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ELECTROMAGNETIC COMPATIBILITY & FUNCTIONAL SAFETY

Annex J - Heavy Engineering

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Annex J

A proposed EMC control procedure for heavy engineering projects

Abstract

In the heavy engineering industries, projects can range from small to very large indeed, and they are usually carried out for the customer by contractors and sub-contractors.

This proposed procedure provides top-down control of the EMC of such projects. It has been developed by senior engineers in heavy industry following serious and costly operational problems with projects that were claimed by their contractor to meet the EMC Directive, but which could not function correctly due to EMC shortcomings.

This procedure controls all aspects of EMC, including EMC-related functional safety.

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J1. Executive Summary

Failure of electrical/electronic systems to achieve electromagnetic compatibility (EMC) often results in commissioning delays, under-performance, unreliability and potential unsafe working of plant and equipment.

These commercial and safety problems are destined to escalate as the proportion of sophisticated, but inherently sensitive, electronics deployed in the heavy engineering environment continues to increase.

Whilst legislation has recognised these problems, in that the majority of electrical/electronic plant and equipment (defined as apparatus) currently made or sold within the EEC has to comply in full with the EMC Directive 89/336/EEC, the presence of CE marking cannot, on its own, ensure such problems will be avoided in practice – particularly in the demanding electromagnetic (EM) environments encountered in heavy engineering.

Experience indicates that the best solution is to design out these problems from the outset.

Consequently, this proposed procedure defines a procedure for the procurement of electrical/electronic apparatus in order to avoid unwanted electrical interference or undue susceptibility to interference, and also to help achieve due diligence in meeting legal obligations.

A simple form with supporting checklists, together with a database of generic measurements, are proposed to simplify the task of assessing the EM environment into which the proposed apparatus is to be installed.

A key feature of this procedure is the "Contract Requirement Specification for Electromagnetic Performance" for inclusion in enquiries for apparatus which may generate, or be unduly susceptible to, unwanted electrical interference.

This procedure controls all aspects of EMC, including EMC-related functional safety issues.

J2. Introduction

Failure of electrical apparatus [1] to achieve the necessary EM performance often results in commissioning delays, under performance, and increased costs of maintenance of electrical/electronic systems. These problems are destined to increase as the proportion of sophisticated but inherently sensitive electronics deployed in the heavy engineering environment continues to increase.

Legislation has recognised these problems and the majority of electrical/electronic apparatus currently made or sold within the EEC has to comply in full with the EMC Directive 89/336/EEC [2] (the EMC Regulations [2] in the UK). See also the European Commission Guidelines on the EMC Directive 89/336/EEC, July 1997 [3].

The end-user has a legal obligation under the UK EMC Regulations to only "take into service" apparatus that complies with the essential requirements [4] of the EMC Directive, and needs to be able to demonstrate due diligence in doing so.

Note that the purchase of CE marked apparatus, cannot, on its own, ensure that interference problems are avoided, or that legal due diligence can be demonstrated on the part of the end-user.

In any event, most pure components that form part of the apparatus (the final system or installation) might be CE marked, but this might have nothing to do with demonstrating compliance with the EMC Directive, since the EMC Directive might not be directly applicable to these components.

In essence, all that is required, is that all new electrical/electronic apparatus is assessed in terms of just two essential performance criteria in order to achieve overall 'EM Performance':

- As a prospective sufferer from the electromagnetic threats present in its intended operational environment (this is a measure of its immunity);
- As a prospective source of undesirable interference to other apparatus in its intended operational environment (this is a measure of its *emissions*).

Experience indicates that the best solution is to design out these problems from the outset.

This volume of the proposed procedure relates, therefore, to the procurement of electrical/electronic apparatus in order to avoid unwanted electrical interference or undue susceptibility to interference, and also to help demonstrate due diligence in meeting our legal obligations in respect of safety, the outside world, and third parties.

To achieve this, a preliminary assessment should first be completed using the end-user proforma shown in section J9 of this proposed procedure (and checklists in Appendix J10) .

The results of this assessment can then used to agree the EM performance requirements and post-contract EM Performance testing of the proposed apparatus in the enquiry specification. The results of any assessment should also be fed back for inclusion in the end-user EM Performance Database [5].

A key feature of this approach is the end-user "Contract Requirement Specification for Electromagnetic Performance" (see section J12 of this proposed procedure) which should be included as part of any enquiry which involves electrical or electronic apparatus which could potentially be affected by, or be the cause of, EM incompatibility problems.

J3. The objectives of this proposed procedure

- a) To provide guidance on assessing the implications for the Electromagnetic Performance of equipment, and the procedures that should be taken to eliminate the effects of interference on the performance of apparatus, together with any resulting safety hazards.
- b) To provide guidance to the end-user's Engineers when assessing the Contractor/Supplier's response to electromagnetic performance issues in relation to a contract.
- c) To highlight the steps in this proposed procedure that have implications for machine safety are also a necessary part of the hazards and risk assessments required under the Machinery Safety Directive [5].
- d) To enable those involved in selecting/specifying electrical/electronic apparatus to identify the technical issues involved, the solutions available, and sources of further guidance.
- e) To assist in documenting the end-user's due diligence in complying with the essential requirements of the EMC Directive.

J4. How to apply this proposed procedure

J4.1 The procedure

See flow chart J4.1 below for an overview of the EM Performance assessment procedure.

During the preliminary phase of a project (creation of the enquiry document and the tendering process) this procedure may be applied to an adequate level of detail to ensure that potential Contractors quote as accurately as is required for that phase.

During the final (contract) phases of a project, iteration of the procedures may be necessary to achieve the required level of specification accuracy.

Some projects may benefit by starting off using this proposed procedure to agree a tentative EM Performance specification, tightening it up as time goes by and the number of active tenders reduces until the full and accurate EM Performance specification is identified prior to the placing of the final contract. This is most likely to be true for major projects, or projects where the final configuration of the proposed new apparatus has some flexibility.

Other projects may benefit from applying this proposed procedure right from the start with a level of detail and accuracy that requires no further iteration right through the project. This is most likely to be true for upgrade projects, minor projects, or where the final configuration of the apparatus is pre-defined.

J4.2 Competency of personnel

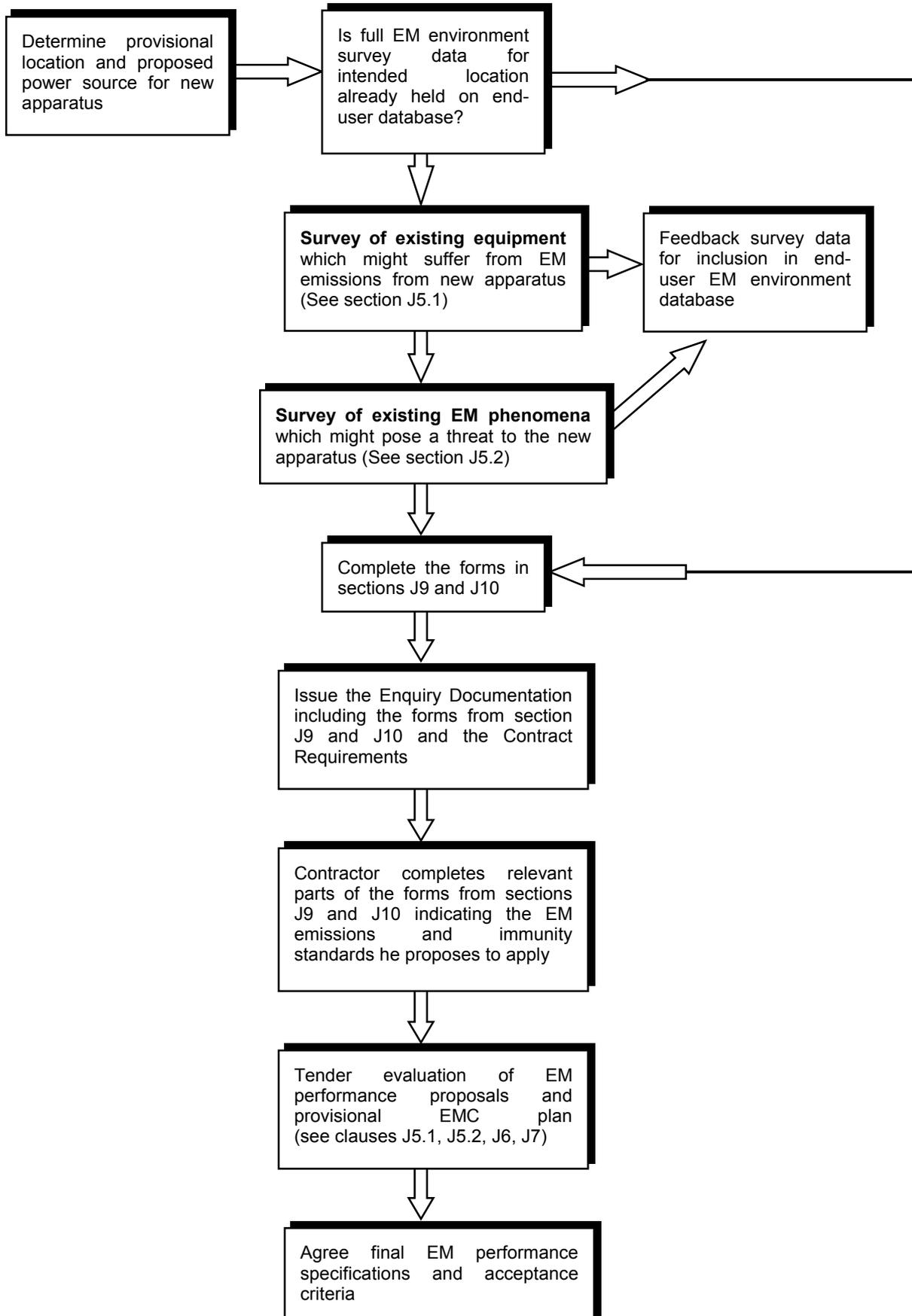
Individuals with responsibility for safety, or engaged upon safety-related tasks of any description, must have been recognised as being competent in safety disciplines to the level required.

A similar requirement exists for EMC competency, but it must be understood that most EMC expertise has been concerned with meeting Directives and/or standards and may not be suitable for EMC-related functional safety activities – which must consider reasonably foreseeable EM disturbances, even where they have a very low probability.

See references [8], [9], and [10] for general guidance on competency.

For more on EMC competency for functional safety work refer to Section 14 in the Core of this guidance document.

Chart J4.1 Overview of the proposed EM performance assessment procedure



J5. The proposed procedure for determining EM performance

J5.1 EM emissions (EM threats *from* new apparatus)

J5.1.1 Selecting the most appropriate emissions standard(s)

All apparatus containing electrical and/or electronic items gives rise to electromagnetic emissions. High levels of electromagnetic emissions from the proposed apparatus can cause:

- Errors or malfunctions in other existing or planned apparatus on the site;
- Problems with radio-communications and telecommunications both on and off site;
- Problems with electronic systems both on and off site.

The electromagnetic emissions from a given apparatus are not a reliability issue for that apparatus itself, so it may be tempting to ignore them. This temptation must be resisted, because *emissions may cause operational/safety malfunctions of existing installed apparatus and are the most likely cause of legal action against the end-user* [4], because emissions from the apparatus may cause interference problems outside the works boundary.

Consequently it is necessary to inform the prospective suppliers of new apparatus of all existing equipment in the vicinity which may be affected by emissions from any new apparatus. Completion of the section J9 proforma of this proposed procedure allows an initial assessment of existing equipment and their distance from any proposed new apparatus. This assessment can be complete in itself, or it may identify particularly sensitive equipments which need additional work to quantify.

In most cases, it is expected that compliance of the proposed apparatus with the most relevant harmonised EMC emissions standard [6] will be enough to ensure that other equipment and radio-communications on and off the site will not be interfered with.

- For the heavy industrial environment typical of a heavy engineering BS EN 50081-2 (generic), BS EN 55022 Class A (computer equipment), or BS EN 55011 ("ISM" equipment) are likely to be the most relevant emissions standards.
- For the commercial environment typical of an office building running from a different distribution transformer than that used by heavy power apparatus, BS EN 50081-1 (generic), BS EN 55022 Classes A or B (information technology), BS EN 55014 (electrical appliances), or BS EN 55015 (lighting) are likely to be the most relevant emissions standards.
- Apparatus that meets the emissions standards for the commercial environment will also meet the emissions standards for the heavy industrial environment, usually with an improved margin.

Bear in mind that the most relevant harmonised standard should only be considered to be the *minimum* requirement, and in some circumstances improved emissions performance may be required.

The following steps will analyse what can be emitted by the proposed apparatus, compare them with the chosen emissions standard(s) and the requirements of any nearby equipment, decide what emissions phenomena and levels are significant, and finally agree the emissions performance specification with the contractor/supplier.

Important Safety Note – non-ionising radiation

Under no circumstances may apparatus operators, maintenance or service personnel, or third parties, be exposed to levels of electromagnetic fields (i.e. non-ionising radiation) which could exceed what is considered acceptable by the end-user's Radiation Protection Advisers.

Where the possibility of such exposure exists, always follow the guidance of the end-user's Radiation Protection Advisor (or other responsible health and safety expert) for the site.

J5.1.2 Comparing the emissions from the proposed apparatus with the chosen emissions standard(s)

There is a need to assess the emissions standard proposed by the Contractor for the new apparatus to check whether it adequately covers the required emissions performance.

EU harmonised EMC emissions standards [6] compromise between technical and commercial issues, and their official purpose is to help break down political barriers to trade within Europe. The end-user's concern is more with actual operational and safety performance and reliability than with cross-border trade agreements, so harmonised EMC emissions standards need to be regarded as minimum requirements which may not in fact be adequate to address the end-user's realistic engineering necessities.

Examples of apparatus which can meet harmonised EMC emissions standards and still present severe emissions problems include:

- 50Hz electromagnetic stirrers, which generate powerful 50Hz magnetic fields (the generic emissions standards don't specify emissions limits at 50Hz);
- Arcing contactors, especially if they suffer from re-striking (the harmonised generic industrial emissions standard EN 50081-2 does not specify any limits for short-term emissions such as these that happen less than five times a minute);
- Powerful DC drives, the motor cables of which can generate powerful DC magnetic fields (no harmonised emissions standards include limits for DC field emissions);
- ISM apparatus (which complies with EN 55011) such as plastic welders or sealers, induction heaters, microwave cookers or dryers, can have *extremely* intense emissions in certain radio frequency bands, even creating personnel safety hazards.

Any high-power electrical apparatus may be capable of causing unacceptable levels of electromagnetic emissions. The particular problems of powerful radio frequency emissions from ISM apparatus is addressed in a later section.

It is necessary to deal with the above possibilities to ensure the reliability of other apparatus, and also for the end-user to be able to demonstrate legal "due diligence" in EMC.

- a) All the possibilities for electromagnetic emissions from the proposed apparatus are to be assessed.

Section J11 of this proposed procedure gives a list of the electromagnetic phenomena, and what typically causes them.

Volume 2 of this proposed procedure lists the IEC 1000-2-x series, which will also be found very helpful in determining what there is in the proposed apparatus that could cause significant emissions. Also, Volume 2 of this proposed procedure lists the electromagnetic phenomena covered by the generic emissions standard for the industrial environment, and provides a few important notes on the implications of this standard. Other standards will be different.

- b) Compare the emissions possibilities for the proposed apparatus with those adequately covered (for the intended use of the proposed apparatus) by the chosen harmonised standard.
- c) Where the proposed apparatus is ISM, *proceed to step J5.1.3*
- d) Where the proposed apparatus is not ISM, and where there *are* likely to be significant emissions not adequately covered by the chosen standard, *proceed directly to step J5.1.4*
- e) Where the apparatus is not ISM, and there are *no* likely significant emissions possibilities not adequately covered by the chosen standard, *proceed directly to step J5.1.4*

J5.1.3 The particular problems of RF emissions from "ISM" apparatus

Of particular concern when assessing the emissions of the proposed apparatus is "ISM apparatus" – i.e. it employs electromagnetic energy to achieve its intended function. Examples of such apparatus include:

- Induction heating
- RF excited welding
- Dielectric heating, such as plastic welders and sealers
- Ultrasound equipment
- Microwave heating or drying
- Spark erosion equipment

The harmonised EMC emissions standard for "ISM apparatus" is EN 55011. It is vital to understand that *this standard allows extremely powerful electromagnetic emissions to occur* in certain allocated frequency bands.

Although this standard is intended to protect radio-communications, which use other frequency bands, the very high levels of RF emissions it allows can be more than sufficient to interfere with other types of electronic systems, and can even be sufficient to cause health hazards for operators, maintenance and service personnel, and third parties.

- The actual worst-case field strengths emitted into the environment from the proposed "ISM" apparatus should be identified and compared with the EMC immunity specifications of the other apparatus in its vicinity (or likely to be in its vicinity in future) *according to step J5.1.4*

Important Safety Note – non-ionising radiation

ISM apparatus should always be checked for safety by the end-user's Radiation Protection Advisors (or other responsible Health and Safety expert) before it is first used, and also at intervals during its life, as regards its emissions of non-ionising radiation. It is quite common for there to be prohibited areas around such equipment.

J5.1.4 Determining the acceptable consequences of interference

Having predicted the emissions from the proposed apparatus, this step assesses whether there is likely to be a lack of adequate immunity to these emissions by other (nearby) apparatus.

This could be a particular problem for older apparatus containing electronic systems (especially apparatus the design of which pre-dated the implementation of the EMC Directive: 1/1/96). Although such apparatus may be functioning reliably at present, it may not be known whether it is likely to suffer from the different kinds (or higher levels) of electromagnetic emissions from the new apparatus.

It may also be a problem for existing or planned apparatus even though it does have good EM Performance and/or meets the EMC Directive, where the proposed new apparatus has significantly high levels of emissions (especially likely for ISM equipment).

It may be that the proposed apparatus has significant emissions of electromagnetic phenomena which are not adequately covered by the relevant harmonised standard, or which are not adequately covered by the immunity specifications of the other apparatus.

- a) Assess the potential for interference by considering the individual functions provided by the other apparatus, according to the guidelines given in Volume 2. This will establish which are the more critical functions, and establish acceptable performance criteria for them.

- b) Then assess the immunity of this other apparatus with regard to the emission phenomena and emission levels as assessed for the proposed apparatus, and decide on the likelihood of problems arising for each of the apparatus's functions.
- c) Then decide whether the possible interference consequences are significant or not. e.g. where the proposed apparatus emits continuous interference at a frequency or level which could interfere with a safety critical function (another apparatus, a walkie-talkie system, or whatever) – this will have the highest level of significance.

E.g. where the proposed apparatus emits a transient which can only upset a non-critical monitoring function which will restore itself without change of operational state or loss of data – this might be regarded as insignificant.

- d) All consequences identified as *significant* are to result in agreed and documented actions to prevent them – to the degree required by the criticality of the function.

Considerable expertise may be needed to solve some of these interference problems. Possible solutions include (amongst others):

- Agreeing an emissions limit on the proposed apparatus for the emissions phenomenon concerned, even where this goes outside the requirements of the harmonised standard.
- Modifying the other apparatus to increase its immunity to the problem emission, e.g. by fitting filters and shielding, re-routing cables, etc.
- Moving the other apparatus further away to reduce the likelihood of radiated interference, and/or powering it from a different AC supply network or from a different distribution transformer to reduce the likelihood of conducted interference at low frequencies.
- A combination of all the above.

Where the original manufacturer of older apparatus cannot help with the assessment of its immunity, considerable EMC expertise may be required. Site tests of immunity are possible, and would be based upon the anticipated emissions from the proposed apparatus and the significance of any interference on functionality.

It is recommended that if such expertise is required, it is employed when the siting of the proposed new apparatus is being decided. Generally the most effective solution to such problems is physical segregation, this often has a very low cost when considered early in a project, but a very high cost if implemented post-installation.

When all the above is complete, the emissions performance for the proposed apparatus should be agreed with the contractor as follows:

- a) Agree the emissions phenomena from the proposed apparatus which it is necessary to control to prevent interference with other apparatus and to meet legal requirements;
- b) Agree a list of the levels of the individual emissions phenomena to be achieved.

This specification could be achieved as follows:

- The simplest case is merely identifying the relevant harmonised standard required for the presumption of conformity. (Although it is hoped that this will suffice in many cases, the end-user will from time to time use apparatus for which no harmonised standards are adequate.);
- It may be possible to merely identify and agree the relevant harmonised emissions standard and specify lower emissions limits (e.g. to protect critical radio links);
- It will be necessary from time to time to specify electromagnetic phenomena which are not covered by the relevant harmonised emissions standard (e.g. 50Hz or DC magnetic fields, or transient emissions) and set limits for them. This will generally best be achieved by agreeing a harmonised immunity standard and modifying it with a few deviations or additions.

- Agree and describe in detail any actions which may be required to limit or accommodate the emissions from the proposed apparatus (e.g. increasing the distance to possibly sensitive equipment) in order to achieve the agreed functionality and safety functionality of other apparatus.

Any minimum separation distances must be included by the contractor in the apparatus specification. They must also be stored and displayed in such a way that they are automatically employed when any future apparatus (or modifications to existing apparatus) within or near the proposed apparatus is specified.

J5.2 EM immunity (EM threats to the new apparatus)

J5.2.1 Assessing and specifying the EM environment

Many types of equipment used in heavy engineering are significant sources of electromagnetic energies (refer to section J11 for more information). These energies can "pollute" the electromagnetic environment and compromise the correct operation of other electrical or electronic apparatus in that vicinity.

Consequently it is necessary to specify the existing electromagnetic environment (especially its major threats) in the specification of any new apparatus.

- a) The electromagnetic environment in which the proposed apparatus is intended to operate needs to be assessed. Completion of the forms in sections J9 and J10 of this proposed procedure allows an initial assessment to be made concerning the types and levels of electromagnetic threats in a given location. This assessment can be complete in itself, or it may identify particular threats which need additional work to quantify.

E.g. there may be a need to consult with internal/external EMC experts and/or Power and Distribution Department, to establish power supply criteria.

- b) EM site measurements are a possible method of identifying threats in more detail. Suppliers of such services may be found in a number EMC industry proposed procedures.
- c) Another possible method is to use analyses and calculations, and/or the BS IEC 1000-2-x series of standards which are intended to help assess the environment (listed in Volume 2 of this proposed procedure.)

Some possible electromagnetic threats in the environment may be dismissed as insignificant during this activity. The project documentation should show the complete technical arguments used for any such dismissals.

J5.2.2 Comparison with harmonised immunity standards

EU harmonised EMC immunity standards [6] are a compromise between technical and commercial concerns whose aim is to help break down political barriers to trade within Europe. The end-user's concern is more with actual operational and safety performance than with cross-border trade agreements, and harmonised EMC immunity standards need to be regarded as minimum requirements which may not in fact be adequate to address the end-user's realistic engineering/operational necessities.

The Generic Immunity Standard BS EN 50082-2 will usually be the most relevant for the end-user's apparatus, and a checklist of the threat phenomena and levels it covers is shown in Volume 2 of this proposed procedure.

The following comparisons should then to be made between the assessed EM environment (from J5.2.1) and the standard indicated by the Contractor in the tender documentation:

- a) The individual electromagnetic threat phenomena themselves: to see if the standard covers all the significant threats.

Of particular concern here are voltage surges, supply dips and interruptions, and DC magnetic fields, none of which are included yet in the generic industrial immunity standards.

- b) The levels and ranges of the significant threat phenomena.

Of particular concern here are threats which are more powerful than those in the standard, e.g. when an operator uses a walkie-talkie whilst controlling the apparatus, or for e.g. when an RF induction heater or electromagnetic stirrer (or any of their cables) is nearby.

- c) In many cases the electromagnetic environment may be assessed to be the same as that described by the relevant immunity standard. *In such cases proceed directly to J5.2.4*

J5.2.3 Where the electromagnetic environment does not match a harmonised standard

In this situation there are a number of possibilities, the four main ones being:

- a) Moving the intended location of the apparatus to a place where the environment is easier for the apparatus to cope with.

This is often the most cost-effective solution if done at the tender/design stage.

- b) Improvement of the intended operational environment, e.g. by improving shielding, filtering and lightning protection measures of the apparatus to reduce exposure to damaging surges.

- c) Agreeing with the contractor and uniquely specifying the EMC immunity for the proposed apparatus so that it covers the actual electromagnetic environment assessed in J5.2.1.

This will generally be achieved by specifying a harmonised immunity standard and modifying it with a few deviations or additions. The cost effectiveness of this needs to be carefully considered.

- d) Limitations to use.

This especially applies to the use of mobile phones and walkie-talkies near to the apparatus. Limiting the use of such mobile radio transmitters around apparatus should always be considered as an alternative to specifying more onerous immunity standards.

Important Safety Note – functional safety

Safety and other critical functions need to have adequate EM immunity even when faults, human errors, low-probability EM disturbances, and foreseeable misuse are taken into account.

Foreseeable misuse includes the possibility that people will forget or ignore warnings not to use cellphones or walkie-talkies.

All reasonably foreseeable EMC-related functional safety issues should be addressed by the hazards and risk assessment which is undertaken as a necessary part of compliance with the Low Voltage Directive and Machinery Directive.

The use of the standard IEC 61508 [7] is strongly recommended when dealing with the functional safety of any electrical/electronic/programmable electronic systems.

J5.2.4 Determining the acceptable consequences of interference

- a) The proposed apparatus must be assessed for the possible consequences of it being interfered with.

This requires that all the potentially degraded functional, functional safety, and health and safety performances are *quantified* for the acceptable performance of apparatus concerned, and the processes it employs, during exposure of the apparatus to any reasonably foreseeable EM disturbances in its environment, including those caused by earth-faults, other faults, errors, misuse, and low-probability events such as lightning.

- b) The table shown in J5.2.5 is a proposed procedure to aid in the selection of the amount and nature of degraded performance which may be allowed for the various functions possible in a proposed apparatus when it is exposed to the various types of EM threats in its intended operational environment.
- c) Volume 2 of this proposed procedure includes some examples of EMC problems that are known to have occurred. Many other unexplained malfunctions may be due to EMC problems.

The apparatus' EM Performance final specification is incomplete until its "performance criteria" are quantified and agreed.

Actions are needed if the possible performance or safety degradations are unacceptable, and must be documented.

Important Safety Notes

This proposed procedure does not allow *ANY* degradation from normal functional performance for protection and safety-related functions, for any EM phenomena, regardless of their probability of occurrence.

It is necessary to consider foreseeable misuse (such as operation with enclosure doors open) when considering safety-related issues.

This is fully in line with the requirements of the Machinery Safety Directive [6], but it often appears that many machinery manufacturers do not take account of EMC-related safety even though fatal accidents have occurred which have been attributed to EMC problems.

J5.2.5 Selecting appropriate levels of functional performance for different types of EM threat (in descending order of criticality)

Functions (*)	Functional requirements versus the nature of the EM disturbance (for EM threats to the apparatus)				
	Continuous phenomena	Frequent Transients	Infrequent Transients		
Protection, teleprotection, and safety (**)	Normal performance within the limits set by the apparatus's functional and functional safety specifications				
On-line control of processes					
Counting					
Command and control				Short delay (1)	
Supervision				Temporary loss, self-recovered (2)	
Man-machine interface				Stop and reset (3)	
Alarm				Short delay (4), temporary wrong indication	
Data transmission and telecommunication (***)				No loss, possible bit error rate degradation (5)	Temporary loss (5)
Data acquisition and storage				Temporary degradation (2) (6)	
Metering				Temporary degradation, self-recovered (7)	
Off-line processing	Temporary degradation (6)	Temporary loss and reset (6)			
Monitoring	Temporary degradation	Temporary loss			
Self-diagnosis	Temporary loss, self-recovered (8)				

- * For apparatus with multiple functions, as well as for concurrent functions (e.g. supervision and monitoring), the performance related to the most critical function applies.
 - ** For teleprotection using power line carrier the "normal performance" during the switching of HV isolators may need an appropriate validation procedure.
 - *** Only where used in automation and control systems as an auxiliary function to other ones, e.g. to implement co-ordination.
- 1 A delay which is insignificant compared to the time constant of the controlled process is acceptable.
 - 2 Temporary loss of data acquisition, and deviation in event scheduling time is acceptable, but the correct sequence of events shall be maintained.
 - 3 Manual restoration by operators is allowed.
 - 4 With respect to the degree of urgency (not to the process).
 - 5 Temporary bit error rate degradation can affect the communication efficiency; automatic restoration of any stoppage of the communication is mandatory.
 - 6 No effect on stored data or processing accuracy.
 - 7 Without affecting the metering accuracy of analogue or digital indication.
 - 8 Within the system diagnostic cycle.

J6. Provision of installation, commissioning, operation, and maintenance instructions

The Contractor shall provide for all proposed apparatus full and accurate instructions which describe the following in detail:

- a) Its intended operational electromagnetic environment (agreed with the end-user for the apparatus);
- b) Any limitations to use (agreed with the end-user and incorporated into the apparatus's EM Performance specification);
- c) How the apparatus is to be installed and commissioned to achieve the EM Performance required by the end-user.
- d) This must including full details of the types of cables and connectors to be used, how they are to be routed and terminated, the skill levels and any special training or tools required for installers, commissioning personnel, etc.
- e) How the apparatus is to be operated and maintained to continue to achieve the end-user's required EM Performance for the expected life of the apparatus.
- f) This must including full details of any replacement (lifed) parts required, how they are to be installed, the skill levels and any special training required for operators and maintenance personnel, etc.

J7. EM performance acceptance criteria

J7.1 Specifying the final EM performance acceptance criteria

The agreed EM Performance specification for the apparatus is to detail the final (hand-over) acceptance criteria for the EM Emissions and Immunity of the proposed apparatus

This is especially important for the more critical or safety-related functions, both for the immunity of proposed apparatus itself, and the effects of its emissions on other apparatus.

There are a number of ways of achieving the necessary confidence that the desired EM performance has been achieved. Here are a few of the more common:

- On-site acceptance testing is an obvious and commonly-used method, and has the advantage of testing the finished apparatus. But if problems are found at this late stage they are bound to result in significant delays and expense.

Alternatives to site testing are listed below. These have the advantage that they cost less and should result in a higher probability that the finished apparatus has the required EM performance.

Even if final site testing is still to be carried out, best results will be achieved if the Contractor specifies that work such as that described below is carried out:

- Testing of completed control panels in a test laboratory, when they are connected to representative cables using good-practice installation methods (refer to Volume 2 of this proposed procedure for EMC Best Practice Guidelines for Electrical Installations).
- The construction of control panels from sub-assemblies with individual laboratory-proven immunity performance, plus quality-controlled assembly and installation practices known to be good for EMC (refer to Volume 2 of this proposed procedure for EMC Best Practice Guidelines for the Design and Assembly of Control Panels).
- An EMC Technical Construction File, approved by an EMC Competent Body, *which is checked by the end-user* to ensure that it covers the environment (threats), performance criteria, installation methods, emissions, and any limitations to use in accordance with the agreed EM Performance specification for the apparatus.

N.B. It may not be sufficient for the end-user's legal "due diligence" to rely solely upon a CE mark and/or EMC Declaration of Conformity from the manufacturer of the apparatus.

To help prevent delays late in a project: consider making a stage payment dependant on acceptable final site test results. This helps ensure that manufacturers use good practice, and so helps to achieve the aims of this document – trouble-free apparatus purchasing, installation, and operation.

Important Safety Notes

EMC testing can never prove that an apparatus is totally safe (as regards EMC-related functional safety). This is because EM disturbances have a statistical distribution and it is impossible to know what the most extreme level of a disturbance of a given type may be –so it can't be tested for.

To ensure that EMC-related safety is properly taken care of requires a competent analysis of the reasonably foreseeable EM disturbances, and EMC testing (usually) at the levels considered necessary to achieve the required safety integrity level (e.g. according to IEC 61508 [7]).

J7.2 A note on installation methods

Apparatus which has been EMC tested and proven to meet an immunity standard (or otherwise specified immunity performance) at a test laboratory (or any site other than its final site) may fail to achieve its expected immunity performance if it is not installed in *exactly the same way* as it was installed when it was tested.

Hence the requirement for the proposed apparatus to be provided with full instructions on installation methods, including the types of cables and connectors, how they are to be routed and terminated, earthing, etc.

For similar reasons, apparatus should always be provided with full instructions on how to maintain EM Performance over its anticipated life, including maintenance, servicing, and operation. Refer to section J6 for more guidance.

Important safety notes

On-site acceptance tests should always be conducted wherever there are any implications for safety or other critical functions, whether for the proposed apparatus or other apparatus that may possibly be affected by the emissions from the proposed apparatus.

If such final site tests are not carried out there must be a perfectly acceptable reason for this decision carefully described and documented in the project file (and in any Technical Construction File).

(However, as described above, EMC testing alone is not sufficient proof that the EMC-related functional safety issues have been correctly dealt with.)

J8. References and Notes

[1] 'Apparatus' is defined within the Directive as 'all electrical and electronic appliances together with equipment and installations containing electrical and/or electronic components'.

[2] The Electromagnetic Compatibility Directive, 89/336/EEC, amended by 91/263/EEC, 92/31/EEC, 93/68/EEC, and 93/97/EEC.

Implemented in UK law as *The Electromagnetic Compatibility Regulations 1992*, SI 1992 No 2372 (ISBN 0-11-025372-8) amended by SI 1994/3080 (ISBN 0-11-043614-8) and SI 1995 No 3180 (ISBN 0-11-053758-0). All these Statutory Instruments are now fully in force in the UK, and all are available from The Stationery Office. Tel: 0207 873 9090, fax: 0207 873 8247.

[3] *European Commission Guidelines on the EMC Directive 89/336/EEC, July 1997*. Available free from the web-page given in [6].

[4] The "essential requirements" of the EMC Directive, which the end-user has to show "due diligence" in complying with for all new apparatus, require that no actual interference is caused or suffered from, regardless of its frequency or rate of occurrence. It is worth noting that in the UK (and most of the EU) compliance with a harmonised [6] standard does not on its own automatically ensure compliance with legal requirements.

In the UK, Trading Standards Officers have the authority to shut down factory operations for up to six months, if they are satisfied that the equipment or apparatus is the likely cause of an interference problem. Such actions can cause significant loss of production capacity, failure to meet contract terms, etc., and would usually have a severe negative financial impact.

[5] *The Machinery Safety Directive: 98/37/EC* as amended. Implemented in UK law by *The Supply of Machinery (Safety) Regulations 1992* SI 1992 No. 3073 (ISBN 0-11-025719-7), amended by SI 1994 No 2063 (ISBN 0-11-045063-9). All these Statutory Instruments are now fully in force in the UK, and all are available from HMSO (now called The Stationery Office. Tel: 0207 873 9090, fax: 0207 873 8247).

[6] A harmonised EMC standard is one that has been listed under the EMC Directive in the Official Journal of the European Communities. For an up-to-date list of harmonised EMC standards consult the Official Journal of the European Community (OJEC) or visit:

<http://europa.eu.int/comm/dg03/directs/dg3b/newappro/eurstd/harmstds/reflist/emc.html>

[7] IEC 61508 *Functional safety of electrical / electronic / programmable electronic safety-related systems*

IEC 61508-1 Part 1: *General Requirements*

IEC 61508-2 Part 2: *Requirements for electrical / electronic / programmable electronic safety-related systems*

IEC 61508-3 Part 3: *Software requirements*

IEC 61508-4 Part 4: *Definitions and abbreviations*

IEC 61508-5 Part 5: *Examples of methods for the determination of safety integrity levels*

IEC 61508-6 Part 6: *Guidelines on the application of parts 2 & 3*

IEC 61508-7 Part 7: *Overview of techniques and measures*

[8] Safety, Competency, and Commitment – Competency Guidelines for Safety-Related System Practitioners 180pp ISBN 0 85296 787 X, available from IEE Publications, Ref: PA 023

[9] IEE Professional Brief Professional Conduct, 1992

[10] The Engineering Council Guidelines on Risk Issues, 1993

J9. Electromagnetic performance survey information proforma

This is a summary information form for issuing to prospective suppliers (tenderers), to enable them to assess the electromagnetic performance and standards for emissions and immunity required for their proposed apparatus

NOTES:

- 1. To be included with the enquiry documentation provided by the customer**
- 2. To be completed by the prospective supplier (the tenderer) and returned with the proposal (the tender)**

Plant/Area:.....

Completed by:.....

Date:.....

PROJECT TITLE:.....

J10. Checklist: apparatus which could suffer Electromagnetic Compatibility (EMC) problems

LOCATION..... PROJECT TITLE.....

EQUIP		DISTANCE	
ANALYTICAL EQUIPT	GAS DETECTORS		RADIO (DATA TRANSMISSION)
ATR SYSTEMS	HV CABLES		RADIO (MICROWAVE SYSTEMS)
CAD SYSTEMS	INFRARED EQUIPT		RADIO (PAGING SYSTEMS)
CARD PASS SYSTEMS	INSTRUMENTATION SYSTEMS		RADIO CONTROL EQUIPT
CHART RECORDERS	INSTRUMENTATION CABLES		RADAR EQUIPT (IN VICINITY)
CNC LATHE SYSTEMS	INTRUDER/BURGLAR ALARMS		ROUTERS (COMPUTER)
CIRCUIT BREAKER PROTECTION	LASER EQUIPT		SERVERS (COMPUTER)
CO MONITORS	LV CABLES		SCADA SYSTEMS
COMPUTER CONTROL UNITS	COMPUTER LINE DRIVERS		TELEPHONE EXCHANGE EQUIPT
CCTV MONITORS	COMPUTER MODEMS		TELEPHONE ANSWERING MACHINE
CCTV CAMERAS	PC'S (DESK)		TELEPHONES
CCTV CONTROL SYSTEMS	PC'S (PORTABLE)		VIDEO CONFERENCE EQUIPT
CCTV CABLES	PLC,S		VARIABLE SPEED DRIVES
COMMS/DATA CABLES	PHOTOCOPIERS		WEIGHING SYSTEMS/EQUIPT
DIGITAL DISPLAYS	PROCESS CONTROL COMPUTERS		
DC CABLES	PRINTERS (ALL TYPES)		

J11. Possible electromagnetic disturbances in the environment of the apparatus

Table J1: Continuous disturbances

Table J2: Additional details on radiated fields from radio transmitters

Table J3: Transient disturbances with a *high* probability of occurrence

Table J4: Transient disturbances with a *low* probability of occurrence

Table J1 Continuous EM disturbances

The electromagnetic disturbances, their principal sources or causes, and some examples and comments.	Basic standards allowing assessment of the environment	Basic test methods for emissions from an apparatus	Apparatus particularly susceptible to the phenomena	Basic test methods for immunity, and degrees of threat
<p>AC or DC supply voltage variations (slow variations)</p> <p>Most supply variations do not exceed 10%, although in some parts of some countries (even in the EU) the official figures for supply tolerance should not be accepted without question.</p> <p>In certain industries, excessive variations may be caused by very heavy loads, such as arc furnaces, welding, electrolysis and electroplating, and other continuous loads with varying current demands.</p>	IEC 61000-2-5		All normal electronic equipment considered susceptible at >±10%.	IEC 61000-4-14, -28, and -29
<p>AC supply phase unbalance</p> <p>Caused by asymmetrical loads, or large single-phase loads.</p>	IEC 61000-2-5		Three-phase equipment which relies upon phase balance (e.g. AC motors, transformers).	IEC 61000-4-14, and -27
<p>DC supply ripple</p> <p>Caused by AC rectification, or battery charging. A consideration for equipment that operates from rectified AC or batteries that are charged during its operation.</p>	IEC 61000-2-5		Neutral cables may overheat. Contact breakers may trip or fuses blow unexpectedly	1: 2% F _{nom} 2: 3% F _{nom} X: special (case by case)
			All normal electronic equipment considered susceptible at >±10%.	IEC 61000-4-17

Harmonics and interharmonics of the AC power supply

(= waveform distortion)

- Non-linear loads:
- static frequency and cyclo-converters
- induction motors
- welding
- AC-DC power converters (e.g. adjustable speed drives or large numbers of single-phase computers)
- transformers driven into saturation.
- Strongly-disturbed networks (e.g. in steelworks) can exceed 10% THD.
- Supply network resonances can create very high levels at certain frequencies.
- Supplies in developing countries (e.g. China) can have very heavy levels of harmonic distortion indeed.

AC or DC magnetic fields

Medium and High-voltage supply distribution. Heavy power use. Principal sources are power conductors.

- Audio-frequency magnetic fields also exist near audio power amplifiers and induction loop systems.
- All cables carrying currents, whether analogue or digital, leak magnetic fields to some extent, and this may be important for very sensitive circuits.
- 100A/m has been seen 10m from steel rolling mill DC drive cables ($\pm 8kA$), and $> 1000A/m$ at 1m.
- A 1.1kHz 800kW steel billet induction heater has been seen to emit 100A/m at 1m
- A 230kHz 400kW steel tube welder with a coil diameter of 50mm can create 40A/m at 0.25m from its coil.
- A 50Hz 6MW copper billet heater generated 430A/m at a distance of 1m.
- A 700Vdc 60kA electrolytic process can create 15kA/m at operator position.
- At ground level under an overhead 400kV line: 32A/m.
- At ground level above an underground 400kV line: 160A/m.
- Directly under high voltage lines, field strengths in the range 10 to 16 A/m for every 1000 Amps in the lines are encountered. At a lateral distance of 30m from the lines, fields is reduced to 3 to 5A/m for every 1000 Amps (HP App Note 1319)

IEC 61000-2-4 IEC 61000-2-5	IEC 61000-3-2 ($\leq 16A/\phi$, LV)	Power converters and other electronics, which use zero waveform peak, or slew rate of supply waveform for timing or other purposes.	IEC 61000-4-7 and -13
	IEC61000-3-4 ($>16A/\phi$, LV)	AC/DC power supplies can output lower than expected voltages due to supply waveform distortion, leading to erroneous operation of any/all electronics.	1: 4% THD 2: 8% THD 3: 10% THD X: special (case by case)
	IEC 61000-3-6 (MV or HV)	Power factor correction capacitors, distribution transformers, cables, AC motors, and switchgear can overheat and be damaged, with risks of fire and even explosion.	
	IEC 61000-3-9 (interharmonics)	Excessive acoustic noise and vibration can occur with actual structural damage, and AC motor bearings can fail early.	
	No basic IEC or EN test method.	Nuisance tripping of overcurrent protection devices (fuses, MCBs, etc).	IEC 61000-4-8
	Search coil method: Annex A of EN 55103-1	CRT-based displays and computer monitors start to suffer visible image degradation at $>1A/m$.	1: 3A/m
NRPB-R265 (ISBN 0-85951-368-8)		(CRTs can achieve 20A/m or more when fitted with magnetic shielding or cancellation devices.)	2: 10A/m 3: 30A/m 4: 100A/m X: special (case by case)
IEC 61000-2-5		(LCD and plasma displays do not suffer from this problem.)	
		Microphones, loudspeakers, Hall effect, and other magnetic transducers can produce erroneous outputs.	
		Hearing aids with inductive loop pickup (the "T" setting) are very sensitive to low-level magnetic fields, which may be many tens of meters from power, telecomm, or data cables.	

- High-voltage sub-stations (220 and 400kV) can produce fields of 9 to 14 A/m near a line carrying 500A. In the relay room, 1 to 7 A/m fields are encountered, with 0.7 A/m in the equipment room.

- Power/industrial plant bus-bars carrying 2200A produce fields of 6 to 85 A/m depending on distance (roughly 0.3 to 1.5m respectively) Hewlett Packard Application Note 1319
- Commercial premises under-floor heating can create 160A/m at floor level, 16A/m at 1m height above floor.
- 8A/m has been seen at floor level in a multi-storey office, above a sub-floor carrying cables from distribution transformer to switch-room, and up to 2A/m at desk height.
- A TIG welder has been seen to emit 800A/m at the surface of the welding cable and surface of its power supply, and \leq 160A/m at the operator's position.
- A 1kW water pump has been seen to emit 800A/m at 10mm distance, and 3A/m at 400mm, whereas an 18kW motor emitted 6A/m at 200mm.
- Most household appliances generate magnetic fields in the range 0.03 to 10 A/m, with a maximum of 20 A/m, all at a distance of 0.3m from their surface. At 1.5m, field strengths are typically below 0.1 A/m with a maximum of 0.4 A/m (Hewlett Packard Application Note 1319).

AC or DC electric fields

Medium and High-Voltage supply distribution. Heavy power use. Principal sources are power conductors.

- A 490kHz 8kW steel tube heater with a coil diameter of 60mm has been seen to emit 100V/m at 0.3m from its coil.
- A 20kHz 1.5kW induction cooker hob generated 28V/m at 250mm
- 1kV/m = outdoors under 30kV lines, or indoors under 765kV lines
- 10kV/m = outdoors under 400kV lines
- 20kV/m = outdoors under 765kV lines

Signalling voltages on the AC power supply

Ripple control (100Hz to 3kHz) and power-line carrier systems (3 to 95kHz) used by electric utilities.

Signalling in end-user premises (95 to 148.5kHz)

- Supply network resonances can create very high levels at certain frequencies.

Conducted interference DC to 150kHz in all conductors (voltages and currents)

Industrial electronics (power semiconductor devices such as rectifiers, thyristors, IGBTs, FETs, etc), leakage currents of RF filters and other earth currents, VLF and ELF radio transmitters. This phenomenon is most likely to be observed in very large installations using large amounts of power.

- 50V differences in earth potentials are allowed by UK wiring regulations
- Practical experiences in Sweden reveal the following levels of 50Hz conducted interference:

<p>Unshielded sensitive or high-impedance analogue circuits or transducers.</p> <p>Sparks due to high electric field strengths can ignite flammable materials and atmospheres.</p>	<p>NRPB-R265 (ISBN 0-85951-368-8)</p> <p>IEC 61000-2-5</p>	<p>IEC 61000-3-8 (outside Europe)</p> <p>EN 50065 (in Europe)</p>	<p>IEC 61000-2-1</p> <p>IEC 61000-2-2</p> <p>IEC 61000-2-12</p> <p>IEC 61000-2-5</p>	<p>Power converters and other electronics, which uses the zero crossing, peak, slew rate, or other characteristics of the supply waveform for timing or other functions.</p> <p>Long wave and medium wave radio receivers.</p> <p>Analogue telephone systems. Sensitive instrumentation (e.g. temperature, flow, weight), audio, and video.</p>	<p>1: 0.1kV/m 2: 1kV/m 3: 10kV/m 4: 20kV/m X: special (case by case)</p> <p>IEC 61000-4-13 (to 2.4kHz only)</p> <p>1: 5% Vrms 2: 9% Vrms (0.1 – 3kHz only) X: special</p> <p>These levels are for close proximity to the emitters.</p> <p>IEC 61000-4-16</p> <p>1: 1Vrms 2: 3V 3: 10V 4: 20V X: special (case by case)</p>

1V in protected environments (e.g. installations that meet IEC61000-5-2);
250V in unprotected installations (typical of older plant);
500V in outdoor installations associated with HV switchgear.

<p>Conducted interference above 150kHz in all conductors (voltages and currents)</p> <p>Most importantly from the RF fields generated by fixed and mobile radio and TV transmitters and some ISM equipment (especially Group 2 of BSEN 55011). Also coupled into conductors from synchronous (clocked) digital circuits and semiconductor power converters. May apply less, or only in certain frequency bands, or not at all, to equipment and all cables used in screened rooms (depends on the screening performance of the room). Also see footnote to Table J2</p>	<p>IEC 61000-2-3 IEC 61000-2-5</p>	<p>EN 55022, 55013, 55014, or 55015 (residential, commercial, light industrial) EN 55011 (ISM or heavy industrial)</p>	<p>Radio receivers. Digital control and signal processing suffers 'phantom' keypresses, false addresses or data, software looping, and crashes (broadly in order of increasing disturbance). Digital outputs can take on any combinations of states. Sensitive analogue instrumentation (e.g. temperature, flow, weight), audio, and video. Analogue telephones. As above.</p>	<p>IEC 61000-4-6 1: 1V (7 mA) 2: 3V (21 mA) 3: 10V (70 mA) 4: 30V (210 mA) X: special (case by case)</p>
<p>Radiated interference above 150kHz</p> <p>Most importantly from fixed and mobile radio transmitters, and some ISM equipment (especially equipment covered by Group 2 of BSEN 55011). Also from synchronous (clocked) digital circuits and semiconductor power converters such as PSUs and AC motor drive inverters. May apply less, or only in certain frequency bands, or not at all, to equipment and all cables used in screened rooms (depends on the screening performance of the room).</p> <ul style="list-style-type: none"> • MHz-operation dielectric heaters of 3 to 15kW have been known to create 300V/m at the operator's position. • Hand-held walkie-talkies and cellphones can generate 30 V/m field strengths at distances of 400mm and 250mm, respectively. (Greater fields at smaller distance) • A 1200kW medium-wave broadcasting station generated 32V/m at 0.5km. • A wire-type spark erosion machine generated the equivalent of 0.02V/m field at 1m. <p>See Table J2</p> <p>Radiated interference above 150kHz from high-voltage power lines</p> <p>Broadband (random) noise caused by:</p> <ul style="list-style-type: none"> • Corona discharge in the air at the surfaces of conductors and fittings • Discharges and sparking at highly-stressed areas of insulators • Sparking at loose or imperfect contacts 	<p>NRPB-R265 (ISBN 0-85951-368-8) IEC 61000-2-5 BS 5409-1 CISPR 18-1</p>	<p>EN 55022, 55013, 55014, or 55015 (residential, commercial, light industrial) EN 55011 (ISM or heavy industrial) BS 5409-2, -3 CISPR 18-2, -3</p>	<p>High levels of radiated interference can cause sparks and ignite flammable materials and atmospheres. Radio receivers</p>	<p>IEC 61000-4-3, and ENV50204 (for GSM) 1: 1V/m 2: 3V/m 3: 10V/m 4: 30V/m X: special (case by case)</p>

Table J2 Additional details on continuous radiated threats from fixed and mobile radio transmitters

The distances given below assume free-space radiation – but actual radiated threats can be *at least doubled* by reflections and resonances of metal structures and the apparatus itself. An "engineering margin" is required depending upon the criticality of the function concerned (suggest *at least* doubling distances derived from the table below, in all cases).

Total emitted RF power, and type of radio transmitter typical of the UK

	Proximity for 1V/m	Proximity for 3 V/m	Proximity for 10 V/m	Proximity for 30 V/m
0.8W typical (2W maximum) hand-held GSM cellphone, and 1W leakage from domestic microwave oven	5 (7.8)m	1.6 (2.5)m	0.5 (0.8)m	0.16 (0.25)m
4W private mobile radio (hand-held) (e.g. typical VHF or UHF walkie-talkies)	11 m	3.6 m	1.1 m	0.36 m
10W emergency services walkie-talkies, and CB radio	16 m	5.0 m	1.6 m	0.5 m
20W car mobile cellphone, also aircraft, helicopter, and marine VHF radio-communications	25 m	8 m	2.5 m	0.8 m
100W land mobile (taxi, emergency services, amateur); paging, cellphone, private mobile radio base stations	54 m	18 m	5.4 m	1.8 m
1.0 kW DME on aircraft and at airfields; 1.5kW land mobile transmitters (e.g. some CBs)	210 m	70 m	21 m	7 m
25kW marine radars (both fixed and ship-borne)	850 m	290 m	89 m	29 m
100kW long wave, medium wave, and FM radio broadcast (Droitwich is 400kW)	1.7 km	580 m	170 m	58 m
300kW VLF/ELF communications, navigation aids	3 km	1 km	300 m	100 m
5MW UHF TV broadcast transmitters	12 km	4 km	1.2 km	400 m
100MW ship harbour radars	55 km	18 km	5.5 km	1.8 km
1GW air traffic control and weather radars	170 km	60m	17 km	6 km
10GW some military radars	550 km	180 km	55 km	18 km

A note on attenuation of field strength by buildings: The attenuation of a double-brick wall in the UK may be assumed to be one-third on average, but can be zero at some (unpredictable) frequencies. The attenuation of a typical steel-framed building can be much better than this except over 50 to 200MHz, depending on position in the building.

A note on radars: Peak threats from radars may be 30 times higher than the average values given above: this depends on the type of and the radar pulse characteristics. Radar fields are line-of-site, and the very high powers of ground-based radars may be considerably attenuated by geographical features such as hills or the curvature of the earth. Fixed radars are normally aligned so as not to include people or buildings in their main beam.

Conducted disturbances: a rule-of-thumb for conducted interference currents above 150kHz due to mobile and fixed transmitters such as those above, is to assume a cable characteristic impedance of 150Ω. Then the conducted currents = (V/m) divided by 150. E.g. 30V/m at 400MHz can give rise to 200mA of current at 400MHz.

Table J3 Transient disturbances with high probabilities of occurrence

(refer to IEC 61000-2-5 for help in assessing an environment for these phenomena)

The electromagnetic phenomena, their principal sources or causes, and some examples and comments	Basic test methods for emissions of these phenomena	Apparatus particularly susceptible to these phenomena	Basic test methods, and degrees of threat (sometimes called compatibility levels)
<p>Voltage dips (duration \square 20ms) and short interruptions on AC and DC power supplies</p> <p>Load switching (especially power-factor correction capacitors and induction motors) and fault clearance in LV power supply networks.</p> <ul style="list-style-type: none"> Practical experiences in Sweden indicate the following typical durations of supply interruption: 20ms in protected areas (e.g. an installation that is constructed in accordance with IEC61000-5-2) 600ms in unprotected installations (typical of older plant) and outdoor installations associated with MV and HV switchgear. <p>Brief voltage fluctuations on AC and DC power supplies</p> <p>Load switching in LV power supply networks.</p>	<p>IEC 61000-3-3 ($\leq 16A/\phi$ from LV supplies)</p> <p>IEC61000-3-5 ($> 16A/\phi$ from LV supplies)</p> <p>IEC 61000-3-7 (supplied by MV or HV)</p> <p>IEC 61000-3-11 (conditional connection to public LV supply, $< 75A/\phi$)</p> <p>As above</p>	<p>All digital systems (and the software running on them) can fail if their regulated DC rails fall below minimum. Specific devices and circuit techniques are available for protection and automatic recovery but are not universally used.</p> <p>Analogue signal processing can also fail, but will generally recover when the supply quality is back to normal.</p> <p>Relays and contactors can drop out momentarily.</p> <p>Direct-on-line (DOL) motors can trip out, and can suffer damage to their rotors.</p> <p>Variable-speed motor drives can trip out. Synchronism can be lost in multi-drive systems, possibly causing damage.</p> <p>High intensity discharge lamps can go out, sometimes taking up to a minute to restart.</p> <p>As above.</p>	<p>IEC 61000-4-11 (AC) and -29 (DC)</p> <p>Dips can vary from 10 to 99% of Vnom</p> <p>IEC 61000-4-11 (AC) and -29 (DC)</p>
<p>Conducted and radiated fast transient bursts</p> <p>Arcing during initial opening of contacts feeding an AC or DC load, worst with inductive loads.</p> <p>Applies to conductors connected to these loads, conductors connected to AC or DC supplies, and (to a lesser extent) conductors which may be in proximity to the cables mentioned above.</p> <ul style="list-style-type: none"> Practical experiences in Sweden indicate the following typical levels of fast transients: 2kV in protected areas (installations meeting IEC61000-5-2); 4kV in unprotected installations (typical of older plant); 8kV in outdoor installations associated with HV switchgear. 	<p>EN 55014</p> <p>"discontinuous disturbance"</p>	<p>All digital systems (and the software running on them) can fail. Specific devices and circuit techniques are available for protection and automatic recovery but are not universally used.</p> <p>Analogue signal processing can also suffer errors, but will generally recover after the burst.</p>	<p>IEC 61000-4-4</p> <p>1: 500V 2: 1kV 3: 2kV 4: 4kV X: Special (case by case)</p> <p>IEC 61000-4-4</p> <p>1: 500V 2: 1kV 3: 2kV 4: 4kV X: Special (case by case)</p>

<p>Voltage surges on AC and DC power supplies and all long cables (including telecomms)</p> <p>Load changes in LV power supply networks, especially reactive loads such as power factor correction capacitors and resonating circuits associated with switching devices (e.g. thyristors).</p> <p>The ring wave phenomenon described by IEC 61000-4-12 is mainly applicable to equipment connected to AC supplies in certain countries (such as the USA).</p> <ul style="list-style-type: none"> 1989 data indicates that remote buildings with overhead power lines can expect to see 3kV "voltage spikes" on their incoming AC supply 60 times/year. 1980 data indicates that AC supply transients between 200 and 2kV peak may be expected to occur every week in typical industrial and residential areas fed by underground cables. 1994-96 data from a variety of UK premises show that line-to-line transients of up to 840V can occur several times a day (worst case 35/day), with lower rates in heavy power industries. <p>Conducted damped oscillatory wave (duration measured in seconds)</p> <p>Power switching with re-striking of the arc</p> <ul style="list-style-type: none"> Practical experiences in Sweden indicate the following typical levels of damped oscillation surges: 0.5kV in protected areas (e.g. which meet IEC 61000-5-2) 1kV in unprotected installations (typical of older plant) 2.5kV in outdoor installations associated with HV switchgear. <p>Electrostatic discharge (personnel discharge, machine discharge, or furniture discharge)</p> <p>Tribocharging of personnel, workpieces (including some liquids, dusts, and vapours), and unearthed metalwork.</p> <p>Direct and indirect discharges can occur. Equipment used in controlled-ESD environments (e.g. semiconductor assembly areas) may be exempted from some or all ESD requirements (case-by-case basis).</p> <ul style="list-style-type: none"> Personnel ESD events of 15kV have been observed during very dry conditions (and are not uncommon in Scandinavia during their dry winters). IBM have observed a PVC cable charging to 4.5kV when dragged across a carpet. 	<p>The semiconductors in off-line electronic circuits (e.g. switch-mode power converters) and all semiconductors connected to long cables, are the most prone to suffering actual damage from differential (line-to-line) surges.</p> <p>All electronics can suffer actual damage from CM surges (line-to-ground) if they have inadequate creepage, clearance, or insulation resistance, at any point in the product where the surge voltages exist.</p> <p>Surges like these don't usually have enough HF content to upset software or analogue processing, unless they cause sparks to occur in or near a circuit (e.g. in spark-gap suppressers?)</p>	<p>IEC 61000-4-5 (unidirectional) and IEC 61000-4-12 (ring wave)</p> <p>1: 0.5kV CM 0.25kV DM</p> <p>2: 1kV CM 0.5kV DM</p> <p>3: 2kV CM 1kV DM</p> <p>X: Special (case by case)</p>
<p>EN 55014 "discontinuous disturbance"</p>	<p>As above, with greater possibilities of actual damage due to the longer duration and hence greater energy of the surge.</p> <p>All digital logic (and software running on it) can glitch seriously without automatic recovery due to electrostatic discharge events.</p> <p>Analogue signal processing can also suffer errors, but will generally recover.</p> <p>If the discharges get into the conductors or devices in connectors, cables, keyboards, and the like they can destroy internal circuitry.</p> <p>Membrane control panels and LCD displays can be particularly susceptible to damage from discharges applied around their edges.</p>	<p>IEC 61000-4-12 damped oscillatory wave</p> <p>1: 0.5kV CM 0.25kV DM</p> <p>2: 1kV CM 0.5kV DM</p> <p>X: Special (case by case)</p> <p>IEC 61000-4-2 (for personnel discharge only)</p> <p>1: 1kV 2: 4kV 3: 8kV 4: 16kV X: Special (case by case)</p>

Table J4 Transient phenomena with low probabilities of occurrence

(refer to IEC 61000-2-5 for help in assessing an environment for these phenomena)

The electromagnetic phenomena, their principal sources or causes, and some examples and comments	Apparatus particularly susceptible to these phenomena	Basic test methods, and degrees of threat (sometimes called compatibility levels)
<p>Voltage dips (duration ≥20ms) and interruptions on AC and DC power supplies</p> <p>Faults and fault-clearance in MV and HV supplies and their distribution networks</p> <ul style="list-style-type: none"> • A survey of 126 sites in western Europe found 300 dips/year, most lasting under 0.5 seconds with under 60% depth of dip • A UK survey of 11 sites found 50 dips/year, most lasting under 0.5 seconds with under 60% depth of dip • Practical experiences in Sweden indicate that 600ms supply interruptions are to be expected in unprotected installations (typical of older plant) and outdoor installations associated with HV switchgear. • A three-year survey in South Africa (94-97) found the worst sites had an average of 100 dips a month, with the average dip lasting for 80ms, whereas the best sites had an average of 25 dips/month with the average dip lasting for 70ms. <p>AC power supply frequency variation</p> <p>Major faults in supply networks</p>	<p>All digital logic (and the software running on it) can fail if their regulated DC rails fall below the minimum. Specific devices and circuit techniques are available to prevent this but not universally used.</p> <p>Analogue signal processing can also fail, but will generally recover when the power quality is back to normal.</p> <p>Relays and contactors can drop out momentarily.</p> <p>Direct-on-line (DOL) motors can trip out, and can suffer damage to their rotors.</p> <p>Variable-speed motor drives can trip out.</p> <p>Synchronism can be lost in multi-drive systems, possibly causing damage.</p> <p>High intensity discharge lamps can go out, sometimes taking up to a minute to restart when power returns.</p> <p>Real-time clocks operating from the supply frequency.</p> <p>Processes in which the rates of production are related to supply frequency, e.g. an induction motor driven machine may get unacceptably out of step with a DC motor or stage timed from a more stable source.</p> <p>All semiconductors connected to long cables are most prone to suffering actual damage from these surges if they have inadequate creepage, clearance, voltage withstand or insulation resistance, at any point in the product where the surge voltages exist.</p> <p>Surges like these don't usually have enough HF content to upset digital systems or software, unless they cause sparks in or near the product (e.g. in spark-gap suppressers)</p>	<p>IEC 61000-4-11 (AC) and -29 (DC)</p> <p>Dips can vary from 10 to 99% of nominal supply voltage.</p> <p>IEC 61000-4-14 and -28</p> <p>1: 2% of nominal frequency 2: 3% of nominal frequency X: Special (case by case)</p>
<p>Short duration AC or DC voltages in all long signal, control, telecommunication, and data cables</p> <p>Associated with faults in areas of heavy power use (especially earth faults)</p> <p>These are generally common-mode (CM) voltages at the frequency of the power supply. They can equal the full supply voltage for the time taken for fault clearance (e.g. by fuses), especially where the earth is not equipotential - typical of older installations that were not constructed in accordance with IEC 61000-5-2.</p> <p>Meshed common-bonding (earth) systems can reduce this exposure (see IEC 61000-5-2:1998).</p>		

<p>Voltage surges on AC and DC power supplies and all long cables (including telecomms)</p> <p>Lightning, and field collapse in loads with large stored energies (e.g. large motors, superconducting magnets)</p> <ul style="list-style-type: none"> 1989 data indicates that remote buildings with overhead power lines can expect to see 10kV "voltage spikes" on their incoming AC supply 10 times/year, and 3kV spikes 60 times/year Practical experiences in Sweden indicate the following typical levels of lightning surges: <ul style="list-style-type: none"> 1kV in protected areas (e.g. installations meeting IEC61000-5-2); 3kV in unprotected installations (typical of older plant); 5kV in outdoor installations associated with HV switchgear. Superconducting magnets can suffer unpredictable field collapse, creating surges containing 1MJ (Megajoule) of energy. <p>Short duration (pulsed) magnetic fields</p>	<p>The semiconductor in off-line electronic circuits (e.g. switch-mode power converters) and all semiconductors connected to long cables, are the most prone to suffering actual damage from differential (line-to-line) surges.</p> <p>All electronics can suffer actual damage from CM surges (line-to-ground) if they have inadequate creepage, clearance, or insulation resistance, at any point in the product where the surge voltages exist.</p> <p>Surges like these don't usually have enough HF content to upset software, unless they cause sparks in or near the product (e.g. in spark-gap suppressers?)</p>	<p>IEC 61000-4-5 (unidirectional) and IEC 61000-4-12 (ring wave)</p>
<p>Lightning and fault currents in earth conductors, supply networks, traction systems.</p> <p>Mainly applies to equipment used outdoors, and in electrical plants and switchyards.</p> <p>Conducted voltage surges due to fuse operation</p> <p>Fuse opening causes flyback and dumping of stored energy in inductive sources (e.g. the mains supply network) and loads.</p>	<p>CRT-type VDUs may suffer momentary image movement.</p> <p>Half effect and other magnetic transducers (such as current transformers) may suffer temporary output errors.</p>	<p>2: 1kV CM 0.5kV differential 3: 2kV CM 1kV differential 4: 4kV CM 2kV differential X: Special (case by case) Note that exposed sites can suffer from surges of up to 10kV several times a year. IEC 61000-4-9</p>
<p>Conducted voltage surges due to fuse operation</p> <p>Fuse opening causes flyback and dumping of stored energy in inductive sources (e.g. the mains supply network) and loads.</p>	<p>The semiconductor in off-line electronic circuits (e.g. switch-mode power converters) and all semiconductors connected to long cables, are the most prone to suffering actual damage from differential (line-to-line) surges.</p> <p>All electronics can suffer actual damage from CM surges (line-to-ground) if they have inadequate creepage, clearance, or insulation resistance, at any point in the product where the surge voltages exist.</p> <p>Surges like these don't usually have enough HF content to upset software, unless they cause sparks in or near the product (e.g. in spark-gap suppressers).</p>	<p>IEC 61000-4-5 1: 0.5 of the peak supply voltage 2: 1 times peak supply voltage 3: 2 times peak supply voltage X: Special (case by case)</p>

Radiated (damped oscillatory) magnetic fields

CRT-type VDUs may suffer momentary image movement.

IEC 61000-4-10

<p>HV and HV switching by isolators: Mainly applies to equipment used in high-voltage substations and switchyards.</p> <p>Conducted damped oscillatory surges on power lines and all other cables</p> <p>Switching of isolators in HV/MV open-air stations, particularly the switching of bus-bars.</p> <ul style="list-style-type: none"> Practical experiences in Sweden indicate the following typical levels of damped oscillation surges: 0.5kV in protected areas (e.g. installations meeting IEC61000-5-2) 1kV in unprotected installations (typical of older plant) 2.5kV in outdoor installations associated with HV switchgear. 	<p>As above.</p> <p>Hall effect and other magnetic transducers (such as current transformers) may suffer temporary output errors.</p>	<p>IEC 1000-4-12</p>
<p>Radiated pulsed fields near gas-insulated substations</p> <p>HV/MV disconnect switching in gas-insulated substations (rise time around 10ns)</p> <ul style="list-style-type: none"> A 25mm gap in an SF6 switch was stressed to breakdown at 80kV and gave the following maximum fields: At 2 metres distance: 340 V/m/ns and 608 A/m/ns; At 10 metres distance on the other side of a plasterboard wall: 11 V/m/ns and 29 A/m/ns. <p>The duration of the pulsed fields is generally such that a rate of change figure of 10V/m/ns translated into a field strength well in excess of 10V/m.</p> <p>Radiated short duration (pulsed) fields</p> <p>HV/MV disconnect switching in open-air substations (rise times around 100ns), and due to lightning ground strikes (rise times between 100 and 500ns).</p> <p>The duration of these fields is such that a rate of change of 10 V/m/ns translates into a field strength well in excess of 10V/m.</p>	<p>Likely to have a more catastrophic effect on digital systems and software than on analogue circuits.</p> <p>Sensitive circuits (whether analogue or digital) could suffer actual damage from these pulsed fields.</p> <p>Equipment intended to be exposed to these pulsed fields will generally need to be designed specially.</p> <p>As above</p>	<p>1: 0.5kV CM 0.25kV differential 2: 1kV CM 0.5kV differential 3: 2kV CM 1kV differential (2.5kV CM for substation equipment) 4: 4kV CM 2kV differential X: Special (case by case)</p> <p>1: 100 V/m/ns 2: 300 V/m/ns 3: 1000 V/m/ns 4: 3000 V/m/ns 5: 10,000 V/m/ns X: Special (case by case)</p> <p>1: 30 V/m/ns 2: 100 V/m/ns 3: 300 V/m/ns 4: 1000 V/m/ns 5: 3,000 V/m/ns X: Special</p>

Radiated short duration (pulsed) fields under overhead lines

As above

- 1: 3 V/m/ns
- 2: 10 V/m/ns
- 3: 30 V/m/ns
- 4: 100 V/m/ns
- 5: 300 V/m/ns
- X: Special

<p>Where the lines carry pulse currents (due to HV/MV disconnect switching in substations or lightning), (rise times around 1µs)</p> <p>The duration of the pulsed fields is generally such that a rate of change figure of 10 V/m/ns translates into a field strength well in excess of 10V/m.</p> <p>Direct lightning strike</p> <p>Exposed equipment or its cables not fully protected by a lightning protection system.</p>	<p>Actual physical damage to all types of electronic components, and many electrical and even structural elements (PCB traces, wires, cables, metalwork).</p> <p>Software processes will almost certainly fail, along with any other digital or analogue circuit functions.</p> <p>Possibility of toxic fumes, smoke, and fire from damaged components and materials.</p>	<p>1% of strikes exceed 200kA, see BS 6651 and IEC 61312</p>
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J12. Proposed Contract Requirement Specification for Electromagnetic Performance

J12.1 Scope

The majority of electrical apparatus (as defined in {1}) currently made or sold within the EEC has to comply in full with the Electro Magnetic Compatibility (EMC) Directive 89/336/EEC (the EMC Regulations in the UK {2}).

The specific requirement within the end-user's company, however, is that all future installations need only meet the Essential Protection Requirements of the EMC Directive together with certain Health & Safety Requirements.

Consequently, this specification relates to the end-user's procurement of electrical/electronic equipment, systems, fixed installations etc. in order to avoid all unwanted electrical interference or undue susceptibility to interference.

J12.2 Basic requirements

All apparatus supplied under this contract specification is required to meet:

- a) The Essential Protection Requirements of the EMC Directive, i.e. *it shall*:
 - have an adequate level of intrinsic immunity to electromagnetic disturbances in its intended operational environment to enable it to operate as intended, and -
 - not emit electromagnetic disturbances which would prevent any other plant or any other apparatus (such as radio receivers) from operating as intended.

(N.B. on the end-user's sites, the Essential Protection Requirements might not be fully met by only using currently available standards {3})

- b) Where appropriate, the Essential Health and Safety Requirements of the Machinery Safety Directive {4}, MSD, as far as the possible effects of EM interference are concerned.

(N.B. The hazards and risk analysis carried out for the apparatus under the MSD should take account of the effects of all reasonably foreseeable EM interference, including those caused by misuse and fault conditions {5}).

- c) Where appropriate, the Principal Elements of the Safety Objectives of the Low Voltage Directive.

J12.3 Actions required

- a) Where appropriate, to support the enquiry documentation, the end-user will issue EM Performance Assessment Data which will identify:
 - The EM threats to the immunity of the proposed apparatus at its intended location
 - Any sensitive apparatus which could be interfered with by the proposed new apparatus.

(N.B. The extent and format of any EM Performance Assessment will depend on the needs of each application)

- b) Where appropriate, and as agreed with the end-user, a post-commissioning EM Performance Assessment may be undertaken, to establish that the end-user's Basic Requirements have been achieved.

(N.B. Where appropriate, a stage payment of the contract may be made conditional upon the achievement of the end-user's Basic Requirements.)

- c) The Contractor shall install the apparatus in compliance with the supplier's instructions or other best practice so as to enable the apparatus to function correctly and comply with the end-user's Basic Requirements.
- d) The Contractor shall provide the end-user with any relevant design, installation, commissioning, operation, and maintenance information (e.g. cabling requirements) such that the end-user and/or its subcontractors are able to achieve full compliance with the end user's Basic Requirements.
- e) The Contractor shall provide for each item of apparatus:
- A Provisional EM Performance Plan with his Tender, as detailed in Section J12.4.
 - A Contract EM Performance Plan, before detail design commences, as detailed in Section J12.5, to demonstrate that he will be applying 'due diligence' throughout the Contract.

J12.4 The provisional EM performance plan

The Provisional EM Performance Plan for the proposed apparatus shall include the following:

- a) Acceptance of the EM threats at the intended operational location of the proposed apparatus.
- b) Identification of all significant sources of the apparatus's EM emissions.
- c) Confirmation that all aspects of the apparatus – (especially where they are related to safety or other critical operations) – will meet the end-user's Basic Requirements.
- d) Reference to relevant National (or other) Standards/Codes of Practice to be used in order to ensure compliance with the end-user's Basic Requirements.
- e) The means of monitoring due diligence throughout the contract in order to ensure compliance with the end-user's Basic Requirements.
- f) Identification of the EMC documentation to be supplied on contract completion, including relevant design, installation, commissioning, operation (including "limitations as to use") and maintenance instructions.
- g) Identification of the proposed EM performance and acceptance criteria.

J12.5 The contract EM performance plan

This should be carried out before detailed design commences in order to demonstrate that the contractor will be applying the required 'due diligence'

The Contract Plan for the proposed apparatus shall include all items from the Provisional Plan, *plus* the following additional items:

- a) A description of the means of achieving the end-user's Basic Requirements and confirmation of the agreed performance and acceptance criteria.
- b) Where sub-contractors are used, identification of the nominated 'EMC design authority' for the contract.

- c) Where use is made (in full or in part) of any third-party systems, products, components, or other apparatus which are claimed by their suppliers to have the EM performance required by the Contractor to fulfil his obligations under his contract with the end-user – the Contractor will make available, as required, adequate evidence of their relevant EM performance and assembly/installation requirements.

N.B. This evidence will often be obtained from the third-party supplier, but it should be noted that CE marking alone will often be insufficient {6}.

- d) A similar requirement to c) above exists where the Contractor uses third-party services. The Contractor shall ensure, where necessary, that the service provider has the necessary EMC competence and that his work does not compromise the Contractor's compliance with his contract with the end-user.

(N.B. Evidence of competence and the quality of the services to be undertaken is to be provided, if required.)

- e) Provision of relevant design, installation, commissioning, operation (including "limitations as to use") and maintenance instructions.

J12.6 References and notes for section J12

- {1} 'Apparatus' is defined by the EMC Directive as 'all electrical and electronic appliances together with equipment and installations containing electrical and/or electronic components'.

Within the context of this specification, this definition includes apparatus supplied to the end-user either as-new, second hand or re-furbished/repared and includes components, equipment, sub assemblies (e.g. control panels), fixed installations etc.

- {2} Statutory Instrument No. 1992//2372: Electromagnetic Compatibility Regulations, as amended refers (this transposes the EMC Directive into UK law with effect from 1 January 1996).

- {3} The operational environment in areas of some end-user sites can have EM characteristics which differ from, or are not found, in currently available harmonised EMC standards. In such areas, CE marking and/or compliance with a harmonised EMC standard does not necessarily ensure compliance with either the Essential Protection Requirements of the EMC Directive or with the end-user's Basic Requirements.

- {4} Refer to BS EN 292, in particular Part 1 sections 3.12 and 4.7, and also Part 2 section 3.7.3 'Applying safety principles when designing control systems'.

- {5} Compliance with the Essential Protection Requirements of the EMC Directive only addresses normal use, and so does not necessarily achieve the levels of safety required by the Machinery Safety Directive.

Note that CE marking and/or Declarations of Conformity to the EMC Directive, are not necessarily considered sufficient evidence on their own that the third party has applied sufficient due diligence, or that his products have adequate EM performance, to meet the end-user's Basic Requirements.