CHAPTER

Chassis systems

7.1 Brakes

7.1.1 Introduction

The main braking system of a car works by hydraulics. This means that when the driver presses the brake pedal, liquid pressure forces pistons to apply brakes on each wheel. A handbrake system, usually operated by a lever and cables, is used for parking. Most handbrakes operate on the rear wheels (Figure 7.1).

Two types of light vehicle brakes are used. Disc brakes were traditionally used on the front wheels of cars but now are used on all four wheels of most modern vehicles. Braking pressure forces brake pads against both sides of a steel disc. Drum brakes are fitted on the rear wheels of some cars and on all wheels of older vehicles. Braking pressure forces brake shoes to expand outwards into contact with a drum. The important part of brake pads and shoes is a friction lining that grips well and withstands wear.

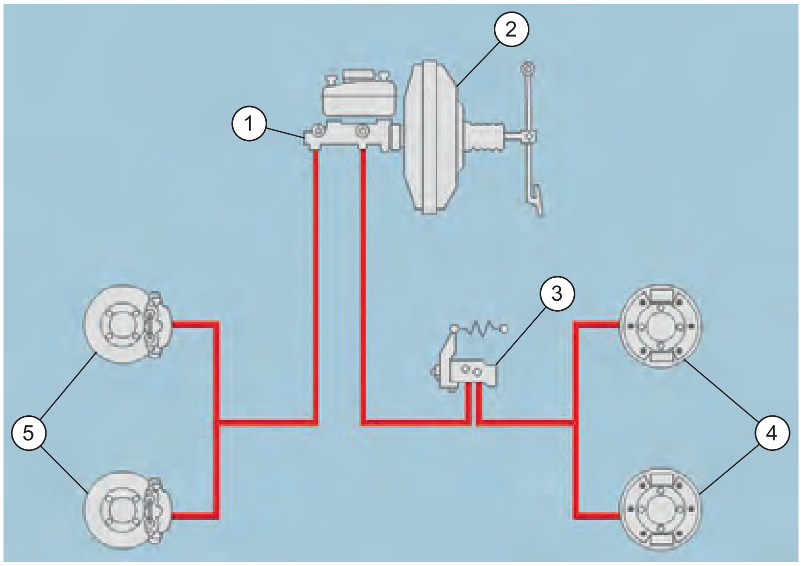

Figure 7.1 Brake system: 1 – master cylinder; 2 – brake servo booster; 3 – pressure regulator; 4 – brake shoes; 5 – brake discs (rotors) and pads

7.1.2 Principle of hydraulic braking

A complete system includes a master cylinder operating several wheel cylinders. The system is designed to give the power amplif cation needed for braking the particular vehicle. On any vehicle, when braking, a lot of the weight is transferred to the front wheels. Most braking effort is therefore designed to work on the front brakes. Some cars have special hydraulic valves to limit rear wheel braking. This reduces the chance of the rear wheels locking and skidding.

The main benef ts of hydraulic brakes are as follows:

- almost immediate reaction to pedal pressure (no free play as with mechanical linkages);
- automatic even pressure distribution (f uid pressure effectively remains the same in all parts of the system);
- increase in force (liquid lever).

Caution and regular servicing is required to ensure the following:

- no air must be allowed in the hydraulic circuits (air compresses and would not transfer the force);
- correct adjustment must be maintained between shoe linings to drums and pads to discs (otherwise the pedal movement would be too large);
- lining materials must be free from contamination (such as oil, grease or brake f uid).

Key fact

Most braking systems have a separate mechanical brake which is a good safety feature.

A separate mechanical system is a good safety feature. Most vehicles have the mechanical handbrake working on the rear wheels but a few have it working on the front – take care.

Note the importance of f exible connections to allow for suspension and steering movement. These f exible pipes are made of high-quality rubber and are covered in layers of strong mesh to prevent expansion when under pressure.

Extra safety is built into braking systems by using a double-acting master cylinder (Figure 7.2). This is often described as tandem and can be thought of as two cylinders in one housing. The pressure from the pedal acts on both cylinders

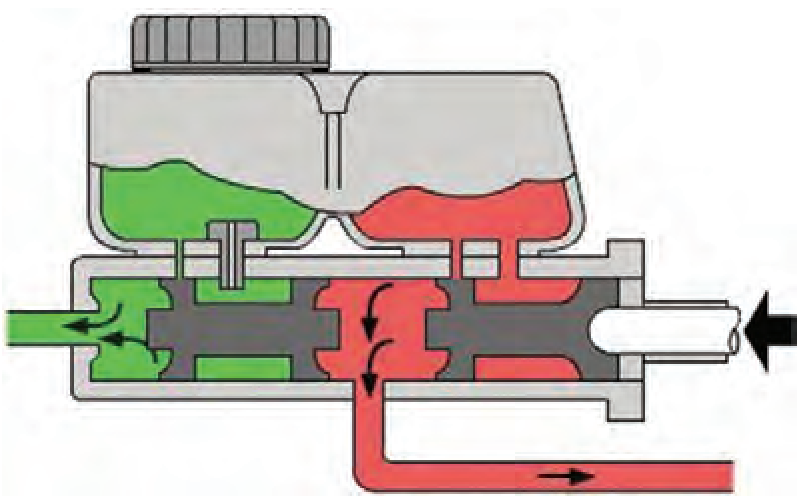

Figure 7.2 Master cylinder operation

but f uid cannot pass from one to the other. Each cylinder is then connected to a complete circuit. This can be by a number of methods:

- diagonal split;
- separate front and rear;
- duplicated front.

7.1.3 Disc and drum brake systems

Figure 7.3 shows a typical disc brake, calliper pads and disc. The type shown is known as single-acting sliding calliper. This is because only one cylinder is used but pads are still pressed equally on both sides of the disc by the sliding action. Disc brakes keep cooler because they are in the airstream and only part of the disc is heated as the brakes are applied. They also throw off water better than drum brakes. In most cases, servicing is minimal. Disc brakes are self-adjusting, and replacing pads is usually a simple task. In the type shown, just one bolt has to be removed to hinge the calliper upwards (Figure 7.4).

Disc brakes provide for good braking and are less prone to brake fade than drum brakes. This is because they are more exposed and can get rid of heat more easily. Brake fade occurs when the brakes become so hot that they cannot transfer energy any more and stop working. This type of problem can happen, for example, after keeping the car brakes on for a long time when travelling down a long steep hill. This is why a lower gear should be used to employ the engine as a brake. It is clearly important to use good-quality pads and linings because inferior materials can fail if overheated.

Drum brakes operate by shoes being forced onto the inside of the drum. Shoes can be moved by double- or single-acting cylinders. The most common layout is to use one double-acting cylinder and brake shoes on each rear wheel of the vehicle, and disc brakes on the front wheels. A double-acting cylinder simply means that as f uid pressure acts through a centre inlet, pistons are forced out of both ends.

Key fact

Disc brakes are self-adjusting.

Figure 7.3 Brake caliper and ventilated disc (rotor)

Key fact

Drum brakes are more affected by wet and heat than disc brakes because both water and heat are trapped inside the drum.

Figure 7.4 Drum brakes showing the shoes and wheel cylinder

7.1.4 Brake adjustments

Brakes must be adjusted so that the minimum movement of the pedal starts to apply the brakes. The adjustment in question is the gap between the pads and disc and/or the shoes and drum.

Disc brakes are self-adjusting because as pressure is released it moves the pads just away from the disc. Drum brakes are different because the shoes are moved away from the drum to a set position by a pull off spring. The set position is adjustable and this can be done in a number of ways.

- Self-adjusting drum brakes are almost universal now. On light vehicles, a common type uses an offset ratchet which clicks to a wider position if the shoes move beyond a certain amount when operated. Modern cars frequently have a self-adjusting handbrake.
- Screwdriver adjustment through a hole in the wheel and drum is also used. This is often a type of nut on a threaded bar which pushes the shoes out as it is screwed along the thread. This method can also have an automatic adjuster f tted.
- An adjustment screw on the back plate is now quite an old method in which a screw or square head protruding from the back plate moves the shoes by a snail cam.

Key fact

You must ensure that the brakes are not rubbing as this would build up heat and wear the friction material very quickly

The adjustment procedure stated by the manufacturer must be followed. As a guide, though, most recommend tightening the adjuster until the wheels lock and then moving it back until the wheel is just released. You must ensure that the brakes are not rubbing as this would build up heat and wear the friction material very quickly. As an aid to fault diagnosis, the effects of incorrect adjustment are as follows:

- reduced braking eff ciency;
- unbalanced braking;
- excessive pedal travel.

Key fact

Servo systems are designed to give little assistance for light braking but increase the assistance as pedal pressure is increased.

7.1.5 Servo-assisted braking

Servo systems are designed to give little assistance for light braking but increase the assistance as pedal pressure is increased. A common servo system uses low pressure (vacuum) from the manifold on one side, and the higher atmospheric pressure on the other side of a diaphragm. The low pressure is taken via a non-return safety valve from the engine inlet manifold. This pressure difference causes a force, which is made to act on the master cylinder (Figure 7.5).

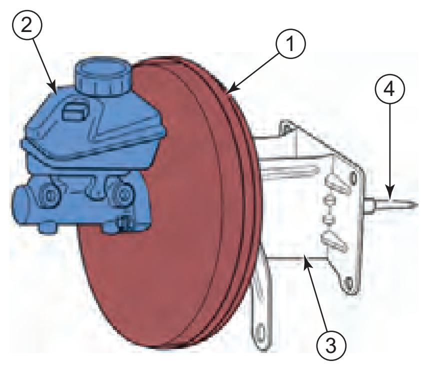

Figure 7.5 Servo unit: 1 – brake servo (booster); 2 – master cylinder and fluid reservoir; 3 – bracket; 4 – diaphragm rod connection to brake pedal

Hydraulic power brakes use the pressure from an engine-driven pump. This pump will often be the same one used to supply the power-assisted steering. Pressure from the pump is made to act on a plunger in line with the normal master cylinder. As the driver applies force to the pedal, a servo valve opens in proportion to the force applied by the driver. The hydraulic assisting force is therefore also proportional. This maintains the important ‘driver feel’.

A hydraulic accumulator (a reservoir for f uid under pressure) is incorporated into many systems. This is because the pressure supplied by the pump varies with engine speed. The pressure in the accumulator is kept between set pressures in the region of 70 bar.

Warning: If you have to disconnect any components from the braking system on a vehicle f tted with an accumulator, you must follow the manufacturer’s recommendations on releasing the pressure f rst.

7.1.5.1 Brake f uid

Always use new and approved brake f uid when topping up or renewing the system. The manufacturer's recommendations must always be followed. Brake f uid is hygroscopic, which means that over a period of time it absorbs water. This increases the risk of the f uid boiling due to the heat from the brakes. Pockets of steam in the system would not allow full braking pressure to be applied. Many manufacturers recommend that the f uid should be changed at regular intervals – in some cases once per year or every 30 000 km.

Safety f rst

Make sure the correct grade of fluid is used.

7.2 Diagnostics – brakes

7.2.1 Systematic testing

If the reported fault is the handbrake not holding, proceed as follows:

1. Conf rm the fault by trying to pull away with the handbrake on.
2. Check the foot brake operation. If correct, this suggests the brake shoes and drums (or pads and discs) are likely to be in good order.
3. Consider this: Do you need to remove the wheels and drums or could it be a cable fault?
4. Check cable operation by using an assistant in the car while you observe.
5. Renew the cable if seized.
6. Check handbrake operation and all associated systems.

7.2.2 Test equipment

7.2.2.1 Brake f uid tester

Because brake f uid can absorb a small amount of water, it must be renewed or tested regularly. It becomes dangerous if the water turns into steam inside the cylinders or pipes, causing the brakes to become ineffective. The tester measures the moisture content of the f uid.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.2.2.2 Brake roller test

This is the type of test carried out as part of the annual safety test. The front or rear wheels are driven into a pair of rollers. The rollers drive each wheel of the car and as the brakes are applied the braking force affects the rotation. A measure of braking eff ciency can then be worked out (Figure 7.6).

Figure 7.6 Gauges on a rolling road brake tester

Figure 7.7 Checking for brake disc run out with a dial gauge

7.2.3 Dial gauge

A dial gauge, sometimes called a clock gauge or a dial test indicator (DTI), is used to check the brake disc for run out. The symptoms of this would often be vibration or pulsation when braking. Manufacturers recommend maximum run out f gures. In some cases, the disc can be re-ground but if in any doubt it is often safer and more cost effective to f t new discs. This would also be done in pairs (Figure 7.7).

7.2.4 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.1.

Table 7.1 Tests and information required

Test carried out	Information required
Brake roller test	Required braking efficiency: 50% for first-line brakes, 25% for second-line brakes and 16% for the parking brake. On modern vehicles, half of the main system is the second line (dual-line brakes). Old vehicles had to use the parking brake as the second line, therefore it had to work at 25%
Brake fuid condition	Manufacturers specify maximum moisture content

7.2.5 Brakes fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive pedal travel	Incorrect adjustment	Adjust it! But check condition as well
Poor performance when stopping	Pad and/or shoe linings worn Seized calliper or wheel cylinders Contaminated linings	Renew Renew or free off, if possible, and safe Renew (both sides)
Car pulls to one side when braking	Seized calliper or wheel cylinder on one side Contaminated linings on one side	Overhaul or renew if piston or cylinder is worn Renew (both sides)
Spongy pedal	Air in the hydraulic system Master cylinder seals failing	Bleed system and then check for leaks Overhaul or renew
Pedal travels to the floor when pressed	Fluid reservoir empty Failed seals in master cylinder Leak from a pipe or union	Refill, bleed system and check for leaks Overhaul or renew Replace or repair as required
Brakes overheating	Shoe return springs broken Callipers or wheel cylinders sticking	Renew (both sides) Free off or renew if in any doubt
Brake judder	Linings worn Drums out of round Discs have excessive run out	Renew Renew Renew
Squeaking	Badly worn linings Dirt in brake drums Anti-squeal shims missing at rear of pads	Renew Clean out with proper cleaner Replace and smear with copper grease

7.2.6 Brakes fault diagnosis table 2

Symptom	Possible cause
Brake fade	Incorrect linings Badly lined shoes Distorted shoes Overloaded vehicle Excessive braking
Spongy pedal	Air in system Badly lined shoes Shoes distorted or incorrectly set Faulty drums Weak master cylinder mounting
Long pedal	Discs running out pushing pads back Distorted damping shims Misplaced dust covers Drum brakes need adjustment Fluid leak Fluid contamination Worn or swollen seals in master cylinder Blocked filler cap vent

(Continued)

Symptom	Possible cause
Brakes binding	Brakes or handbrake maladjusted No clearance at master cylinder push rod Seals swollen Seized pistons Shoe springs weak or broken Servo faulty
Hard pedal – poor braking	Incorrect linings Glazed linings Linings wet, greasy or not bedded correctly Servo unit inoperative Seized calliper pistons Worn dampers causing wheel bounce
Brakes pulling	Seized pistons Variation in linings Unsuitable tyres or pressures Loose brakes Greasy linings Faulty drums, suspension or steering
Fall in fluid level	Worn disc pads External leak Leak in servo unit
Disc brake squeal – pad rattle	Worn retaining pins Worn discs No pad damping shims or springs
Uneven or excessive pad wear	Disc corroded or badly scored Incorrect friction material
Brake judder	Excessive disc or drum run out Calliper mounting bolts loose Worn suspension or steering components

7.2.7 Brake hydraulic faults

Brake hose clamps will assist in diagnosing hydraulic faults and enable a fault to be located quickly. Proceed as follows:

1 Clamp all hydraulic flexible hoses and check the pedal.
2 Remove the clamps one at a time and check the pedal again (each time).
3 The location of air in the system or the faulty part of the system will now be apparent.

7.3 Antilock brakes

7.3.1 Introduction

The reason for the development of antilock brakes (ABS) is very simple. Under braking conditions, if one or more of the vehicle wheels lock (begins to skid), then this has a number of consequences:

- braking distance increases;
- steering control is lost;
- tyre wear is abnormal.

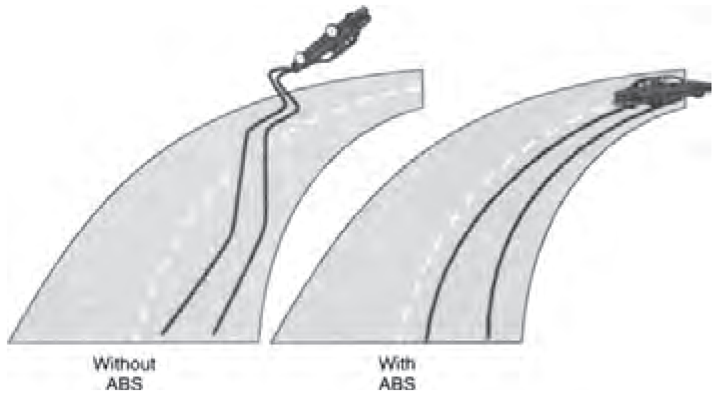

Figure 7.8 Advantages of ABS

The obvious consequence 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 when a tyre skids, 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 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 7.8 shows how ABS can help to maintain steering control even under very heavy braking conditions.

Key fact

The maximum deceleration of a vehicle is achieved when maximum energy conversion is taking place in the brake system – not between the tyres and road.

7.3.1.1 Requirements of ABS

A good way of considering the operation of a complicated 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, conventional brakes must still operate to their full potential. In addition, a warning must be given to the driverThis is normally in the form of a simple warning light
Manoeuvrability must be maintainec	Good steering and road holding must continue when the ABS system is operating. This is arguably the key issue as being able to swere round a hazard while 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

(Continued)

Operational inf uences	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 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 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 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 recognise 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 antilock brake systems are in use, but all operate to achieve the requirements as set out above.

7.3.2 General system description

Key fact

As with many other systems, ABS can be considered as a central control unit with a series of inputs and outputs.

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 7.9. 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 this 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.

From the wheel speed sensors, the electronic control unit (ECU) calculates the components given in Table 7.2.

7.3.3 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.

7.3.3.1 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

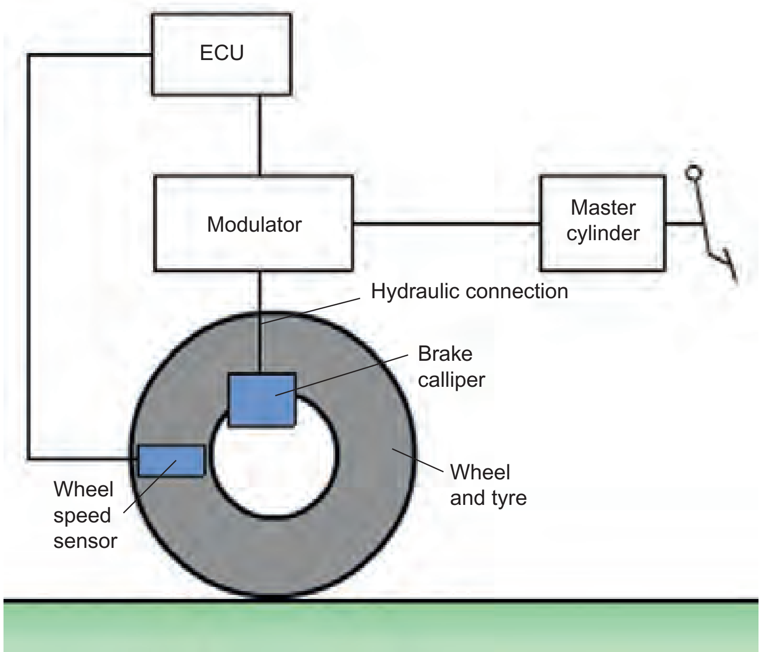

Figure 7.9 ABS closed loop block diagram

Table 7.2 ABS calculations

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 the vehicle reference speed as the starting point and decreases it in a linear manner The rate of decrease 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 are used as the controlled variable. The actual strategy used for ABS control varies with the operating conditions

around which is wound a coil of wire. As the toothed wheel rotates, the changes in inductance of the magnetic circuit generates a signal, the frequency and voltage of which are proportional to wheel speed. The frequency is the signal used by the ECU. The coil resistance is in the order of 800–1000 Ω. Coaxial cable is used to prevent interference affecting the signal. Some systems now use 'Hall effect' sensors.

Safety f rst

Note: ABS problems may require specialist attention – but don't be afraid to check the basics. An important note, however is that some systems require special equipment to reinitialise the ECU if it has been disconnected.

7.3.3.2 Electronic control unit

The function of the 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 programme 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.

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 microprocessors;
- operation of valves and relays;
- operation of fault memory control;
- reading and writing functions of the internal memory.

All this takes less than 300 ms.

7.3.3.3 Hydraulic modulator

A hydraulic modulator has three operating positions:

1. pressure build-up brake line open to the pump;
2. pressure holding brake line closed;
3. pressure release brake line open to the reservoir.

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. Figure 7.10 shows an ABS hydraulic modulator with integrated ECU.

Figure 7.10 Hydraulic modulators (Source: Bosch Media)

7.4 Diagnostics – antilock brakes

7.4.1 Systematic testing procedure

If the reported fault is the ABS warning light staying on, proceed as given in Figure 7.11 (a scanner may be needed to reset the light).

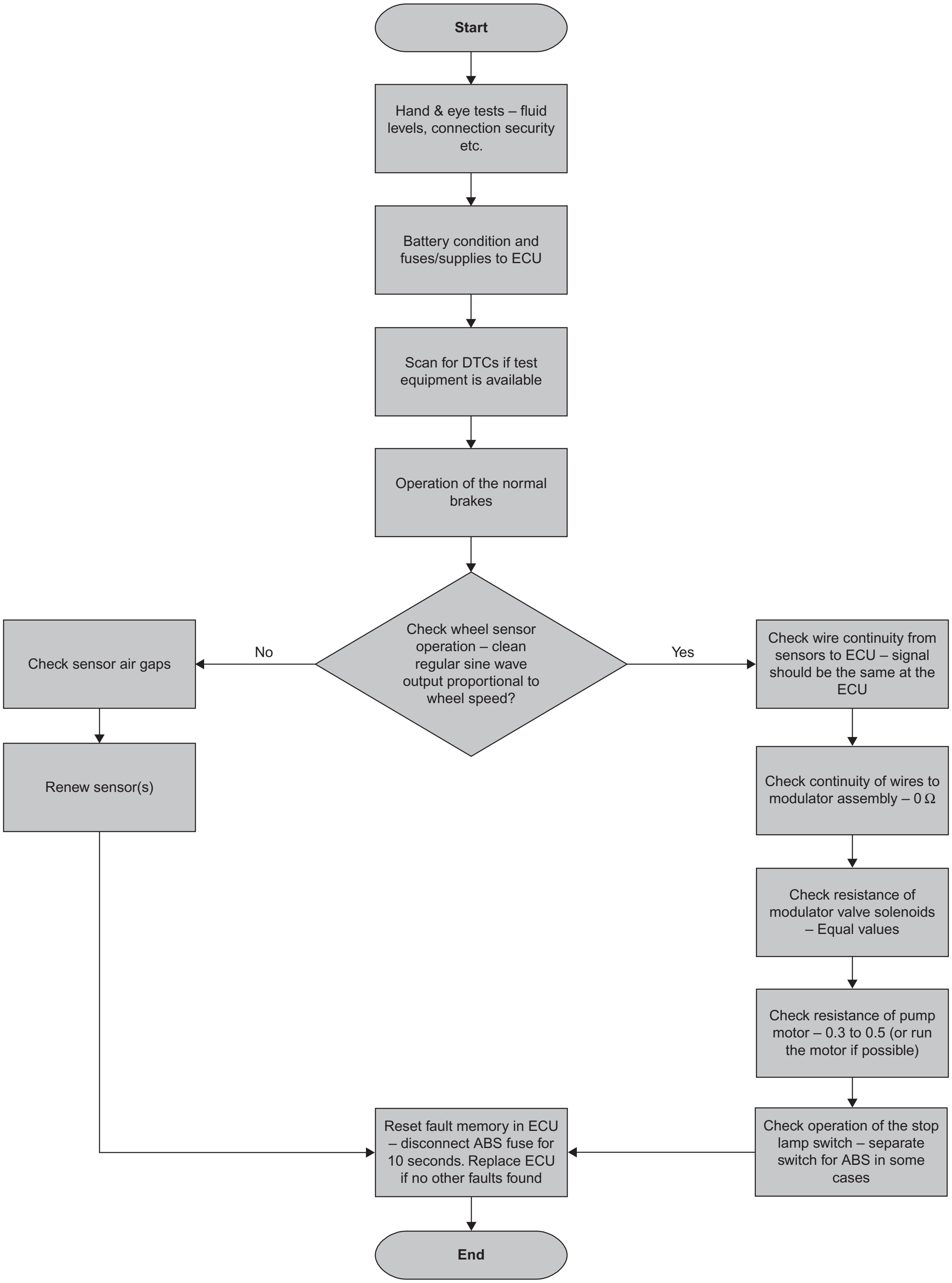

Figure 7.11 ABS diagnosis chart

7.4.2 Antilock brakes fault diagnosis table

Symptom	Possible cause
ABS not working and/or warning light on	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
Warning light comes on intermittently	Wheel sensor air gap incorrect Wheel sensor air gap contaminated Loose wire connection

Mercedes Benz C220 2.2 Sport D

ABS diagnostics

Removal/bleeding the system

Speed sensor
- The sensors are protected by tubes which are handed left and right for the vehicle
- Remove safety harness from nearest block connector
- Remove rear road wheel for access to sensor if needed
- Remove brake calliper
- Remove sensor retaining bolt(s) and remove sensor and shims if fitted
- Lightly lubricate sensor sleeve and push in sensor as far as it will go, do not rotate wheel
- Refit sensor retaining bolt and tighten to correct torque
- Check air gap and adjust if needed
- Reconnect harness

Hydraulic control unit
- Disconnect battery
- Remove fluid regulator
- Remove relay cover if fitted
- Remove earth lead
- Remove assistance cable from the centrifugal regulator
- Fit absorbent cloth underneath hydraulic control unit
- Undo hydraulic pipe(s)
- Disconnect retaining nuts/bolts/bracket/mountings
- Remove hydraulic control unit
- Refit in reverse order
- Tighten mounting nuts/bolts to correct torque
- Tighten hydraulic pipes to correct torque
- Bleed system—see bleed instructions

Electronic control unit
- Disconnect battery
- Remove battery, if needed and tray
- Remove seat/trim or mountings for access
- Remove wiring multi-plug/block
- Remove ECU securing screws/bolts or strap
- Remove ECU
- Refit in reverse order

G or acceleration sensor
- This operation only applies to four wheel drive models
- Disconnect electrical connections
- Drill out mounting bolts
- Remove mounting bolts/nuts and remove unit
- Fit unit with arrow pointing in direction of vehicle movement

Bleeding the brakes
- Do not switch on ignition before bleeding the system as this could cause air bubbles to form in the hydraulic unit
- Bleed system without the aid of the servo, on a level surface and without the wheels suspended
- If the hydraulic control unit is fitted with bleed screw(s), bleed these first in the conventional manner. Bleed screw first then second bleed screw (if fitted with two bleed screws)
- Cars fitted with delay valve must be bled before the remainder of the system
- To bleed delay valve release screw (below bleed screw) one turn
- Pump pedal 10 times and hold pressure
- Open bleed screw and close before pressure is completely lost
- For cars with diagonally split systems bleed each system in turn starting with right rear, left front, left rear, right front
- For cars with front/rear split systems bleed rear first then front
- Fill fluid reservoir
- Check operation of warning lights
- Low speed road tests and check ABS operation

Figure 7.12 ABS repair process example

7.4.3 Bleeding antilock brakes

Special procedures may be required to bleed the hydraulic system when ABS is f tted. Refer to appropriate data for the particular vehicle. An example is reproduced in Figure 7.12.

7.5 Traction control

7.5.1 Introduction

The steerability of a vehicle is not only lost when the wheels lock up on braking, the same effect arises 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 move. 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 traction control system (TCS), anti-slip regulation (ASR), or just traction control (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 7.13 shows a block diagram of a traction control system. Note the links with ABS and the engine control system.

Key fact

Traction control is usually combined with ABS.

Traction control will intervene to

- maintain stability;
- reduce yawing moment reactions;
- provide optimum propulsion at all speeds;
- reduce driver workload.

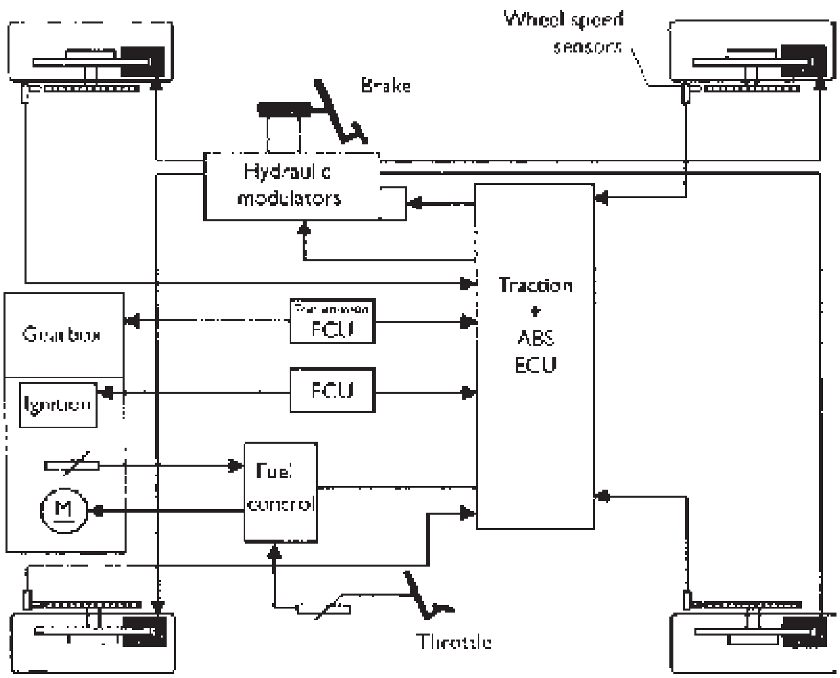

Figure 7.13 Integrated traction control system

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 a time when the driver might not have been able to cope with the situation.

7.5.2 Control functions

Control of tractive force can be by a number of methods.

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 drivers 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. 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 that passenger comfort is maintained

7.5.3 System operation

The description that follows is for a vehicle with an electronic accelerator (drive by wire). 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 servomotor. When accelerating, the increase in engine torque leads to an increase in driving torque at the wheels. To achieve 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 on at least 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 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. All these take place without the driver touching the brake pedal. The summary of this is that the braking force must be applied to the slipping wheel so as to equalise the combined braking coefficient for each driving wheel.

Safety first

Note: Traction control (TCR or TCS or ASC) is usually linked with the ABS and problems may require specialist attention – but don't be afraid to check the basics. As with ABS, note that some systems require special equipment to reinitialise the ECU if it has been disconnected.

7.6 Diagnostics – traction control

7.6.1 Systematic testing

If the reported fault is the traction control system not working, proceed as given in Figure 7.14.

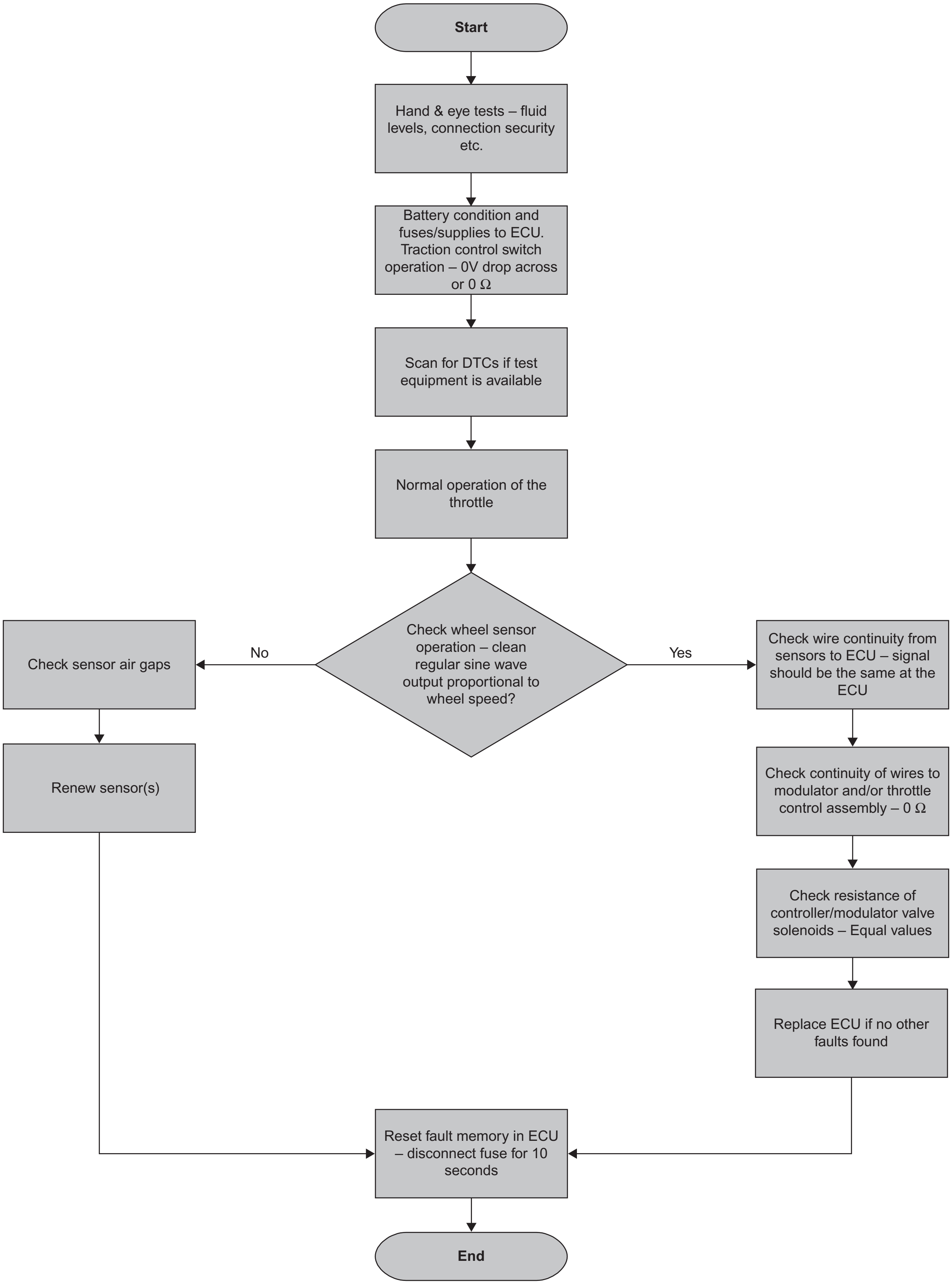

Figure 7.14 Traction control diagnosis chart

7.6.2 Traction control fault diagnosis table

Symptom	Possible cause
Traction control inoperative	Wheel sensor or associated wiring open circuit/high resistance Wheel sensor air gap incorrect Power supply/earth to ECU low or not present Switch open circuit ABS system fault Throttle actuator inoperative or open circuit connections Communication link between ECUs open circuit ECU needs to be initialised

7.7 Steering and tyres

The tyre performs two basic functions:

1. It acts as the primary suspension, cushioning the vehicle from the effects of a rough surface.
2. It provides frictional contact with the road surface. This allows the driving wheels to move the vehicle. The tyres also allow the front wheels to steer and the brakes to slow or stop the vehicle.

Key fact

Modern tyres are almost always tubeless.

The tyre is a f exible casing which contains air. Tyres are manufactured from reinforced synthetic rubber. The tyre is made of an inner layer of fabric plies which are wrapped around bead wires at the inner edges. The bead wires hold the tyre in position on the wheel rim. The fabric plies are coated with rubber, which is moulded to form the side walls and the tread of the tyre. Behind the tread is a reinforcing band, usually made of steel, rayon or glass f bre. Modern tyres are mostly tubeless, so they have a thin layer of rubber coating the inside to act as a seal.

7.7.1 Construction of a tubeless radial tyre

The wheel is made with a leak-proof rim and the valve is rubber mounted into a hole formed in the well of the rim. The tyre is made with an accurate bead, which f ts tightly onto the rim. A thin rubber layer in the interior of the tyre makes an airtight seal.

Key fact

The plies of a radial tyre pass from bead to bead at 90° to the circumference, or radially

The plies of a radial tyre pass from bead to bead at 90° to the circumference, or radially. There is a rigid belt band consisting of several layers of textile or metallic threads running round the tyre under the tread. Steel wire is often used in the construction of radial tyres. The radial tyre is f exible but retains high strength. It has good road holding and cornering power. In addition, radial tyres are economical due to their low 'rolling resistance' (Figure 7.15).

A major advantage of a radial tyre is its greatly improved grip even on wet roads. This is because the rigid belt band holds the tread f at on the road surface, when cornering. The rigid belt band also helps with the escape of water from under the tyre.

7.7.2 Steering box and rack

Steering boxes contain a spiral gear known as a worm gear, or something similar, which rotates with the steering column. One form of design has a nut wrapped

Figure 7.15 Tyres

round the spiral and is therefore known as a worm and nut-steering box. The grooves can be f lled with recirculating ball bearings, which reduce backlash or slack in the system and also reduce friction, making steering lighter. On vehicles with independent front suspension, an idler unit is needed together with a number of links and several joints. The basic weakness of the steering box system is in the number of swivelling joints and connections. If there is just slight wear at a number of points, the steering will not feel, or be, positive.

The steering rack is now used almost without exception on light vehicles. This is because it is simple in design and very long lasting. The wheels turn on two large swivel joints. Another ball joint (often called a track rod end) is f tted on each swivel arm. A further ball joint to the ends of the rack connects the track rods. The rack is inside a lubricated tube and gaiters protect the inner ball joints. The pinion meshes with the teeth of the rack, and as it is turned by the steering wheel, the rack is made to move back and forth, turning the front wheels on their swivel ball joints. On many vehicles now, the steering rack is augmented with hydraulic power assistance (Figure 7.16).

Key fact

The steering rack is now used on almost all light vehicles because it is simple in design, long lasting and makes optimum use of available space.

7.7.3 Power-assisted steering

Rack and pinion steering requires more turning effort than a steering box, although this is not too noticeable with smaller vehicles. However, most cars, in particular heavier ones with larger engines or with wider tyres, which scrub more, often benef t from power steering.

Many vehicles use a belt-driven hydraulic pump to supply f uid under pressure for use in the system. Inside the rack and pinion housing is a hydraulic valve, which is operated as the pinion is turned for steering. The valve controls the f ow of oil into a cylinder, which has a piston connected to the rack. This assists with the steering effort quite considerably.

A well-designed system will retain ‘feel’ of road conditions for the driver to control the car. Steering a slow-moving heavier vehicle when there is little room can be tiring or even impossible for some drivers. This is where power steering has its best advantage. Many modern systems are able to make the power steering

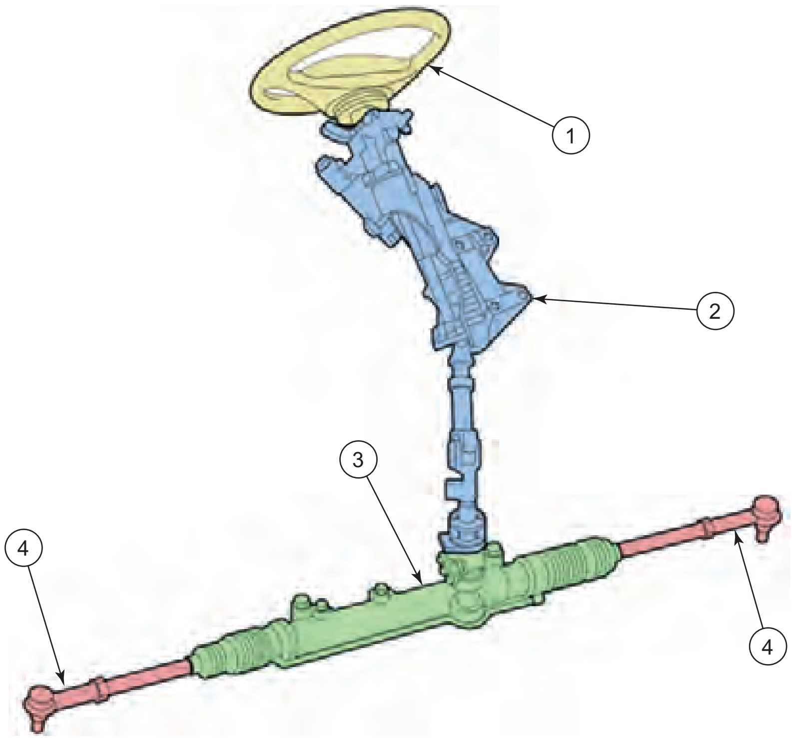

Figure 7.16 Steering system: 1 – steering wheel; 2 – column; 3 – rack; 4 – track rod ends

Figure 7.17 Electric power steering (Source: ZF)

progressive. This means that as the speed of the vehicle increases, the assistance provided by the power steering reduces. This maintains better driver feel.

Many modern systems use electric power steering. This employs a powerful electric motor as part of the steering linkage. There are two main types of electric power steering:

- replacing the conventional hydraulic pump with an electric motor while the ram remains much the same;
- a drive motor, which directly assists with the steering and which has no hydraulic components (the most common method now).

The second system uses a small electric motor acting directly on the steering via an epicyclic gear train. This completely replaces the hydraulic pump and servo cylinder. It also eliminates the fuel penalty of the conventional pump and greatly simplif es the drive arrangements. Engine stall when the power steering is operated at idle speed 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 f tted into the steering column. Other methods are also used, but the optical is most common (Figure 7.17).

Key fact

Many modern systems use electric power steering.

7.7.4 Steering characteristics

The steering characteristics of a vehicle, or in other words, the way in which it reacts when cornering, can be described by one of three headings:

1. oversteer;
2. understeer;
3. neutral.

Oversteer occurs when the rear of the vehicle tends to swing outward more than the front during cornering. This is because the slip angle on the rear axle is significantly greater than the front axle. This causes the vehicle to travel in a tighter circle, hence the term oversteer. If the steering angle is not reduced, the vehicle will break away and all control will be lost. Turning the steering towards the opposite lock will reduce the front slip angle.

Understeer occurs when the front of the vehicle tends to swing outward more than the rear during cornering. This is because the slip angle on the rear axle is signif cantly smaller than the front axle. This causes the vehicle to travel in a greater circle, hence the term understeer. If the steering angle is not increased, the vehicle will be carried out of the corner and all control will be lost. Turning the steering further into the bend will increase the front slip angle. Front-engined vehicles tend to understeer because the centre of gravity is situated in front of the vehicle centre. The outward centrifugal force therefore has a greater effect on the front wheels than on the rear.

Neutral steering occurs when the centre of gravity is at the vehicle centre and the front and rear slip angles are equal. The cornering forces are therefore uniformly spread. Note, however, that understeer or oversteer can still occur if the cornering conditions change.

Figure 7.18 Positive camber

7.7.5 Camber

On many cars, the front wheels are not mounted vertically to the road surface. Often they are tilted outwards at the top. This is called positive camber (Figure 7.18), and has the following effects:

- easier steering, less turning effort required;
- less wear on the steering linkages;
- less stress on main components;
- smaller scrub radius, which reduces the effect of wheel forces on the steering.

Negative camber has the effect of giving good cornering force (Figure 7.19). Some cars have rear wheels with negative camber. With independent suspension systems, wheels can change their camber from positive through neutral to negative as the suspension is compressed. This varies, however, with the design and position of the suspension hinge points.

Figure 7.19 Negative camber

Key fact

Typical value for camber is approximately 0.5° (values will vary so check specs).

7.7.6 Castor

The front wheels tend to straighten themselves out after cornering. This is due to a castor action. Supermarket trolley wheels automatically run straight when pushed because the axle on which they rotate is behind the swivel mounting. Vehicle wheels get the same result by leaning the swivel pin mountings back so that the wheel axle is moved slightly behind the line of the swivel axis. The further the axle is behind the swivel, the stronger will be the straightening effect. The main effects of a positive castor angle (Figure 7.20) are

- self-centring action;
- helping in determining the steering torque when cornering.

Key fact

Typical castor value is approximately 2–4° (values will vary so check specs)

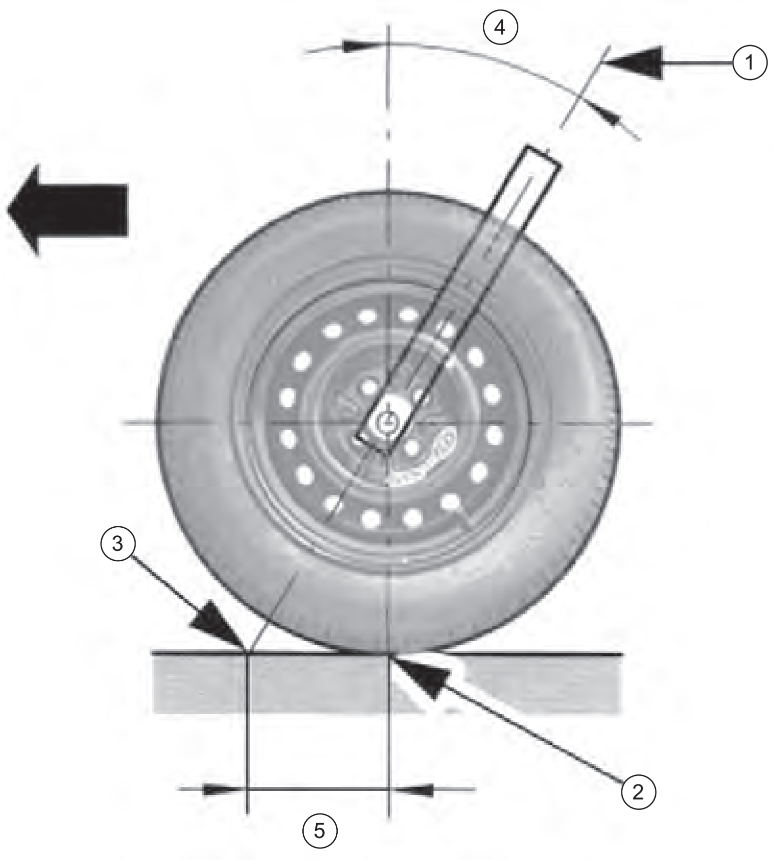

Figure 7.20 Castor angle – Positive: 1 – steering axis; 2 – wheel contact point; 3 – positive castor point of intersection of steering axis with the road surface; 4 – castor angle

Negative castor is used on some front wheel drive vehicles to reduce the return forces when cornering (Figure 7.21). Note that a combination of steering geometry angles is used to achieve the desired effect. This means that in some cases the swivel axis produces the desired self-centre action so the castor angle may need to be negative to reduce the return forces on corners.

7.7.7 Swivel axis inclination

Definition

SAI: Swivel axis inclination

KPI: King pin inclination

The swivel axis is also known as the steering axis. Swivel axis inclination (Figure 7.22) means the angle compared to vertical made by the two swivel joints when viewed from the front or rear. On a strut-type suspension system, the angle is broadly that made by the strut. This angle always leans towards the middle of the vehicle. The swivel axis inclination (also called kingpin inclination) is mainly for

- producing a self-centre action;
- improving steering control on corners;
- giving a lighter steering action.

Key fact

Typical KPI/SAI value is approximately 7–9° (values will vary so check specs)

Scrub radius, wheel camber and swivel axis inclination, all have an effect on one another. The swivel axis inclination mainly affects the self-centring action, also known as the aligning torque. Because of the axis inclination, the vehicle is raised slightly at the front as the wheels are turned. The weight of the vehicle therefore tries to force the wheels back into the straight-ahead position.

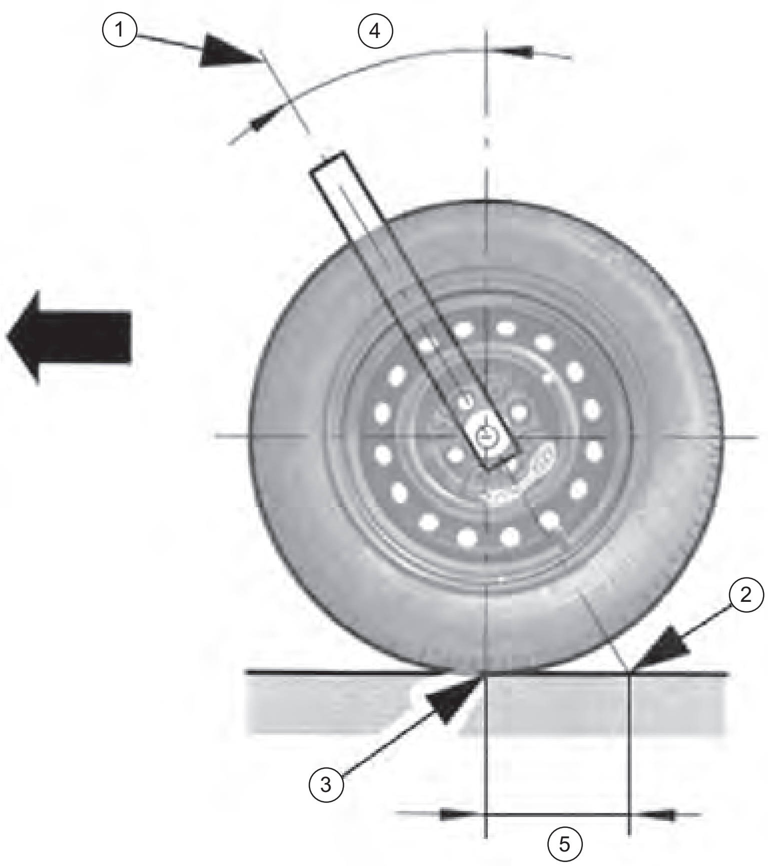

Figure 7.21 Castor angle – Negative: 1 – steering axis; 2 – wheel contact point; 3 – negative castor point of intersection of steering axis with the road surface; 4 – castor angle

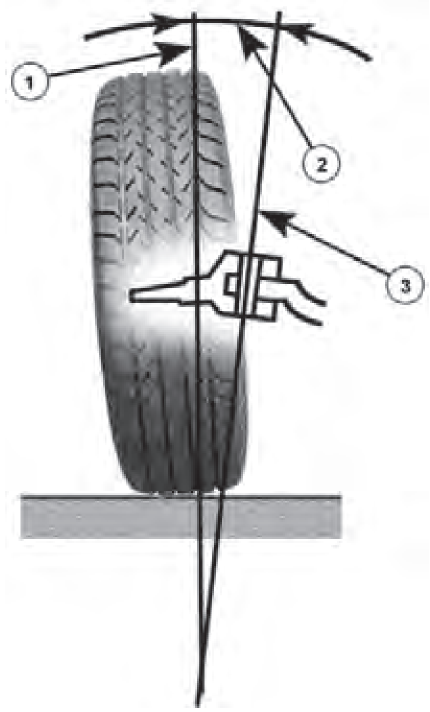

Figure 7.22 King pin or swivel axis inclination: 1 – perpendicular; 2 – swivel angle; 3 – steering axis

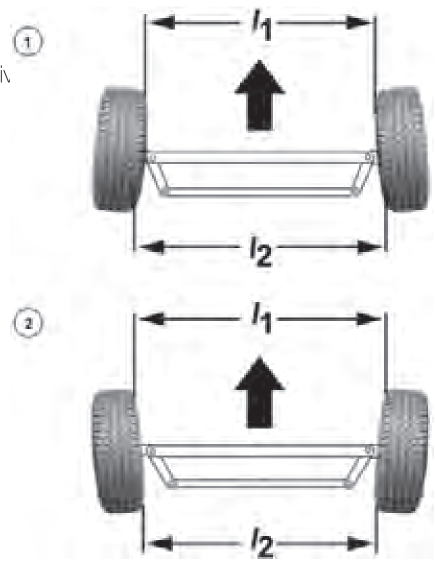

Figure 7.23 Tracking: 1 – toe-in; 2 – toe-out

7.7.8 Tracking

As a front wheel drive car drives forward, the tyres pull on the road surface, taking up the small amount of free play in the mountings and joints. For this reason, the tracking is often set toe-out so that the wheels point straight ahead when the vehicle is moving. Rear wheel drive tends to make the opposite happen because it pushes against the front wheels. The front wheels are therefore set toe-in. When the car moves, the front wheels are pushed out taking up the slack in the joints, so the wheels again end up straight ahead. The amount of toe-in or toe-out is very small, normally not exceeding 5 mm (the difference in the distance between the front and rear of the front wheels). Correctly set tracking ensures true rolling of the wheels and therefore reduced tyre wear. Figure 7.23 shows wheels set toe-in and toe-out.

Key fact

As a front wheel drive car drives forward, the tyres pull on the road surface, forcing the toe-out of the wheels inwards – resulting in them being parallel (but check data).

7.7.9 Scrub radius

The scrub radius is the distance between the contact point of the steering axis with the road and the wheel centre contact point. The purpose of designing in a scrub radius is to reduce the steering force and to prevent steering shimmy. It also helps to stabilise the straight-ahead position. It is

Table 7.3 Scrub radius

Scrub radius	Description	Properties
Negative	The contact point of the steering axis hits the road between the wheel cent and the outer edge of the wheel	Braking forces produce a torque which tends to make the wheel turn inwards. The result of this is that the wheel with the greatest braking force is turned in with greater torque. This steers the vehicle away from the side with the heaviest braking producing a built-in counter steer action which has a stabilising effect
Positive	The contact point of the steering axis hits the road between the wheel cent and the inner edge of the wheel	A positive scrub radius makes turning the steering easier However, braking forces produce a torque, which tends to make the wheel turn outwards. The result of this is that the wheel with the greatest braking force is turned out with greater torque. Under different road conditions, this can have the effect of producing an unwanted steering angle
Zero	The contact point of the steering axis hits the road at the same place as th wheel centre	This makes the steering heavy when the vehicle is at rest because the wheel cannot roll at the steering angle. However no separate turning torque about the steering axis is created

Key fact

The scrub radius is the distance between the contact point of the steering axis with the road and the wheel centre contact point.

possible to design the steering with a negative, positive or zero scrub radius as described in Table 7.3.

From the information given, you will realise that decisions about steering geometry are not clear-cut. One change may have a particular advantage in one area but a disadvantage in another. To assist with fault diagnosis, a good understanding of steering geometry is essential.

7.8 Diagnostics – steering and tyres

7.8.1 Systematic testing

If the reported fault is heavy steering, proceed as follows:

1. Ask if the problem has just developed. Road test to conf rm.
2. Check the obvious such as tyre pressures. Is the vehicle loaded to excess? Check geometry?
3. Assuming tyre pressure and condition is as it should be, we must move on to further tests.
4. For example, jack up and support the front of the car. Operate the steering lock to lock. Disconnect one track rod end and move the wheel on that side, and so on.
5. If the fault is in the steering rack, then this should be replaced and the tracking should be set.
6. Test the operation with a road test and inspect all other related components for security and safety.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.8.2 Test equipment

7.8.2.1 Tyre pressure gauge and tread depth gauge

These are often underrated pieces of test equipment. Correctly inf ated tyres make the vehicle handle better, stop better and use less fuel. The correct depth

Figure 7.24 Basic mirror-type tracking gauges

of tread means the vehicle will be signif cantly safer to drive, particularly in wet conditions.

7.8.2.2 Tracking gauges

The toe-in and toe-out of a vehicle's front wheels are very important. Many types of tracking gauges are available. One of the most commonly used is a frame placed against each wheel with a mirror on one side and a moveable viewer on the other (Figure 7.24). The viewer is moved until marks are lined up and the tracking can then be measured.

7.8.2.3 Wheel balancer

This is a large f xed piece of equipment in most cases. The wheel is removed from the car, f xed onto the machine and spun at high speed. Sensors in the tester measure the balance of the wheel. The tester then indicates the amount of weight which should be added to a certain position. The weight is added by f tting small lead weights (Figure 7.25).

7.8.3 Four-wheel alignment

Standard front-wheel alignment is simply a way of making sure the wheels are operating parallel with one another and that the tyres meet the road at the correct angle. Four-wheel alignment makes sure that the rear wheels follow the front wheels in a parallel path.

Different manufacturers set different specif cations for the angles created between the suspension, steering, wheels and the frame of the vehicle. When these angles are correct, the vehicle is properly aligned.

The main reasons for correct alignment are to ensure that the vehicle achieves

- minimum rolling friction;
- maximum tyre mileage;
- stability on the road;
- steering control for the driver.

Figure 7.25 Wheel balancer

Figure 7.26 Laser alignment systems give digital readouts

Diagnosing incorrect alignments is usually just a matter of examining the

- tyres for unusual wear;
- wheels for damage;
- steering wheel for position.

In addition, a road test is usually necessary to check that the vehicle is not pulling to one side, wandering or weaving. Four basic wheel settings or angles determine whether a vehicle is properly aligned (Figures 7.26 and 7.27).

- Camber is the inward or outward tilt of a wheel compared to a vertical line. If the camber is out of adjustment, it will cause tyre wear on one side of the tyre's tread.

Figure 7.27 Scale to show angle of wheels

Table 7.4 Tests and information required

Test carried out	Information required
Tracking	The data for tracking will be given as either an angle or a distance measurement. Ensure you use the appropriate data for your type of test equipment. The distance will be a figure such as 3mm toe-in, and if as an angle such as 50' toe-in (50' means 50 minutes). The angle of 1° is split into 60 minutes, so in this case the angle is 50/60 or 5/6 of a degree
Pressures	A simple measurement which should be in bars. You will find, however, many places still use PSI (pounds per square inch). As in all other cases, only compare like with like
Tread depth	The minimum measurement (e.g. 1.6mm over 75% of the tread area but please note the current local legal requirements)

- Caster is the degree that the car's steering axis is tilted forward or backward from the vertical as viewed from the side of the car. If the caster is out of adjustment, it can cause problems with self-centring and wander. Caster has little effect on tyre wear.
- Toe refers to the directions in which two wheels point relative to each other. Incorrect toe causes rapid tyre wear to both tyres equally. Toe is the most common adjustment and it is always adjustable on the front wheels and is adjustable on the rear wheels of some cars.

7.8.4 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.4.

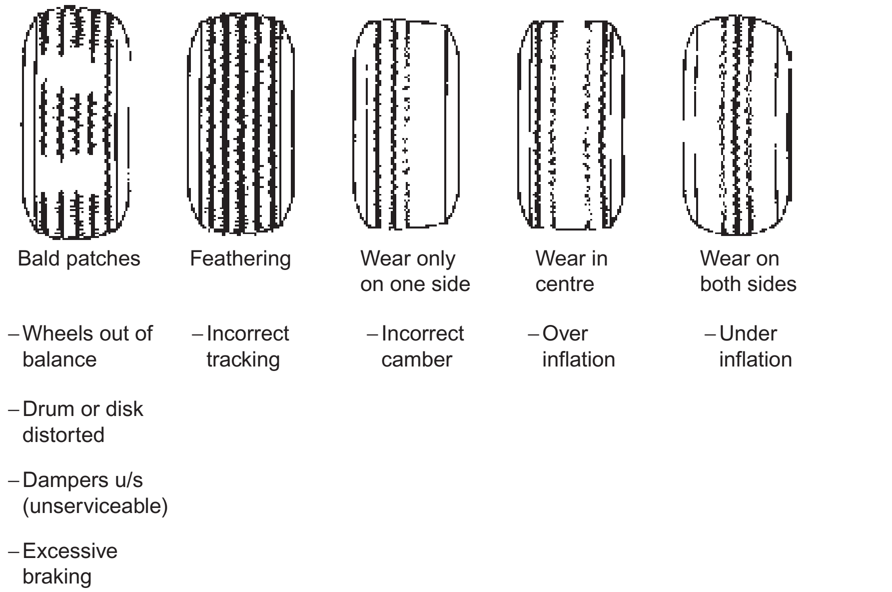

Figure 7.28 Tread wear patterns are a useful diagnostic aid

7.8.5 Tyres fault diagnosis table

The following table lists some of the faults which can occur if tyres and/or the vehicle are not maintained correctly. Figure 7.28 shows the same.

Symptom	Possible cause/fault
Wear on both outer edges of the treac	Under infation
Wear in the centre of the tread all rour the tyre	Over infation
Wear just on one side of the tread	Incorrect camber
Feathering	Tracking not set correctly
Bald patches	Unbalanced wheels or unusual driving technique!

7.8.6 Tyre inf ation pressures

The pressure at which the tyres should be set is determined by a number of factors such as

- load to be carried;
- number of plies;
- operating conditions;
- section of the tyre.

Tyre pressures must be set at the values recommended by the manufacturers. Pressure will vary according to the temperature of the tyre – this is affected by operating conditions. Tyre pressure should always be adjusted when the tyre is cold and be checked at regular intervals.

Safety f rst

Tyre pressures must always be set at the values recommended by the manufacturer.

7.8.7 Steering fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive free play at steering wheel	Play between the rack and pinion or in the steering box Ball joints or tie-rod joints worn Column coupling loose or bushes worn	Renew in most cases but adjustment may be possible Renew Secure or renew
Vehicle wanders, hard to keep in a straight line	As above Alignment incorrect Incorrect tyre pressure or mix of tyre types is not suitabl Worn wheel bearings	As above Adjust to recommended setting Adjust pressures or replace tyres as required Renew
Stiff steering	Wheel alignment incorrect Tyre pressures too low Ball joints or rack seizing	Adjust to recommended setting Adjust pressures Renew
Wheel wobble	Wheels out of balance Wear in suspension linkages Alignment incorrect	Balance or renew Renew Adjust to recommended setting
Under steer or over steer	Tyre pressures incorrect Dangerous mix of tyre types Excessive free play in suspension or steering system	Adjust pressures Replace tyres as required Renew components as required

7.8.8 Steering, wheels and tyres fault diagnosis

Symptom	Possible cause
Wandering or instability	Incorrect wheel alignment Worn steering joints Wheels out of balance Wheel nuts or bolts loose
Wheel wobble	Front or rear Wheels out of balance Damaged or distorted wheels/tyres Worn steering joints
Pulling to one side	Defective tyre Excessively worn components Incorrect wheel alignment
Excessive tyre wear	Incorrect wheel alignment Worn steering joints Wheels out of balance Incorrect infation pressures Driving style! Worn dampers
Excessive free-play	Worn track rod end or swivel joints Steering column bushes worn Steering column universal joint worn
Stiff steering	Lack of steering gear lubrication Seized track rod end joint or suspension swivel joint Incorrect wheel alignment Damage to steering components

7.9 Suspension

7.9.1 Introduction

The purpose of a suspension system can best be summarised by the following requirements:

- cushion the car, passengers and load from road surface irregularities;
- resist the effects of steering, braking and acceleration, even on hills and when loads are carried;
- keep tyres in contact with the road at all times;
- work in conjunction with the tyres and seat springs to give an acceptable ride at all speeds.

The above list is diff cult to achieve completely, so some sort of compromise has to be reached. Because of this, many different methods have been tried, and many are still in use. Keep these four main requirements in mind and it will help you understand why some systems are constructed in different ways.

Key fact

A suspension system reduces road shocks so providing comfort to the passengers and preventing damage to the load and vehicle components.

A vehicle needs a suspension system to cushion and damp out road shocks so providing comfort to the passengers and preventing damage to the load and vehicle components. A spring between the wheel and the vehicle body allows the wheel to follow the road surface. The tyre plays an important role in absorbing small road shocks. It is often described as the primary form of suspension. The vehicle body is supported by springs located between the body and the wheel axles. Together with the damper, these components are referred to as the suspension system.

As a wheel hits a bump in the road, it is moved upwards with quite some force. An unsprung wheel is affected only by gravity, which will try to return the wheel to the road surface but most of the energy will be transferred to the body. When a spring is used between the wheel and the vehicle body, most of the energy in the bouncing wheel is stored in the spring and not passed to the vehicle body. The vehicle body will now only move upwards through a very small distance compared to the movement of the wheel.

7.9.2 Suspension system layouts

On older types of vehicle, a beam axle was used to support two stub axles. Beam axles are now rarely used in car suspension systems, although many commercial vehicles use them because of their greater strength and constant ground clearance (Figure 7.29).

The need for a better suspension system came from the demand for improved ride quality and improved handling (Figure 7.30). Independent front suspension (IFS) was developed to meet this need. The main advantages of independent front suspension are as follows:

- When one wheel is lifted or drops, it does not affect the opposite wheel.
- The unsprung mass is lower, therefore the road wheel stays in better contact with the road.
- Problems with changing steering geometry are reduced.

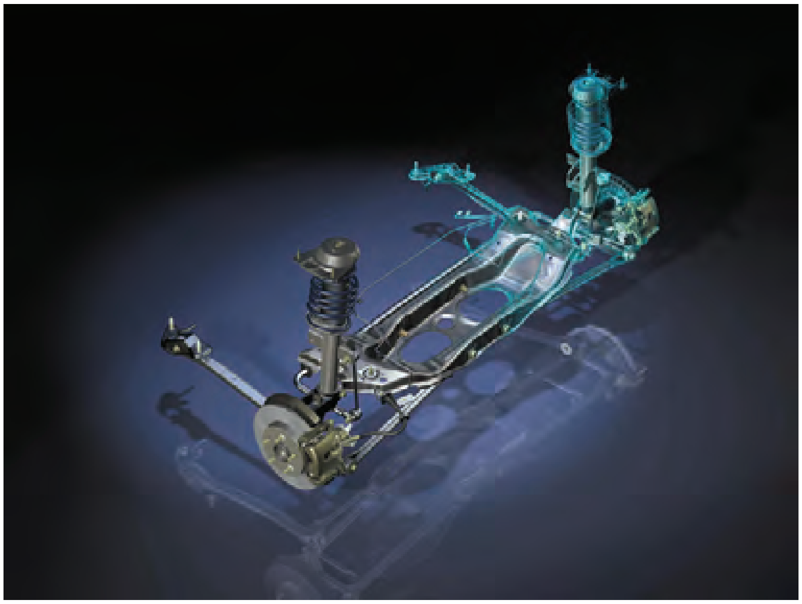

Figure 7.29 Rear suspension layout(Source: Ford Media)

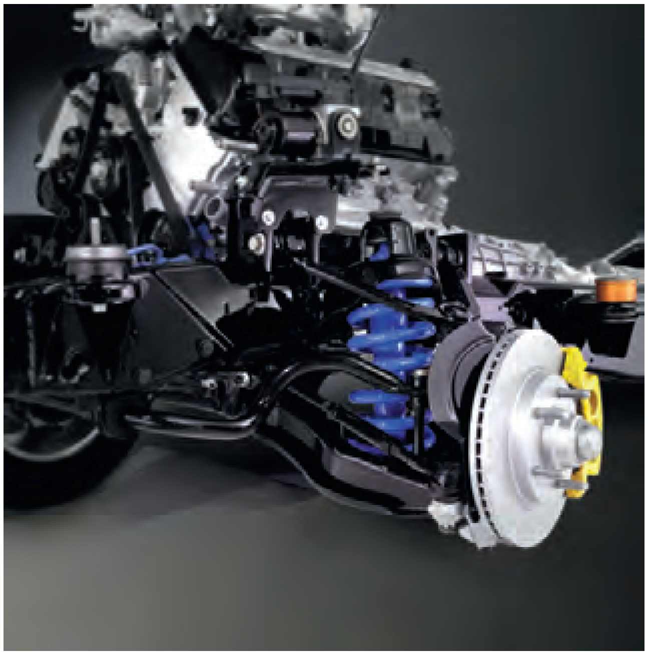

Figure 7.30 Front wishbone suspension system

- There is more space for the engine at the front.
- Softer springing with larger wheel movement is possible.

There are a number of basic suspension systems in common use. Figure 7.31 shows a front suspension layout on a Jaguar.

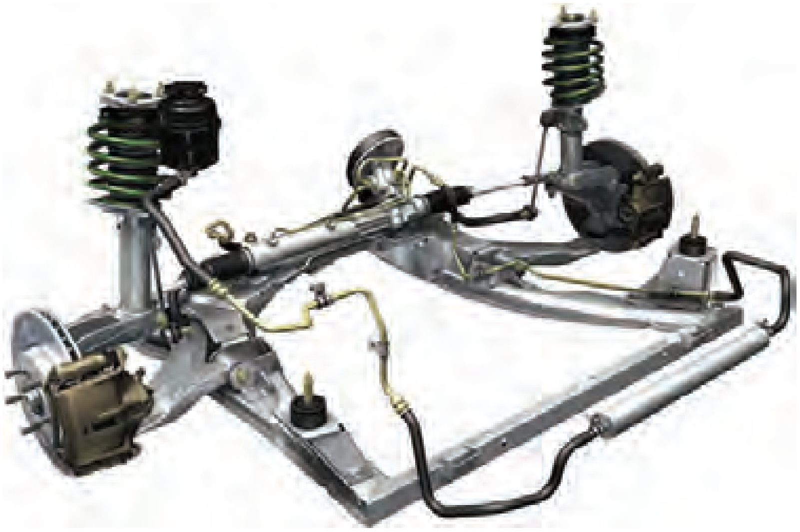

Figure 7.31 Front suspension struts (Source: Jaguar Media)

Table 7.5 Front axle suspension

Name	Description	Advantages	Disadvantages
Double transverse arms	Independently suspended wheels located by two arms perpendicular to direction of travel. The arms support stub axles	Low bonnet line Only slight changes of track and camber with suspension movements	A large number of pivot points is required High production costs
Transverse arms with leaf spring	A traverse arm and a leaf spring locate the wheel	The spring can act as an anti-roll bar, hence low cost	Harsh response when lightly loaded Major changes of camber as vehicle is loaded
Transverse arm with McPherson strut	A combination of the spring, damper, wheel hub, steering arm and axle joints in one unit	Only slight changes in track and camber with suspension movement Forces on the joints are reduced because of the long strut	The body must be strengthened around the upper mounting A low bonnet line is difficult to achieve
Double trailing arms	Two trailing arms support the stub axle. These can act on torsion bars often formed as a single assembly	No change in castor, camber or track with suspension movement Can be assembled and adjusted off the vehicle	Lots of space is required at the front of the vehicle Expensive to produce Acceleration and braking cause pitching movements which in turn changes the wheel base

7.9.3 Front axle suspensions

As with most design aspects of the vehicle, compromise often has to be reached between performance, body styling and cost. Table 7.5 compares the common front axle suspension systems.

Table 7.6 Rear axle suspension

Name	Description	Advantages	Disadvantages
Rigid axle with leaf springs	The fnal drive, differential and axle shafts are all one unit	Rear track remains constant, reducing tyre wear Good directional stability because no camber change causes body roll on corners Low cost Strong design for load caying	High unsprung mass The interaction of the wheels causes lateral movement. reducing tyre adhesion when the suspension is compressed on one side
Rigid axle with A-bracket	Solid axle with coil springs and a central joint supports the axl on the body	Rear of the vehicle pulls down on braking which stabilises the vehicle	High cost Large unsprung mass
Rigid axle with compression/tension struts	Coil springs provide the springing and the axle is located by struts	Suspension extension is reduced when braking or accelerating The springs are isolated from these forces	High loads on the welded joints High weight overall Large unsprung mass
Torsion beam trailing arm axle	Two links are used, connected by a 'U' section that has low torsional stiffness but high resistance to bending	Track and camber does not change Low unsprung mass Simple to produce Space saving	Torsion bar springing on this system can be more expensive than coil springs
Torsion beam axle with Panhard rod	Two links are welded to an axe tube or 'U' section and lateral forces are taken by a Panhard rod	Track and camber do not change Simple fexible joints to the bodywork	Torsion bar springing on this system can be more expensive than coil springs
Trailing arms	The pivot axis of the trailing arms is at 90° to the direction of vehicle travel	When braking, the rear of the vehicle pulls down, giving stable handling Track and camber do not change Space saving	Slight change of wheel base when the suspension is compressed
Semi-trailing arms – f xed-lengthdrive shafts	The trailing arms are pivoted at an angle to the direction of travel. Only one universal joint (UJ) is required because the radius of the suspension arm is the same as the driveshaft when the suspension is compressed	Only very small dive when braking Lower cost than when variable length shafts are used	Sharp changes in track when the suspension is compressed resulting in tyre wear Slight tendency to oversteer
Semi-trailing arms – variable length drive shafts	The fnal drive assembly is mounted to the body and two UJs are used on each shaft	The two arms are independent of each other Only slight track changes	Large camber changes High cost because of the drive shafts and joints

7.9.4 Rear axle suspensions

Table 7.6 compares the common rear axle suspension systems.

7.9.5 Anti-roll bar

The main purpose of an anti-roll bar is to reduce body roll on corners. The anti-roll bar can be thought of as a torsion bar. The centre is pivoted on the body

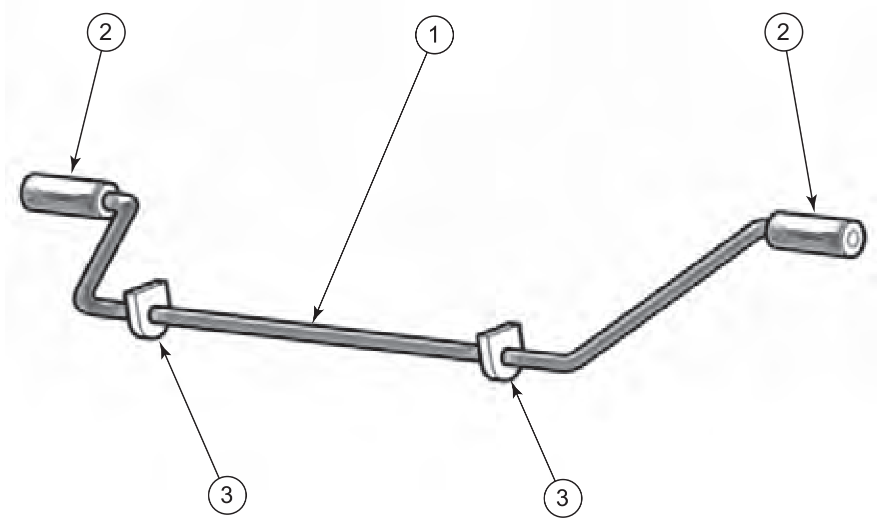

Figure 7.32 Anti-roll bar: 1 – torsion bar; 2 – pivots on suspension lower arms; 3 – fixings to vehicle body

and each end bends to make connection with the suspension/wheel assembly. When the suspension is compressed on both sides, the anti-roll bar has no effect because it pivots on its mountings (Figure 7.32).

As the suspension is compressed on just one side, a twisting force is exerted on the anti-roll bar. The anti-roll bar is now under torsional load. Part of this load is transmitted to the opposite wheel, pulling it upwards. This reduces the amount of body roll on corners. The disadvantages are that some of the 'independence' is lost and the overall ride is harsher. Anti-roll bars can be f tted to both front and rear axles.

7.9.6 Springs

The requirements of the springs can be summarised as follows:

- absorb road shocks from uneven surfaces;
- control ground clearance and ride height;
- ensure good tyre adhesion;
- support the weight of the vehicle;
- transmit gravity forces to the wheels.

There are a number of different types of spring in use on modern light vehicles. Table 7.7 lists these together with their main features.

Key fact

Strictly speaking, a damper damps out spring oscillations, but as it also absorbs shock it is also called a shock absorber.

7.9.7 Dampers

The functions of a damper can be summarised as follows (Figure 7.33):

- ensure directional stability;
- ensure good contact between the tyres and the road;

Table 7.7 Spring features

Name	Comments	Characteristics
Coil springs	The most common spring currently in use on light vehicles. The coil spring is a torsion bar wound into a spiral	Can be progressive if the diameter of the spring is tapered conically Cannot transmit lateral or longitudinal forces, hence the need for links or arms Little internal damping Little or no maintenance High travel
Leaf springs	These springs can be single or multiple leaf. They are most often mounted longitudinally Nowadays they are only used on commercial vehicles	Can transmit longitudinal and lateral forces Short travel High internal damping High load capacity Maintenance may be required Low height but high weight
Torsion bar springs	A torsion bar is a spring where twisting loads are applied to a steel bar. They can be round or square section, solid or hollow. Their surface must be finished accurately to eliminate pressure points, which may cause cracking and fatigue failure. They can be fitted longitudinally or laterally	Maintenance free but can be adjusted Transmit longitudinal and lateral forces Limited self-damping Linear rate Low weight May have limited fatigue life
Rubber springs	Nowadays rubber springs are only used as a supplement to other forms of springs. They are, however, popular on trailers and caravans	Progressive rate Transmit longitudinal and lateral forces Short travel Low weight and low cost Their springing and damping properties can change with temperature
Air springs	Air springs can be thought of as being like a balloon or football on which the car is supported. The system involves compressors and air tanks. They are not normally used on light vehicles	Expensive Good-quality ride Electronic control can be used Progressive spring rate High production cost
Hydro-pneumatic springs	A hydro-pneumatic spring is a gas spring with hydraulic force transmission. Nitrogen is usually used as the gas. The damper can be built in as part of the hydraulic system. The springs can be hydraulically connected together to reduce pitch or roll. Ride height control can be achieved by pumping oil into or out of the working chamber	Progressive rate Ride height control Damping built-in Pressurised oil supply is required Expensive and complicated

- prevent build-up of vertical movements;
- reduce oscillations;
- reduce wear on tyres and chassis components.

There are a number of different types of damper. These are listed in Table 7.8.

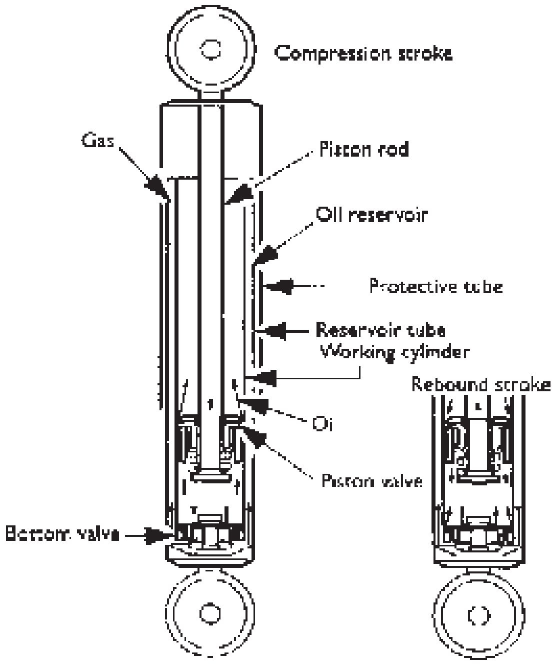

Figure 7.33 Twin-tube gas damper

Table 7.8 Types of damper

Friction damper	Not used on cars today, but you will find this system used as part of caravan or trailer stabilisers
Lever-type damper	Used on earlier vehicles, the lever operates a piston which forces oil into a chamber
Twin-tube telescopic damper	This is a commonly used type of damper; it consists of two tubes. An outer tube forms a reservoir space and contains the oil displaced from an inner tube. Oil is forced through a valve by the action of a piston as the damper moves up or down. The reservoir space is essential to make up for the changes in volume as the piston rod moves in and out
Single-tube telescopic damper	This is often referred to as a gas damper. However, the damping action is still achieved by forcing oil through a restriction. The gas space behind a separator piston is to compensate for the changes in cylinder volume caused as the piston rod moves. It is at a pressure of approximately 25 bar
Twin-tube gas damper (Figure 7.33)	The twin-tube gas damper is an improvement on the well-used twin-tube system. The gas cushion is used in this case to prevent oil foaming. The gas pressure on the oil prevents foaming, which in turn ensures constant operation under all operating conditions. Gas pressure is lower than for a single-tube damper at approximately 5 bar
Variable rate damper	This is a special variation of the twin-tube gas damper. The damping characteristics vary depending on the load on the vehicle. Bypass grooves are machined in the upper half of the working chamber. With light loads, the damper works in this area with a soft damping effect. When the load is increased, the piston moves lower down the working chamber away from the grooves resulting in full damping effect
Electronically controlled dampers	These are dampers where the damping rate can be controlled by solenoid valves inside the units. With suitable electronic control, the characteristics can be changed within milliseconds to react to driving and/or load conditions

7.10 Diagnostics – Suspension

7.10.1 Systematic testing

If the reported fault is poor handling, proceed as follows:

1 Road test to conf rm the fault.
2 With the vehicle on a lift, inspect obvious items like tyres and dampers.
3 Consider if the problem is suspension related or in the steering, for example. You may have decided this from road testing.
4 Inspect all the components of the system you suspect; for example, dampers for correct operation and suspension bushes for condition and security. Let's assume the fault was one front damper not operating to the required standard.
5 Renew both of the dampers at the front to ensure balanced performance.
6 Road test again and check for correct operation of the suspension and other systems.

7.10.2 Test equipment

7.10.2.1 Damper tester

The operating principle of a damper tester is shown in Figure 7.34, which indicates that the damper is not operating correctly in this case. This is a device that will draw a graph to show the response of the dampers. It may be useful for providing paper evidence of the operating condition but a physical examination is normally adequate.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.10.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.9.

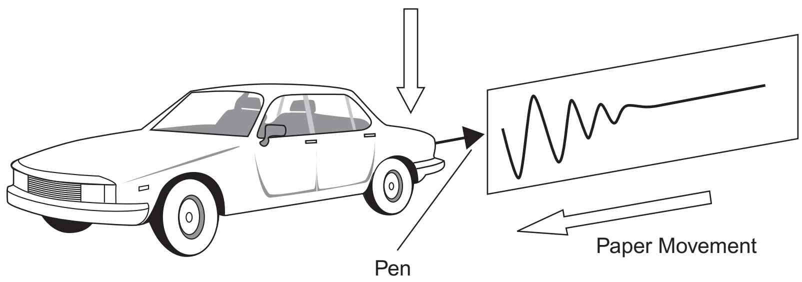

Figure 7.34 Representation of a damper (shock absorber) test – the symptoms suggest a faulty damper

Table 7.9 Tests and information required

Test carried out	Information required
Damper operation	The vehicle body should move down as you press on it, bounce back just past the start point and then return to the rest position
Suspension bush condition	Simple levering, if appropriate, should not show excessive movement, cracks or separation of rubber bushes
Trim height	This is available from data books as a measurement from say the wheel centre to a point on the car wing above

7.10.4 Suspension fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive pitch or roll when driving	Dampers worn	Replace in pairs
Car sits lopsided	Broken spring Leak if hydraulic suspension	Replace in pairs Rectify by replacing unit ottifng new pipes
Knocking noises	Excessive free play in a suspension joint	Renew
Excessive tyre wear	Steering/suspension geometry incorrect (may be due to accident damage)	Check and adjust or replace any 'bent' or out of true components

7.10.5 Suspension fault diagnosis table 2

Symptom	Possible cause
Excessive pitching	Defective dampers Broken or weak spring Worn or damaged anti-roll bar mountings
Wandering or instability	Broken or weak spring Worn suspension joints Defective dampers
Wheel wobble	Worn suspension joints
Pulling to one side	Worn suspension joints Accident damage to suspension alignment
Excessive tyre wear	Worn suspension joints Accident damage to suspension alignment Incorrect trim height (particularly hydrolastic systems)

7.11 Active Suspension

7.11.1 Active suspension operation

A traditional or a conventional suspension system, consisting of springs and dampers, is passive. In other words, once it has been installed in the car, its characteristics do not change (Figure 7.35).

The main advantage of a conventional suspension system is its predictability. Over time, the driver will become familiar with a car's suspension and understand its capabilities and limitations. The disadvantage is that the system has no way of compensating for situations beyond its original design (Figure 7.36).

An active suspension system (also known as computerized ride control) has the ability to adjust itself continuously. It monitors and adjusts its characteristics to suit the current road conditions. As with all electronic control systems, sensors supply information to an ECU which in turn outputs to actuators. By changing its characteristics in response to changing road conditions, active suspension offers improved handling, comfort, responsiveness and safety (Figure 7.37).

Key fact

An active suspension system has the ability to adjust itself continuously

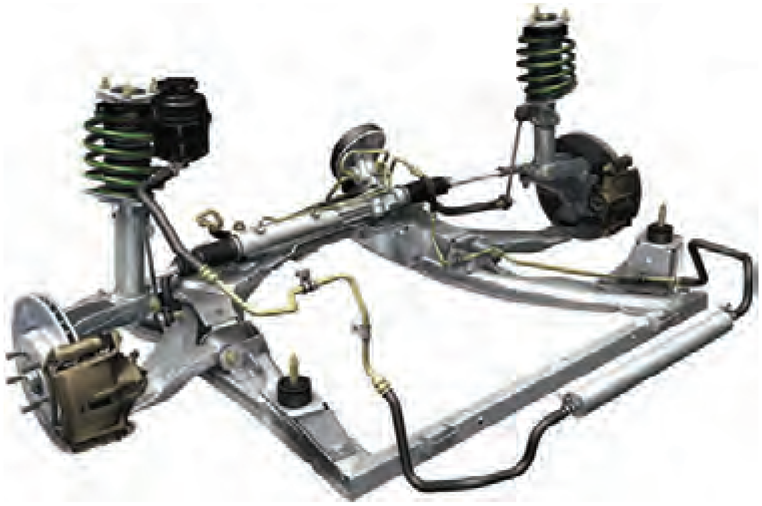

Figure 7.35 Jaguar suspension system (Source: Jaguar Media)

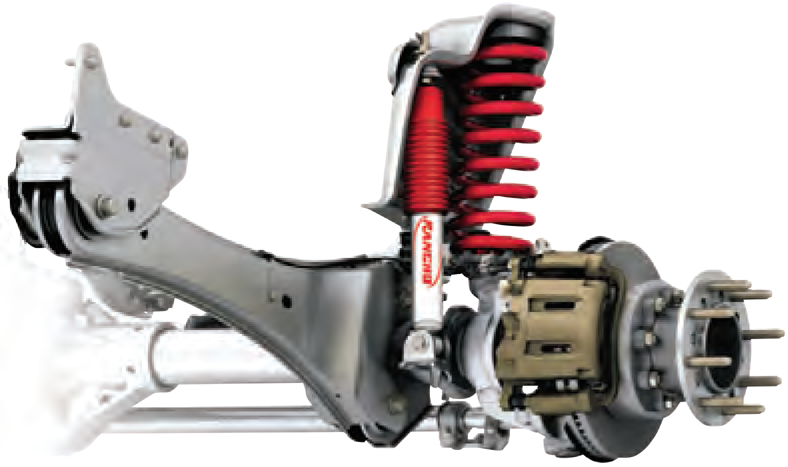

Figure 7.36 Suspension system (Source: Ford Media)

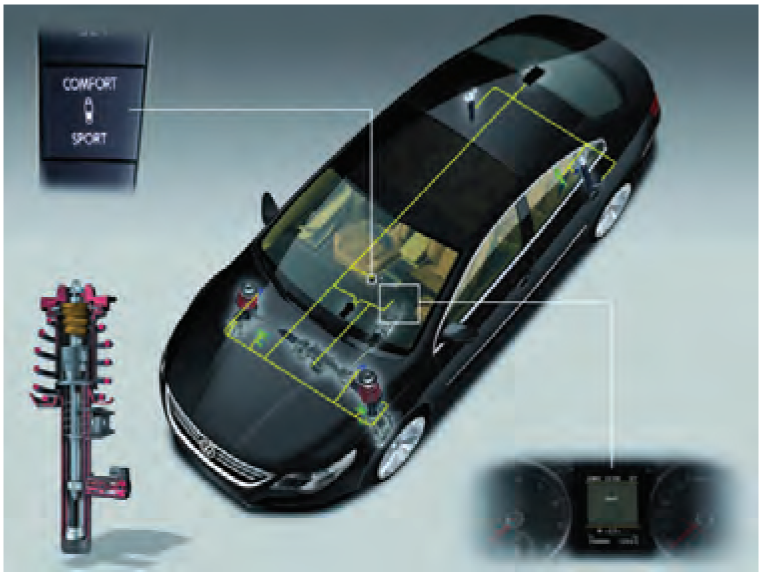

Figure 7.37 Active suspension also allows adjustments; in this case, between sport and comfort settings (Source: Volkswagen Media)

Figure 7.38 Potholes

Active suspension systems consist of the following components:

- electronic control unit;
- adjustable dampers and springs;
- sensors at each wheel and throughout the car;
- levelling compressor (some systems).

Components vary between manufacturers, but the principles are the same.

Active suspension works by constantly sensing changes in the road surface and feeding that information to the ECU, which in turn controls the suspension springs and dampers. These components then act upon the system to modify the overall suspension characteristics by adjusting damper stiffness, ride height (in some cases) and spring rate.

Assume that a car with conventional suspension is cruising down the road and then, after turning left, hits a series of potholes on the right-hand side, each one larger than the next (Figure 7.38). This would present a serious challenge to a conventional suspension system because the increasing size of the holes could set up an oscillation loop and bottom out the system. An active system would react very differently.

Sensors send information to the ECU about yaw and lateral acceleration. Other sensors measure excessive vertical travel, particularly in the right-front region of the car, and a steering angle sensor provides information on steering position.

The ECU analyses this information in approximately 10 ms. It then sends a signal to the right-front spring to stiffen up. A similar signal is sent to the right-rear spring, but this will not be stiffened as much. The rigidity of the suspension dampers on the right-hand side of the vehicle is therefore increased. Because of these actions, the vehicle will drive through the corner, with little impact on driveability and comfort.

One of the latest types of sensor is produced by Bosch. The sensor simultaneously monitors three of a vehicle's movement axes – two acceleration

Figure 7.39 Integrated sensor(Source: Bosch Media)

Figure 7.40 Suspension strut and actuator connection(Source: Delphi Media)

or inclination axes (*ax*, *ay*) and one axis of rotation (Ω*z*). Previously, at least two separate sensors were required for this. The integration of the sensors for lateral acceleration and yaw rate reduces space requirements in the vehicle and the assembly work for the complete system (Figure 7.39).

There are a number of ways of controlling the suspension. However, in most cases it is done by controlling the oil restriction in the damper. On some systems, ride height is controlled by opening a valve and supplying pressurised f uid from an engine-driven compressor.

Other systems use special f uid in the dampers that reacts to a magnetic f eld, which is applied from a simple electromagnetic coil. The case study of a Delphi system in the next section looks at this method in detail (Figure 7.40).

The improvements in ride comfort are considerable, which is why active suspension technology is becoming more popular. In simple terms, sensors provide the input to a control system that in turn actuates the suspension dampers in a way that improves stability and comfort.

7.11.2 Delphi MagneRide case study

MagneRide was the industry's f rst semi-active suspension technology that employs no electro-mechanical valves and small moving parts. The MagneRide magneto-rheological (MR) f uid-based system consists of MR f uid-based single-tube struts, shock absorbers (dampers), a sensor set and an on-board controller (Figure 7.41).

MR f uid is a suspension of magnetically soft particles such as iron microspheres in a synthetic hydrocarbon base f uid. When MR f uid is in the 'off' state, it is not magnetised, and the particles exhibit a random pattern. But in the 'on' or magnetised state, the applied magnetic f eld aligns the metal particles into f brous structures, changing the f uid rheology to a near plastic state (Figure 7.42).

Def nition

Rheology: The study of friction between liquids.

Figure 7.41 MagneRide suspension components(Source: Delphi Media)

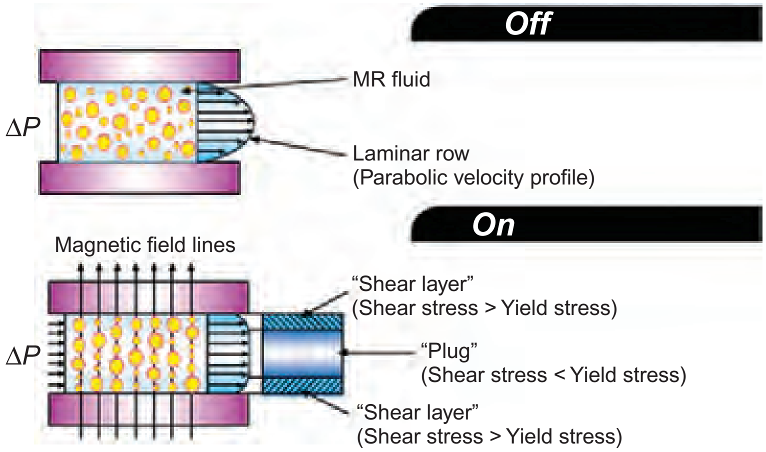

Figure 7.42 Fluid in the on and off states(Source: Delphi Media)

By controlling the current to an electromagnetic coil inside the piston of the damper, the MR f uid's shear strength is changed, varying the resistance to f uid f ow. 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 (Figure 7.43).

The layout in Figure 7.44 shows the inputs and outputs of the MagneRide system. Note the connections with the ESP system and how the information is shared over the controller area network (CAN).

The MagneRide system, produced by Delphi, uses a special f uid in the dampers. The properties of this f uid are changed by a magnetic f eld. This allows for very close control of the damping characteristics and a signif cant improvement in ride comfort and quality.

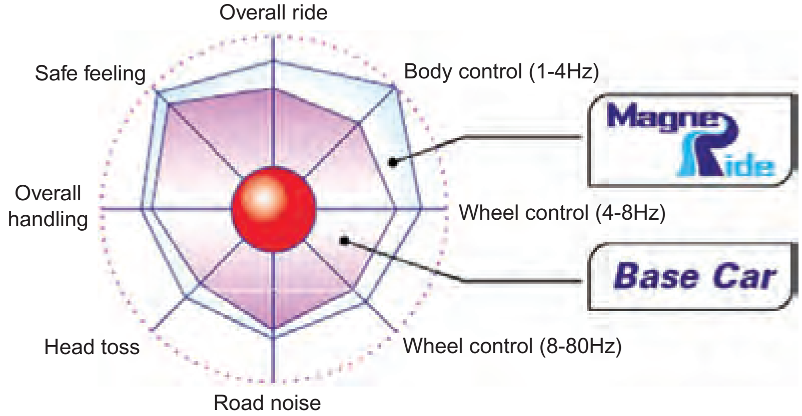

Figure 7.43 Representation of improvements when suspension is controlled (Source: Delphi Media)

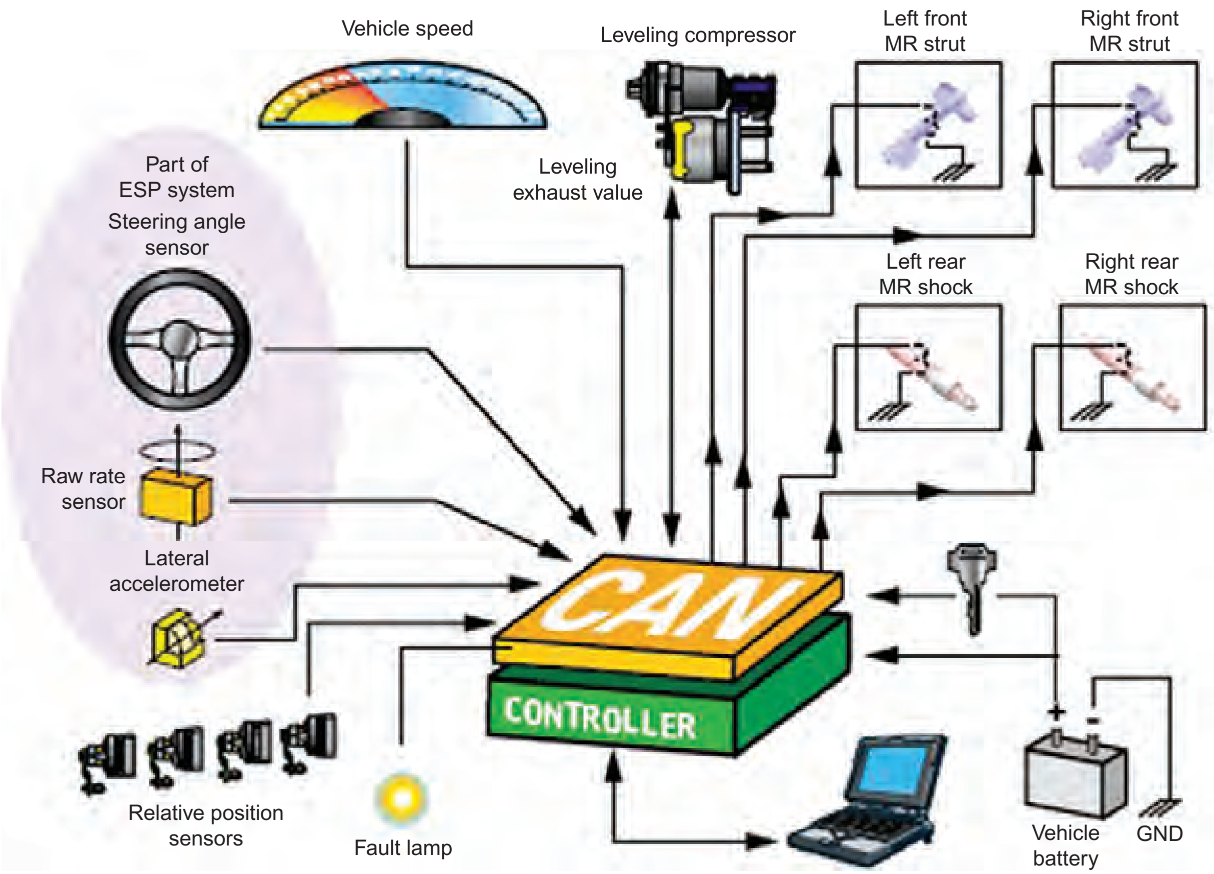

Figure 7.44 Control system (Source: Delphi Media)

7.12 Diagnostics – active suspension

7.12.1 Systematic testing

Even for an active system it may be useful to treat it like a conventional system at f rst. If the reported fault is poor handling and/or an MIL and code indicates a suspension problem, proceed as follows:

1 Conf rm the fault and scan for codes.

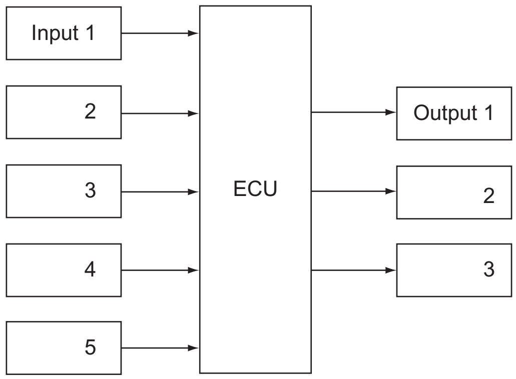

Figure 7.45 System block diagram

2. With the vehicle on a lift, inspect obvious items like tyres and dampers for leaks.
3. Inspect all the components of the system you suspect and look for leaks.
4. Check mountings for damage and sensor wiring.
5. Check sensors and actuators (see section 7.12.2 and chapter 4).

7.12.2 Back to the black box

Key fact

Most vehicle systems involve an ECU.

Active suspension systems now revolve around an ECU, and the ECU can be considered to be a 'black box'; in other words, we know what it should do but the exact details of how it does it are less important.

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 (ground) connections are OK, then the fault must be in 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 (Figure 7.45).

Key fact

If the readings of all similar items connected to an ECU are the same, then it is reasonable to assume the f gure is almost certainly correct.

Normal fault-f nding or testing techniques can be applied to the sensors and actuators. For example, if the system uses four movement sensors, then an easy test is to measure their output. Even if the correct value is 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 reading is obtained on the end of the sensor wires at the ECU, then almost all of the 'inputs' have been tested with just a few readings. The same technique will often work with 'outputs'.

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.

CHAPTER

Electrical systems

8.1 Electronic components and circuits

8.1.1 Introduction

This section describing the principles and applications of various electronic components and circuits is not intended to explain their detailed operation. Overall, an understanding of basic electronic principles will help to show how electronic systems operate. These can range from a simple interior light delay unit to the most complicated engine management system. Testing individual electronic components is a useful diagnostic procedure.

8.1.2 Components

The symbols for the electronic components discussed in this section are shown in Figure 8.1.

Resistors are probably the most widely used component in electronic circuits. Two factors must be considered when choosing a suitable resistor: the ohms value and the power rating. Resistors are used to limit current f ow and provide f xed voltage drops. Most resistors used in electronic circuits are made from small carbon rods; the size of the rod determines the resistance. Carbon resistors have a negative temperature coeff cient (NTC) and this must be considered for some applications. Thin-f lm resistors have more stable temperature properties and are constructed by depositing a layer of carbon onto an insulated former such as glass. The resistance value can be manufactured very accurately by spiral grooves cut into the carbon f lm. For higher power applications, resistors are usually wire wound. Variable forms of most resistors are available. The resistance of a circuit is its opposition to current f ow.

Key fact

Resistors are used to limit current f ow and provide f xed voltage drops.

A capacitor is a device for storing an electric charge. In its simple form, it consists of two plates separated by an insulating material. One plate can have excess electrons compared to the other. On vehicles, its main uses are for reducing arcing across contacts and for radio interference suppression circuits as well as in electronic control units (ECUs). Capacitors are described as two plates separated by a dielectric. The area of the plates, the distance between them and the nature of the dielectric determine the value of capacitance. Metal foil sheets insulated by a type of paper are often used to construct capacitors. The sheets are rolled up together inside a tin can. To achieve higher values of capacitance it is necessary to reduce the distance between the plates in order to keep the overall size of the device manageable. This is achieved

Key fact

A capacitor is a device for storing an electric charge.

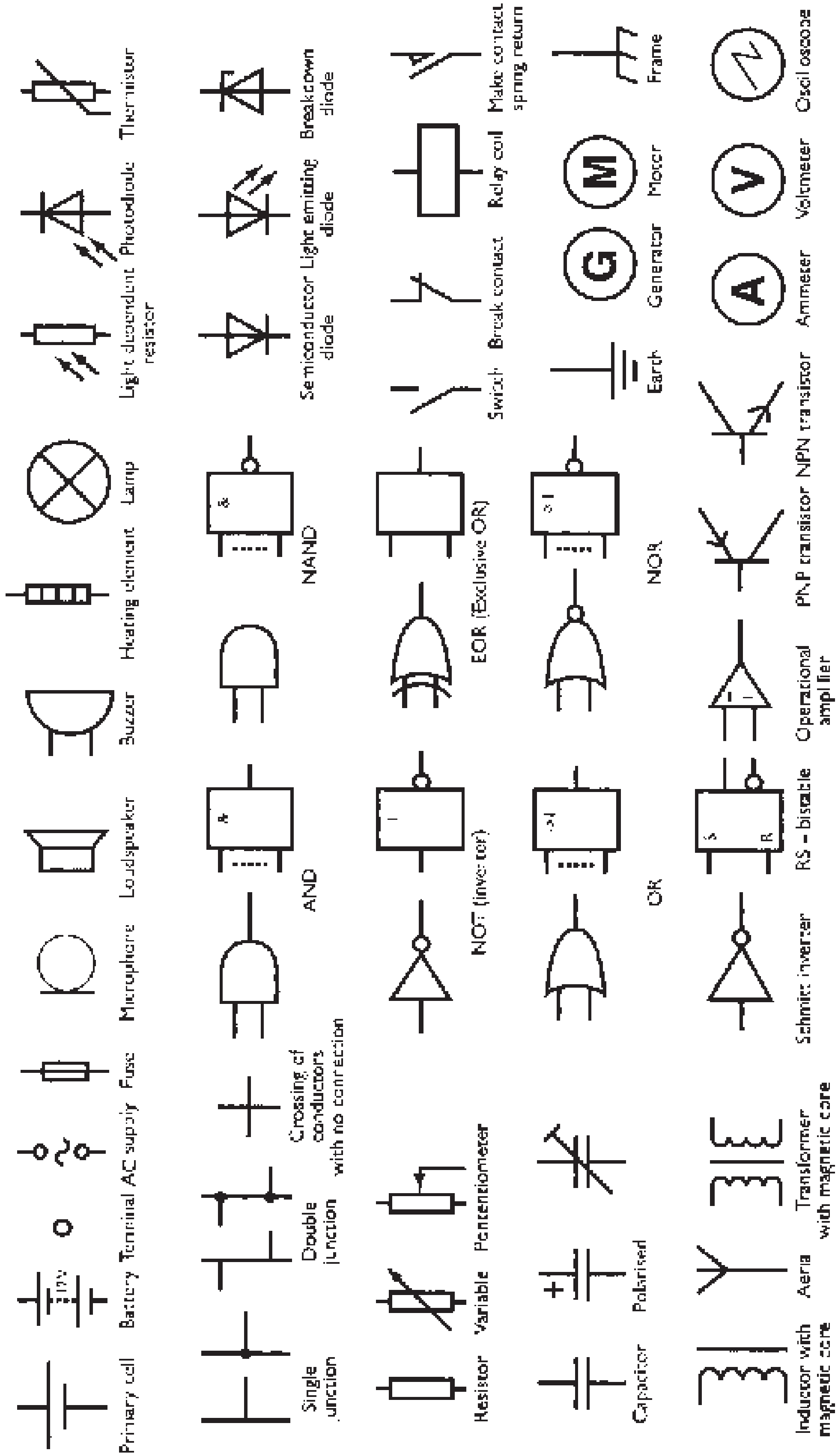

Figure 8.1 Circuit symbols

by immersing one plate in an electrolyte to deposit a layer of oxide typically 10^{-4} mm thick, thus ensuring a higher capacitance value. The problem, however, is that this now makes the device polarity conscious and only able to withstand low voltages.

Diodes are often described as one-way valves, and for most applications, this is an acceptable description. A diode is a PN junction allowing electron f ow from the N-type material to the P-type material. The materials are usually constructed from doped silicon. Diodes are not perfect devices and a voltage of approximately 0.6 V is required to switch the diode on in its forward biased direction.

Key fact

Diodes are often described as one-way valves.

Zener diodes are very similar in operation with the exception that they are designed to breakdown and conduct in the reverse direction at a predetermined voltage. They can be thought of as a type of pressure relief valve.

Transistors are the devices that have allowed the development of today's complex and small electronic systems. The transistor is used as either a solid state switch or as an amplif er. They are constructed from the same P- and N-type semiconductor materials as the diodes and can be made in either NPN or PNP format. The three terminals are known as the base, collector and emitter. When the base is supplied with the correct bias, the circuit between the collector and emitter will conduct. The base current can be in the order of 50–200 times less than the emitter current. The ratio of the current f owing through the base compared to the current through the emitter is an indication of the amplif cation factor of the device.

Key fact

The transistor is used as either a solid state switch or as an amplif er

A Darlington pair is a simple combination of two transistors which will give a high current gain, typically several thousand. The transistors are usually mounted on a heat sink and overall the device will have three terminals marked as a single transistor – base, collector and emitter. The input impedance of this type of circuit is in the order of 1 MΩ; hence, it will not load any previous part of a circuit connected to its input. The Darlington pair conf guration is used for many switching applications. A common use of a Darlington pair is for the switching of coil primary current in the ignition circuit.

Another type of transistor is the f eld effect transistor (FET). This device has higher input resistance than the bipolar type described above. They are constructed in their basic form as n-channel or p-channel devices. The three terminals are known as the gate, source and drain. The voltage on the gate terminal controls the conductance of the circuit between the drain and the source.

Inductors are most often used as part of an oscillator or amplif er circuit. The basic construction of an inductor is a coil of wire wound on a former. It is the magnetic effect of the changes in current f ow which gives this device the properties of inductance. Inductance is a diff cult property to control particularly as the inductance value increases. This is due to magnetic coupling with other devices. Iron cores are used to increase the inductance value.

This also allows for adjustable devices by moving the position of the core. Inductors, particularly of higher values, are often known as chokes and may be used in DC circuits to smooth the voltage.

8.1.3 Integrated circuits

Key fact

Integrated circuits or ICs are constructed on a single slice of silicon often known as a substrate.

Integrated circuits (ICs) are constructed on a single slice of silicon often known as a substrate. Combinations of some of the components mentioned previously can be used to carry out various tasks such as switching, amplifying and logic

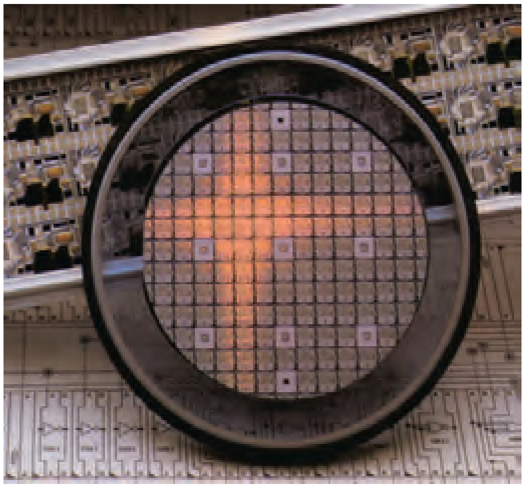

Figure 8.2 Silicon wafer used in the construction of integrated circuits

functions. The components required for these circuits can be made directly onto the slice of silicon. The great advantage of this is not just the size of the ICs but the speed at which they can be made to work due to the short distances between components. Switching speed in excess of 1 MHz is typical.

The range and type of integrated circuits now available is so extensive that a chip is available for almost any application. The integration level of chips is now exceeding VLSI (very large scale integration). This means that there can be more than 100 000 active elements on one chip. Development in this area is moving so fast that often the science of electronics is now concerned mostly with choosing the correct combination of chips, and discrete components are only used as f nal switching or power output stages. Figure 8.2 shows a highly magnif ed view of a typical IC.

8.1.4 Digital circuits

With some practical problems, it is possible to express the outcome as a simple yes/no or true/false answer. Let's take a simple example: if the answer to the f rst or the second question is 'yes', then switch on the brake warning light; if both answers are 'no' then switch it off.

1. Is the handbrake on?
2. Is the level in the brake f uid reservoir low?

In this case, we need the output of an electrical circuit to be 'on' when either one or both of the inputs to the circuit are 'on'. The inputs will be via simple switches on the handbrake and in the brake reservoir. The digital device required to carry out the above task is an OR gate. An OR gate for use on this system would have two inputs (a and b) and one output (c). Only when 'a' OR 'b' is supplied, will 'c' produce a voltage.

Once a problem can be described in logic states then a suitable digital or logic circuit can also determine the answer to the problem. Simple circuits can also be constructed to hold the logic state of their last input; these are in effect simple forms of 'memory'. By combining vast quantities of these basic digital building blocks, circuits can be constructed to carry out the most complex tasks in a fraction of a second. Because of IC technology, it is now possible to create hundreds of thousands if not millions of these basic circuits on one chip. This has given rise to the modern electronic control systems used for vehicle applications as well as all the countless other uses for a computer.

In electronic circuits, true/false values are assigned voltage values. In one system, known as TTL (transistor–transistor–logic), true or logic ‘1’ is represented by a voltage of 3.5 V and false or logic ‘0’ by 0 V.

Key fact

In electronic circuits, true/false values are assigned voltage values.

8.1.5 Electronic component testing

Individual electronic components can be tested in a number of ways but a digital multimeter is normally the favourite option. Table 8.1 suggests some methods of testing components removed from the circuit (Figures 8.3 and 8.4).

Table 8.1 Electronic component test methods

Component	Test method
Resistor	Measure the resistance value with an ohmmeter and compare this to the value written or colour coded on the component
Capacitor	A capacitor can be difficult to test without specialist equipment but try this. Charge the capacitor up to 12 V and connect it to a digital voltmeter. As most digital meters have an internal resistance of approximately 10 MΩ, calculate the expected discharge time (T = 5CR) and see if the device complies. A capacitor from a contact breaker ignition system should take approximately five seconds to discharge in this way
Inductor	An inductor is a coil of wire, so a resistance check is the best method to test for continuity
Diode	Many multimeters have a diode test function. If so, the device should read open circuit in one direction and approximately 0.4–0.6 V in the other direction. This is its switch on voltage. If no meter is available with this function, then wire the diode to a battery via a small bulb; it should light with the diode one way and not the other
LED	LEDs can be tested by connecting them to a 1.5 V battery. Note the polarity though; the longest leg or the flat side of the case is negative
Transistor (bipolar)	Some multimeters even have transistor testing connections but, if not available, the transistor can be connected into a simple circuit as Figure 8.4 and voltage tests carried out as shown. This also illustrates a method of testing electronic circuits in general. It is fair to point out that without specific data it is difficult for the non-specialist to test unfamiliar circuit boards. It is always worth checking for obvious breaks and dry joints though
Digital components	A logic probe can be used. This is a device with a very high internal resistance, so it does not affect the circuit under test. Two different coloured lights are used; one glows for a ‘logic 1’ and the other for ‘logic 0’. Specific data is required in most cases but basic tests can be carried out

Figure 8.3 Electronic components

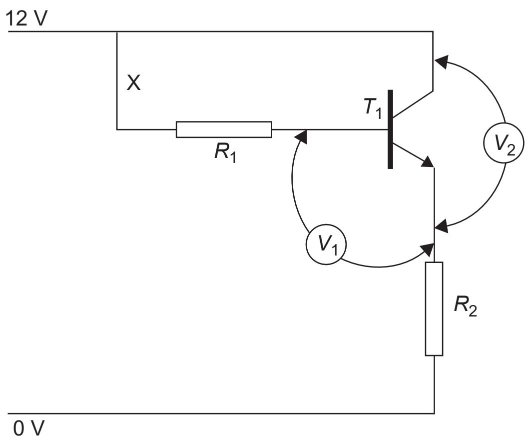

Figure 8.4 Transistor testing: Use resistors $R_1 = R_2$ of approximately 1 kΩ, when connected as shown, V_1 should read 0.6–0.7 V and V_2 approximately 1 V. Disconnect wire X, V_1 should now read 0 V and V_2 12 V

8.2 Multiplexing

8.2.1 Overview

Def nition

CAN: Controller area network.

The number of vehicle components which are networked has considerably increased the requirements for the vehicle control systems to communicate with one another. The CAN (controller area network) developed by Bosch is today's communication standard in passenger cars. However, there are a number of other systems.

Multiplexing is a process of combining several messages for transmission over the same signal path. The signal path is called the data bus. The data bus is basically just a couple of wires connecting the control units together. A data bus consists of a communication or signal wire and a ground return, serving all multiplex system nodes. The term 'node' is given to any sub-assembly of a multiplex system (such as a control unit) that communicates on the data bus.

On some vehicles, early multiplex systems used three control units (Figure 8.5). These were the door control unit, the driver's side control

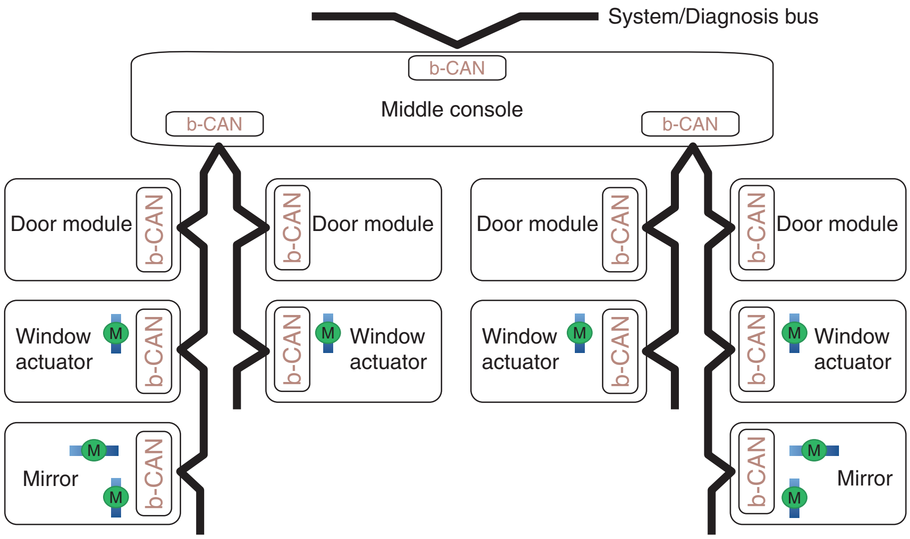

Figure 8.5 Sub-system for doors on an earlier system

unit and the passenger's side control unit. These three units replaced the following:

- integrated unit;
- interlock control unit;
- door lock control unit;
- illumination light control;
- power window control unit;
- security alarm control unit.

When a switch is operated, a coded digital signal is generated and communicated, according to its priority, via the data bus. All control units receive the signal but only the control unit for which the signal is intended will activate the desired response.

Only one signal can be sent on the BUS at any one time. Therefore, each signal has an identif er that is unique throughout the network. The identif er def nes not only the content but also the priority of the message. Some systems make changes or adjustments to their operation much faster than other systems. Therefore, when two signals are sent at the same time, it is the system which requires the message most urgently whose signal takes priority (Figure 8.6).

A multiplex control system has the advantage of self-diagnosis. This allows quick and easy troubleshooting and verif cation using diagnostic trouble codes (DTCs).

Many vehicles contain over a kilometre of wiring to supply all their electrical components. Luxury models may contain considerably more because of elaborate drivers' aids. The use of multiplexing means that considerably less wiring is used in a vehicle along with fewer multi-plugs and connectors, etc. An additional advantage of multiplexing is that existing systems can be upgraded or added to without modif cation to the original system.

8.2.2 Controller area network

CAN is a serial bus system especially suited for networking 'intelligent' devices as well as sensors and actuators within a system or sub-system. It operates in

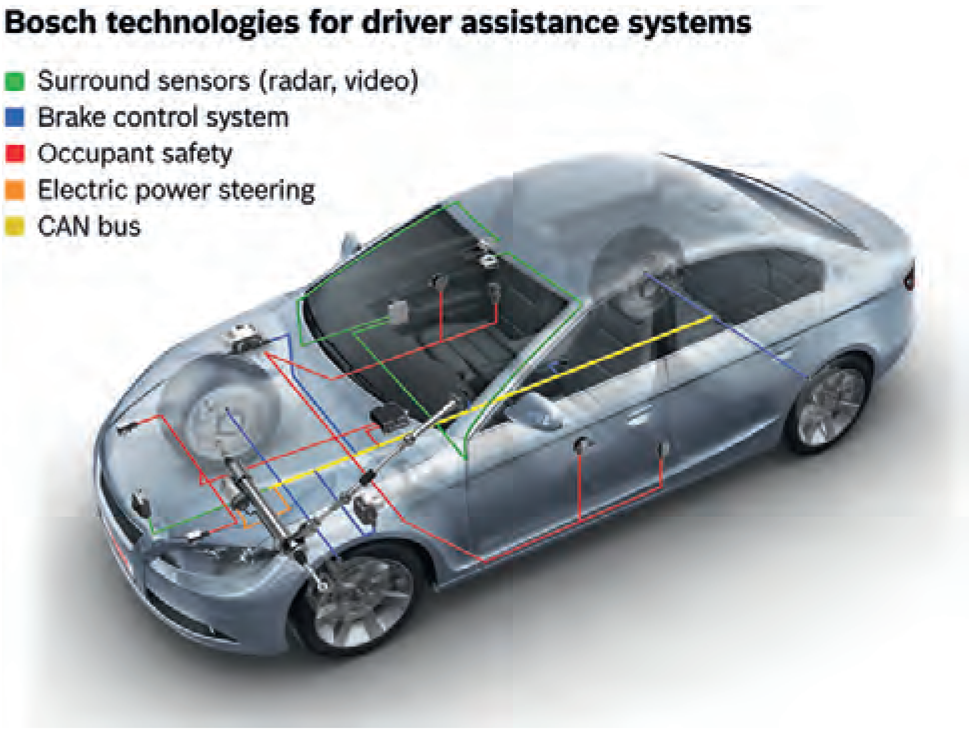

Figure 8.6 A data bus connects all networked components

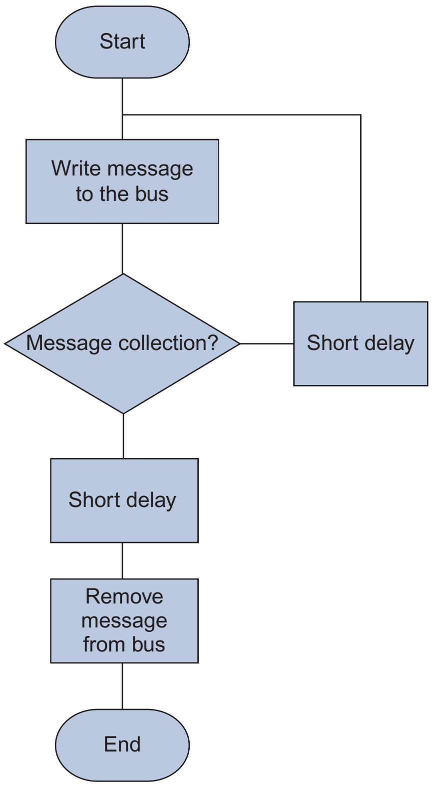

Figure 8.7 Much simplified CAN message protocol flowchart

Key fact

CAN is a serial bus system with multi-master capabilities.

Key fact

Fast controller area network (F-CAN) and basic (or body) controller area network (B-CAN) share information between multiple electronic control units (ECUs).

a broadly similar way to a wired computer network. CAN stands for controller area network and means that control units are able to interchange data. CAN is a high-integrity serial data communications bus for real-time applications. It operates at data rates of up to 1 Mbit/s. It also has excellent error detection and confinement capabilities. It was originally developed by Bosch for use in cars but is now used in many other industrial automation and control applications.

CAN is a serial bus system with multi-master capabilities. This means that all CAN nodes are able to transmit data and several CAN nodes can request use of the bus simultaneously. In CAN networks, there is no addressing of subscribers or stations, like on a computer network, but instead, prioritized messages are transmitted. A transmitter sends a message to all CAN nodes (broadcasting). Each node decides on the basis of the identifier received whether it should process the message or not. The identifier also determines the priority that the message enjoys in competition for bus access (Figure 8.7).

Fast controller area network (F-CAN) and basic (or body) controller area network (B-CAN) share information between multiple ECUs. B-CAN communication is transmitted at a slower speed for convenience related items such as electric windows. F-CAN information moves at a faster speed for real-time functions such as fuel and emissions systems. To allow both systems to share information, a control module translates information between B-CAN and F-CAN (Figure 8.8).

The ECUs on the B-CAN and F-CAN transmit and receive information in the form of structured messages that may be received by several different ECUs on the network at one time. These messages are transmitted and received across a communication circuit that consists of a single wire that is shared by all the ECUs. However, as messages on the F-CAN network are typically of higher importance, a second wire is used for communication circuit integrity monitoring. This CAN-high and CAN-low circuit forms the CAN bus (Figure 8.9).

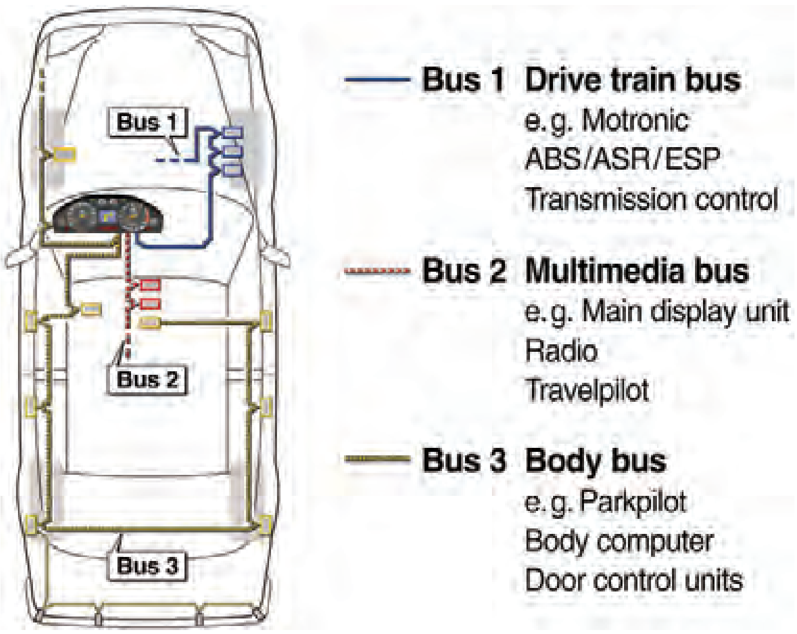

Figure 8.8 Three different speed buses in use (Source: Bosch Media)

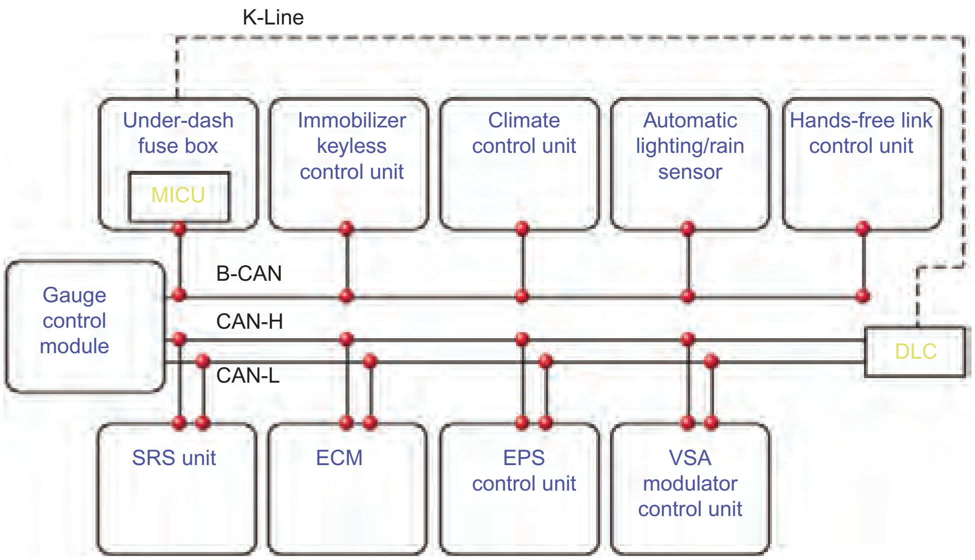

Figure 8.9 F-CAN uses CAN-H (high) and CAN-L (low) wires

A multiplex control unit is usually combined with the under-dash fuse/relay box. It controls many of the vehicle systems related to body electrics and the B-CAN. It also carries out much of the remote switching of various hardwired and CAN-controlled systems.

One of the outstanding features of the CAN protocol is its high transmission reliability. The CAN controller registers a station's error and evaluates it statistically in order to take appropriate measures. These may extend to disconnecting the CAN node producing the errors (Figure 8.10).

Each CAN message can transmit from 0 to 8 bytes of user information. Longer messages can be sent by using segmentation, which means slicing a longer message into smaller parts. The maximum transmission rate is specif ed as

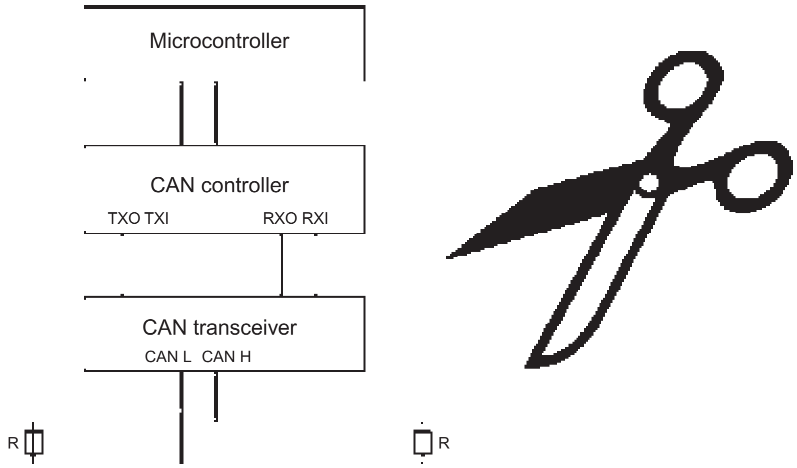

Figure 8.10 CAN nodes can be disconnected by the control program

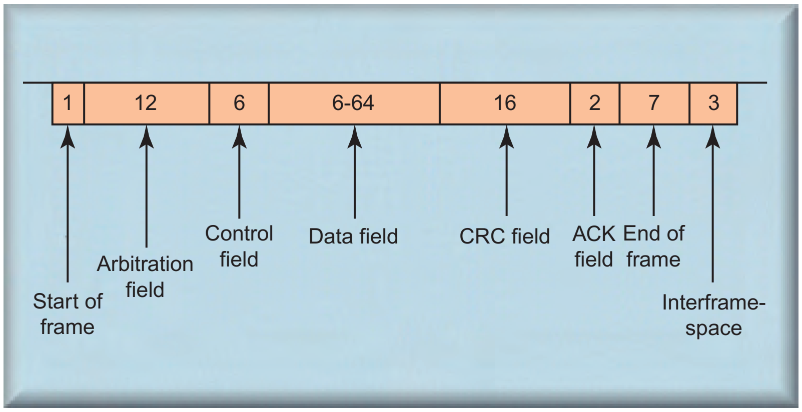

Figure 8.11 Message format (the three spaces are not part of the message)

1 Mbit/s. This value applies to networks up to 40 m which is more than enough for normal cars and trucks.

CAN is a serial bus system designed for networking ECUs as well as sensors and actuators.

8.2.3 CAN data signal

Key fact

The CAN message signal consists of a sequence of binary digits or bits.

The CAN message signal consists of a sequence of binary digits or bits. A high voltage present indicates the value 1, a low or no voltage indicates 0. The actual message can vary between 44 and 108 bits in length. This is made up of a start bit, name, control bits, the data itself, a cyclic redundancy check (CRC) for error detection, a conf rmation signal and f nally a number of stop bits (Figure 8.11).

A binary format message can be something like 100010101000101011111100001 110101111010101010100011111010111100110011000001111110101010000 11 1111111000000001

3-452 Section of an actual electrical signal

The message identif er or name portion of the signal (part of the arbitration f eld) identif es the message destination and also its priority. As the transmitter puts a message on the data bus it also reads the name back from the bus. If the name is not the same as the one it sent, then another transmitter must be in operation, which has a higher priority. If this is the case, it will stop transmission of its own message. This is very important in the case of motor vehicle data transmission.

Errors in a message are recognised by what is known as a CRC. This is an error detection scheme in which all the bits in a block of data are divided by a predetermined binary number. A check character, known to the transmitter and receiver, is determined by the remainder. If an error is recognised, the message on the bus is destroyed. This in turn is recognised by the transmitter, which then sends the message again. This technique, when combined with additional tests, makes it possible to discover all faulty messages.

The CRC f eld is part of the overall message. (The basic idea behind CRCs is to treat the message string as a single binary word M, and divide it by a keyword k that is known to both the transmitter and the receiver. The remainder r left after dividing M by k constitutes the 'check word' for the given message. The transmitter sends both the message string M and the check word r, and the receiver can then check the data by repeating the calculation, dividing M by the keyword k, and verifying that the remainder is r.)

Because each node in effect monitors its own output, interrupts disturbed transmissions, and acknowledges correct transmissions, faulty stations can be recognised and uncoupled (electronically) from the bus. This prevents other transmissions from being disturbed.

A CAN message may vary between 44 and 108 bits in length. This is made up of a start bit, name, control bits, the data itself, CRC error detection, a conf rmation signal and f nally a number of stop bits.

Def nition

The cyclic redundancy check (CRC) f eld is part of the overall message. (The basic idea behind CRCs is to treat the message string as a single binary word M, and divide it by a keyword k that is known to both the transmitter and the receiverThe remainder r left after dividing M by k constitutes the 'check word' for the given message. The transmitter sends both the message string M and the check word, and the receiver can then check the data by repeating the calculation, dividing M by the keyword k, and verifying that the remainder is.)r

8.2.4 Local interconnect network

A local interconnect network (LIN) is a serial bus system especially suited for networking 'intelligent' devices, sensors and actuators within a sub-system. It is a concept for low-cost automotive networks, which complements existing automotive multiplex networks such as CAN.

LIN enables the implementation of a hierarchical vehicle network. This allows further quality enhancement and cost reduction of vehicles (Figure 8.12).

The LIN standard includes the specif cation of the transmission protocol, the transmission medium, the interface between development tools, and the interfaces for software programming. LIN guarantees the interoperability of network nodes from the viewpoint of hardware and software, and predictable electromagnetic compatibility (EMC) behaviour (Figure 8.13).

LIN is a time-triggered single-master, multiple-slave network concept. It is based on common interface hardware, which makes it a low-cost solution. Additional attributes of LIN are

- multicast reception with self-synchronisation;
- selectable length of message frames;
- data checksum security and error detection;
- single-wire implementation;
- speed up to 20 kbit/s.

LIN provides a cost-eff cient bus communication where the bandwidth and versatility of CAN are not required. It is used for non-critical systems.

Key fact

LIN is a concept for low-cost automotive networks, which complements existing automotive multiplex networks such as CAN.

Def nition

EMC: Electromagnetic compatibility EMC requirements stipulate that a device shall not cause interference within itself or in other devices, or be susceptible to interference from other devices.

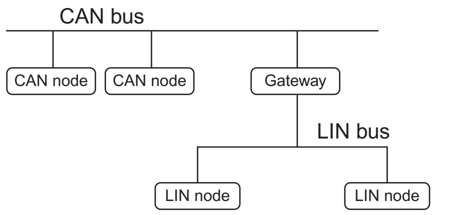

Figure 8.12 Structure using CAN and LIN

Key fact

FlexRay can cope with the requirements of X-by-wire systems.

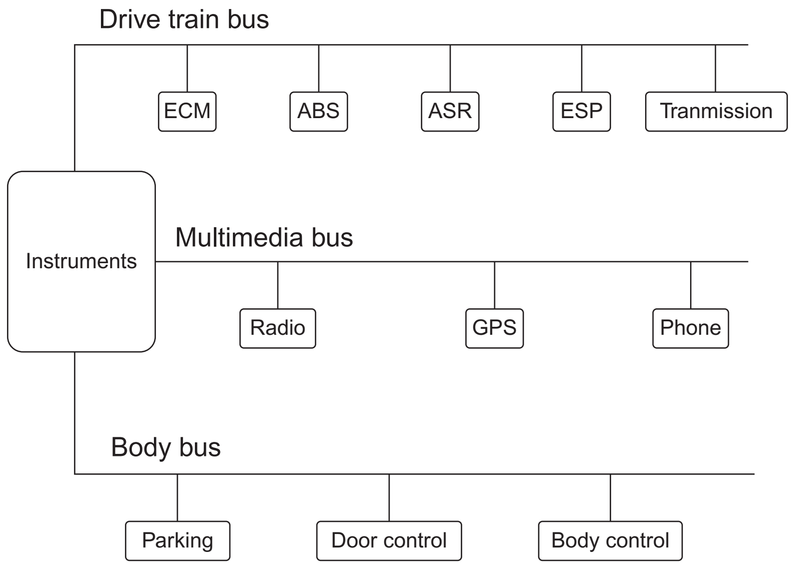

Figure 8.13 Standards allow communication between different systems

8.2.5 FlexRay

Figure 8.14 FlexRay logo

FlexRay is a fast and fault-tolerant bus system for automotive use. It was developed, using the experience of well-known original equipment manufactures (OEMs). It is designed to meet the needs of current and future in-car control applications that require a high bandwidth. The bit rate for FlexRay can be programmed to values up to 10 Mbit/s (Figure 8.14).

The data exchange between the control devices, sensors and actuators in automobiles is mainly carried out via CAN systems. However, the introduction of X-by-wire systems has resulted in increased requirements. This is especially so with regard to error tolerance and speed of message transmission. FlexRay meets these requirements by message transmission in f xed time slots, and by fault-tolerant and redundant message transmission on two channels (Figure 8.15).

The physical layer means the hardware, that is, the actual components and wires. FlexRay works on the principle of time division multiple access (TDMA). This means that components or messages have f xed time slots in which they have exclusive access to the data bus. These time slots are repeated in a cycle and are just a few milliseconds long.

FlexRay communicates via two physically separated lines with a data rate of up to 10 Mbit/s on each. The two lines are mainly used for redundant and therefore fault-tolerant message transmission, but they can also transmit different messages.

FlexRay is a fast and fault-tolerant bus system that was developed to meet the needs of high bandwidth applications such as X-by-wire systems. Error tolerance and speed of message transmission in these systems is essential (Figure 8.16).

Key fact

FlexRay communicates via two physically separated lines with a data rate of up to 10Mbit/s on each.

8.3 Diagnostics – multiplexing

The integrity of the signal on the CAN can be checked in two ways. The f rst way is to examine the signal on a dual-channel scope connected to the CAN-high and CAN-low lines (Figure 8.17).

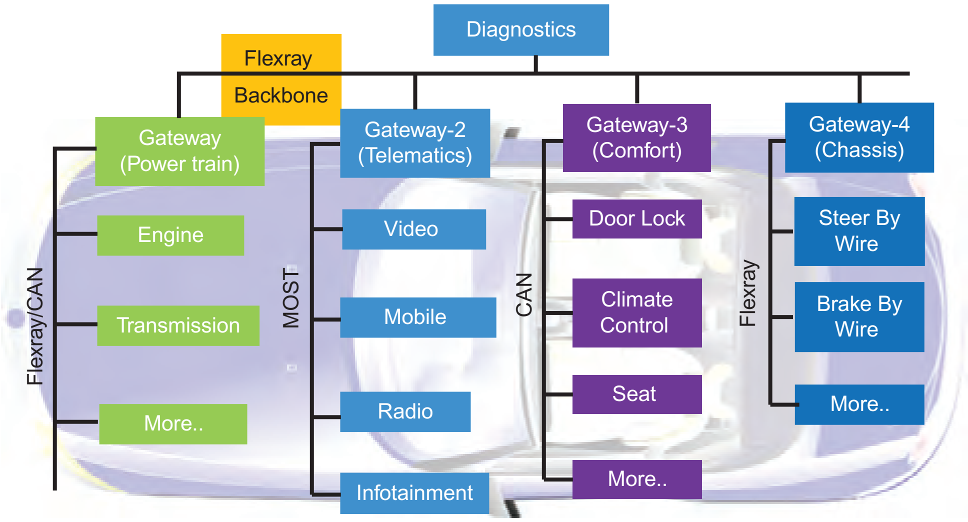

Figure 8.15 FlexRay backbone

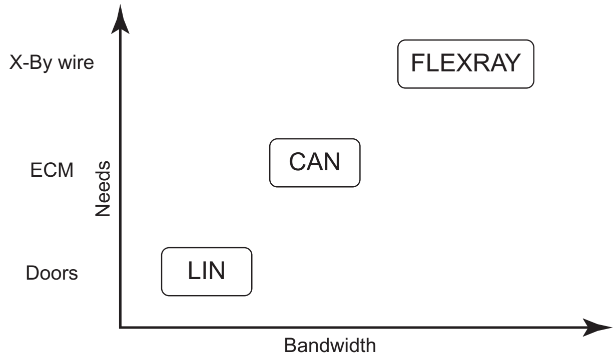

Figure 8.16 Comparing requirements and data rates of the three systems

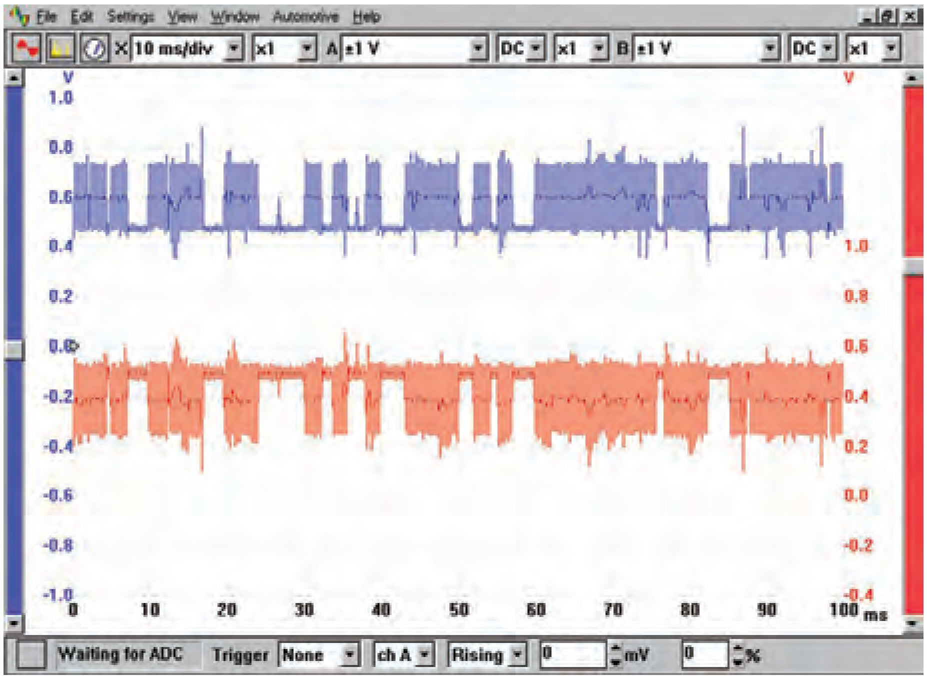

Figure 8.17 CAN signals

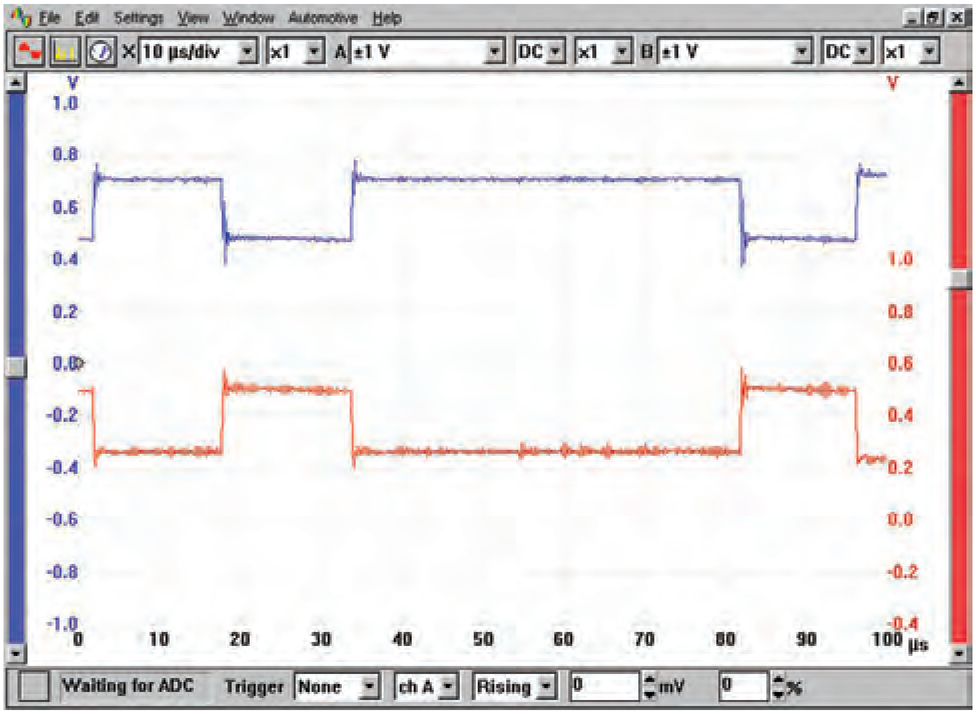

Figure 8.18 CAN signals on a fast timebase

In this display, it is possible to verify that

- data is being continuously exchanged along the CAN bus;
- the voltage levels are correct;
- a signal is present on both CAN lines.

CAN uses a differential signal, so the signal on one line should be a coincident mirror image of the data on the other line. The usual reasons for examining the CAN signals is where a CAN fault has been indicated by OBD, or to check the CAN connection to a suspected faulty CAN node. Manufacturers' data should be referred to for precise waveform parameters.

Key fact

CAN uses a differential signal, so the signal on one line should be a coincident mirror image of the data on the other line.

The following CAN data is captured on a much faster timebase and allows the individual state changes to be examined (Figure 8.18). This enables the mirror image nature of the signals, and the coincidence of the edges to be verif ed.

The signals are equal and opposite and they are of the same amplitude (voltage). The edges are clean and coincident with each other. This shows that the vehicle data bus (CAN bus) is enabling communication between the nodes and the CAN controller unit. This test effectively verif es the integrity of the bus at this point in the network. If a particular node is not responding correctly, the fault is likely to be the node itself. The rest of the bus should work correctly.

It is usually recommended to check the condition of the signals present at the connector of each of the ECUs on the network. The data at each node will always be the same on the same bus. Remember that much of the data on the bus is safety critical, so do *not* use insulation piercing probes!

PicoTech have produced the CAN test box. This gives easy access to the 16 pins of the diagnostic connector that is f tted to all modern vehicles. Depending on the conf guration of the vehicle, this may allow you to check power, ground and CAN bus signal quality (Figure 8.19).

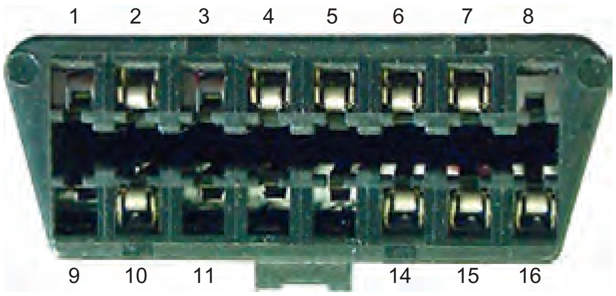

Figure 8.19 16 Pin data link connector

Connector design and location is dictated by an industry wide (OBD2) standard. Vehicle manufacturers can use the empty DLC terminals for whatever they would like. However, the DLC of every vehicle is required to provide pins 4 and 5 and 16 as def ned below. Further, after the CAN protocol was fully implemented in the 2008 model year, all vehicles must use pins 6 and 14 as def ned below:

- Terminal 2 – SAE J1850 10.4 kbits/s (kbps) variable pulse width serial data (GM Class-2) or SAE J1850 41.6 kbps pulse width modulation serial data high line (Ford)
- Terminal 4 – Scan tool chassis ground
- Terminal 5 – Common signal ground for serial data lines (Logic Low)
- Terminal 6 – ISO 11898/15765/SAE J2284 CAN serial data high line
- Terminal 7 – ISO 9141 K serial data line or ISO 14230 (Keyword 2000) serial data line (DaimlerChrysler/Honda/Toyota)
- Terminal 10 – SAE J1850 41.6 kbps pulse width modulation serial data low line (Ford)
- Terminal 14 – ISO 11898/15765/SAE J2284 CAN serial data low line
- Terminal 15 – ISO 9141 L serial data line or ISO 14230 (Keyword 2000) serial data line (DaimlerChrysler/Honda)
- Terminal 16 – Scan tool power (unswitched battery positive voltage)

With the test leads supplied, a PicoScope automotive scope, or any other suitable scope may be connected to the CAN test box. This allows the monitoring of any signals present, such as CAN high and CAN low.

The CAN test box has a 2.5 m cable so that work can be carried out at a convenient location away from the diagnostic connector. An additional pass-through connector allows a scan tool to be connected at the same time as a scope. Its 4-mm sockets are backlit by LEDs to show the state of each pin on the connector. The CAN test box is powered by the diagnostic connector, so batteries or a mains adaptor are not needed (Figure 8.20).

In the two CAN scope patterns shown previously, the second is on a timebase 1000 times faster than the f rst so that more details of the signal are shown. The connection for one of the traces is to pin 6 and the other to pin 14.

The second way of checking the CAN signals is to use a suitable reader or scanner.

The KTS 200 controller diagnostic tester from Bosch is a good example of and OBD/CAN reader as it offers a wide range of features (Figure 8.21). It reads diagnostic codes and CAN data. The device can be used both as a full controller diagnostic tester, complete with a testing scope, and for straightforward servicing work on vehicles.

Figure 8.20 CAN test box (Source: PicoTech)

Figure 8.21 KTS 200 kit

Key fact

Since 2008, all vehicles sold in the European Union and United States are required to have implemented CAN.

It is powered via the diagnostic cable, the cigarette lighter cable or a power pack.

OBD has been in use for some time in its different formats. However, the CAN protocol is a popular standard and is making signif cant in-roads into the market. Since 2008, all vehicles sold in the European Union and United States are required to have implemented CAN. This should f nally eliminate the ambiguity of the several existing signalling protocols (Figure 8.22).

8.4 Lighting

8.4.1 External lights

Figure 8.23 shows the rear lights of a modern car. Note how in common with many manufacturers, the lenses are almost smooth and clear. This is because

Figure 8.22 OBD connector on a BMW

Figure 8.23 BMW rear lights

the reflectors now carry out diffusion of the light. Regulations exist relating to external lights. Table 8.2 is a simplified interpretation of current rules.

Key fact

LED lights are now allowed and are specified by light output rather than wattage.

8.4.2 Lighting circuits

Figure 8.24 shows a simplified lighting circuit. While 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 side lights are on. Another example is how the headlights cannot be operated without the side lights first being switched on.

Table 8.2 Lighting features

Sidelights	A vehicle must have two sidelights each with wattage of less than 7W. Most vehicles have the sidelight incorporated as part of the headlight assembly
Rear lights	Again two must be fitted each with wattage not less than 5W. Lights used in Europe must be 'E' marked and show a diffused light. Position must be within 400mm from the vehicle edge and over 500mm apart and between 350 and 1500mm above the ground
Brake lights	Two lights often combined with the rear lights. They must be between 15 and 36W each, with diffused light, and must operate when any form of first line brake is applied. Brake lights must be between 350 and 1500mm above the ground and at least 500mm apart in a symmetrical position. High-level brake lights are now allowed, and if f tted, must operate with the primary brake lights
Reverse lights	No more than two lights may be fitted with a maximum wattage each of 24W. 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	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	One or two may be fitted, but if only one, it must be on the offside or centre line of the vehicle. They must be between 250 and 1000mm above the ground and over 100mm from any brake light. The wattage is normally 21W and they must only operate when either the side lights, 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 1200mm above the ground and more than 400mm 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 500mm 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

Safety f rst

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

Dim dip lights are achieved in one of two ways. The f rst 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. The most cost-effective method is using a resistor, but this has the problem that the resistor (approximately 1 Ω) gets quite hot and hence has to be positioned appropriately. Figure 8.25 shows a typical vehicle lighting circuit.

8.4.3 Gas discharge lighting

Xenon gas discharge headlamps (GDL) are now f tted to some vehicles. They have the potential to provide more effective illumination and new design possibilities for the front of a vehicle. The conf ict between aerodynamic

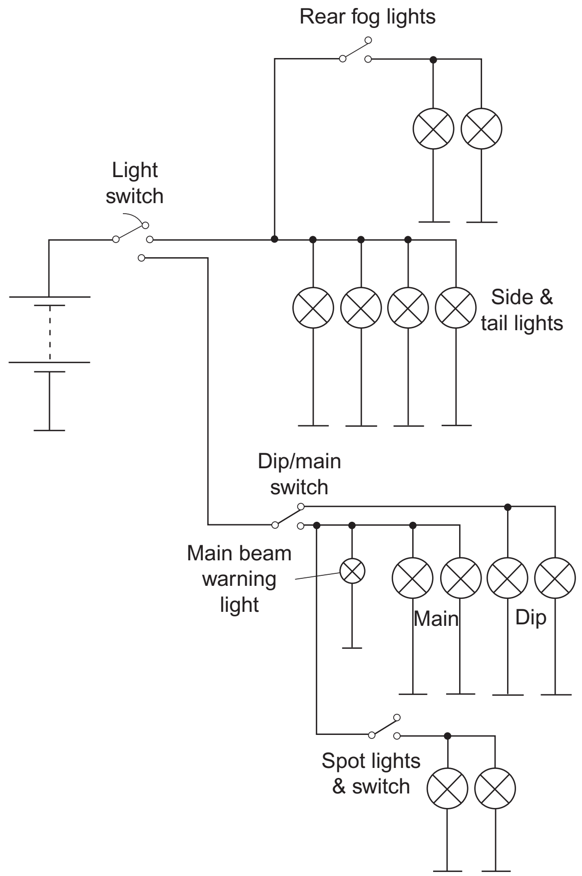

Figure 8.24 Simplified lighting circuit

styling and suitable lighting positions is an economy/safety trade off, 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:

- Bulb – this operates in a very different way from conventional incandescent bulbs. A much higher voltage is needed.
- 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 continuous use and finally monitors operation as a safety aspect.
- 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 and hence more production costs are involved.

8.4.4 LED lighting

The advantages of LED lighting are clear, the greatest being reliability. LEDs have a typical rated life of over 50 000 hours compared to 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.

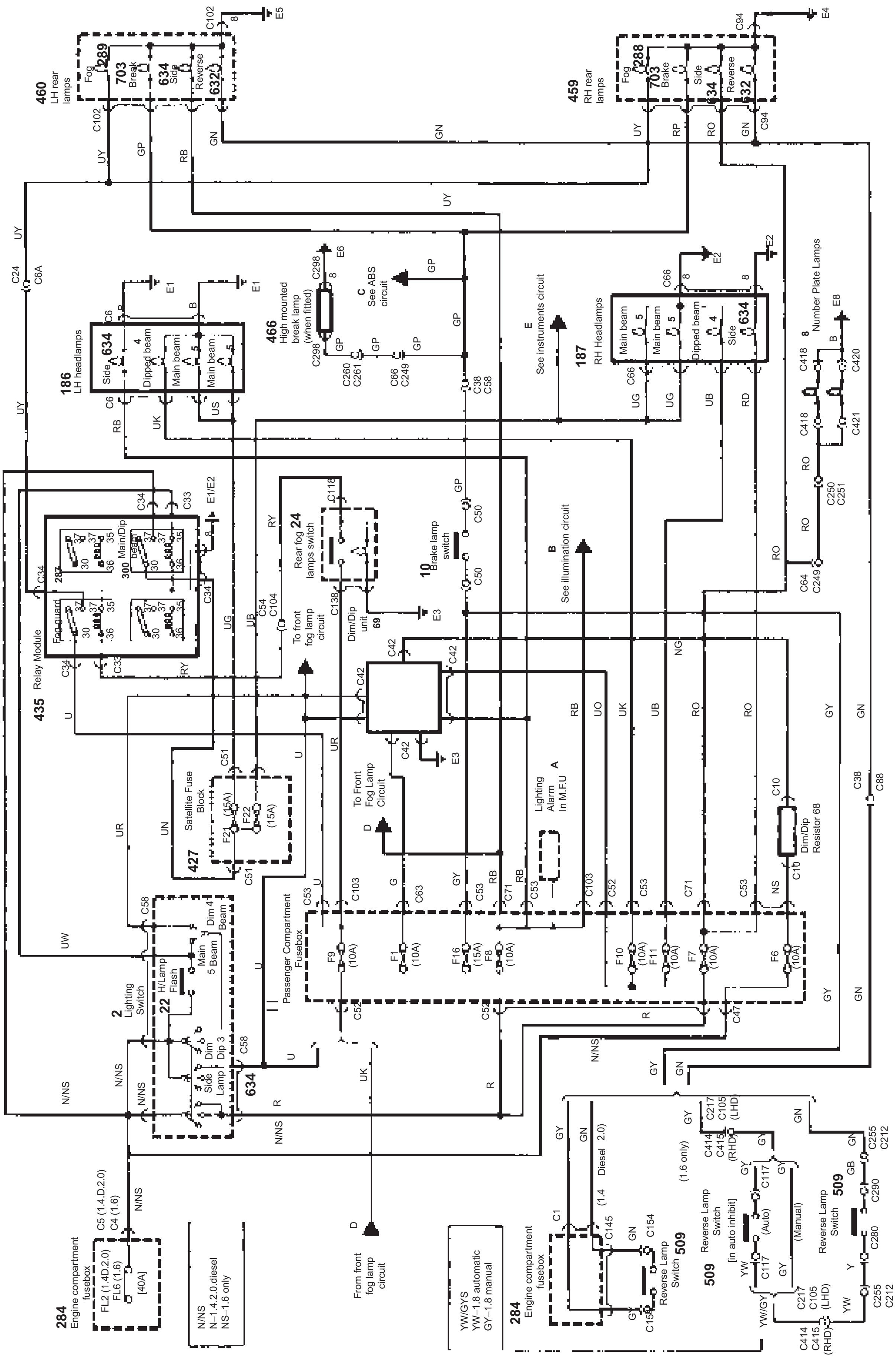

Figure 8.25 Complete lighting circuit

Figure 8.26 Xenon lighting

Figure 8.27 Adaptive lighting using LEDs

Key fact

LEDs have a typical rated life of over 50000 hours compared to just a few thousand for conventional lamps, which must make them incandescent.

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. This time is approximately the difference between 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 potentially a major contribution to road safety. LEDs as high-level brake lights are becoming popular because of the shock resistance, which will allow them to be mounted on the boot lid (Figures 8.26 and 8.27).

Heavy vehicle side marker lights are an area of use where LEDs have proved popular. Many lighting manufacturers are already producing lights for the aftermarket. 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.

8.5 Diagnostics – lighting

8.5.1 Testing procedure

The process of checking a lighting system circuit is broadly presented in Figure 8.28.

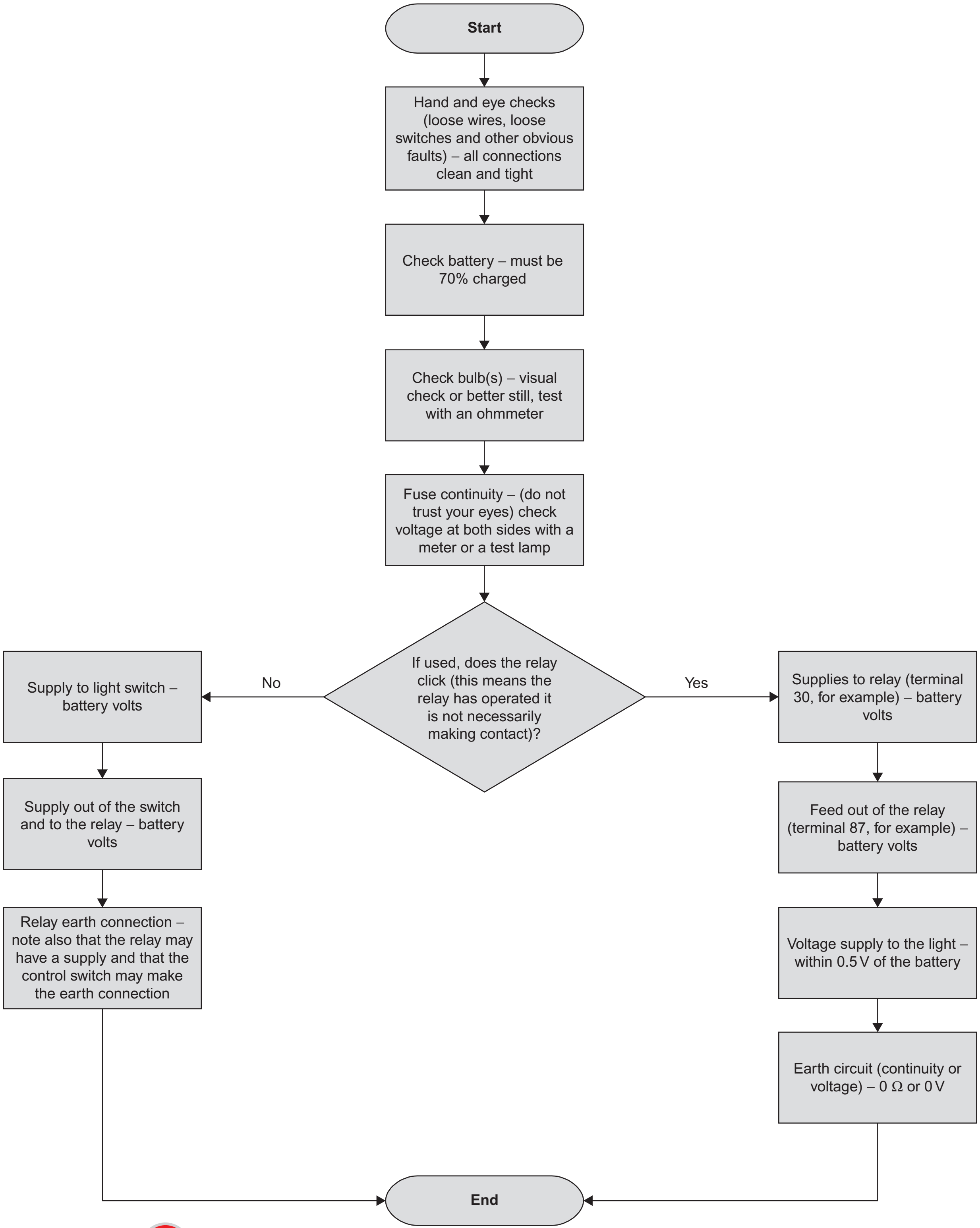

Figure 8.28 Lighting system diagnostics chart

Key fact

A circuit should be able to supply a minimum of 95% of the available battery voltage to the consumers (bulbs, etc.).

Figure 8.29 shows a simplif ed dim dip lighting circuit with meters connected for testing. A simple principle to keep in mind is that the circuit should be able to supply all the available battery voltage to the consumers (bulbs, etc.). A loss of 5% may be acceptable.

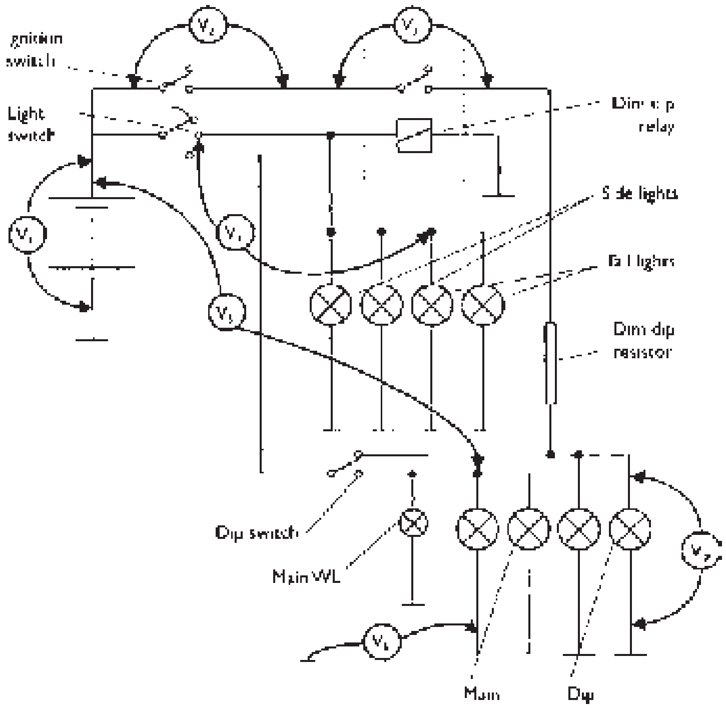

Figure 8.29 Lighting circuit under test

With all the switches in the 'on' position appropriate to where the meters are connected, the following readings should be obtained:

- V1 12.6 V (if less, check battery condition);
- V2 0–0.2 V (if more, the ignition switch contacts have a high resistance);
- V3 0–0.2 V (if more, the dim dip relay contacts have a high resistance);
- V4 0–0.2 V (if more, there is a high resistance in the circuit between the output of the light switch and the junction for the tail lights);
- V7 12–12.6 V if on normal dip or approximately 6 V if on dim dip (if less, then there is a high resistance in the circuit – check other readings, etc., to narrow down the fault).

8.5.2 Lighting fault diagnosis table

Symptom	Possible fault
Lights dim	High resistance in the circuit Low alternator output Discoloured lenses or reflectors
Headlights out of adjustment	Suspension fault Loose fittings Damage to body panels Adjustment incorrect
Lights do not work	Bulbs blown Fuse blown Loose or broken wiring/connections/fuse Relay not working Corrosion in light units Switch not making contact

Figure 8.30 Headlights

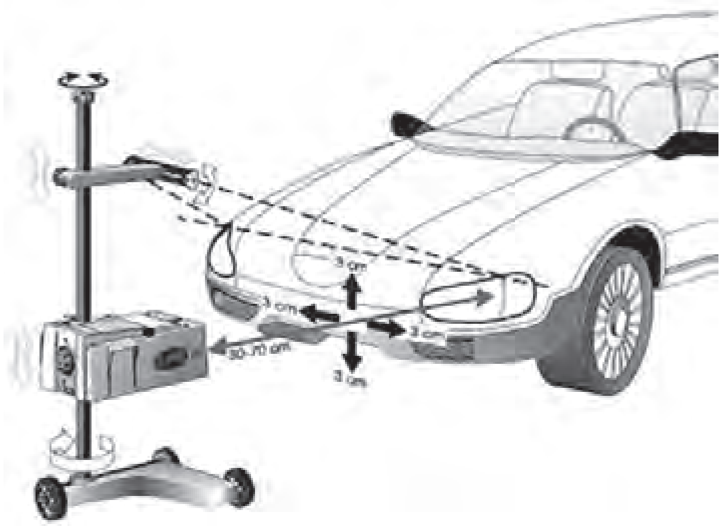

Figure 8.31 Headlamp alignment(Source: Hella)

8.5.3 Headlight beam setting

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

Move the beam setter into position in front of the headlamp to be checked, and align the beam setter box with the middle of the headlamp (Figures 8.30 and 8.31). It must not be more than 3 cm out of line horizontally or vertically. The distance between the front edge of beam setter box and the headlamp should

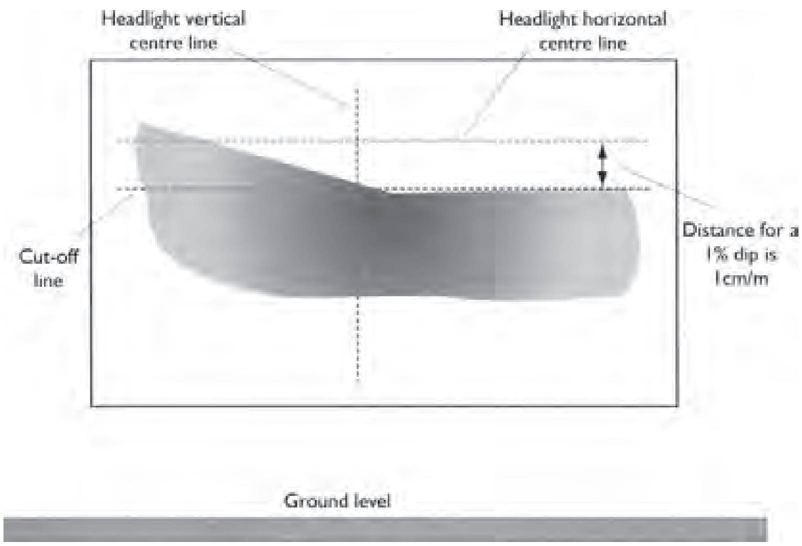

Figure 8.32 Asymmetric dip beam pattern

be between 30 and 70 cm. The beam setter must be re-adjusted before each headlamp is checked.

When adjusting the headlamps, the given inclination for the cut-off line (from a data book, etc.) must be set on the alignment equipment. The beam is now adjusted until the cut-off line and break off are in the correct position on the screen of the aligner.

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 onto 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 8.32.
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 in most cases be 1 cm 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.

Note: If the required dip is 1% then 1 cm* per 1 m. If 1.2% is required, then 1.2 cm per 1 m, etc. Always check data for actual settings.

8.6 Auxiliaries

8.6.1 Wiper motors and linkages

Most wiper linkages consist of series or parallel mechanisms. Some older types use a f exible 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 which the blades must reverse, 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 8.33).

Key fact

Most wiper linkages consist of series or parallel mechanisms.

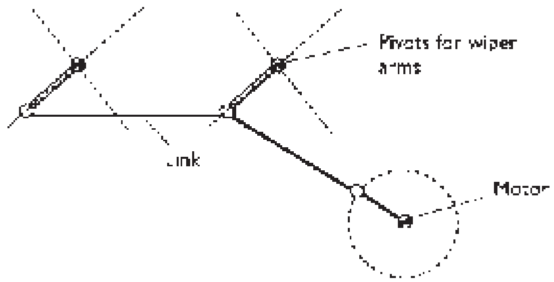

Figure 8.33 Wiper linkage

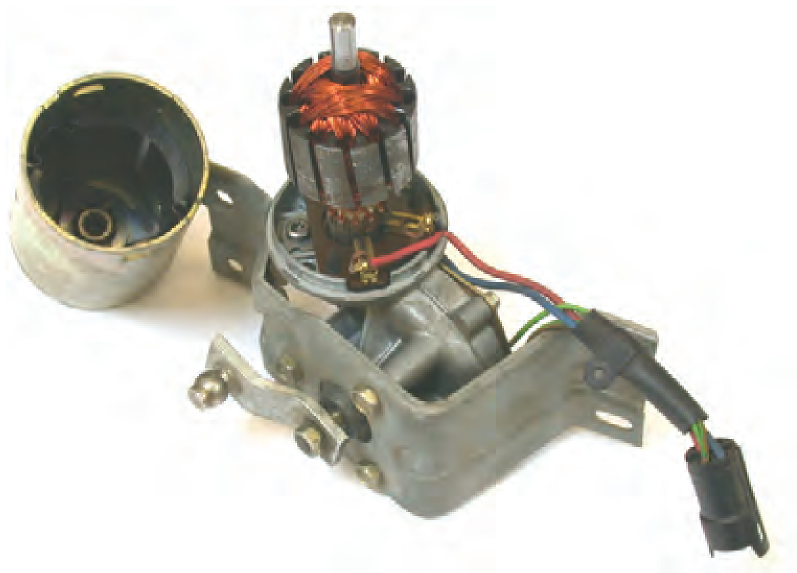

Figure 8.34 Wiper motor using three brushes for two-speed operation

Figure 8.35 Wiper motor

Most if not all wiper motors now in use are 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, hence increasing current and therefore speed. Typical specif cations for wiper motor speed and hence wipe frequency are 45 rpm at normal speed and 65 rpm at fast speed. The motor must be able to overcome the starting friction of each blade at a minimum speed of 5 rpm (Figure 8.34).

The wiper motor or the associated circuit often has some kind of short circuit protection (Figure 8.35). 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 f tted.

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 f tted in the line to the jets to prevent water siphoning back to the reservoir. This also allows 'instant' operation when the washer button is pressed. The washer circuit is normally linked in to the wiper

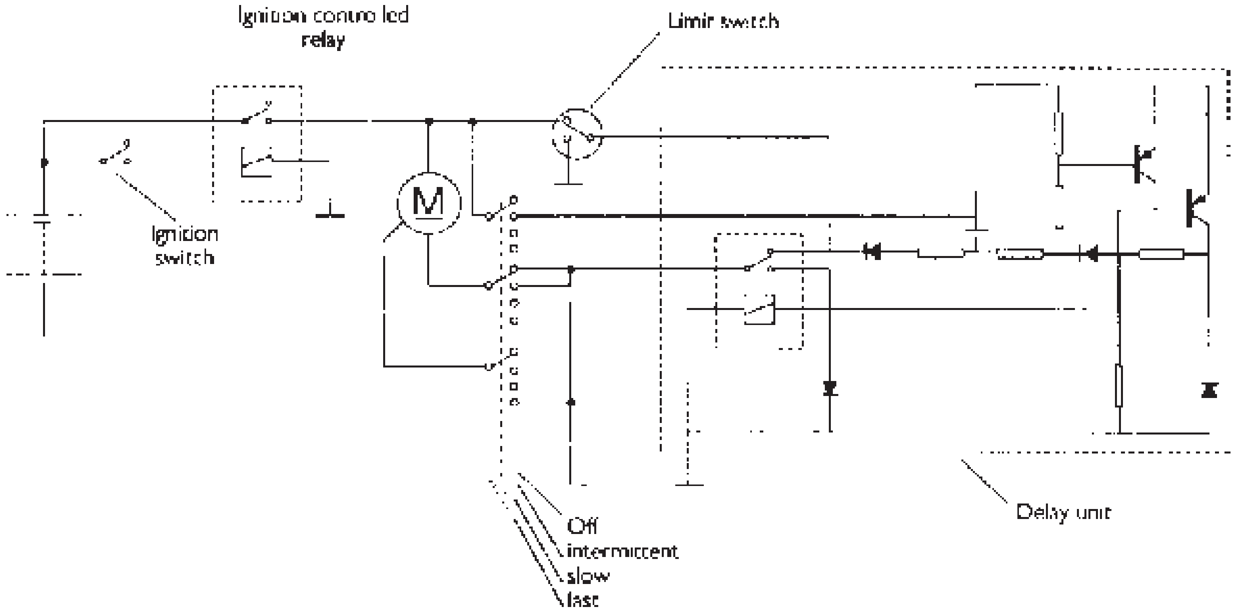

Figure 8.36 Traditional wiper circuit

circuit such that when the washers are operated the wipers start automatically and will continue for several more sweeps after the washers have stopped.

8.6.2 Wiper circuits

Figure 8.36 shows a circuit for fast, slow and intermittent wiper control. The switches are shown in the off position and the motor is stopped and is 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.

Many vehicles use a system with more enhanced facilities. This is regulated by, what may be known as, a central control unit (CCU), a multi-function unit (MFU) or a general electronic module (GEM). These units often control other systems as well as the wipers, thus allowing reduced wiring bulk under the dash area. Electric windows, headlights and heated rear window, to name just a few, are now often controlled by a central unit (Figure 8.37).

Using electronic control, a CCU allows the following facilities for the wipers:

- front and rear wash/wipe;
- intermittent wipe;
- time delay set by the driver;
- reverse gear selection rear wipe operation;

Key fact

A central control unit (CCU), a multi-function unit (MFU) or a general electronic module (GEM) is now often used to control a range of auxiliary components.

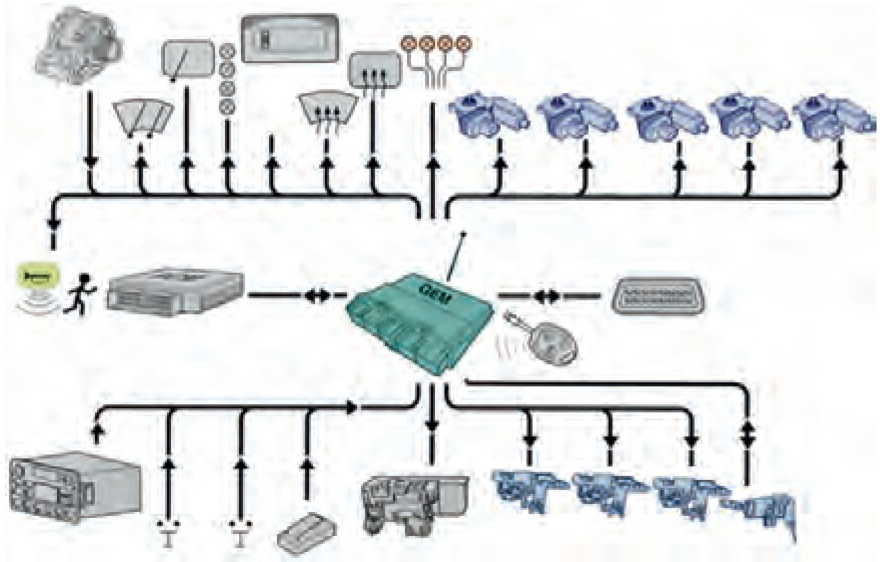

Figure 8.37 GEM and components (Source: Ford Motor Company)

- rear wash/wipe with 'dribble wipe' (an extra wipe several seconds after washing);
- stall protection.

8.6.3 Two-motor wiper system

More and more carmakers are exploiting the advantages of the two-motor wiper systems where each of the wiper arms is driven by its own electric motor. The advantage is the largest possible wiped area, yet they are compact in construction. This system is fitted, for example, in the new Ford Galaxy, as well as in the recently launched Mercedes-Benz S-Class.

Key fact

The two-motor wiper system synchronises its two drives electronically.

The two-motor wiper system synchronises its two drives entirely electronically (Figure 8.38). Integrated sensors continuously monitor the precise position of the wiper arms. This allows the change in direction to be individually determined; the change can, therefore, always take place very close to the A-pillar, which provides the widest possible field of view under all conditions. When the wiper is switched off, the wiper arms and blades can disappear completely under the engine bonnet/hood. This improves aerodynamics and reduces the risk of injury to pedestrians and cyclists in the event of an accident. It is also possible for the wiper equipment to work fully automatically when combined with the rain and light sensors.

At present, approximately 5% of all the cars manufactured in Europe are fitted with a two-motor wiper system. This proportion is expected to double over the next five years.

8.6.4 Headlight wipers and washers

There are two ways in which headlights are cleaned, first by high-pressure jets and second by small wiper blades with low-pressure water supply. The second

Figure 8.38 Two wiper motors must be synchronised (Source: Bosch Media)

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 f uid freezing. It is expected that the wash system should be capable of approximately 50 operations before ref lling of the reservoir is necessary. 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 is pushed from its retracted position, f ush with the bodywork. When the washing is completed, the jet is then retracted back into the housing.

8.6.5 Indicators and hazard lights

Direction indicators have a number of statutory requirements. The light produced must be amber, but they may be grouped with other lamps. The f ashing 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 f ash perceptibly.

Key fact

Indicator fash rate must be between one and two per second with a relative 'on' time of between 30% and 57%.

Legislation as to the mounting position of the exterior lamps exists such that the rear indicator lights must be within a set distance of the tail lights and within a set height. The wattage of indicator light bulbs is normally 21 W at 6, 12 or 24 V as appropriate. Figure 8.39 shows a typical indicator and hazard circuit.

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.

Key fact

Flasher units are rated by the number of bulbs they are capable of operating.

8.6.6 Brake lights

Most brake light circuits 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

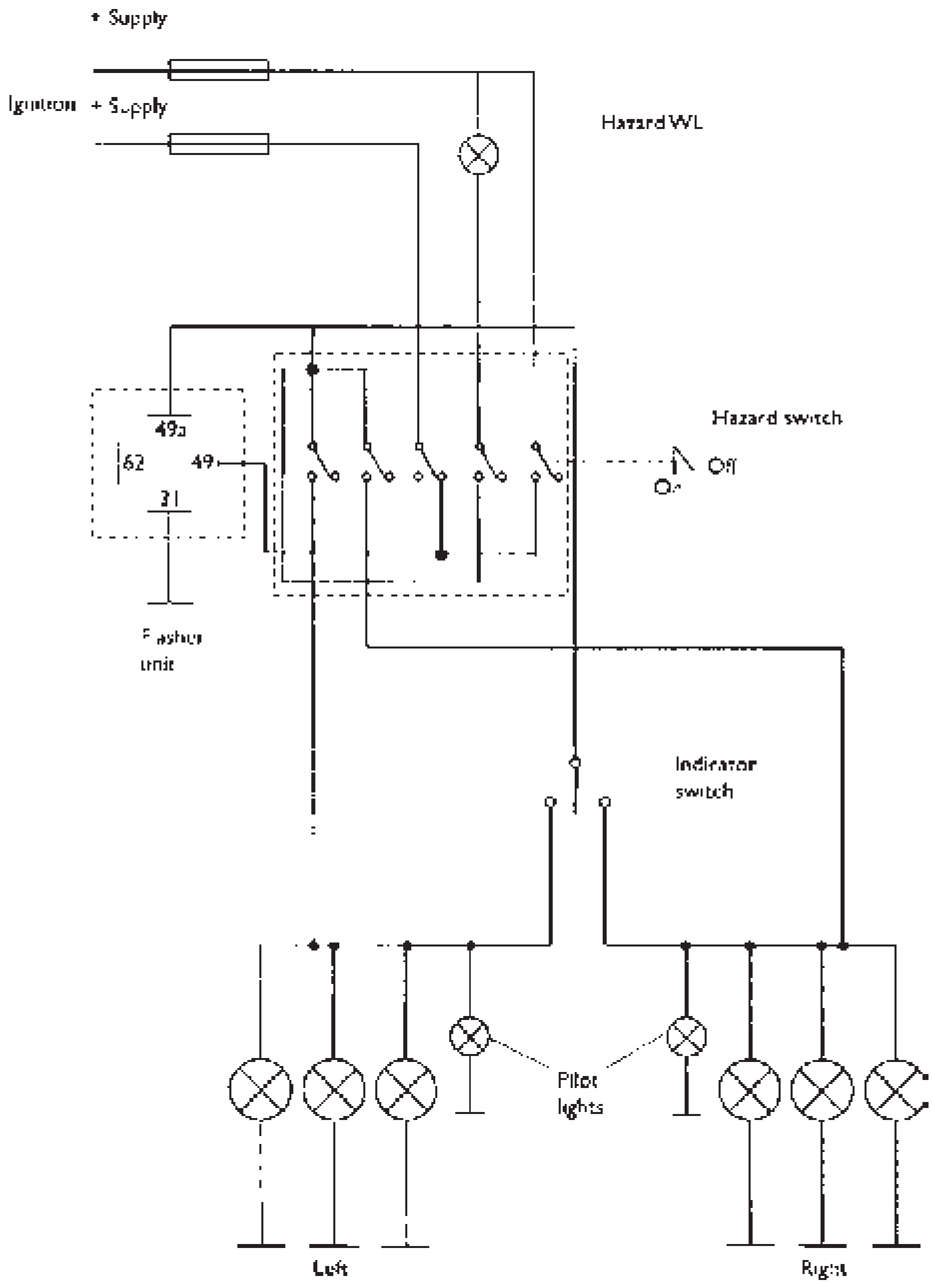

Figure 8.39 Indicator and hazard circuit

cruise control may be found. This is to cause the cruise control to switch off as the brakes are operated (Figure 8.40).

8.6.7 Electric horns

Regulations in most countries state that the horn (or audible warning device) should produce a uniform sound. This 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 electromagnetic switching. Current f ow causes an armature to which is attached a tone disc, to be attracted towards a stop. This opens a set of contacts which 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 note gives

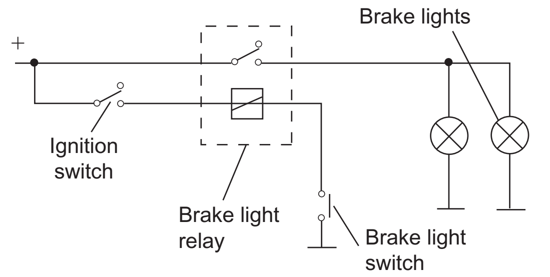

Figure 8.40 Simple relay operated circuit used for brake lights (stoplights)

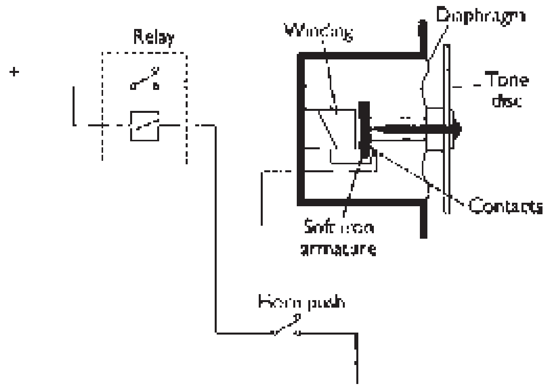

Figure 8.41 Typical horn together with its associated circuit

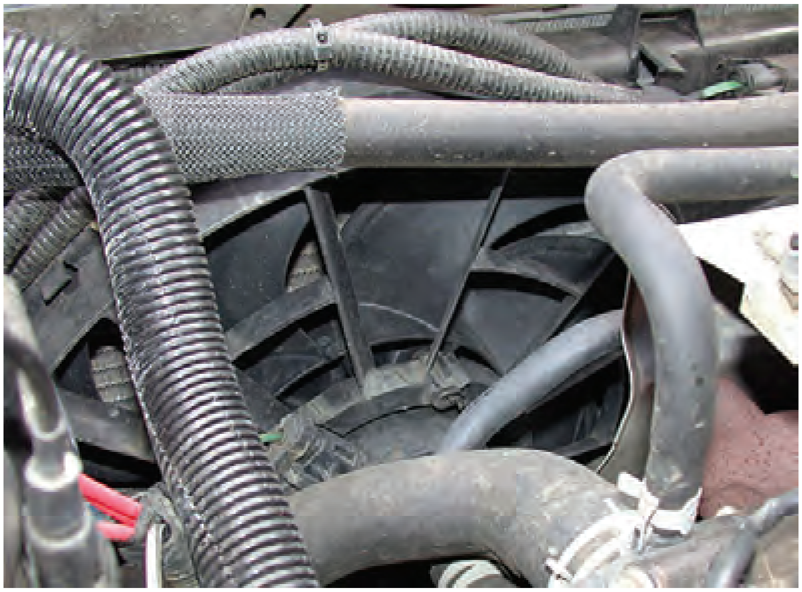

Figure 8.42 Engine cooling fan in position

good penetration through traff c 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 8.41).

8.6.8 Engine cooling fan motors

Most engine cooling fan motors (radiator cooling) are simple PM types. The fans used often have the blades placed asymmetrically (balanced but not in a regular pattern) to reduce noise when operating (Figure 8.42).

Key fact

The standard horn operates by simple electromagnetic switching.

Def nition

PM: Permanent magnet.

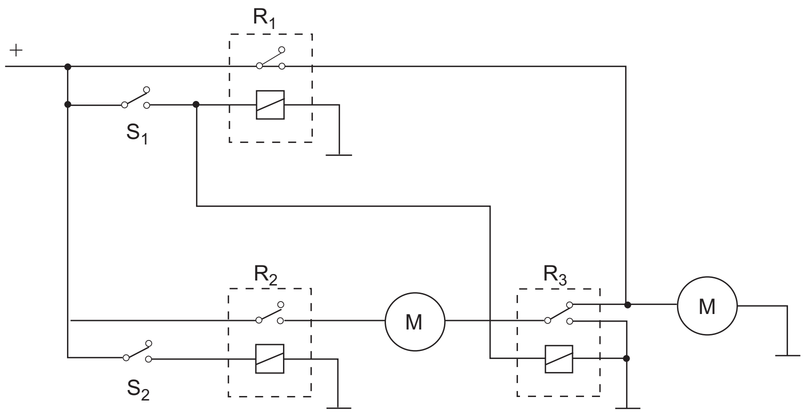

Figure 8.43 Two-speed, twin cooling fan circuit

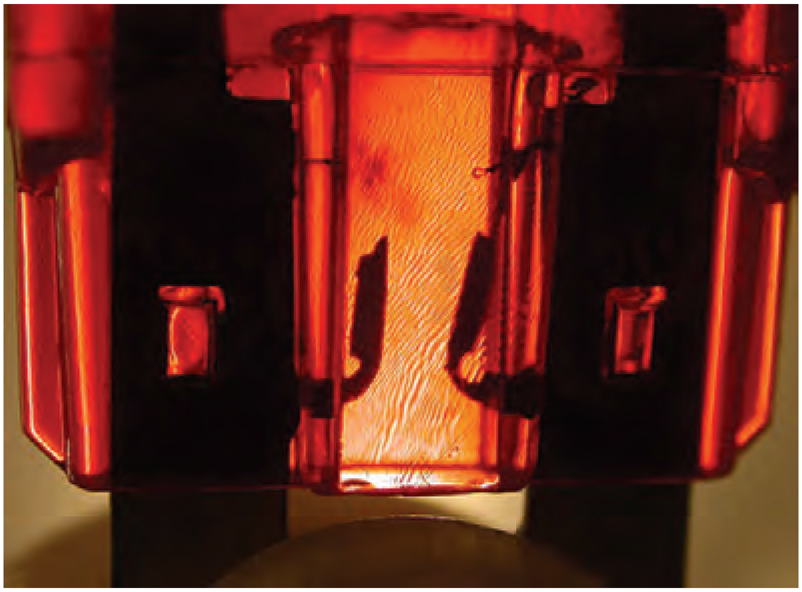

Figure 8.44 Remember to check the obvious first – like this blown fuse

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 above (Figure 8.43).

8.7 Diagnostics – auxiliary

8.7.1 Testing procedure

The process of checking an auxiliary system circuit is broadly as presented in Figure 8.45.

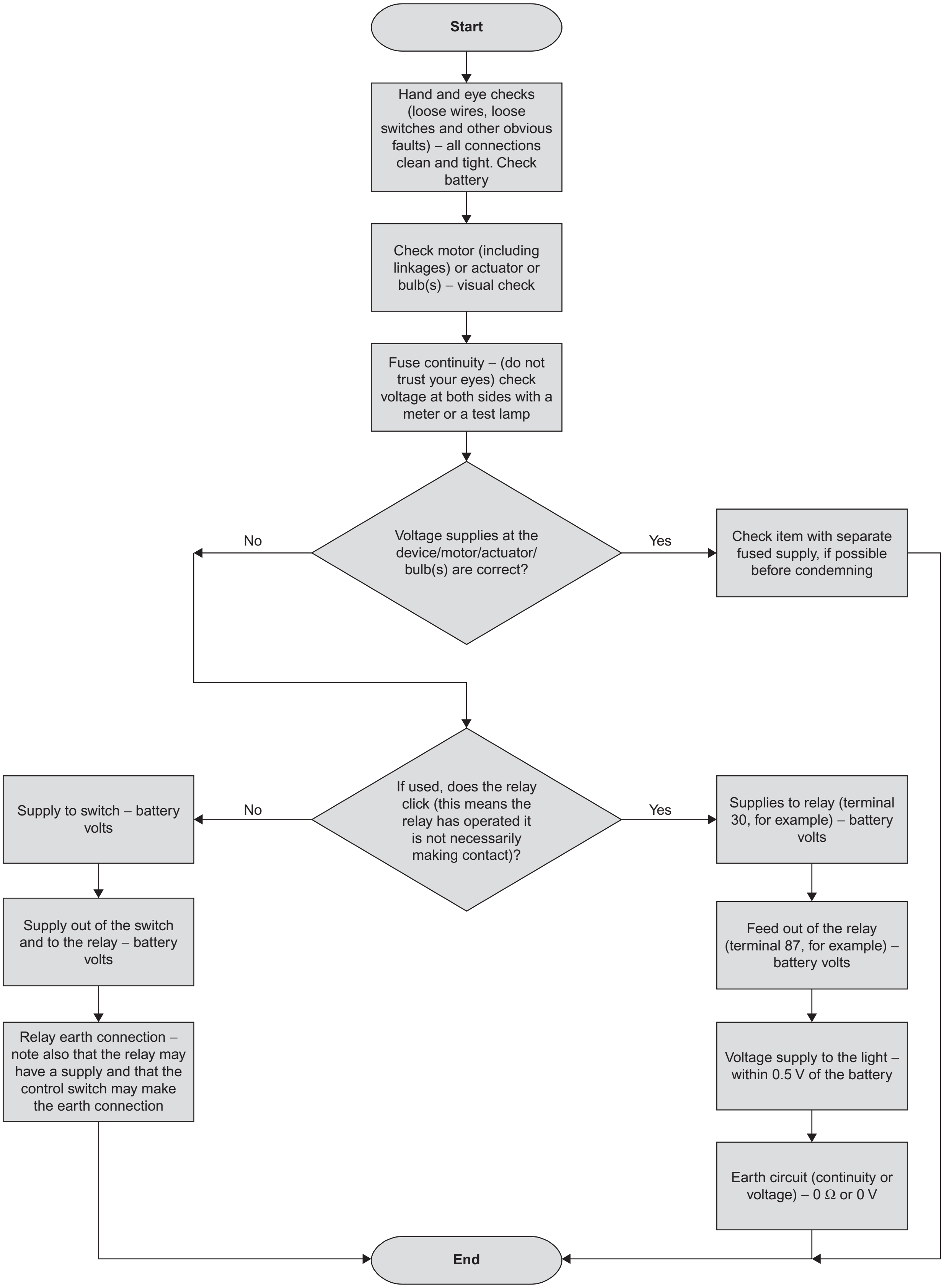

Figure 8.45 Auxiliary systems diagnosis chart

8.7.2 Auxiliaries fault diagnosis table

Symptom	Possible fault
Horn not working or poor sound quality	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	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 Blades and/or arm springs in poor condition
Washers not working or poor operation	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 fuid additive used
Indicators not working or incorrect operating speed	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	Loose or broken wiring/connections/fuse Switch not making contact Motor brushes worn Speed selection resistors open circuit

8.7.3 Wiper motor and circuit testing

Very modern wiper systems may need the assistance of a suitable scanner when diagnosing faults. However, don't forget the obvious tests such as correct voltage supplies, earth/ground connections and correct switch operation. All of which can be tested using a simple multimeter (Figure 8.46).

Figure 8.47 shows a procedure recommended by Lucas for testing an early type of wiper motor. The expected reading on the ammeter should not be more than approximately 5 A. Several types of wiper motor are in current use, so take care to make the appropriate connections for this test. Remember to use a fused jumper lead as a precaution.

Figure 8.46 Reversible wiper motor and drive linkage (Source: Bosch Media)

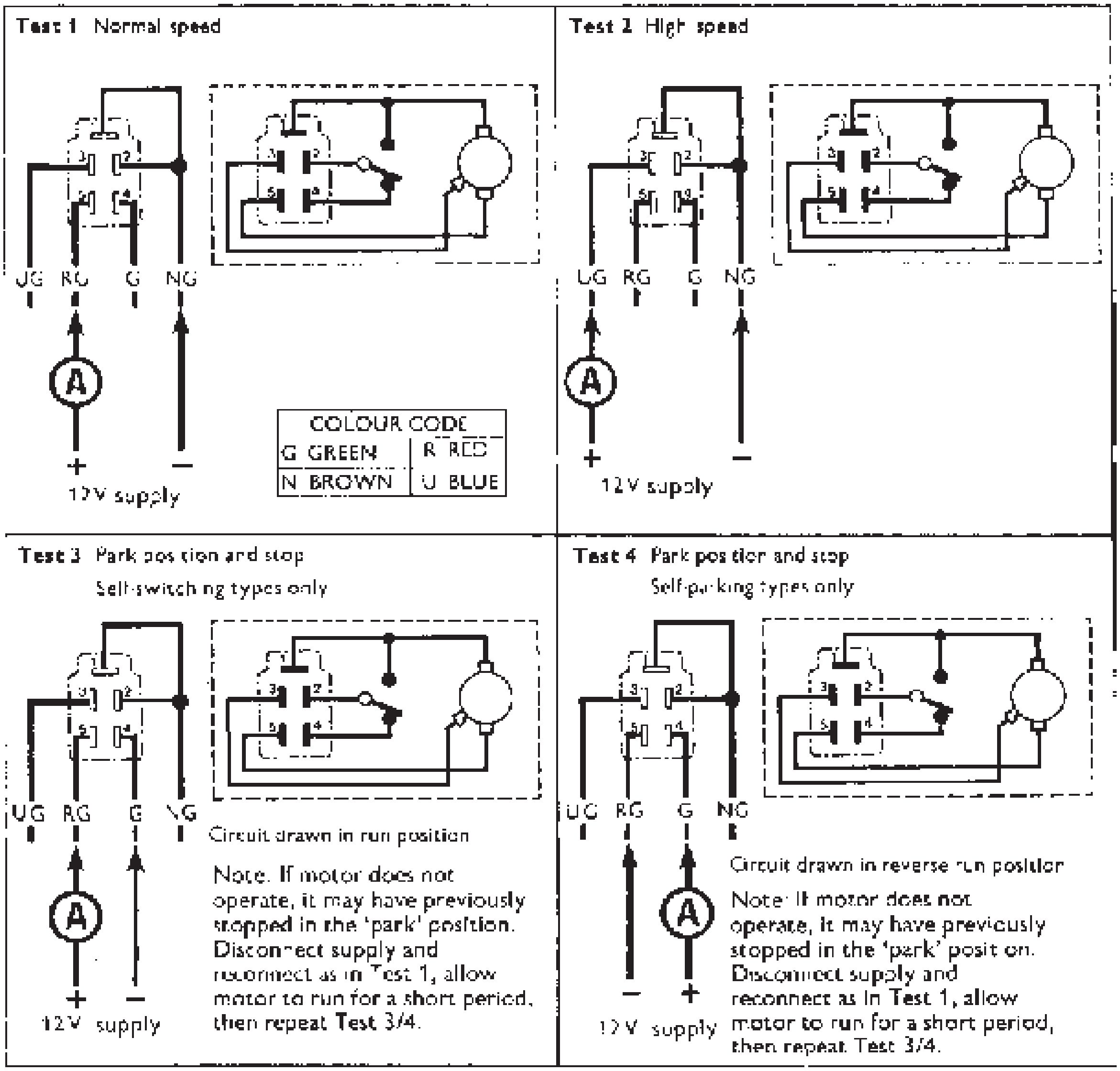

Figure 8.47 Early type wiper motor test procedure

8.8 In-car entertainment security and communications

8.8.1 In-car entertainment

Definition

MP3: An audio file format, based on MPEG (Moving Picture Expert Group) technology. It creates very small files suitable for streaming or downloading over the Internet.

Controls on most sets will include volume, treble, bass, balance and fade. A digital display will provide a visual output of operating condition (Figure 8.48). 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. An MP3 input is now often provided.

Many in-car entertainment (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.

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 mid-range and two front-door tweeters for high-frequency notes (Figure 8.49). 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 fall generally into the following categories:

- tweeters high-frequency reproduction;
- mid-range frequency reproduction (treble);

Figure 8.48 ICE display and sub-woofer

- woofers low-frequency reproduction (bass);
- sub-woofers very low frequency reproduction.

The radio data system (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.
- There can be automatic tuning to the best available signal for the chosen radio station. For example, in the United Kingdom, a journey from the south of England to Scotland would mean the radio would have to be retuned up to 10 times. RDS will do this without the driver even knowing.
- Traff c information broadcasts can be identif ed and a setting made so that whatever you are listening to at the time can be interrupted.

The radio broadcast data system (RBDS) is an extension of RDS which has been in use in Europe since 1984. The system allows the broadcaster to transmit text information at the rate of approximately 1200 bits/s. The information is transmitted on a 57 kHz suppressed sub-carrier as part of the FM 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 and include

- song title and artist;
- traff c, accident and road hazard information;

Def nition

RDS: Radio data system. Traff c information system on FM. RDS shows station name display and delivers traffc bulletins; it also locks onto the best possible frequency for a station in a particular part of the country.

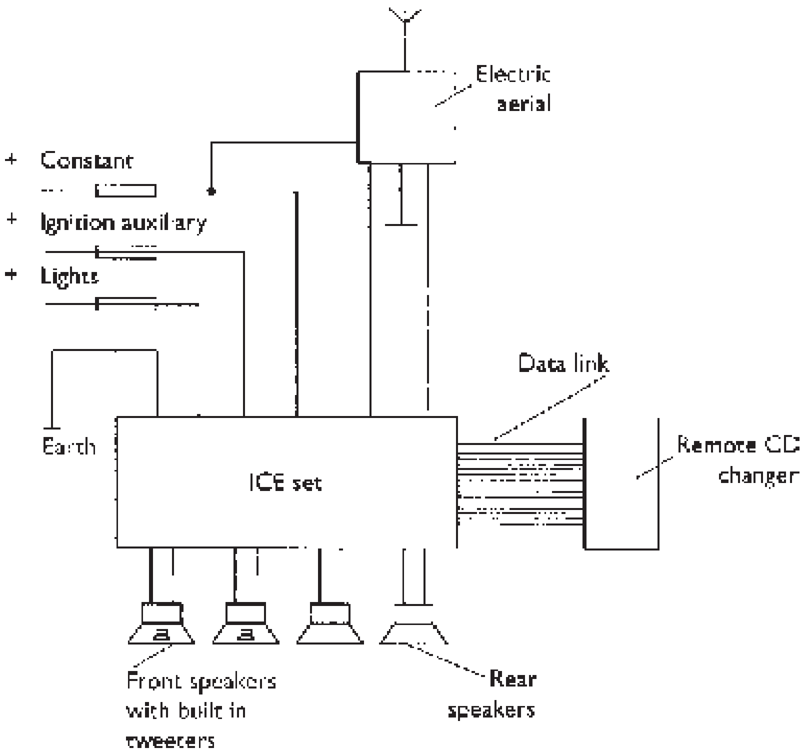

Figure 8.49 ICE circuit

- 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.

8.8.2 Security systems

Car and alarm manufacturers are constantly f ghting to improve security. Building the alarm system as an integral part of the vehicle electronics has made signif cant improvements. Even so, retrof t 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.

Most alarm systems 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 one or two minutes. The alarms are triggered instantly when entry point is breached. Most systems are two pieces, with separate control unit and siren; most will have the control unit in the passenger compartment and the siren under the bonnet.

Most systems now come with remote 'keys' that use small button-type batteries and may 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 f ashing lights, most systems draw approximately 5 A. Without f ashing lights (siren only), the current drawn is less than 1 A. The sirens produce a sound level of approximately 95 dB, when measured 2 m in front of the vehicle.

Key fact

Most factory-f tted alarms are combined with the central door locking system.

The system, as is usual, can be considered as a series of inputs and outputs. This is particularly useful for diagnosing faults. Most factory-f tted 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, as well as setting the alarm, closes the windows and sunroof and locks the doors (Figure 8.50).

A security code in the engine ECU 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 which is programmed with the required information. Even the correct 'cut' key will not start the engine.

Of course, nothing will stop the car being lifted onto a truck and driven away, but this technique will mean a new engine control ECU will be needed.

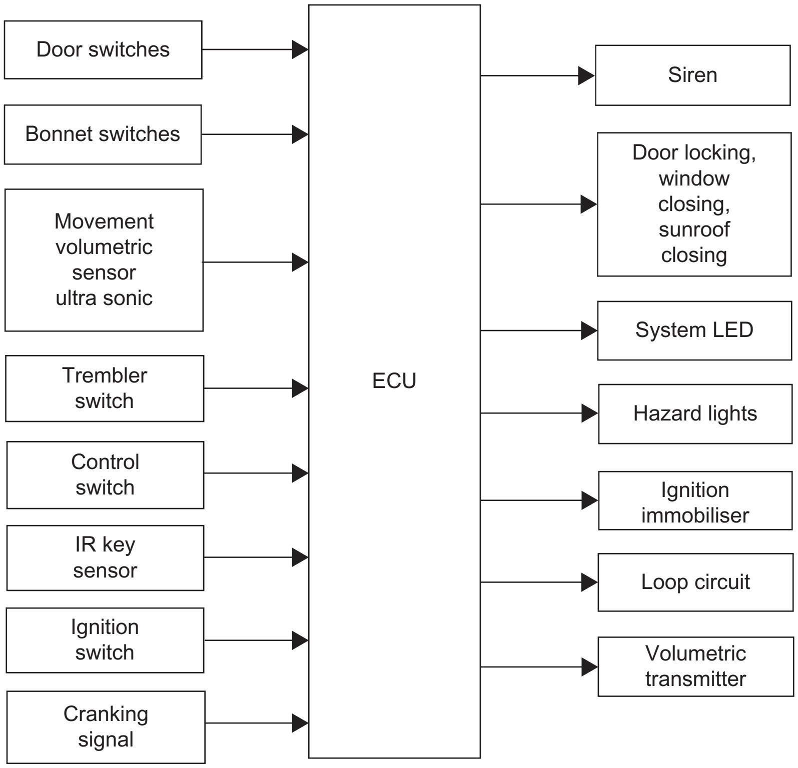

Figure 8.50 Block diagram of an alarm system

8.8.3 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.

Around this time, it was a specialised job to f t a car phone, but now this never happens. Many cars can link to standard mobile/cell now using Bluetooth. So, 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 only ever be by the simple pocket-sized mobile cell phone and that there is no further market for the car telephone. Hands free conversions may still be important, but even these are built into many cars.

Key fact

The car phone is no more – standard mobiles and Bluetooth hands-free have taken over

CB radios and short-range two-way systems such as those used by taxi f rms and service industries will still have a place for the time being. Even these will decline as the cellular network becomes cheaper and more convenient to use.

8.9 Diagnostics – ICE, security and communication

8.9.1 Testing procedure

The process of checking an ICE system circuit is broadly as presented in Figure 8.51.

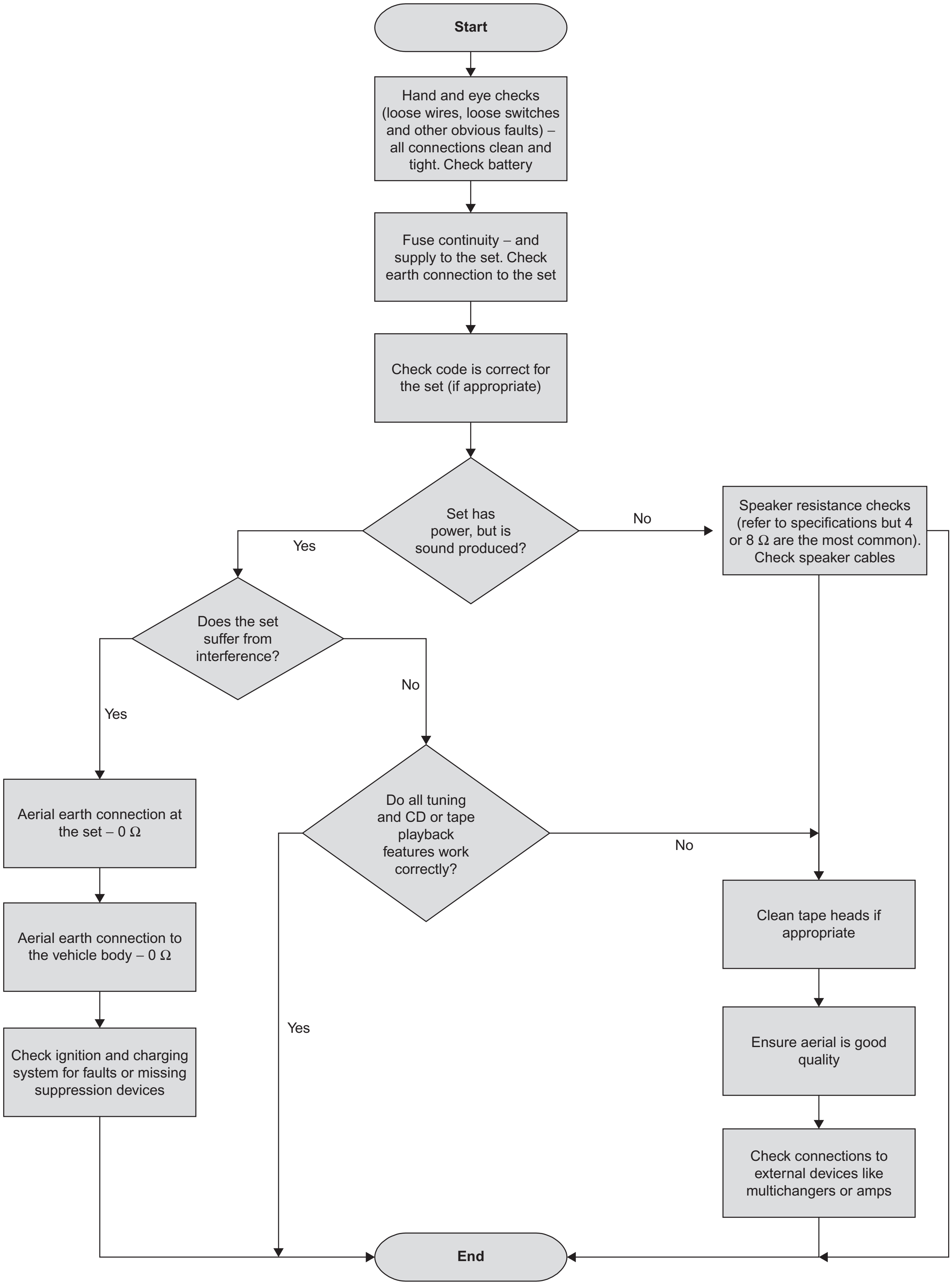

Figure 8.51 ICE system diagnosis chart

8.9.2 ICE, security and communication system fault diagnosis table

Symptom	Possible fault
Alarm does not operate	Fuse blown Not set correctly Remote key battery discharged Open circuit connection to alarm unit ECU fault Receiver/transmitter fault Volumetric transmitter/receiver fault
Alarm goes off for no apparent reason	Drain on battery Loose connection Vibration/trembler/movement detection circuit set too sensitive Self-discharge in the battery Window left open allowing wind or even a bird or insect to cause interior movement Somebody really is trying to steal the car Loose connection
Radio interference	Tracking HT components Static build up on isolated body panels High-resistance or open circuit aerial earth Suppression device open circuit
ICE system does not produce sound	Set not switched on! Loose or open circuit connections Trapped wires Connections to separate unit (amplifier, equaliser, etc.) incorrect Fuse blown
Unbalanced sound	Fade or balance controls not set correctly Speakers not wired correctly (front right, front left, rear right, rear left, etc.) Speaker open circuit or reduced output
Phasing	Speaker polarity incorrect. This should be marked, but if not, use a small battery to check all speakers are connected the same way. A small DC voltage will move the speaker cone in one direction.
Speaker rattle	Insecure speaker(s) Trim not secure Inadequate baffles
Crackling noises	If one speaker – then try substitution If one channel – swap connections at the set to isolate the fault If all channels but only the radio then check interference Radio set circuit fault
Vibration	Incorrect or loose mounting
Hum	Speaker cables routed next to power supply wires Set fault
Distortion	Incorrect power rating speakers

(Continued)

Symptom	Possible fault
Poor radio reception	Incorrect tuning 'Dark' spot/area. FM signals can be affected by tall buildings, etc. Aerial not fully extended Aerial earth loose or high resistance Tuner not trimmed to the aerial (older sets generally) Aerial sections not clean
Telephone reception poor	Low-battery power Poor reception area Interference from the vehicle Loose connections on hands free circuit

Key fact

Most modern cars have to meet stringent EMC standards.

8.9.3 Interference suppression

The process of interference suppression on a vehicle is to reduce the amount of unwanted noise produced from the speakers of an ICE system. This was at one time quite diff cult but now most modern cars have to meet EMC standards so no additional work is needed. There will always be older cars and exceptions, so read on!

To aid the discussion, it is necessary to f rst understand the different types of interference. Figure 8.52 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 f eld strength compared to the interference f eld strength at the receiver.

There are two overall issues to be considered relating to suppression of interference on a vehicle. These are as follows:

- Short range – the effect of interference on the vehicle's radio system.
- 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;
- capacitive coupling by an electric f eld;
- inductive coupling magnetic linking.

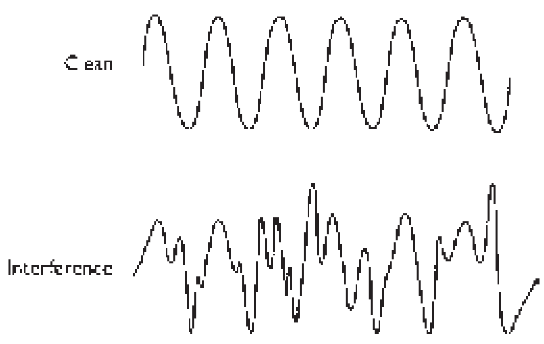

Figure 8.52 Radio signals

The sources of interference in the motor vehicle can be summarised 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, in particular the high-tension side. Voltages up to 50 kV are now common and the current for a fraction of a second when the plug f res 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 in the order of 500 kW.

The charging system produces noise because of the sparking at the brushes. Electronic regulators produce few 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.

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 on the wing, then a spark can be discharged. Using bonding straps to ensure all panels stay at the same potential easily prevents this. Because of the action of the tyres, a potential can build up between the wheel rims and the chassis unless suitable bonding straps are f tted. The arc to ground can be as much as 10 kV.

There are f ve 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 approximately 20 kΩ 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 that 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 can be used to good effect, for example metal covers on the plugs.

Capacitors and inductors are used to act as f lters. 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.

Key fact

Capacitors and inductors can be used as electrical lters.

By choosing suitable values of capacitor in parallel and/or inductor in series, it is possible to f lter out unwanted signals of certain frequencies.

Several types of aerial 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 f eld of the vehicle. For reception in the AM bands, the aerial represents a capacitance of 80 pF with a shunt resistance of approximately 1 MΩ. The set will often incorporate a trimmer to ensure that the aerial is matched to the set. Contact resistance between all parts of the aerial should be less than 20 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 approximately 80 cm. Because of the magnetic and electrical f eld of the vehicle and the effect of the coaxial cable, the most practical length is approximately 1 m. Some smaller aerials are available but while 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 for insensitivity to moisture, but produce a weaker signal often requiring an aerial amplif er 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 ref ected signals and causes less f utter.

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 – whether it f ts with the style of the vehicle;
- angle of f tting – vertical is best for AM and horizontal for FM.

Most quality sets also include a system known as interference absorption. This is a circuit built in to the set consisting of high-quality f lters and is not adjustable.

8.10 Body electrical systems

8.10.1 Electric seat adjustment

Adjustment of the seat is achieved by using a number of motors to allow positioning of different parts of the seat. A typical motor reverse circuit is shown in Figure 8.53.

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. Movement is often possible in the following ways:

- front to rear;
- cushion height rear;
- cushion height front;
- backrest tilt;
- headrest height;
- lumbar support.

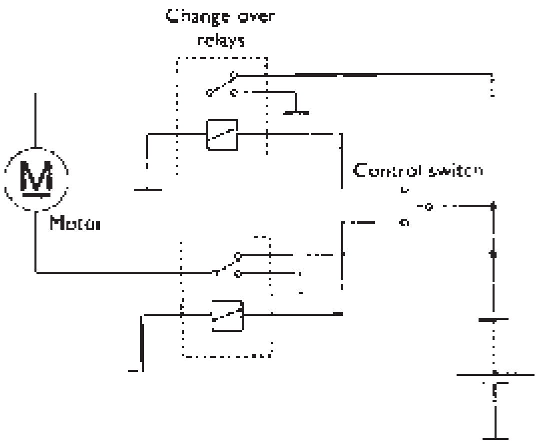

Figure 8.53 Motor reverse circuit using a centre-off changeover switch and two changeover relays

When seat position is set, some vehicles have position memories to allow automatic repositioning, if the seat has been moved. This is often combined with electric mirror adjustment. Figure 8.54 shows how the circuit is constructed to allow position memory. As the seat is moved, a variable resistor, mechanically linked to the motor, is also moved. The resistance value provides feedback to an ECU.

This can be 'remembered' in a number of ways; the best technique is to supply the resistor with a f xed 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. Position of the seats can still be adjusted by operating the switches as normal.

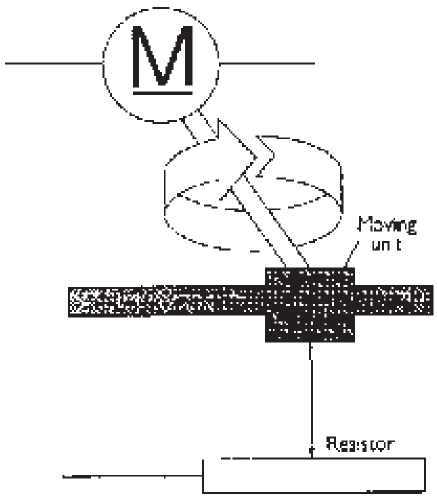

Figure 8.54 One method for position memory

8.10.2 Electric mirrors

Many vehicles have electrical 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 f rst switched on and can also be linked to the heated rear window circuit. The following f gure shows an electrically operated mirror circuit, which includes feedback resistors for positional memory (Figure 8.55).

8.10.3 Electric sunroof operation

The operation of an electric sunroof 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 energised. The mechanism used to achieve this is much like that used in ball point pens that use a button on top (Figure 8.56).

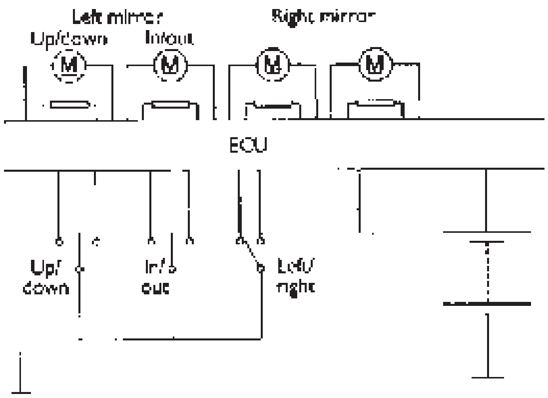

Figure 8.55 Mirror adjustment circuit

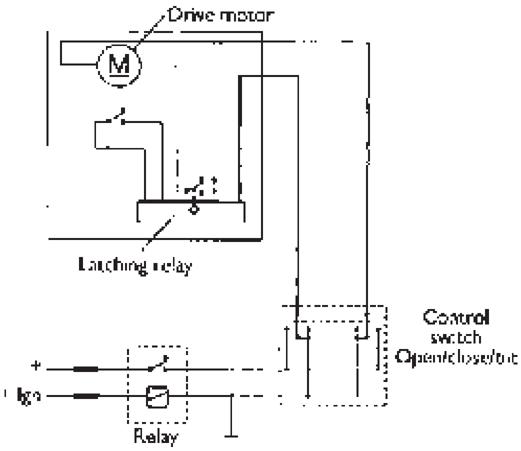

Figure 8.56 Sunroof circuit example

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 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 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.

8.10.4 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.

The main control unit in the following f gure contains two changeover relays. These are actuated by either the door lock switch or, if f tted, the remote infrared key. The motors for each door lock are simply wired in parallel and all operate at the same time (Figure 8.57).

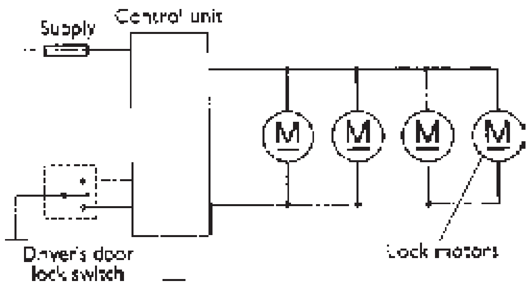

Figure 8.57 Door lock circuit

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.

Remote central door locking is controlled by a small hand-held transmitter and an infrared or RF 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 again operate the locks. This technique prevents a scanning-type transmitter unit from being used to open the doors.

8.10.5 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 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.

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, gets trapped in the window, there is a serious risk of injury. To prevent this, the back-off feature is used. An extra commutator is f tted to the motor 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 initialised.

Key fact

To prevent children (or others) becoming trapped in an auto-close window, a back-off feature is used.

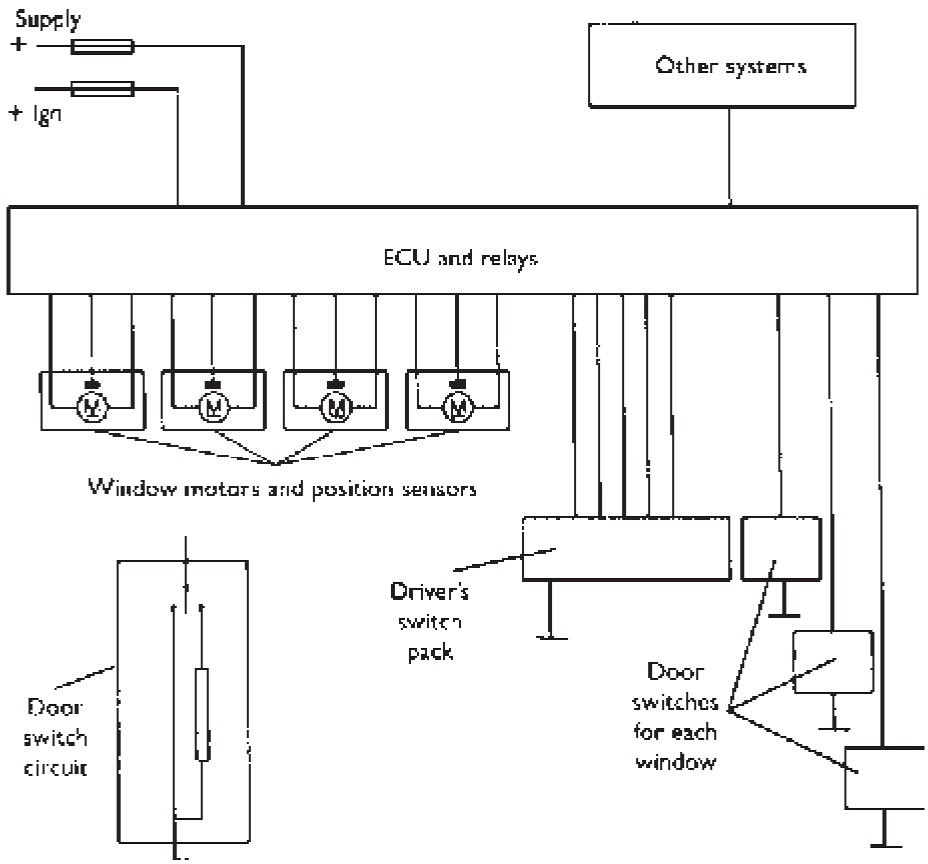

Figure 8.58 Electric window circuit

This is often done simply by operating the motor to drive the window f rst 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.

Lazy lock feature allows the car to be fully secured by one operation of a remote key. This is done by the link between the door lock ECU and the window and sunroof ECUs. A signal is supplied which causes all the windows to close in turn and then the sunroof, and f nally locks the doors. The alarm will also be set, if required. The windows close in turn to prevent the excessive current demand which would occur if they all tried to operate at the same time.

A circuit for electric windows is shown in Figure 8.58. Note the connections to other systems such as door locking and the rear window isolation switch. This is commonly f tted to allow the driver to prevent rear window operation for child safety, for example.

8.11 Diagnostics – body electrical

8.11.1 Testing procedure

The following procedure is very generic but with a little adaptation can be applied to any electrical system. Refer to manufacturer's recommendations if in any doubt. The process of checking any system circuit is broadly as presented in Figure 8.59.

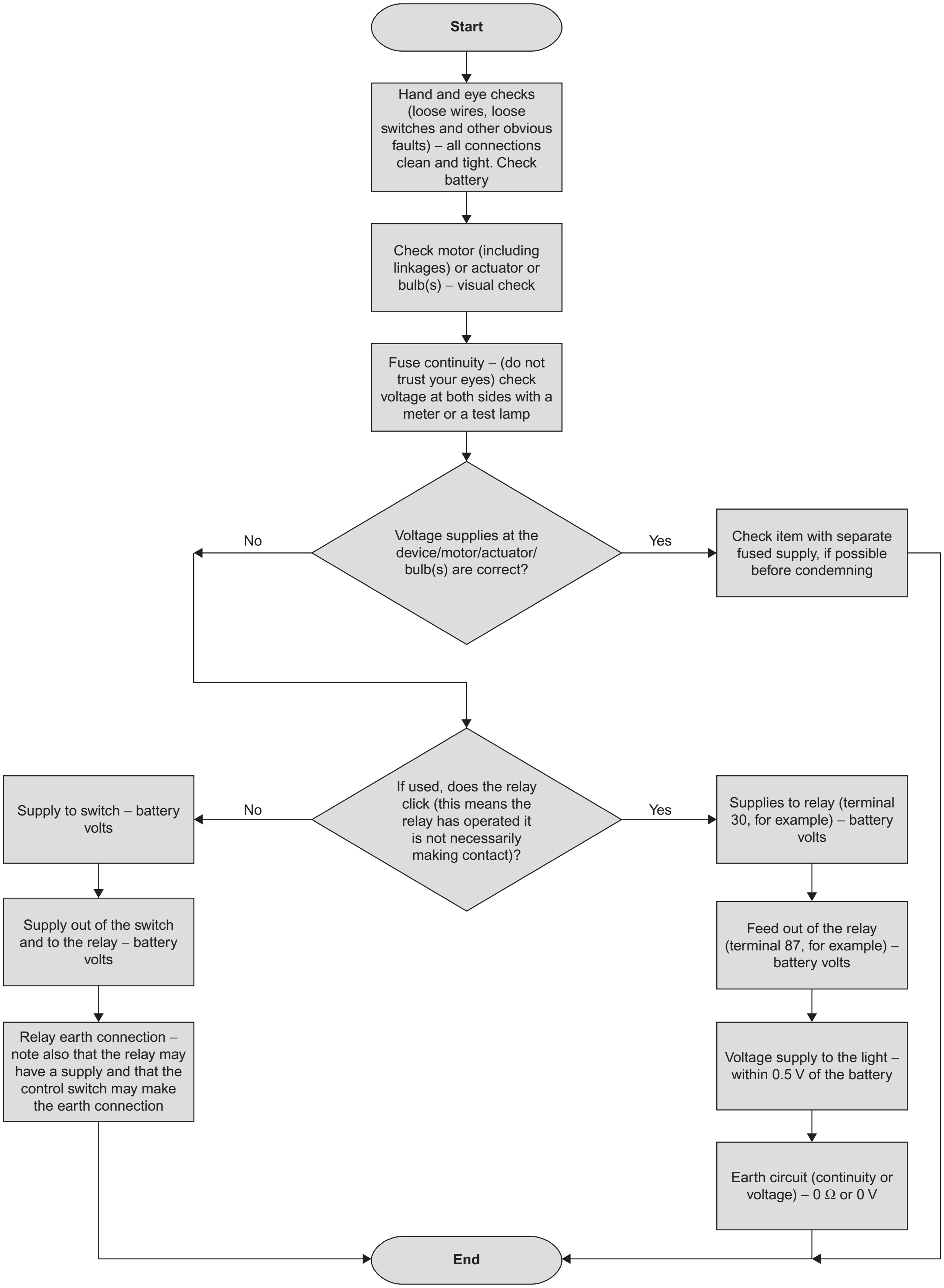

Figure 8.59 Auxiliary and body systems diagnosis chart

8.11.2 Body electrical systems fault diagnosis table

Symptom	Possible fault
Electric units not operating	If ALL units not operating Open circuit in main supply Main fuse blown
Unit = window, door lock, mirror, etc.	Relay coil or contacts open circuit or high resistance If ONE unit is not operating Fuse blown Control switch open circuit Motor seized or open circuit Back-off safety circuit signal incorrect (windows)

8.11.3 Circuit systematic testing

The circuit shown in Figure 8.60 is for a power hood (meaning roof in this case) on a vehicle. The following faultf nding guide is an example of how to approach a problem with a system such as this in a logical manner.

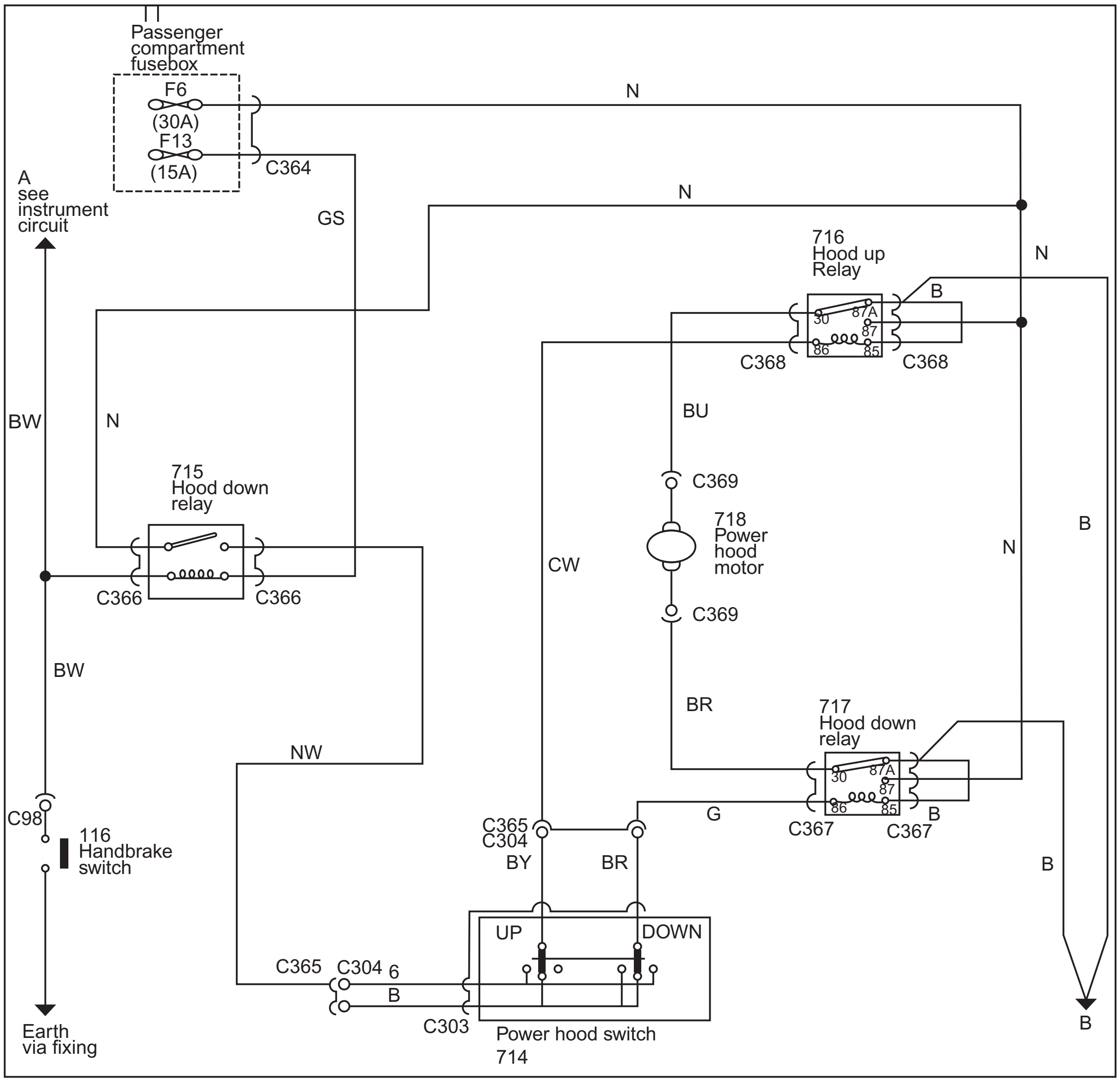

Figure 8.60 Power hood (roof) circuit

If the power hood will not operate with the ignition switch at the correct position and the handbrake applied, proceed as follows:

1 Check fuses 6 and 13.
2 Check 12 V supply on N wire from fuse 6.
3 Check for 12 V on GS wire at power hood relay.
4 Check continuity from power hood relay to earth on BW wire.
5 Check power hood relay.
6 Check for 12 V on NW wire at hood switch. Check for 12 V on N wire at hood up and down relays.
7 Check continuity from hood up and down relays to earth on B wire.
8 Check switch operation.
9 Check pump motor operation.

If the power hood will operate in one direction only, proceed as follows:

1 Check for 12 V on N wire at hood up or down relay as appropriate.
2 Check continuity from hood up or down relay to earth on B wire.
3 Check relay.

8.12 Instrumentation

8.12.1 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 utilising the heating effect of electricity and the widely adopted benef t of the bimetal strip. As a current f ows 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 f owing. Provided the sensor can vary its resistance in proportion to the measurement (e.g. fuel level), the gauge will indicate a suitable representation as long as it has been calibrated for the particular task. Figure 8.61 shows a representation of a typical thermal gauge circuit.

Key fact

With a bimetal strip, the amount of bend is proportional to the heat, which in turn is proportional to the current fowing.

Thermal-type gauges are used with a variable resistor and f oat in a fuel tank or with a thermistor in the engine water jacket. 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 system voltage increased, the

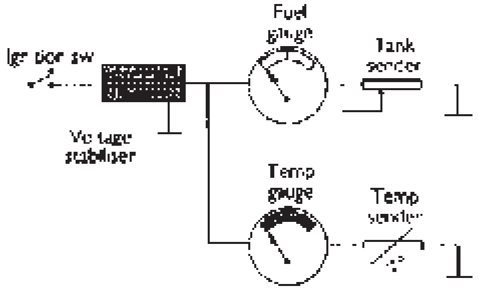

Figure 8.61 Simplif ed thermal gauge circuit

current f owing would increase and hence the gauges would read higher. Most voltage stabilisers are simple zener diode circuits.

Air-cored gauges work on the same principle as a compass needle lining up with a magnetic f eld. The needle of the display is attached to a very small permanent magnet. Three coils of wire are used and each produces a magnetic f eld. The magnet will line up with the resultant of the three f elds. The current f owing and the number of turns (ampere-turns) determine the strength of the magnetic f ux produced by each coil. As the number of turns remains constant, the current is the key factor. Figure 8.62 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.

Key fact

Air-cored gauges work on the same principle as a compass needle lining up with a magneticfeld.

The air-cored gauge has a number of advantages. It has almost instant response, and as the needle is held in a magnetic f eld 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 f owing in all three coils, variations are cancelled out negating the need for voltage stabilisation. Note that the operation is similar to the moving iron gauge.

8.12.2 Digital instrumentation

The block diagram shown in Figure 8.63 is the representation of a 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 (read only memory) section, which allows it to be programmed to a specif c vehicle. The gauges used are as described in the

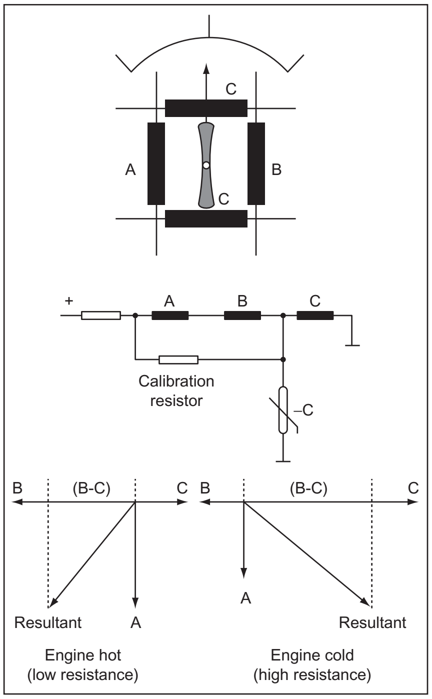

Figure 8.62 Principle of an aicored gauge and the circuit used for engine temperature

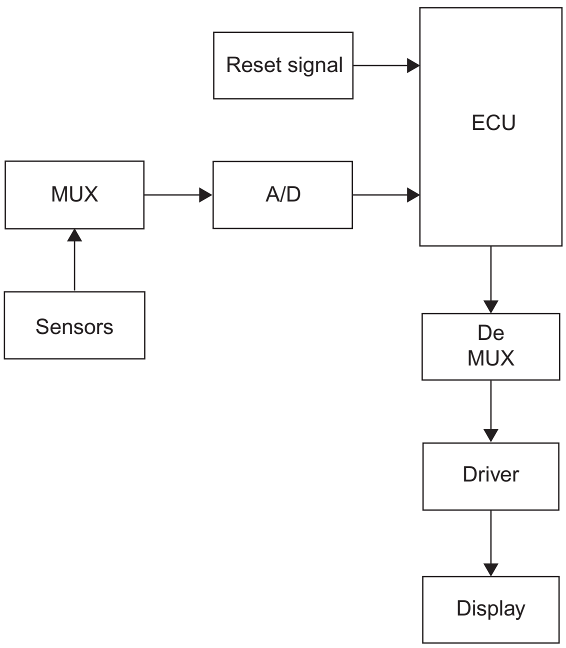

Figure 8.63 Digital instrumentation block diagram

above sections. Some of the extra functions available with this system are described brief y 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 f uctuating as the cooling system thermostat operates, the gauge can be made to read only at say f ve set f gures. 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 f ve 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 f ash: 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.

8.12.3 Vehicle condition monitoring

Vehicle condition monitoring (VCM) is a sort of enhancement to the normal instrumentation system. For example, a warning light added to a gauge as shown in Figure 8.64.

Figure 8.64 Low fuel warning

A system may include driver information relating to the following list:

- high engine temperature;
- low fuel;
- low brake f uid;
- worn brake pads;
- low coolant level;
- low oil level;
- low screen washer f uid;
- low outside temperature;
- bulb failure;
- doors, bonnet, hood or boot open warning.

A circuit is shown in Figure 8.65 that 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 f uid and temperature level monitoring systems work in a similar way to the systems described earlier, but in some cases the level of a f uid is by a f oat and switch.

Oil level can be monitored by measuring the resistance of a heated wire on the end of the dip stick. 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 resistance.

Key fact

Many of the circuits monitored use a dual-resistance system so that the circuit itself is also checked.

Many of the circuits monitored use a dual-resistance system so that the circuit itself is also checked (Figure 8.66). In effect, it will produce one of three possible outputs: high-resistance, low-resistance or an out-of-range reading. The high- or

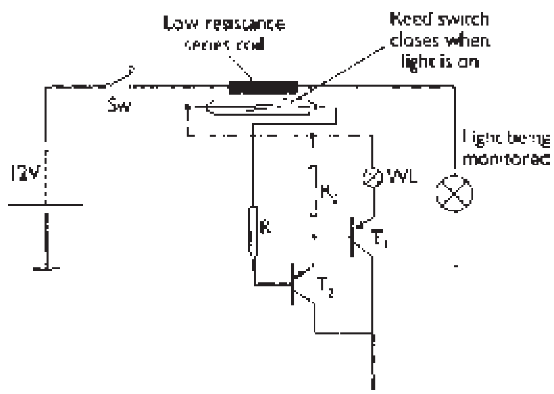

Figure 8.65 Bulb failure warning circuit

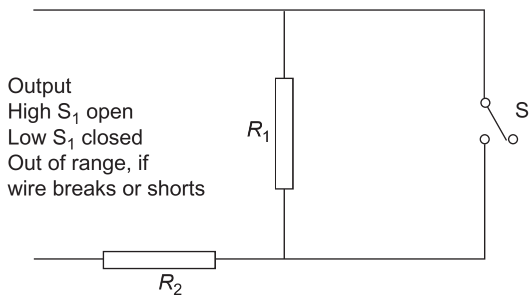

Figure 8.66 Dual-resistance self-testing system

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.

The display on earlier cars was often just a collection of LEDs or a backlit liquid crystal display (LCD). These were even arranged into suitable patterns and shapes such as to represent the circuit or system being monitored.

However, the current trend is to just present information as requested by the driver or to present only what is important at any particular time. Low outside temperature or ice warning is often a large snowflake, or a tyre pressure issue is notified using a symbol shown in Figure 8.67.

8.12.4 Trip computer

The trip computer used on many top range vehicles is arguably an expensive novelty, but is popular nonetheless. 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. 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.

8.12.5 Displays

If the junction of a diode is manufactured in a certain way, light will be emitted from the junction when a current is made to pass in the forward biased direction. This is an 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 (Figure 8.68).

LED displays are tending to be replaced with the liquid crystal type for automobile use, which can be backlit to make it easier to read in the daylight.

Figure 8.67 Low tyre pressure warning symbol

Figure 8.68 Instrument display combining analogue and digital displays

Key fact

LED displays are tending to be replaced with the liquid crystal type for automobile use, 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.

Liquid crystals are substances that do not melt directly from a solid to the liquid phase, but first pass through a para-crystalline 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.

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 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 and TV screens.

8.13 Diagnostics – instruments

8.13.1 Testing procedure

The process of checking a thermal gauge fuel or temperature instrument system is broadly as presented in Figure 8.69.

8.13.2 Instrumentation fault diagnosis table

Symptom	Possible fault
Fuel and temperature gauges both read high or low	Voltage stabiliser
Gauges read full/hot or empty/cold all the time	Short/open circuit sensors Short or open circuit wiring
Instruments do not work	Loose or broken wiring/connections/fuse Inoperative instrument voltage stabiliser Sender units (sensor) faulty Gauge unit fault (not very common)

8.13.3 Black box technique for instrumentation

Instrumentation systems, like most others, 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. Figure 8.70 shows an instrumentation system where the instrument pack could be considered as a black box. Normal faultfinding or testing techniques can now be applied to the sensors and supply circuits.

Remember also the 'sensor to ECU method' of testing described in Chapter 2. A resistance test carried out on a component such as the tank unit (lower right) would give a direct measure of its resistance. A second reading at the instrument pack between the GB and BP wires, if the same as the first, would confirm that the circuit is in good order.

Safety first

Warning: The circuit supply must always be off when carrying out ohmmeter tests.

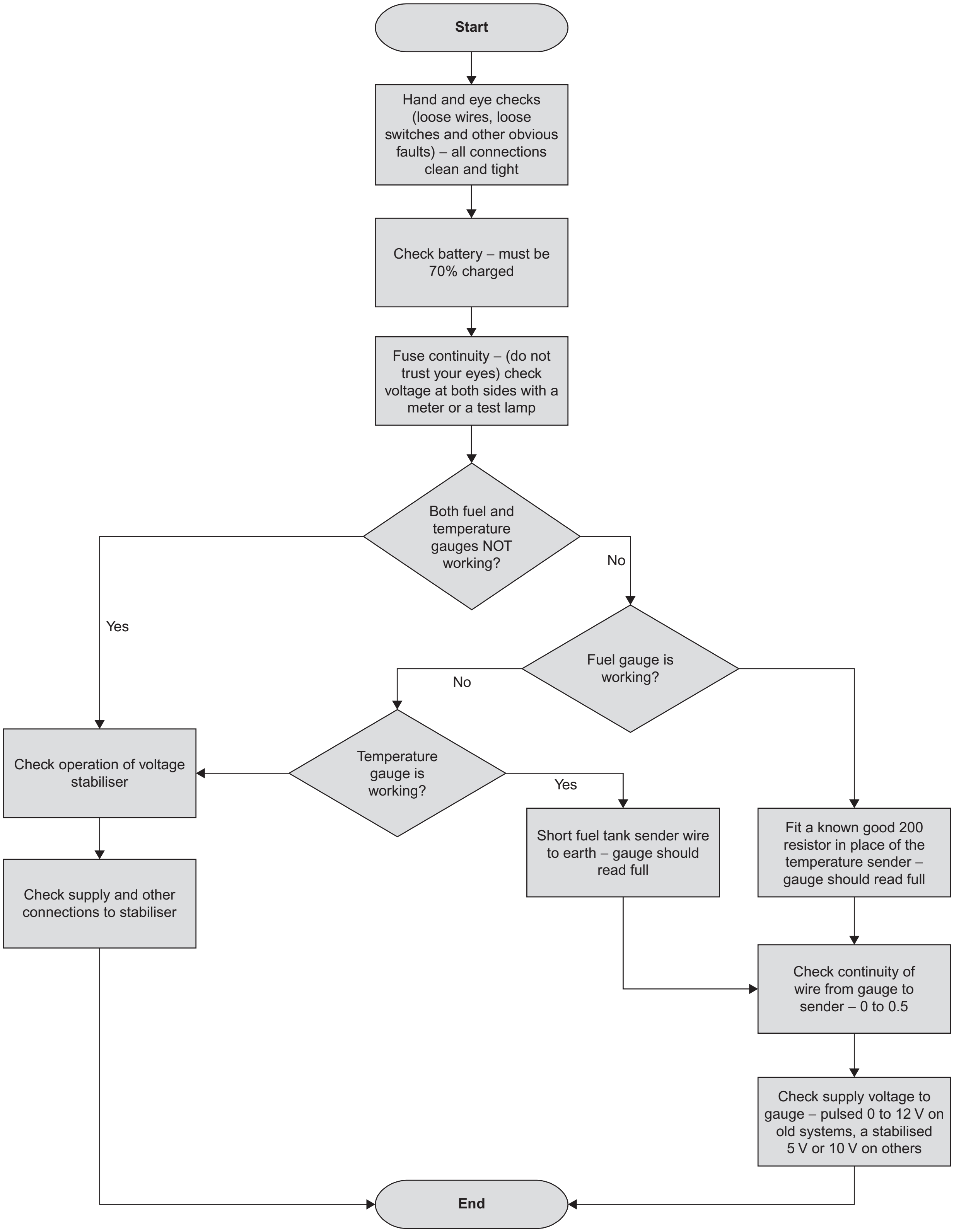

Figure 8.69 Instrumentation diagnosis chart

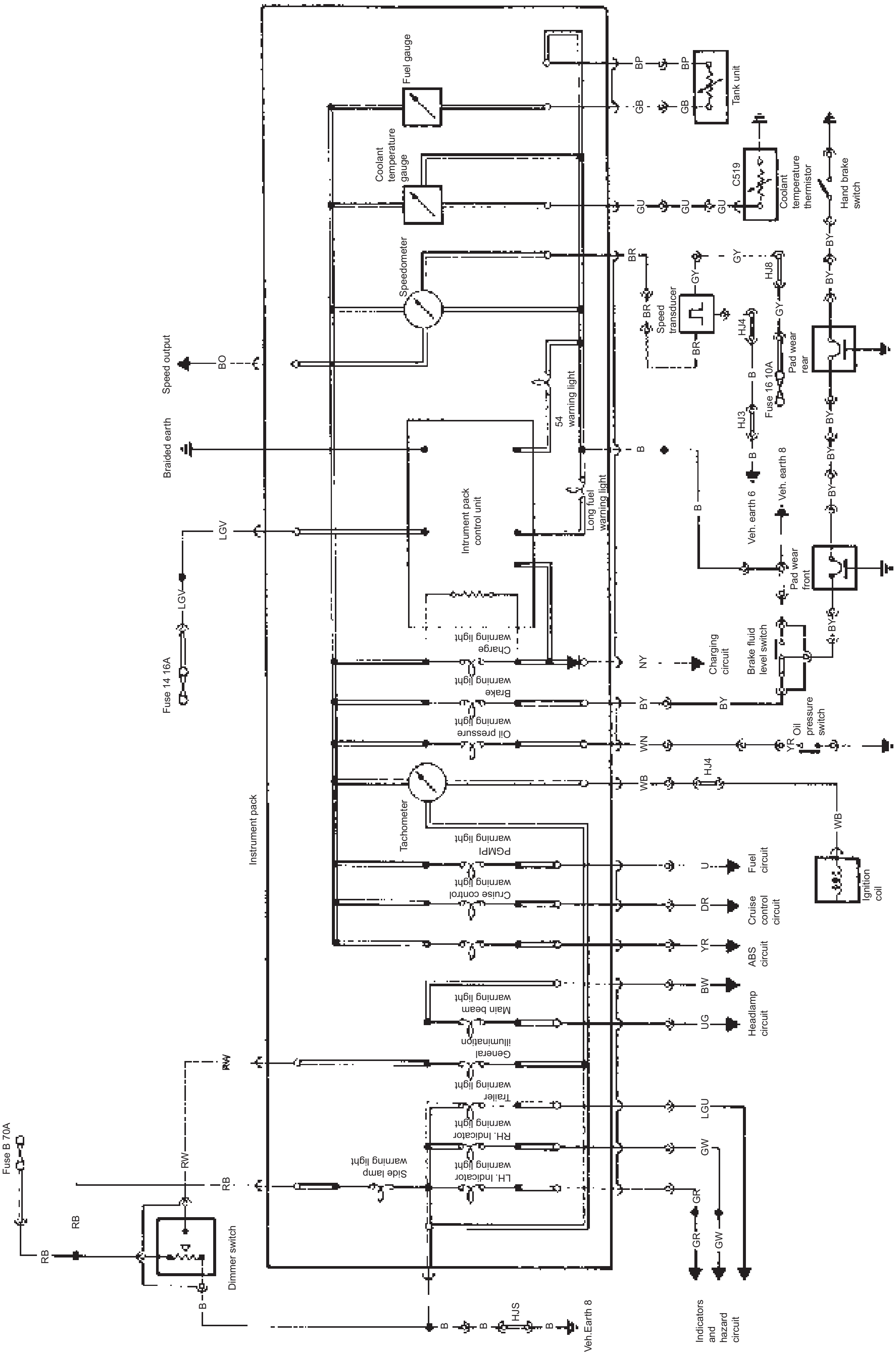

Figure 8.70 Instrumentation circuit

8.14 Heating, ventilation and air conditioning

8.14.1 Ventilation and heating

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 def nition 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. When the vehicle is moving, the airf ow over the vehicle will cause a higher pressure in this area. Suitable f aps and drains are utilised to prevent water entering the car through this opening.

By means of distribution trunking, control f aps and suitable ‘nozzles’, the air can be directed as required. This system is enhanced with the addition of a variable speed blower motor. 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.

Def nition

Plenum chamber: A pressurised housing containing a gas or fluid (typically air) at positive pressure (pressure higher than surroundings). One function of a plenum can be to equalise pressure for more even distribution, because of irregular supply or demand.

8.14.2 Heating system – water-cooled engine

Heat from the engine is utilised to increase the temperature of the car interior. This is achieved by use of a heat exchanger, called the heater matrix. Because of 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 airf ow. 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 f ap, 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 airf ow with vehicle speed. Some systems use a valve to control the hot coolant f owing to the heater matrix (Figure 8.71).

Def nition

HVAC: Heating, ventilation and air conditioning.

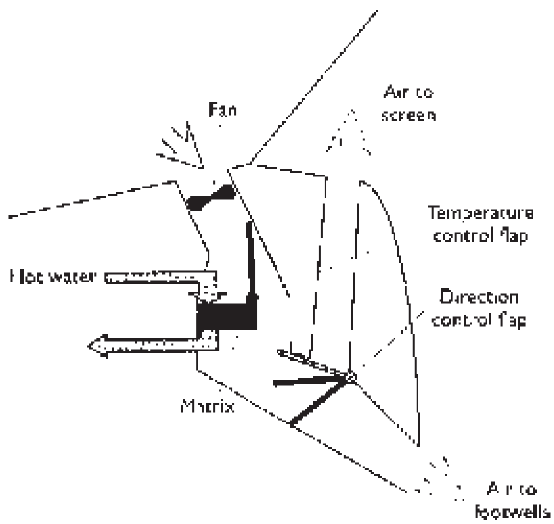

Figure 8.71 Heating and ventilation system

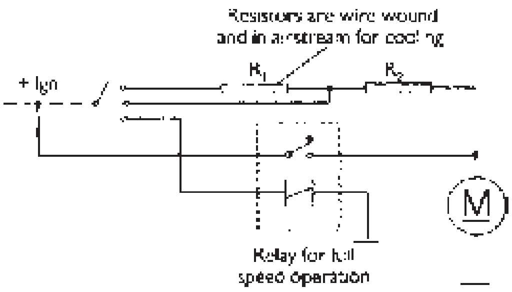

Figure 8.72 Three-speed motor control circuit

By a suitable arrangement of f aps, 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 passenger footwells. Most vehicles also have small vents directing warm air at the driver's and front passenger's side windows. Fresh cool air outlets with directional nozzles are also f tted.

One f nal 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 the outside air may not be very clean, for example, in heavy congested traff c.

8.14.3 Heater blower motors

The motors used to increase airf ow 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. Varying the voltage supplied controls motor speed. This is achieved by using dropping resistors. The speed in some cases is made 'inf nitely' variable, by the use of a variable resistor. In most cases, the motor is controlled to three or four set speeds.

Figure 8.72 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 Ω or less (Figure 8.73).

8.14.4 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.

This system requires control of the blower motor, blend f ap, direction f aps and the fresh or recirculated air f ap. 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.

Figure 8.73 Blower motor and fan

8.14.5 Air conditioning introduction

A vehicle f tted 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 utilises the standard heating and ventilation components, but with the important addition of an evaporator, which both cools and dehumidif es the air.

Air conditioning can be manually controlled or, as is not 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. To understand the principle of refrigeration, the following terms and def nitions will be useful.

- Heat is a form of energy.
- Temperature means the degree of heat of an object.
- Heat will only f ow 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 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.

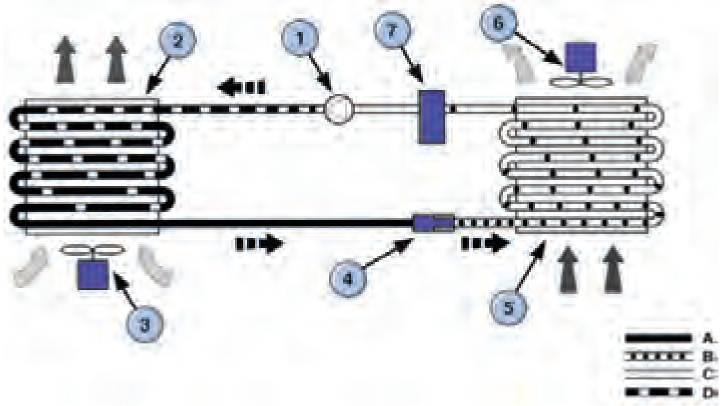

Figure 8.74 AC system layout: 1 – compressor; 2 – condenser; 3 – auxiliary fan (depending on model); 4 – fixed orifice tube; 5 – evaporator; 6 – heater/air conditioning blower; 7 – suction accumulator/drier; A – high-pressure warm liquid; B – low-pressure cool liquid; C – low-pressure, gaseous and cool; D – high-pressure, gaseous and hot (Source: Ford Motor Company)

Figure 8.75 AC components

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) based rather than chlorofluorocarbon (CFC), due to the problems with atmospheric ozone depletion associated with CFC-based refrigerants. A key to understanding refrigeration is to remember that low-pressure refrigerant will have low temperature, and high-pressure refrigerant will have a high temperature.

Figure 8.74 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 is outside the car, usually in the air stream; and 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. Figure 8.75 shows some typical components of an air conditioning system.

Key fact

On an AC system, the evaporator is situated in the car; the condenser is outside the car; usually in the air stream; and the compressor is driven by the engine.

8.14.6 Air conditioning overview

The operation of the system is a continuous cycle. The compressor pumps low pressure but heatladen vapour from the evaporator, compresses it and pumps it as a superheated 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 f ns 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 bag 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 f ow 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 f ns. The low-pressure vapour leaves the evaporator returning to the pump, thus completing the cycle.

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 f tted 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.

8.14.7 Automatic temperature control

Full temperature control systems provide a comfortable interior temperature in line with the passenger controlled input. The ECU 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 currently will set the system to full defrost or demist.

A number of sensors are used to provide input to the ECU.

- Ambient temperature sensor mounted outside the vehicle to allow compensation for extreme temperature variation. This device is usually a thermistor.
- Solar light sensor 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 f aps 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

Key fact

Control of the HVAC faps can be either by solenoid controlled vacuum actuators or by small motors.

Figure 8.76 Heated seat

variable. These systems are able to provide a comfortable interior temperature in exterior conditions ranging from −10 to +35 °C even in extreme sunlight.

8.14.8 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 f rst appears. The heater must meet the following criteria:

- The heater must only supply the heat loss experienced by the person's body.
- Heat is 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 f t the design of the seat.
- The elements must pass the same rigorous tests as the seat, such as squirm, jounce and bump tests.

In order for the passengers (including the driver) to be comfortable, rigorous tests have been carried out to f nd the optimum heat settings and the best position for the heating elements. Many tests are carried out on new designs, using manikin with sensors attached, to measure the temperature and heat f ow (Figure 8.76).

The cable used for most heating elements 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.

8.14.9 Screen heating

Heating of the rear screen involves a very simple circuit. 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 will often contain a timer relay to prevent the heater being left on for 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 f tted (Figure 8.77).

Front windscreen heating is being introduced on many 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 in to the glass. As with the heated rear window, this device can consume a large current and is operated by timer relay.

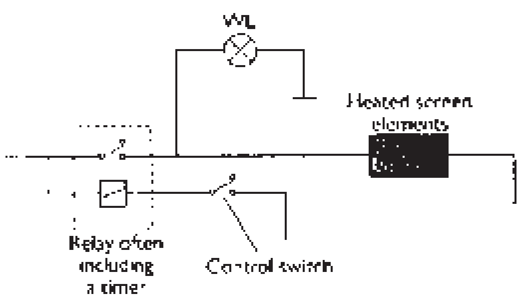

Figure 8.77 Screen heating circuit

8.15 Diagnostics – HVAC

8.15.1 Testing procedure (Figure 8.78)

The process of checking an air conditioning system is broadly as presented in Figure 8.79.

Safety f rst

Warning: Do not work on the refrigerant side of air conditioning systems unless you have been trained and have access to suitable equipment.

8.15.2 Air conditioning fault diagnosis table

Symptom	Possible fault
After stopping the compressor, pressure falls quickly to approximately 195kPa 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 then 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	Oily marks (from the lubricant in the refrigerant) near joints or seals indicate leaks

Figure 8.78 Circuit voltage testing

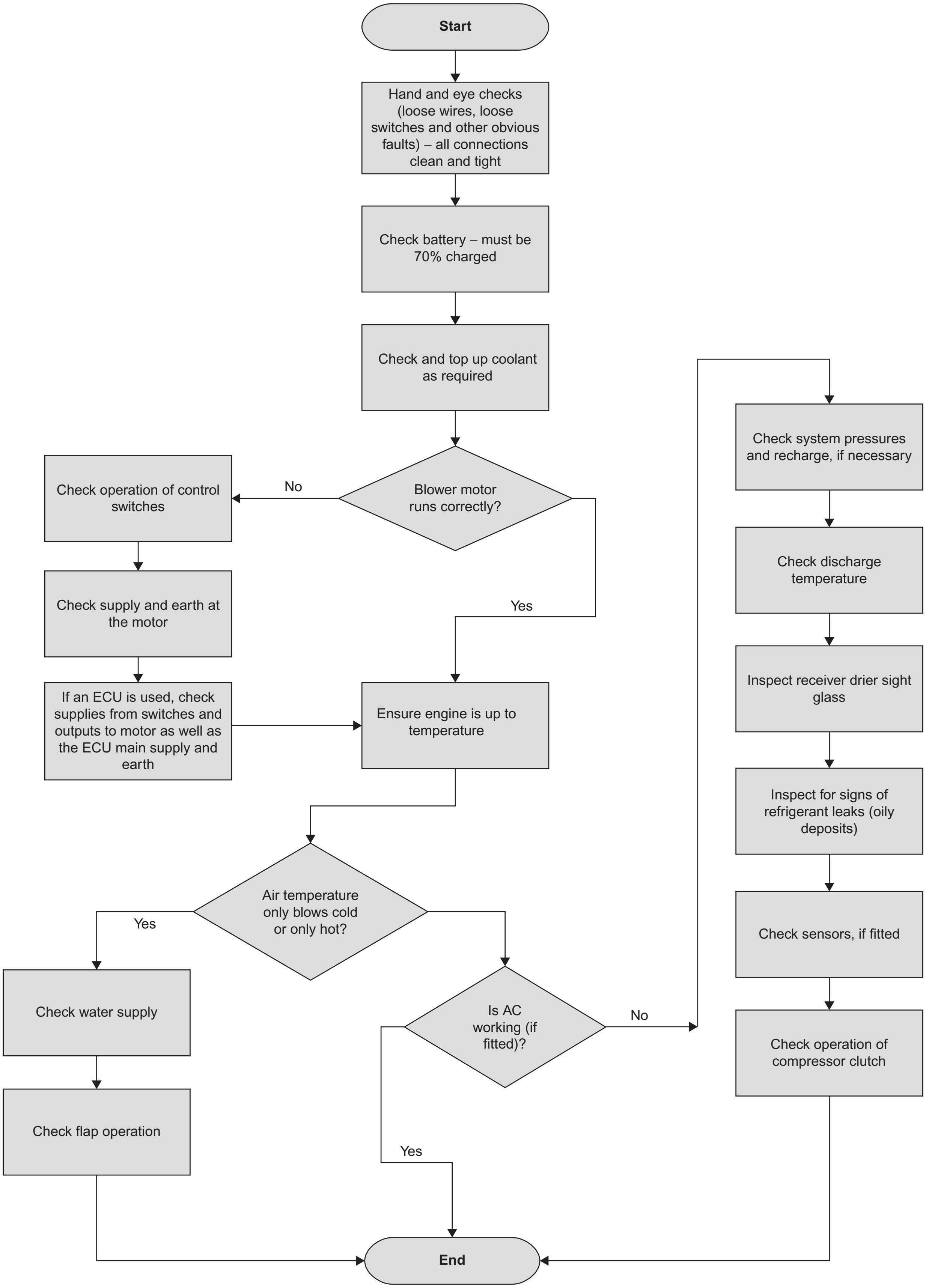

Figure 8.79 HVAC system diagnosis chart

8.15.3 Heating and ventilation fault diagnosis table

Symptom	Possible fault
Booster fan not operating at any speed	Open circuit fuse/supply/earth Motor inoperative/seized Dropping resistor(s) open circuit Switch open circuit Electronic speed controller not working
Booster fan only works o full speed	Dropping resistor(s) open circuit Switch open circuit Electronic speed controller not working
Control fap(s) will not move	Check vacuum connections (many work by vacuum-operated actuators) Inspect cables
No hot air	Matrix blocked Blend fap stuck
No cold air	Blend fap stuck Blocked intake
Reduced temperature when set to 'Hot'	Cooling system thermostat stuck open Heater matrix partially blocked Control fap not moving correctly

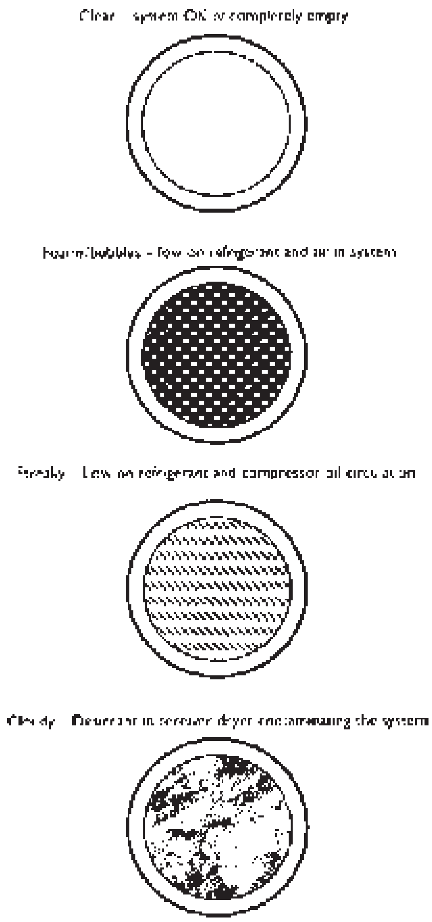

Figure 8.80 AC receiver drier sight glass

8.15.4 Air conditioning receiver

A very useful guide to diagnostics is the receiver drier sight glass. Figure 8.80 shows four possible symptoms and suggestions as to the possible fault.

8.16 Cruise control

8.16.1 Introduction

Cruise control is the ideal example of a closed loop control system as shown in Figure 8.81. 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 as if it is 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

Def nition

Negative feedback acts to reduce the input signal that caused it, is also known as a self-correcting or balancing loop. Negative feedback loops are goal seeking, for example, a temperature sensor in a system that compares actual temperature with desired temperature and acts to reduce the difference.

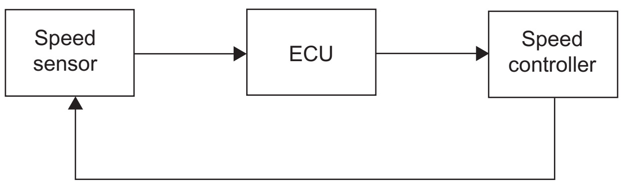

Figure 8.81 Cruise control – closed control loop negative feedback

Table 8.3 Cruise control components

Actuator	A number of methods are used to control the throttle position. Vehicles fitted with drive 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 three simple valves control
Main switch and warning lamp	This is a simple on/off switch located in 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 they are part of the steering wheel slip rings are needed to transfer the connection. The 'set' button programmes 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 to temporarily 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 overspeeding if the cruise tried to accelerate to a high road speed with the gear selector in '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
Headway sensor	Only used on 'active' systems, this device uses radar or light to sense the distance from the vehicle in front

speed and will resume this again at the touch of a button. To summarise 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 after the brakes are applied;
- store the last set speed;
- contain built-in safety features.

8.16.2 System description

The main switch switches on the cruise control; this in turn is ignition controlled. Most systems do not retain the speed setting in memory when the main switch

Figure 8.82 Headway sensor and control electronics

has been turned off. Operating the 'set' switch programs the memory, but this will normally work only if conditions similar to the following are met:

- 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 approximately 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.

8.16.3 Components

The main components of a typical cruise control system are given in Table 8.3 (Figure 8.82).

8.17 Diagnostics – cruise control

8.17.1 Systematic testing

If the cruise control system will not operate then, considering the ECU as a black box, the procedure presented in Figure 8.83 should be followed.

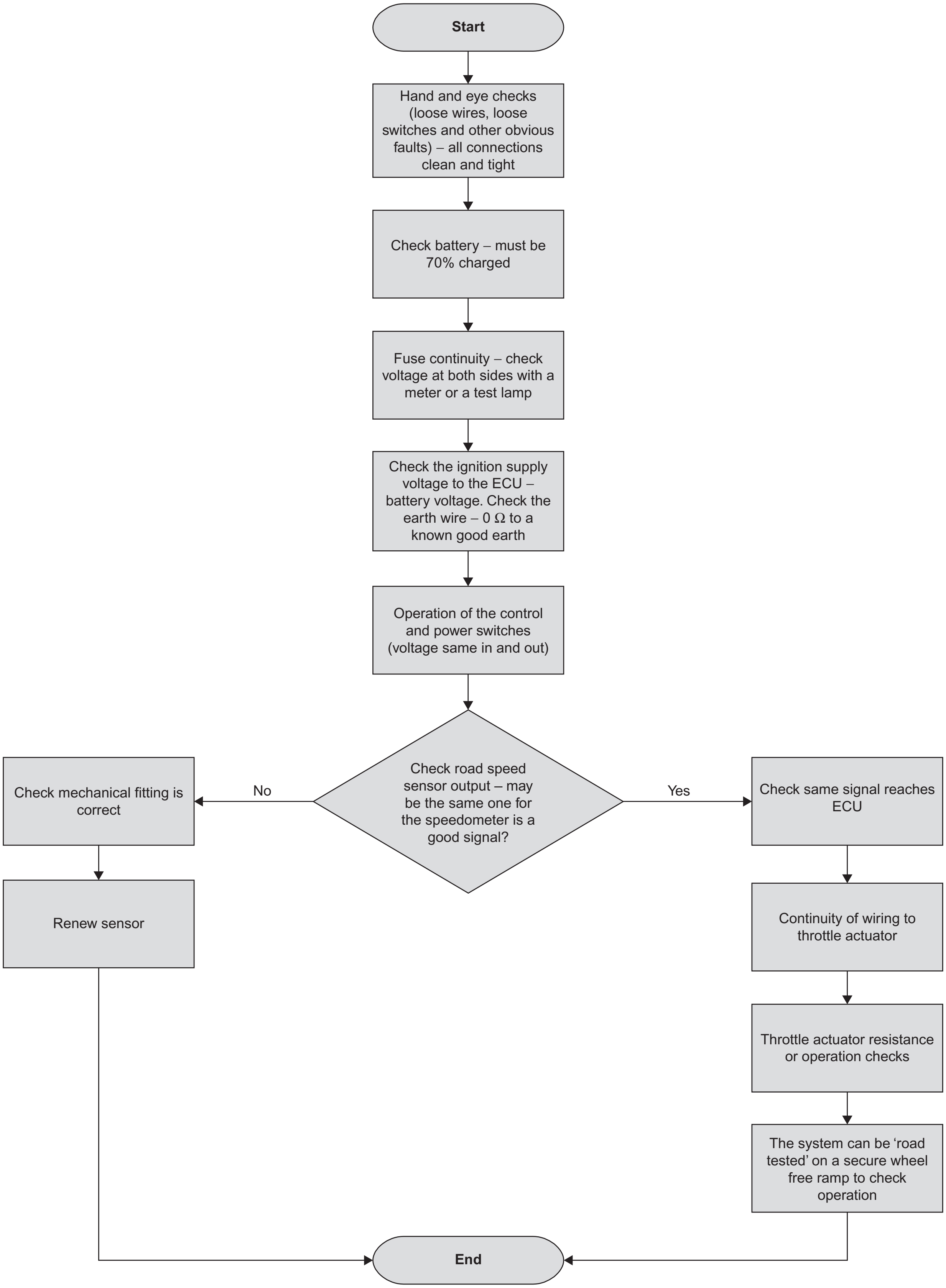

Figure 8.83 Cruise control fault diagnosis chart

8.17.2 Cruise control fault diagnosis table

Symptom	Possible fault
Cruise control will not se	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 General wiring fault
Surging or uneven speec	Actuator cable out of adjustment ECU fault Engine/engine management fault

8.18 Airbags and belt tensioners

8.18.1 Introduction

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. 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 works once.

The sequence of events in the case of a frontal impact at approximately 35 km/h, as shown in Figure 8.84, is as follows:

1 Driver in normal seating position prior to impact.
2 Approximately 15 ms after the impact the vehicle is strongly decelerated and the threshold for triggering the airbag is reached. The igniter ignites the fuel tablets in the inf ater.

Safety f rst

At speeds in excess of 40 km/h, the seat belt alone is no longer adequate.

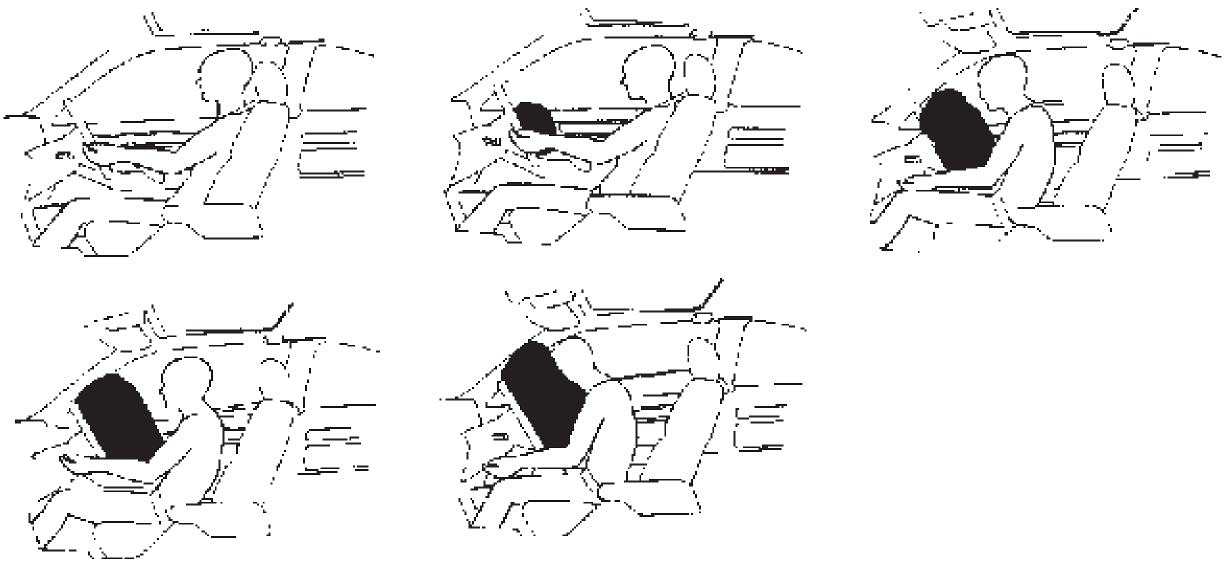

Figure 8.84 Airbag deployment

3 After approximately 30 ms, the airbag unfolds and the driver will have moved forward as the vehicle crumple zones collapse. The seat belt will have locked or been tensioned depending on the system.
4 At 40 ms after the impact the airbag will be fully inf ated and the driver's momentum will be absorbed by the airbag.
5 Approximately 120 ms after the impact the driver will be moved back into the seat and the airbag will have almost def ated 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.

8.18.2 Components and circuit

The main components of a basic airbag system are as follows:

- driver and passenger airbags;
- warning light;
- passenger seat switches;
- pyrotechnic inf ater;
- igniter;
- crash sensor(s);
- ECU.

Key fact

The airbag is made of a nylon fabric with a coating on the inside.

The airbag is made of a nylon fabric with a coating on the inside. Prior to inf ation, the airbag is folded up under suitable padding which has specially designed break lines built in. Holes are provided in the side of the airbag to allow rapid def ation after deployment. The driver's air bag has a volume of approximately 60 L and the passenger airbag approximately 160 L. Figure 8.86 shows a steering wheel with an airbag f tted in the centre.

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 (Figure 8.85).

A seat switch on the passenger side may prevent deployment when not occupied. This may be more appropriate to side-impact airbags.

The pyrotechnic inf ater and the igniter can be considered together. The inf ater 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, 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 f lter and the bag inf ates 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 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 that the bag

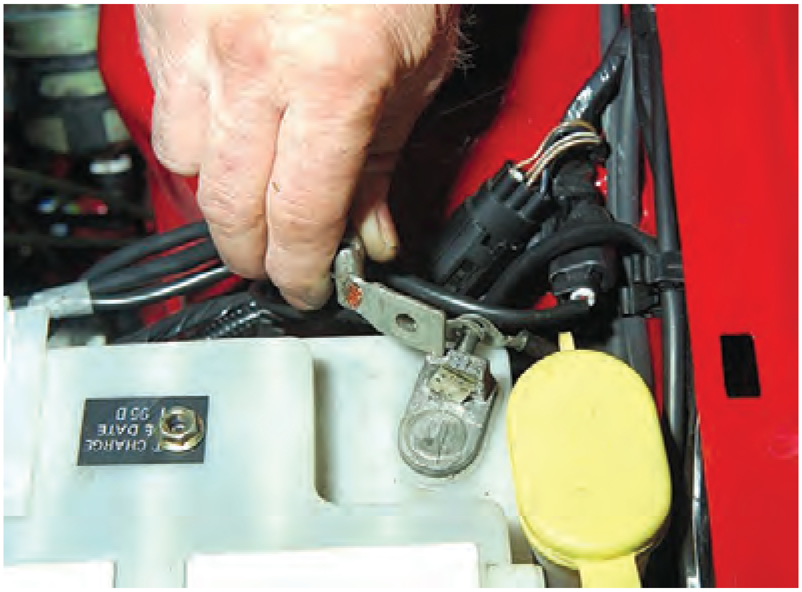

Figure 8.85 Remember – always disconnect the battery earth/ground if other components are to be removed (also check if a memory keeper should be fitted)

Figure 8.86 The driver's airbag is incorporated into the steering wheel

is deployed only in the case of sufficient frontal impact. Note 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 8.86).

The final component to be considered is the ECU or diagnostic control unit. When a mechanical-type crash sensor is used, in theory no electronic unit would be required. A simple circuit could be used to deploy the airbag when the sensor switch operated. However, it is the system monitoring or diagnostic part of the ECU which 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.

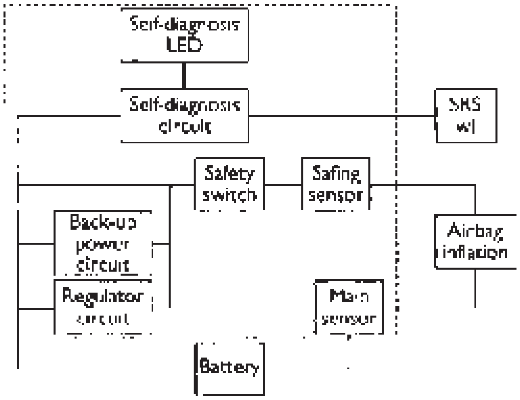

Figure 8.87 SRS block diagram

Figure 8.88 Seat belts and tensioner (Source: Volvo Media)

A block diagram of an airbag circuit is shown in Figure 8.87. Note the 'saf ng' 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 approximately 10 ms at a vehicle speed of 50 km/h to decide if the supplementary restraint systems (SRS) should be activated. In this time, approximately 10 000 computing operations are necessary. Data for the development of these algorithms is based on computer simulations but digital systems can also remember the events during a crash allowing real data to be collected.

8.18.3 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. The two main types are

- spring tension;
- pyrotechnic.

The mechanism used by one type of seat belt tensioner works by explosives. When the explosive charge is f red, the cable pulls a lever on the seat belt reel, which in turn tightens the belt. The unit must be replaced once deployed. This feature is sometimes described as anti-submarining (Figures 8.88 and 8.89).

Key fact

A seatbelt tensioner unit must be replaced once deployed.

Figure 8.89 The reason for SRS (Source: Saab Media)

8.19 Diagnostics – airbags and belt tensioners

8.19.1 Systematic testing

The only reported fault for airbags should be that the warning light is staying on. If an airbag has been deployed, then all the major components should be replaced. Some basic tests that can be carried out are presented in Figure 8.90.

Safety first

Warning: Careless or incorrect diagnostic work could deploy the airbag causing serious injury. Leave well alone if in any doubt.

8.19.2 Airbags and belt tensioners fault diagnosis table

Symptom	Possible cause
Warning light on	Wiring fault Fuse blown or removed ECU fault Crash sensor fault Igniter fault

Safety first

Warning: Do not carry out any electrical tests on the airbag circuit.

8.19.3 Deactivation and activation procedures

Airbag simulators are required to carry out diagnosis and testing of the airbag system. For the frontal airbag(s), this tool may be as simple as a 2.5 Ω resistor, used to simulate an airbag module connection to the system. Do not short circuit the airbag module connections with a jumper wire. If a jumper wire is used to short circuit the airbag module connections, a lamp fault code will be displayed and a diagnostic trouble code logged by the airbag control module.

Safety first

Warning: Do not work on airbag circuits unless fully trained.

Ford recommend the following procedure for the airbag system fitted to the Ford Focus.

8.19.3.1 Deactivation procedure

Warning: The backup power supply must be depleted before any work is carried out on the supplementary restraint system. Wait at least one minute after

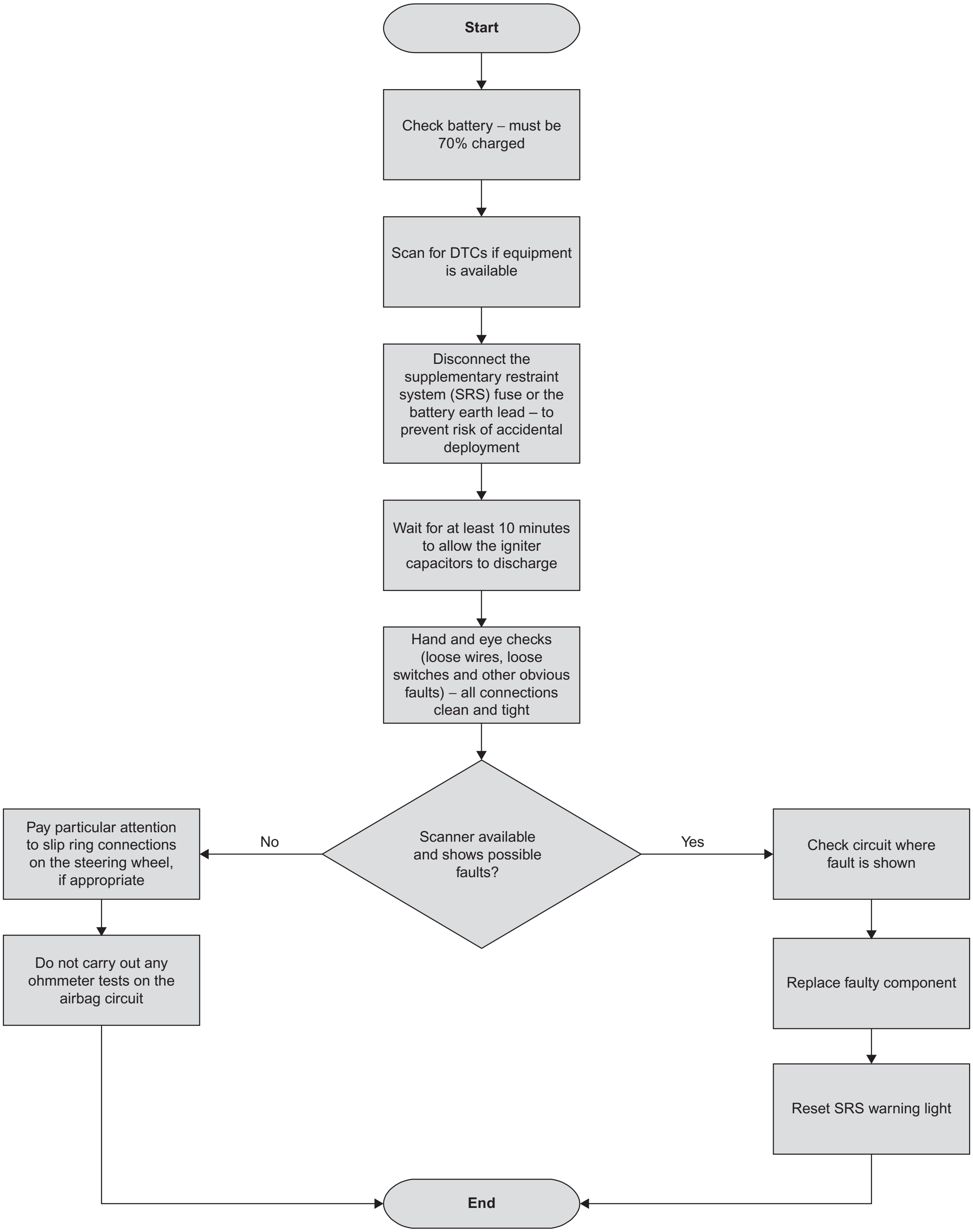

Figure 8.90 SRS diagnosis chart

disconnecting the battery ground cable. Failure to follow this instruction could cause accidental airbag deployment and may cause personal injury.

1 Disconnect the battery ground cable.
2 Wait one minute for the backup power supply in the Airbag Control Module to deplete its stored energy.

Warning: Place the airbag module on a ground wired bench, with the trim cover facing up to avoid accidental deployment. Failure to follow this instruction may result in personal injury.

1 Remove the driver airbag module from the vehicle.
2 Connect the airbag simulator to the sub-harness in place of the driver airbag module at the top of the steering column.
3 Remove the passenger airbag module.
4 Connect the airbag simulator to the harness in place of the passenger airbag module.
5 Disconnect the driver f ve-way under seat connector.
6 Connect the airbag simulator to driver f ve-way under seat f oor harness in place of the seat belt pre-tensioner and side airbag.
7 Disconnect the passenger f ve-way under seat connector.
8 Connect the airbag simulator to the passenger f ve-way under seat f oor harness in place of the seat belt pre-tensioner and side airbag.
9 Reconnect the battery ground cable.

8.19.3.2 Reactivation procedure

Warning: The airbag simulators must be removed and the airbag modules reconnected when reactivated to avoid non-deployment in a collision. Failure to follow this instruction may result in personal injury.

1 Disconnect the battery ground cable.
2 Wait one minute for the backup power supply in the Airbag Control Module to deplete its stored energy.
3 Remove the driver airbag simulator from the sub-harness at the top of the steering column.
4 Reconnect and install the driver airbag module.
5 Remove the passenger airbag simulator from the passenger airbag module harness.
6 Reconnect and install the passenger airbag module.
7 Remove the airbag simulator from the driver f ve-way under seat connector.
8 Reconnect the driver f ve-way under seat connector.
9 Remove the airbag simulator from the passenger f ve-way under seat connector.
10 Reconnect the passenger f ve-way under seat connector.
11 Reconnect the battery ground cable.
12 Prove out the system, repeat the self-test and clear the fault codes.

Note: This section is included as general guidance; do not assume it is relevant to all vehicles.