TRANSPORT RESEARCH LABORATORY

An investigation into the electromagnetic compatibility of equipment used in vehicle conversions for disabled motorists

Prepared for Mobility Unit, Department of the Environment, Transport and the Regions

I C P Simmons, L M Pearce and S D Phillips

TRL REPORT 321

First Published 1997
ISSN 0968-4107

Transport Research Foundation Group of Companies
Transport Research Foundation (a company limited by guarantee) trading as Transport Research Laboratory. Registered in England, Number 3011746.

TRL Limited. Registered in England, Number 3142272.
Registered Offices: Old Wokingham Road, Crowthorne, Berkshire, RG45 6AU.

CONTENTS

Executive Summary

The everyday environment includes a large number of sources of electromagnetic waves. These may emit electromagnetic radiation intentionally or unintentionally - for example, radio broadcast transmitters and electric arc welders respectively. Other sources may be naturally occurring such as lightning. In addition the modern motor vehicle can generate electromagnetic disturbances itself, for example the spark ignition system. Vehicle mounted transmitters can also pose a threat. Electronic devices are sensitive to this type of radiation and it is important that electronic systems have adequate protection to ensure they operate both safely and reliably.

Electronic control systems offer considerable benefits for disabled motorists. Typical systems include electronic steering, braking and accelerator controls, all operated by means of a single joystick. Clearly such systems are safety critical and it is important that they undergo rigorous testing before they are put into service. Electromagnetic compatibility (EMC) is the ability of an electronic system to operate correctly when subjected to electromagnetic waves as well as controlling its own electromagnetic emissions that could affect other systems.

From the 1st January 1996 the Generic EMC Directive, 89/336/EEC, came into force requiring that virtually all electrical and electronic apparatus must comply unless it is covered by a product specific EMC Directive. The specific Automotive EMC Directive, 95/54/EC, came into force at the same time and specifies a range of test methods that can be performed on both whole vehicles and sub-assemblies. Test levels for immunity to, and emissions of radio frequencies are defined.

Six vehicles have been tested by TRL to examine their compliance with the Automotive EMC Directive. These include two vehicles fitted with electronic brake and accelerator and two other vehicles, of similar design, fitted with electronic steering, braking and accelerator. Each of these vehicles was put through the radio frequency (RF) immunity test using the bulk current injection method. All of these vehicles demonstrated faults when subjected to the test. One of the vehicles fitted with electronic steering had been involved in two incidents on the road, one of which resulted in an accident thought to be due to loss of steering. This vehicle was used as a case study to try to improve its performance. The manufacturer made a number of changes as recommended by TRL after which the vehicle successfully passed the test. Part of this study included measurements of the electric field strength at the sites where the two incidents had occurred but no significant sources were found.

The opportunity arose to compare the full-scale chamber test and bulk current injection using one of the vehicles fitted with electronic braking and accelerator. As has been found in other research, it is difficult to compare these two methods. However, whilst the point by point failures were not the same, both test methods resulted in failure to meet the test requirements.

Recommendations are made on the testing requirements of different systems with particular requirements for equipment to be used by disabled motorists.

A number of techniques are available to help improve the electromagnetic compatibility of electronic circuits. These are described in the main report. These include screening methods, wiring layout, installation, the use of filters, circuit layout and power supplies.

1 Introduction

Electromagnetic waves are found in the everyday environment; common examples are radio and television transmitters, portable telephones and overhead power lines. Some sources are intentional, such as radio transmitters, others unintentional, such as electric arc welding, and some natural phenomena, such as lightning. Disturbances can be continuous, such as radio broadcasts, or transient, for example, lightning.

The modern motor vehicle utilises a significant proportion of electronic and electrical systems to control an ever increasing range of functions. Engine management, anti-lock braking systems, electronic suspension control and electronic transmissions are typical examples. Disabled drivers are able to benefit from the use of electronic systems to provide control of braking, accelerator and steering using sophisticated microchip control systems based around a simple joystick as the means of operating the vehicle. Clearly it is essential that these systems function correctly and reliably at all times.

There are two aspects of electromagnetic compatibility (EMC): immunity and emissions. Electronic systems are particularly at risk as they typically operate using low levels of current. Immunity is the ability of a system to operate correctly in the presence of electromagnetic waves or conducted disturbances, whilst emissions are the level of disturbance that a device can generate.

On the 1st January 1996 the Generic EMC Directive, 89/336/EEC came into force. This does not specify particular test methods or levels, leaving the decision to the test house. At the same time the Automotive EMC Directive, 95/54/EC, also came into force and deals with the specific requirements of motor vehicles. This Directive takes precedence over the Generic Directive for automotive applications and includes specific test methods and pass levels.

The Automotive EMC Directive currently applies to original equipment only but after-market products will need to comply with it from 1 October 2002. Equipment fitted to vehicles for disabled drivers comes under the category of vehicles modified after production and hence will be required to comply with the Directive from 1 October 2002. In the interim period Member States' national requirements will be applicable. The UK national requirements are contained in Regulation 60 of The Road Vehicles (Construction and Use) Regulations 1986 (as amended by SI 1996 No.2329). This Regulation enacts the Automotive EMC Directive in UK legislation and requires all electronic sub-assemblies (ESAs) fitted on or after 1 October 2002 to an approved vehicle to comply with the Directive. Although requirements are not specified for after-market products prior to 1 October 2002, manufacturers should be aware that Regulation 100 of the Construction and Use Regulations requires that all motor vehicles and their parts and accessories shall at all times be in such condition that no danger is caused or likely to be caused to any person in the vehicle or on the road. As such, manufacturers should establish the performance of their products and it is recommended that the test procedures described in the Automotive EMC Directive are used during this interim period.

Whilst the Automotive EMC Directive (95/54/EC, 1995) offers harmonised requirements within the European Community these should be treated as minimum requirements. In addition none of the test methods provide a perfect solution but are amongst the best available at present.

This report describes a series of tests undertaken to examine the immunity of several types of electronic control fitted to vehicles adapted for disabled drivers. The appropriate legislative requirements are discussed based upon the UK Department of the Environment, Transport and the Regions Guidance Note (Department of the Environment, Transport and the Regions, 1996); recommendations for testing are proposed. Some guidelines are given as good practice for electronic design to minimise EMC problems.

2 Current immunity levels of different electronic controls

2.1 Scope of the tests

A number of test methods are available to examine the radio frequency (RF) immunity of electronic equipment fitted to vehicles. These include tests on full-scale vehicles as well as components. For the series of tests described below, full-scale vehicles were available and the bulk current injection test method was used. A comparison was also made between two methods of testing for immunity (see section 2.3).

Tests were carried out by TRL on six vehicles including adapted cars and multi-purpose vehicles. Table 1 lists the vehicles and equipment tested. The bulk current injection (BCI) technique was used, as described below in section 2.2.1 (also see the Automotive EMC Directive 95/54/EC, 1995). The vehicles were tested on a rolling road where appropriate. One of the vehicles was also tested using the full-scale chamber test, also specified in the Directive. In

Table 1 List of vehicles and equipment tested for immunity

Vehicle number	*Type of vehicle*	*Equipment tested*
1	Saloon	Electronic braking and acceleration
2	Saloon	Electronic braking and acceleration (different manufacturer to Vehicle 1)
3	Multi-purpose vehicle	Electronic braking, acceleration and steering (joystick operated)
4	Multi-purpose vehicle	Electronic braking, acceleration and steering (joystick operated)
5	Multi-purpose vehicle	Radio-controlled nearside access door
6	Multi-purpose vehicle	Electric accelerator control

addition a range of mobile transmitters were simulated to examine their possible effects on each electronic controller. These included a citizens' band radio operating at 27 MHz with 11 W power, mobile radios operating at 86, 172 and 454 MHz with 25 W power and a cellular telephone operating in the 900 MHz band.

2.2 Test methods for immunity to radio frequency disturbances

2.2.1 Bulk current injection

The bulk current injection method has been used for many years and is included in a number of international standards (for example ISO 11451, 1995 and ISO 11452, 1995). It can be performed on full-scale vehicles, as used for this series of tests, or on components. A schematic representation of the test equipment is shown in Figure 1. A toroidal (ring shaped) transformer-like clamp, known as an injection probe, is placed around the vehicle wiring loom and an RF disturbance signal is injected into the system under test. The injection probe is positioned on the wiring loom 10 cms from the electronic control unit under test. The test signal is generated by means of an RF signal generator and appropriate power amplifiers. Calibration is performed using a special jig.

This test method does not require the use of a high performance screened room as stray emissions are generally low. However, at certain frequencies where resonant effects occur, stray emissions can be higher but are unlikely to cause problems with the test. These effects are caused by reactions between the injection probe and the vehicle wiring loom and will vary for different vehicles.

Whilst the required test level, according to the Automotive EMC Directive (95/54/EC, 1995) is 60 mA for Type Approval purposes, it is important to consider the measurement uncertainty of these results. Testing is performed using equivalent jig current as the level of the injected disturbance. This is the current measured during the calibration of the injection probe as specified in the EMC Directive. Typically in EMC testing, nominally similar tests can differ by a factor of up to two in sheer estimates of the power to which the system being tested is immune. For this reason the test level was raised to 84.7 mA, for the purposes of these tests, representing an increase in the power of 3 dB (ie a doubling of the power). For safety critical systems it is essential to add this uncertainty factor to the test level.

2.2.2 The full-scale chamber test

The full-scale vehicle test is another of the test methods described in the Automotive EMC Directive (95/54/EC, 1995) and is performed in a 'semi-anechoic' chamber, ie a room which is designed to absorb electromagnetic waves, but which has a solid floor, for example concrete, so is not totally anechoic. The anechoic chamber is generally accepted as the test method most representative of the real world. A schematic diagram is shown in Figure 2. This shows the position of the test vehicle and transmitting aerial inside the chamber. The RF disturbance signal is generated using a signal generator and power amplifiers. Calibration is performed using the substitution method where a field strength measuring probe, which monitors the electric field, is placed at a reference point inside the chamber. The test vehicle is then substituted for the probe. The method is described more fully in the Directive 95/54/EC (1995).

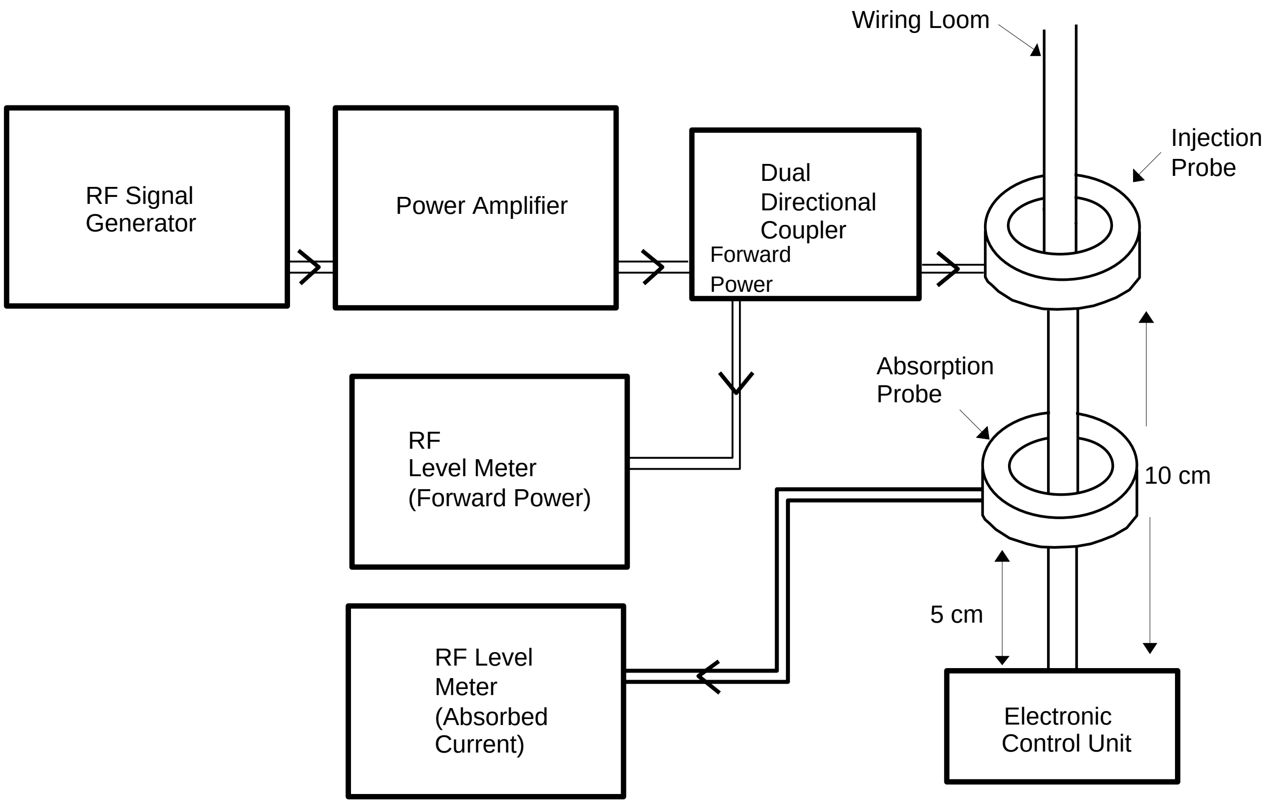

Figure 1 Schematic of bulk current injection equipment

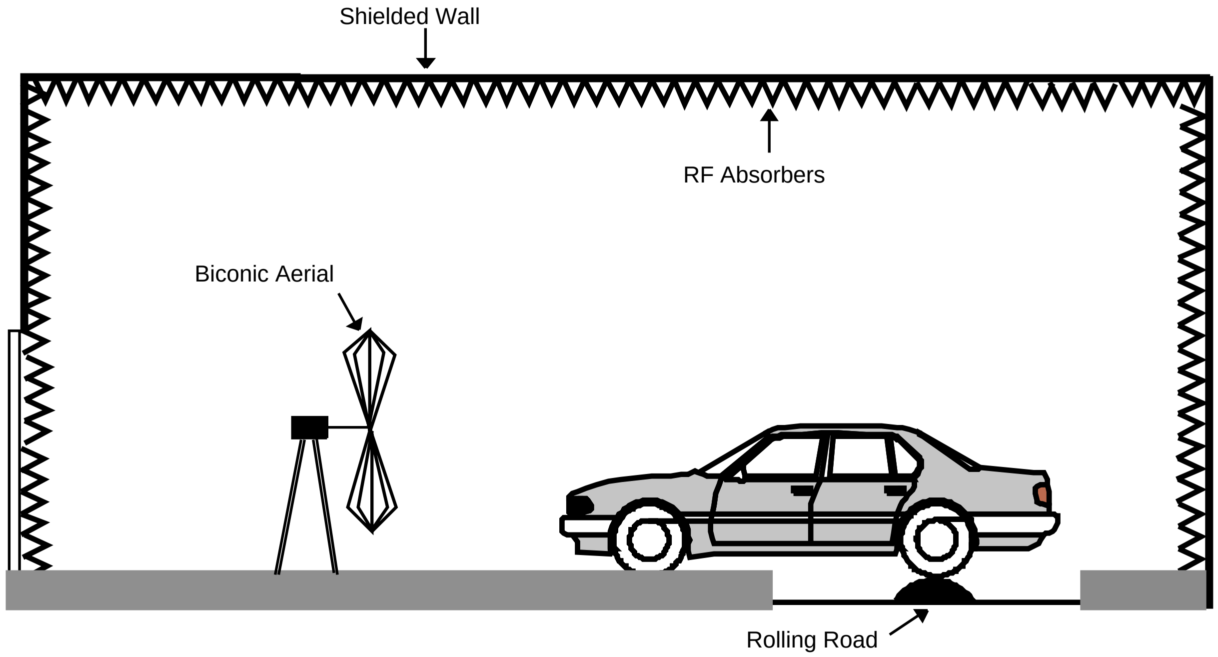

Figure 2 Example of a whole vehicle radiated immunity test

In order to carry out the chamber test it was necessary to build a 'robot-driver' to exercise the brake/accelerator control remotely from the control room. The chamber test was performed as specified in the Automotive EMC Directive (95/54/EC, 1995).

The failure modes and test cycles were similar to those used for the tests using bulk current injection. The required test level of 30 V/m was raised to 35 V/m, for the purposes of these tests, to accommodate the measurement uncertainty of this particular facility.

2.2.3 Frequency range

The Automotive EMC Directive implies that all the suggested test methods cover the frequency range of 20 MHz to 1000 MHz. This is not strictly true and different test methods have limited frequency response. In practice a list of spot frequencies is used. It is recommended by the present authors that this list should comprise, as a minimum, spot frequencies commencing at 20 MHz and increased by 2 per cent up to 1 GHz (that is 1.02 times the previous frequency value). This is in line with the calibration requirements of the Automotive EMC Directive (95/54/EC, 1995). However, it is important that the selected frequencies also include known sources which are thought likely to cause problems; these sources may be grouped into appropriate bands. These bands may vary between the EC Member States. The Directive also requires that 14 spot frequencies are selected specifically for witnessed testing by the Approval Authority who will require evidence that the manufacturer has tested the product over the full frequency range. Results from vehicle testing indicate that the majority of failures occur at frequencies below 400 MHz. Sources above this frequency that are likely to cause problems are mainly vehicle mounted transmitters, for example, private mobile radios. A test result showing immunity to disturbances up to 400 MHz supported by tests using real mobile transmitters fitted to a vehicle should provide an acceptable solution. However, the current Automotive EMC Directive (95/54/EC) requires testing over the full frequency range up to 1 GHz. It is much more cost effective to fit the vehicle with the equipment and check its operation for each installation than to carry out a specific immunity test. For example such testing would not require the complex and expensive facilities of a semi-anechoic chamber.

In the future it is likely that vehicles will be fitted with transmitters with operating frequencies higher than 1 GHz. It would be totally unsatisfactory to keep raising the frequency limits of testing which would further increase costs for both the vehicle manufacturer and the test house. It is perfectly reasonable to fit the equipment to the vehicle and test it as it would be normally used.

2.2.4 System layout

The layout of the equipment under test will significantly affect the test results. Some test methods are more sensitive than others.

Whole vehicle tests present a particular problem as each vehicle will have a different electromagnetic 'signature'. In simple terms the variations in geometric shape of the test vehicles will distort the electromagnetic field considerably. Differences in the construction of test chambers and variations in wiring layout on the vehicle will also add to the variability. It is important that systems that are distributed about a vehicle, notably on large vehicles such as trucks and buses, are tested adequately. There is little point in carrying out a test at the front of a vehicle when electronic systems are fitted at the rear or centrally. This is one reason why the component test route may be more suitable for larger vehicles.

Clearly the most important factor is to try to perform the test with a realistic system layout. This is straightforward when testing full-scale vehicles and simply requires that the test equipment is as unobtrusive as possible. The use of fibre optic cables for the test equipment is recommended to avoid coupling of the disturbance. As these cables transmit signals optically they are not affected by electromagnetic waves. However, it is important to protect the electronic circuits that transmit and receive the optical signals. Component tests need to be carried out in as realistic a manner as possible. In particular, the wiring loom should be representative of that used on the full-scale application although this is not always practical. It is important that the wiring loom is arranged so as to allow coupling of the disturbance into it. For example, the 800 mm stripline test which has a dominant vertically polarised electric field should have a vertical run of wiring loom.

For the programme of tests carried out on the vehicles shown in Table 1, the wiring looms were easily accessible and it was relatively straightforward to connect the bulk current injection probe 10 cms from the electronic control unit. The only additional wiring was the cable feeding the injection probe which was routed as directly as possible out of the vehicle through the offside front window.

2.2.5 Excitation test cycles and simulated signals

It is essential that the equipment being tested is exercised in a realistic manner. The Directive adopts a constant 40 km/h cycle for all systems. This may be acceptable at the present time but is unlikely to be valid as systems become more complex and control highly safety critical applications such as steering.

The UK Type Approval test for anti-lock braking systems uses a cycle comprising braking, accelerating and constant speed sections during which time the warning lamp is monitored. Speed limiters, cruise controls and engine management can be tested using a constant speed cycle. However, this is not appropriate for more complex systems such as electronically controlled steering systems (‘steer by wire’) which needs to function reliably all of the time it is operating. The consequences of such a system failing could be catastrophic. Other systems, for example electronic suspension or transmission, also need more specific test cycles that will realistically exercise the system.

Some suggested test cycles are given in Table 2.

For the programme of tests described in this report, it was necessary to exercise the steering, accelerator and brake.

The test vehicle was tethered to the floor of the laboratory and the front of the vehicle raised and supported on axle stands. Each of the vehicles tested was front wheel drive so there was no need to raise the rear wheels. The vehicle speed was set to a nominal 2000 rpm in second gear. Hence a simple constant speed cycle was achieved. In addition, the steering, brake and accelerator were operated to test for normal functioning. This was achieved by turning the steering to full lock in each direction, applying the brake and both increasing and decreasing the engine speed using the accelerator. As the bulk current injection method does not radiate high levels of electromagnetic field it was possible for the test engineer to operate the joystick control through the open offside front window.

2.2.6 Definition of a failure

Defining the failure criteria for a particular system presents a major problem. Ultimately the testing authority will need to agree with the manufacturer the exact nature of a failure. There is currently a trend to avoid lists for different systems and to adopt a generic approach. This is unlikely to be effective in practice when defining failure criteria and a list is probably inevitable. However, there are some groups of equipment that could be covered by a generic failure condition.

At present, some failure modes have been defined for anti-lock braking systems (ABS) and speed limiters (Table 2). An illumination of the system warning lamp is accepted as the failure mode for ABS. In the case of speed limiters, a speed variation of plus or minus 3 km/h is accepted as normal but further deviation is termed a failure. This may be appropriate to other systems such as cruise control and engine management.

Difficulties arise as systems become more complex. An

Table 2 Suggested exercise cycles and failure modes

System	*Excitation cycle*	*Failure mode*
Anti-lock brakes	DETR cycle	Illumination of warning lamp
Engine management	Constant speed	Speed variation > 3 km/h
Cruise control	Constant speed	Speed variation > 3 km/h
Speed limiter	Constant speed	Speed variation > 3 km/h
Suspension control	Constant speed	Displacement range check
Transmission control	Gearchange cycle	Incorrect selection/failure to select
Electronic steering	Constant speed and steering cycle #1	Wheel movement range check/failure to steer when demanded/unwanted movements
Electronic accelerator	Constant speed and increase/decrease cycle #1	Speed variation > 3 km/h / failure to respond to demand
Electronic brake	Constant speed and brake cycle #1	Undesired brake operation/failure of brake to respond to demand

#1 A constant speed is useful to determine whether the system under test operates erroneously, that is operating when no demand is made of it. In addition it is important to ensure that the system operates correctly when demanded. It is suggested that the steering is operated from left to right over its full range and the operation checked. Results from the test programme indicated that the rate of operation could vary with the level of disturbance and it was necessary to make a judgement as to the level of the loss of control. For braking and accelerator systems a simple check of whether the vehicle responds correctly should be made and, as before, the rate of response should be monitored in relation to the controllability of the vehicle.

obvious example is a ‘steer by wire’ system which is required to operate perfectly 100 per cent of the time. Such a system needs to be rigorously tested to ensure its safe operation. It is suggested that a dynamic steering check be made, using a special rig. This will complicate the test but is essential for systems that require the highest levels of integrity. As an example, steering could be checked by lifting the vehicle off the ground with the wheels removed and actually driving it whilst measuring any movement in the position of the wheel hubs, that is any unintentional steering motion. In addition the steering should be operated and its function checked.

In the programme of tests reported here, failure modes were defined by the authors. For braking, accelerations and steering, the systems were deemed to have failed if they did not respond when desired, and if they operated unintentionally. The movement of the offside front wheel was used as a means to monitor the steering action. Accelerator failure was chosen to be a variation of the engine speed when no input was made and failure to respond when demanded. In practice the moment of failure was easy to detect.

2.3 Electronic brake and accelerator systems

Vehicle 1, a medium sized saloon car, was fitted with an electronic control of the brake and accelerator by means of a small hand operated lever. Bulk current injection, described above, was used to test the immunity of this system. The results of the test are shown as a fault profile (Figure 3). This also indicates the mode of failure at a particular level of disturbance, measured as injected current, with respect to frequency. Three failure modes were noticed for this system; brake failure, no response from the accelerator and a speed variation. All the faults occurred over a limited frequency range of 35-75 MHz. No faults were recorded when carrying out the mobile transmitter simulation.

Vehicle 2, a different saloon car, was fitted with an electronic brake and accelerator system operated by hand using a small lever. Bulk current injection was again used as the test method. The fault profile is shown in Figure 4. The braking system functioned correctly at all the frequencies tested but failures of the accelerator, that is no response when demanded, were recorded at a number of frequencies below about 400 MHz. In addition the vehicle slowed at several frequencies between 600 and 1000 MHz. The mobile transmitter simulation caused the vehicle to slow when using a signal at 86 MHz but no other failures were recorded with other simulated transmitters.

Vehicle 2 was used to compare the BCI procedure with the whole vehicle chamber test (see section 2.2.2), using the semi-anechoic chamber at the Motor Industry Research Association (MIRA).

A fault profile for the chamber test is shown in Figure 5. This is completely different in pattern to the results using bulk current injection, shown in Figure 4. The vehicle exhibited faults by decelerating and accelerating when the level of disturbance was increased and two frequency groups were apparent, one below 100 MHz and the other between about 300 and 370 MHz. No faults were recorded above 400 MHz. Precise details of the faults were not recorded by the test house. The only common factors

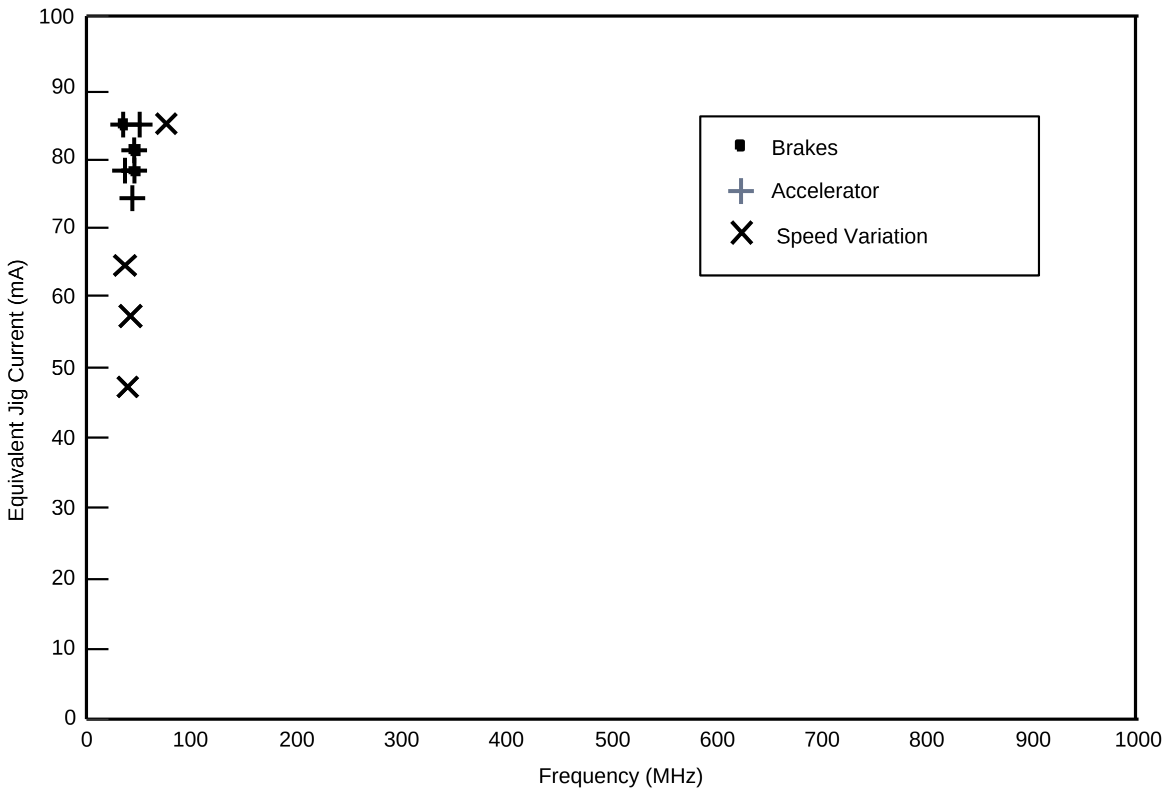

Figure 3 Fault profile for vehicle 1, a medium sized saloon car fitted with electronic braking and accelerator. Tested using bulk current injection

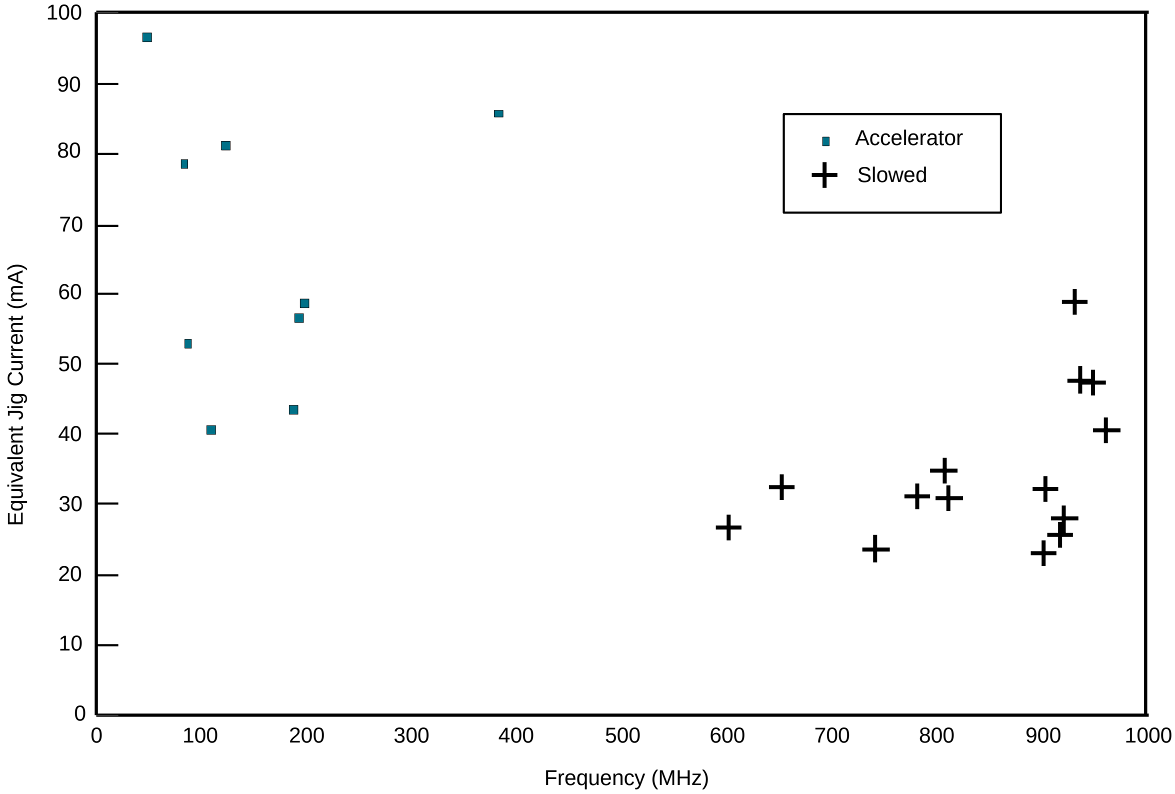

Figure 4 Fault profile for vehicle 2, a medium sized saloon car fitted with electronic braking and accelerator. Tested using bulk current injection

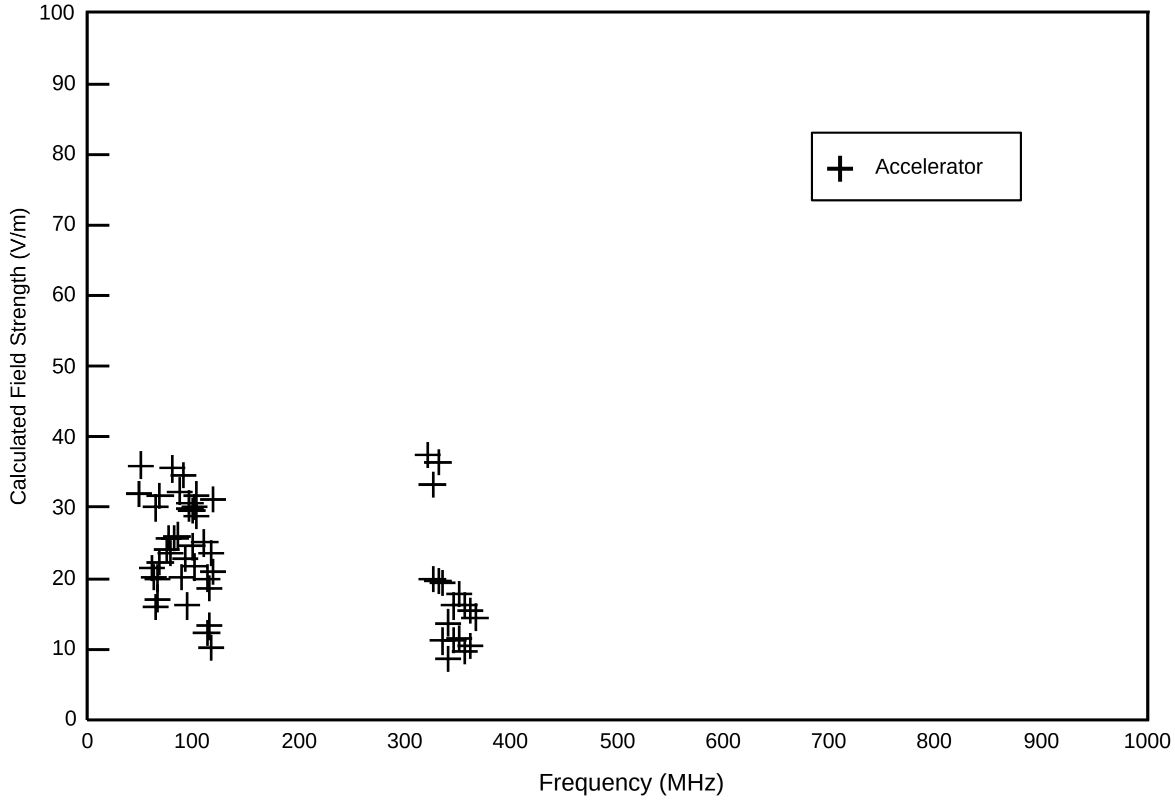

Figure 5 Fault profile for vehicle 2, a medium sized saloon car fitted with electronic braking and accelerator. Tested using the full scale chamber

between the two test methods were that the equipment failed to meet the requirements of the Directive and similar failure modes occurred. These results demonstrate the difficulty in comparing test methods and highlight the potential difficulties in interpreting the Directive.

2.4 Electronic steering, brake and accelerator

2.4.1 Experience with a modified camper van

Vehicle 3, a left hand drive multi-purpose vehicle adapted for use by a disabled driver, was fitted with a small joystick control. This device enabled full electronic control of braking, accelerator and steering by means of the single joystick.

Vehicle 3 was involved in two incidents whilst being driven by its owner, one resulting in an accident and the other temporary loss of steering. It was thought possible that the steering problem which occurred may have been caused by an electromagnetic disturbance. It was decided to try to identify whether there was a source of disturbance near the two accident sites.

2.4.2 On-site measurements of electric field strength

A small passenger car was fitted with a receiving aerial on the roof, connected to a spectrum analyzer inside the vehicle which was, in turn, connected to a hard copy plotter. The driver was able to record the electromagnetic environment at any time, and produce a plot of the results showing the relative levels of the signals present in the environment at frequencies between 10 kHz and 1 GHz.

The vehicle was driven past the accident site twelve times between 1115 hours and 1125 hours, 1300 hours and 1330 hours and 1510 hours and 1525 hours. The tests were performed at the same time of day and the same day of the week that the accident had occurred.

There was no electromagnetic activity present on any of these occasions likely to have caused a failure to the electronics of the adapted vehicle. Levels were less than 1 V/m which is low. It should also be remembered that the Automotive EMC Directive requires equipment to be immune to 30 V/m. This indicates that the disturbance present at the time of the incident, if there was any, was not generated by a fixed and continuous source. It is possible that there was a transient source transmitting at that time, possibly a police car, or other vehicle fitted with a mobile transmitter.

A similar test was carried out at the site of the second incident where the steering failed temporarily but did not result in an accident. The instrumented vehicle was driven past the incident site six times between 1320 hours and 1420 hours, corresponding with the day and time of the incident. Again, no significant signals were present. This second site was fairly remote, so it is unlikely that emergency vehicles could have been close enough for their transmissions to have affected a vehicle without the driver being aware of their presence. Other sources could have been amateur radio, public utility vehicles or lightning. Overhead power lines were situated close to this site. These power cables can generate very high levels of both electric and magnetic fields but of low frequency, 50 Hz with some harmonics. These signals were outside the frequency range of the field strengths measured, as it is generally thought that such disturbances are unlikely to affect electronic systems fitted to vehicles. However, the possible effects of low frequency fields on electronic systems merits further investigation.

2.4.3 RF immunity tests

Vehicle 3 was subjected to the bulk current injection method described earlier. A fault profile is shown in Figure 6. Faults were observed for brakes, accelerator and steering but, whilst most of these occurred below about 100 MHz, failures were noticed up to 400 MHz. In many instances all three functions failed at the same time, often at low levels of disturbance. These levels of disturbance were higher than those found in the environment described in section 2.4.2. Typically the braking system faults were complete loss of braking when demanded and usually prior to this condition a sluggish response. Accelerator faults were typically complete loss or sluggish response. Steering faults were either complete loss of steering when demanded, sluggish response or loss of left or right steering only. Simulated mobile transmitter tests caused the steering and accelerator to fail in a similar manner as before at 86 MHz and the steering to fail at 172 MHz.

Vehicle 3 was used as a case study to try to improve its performance in line with the requirements of the Directive. TRL made several recommendations to the manufacturer along similar lines to those described in Appendix A. The system was modified accordingly and the vehicle tested again.

On this occasion the vehicle passed the test at the required level of 84.7 mA, meeting the requirements beyond those of the Automotive EMC Directive. This clearly demonstrates that EMC problems can be overcome using some basic design rules.

Vehicle 4, a similar multi-purpose vehicle to vehicle 3, was fitted with the same model of electronic control. The fault profile is shown in Figure 7. In this case the accelerator did not exhibit faults although both braking and steering failed in a similar manner to the faults found with vehicle 3. As before, the majority of faults occurred below 100 MHz but failures were recorded at much higher frequencies up to about 950 MHz. Simulated mobile transmitter tests caused complete steering and brake failure at 86 MHz and sluggish response of the steering at 172 MHz.

Other tests were carried out on a modified van with a radio-controlled door which passed all the tests and another van fitted with an electrically controlled accelerator. In this case an on-off switch controlled a small electric motor which pulled or released the accelerator cable. This failed to pass the immunity test. The motor pulled the cable to accelerate the vehicle as the level of disturbance was increased.

Previous tests performed on four similar infra-red remote control systems demonstrated that different vehicle types could produce different results when tested at the same frequencies. Although worrying, this is not altogether surprising and demonstrates the influence of the vehicle on the test result. This is just one of the reasons for the current research programme on EMC at TRL. In some instances the vehicle windscreen wipers and headlamps operated

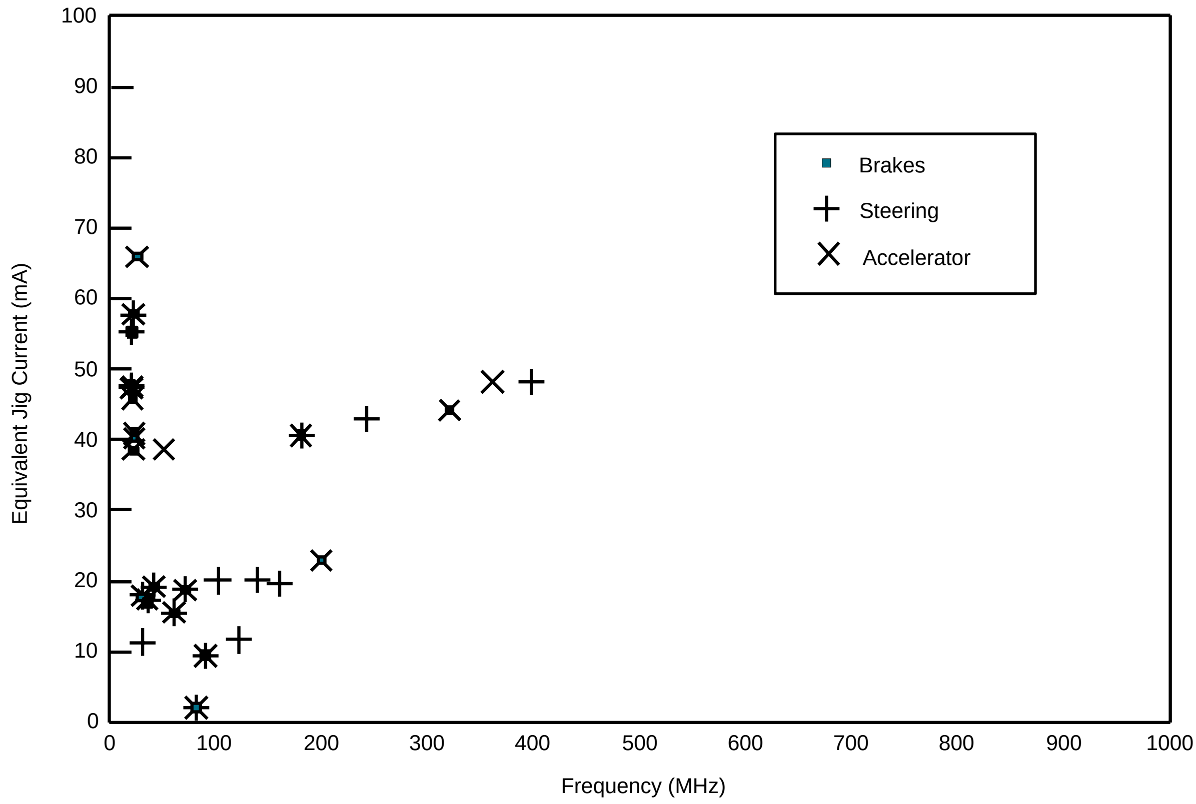

Figure 6 Fault profile for vehicle 3, a camper van fitted with electronic steering, braking and accelerator. Tested using bulk current injection

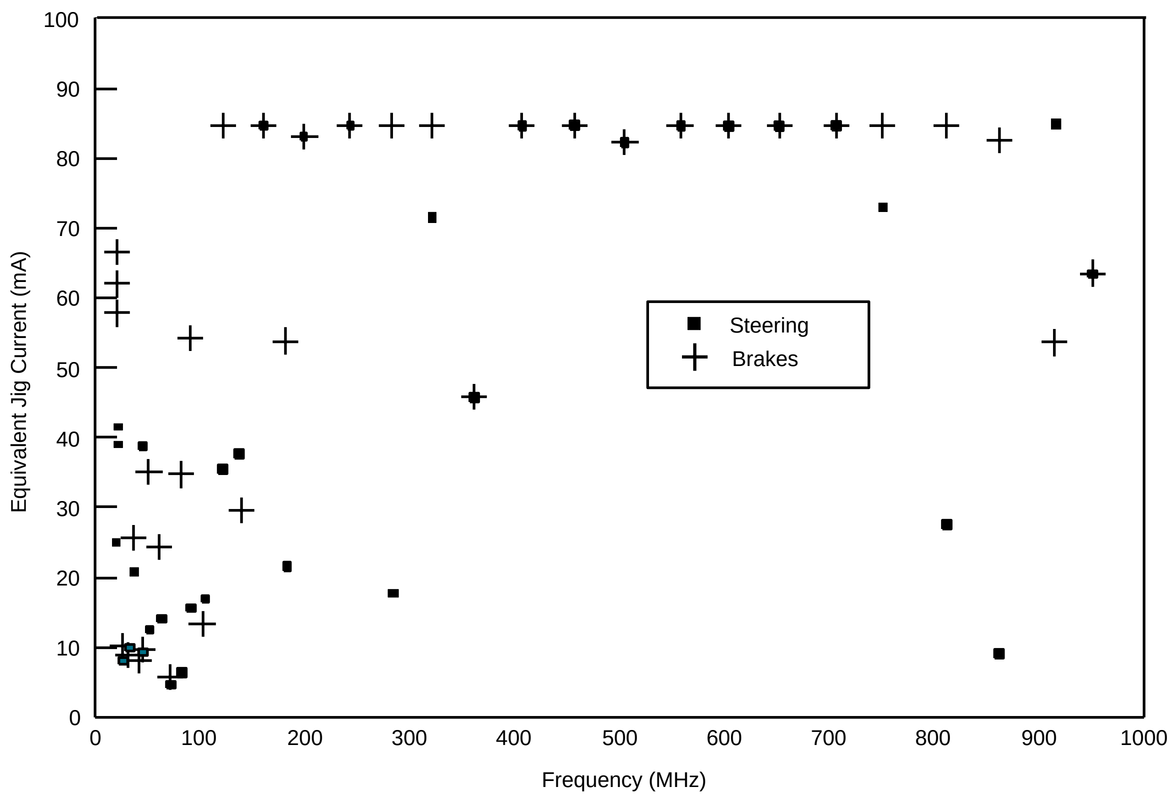

Figure 7 Fault profile for vehicle 4, a modified camper van fitted with electronic steering, braking and accelerator. Tested using bulk current injection

erroneously, failures were observed at levels of injected current of 22 mA. Variations in the test results for different vehicles are to be expected and this can be explained simply by considering the vehicle as a complex array of interacting aerial elements. Any length of conducting material, for example the chassis, wiring loom or even the steering wheel, can act as a receiving or transmitting aerial. This clearly demonstrates the complex nature of electromagnetic effects on vehicles.

TRL is continuing its research programme to try to improve EMC test methods in order to achieve more representative cost effective methods. This includes reviewing developments in technology to ensure that appropriate test methods are available to ensure the safe operation of these systems. There is a strong case to try to simplify testing and reduce the number of test methods. In addition it is important to bear in mind the cost of testing for low volume manufacturers. There is also scope to develop a code of practice for manufacturers and installers of electronic equipment fitted to vehicles modified for disabled drivers. An alternative approach would be to introduce random testing instead of testing every product for those systems that are not safety critical.

3 Discussion and recommendations

Four vehicles, fitted with electronic systems controlling the primary controls, numbers 1 to 4 in Table 1, were tested for their immunity to electromagnetic disturbances. All four systems tested failed to meet the requirements of the Automotive EMC Directive, as interpreted by TRL. The effects observed ranged from sluggish response of the braking and steering to total loss of either or both. In some cases it was possible to alter the vehicle speed by adjusting the level of the RF disturbance.

EMC should be considered at the initial stages of the design of electronic equipment. Attempts to solve EMC problems after a design has been completed can be time consuming, costly and may be ineffective.

The Automotive EMC Directive provides a minimum common standard for the European Community. It does not apply to after market products until 2002. The systems tested in this report do not therefore have to comply with the Directive until this date. However, in the meantime, manufacturers are still legally obliged to ensure vehicles can be operated safely according to product liability and The Road Vehicles (Construction and Use) Regulations 1986, as amended, (Her Majesty's Stationery Office, 1986).

Applications of vehicle electronic systems include a number of safety critical systems, particularly for vehicles modified for disabled drivers, and the test requirements for these systems will need to be considered carefully. A system which, when failing, could cause a vehicle to become uncontrollable, should be subjected to stricter and more encompassing tests than those required for systems which could cause a lower level hazard. The International Electrotechnical Commission has produced a draft standard on functional safety of safety-related system (IEC 1508, 1995). This has been proposed as a generic standard but has important features appropriate to the automotive sector. These include the concept of integrity levels for different systems depending upon their application. However, these levels depend upon the number of possible fatalities, a criterion which may not be particularly suitable for the automotive industry. It is suggested by the present authors that it is more appropriate to base integrity levels on the degree of controllability of the vehicle. This can be estimated by examining the function of the system in question, and judging the effect of a system failure on the controllability of the vehicle. Such controllability requirements are recommended for the development of vehicle based software by the Motor Industry Software Research Association, (MISRA, 1994). It should be borne in mind that controllability does not cover the full story and the context of each application needs to be considered separately. Although aimed at software development, the integrity levels proposed by MISRA (1994) are relevant to vehicle systems in general.

Table 3 shows the MISRA (1994) recommendations for integrity levels.

Table 3 Recommended integrity levels proposed by MISRA

Integrity level	*Description*
4	Uncontrollable
3	Difficult to control
2	Debilitating
1	Distracting
0	Nuisance

When determining which tests should be applied to the system, it is also important to consider the measurement uncertainty of the test itself. None of the EMC test methods are perfect and each has its own level of uncertainty. It is important to balance the level of uncertainty against the risk of systems being tested and deemed to pass when in practice they might fail. It is recommended that systems where faults cannot be tolerated should have the measurement uncertainty added to the pass level. This ensures that test uncertainty does not allow to pass a system that would, under slightly different conditions, fail to meet the pass level.

The following list is the authors' recommendations for the factors that need to be considered when testing electronic systems for emissions and immunity against electromagnetic disturbances:

Tests specified in legislation:

i RF emissions as described in 95/54/EC

ii RF immunity as described in 95/54/EC

Tests additionally recommended:

iii Immunity to transients

iv Immunity to electrostatic discharge

v Requirements for radio transmitters used in vehicles as defined below

vi Protection from lightning

vii MISRA guidelines for software

viii System safety according to IEC 1508

ix Failure mode and or fault tree analysis as defined in IEC 812 and IEC 1025 respectively

x Requirements for measurement uncertainty, for example NAMAS NIS 81

xi Effects of low frequency electric and magnetic fields.

The precise testing requirements for each system need to be agreed by the approving authority and the manufacturer. Some useful guidance on transients are provided by the International Standards Organisation (ISO 7637, 1990), and similarly for electrostatic discharges (ISO TR 10605, 1994). There are no specific requirements for lightning protection relating to vehicles but British Standard BS 6551 (1990) which is relevant to structures, offers some useful guidance on this topic.

A special case exists when vehicles are fitted with mobile transmitting devices. These include mobile radios, telephones, alarm systems and tracking devices. Some of these devices, which may not have been originally designed for vehicles use, may have been tested to other regulations and may carry the CE marking. It is important that these systems are fully tested to meet the requirements for vehicle equipment when they are to be used in vehicle applications. It is always useful to actually test such a system in the vehicle in which it is going to be used but, in addition specific requirements have been agreed for the UK by the Department of the Environment, Transport and the Regions and the Radiocommunications Agency. Mobile radio equipment that is permanently installed in vehicles should comply with 95/54/EC as well as the Radiocommunications Agency regulations (Wireless Telegraphy Act (section 84), 1984) which include a spurious emissions test. Hand portable mobile transmitters, for example mobile telephones, should comply with 89/336/EEC but, if they are to be used in vehicles then any effects on the vehicle should be considered. Vehicle installation kits for using portable transmitters in vehicles should comply with 95/54/EC. This approval is for the installation kit and not the transmitter. Radio alarm systems and tracking devices should be tested in accordance with 95/54/EC.

Table 4 shows the present authors' proposals for how the MISRA integrity levels in Table 3 may be assigned to systems used in vehicle conversions for disabled people. Table 4 also gives suggestions for which EMC tests should be applied to each type of system. It should be noted that this Table is a suggestion and that issues other than vehicle controllability may need to be considered. Table 4, for example, shows that failure of the access ramp may not greatly affect the controllability of the vehicle, but it may still be a hazard.

4 Conclusions

The Automotive EMC Directive (95/54/EC, 1995) provides harmonised legislation for the control of electromagnetic radiation and protection of electronic systems fitted to vehicles.

The Directive provides a minimum standard of compliance.

The present authors suggest that safety critical systems such as electronic steering, braking and acceleration require a higher level of testing than specified in the Directive.

It is suggested that the systems also be tested for transients and electrostatic discharges.

TRL tested four vehicles fitted with safety critical controls. All four failed to meet the immunity requirements of the Directive. However, one system was modified, following recommendations from TRL, and subsequently passed the requirements of the Directive.

Proposals for how such systems should be tested are described.

Table 4 Examples of suggested requirements for testing

Device operation	*Integrity level*	*Test requirements*
Steering (left and right), accelerator and brake eg 4 way joystick	4	i-xi
Steering (left and right) eg 2 way joystick or mini steering wheel	4	i-xi
Accelerator and brake eg 2 way joystick	3	i-xi
Accelerator	3	i-xi
Brake	3	i-xi
Engine speed	3	i-xi
Parking brake	2	i-v and vii
Gear selection	2	i-v and vii-xi
Indicators	0	None for EMC
Horn	1	None for EMC
Lights	2	None for EMC
Wipers	2	None for EMC
Seat position	2	i-v and xi
Access/egress equipment eg suspension, lift, ramp etc. See note 1	2	i-v and xi
Wheelchair stowage equipment eg hoist. See note 1	2	i-v and xi

Note 1 Integrity levels are based upon specific requirements for disabled motorists.

5 References

British Standards Institution (1990). *British code of practice for protection of structures against lightning*. British Standard BS 6551. London. British Standards Institution.

Commission of the European Communities (1989). *Council Directive on the approximation of the laws of the Member States relating to electromagnetic compatibility. 89/336/EEC*. Brussels, Belgium. Commission of the European Communities.

Commission of the European Communities (1995). *Council Directive relating to suppression of radio interference of spark ignition engines and relating to electromagnetic compatibility of motor vehicles. 95/54/EC*. Brussels, Belgium. Commission of the European Communities.

Department of the Environment, Transport and the Regions (1996). *A guidance note on the Automotive EMC Directive*. Notes available from the VSE 4 Division, Department of the Environment, Transport and the Regions, Great Minster, London. Department of the Environment, Transport and the Regions.

ERA Technology (1995). *Designing for electromagnetic compatibility a practical guide*. ERA Report 95-0030. Leatherhead, Surrey. ERA Technology Ltd.

Her Majesty's Stationery Office (1986). *The Road Traffic Act 1078. The road vehicle (construction and use) regulations 1986*. London. Her Majesty's Stationery Office.

International Electrotechnical Commission, (1985). *Analysis techniques for system reliability - procedure for failure mode and effects analysis (FMEA)*. IEC 812. Geneva, Switzerland. International Electrotechnical Commission.

International Electrotechnical Commission, (1990). *Fault tree analysis*. IEC 1025. Geneva, Switzerland. International Electrotechnical Commission.

International Electrotechnical Commission, (1995). *Draft International Standard. Functional safety; safety related systems*. IEC 1508. Geneva, Switzerland. International Electrotechnical Commission.

International Standards Organisation (1990). *Road vehicles - electrical interference by conduction and coupling*. ISO 7637. Geneva, Switzerland. International Standards Organisation.

International Standards Organisation (1994). *Road vehicles - electrical disturbances from electrostatic discharges*. ISO TR 10605. Geneva, Switzerland. International Standards Organisation.

International Standards Organisation (1995). *Road vehicles - electrical disturbances by narrowband radiated electromagnetic energy vehicle test method*. ISO 11451. Geneva, Switzerland. International Standards Organisation.

International Standards Organisation (1995). *Road vehicles - electrical disturbances by narrowband radiated electromagnetic energy component test method*. ISO 11452. Geneva, Switzerland. International Standards Organisation.

Motor Industry Software Research Association (MISRA), (1994). *Development guidelines for vehicle based software*. Nuneaton, Warwickshire. Motor Industry Software Research Association.

Radiocommunications Agency (1984). *The Wireless Telegraphy Act*. London. Radiocommunications Agency.

Appendix A: Standard techniques for improving EMC

It is essential that the EMC aspects of any design are considered at an early stage and form part of the basic design itself. It is difficult and inefficient to attempt to put right EMC problems once a design has been completed.

Various literature is available on the subject of good practice for EMC, (ERA Technology, 1995), but a summary of some of the more important techniques is given below.

1 Good quality earthing:

- For systems comprising two or more units and at frequencies less than about 1 MHz, use a single point earth.
- At high frequencies use multi-point earthing with low inductance connections.
- Separate earth return lines may be useful. Also completely isolating a system, if this is practical, may improve performance. For vehicle applications the use of a single earth point at the battery may be acceptable.

2 To reduce coupling of unwanted signals:

- Screened leads.
- Screened enclosures.
- Ensure screening continuity when using connectors.
- Apertures must be kept as small as possible.

3 All leads:

- Ensure integrity of connections.
- Keep as short as possible.

4 Cable routing:

- Do not run cables carrying power supplies and sensitive signals together.
- Separate cables as much as possible. This may not be practical in many vehicle applications due to lack of space.
- Do not run cables together in parallel when pickup is likely.
- Route cables carrying radio frequency signals well separated from all other cables. Ideally within a metal conduit if this is possible.

5 Disturbance coupling:

- Try to keep sources of disturbance segregated from cables.
- Try to reduce pickup loops which may couple disturbances.

6 Signal levels:

- It is important to make signal levels as high as possible to obtain a satisfactory signal to noise ratio.

7 Filters:

- The use of filters inside and outside the electronics units can help reduce interference.
- The use of chokes, ferrite beads and capacitor/resistor filters is suggested.

8 Circuit layout:

- Digital and analogue circuits should be kept apart.
- High and low level circuits should also be kept apart.
- The printed circuit board should have thicker tracks for the power supply rails.
- Printed tracks should be able to cope with possible high power levels, for example, relay outputs.
- Unused parts of the board should be made a ground plane.
- If possible use a ground plane on the reverse side of the board.

9 Power Supplies:

- Use power supplies that offer radio frequency protection.
- Beware of switched mode power supplies that can generate high frequency disturbances. (Note possible use of DC-DC converters in vehicle applications.)

10 Testing:

- Ensure that appropriate tests have been carried out on the equipment and it is fit for purpose.

11 Codes of practice:

- Be aware of codes of practice, for example installation of radio transmitters.

Abstract

Electronic systems for disabled drivers include a number of safety critical systems, for example, joystick operation of steering, brakes and accelerator. It is essential that these systems are both safe and reliable. An important aspect of safe and reliable operation is immunity from interference by electromagnetic radiation.

This report summarises the requirements of the Automotive Electromagnetic Compatibility (EMC) Directive, 95/54/EC with particular reference to vehicles for disabled motorists. Recommendations are suggested for appropriate test methods. Guidelines are provided to aid the design and installation of electronic equipment for vehicle applications.

The report also includes an analysis of the immunity performance of several safety critical systems that have been tested in accordance with the Automotive EMC Directive. In one case, a vehicle that failed to meet the performance requirements was involved in an accident. This example was used to demonstrate how improving the design and installation enabled the system to finally pass the RF immunity requirements.

Related publications

CR202 *A comparison of EMI/EMC test procedures for road vehicles* by W Gibbons *et al*. 1990 (price code C, £15)

PA3106/95 *Susceptibility of electronic systems fitted to vehicles for disabled people* by I C P Simmons. 1995 (price code AA, £10)

Prices current at November 1997

For further details of these and all other TRL publications, telephone Publication Sales on 01344 770783 or 770784, or visit TRL on the Internet at http://www.trl.co.uk.