The EMC building: design and construction strategies

The hazards posed by electromagnetic fields must be factored into modern building design for the protection of both workers and vital electronics.

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As the technologies located in industrial, scientific, and commercial buildings becomes ever more complex, interference problems caused by electromagnetic fields (EMF) are increasing in frequency and severity. These problems can impact the efficient use of the building, the performance of electronic equipment within the building, and the productivity of the workers housed therein.

This article examines how electromagnetic fields can affect electronic equipment, as well as human health. The sources of potentially hazardous electromagnetic fields inside a typical building are identified and listed, as are the sites requiring extraordinary degrees of protection. The article discusses the best protection strategies for varying situations.

Today, almost every environment teems with electromagnetic sources. Electrical (E) field (high frequency) sources, such as cellular phone networks, are now common (5 to 15 cell phone repeaters per square mile in urban areas); and the incidence of electromagnetic "smog" (high electromagnetic field levels in nonrestricted areas) has increased at an alarming rate. These high EMF source levels and electronic equipment designs using wide frequency ranges can pose a serious threat to high-speed electronics. For example, 15 percent of all computer server crashes can be attributed to electromagnetic interference.

Magnetic (H) field (low-frequency) interference is a long-standing, but nonetheless, significant problem. Like high frequency E-fields, high H-field levels pose a real danger. Magnetic interference can have a detrimental affect on both electronics and human health. Many reports have alleged a correlation between high exposures to magnetic fields and a significant rise in the incidence of some illnesses, including tumors and certain cancers.

In an ideal world, EMF protection would be factored into building design and construction for the protection of both workers and equipment. In fact, in the near future, the reduction of EMF fields may become part of governmentally enforced building codes.

MAGNETIC (H) FIELD SOURCES

H-fields are produced by electric current and vary over time. Since they pass unaltered through earth, concrete, and most building materials, effective shielding can be difficult to achieve. Shielding from H-fields is achieved through absorption.

ELF (extra low frequency), or power frequency, magnetic fields are the natural consequence of the use and distribution of electricity. The strength and area of magnetic fields emitted are proportional to the amount of current being used.

The strength of an H-field decreases with distance as a function of the source type. From single conductor sources, magnetic field strength decreases in direct proportion to the distance from the source (1/D). From multiple conductor sources, magnetic field strength decreases as the square of the distance ($1/D^2$); and, from coils or loops, magnetic field strength decreases as the cube of the distance ($1/D^3$). Clearly, an accurate assessment of field source types is critical for EMF reduction or shielding

The main sources of magnetic fields in buildings are:

- Main transformer (up to 1000 mG inside the transformer room; 22 kV to 400 V; 250 kVA)
- Service entrance or distribution electric panel (from 100 mG to 350 mG at 1 m from the panels; 63 A to 500 A)
- Power cable risers (from 20 mG to 250 mG at 1 m from the cables; 63 A to 500 A)

IMMUNITY FROM H-FIELDS

High magnetic field levels can affect both electronic equipment and workers. The most common magnetic field effect is computer monitor flickering. This annoying effect takes place in countless offices every day.

A magnetic field higher than 10-25 mG will usually cause computer monitor flickering (depending on the type of monitor). At these radiation levels, the vibration of the screen is not very annoying, but the flicker can have a deleterious effect on the operator's sight. Continuous exposure to magnetic fields higher than 10 mG for a long period of time could result in serious health problems for the worker.

In many cases, computer monitor flickering is not a problem in itself but an indication of a serious problem with magnetic field levels that could damage human health. At a level over 40 mG, headaches will interfere with worker productivity.

ELECTRIC (E) FIELD SOURCES

Any electrical device when plugged in, but not necessarily turned on, generates electric fields. Measured in volts per meter (V/m) and given a relatively constant field strength over time, shielding from electric fields can be achieved fairly easily with common conductive materials. Electric fields are substantially altered by most materials—particularly if they are run to ground.

As noted above, E-fields are created by high frequency electronic and electromechanical switching devices and transmission signals.

Decreases in E-field strength are calculated as the square of the distance ($1/D^2$) from the source. However, the proliferation of wireless telecom devices and the ever faster computing and switching speeds of modern technology, have created a situation in which E-fields are becoming a major problem. Achieving electromagnetic compatibility (EMC) is more difficult, and virtually no area can be considered entirely safe from this problem.

Usually, electric field sources can be found outside any building. Common E-field sources found outdoors include:

- Mobile phone stations
- Broadcast antennas (radio and TV)
- Radar
- Lightning

Other sources of electric interference can be located inside a building; these include:

- Internal GSM networks
- Machinery (AC Drives, EDM machines, welding machines, etc.)

This interference can have a critical impact on electronic equipment (*e.g.*, computers). The indirect effects of high frequency E-fields on human health and safety are fully regulated in Europe by laws such as the European EMC 89/336 Directive. However, it is probable that more governments will soon enact new laws regarding direct human exposure to RFI.

IMMUNITY FROM E-FIELDS

As yet, there are no data which establish a correlation between E-fields and hazards to humans, even though some preliminary medical research indicates that avoidance of overexposure to E-fields would be prudent.

However, an undisputed effect of high frequency electric radiation is its impact on sophisticated electronics and computer networks. It is quite common to find electric field levels in nonrestricted areas far above the maximum immunity levels set by international standards.

European standard EN 61000-4-3 mandates that all electronic equipment must operate without any problems in electric field environments up to 1, 3 or 10 V/m (depending on the level of severity). The standard limit in a commercial, industrial, or scientific building is 3 V/m.

Also, a survey by the Federal Communications Commission (FCC), "Measurements of environmental electromagnetic fields," shows that values above the standard limits are quite common (Table 1).

These are values measured in nonrestricted areas. Too often, electronic equipment is routinely placed in an environment with an electromagnetic field higher than the device's design can withstand. This placement can result in malfunction, and the equipment's supplier cannot be held responsible for these problems.

RELATED STANDARDS & HUMAN HEALTH

As yet, there are no established international criteria regarding EMF health hazard levels.

For electric fields, the EN (European Norms enforced by the European Union, under CENELEC

ANTENNAE		
Antenna type	**E-field (V/m)**	**Magnetic field (mG)**
Dipole (80 W)	2.6 - 51.1	1.6 - 9.8
Open line "modified T" (500 W)	4.5 - 27.5	4.6 - 38
"Inverted V" dipole (100 W)	0.2 - 43	0.5 - 15.5
Horizontal loop (100 W)	2.1 - 85.1	2.26 - 16.3
Vertical radiator (800 W)	3.5 - 47	17.6 - 169
"Inverted V" dipole (1400 W)	13.4 - 34	2.5 - 8.6
Center field dipole (120 W)	8.9 - 17.7	1.1 - 32.2
Vertical Whip (140 W)	3.2 - 36.3	1.5 - 3.5
Yagi (100 W)	5.1 - 10	1 - 2
Horizontal loop (100 W)	2.1 - 11.6	0.6 - 3.1
Dipole (100 W)	22 - 97	1.3 - 8.8
Yagi (5 element) (1000 W)	11.7 - 15.2	5 - 6.3
"Half-sloper" Dipole (100 W)	5 - 96	2.5 - 11.3
Yagi (3 element) (450 W)	3 - 68	1.3 - 2.3
¼-wave whip (85 + 10 W)	15 - 63	6.3 - 20.1
VHF Discone (250 W)	7 - 27	5 - 7.5

Table 1. Typical E- and H-field measurements for various antenna types.

and IEC advice) have already established limits with which all equipment must comply.

For magnetic fields, there are several studies and proposed standards; each calling for different levels of "safe" exposure and varying degrees of restriction.

Worthy of particular attention, the NCRM standard is realistic, generally applicable, and safe. It is the result of comprehensive research studies carried out in 1995. Over 1000 sites were measured by the National Council on Radiation and Measurements (NCRM), a U.S. organization. A reading of 10 mG was established as the maximum allowable background EMF level not hazardous to human health in both offices and homes. (Measurements were not carried out immediately adjacent to appliances and machines).

Others standards, such as the Swedish MPRII, set a 2.5-mG limit for EMF measured at 50 cm from cathode ray tubes (CRTs); but this standard is limited to a few types of equipment, and it offers no criteria for open rooms and areas.

Additional research by the U.S. Electric Power Research Institute (EPRI) has indicated 2 mG as a boundary level for exposure to magnetic fields. Below this level, exposure is regarded as so low as to be completely inconsequential. Significantly, exposures above the 2-mG level are regarded as measurable exposures, but they are not deemed harmful or dangerous. In fact, 10 mG is the established cutoff level.

Specifically, 10 mG is the maximum acceptable level of the background magnetic field measured at the center of a room at a height of one meter. The measurement is taken at least 3 meters away from electronic equipment, while the equipment inside the room is turned off and the electrical network of the building is operating at a minimum 50% of its maximum load.

Levels exceeding this limit would fail safety criteria and would require countermeasures in the equipment installation, in the building interior, at the specific building site, or in the equipment itself.

If machines operating in the room are CE certified (having passed European EMC standards), the risk of high frequency emissions should be nonexistent.

In most existing installations, the 10-mG limit is difficult to achieve because of existing non-shielded cable risers and transformers. Obviously, suitable countermea-

Organization	NCRM	MPRII	EPRI
Country	U.S.A.	SWEDEN	U.S.A.
Maximum permissible magnetic field background	10 mG		
Maximum CRT emission permissible at 50 cm		2.5 mG	
Exposure non-existent			Below 2 mG
Hazardous limit			Above 10 mG

Table 2. Maximum permissible exposure limits.

sures should be specified and applied at the design and installation stages to achieve acceptable levels.

RELATED STANDARDS: ELECTRONIC EQUIPMENT MAGNETIC FIELD IMMUNITY

IEC 1000-4-8: TESTING AND MEASUREMENT TECHNIQUES – MAGNETIC FIELD IMMUNITY TEST

The objective of this standard is to establish a common reference for evaluating the performance of equipment and installations when subjected to magnetic field strengths commonly found in an industrial setting.

RELATED STANDARDS: ELECTRONIC EQUIPMENT ELECTRIC FIELD IMMUNITY

IEC 1000-4-3: TESTING AND MEASUREMENT TECHNIQUES – RADIATED, RADIO-FREQUENCY, ELECTROMAGNETIC FIELD IMMUNITY TEST

This section of IEC 1000-4 covers the immunity of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and sets forth the required test procedures.

Test levels. The preferred test levels in the frequency range of 80 MHz to 1000 MHz is given in Table 3.

Selection of test levels. The test levels and frequency bands are selected to match the electromagnetic radiation environment to which the EUT (equipment under test) might be exposed when finally installed. When selecting an appropriate test level, the consequences of possible failure should be considered. A more stringent test level should be employed if the consequences of a failure would be serious.

For equipment intended to operate in a variety of locations, the following guidance should be used in selecting the test level to be applied.

The following classes are related to the test levels listed in Table 3; they should be regarded as general guidelines for the selection of the corresponding levels.

- Class 1: Low-level electromagnetic radiation environment. Levels typical of local radio/television stations located at more than a 1 km distance, and low power transmitters/receivers.
- Class 2: Moderate electromagnetic radiation environment. Low power portable transceivers (typically less than a 1-W rating) are in use, but with restrictions on use in close proximity to the equipment, *i.e.*, a typical commercial environment.
- Class 3: Severe electromagnetic radiation environment. Portable transceivers (2-W rating or greater) are in use relatively close to the equipment but not less than 1 m distance. High power broadcast transmitters are in close proximity to the equipment, and ISM equipment may be located nearby, *i.e.*, a typical industrial environment.
- Class X: X is an open level which may be negotiated and specified in the product standard or equipment specification.

Test Level	Test Field Strength (V/m)
1	1
2	3
3	10
X	Special

NOTE: X is an open test level. This level may be given in the product specification.

Table 3. Preferred Test Levels.

IEC 1000-4-4: TESTING AND MEASUREMENT TECHNIQUES – ELECTRICAL FAST TRANSIENT/BURST IMMUNITY TEST

The objective of this standard is to establish a common and reproducible basis for evaluating the performance of electrical equipment and installations when subjected to repetitive fast transients (bursts) on supply, signal, and control ports.

IEC 1000-4-5: TESTING AND MEASUREMENT TECHNIQUES – SURGE IMMUNITY TEST

The objective of this standard is to establish a common reference for evaluating the performance of equipment and installations when subjected to high energy disturbances on the power and interconnection lines.

SHIELDING STRATEGIES

Primary EMF problems that can be normally measured inside buildings are:

- Magnetic Fields (H)
  - low frequency radiated interferences; CRT flickering
  - health hazards
- Electric Fields (E)
  - High frequency radiated interference: logic problems in electronics, malfunction of machinery
  - High frequency, electrically conducted noise
  - High frequency interference on the power cables; logic problems, data and/or memory loss,
  - High voltage transients,
  - High frequency, short duration spikes coming through the main supply causing equipment destruction, malfunction, and system hang-up.

For reducing the electromagnetic fields found inside buildings or facilities, there are three general strategies:

1. Shield the H- or E-field radiation source.

   This technique consists of identifying the radiation source and installing a shielding system to reduce the radiation levels as required. The typical sources of electromagnetic fields are: transformers, power cable riser systems, and main and distribution electrical panels.

2. Shield the H- or E-field radiation-sensitive room/site.
   If the source is difficult to identify or to shield, the easiest alternative is to shield and protect the specific room in the building (*e.g.*, laboratories or computer rooms).
3. Shield using a combination of the two techniques listed above.
   The solution that results in the best performance is the combination technique. Planning ahead and providing proper magnetic shielding for all H-field emission sources will save time and money, and only very sensitive rooms will require E-field shielding.

Additional steps for optimal planning and design include shielding the power cables and avoiding high magnetic fields in all areas near the cables.

Figure 1 pinpoints key building locations where problems may arise. Possible "culprits" and "victims" of interference are indicated.

Different specific solutions are possible, depending on the amount budgeted for shielding in a particular construction project.

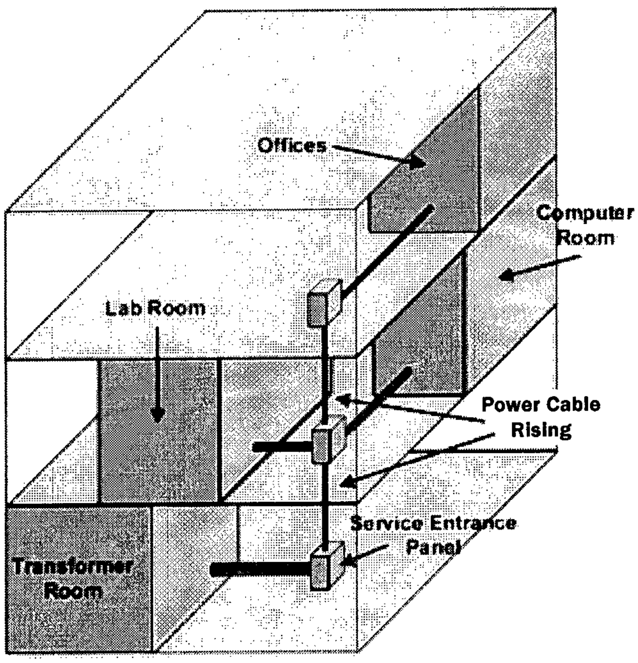

Figure 1. Key EMF problem areas in buildings.

MAGNETIC SHIELDED ROOM

This type of room is usually small, so the cost of shielding will be relatively inexpensive, although the installation can be quite complex. Shielding panels utilizing high ferrite materials can be used to make an enclosure in the room. This choice is the best solution to avoid magnetic fields generated by main transformers and electric panels.

ELECTRIC SHIELDED ROOM

An electric shielded room is a solution for critical locations, such as Data Processing Centers (DPC), laboratories, and clean rooms. Depending on the size of the room, this can be a rather expensive solution, but it's the only way to assure a clean electromagnetic environment for computers and lab equipment and to achieve optimal electronic performance.

In an environment free of electromagnetic fields, electronics work with greater efficiency, computer networks reach a greater speed, and a lot of problems are avoided, *e.g.*, systems freeze-ups and glitches.

SHIELDED CABLE TRUNKING

This solution will be a "must" in the design and construction of buildings in the future. Transformer rooms are usually located far away from work spaces and residential areas in buildings, but cable runs throughout the entire building are a significant source of magnetic field radiation.

Consequently, one crucial factor in building design must be the protection of both human health and electronic systems from the hazards posed by magnetic fields. The radiation arising from cabling runs throughout the building must be taken into account.

SHIELDED ENCLOSURE

Shielded enclosures are an alternative solution for delicate electronic equipment such as computer servers and routers.

In most cases, the cost of shielding an entire computer room is prohibitive; nonetheless, network elements and mission-critical computers must be shielded. Often, the best solution in these cases is to collocate all critical equipment and to place them inside a properly shielded enclosure.

These kinds of electronic devices are usually located inside standard rack-type cabinets. The optimal solution is to replace the standard enclosure with a shielded enclosure. This relatively modest increase in cost will assure the protection of the most delicate equipment, which can be vital to a company's operation.

CONCLUSIONS

Today, the levels of electromagnetic fields in our environment are already quite high and still increasing. Consequently, protection against EMF must be factored into all current and future building designs.

Most economic activities rely heavily on nonstop, mission-critical computing equipment (*e.g.*, banking, insurance, government, brokerages). The chance of a computer breakdown or server crash, even if remote, must be avoided as the ultimate costs can be disastrous. EMF is reported to cause 15% of total server crashes.

Understandably, concern about the effects of electromagnetic radiation on both electronics and human health is growing as many reports have indicated that high levels of both electric and magnetic radiation are dangerous.

Electromagnetic protection will be a "must" in building design in the near future and probably will be demanded by customers and required by law. Engineers, architects, and consultants must deal with this problem in the design stage to forestall the possibility of complaints and expensive remodeling of completed buildings.

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