EMC STANDARDS

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Assessing an Electromagnetic Environment

Helping you solve your EMC problems

1 Brassey Road, Old Potts Way, Shrewsbury, SY3 7FA T:+44 (0) 1785 660 247 E:info@emcstandards.co.uk

Assessing an electromagnetic environment

Created by Cherry Clough Consultants, http://www.cherryclough.com phone: +44 (0)1785 660 247. Last updated by Eur Ing Keith Armstrong C.Eng, FIEE/IET, Senior MIEEE, ACGI on the 11th February 2017, email: keith.armstrong@cherryclough.com. Correction to page 9, 28 December 2018: "Conducted damped oscillatory wave".

This is a general guide to assessing an EM environment for all manner of EMC applications. Mostly IEC standards are listed in these tables. Many other EMC standards exist (e.g. DEF-STAN 59-411, MIL-STD-464, DO-160, IEEE standards, ITU and other telecommunication standards, national standards, company and other private standards, etc.) and these might be found to be more relevant or more useful. We accept no responsibility for the accuracy of all this information, please always check for yourself.

Please note that simply applying the immunity standards listed in the right-hand column may not be adequate where EMC-related functional safety is an issue, or where high reliability systems are required, e.g. for telecommunications central offices, legal metrology, etc. IEC 61000-1-2 is the most relevant standard for EMC for functional safety, but even that may not be adequate. Refer to the IET's Code of Practice on Electromagnetic Resilience, published in 2017.

Contents

Table 1: Continuous 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 (sometimes called compatibility levels)
AC or DC supply voltage variations (slow variations) 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. 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.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)		All normal electronic equipment considered susceptible at >±10%.	IEC 61000-4-14, and –29 1: ±3% Vnom 2: ±10% Vnom 3: ±15% Vnom X: special (case by case)

AC supply phase unbalance Caused by asymmetrical loads, or large single-phase loads.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		Three-phase equipment which relies upon phase balance (e.g. AC motors, transformers). Neutral cables may overheat. Contact breakers may trip or fuses open unexpectedly.	IEC 61000-4-27 1: 2% Fnom 2: 3% Fnom X: special (case by case)
DC supply ripple Caused by AC rectification, or battery charging. A consideration for equipment that operates directly from rectified AC or batteries that are charged during its operation.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		All normal electronic equipment considered susceptible at >±10%.	IEC 61000-4-17
AC power supply frequency variation The mains frequency is varying slowly all the time as a consequence of the balance between the total load and generating availability on the HV 'national grid'. The specified frequency of 50Hz (or 60Hz) is a long-term average, usually requiring several hours. EN 50160 specifies variations within ±1% for 95% of a week, and within +4%, -6% over a full week. (5% of a week is almost 8.5 hours)	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)	N/A	Real-time clocks operating from the supply frequency. 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.	IEC 61000-4-28 1: No test 2: ±3% of nominal 3: +4, -6% of nominal 4: ±15% of nominal X: Special (case by case)
Harmonics and interharmonics of the AC power supply (= waveform distortion) Mostly caused by non-linear loads, e.g… • Static frequency and cyclo-converters • Large induction motors • Welding • AC-DC power converters (e.g. adjustable speed drives or large numbers of single-phase computers) • Transformers driven into saturation But supply network resonances can also create very high levels at certain frequencies. Some types of harmonic distortion can create multiple zero-crossings of the supply waveform. Some examples: • Typical UK/EU mains supplies have THD levels approaching 4%, but some premises can have up to 8%. • Strongly-disturbed networks (e.g. in steelworks) can exceed 10% THD. • Supplies in developing countries (e.g. China) can have very heavy levels of harmonic distortion indeed, the mains waveshape has been known to approach a squarewave in some industrial areas.	IEC 61000-2-4 IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)	IEC 61000-3-2 (≤16A/ϕ, LV) IEC61000-3-4 (>16A/ϕ□□LV) IEC61000-3-12 (conditional connection to public LV supply, <75A/ϕ) IEC 61000-3-6 (MV or HV) IEC 61000-3-9 (interharmonics)	Power converters and other electronics which use zero crossing, peak, or slew rate of supply waveform for timing or other purposes. AC/DC power supplies can output lower than expected voltages due to supply waveform distortion, leading to erroneous operation of any/all electronics. Power factor correction capacitors, transformers, cables, AC motors, and switchgear can experience overheating and overvoltages and can be damaged, with risks of fire and even explosion. Excessive acoustic noise and vibration can occur with actual structural damage. AC motor bearings can fail early due to mechanical stress and HF bearing currents. Nuisance tripping of overcurrent protection devices (fuses, MCBs, etc).	IEC 61000-4-7 and -13 1: 4% THD 2: 8% THD 3: 10% THD X: special (case by case)

AC or DC magnetic fields up to 150kHz Can be created over large areas by MV or HV supply distribution or heavy power use, especially where ‘send’ and ‘return’ conductors are separated. Principal sources are power conductors and magnetic components such as motors and transformers. Where separate conductors are used for send and return and not combined into one cable (e.g. overhead power lines, electrified railways) magnetic field emissions can be very powerful indeed, especially near to the power conductors. Fields from transformers decay more rapidly with distance than do those from separated conductors. Audio-frequency magnetic fields also exist near audio power amplifiers and their cables and loudspeakers, and induction loop systems. All conductors carrying currents (whether analogue or digital) and all transformers emit magnetic fields to some extent, and this may be important for very sensitive circuits if they are nearby (e.g. cellphones can emit significant levels of audio-frequency magnetic fields due to currents in their DC power supplies and batteries). • 100A/m has been seen 10m from steel rolling mill DC drive cables (±8kA), and > 1000A/m at ≤ 1m. • A 1.1kHz 800kW steel billet induction heater has been seen to emit 100A/m at 1m • 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’s Application Note 1319) • 1.8A/m was measured in 2000 at 10m away from a 500kV AC transmission line tower in Brazil, 0.45A/m inside a house which was “nearby the TL”. • 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. • In power/industrial plants, bus-bars carrying 2200A produce fields of 6 to 85 A/m depending on distance (roughly 0.3 to 1.5m respectively) (HP’s Ap 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 up to 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 (HP’s Application Note 1319).	IEC 61000-2-7 NRPB-R265 (ISBN 0-85951-368-8) IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1	No basic IEC or EN test method. Search coil method: Annex A of EN 55103-1	CRT-based displays and computer monitors typically start to suffer visible image degradation at >1A/m. (CRTs can achieve 20A/m or more when fitted with magnetic shielding or cancellation devices.) LCD and plasma displays do not suffer from this. 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. Sensitive circuits (those using low levels of current and/or voltage for their signals) are more likely to be susceptible. Sparks at metal connections carrying circulating currents due to strong magnetic fields can cause fire and explosion hazards where there are flammable materials present.	IEC 61000-4-8 (magnetic fields) 1: 3A/m 2: 10A/m 3: 30A/m 4: 100A/m X: special (case by case) No IEC test standards for electric fields.

- A survey of 24 locations in two UK hospitals in 2000 gave an averaged 50Hz field strength of 0.09A/m (equivalent to 111nT) with a range from 4mA/m to 2.4A/m (equivalent to: 5nT to 3µT). Comparable fields measured by the same person in domestic premises found fields of around 4mA/m, except near washing machines, cookers, storage heaters, etc.) where the fields could be 40mA/m.				
AC or DC electric fields up to 150kHz Medium and High-Voltage supply distribution. Heavy power use. Principal sources are power conductors where the send and return paths are separated and not combined in one cable. - 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 - 1.33kV/m was measured in 2000 at 10m away from a 500kV AC transmission line tower in Brazil, 48V/m inside a house which was “nearby the TL”.	NRPB-R265 (ISBN 0-85951-368-8) IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		Unshielded sensitive or high-impedance analogue circuits or transducers. Sparks between metallic objects in high electric field strengths can ignite flammable materials and atmospheres.	1: 0.1kV/m 2: 1kV/m 3: 10kV/m 4: 20kV/m X: special (case by case)
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.	IEC 61000-2-1 IEC 61000-2-2 IEC 61000-2-12 IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1	IEC 61000-3-8 (outside Europe) EN 50065 (in Europe)	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.	IEC 61000-4-13 (to 2.4kHz only) 1: 5% Vrms 2: 9% Vrms (0.1 – 3kHz only) These levels are for close proximity to the emitters.
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 or near installations using large amounts of power, and in proximity to VLF/ELF transmitters. - 50V differences in earth potentials are allowed by UK electrical safety regulations and occur in some premises. - Practical experiences in Sweden show that the following levels of 50Hz conducted interference may be expected: 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.	IEC 61000-2-1 IEC 61000-2-2 IEC 61000-2-4 IEC 61000-2-5 IEC 61000-2-6 IEC 61000-2-12 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		Long wave and medium wave radio receivers. Analogue telephone systems. Sensitive instrumentation (e.g. temperature, flow, weight), audio, and video.	IEC 61000-4-16 1: 1Vrms 2: 3V 3: 10V 4: 20V X: special (case by case)
Conducted interference above 150kHz in all conductors (voltages and currents) Most importantly from the RF fields generated by fixed and mobile radio and TV transmitters and some ISM equipment (especially Group 2 of EN 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	IEC 61000-2-3 IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1	EN 55022, 55013, 55014, or 55015 (residential, commercial, light industrial) EN 55011	Radio receivers. Digital control and signal processing can suffer "phantom" keypresses, false addresses or data, software looping, and crashes. Outputs can assume any combination of states. Sensitive analogue instrumentation	IEC 61000-4-6 1: 1V (7 mA) 2: 3V (21 mA) 3: 10V (70 mA) 4: 30V (210 mA)

used in screened rooms (depends on the screening performance of the room). Also see footnote to Table 2		(ISM or heavy industrial)	(e.g. temperature, flow, weight), audio, and video. Analogue telephones.	X: special (case by case)
Radiated fields above 150kHz Most importantly from fixed and mobile radio and radar transmitters, and some ISM equipment (especially equipment covered by Group 2 of EN 55011 or CISPR 11). 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). • MHz-operation dielectric heaters of 3 to 15kW have been known to create 300V/m at the operator's position. • A 230kHz 400kW steel tube welder with a coil diameter of 50mm can create 40A/m at 0.25m from its coil. • 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. • Paulista Avenue in São Paulo, Brazil, is a busy financial district with TV and radio broadcasting towers plus many other wireless services. Site surveys in 2000 discovered maximum fields of 19V/m at 92.9MHz with minimum fields of 6V/m throughout the avenue. Paulista Avenue, Campinas City, Brazil, had maximum field strengths of 20V/m due to proximity of broadcast transmitters in 2000. São Paulo airport had maximum fields strengths of 0.8V/m. • Some Group 2 ISM equipment (as defined by EN 55011 or CISPR 11) emits fields outside their enclosures which can be strong enough to be a hazard to human health (typically regarded as being 60V/m). • The DO160 commercial aerospace “HIRF” standards require testing with 3kV/m peak and 300V/m average at frequencies between 1 and 18GHz to simulate radar threats. • Radar threats on the decks of military ships can be as high as 27kV/m peak and 1,230V/m average in certain frequency bands 1-40GHz (MIL-STD-464). • See Table 2	NRPB-R265 (ISBN 0-85951-368-8) IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1	EN 55022, 55013, 55014, or 55015 (residential, commercial, light industrial) EN 55011 (ISM or heavy industrial)	As above. High levels of radiated interference can cause sparks and ignite flammable materials and atmospheres.	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)
Radiated interference above 150kHz from high-voltage power lines Broadband (random) noise caused by: • 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	BS 5409-1 CISPR 18-1	BS 5409-2, -3 CISPR18-2, -3	Radio receivers	

Table 2: Additional details on continuous radiated threats from fixed and mobile radio and radar transmitters

The distances given below assume free-space radiation (e.g. omnidirectional antennae) and a simplistic relationship ($E = \sqrt{(30P)}/d$) between radiated power (P) and field strength (E) in V/m. IEC 60601-1-2:2001 Tables 203-206 and Figures 204, 205 (pages 24 -29) might give better guidance than the table below.

Remember that actual radiated threats can be at least doubled by reflections and resonances of metal structures and the apparatus itself. Where safety-related functions are concerned, a "safety margin" is required which depends on the Safety Integrity Level (see IEC 61508) of the safety-related system concerned (suggest at least doubling the distances in the table below, in all safety-related cases).

Total emitted RF power, and type of radio transmitter typical of the UK	Proximity (d) for 1V/m	Proximity (d) for 3 V/m	Proximity (d) for 10 V/m	Proximity (d) for 30 V/m
0.8W typical (2W maximum) hand-held GSM cellphone, and 1W leakage from domestic microwave ovens	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 (taxis, 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 illegal CBs on trucks)	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 (10dB) on average, but can be zero at some (unpredictable) frequencies that can very depending on the weather. The attenuation of a typical steel-framed building can be much better than this below about 10MHz, depending on position within 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 radio transmitters is to assume a cable characteristic impedance of 150Ω. Then the conducted currents = (V/m) divided by 150. E.g. a 30V/m field gives rise to 200mA of current.

A note on industrial RF processing equipment (e.g. ISM equipment covered by CIPSR 11 or EN 55011)
These can be very powerful indeed (e.g. MW) are do not use omnidirectional antennas. Their field strength ‘contour maps’ can only be determined by a site survey.

Table 3: Transient disturbances with high probabilities of occurrence

(Please note that there is no accepted definition of just what is meant by “high” or “low” probability in this context)

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 disturbances**	**Basic test methods for immunity, and degrees of threat** (sometimes called compatibility levels)
Voltage dips or sags and short interruptions on AC and DC power supplies Load switching (especially power-factor correction capacitors and 1induction motors). Fault clearance of short-circuits in LV, MV, and HV power distribution networks. • 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. • Sudden phase shifts can accompany voltage dips • Overhead networks are more likely to suffer, due to their exposure to climate (winds, rain, snow, ice), lightning, and fires from vegetation or buildings (heated air ionises more easily) • Arc furnace loads are a cause of short dips and interruptions.	IEC 61000-2-8 IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)	IEC 61000-3-3 (≤16A/ϕ from LV supplies) IEC61000-3-5 (>16A/ ϕ from LV supplies) IEC 61000-3-7 (supplied by MV or HV) IEC 61000-3-11 (conditional connection to public LV supply, <75A/□)	All digital systems (and the software running on them) can fail if their regulated DC rails fall below minimum specified levels. Specific devices and circuit techniques are available for protection and automatic recovery but are not universally used. Analogue signal processing can also fail, but will generally recover when the supply quality is back to normal. Relays and contactors can drop out momentarily. Those held on reduced voltage may not pull back in afterwards. Direct-on-line (DOL) motors can be tripped out, and can suffer damage to their rotors. Variable-speed motor drives can trip out. Synchronism can be lost in multi-drive systems, possibly causing damage. High intensity discharge lamps can go out, sometimes taking up to a minute to restart. Some circuits are susceptible to the transient phase shift which can accompany a dip. Inrush current following a deep dip or interruption can be large, possibly causing a prolongation of the dip (with its own problems) or causing an overcurrent trip to occur, removing power completely. See sections 4 and 8.3 of IEC 61000-2-8. Modern equipment tends to be more susceptible to dips and interruptions, and this has led to considerable economic loss and increased safety risks.	IEC 61000-4-11 (AC) and -29 (DC) Dips can vary from 10 to 99% of Vnom The ITIC (CBEMA) curve.

Brief voltage fluctuations on AC and DC power supplies Brief fluctuations in the loading on LV AC power supply networks and DC supplies.	IEC 61000-2-8 IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)	As above	As above.	IEC 61000-4-11 (AC) and -29 (DC) 1: 3% of Vnom 2: 10% of Vnom X: Special (case by case)
AC power supply frequency variation The mains frequency is varying slowly all the time as a consequence of the balance between the total load and generating availability on the HV 'national grid'. The specified frequency of 50Hz (or 60Hz) is a long-term average, usually requiring several hours. EN 50160 permits variations to be within +4%, -6% for as much as 5% of a week (almost 8.5 hours, not necessarily in one period).	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1 EN 50160 (in EU)	N/A	Real-time clocks operating from the supply frequency. 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.	IEC 61000-4-28 1: No test 2: ±3% of nominal 3: +4, -6% of nominal 4: ±15% of nominal X: Special (case by case)
Conducted and radiated fast transient bursts Arcing during initial opening of contacts feeding an AC or DC load, worst with inductive loads. 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. • 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.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1	EN 55014 ("discontinuous disturbance")	All digital systems (and the software running on them) can fail when affected by fast transient bursts. Specific devices and circuit techniques are available for protection and automatic recovery but are not universally used. Analogue signal processing can also suffer errors, but will generally recover after the burst.	IEC 61000-4-4 1: 500V 2: 1kV 3: 2kV 4: 4kV X: Special (case by case)
Voltage surges on AC and DC power supplies and all long cables (including telecomm's) Load changes in LV power supply networks, especially large reactive loads such as motors (e.g. for lifts/elevators), power factor correction capacitors and resonating circuits associated with switching devices (e.g. thyristors). Arc furnace loads are another cause of surges in power networks. The ring wave phenomenon described by IEC 61000-4-12 is mainly applicable to AC supplies in certain countries (such as the USA), depending on the way they distribute electricity. • 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.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		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. 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. 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?) Ring wave surges place more stress on mains rectifiers than unidirectional surges.	IEC 61000-4-5 (unidirectional) and IEC 61000-4-12 (ring wave) 1: 0.5kV CM 0.25kV DM 2: 1kV CM 0.5kV DM 3: 2kV CM 1kV DM X: Special (case by case) IEC 60364-4-443 and IEC 60364-4-444 are also relevant, but are

• 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 (probably because the supply impedance is lower).				not test standards.
Conducted damped oscillatory wave Power switching with re-striking of the arc (duration measured in seconds). • 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.	IEC 61000-2-5 IEC 61000-4-1 Table 1 IEC 61000-1-1	EN 55014 ("discontinuous disturbance")	As above, with greater possibilities of actual damage due to the longer duration and hence greater energy of the surge. The oscillatory nature of the surge places more stress on mains rectifiers than the unidirectional surges described by IEC61000-4-5.	IEC 61000-4-18 (damped oscillatory wave) 1: 0.5kV CM 0.25kV DM 2: 1kV CM 0.5kV DM X: Special (case by case)
Transient electric and magnetic fields Caused by the transient voltages and currents associated with the transients and surges listed above. • Measurements in a number of *domestic* properties in the USA in 2000 found transient low-frequency magnetic fields with values up to 2.4A/m and transient high-frequency magnetic fields with values up to 0.4A/m. Frequency content of the transients ranged form 60Hz to 50MHz. Frequency components above 10kHz had levels of up to 0.04A/m. The number of transients per day were typically between 100 and 900 but some premises had over 1500 (estimated).	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		Transient magnetic and electric fields are mostly caused by surges and transients in the supply distribution and they induce transient voltages and currents respectively on all conductors that are not adequately shielded. All types of circuits are considered vulnerable, with sensitive circuits (those using low levels of current and/or voltage for their signals) especially susceptible. The degree of circuit upset depends upon the peak value and waveshape (frequency content) of the generating surge or transient, the coupling characteristics to the victim conductor (e.g. mutual inductance, stray capacitance), and the sensitivity of the victim circuit. Sensitive instrumentation in heavy power installations are the most likely to suffer problems due to this type of disturbance. Since inductive and capacitive stray coupling increases linearly with frequency, even low levels of high frequency transients can be the most troublesome. The resulting effects cover the full range of possible circuit and software errors. CRT type devices will suffer from transient errors when exposed to transient electric or magnetic fields, due to their effect on the electron beam direction.	IEC 61000-4-18 (damped oscillatory wave) 1: 0.5kV CM 0.25kV DM 2: 1kV CM 0.5kV DM X: Special (case by case)

Electrostatic discharge (personnel discharge, machine discharge, or furniture discharge) Tribocharging of personnel, workpieces (including some liquids, dusts, and vapours), and unearthed metalwork. 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). • Personnel ESD events of over 20kV 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.	IEC 61000-2-5 IEC 61000-4-1 Tables 1, 2 IEC 61000-1-1		All digital logic (and software running on it) can glitch seriously without automatic recovery due to electrostatic discharge events. Analogue signal processing can also suffer errors, but will generally recover. If the discharges get into the conductors or devices in connectors, cables, keyboards, and the like they can destroy internal circuitry. Membrane control panels and LCD displays can be particularly susceptible to damage from discharges applied around their edges.	IEC 61000-4-2 (for personnel discharge only) 1: 1kV 2: 4kV 3: 8kV 4: 16kV X: Special (case by case)

Table 4: Transient phenomena with low probabilities of occurrence

(Please note that there is no accepted definition of just what is meant by “high” or “low” probability in this context)

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 these disturbances	**Basic test methods for immunity, and degrees of threat** (sometimes called compatibility levels)
Voltage dips or sags and interruptions on AC and DC power supplies Faults and fault-clearance in MV and HV supplies and their distribution networks. Overhead networks are more likely to suffer. • 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. • IEC 61000-4-11 quotes a UNIPEDE study in 1991 (No. 50.02) that found over 180 dips and interruptions lasting more than 100ms and less than 3 seconds in public supply systems, per year. • Sudden phase shifts can accompany voltage dips	IEC 61000-2-8	IEC 61000-3-3 (≤16A/ ϕ from LV supplies) IEC61000-3-5 (>16A/ ϕ from LV supplies) IEC 61000-3-7 (supplied by MV or HV) IEC 61000-3-11 (conditional connection to public LV supply, <75A/ϕ)	All digital systems (and the software running on them) can fail if their regulated DC rails fall below minimum specified levels. Specific devices and circuit techniques are available for protection and automatic recovery but are not universally used. Analogue signal processing can also fail, but will generally recover when the supply quality is back to normal. Relays and contactors can drop out momentarily. Those held on reduced voltage may not pull back in afterwards. Direct-on-line (DOL) motors can be tripped out, and can suffer damage to their rotors. Variable-speed motor drives can trip out. Synchronism can be lost in multi-drive systems, possibly causing damage. High intensity discharge lamps can go out, sometimes taking up to a minute to restart. Some circuits are susceptible to the transient phase shift which can accompany a dip. Inrush current following a deep dip or interruption can be large, possibly causing a prolongation of the dip (with its own problems) or causing an overcurrent trip to occur, removing power completely. See sections 4 and 8.3 of IEC 61000-2-8. Modern equipment tends to be more susceptible to dips and interruptions, and this has led to considerable economic loss and increased safety risks.	IEC 61000-4-11 (AC) and -29 (DC) Dips can vary from 10 to 99% of nominal supply voltage.

Voltage fluctuations on AC and DC power supplies ‘Brownouts’ and ‘swells’ are typically caused by excessive loading of LV power supply networks, or faults in MV and HV power distribution. More common on locally-generated mains supplies. • The 230Vac supply on an offshore oil exploration rig in the 1970s was known to fall to zero for a second or two when the drill motor was switched on, and to overshoot to 480Vrms for one or two seconds when it was switched off. • Parts of Spain in the late 1990’s were know to suffer regular ‘brownouts’ every afternoon in which the nominal 230V mains supply would fall to under 180Vrms. • A UK village in 1999 saw its nominal 230V supply fall to 115V and remain at that level for 8 hours.			As above, plus possible overheating damage to the insulation of AC and some types of DC motors if they stall due to the reduced voltage. Damaged insulation can lead to premature failure, and electric shock and fire hazards. Industrial motor control centres usually include undervoltage protection which prevents insulation damage during a sag or brownout, but the damage to the machine or process, and the lost production caused by uncontrolled shut-down of individual motors can be significant.	IEC 61000-4-11 (AC) and -29 (DC) > 10% of Vnom
AC power supply frequency variation Major faults in supply networks			Real-time clocks operating from the supply frequency. 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.	IEC 61000-4-28 1: No test 2: ±3% of nominal 3: +4, -6% of nominal 4: ±15% of nominal X: Special (case by case)
Short duration AC or DC voltages in all long signal, control, telecommunication, and data cables Associated with faults in areas of heavy power use (especially earth faults) 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. Meshed common-bonding (earth) systems can reduce this exposure (see IEC 61000-5-2:1998).			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. 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)	
Voltage surges on AC and DC power supplies and all long cables (including telecomm's) Lightning, and field collapse in loads with large stored energies (e.g. large motors, superconducting magnets) • 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: 1kV in protected areas (e.g. installations meeting IEC61000-5-2);			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. 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. 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?)	IEC 61000-4-5 (unidirectional) and IEC 61000-4-12 (ring wave) 2: 1kV CM 0.5kV differential 3: 2kV CM 1kV differential 4: 4kV CM 2kV differential X: Special (case by case)

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. • Mains power surges in small (e.g. domestic) premises are usually limited to around 6kV by the flash-over voltage of their mains sockets. Industrial 3 phase distribution using only IEC 309 sockets will flash-over at higher voltages if additional surge protection is not fitted. In large installations the surge voltage decays the further it has to travel, mostly due to the loads on the network. UK experience is that urban domestic premises fed by underground cables can expect 3 off 6kV surges per year due to thunderstorm activity. • Experience with the reliability of a high-volume product in the EU indicates that 5kV or greater surges can be expected annually at locations throughout the EU.			Most lightning protection standards are only concerned with protecting structures and people from the effects of lightning, but BS6651 Annex C, IEC 61312-1, and IEC 60364-4-443 *do* address protecting electronic equipment and provide useful procedures for assessing the likely lightning surge exposure of equipment in a wide variety of locations. Note that the USA has a higher lightning incidence than the EU, and South Africa, parts of Australia, and all tropical countries (e.g. Malaysia, the Philippines, etc.) have higher lightning incidence still (and probably more intense lightning events too) so local lightning maps (isokeraunic maps) and national lightning standards should be referred to. In the USA IEEE C62.41 and C62.64 may be used. Some countries may have mandatory requirements for equipment lightning protection that need to be met.	Note that exposed sites can suffer from surges of up to 10kV several times a year.
Lightning electromagnetic pulse (LEMP) Caused by lightning up to 5km distance, including cloud-to-cloud discharges.			All electronics are considered vulnerable, especially those connected to long cables.	IEC 61312-1
Short duration (pulsed) magnetic fields Fault currents in earth conductors, supply networks, traction systems. Mainly applies to equipment used outdoors and in electrical plants and switchyards, or close to distribution transformers.			CRT-type VDUs may suffer momentary image movement. Hall effect and other magnetic transducers (such as current transformers) may suffer temporary output errors. Coupling into audio and instrumentation systems can cause momentary noise and errors. Coupling into digital circuits can cause data loss or software malfunction of any extent, depending on the data integrity techniques employed. Very intense fields and/or high levels of coupling can cause overvoltages which can permanently damage semiconductors. Sparks between metallic objects in high magnetic field strengths can ignite flammable materials and atmospheres.	IEC 61000-4-9
Electric fields caused by thunderstorms Thunderstorm clouds can cause high levels of 'dc' electrostatic fields, especially in the vicinity of a future lightning strike. Fields of up to 500kV/metre can be experienced over an area of 100m from the eventual strike point, with fluctuating fields of (500kV/m)/microsecond occurring during a strike.			Unshielded sensitive or high-impedance analogue circuits or transducers. Sparks between metallic objects in high electric field strengths can ignite flammable materials and atmospheres.	IEC 61312-1 refers, but is not a test standard for this phenomenon
Conducted voltage surges due to fuse operation Fuse opening causes flyback and dumping of stored energy in			The semiconductors in off-line electronic circuits (e.g. switch-mode power converters) and all semiconductors	Refer to telecommunications

inductive sources (e.g. the mains supply network) and loads.			connected to long cables, are the most prone to suffering actual damage from differential (line-to-line) surges. 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. 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).	'resistability' standards and recommendations (e.g. Telcordia, ITU, see Appendix below) for immunity tests to this type of disturbance
Conducted damped oscillatory surges on power lines and all other cables Switching of isolators in HV/MV open-air stations, particularly the switching of bus-bars. • 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.			As above.	IEC 1000-4-18 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)
Showering arcs from electro-mechanical switches in heavy power installations Equipment in proximity to such arcs (or connected to the same power network as the switched cables) suffer from both conducted and radiated broadband noise due to the restriking arc.				IEC 61255-22-4:2002 IEC 61255-22-1:2002 NEMA ICS 1-2000 www.nema.org IEEE Std C37.901-2002
Radiated (damped oscillatory) magnetic fields MV and HV switching by isolators. Mainly applies to equipment used in high-voltage substations and switchyards.			CRT-type VDUs may suffer momentary image movement. Hall effect and other magnetic transducers (such as current transformers) may suffer temporary output errors. Coupling into audio and instrumentation systems can cause momentary noise and errors. Coupling into digital circuits can cause data loss or software malfunction of any extent, depending on the data integrity techniques employed. Very intense fields and/or high levels of coupling can cause overvoltages which can permanently damage semiconductors. Sparks between metallic objects in high magnetic field strengths can ignite flammable materials and	IEC 61000-4-10

			atmospheres.	
Radiated pulsed fields near gas-insulated substations HV/MV disconnect switching in gas-insulated substations (rise time around 10ns) • 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. 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.			Likely to have a more catastrophic effect on digital systems and software than on analogue circuits. Sensitive circuits (whether analogue or digital) could suffer actual damage from these pulsed fields. Equipment intended to be exposed to these pulsed fields will generally need to be designed specially.	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)
Radiated short duration (pulsed) fields HV/MV disconnect switching in open-air substations (rise times around 100ns), and due to lightning ground strikes (rise times between 100 and 500ns) 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.			As above	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
Radiated short duration (pulsed) fields under overhead lines Where the lines carry pulse currents (due to HV/MV disconnect switching in substations or lightning), (rise times around 1□s)			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 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.
Direct lightning strike Exposed equipment or its cables not fully protected by a lighting protection system.			Substantial physical damage to all types of electronic components, and many electrical and even structural elements (PCB traces, wires, cables, enclosures, metalwork). Software processes will almost certainly fail, along with any other digital or analogue circuit functions. Possibility of toxic fumes, smoke, and fire from damaged components and materials. Damaged enclosures, cables and insulation can expose people to electric shock hazards.	1% of strikes exceed 200kA see BS 6651, IEC 61024-1 and IEC 61312-1

Appendix

Techniques for assessing an electromagnetic environment, plus guidelines for simple calculations

Eur Ing Keith Armstrong C.Eng MIEE MIEEE
Partner, Cherry Clough Consultants, http://www.cherryclough.com
Phone: +44 (0)1457 871 605, fax: +44 (0)1457 820 145, email: keith.armstrong@cherryclough.com

Note: A 'rule of thumb' is an expression that refers to a simple calculation or engineering guide or estimate. Most rules of thumb can only give an estimation of the order of magnitude.

Appendix contents

1. The process of assessing the EM environment

What EM threats are present that could interfere with the apparatus?

What EM threats are emitted by the apparatus and might interfere with sensitive equipment, even if it is not nearby?

It is always best to agree specifications for the above with the customer in a written contract, which should include limitations to use, to ease design and manufacture without harming sales too much.

1.1 Assessing EM threats to the apparatus

First decide where the apparatus is to be installed (if it is fixed equipment) or the range of locations where it could foreseeably be used (especially if it is portable).

Initial assessment of EM threats is relatively easy, for example (in household, commercial and industrial situations) by using an initial checklist of simple questions and assessing its results (see below) using the tables above, IEC 61000-2-5, the IEC 61000-2-x series (see below), EM emissions data on other apparatus nearby and/or interconnected by cables (supplies, signal, data, control, etc.), plus researching numerous other relevant sources of information (see below).

This assessment should be supported by simple calculations using known currents, powers, distances, etc. (see later) and (where practicable) by simulation on a computer using a ‘calibrated’ program.

Significant EM threats are then compared with proposed technology and construction of the equipment concerned. Most of them will be found to be so negligible that further investigation is not warranted. But there will often be a few threats that will need to be investigated in mode detail.

Instrumented site surveys should be done for the worrisome disturbances, but are only cost-effective for frequent and continuous EM disturbances, or for transient disturbances that can be made to occur (e.g. by switching large machines off and on, simulating earth-faults, opening circuit-breakers, etc.). Low probability disturbances that are uncontrollable (such as lightning) may need to be assessed from literature (articles, books, standards, etc.) and/or calculations. Fault events need to be assessed too. Consider fault currents, fuse-blowing transients, proximity of arcs and sparks.

1.2 An example of a checklist of simple EMC questions

This checklist should be completed by salespeople in conjunction with potential customers, and used by EMC specialists working for the Technical or Engineering Department.

The purpose of this checklist is to help ***begin*** the process of assessing the electromagnetic environments that equipment could be exposed to — to assist with design and development that will achieve reliable products with low warranty costs, that will also comply with legal regulations that include EMC requirements (especially the EU’s EMC, R&TTE and Medical Devices Directives, etc., that include immunity requirements).

For custom engineering projects an EM environment assessment should be a contributory factor to each tender submittal, or quotation of price or delivery. For volume-manufactured products, an EM environment assessment should contribute to the initial technical specification process.

SAFETY NOTE: Where inaccuracy, errors or malfunctions in electrical, electronic and/or programmable electronic devices could *possibly* have safety implications — checklists like this can also be used as the start of the EM environment assessment process. In such cases, what matters is not just the environments that the equipment is *intended* to be used in, the replies to this checklist’s questions should also consider the worst-case EM phenomena resulting from *all reasonably foreseeable operational environments*, over the whole of the anticipated lifecycle of the final installation, including incidental and accidental uses of the equipment, and foreseeable misuse. Never assume that people could not be stupid enough to do something – you would be wrong.

Questions a) to f) below are intended to use with EMC Directive compliance, to identify whether the final product will be used in domestic, commercial, or light industrial environments, or in industrial environments. Of course, some equipment might be used in all these environments.

Where a product-specific standard is relevant (e.g. EN 55014-1 and –2; EN 55013 and EN 55020; EN 55024; etc.) it may be best to apply the most relevant generic standards *as well*, to help overcome the well-known shortcomings in some product standards.

a) Will the final product be operated from a low-voltage AC mains supply where the distribution transformer supplies only one organisation? YES ☐ NO ☐

b) Will the final product's low voltage AC mains supply be shared by heavy power equipment, industrial manufacturing or processes and the like? YES ☐ NO ☐

c) Will the final product be physically located >30m from all radio or TV *receiver* antennas or other very sensitive electronic devices? YES ☐ NO ☐

d) Will the final product be physically located >10m from all radio or TV *receiver* antennas or other very sensitive electronic devices? YES ☐ NO ☐

e) Will the final product be physically located >30m from heavy power equipment, such as used in industrial manufacturing or processes, electric traction, or the like, and be powered from separate mains supplies? YES ☐ NO ☐

f) Will the final product be located in electricity generation or distribution facilities, or take part in electricity generation or distribution functions? YES ☐ NO ☐

Questions g) onwards (below) are intended to identify whether the final product could be used in an unusual or exotic electromagnetic environment – because in such cases compliance with the EMC Directive's Protection Requirements could mean applying tougher restrictions on emissions and/or tougher specifications for immunity than are required by either product or generic standards.

If the answer to any of questions in g) onwards is YES, please give as many details as are available (e.g. type of equipment, physical proximity, whether the AC or DC power supplies are shared, etc.). Please list all the *possible* candidates, even though many of them may turn out not to present any difficulties. Sketches of physical relationships and cable interconnections are welcomed. Please continue on as many supplementary sheets as required.

g) Will more than one final product be operated simultaneously, connected to the same LV mains supply or situated in closer proximity than 10m? YES ☐ NO ☐

h) Will the final product be <10m from a radio or TV receiver antenna? Will it be <100m from, or share the same power supply as, very sensitive equipment that – if its electronics or software malfunctions – could have safety or other unacceptable implications? (e.g. certain types of medical or scientific equipment, some industrial sensors, etc.) YES ☐ NO ☐

If the answer is Yes, please provide all details.

i) Will the final product be <5m from indoor cellphone base-stations, <30m from outdoor cellphone base-stations or paging system transmitters, <3km from broadcast radio or TV transmitters, <1km from marine vessels, or <50km line-of-sight from fixed radar installations (e.g. airports, harbours, military installations)? YES ☐ NO ☐

If the answer is Yes, please provide all details.

j) Might hand-portable radio communication devices be used <3m to the final apparatus (e.g. cellphones; walkie-talkies, handyphones, wireless-enabled personal organisers, wireless-enabled PCs or PDAs, etc.)? YES ☐ NO ☐

If the answer is Yes, please provide all details.

k) Might vehicle mobile radio communications be used <10m to the final product? (e.g. motor cars, fire engines, police cars or helicopters, aircraft, delivery vehicles, etc.) YES ☐ NO ☐

If the answer is Yes, please provide all details.

l) Will the final product be <30m from heavy power equipment or equipment that uses radio-frequency energy, or share their mains supplies or cable routes? (e.g. gas-insulated/other HV switchgear; HV transformers; electromagnetic stirrers; arc furnaces; aluminium smelters; electroplaters; electrolytic processes; electric welding; arcs >10milliseconds; plastic welders or sealers; induction heaters; industrial microwave heaters or dryers; diathermic processes; RF-assisted welders; RF-assisted wood or card gluers; electromagnetic pulse devices; variable speed drives for AC or DC motors >100kW or their motors; etc.) YES ☐ NO ☐

If the answer is Yes, please provide all details.

m) Will the final product be <100m from overhead HV cables, <10m from overhead MV cables, or <30m from LV or d.c. cables where the send and return (e.g. phases and neutrals) are run separately (including electric underfloor heating and the like)? YES ☐ NO ☐

If the answer is Yes, please provide all details.

n) Will any of the final product's control, signal, comm's, or data cables exit the building? YES ☐ NO ☐

If the answer is Yes, please provide all details.

o) Will the final product be exposed to direct lightning strike? Or exposed to uncontrolled voltage surges from equipment with very large energy storage (e.g. large motors or generators, superconducting magnets, etc.)? YES ☐ NO ☐

If the answer is Yes, please provide all details.

p) Is the final product protected by a structure that provides lightning protection for electronic equipment to BS 6651 Annex C (or equivalent)? YES ☐ NO ☐

If the answer is Yes, please provide all details.

q) If any of the electrical or electronic devices, systems, or software in the final product suffered from errors or malfunctions, could the consequences possibly include safety incidents, serious financial losses, or significant environmental damage? YES ☐ NO ☐

If the answer is Yes, please provide all details.

1.3 Engineering analysis of EMC requirements

The above 'Initial EM Checklist' is ideally completed before a project is undertaken, to help identify problem areas that might require special EMC engineering techniques, or special EMC tests to be used.

It is then analysed by engineers who have the necessary EMC competency, feeding appropriate cost and timescale estimates into the tender submittal and quotation process.

If this work is not done before tender submittal or quotation, it should be done before the serious design work is started. Interference is an increasing problem for a number of reasons, and it is increasingly important to deal with it early on to meet project budgets and timescales, and reduce financial risks.

The engineers performing this task will need appropriate competency with assessing electromagnetic environments, EMC emissions and immunity standards and how testing using them is actually performed.

SAFETY NOTE: Where functional safety is an issue, the engineers should have appropriate competency in EMC and safety, including experience in applying both IEC 61508 and IEC 61000-1-2. The IET's Code of Practice on Electromagnetic Resilience will help with understanding Annex B of 61000-1-2.

1.4 Sources of information on the EM environment

The IEC 61000-2-x series generally addresses the household, commercial or industrial environments, but electronic equipment can find itself in other environments such as military, marine, automotive, civil aviation, space, etc., and there are other standards and documents that provide information on the likely magnitudes of the EM threats in such situations.

Although telecomm's are generally located in household, commercial or industrial environments, the telecomm's industry places great emphasis on reliability, especially for 'central office' (telephone exchange) equipment, so their immunity requirements can be a lot tougher. Also, some telecomm's equipment is located outdoors in situations very exposed to lightning (e.g. on a pole). So telecomm's 'resistibility' and immunity standards can be very helpful when high reliability is required.

For International Telecommunication Union (ITU) EMC recommendations: visit www.itu.org, click on 'ITU Publications Online' then click on 'ITU-T Recommendations' then click on 'K', to see the list of their EMC standards. Note that they sometimes use the word 'resistibility' to mean immunity. They usually make a small charge for providing these standards.

Telcordia in the USA is the successor to Bell Telephone Labs and maintains a number of Telecomm standards that are widely used in the USA to ensure high reliability of telecomm network equipment despite earthquakes, lightning, and all other manifestations of the physical environment. Visit http://telecom-info.telcordia.com and click on 'Technical Documents' to visit their Information Superstore. Then click on 'Document Centre' and look for relevant documents. It may be necessary to search the site for 'electromagnetic' or 'lightning' since few of the documents mention EMC in their titles. A very important EMC document is GR-1089-CORE "Electromagnetic Compatibility and Electrical Safety - Generic Criteria for Network Telecommunication Equipment".

Military EM environments are often different, sometimes harsher than household, commercial or industrial environments, and information on them is contained in the immunity tests and test levels of Military standards. There are military EMC standards for ships, land vehicles, and aircraft, and they are all different.

For British Defence EMC standards: visit http://www.dstan.mod.uk (click on "Standards" then follow the instructions) to download appropriate parts of DEF STAN 59-41. For the US Military EMC standards MIL-STD-461E and -464: the official site is supposed to be www.astimage.daps.dla.mil but if this doesn't work the Google search engine (www.google.com) will turn up locations where you can download them for free, for example. (at the time of writing) http://www.multilek.ca/Specifications.htm. Simply typing the MIL standard's reference number into Google will usually find a number of sites where it can be downloaded.

Civil aircraft EM environments are covered by RTCA/DO-160E, published by RTCA Inc. in 2004 (www.rtca.org), which is continually being improved. The civil working groups developing this standard are SC135 (in USA) and EUROCAE WG 14 (in Europe), and Google should find their websites. It is interesting to note that over the past 15 years there has been a dramatic increase in immunity test levels required by DO-160, with the maximum test limits for radiated immunity increasing from 1V/m to over 6kV/m.

Road (automotive) and roadside EM environments are again different from household, commercial or industrial environments, and the UK's Motor Industry Research Association (MIRA http://www.mira.co.uk) surveys the EM environment of the UK's roads every few years and publishes a report that can be purchased.

Rail networks also have special EM threat characteristics. A great deal of information on railway EM environments has been collected, but is probably in the hands of the rail network operators and their prime contractors. It might be worthwhile looking in the EN 50121 series (railway EMC) but (like medical EMC standards) they only describe the 'normal' environment and do not give much help when it comes to worst-case or low-probability threats. Some EMC consultancies specialise in railway EMC (e.g. York EMC Services http://www.york-emc.co.uk and ERA Technology Ltd http://www.era.co.uk) and they may be able to help.

The marine (non-military) EM environment is addressed in IEC 60533, which also includes some procedures for ensuring compatibility when its minimum immunity requirements are not enough.

A site's electricity supply Authority should be able to provide data on the disturbances that can occur in their supplies, and may be able to provide data on the actual disturbances present at a given location (for a fee). However, they can be unwilling to admit how bad their services are with regard to dips, short interruptions, overvoltages and waveform distortions. We would expect thick reports citing many years of serious measurements, and appropriate data reduction in to a digestible form, so if all you get is bland assurances that they comply with their statutory requirements it may be better to rely on the relevant IEC 61000-2 series and/or on-site measurements (over a lengthy period) if they can be arranged.

Military authorities have 'contour maps' of field strengths from fixed transmitters over most of the world, but it may be hard to obtain them unless you are a member of that country's military or an allied nation.

The UK's Civil Aviation Authority (www.caa.co.uk) keep a record of all the radars in use in the UK (frequencies, power levels, and pulse characteristics), and are a good source of information on mobile radars. They may also be able to help with field strength 'contour maps' from fixed transmitter and industrial RF processing sites. Presumably other countries' equivalent authorities are similar. Civilian pilots can also get 'contour maps' of no-fly areas from appropriate civil authorities, but they might not give actual field strength information.

Lightning protection standards (e.g. BS 6651, IEEE C62-41, IEC 61024-1 and IEC 61312-1) and lightning incidence maps ('isokeraunic' maps) and knowledge of the site's lightning protection system helps determine the threats from lightning. Isokeraunic maps are available from a number of sources, including national weather forecasting organisations. But it is probably easiest to search for them, for the area concerned, using the Google search engine (http://www.google.com).

IEEE International EMC Symposia are also a good source of information on real-world EM environments (http://www.ieee.org).

Simulation of the EM environment is increasingly possible, and some software products are available, e.g. for the fields created by overhead HV power lines. Some consulting companies have written their own software and can offer bureau services (e.g. Qinetiq, BAE Systems, ERA Technology).

For *intentional* interference, Metatech Corporation are experts in assessing EM environments and intentional interference and their website http://www.metatechcorp.com has a number of useful downloads.

1.5 What if you can't predict the environment?

This is usually only a problem for custom engineers where the customer is unhelpful.

Choose the most relevant harmonised standards and "apply" their informative annexes too. Put the EM environments they cover in the contract, with their limitations to use written out in full, and get the customer to agree to them.

Then if/when things go wrong due to EM problems with the environment, you will have some leverage

1.6 Example of limitations to use – emissions

Developed from Section 3 of the heavy industrial generic emission standard EN 61000-6-4:

"This apparatus might interfere with radio and television reception when it is used closer than 30 metres to the receiving antenna(e). And it might also interfere with highly susceptible apparatus being used in proximity. In all such instances the user is responsible for employing special mitigation measures, at his own expense."

1.7 Example of limitations to use – immunity

Developed from Section 3 of the heavy industrial generic immunity standard EN 61000-6-2:

"Situations may arise where the electromagnetic disturbances in the environment may exceed the immunity of this apparatus, e.g. where it is installed in proximity to ISM equipment (as defined by EN 55011) or where a mobile transmitter is used in proximity. "In all such instances the user is responsible for employing special mitigation measures, at his own expense."

2. Estimating the low frequency radiated fields emitted by long conductors

At frequencies from DC to 100 kHz it is possible to crudely estimate the strengths of the electric and magnetic fields emitted by voltages and currents in conductors, using the simple formulae below. Measurements of electric and magnetic fields at these low frequencies are easy to do, for fields of magnitudes down to 0.1 V/m, or 0.1 A/m, using low-cost handheld instruments, so the main use for these rules-of-thumb will be where the apparatus concerned does not yet exist.

These rules-of-thumb will mostly be used for estimating high levels of magnetic fields from conductors carrying high levels of DC and AC power, such as motor drives, electromagnetic stirrers, etc., especially to determine whether CRT type monitors in the vicinity will give stable images.

These rules assume free-space radiation, but actual fields strengths will be modified by the proximity of cables, cable trays ducts and conduits, equipment and cabinets, structural steelwork, etc., and may be higher or lower than those estimated from these simple formulae.

Where safety-related issues are concerned it will be important to perform more exact assessments or by performing measurements as soon as possible, even on partially constructed apparatus or apparatus of a similar type. If these rules are to be used in the initial stages of a project on safety-related issues their results should be multiplied by at least 10 to provide a suitable margin for error until a more accurate assessment or measurement can be made. The actual margins required will then depend upon the safety integrity level (see IEC 61508) of the safety-related function(s) concerned.

These rules-of-thumb all assume that the length of the conductors is much greater than the distance (d) at which the field strength is to be estimated. When the cable length equals d, a rule of thumb would be to divide the field by two, with further reductions as the cables become even shorter.

2.1 Estimating electric field emissions at low frequencies (DC-100 kHz)

Electric field strength is given the symbol E and measured in Volts/metre (V/m).

EMC test equipment is usually calibrated in dBμV/m, where 0 dBμV/m = 1μV/m, since EMC was traditionally concerned with interference to radio receivers which were intended to pick up radio signals with merely a few μV/m field strength.

Personnel hazard measuring instruments for non-ionising radiation are usually calibrated in kV/m, since it is long-term exposure to such magnitudes of electric fields that may cause health problems.

Electric fields are difficult to calculate for real-life situations because free-space conditions are never found and the proximity of other conductors, metalwork, and ground have a profound effect. A *very* crude rule of thumb for the electric field between a long single conductor and anything else is to divide their voltage difference (V_{diff}) by their spacing (s) in metres: $E = V_{diff} \div s$

> **E.g.** A long cable carrying 1 kV is 1 metre from an opto-isolator device which may be assumed to be at earth potential. The resulting electric field experienced by the opto-isolator is 1 kV/m. (At 2 metres distance the field would be reduced to 500 V/m.)
>
> Where there are multiple long cables running in free space, the electric field at any point is the vector sum of all their individual contributions. In most cases cables are run parallel to each other, so the vector addition is merely a straight addition of the fields.
>
> **E.g.** for +1 kV on a long cable 1 metre away from an "earthy" optical sensor, with a second long cable run in parallel with 100 mm spacing from the first cable and 1.1 metres from the optical sensor: when the second cable carries an equal and opposite voltage of -1 kV the resulting field strength at the optical sensor is very approximately (1,000) + (-909) = 91 V/m.
>
> If instead of 100 mm the cable spacing was reduced to 10 mm, the resulting field strength at the optical sensor would be roughly (1,000) + (-990) = 10 V/m.
>
> The presence of large masses of earthed metalwork nearby is likely to reduce the size of electric fields. If this mass of earthed metalwork is between the conductor with the high voltage and the sensitive part, it may reduce the electric field dramatically by acting as a shield. (If the mass of metalwork is not earthed its shielding effect could be much less.)

2.2 Estimating magnetic field emissions at low frequencies (DC-100 kHz)

Magnetic fields are measured in Amps/metre (A/m), Tesla (T), or Gauss (G).

Conversion factors between these three units *in free air* are: 1 A/m ≈ 1.25 μT ≈ 12.5 mG
1 T = 10 kG ≈ 800 kA/m
1 G = 100 μT ≈ 80 A/m

EMC test equipment is usually calibrated in dBμA/m, where 0 dBμA/m = 1 μA/m, since EMC was traditionally concerned with interference to radio receivers which were intended to pick up radio signals with merely a few μA/m field strength.

Personnel hazard measuring instruments for non-ionising radiation are usually calibrated in kAmps/metre, kGauss, or Tesla, since it is long-term exposure to these magnitudes of magnetic fields that may cause health problems.

In the special case of a long single conductor in free space, the magnetic field strength it produces at a nearby point may be calculated from Amps ÷ (2πd), in A/m, where d is the perpendicular line-of-site distance from the point concerned to the centre of the conductor (in metres).

> **E.g.** For 100A in a long cable that is 1 metre away (the shortest distance at right angles to cable run) the field strength according to this formula is 16 A/m (approx. 20 μT).

Where there are two or more long cables similarly running in free space, the magnetic field at a point is the vector sum of all their individual contributions. In most cases these cables will be running parallel to each other (e.g. send and return currents to a DC motor, three-phase or three-phase-plus-neutral power) and the maximum resulting field strength is simply the straight addition of their individual fields.

E.g. For +100 A in a long cable 1 metre away with its -100 A return current in a parallel cable 1.1 metres away (e.g. a cable spacing of 100 mm when the point of interest and the two cables all lie in a plane): the field strength at the point of interest is (16) + (-14.5) = 1.5 A/m.

If instead the cable spacing is 10mm (i.e. the send/return cables are almost side-by-side, since d is measured to the centre of the conductor) the resulting field strength is (16) + (-15.8) = 0.2 A/m.

2.3 Notes on running conductors close together:

The above examples show the great reduction in electric and magnetic fields which can be achieved by running send and return conductors, carrying equal and opposite voltages and currents, as close together as possible. Twisting send/return conductors together is even better (although easier for small-signal cables than for power).

For three-phase (or three-phase and neutral) power conductors the voltages and currents (and hence their fields) are all at 120^{o} to each other, and running them together in a single cable or bundle (with a twist if possible) helps reduce electric and magnetic fields in exactly the same way.

Where very heavy currents are concerned, the mechanical stresses caused by running cables with opposing currents close to each other may damage the insulation in the cables in a relatively short period of time, leading to fire or shock hazards. Busbars which use solid insulation may be a better solution in such cases.

As well as considerably reducing the emitted electric and magnetic fields, running send/return or three-phase power conductors closely together also helps to reduce their pickup of interference from their environment, so this technique is important for immunity as well as for emissions.

2.4 Notes on frequencies higher than 100 kHz:

At higher frequencies the wavelengths become comparable with typical cable lengths in industrial situations, making the above rules-of-thumb useless.

Where intentional radio transmitters are involved Table 2 gives useful guidance on field strengths, but for other high-frequency signals it is impossible to use the above rules-of-thumb and measurements are the only option.

Crude measurements may be done with simple low-cost test gear, but if the apparatus concerned is of recent manufacture, its manufacturer should already have emission test results.

3. Estimating how radiated fields vary with distance

Where the field strength at one distance from the emitter is known (e.g. from manufacturers test results, or from a calculation) the rules-of-thumb below allow the field strength at other distances (d) to be crudely estimated.

These simple rules work over a very wide frequency range, at least to 1GHz, providing the distances concerned are not too near to the emitter (less than $\lambda/6$, see 2.3).

These rules assume free-space radiation, but actual field strengths will be modified by the proximity of cables, cable trays ducts and conduits, equipment and cabinets, structural steelwork, etc. Consequently an "engineering margin" of at least 100% is recommended over and above the levels calculated using these rules to allow for these real-world effects, but it should be realised that such effects can sometimes cause field strengths to be 10 times (+1,000%) or reduced to negligible values, especially at frequencies above 10 MHz.

Where safety-critical functions are concerned it will be important to initially either measure the actual field, or allow for the level to be at least 10 times higher than these calculations give and then measure the actual field as soon as it becomes possible to do so.

3.1 Electric field strength

Electric field strength tends to be proportional to Volts ÷ d

> **E.g.** An ISM apparatus is known to emit 135 dBμV/m (= 5.6 V/m) at 84 MHz at 3 metres radial distance from a part of its structure.
>
> At 1 metre radially from the same part of its structure it may be expected to have a field strength of the order of 145 dBμV/m (= 17.8 V/m).
>
> At 30 metres radial distance from that part it may be expected to have a field strength of the order of 115 dBμV/m (= 0.56 V/m).

3.2 Magnetic field strength

For single conductors, magnetic field strength tends to be proportional to Amps ÷ d

> **E.g.** A long single cable is known to emit a magnetic field strength of 16 A/m at a distance of 1 metre (perpendicular to the run of the cable).
>
> The field strength at 100 mm distance may be expected to be of the order of 160 A/m.
>
> The field strength at 10 metres distance may be expected to be of the order of 1.6 A/m (which is still too high for a normal CRT-type computer monitor to be sure of meeting the Health and Safety "VDU Directive").

Where a number of conductors run very close together in parallel and carry currents that balance out (e.g. send and return currents to a DC motor, three-phase or three-phase-plus-neutral power), at distances (d) which are very much larger than the separation between the individual conductors the resulting magnetic field strength tends to be proportional to {(Amps) × (separation)} ÷ d^2

> **E.g.** A pair of DC drive cables (send/return) have a spacing of 10 mm, and are known to create a magnetic field of 0.2 A/m at a distance of 1 metre.
>
> At a distance of 2 metres their magnetic field may be expected to be of the order of 0.05 A/m.

For transformers, solenoids, and the coils of induction heaters, the magnetic field strength tends to be proportional to Amps ÷ d^3.

> **E.g.** An 800 kW 1.1 kHz steel billet induction heating coil is known to produce 100 A/m at 1 metre distance from the side of its coil.
>
> At 100 mm distance it may be expected to create a field of the order of 100 kA/m, getting close to the levels at which health hazards may occur.

At 10 metres distance it may be expected to create a field of roughly 0.1 A/m, quite low enough to be confident about fitting a CRT type of monitor at this distance and achieving good image stability.

Mixtures: in the real world coils and transformers are connected to other devices and to cables, and the rate of change of magnetic field strength with distance will be a mixture of all three of the above approximations.

E.g. In the above example of the steel billet induction heater, although the 1.1 kHz magnetic field emitted by the coil has diminished to roughly 0.1 A/m at a distance of 10 metres, the 11 kV 3ϕ 50 Hz power cables to its power electronics cabinet would be likely to be carrying around 100 Amps each.

If these long cables had a spacing of 100 mm from each other in the same plane as the computer monitor, and were 5 metres away from it on average, their magnetic field would be of the order of 0.06 A/m, still a negligible amount.

However, if the power to the electronics cabinet was supplied at 1.1 kV 3ϕ 50Hz and their three 1000 A supply cables were each spaced apart by 500 mm: at 5 metres distance their resulting 50 Hz magnetic field would be of the order of 3 A/m, which could be expected to have a significant effect on the image stability on a normal CRT-type VDU.

3.3 The relationship between electric and magnetic fields at higher frequencies

All fields are emitted as either electric or magnetic fields, but after travelling a distance equivalent to roughly one-sixth of their wavelength they all turn into electromagnetic fields.

Electromagnetic fields consist of both electric and magnetic fields in a ratio that depends on the characteristic impedance of the medium they are travelling in. For air, the characteristic impedance is 377Ω, so it is possible to measure either the electric or magnetic component and calculate the other by dividing or multiplying by 377.

The wavelength (λ) of a frequency (f) is given by $\lambda = v/f$, where v is the velocity of propagation (the speed of light) in the medium the wave is travelling in.

In air, $v = 3.10^8$ metres/sec so the wavelength of a 30 MHz wave in air is 10 metres, so at more than about 1.5 metres from an emitter, whether it initially emit electric or magnetic fields, the result will be an electromagnetic wave with its electrical (E) and magnetic (H) field components in the ratio E/H = 377 (just like V/I=R, Ohms law).

Below 30MHz, most test methods measure the magnetic component of electromagnetic fields with a loop antenna. Above 30 MHz most test methods use an electric-field antenna. However, the results from each type of antenna can easily be converted into E or H fields as required.

In PVC cables the velocity of propagation is less than in air, and is often as low as 2.10^8 metres/sec (depending on the cable type). This means that all frequencies have shorter wavelengths when they are conducted in a cable, compared with being radiated through the air.

In section 1 we deliberately limited the frequency range of the simple formulae to 100 kHz, since the wavelength (in air) at this frequency is 3,000 metres. One-sixth of this λ is 500 metres, a large enough distance to enable us to ignore the effects of wavelength even in a large building.

4. A list of the current standards in the IEC 61000-2-x series

These standards will be found to be very useful in helping to assess the electromagnetic environment without using site surveys. IEC 61000-2-5 is particularly helpful.

(Note that all the IEC 1000 series are gradually being renumbered as the IEC 61000 series. Consequently some of the numbers are still using the 1000 series.)

IEC 61000-2-1	Description of the environment. Electromagnetic environment for low frequency conducted disturbances and signalling in public power supply systems. *(Low voltage power systems, i.e. up to 1kV rms)*
IEC 61000-2-2	Compatibility levels for low frequency conducted disturbances and signalling in public power supply systems.
IEC 61000-2-3	Description of the environment. Radiated and non-network related conducted phenomena.
IEC 61000-2-4	Compatibility levels in industrial plants for low frequency conducted disturbances.
IEC 61000-2-5	Classification **of electromagnetic environments.**
IEC 61000-2-6	Guide to the assessment of the emissions levels in the power supply of industrial plants as regards low-frequency conducted disturbances.
IEC 61000-2-7	Low frequency magnetic fields in various environments.
IEC 61000-2-8	Voltage dips, short interruptions and statistical measurements.
IEC 61000-2-9	Immunity of high-altitude nuclear pulse. Description of the HEMP environment. Radiated disturbances. *(HEMP = High altitude electromagnetic pulse from nuclear explosions, also relevant to lightning exposure)*
IEC 61000-2-10	Description of the HEMP environment - Conducted disturbance.
IEC 61000-2-11	Classification of HEMP environment.
IEC 61000-2-12	Compatibility levels for low frequency conducted disturbances and signalling in public medium voltage power supply systems.

When adopted by BSI these standards become BS IEC 61000-2-x.

New standards are being added all the time, as well as existing standards being modified.

Always check for the latest situation, best by visiting the BSI Standards website http://www.bsi-global.com or the IEC website http://www.iec.ch and looking in their lists of current standards, or else look in their printed or CD-ROM catalogues.

(Can easily purchase IEC standards with a credit card from their webstore:
http://www.iec.ch/webstore/welcome-webstore.htm)