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ELECTROMAGNETIC COMPATIBILITY & FUNCTIONAL SAFETY

Annex G - Road Transport

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Annex G

EMC and Functional Safety in Road Transport

Abstract

The automotive EMC environment is one of the most severe and the most unpredictable. Road vehicles are inherently mobile and thus able to drive near to any fixed transmitter. Vehicle owners and operators believe it to be their right to attach any sort of transmitter (even very high-powered ones) to the vehicle while expecting it to function correctly. Owners also expect to be able to fit electronic equipment into the vehicle and power it off the vehicle's power supply. Road vehicles do not generally fall under Directive 89/336/EEC but instead have their own product-specific EMC Directive, 95/54/EC. Although this adequately covers the fixed transmitter situation, it does not effectively deal with the possibility of mobile transmitters being installed on the host vehicle. Conducted transients are excluded from 95/54/EC since they are internal to the vehicle itself; however, this does not take into account the fitting of aftermarket accessories. ESD requirements are also excluded from 95/54/EC.

Despite the safety-related nature of vehicle EMC, at the time of writing, the author of this section of the report was not aware of any vehicle accidents being caused as a result of an EMC problem. This is almost certainly due to the fact that vehicle manufacturers, driven by product liability legislation, go to enormous lengths to ensure that their vehicles will not suffer from EMC problems.

Avoidance of EMC problems is achieved by a combination of tight specifications (both vehicle and sub-assembly), tight control of sub-assembly suppliers, good design, extensive testing of both vehicles and sub-assemblies, and by regarding the Automotive EMC Directive as being inadequate to achieve EMC for safety-related systems.

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G1. Introduction

The motor car was the first consumer product to be covered by mandatory EMC legislation. In 1952 a Statutory Instrument was enacted in the UK to limit the emissions from vehicle spark ignition systems to prevent interference with domestic radio and television reception. In 1972, the emissions legislation was harmonised across the then European Economic Community by promulgating Directive 72/245/EEC (Ref. 1).

In the 1950s and 1960s, car radios became increasingly popular and improved suppression of the ignition system was required because of the close proximity of the receiving antenna and the relatively weak wanted signal compared with a domestic installation. There was also the problem of conducted transients from both the ignition system and other vehicle electrical equipment, which could potentially cause audible noise on the radio. These transients were conducted into the radio via the power supply leads and were often suppressed at source by means of shunt capacitors and at the radio itself by means of series inductors.

The importance of suppressing transients increased in the 1970s due to the introduction of solid state electronics into the vehicle. Electronics were initially used for alternator rectification and voltage regulation and for augmenting the mechanical contact breaker points to improve ignition system performance and reduce contact breaker wear. Good transient suppression was essential to prevent damage to the semiconductors.

For many years a combination of legislation and customer satisfaction requirements for fuel economy, reliability, and safety have led to the introduction of electronic systems into vehicles to control functions that were originally based on purely mechanical devices. In the 1980s, the electronic fuel injection system replaced the mechanical carburettor and gave significantly improved driveability, fuel economy and reductions in exhaust gas emissions. Electronic ABS (anti-lock braking systems) and airbags became available for improved safety and cruise controls for reducing driver fatigue. These and other developments have led to vehicles incorporating a large number of independent electronic systems whose common connections are sometimes only the power supply terminals.

As the electronic content of vehicles has increased and as the safety of the vehicle has become more dependent on the correct functioning of the electronics systems, so EMC has increased in importance. The EMC phenomena which can affect the safety of the vehicle are conducted transients, radiated immunity and ESD. These will be looked at in more detail in Section G2.

An executive or luxury car will have many, if not all, of the following electronic systems fitted:

- Engine Management System incorporating multipoint fuel injection with programmed ignition.
- Engine Immobiliser
- Electronic Throttle – mechanical link between driver and throttle is supplemented with or replaced by an electronic system
- Electronically Controlled Transmission
- ABS (anti-lock brakes)
- Traction Control
- Cruise Control
- Suspension Control – electronic control of dampers alters the hardness of the suspension to suit different road surfaces and driving modes

- Electronically Controlled Power Assisted Steering
- Supplemental restraint systems (e.g. airbags, seat belt pre-tensioners)
- Electronic Instrument Pack and Vehicle Condition Monitor
- Direction Indicator Flasher Unit
- Burglar Alarm plus Remote Keyless Locking and Entry System
- Memory Controlled Seats and Mirrors
- Heated Rear Window Timer and Courtesy Lamp Delay Unit
- Programmed Wash/Wipe Control
- Individual Temperature Controls
- Diagnostic Package
- Trip Computer/Digital Clock
- Electronically Controlled In-Car Entertainment Package
- Automatic Route Guidance

Even a low-cost family saloon or hatchback will have a significant number of electronic systems fitted, some of which have the potential to endanger the safety of the vehicle occupants or other road users, should an error or mis-operation occur.

In the next few years, fully electronic braking (where there is no mechanical link between the brake pedal and actuators) and anti-collision systems (including automatic braking and steering) are likely to be introduced. Thus the importance of EMC from a safety viewpoint is likely to increase dramatically.

G2. Automotive EMC Phenomena and Standards

To summarise, the EMC phenomena that need to be considered are:

- Broadband radiated emissions
- Narrowband radiated emissions
- Conducted transient emissions
- Conducted transient immunity
- Radiated immunity
- ESD

Each of these will now be considered in turn.

G2.1 Broadband and narrowband radiated emissions

Broadband radiated emissions have been subject to statutory control (at least in the case of vehicles with spark ignition engines) since the early 1950s to prevent interference to domestic radio and television reception. Narrowband emissions were not subject to statutory control until the advent of the Automotive EMC Directive, 95/54/EC (Ref. 2). However, for the last decade or more, both broadband and narrowband emissions have been tightly controlled by the vehicle manufacturers to ensure that the reception on the on-board radio is adequate. Indeed, virtually all EMC problems with vehicles relate to customer complaints of poor radio reception. Radiated emissions from the ignition system, electric motors and the alternator dominate the broadband emissions from the vehicle. Narrowband emissions originate from the various microprocessor clocks built into all the modern electronic modules. It should also be noted that pulse-width modulation (PWM) circuits used for motor control (e.g. electric power assisted steering) or lighting control can be significant sources of both broadband and narrowband emissions.

The relevant standards are:

- CISPR 12 (Ref. 3)
  This is concerned essentially with the protection of domestic radio/TV reception and automotive legislation uses this standard as a basis for its radiated emissions requirements.
- CISPR 25 (Ref. 4)
  This is concerned with the protection of receivers used on-board either the host vehicle or an adjacent vehicle. The level of protection required (i.e. the pass level) is selected by the vehicle manufacturer.
- 95/54/EC
  This provides statutory limits for both broadband and narrowband emissions essentially to protect all RF spectrum users in general, and especially domestic radio/TV reception.

There are generally no safety issues connected with radiated emissions from vehicles. The worst effect is normally interference to the on-board radio. Interference to domestic radio receivers is unlikely because of the separation between a vehicle and domestic receiver, the legislation and, not least, the intolerance of customers to on-board radio interference.

G2.2 Conducted transient emissions and conducted transient immunity

Control of conducted transients in a vehicle is not covered by legislation in the same way as transients internal to any other system are not. However, there is a standard as follows:

- ISO 7637 (Ref. 5)
  This is principally concerned with conducted transient immunity tests on vehicle electronic systems.

Seven transient types are covered, although only five are normally used for cars. As well as conducted transient tests, there are tests for transients inductively/capacitively coupled into adjacent wires. Transients for 24V systems are also included (e.g. for trucks). A choice of four severity levels is given and it is up to the vehicle manufacturer to choose the severity level. A test method is also described to measure transient emissions levels but no suggested maximum limits are given. A vehicle manufacturer could thus choose either to tolerate a high level of transients on his vehicle wiring system – in other words choose to suppress at the victim – or, alternatively, to allow only a very low level of transients on the vehicle by always suppressing at the source. This is fine as far as OEM vehicle parts are concerned because the component supplier will know the vehicle manufacturer's requirements. However, it is unsatisfactory for the after-market situation since a component could be added to the vehicle which was not sufficiently immune to the vehicle transient levels. Worse still, a component could be added which generated a sufficiently severe set of transients to interfere with the operation of the vehicle controls. This is a potential safety hazard. The solution is to either:

- Forbid the addition of after-market components (e.g. burglar alarms, mobile phone chargers).

or

- Provide to all who have an interest in the supply of after-market components the details of the vehicle manufacturer's transient specification for the vehicle concerned.

G2.3 Radiated Immunity

Since the mid-1980s, most vehicle manufacturers have been testing their vehicles for radiated immunity, typically using field strengths of up to 50 V/m or even 100 V/m. However, apart from a requirement to ensure that antilock braking systems (ABS) were sufficiently immune to electromagnetic fields (Ref. 6) and product liability requirements, there was no legislation covering automotive system radiated immunity until the advent of the Automotive EMC Directive.

The radiated immunity environment for a vehicle is exceptionally severe. Vehicles are able to drive nearby or even onto the actual sites of fixed transmitters. However, the principal threat comes from mobile transmitters fitted to the host vehicle or, in exceptional cases, from transmitters fitted to adjacent vehicles. Examples of this are emergency services, mobile data (both existing analogue systems and the new TETRA digital system), and radio amateurs. The threat is exacerbated by the possibility of the fitting of transmitters which transmit illegally high levels of power.

Fields from fixed transmitters experienced by vehicles rarely exceed 1-10 V/m. In contrast, vehicles may be exposed to fields of the order of 200 V/m from mobile transmitters. A survey of the UK automotive environment was carried out in the 1980s and although the environment has changed significantly since then, it gives a good idea of the sort of field strengths that a vehicle may encounter (Ref. 7).

Given the relatively inexpensive cost of vehicles (in Pounds Sterling per kilogram they are similarly priced to domestic appliances and much lower cost than consumer electronics such as computers) it is not practical for vehicle manufacturers to protect the electronics against fields of this magnitude. The nature of the vehicle system architecture also makes radiated immunity design difficult. There

are many sensors located around the vehicle connected to electronic control boxes by cables of up to 4m in length; given that there are the order of 1,000 wires in an executive car, it is not practical, due to cost, weight and size constraints, to screen the cables.

It is not far wide of the mark to suggest that, with increasing vehicle electronic complexity, military levels of radiated immunity are required for automotive systems that cost two orders of magnitude less than their military counterparts. The safety implications of radiated immunity will be explored in more detail in Section 3. It is interesting to consider that vehicle manufacturers are expected to allow their customers to fit all sorts of transmitters to their vehicles yet no other manufacturer – eg aircraft, domestic appliance or computer manufacturer – would seriously allow such behaviour. The majority of vehicle manufacturers advise that mobile phones, and other radio systems, are only used inside a vehicle with an external antenna. The UK's Radiocommunications Agency publishes MPT 1362 (Ref. 15) to guide installers and the same advice is present in this document with the additional requirement of a road test to check the safe operation of the vehicle. An essential requirement in the automotive type approval procedures under 95/54/EC for after-market transmitting equipment requires the proving to the Technical Service that the normal operation of the vehicle is not affected by the transmitter operating. (This includes mobile phone installation kits.)

ISO have produced a set of standards for radiated immunity testing of both vehicles and components, ISO 11451 (Ref. 8) and ISO 11452 (Ref. 9) respectively. Each gives a number of different test methods. As with ISO 7637, the test level is determined by the vehicle manufacturer.

G2.4 ESD

ESD is not covered by legislation in the automotive field and the degree to which testing is carried out depends on the vehicle or component manufacturer. The most likely time for a discharge is when locking or unlocking the door, when charge may be transferred from the human body to the vehicle. Once the driver and passengers are seated in the vehicle, the chances of discharges are significantly reduced, though not eliminated. Nevertheless, some manufacturers quite rightly take the view that discharges may occur during vehicle assembly, vehicle repair, when someone reaches in through the window of a vehicle to operate a control from the outside, when entering or leaving the vehicle, and during operation.

The principal impact of ESD on safety is if a discharge occurs when the vehicle is stationary, as described above, and causes a latent failure which manifests itself whilst the vehicle is being driven.

The appropriate ISO standard for vehicle and component tests is ISO TR 10605 (Ref. 10).

G3. The Automotive EMC Directive

G3.1 Introduction

The automotive industry viewed the advent of the general EMC Directive with alarm. Responsible manufacturers were already testing their vehicles to stringent radiated immunity levels and it was felt that 89/336/EEC was not suitable for the automotive situation. For one thing, EuroNorms (for certifying compliance) were being developed for most areas but not for vehicles and the automotive industry was faced with the prospect of having to compile vast technical construction files at substantial cost.

Vehicles are covered by over 40 old-approach type-approval Directives and it seemed sensible to retain automotive EMC within the type approval framework. The industry therefore persuaded the Commission that this should be the case.

Between 1989 and 1991, an ad hoc committee of around 15 representatives of the major European vehicle manufacturers met about a dozen times to write a draft Directive (Ref. 11). This was under the auspices of CCMC (which then became ACEA), a trade association representing indigenous European vehicle manufacturers; test houses, Ford, GM and Japanese manufacturers were excluded.

After fine-tuning and approval by national governments (e.g. the then Department of Transport in UK) the Automotive EMC Directive was published in late 1995.

G3.2 The product scope of the Directive

The Directive applies to all vehicles and their components which come under the scope of the framework Directive 70/156/EEC, as amended by 92/53/EC (Ref. 12). This covers only vehicles which have a maximum speed in excess of 25km/hour, have 4 wheels or more and are intended for use on a public road. Components are any items of electrical/electronic equipment intended for fitting (permanent or temporary) to a vehicle.

It is important to note that 70/156/EEC and hence 95/54/EC:

- Includes vehicle trailers, e.g. caravans and trailer units of trucks.
- Excludes agricultural/forestry tractors, mobile machinery and vehicles which run on rails (e.g. trams and trains).

A separate Directive now exists for 2- and 3-wheel vehicles, principally motorcycles (Ref. 13) though there is some confusion as to the date on which the immunity provisions take effect. This Directive is technically very similar to the Automotive EMC Directive.

G3.3 The technical scope of the Directive

The Directive allows certification of a vehicle either by testing the whole vehicle or by testing components or a mixture of the two. Component tests are important in the case of truck/bus manufacturers since few chambers are large enough to allow whole-vehicle testing.

The Directive is based on the existing 72/245/EEC spark ignition interference Directive but tests for narrowband radiated emissions from all systems and the radiated immunity of ‘safety-related’ components have now been incorporated. No tests for transients or ESD are specified. Only systems which can “directly affect the driver’s direct control of the vehicle” and lighting/signalling systems are covered by the immunity requirements. Other components are excluded from immunity

testing. There is a possibility that different test authorities may place different interpretations on what is and is not a “direct control component”.

For component immunity, five alternative test methods are allowed – a consequence of allowing a large committee to write a Directive! There is concern that some of the test methods are used outside of the frequency ranges for which they are appropriate. Hence the correlation between the individual component tests, let alone correlation of component tests with whole-vehicle tests, can be expected to be poor.

For the whole-vehicle tests, the pass level is 30 V/m with an amplitude modulated field. However, the method of defining the amplitude means that the field is an unmodulated carrier of 16.7 V/m with 80% amplitude modulation then applied. Thus the test level is not as high as is commonly thought. Further, the whole-vehicle test is conducted using only one antenna position (in front of the vehicle or as decided by the Approval Authority's Technical Service) and only one polarisation (either vertical or horizontal at the choice of the Approval Authority's Technical Service and agreed with the manufacturer).

Thus the radiated immunity requirements, although perhaps adequate when the Directive was conceived, are now inadequate for the environment given the tremendous growth in safety-related automotive electronics that has occurred over the last few years. However, it should be pointed out that it is quite normal for automotive Directives to be inadequate and that manufacturers frequently exceed Directive requirements as a matter of course.

To sum up, the Directive is inadequate from a safety viewpoint in that:

- It does not fully cover the fitting of after-market equipment including mobile transmitters.
- Its tests are limited rather than thorough.
- Radiated immunity tests are only carried out at a steady state speed. The Directive does not test for dynamic situations such as changing gear, unlocking the vehicle or reading an ignition key transponder to allow the vehicle to start.
- It does not include transient requirements and so does not adequately cover after-market products and their potential to interfere with OEM systems.
- It does not require ESD tests.

Finally, its phased introduction means that some products are not covered until 2002. This only applies to products in existence before 1996. New products should comply now but the offence of not complying is not to be applied until 2002.

The likelihood of immunity problems is increasing as the number of mobile telephones increases. Use of digital modulation increases the likelihood of interference.

However, in mitigation it should be borne in mind that:

The Directive requires the Approval Authority to see evidence of compliance of any system that affects the direct control of the vehicle if the defined tests do not do this.

Product liability and quality are the driving force behind safety; mandatory immunity requirements are not as important as it first seems.

- Around 45,000 deaths are caused on EU roads per annum; not one of these has ever been attributed to an EMC problem. Most are due to driver arrogance, incompetence and error.
- The current most likely cause of an accident when using a car telephone while driving is lack of concentration and not EMC but the balance may change as vehicle complexity increases.
- On-board radio reception quality is the driving force behind emissions reduction.

- The Directive must be regarded as setting ***minimum*** requirements for automotive EMC rather than something to be regarded as a standard. Indeed, this is how reputable manufacturers regard it. However, inevitably it has become regarded as a 'state-of-the-art' standard and other manufacturing sectors (e.g. construction equipment and agricultural and forestry machinery) have based their standards on it without understanding its limitations.

The other phenomenon covered by the Automotive EMC Directive is radiated emissions. Since these do not generally have safety-related implications, suffice to say that the levels are fairly similar to those for consumer products.

G4. Known automotive incidents

As far as the UK press is concerned, the best known automotive EMC 'incident' involved a serious accident caused by a car driven by a lady called Nellie Mole. During court proceedings, her solicitor, regrettably supported by a consultant who was an IEE member, claimed that radio interference from a nearby taxi had caused the car to take off out of control and refused to stop however hard she pressed the brake. Since the throttle was controlled by a Bowden cable this was technically impossible since whatever fault occurs with the engine management system, a significant increase in power output can only occur if the throttle allows more air into the engine. The vehicle was fitted with an automatic gearbox and the problem appeared to be due to the driver mistakenly pressing the accelerator rather than the brake. When such a mistake occurs, the driver tends to press the wrong pedal even harder – with devastating results. This is a good example of EMC certification being necessary to prove that a problem had ***not*** been caused by EMC; the vehicle type concerned had been thoroughly tested.

One of the earliest problems reported (during the early 1980s) concerned vehicles on a German Autobahn stopping near to a broadcast radio transmitter due to interference with the engine management systems. Eventually, a Faraday cage had to be erected over the road to prevent the problem!

In the UK, again during the early 1980s, many radio amateurs noticed that their vehicle direction indicators would double their flash rate if they operated amateur radio transmitters within their vehicles. Many mobile phone users noticed that the phone would unlock the car doors and unset the security system.

The major problem of the mid to late 1990s has concerned the fitment of security systems to vehicles – the type where a radio transmitting key fob is used to lock/unlock the doors and set/unset the engine immobiliser. Unfortunately, the frequency currently allocated to new key fob systems (433.92MHz) is in a band allocated to a number of other low-power devices and in a section of the RF spectrum where the prime user is the military and then radio amateurs. This has caused numerous motorists to be locked out of their vehicles. Further lock-out problems have been shown to be caused by the launch of the TETRA service. TETRA creates even greater problems for older style radio keyfob central locking and security systems in the UK operating at 418MHz, closer to the frequencies used by TETRA. These problems are due to the very low selectivity of the receivers used in order to produce a low-cost product. Their immunity to blocking by off-frequency sources is not adequate for operation in this crowded part of the RF spectrum.

A committee (Ref. 14) was set up to look into the problem, the RAKE (Radio Activated Key Entry) committee. Although the longer-term aim has been to improve receiver selectivity and persuade the CEPT to allocate a new frequency for key fobs, one piece of advice to customers is somewhat disturbing: "Where possible, do not park near large electronic and radio communication installations; close to airport buildings and radar units; masts etc."

NOTE that equipment suppliers of short range low power devices using the 433 MHz ISM band are required by the Radiocommunications Agency to advise customers that they may be subject to radio interference by licensed users of the radio spectrum.

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