Chapter 17

EMC management

17.1 Managing the EMC process

Implementing a strategy of EMC compliance within a company is much more than simply ensuring that the product designers make their designs meet the standards – although this is a first step. EMC awareness, like quality and safety awareness needs to extend vertically and horizontally throughout the company if it is to be effective. This means that each department must know what its role is in maintaining a product's EMC and why. This applies with particular force to the purchasing, production and installation groups.

It also means that business and management decisions affecting EMC should be made in a similar climate of awareness. Investment decisions on EMC test facilities are a clear case in point, as also are marketing decisions on the specification and life cycle for a particular product range, and the question of whether to launch a marginally compliant or non-compliant product. Appointing an "EMC specialist" to take responsibility for these issues is better than no co-ordinated policy at all, but should only be the first step towards an integrated understanding throughout the company.

17.1.1 Putting EMC in context

Most products are already subject to a range of environmental or safety specifications. These requirements are partly fixed by legislation and partly to ensure "fitness for use" of the product, and they include factors such as temperature and relative humidity ranges over which the equipment must operate, together with ergonomic aspects and control of hazards (such as heat or electric shock) associated with the unit. EMC is best regarded as simply another of these specifications.

Immunity to external EM disturbances is clearly an environmental issue. A product must function reliably in its intended environment, and if this environment includes EM disturbances then these should be incorporated in the environmental specification. One of the functions of EMC immunity standards is to provide some guidance in defining this environmental requirement. Control of emissions is more properly a regulatory function unless such emissions have an intra-system aspect – that is, if they affect the proper operation of the overall system or its installation.

17.1.1.1 Selling EMC within the company

Management throughout the company must be convinced of the worth of EMC before it will give its commitment to effort and resources. First and foremost, the impact of EMC legislation must be made absolutely clear. Beyond this, you can monitor pressure from customers, competitors and third party approvals bodies and use it to justify the need for effort. The link between good EMC and product quality should be continually stressed.

There are two particular difficulties in the way of a wide appreciation of EMC [36] – one is the sheer unfamiliarity of the topic in a world where most designers have avoided analogue subjects in favour of digital, the other is a perception of EMC as a cost rather than a benefit. These can be overcome by documenting and presenting details of EMC-specific actions that may already have been taken on a particular product that is familiar to all. Shared experience is a powerful educational force. Documenting the knowledge gained on a particular project will also avoid the risk of creating EMC "gurus", which in the long term benefits neither the company nor its engineers. Documenting solutions – rather than failures – results in a positive "get-it-right-this-time" culture in the design group. But there is a flip side to this: it's easy to get stuck in an attitude that says "this is what worked last time, so we'll do it again". Taking that approach without understanding *why* it worked is dangerous. Or to put it another way, a lot of EMC problems arise because designers are *following* EMC design rules (*pace* section 17.2.2), without appreciating what they are for.

17.1.1.2 Costs and timescales

Addressing EMC early in the product development cycle is easier and more cost-effective than any wait-and-see approach. The early stages of a design allow designers the most freedom to achieve EMC. The packaging and circuit layout, for example, are subject to the fewest constraints. As the product design evolves towards production, changes become increasingly difficult and expensive. For example, a radiated emission problem that might have been solved earlier by judicious PCB layout may require changes to the packaging and interfaces. The key to cost-effective EMC is to instil among circuit and packaging designers an appreciation for good EMC design practices.

A critical factor in product development is not just the overall development cost but also the timescale. In many product sectors the marketing window of opportunity is short, so lost time in bringing the product out translates to lost sales and poor profits. If ignored for long, EMC requirements will undoubtedly impact time to market. Every EMC test house has a long, sad list of companies which have optimistically brought their product along the day before launch only to find they were non-compliant.

The two ways to prevent this happening are to ensure that EMC is treated as part of the overall specification, so that its dictates are adhered to right from the start of the project; and to continually monitor the EMC profile throughout the development stage so that late surprises are eliminated. It is also wise to assume that one re-test *will* be needed – even when all the design principles are adhered to, initial compliance is not certain – and to factor this in to the development schedule (see section 17.3.1.3).

17.1.2 The EMC co-ordinator

A typical first step for a company implementing an EMC control policy is to appoint an EMC co-ordinator. By default this is often a design engineer who has more knowledge than anyone else of RF topics, although it may be viewed as a job for a quality engineer. The magnitude of the task facing this individual must be appreciated, and the powers that are delegated to him or her have to be sufficient to deal with all the issues that will arise. In particular, the distinction between engineering decisions† and business or legal decisions‡ must be strictly maintained; or else the co-ordinator's function must clearly include legal and business authority, and his or her training must reflect this responsibility [136].

† "It's 2dB under the limit; we need a 6dB margin to cover uncertainties; we can't ship it".

‡ "It's 2dB under the limit; we need the product on the market; of course we can ship it".

Shepherding an individual project through EMC compliance can absorb (if it is done thoroughly) between 10 and 20% of the development cost. Thus for every 5–10 design engineers employed, there should be one EMC engineer. For companies with large development departments and a wide range of products, a separate EMC department (perhaps allied with the quality department) is justifiable. Conversely, for small companies the job may best be filled by a retained consultant. Some of the job functions that may be expected are to:

- oversee and advise the design process;
- interpret EMC standards requirements for the company's product range;
- devise test and control plans and schedules;
- control/sign-off EMC-related engineering changes;
- liaise with all departments on EMC matters;
- keep abreast of developments in the EMC field.

17.2 The design process

17.2.1 The product specification

A project begins, at least theoretically, with a specification. This will naturally concentrate on the functional requirements of the product or system. As soon as there is reasonable stability in these requirements, particularly once the interfaces have been settled, you should be looking at the EMC aspects.

The specification should at least be clear on what environment the product is intended for. Harmonised standards are linked to environments and the EMC Directive is explicit that compliance is expected when the apparatus is "used for its intended purpose", including a restriction on use in residential areas if necessary. Other environmental requirements, such as temperature range, vibration, humidity and hazardous area certification, also need to be set at the start and EMC should be simply another one of these.

If the project is negotiated to a contract then this may also specify EMC requirements, usually by reference to standards which are industry- or product-specific. This would be typical in the defence industry and in some other sectors, such as automotive and railway industries. It's not unusual for such requirements to be extremely vague in the early stages, before the product's outlines are clearly established, and because procurement engineers are often unfamiliar with the detail of EMC standards. This means that there will be room for detailed negotiation when specifics become available, but the existence of a clear management approach which takes EMC on board will make these negotiations easier.

Whether or not a contract is involved, the highest level of specification will generally concentrate on reference to standards, and your main aim is to understand the design implications of the tests that these standards set.

17.2.2 Design rules

As a matter of course, every design group should have some general rules to work against that address EMC performance. Appendix A and section 12.2.5 in this book give some suggestions, but it is impossible to give a single set of inviolate rules that will apply to all kinds of product. The variety of forms of construction (plastic case, metal

case, rack, cabinet), PCB technology (single-sided through to 20 or more layers), circuit complexity (simple analogue through to multi-clocked dense processing) and of course EMC performance requirements, ensures this. Rules which may be essential for a high-performance military requirement can be inappropriate for a simple consumer device. Rather, it is better to have a list of issues that should be addressed with an understanding of the principles involved. So, as a minimum, you should consider:

- circuit design: analogue bandwidth limitation, power segmentation and decoupling, power bus regulation, conversion and distribution, choice of clock frequencies, clock distribution and buffering, risetime and slew rate limitations;
- PCB layout: 0V plane(s), power plane(s), layer stackup, decoupling placement, component placement, constant impedance layers, heatsink and mechanical aspects, ground connections and general routing;
- interfaces: power supply filtering, low frequency unscreened cable port filtering, high frequency unscreened cable port balance and common mode chokes, connection of screen to chassis for screened cable ports;
- enclosure design: aperture size and location, bonding of structural parts, use of conductive gaskets, mating surface treatment and paint masking, PCB-to-enclosure connections, localized screening, moulding design for conductive coatings and choice of coating.

The implementation of these aspects for any given design is the responsibility of each designer, but it can be validated through the process of design review.

17.2.3 Design reviews

Reviews at every stage of a product's design can help to ensure proper EMC control. In these, the product's own designers are subjected to peer review by other designers not involved in that project, and consensus decisions are reached on the validity of each design aspect. The design reviews should be key milestones in the development process, and progress to the next development stage should be conditional on the successful outcome of each review. This self-imposed discipline offers a formal method for checking that EMC aspects (and others, such as safety) are being addressed throughout the process. There is a further hidden advantage – the minutes of design review meetings are convincing evidence, if challenged on its compliance statement, that a company has been pro-active in addressing EMC and safety issues.

The practical implication of this is that the EMC co-ordinator should be present at each design review and should be included in the sign-off for the review. It is this person's responsibility to question each design decision that may have an implication for the product's EMC profile. The design team cannot (and indeed should not) follow EMC design rules absolutely rigorously because in many cases this would load the unit cost excessively. But there will be many occasions where design choices have an EMC dimension; and where problems have occurred, the designers must not only understand the cause but must also be able to follow the steps needed to eliminate the problem from a future design.

If you want to follow a specific format for the EMC part of design reviews, start with the lists given in Appendix A and section 12.2.5.

17.2.4 Identifying EMC-critical aspects

A vital part of the process, which should be emphasized in the design reviews, is the identification of those aspects of the design which are likely to create difficulties in the compliance tests. This will never be 100% successful, or it wouldn't be necessary to do the tests at all. Rather, the idea is to anticipate and deal with potential problems before they become show-stoppers. This process relies to a great extent on experience, on how previous products of a similar type fared in their tests; and this means that good records of test results need to be kept in order to nurture this experience. Just achieving a pass is not enough: you should know by what margin the product passes, either below the emissions limit at relevant frequencies, or above the minimum stress level for immunity. This will then guide you for the next design.

Aspects of the new design for which there is no experience automatically become critical. Instances might be a different interface (say, USB or Ethernet), or a new processor with a higher frequency clock, or a greater sensitivity A-D converter. Over and above the normal good practice in board layout and interface protection, such extensions need to be treated with extra care.

Any of the following should trigger more investigation in the early stages:

- wideband, high-speed signals entering or leaving via interfaces;
- clock and data bus signals distributed around a large board, or around a whole system via a backplane or inter-board cables;
- high-power, high frequency switching circuits;
- microvolt or millivolt level signal amplification, including wireless-on-board.

17.3 Test management

Chapter 9 discusses the planning of EMC tests in detail. Managing these tests is itself a significant activity.

17.3.1 When to do the tests

One issue which faces project managers is, at what point in the product's development should EMC testing be carried out. The worst time to find out that a product has EMC problems is when the design has been finished, the tooling and PCB layout has all been signed off and the launch date is looming. But on the other hand, if you test a product too early, the test results won't reflect the performance of the final production build. So what timing is best?

17.3.1.1 Initial look-see tests

In fact, it is wise to plan for at least two sets of tests: an initial look-see, and a final compliance test. This gets around the dilemma, but at the apparent cost of doubling the testing budget. Actually, it needn't be as bad as that. The initial look-see doesn't have to follow the full compliance methods of testing as per the standards. As long as you are familiar enough with the principles and limitations of the tests, what are known as "pre-compliance" methods can be adequate to flush out any major problems that will clearly cause failures in the final compliance stage. This reduces their cost, allowing either a lower budget or more comprehensive coverage: different design options can be evaluated without the high per-hour cost of a fully compliant test lab.

If this two-stage approach is followed, you can afford to be flexible about the timing of the initial tests. In essence, you will want to test as early as possible while still using a representative build. One school of thought says that there is no point in testing anything until the final build is reached, because even minor changes in the run-up to production can have dramatic EMC effects. This is true, but it overlooks the value of knowing whether you are even in the right ballpark, and not being hit by nasty surprises when you can least afford them. The purpose of the early tests is to identify if there are any gross issues which have to be immediately addressed in the design, accepting that later design changes may affect these one way or the other. For this purpose it may even be appropriate to test just a part of the design about which you are unsure; for instance,

- a new high-speed interface, to choose between filtering and cable shielding options, and to identify particularly emissive or susceptible data rates and formats;
- a video circuit, to check the impact of different levels and frequencies of applied RF disturbance on picture quality;
- shielding effectiveness of different enclosure designs or conductive gaskets, before committing to tooling.

And, of course, not all tests may need to be done at this stage; usually the most relevant are the RF emissions and immunity tests, and possibly the fast transient and surge immunity. ESD immunity is highly dependent on layout, grounding and enclosure design and is only really valid once these aspects are settled and a representative model is available. The other tests are also affected by these factors but to a lesser extent, and it is worth doing them earlier, especially if you can identify and control likely critical coupling paths. For example, if the interface grounding regime can be made representative, it is often possible to do the conducted emissions and immunity tests without a proper enclosure, at least to indicate what aspects to address in the next build.

A further use for initial testing is to develop knowledge of the effects of operating mode and build state on the EMC profile. This will then allow you to justify the choice of particular configurations and modes as worst case in the final compliance test without so much time-consuming investigation at this late stage.

17.3.1.2 Compliance tests

The second question is, at what point should the compliance tests be done?

This question is at least as much determined by company policy as by engineering considerations. This is because, for the purpose of self certification to Directives, it is "the manufacturer's responsibility" to declare compliance and therefore it must involve commercial and legal aspects as well as engineering ones. The same consideration applies to contractually set obligations.

The problem with these tests is that they are normally going to be performed when the pressure to release the product is most intense: just before (or, worse, after) the published launch date. The criteria which you should apply to check whether the product is ready to test are:

- have all engineering changes except trivial ones (such as case colour, or the external moulding detail) been frozen: will the product being tested be essentially the same as that which goes to market?
- are all relevant software functions available, debugged and complete?
- is all necessary support equipment, including the correct cables, available and working properly?

- are enough samples of the product meeting the above criteria available to carry out the tests adequately?

It's rarely possible to be able to tick all these boxes fully and still meet launch schedules. Any deviation from the best case should be evaluated for the risk it poses to the validity of the test outcome, particularly the questions of engineering and software changes. After the compliance test has been completed successfully, further changes should only be allowed if they can be shown by analysis to have no expected effect on the outcome if they were to be re-tested. Very rarely is the EMC engineer able to certify this completely: any such change will carry some risk with it. The project manager has to judge the moment of the compliance test to minimize this risk and still meet the schedule.

17.3.1.3 Planning for different outcomes

It is only natural that the project manager should be optimistic about the outcome of a set of EMC tests. But it is more realistic to expect that some failures will occur, and to identify the risk of this happening and plan to mitigate it. In the early days of EMC compliance, test houses were reporting that most products failed their tests at the first try. This depressing situation has eased somewhat with a greater understanding of the subject, but there would be no point in the tests if all products were guaranteed to pass.

There are various ways to anticipate difficulties at the compliance test stage. One is to allow sufficient schedule flexibility to cope with a board or enclosure re-spin between the initial compliance test and final sign-off, with an option on a further test date if this is needed. Another is to provide for several variations in the design itself, which can be selected on the fly until one is found that achieves the best pass, or which are implemented in different builds of the product that can be tested at the same time. If you have a good set of pre-compliance results, you will be in a better position to evaluate the risks of each design option. As with the timing of the tests, the project manager has to juggle the competing merits of design implementations of differing costs with the need to minimize the risk of long delays to the project caused by test failures.

17.3.2 In-house or external?

17.3.2.1 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 dealing with the product design!)

17.3.2.2 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 disadvantage is that not only must you invest in test equipment and facilities, but also in training staff to use them and to keep up to date with the highly fluid world of EMC regulations and test methods. An external test lab 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, 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 gained 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 too much concern for the money that is being spent in the process. 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 with the minimum need for facilities and kit.

If the product will be self certified to harmonised 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, are happier having independent confirmation of compliance from an organization whose competence in the field is recognized – and this is sometimes a commercial requirement anyway.

17.3.2.3 Accreditation

The requirement for confirmation of integrity of a test facility is met by accreditation, which is based on the ISO 17025 standard. 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 is achieved under the EA Multilateral Agreement (MLA), between the European groups responsible for accreditation of test facilities (full members of EA, the European co-operation on Accreditation). Under this agreement the signatories recognise and accept the equivalence of the accreditation systems operated by the signing members, and also the reliability of the conformity assessment results provided by each member's accredited bodies. EA MLA signatories are listed in Table 17.1. Similar systems operate outside Europe with bilateral Mutual Recognition Agreements.

The test plan requirements of accreditation are covered in section 10.1.1, and the report formats are discussed next. What else do you get from accredited tests?

Table 17.1 European organizations responsible for test accreditation (MLA signatories)

Albania	DPA	Luxembourg	OLAS
Austria	AA	Malta	NAB-Malta
Belgium	BELAC	Norway	NA
Bulgaria	BAS	Poland	PCA
Cyprus	CYS-CYSAB	Portugal	IPAC
Czech Republic	CAI	Republic of Croatia	HAA
Denmark	DANAK	Romania	RENAR
Estonia	EAK	Serbia	ATS
Finland	FINAS	Slovakia	SNAS
France	COFRAC	Slovenia	SA
Germany	DAkkS	Spain	ENAC
Greece	ESYD	Sweden	SWEDAC
Hungary	NAT	Switzerland	SAS
Ireland	INAB	FYR Macedonia	IARM
Italy	ACCREDIA	The Netherlands	RvA
Latvia	LATAK	Turkey	TURKAK
Lithuania	LA	UK	UKAS

Accreditation for EMC is normally granted on a per-standard or per-test basis, so you need to be sure when choosing a lab that it holds accreditation for the tests and standards that you want it to do. When a test lab undergoes accreditation, its quality system is inspected and has to meet similar requirements to the well-known ISO-9000 demands. Additionally, the assessor(s) will look at the adequacy and calibration of equipment, use of the correct test procedures, all manner of records and reports, and the training, technical competence and authorization of the test engineers. As a result, it would be very rare for an accredited report to be challenged as support for a statement of compliance. The function of an accredited report as compared to a non-accredited one is therefore mostly to provide a form of insurance against future challenges.

17.3.3 The various types of report

The report can range from a test house certificate which merely states whether the EUT did or did not meet its specification, to a detailed test report which includes all results and test procedures. Most UK test houses would be able to deliver a report to UKAS standards, which contains essential results and information without detailing lab procedures. For the purpose of complying with the EMC Directive, you need to know whether you want a certificate of compliance with an EN standard or a report for insertion into a technical file for the EMC Assessment. For self declaration to harmonised standards, the form of the report is set by the level of detail you need for your own (or your customers') purposes. This may be set by contractual requirements for applications outside the EU Directives.

A simple certificate stating "pass" (preferably not "fail"!) is cheap and quick; more detailed reports will be more costly and can take several weeks to be produced by the lab. But there are advantages to having more detail, if the report is going to be scrutinized in future, either because of a legal challenge to your declaration of conformity or more likely because a customer wants to satisfy themselves of the compliance of the product. If the report clearly states what individual tests were done, to what ports, under what conditions of operation, with what monitoring equipment and with which performance criteria, then it can be reviewed by a third party for

completeness and relevance and can if necessary allow the tests to be repeated at another lab. If it lacks this detail, then its worth is questionable, and in the worst case a customer or an enforcement authority may not accept its validity.

Another debate is whether the report should contain all the test results, quantified: for instance, the actual levels of emissions. CISPR 22/EN 55022 requires the six highest to be reported and this is often taken as a guide for any emissions report. It allows an external reader to judge how much margin the product has and at what frequencies, and this is valuable if the product will be used as part of a system which must itself be certified. An emissions plot is also sometimes provided. By itself this is of little use for knowing the actual emissions levels, but can be helpful in showing the general profile of the product. In fact, providing these details is more beneficial to the product's designer than to most other users of the report.

Chapter 9 discusses test planning in depth, and a good test plan can be used in conjunction with the test report to expand on and reinforce its content.

17.4 Compliance during production and beyond

EMC control does not stop when the product has moved from design into production. Both the EMC and Radio Equipment Directives require the manufacturer to take "all measures necessary" to maintain the compliance of each individual item (see section 2.2.4), but do not specify what these measures might be.

17.4.1 Degrees of quality assurance

The RED differs from the EMCD in that it offers a number of different options for compliance of different classes of radio product, from straight self certification including technical documentation, through additional tests agreed by a Notified Body, to full quality assurance with assessment and surveillance by a Notified Body. This last is equivalent to Module H as defined in the framework Directive 93/465/EEC on conformity assessment procedures. The requirements of the quality system that is mandated by this Module are given in the RED [198] and are summarized as follows:

> The quality system shall ensure compliance of the products with the requirements of the Directive that apply to them. All the elements, requirements and provisions adopted by the manufacturer shall be documented in a systematic and orderly manner in the form of written policies, procedures and instructions. That quality system documentation shall permit a consistent interpretation of the quality programmes, plans, manuals and records.
>
> It shall, in particular, contain an adequate description of:
>
> – the quality objectives and the organizational structure, responsibilities and powers of the management with regard to design and product quality,
>
> – the technical design specifications, including standards, that will be applied and, where the relevant harmonised standards will not be applied in full, the means that will be used to ensure that the essential requirements of the Directive that apply to the products will be met,
>
> – the design control and design verification techniques, processes and systematic actions that will be used when designing the products pertaining to the product category covered,
>
> – the corresponding manufacturing, quality control and quality assurance techniques, processes and systematic actions that will be used,
>
> – the examinations and tests that will be carried out before, during and after manufacture, and the frequency with which they will be carried out,

– the quality records, such as inspection reports and test data, calibration data, reports concerning the qualifications of the personnel, etc.,

– the means of monitoring the achievement of the required design and product quality and the effective operation of the quality system.

This is as good a description as any of the requirements of a quality system that would be necessary fully to control the EMC compliance process. Naturally it aligns closely with global standards such as the ubiquitous ISO-9000, but extends it to deal with issues specific to EMC.

17.4.2 Production QA testing

There are two reasons why the EMC performance of a product in series production might differ from that of the product when it was tested. One is that the formal build state may be different, as a result of engineering design changes. The other is that production tolerances, both in electronic components and mechanical construction, will vary the emission level from noise sources or the susceptibility of victim circuits.

Strictly speaking, to be absolutely sure that these variations have not taken the product outside compliance you would need to EMC test each unit as it comes out of production. In most cases this is not realistic. A more tenable option is to operate a sample testing system. The tests to be applied to each sample could be a full suite of standard compliance tests, or could be simpler comparative tests of key parameters – such as certain emission or susceptible frequencies measured on critical cable ports, to avoid radiated tests – compared against a transfer standard or "golden product" [152] which is known to comply with the full test suite.

17.4.2.1 Sample testing regime

The question then arises, how often should samples be tested? One suggested solution is to base the sampling only on known changes, assuming that a margin has been built into the design for production tolerances, and to institute a points system for engineering changes. Each change is awarded a given number of EMC points, depending on its likely seriousness in affecting the EMC profile. When, as a result of changes, a certain number of points have accumulated, the product is submitted to a re-test. Of course, the key to this system is knowing how to allocate points to changes and deciding what the re-test trigger level should be. This is likely to be based largely on guesswork at first, although experience and knowledge of the critical areas gained during development will help refine the process.

Another approach is to base the sample test period on the measured margin exhibited during the initial compliance test [68]. The closer to the emissions limits was the initial measurement, then the more frequent should be testing of production samples. Continual sampling in this way will help build up a database of the statistical spread of levels, enabling a good degree of confidence that the product complies with the 80/80 rule (see section 2.2.4.1 on page 42). This is also one of the hidden functions of the signature on the declaration of compliance (see section 2.2.3.4): the signatory must be of sufficient seniority to be able to insist on a commitment to re-verification (since the signature commits the company to compliance of every product that is sold)[130]. The EMC co-ordinator, or test authority, should produce a document stipulating the re-verification testing that will be required during the product's life, related to the quality of pass during the initial compliance test. This forms part of the

EMC-specific documentation for that product, is signed by the product manufacturing manager, and is maintained along with the compliance declaration.

17.4.2.2 ISO-9000

Within a company that has accreditation to ISO-9000, procedures can be set up and documented to ensure that EMC is maintained during production. These procedures will depend on a thorough knowledge of what aspects of the production process are important to EMC. Therefore it will be necessary to revise the company's operations in three ways [25]:

- determination by the design authority of all EMC-critical parts, assembly and installation methods, and processes;
- clear marking of these parts and work instructions to make plain to all concerned that they *are* critical, and a procedure to invoke the EMC authority when changes are needed;
- optimizing the level of in-house testing for early detection of variations.

Each of these issues can be addressed through the procedures listed in the company's quality manual.

17.4.2.3 Other parts of the company

EMC responsibility extends further than just the design and manufacture of a product. Larger equipment and distributed systems are built on- or off-site by production fitters and installers. Equipment in the field is repaired by service technicians. Each of these groups will either need to have a knowledge of EMC approaching that of the designers, or they will need to follow tightly controlled procedures.

Similarly, the purchasing group can influence the EMC performance of a product. Components and sub-assemblies must be procured to EMC-related specifications if they are expected to have an effect on the final system's EMC profile: for instance, alternative sources of digital parts must not include devices which have faster switching times. The purchasing managers should be made aware of their responsibility through training, and procurement specifications must include a section devoted to EMC requirements.

17.4.3 Engineering change control

Section 17.4.2.1 above referred to a re-test regime that was based on an accumulation of changes during production. This implies that a system is in place to record and evaluate these changes. In most companies, certainly those that operate a quality system, engineering change control is a formal process, in which every design change after a product has gone into production is reviewed and documented before it is actioned. For EMC purposes, this process must cover any change that has implications for the compliance status.

Whatever change control is in place, the change document template should include a decision box to indicate whether it is an EMC-related change or not. Who actually makes this decision is a moot point; it depends on the degree of EMC expertise in the company and in whom it resides. Typically, it will require review by the EMC co-ordinator, but it may be the responsibility of the appropriate design engineer. Changes which are EMC-related should then be evaluated to decide whether they do not require a re-test at all, whether they should contribute to an aggregated re-test requirement or whether they justify a re-test in themselves. To aid traceability throughout the company

and to support a compliance declaration, the decisions and their rationale should be documented within the system.

17.5 The control plan and documentation for Directives

All of the management activity discussed in this chapter implies that some level of EMC-related documentation will be necessary for each project. This is best described as an "EMC Control Plan".

17.5.1 The purpose of the control plan

The EMC control plan is a document, part of the specification of a new product, which lays down a schedule and a method to define how work towards the product's EMC compliance will be undertaken. Some projects within the military and aerospace sectors require this plan to be submitted as part of the tender documentation. Even if it is not a contractual requirement, the use within the design team of a detailed plan, showing which actions need to be taken and when, is a discipline that will reap benefits at the tail end of the design process when EMC performance comes to be evaluated. Sadly, if this discipline has not been applied the EMC performance often turns out to be the Achilles heel of the product. Within a properly structured design environment the incorporation of an EMC control plan is not a major overhead.

Responsibility for EMC can be vested in the EMC co-ordinator or in an individual who is a member of the product design team. Their task is to develop the EMC control and test plans and within these to define the test set-up, operating modes and test failure criteria for the product. Familiarity with the appropriate standards and test methods as they apply to the product is essential. Structuring the EMC control in this way results in a strong "sense of ownership" of the EMC aspects of the product, but may not be an efficient way to establish and maintain the expertise in EMC that will be needed throughout the company. Alternatively, the company may have established a separate EMC control group, which oversees the EMC aspects of all product developments on an internal consultancy basis. Whilst this approach allows a company to build up a strong core of EMC-specific expertise, it may result in friction between the product development team and the EMC control engineers which may not eventually give the optimum product-specific solution.

DEF STAN 59-411

For military projects where the UK MoD procures to DEF STAN 59-411, part 2 of this standard [219] has explicit requirements for the formulation of both an EMC Control Plan and an EMC Test Plan.

The Control Plan essentially states how EMC will be achieved, particularly:

> The management and organisational procedures by which the EMC control programme will be implemented and liaison effected … The electrical, mechanical and installation design for EMC, including production and maintenance implications. The screening of the equipment cases, cable form screening policy, filtering and system grounding together with bonding policies … A Test and Qualification Programme for development models and all qualification testing.

Its purpose is to ensure that EMC requirements as defined by the Project Specification and DEF STAN are adequately addressed, to ensure the development of a cost-effective EMC control programme and to identify responsibilities.

17.5.2 The EMC Assessment

Under the first edition EMC Directive, a properly structured and documented control plan formed a valuable and major part of the Technical Construction File if this route to compliance was being followed. Under the later editions, it is pretty much a necessity in order to comply with the requirement for an EMC Assessment.

The requirements of the third edition EMCD were discussed in depth in Chapter 2. To briefly repeat its requirement here:

> The manufacturer shall perform an electromagnetic compatibility assessment of the apparatus, on the basis of the relevant phenomena, with a view to meeting the essential requirements set out in point 1 of Annex I.
>
> The electromagnetic compatibility assessment shall take into account all normal intended operating conditions. Where the apparatus is capable of taking different configurations, the electromagnetic compatibility assessment shall confirm whether the apparatus meets the protection requirements set out in point 1 of Annex I in all the possible configurations identified by the manufacturer as representative of its intended use.
>
> The manufacturer shall establish the technical documentation. The documentation shall make it possible to assess the apparatus conformity to the relevant requirements, and shall include an adequate analysis and assessment of the risk(s).
>
> The technical documentation shall specify the applicable requirements and cover, as far as relevant for the assessment, the design, manufacture and operation of the apparatus. The technical documentation shall, wherever applicable, contain at least the following elements:
>
> — a general description of the apparatus;
>
> — conceptual design and manufacturing drawings and schemes of components, sub-assemblies, circuits, etc.;
>
> — descriptions and explanations necessary for the understanding of those drawings and schemes and the operation of the apparatus;
>
> — a list of the harmonised standards applied in full or in part the references of which have been published in the Official Journal of the European Union and, where those harmonised standards have not been applied, descriptions of the solutions adopted to meet the essential requirements of this Directive, including a list of other relevant technical specifications applied. In the event of partly applied harmonised standards, the technical documentation shall specify the parts which have been applied;
>
> — results of design calculations made, examinations carried out, etc.;
>
> — test reports.
>
> – Annex II

The control plan is clearly able to form the overall framework for this requirement for technical documentation. Much of the content that is required by Annex II above will be delegated to the test plan and the ensuing test reports, if testing to harmonised standards forms the main part of the EMC compliance approach. The explicit requirement for a confirmation that all possible configurations meet the essential requirements will often mean that a more extensive analysis to support testing of limited configurations is needed, and this should be documented in the control plan, as should any rationale for deviations from or limitation of the full tests required by the harmonised standards.

17.5.3 Contents

The control plan can be divided into two major sections, one defining the EMC risks, analyses and best design practice which is to be followed in developing the product, the other defining responsibilities, project reviews and control stages.

Part I

1 Definition of EMC phenomena to be addressed; catalogue of probable sources and victims; site- and installation-specific aspects; rationale for choice of applicable harmonised standards, and listing of these standards

2 Reference to test plan, and if necessary, analysis matrix for products that may take multiple configurations to support limited testing

3 Design practice

This section can draw on the various EMC control methods as discussed in Chapters 11 to 14 of this book. Coverage should be as detailed as possible given what is already known about the design of the product.

- Grounding regime, including a ground map
- Control and layout of interfaces
- Use of screened connectors and cable
- PCB layout
- Circuit techniques
- Choice of power supply
- Filtering of power ports
- Filtering and isolation of signal ports
- Packaging design including screening

Part II

4 Project management

Mandatory EMC design reviews, control stages and checkpoints, and who is responsible for overseeing them; these can normally be incorporated into the overall project management scheme but there may be advantages in separating out the EMC functions.

- Responsibility for progressing EMC aspects
- Preliminary design review
- Design testing
- Detailed design review
- Pre-compliance confidence testing
- Final design review
- Compliance test or certification
- Responsibility for Declaration of Conformity
- Production quality assurance