Chapter 5

Other standards and legislation

Chapter 4 covered the commercial standards, deriving from the IEC, that are relevant for the EMC and R&TTE 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 The Automotive EMC Directive

In Europe, the EMC both of whole vehicles and their electronic sub-assemblies is covered by the Automotive EMC Directive. This is 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 electronic vehicle sub-assemblies. 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 [184] was published on 13th November 2004. The timescale for adoption laid out in the second edition is as follows:

- entry into force: 3rd December 2004
- transposition: Member States shall adopt and publish the provisions necessary to comply with this Directive by 31st December 2005, and apply them as from 1st January 2006.

- from 1st January 2006, Member States must recognize equipment or vehicles which comply with the new Directive.
- transitional provisions: from 1st July 2006, new vehicles and equipment must comply; existing vehicles and equipment need not comply till 1st January 2009.

What changes?

The main modifications are:

- The Directive allows 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 is not sufficient: the applicable requirements must be matched to the vehicle environment.
- The test provisions and reference limits take into account the work done in international harmonisation. The Directive now refers 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 are given (including, for instance, the requirement for immunity to GSM pulse modulation in the 800–2000 MHz frequency range). This mostly replaces the explicit but confused methods for immunity and emissions testing given in the text of the first Directive. Testing must, though, be carried out by a test house accredited to ISO 17025.
- The new Directive contains 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 gives particular attention to safety related functions and components. It introduces 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 is 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 cellphones) 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 Tests in the second edition

The Directive 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 Automotive Directive 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: — Absorber chamber test: according to ISO DIS 11452-2: 2003 (30V/m) — TEM cell testing: according to ISO 11452-3: 3rd edition 2001 (75V/m) — Bulk current injection testing: according to ISO DIS 11452-4: 2003 (60mA) — Stripline testing: according to ISO 11452-5: 2nd edition 2002 (60V/m) — 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

5.1.2 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 the Automotive EMC Directive 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 (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	1MHz – 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	J1113-24	TEM cell	10kHz – 200MHz, 50 – 100 – 150 – 200V/m
	ISO 11452-5	–	Stripline	10kHz – 200MHz, 50 – 100 – 150 – 200V/m
	–	J1113-25	Tri-plate	10kHz – 500MHz, 50 – 100 – 150 – 200V/m
	–	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:
  - P: a passive electrical module consisting of only passive components, connected to the vehicle power supply.
- Inductive Devices:
  - R: relays, solenoids and horns.
- Electric Motors:
  - BM: a brush commutated dc electric motor.
  - 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 supplier 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).
  - AY: an electronic module that contains a magnetically controlled relay within its package.

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 [211]

Type	ID	Applicable	Description
Emissions			
Radiated RF	RE 310	BM, EM, all A	0.15–2500 MHz, based on CISPR 25 Ed. 2, ALSE method
Conducted RF	CE 420	BM, EM, all A	LW, MW, FM broadcast bands, based on CISPR 25 Ed. 2
Conducted Transient	CE 410	R, BM, EM, AX, AY	Based on ISO 7637-2 emissions
Radiated immunity			
RF Immunity	RI 112, RI 114	EM, all A	BCI (ISO 11452-4), 1–400MHz; ALSE method (ISO 11452-2) or reverberation chamber method (IEC 61000-4-21), 400–3100 MHz
Magnetic Field	RI 140	AM	Based on MIL-STD-461E, RS101 50Hz–10kHz
Coupled transients			
Inductive	RI 130	EM, all A	In-house chattering relay method
Charging System	RI 150	EM, all A	In-house 0.6–10kHz (sinewave) inductively coupled to test harness
Conducted immunity			
Continuous	CI 210	EM, A, AM, AX, AY	In-house AF ripple 50Hz–10kHz on power and control circuits
Transient	CI 220	P, EM, A, AM, AX, AY	Similar to ISO 7637-2 with additional test pulses
Power Cycle	CI 230	EM, A, AM, AX, AY	In-house, voltage fluctuations on engine start
Ground Offset	CI 250	EM, A, AM, AX, AY	In-house, AC ground voltage offset, 50Hz–1kHz (sinewave)
Voltage Dropout	CI 260	EM, all A	In-house, verification of controlled recovery of hardware and software from power interruptions, various waveforms
Over-voltage	CI 270	All except BM, AS	-14, +19 and +24V on power supply or control circuits
ESD	CI 280	P, EM, all A	Based on ISO 10605

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

Military equipment is generally not 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. Even so, it is becoming more common for military contracts to specify CE compliance in addition.

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.

Other countries do have their own variants of the military tests, and in the UK the DEF STAN 59-41 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. DEF STAN 59-41 is at the time of writing undergoing a substantial revision (to become DEF STAN 59-411), which will make detailed changes to some of the tests but is more focussed on revising the structure to incorporate other defence-related EMC subjects, particularly systems trials.

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 6.4.4 and 7.3 later describe the most significant technical features of the military emissions and immunity tests; the requirements are summarized below.

5.2.1 DEF STAN 59-41

At present this group of standards is organized as follows [202]:

Control and management:

- Part 1: **Introduction & Guide** – provides definitions and advice on the selection and specification of EMC requirements, including selection of limits; 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
- Part 2: **Management & Planning** – discusses test plans and control plans

Testing:

- Part 3: **Technical Requirements, Test methods & Limits** – divided into three categories:
  - Section 1: Man Worn Man Portable Equipment
  - Section 2: Military Support Equipment for Use in a Civilian Environment
  - Section 3: LRU and Sub Systems – generally the most comprehensive of the three, contains a large section on general test requirements, but also refers to Part 5 for certain test equipment
- Part 4: **Large equipment testing** – gives changes from Part 3 for large equipment, likely to be extensively revised and incorporated with section on systems trials
- Part 5: **Specialized EMC test equipment** – covers transient and pulse generators and calibration jigs, monitor loops and voltage probes, Line Impedance Stabilization Networks (LISN), method of damping and verification of screened rooms, and a supply frequency filter for the voltage probe

EMC Design Guidelines:

- Part 6: **Military Vehicles Installation Guidelines**
- Part 7: **HM Ships Installation Guidelines**

In the new format of the standard, whose revision is ongoing at the time of writing [60], Parts 1 and 2 are combined into Volume 1, *Management and Planning*; a new Volume 2, *Electromagnetic Environments*, will be created; Parts 3 and 5 will be combined into Volume 3, *Test Methods and Limits for Sub Systems*; the existing Part 4 and other documents will be combined into a greatly expanded Volume 4, *Platform and System Tests and Trials*; and Parts 6 and 7 along with other DEF STANs will be combined into Volume 5, *Code of Practice for Tri-Service Design and Installation*.

The following tables give the menu of tests currently available in Part 3 Section 3.

Table 5.5 DEF STAN 59-41 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 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	14kHz to 18GHz	Various antennas, 1m from EUT in screened room
DRE 02	Magnetic field radiated emissions	20Hz to 100kHz	Search coil 70mm from each face of the EUT
DRE 03	Radiated emissions – installed antenna, land systems	1.6 to 76MHz	Clansman rod or “L” antenna at 1m from EUT

Table 5.6 DEF STAN 59-41 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	5kV, 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 59-41 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 14kHz 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 equpt
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 [209], 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 59-41 tests, but there are a number of different methods and even the similar tests have detailed differences.

Table 5.8 MIL-STD-461E 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

Table 5.8 MIL-STD-461E emissions tests (Continued)

Test	Type	Frequency range	Method
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-461E 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, cross modulation, 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 and grounds excluded
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 to 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
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

Table 5.9 MIL-STD-461E susceptibility tests (Continued)

Test	Description	To test immunity	Method
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

5.3 Aerospace

EMC test requirements for civil aerospace equipment are defined in two documents:

- EUROCAE/ED-14E in Europe
- RTCA/DO-160E 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 regular changes: at the time of writing the current issue is E, published in September 2004. 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 the R&TTE Directive is radio transmitters for aircraft and air traffic management systems, 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 [210] 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 [35][145]. 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-160E/ED-14E 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 MIL-STD-462D method CS06
Section 18	AF conducted susceptibility	Differential mode injected AF on power inputs, up to 10Hz–150kHz; similar to MIL-STD-461E method CS101

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

Part	Test	Description of requirement
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 for EUT; similar to MIL-STD-462D method RS02
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
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 [138].

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* [197]. 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 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.

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.

5.4.3.2 EN 50121 and the EMC Directive

This standard was written principally to allow railway operators to demonstrate compliance with the EMC Directive, via the standards route. It is also intended to achieve EMC between various parts of the railway. So far, the first of these purposes has not been achieved, for a mixture of reasons: it deals in part with installations, and installations so far do not require CE Marking; and there is considerable disquiet within CISPR and at the European level that the RF emissions levels it sets are far too lax, and out of step with other CISPR-based limits. As a result it has not been harmonised, and therefore equipment and installations using it under the first edition EMCD could only use the Technical Construction File route. Now that the second edition EMCD has swept away the TCF route and requires simply an EMC Assessment, which may or may not use harmonised standards, the way seems to be clearer for the railway industry to use EN 50121 together with an EMC Assessment for compliance purposes.

Unfortunately, it is noticeable on looking through the various parts of the standard how many omissions there are, both explicit and implicit. Very often these seem to fall under the heading of "too difficult": or at least, too complex to be put into a European standard, and best left to individual circumstances. Industry sources suggest that the limits, particularly those in Part 2 for emissions to the outside world, were arrived at simply by a process of measuring what was actually occurring in real life, and drawing an envelope which encompassed all the measurements, on the basis that this would continue to be achievable in the future and there hadn't been enough complaints of radio interference so far to worry about. A comparison of some of these against comparable CISPR limits is shown in Figure 5.1. It is perhaps unsurprising that the CENELEC Technical Board have not yet seen fit to recommend this series of standards as suitable for declaring compliance with the EMC Directive.

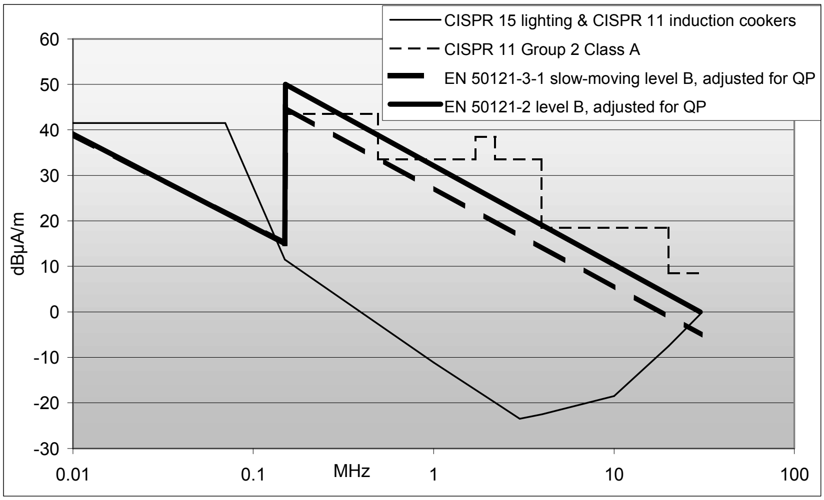

Figure 5.1 Comparison between CISPR and EN 50121 magnetic field emission limits

NB all limits are expressed at a distance of 10m; the values for EN 50121 were reduced by 20dB to allow for the difference between peak and quasi-peak detection, as assumed by the standard; Level B is for 15kV AC, 3kV DC and 1.5kV DC systems, level A for 25kV AC systems is 5dB higher