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

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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.

1. The process of assessing the EM environment

What EM threats are present which 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?

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 *all reasonably foreseeable environments*, 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 e) 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 supply from the distribution transformer is shared by more than 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 a radio or TV *receiver* antenna? YES ☐ NO ☐

d) Will the final product be physically located <30m from heavy power equipment, industrial manufacturing or processes and the like? YES ☐ NO ☐

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

Questions f) 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 f) 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 <u>*possible*</u> 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.

f) 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.

h) 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.

i) 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.

j) 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 safety is an issue, the engineers should have appropriate competency in EMC and safety, including experience in applying IEC 61508 and IEC/TS 61000-1-2. Some military and avionics EMC engineers with experience of MIL-STD-464 (or equivalents) may be suitable, but most of them will not be familiar with applying IEC 61508 and IEC/TS 61000-1-2. At the moment the only appropriate training course (outside of the military) known to exist worldwide is the one run by the Institution of Electrical Engineers (London, UK, www.iee.org.uk).

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/home.htm and 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 you can download them from 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 RCTA/DO-160D, published by RTCA Inc. in 1997 (www.rcta.org), which is continually being improved. The civil working groups developing this standard (DO-160E is due in 2004) 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)