking aid system that uses sensors mounted in the rear



Figure 16.49 Intelligent airbag system



Figure 16.50 Digital audio broadcast recordable radio (Source: Bosch)

bumper. Parking aid systems feature both front and rear sensors. As the vehicle approaches large objects, such as other vehicles or general obstacles, it beeps warning sounds. The frequency of beeping increases as the object is approached – until a solid tone is emitted at a distance of about 25 cm (10 inches).

Low-cost, high-performance ultrasonic range sensors are fitted to the vehicle. Generally, four intelligent sensors are used to form a detection zone as wide as the vehicle. A microprocessor monitors the sensors and emits audible beeps during slow reverse parking to help the driver back up or park the vehicle.

This leads to easier and convenient reversing and parking manoeuvres, especially for vehicles where drivers have limited view at the front, rear or corners of the vehicle.

16.8.10 Alarms and immobilizers

The anti-theft alarm circuit shown here is typical of many. As with all complex systems it can be considered as a black box with inputs and outputs. The inputs are signals from key and lock switches as well as monitoring sensors. The outputs are the alarm horn and the hazard lights but also starter inhibitor relays, etc.

Alarm system

This system can be operated by remote control or using the key in a door lock. When first activated, the system checks that the doors and tailgate are closed by monitoring the appropriate switches. If all is in order, the anti-theft system is then activated after a 20-second delay. The function indicator (LED) flashes rapidly during this time and then slowly once the system is fully active.

The alarm can be triggered in a number of ways:

- Opening a door, the tailgate or the bonnet/hood
- Removal of the radio connector loop.
- Switching on the ignition.
- Movement inside the vehicle.

If the alarm is triggered the horn operates for 30 seconds and the hazard lights for 5 minutes. This stops if the remote key or door key is used to unlock the vehicle.

Passive anti-theft system (PATS)

This system is a vehicle immobilizer developed by Ford. It is activated directly through the ignition switch by means of an electronic code stored in a special key. Each key has a transponder that stores the code, which does not require a battery. The key code is read by the receiver (which is part of the

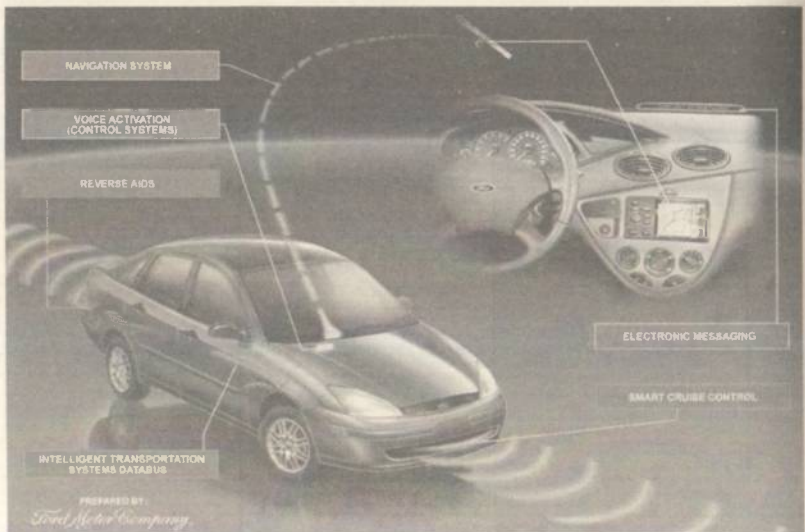


Figure 16.51 Reversing aid as part of a control system (Source: Ford)

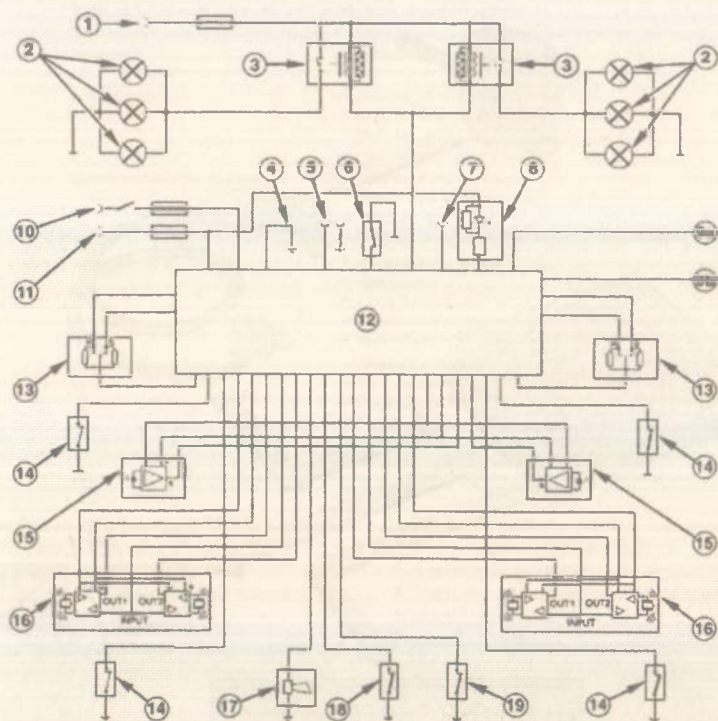


Figure 16.52 Anti-theft alarm system with remote control and interior monitoring (Source: Ford). 1. Battery supply 2. Hazard lights. 3. Hazard lights alarm relay. 4. Earth/Ground. 5. Diagnostic connector. 6. Bonnet/Hood switch. 7. Connector for radio theft protection. 8. Function light. 9. Input signal locked/unlocked. 10. Ignition supply. 11. Battery supply. 12. Anti-theft alarm ECU. 13. Left/Right door key switch. 14. Door switches. 15. Infrared receiver. 16. Ultrasound sensors. 17. Horn. 18. Tailgate switch. 19. Tailgate key switch

ignition switch) when the key is turned from position 0 to 1 or 2 (usually marked as I or II). If the code matches the one stored in the module, then it allows the engine to start. These systems operate independently of the alarm.

Key programming

Some keys and/or remotes for later vehicles may need to be reprogrammed if, for example, the battery goes flat or a new key is required. There are several methods of programming remote keys. However, different manufacturers use various methods and it is therefore not possible to cover all of these. A few methods are described here as examples.

PATS key programming:

In earlier systems a red key is used as a master, it is exactly the same as the other keys apart from

its colour. This key is the only one that can program new keys – if lost the whole system has to be reprogrammed by a dealer – and a new master supplied.

To program a red key system insert the master key into the ignition and turn it to position II. When the light on the clock goes out remove the key. The light will come back on if the master key was used. While the light is still on, insert the new key and turn to position II. The light will flash twice and the key is programmed.

To program a two key system both of the original keys are needed. Insert the keys one after the other in the ignition, turn to position II and then remove. After the second key is removed, insert the new un-programmed key, switch to position II and then remove it. The new key is now programmed.

Remember not to put an un-programmed PATS key in the ignition unless following the above

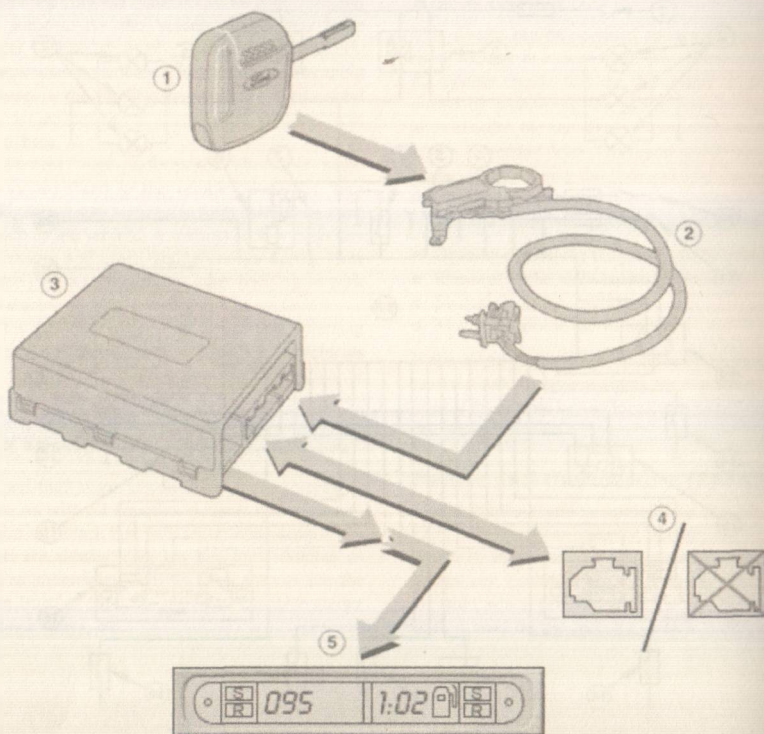


Figure 16.53 PATS components (Source: Ford). 1. Key with integrated transponder; 2. Transmitter/Receiver; 3. PATS module; 4. Engine start – yes/no; 5. Clock with integrated function indicator

procedure – it will immobilize the vehicle for 30 minutes!

Remote keys (example only):

Switch the ignition from I to II quickly 4 times – this illuminates the alarm warning light. Remove the key from the ignition and point it at the remote sensor (interior mirror usually). Press and hold one of the buttons until the light on the remote flashes. Keep holding the first button, press the other button 3 times and finally release both buttons. The light on the remote and the warning light will flash 5 times – the remote key is now programmed.

On some vehicles, switching the ignition from I to II quickly 4 times will activate a chime. Remove the key and press any of the buttons to activate another chime. Finally, replace the key and turn the ignition to position II – the remote key is now programmed.

A useful tip is that on many remotes changing the batteries within 15 seconds will mean they do not need to be reprogrammed.

Fault diagnosis

Many vehicle manufacturers use equipment connected to a diagnostic link connector (DLC) to check several systems, including alarms. This is the same DLC as used for engine management diagnostics. See the sections on OBD for more details. Test equipment is becoming available that can be used by independent repairers. However, it is not often cost effective to purchase this for specific vehicles.

As with others, an alarm system can be treated as a black box system. In other words, checking the inputs and outputs for correct operation means the complexity inside the ECU can be largely ignored. Note that most alarms will not set if the module

Table 16.1 Common symptoms and possible faults of comfort systems

Symptom	Possible fault
Radio interference	<ul style="list-style-type: none"> • Tracking HT components. • Static build-up on isolated body panels. • High resistance or open circuit aerial earth. • Suppression device open circuit.
Electric windows not operating	<p>If all windows not operating:</p> <ul style="list-style-type: none"> • Open circuit in main supply. • Main fuse blown. • Relay coil or contacts open circuit or high resistance. <p>If one window is not operating:</p> <ul style="list-style-type: none"> • Fuse blown. • Control switch open circuit. • Motor seized or open circuit. • Back-off safety circuit signal incorrect.
Cruise control will not set	<ul style="list-style-type: none"> • Brake switch sticking on. • Safety valve/circuit fault. • Diaphragm holed. • Actuating motor open circuit or seized. • Steering wheel slip ring open circuit. • Supply/earth/fuse open circuit.

is receiving an incorrect input signal when it is activated (door switch open/closed for example). A generic diagnostic procedure for an anti-theft alarm system is listed as follows (a circuit diagram helps but is not essential):

1. Check ignition and battery power supplies and earth/ground connections to the alarm module.
2. Test operation of all 'entry' switches at the module connector. Look for a low/high voltage as the switches are operated. If incorrect, trace the specific circuit after testing the switch itself.
3. Measure the voltage signals from the key switches as the key is turned in each lock.
4. Check the radio loop circuit for continuity.
5. Test continuity of ultrasonic sensor wiring if fitted.
6. The horn/siren can be tested using a fused jumper wire (disconnect it first).

Important: Only use a digital voltmeter for the tests because a lamp could overload a circuit in the module.

Remember, most electrical faults are simple – broken wires or connectors or open circuit switches. Don't be too hasty in condemning the ECU/module!

16.9 Diagnosing comfort and safety system faults

16.9.1 Introduction

As with all systems the six stages of fault-finding should be followed.

1. Verify the fault.
2. Collect further information.
3. Evaluate the evidence.
4. Carry out further tests in a logical sequence.
5. Rectify the problem.
6. Check all systems.

The procedure outlined in the next section is related primarily to stage 4 of the process. Table 16.1 lists just a few faults as examples for this chapter.

16.9.2 Testing procedure

The following procedure is very generic but with a little adaptation can be applied to any electrical system. Refer to the manufacturer's recommendations if in any doubt. The process of checking any system circuit is broadly as follows.

1. Hand and eye checks (loose wires, loose switches and other obvious faults) – all connections clean and tight.
2. Check battery (see Chapter 5) – must be 70% charged.
3. Check motor/solenoid/linkage/bulbs/unit – visual check.
4. Fuse continuity – (do not trust your eyes) voltage at both sides with a meter or a test lamp.
5. If used, does the relay click (if yes, jump to stage 8) – this means the relay has operated, but it is not necessarily making contact.
6. Supply to switch – battery volts.
7. Supply from the switch – battery volts.
8. Supplies to relay – battery volts.

9. Feed out of the relay – battery volts.
10. Voltage supply to the motor – within 0.5 V of the battery.
11. Earth circuit (continuity or voltage) – 0 Ω or 0 V.

16.9.3 ECU auto-diagnostic function

Many ECUs are equipped to advise the driver of a fault in the system and to aid the repairer in detection of the problem. The detected fault is first notified to the driver by a dashboard warning light. A code giving the details is held in RAM within the ECU. The repairer, as an aid to fault-finding, can read this fault code.

Each fault detected is memorized as a numerical code and can only be erased by a voluntary action. Only serious faults will light the lamp but minor faults are still recorded in memory. The faults are memorized in the order of occurrence.

Faults can be read as two-digit numbers from the flashing warning light by shorting a diagnostic wire to earth for more than 2.5 seconds but less than 10 seconds. Earthing this wire for more than 10 seconds will erase the fault memory as does removing the ECU constant battery supply. Earthing a wire to read fault codes should only be carried out in accordance with the manufacturer's recommendations. The same coded signals can be more easily read on many after-sales service testers. On some systems it is not possible to read the fault codes without a code reader.

16.9.4 Fault-finding by luck

If four electric windows stopped working at the same time, it would be very unlikely that all four motors had burned out. On the other hand, if just one electric window stopped working, then it may be reasonable to suspect the motor. It is this type of reasoning that is necessary when fault-finding. However, be warned, it is theoretically possible for four motors to burn out apparently all at the same time!

Using this 'playing the odds' technique can save time when tracing a fault in a vehicle system. For example, if both stop lights do not work and everything else on the vehicle is OK, I would suspect the switch (stages 1 to 3 of the normal process). At this stage though, the fault could be anywhere – even two or three blown bulbs. Nonetheless a quick test at the switch with a voltmeter would prove the point. Now, let us assume the switch is OK and it produces an output when the brake pedal is pushed down. Testing the length of wire from the front to

A B C D E F G H I J K

Figure 16.54 Representation of a wire with an open circuit between 'H' and 'I'

the back of the vehicle further illustrates how 'luck' comes into play.

Figure 16.54 represents the main supply wire from the brake switch to the point where the wire 'divides' to each individual stop light (the odds say the fault must be in this wire). For the purpose of this illustration we will assume the open circuit is just before point 'I'. The procedure continues in one of the two following ways.

One

- Guess that the fault is in the first half and test at point F.
- We were wrong! Guess that the fault is in the first half of the second half and test at point I.
- We were right! Check at H and we have the fault ... On test number *three*.

Two

- Test from A to K in a logical sequence of tests.
- We would find the fault ... On test number *nine*.

You may choose which method you prefer!

16.10 Advanced comfort and safety systems technology

16.10.1 Cruise control and system response

Figure 16.55 shows a block diagram of a cruise control ECU. Many cruise control systems work by the proportional-integral control technique. Proportional control means that an error signal is developed via the feedback loop, which is proportional to the difference between the required and actual outputs. The final output of a cruise control system is the vehicle speed but this depends on the throttle position, which is controlled by the actuator. The system electronics must take into account the lag between throttle movement and the required change in vehicle speed.

If the system overreacts, then the vehicle speed would become too high and then an over-reaction would cause the speed to become too low and so on. In other words, the system is not damped correctly (under damped) and will oscillate, much like a

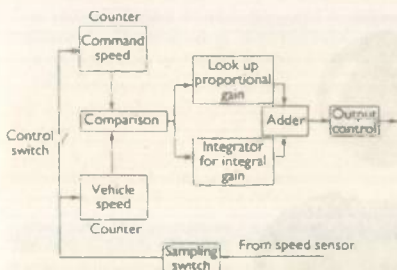


Figure 16.55 Cruise control system – detailed block diagram

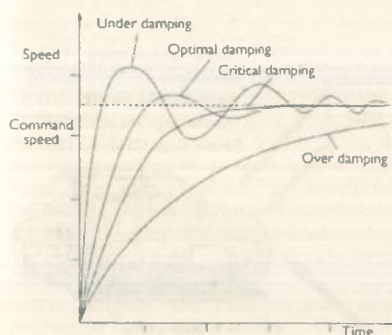


Figure 16.56 Damping factors

suspension spring without a damper. Proportional control alone is prone to this problem because of steady-state errors in the system. To improve on this, good system design will also include integral control. Thus, the final signal will be the sum of proportional and integral control signals. An integral controller produces a signal, which is a ramp, increasing or decreasing, proportional to the original error signal.

The use of integral control causes the final error signal to tend towards zero. The combination therefore of these two forms of control in the weighting given to each determines the damping factor of the control electronics. Figure 16.56 shows the effect on vehicle speed of different damping factors. These four responses are well known in engineering and electronics and can be modelled by mathematics to calculate the response of a system.

The above technique can be based on analogue or digital electronics. The principle is much the same in that for any system the proportional and

integral control can be used. The theoretical values can be calculated prior to circuit design as follows:

$$G_i = \omega_n^2 M$$

$$G_p = (2d\omega_n M) - C$$

where G_i = integral gain, G_p = proportional gain, ω_n = natural frequency of the system ($2\pi f_n$), M = mass of the vehicle, C = experimentally determined frictional factor (mechanical), and d = damping coefficient.

16.10.2 Radio suppresser calculations

Capacitors and inductors are used to act as filters. This is achieved by using the changing value of 'resistance' to alternating signals as the frequency increases. The correct term for this resistance is either capacitive or inductive reactance. These can be calculated as follows:

$$X_C = \frac{1}{2\pi fC}$$

$$X_L = 2\pi fL$$

where X_C = capacitive reactance (ohms), X_L = inductive reactance (ohms), C = capacitance (farads), L = inductance (henrys), f = frequency of the interference (hertz).

Using the above formulae gives the following results with a 0.1 mF capacitor and a 300 mH inductor, first at 50 Hz and then at 1 MHz.

Frequency	100 Hz	1 MHz
Capacitive reactance	15.5 k Ω	1.6 Ω
Inductive reactance	0.18 Ω	1.9 K Ω

By choosing suitable values of a capacitor in parallel and/or an inductor in series it is possible to filter out unwanted signals of certain frequencies. To home in on a specific or resonant frequency a combination of a capacitor and inductor can be used. The resonant frequency of this combination can be calculated:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

When the range of the interference frequency is known, suitable values of components can be determined to filter out its effect.

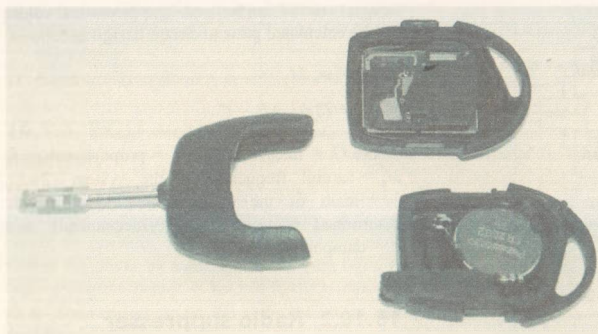


Figure 16.57 Standard key and remote transmitter

16.11 New developments in comfort and safety systems

16.11.1 Key words

Remote keyless entry (RKE)

Remote keyless entry has been a feature on many cars for a number of years. Remote keys work by transmitting either radio frequency or infrared signals. Door locking is controlled by a small hand-held transmitter and a receiver unit, as well as a decoder in the main control unit. This layout varies slightly between different manufacturers.

When the remote key is operated (by pressing a small switch), a complex code is transmitted. The number of codes used is in excess of 50 000. The receiver sensor picks up this code and sends it in an electrical form to the main control unit. If the received code is correct, the relays are triggered and the doors are either locked or unlocked. On some systems, if an incorrect code is received on three consecutive occasions when attempting to unlock the doors, the system will switch itself off until the door is opened by the key. This action resets the system and allows the correct code to operate the locks again. This technique prevents a scanning type transmitter unit from being used to open the doors.

Passive keyless entry (PKE)

Passive keyless entry systems¹ mean the driver doesn't even need to press a button to unlock the vehicle! The electronic key is simply carried in a

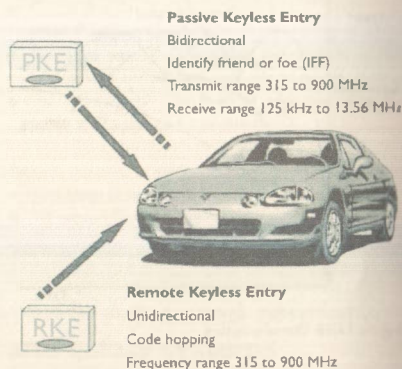


Figure 16.58 Remote and Passive Keyless Entry systems



Figure 16.59 Numerical keypad on the door (Source: Ford)

pocket, on a belt clip or in a bag. The controllers in the doors communicate with the key using radio frequency (RF). This action determines if the correct key is present and, if it is, the doors are unlocked.

¹ Joerge Becker, Passive Keyless Entry and Drive Systems, Auto Technology, June 2002

This communication event is triggered by lifting the door handle, or in some cases the vehicle will even unlock as the key holder approaches it.

PKE systems need the same level of security as any other remote locking method. Conventional RKE is a unidirectional process. In other words, signals are only sent from the key to the receiver. With PKE the communication is two-way. This is because the PKE system carries out an 'identity friend or foe' (IFF) operation for security purposes. The vehicle sends a random challenge to the key; the key encrypts this value and sends it back to the vehicle. The vehicle then performs the same encryption, compares the result with that sent by the key, and unlocks the doors if the values match.

Battery life is a critical issue for PKE. To obtain the required range of operation, 1.5 m (5 ft), the detection circuit in the key needs to be sensitive enough to detect just a few mV; this consumes significant power. There is also an issue with power consumption for the base station (vehicle) if the doors are designed to unlock as the key approaches. To achieve this the base station must poll continuously. In other words, it must keep looking for the key. This consumes battery power, which could be an issue if the vehicle was left for a long period. However, this method does have the advantage that the doors will always be locked unless a key is present.

If the method of lifting a handle is used as a trigger, then no power is consumed until needed. The down side of this method is that the user will want to feel the door unlock as the handle is lifted. However, Texas Instruments has developed a low-frequency RF chip. With a standby current of 5 μ A and less than 10 mV peak-to-peak sensitivity, the chip therefore provides a long battery life. It comes in an industry-standard package small enough to fit into a key fob or credit card device. This type of system is likely to become very common. Some PKE systems can even be set up to recognize multiple keys. The car could even be programmed to 'know' who was driving and set seat and mirror positions automatically!

Passive keyless go and exit

When the driver enters a car the key remains in a 'pocket' or at least it will be inside the vehicle. This means assuming that the key is being recognized, engine starting can be by a simple start button. As the button is pressed the same authentication process that takes place for the door locks starts. The engine can only be started if the key is inside the car, which is a technical challenge for the designers. For example, the key could be in a jacket hanging above the back seat, or it could be in the jacket outside on the roof.

Philips Semiconductors have produced a system with receive signal strength identification (RSSI), which can detect whether the key is inside or outside the vehicle. After the occupants have left the vehicle, the doors can be locked by pressing a handle or as the driver leaves the vicinity. 'Inside/outside' detection is also necessary for this scenario so the key cannot be locked in the car.

Keypad entry

In vehicles equipped with a keypad entry system, the vehicle doors and the boot can be locked and unlocked without using a key. Before unlocking the boot or a passenger door, the driver's door must be unlocked. Usually, if more than five seconds pass between pressing numbers on the keypad, the system will shut down and the code has to be entered again.

To unlock the driver's door, the factory code or a personal code is entered. All codes have five numbers. After the fifth number is pressed, the driver's door unlocks. The passenger doors can then be unlocked by pressing the 3/4 button within five seconds of unlocking the driver's door. To unlock the boot, the 5/6 button must also be pressed within five seconds. If this time is exceeded, the code to open the driver's door must be re-entered.

The keypad can also be used to lock the doors. To lock all of the car doors at the same time, 7/8 and 9/0 need to be pressed at the same time. It is not necessary to enter the keypad code. This will also arm the anti-theft system if fitted.

16.11.2 GM Dialogue Manager

A new technology that 'knows' when drivers are too busy to receive certain information has been developed by GM-Saab. As drivers demand more information from their vehicles, manufacturers need to find ways to deliver it safely. The technology is designed to lessen attention demands on the driver and adjust certain vehicle information based on driver status and/or preference.

The system is designed to manage information flow to the driver based upon the current driving environment. To do this, the technology takes into account vehicle factors such as speed, wiper movement and other vehicle data. Based on these factors, the Dialogue Manager decides if it is a good time to relay messages to the driver via the information centre. If the 'vehicle' perceives that the driver is experiencing a demanding driving environment, the system will delay messages that aren't safety-critical until the car senses a less demanding situation.

Systems such as this are designed to reduce driver workload; a term for both physical and mental

demands on a driver. GM researchers are already working on more sophisticated versions of the Dialogue Manager. These will take into account more vehicle factors and classify vehicle information into more categories.

One example of a more sophisticated version of the Dialogue Manager is that it would enable a vehicle to map out a travel route for the driver – without manual input of an address – based solely on the correct recognition of the driver and their personal calendar and appointments scheduled for that day. Eventually this technology would also be capable of identifying a delay in the original route, resulting in the vehicle modifying the route to achieve both energy and time efficiency. Another example could allow the vehicle to delay an incoming call from an embedded phone when demanding situations are identified.²

16.12 Self-assessment

16.12.1 Questions

1. State what is meant by active and passive safety.
2. Draw a simple motor reverse circuit and explain its operation.
3. Describe briefly six features of a high-end ICE system.
4. State five sources of radio interference.
5. Explain why fault-finding sometimes involves 'playing the odds'.
6. Describe the operating sequence of a driver's airbag.
7. Define 'Latching relay'.
8. Describe, with the aid of a block diagram, the operation of a cruise control system.
9. State four advantages of an intelligent airbag.
10. Explain the key features of a top-end alarm system.

16.12.2 Assignment

Investigate the development of the 'Auto PC' with particular reference to:

- Digital map databases.
- Vehicle diagnostics programs.

Produce a report on some of the issues connected with these developments. A good technique for starting on this type of assignment is to ask the question: 'Who gains and who loses?'

Consider also issues of updating and cost.

16.12.3 Multiple choice questions

An electric window has a Hall type sensor fitted. Technician A says this is used to determine the window position. Technician B says this is part of the 'bounce back' safety feature. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

A window lift motor drives through a worm gear because this:

1. increases speed and torque
2. reduces speed and torque
3. increases speed and reduces torque
4. reduces speed and increases torque

The frequency reproduction from a 'tweeter' type speaker would be described as:

1. high
2. middle range
3. low
4. very low

In order for a radio to interrupt listening and broadcast traffic announcements it will receive signals described as:

1. AM
2. RDS
3. CD
4. PC

When discussing ways in which to disable a vehicle to prevent theft, Technician A says two ways to do this are ignition circuit cut-off and fuel system cut-off. Technician B says starter circuit cut-off and engine ECU code lock. Who is right?

1. A only
2. B only
3. Both A and B
4. Neither A nor B

Which of the following would provide an input signal to an alarm system:

1. volumetric sensor
2. volumetric transmitter
3. ignition immobilizer
4. unbroken loop circuit

Which of the following would be regarded as a passive safety feature:

1. airbag
2. seat-belt
3. belt tensioner
4. all of the above

¹GM, 2003, Press information

Which of the following would be regarded as an active safety feature:

1. good road holding
2. side airbags
3. seat-belt tensioner
4. all of the above

Following a frontal impact, the time taken to fully inflate an airbag will be approximately:

1. 10 ms
2. 20 ms

3. 30 ms
4. 40 ms

To prevent the risk of accidental deployment of an airbag:

1. remove the SRS fuse and wait 10 minutes
2. remove the SRS fuse and discharge the capacitors manually
3. wait 10 seconds and remove the SRS fuse
4. wait 10 seconds and discharge the capacitors manually

17

Electric vehicles

17.1 Electric traction

17.1.1 Introduction

The pressure to produce a non-fossil-fuel vehicle is increasing. Indeed, recent legislation has set the requirement for the production of zero emission vehicles (ZEVs). The development of the electric vehicle is still in a state of flux (pun intended), but some major manufacturers now have electric vehicles available for sale to the general public.

In 1990, General Motors announced that its EV, the 'Impact', could accelerate to 100 km/h in just 8 s, had a top speed of 160 km/h (100 mile/h) and had a range of 240 km between charges. Running costs were about double the fossil-fuel equivalent but this cost was falling. The car was a totally new design with drag-reducing tyres and brakes which, when engaged, act as generators (regenerative braking). The car was powered by a 397 kg array of advanced gel electrolyte lead-acid batteries (32 at 10 V) and two small AC electric motors to drive the front wheels. The recharging time was about 2 hours but this could be reduced to 1 hour in an emergency. This was very impressive, but things have moved on still.

The following sections look at some of the issues in more detail, but the subject of 'electric vehicles' could (and does) fill many books in its own right. This chapter is presented as an introduction to a technology that is certain to become a major part of the general motor trade. The 'Case Studies' section looks, amongst other things, at two EVs in current use.

17.1.2 Electric drive vehicle layout

Figure 17.1 shows the general layout in block diagram form of an electric vehicle (EV). Note that the drive batteries are often a few hundred volts, so a lower 12/24 V system is still required for 'normal' lighting and other systems. Some of the components shown are optional.

17.1.3 EV batteries

A number of options are available when designing the electric car but, at the risk of over-simplification, the most important choice is the type of batteries.

Table 17.1 summarizes the current choice relating to batteries and will allow some comparisons to be made. Further details relating to some of these and other battery developments can be found in Chapter 5.

Currently the main advantage of lead-acid batteries is the existing mature technology, which is accepted by the motor industry. The disadvantage is their relatively low specific power. The sodium-sulphur battery is a good contender but has a far greater cost and new technologies are needed to cope with the operating conditions such as the high temperatures. Significant developments are occurring in relation to lithium-based batteries. However, most batteries in general use are lead-acid or nickel-based.

17.1.4 Drive motors

There are several choices of the type of drive motor. The basic choice is between an AC and a DC motor.

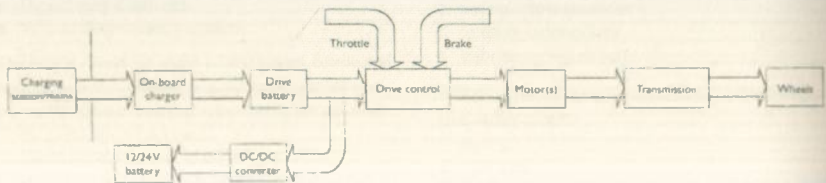


Figure 17.1 General electric vehicle (EV) layout

Table 17.1 Factors relating to batteries

Battery	Symbols	Specific energy, Wh/kg (Watt hours per kilogram)	Relative cost per kW/h (average est. in 1994)	Operating temperature range, °C	Cycle life, 80% depth of discharge (DOD)
Lead-acid	Pb-Acid	27-33	1	0-60	450-600
Nickel-cadmium	NiCd	35-64	10	-20-60	2000-500
Nickel-metal-hydride	NiMH	50-51	8	-20-60	500
Nickel-iron	NiFe	51	8	-20-60	1000
Zinc-bromine	ZnBr	56	5		500
Nickel-zinc	NiZn	73-79	3.5	-20-60	600
Lithium-ion/polymer	Li-ion	90	-	-20-60	1200-2000
Sodium-sulphur	NaS	79-81	6.5	300-380	1000
Silver-zinc	AgZn	117-139	15		100
Zinc air	Zn-Air	144-161	15	-20-40	150

The AC motor offers many control advantages but requires the DC produced by the batteries to be converted using an inverter. A DC shunt wound motor rated at about 50 kW is a popular choice for the smaller vehicles but AC motors are likely to become the most popular. The drive motors can be classed as AC or DC but it becomes difficult to describe the distinctions between an AC motor and a brushless DC motor.

AC motors

In general, all AC motors work on the same principle. A three-phase winding is distributed round a laminated stator and sets up a rotating magnetic field that the rotor 'follows'. The speed of this rotating field and hence the rotor can be calculated:

$$n = 60 \frac{f}{p}$$

where n = speed in rev/min; f = frequency of the supply; and p = number of pole pairs.

Asynchronous motor

The asynchronous motor is often used with a squirrel cage rotor made up of a number of pole pairs. The stator is usually three-phase and can be star or delta wound. This is shown in Figure 17.2. The rotating magnetic field in the stator induces an EMF in the rotor which, because it is a complete circuit, causes current to flow. This creates magnetism, which reacts to the original field caused by the stator, and hence the rotor rotates. The amount of slip (difference in rotor and field speed) is about 5% when the motor is at its most efficient.

Synchronous with permanent excitation

This motor has a wound rotor known as the inductor, which is a winding magnetized by a DC

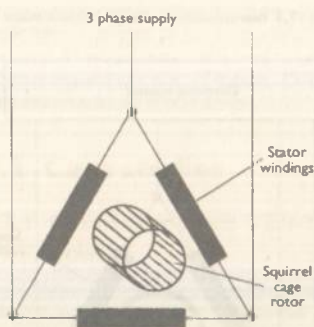


Figure 17.2 An asynchronous motor is used with a squirrel cage rotor made up of a number of pole pairs

supply, via two slip rings. The magnetism 'locks on' to the rotating magnetic field and produces a constant torque. If the speed is less than n (see above), fluctuating torque occurs and high current can flow. This motor needs special arrangements for starting rotation. An advantage, however, is that it makes an ideal generator. The normal vehicle alternator is very similar. Figure 17.3 shows a representation of the synchronous motor.

EC motors (electronically controlled)

The EC motor is, in effect, half way between an AC and a DC motor. Figure 17.4 shows a representation of this system. Its principle is very similar to the synchronous motor above except the rotor contains permanent magnets and hence no slip rings. It is sometimes known as a brushless motor. The rotor operates a sensor, which provides feedback to the control and power electronics. This control system produces a rotating field, the frequency of which determines motor speed. When used as a drive

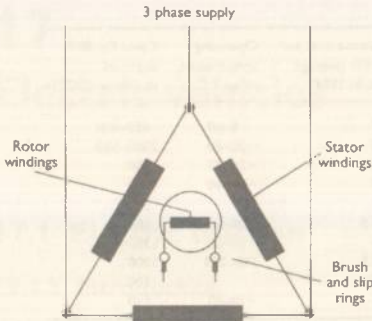


Figure 17.3 Representation of the synchronous motor

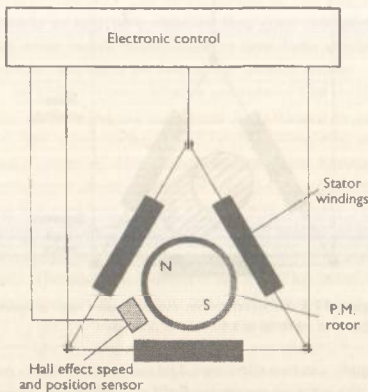


Figure 17.4 The EC motor is, in effect, halfway between an AC and a DC motor

motor, a gearbox is needed to ensure sufficient speed of the motor is maintained because of its particular torque characteristics. Some schools of thought suggest that if the motor is supplied with square-wave pulses it is DC, and if supplied with sine wave pulses then it is AC. This leaves a problem describing motors supplied with trapezoidal signals!

DC motor – series wound

The DC motor is a well proven device and has been used for many years on electric vehicles such as milk floats and fork lift trucks. Its main disadvantage is that the high current has to flow through the brushes and commutator.

The DC series wound motor has well known properties of high torque at low speeds. Figure 17.5 shows how a series wound motor can be controlled

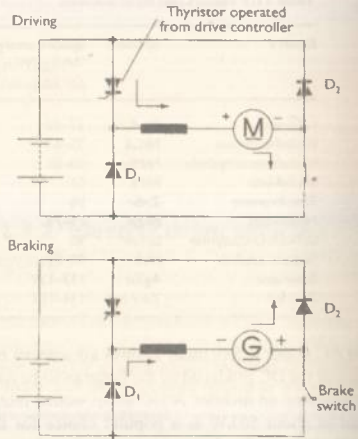


Figure 17.5 A series wound motor can be controlled using a thyristor and can also provide simple regenerative braking

using a thyristor and also provide simple regenerative braking.

DC motor – separately excited shunt wound

The fields can be controlled either by adding a resistance or using chopper control in order to vary the speed. Start-up torque can be a problem but, with a suitable controller, can be overcome. This motor is also suitable for regenerative braking by increasing field strength at the appropriate time. Some EV drive systems only vary the field power for normal driving and this can be a problem at slow speeds due to high current.

17.1.5 EV summary

The concept of the electric vehicle is not new, the essential battery technology was developed in the late 19th century and many such cars were being manufactured by the year 1900. Although some models achieved high speeds at that time, the electric car was generally slow and expensive to operate. Its range was also limited by its dependence on facilities to recharge the battery. Many of these problems have been overcome, but not all of them. Cost is still an issue, but 'cost' is a relative value and when the consequences of pollution are considered the 'cost' may not be as high as it appears.

Although advances in battery technology have increased the range of the EV, the maximum cruising

speed is also limited, as is the number of accessories that can be placed on the car. On the other hand, the electric car is expected to be mechanically more dependable and durable than its fossil-fuelled equivalent.

17.2 Hybrid vehicles

17.2.1 Introduction

The concept of a combined power source vehicle is simple. Internal combustion (IC) engines produce dangerous emissions and have poor efficiency at part load. Electric drives produce 'no' emissions but have a limited range. The solution is to combine the best aspects and minimize the worst. Such is the principle of the hybrid drive system.

One way of using this type of vehicle is to use the electric drive in slow traffic and towns, and to use the IC engine on the open road. This could be the most appropriate way for reducing pollution in the towns. Sophisticated control systems actually allow even better usage such that under certain conditions both the motor and the engine can be used.

17.2.2 Types of hybrid drives

Figure 17.6 shows how the principle of hybrid drive can be applied in a number of ways. It is also possible to use different types of engine such as petrol, diesel or even gas turbine. The layout of the drives can be thought of as series or parallel. The parallel arrangement seems to be proving to be more popular due to its greater flexibility. The series arrangement, however, allows the fossil-fuel engine to run at a constant speed driving the generator. This makes use of the combustion engine in its own right more efficient, but the double energy conversion process (mechanical to electrical to mechanical) is less efficient than driving the vehicle transmission

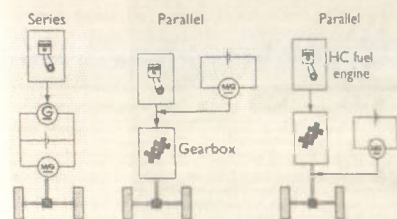


Figure 17.6 The hybrid drive principle can be applied in a number of ways

directly. The other advantage of series connection is that a transmission (gearbox) is not essential.

17.2.3 Summary

The hybrid or combined power source vehicle is likely to become popular. It appears to be the ideal and obvious compromise whilst drive and battery technology is developing. It may become possible in the future to produce a fossil-fuel engine which, when running at a constant speed, will produce a level of emissions that, if not zero, is very close to zero. This, when combined with a highly efficient electric motor and battery storage system, may be an acceptable ZEV (zero emission vehicle).

It has now become accepted that there will be no miracle battery, at least in the foreseeable future. The energy density of fossil fuels is of an order of magnitude beyond any type of battery. This gives further credence to the hybrid design.

17.3 Case studies

17.3.1 General motors – EV-1 (1999 version)

General Motors has arguably led the motor industry in electric vehicle development since the 1960s and, most recently, has made a major commitment of nearly half a billion dollars to its Impact and PrEView electric vehicle development programmes. As a direct result of these initiatives, GM developed the EV-1 electric car as the world's first specifically designed production electric vehicle, and became the first to go on sale (in the USA) in 1996. The EV-1 is shown in Figure 17.7.

Marketed as a stylish two-passenger coupé, the EV-1 has a drag coefficient of just 0.19 and an aluminium spaceframe chassis (40% lighter than steel) with composite body panels. Weighing just 1350 kg in total, the car has an electronically regulated top speed of 128 km/h (80 mile/h) – although a prototype EV-1 actually holds the world land-speed record for electric vehicles at 293 km/h (183 mile/h)! It can reach 96 km/h (60 mile/h) from a standing start in less than 9 s. The key to the success of the EV-1 is its electrical powertrain, based on a 103 kW (137 HP) three-phase AC induction motor with an integral, single-speed, dual-reduction gear-set driving the front wheels. The unit requires no routine maintenance for over 160 000 km (100 000 miles).

The battery pack uses 26, 12 V maintenance-free lead-acid batteries, giving a total voltage of 312 V and a range of 112 km (70 miles) per charge in

urban conditions and 144 km (90 miles) on the open road. However, new nickel-metal-hydride (NiMH) batteries were phased into production during 1998, almost doubling the EV-1's range to 224 km (140 miles) in the city and 252 km (160 miles) on highways. An innovative regenerative braking system helps to extend that range still further by converting the energy used when braking back into electricity in order to recharge the battery pack partially.

Full recharging can be carried out safely in all weather conditions and takes 3–4 hours using a 220 V standard charger or 15 hours using the on-board 110 V convenience charger. Compared with normal fossil fuels, the lower cost of domestic electricity means operating costs are relatively low.

Regenerative braking is accomplished by using a blended combination of front hydraulic disc and rear electrically applied drum brakes and the electric propulsion motor. During braking, the electric motor generates electricity (regenerative) which is then used to partially recharge the battery pack.

The EV-1 comes with traction control, cruise control, anti-lock brakes, dual airbags, power windows, door locks and outside mirrors, AM/FM CD/cassette, tyre inflation monitor system and numerous other features.

17.3.2 Nissan – Altra

Nissan recently confirmed pricing for its Altra EV following the success of initial trials in the US during 1998. The Altra is an estate built for the US market and the EV version is the first zero-emission Nissan to go on sale outside Japan. The Altra EV is shown in Figure 17.8.

The Altra has a water-cooled, permanent magnet, synchronous electric motor, which is the first to use the highly efficient neodymium-iron-boron alloy (Nd-Fe-B). The alloy was discovered by accident, when an order for materials was misinterpreted! The Hitachi motor is one of the most powerful in the world, developing 62 kW (84 PS) and 159 Nm



Figure 17.7 General Motors EV-1 (Source: GM Media)



Figure 17.8 Nissan Altra EV

with a maximum rotor speed of 13 000 rev/min. Average motor speed is 8000–9000 rev/min and the power-to-weight ratio of the 39 kg motor is 1.6 kW/kg – one of the best in the EV field.

A lithium-ion battery pack, developed by the Sony Corporation in a deal that is so far unique to Nissan, provides the power. It delivers a nominal output of 345 V from 12 modules of 8 cells, each producing 36 V when fully charged and 20 V when discharged. The gross weight of the battery pack is 350 kg and it has an energy density of 90 Wh/kg across the normal temperature range. Battery life is rated at 1200 cycles (to a 5% drop in efficiency) but Nissan claims batteries have endured in excess of 2000 cycles without significant further loss. The battery pack is mounted in a double-walled aluminium tray bolted to the centre of the platform between the front and rear axles beneath a flat floor; a dedicated ventilation system and fan keep it cool.

A vector controller developed by Nissan features twin fully redundant CPUs. The controller is water-cooled and has an input range of 216–400 V. Data are gathered on the state of charge, driving strategy, history, use of auxiliary systems and the function of the regenerative braking system to make accurate range predictions. It also performs relay control for battery cooling, provides the communication between the power supply and the Li-ion cell controller and determines the charging strategy based on the data it has collected.

Batteries are charged using an external inductive charger, which consists of a paddle inserted into a charging port in the front of the car. A fast charge takes 5 hours and provides a claimed range of 193 km, although on busy roads 135 km is more realistic.

The Altra has hydraulic power steering driven by an electric, rather than mechanical, hydraulic pump, which operates only when power assistance is required. A standard 12 V lead-acid battery, charged via a water-cooled DC/DC transformer from the main battery, powers auxiliary systems. Heating, ventilation and air conditioning consumes 50% of the energy of a conventional system in air conditioning mode and 66% when heating the cabin. R134a refrigerant serves both purposes and the system, like the power steering, uses an electric pressurization pump operating on demand.

The regenerative braking system operates on two levels.

- First stage – triggered when the driver lifts off the throttle and provides 'a similar feel to that of a conventional car.'
- Second stage – is much more substantial and occurs when the driver applies moderate braking

effort. The braking system itself has standard four-channel ABS.

Passive and active safety is unaffected by the extra weight compared with the standard vehicle; there are the standard front airbags, door beams and 8 km/h (5 mile/h) front and rear impact bumpers.

The instrument panel is digital with a large tachometer. Seven warning lamps alert the driver of 50 potentially dangerous situations with the battery or drive systems. Should critical problems arise, the systems can be shut down automatically to avoid damage.

17.3.3 'Nelco' – hybrid drive

A company called 'Nelco' has developed an interesting idea in hybrid EV drive technology. The system is based around a drive package that could potentially be used to power existing internal combustion engine cars. The claimed performance is equivalent to a conventional front-wheel drive car, with two-thirds of the fuel consumption and just one-third of the noxious emissions. Figure 17.9 shows the parallel layout used for this system. It is hoped that the vehicle could have a range of 800 km (500 miles) and a top speed of 160 km/h (100 mile/h). The main components used are a deep discharge-tolerant lead-acid battery, a permanent magnet brushless DC motor and a 'Norton' rotary engine.

The special battery uses lead tin foil plate construction, which was developed for the aircraft industry. This allows deep cycling and long life as high internal pressures prevent loss of active material during deep discharge. Tests have shown that 18 batteries rated at 30 Ah and 12 V, can provide 50 kW for 5 minutes. Hawker Siddeley has developed a flat array of cells that can be placed under the passenger compartment of the vehicle. The pack measures 120 × 120 × 4 cm², weighs 170 kg and can supply 7.5 kWh. The battery can withstand 1100 discharges to 80% depth of discharge (DOD) and 11 000 cycles to 20% DOD. This is expected to last the life of the vehicle. The reason for this long life is a battery thermal management system, which

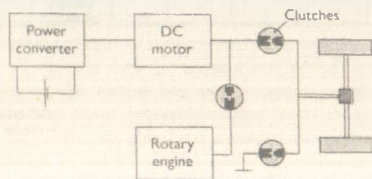


Figure 17.9 Parallel layout used for the 'Nelco' system

keeps the lead-acid cells at a constant 30–40°C which is the most efficient operating temperature.

Norton rotary engines achieved fame by winning major awards in the motorcycle racing world. This engine has a fast warm-up and only an 8 Nm starting torque. Two electrically preheated catalytic converters are used and the injection system operates the engine on a lean burn setting at high load. The engine supplies a constant output with the electric motor adding power for transient loads.

Figure 17.10 shows a sectional representation of the permanent magnet brushless DC motor. The actual motor used weighs 45 kg and is liquid cooled; oil is used as the coolant to prevent freezing. A sophisticated inverter and control circuit controls the motor. The voltage supply to the motor is

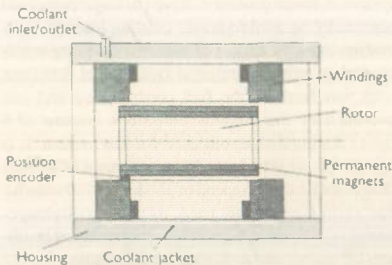


Figure 17.10 Permanent magnet brushless DC motor

converted from the 216 V DC of the batteries to a 300 V DC stabilized rail. The motor is supplied with three-phase power as either trapezoidal or square waves, the phase of which can be altered to control braking or acceleration. The accelerator position provides an input to the control module and a Hall effect rotor position sensor provides a feedback signal. The position feedback is to ensure the three phases of the motor are energized in the correct order.

The whole power unit weighs about 100 kg compared with 200 kg for a conventional system. The batteries, however, add a further 130 kg above the normal, but allow a 48 km (30 mile) range without running the engine.

17.3.4 A sodium-sulphur battery EV system

The layout or interconnection of components on an EV depends on the type of battery and drive motor. Figure 17.11 represents a system using sodium-sulphur (NaS) batteries, and a shunt wound DC motor using conventional brushes.

Altering the field current and/or the armature current changes the speed and torque of this type of motor. The control characteristics used on this type of drive system are shown in Figure 17.12. The vehicle starts accelerating at time = zero. In the early stages of acceleration the field is held constant

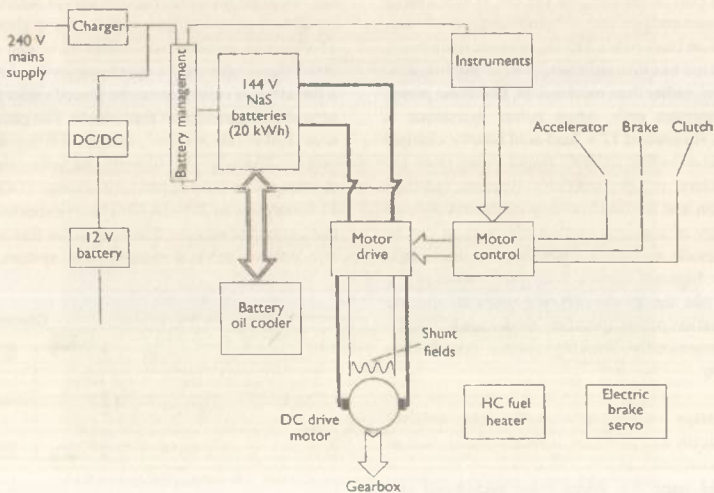


Figure 17.11 Layout that could be typical of a system using sodium-sulphur batteries and a shunt wound DC motor

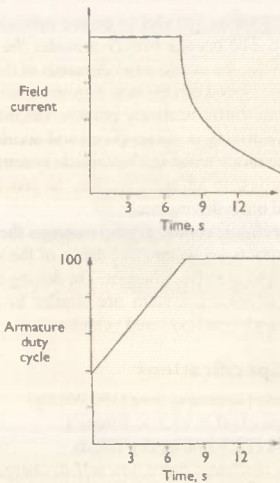


Figure 17.12 The control characteristics that can be used on this type of drive system

and the armature current is limited so as to match the demand.

As speed increases, the field current is decreased which will weaken the main fields so reducing the back EMF from the armature. The armature current demand can be met allowing increased speed. A motor such as this is likely to be air cooled. Some systems do, however, use liquid coolant. A variable regenerative braking system is used to maximize the efficiency of the system. This allows the batteries to be recharged during braking.

Batteries are often connected in series to increase the voltage. Motor design is easier for higher voltages mainly due to less current being required for the same power transfer. A battery management system is used to ensure the battery charge and discharge rates are controlled to the optimum value. A number of warning functions can be built in to indicate an abnormality and a warning about the remaining range of the vehicle is also possible. This information is displayed on the instrument pack.

The drive controller is made using existing power transistor technology. The transistors are controlled by a microprocessor, which in turn has its characteristics set by software. The controller receives input signals from the brake and accelerator pedals by using simple potentiometers. Signals from the other controls are from basic switches.

A simple method of controlling the rest of the vehicle electrical system is by fitting a conventional

12 V lead-acid battery. This can be charged when required from the drive batteries via a DC/DC converter.

17.3.5 Gas turbine hybrid

The state-of-the-art gas turbine engine is very attractive to the automotive industry and is in line with environmental pressures towards low emissions and low fuel consumption. The turbine engine has a number of useful features:

- Good thermal efficiency.
- Clean combustion.
- High power-to-weight ratio.
- Multifuel capability.
- Smoothness of operation.

These advantages could make it a natural successor to the reciprocating engine. The automotive gas turbine is still in its infancy, despite many technical achievements made since the world's first gas turbine car – the Rover 'Jet 1'. The technical challenge posed by the automotive gas turbine remains considerable and is, in many ways, even greater today. This is mainly due to the challenge created by advancing combustion, mechanical, aerodynamics, material and electrical technologies.

A further factor that has been added, and which was described earlier, is the hybrid electrical vehicle system, for which the gas turbine engine is most suitable. The design scope of hybrid systems is also very wide. The gas turbine engine has many features that suit automotive applications. For example, it is compact and light, which allows flexibility in power train layout. This reduces the vehicle weight, which results in better vehicle performance and economy.

Modern combustion chamber design makes the engine produce very low emissions of all pollutants, even when burning diesel. This can be achieved without having to use catalytic converters. These advantages are becoming increasingly important in the current market place.

Compared with an equivalent reciprocating engine, gas turbines are smooth and quiet in operation, can run on various types of hydrocarbon fuel, and their inherent mechanical simplicity will result in improved reliability and increased servicing intervals.

Compared with the conventional reciprocating engine, the turbine has, until recently, had poor transient power response and part load fuel economy. There has also been a natural resistance to change by the automotive industry because of its huge investments in the infrastructure of the existing engine's manufacture and service. When the



Figure 17.13 Inductive charging could help the development of the electric vehicle

advantages of the turbine are combined with the advances in hybrid electrical systems, an exciting combination offers great potential for the future of the hybrid technique.

17.3.6 Inductive charging

The Nissan Altra, as described earlier in this chapter, uses inductive charging. In this case a 'paddle' connected to an external power source, is used to plug into a 'socket' in the car. The risk of electric shock and the possibility of over-heating due to 'loose' connections are almost eliminated.

'Drive in' inductive charging is a possible development to help the advance of the electric vehicle. The principle is shown in Figure 17.13. A coil, which forms the secondary winding of a transformer, is positioned on the car in a suitable position. The primary winding of the transformer could be placed on a movable core which, when the vehicle is parked, could automatically lift into position and allow a magnetic link with the secondary winding.

17.3.7 ZOXY battery system – 'chemTEK'

The ZOXY zinc-air battery is not really a battery in the traditional sense. The core of the ZOXY 'P280' is a single, easy-to-handle and flexible unit. The battery dimensions are $220 \times 135 \times 39 \text{ mm}^3$ and it weighs only 2 kg. Its energy density of 150 Wh/kg is five times the amount of lead-acid batteries. The ZOXY battery will keep its charge for very long periods; its typical energy discharge is under 1%. If the air supply is interrupted, the self-discharge falls well below 1%. Another advantage of the ZOXY system is that it works in a wide temperature range (-20°C to $+40^\circ\text{C}$).

Although production levels currently are relatively small, the costs of the ZOXY are equal to the costs of ordinary lead-acid batteries per unit of energy. With economies of scale, the cost level of a ZOXY battery would fall considerably below that of its lead-acid counterpart.

While the ZOXY zinc-air battery is a 'high-energy reservoir', an additional 'booster' may be used for

high acceleration vehicles to ensure optimum performance. The booster battery provides the power necessary for the acceleration demands of the vehicle. Higher speed driving may require an ability to merge into traffic relatively quickly. On the other hand, city driving is slower-paced and acceleration requirements are reduced. The cascade system, using two batteries, is an excellent way to provide for these and other driving needs.

An electronic control system manages the use of both battery types without the driver of the vehicle ever being aware of the changes. The driving characteristics of such a system are similar to petrol/gasoline and diesel-powered vehicles.

P280 Specifications

- Extended operating time (150 Wh/kg).
- Volume ($33.0 \times 13.5 \times 3.9 \text{ cm}^3$).
- Weight (1.25/2.00 kg dry/filled).
- Stable discharge curve, low self-discharge.
- Low-sensitivity to temperature changes (-20°C to $+40^\circ\text{C}$).
- Environmentally friendly.
- Voltages nominal/shut-off 1.1/0.6 V.
- Nominal current/peak current 0–30/40 A.
- Capacities at 10/20 A 320/280 Ah.
- Energy content at 10/20 A 300/250 Wh.

17.3.8 Hybrid case study – Ford

The Ford Escape hybrid, when it goes into production, will be one of the most fuel-efficient and practical SUVs on the market. The Escape hybrid will deliver between 35–40 miles per gallon (less than 6 ltr/100 km) in city driving. It will meet Stage IV emissions rules in Europe before they take effect in 2004, and achieve certification under California's Super Ultra Low Emission Vehicle (SULEV) and Partial Zero Emission Vehicle (PZEV) emissions standards. Timing of Escape hybrid is on track to arrive in dealer showrooms in late summer 2004.

The Escape hybrid is designed to provide the same acceleration and functionality as the 200-hp V-6 version. It uses a combination of a fuel-efficient Atkinson cycle (see Note 1 on page 453) four-cylinder gasoline engine and an electric motor. Overall fuel economy is nearly double that of the V-6 Escape. The Escape hybrid recovers a substantial portion of what would otherwise be 'lost energy' by employing regenerative braking. The Escape hybrid is a full hybrid able to run on either its internal combustion engine and/or its electric motor – depending on which will deliver the most efficient fuel performance.

Hybrid electric vehicles use a combination of electric storage batteries and an internal combustion

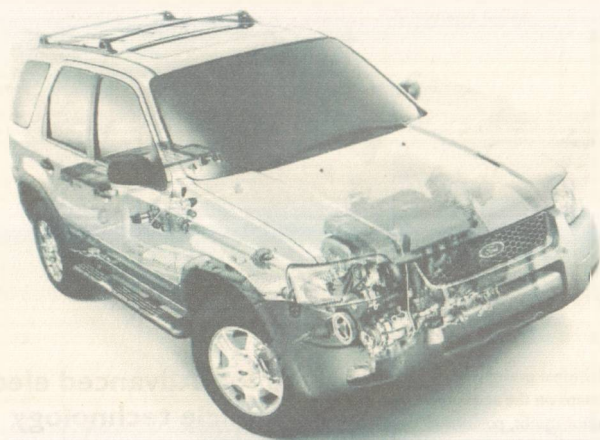


Figure 17.14 Ford Escape hybrid (Source: Ford)

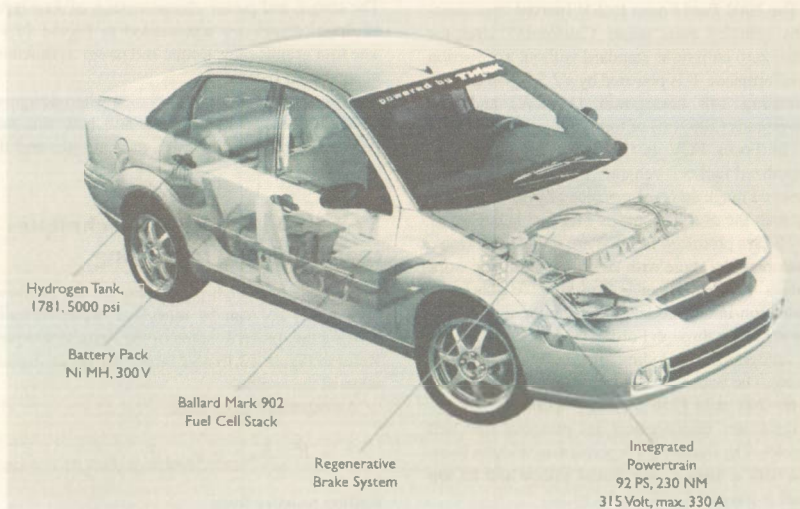


Figure 17.15 Ford Focus hybrid (Source: Ford)

engine to provide increased operating efficiency. The batteries supply electricity to drive an electric traction motor, and the engine runs as necessary to recharge the batteries or to provide additional power for acceleration. The Escape hybrid will feature an electric drivetrain and a fuel-efficient four-cylinder engine. With regenerative braking and nearly

instantaneous start-stop capability for the engine (thanks to a powerful combined starter-generator) the front wheel drive Escape hybrid is expected to deliver between 35–40 mpg on the city cycle.

The generator motor shuts down the internal combustion engine when the vehicle is coasting (over-*run*) or stopped, saving the fuel normally spent in

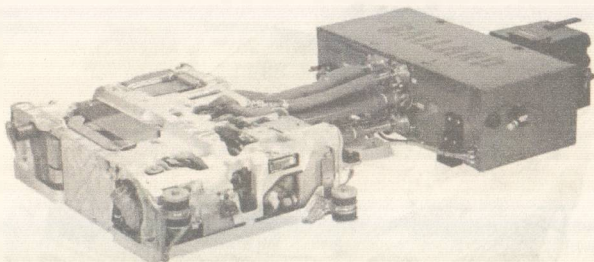


Figure 17.16 Ford Focus hybrid powertrain (Source: Ford)

idling. When additional power is called for, such as when the driver steps on the accelerator pedal from a stop, the generator-motor, positioned between the engine and transmission, instantaneously restarts the engine in less than 0.2 seconds. The Escape hybrid is anticipated to be capable of being driven more than 500 miles (800 km) on a single tank of fuel.

The 2003 Ford Focus PZEV (partial zero emissions vehicle) even meets California's stringent partial zero emissions standard without a reduction in performance. It is powered by a 2.3-ltr I-4 engine, generating 148 horsepower (110 kW) and 152 foot-pounds (206 Nm) of torque.

The Focus FCV is the motor industry's first 'hybridized fuel cell vehicle', bringing together the improved range and performance of hybrid technology with the overall benefits of a fuel cell. Five of the 15 cars produced in 2002 are in a collaborative developmental stage with key customers. The work enables Ford to receive real-time feedback on production-intent models. The remaining 10 vehicles are going through Ford's standard internal testing programs, including crash and emissions testing. The Focus FCV is expected to demonstrate a 160–200 mile (250–320 km) operating range – a significant improvement on previous fuel cell vehicles. The Focus FCV's performance levels compare with a more conventional saloon and its top speed is governed at 80 mph.

Note 1: The Atkinson engine is effectively an Otto-cycle engine but with a different method of linking the piston to the crankshaft. The arrangement of crank levers allows the Atkinson to cycle the piston through all four strokes in only one revolution of the main crankshaft. It also allows the strokes to be different lengths; the inlet and exhaust strokes are longer than the compression and power strokes.

17.4 Advanced electric vehicle technology

17.4.1 Motor torque and power characteristics

The torque and power characteristics of four types of drive motors are represented in Figure 17.17. The four graphs show torque and power as functions of rotational speed.

A significant part of the choice when designing an EV is the drive motor(s), and how this will perform in conjunction with the batteries and the mass of the vehicle.

17.4.2 Optimization techniques – mathematical modelling

The effects of design parameters on the performance of an EV can be modelled mathematically. This section presents some of the basic techniques. Refer to Figure 17.18 and Table 17.2 for an explanation of the symbols.

Aerodynamic drag force:

$$F_a = \frac{\rho C_d A_f}{2} (V_v \pm V_{wind})^2$$

Rolling resistive force:

$$F_r = \mu_r mg \cos(\theta)$$

Climbing resistive force:

$$F_c = mg \sin(\theta)$$

Therefore the total resistive force is:

$$F_{resistive} = F_a + F_r + F_c$$

Force developed at the wheels:

$$F_{dw} = F_{motor} \eta_c \eta_m$$

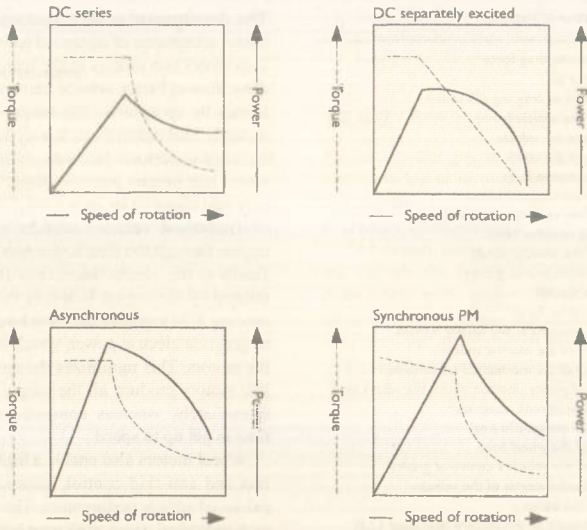


Figure 17.17 Motor torque and power characteristics

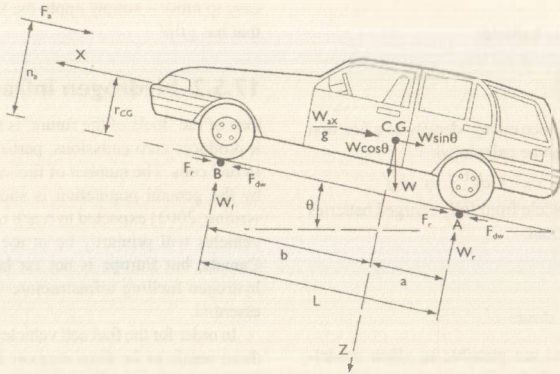


Figure 17.18 Mathematical modelling - values used

The tractive effort therefore is:

$$F_{\text{tractive}} = F_{\text{dr}} - F_{\text{resistive}}$$

The maximum tractive force that can be developed:

$$F_{\text{dr,max}} = \frac{\alpha \mu_a W / L}{1 + \mu_a h_{\text{CG}} / L}$$

The effective mass of a vehicle is:

$$m_{\text{eff}} = m + \frac{J_{\text{eff}}}{r^2}$$

Acceleration time can now be shown to be:

$$t = m_{\text{eff}} \int_0^{v^2} \frac{dV}{F_{\text{tractive}}}$$

Power required to hold the vehicle at a constant speed:

$$\text{Power} = \frac{V_v F_{\text{resistive}}}{\eta_c \eta_m}$$

Table 17.2 Explanation of symbols

F_a	Aerodynamic drag force
ρ	Density of air
C_d	Coefficient of drag, e.g. 0.3 to 0.4
A_f	Area of the vehicle front
V_v	Velocity of the vehicle
V_{wind}	Velocity of the wind
F_r	Rolling resistive force
μ_r	Road coefficient of friction
μ_{constr}	Tyre rolling coefficient of friction
F_g	Climbing resistive force
m	Mass of the vehicle (total)
g	Acceleration due to gravity
θ	Angle of the hill
$F_{resistive}$	Total resistive force
F_{dev}	Force developed at the driving wheels
η_e	Efficiency of the electric motor
η_m	Efficiency of the mechanical transmission
a	Centre of gravity position within the wheel base
μ_a	Coefficient of road adhesion
W	Weight of the vehicle (mg)
L	Length of the wheel base
h_{cg}	Height of the vehicle's centre of gravity
J_{eff}	Total effective inertia of the vehicle
M_B	Mass of the battery
Y	Power density of the battery (see Table 17.1)
x_i	Correlation between energy density as a function of power density

Power density of the batteries:

$$y = \frac{\text{Power}}{M_s}$$

The correlation between energy density as a function of power density can be calculated:

$$x_i = ay^5 + by^4 + cy^3 + dy^2 + ey + f$$

The range of the vehicle from fully charged batteries can be calculated from:

$$\text{Hours} = \frac{x_i}{y}$$

$$\text{Range} = V_v \times \text{Hours}$$

Further calculations are possible to allow modelling – a subject which, if grasped, can save an enormous amount of time and money during development. The information presented here is extracted from an excellent research paper. (Reference: SAE paper 940336.)

17.5 New developments in electric vehicles

17.5.1 Motors in wheel – GM

GM engineers have developed a potential breakthrough technology called wheel hub motors.

This development could dramatically increase consumer acceptance of advanced technology vehicles. Two wheel hub motors in the rear of a front-wheel drive four-cylinder vehicle can increase torque at launch by up to 60%. The torque is also available instantly. This means that a four-cylinder engine could be made to perform like a six-cylinder engine. The wheel hub motors generate about 25 kW each and only add about 15 kg each.

Traditional vehicles transfer energy from the engine through the clutch, gearbox, driveshafts and finally to the wheels. More than 10% of the power created by the engine is lost in this 'transmission' process. GM's system uses a hybrid electric vehicle to generate electric power, which is sent directly to the motors. This minimizes the energy lost. Wheel hub motors produce all the torque that is available immediately, whereas conventional engines take time to get up to speed.

Wheel motors also enable a higher level of traction and anti-skid control, improved steering and enhanced vehicle performance. The ability to control each individual wheel, with even better response than current traction control systems, brings added benefits. For example, a vehicle stuck in mud would be easy to move – simply apply the traction to the tyre that has grip!

17.5.2 Hydrogen infrastructure

One of the 'fuels of the future' is hydrogen because it produces zero emissions, particularly when used in fuel cells. The number of fuel cell vehicles in use by the general population is soon (at the time of writing, 2003) expected to reach one million. These vehicles will primarily be in use in the USA and Canada, but Europe is not far behind. A suitable hydrogen fuelling infrastructure will soon become essential.

In order for the fuel cell vehicle market to expand, there needs to be firm support from government that the hydrogen fuelling infrastructure will be supported. This building of consensus and developing routes towards a good hydrogen infrastructure will be necessary. One estimate is that California, a leading US state in respect of clean air, will need some 1900 hydrogen fuelling stations by 2015.

It is difficult to predict how quickly fuel cell vehicles will move into the consumer market. It is likely that they will be used by some fleet customers first. However, it is interesting to note that the development of the vehicle technology is only half the battle. If there is nowhere convenient to refuel then consumers (you and I) will not make the change!

17.6 Self-assessment

17.6.1 Questions

1. State what is meant by ZEV.
2. Describe briefly the term 'Hybrid'.
3. Explain what is meant by, and the advantages of, inductive charging.
4. Describe with the aid of sketches the different ways in which a hybrid vehicle can be laid out.
5. Explain the term 'Power density'.
6. List five types of EV batteries.
7. The GMEV-1 uses lead-acid or alkaline batteries. State three reasons for this.
8. Describe with the aid of a sketch the operation of a synchronous motor.

9. State four types of EV drive motor.
10. Describe how the Nissan Altra calculates the current range of the car.

17.6.2 Assignment

A question often posed about so-called ZEVs: as the electricity has to be generated at some point, often from burning fossil fuels, then how can they be said to produce no emissions?

The answer, in my opinion, is that at the point of use the vehicles are ZEVs. The production of the electricity for recharging, which will mostly be during the night, allows power stations to run at optimum efficiency and hence overall emissions are reduced.

Research and comment on this issue.

18

World Wide Web

18.1 Introduction

If you have access to a computer and modem then you are no doubt already interested in the Internet and the World Wide Web (WWW). In this short chapter I want to highlight some of the resources available to you on the net and on disk. This chapter will show how useful the web is when researching for information or downloading useful programs.

18.1.1 Latest news ...

Here are some interesting technologies together with a web link. Please note that the 'root' web address is given because many more detailed links become out of date. You will have to 'dig' a little to find the specific details. The snippets of information and links are presented in no particular order or for any reason other than that I found them interesting.

The best link to follow is www.automotive-technology.co.uk because all the links in this chapter, and many more, can be found there.

The Visteon Torque Enhancement System is said to achieve large engine performance from a small turbocharged engine. This system uses an electronically controlled, electrically powered supercharger as part of an integrated air management system. www.visteon.com

Eberspaecher have developed a dual flow exhaust system with a new type of honeycomb in the catalytic converter. This reduces resonance and means the silencer shells can be 25% thinner and therefore lighter. www.eberspaecher.com

Omron has developed an advanced miniature camera, used for automotive safety applications. The camera is very sensitive and can work well in very difficult light conditions such as in tunnels or very bright sunlight. www.omron.com

Toyota are introducing a hybrid vehicle that uses constantly variable transmission. The vehicle qualifies as an ultra low emission vehicle (ULEV) and it can generate 1500 W of power when it is stationary or moving. www.toyota.co.jp

A new flat six-engine from Subaru uses an active valve control system. The engine is said to be one of the lightest 6-cylinder engines in the world. www.subaru.co.jp

A SilverVision bulb made by Schott is interesting. It appears silver when not lit but produces amber light when it is. The bulbs are interchangeable with standard types. www.us.schott.com

CO₂ as a substitute for R134a refrigerant in air conditioning systems is under test by Behr. CO₂ is more dense than R134a so lower flow rates achieve the same level of cooling. However, higher pressures mean that the AC components have to be stronger. www.behrgroup.com

A Swedish company called Active Attention has developed a system called Alerta, which has the ability to measure a driver's ability to control a vehicle. It does this by measuring steering wheel torque and changes in lateral inertia. www.active-attention.com

Non-contact sensors mean that the sensor never suffers from wear and tear. Tyco Electronics is a major supplier in this area. www.tycoelectronics.com

Dura have developed a smart parking brake. Levers and/or foot pedals are replaced by an electro-mechanical device, which interfaces with the conventional rear brakes. A simple one-touch switch controls operation. It was first used on the Jaguar S-Type in 2003. A major advantage of the system as well as ease of operation is that it frees up valuable space. www.duraauto.com

Beru produce a tyre safety system (TSS). This permanently monitors tyre pressures and warns of any deviation. www.beru.com

Bosch, along with many other developments, has now produced an on-board network structure with Multiplex technology that greatly simplifies the body electronics of a commercial vehicle. www.bosch.com

18.2 Automotive technology - electronics

The Automotive Technology (AT) program is all about learning how complex automotive systems

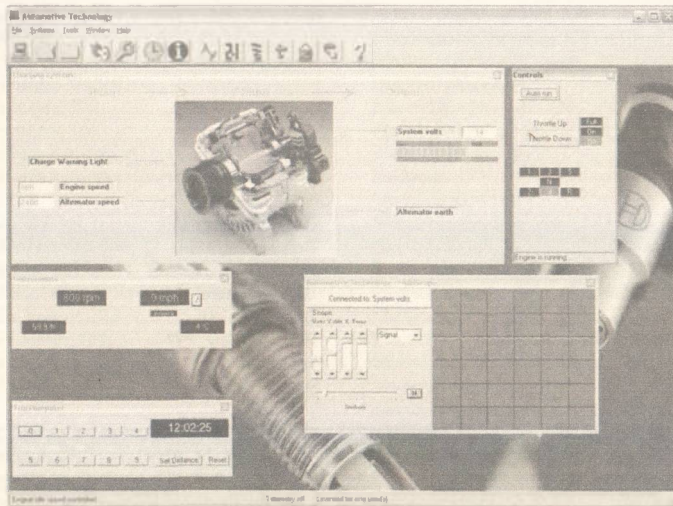


Figure 18.1 'It is all about INPUTS and OUTPUTS'

work – and how to fix them when they do not! AT Electronics helps you learn how systems (engine management in particular) operate, how the inputs to a system affect its outputs, and what the effects are when a fault occurs. Diagnostic routines, which are built into the program, will allow you to put into practice some of the skills you develop but ensure that you work in a logical way.

The MultiScope feature allows you to examine signals from sensors and those supplied to actuators. It also contains a scanner and multimeter to show typical readings. A telemetry screen, text and pictures window can also be used. Learning tasks, which are part of the help file, will help you work your way through the program.

The program allows you to control the inputs to systems and note the effect this has on the outputs. In this way you will start to understand the operation of automobile electronic systems. Figure 18.1 shows the charging system simulation. In this case an example of the inputs would be engine/alternator speed and an example of the outputs would be the system voltage.

Diagnostics are possible by creating a fault and carrying out tests to locate it! A database is built into the program to assist with this and MultiScope has lots of functions to help. The methods used are appropriate for use on real systems. This is an ideal training system for trainees and students. The main simulation windows relate the engine management, starting and charging – but others are 'under construction'.

The shareware program can be downloaded from www.automotive-technology.co.uk

18.3 Self-assessment

18.3.1 Questions

1. State the web address of Ford in the UK, Australia, New Zealand and USA.
2. Check and comment on the latest news from www.automotive-technology.co.uk
3. Calculate the efficiency of a modern charging system AND send me the answer via email.
4. State four advantages AND four disadvantages of research via the web.
5. Describe briefly why this chapter only has FIVE questions!

18.3.2 Assignment

Look back at any of the other assignments in this book and choose one for further study. Your task is to use the web as your research tool. Produce a report on the latest technology developments in your chosen subject area. Email it to me if you wish and I may be able to use it in the next edition.

Good luck with your future studies and work – keep in touch: tom.denton@automotive-technology.co.uk

Index

Acceleration, 266
Accelerometer, 420
Accuracy, 36, 58, 59
Active roll reduction, 380
Active suspension, 374
Active valve train, 241
Actuators, 36, 46
Advance angle, 170
After-burning, 246
After-start enrichment, 265
Air bags, 421
Air conditioning, 356, 358, 361, 365
Air shrouding, 242
Airbags, 418, 425
Air-cored gauge, 335, 344
Alkaline batteries, 120
Alternator, 75, 128
Ampere's law, 17
Ampere-hour capacity, 112
Amplifier, 21, 23
Analogue display, 340
Analogue to digital conversion (A/D), 26, 183
Antilock Brake System (ABS), 370, 376, 384, 389, 394, 398
Armature, 152
Armature reaction, 366
Artificial intelligence, 280
Asynchronous motor, 444
Atom, 12
Audio, 429
Auto PC, 415
Automatic clutch, 382
Automatic temperature control, 360
Automatic transmission, 377
Automotive technology – electronics, 457

Back lighting, 341
Batteries, 110
Battery, 449
Battery acid, 11
Beam setting, 298
Bending light, 312
Bifocal, 294
Bimetal strip, 333
Black box technique, 391
Blower motors, 357
Blue tooth, 103, 106

Boost charging, 113
Brake assist, 381
Brake lights, 293, 322
Brake pressure, 371
Brake slip, 371
Brake-by-wire, 397
Bridge circuits, 23
Buses, 31

Cables, 83
Capacitance, 14, 40
Capacitor, 18, 20, 53
Capacitor discharge ignition, 179
Carbon monoxide, 206
Carburation, 208
Carburettor, 209
Catalysts, 228
Catalytic converter, 248, 285, 246
Cell, 111
Central processing unit, 31
Centrifugal advance, 172
Characteristic curves, 155
Charging, 128, 143, 451
Charging circuit, 135
Charging voltages, 129
Chemical effect, 12
Chloro fluoro carbon (CFC), 358
Circuit breakers, 88
Circuit diagrams, 97
Circuit numbering, 84
Circuit symbols, 19
Circuits, 151
Closed loop, 83, 247
Clutch actuator, 382
Cold cranking amps, 112
Cold running, 265
Colour codes, 84, 85
Combinational logic, 27
Combustion, 199
Combustion control, 284
Common rail high-pressure pump, 232
Common rail injection, 232
Communications, 429
Compact disk (CD), 352
Compound wound meter, 154
Compression ignition, 203
Compressor, 359, 362, 368

460 Index

Condensor, 362
Conduction, 366
Constant dwell, 174
Constant energy, 175, 193
Contact breakers, 172
Contact breakers, 191
Controller area networks (CAN), 107
Controller area networks (CAN), 69, 93, 96, 106, 147
Convection, 366
Conventional current flow, 12
Coolant sensor, 181
Cooling, 287
Cooling fan motors, 323
Crankshaft sensor, 180
Cruise control, 407, 437
Current flow diagrams, 98

Damping, 333
Darlington pair, 25
Day running lights, 293
DC motor, 445
Detonation, 201
Development of, 9
Diagnostic link connector, 79
Diagnostic socket, 243
Diagnostic software, 80
Diagnostic trouble code, 79
Diagnostics, 106
Diesel common rail, 230
Diesel fuel injection, 214
Digital audio broadcast, 412, 432
Digital circuits, 26
Digital instrumentation, 336
Digital oscilloscope, 62
Digital to analogue conversion, 25, 26
Digital versatile disk (DVD), 352
Dim-dip, 299, 302
Diodes, 20
Dipped beam, 302
Direct ignition, 185, 194
Direct injection, 286
Discharge tester, 114
Distributorless ignition, 184, 193
Door lock actuator, 405
Door locking, 405
Drive motors, 443
Drive-by-wire, 383
Dwell, 174, 275
Dwell angle, 177, 240
Dynastart, 160

EC motors, 444
ECU, 319, 372, 376, 404, 418, 437
Efficiency, 118, 143, 167

Electric engine cooling, 331
Electric power steering, 379
Electric vehicle (EV), 443
Electric vehicles, 443
Electric window, 405, 427
Electro hydraulic braking, 398
Electrochemistry, 115
Electrode, 187
Electrode gap, 188
Electroluminescent, 354
Electrolyte, 111
Electromagnetic compatibility (EMC), 100
Electron flow, 12
Electronic clutch, 380
Electronic control of diesel injection, 217
Electronic control unit (see also ECU), 182, 213
Electronic heating control, 358
Electronic wiper control, 330
EMC, 100
Emission regulations, 207
Emissions, 205, 248, 287
Engine analyser, 63
Enrichment, 224
Equivalent circuit, 150
EV batteries, 443
Evaporator, 359, 362
Exhaust emission, 171, 205, 216, 234
Exhaust gas, 11, 64
Exhaust gas oxygen sensor, 44
Exhaust gas recirculation (EGR), 245, 248

Faraday's law, 17
Field coils, 153
Field poles, 152
Field windings, 153
Filament, 291
Filter, 24
Flasher unit, 322, 324
Fleming's rules, 17
Focal point, 296
Fog lights, 293
Fuel cells, 121
Fuel injection, 210
Fuel injector, 47
Fuel pressure regulator, 213
Fuel pump, 213
Fuel supply, 262
Fuses, 88

Gas discharge, 299
Gas discharge lamp, 299, 309
Gas discharge lighting, 314
Gas turbine, 450
Gas-by-wire, 289
Gasoline direct injection (GDI), 251, 396

- Gauges, 333
- Global positioning system (GPS), 348, 352
- Glow plug, 220

- Hall effect, 38, 53, 74, 175, 334
- Hall effect sensor, 51
- Halogen, 291
- Head up display (HUD), 353
- Headlamp, 300
- Headlamp levelling, 307
- Headlight adjustment, 298
- Headlight cleaners, 323
- Headlight patterns, 296
- Head-up display, 309, 342
- Heat range, 186, 189
- Heating and ventilation, 356
- Heating effect, 12
- Heavy vehicle starters, 159
- HFC, 358
- High resistance, 13
- High tension, 170
- Holography, 347
- Homifocal reflector, 295
- Horns, 322
- Hot film air mass flow meter, 42
- Hot wire air flow meter, 223
- HVAC, 357
- Hybrid, 448, 450, 452
- Hybrid drives, 446
- Hybrid vehicles, 446
- Hydraulic modulator, 373
- Hydrocarbons, 206
- Hydrogen, 455
- Hydrometer, 114

- Idle control actuator, 212
- Idling phase, 265
- Ignition, 170, 300
- Ignition angle, 182
- Ignition coil, 171, 196
- Ignition timing, 240, 274
- In car entertainment (ICE), 410
- Indicators, 292, 324
- Inductance, 14
- Induction, 16
- Inductive pulse generator, 176
- Inductive sensor, 38
- Inductor diode, 53
- Inductors, 20
- Inertia starters, 155
- Infrared lights, 307
- Injection cut-off, 266
- Injection duration, 273, 276
- Injector, 75, 263
- Inlet manifold, 241

- Instrument lighting, 354
- Integrated circuit, 20
- Integrated starter alternator damper, 160
- Integrated starter generator, 161, 164
- Intelligent airbag sensing, 431
- Intelligent front lighting, 311
- Interference, 413
- Intermediate transmission, 158
- Intermittent wipe, 320
- Internal resistance, 118
- Internet, 457

- Jetronic variations, 219
- Jewel aspect, 306

- Key programming, 434
- Keypad entry, 440
- Kirchhoff's laws, 17
- Knock protection, 266
- Knock sensor, 41, 181

- Lambda, 44
- Lambda control, 240
- Lambda diesel, 237
- Lambda sensor, 54, 76, 212
- Lead-acid batteries, 111
- Lean burn, 227, 282
- LED displays, 340
- LED lighting, 299, 301
- Lenses, 296, 297
- Lenz's law, 17
- Light bulb, 291
- Light emitting diode (LED), 53, 301, 314, 339, 353
- Light sensors, 44
- Lighting circuit, 299
- Limited slip differential, 381
- Linear lighting, 306
- Linear wiper system, 327
- Liquid crystal, 340
- Load advance, 191
- Lock torque, 166
- Log gates, 27
- Lost spark, 184
- Luminous flux, 310

- Magneride, 400
- Magnetic Effect, 12
- Magnetic field, 18, 152, 348
- Magnetism, 15, 152
- Main beam, 302
- Manifold absolute pressure sensor, 180, 261
- Measurement, 35
- Memory, 31
- Memory circuits, 29

- Microcontroller, 33
- Microprocessor, 30, 32
- Mirrors, 403
- Mobile communications, 414
- Molecule, 11
- Motor characteristics, 153
- Motors, 15
- Motors in wheel, 455
- Motronic, 68
- Moving iron, 334
- Multimedia, 409
- Multimeter, 59
- Multiplexed displays, 346
- Multiplexed wiring, 91
- Multipoint, 211
- Multipoint injection, 221
- MultiScope, 278, 458
- Mutual induction, 16

- Navigation system, 344
- Neon, 306
- Night vision, 308
- Nitrogen oxides, 206
- Noise control, 424

- Obstacle avoidance, 421
- Obstacle avoidance radar, 422
- Ohm's law, 13, 17, 116
- Oil pressure, 337
- On board diagnostics (OBD), 66, 68, 69, 78, 106, 243
- Open circuit, 13
- Open loop systems, 83
- Optical pulse generator, 178
- Oscilloscope, 57
- Oxygen sensor, 43, 60

- Parallel circuit, 15
- Parking aid, 432
- Particulate filters, 235
- Particulate matter, 206
- Passive anti-theft system, 433
- Passive keyless entry, 439
- Permanent magnet (PM) motor, 329
- Permanent magnet motors, 154
- Permanent magnet starters, 157
- Piezo injector, 233
- Piezoelectric inline injectors, 232
- Plenum chamber, 356
- Ports, 31
- Position memory, 404
- Power steering, 387
- Pre-engaged starter, 156, 159
- Pre-ignition, 201
- Pressure sensing, 242

- Primary circuit, 74
- Programmed ignition, 180, 193

- Quantization, 347

- Radar, 421
- Radiation, 366
- Radio data systems (RDS), 345, 411
- Radio reception, 411
- Rain sensor, 45
- Random access memory (RAM), 30, 183
- Rate of burning, 200
- Read only memory (ROM), 183, 245, 264
- Read only memory, 30
- Rear lights, 293
- Rear wiper, 321
- Receiver-drier, 363
- Rectification, 131
- Rectifier, 132
- Reflectors, 293, 296, 307
- Refraction, 297
- Refrigeration, 358
- Regenerative braking, 168
- Regulator, 134, 137
- Relays, 15
- Remote keyless entry, 439
- Reserve capacity, 112
- Resistance, 14, 40, 59
- Resistor, 14, 18, 53
- Reverse sensing, 432
- Reversing lights, 293
- Roller clutch, 157
- Rolling code, 406
- Rotary idle actuator, 48
- Rotor, 130

- Scanner, 66
- Schmitt trigger, 23
- Schmitt trigger, 336
- Screen heating, 361
- Seat adjustment, 403
- Seat heating, 360
- Seat-belt tensioners, 421
- Secondary circuit, 74
- Security, 416
- Sensors, 36, 333
- Sequential logic, 28
- Sequential petrol injection, 218
- Series circuit, 15
- Series wound meter, 154
- Short circuit, 13
- Shunt wound meter, 154
- Sidelights, 293, 302
- Single point injection, 211, 225
- Slip, 393

- 40.000
- Use us jobs
- Smart charging, 144
 - Sodium sulphur battery, 122
 - Solenoid, 46
 - Spark plugs, 185
 - Speakers, 410
 - Speed advance, 191
 - Speedometers, 336
 - Square wave, 176
 - Starter circuit, 156, 162
 - Starter motor, 150
 - Starter-generator, 167
 - Starting, 149, 265
 - Stator, 130
 - Steer-by-wire, 396
 - Stepper motor, 25, 48
 - Strain gauge, 39
 - Stratification, 202, 244
 - Sunroofs, 403
 - Switches, 90, 92
 - Symbols, 97
 - Synchronous motors, 50
 - System, 82, 149

 - Tachometer, 336
 - Telematics, 345, 350, 429
 - Tensioners, 418
 - Terminal designation numbers, 85
 - Terminal diagram, 98, 101
 - Terminals, 89
 - Thermistor, 36, 53, 333
 - Thermocouple, 37
 - Throttle control, 376
 - Throttle position sensor, 212
 - Throttle potentiometer, 40, 53
 - Timers, 24
 - Timers and counters, 28
 - Torque, 149
 - Traction control, 375, 395, 398
 - Transistor, 20, 53
 - Trip computer, 338
 - Tungsten, 291

 - Turn angle sensor, 348
 - Two-stroke, 282
 - Tyre pressure warning, 423

 - Ultra-capacitors, 121
 - Ultra-lean mixture, 255
 - Ultraviolet, 301
 - Unit injector, 231

 - Vacuum advance, 172
 - Vacuum fluorescent, 341
 - Valve timing, 240, 244
 - Variable compression ratios, 288
 - Variable resistor, 334
 - Variable valve timing, 242
 - Vehicle condition monitoring, 337
 - Visual display, 339
 - Voltage regulators, 133
 - Voltage stabilizer, 335
 - Voltmeter, 118
 - Volumetric efficiency, 258

 - Water-cooled alternators, 144
 - Waveforms, 63, 73, 74
 - Wheel acceleration, 371
 - Wheel speed sensors, 372
 - Window control circuit, 406
 - Windscreen washers, 318
 - Wiper circuit, 319, 325
 - Wiper motors, 318
 - Wipers, 317
 - Wiring harness, 85, 87
 - World Wide Web, 457

 - X-by-wire, 8, 395
 - Xenon, 305, 314
 - Xenon headlamp, 304

 - Zener diode, 134, 334
 - Zero emission vehicle (ZEV), 443