EMC for Product Designers

Third edition

Tim Williams

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BUTTERWORTH
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Preface

The most popular TV programme in the UK over Christmas 1991 was *Auntie's Bloomers*. Millions of viewers watched a selection of clips from the BBC's archives, showing various well known television personalities at embarrassing moments while the camera was running, clips that never made it to the final programme. For a significant fraction of these viewers, their enjoyment would have been spoilt by a bloomer of another kind. In the first half of 1985, before a service charge was introduced, the UK's Radio Investigation Service was receiving an average of 1900 complaints a month relating to broadcast reception, and about 80% of the RIS's resources were devoted to domestic radio and TV reception problems. Spots, hash, snowstorms, colour and vision distortion and occasionally complete loss of picture are all symptoms of the same cause – electromagnetic interference.

It is irritating for the viewer when the picture flickers or is wiped out during a crucial programme, just as it is irritating for a music lover who has carefully taped an important broadcast on FM radio only to find that the quiet passages are ruined by the intrusion of the neighbour's electric drill. It is far more critical when the emergency services are unable to communicate within a city centre because their radio signals are obscured by the electromagnetic "smog" emitted by thousands of computer terminals in the buildings around them.

The coexistence of all kinds of radio services, which use the electromagnetic spectrum to convey information, with technical processes and products from which electromagnetic energy is an undesirable by-product, creates the problem of what is known as *electromagnetic compatibility* (EMC). The solution is a compromise: radio services must allow for a certain degree of interference, but interfering emissions may not exceed a certain level, which normally involves measures to limit or suppress the interference energy. There is an economic tradeoff inherent in this compromise. A lower level of interference would mean that less powerful transmitters were necessary, but the suppression costs would be higher. Alternatively, accept high power transmitters – with the attendant inefficient spectrum usage – in return for lower suppression costs. This economic balance has been tested over the past decades with the establishment of various standards for allowable levels of interference.

The problems of EMC are not limited to interference with radio services. Increasingly, electronic equipment of all kinds is becoming more susceptible to malfunctions caused by external interference. This phenomenon is more and more noticeable for two reasons: the greater pervasiveness and interaction of electronic products in all aspects of daily life, and the relatively worse immunity of modern equipment using plastic cases and microprocessors. Susceptibility to interference is now an issue for many kinds of electronic device, especially those whose continued correct operation is vital for safety or economic reasons. Automotive and aviation control systems are examples of the former category, banking and telecommunication networks are examples of the latter.

There is now an urgent need for mandatory measures to be taken to protect and ensure equipment's EMC. Various national administrations have taken ad hoc measures in the past to impose restrictions on some of the electromagnetic properties of some types of product. These measures have often come to be seen as implementing back-door methods of protectionism,

In an heroic effort to recognize the need for EMC protection measures and at the same time to eliminate the protectionist barriers to trade throughout the European Community, the European Commission adopted in 1989 a Directive "on the approximation of the laws of the Member States relative to electromagnetic compatibility", otherwise known as the EMC Directive. It is discussed in detail in Chapter 1 of this book.

The adjective "heroic" is used above because the eventual implementation of the requirements of the EMC Directive is proving to be a task worthy of any Hercules. Both the scope of the Directive and the EMC phenomena it covers are exhaustive, but it is framed in extremely general terms. The interpretation of these terms is taking considerable effort, as is the generation of standards against which compliance with the Directive can be judged. As an example of the latter, CENELEC (the European standards body) was mandated to produce several new standards within two years, when the normal process for generating international standards takes at least five years.

Practically speaking, the new standards started appearing in a steady stream during 1992 and succeeding years, and they will undoubtedly be subject to continual revision as experience is gained with their use. One consequence of the early lack of availability of these standards is that the Directive's initial timetable was extended to include a transitional period of four years during which its observance was optional.

The task facing manufacturers who must comply with the Directive is, many feel, equally heroic. There is virtually no type of product for which the Directive's requirements were being met in their entirety already. Many manufacturers of data processing or household equipment already met emission standards required by American, German or previous EC legislation and for them it was, in the words of one commentator, "business as usual". But the Directive also requires equal attention to be given to a product's immunity. Few products which met emission standards had also been tested for immunity. There are some product sectors which already exercised immunity standards on a contractual basis – but few of these also tested for emissions. This is only pragmatic, since emissions legislation concentrates on protecting the innocent spectrum user while immunity standards are intended to safeguard the product's own end user, and it is still at present rare for these needs to co-exist in the same environment. For the first time, the Directive has brought together mandatory requirements for both emission suppression and immunity.

By the end of 1995, every company that manufactures or imports electrical or electronic products should have in place measures that will enable its products to comply with the Directive. This means that an awareness of EMC will have to penetrate every part of the enterprise. EMC is undoubtedly affected by the design of the product, and the design and development group is where the awareness normally starts. But it also depends on the way an individual product is put together, so it affects the production department; by the way it is installed, so it affects the installation and service technicians, and the user documentation; it needs to be assured for each unit, so it affects the test department; it impacts the product's marketing strategy and sales literature, so it affects the sales and marketing departments; and it ultimately affects the viability and liabilities of the company, so it must be understood by the senior management.

There are various means of implanting and cultivating this awareness. The many EMC training courses and awareness seminars are a good starting point. It would be possible to bring in consultants to handle every aspect of the EMC compliance process, but for many products this would be expensive and cumbersome and would not necessarily result in improved awareness and expertise within the company where it was really needed. It would also be possible to send every appropriate member of staff on a training course. This would certainly raise awareness but it may not prove so effective in the long run, since EMC techniques also need to be practised to be properly understood. It would also be expensive, but some of the

A good compromise is to nominate one person, or a group if the resources are available, to act as the centre of EMC expertise for the company. His, her or its responsibility should be to implement the requirements of the EMC Directive and any other EMC specifications to which the company may need to work. In the long term, it should also be to make the EMC centre redundant: to imbue a knowledge of EMC principles into each operating division so that they are a natural part of the functioning of that division. This, though, would take years of continuous oversight and education. Meanwhile, the tasks would include:

- reviewing each new product design throughout the development and prototyping stages for adherence to EMC principles, and advising on design changes where necessary;
- drawing up and implementing an EMC test and control plan for each product;
- supervising pre-compliance and compliance tests both in house and in liaison with external test houses;
- maintaining an intimate knowledge of the EMC standards and legislation that apply to the company's products;
- liaising with marketing, sales, production, test, installation and servicing departments to ensure that their strategies are consistent with EMC requirements.

There are probably more detailed tasks involved, but this serves as an indication of the breadth of scope of the EMC engineer's job. It is comparable to that of the quality department, and indeed can sometimes be incorporated within that department.

Preface to the third edition

The second edition of this book was published in 1996, and this third edition comes out five years later. In that time the EMC Directive has been fully functional and the vast majority of manufacturing companies have become familiar with it. But the EMC world has not stood still: new product standards have been published, new test methods have become established and much has been learned to improve old tests. Although Maxwell's laws haven't changed, there is more understanding of how best to apply them to maximize the compatibility of individual products. The onward and upward march of clock speeds and the shrinking of product, package and interconnect.xiv Preface dimensions has continued. And so, even if you were familiar with the second edition, you will find quite a lot of new material in this one.

This book is intended to help the work of the company's EMC centre. It seems to be serving its purpose: I have been pleasantly surprised by how widely it has been recommended. It can be used as a reference for the EMC engineer, as background reading for designers and technicians new to the subject, or as part of the armoury of the development group tackling a new project. It is structured into two parts. The first part (Chapters 1–4) discusses the European legislative framework now erected to encompass EMC, and the test techniques that are used to demonstrate compliance with that framework. The first two chapters are mainly non-technical in nature. Chapter 1 introduces the subject of interference, and goes on to discuss the provisions of the EMC Directive and the means of achieving compliance with it. Chapter 2 details the standards-making structure and describes the various harmonized standards that are now in existence and which are relevant for compliance with the Directive. Chapter 3 covers the test methods for RF emissions and mains input current harmonics that are laid down in the standards and which will need to be followed both in-house and by external test houses. Chapter 4 does the same for the immunity tests: RF immunity, ESD and transient immunity, as well as the low frequency techniques of magnetic field and voltage dips and interruptions.

and suppression components to an existing design to enable it to meet EMC standards. This brute force method is expensive, time consuming and inefficient. Far better is to design to the appropriate principles from the start, so that the product has a good chance of achieving compliance first time, or if it doesn't then modifications are made easy to implement.

Chapter 5 covers the basic principles involved in coupling electromagnetic interference from a source to a victim. Chapter 6 looks at the techniques which can be applied before resorting to the more traditional methods of screening and suppression: attention to equipment and PCB layout and grounding, and Chapter 7 discusses choice of circuit configuration, components and software features. Chapter 8 carries on to detail the accepted "special" EMC techniques which include cable configuration and termination, filtering methods and components, and shielding. Chapter 9 discusses EMC management and control principles and finally, a series of appendices gather together some of the more detailed reference information.

Much of the book has grown out of course notes that were prepared for seminars on Design and Test for EMC, and I am grateful to those designers who attended these seminars and stimulated me to continually improve and hone the presentation. Many people have helped with its progress. I would particularly like to acknowledge the work of Prof. Andy Marvin and Dr John Dawson and their colleagues at York University, as well as that of Dr Jasper Goedbloed and Prof. Piet van der Laan. I have had a long and fruitful relationship with Schaffner-Chase EMC, and am continually grateful especially to David Riley, John Dearing, Ray Hughes and Nick Smith. I must also mention Adrian McLeod, editor of *Approval* magazine, and particularly my consultant colleagues, Dave Imeson, Keith Armstrong and Phil Carter. As always the responsibility for this book remains the author's alone. I hope you find it useful.

Tim Williams
December 2000

Chapter 1

Introduction

1.1 What is EMC?

Electromagnetic interference (EMI) is a serious and increasing form of environmental pollution. Its effects range from minor annoyances due to crackles on broadcast reception, to potentially fatal accidents due to corruption of safety-critical control systems. Various forms of EMI may cause electrical and electronic malfunctions, can prevent the proper use of the radio frequency spectrum, can ignite flammable or other hazardous atmospheres, and may even have a direct effect on human tissue. As electronic systems penetrate more deeply into all aspects of society, so both the potential for interference effects and the potential for serious EMI-induced incidents will increase.

Some reported examples of electromagnetic incompatibility are:

- in Germany, a particular make of car would stall on a stretch of Autobahn opposite a high power broadcast transmitter. Eventually that section of the motorway had to be screened with wire mesh;
- on another type of car, the central door locking and electric sunroof would operate when the car's mobile transmitter was used;
- new electronic push-button telephones installed near the Brookmans Park medium wave transmitter in North London were constantly afflicted with BBC radio programmes;
- in America, police departments complained that coin-operated electronic games were causing harmful interference to their highway communications system;
- interference to aeronautical safety communications at a US airport was traced to an electronic cash register a mile away;
- the instrument panel of a well known airliner was said to carry the warning "ignore all instruments while transmitting HF";
- electronic point-of-sale units used in shoe, clothing and optician shops (where thick carpets and nylon-coated assistants were common) would experience lock up, false data and uncontrolled drawer openings;
- when a piezo-electric cigarette lighter was lit near the cabinet of a car park barrier control box, the radiated pulse caused the barrier to open and drivers were able to park free of charge;
- lowering the pantographs of electric locomotives at British Rail's Liverpool Street station interfered with newly installed signalling control equipment, causing the signals to "fail safe" to red;

- perhaps the most tragic example was the fate of HMS Sheffield in the Falklands war, when the missile warning radar that could have detected the Exocet missile which sank the ship was turned off because it interfered with the ship's satellite communications system.

Mobile cellular telephones are rapidly establishing themselves, through their sheer proliferation, as a serious EMC threat. Passengers boarding civil airliners are now familiar with the announcement that the use of such devices is not permitted on board. They may be less familiar with why this is regarded as necessary. The IFALPA International Quarterly Review has reported 97 EMI-related events due to passenger "carry-on" electronic devices since 1983. To quote the Review:

> ... By 1990, the number of people boarding aeroplanes with electronic devices had grown significantly and the low-voltage operation of modern aircraft digital electronics were potentially more susceptible to EMI.
>
> A look at the data during the last ten years indicates that the most likely time to experience EMI emissions is during cruise flight. This may be misleading, however. During the last three years, 43% of the reported events occurred in cruise flight while an almost equal percentage of events occurred in the climb and approach phases.
>
> Of particular note: during the last three years the number of events relating to computers, compact disc players, and phones has dramatically increased and these devices have been found to more likely cause interference with systems which control the flight of the aircraft.
>
> Recognising an apparent instrument or autopilot malfunction to be EMI related may be difficult or impossible in many situations. In some reported events the aircraft was off course but indications in the cockpit displayed on course. Air traffic controllers had to bring the course deviations to the attention of the crews. It is believed that there are EMI events happening that are not recognised as related to EMI and therefore not reported.

Particular points noted by the Review were that:

- events are on the rise
- all phases of flight are exposed (not just cruise)
- many devices may cause EMI (phones, computers, CD players, video cameras, stereos)
- often there will be more than one device on a flight
- passengers will turn on a device even after being told to turn it off†
- passengers will conceal usage of some devices (phones, computers)
- passengers will turn devices on just after take-off and just prior to landing
- phones are a critical problem
- specific device type and location should be recorded and reported by the crew
- when the emitting EMI device is shut off, the aircraft systems return to normal operation (in the case of positioning errors a course change may be necessary)

† Especially if they regard their need for personal communication as more important than a mere request from the crew. [57] reports that an aircraft carrying a German foreign minister was forced to make an emergency landing "after key cockpit equipment cut out". It was claimed that mobile phone transmissions could be the only explanation and it was said that, "despite repeated requests from the crew, there were still a number of journalists and foreign office personnel using their phones".

- flight attendants should be briefed to recognize possible EMI devices

In 2000, the Civil Aviation Authority carried out tests on two aircraft parked at Gatwick which reinforces the ban on the use of mobile phones while the engine is running [57]. The tests revealed that interference levels varied with relatively small changes in the phone's location, and that the number of passengers on the flight could affect the level, since they absorbed some of the signal.

Another critical area with potentially life-threatening consequences is the EMC of electronic medical devices. A 1995 review article [116] described three incidents in detail and listed more than 100 EMI problems that were reported to the US Food & Drug Administration between 1979 and 1993. It states bluntly that:

> EMI-related performance degradation in electronic medical devices has resulted in deaths, serious injuries, and the administration of inappropriate and possibly life-threatening treatment.

The detailed case studies were as follows:

- apnea monitors: the essential function of an apnea monitor is to sound an alarm when breathing stops; the devices are used in hospitals and frequently prescribed for home use in the case of infants who either have exhibited or are at risk of experiencing prolonged apnea. Because there had been numerous reports of unexplained failure on the part of apnea monitors to alarm even upon death, their susceptibility to radiated RF was evaluated by the CDRH†. Most commercial apnea monitors were found to erroneously detect respiration when exposed to relatively low field strengths, a situation that could result in failure to alarm during apnea. Most monitors were found to be susceptible above 1V/m; one particular model was susceptible to pulsed fields above 0.05V/m.
- anaesthetic gas monitor: the CDRH received several reports of erroneous displays and latch-up of an anaesthetic gas monitor during surgery. None of the reports mentioned EMI as a possible cause. FDA investigators found that the manufacturer had a list of 13 complaint sites, and his own investigations revealed that interference from certain types of electrosurgery units disrupted the communication link between the monitor and a central mass spectrometer, causing the monitor to fail to display the concentration of anaesthetic gas in the operating room during surgery.
- powered wheelchairs: a QA manager at a large wheelchair manufacturer had received reports of powered wheelchairs spontaneously driving off kerbs or piers when police or fire vehicles, harbour patrol boats, or CB or amateur radios were in the vicinity. Though CDRH databases showed reports of unintended motion – in several cases involving serious injury – none of these incidents had been attributed to EMI. When CDRH investigated the EMI susceptibility of the motion controllers on various makes of powered wheelchairs and scooters, they discovered susceptibilities in the range of 5 to 15V/m. At the lower end of the range, the electric brakes would release, which could result in rolling if the chair happened to be stopped on an incline; as the field strength at a susceptible frequency was increased, the wheels would actually begin turning, with the speed being a function of field strength.

These are all examples of the lack of a product's "fitness for purpose": that is, to operate

† CDRH: Center for Devices and Radiological Health, US FDA

correctly and safely in its intended environment, which includes the electromagnetic environment. There are clear safety implications in the reports. Not only the US is affected, as can be deduced from the following items:

> The UK Department of Health has issued guidelines banning the use of cordless, cellular and mobile phones within certain areas in hospitals, because their electromagnetic field can interfere with medical equipment, including life-support machines... The DoH has been forced to issue the guidelines following a number of reported cases where medical equipment has been reset, or stopped working, due to the interference from cellular phones.
>
> *Electronics Weekly 8th February 1995*

> The problem of interference to hearing aids has been known for some time. Digital mobile phones use a form of radio transmission called Time Division Multiple Access (TDMA), which works by switching the radio frequency carrier rapidly on and off. If a hearing aid user is close to a digital mobile telephone, this switching of the radio frequency carrier may be picked up on the circuitry of the hearing aid. Where interference occurs, this results in a buzzing noise which varies from very faint to maximum volume of the aid... [A specialist standards panel] has determined that, although digital mobile telephones are being looked at as the source of likely interference, all radio systems using TDMA or similar transmissions are likely to cause some interference.
>
> *BSI News December 1993*

In a lighter vein, probably the least critical EMC problem this author has encountered is the case of the quacking duck: there is a toy for the under-5's which is a fluffy duck with a speech synthesizer which is programmed to quack various nursery rhyme tunes. It does this when a certain spot (hiding a sensor) on the duck is pressed, and it shouldn't do it otherwise. Whilst it was in its Christmas wrapping in our house, which is not electrically noisy, it was silent. But when it was taken to our daughter's house and left in the kitchen on top of the fridge, next to the microwave oven, it quacked apparently at random and with no-one going near it. Some disconcerting moments arose before it was eventually explained to the family that this was just another case of bad EMC and that they shouldn't start to doubt their sanity!

1.1.1 Compatibility between systems

The threat of EMI is controlled by adopting the practices of electromagnetic *compatibility* (EMC). This is defined [146] as "the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment". The term EMC has two complementary aspects:

- it describes the ability of electrical and electronic systems to operate without interfering with other systems;
- it also describes the ability of such systems to operate as intended within a specified electromagnetic environment.

Thus it is closely related to the environment within which the system operates. Effective EMC requires that the system is designed, manufactured and tested with regard to its predicted operational electromagnetic environment: that is, the totality of electromagnetic phenomena existing at its location. Although the term "electromagnetic" tends to suggest an emphasis on high frequency field-related phenomena, in practice the definition of EMC encompasses all frequencies and coupling paths, from DC through mains supply frequencies to radio frequencies and microwaves.

1.1.1.1 *Subsystems within an installation*

There are two approaches to EMC. In one case the nature of the installation determines the approach. EMC is especially problematic when several electronic or electrical systems are packed in to a very compact installation, such as on board aircraft, ships, satellites or other vehicles. In these cases susceptible systems may be located very close to powerful emitters and special precautions are needed to maintain compatibility. To do this cost-effectively calls for a detailed knowledge of both the installation circumstances and the characteristics of the emitters and their potential victims. Military, aerospace and vehicle EMC specifications have evolved to meet this need and are well established in their particular industry sectors.

Since this book is concerned with product design to meet the EMC Directive, we shall not be considering this "intra-system" aspect to any great extent. The subject has a long history and there are many textbooks dealing with it.

1.1.1.2 *Equipment in isolation*

The second approach assumes that the system will operate in an environment which is electromagnetically benign within certain limits, and that its proximity to other sensitive equipment will also be controlled within limits. So for example, most of the time a personal computer will not be operated in the vicinity of a high power radar transmitter, nor will it be put right next to a mobile radio receiving antenna. This allows a very broad set of limits to be placed on both the permissible emissions from a device and on the levels of disturbance within which the device should reasonably be expected to continue operating. These limits are directly related to the class of environment – domestic, commercial, industrial etc. – for which the device is marketed. The limits and the methods of demonstrating that they have been met form the basis for a set of standards, some aimed at emissions and some at immunity, for the EMC performance of any given product in isolation.

Note that compliance with such standards will not guarantee electromagnetic compatibility under all conditions. Rather, it establishes a probability (hopefully very high) that equipment will not cause interference nor be susceptible to it when operated under *typical* conditions. There will inevitably be some special circumstances under which proper EMC will not be attained – such as operating a computer within the near field of a powerful transmitter – and extra protection measures must be accepted.

1.1.2 The scope of EMC

The principal issues which are addressed by EMC are discussed below. The use of microprocessors in particular has stimulated the upsurge of interest in EMC. These devices are widely responsible for generating radio frequency interference and are themselves susceptible to many interfering phenomena. At the same time, the widespread replacement of metal chassis and cabinets by moulded plastic enclosures has drastically reduced the degree of protection offered to circuits by their housings.

1.1.2.1 *Malfunction of systems*

Solid state and especially processor-based control systems have taken over many functions which were earlier the preserve of electromechanical or analogue equipment such as relay logic or proportional controllers. Rather than being hard-wired to perform a particular task, programmable electronic systems rely on a digital bus-linked architecture in which many signals are multiplexed onto a single hardware bus under software control. Not only is such a structure more susceptible to interference, because

of the low level of energy needed to induce a change of state, but the effects of the interference are impossible to predict; a random pulse may or may not corrupt the operation depending on its timing with respect to the internal clock, the data that is being transferred and the program's execution state. Continuous interference may have no effect as long as it remains below the logic threshold, but when it increases further the processor operation will be completely disrupted. With increasing functional complexity comes the likelihood of system failure in complex and unexpected failure modes.

Clearly the consequences of interference to control systems will depend on the value of the process that is being controlled. In some cases disruption of control may be no more than a nuisance, in others it may be economically damaging or even life threatening. The level of effort that is put into assuring compatibility will depend on the expected consequences of failure.

Phenomena

Electromagnetic phenomena which can be expected to interfere with control systems are:

- supply voltage interruptions, dips, surges and fluctuations;
- transient overvoltages on supply, signal and control lines;
- radio frequency fields, both pulsed (radar) and continuous, coupled directly into the equipment or onto its connected cables;
- electrostatic discharge (ESD) from a charged object or person;
- low frequency magnetic or electric fields.

Note that we are not directly concerned with the phenomenon of component damage due to ESD, which is mainly a problem of electronic production. Once the components are assembled into a unit they are protected from such damage unless the design is particularly lax. But an ESD transient can corrupt the operation of a microprocessor or clocked circuit just as a transient coupled into the supply or signal ports can, without actually damaging any components (although this may also occur), and this is properly an EMC phenomenon.

Software

Malfunctions due to faulty software may often be confused with those due to EMI. Especially with real time systems, transient coincidences of external conditions with critical software execution states can cause operational failure which is difficult or impossible to replicate, and the fault may survive development testing to remain latent for years in fielded equipment. The symptoms – system crashes, incorrect operation or faulty data – can be identical to those induced by EMI. In fact you may only be able to distinguish faulty software from poor EMC by characterizing the environment in which the system is installed.

1.1.2.2 Interference with radio reception

Bona fide users of the radio spectrum have a right to expect their use not to be affected by the operation of equipment which is nothing to do with them. Typically, received signal strengths of wanted signals vary from less than a microvolt to more than a millivolt, at the receiver input. If an interfering signal is present on the same channel as the wanted signal then the wanted signal will be obliterated if the interference is of a similar or greater amplitude. The acceptable level of co-channel interference (the

"protection factor") is determined by the wanted programme content and by the nature of the interference. Continuous interference on a high fidelity broadcast signal would be unacceptable at very low levels, whereas a communications channel carrying compressed voice signals can tolerate relatively high levels of impulsive or transient interference. Digital communications are designed to be even more immune, but this just means that when the interference reaches a higher level, failure of the link is sudden and catastrophic rather than graceful.

Field strength level

Radiated interference, whether intentional or not, decreases in strength with distance from the source. For radiated fields in free space, the decrease is inversely proportional to the distance provided that the measurement is made in the far field (see section 5.1.4.2 for a discussion of near and far fields). As ground irregularity and clutter increase, the fields will be further reduced because of shadowing, absorption, scattering, divergence and defocussing of the diffracted waves. Annex D of EN 55 011 [136] suggests that for distances greater than 30m over the frequency range 30 to 300MHz, the median field strength varies as $1/d^n$ where n varies from 1.3 for open country to 2.8 for heavily built-up urban areas. An average value of $n = 2.2$ can be taken for approximate estimations; thus increasing the separation by ten times would give a drop in interfering signal strength of 44dB.

Limits for unintentional emissions are based on the acceptable interfering field strength that is present at the receiver – that is, the minimum wanted signal strength for a particular service modified by the protection ratio – when a nominal distance separates it from the emitter. This will not protect the reception of very weak wanted signals nor will it protect against the close proximity of an interfering source, but it will cover the majority of interference cases and this approach is taken in all those standards for emission limits that have been published for commercial equipment by CISPR (see Chapter 2). CISPR publication 23 [153] gives an account of how such limits are derived, including the statistical basis for the probability of interference occurring.

Below 30MHz the dominant method of coupling out of the interfering equipment is via its connected cables, and therefore the radiated field limits are translated into equivalent voltage or current levels that, when present on the cables, correspond to a similar level of threat to HF and MF reception.

Malfunction versus spectrum protection

It should be clear from the foregoing discussion that RF emission limits are not determined by the need to guard against malfunction of equipment which is not itself a radio receiver. As discussed in the last section, malfunction requires fairly high energy levels – RF field strengths in the region of 1–10 volts per metre for example. Protection of the spectrum for radio use is needed at much lower levels, of the order of 10–100 microvolts per metre – ten to a hundred thousand times lower. RF incompatibility between two pieces of equipment neither of which intentionally uses the radio spectrum is very rare. Normally, equipment immunity is required from the local fields of intentional radio transmitters, and unintentional emissions must be limited to protect the operation of intentional radio receivers. The two principal EMC aspects of emissions and immunity therefore address two different issues.

Free radiation frequencies

Certain types of equipment, collectively known as industrial, scientific and medical (ISM) equipment, generate high levels of RF energy but use it for purposes other than

communication. Medical diathermy and RF heating apparatus are examples. To place blanket emissions limits on this equipment would be unrealistic. In fact, the International Telecommunications Union (ITU) has designated a number of frequencies specifically for this purpose, and equipment using only these frequencies (colloquially known as the "free radiation" frequencies) is not subject to emission restrictions. Table 1.1 lists these frequencies.

Centre frequency, MHz	Frequency range, MHz	
6.780	6.765 – 6.795	*
13.560	13.553 – 13.567	
27.120	26.957 – 27.283	
40.680	40.66 – 40.70	
433.920	433.05 – 434.79	*
2,450	2,400 – 2,500	
5,800	5,725 – 5,875	
24,125	24,000 – 24,250	
61,250	61,000 – 61,500	*
122,500	122,000 – 123,000	*
245,000	244,000 – 246,000	*

*: maximum radiation limit under consideration, use subject to special authorization

Frequency, MHz	Maximum radiation limit	Notes
0.009 – 0.010	unlimited	Germany
3.370 – 3.410	unlimited	Netherlands
13.533 – 13.553	110dBμV/m at 100m	UK
13.567 – 13.587	110dBμV/m at 100m	UK
83.996 – 84.004	130dBμV/m at 30m	UK
167.992 – 168.008	130dBμV/m at 30m	UK
886.000 – 906.000	120dBμV/m at 30m	UK

Frequencies designated on a national basis in CENELEC countries

Table 1.1 ITU designated industrial, scientific and medical free radiation frequencies
Source: EN55011:1991

Co-channel interference

A further problem with radio communications, often regarded as an EMC issue although it will not be treated in this book, is the problem of co-channel interference from unwanted transmissions. This is caused when two radio systems are authorized to use the same frequency on the basis that there is sufficient distance between the systems, but abnormal propagation conditions increase the signal strengths to the point at which interference is noticeable. This is essentially an issue of spectrum utilization.

A transmitted signal may also overload the input stages of a nearby receiver which is tuned to a different frequency and cause desensitization or distortion of the wanted signal. Transmitter outputs themselves will have spurious frequency components present as well as the authorized frequency, and transmitter type approval has to set limits on these spurious levels.

1.1.2.3 *Disturbances on the mains supply*

Mains electricity suffers a variety of disturbing effects during its distribution. These may be caused by sources in the supply network or by other users, or by other loads within the same installation. A pure, uninterrupted supply would not be cost effective; the balance between the cost of the supply and its quality is determined by national regulatory requirements, tempered by the experience of the supply utilities. Typical disturbances are:

- *voltage variations*: the distribution network has a finite source impedance and varying loads will affect the terminal voltage. Not including voltage drops within the customer's premises, an allowance of ±10% on the nominal voltage will cover normal variations in the UK. The effect of the shift in nominal voltage from 240V to 230V, as required by CENELEC Harmonization Document HD 472 S1 : 1988 and implemented in the UK by BS 7697 : 1993 [161], is that from 1st January 1995 the UK nominal voltage is 230V with a tolerance of +10%, –6%. After 1st January 2003 the nominal voltage will be 230V with a tolerance of ±10% in line with all other Member States.
- *voltage fluctuations*: short-term (sub-second) fluctuations with quite small amplitudes are annoyingly perceptible on electric lighting, though they are comfortably ignored by electronic power supply circuits. Generation of flicker by high power load switching is subject to regulatory control.
- *voltage interruptions*: faults on power distribution systems cause almost 100% voltage drops but are cleared quickly and automatically by protection devices, and throughout the rest of the system the voltage immediately recovers. Most consumers therefore see a short voltage dip. The frequency of occurrence of such dips depends on location and seasonal factors.
- *waveform distortion*: at source, the AC mains is generated as a pure sine wave but the reactive impedance of the distribution network together with the harmonic currents drawn by non-linear loads causes voltage distortion. Power converters and electronic power supplies are important contributors to non-linear loading. Harmonic distortion may actually be worse at points remote from the non-linear load because of resonances in the network components. Not only must non-linear harmonic currents be limited but equipment should be capable of operating with up to 10% total harmonic distortion in the supply waveform.
- *transients and surges*: switching operations generate transients of a few hundred volts as a result of current interruption in an inductive circuit. These transients normally occur in bursts and have risetimes of no more than a few nanoseconds, although the finite bandwidth of the distribution network will quickly attenuate all but local sources. Rarer high amplitude spikes in excess of 2kV may be observed due to fault conditions. Even higher voltage surges due to lightning strikes occur, most frequently on exposed overhead line distribution systems in rural areas.

All these sources of disturbance can cause malfunction in systems and equipment that do not have adequate immunity.

Mains signalling

A further source of incompatibility arises from the use of the mains distribution

network as a telecommunications medium, or mains signalling (MS). MS superimposes signals on the mains in the frequency band from 3kHz to 150kHz and is used both by the supply industry itself and by consumers. Unfortunately this is also the frequency band in which electronic power converters – not just switch-mode power supplies, but variable speed motor drives, induction heaters, fluorescent lamp inverters and similar products – operate to their best efficiency. There are at present almost no pan-European standards which regulate conducted emissions on the mains below 150kHz, although EN 50065-1 [138] sets the frequency allocations and output and interference limits for MS equipment itself. Overall, compatibility problems between MS systems and such power conversion equipment can be expected to increase.

1.1.2.4 Other EMC issues

The issues discussed above are those which directly affect product design to meet commercial EMC requirements, but there are some other aspects which should be mentioned briefly.

EEDs and flammable atmospheres

The first is the hazard of ignition of flammable atmospheres in petrochemical plant, or the detonation of electro-explosive devices in places such as quarries, due to incident RF energy. A strong electromagnetic field will induce currents in large metal structures which behave as receiving antennas. A spark will occur if two such structures are in intermittent contact or are separated. If flammable vapour is present at the location of the spark, and if the spark has sufficient energy, the vapour will be ignited. Different vapours have different minimum ignition energies, hydrogen/air being the most sensitive. The energy present in the spark depends on the field strength, and hence on the distance from the transmitter, and on the antenna efficiency of the metal structure. BS 6656 [158] discusses the nature of the hazard and presents guidelines for its mitigation.

Similarly, electro-explosive devices (EEDs) are typically connected to their source of power for detonation by a long wire, which can behave as an antenna. Currents induced in it by a nearby transmitter could cause the charges to explode prematurely if the field was strong enough. As with ignition of flammable atmospheres, the risk of premature detonation depends on the separation distance from the transmitter and the efficiency of the receiving wire. EEDs can if necessary be filtered to reduce their susceptibility to RF energy. BS 6657 [159] discusses the hazard to EEDs.

Data security

The second aspect of EMC is the security of confidential data. Low level RF emissions from data-processing equipment may be modulated with the information that the equipment is carrying – for instance, the video signal that is fed to the screen of a VDU. These signals could be detected by third parties with sensitive equipment located outside a secure area and demodulated for their own purposes, thus compromising the security of the overall system. This threat is already well recognized by government agencies and specifications for emission control, under the Tempest scheme, have been established for many years. Commercial institutions, particularly in the finance sector, are now beginning to become aware of the problem.

Electromagnetic weapons

The idea that an intense broadband radiated pulse could be generated intentionally, and used to upset the operation of all potentially susceptible electronics within a certain

range, is gaining credence. Because of the almost universal social reliance on electronic systems, an attack that simultaneously crashed many computer networks could indeed have substantial consequences. It is known that US and other military researchers are working on such technology, but we can also imagine less sophisticated devices being within reach of many other organizations or individuals.

The more sensationalist press, of course, has a field day with this idea – phrases such as "frying computer chips" are used with abandon. Realistically, the amount of energy needed to generate a wide-area pulse would be so enormous that only disruption, not damage, is at all likely. This is precisely the effect of a high altitude nuclear explosion, which generates a sub-nanosecond nuclear electromagnetic pulse (NEMP) that is disruptive over an area of hundreds of square kilometres. The idea that attracts military researchers now is to do this more discreetly. The limitation of any such weapon is its uncertainty. Unless you know exactly what kind of electronics you are attacking, and how well protected it is, it is hard to predict the damage that the weapon will cause. Equipment that is immune to a local electrostatic discharge (ESD, as described in these pages), is likely to have good immunity to electromagnetic warfare.

1.1.3 The compatibility gap

The increasing susceptibility of electronic equipment to electromagnetic influences is being paralleled by an increasing pollution of the electromagnetic environment. Susceptibility is a function partly of the adoption of VLSI technology in the form of microprocessors, both to achieve new tasks and for tasks that were previously tackled by electromechanical or analogue means, and the accompanying reduction in the energy required of potentially disturbing factors. It is also a function of the increased penetration of radio communications, and the greater opportunities for interference to radio reception that result from the co-location of unintentional emitters and radio receivers.

At the same time more radio communications mean more transmitters and an increase in the average RF field strengths to which equipment is exposed. A study has been reported [31] which quantified this exposure for a single site at Baden, Switzerland, for one year; this found the background field strength in the shortwave band regularly approaching, and occasionally exceeding, levels of 1V/m. Also, the proliferation of digital electronics means an increase in low-level emissions which affect radio reception, a phenomenon which has been aptly described as a form of electromagnetic "smog".

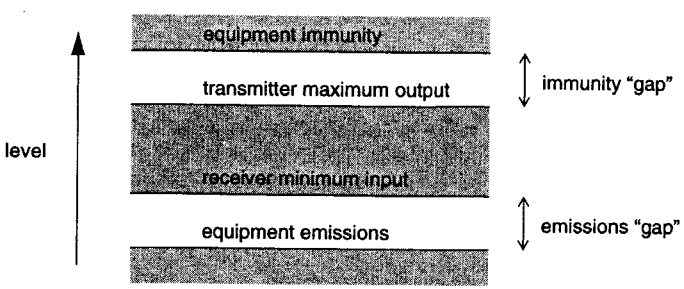

Figure 1.1 The EMC gap

These concepts can be graphically presented in the form of a narrowing electromagnetic compatibility gap, as in Figure 1.1. This "gap" is of course conceptual rather than absolute, and the phenomena defined as emissions and those defined as immunity do not mutually interact except in rare cases. But the maintenance of some artificially-defined gap between equipment immunity and radio transmissions on the one hand, and equipment emissions and radio reception on the other, is the purpose of the application of EMC standards, and is one result of the enforcement of the EMC Directive.

1.2 The EMC Directive

The relaxed EMC regime that had hitherto existed throughout most of Europe has now been totally overturned with the adoption on 1st January 1992 by the European Commission of the EMC Directive, 89/336/EEC [162]. This is widely regarded to be "the most comprehensive, complex and possibly contentious Directive ever to emanate from Brussels" [34]. The remainder of this chapter examines the provisions of the Directive and how manufacturers will need to go about complying with it.

1.2.1 The new approach directives

Of the various aims of the creation of the Single European Market, the free movement of goods between European states† is fundamental. All member states impose standards and obligations on the manufacture of goods in the interests of quality, safety, consumer protection and so forth. Because of detailed differences in procedures and requirements, these act as technical barriers to trade, fragmenting the European market and increasing costs because manufacturers have to modify their products for different national markets.

For many years the Commission tried to remove these barriers by proposing Directives which gave the detailed requirements that products had to satisfy before they could be freely marketed throughout the Community, but this proved difficult because of the detailed nature of each Directive and the need for unanimity before it could be adopted. In 1985 the Council of Ministers adopted a resolution setting out a "New Approach to Technical Harmonisation and Standards".

Under the "new approach", directives are limited to setting out the essential requirements which must be satisfied before products may be marketed anywhere within the EU. The technical detail is provided by standards drawn up by the European standards bodies CEN, CENELEC and ETSI. Compliance with these standards will demonstrate compliance with the essential requirements of each Directive. All products covered by each Directive must meet its essential requirements, but all products which do comply, and are labelled as such, may be circulated freely within the Community; no member state can refuse them entry on technical grounds. Decisions on new approach Directives are taken by qualified majority voting, eliminating the need for unanimity and speeding up the process of adoption.

A document was published in early 2000 [165] by the European Commission setting out the way in which new approach Directives should be implemented in a relatively harmonized fashion.

Contents

A new approach Directive contains the following elements [164]:

† Appendix D lists the EU and EEA Member States.

- the *scope* of the Directive
- a statement of the *essential requirements*
- the *methods of satisfying* the essential requirements
- how *evidence of conformity* will be provided
- what *transitional arrangements* may be allowed
- a statement confirming entitlement to *free circulation*
- a *safeguard procedure*, to allow Member States to require a product to be withdrawn from the market if it does not satisfy the essential requirements

It is the responsibility of the European Commission to put forward to the Council of Ministers proposals for new Directives. Directorate-General III of the Commission has the overall responsibility for the EMC Directive. The actual decision on whether or not to adopt a proposed Directive is taken by the Council of Ministers, by a qualified majority of 54 out of 76 votes (the UK, France, Germany and Italy each have ten votes; Spain has eight votes; Belgium, Greece, The Netherlands and Portugal each have five votes; Denmark and Ireland have three votes and Luxembourg has two votes). Texts of Directives proposed or adopted are published in the *Official Journal of the European Communities*. Consultation on draft Directives is typically carried out through European representative bodies and in working parties of governmental experts.

1.2.1.1 Other Directives

Apart from the EMC Directive, other new approach Directives adopted at the time of writing which may affect some sectors of the electrical and electronic engineering industry are:

- Toy safety (88/378/EEC)
- Non-automatic weighing machines (90/384/EEC)
- Medical devices (93/42/EEC)
- Active implantable electromedical devices (90/385/EEC)
- Machinery safety (89/392/EEC)
- Gas appliances (90/396/EEC)
- Lifts (95/16/EC)
- Refrigeration appliances (96/57/EC)
- Telecommunications terminal equipment (98/13/EC)
- In vitro diagnostic medical devices (98/79/EC)
- Radio and telecommunications terminal equipment (99/5/EC)

In addition to this list, there are two other Directives which are relevant although they are not strictly "new approach" Directives. These are the "Low Voltage" Directive (73/23/EEC)(LVD) and the Automotive EMC Directive (95/54/EC). The LVD is concerned with safety, not EMC, but as a result of the CE Marking Directive (see section 1.2.4) the CE Mark now attests to conformity with this Directive as well as any other applicable new approach Directives.

The Automotive EMC Directive requires type approval for EMC of all vehicles and electronic vehicle sub-assemblies. It is an amendment to the early Directive 72/245/EEC which controlled ignition interference emissions. Unlike the EMC Directive, it includes within its annexes all the applicable technical requirements and

test methods, many of which are quite different to the standards discussed in Chapter 2 of this book. Automotive electronic systems within its scope should be automatically excluded from the scope of the EMC Directive. This is clear enough for systems which 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 is not clear. Sub-assemblies appear to be exempted from the Automotive Directive until 1st October 2002, but one interpretation of this exemption is that the EMC Directive then *does* apply to them. It seems possible that different member states will make different interpretations.

1.2.1.2 *The R & TTE Directive*

The Radio & Telecommunications Terminal Equipment Directive (99/5/EC) went into effect on April 8th 2000, with a transition period to April 7th 2001; after this date all equipment within the scope must comply with its provisions. It is a development of the earlier telecoms equipment Directive, 98/13/EC. Included in its scope is all telecoms terminal equipment, and all radio equipment, and it supersedes the EMC Directive for this equipment – although the EMC requirements are maintained, so that on that score at least there is little change. Explicit exceptions are:

- apparatus exclusively used for public security, defence, state security, and state activities in the area of criminal law;
- marine equipment, civil aviation equipment and air traffic management equipment (all covered by their own regulations);
- amateur radio equipment, broadcast radio receivers, and cabling and wiring.

It represents a fairly fundamental shift in the way that radio and telecom equipment, previously subject to national and pan-European type approval regimes, are regulated. The goals which the R&TTE Directive addresses were, basically, simplified and relaxed procedures, minimum essential requirements, consistency with the EC's approaches and a responsiveness to market needs.

Requirements

The R & TTE requirements incorporate the requirements of the LVD and EMCD and allow a continuation of the conformity assessment regime already in place for those Directives. An important extension is the removal of the lower voltage limit (50V AC or 75V DC) for application of the LVD. This means that safety requirements apply even to handheld, battery powered apparatus, meaning, for example, mandatory application of safe radiation limits, so that mobile handheld transmitters should be subject to such assessment.

Type approval of radio transmitters has been abolished, with the additional requirement for effective use of the spectrum so as to avoid harmful interference. This does not preclude national authorities from applying restrictions on the grounds of local spectrum management through the licensing process, but they must not attempt to enforce a type-approval regime in this context. There is a requirement to inform the relevant national authorities whenever it is intended to place on the market equipment that uses non-harmonized spectrum allocations. The authorities then have a four week period within which to raise objections.

The Directive also allows the Commission to impose extra requirements for certain classes of equipment, but to date this has not been applied. A particular requirement for terminal equipment is the prevention of harm to the network or its functioning which

causes an unacceptable degradation of service to persons other than the use of the apparatus. This aspect was traditionally handled by the type approval process. There are concerns that leaving the network requirement specifications hanging, as it were, in mid-air will damage the pan-European harmonization of the wired sector of the telecoms industry.

1.2.2 Background to the legislation

In the UK, previous legislation on EMC has been limited in scope to radio communications. Section 10 of the Wireless Telegraphy Act 1949 enables regulations to be made for the purpose of controlling both radio and non-radio equipment which might interfere with radio communications. These regulations have taken the form of various Statutory Instruments (SIs) which cover interference emissions from spark ignition systems, electromedical apparatus, RF heating, household appliances, fluorescent lights and CB radio. The SIs invoke British Standards which are closely aligned with international and European standards.

The power exists to make regulations regarding the immunity to interference of radio equipment but this has so far not been used.

At the European level various Directives have been adopted over the years, again to control emissions from specific types of equipment. Directive 72/245 EEC, adopted in June 1972, regulates interference produced by spark ignition engines in motor vehicles. Directives 76/889 EEC and 76/890 EEC, amended by various other subsequent Directives, apply to interference from household appliances and portable tools, and fluorescent lamps and luminaires. These latter two were superseded and repealed by the EMC Directive. Each member state is required to implement the provisions of these Directives in its national legislation, as described above for the UK.

This previous legislation is not comparable in scope to the EMC Directive, which covers far more than just interference to radio equipment, and extends to include immunity as well as emissions.

1.2.3 Scope, requirements and exceptions

The EMC Directive, 89/336/EEC, applies to apparatus which is liable to cause electromagnetic disturbance or which is itself liable to be affected by such disturbance. "Apparatus" is defined as all electrical and electronic appliances, equipment and installations. Essentially, anything which is powered by electricity is covered, regardless of whether the power source is the public supply mains, a battery source or a specialized supply.

An electromagnetic disturbance is any electromagnetic phenomenon which may degrade performance, without regard to frequency or method of coupling. Thus radiated emissions as well as those conducted along cables; and immunity from EM fields, mains disturbances, conducted transients and RF, electrostatic discharge and lightning surges are all covered. *No* specific phenomena are *excluded* from the Directive's scope.

In 1997 a 60-page document was produced by the EC entitled "Guidelines on the application of Council Directive 89/336/EEC" [166]. By this time the Directive had been operational for over a year and some experience had been gained in the difficulties it was causing. The Guidelines are generally helpful, although sometimes written in rather tortuous prose, and they are referred to several times in this chapter.

1.2.3.1 Essential requirements

The essential requirements of the Directive (Article 4) are that the apparatus shall be so constructed that:

- the electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended;
- the apparatus has an adequate level of intrinsic immunity to electromagnetic disturbance to enable it to operate as intended.

The intention is to protect the operation not only of radio and telecommunications equipment but any equipment which might be susceptible to EM disturbances, such as information technology or control equipment. At the same time, all equipment must be able to function correctly in whatever environment it might reasonably be expected to occupy. Notwithstanding these requirements, any member state has the right to apply special measures with regard to the taking into service of apparatus, to overcome existing or predicted EMC problems at a specific site or to protect the public telecommunications and safety services. Compliance with the essential requirements will be demonstrated via one of two main paths, that is self-certification to harmonized standards or by a technical construction file. These are discussed in section 1.3.

1.2.3.2 Sale and use of products

The Directive applies to all apparatus that is placed on the market or taken into service. The definitions of these two conditions do not appear within the text of the Directive but are the subject of several paragraphs in the Guidelines [166].

Placed on the market

The "market" means the market in any or all of the European Economic Area (EEA); products which are found to comply within one state are automatically deemed to comply within all others. "Placing on the market" means the *first* making available of the product within the EEA, so that the Directive covers only new products manufactured within the EEA, but both new and used products imported from a third country. Products sold second hand within the EEA are outside its scope. Where a product passes through a chain of distribution before reaching the final user, it is the passing of the product from the manufacturer into the distribution chain which constitutes placing on the market. If the product is manufactured in or imported into the EEA for subsequent export to a third country, it has not been placed on the market.

The Directive applies to each individual item of a product type regardless of when it was designed, and whether it is a one-off or high volume product. Thus items from a product line that was launched at any time before 1996 must comply with the provisions of the Directive after 1st January 1996. Put another way, there is no "grandfather clause" which exempts designs that were current before the Directive took effect. However, products already *in use* before 1st January 1996 do not have to comply retrospectively.

Taken into service

"Taking into service" means the first *use* of a product in the EEA by its final user. If the product is used without being placed on the market, if for example the manufacturer is also the end user, then the protection requirements of the Directive still apply. This means that sanctions are still available in each member state to prevent the product from being used if it does not comply with the essential requirements or if it causes an actual

or potential interference problem. On the other hand, it should not need to go through the conformity assessment procedures to demonstrate compliance (article 10, which describes these procedures, makes no mention of taking into service). Thus an item of special test gear built up by a lab technician for use within the company's design department must still be designed and installed so as not to cause or suffer from interference, but should not need to follow the procedure for applying the CE mark.

If the manufacturer resides outside the EEA, then the responsibility for maintaining the certificate of conformity with the Directive rests with the person placing the product on the market for the first time within the EEA, i.e. the manufacturer's authorized representative or the importer. Any person who produces a new finished product from already existing finished products, such as a system builder, is considered to be the manufacturer of the new finished product.

1.2.3.3 Exceptions

There are a few specific exceptions from the scope of the Directive, but these are not such as to offer cause for much relief. Self-built amateur radio apparatus (but not CB equipment) is specifically excluded. In the UK regulations, apparatus for use in a sealed electromagnetic environment is also excluded.

Military equipment is excluded as a result of an exclusion clause in the Treaty of Rome, but equipment which has a dual military/civil use will be covered when it is placed on the civilian market. Education and training equipment, according to the UK regulations, need not meet the essential requirements – since its whole purpose is deliberately to emit or be susceptible to interference – provided that its user ensures that it does not cause interference outside its immediate environment, and provided that it is accompanied by a warning that its use outside the classroom or lab invalidates its EMC conformity. Immunity requirements are waived.

The only other exclusions are for those types of apparatus which are subject to EMC requirements in other Directives or regulations. At the time of writing these are:

- medical devices, active implantable medical devices, and in vitro diagnostic medical devices (all phenomena)
- motor vehicles
- aircraft equipment, covered by regulation 3922/91
- marine equipment
- non-automatic weighing machines (immunity)
- electricity meters (immunity)
- radio and telecommunications terminal equipment

1.2.3.4 Components

The question of when does a "component" (which is not within the scope of the Directive) become "apparatus" (which is) has been problematical. The Commission's guidelines introduce the concept of the "direct function", that is, any function which fulfils the intended use specified by the manufacturer in the instructions to the end user. It is available without further adjustment or connections other than those which can be performed by a technically naive user. Any component without a direct function is clearly not apparatus and is therefore outside the scope of the Directive. Thus individual small parts such as ICs and resistors are definitely outside the Directive.

If a component can be said to have a direct function, the question then becomes, is

it intended to be placed on the market for distribution and final use? If so, then it is apparatus and must follow the full procedure required by the Directive. If not, then such components must be intended for incorporation into apparatus by other manufacturers, who take on the responsibility for compliance of their final product.

A component may be more complex provided that it does not have a direct function and its only purpose is to be incorporated inside an apparatus, but the manufacturer of such a component must indicate to the equipment manufacturer how to use and incorporate it. The distinction is important for manufacturers of board-level products and other sub-assemblies which may appear to have a direct function and are marketed separately, yet cannot be used separately from the apparatus in which they will be installed.

However, in the particular case of plug-in cards for personal computers, which are supplied by a third party for the user to insert, the situation has been clarified: although such boards clearly need a computer to have any purpose, they are placed on the market for the final end user and therefore need to carry a CE mark. They will need to be tested against harmonized standards in a "representative" host computer, and certified accordingly.

The twin requirements of "direct function" and "intended for the final consumer" are generally helpful in defining what is and is not a component. For products which may be both supplied to OEMs for incorporation into other apparatus, and supplied to the end user – an example might be some types of industrial sensor – then the item becomes apparatus and needs separate certification. If the manufacturer can insist that the item is only ever sold to OEMs then it is a component. This distinction has been made by many suppliers to shrug off the responsibility of ensuring that their products are properly specified for EMC ("Oh no, the Directive doesn't apply to us, we make components"). But in the medium term these laggards will find that all their customers are demanding EMC performance specs anyway, to help them meet their own responsibilities.

At the other extreme of complexity, the Directive specifically does *not* apply to apparatus which is not liable to cause or be susceptible to interference – so-called "benign" apparatus. No guidance is given as to how to assess such lack of liability, but for instance a battery operated torch or a domestic electric fire would clearly fall under this heading – although the same could not be said for example of a battery operated device containing a motor.

1.2.4 The CE mark and the declaration of conformity

The manufacturer or his authorized representative is required to attest that the protection requirements of the Directive have been met. This requires two things:

- he issues a declaration of conformity which must be kept available to the enforcement authority for ten years following the placing of the apparatus on the market;
- he affixes the CE mark to the apparatus, or if this is not possible, to its packaging, instructions or guarantee certificate, in that order of priority.

A further Directive concerning the affixing and use of the CE mark was adopted in 1993 [168]. This Directive harmonized the provisions regarding CE marking among the various previous new approach Directives. The mark consists of the letters CE as shown in Figure 1.2. The mark should be at least 5mm in height and be affixed "visibly, legibly and indelibly" but its method of fixture is not otherwise specified. Affixing this mark

indicates conformity not only with the EMC Directive but also with the requirements of any other Directives relevant to the product which provide for CE marking – for instance, an electrical toy with the CE mark indicates compliance both with the Toy Safety Directive and the EMC Directive. Many electrical products fall under the scope of the Low Voltage Directive and the CE mark also indicates compliance with this. But during the transition period of any such applicable Directive, the CE mark need not indicate compliance; those Directives which *are* complied with should be listed in the appropriate documentation, such as the declaration of conformity.

Figure 1.2 The CE mark

The EC declaration of conformity is required whether the manufacturer self-certifies to harmonized standards or follows the technical file route (section 1.3). It must include the following components:

- a description of the apparatus to which it refers;
- a reference to the specifications under which conformity is declared, and where appropriate to the national measures implemented to ensure conformity;
- an identification of the signatory empowered to bind the manufacturer or his authorized representative.

1.2.4.1 Description

The description of the apparatus should be straightforward; assuming the equipment has a type number, then reference to this type number (provided that supporting documentation is available) should be sufficient. Difficulties arise when the type is subjected to revision or modification. At what stage do modifications or updates result in a new piece of equipment that would require re-certification? If the declaration of conformity refers to the Widget 2000 with software version 1.0 launched in 1993, does it continue to refer to the Widget 2000S of 1996 with version 3.2? The sensible approach would be to determine whether the modifications had affected the EMC performance and if so, re-issue the declaration for the new product; but this will require that you re-test the modifications, with the attendant cost penalties, or you exercise some engineering judgement as to whether a minor change will affect performance. No general guidance can be given on this point, but it should be clear that the breadth of the EMC requirements means that very few modifications will have absolutely no effect on a product's EMC performance.

1.2.4.2 Signatory

The empowered signatory will not necessarily be competent to judge the technicalities of what is being declared. Normally this will be one of the directors of the manufacturing or importing company. In small companies the technical director will probably be close enough to the product in question to understand the detail of its EMC

performance, but in medium or large-scale enterprises the directors will increasingly have to rely on the technical advice of their product development and manufacturing engineers and/or the EMC test and management personnel. Such companies will have to define clearly the levels of responsibility that exist for each person involved in making the declaration.

1.2.4.3 *Specifications*

The reference to the specifications under which conformity is declared does not necessarily mean that you have to *test* to these specifications. Three possibilities are apparent. Firstly, you may deem that the product intrinsically meets the requirements of the Directive and does not need testing. An example might be a simple linear unregulated stand-alone power supply which is below the power level at which harmonic currents are controlled. Provided that you can convince the signatory that this is a competent engineering judgement then there is no reason not to make a valid declaration on this basis. Most electronic products will not be able to follow this option.

Secondly, you may be able to make a declaration based on pre-existing test results. If for example you have already been conforming to existing non-harmonized standards, then you may be confident enough to state that the product will meet the appropriate harmonized standards without further testing, or with only partial testing.

The final option is to test fully to harmonized standards or to choose the technical file route. For a sophisticated product either of these will be lengthy and expensive and may involve some complex judgements as to what tests to apply, especially if appropriate standards are not available. For new products though, testing will be essential. A fourth option, of course, is not to test at all; just make the declaration, stick on the CE mark and hope that nobody ever notices. A reputable company, of course, won't take this route, but the possibility of competitors doing so may be a factor in assessing your market position.

1.2.5 Manufacturing quality assessment

The Directive covers every individual, physically existing finished product, but it would be impractical to test every item in series production fully for all the EMC characteristics that it must exhibit. The Directive itself is silent on quality assurance procedures, although the Commission's Guidelines reminds manufacturers of their responsibility to ensure ongoing conformity. The conformity assessment procedures for all the technical harmonization Directives are contained in Council Decision 90/683/EEC [167]. This document contains a range of modules which may be applied in the case of each specific Directive. However, the EMC Directive does not specifically refer to this Decision, and therefore conformity assessment requirements have been left somewhat open.

1.2.5.1 *Production control*

The EC's guidance document [166] suggests that "the manufacturer takes all necessary measures in order to ascertain that the manufacturing process ensures compliance of the manufacturer's products with the applicable protection requirements of the Directive as described in the declaration of conformity". No specific means of determining what these measures might be are mentioned in either the Directive or the Council Decision.

CISPR sampling schemes

For many years before the adoption of the EMC Directive, the standards committee

CISPR (see section 2.1.1.2) had recognized the need for some form of production quality testing, and had incorporated sampling schemes into the emission standards which form the basis of EN 55011, EN 55014 and EN 55022. The purpose of these schemes is to ensure that at least 80% of series production complies with the limits with an 80% confidence level, the so-called 80/80 rule. Practically, to comply fully with the 80/80 rule the manufacturer has to aim at about 95% of the products being in compliance with the specified limit.

The first scheme requires measurements of the actual emission levels from between 3 and 12 identical items, from which the mean and standard deviation are derived. The limit levels are then expressed in the form:

$$L \geq \bar{X} + k \cdot S_n \qquad (1.1)$$

where $\bar{X}$ is the arithmetic mean and S_n the standard deviation of the measured emission levels, and k is a constant derived from the non-central t-distribution between 2.04 and 1.2 depending on sample size

If the emission levels are similar between items (a low value of S_n) then a small margin below the limit is needed; if they are highly variable, then a large margin is needed. This sampling method can only be applied to emissions measurements and cannot be used for immunity.

A second scheme which is applicable to both emissions and immunity is based on recording test failures over a sample of units. Compliance is judged from the condition that the number of units with an immunity level below the specified limit, or that exceed the emissions limits, may not exceed c in a sample of size n, as per the table below: this test is based on the binomial distribution and produces the same result as the first, in accordance with the 80/80 rule.

n	7	14	20	26	32
c	0	1	2	3	4

As well as the above sampling schemes, published EN standards also allow a single test to be made on one item only, but then advise that subsequent tests are necessary from time to time on samples taken at random from production. The banning of sales is to occur only after tests have been carried out in accordance with one or other sampling scheme.

1.2.6 Systems and installations

A particularly contentious area is how the Directive applies to two or more separate pieces of apparatus sold together or installed and operating together. It is clear that the Directive applies in principle to systems and installations. The Commission's Guidelines [166] define a system as several items of apparatus combined by the same person (the system manufacturer) to fulfil a specific objective and intended to be placed on the market for distribution as a single functional unit for an end user. An installation is several combined items of apparatus or systems assembled at a given place to operate together in a given environment to fulfil a specific objective, but not intended to be placed on the market as a single functional or commercial unit. A fixed installation cannot "enjoy free movement" within the EEA, in contrast to a system (or a moveable installation) which can. Therefore a typical system would be a personal computer

workstation comprising the PC, monitor, keyboard, printer and any other peripherals. If the units were to be sold separately they would have to be tested and certified separately; if they were to be sold as a single package then they would have to be tested and certified as a package.

Any other combination of items of apparatus, not initially intended to be placed on the market together, is considered to be not a system but an installation. Examples of this would appear to be computer suites, telephone exchanges, electricity substations or television studios. Each item of apparatus in the installation is subject to the provisions of the Directive individually, under the specified installation conditions. [24] discusses the application of the EMC Directive to systems and installations in more detail.

As far as it goes, this interpretation is useful, in that it allows testing and certification of installations to proceed on the basis that each component of the installation will meet the requirements on its own. The difficulty of testing large installations *in situ* against standards that were never designed for them is largely avoided. Also, if an installation uses large numbers of similar or identical components then only one of these needs to be actually tested.

1.2.6.1 *Large systems*

The definition unfortunately does not help system builders who will be "placing on the market" – i.e. supplying to their customer on contract – a single installation, made up of separate items of apparatus but actually sold as one functional unit. Many industrial, commercial and public utility contracts fall into this category. According to the published interpretation, the overall installation could be regarded as a system and therefore should comply as a package. As it stands at present, there are no standards which specifically cover large systems, i.e. ones for which testing on a test site is impractical, although some emissions standards do allow measurements *in situ*. These measurements are themselves questionable because of the difficulty of distinguishing external interference at the measurement position from that due to the installation, and because the variability of the physical installation conditions introduces reflections and standing waves which distort the measurement. There are no provisions for large systems in the immunity standards. Therefore the only compliance route available to system builders is the technical construction file (TCF, see section 1.3.2), but there is little guidance as to how to interpret the Directive's essential requirements in these cases.

The principal dilemma of applying the Directive to complete installations is that to make legally relevant tests is difficult, but the nature of EMC phenomena is such that to test only the constituent parts without reference to their interconnection is meaningless. Two possibilities have been explored in TCFs to date. The first is to ensure that the system is built out of individual items which are themselves compliant, and that the method of installation follows suppliers' instructions such that this compliance is not breached. The TCF would reference installation drawings and work instructions that ensure this. An early example of suppliers' documentation can be found in IMO's booklet "A drive user's guide to installation and EMC" [79], although this contains the less-than-reassuring statement that:

> If strict conformity with emission standards is either required or obligatory, it will be necessary to conduct RF measurement tests of the complete system installation.

The alternative is to perform limited site testing once the installation has been assembled to show that it is compliant. Since this would be less comprehensive, it would need to be balanced by a greater amount of documentation in the form of a matrix

defining the EMC threats and a rationale for the claim to compliance, including a justification for the tests that were done.

An ETSI standard ETS 300127 [142], written around large telecommunication systems, has been published to remedy the deficiencies in radiated emissions testing. It allows testing of a minimum representative system on an open area test site; such a system contains at least one of each sub-unit type which will be included in operational systems, and comprises the minimum configuration (including interface lines) of any system that is offered for sale. The system cable configuration is specifically addressed in this standard. The test on the representative system is used for demonstration of compliance. The EMC performance of new functional modules can be assessed against those that they replace. The representative system continues to conform when a functional module has been replaced by a new functional module which exhibits emissions similar to or less than the original unit. This approach has much to recommend it outside the telecoms sector, and system builders in other areas would be well advised to study this standard. A similarly worded section has been proposed as a revision to EN 55022.

It is possible that one-off installations which are manufactured to a customer's individual requirements, rather than being available off the shelf, could be treated under the provisions of taking into service. In this case it might not be subject to the need for testing and certification, but would still have to meet the protection requirements, and the user would be responsible for any special measures if the installation caused excessive interference.

1.2.7 Implementation, enforcement and sanctions

Member states cannot impede for EMC reasons the free circulation of apparatus covered by the Directive which meets its requirements when properly installed and maintained, and used for its intended purpose. They must presume that apparatus which bears the CE mark and conforms to the relevant standards, or for which a technical construction file exists, does in fact comply with the protection requirements unless there is evidence to the contrary.

On the other hand, member states are required to ensure that equipment which is found not to comply is not placed on the market or taken into service, and to take appropriate measures to withdraw non-compliant apparatus from the market. Legislation which translates the Directive's requirements into national law in each member state was required to be in place by 1st July 1991, although in the UK at least this timetable slipped because of the need for clarification on some points by the Commission, and the implementing legislation was not published until October 1992 [170]. In English law it is customary to interpret comprehensively the requirements of EU Directives, whereas in other European countries the regulations tend to be more general.

In the UK the enforcement regime [170][84] includes the issue of "prohibition notices" and "suspension notices" which prohibit the supply or use of specified equipment which the enforcement authorities believe does not comply with the EMC requirements. The notice may or may not have immediate effect, depending on the urgency of the situation; an appeal procedure allows persons on whom a notice is served to make representations for it to be revoked. Enforcement authorities can also apply to a court for forfeiture of apparatus, with its consequent destruction, modification or disposal, and officers of the enforcement authorities may be empowered to enter premises and inspect or seize apparatus and documents.

1.2.7.1 Offences

The EMC legislation does include criminal sanctions. But because of the difficulty of judging whether or not apparatus actually complies with the requirements, the UK legislators have not created an absolute criminal offence of supplying or using non-compliant equipment. Users and retailers cannot normally be expected to know whether or not the apparatus in question is non-compliant. Criminal offences on other fronts will be necessary, for instance to guard against misuse of the CE mark or the provision of false or misleading information to a competent or notified body, and to penalize breaches of prohibition notices.

1.2.7.2 Practice

Two important questions are: how is enforcement operated in practice, and is the Directive enforced equally in all Member States (the so-called "level playing field"). These questions are directly related to the resources that national governments are prepared to devote to the task. The UK DTI has indicated that its enforcement efforts will be complaint-driven. As well as investigating interference complaints arising from actual use of apparatus, it will be open to complaints that apparatus does not conform to the Directive's requirements regardless of whether or not there is a problem in its use. A possible source of complaint will therefore be from companies testing samples of their competitors' equipment and, if they find that it does not comply, "shopping" them to the authorities. It is also likely, though, that such complaints will need to be backed by serious evidence of non-compliance before the authority will take them seriously.

On the other hand, the German authorities have stated that it will be necessary to gain information from the market in the form of random spot checks in order to react to violations [109]. Germany already had a strong regime for the control of RF emissions in the form of the mandatory VDE standards, and these were stricter than the EN standards which are now used to demonstrate compliance with the Directive. The Germans are concerned that the Directive might dilute the effectiveness of their previous regime and will therefore be insisting that it is thoroughly enforced.

It is apparent that differences in enforcement practices within the various Member States will work contrary to the stated intent of the Directive, which is to reduce technical barriers to trade. Article 9 of the Directive requires that "where a Member State ascertains that apparatus accompanied by (a means of attestation) does not comply with the protection requirements..., it shall take all appropriate measures to withdraw the apparatus from the market, prohibit its placing on the market or restrict its free movement" and shall immediately inform the Commission of any such measure. If the Commission finds, after consultation, that the action is justified, it will inform all other Member States. The competent Member State shall then take appropriate action against the author of the attestation. Therefore any Member State can take immediate action to prohibit an offending apparatus from its own market, but sanctions against the company that put the apparatus on the market in another Member State are dependent on the deliberations of the Commission and on the enforcement practices of the latter Member State.

1.2.7.3 Interpretation

As has already been indicated, the Directive is so widely drawn that many of its provisions have to be the subject of interpretation. You might expect that this interpretation would be the function of the EC or of the national implementing authorities, but it has been remarkably difficult to obtain answers to detailed questions

of interpretation from such authorities, especially so when there is a technical dimension to the question. The Guidelines have given considerable interpretive help, but do not cover many more abstruse technical issues.

In the UK, a group known as the EMC Test Laboratories Association (EMCTLA) was formed primarily to ensure a reasonable uniformity of approach to the assessment of technical construction files by different competent bodies. Within that association, a working group has been set up which responds to queries regarding the implementation of the Directive and issues technical guidance notes which have a reasonably wide circulation, and which can form the basis for a uniform interpretation. These guidance notes are available from competent bodies and also from the EMC Clubs which have been set up across the country to provide a forum for companies to share experiences. The EMCTLA has been instrumental in founding a pan-European Association of Competent Bodies which is intended to spread this uniform approach within the EU.

1.2.7.4 National requirements

Table 1.2 details the present state of the Directive including those which amend it, and refers to the UK legislation which implements it. Table 1.3 lists the regulations that implement the Directive in other countries. It also covers the EMC requirements of countries outside the EU as far as possible.

Table 1.2 UK regulations implementing EC Directives

UK regulation	Directive
SI 1992 no 2372 The EMC Regulations	89/336/EEC (The EMC Directive), amended by 92/31/EEC (EMC amending Directive) 91/263/EEC (TTE Directive)
SI 1994 No 3080 The EMC (Amendment) Regulations	93/68/EEC (CE Marking Directive) 93/97/EEC (Satellite Earth Station Directive) 93/42/EEC (Medical Devices Directive)

Table 1.3 National regulations on EMC [28]

Country	Regulation
EU	
Austria	EMVV 1993 + 1995
Denmark	Law 475 and Order 475 in force July 1994
Finland	MTI Decision no. 1696-93
France	Decree 92-587 + 95-283 in force 13th March 1995
Germany	EMC law in force 10th November 1992
Italy	Decree 476 of 4th December 1992
Luxembourg	Regulation of the Grand-Duché of 21st April 1993
The Netherlands	Besluit van 14-8-95, Staatsblad No 387 + Staatscourant 163, 24th August 95
Portugal	Decree law 74/92 April 92, Edict 767-A/93 August 93
Spain	Real Decreto no 444/1994 of 11th March 1994

Table 1.3 National regulations on EMC [28] (Continued)

Country	Regulation
Sweden	Act on EMC SFS 1992:1512, Regulation ELS Ä-FS 1993:15 + 1994:2
EEA	
Norway	Electrical equipment regulations January 1993
Iceland	Regulation No 146/1994 on EMC 28th February 1994
Rest of World	
Australia	Spectrum Management Agency, via generic standards
Japan	VCCI, via CISPR standards
USA	FCC Rules

1.3 Compliance with the Directive

Of themselves, the essential requirements are too generalized to enable manufacturers to declare that their product has met them directly. So Article 10 of the Directive provides alternative routes (Figure 1.3) for manufacturers to achieve compliance with them.

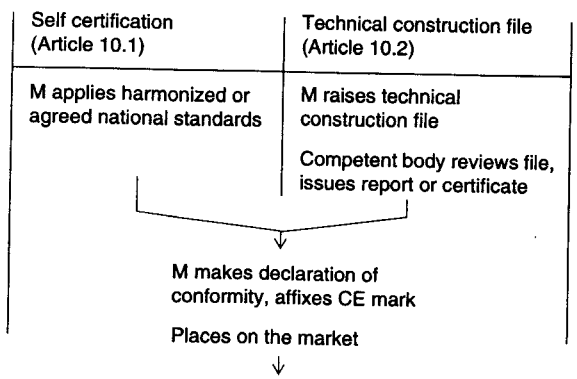

Figure 1.3 Routes to compliance

1.3.1 Self certification

The route which is expected to be followed by most manufacturers is self certification to harmonized standards. Harmonized standards are those CENELEC or ETSI standards which have been announced in the *Official Journal of the European Communities* (OJEC). In the UK these are published as dual-numbered BS and EN standards.

The potential advantage of certifying against standards from the manufacturer's point of view is that there is no mandatory requirement for testing by an independent

test house. The only requirement is that the manufacturer makes a declaration of conformity (see section 1.2.4) which references the standards against which compliance is claimed. Of course the manufacturer will normally need to test the product to assure himself that it actually does meet the requirements of the standards, but this could be done in-house. Many firms will not have sufficient expertise or facilities in house to do this testing, and will therefore have no choice but to take the product to an independent test house. This is discussed further in section 1.3.4. But the long term aim ought to be to integrate the EMC design and test expertise within the rest of the development or quality department, and to decide which standards apply to the product range, so that the prospect of self certification for EMC is no more daunting than the responsibility of functionally testing a product before shipping it.

1.3.2 The technical construction file

The second route available to achieve compliance is for the manufacturer or importer to generate a Technical Construction File. This is to be held at the disposal of the relevant competent authorities as soon as the apparatus is placed on the market and for ten years after the last item to which it relates has been supplied. The Directive specifies that the technical construction file should describe the apparatus, set out the procedures used to ensure conformity with the protection requirements and should contain a technical report or certificate obtained from a competent body.

The purpose of the technical construction file route is to allow compliance with the essential requirements of the Directive to be demonstrated when harmonized or agreed national standards do not exist, or exist only in part, or if the manufacturer chooses not to apply existing standards for his own reasons. Since the generic standards are intended to cover the first two of these cases, the likely usage of this route will be under the following circumstances:

- when existing standards cannot be applied because of the nature of the apparatus or because it incorporates advanced technology which is beyond their breadth of concept;
- when testing would be impractical because of the size or extent of the apparatus, or because of the existence of many fundamentally similar variants;
- when harmonized standards exist but the manufacturer decides to apply them in part only;
- when the apparatus has already been tested to standards that have not been harmonized or agreed but which are nevertheless believed to meet the essential requirements.

1.3.2.1 Contents

The UK DTI produced a guidance document to clarify the expected level of detail in the TCF [171], and this document suggests circumstances in which the TCF might be used, and also suggests the basic requirements for contents. These are:

- an identification of the apparatus (which may be a series of variants)
- a technical description
- a technical rationale for the procedures used to ensure conformity
- details of design elements that are significant for EMC

- test evidence where appropriate
- a report or certificate from a competent body

The technical file may or may not contain test data. The critical item is the technical report or certificate issued by a competent body, and this is what distinguishes this route from the previous one. Essentially, you are required to get an independent qualified opinion on the validity of your belief that the product meets the essential requirements. The competent body should review the technical file to check the rationale for the product's EMC, and the testing that has been done (if any). Either a report or certificate may be issued, both having equivalent weight; and if you have been able to partially apply harmonized standards then this document need only certify conformity with those aspects not covered by these standards.

1.3.2.2 Technical file versus standards

A potentially frequent use of this route would therefore be to test emissions to a harmonized standard but to decide that immunity needed a more product-oriented approach, and to use the technical construction file to certify this aspect. Alternatively, you may decide that an unwarranted amount of effort would be expended in testing against phenomena which experience indicates would not cause problems in real applications. If you can persuade the competent body that this is indeed the case then the technical file and its associated report need merely state this to be so.

Although the technical file route is for use where existing standards are inapplicable, in practice the competent body who issues the report or certificate will have regard to existing standards, methods of measurement and limits in order to judge whether the equipment meets the essential requirements. A close working relationship between the manufacturer and the competent body he chooses will be needed, and this should be established at the outset, before the generation of a TCF is begun. The expertise and qualifications needed of a competent body are discussed in section 1.3.4.

1.3.3 Radio transmitters and telecom terminal equipment

Article 10.5 of the EMC Directive used to require radio transmitters (which may also be TTE, such as cellphone transmitters) to undergo EMC-specific type examination, which needed certification from a notified body. This was different from a competent body. With the entry into force of the R&TTE Directive (section 1.2.1.2) radio transmitters and receivers, and telecom terminal equipment, still follow different routes to compliance compared to other electronic apparatus, since they are complying with a different Directive.

The conformity assessment procedures allowed under the R&TTE Directive are outlined in Figure 1.4. Their applicability varies depending on whether the equipment is telecoms terminal, or radio equipment; the receiving part of radio equipment is treated as telecoms equipment. In either of the cases of annexes ii or iii, there is no absolute requirement for the involvement of a notified body. The specific tests in annex iii must be identified by a notified body unless they are already defined in the harmonized standard(s). Otherwise, these annexes represent pure self-certification on the part of the manufacturer.

The Full Quality Assurance method of Annex v may be an attractive route for a large manufacturer of radio equipment, since it is the only option that avoids the case-by-case involvement of a notified body for radio terminals whose tests are not defined in harmonized standards.

Conformity assessment annexes

ii: Internal Production Control with technical documentation

iii: Annex ii plus specific tests

iv: Annex iii plus Technical Construction File submitted to a notified body

v: Full Quality Assurance assessed by a notified body

Annexes applicable:

Telecoms equipment: ii (preferred), iv or v

Radio equipment with harmonized standards: iii (preferred), iv or v

Radio equipment without harmonized standards: iv or v

Figure 1.4 Compliance with the R&TTE Directive

1.3.4 Testing and the competent body

Except in the case of products which it is clear will intrinsically not cause interference or be susceptible to it, such as the electric fire or pocket torch mentioned earlier, each manufacturer will need to submit products to some degree of EMC testing to be sure that they comply with the Directive. Chapters 3 and 4 consider EMC test methods in detail. To cover the eventual requirements of the standards, the scope of the tests will need to include mains harmonic, conducted and radiated RF emissions, plus immunity to RF, transients, electrostatic discharge and supply disturbances. A test facility to address all these phenomena at compliance level is beyond the budget of all but the largest companies. Not only are a screened room, an open area test site plus all the test equipment needed, but also the staff to run the facility – which itself requires a level of skill, experience and competence not usually found in most development or test departments. A large company may have the product volume and available capital which justifies investment (of the order of £1m) in an in-house facility of this nature. There are several such companies throughout Europe who have already taken this step. If they will be certifying exclusively to harmonized standards then no external constraints are placed on the operation of these in house test facilities. If they require competent body status in order to use the technical file route, then this is also possible provided that they have been accredited (see later).

1.3.4.1 Options for testing

Small to medium sized enterprises will not be able to afford their own full-scale test facilities and their choices are limited:

- join and help finance a consortium of similar companies which operates a test facility jointly for the benefit of its members;
- use an independent test house for all their EMC test requirements;
- establish a rudimentary EMC test capability in-house for confidence checking, and use an independent test house for compliance testing only.

The first option has not been established on a widespread basis in the UK, although

there are precedents in the form of co-operative "research clubs" in other fields. The second option will be expensive and has the disadvantage that experience gained in testing your own products is not brought in house to apply to future products. The expense could be diluted by using cheaper, non-accredited test houses for confidence checking and saving the accredited test houses for full compliance testing. It is though more preferable to develop a close relationship with one test house with which you feel comfortable than to change test houses at will. And unfortunately the nature of EMC testing is that there are large measurement uncertainties to contend with, and there is no guarantee that a test at one facility will produce the same results as an apparently identical test at another. (This has given rise to the rather cynical strategy of hawking a marginal product around several test houses until a "pass" is achieved, on the basis that this is cheaper than optimizing the product design!)

1.3.4.2 *In-house testing*

The problem of measurement uncertainty also applies to the third option, with possibly greater force because the confidence checks are done in a largely uncontrolled environment. Even for confidence checks, the equipment budget needed to carry them out is by no means negligible. It can be reduced by hiring expensive equipment at the appropriate time if the work load is light. A further but less obvious disadvantage is that not only must you invest in test equipment and facilities, but also in training staff to use them and in keeping up to date with the highly fluid world of EMC regulations and test methods. An external test house will have (reasonably) up to date equipment, facilities and expertise.

The advantage of the in-house approach is that you can carry out testing at any stage of the product design and production cycle (see section 9.2 on the EMC control plan), and the process of EMC confidence testing helps to instil in the design team an awareness not only of the test techniques, but also of the effectiveness of the various design measures that are taken to improve EMC. The benefit of this will be reaped in future designs. Also, designers will be under much less stress if they have the ability to test and re-test modifications made at the bench without a concern for the money that is being spent in the process.

If the product will be certified to harmonized standards then there is no need to use an external test house at all, provided that you are confident in the capability and accuracy of your own tests. Nevertheless many firms, and especially their empowered signatory who signs the declaration of conformity, would be happier having independent confirmation of compliance from an organization whose competence in the field is recognized – and this is sometimes a commercial requirement anyway. It would be perfectly in order to choose some tests, perhaps those involving RF emissions or immunity, to be performed outside while others such as transient, ESD and mains disturbance immunity are done in-house.

1.3.4.3 *Competent bodies*

If you choose the technical file route then you have to involve an independent competent body. The Directive lays down a number of requirements that must be met by anyone seeking competent body status:

- availability of personnel and of the necessary means and equipment;
- technical competence and professional integrity;

- independence of staff and technical personnel in relation to the product in question;
- maintenance of professional secrecy;
- possession of civil liability insurance.

Accreditation

Many of these requirements are met by accreditation, which in Europe has been based on the EN45000 series of standards (now being superseded by ISO 17025). This covers organization and management, calibration and maintenance of test equipment, measurement traceability and procedures, records and reports, the quality system, and staff competence. In the UK the body which handles accreditation is UKAS, the UK Accreditation Service. Mutual recognition of test house accreditation throughout Europe has yet to be achieved, and this is a major aim of the European Organization for Testing and Certification (EOTC). The European groups responsible for accreditation of test facilities (members of EA, the European co-operation on Accreditation) are given in Table 1.4.

Accreditation is a major requirement for appointment as a competent body for the purposes of the EMC Directive, but not the only one. In the UK, the Secretary of State for Trade and Industry has actually appointed competent bodies, and the DTI has indicated that a further requirement is the capability to make engineering judgements on the contents of a technical file, which has not been a feature of test accreditation. At the same time, competent bodies will need to have access to adequate test facilities, which means that independent consultants can also act as competent bodies if they have an agreement with a test facility.

A competent body must be resident within the EU, although with the fulfilment of the EU/US Mutual Recognition Agreement, US test labs can apply for competent body status. It may be possible for a manufacturer to gain competent body status for his own test facility, assuming it meets the accreditation criteria, provided that it can demonstrate managerial independence from the groups responsible for the products being tested.

Table 1.4 European organizations responsible for test accreditation

Austria	BmWA
Belgium	BELTEST
Denmark	DANAK
Finland	FINAS
France	COFRAC
Germany	DAR
Greece	ESYD
Iceland	ISAC
Ireland	NAB
Italy	SINAL
The Netherlands	RvA
Norway	Justervesenet
Portugal	IPQ
Spain	ENAC
Sweden	SWEDAC
Switzerland	SAS
UK	UKAS

1.3.5 Standards

The self-certification route (section 1.3.1) is the preferred route to demonstrating compliance with the Directive. This route depends on the availability of standards which can be applied to the product in question. The detail of the appropriate standards is covered in Chapter 2; this section will discuss their general availability and applicability.

Prior to the adoption of the EMC Directive, the EMC standards regime had developed in a somewhat piecemeal fashion. The existing standards fell into a number of categories:

- RFI: intended to protect the radio spectrum from specific interference sources, such as information technology equipment, motor vehicle ignition, household appliances or fluorescent lights
- mains emissions: specifically harmonic currents and short-term variations, to protect the low-voltage power distribution network
- product- and industry-specific: to ensure the immunity from interference of particular types of product, such as process instrumentation or legal metrology, or to regulate emissions from equipment that will be used in a specific environment, such as marine equipment

These standards are not over-ridden by the Directive; those which have been harmonized by CENELEC may be applied to products within their scope and are regarded as adequate to demonstrate compliance. The same applies to non-harmonized standards which have been notified to and agreed by the Commission.

1.3.5.1 The generic standards

In the early days of the EMC Directive, there were many industry sectors for which no product-specific standards had been developed. This was especially so for immunity, which was a new concept for many products. In order to fill this gap wherever possible, CENELEC gave a high priority to developing the Generic Standards. These are standards with a wide application, not related to any particular product or product family, and are intended to represent the essential requirements of the Directive. They are divided into two standards, one for immunity and one for emissions, each of which has separate parts for different environment classes (Table 1.5).

	Part 1	Part 2	
EN 50 081 Emissions	Domestic, Commercial, Light Industrial	Industrial	NB see also the IEC 61000-6 series of generic standards
EN 50 082 Immunity			

Table 1.5 The generic standards

Where a relevant product-specific standard does exist, this takes precedence over the generic standard. It will be common, though, for a particular product – such as a fire alarm – to be covered by one product standard for mains harmonic emissions, another

for immunity and the generic standard for emissions. All these standards must be satisfied before compliance with the Directive can be claimed. Other mixed combinations will occur while a comprehensive range of product standards is being developed, and there will always be unusual products that "fall through the cracks".

Environment classes

The distinction between environmental classes is based on the electromagnetic conditions that obtain in general throughout the specified environments [122]. The inclusion of the "light industrial" environment (workshops, laboratories and service centres) in class 1 has been the subject of some controversy, but studies have shown that there is no significant difference between the electromagnetic conditions at residential, commercial and light industrial locations. Equipment for the class 2 "industrial" environment is considered to be connected to a dedicated transformer or special power source, in contrast to the class 1 environment which is considered to be supplied from the public mains network.

1.3.5.2 Performance criteria

A particular problem with immunity is that the equipment under test may exhibit a wide variety of responses to the test stimulus. This can range from a complete lack of response, through a degradation in the accuracy of measured variables to total corruption of its operation. The same problem does not exist for emissions, where comparison with a defined test limit is possible. To account for this variety, the generic immunity standards include three generalized performance criteria for the purpose of evaluating test results. In the test report, you must include a functional description and a specific definition of performance criteria based on these, during or as a consequence of the EMC testing. The definitions of these criteria can be found in section 9.3.4 on page 317. Most noteworthy is that the criteria are grounded on what performance the user may reasonably expect *or is told to expect*. In other words, if you specify a given performance loss during application of the immunity test and write this into the user documentation, then provided the equipment does not actually become unsafe as a result of the test, you have met the requirements of the generic standards.

1.3.5.3 Basic and product standards

The tests defined in the generic standards are based only on internationally approved, already existing standards. For each electromagnetic phenomenon a test procedure given by such a standard is referenced, and a single test level or limit is laid down. No new tests are defined in the body of any generic standard.

Those standards which are referenced in the generic standards, for example the various parts of EN 61000 along with some of the CISPR standards, are known as "basic" standards. This means that such standards are entirely devoted to aspects of EMC that will prove to be of general interest and use to all committees developing other standards – for instance, product specific standards. Generally, a product specific standard will take a form similar to the generic standard, with similar limits, but will be more specific as regards operational modes and configurations, and about performance criteria that are considered acceptable. It will refer to the basic standards for the test methods wherever possible.

1.4 Action for compliance

The steps to take for a new product to achieve compliance with the EMC Directive and bear the CE mark can be detailed as follows (ignoring radio transmitters and telecoms terminal equipment, and medical devices, and other types of product which are subject to their own Directives).

A. Self certification

1. From the marketing specification, determine what type of product it will be and what environment it will be sold for use within, and hence which if any product-specific standards (see section 2.5) apply to it. If your company only ever makes or imports products for one particular application then you will be able to use the same product-specific standard(s) for all products.
2. If no product-specific standards apply, check the generic standards to see if the tests specified in them are applicable. The environmental classification will depend on the intended power supply connection.
3. If you cannot apply the generic standards, or don't wish to for the reasons discussed in section 1.3.2, then you will need to follow the technical file route (B).
4. Having determined what standards you will use, decide on the test levels and to what ports of the equipment (enclosure, power leads, signal/control leads) they will apply. In some cases there will be no choice, but in others the test applicability will depend on factors such as length of cable, EUT configuration and class of environment.
5. From this information you will be able to draw up a test plan, which specifies in detail the version and configuration of the EUT and any associated apparatus, the tests that will be applied to it and the pass/fail criteria. Test plans are covered in greater depth in section 9.3. You can discuss this with your selected test house or your in-house test facility staff, and it will form the basis for your contract with them and also for the technical documentation required by the provisions of the Directive.
6. Knowing the requirements of the test plan will enable you to some degree to incorporate cost effective EMC measures into the product design, since the test limits and the points to which they will be applied will have been specified.
7. As the design progresses through prototype and pre-production stages you can make pre-compliance confidence tests to check the performance of the product and also the validity of the test plan. It is normal for both design and test plan to undergo iterative modifications during this stage.
8. Once the design has been finalized and shortly before the product launch you can then perform the full compliance tests on a production sample, the results of which are recorded in the technical documentation. Provided that confidence tests were satisfactory this should be no more than a formality.
9. You are then at liberty to mark the product, and/or its packaging or documentation with the CE mark (if there is no other Directive to satisfy) and your empowered signatory can sign the Declaration of Conformity, to be kept for ten years. The product can be placed on the market.

10. Once the product is in series production you must take steps to ensure that it continues to comply with the protection requirements.

B. Technical construction file

1. Your product is such that you cannot or will not apply harmonized standards to it to cover the essential requirements in full. In this case, you must work with a competent body.
2. Having chosen a competent body (in the UK, the DTI maintains a list of these – it is also possible to work with a competent body in any other Member State), discuss with them the design features and test requirements that they would need to see to satisfy them that the product complied with the Directive. From this discussion you should be able to draw up a test plan as in A.5 above. From this point, you can continue as in A.6 and 7.
3. By the time the product has been finalized you will have created the technical construction file as described in section 1.3.2. This may or may not include compliance tests as agreed with, and possibly but not necessarily performed by, the competent body. The competent body will then review the complete technical file and, provided they are satisfied, will issue a report or certificate to say so.
4. At this point you are at liberty to proceed as in A.9 and 10 above.

1.5 Just when you thought it was safe...

The great sage J G Bennett, when he wanted to make sure his disciples were thinking for themselves, was prone to say after a long and exhaustive exposition of an abstruse point of philosophy, "Now, forget all of this...". You may be tempted to feel the same way, since there is a completely new edition of the EMC Directive on the horizon. At the time of writing, it is still under active discussion and revision, so it would be foolish to pre-empt the inevitable changes and review it in detail. This short section will just give a brief comment on the more important features that are emerging.

1.5.1 SLIM

In 1998 the EMC Directive was subject to a review under the SLIM (Simpler Legislation for the Internal Market) process. Ten governmental experts were charged with making recommendations for improvements and simplifications to the Directive. Their report looked at the following areas amongst others:

- functional safety – explicitly, not to be part of the EMC Directive
- immunity requirements – to be retained, but clarified
- standards – a strategic review panel to be set up
- large machines and installations – not subject to conformity assessment
- definitions of certain types of environment

The SLIM recommendations have formed the foundation for a complete re-write of the EMC Directive, but it would be wrong to suggest that everything the SLIM group recommended has been taken on board unaltered in the new edition.