Chapter 5

# Other standards and legislation

Chapter 4 covered the commercial standards, deriving from the IEC, that are relevant for the EMC and Radio Equipment Directives. Although comprehensive, these are by no means the only test standards or legislation that can be found for EMC. This chapter looks at a range of other sectors that have their own EMC framework: automotive, military, civil aerospace and rail.

## 5.1 Automotive

The automotive sector has for a long time had its own EMC requirements.

### 5.1.1 UNECE Reg 10 and the Automotive EMC Directive

In Europe, the EMC both of whole vehicles and their electronic sub-assemblies was covered by the Automotive EMC Directive. This was a type-approval Directive, not a New Approach one, and instead of the CE Mark requires that products which comply with its requirements are 'e' marked.

#### *5.1.1.1 The first edition*

The original Automotive EMC Directive 95/54/EC required type approval for EMC of all vehicles and electrical/electronic vehicle sub-assemblies (ESAs). It was an amendment to the early Directive 72/245/EEC which controlled ignition interference emissions. Unlike the EMC Directive, it included within its annexes all the applicable technical requirements and test methods, many of which are quite different to the commercial standards discussed in Chapter 4 of this book. Automotive electronic products within its scope should be automatically excluded from the scope of the EMC Directive. This was clear enough for systems that are intended to be mounted in new vehicles which are themselves within the scope, but for aftermarket products (i.e. items which are sold for vehicular use but not supplied as original equipment) the situation was confused. Sub-assemblies were exempted from the Automotive Directive until 1st October 2002.

#### *5.1.1.2 The second edition*

The second edition Automotive EMC Directive 2004/104/EC [195] was published on 13th November 2004.

*What changed?*

The main modifications were:

- The Directive allowed for aftermarket equipment, not related to safety critical functions, to be provided with a self-declaration according to the procedures of Directive 89/336/EEC (the EMC Directive, first edition) or 1999/5/EC (the R&TTE Directive) from manufacturers, replacing conventional third party type approval but still subject to a Technical Service assessment. But, "Part of this declaration must be that the ESA fulfils the limits defined in ... this Directive". So a simple CE-marking to the EMC or R&TTE Directive's own standards was not sufficient: the applicable requirements must be matched to the vehicle environment.

- The test provisions and reference limits referred to CISPR standards for emissions tests (CISPR 12 and 25) and ISO standards for immunity tests (ISO 7637, 11451 and 11452). Extra conditions for applying the tests were given (including, for instance, the requirement for immunity to GSM pulse modulation in the 800–2000 MHz frequency range). This mostly replaced the explicit but confused methods for immunity and emissions testing given in the text of the first Directive. Testing, though, had to be carried out by a test house accredited to ISO 17025.
- The new Directive contained for the first time provisions relating to transient disturbances conducted along supply lines, specifically emissions of and immunity from transients according to ISO 7637-2.
- The Directive gave particular attention to safety related functions and components. It introduced the concept of "immunity-related functions", which are:
  - functions related to the direct control of the vehicle,
  - functions related to driver, passenger and other road-user protection,
  - functions which, when disturbed, cause confusion to the driver or other road users,
  - functions related to vehicle data bus functionality, and
  - functions which, when disturbed, affect vehicle statutory data.

  The vehicle or equipment is considered as complying with immunity requirements if, during the immunity tests, there is no degradation of performance of these "immunity-related functions". This was more stringent than 95/54/EC which did not require immunity testing at all if equipment did not affect the driver's direct control of the vehicle.

There are other detailed issues which should not be overlooked. Particularly for vehicle manufacturers, "The vehicle manufacturer must provide a statement of frequency bands, power levels, antenna positions and installation provisions for the installation of RF transmitters, even if the vehicle is not equipped with an RF transmitter at time of type approval. This should cover all mobile radio services normally used in vehicles. This information must be made publicly available following the type approval. Vehicle manufacturers must provide evidence that vehicle performance is not adversely affected by such transmitter installations". The issue of after-market fitment of radio transmitters (not just mobile cell phones) will cause some difficulties for both vehicle manufacturers, who cannot expect to know all types of radio transmitter that will "normally" be fitted to their products throughout their life, and for radio manufacturers, who certainly don't want to have their products approved for individual vehicles.

Spot frequency testing is only required if the Technical Service has to validate test evidence supplied for inclusion in the type approval.

### 5.1.1.3 UNECE Regulation 10

The Automotive EMC Directive has now been superseded by UNECE Regulation 10, at the time of writing up to version 5. This took on board pretty much all the content of Directive 2004/104/EC. However, it has now added a significant extra section for "additional requirements for vehicles and ESAs providing coupling systems for charging the rechargeable energy storage system (REESS) regarding the control of emissions and immunity from this connection between the vehicle and power grid". This is, of course, an acknowledgement that electric vehicles will have to be connected while recharging, and the EMC environment in this mode is quite different to the environment found when the vehicle is mobile on the road.

### 5.1.1.4 Tests in UNECE 10

The Regulation refers to various international standards for the measurement methods, but with modifications and extensions. Table 5.1 shows the tests which are required for electronic sub-assemblies (whole vehicle tests are also mandated but are not discussed here).

**Table 5.1** UNECE Reg 10 tests for ESAs

| Test type | Frequency range | Method |
|---|---|---|
| Radiated broadband emissions, Annex VII | 30–1000MHz | CISPR 25: 2002, semi-anechoic chamber or OATS |
| Radiated narrowband emissions, Annex VIII | 30–1000MHz | CISPR 25: 2002, semi-anechoic chamber or OATS |
| Radio frequency immunity, Annex IX | 20–2000MHz; full levels apply over 90% of this range, 5/6 of the full levels apply over whole range | Any combination of the following:<br>— Absorber chamber test: according to ISO 11452-2: 2004 (30V/m)<br>— TEM cell testing: according to ISO 11452-3: 3rd edition 2001 (75V/m)<br>— Bulk current injection testing: according to ISO 11452-4: 2005 (60mA)<br>— Stripline testing: according to ISO 11452-5: 2nd edition 2002 (60V/m)<br>— 800 mm stripline: according to paragraph 4.5 of Annex IX (15V/m) |
| Conducted transients, Annex X | N/A | Both emissions and immunity to be tested, using method and test pulses 1, 2a, 2b, 3a, 3b and 4 of ISO 7637-2:2002 |

### 5.1.1.5 Additional specifications in REESS charging mode configuration

When an electric vehicle is coupled to the power grid for charging its battery, a whole different set of specifications apply: quite unfamiliar to automotive manufacturers, but completely familiar to the commercial sector and anyone who has looked at Chapter 4 of this book. Both the whole vehicle and ESAs are subject to requirements on the power port. In short form (over and above the radiated and transient immunity and emission requirements in other configurations) the requirements are:

- AC supply harmonic limits, according to IEC 61000-3-2 or 61000-3-12
- AC supply voltage changes, fluctuations and flicker limits, according to IEC 61000-3-3 or 61000-3-11

- Conducted RF emissions limits 150kHz–30MHz on AC or DC power lines, according to IEC 61000-6-3
- Conducted RF 150kHz–30MHz limits on telecom ports (network and telecommunication access), according to IEC 61000-6-3
- EFT/Burst immunity on AC or DC power lines, according to IEC 61000-4-4
- Surge immunity on AC or DC power lines, according to IEC 61000-4-5

However: if either the vehicle/ESA is to be used on DC charging stations with a cable shorter than 30m, or will be connected to a "local/private DC charging station without additional participants", then RF conducted emissions limits, EFT/burst and surge immunity need not apply.

### 5.1.2 ISO, CISPR and SAE standards

There are several international standards which give general test methods for vehicles and their components but which are not of themselves mandatory. These are referenced in Regulation 10 as shown in the table above. CISPR has two vehicle-related emissions standards, and there is a series of immunity standards published by ISO with a similar series published by SAE, the American Society of Automotive Engineers. These are more closely related to the military standards than to commercial ones, but are equivalent to neither. The more important immunity tests are shown in Table 5.2, and the two CISPR emissions tests in Table 5.3.

**Table 5.2** ISO and SAE automotive immunity tests

| Test | ISO | SAE | Requirements | |
|---|---|---|---|---|
| ESD | TR 10605 | J1113-13 | ±4, 6, 7, 8kV – direct (contact) discharge; ±4, 8, 14, 15kV – air discharge<br>(extra ±25kV required on vehicle test, test points accessible from outside vehicle) | |
| Transients | ISO 7637-1, -2, -3 | – | Voltage pulses on supply and signal lines: inductive load supply disconnection and current interruption, switching transients, supply voltage droop, load dump, ignition coil current interruption, alternator field decay | |
| Conducted RF | ISO 11452-4 | J1113-4 | Bulk current injection | 1–400MHz, 25–40–60–80–100mA |
| | ISO 11452-7 | J1113-3 | Direct RF injection | 250kHz–500MHz, 0.05–0.1–0.2–0.3–0.4–0.5W |
| Radiated RF | ISO 11452-2 | J1113-21 | Free field absorber lined chamber | 10kHz–18GHz, 25–40–50–60–80–100V/m |
| | ISO 11452-3<br>ISO 11452-5 | J1113-24 | TEM cell<br>Stripline | 10kHz–200MHz, 50–100–150–200V/m |
| | ISO 11452-11 | J1113-27 | Reverberation chamber | 500MHz–2GHz, 25–40–60–80–100V/m |
| All RF immunity tests use unmodulated CW and 80% AM 1kHz with an equivalent peak test level | | | | |

**Table 5.3** CISPR automotive emissions tests

| | Frequency | Description |
|---|---|---|
| CISPR 12: protection of off-board receivers | Radiated, 30–1000MHz | Both broadband and narrowband (Class B) emissions limits given at 3 or 10m distance, measured on an outdoor test site (not a standard CISPR OATS) or within an anechoic shielded room with a fixed antenna height |
| CISPR 25: protection of on-board receivers | Conducted: bands within 0.15–108MHz | 5μH/50Ω ±10% artificial network, used up to 108MHz |
| | Radiated: bands within 0.15–1000MHz, to be raised to 2.5GHz | 0.15–30MHz, 1m vertical monopole; 30–1000MHz, biconical/log periodic or equivalent, at 1m from EUT on ground plane bench in anechoic shielded room; also includes alternative TEM cell method, and measurement of emissions received by an antenna on the vehicle |

CISPR 12 applies to vehicles and boats driven by an internal combustion engine or electrically, and "devices" (machines such as compressors and chainsaws) with an internal combustion engine. It is a whole vehicle test rather than applying to sub-assemblies, and is intended to protect radio reception away from the vehicle. CISPR 25 by contrast is for protecting radio reception on the vehicle and therefore has various limits set out in bands, for different radio services. It includes both component or module emissions measurements, very similar to the methods in the military standards (see section 5.2), and whole vehicle emissions measurements using the antenna of the type to be supplied with the vehicle.

### 5.1.3 Vehicle manufacturers

From the point of view of the automotive electronic equipment manufacturer, the legislative EMC requirements are almost secondary; these suppliers have principally to consider their customers. Every major vehicle manufacturer has developed their own EMC test requirements, including levels and limits, through a historical process dependent on their exposure to actually occurring field EMC problems, and filtered through their own EMC specialists. These are mostly based on the international or US documents but often with significant variations, and often more stringent. Every vehicle component supplier therefore has to negotiate a maze of detailed requirements and test methods in order to be able to supply their apparatus to a number of vehicle manufacturers (VMs). As an example, the requirements for one vehicle manufacturer are outlined in Table 5.4. Types of apparatus are broken down as follows:

- Passive Modules:
  - D: a module containing only diodes, resistor-ladder networks or thermistors with/without mechanical switches.
- Inductive Devices:
  - R: relays, solenoids and horns.
- Electric Motors:
  - BM: a brush commutated dc electric motor without electronics.
  - EM: an electronically controlled electric motor.

- Active Electronic Modules:
  – A: a component that contains active electronic devices.
  – AS: an electronic component or module operated from a regulated power supply located in another module. This is usually a sensor providing input to a controller.
  – AM: an electronic component or module that contains magnetically sensitive elements or is connected to an external magnetically sensitive element.
  – AX: an electronic module that contains an electric or electronically controlled motor within its package or controls an external inductive device including electric or electronically controlled motor(s); also includes ignition coils with integral drive electronics.
  – AW: an electronic module with no external wiring.

Within this classification of devices, each test has varying degrees of applicability to each type. Also, different levels are applied depending on various aspects of the use of the device. It's probably fair to say that documents such as these (and other vehicle manufacturers have similar specifications) represent the most sophisticated implementation of standardized test methods in any sector.

**Table 5.4** Ford Motor Co Component and Subsystem EMC specification [232]

| Type | ID | Applicable | Description |
|---|---|---|---|
| **Emissions** | | | |
| Radiated RF | RE 310 | EM, all A, maybe D | 0.15–1605MHz, based on CISPR 25 2008, ALSE method |
| Conducted RF | CE 420 | BM, EM, A, AM, AX, maybe D and R | MW, FM broadcast bands, based on CISPR 25 2008 |
| Conducted AF | CE 421 | EM, A, AM, AX | 100Hz–150kHz, in-house current probe method |
| Conducted Transient | CE 410 | R, BM, EM, AX | Based on ISO 7637-2 emissions |
| **Radiated immunity** | | | |
| RF Immunity | RI 112, RI 114, RI 115 | EM, all A, maybe D | BCI (ISO 11452-4), 1–400MHz; ALSE method (ISO 11452-2) or reverberation chamber method (IEC 61000-4-21), 360–3100MHz; near field (ISO 11452-9), 360–2700MHz |
| Magnetic Field | RI 140 | AM, AW | Based on MIL-STD-461E, RS101 50Hz–100kHz |
| **Coupled transients** | | | |
| Inductive | RI 130 | D, EM, all A except AW | In-house chattering relay method, inductively coupled to test harness |
| Charging System | RI 150 | EM, all A except AW | In-house 1–100kHz (sinewave) inductively coupled to test harness |

**Table 5.4** Ford Motor Co Component and Subsystem EMC specification [232] (Continued)

| Type | ID | Applicable | Description |
|---|---|---|---|
| **Conducted immunity** | | | |
| Continuous | CI 210 | EM, A, AM, AX | In-house AF ripple 50Hz–100kHz on power supply |
| Transient | CI 220, CI 221 | D, EM, A, AM, AX | Similar to ISO 7637-2 with additional test pulses |
| Load Dump | CI 222 | D, EM, all A | ISO 7637-2 pulse 5a or 5b |
| Power Cycle | CI 230, CI 231 | EM, A, AM, AX | In-house, voltage fluctuations on engine start |
| Ground Offset | CI 250 | EM, A, AM, AX, AS | In-house, AC ground voltage offset, 2kHz–100kHz (sinewave and transient) |
| Voltage Dropout | CI 260 | EM, all A except AW | In-house, verification of controlled recovery of hardware and software from power interruptions, various waveforms |
| Over-voltage | CI 270 | All except AW, AS | –14, +19 and +27V on power supply or control circuits |
| ESD | CI 280 | All except BM, R | Based on ISO 10605:2008 |

### 5.1.4 Specialist requirements

There are a number of specialist vehicle applications which demand greater attention to EMC. Foremost among these are the police and emergency services, and the procurement agencies for these bodies place their own technical constraints on equipment which will be used in their vehicles. Some of these requirements are particularly severe. The main concerns are:

- emissions within the frequency bands used for communications; since safety-of-life issues ride on these communications, the allowable levels are much lower than you will find in normal CISPR-based standards. With the implementation of TETRA, compliance with these requirements has become more difficult because the whole of each of the TETRA receive bands must be kept clear, with no relaxation allowable for narrowband spot frequencies.
- immunity to on-board radio transmitters, particularly for safety related and law enforcement equipment, and considering the presence of a wide variety of transmitters both personal and vehicle mounted, with the added complication of TETRA communications which can transmit outside the control of the vehicle user.

## 5.2 Military

You might expect military equipment not to be subject to EMC regulation as such. Instead, since military equipment is procured through contract, the EMC specifications can be applied at the contract negotiation stage and this is the usual procedure. This allows the specifications to be fine-tuned and negotiated for a particular application, rather than applied in blanket fashion as happens for commercial products where such pre-purchase technical liaison is unusual. But, for reasons of legal interpretation, it is also common for military contracts to specify CE compliance in addition, as we will see later.

As a result the military standards have evolved to cover certain widely encountered phenomena in a consistent fashion, but without being too prescriptive. Test methods are defined so that test laboratories can use common equipment and procedures, but parameters such as limits, levels to be applied and frequency ranges are left partly open so that they can be adjusted to suit the purpose and product being tested.

Because the US military is a major customer for most Western manufacturers, the US MIL STD series have become *de facto* procurement standards. MIL-STD-461D specified a variety of levels and limits for different purposes, and MIL-STD-462D defined the corresponding test methods. The two were amalgamated into MIL-STD-461E, with a number of changes, in August 1999, and the version current at the time of writing is MIL-STD-461G.

Other countries do have their own variants of the military tests, and in the UK the DEF STAN 59-411 series published by the Ministry of Defence provides a similar variety of tests to the US documents but in a different format, and also gives project planning and documentation requirements along with installation guidelines.

Historically there have been more severe EMC requirements for both emissions and immunity in this sector, since equipment must operate on the "platform" – ship, aircraft, satellite or land vehicle – in close proximity to other apparatus. The internal electromagnetic environment of the platform can usually be closely defined and will typically include several radio transmitters on known frequency bands as well as power supply disturbances due to switching and operation of large motors, actuators, and so on. In addition, the external radio frequency environment, while less predictable, can be quite extreme since the platform can find itself in near proximity and in direct line of sight to very powerful transmitters such as radars and electronic warfare transmitters.

This history, along with the different environmental constraints, explains many of the variations that exist between the military and the commercial standard tests. Even so, it is noticeable that the military tests are far less well controlled in many ways than are their commercial equivalents. Two examples are the use of near field radiated emissions and immunity testing – the antenna is invariably 1m from the EUT, which is mounted on a ground plane bench – and the wide use of current injection probes for conducted emissions and immunity, at frequencies for which the cable looms will be resonant. Both of these practices make for very large uncertainties, which have been much more carefully considered in the IEC/CISPR test methods.

Sections 7.4.4 and 8.3 later describe the most significant technical features of the military emissions and immunity tests; the requirements are summarized below.

### 5.2.1 DEF STAN 59-411

This group of standards is organized as follows [219]:

- Part 1: **Management and Planning** – provides definitions and advice on the selection and specification of EMC requirements, including selection of limits; discusses test plans and control plans and management responsibilities

For LRU (Line Replaceable Unit) and sub-system tests it classifies three types of equipment:

- Type 1: equipment containing electronic components – requires all tests
- Type 2: motors, generators and electromechanical units (excluding items under Type 3) – requires conducted and radiated emissions, and transient tests
- Type 3: Relays, solenoids and transformers – requires only imported/exported transients and power frequency magnetic field
- describes testing of support equipment
- advises on selection of limits

• Part 2: **The Electric, Magnetic and Electromagnetic Environment** – shows how to quantify and identify the EM environment for a variety of scenarios

• Part 3: **Test methods & Limits for Equipment and Sub-Systems** – divided into two categories:

- Annex A: Man Worn Man Portable Equipment
- Annex B: LRU and Sub Systems – generally the more comprehensive
- Annex C specifies the performance requirements for EMC test equipment used in the above tests

• Part 4: **Platform and System Test and Trials** – requirements for EMC tests and trials for platforms and large systems

• Part 5: **Code of Practice for Tri-Service Design and Installation** – recommended design practices for EMC in equipment, systems and platforms

The following tables (5.5 to 5.7) give the menu of tests currently available in Part 3 Annex B.

**Table 5.5** DEF STAN 59-411 emissions tests

| Test | Type | Frequency range | Method |
|---|---|---|---|
| DCE 01 | Conducted emissions on primary power lines | 20Hz to 150MHz | Differential mode, current probe and LISN |
| DCE 02 | Conducted emissions on control, signal and secondary power lines | 20Hz to 150MHz | Common mode, current probe on all harnesses |
| DCE 03 | Exported transients on primary power lines | N/A | Oscilloscope, with contactor and functional switching |
| DRE 01 | Electric field radiated emissions | 10kHz to 18GHz | Various antennas, 1m from EUT in screened room |
| DRE 02 | Magnetic field radiated emissions | 20Hz to 200kHz | Search coil 70mm from each face of the EUT |
| DRE 03 | Radiated emissions – installed antenna, land systems | 1.6 to 30MHz | Clansman rod or “L” antenna at 1m from EUT |

**Table 5.6** DEF STAN 59-411 transient susceptibility tests

| Test | Transient type | Applicability | Levels |
|---|---|---|---|
| DCS 04 | Type 1: 2 to 30MHz switching | Air | 500V, 20A peak, all cables |
| | Type 2: 100kHz switching | Air | 700V, 30A peak, power; 100V, 5A peak, signal lines |
| DCS 05 | Type 1N: 0.5 to 50MHz switching | Land and sea | 10A peak, all cables |
| | Type 1N: NEMP | Land and sea | 100A peak, all cables |
| DCS 06 | Type 2: 100kHz switching | Land and sea | 2kV, 100A peak, power |
| DCS 08 | Lightning EMP/NEMP | Air | 3kV, 30A peak, all cables |
| DCS 09 | Direct Lightning | Air | 2kV, 10kA peak, all cables |
| DCS 10 | Electrostatic Discharge | All | Up to 8kV |
| DCS 12 | LF switching | Sea | Up to 2.5kV peak (power) |

**Table 5.7** DEF STAN 59-411 continuous susceptibility tests

| Test | Description | To test immunity | Method |
|---|---|---|---|
| DCS 01 | Power 20Hz to 50kHz | Ripple on power supply waveform | Coupling transformer in series with power line |
| DCS 02 | Power, signal & control 50kHz to 400MHz | Disturbances induced by local transmitters | Pre-calibrated current injected by current probe onto each cable bundle, primary power lines also tested individually |
| DCS 03 | Control & signal 20Hz to 50kHz | Ripple on adjacent cables | Current passed through test wire, three turns wrapped around cable under test |
| DRS 01 | H Field 20Hz to 100kHz | Magnetic field from e.g. transformers and power cables | Calibrated radiating loop, 5cm from the EUT face |
| DRS 02 | E Field 10kHz to 18GHz | Transmitted fields | Anechoic screened room, E-field sensor monitoring field during test, transmit antenna 1m from boundary of EUT; or alternative method using mode-stirred reverberation chamber above 100MHz for aircraft equipment |
| DRS 03 | Magnetostatic (H Field DC) | High power DC current, degaussing fields | DC current passed through Helmholtz coil assembly |

### 5.2.2 MIL STD 461

This is the principal US military EMC standard for equipment [230], although not by any means the only one, and has been in widespread use for many years. As can be seen, some of its tests are similar to some of the DEF STAN 59-411 tests, but there are a number of different methods and even the similar tests have detailed differences. The latest version G, published in December 2015, added CS117 and CS118 (lightning and ESD susceptibility), plugging a gap which had been apparent in this standard for some time. Other notable changes include an explicit permission for the use of FFT receivers (see section 7.1.1.2) as long as they comply with ANSI C63.2; and there are now more specific cable routing requirements for floor standing equipment setups.

**Table 5.8** MIL-STD-461G emissions tests

| Test | Type | Frequency range | Method |
|---|---|---|---|
| CE 101 | Conducted emissions on power leads | 30Hz to 10kHz | Differential mode, current probe and LISN |
| CE 102 | Conducted emissions on power leads | 10kHz to 10MHz | Voltage measurement on LISN port, each power lead |
| CE 106 | Conducted emissions, antenna terminal | 10kHz to 40GHz depending on EUT operation | Direct connection or via coupler, to antenna port |
| RE 101 | Magnetic field radiated emissions | 30Hz to 100kHz | Search coil 70mm from each EUT face and connector |
| RE 102 | Electric field radiated emissions | 10kHz to 18GHz | Various antennas, 1m from EUT; screened room preferred |
| RE 103 | Radiated emissions – antenna spurious and harmonic outputs | 10kHz to 40GHz depending on EUT operation | Alternative to CE106 for transmitters with integral antennas |

**Table 5.9** MIL-STD-461G susceptibility tests

| Test | Description | To test immunity | Method |
|---|---|---|---|
| CS 101 | Power leads, 30Hz to 150kHz | Ripple on power supply | Coupling transformer in series with power line |
| CS 103 | Antenna port, intermodulation, 15kHz to 10GHz | Presence of intermodulation products | Determined on a case-by-case basis |
| CS 104 | Antenna port, undesired signal rejection, 30Hz to 20GHz | Presence of spurious responses | Determined on a case-by-case basis |
| CS 105 | Antenna port, crossmodulation, 30Hz to 20GHz | Presence of cross-modulation products | Determined on a case-by-case basis |
| CS 109 | Structure current, 60Hz to 100kHz | Currents flowing in the EUT structure | Currents injected by transformer at diagonal extremes across surfaces |
| CS 114 | Bulk cable injection, 10kHz to 200MHz | RF signals coupled onto EUT associated cabling | Pre-calibrated current injected by current probe onto each cable bundle, including power leads with returns excluded |

**Table 5.9** MIL-STD-461G susceptibility tests (Continued)

| Test | Description | To test immunity | Method |
|---|---|---|---|
| CS 115 | Bulk cable injection, impulse excitation | Impulse signals coupled onto EUT associated cabling | As CS114, but with impulse generator giving 30ns pulses at 30Hz repetition rate |
| CS 116 | Damped sinusoidal transients, cables and power leads, 10kHz–100MHz | Damped sinusoidal transients due to excitation of wiring, coupled onto cables and power leads | As CS114, but with damped sinewave generator giving pulses at least once per second at a minimum of 0.01, 0.1, 1, 10, 30, and 100 MHz |
| CS 117 | Lightning induced transients | Multiple burst and multiple stroke transients on interconnecting cables | Various waveforms, applied through injection transformer, similar to DO-160 cable bundle tests |
| CS 118 | Electrostatic Discharge | Personnel-borne ESD | As IEC 61000-4-2, but without reference to that standard |
| RS 101 | Magnetic field 30Hz to 100kHz | Magnetic field from e.g. transformers and power cables | Calibrated radiating loop, 5cm from the EUT face, or place EUT within calibrated Helmholtz coils |
| RS 103 | Electric Field 2MHz to 40GHz | Transmitted fields | Anechoic screened room, E-field sensor monitoring field during test, transmit antenna 1m from boundary of EUT; or alternative method using mode-stirred reverberation chamber |
| RS 105 | Transient electromagnetic field | Unidirectional pulsed radiated field, 2.3/23ns 50kV/m | Transient pulse generator feeding TEM cell, parallel plate transmission line or similar |

### 5.2.3 CE Marking of Military Equipment

For many years it was assumed that military equipment didn't need to be CE Marked for sale within the EU, by virtue of a clause in the Treaty of Rome which exempted "munitions of war" from the European Union legislation. Once legally challenged, however, this understanding has been found to be largely groundless. Defence contracts *can* be excluded from the EU legislation, but only on the basis of "essential security interests"; and it is "for the Member State which seeks to rely on the exemptions to furnish evidence that the exemptions are necessary for the protection of the essential interests of its security". This interpretation has been reinforced by the publication of the Defence Procurement Directive (2009/81/EC) which has created a legal framework for the European defence equipment market.

Needless to say, in most cases the paperwork needed to provide this evidence imposes a greater burden than the additional work needed to show that a product or system which meets military standards, also meets the requirements for CE Marking. And so most companies take the easier route, and CE Mark anyway. This isn't necessarily a straightforward exercise, since the military standards mostly are intended to deal with operational scenarios and may not cover all aspects of the EMC or Radio Directives' essential requirements. Thus in some instances parallel testing, to the contractual defence standards and to the harmonized EN standards, is actually the simplest approach, rather than an extended gap analysis. The issue has exercised affected parties to such an extent that a guidance document, TR 50538:2010 [167], has been published by CENELEC.

### 5.2.4 Commercial off the shelf

There is an expectation that the military should have access to the latest technology in the shortest timescale but at the lowest cost, and consequently often a need to adapt commercial products for military use – commercial-off-the-shelf (COTS). This creates issues because commercial products – IT equipment, power supplies, instrumentation and so on – are pressed into service against EMC requirements they were never designed to meet. Or, as MIL-STD-461 puts it,

> The use of commercial items presents a dilemma between the need for EMI control with appropriate design measures implemented and the desire to take advantage of existing designs which may exhibit undesirable EMI characteristics.

There has been considerable effort over the last few years to try and devise a way forward in such a situation. This has resulted in the concept of a “gap analysis”, in which the commercial specifications which a product is said to meet – usually under the CE Marking regime – are compared with the more stringent project specifications such as the military standards, and the identified “gaps” are filled by extra tests which may show the need for “mitigation measures”. This is the opposite to the process described in the previous section, where military products must be shown to meet CE Marking requirements.

This process, while initially attractive to project managers, can fall at either of two hurdles:

- The product in question, despite its promises, doesn’t actually meet the detail of the specifications that it claims, or else it simply doesn’t claim enough of such detail to be useful. The CE Marking regime is so inherently lax that it would be surprising if it were otherwise;
- The “mitigation measures” which turn out to be necessary make the product unusable in its intended application. For instance, the required extra filtering might double the unit’s size and weight, or the extra shielding might mean no-one could open the door to reach the front panel.

It may also be that the gap analysis simply isn’t able to identify all the gaps, which only eventually show up once the compliance test is done. Consequent delays to the project make it late and over budget. You might expect that companies which specialise in such projects would have learnt long ago of the dangers of postponing an analysis of EMC requirements, and indeed there are many such organizations that have EMC experts in house who can flag issues at an early stage. But there are also many who don’t, and even in the best organizations the in-house EMC specialist doesn’t always get the chance to offer the analysis that is required. Use of COTS comes with many snags, and EMC can be one of the most critical.

## 5.3 Aerospace

EMC test requirements for civil aerospace equipment are defined in two documents: EUROCAE/ED-14 in Europe, and RTCA/DO-160 in the USA.

They describe a series of minimum standard environmental test conditions and applicable test procedures for airborne equipment, intended for everything from light aircraft and helicopters through to large passenger airliners. The documents are worded identically and both are subject to occasional updates: at the time of writing the current issue is G, published in December 2010. There are 26 sections, of which sections 15 through to 23 and section 25 cover various EMC phenomena.

Aircraft themselves are not covered by the EMC Directive within Europe. The legislation that applies to them, and hence to their equipment, is in terms of airworthiness acceptance by the national aviation authorities, overseen by the European Joint Aviation Authorities (JAA). One exception to the scope of both the Radio and EMC Directives is aeronautical products, parts and appliances, for which the original EMC Directive required an EC Type-Examination route to compliance, which in the UK was administered by the CAA as a Notified Body. Passenger-carried electronic devices (PEDs) are of course not covered by these standards, which has led to ongoing concern about their possible effects on aircraft control and navigation systems (see section 1.1.1).

### 5.3.1 DO-160/ED-14

The various sections of DO-160 [231] that are relevant for EMC purposes are given in Table 5.10. Some of the sections are relatively undemanding and well-established; the ones that have undergone the most significant changes in the last few years are section 20 on RF susceptibility and section 22 on lightning induced transients [34][157]. These are in response to the challenges associated with the introduction of both composite structures and fly-by-wire systems in modern aircraft; greater reliability is needed, but at the same time less protection from radiated fields and lightning currents is enjoyed by many of the electrical sub-systems. The radiated RF susceptibility test now refers to the mode-stirred reverberation chamber as an alternative method to the traditional semi-anechoic chamber, which is just as well, since the maximum test levels are impressive: the highest level for Category F from 4–6GHz is 7200V/m pulsed.

#### *5.3.1.1 Lightning induced transients*

The lightning requirements are split between sections 22 and 23, but section 23 is mostly applicable for whole aircraft tests with externally mounted equipment, in very large high-voltage facilities. The tests in section 22 have five levels, the highest of which are far more stringent than levels appearing in the aircraft requirements of military standards. Section 22 suggests four installation protection zones:

- Zone a: well-protected environment, for example within the passenger cabin. Because equipment located in this environment is furthest from the aircraft skin and should be protected through the systems it communicates with, the lowest test level (level 1) applies.
- Zone b: partially protected environments such as equipment electronic bays are distributed around the airframe with cables linking equipment in other zones or to another electronic bay. Cables linking electronic bays, regardless of whether they run through a well protected environment, should be considered as belonging to the equipment bay category. Such equipment requires level 2.
- Zone c: moderately protected environments are considered to be those areas potentially subject to direct electromagnetic interference effects. Cockpit

areas fall into this category and equipment mounted here should be subjected to tests at level 3.

- Zone d: severe electromagnetic effects are most likely in airframes with significant amounts of composite material without wire meshing. Equipment in this category could be landing gear or engine or flight controls. They are recommended to be tested to level 4 or 5. The values for level 4 are more than double, and for level 5 more than five times, the values for level 3. Testing at these levels (up to 3200V and 3200A, though not at the same time) requires a significant test equipment investment.

All cable bundle tests take into account the potential influence of EUT cabling on the impulse, with respect to its amplitude, by defining parameters of $I_{Test}$ and $V_{Limit}$ or $V_{Test}$ and $I_{Limit}$ values. A "Test" value is the ideal that should be reached if possible. The "Limit" value is the maximum allowable value measured in a cable bundle to prevent over-stressing the EUT. When this occurs, the test is deemed to have been completed. The "Test" and "Limit" values do not define the generator impedance; this is given only by the pin injection requirements. Because the cable bundle impedance is so significant, the type and routing of the cable influences whether the "Test" or "Limit" value is reached first.

**Table 5.10** DO-160G/ED-14G EMC tests

| Part | Test | Description of requirement |
|---|---|---|
| Section 15 | Magnetic effect | Compass deflection measurement: separation distance for one degree deflection |
| Section 16 | Power input | Normal and emergency power conditions: variable voltage, frequency and phase unbalance, ripple, surge, dips and interruptions, harmonic emissions |
| Section 17 | Voltage spike | Two categories of transient waveform applied to primary power inputs; similar to the old MIL-STD-462D method CS06 (now defunct) |
| Section 18 | AF conducted susceptibility | Differential mode injected AF on power inputs, up to 10Hz–150kHz; similar to MIL-STD-461E method CS101 |
| Section 19 | Induced signal susceptibility | 400Hz–15kHz electric and magnetic field, and unsuppressed relay coil spikes, induced via near-field coupling to cable bundle; 400Hz 20A magnetic field and 170Vrms electric field for EUT |
| Section 20 | RF susceptibility: conducted | 10kHz–400MHz pre-calibrated bulk current injection on all interconnecting cable bundles; similar to MIL-STD-461E method CS114 |
| | RF susceptibility: radiated | 100MHz–18GHz with antenna in semi-anechoic chamber, similar to MIL-STD-461E method RS103, or mode-stirred reverberation chamber |
| Section 21 | RF emissions: conducted | 150kHz–30MHz using LISN or current probe, on primary power lines and interconnecting cable bundles |
| | RF emissions: radiated | 2MHz–6GHz, various antennas at 1m from EUT |

**Table 5.10** DO-160G/ED-14G EMC tests (Continued)

| Part | Test | Description of requirement |
|---|---|---|
| Section 22 | Lightning induced transient susceptibility | Five levels depending on location (levels 4 and 5 most relevant for exposed locations in composite aircraft), several waveforms including multiple stroke and multiple burst; pin injection, cable bundle induction and ground injection techniques |
| Section 23 | Lightning direct effects | Applies to externally mounted equipment, categories defined depending on lightning protection zones, equipment normally unpowered, generator must create 100's of kV |
| Section 25 | Electrostatic discharge | As IEC 61000-4-2 except EUT bonded to ground plane and air discharge only at 15kV applied |

## 5.4 Rail

The railway industry in Europe is in a somewhat unusual position regarding EMC; on the one hand it has to ensure operational safety, but on the other its installations are covered under the EMC Directive, which has nothing to do with safety. This leads to parallel compliance requirements both for Network Rail and the train operators themselves, and for the suppliers of equipment into the rail industry [149].

### 5.4.1 Railway Group Standards

On the UK mainline system, Railway Group Standards (RGS) are mandatory on all members of the Railway Group, which comprises the infrastructure controller (Network Rail) and the train operating companies as well as associated organizations. Compliance with the route acceptance process is normally demonstrated by way of the Railway Safety Case which is based on the successful application of all relevant RGSs. For EMC, the relevant top-level RGS is GE/RT8015, *Electromagnetic Compatibility between Railway Infrastructure and Trains* [212]. This places generalized requirements for emissions and susceptibility limits on both the trains and the infrastructure. The default levels are those set out in EN 50121 parts 3, 4 and 5, but with the caveat that the rolling stock may have to meet extra requirements based on known emissions or susceptibilities of the infrastructure. This in turn means that the infrastructure controller must establish and maintain information on its systems, and GE/RT8015 devotes considerable space to codifying its responsibilities for this, including:

- identifying all safety-related infrastructure systems which could have their safety performance reduced through EMI;
- analysing the susceptibility of such systems, particularly to determine the nature and level of train emissions which would affect the safety perfomance;
- documenting the analysis and making it available to train operators and other stakeholders, particularly so that the train operator can demonstrate compatibility with the infrastructure system;
- implementing a maintenance and testing regime to ensure that the susceptibility of the system is not worsened.

Since implementing these processes, the railway industry has demonstrated a voracious appetite for consuming all available types of EMC expertise.

#### *5.4.1.1 Typical safety-critical infrastructure and train systems*

GE/RT8015 gives an indication (not exhaustive) of the types of systems and equipment whose safety performance could be affected by EMI, and which should be included in the analysis.

For infrastructure:

- train detection systems (including track circuits and axle counters);
- interlocking systems;
- signals and point operating equipment and their controlling circuits;
- train warning and protection systems;
- telecommunications systems (including voice and data transmission, and supervisory control and data acquisition (SCADA) systems);
- radio systems (including voice and data transmission, fixed and mobile systems).

For trains:

- braking systems;
- traction control systems;
- tilt control systems;
- door control systems;
- coupling systems;
- communications systems;
- lighting systems (internal and external);
- train-borne elements of command and control systems.

### 5.4.2 London Underground standards

The basic framework which gives the EMC requirements for equipment installed within the London Underground (LU) network are set out in LU CED Engineering Standard 2-01018-001 A2 (formerly E 1027). The objective of the standard is to ensure that LU meets the requirements of the EMC Directive and corresponding UK Regulations. 2-01018-001 A2 is very much a top-level document setting out responsibilities and procedures. A companion guideline document, M1027 (5-01018-001) *Manual of EMC best practice*, provides greater technical detail regarding EMC requirements. The top level document includes the requirement for an EMC Control Plan which is detailed in M1027 together with the requirement for an EMC Test Plan.

LU engineering documents are issued by the Chief Engineer's Directorate and a number of these relate to EMC. These documents emphasise the need to provide EMC assurance for the management and improvement of assets on LU, including rolling stock. Unlike the Railway Group Standards for the mainline railway, the top-level standard 2-01018-001 A2 makes it clear from the outset that the main objective is to ensure that LU meets the requirements of the EMC Directive and the corresponding UK Regulations. It also states that compliance with appropriate parts of EN 50121 is a requirement together with any special LU needs.

### 5.4.3 EN 50121

This document was first published as a pre-standard in 1996, and then as a full standard in 2000, with the overall title of “Railway applications – Electromagnetic compatibility”. It was revised and re-published in 2006. It has a total of six parts.

#### *5.4.3.1 Parts of EN 50121*

Part 1: General

- Describes the EM behaviour of the railway system, gives the (generic) immunity performance criteria, and also discusses the management of EMC at the interface between the infrastructure and the trains.

Part 2: Emission of the whole railway system to the outside world

- Sets the RF emissions limits at 10m from the railway track from 9kHz to 1GHz, and gives the methods of measurement. This is not a trivial matter, because the measurement must take place on a real railway, or at least on a section of test track which is representative of a real railway. Ambient and weather conditions can seriously affect the measurement. Most importantly, it may be expected that maximum emissions will occur with the traction unit either at maximum power or at maximum speed (the two conditions may not be the same). But a train at maximum speed will be past the measurement point in a few seconds. So some quite sophisticated test methods have to be developed to allow the capture of the worst case emissions in a realistic measurement time.

Part 3-1: Rolling stock: Train and complete vehicle

- Sets the emission and immunity requirements for all types of rolling stock; its scope ends at the interface of the stock with its respective energy inputs and outputs, i.e. for locomotives it is the sliding contact, for coaches and wagons, it is the AC or DC power connector. The standard does not in fact give any immunity requirements, but it says:

  > the immunity tests and limits in Part 3-2 of this standard were selected in the knowledge that the vehicle should be immune to a level of 20V/m over the frequency range 0.15MHz to 1GHz. It is expected that the assembly of the apparatus into a complete vehicle will give adequate immunity, provided that an EMC plan has been prepared and implemented, using the limits in Part 3-2 of this standard.

  The emissions limits are similar to but slightly lower than those specified in part 2.

Part 3-2: Rolling stock: Apparatus

- Applies emission and immunity requirements for apparatus intended for use on rolling stock; includes separate conducted emission tables for traction power and auxiliary power ports, with no limits applying to traction power and substantially relaxed limits for other ports

Part 4: Emission and immunity of the signalling and telecommunications apparatus

- Applies emission and immunity requirements for signalling and telecom.

Part 5: Emission and immunity of fixed power supply installations and apparatus

- Applies emission and immunity requirements for apparatus and systems intended for use in the railway power supply: this includes the power feed, the supply equipment itself with protection and control circuits, and trackside items such as switching stations, transformers and switchgear.

In all of parts 3-2, 4 and 5 the usual basic standards in the IEC 61000-4 series are referenced, as with the generic standards, with in the main industrial or higher levels of stress: for instance, the RF immunity level in Part 4 is 20V/m, in Part 5 the power line EFT/Burst and surge immunity level is 4kV.

### 5.4.4 EN 50155

This is not an EMC standard and is not harmonized under the EMC Directive, but it describes a general set of requirements for electronic equipment used on rolling stock. This includes a reference to the tests of EN 50121-3-2 but also adds some other requirements, in particular the need for a wide range of supply voltage tolerance – in the majority of cases, a normal voltage range of 0.7–1.25 times nominal, but with extremes between 0.6–1.4 times nominal for 100ms not causing a deviation of function. The standard does not itself mandate galvanic isolation for electrical interfaces but it gives a strong hint that such would be necessary in many applications, and it defines voltage withstand tests where isolation is implemented.

The interaction of these and other power supply specifications with the usual RF emission, immunity and transient immunity requirements means that railway apparatus designers need to treat their interface design with considerable care and forethought.