Guide To Solving AC Power EMF Problems In Commercial Buildings

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Lou Vitale
www.vitatech.net

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Introduction

In large commercial buildings when offices and work areas are located near electrical systems such as **transformers, network protectors, secondary feeders, switchgears, busway risers, and electrical panels**, the occupants are usually exposed to 60-Hz (Hertz) magnetic field levels ranging from 10-1,000 mG (milligauss). Fortunately, magnetic field strength rapidly diminishes as a function of distance from the electrical source. However, approaching the 60-Hz magnetic source, the occupant may be exposed to extremely high 1,000-100,000 mG levels. Occupants are not aware of this potential hazard unless the magnetic source produces electromagnetic interference (EMI) in sensitive electronic equipment (monitors, computers, magnetic media, audio/video equipment, etc.). Once detected, 60-Hz magnetic field management (mitigation) ultimately becomes the responsibility of the building management; otherwise the victims (occupants) may seek legal action. This Guide, which includes a tutorial section on **EMF Fundamentals**, should be a valuable aid to building managers and engineers who have a challenging 60-Hz magnetic field problem.

VDTs - The Canary Birds Of 60-Hz Magnetic Fields

How does one tell if the magnetic field levels are greater than 10 mG without a gaussmeter? Use the EMF equivalent of a coal miner's Canary Bird - a color computer monitor. Place a computer with a color monitor in the area under investigation, select a full-screen display, and rotate the display 360 degrees. If the screen appears to jitter or distort, then the magnetic field exceeds 10 mG. A better alternative is to purchase an inexpensive, but highly accurate, single-axis or a triple-axis gaussmeter ($225) from Less EMF (www.lessemf.com) . With a single-axis gaussmeter, the magnetic field reading in milligauss (mG) is dependent on the orientation of the probe; whereas a triple-axis gaussmeter electronically computes and displays the *resultant* R_{rms} (root-mean-square) sum of three internal orthogonal coils on the *x-, y-* and *z-axis*, as expressed in:

$$R_{rms} = \sqrt{x^2 + y^2 + z^2}$$

Quick Overview On the Subject - Extremely Low Frequency (ELF) EMF

The 60-Hz alternating current (AC) line frequency is defined as an *Extremely Low Frequency (ELF) Electromagnetic Field (EMF)* because the fundamental frequency is between 3-3,000 Hz. This is the bottom of the electromagnetic spectrum near to Direct Current (DC) and the earth's geomagnetic field. ELF electric and magnetic fields emanate (not radiate) from 60-Hz electric power lines, equipment, and appliances. Refer to the **EMF Fundamentals** section, pages 13-14, for more details. Electric fields are only significantly elevated (greater than 1 kV/m) under high voltage transmission lines. Inside commercial buildings, the electric fields are normally below 50 V/m near unshielded 120 VAC electrical wires, and zero if the wires (any voltage) are shielded in conduits. Therefore, the E in EMF from internal 60-Hz power sources is usually not a problem inside commercial buildings.

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Emanating ELF magnetic fields are proportional to the AC current in wires, ground conductors, metal water pipes, HVAC metal ducts, or any conductive material where a current travels. Simply stated, very high current sources emanate very high magnetic field levels. In the United States, magnetic fields, or more accurately magnetic flux density levels (see **EMF Fundamentals - Magnetic Flux Density & Handy Conversion Factors**), are measured in units of milligauss (mG). Unfortunately, magnetic fields are insidious and penetrate through virtually all objects including people and building materials. Therefore, considering the potential health risks and perilous electromagnetic interference (EMI) that emanate from **transformers, network protectors, secondary feeders, switchgears, busway risers, electrical panels, motors, and electric heaters**, all offices and work areas in proximity should be magnetically surveyed by an experienced ELF EMF engineer.

ELF EMF Health Issues - Complex, Confusing & Controversial

What is a safe or acceptable milligauss (mG) level and maximum duration for human exposure? That is a very perplexing and complex question to answer. The National Energy Policy Act of 1992 authorized the Secretary of the Department of Energy (DOE) to establish a five-year, $65 million EMF Research and Public Information Dissemination (RAPID) Program to ascertain the affects of ELF EMF on human health, develop magnetic field mitigation technologies, and provide information to the public. In June 1998 the National Institute of Environmental Health Sciences (NIEHS), which is the research group of the EMF RAPID Program, published a Working Group Report, *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Field*, that clearly states in section 5.1, Carcinogenicity in humans:

The Working Group concluded that ELF EMF are possibly carcinogenic to humans....

The EMF RAPID Program closed the *EMF Information Hotline* in December 1998, then on 4 May 1999 the NIEHS Director Kenneth Olden, Ph.D. deliver his final report, *Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields*, to Congress that stated the following in the Cover Letter and Executive Summary:

> The scientific evidence suggesting that ELF-EMF exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults... The NIEHS concludes that ELF-EMI exposure cannot be recognized at this time as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard.

Furthermore, Dr. Olden writes in the *Conclusions And Recommendations* on pages 37 and 38:

> "...the evidence suggests passive measures such as a continued emphases on educating both the public and the regulated community on means to reducing exposures. NIEHS suggests that the power industry continue its current practice of siting power lines to reduce exposures and continue to explore ways to reduce the creation of magnetic fields around transmission and distribution lines without creating new hazards. We also encourage technologies that lower exposures from neighborhood distribution lines provided that they do not increase other risks from accidental electrocution or fire."

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“Exposures in individual residences are linked to certain characteristics. Their chief causes are improper grounding and improper wiring, which if addressed by properly following current electrical codes, can be mitigated and exposures reduced. Older homes may also have higher ambient exposures, but these must be assessed on a case-by-case basis. Many of the U.S. electric utility companies will measure fields in their customers’ homes and help them to identify sources of high fields; we encourage continuation of this practice. Finally, the NIEHS would encourage the manufacturers of household and office appliances to consider alternatives that reduce magnetic fields...”

Currently, there are no Federal standards for AC ELF electric and magnetic field levels. Most states have not set maximum acceptable ELF electric and magnetic field levels. As shown below the International Commission on Non-Ionizing Radiation Protection (IRPA/INIRC) established 1,000 mG (1 Gauss) as the maximum human exposure limit for the general public over 24 hours.

Table 1: International Commission on Non-Ionizing Radiation Protection Guidelines

Occupational Workers	Electric Field	Magnetic Field
Whole working day	10 kV/m	5,000 mG
Short term (2 hours)	30 kV/m	50,000 mG
For limbs		250,000 mG
General Public:		
Up to 24 hours per day	5 kV/m	1,000 mG
Few hours per day	10 kV/m	10,000 mG

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends 10,000 mG (10 Gauss) and 25 kV/m for occupational workers. Lower levels of 1,000 mG and 1 kV/m are recommended by the ACGIH for occupational workers with cardiac pacemakers. New York and Florida have set 200 mG right-of-way (ROW) limits for new transmission lines. Also, the City of Irvine, California, and Brentwood, Tennessee, set 4 mG limits. Unfortunately, due to the conflicting scientific research and lack of governmental standards, it becomes the client's option to establish an acceptable human exposure. **Based upon our professional engineering experience and review of the current ELF EMF research literature, Vitatech recommends 10 mG (1 µT) as a reasonably achievable human exposure limit.**

Our 10 mG (1 µT) human exposure limit is supported by section 8.4.1.3 option 3 in the National Council of Radiation Protection and Measurements (NCRP) draft report published in the July/August 1995 issue of *Microwave News* (visit the Microwave News Homepage <www.microwavenews.com> for the entire draft report or the Vitatech links page) that states the following on the next page:

8.4.1.3 Option 3: An exposure guideline of 1 µT (10 mG) and 100 V/m: A considerable body of observations has documented bioeffects of fields at these strengths across the gamut from isolated cells to animals, and in man. Although the majority of these reported effects do not fall directly in the category

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of hazards, many may be regarded as potentially hazardous. Since epidemiological studies point to increased cancer risks at even lower levels, a case can be made for recommending 1 µT (10 mG) and 100 V/m as levels not to be exceeded in prolonged human exposures. Most homes and occupational environments are within these values, but it would be prudent to assume that higher levels may constitute a health risk. In the short term, a safety guideline set at this level would have significant consequences, particularly in occupational settings and close to high voltage transmission and distribution systems, but it is unlikely to disrupt the present pattern of electricity usage. These levels may be exceeded in homes close to transmission lines, distribution lines and transformer substations, in some occupational environments, and for users of devices that operate close to the body, such as hair dryers and electric blankets. From a different perspective, adoption of such a guideline would serve a dual purpose: first, as a vehicle for public instruction on potential health hazards of existing systems that generate fields above these levels, as a basis for "prudent avoidance"; and second, as a point of departure in planning for acceptable field levels in future developments in housing, schooling, and the workplace, and in transportation systems, both public and private, that will be increasingly dependent on electric propulsion.

Information (accurate and misleading) about ELF EMF is virtually everywhere. The foremost health journal on the subject is *MICROWAVE NEWS*. Dr. Louis Slesin's website http://www.microwavenews.com covers non-ionizing radiation (ELF to RF/microwave).

Two excellent booklets on the subject, Questions and Answers About EMF Electric and Magnetic Fields Associated with the Use of Electric Power (January 1995) and Questions and Answers EMF In The Workplace (September 1996) were published by the National Institute of Environmental Health Sciences (NIEHS) and DOE.

Questions regarding health issues and exposure levels can only be addressed by a qualified scientist. If you have any specific questions, contact the following U.S. government agencies responsible for ELF EMF health issues and policies:

1. National Institute of Environmental Health Sciences
   P.O. Box 12233, MD NH-10
   Research Triangle Park, North Carolina 27709-2233
   http://www.niehs.nih.gov/health/topics/agents/emf/

2. National Institute for Occupational Safety and Health
   Division of Applied Research and Technology
   4676 Columbia Parkway, Cincinnati, OH 45226
   http://www.who.int/peh-emf/project/mapnatreps/usa/en/index.html

ELF EMF Commercial Surveys - Spot, Contour & Dosimetric

There are three common types of commercial ELF EMF surveys: spot, contour, and dosimetric. Spot surveys collect milligauss (mG) data (single or resultant R_{rms} triple-axis) in spots such as the center of each office, work area, hallway, electrical equipment room, and selected points around the property and building. Contour surveys use a mapping wheel attached to a programmable gaussmeter that collects three-axis and calculated resultant R_{rms} milligauss (mG) data at selected intervals along a path. And, dosimetric surveys collect exposure data at a fixed point (or attached

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to a subject) in timed increments over a defined period (8-24-48 hours). Commercial spot and contour surveys start at $1,500-$3,600 (1,500 ft2 office) and range up to $7,500-$15,000 depending on total area surveyed within each building and around the exterior property (if included).

Professional spot and contour ELF EMF surveys should include milligauss (mG) measurements of the following: perimeter of the property and building; transmission/distribution lines and transformers to the nearest exterior wall; hallways, offices, and common areas; transformer vaults, electrical rooms, and feeders near offices; and selected equipment at 4- and 18-inch distance intervals. All monitors should comply with the Swedish MPR II and IEEE 1140-1994 magnetic field standards (minimum). Finally, the grounding system and water service (metal pipes only) should not carry any excessive and potentially dangerous ground or plumbing currents. Normally, only the magnetic fields are recorded during an ELF EMF survey; however, if there is a high voltage transmission line near or over the property, then the electric fields should also be recorded at set increments to the nearest exterior wall.

ELF EMF spot and contour surveys should comply with the following technical protocols and standards: *California Protocol for Measuring 60 Hertz Magnetic Fields*, prepared by the California Department of Health Services and State Public Utilities Commission; *A Protocol for Spot Measurements of Residential Power Frequency Magnetic Fields*, written by the IEEE Magnetic Fields Task Force, July 1994; and the *IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power lines*, ANSI/IEEE Standard 644-1994.

After the survey is completed, the *ELF EMF survey engineer* should issue a comprehensive final report that includes: detailed drawing of the property, building(s), and nearest electrical sources; recorded spot or contour (with graphical 2-D and 3-D plots) measurements of the surveyed areas including selected equipment; noted grounding and plumbing current problems; and a list of National Electrical Code (NEC) violations (if any). Clients should also receive Risk Assessment Information -- the latest news in ELF EMF scientific research. If the magnetic field levels are significant (≥10 mG) in occupied offices and work areas, then the *ELF EMF survey engineer* should recommend one or several of the following practical ELF mitigation solutions with estimated implementation costs (see **EMF Fundamentals - Magnetic Field Mitigation** for more details regarding the subject):

1. Prudent avoidance (moving people or the EMF source to a safe distance);
2. Rewiring to correct NEC violations - grounding and wire-loop problems;
3. Dielectric couplers on water service lines to eliminate plumbing currents;
4. Magnetic shielding (low-carbon steel, silicon-iron steel, aluminum, mumetal, etc.); and,
5. Active or passive magnetic field cancellation technology.

Common ELF EMF Problems In Commercial Buildings

In the city, transformers and network protectors are placed in secured vaults usually located within the building; whereas, suburban utilities mount the transformers on outside pads. High-current, low- voltage (less than 600 V) feeders supply the main switchgears rated between 1000 and 4000 amps per phase. In multistory buildings, substations (transformers, network protectors & feeders), electrical rooms, and high-current (1,000-2,500 amps) busway risers are necessary for every 10-12 floors. Occupied areas above, below, and adjacent to the substations and busway ris-

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ers are subjected to very high (10-1,000 mG) and extremely high (1,000-100,000 mG) levels. Besides current load, conductor spacing is another critical factor affecting levels. Closely stacked, solid bus bar, busways minimize phase conductor spacing, thereby promoting self-cancellation and lower levels. Refer to **EMF Fundamentals - Loop Magnetic Field Sources & Three-Phase Magnetic Field Sources.**

If a four-wire three-phase circuit (lateral service, feeder or riser busway) is unbalanced by more than 20%, has excessive net currents measured around three phases and neutral with a flexible current probe or ground currents on the metal conduit, then the magnetic emissions become high, thereby presenting a serious EMI threat. Refer to **EMF Fundamentals - Ground, Plumbing & Net Currents** for technical details. Stray grounding currents in the building steel, HVAC ducts, and metal conduits plus plumbing currents on the water pipes also generate highly elevated levels. For example, a simple grounded-neutral short in several single-phase 120 V receptacles out of thousands in a commercial building is normal. This electrical short provides an alternative path via the grounded conduits and building steel for some (if not all) of the branch circuit neutral current to travel back to the grounded-neutral wye of the 208/120 V distribution transformer (electrical source). **Significant ground currents not only produce very high magnetic fields, but are also indicative of electrical wiring problems (NEC violations) or undetected, potentially lethal, electrical shorts in grounded equipment (receptacles, computers, motors, heater coils, compressors, neon signs, dimmers, etc.)**.

Finally, magnetic fields normally induce voltages and currents within objects by electromagnetic induction. Read **EMF Fundamentals - Electrostatic & Electromagnetic Induction** for a succinct tutorial on the subject. Unfortunately, the potential health effects (if any) from magnetically induced circulating *eddy currents* in body tissues are not well understood, therefore long-term exposure to very high (10-1,000 mG) and extremely high (1,000-100,000 mG) levels should be avoided.

AC ELF Electromagnetic Interference (EMI)

Electromagnetic induction occurs when time-varying AC magnetic fields couple with any conductive object including wires, electronic equipment and people, thereby inducing circulating currents and voltages. Read **EMF Fundamentals - Electrostatic & Electromagnetic Induction** for details. In unshielded (susceptible) electronic equipment (computer monitors, video projectors, computers, televisions, LANs, diagnostic instruments, magnetic media, etc.) and signal cables (audio, video, telephone & data), electromagnetic induction generates electromagnetic interference (EMI), which is manifested as visible screen jitter in displays, hum in analog telephone/audio equipment, lost sync in video equipment and data errors in magnetic media or digital signal cables.

Generally, the EMI threshold level in unshielded electronic equipment including 12-15 inch computer monitors and signal cables is 10 mG for AC ELF electric power sources. However, actual EMI immunity depends on the PCB and component layout, circuit design (differential verses unbalanced input amplifiers, signal-to-noise ratio, etc.), outer case composition, geometry and shielding factor (SF). *It should be noted that large 21-inch high resolution computer moni-*

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tors used for desktop publishing and CAD work are susceptible at only 5 mG to screen jitter, which is one-half the normal EMI threshold level for standard 12-15 inch computer monitors.

ELF EMF Contour Survey - Community College In New York City, NY

An actual ELF EMF contour survey, performed on 17 August 1994 at the Community College in New York City, is presented to illustrate the problems associated with transformers, network protectors, high current secondary feeders, and main electrical rooms located near occupied areas. Very high magnetic field levels between 35-150 mG were measured (waist height) by a faculty member in the college fitness center and two adjoining areas (wrestling room and offices) located above four transformers, four network protectors, and the main electrical room. Furthermore, two issues were of concern to the college administration and New York State Dormitory Authority (DASNY) -- recent illness (cancer) of a faculty member who occupied an exposed office for more than ten years, and the dual use of this space as a day care center for faculty, staff and students. The results of the ELF EMF contour survey and dosimetric measurements collected the following month are presented in this section for discussion. This is a very abridged version of the final report.

Site Description

Four underground primary 13.8 KV three-phase feeders terminate in four 2000 kVA transformers located in separate, street-ventilated vaults operating at 60% capacity. High current secondary 460/265 volt feeders (typically 750-1,500 amps/phase) exit from the transformers and connect to the four network protectors in secured adjacent vaults. Each network protector transfers power to a switchgear panel in the main electrical room via an overhead service busway (five feet from the floor above). The four main switchgear panels are rated at 4000 amps each and supply five building busway risers. On the next floor, directly above, is the fitness center (refer to Table 3). Adjacent to the fitness center on either side is the wrestling room and several offices. The fitness center and wrestling room are open areas 40 feet wide by 50 feet long, joined by a common wall. Finally, this is a large academic building over 800,000 ft2.

Survey Instrument-FieldStar 1000 Gaussmeter

All magnetic field (actually magnetic flux density) measurements were recorded with a triple-axis FieldStar 1000 gaussmeter. The FieldStar 1000 is a high-end programmable gaussmeter capable of spot, contour, and dosimetric measurements. When collecting contour path data, a nonmetallic survey wheel is attached to the FieldStar 1000 gaussmeter and the unit is programmed to record mapped magnetic flux density data at selected intervals. The FieldStar 1000 is exactly 1 meter (39.37 inches) above the ground with the survey wheel attached. Along each path, the distance is automatically logged by the survey wheel with the relative direction entered on the keyboard. After completing the contour path survey, magnetic flux density data with distance and directional information is uploaded to a 486 PC computer and processed by the FieldStar graphics software (Windows version 1.0) into detailed plots. Plots normally display a record number, DOS file name, time/date stamp, ID path number, and the following statistical data defined below:

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Peak - maximum magnetic field (flux) value measured in group.
Mean - arithmetic average of all magnetic field (flux) values collected.
Standard deviation - calculated using the formula below, where B is the magnetic field (flux) and N is the number of samples:

$$\sqrt{\frac{\left(\sum\left(B-\bar{B}\right)^2\right.}{(N-1)}}$$

Median, L5 and L95 - calculated by first dividing the data set range into 1000 equal bins, then assigning each data point to a bin as the data is plotted. After the data has been assigned to bins, the number of points in each of the bins is summed beginning at zero. When the total number of points in the sum reaches 5% of the total, the mid-point of that bin is labeled **L95** or the magnetic field value above which the data is 95% of the time. Continuing the sum until 50% of the total is reached, the mid-point of that bin is then the **median.** When the sum reaches 95% of the total number of points in the data set, the mid-point of this bin is then **L5**, or the level above which the magnetic field value is 5% of the time.

Cum Exp - cumulative exposure calculated for dosimetric (timed) data, which is the area under the field versus time curve.

<u>Contour ELF EMF Survey</u>

Within the main electrical room (refer to Table 3), the magnetic field levels were 15-50 mG along the walkway and greater than 500-2,000 mG on the switchgear and main distribution panel surfaces. There were no elevated magnetic field levels measured near the water service from plumbing currents or from the underground primary feeders in the street: unable to check the building grounding system for excess currents. Finally, seven contour surveys were recorded at the community college; only the first contour survey of the fitness center is examined and discussed.

Map Plot, *Figure #1* in Table 3, shows the recorded contour survey path superimposed over a scaled architectural drawing with the transformers, network protectors, and main electrical room below. The contour survey begins at the **Start** point, follows the solid black line marked with letters A-I at the turns, and stops at the **End** point. In order to avoid several piles of stacked mats in the corner, the initial survey path made a quick turn at point A. Data (in milligauss-mG) was recorded at one-foot intervals along the contour path. *Statistical data* is presented under the title, and the 111 peak spot is marked over network protector #4.

Profile Plot, Figure #2 in Table 3, presents recorded (calculated) R_{rms} resultant magnetic field levels as a function of path distance with positional letter marks referenced to the map plot on Figure #1. Over the transformers, the magnetic field levels are below 50-mG, then increase to 90-mG above the transformer secondary feeders and network protectors. Levels peak at 111-mG over network protector #4 that feeds switchgear SWB3. The levels diminish to 65-mG above the overhead busway service feeders that supply switchgears SWB4, SWB2, and SWB1. Except above switch-

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gear SWB3, which is over 40-mG, the other three switchgear panels are below 25-mG. All other levels emanating from the main electrical room are below 10-mG.

3-D Contour Plot, *Figure #3* in Table 3, depicts a three-dimensional graphic where the resultant Rrms magnetic field levels are vertically plotted as a function of the horizontally mapped coordinates. This is a visually informative graphic that vividly shows the 111-mG peak spot located over network protector #4. In the back of the fitness center near the hallway, the magnetic field levels over most of the electrical room, except for switchgear SWB3, are low compared to the transformers, secondary feeders, network protectors, and service busways.

Dosimetric Plot, *Figure #4* in Table 3, displays data collected at the peak spot marked on ***Figure #1*** at 1-minute intervals between 20-22 September 1994. Except for a large spike of unknown origin that occurred at 3:46 A.M. on Thursday, all other data is rather normal. Maximum levels on the floor occurred as follows: 686-mG Tuesday at 3:04 P.M.; 712-mG Wednesday at 1:01 P.M.; and 709-mG Thursday at 9:04 A.M. *Statistical data* includes 26,475 mG hours of cumulative exposure.

Estimated School-In-Session & Worst-Case Seasonal Peak Load (WCSP)

Since the survey was performed during the August vacation, it was necessary to estimate the school-in-session and worst-case seasonal peak load (WCSP) from 1-meter above the floor data -- then extrapolate floor levels from these estimates. At the peak spot in the fitness center, the estimated WCSP $_{\text{school-in-session}}$ floor and 1-meter levels are 850-mG$_{\text{floor}}$ and 185-mG$_{\text{1-meter}}$, respectively. A summary of recorded data is presented in Table 1 on the next page with estimated (extrapolated) school-in-session and worst-case seasonal peak (WCSP) floor level ranges:

Table 2: Contour, Dosimetric & Estimated Magnetic Field Levels

Survey Area-Path Data	1-Meter Height Recorded Data 17 August 1994	Estimated School-In-Session Floor Levels	Estimated WCSP1 School-In-Session Floor Levels
Fitness Center			
Transformers	20-50 mG	130-325 mG	150-375 mG
Transformer secondary feeders	30-90 mG	195-585 mG	225-675 mG
Network protector vaults	40-111 mG	260-722 mG	300-833 mG
Dosimetric: network protector #4 Recorded 20-22 Sept, 1994	(110 mG) calculated	(712 mG) recorded	(825 mG) calculated

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Table 2: (Continued)Contour, Dosimetric & Estimated Magnetic Field Levels

Survey Area-Path Data	1-Meter Height Recorded Data 17 August 1994	Estimated School-In-Session Floor Levels	Estimated WCSP1 School-In-Session Floor Levels
Overhead service feeders	30-100 mG	195-650 mG	225-750 mG
Switchgear panels	10-45 mG	65-293 mG	75-338 mG
Distribution panels	10-20 mG	30-60 mG*	50-100 mG*
Wrestling Room			
Common wall to 25-feet out	38.9 to 3.0 mG	156 to 3.0 mG*	195 to 3.0 mG*
Offices			
Offices: common wall to hall	53.8 to 10 mG	162 to 30 mG*	269 to 50 mG*
Hallway Area			
Front-Fitness Center	3.0-4.5 mG	3.0-14 mG*	3.0-23 mG*

Notes:
1-Worst-case seasonal peak (WCSP)
* - Sources are not directly below, x3-x5 multipliers applied to estimate levels.

Conclusions & Recommendations

Magnetic field levels in the fitness room, wrestling room, and offices are dependent upon the total building load demand. The college plans to install additional electrically driven chillers in the near future that will increase the seasonal load, and subsequently the magnetic field levels in the affected areas. Therefore, the final conclusions are based upon evaluating the collected data and estimating (and extrapolating) the anticipated worst-case seasonal peak (WCSP) school-in-session levels:

1. In the fitness center --
   a. The highest predicted magnetic field levels (883-mG_{floor} and 185-$mG_{1\text{-}meter}$) emanate from the transformer secondary feeders, network protectors, and overhead busway service feeders;
   b. the next highest predicted levels (150-375 mG_{floor} and 33-83 $mG_{1\text{-}meter}$) emanate from the transformers and switchgear panels; and,
   c. the lowest predicted levels (50-100 mG_{floor} and 11-22 $mG_{1\text{-}meter}$) emanate from the distribution panels in the main electrical room
2. In the wrestling room next to the common wall, the highest predicted magnetic field levels (195-mG_{floor} and 58-$mG_{1\text{-}meter}$) emanate from transformer #1 and network protector #1. The levels diminish to under 3-mG approximately 25 feet away.

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3. In the offices next to the common wall, the highest predicted magnetic field levels (269-mG_{floor} and 80-$mG_{1\text{-}meter}$) emanate from transformer #4, network protector #4, and switchgear SWB3. Levels quickly diminish to below 3-mG in the reception area.
4. Hallway (by fitness center) highest predicted levels are below 23-mG_{floor} & 7-$mG_{1\text{-}meter}$.

Final Recommendations:

1. Install a multilayer, three-substrate (silicon-iron, aluminum, and mumetal), rigid magnetic shielding system in the fitness center and one-half of the wrestling room. Refer to EMF Fundamentals - Magnetic Field Mitigation for more information. Note: The client selected a 3-mG minimum performance criteria at 1-meter above the floor in the fitness center and wrestling room from three proposed magnetic shielding design schemes: 3-mG, 10-mG and 20-mG. The shielding system must attenuate the WCSP school-in-session fitness center peak spot of 185-$mG_{1\text{-}meter}$ to 3-$mG_{1\text{-}meter}$. This is a very challenging performance objective.

2. Only use the offices for storage (no magnetic shielding) -- absolutely no occupants.

Magnetic Shield Design & Installation & Final Performance
Two multilayer, three-substrate (silicon-iron, aluminum, and mumetal), ELF magnetic shields were designed by Vitatech for the fitness center and half of the wrestling room. The client requested a complete design/build bid package with engineering drawings and complete installation specifications. Vitatech provided project management for the shield installation.

After each substrate was installed on the floors and walls (silicon-iron sheets, aluminum plates, and specially annealed mumetal sheets), Vitatech inspected the workmanship and recorded the magnetic field profile to monitor shielding performance. When the project was completed on 17 August 1995, an on-site *final performance test* was executed to validate the 3-mG design objective. Coincidentally, the shielding project was completed exactly one-year to the day after the first contour survey. Refer to page 12, ***Figures #5 - #8***, and the paragraphs below for more information regarding the final performance test of the ELF magnetic shields.

Map Plot, Figure #5 in Table 4, shows the **shielded** fitness center recorded contour survey path superimposed over the transformers, network protectors, and main electrical room below. Data was collected at one-foot intervals, one-meter above the floor, along the path. The peak spot over network protector #4 was now only 4.28 mG - it was 111 mG in Figure #1. Statistical data is presented under the title of Figures #5 - #8.

Profile Plot, *Figure #6* in Table 4, presents the shielded fitness center R_{rms} resultant magnetic field levels in referenced to the map plot in Figure #5. The shielded mean (average) level was only 2.96 mG compared to the unshielded 34.5 mG level in Figure #2. Furthermore, the shielded peak spot on the floor was merely 5.2 mG compared to the 720 mG unshielded peak spot in Figure #2. Remarkably, the peak spot shielding factor (SF) was -43 dB on the shielded floor. Slightly elevated levels between 3.2 - 4.2 mG emanated from the shielded walls (denoted with marker letters A-O) around the perimeter of the room.

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3-D Contour Plot, *Figure #7* in Table 4, shows a three-dimensional graphic of the shielded fitness center. The center region of the shielded fitness center is only 2.5 mG compared to the unshielded (mountainous) center area with peaks between 80 - 111 mG in Figure #3.

3-D Contour Plot, Figure #8 in Table 4, presents a three-dimensional graphic of the shielded wrestling room. The shielded mean (average) level was only 1.41 mG compared to the previously unshielded wrestling room 9.25 mG level. Furthermore, the shielded wrestling room peak spot was 3.36 mG (4.1 mG on floor) compared to the unshielded peak spot of 37.6 mG (93.2 mG on floor). Finally, the shielded peak spot shielding factor (SF) was -29 dB floor.

Final Conclusion

The final design objective of 3-mG (±1 mG) was verified in both the *shielded* fitness center (MEAN of 2.96 mG) and the *shielded* wrestling room (MEAN of 1.41 mG). Although the 3-mG objective was achieved, it should be noted this project was difficult and expensive to implement. Achieving the final design objective of 3-mG demanded the utmost cooperation between the college, Vitatech, and the shielding contractor. It is more practical and significantly less expensive (nearly half the cost) shielding any room to 6-10 mG, rather than 3-mG, which was the ultimate challenge in 1995 for this project type.

Table 3: Pre-shield Data

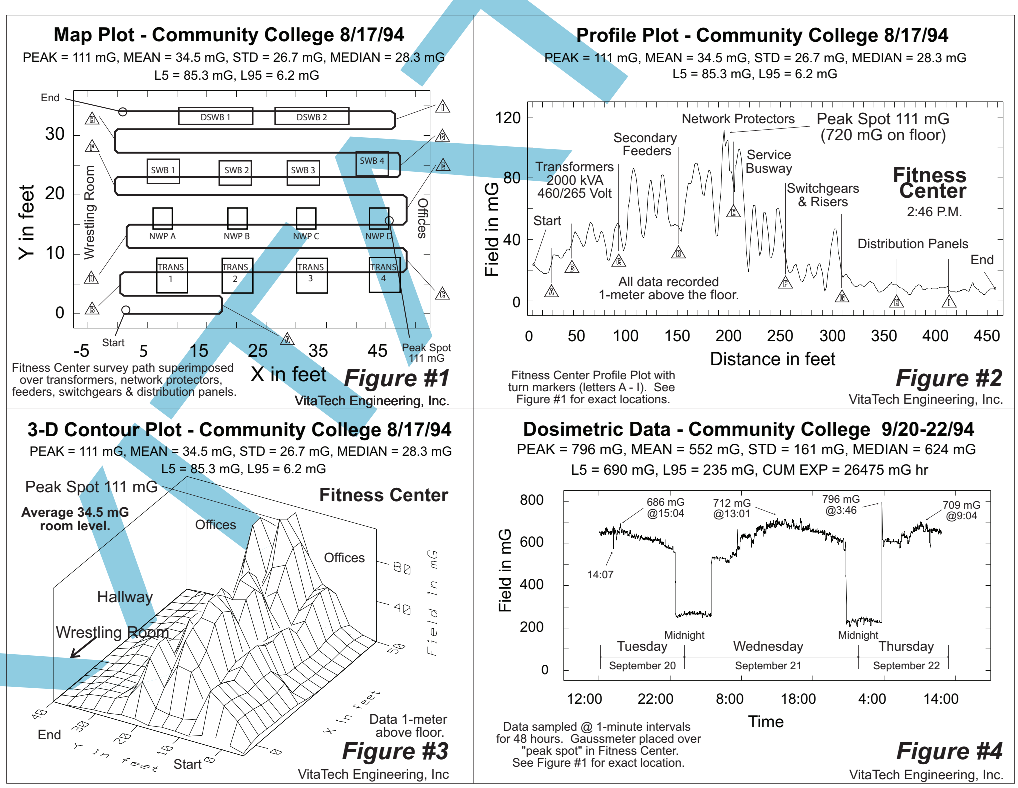


Table 4: Post-shield Data

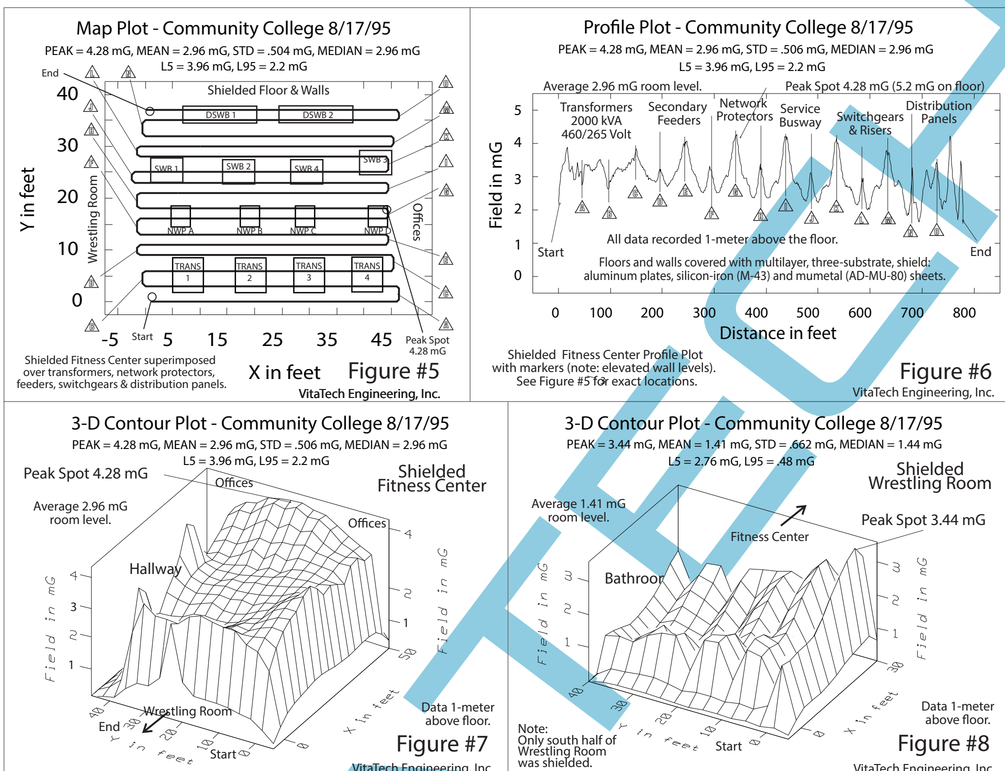


Table 5: Pre & Post Shield Data Comparison #1

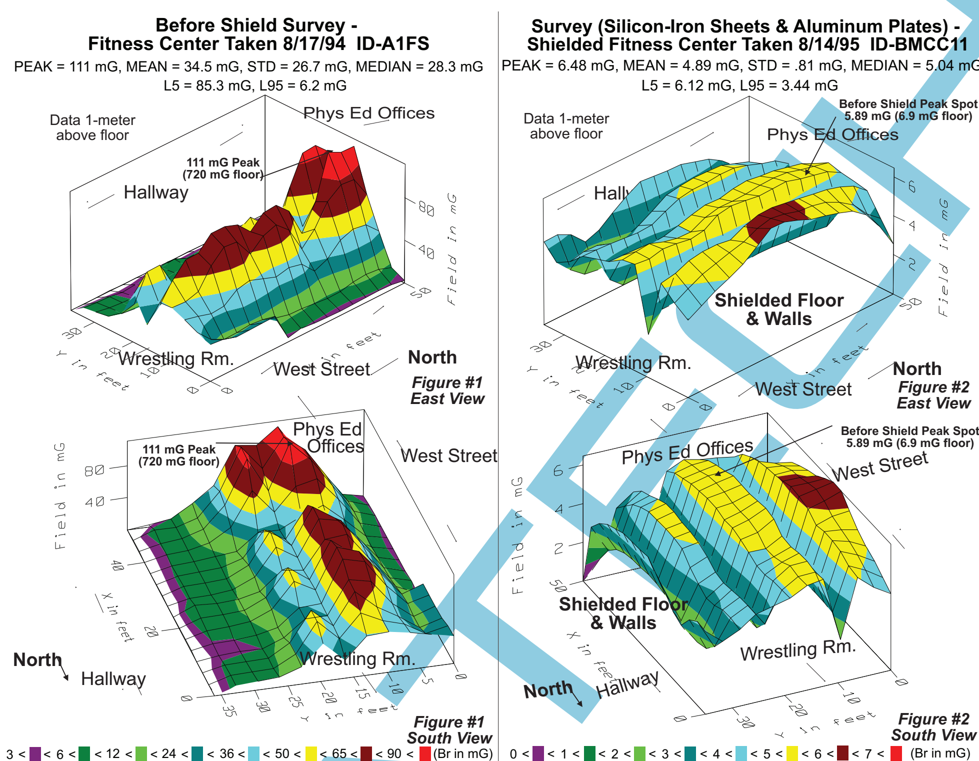
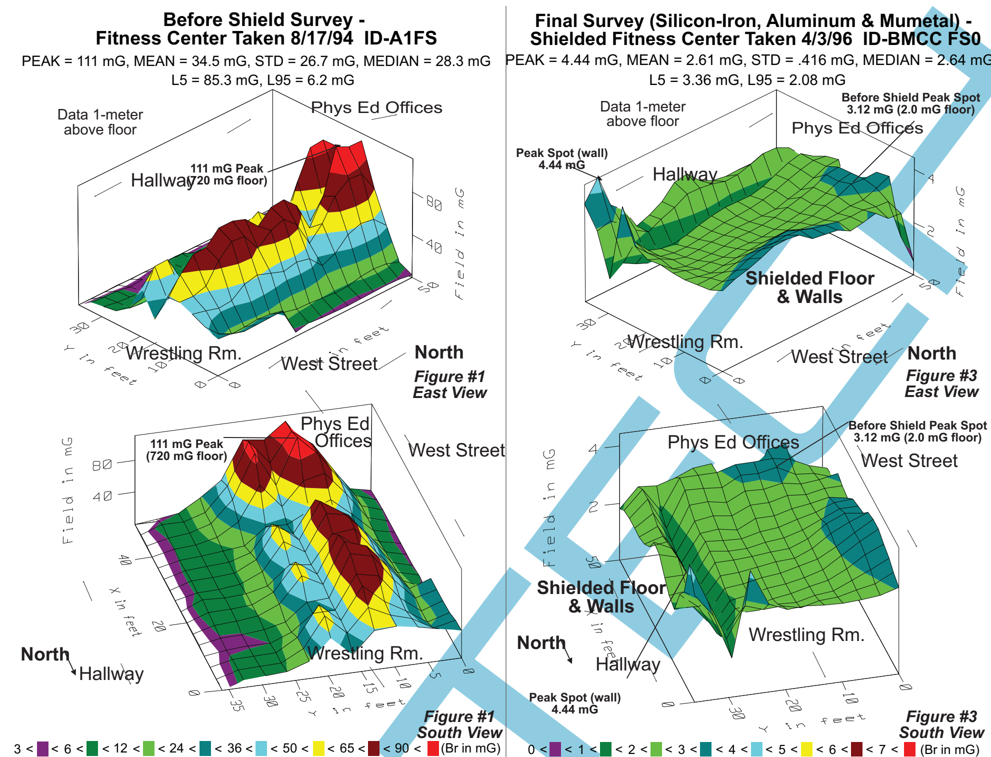


Table 6: Pre & Post Shield Data Comparison #2



EMF Fundamentals - Electric Charge, Current & Voltage

Electric charge, whether negative electrons or positive protons, is measured in units called coulombs (C), where one coulomb has the charge of 6 x 1018 electrons or protons. Electric charges exist both in free space (thunder storms) and on conductive materials (wires, metal, glass, rugs, water, etc.). When an electric charge is in motion it is called current, which is measured in amperes (A). One ampere is equal to one coulomb of electric charge per second past a defined reference point. The electric potential between two points, defined as voltage (V), is the work measured in joules per coulomb (or voltage) necessary to move a unit electric charge between the two points.

EMF Fundamentals - Electric & Magnetic Fields

Electric fields E, a vector quantity measured in volts per meter (V/m), are created by electric charges in free space and on conductive objects. Electric fields emanate out and down toward the ground diminishing in magnitude (field strength) at a linear $1/r_{distance}$ rate from line sources (unshielded transmission lines, etc.) and at a nonlinear $1/r^2_{distance}$ rate from point sources (appli-

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ances). Near extra-high voltage (EHV) transmission lines, defined as between 230-765 kilovolts (kV), one can hear the corona (crackle) produced by ionizing air molecules and sense the presence (tingle) of electric fields on the hair and skin. Under the midspan of a 230 kV and 500 kV transmission line, the electric field strength is 2 kV/m and 7 kV/m, respectively, three feet above the ground; more than enough to illuminate a hand-held fluorescent tube. Fortunately, grounded conductive objects including trees, bushes, buildings, and metal conduits easily attenuate (reduce) or completely shield electric fields. Therefore, properly grounded metal conduits and equipment cases do not emanate electric fields.

Magnetic fields H, a vector quantity measured as amperes per meter (A/m) in the MKS system and oersted (Oe) in the CGS system, are generated when electric charges are moving in free space and within conductors. High current sources such as lightning, transmission and distribution lines, transformers, network protectors, secondary feeders, switchgears, distribution busways, electrical panels, motors, and electric heaters produce very high magnetic fields. Unfortunately, magnetic fields are extremely difficult to shield and easily permeate (penetrate) nearly all materials including people, trees, buildings, equipment, and most metals except special ferromagnetic and highly conductive (copper and aluminum) materials. Normally, people are not able to sense the presence of very high 10-1,000 mG magnetic fields; however, extremely high levels exceeding 100 Gauss (100,000 mG) will cause a temporary visual flickering sensation called magnetophosphenes which disappears when the field is removed.

EMF Fundamentals - Magnetic Flux Density & Handy Conversion Factors

When an emanating magnetic field H permeates through a cross-sectional area of a medium (vacuum, free space or material), it converts to magnetic flux density B according to the following formula where μ is the permeability of the medium:

$$B_{magnetic\,flux density} = uH_{magnetic\,field}$$

The permeability of a vacuum designated as μ_o and free space (air) are nearly identical: 4π x 10-7 henry per meter (H/m) in MKS units and 1-gauss/oersted in CGS units. Magnetic flux density B is defined in MKS units as tesla (T) and in CGS units as gauss (G). It should be noted that in the United States CGS units oersted (Oe), gauss (G), and milligauss (mG) are the normal convention in power engineering and electromagnetics rather than the MKS units, except in scientific journals. Also, when working in free space both gauss (G) and oersted (Oe) are equal in magnitude as shown: $B_{gauss} = \mu_o H_{oersted}$ where μ_o = 1-gauss/oersted. For example, a 0.020 oersted magnetic field H in free space is equal to a magnetic flux density B of 0.020 gauss (20 mG). Although not technically accurate, the terms magnetic field H and magnetic flux density B usually appear synonymous in the engineering literature. Magnetic flux density B is measured with a gaussmeter in milligauss (mG) and easily converted to magnetic field H in either CGS and MKS units with the handy conversion factors listed below:

Table 7: Magnetic Field Conversion Factors

Magnetic Field/Flux MKS and CGS Conversion Factors	
1 gauss (G) = 1 x 10^3 milligauss (mG)	1 milligauss (mG) = 1 x 10^{-7} tesla (T) or 0.1μT
1 gauss (G) = 1 x 10^{-4} tesla (T)	1 milligauss (mG) = (4μ) A/m
1 A/m = 4μ x 10^{-3} oersteds (Oe)	1 tesla (T) = 1 weber (Wb)/m^2

EMF Fundamentals - ELF EMF, 60-Hz Wavelength, DC & AC Fields

Electric power generated in North America is 60-Hz alternating current (AC). This means both the voltage and current are sinusoidally varying (change polarity twice in each cycle or 120 times every second). The 60-Hz AC line frequency has a monstrous wavelength of 3,100 miles (5,000 km) calculated between cycles using: $C_{speed\text{-}of\text{-}light} = (\lambda_{wavelength})(f_{frequency})$. Alternating current (AC) electric and magnetic fields fluctuate in space as the sinusoidally varying voltage and current change polarity, whereas DC fields (like the earth's geomagnetic field) remain statically polarized based upon the direction of the current flow (remember the Right Hand Rule). Incidentally, the geomagnetic (static) field is typically 670 mG at the magnetic poles, 500 mG around the middle latitudes, and 330 mG on the equator. Furthermore, when the distance from a sinusoidally varying source such as 60-Hz AC power is small with respect to the wavelength, the electric and magnetic fields are not coupled and considered separate physical entities. That is why 60-Hz electric fields can be grounded to zero inside a metal conduit; however, the unperturbed magnetic fields will still emanate through the conduit. The opposite is true for radio frequency sources that have significantly shorter wavelengths and radiate coupled electric and magnetic fields into free space.

EMF Fundamentals - Electrostatic & Electromagnetic Induction

Electrostatic induction occurs when alternating 60-Hz electric fields couple with conductive animate (humans) and inanimate objects, thereby inducing currents and voltages within the objects. The actual current consists of minute movements of charged particles: electrons in metallic conductors and ionic conduction in body tissues and fluids. The voltages and currents induced directly into humans are of concern if they are high enough to cause direct biological, physiological, and psychological effects.

If the conductive object is grounded, the induced current that travels through the object to the ground is called the short-circuit current (units in amperes). Generally, in humans and animals the short-circuit current flows from head to feet (called body currents) and can be approximated with the following formula: $I_{short\text{-}circuit\ (microamps)} = 5.4(h^2_{height\ (meters)})(E_{kV/m})$. Examples of measured short-circuit currents in 2 kV/m and 7 kV/m electric fields similar to those under 230 kV and 500 kV overhead transmission line are presented on the next page in microamps (μA):

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Table 8: Electric Fields

Objects	230 kV Line 2 kV/m E Field	500 kV Line 7 kV/m E Field
Human -1.75 meters tall (5' 9")	32 µA	112 µA
Station wagon	220 µA	770 µA
Large school bus	820 µA	2,870 µA
Large Trailer Truck	1,260 µA	4,410 µA

Within elevated electric fields, when a grounded person touches an isolated (ungrounded) conductive object, a perceptible current (tingling sensation) or shock may occur. This phenomena also happens when the person is insulated and the conductive object is grounded. There are three basic classifications for shocks: perception and secondary shocks (which are annoying but not harmful) and primary shocks (which are very dangerous and potentially lethal). A safe perception shock (tingling response) for most men and women is 1.0 mA and 0.65 mA, respectively. Secondary shocks invoke involuntary muscle responses (shaking) that are very annoying and possibly painful. However, primary shocks begin at the let-go current where 99.5% of all subjects can still voluntarily let-go of an energized conductor: 9.0 mA for men and 6.0 mA for women. Unfortunately, beyond the let-go current threshold, a victim's heart may be shocked into ventricular fibrillation resulting in imminent death if not medically treated (defibrillated) within 4-6 minutes. Near transmission lines, the National Electrical Safety Code (N.E.S.C.) specifies 5 mA as the maximum allowable short-circuit current from vehicles, trucks, and equipment. And the American National Standard Institute (ANSI) allows up to 0.5 mA leakage current from portable household appliances and 0.75 mA for fixed appliances.

Electromagnetic induction occurs when alternating 60-Hz magnetic fields couple with animate (humans) and inanimate conductive objects (wires, metal beams, HVAC ducts, etc.), thereby inducing circulating currents and voltages. Magnetically induced body currents in human tissues flow primarily in peripheral loops (called eddy currents) perpendicular to the field; however, current at the center is generally near zero. Magnetic fields from transmission lines will normally induce voltages at the open ends of long, partially grounded, parallel conductors (fences, wires, and exposed pipes). So, dangerous and potentially lethal shocks from electromagnetic induction are also a serious problem.

Unfortunately, electromagnetic induction generates circulating tissue currents in humans near transformers, network protectors, secondary feeders, switchgears, distribution busways, and electrical panels. In calculating the current density in human tissues due to electromagnetic induction, the conductivity of mammalian tissue is assumed to be uniform: $\sigma_{conductivity}$ = 0.1 S/m (siemens/meter). Assuming the human body is within a conducting sphere, the induced voltage E_i in volts/meter (V/m) at a defined radius rmeters representing a waist of 0.145 m (36 in.) is defined as: E_i = $(1 \times 10^{-7})(\pi)(r_{meters})(f_{frequency})$(BmG). The current density J_{body} in microamps/meter2 ($\mu A/m^2$)

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for human body tissues around the waist can be calculated by using: $J_{body} = (\sigma_{conductivity})(E_i)$. On the next page there is a list of 60-Hz calculated electromagnetically induced voltages Ei and current densities J_{body} around a typical waist exposed to various magnetic flux density B_{mG} levels (also equivalent short-circuit currents induced within humans from E_{field} electrostatic induction in italics):

Table 9: Electromagnetic Induction

Magnetic Flux Density	Induced Voltage - E_i	Induced Current Density - J_{body}
5,000 mG	13.667×10^{-3} V/m	1,366.7 µA/m2 *(82.6 kV/m E_{field})*
1,000 mG	2.733×10^{-3} V/m	273.3 µA/m2 *(16.5 kV/m E_{field})*
500 mG	1.367×10^{-3} V/m	136.7 µA/m2 *(8.2 kV/m E_{field})*
100 mG	$.273 \times 10^{-3}$ V/m	27.3 µA/m2 *(1.7 kV/m E_{field})*
50 mG	$.137 \times 10^{-3}$ V/m	13.7 µA/m2 *(800 V/m E_{field})*
10 mG	$.027 \times 10^{-3}$ V/m	2.7 µA/m2 *(200 V/m E_{field})*
3 mG	$.008 \times 10^{-3}$ V/m	0.8 µA/m2 *(50 V/m E_{field})*

EMF Fundamentals - Loop Magnetic Field Sources

The first basic magnetic field source is a single loop (actually multiple) of current that approximates a magnetic dipole such as AC motors, transformers, computers, power supplies, analog clocks, electric stoves, and microwave ovens. Using the Right Hand Rule, a magnetic dipole has a vector dipole moment m (direction of thumb) in amps/meter^2 with a magnitude equal to the product of the loop current I_{amps} (fingers curl around the loop) and the enclosed loop area $A_{square\ meters}$ expressed as: $m = (I_{amps})(A_{square\ meters})$. Magnetic dipoles produce complex magnetic fields that diminish at a $1/r^3$distance rate from the source according to the formula: $B_{mG} = 2(I_{amps})(A_{sq.meters})/r3_{meters}$. For example, the magnetic fields from a distribution transformer can be calculated by using the secondary per phase current I_{amps} and a scaling factor of 1-mGCm3/A for $A_{sq.meters}$ in the above formula.

EMF Fundamentals - Single Conductor Magnetic Field Sources

The second basic magnetic field source is a straight, single conductor of current that is represented by the formula: $B_{mG} = 2(I_{amps})/r_{meter}$. It also applies to ground, plumbing and net currents plus electrically powered subway, rail, and trolley-bus systems with either an overhead electrified cable (pantograph) or third-rail. The magnetic fields from a single conductor are circular emanat-

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ing out from the center and impossible to magnetically shield (with a conduit or enclosure) using any material including highly permeable mumetals (flux-entrapment) or highly conductive copper and aluminum (eddy-current) materials (see EMF Fundamentals - Rigid Magnetic Shielding). Fortunately, passive and active magnetic field cancellation technology will mitigate single conductor and net, ground, and plumbing current magnetic fields.

EMF Fundamentals - Dual Conductor Magnetic Field Sources

The magnetic field for an opposing current pair of dual conductors (single phase pair, electrical appliance cord, knob-and-tube wiring, etc.) separated by a small distance dmeter between the conductors relative to the distance from the pair rmeters diminishes at a nonlinear 1/r2distance rate according to the formula: $B_{mG} = 2(I_{amps})(d_{meters})/r2_{meters}$. This is the famous inverse square law that also applies to radiating radio frequency (RF) EMF, electric fields, light, sound, and of course gravity. Basically, by doubling the distance r_{meter} for a fixed spacing d_{meter} and current load I_{amps}, the magnetic flux density reduces by a factor of four (4). For example, the magnetic flux density B_{mG} levels at 1, 2 & 4-inches (r = 0.025 m, 0.05 m & 0.1 m) from a typical electrical cord (spacing d=.001 m) with a 10 amp load are 32 mG, 8 mG, and 2 mG, respectively.

EMF Fundamentals - Three-Phase Magnetic Field Sources

Electric power around the United States is generated and distributed via three-phase AC transmission, distribution, and service feeder lines to commercial, institutional, and industrial buildings. Each of the three balanced phase voltages and currents are ideally represented as phasers (magnitude and angle) 120 degrees apart. The magnetic field for balanced three-phase circuits of three horizontally or vertically arrayed conductors separated by equal distances dmeter diminishes at a nonlinear $1/r^2$distance rate according to $B_{mG} = 3.46(I_{amps})(d_{meters})/r2_{meters}$. However, if the three-phase circuit is unbalanced and/or there are significant net, ground, and plumbing currents on the service feeder neutral (see next section for more details), then the dominant magnetic field becomes: $BmG = 2(I_{amps})/r_{meter}$, where I_{amps} is the sum of the net, ground, and plumbing currents. Finally, magnetic fields produced by three phase lines are generally elliptically polarized. This means the magnetic field can be represented by a rotating vector that traces an ellipse for every cycle of the conductor currents.

EMF Fundamentals - Ground, Plumbing & Net Currents

Ground currents are a collective term for any errant electrical currents measured in amperes (A) that result from the natural grounding process to earth including currents on conduits, ground wires, ground rods, building steel, metal HVAC ducts, and metal water pipes (also known as plumbing currents). These ground currents normally generate magnetic fields that emanate out from a grounding conductor (ground wire, water pipe, metal HVAC duct, etc.) at a diminishing linear $1/r_{distance}$ rate according to the formula: $BmG = 2(I_{amps})/r_{meters}$. Both ground currents and plumbing currents can be easily calculated by recording the magnetic flux density at a measured distance r_{feet} from the source: $I_{amps} = 0.15(BmG)(r_{feet})$. However, it is much easier to use a

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clamp-on amp meter around a grounding conductor or water pipe (if practical) for an accurate measurement.

Net currents, also known as unbalanced or zero-sequence currents, are the vector sum of all the phase (conductor) currents. In perfectly balanced, single-circuit, three-phase transmission and distribution lines, the net current is zero when all three phase currents are equal. Theoretically, if a clamp-on amp meter could be safely placed around the three phase conductors it would measure zero amps -- indicating no net current. However, if phases A and B were 1000 amps and phase C 1500 amps, there would be a measurable net current of 500 amps. This 500 amp net current produces a magnetic field that also diminishes at a linear $1/r_{distance}$ rate like a ground or plumbing current according to: $BmG = 2(I_{amps})/r_{meters}$. For example, a 500 amp net, ground or plumbing current produces a 1,000 mG field at 1 meter (3.3 ft.), 500 mG at 2 meters (6.6 ft.), 250 mG at 4 meters (13.2 ft.), 200 mG at 5 meters (16.5 ft.),100 mG at 10 meters (33 ft.), and finally a 3 mG at 333.3 meters (1094 ft.).

In commercial buildings, neutral net currents are very problematic in four-wire three-phase wye service feeders (480/277 V and 208/120 V). Ideally, when the three phases are unbalanced and there are absolutely no neutral return currents from harmonic and transient sources (reactive loads such as motors, computers, dimmers, heavy machinery, etc.) and/or errant ground/plumbing currents, the unbalanced return neutral current effectively cancels out the unbalanced phase current resulting in zero net current: if and only if the four conductors are bundled close together within the same conduit or busway. Typically, there are complex harmonic and transient components on the return neutral that generate noisy net currents. Frequently, externally produced ground and plumbing currents from nearby electrical sources leak into the return neutral via the neutral-ground bond in the switchgear and migrate back to the multiground neutral (MGN) system. The cumulative magnetic field that emanates from neutral net, ground, and plumbing currents on service feeders presents a very serious EMI threat to nearby sensitive electronic equipment and occupants.

EMF Fundamentals - Computer Monitors

Since 1990 most computer monitor manufacturers have voluntarily complied with the Swedish MPR2 and recent IEEE 1140-1994 electric and magnetic field video display terminal (VDT) emission standards. Electric and magnetic emissions are measured 50 cm (20 inches) from the monitor for two frequency bands: ELF Band 1 (5 Hz - 2 kHz) and VLF Band 2 (2 kHz - 400 kHz). Typically, a dual band electric field probe is placed at the screen center and should measure less than 25 V/m in ELF Band 1 and 2.5 V/m in VLF Band 2. Next, the monitor is placed on a turn table (lazy susan) and rotated 360 degrees in 22.5 degree increments while dual band magnetic fields are recorded. Magnetic emissions should be less than 2.5 mG in ELF Band 1 and 0.25 mG in VLF Band 2 throughout the full rotation at three fixed heights: center screen and ± 0.3 m (12 inches). Each year PC Magazine publishes a list of monitors that comply with MPR and IEEE standards. It should be noted the color monitors purchased before 1990 generally do not comply with the standards.

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EMF Fundamentals - Magnetic Field Mitigation

There are two basic 60-Hz magnetic field mitigation (reduction) methods: passive and active. Passive magnetic field mitigation includes rigid magnetic shielding with ferromagnetic and highly conductive materials, and the use of passive shield wires installed near transmission lines that generate opposing cancellation fields from electromagnetic induction (beyond the scope of this paper). Active magnetic field mitigation uses electronic feedback to sense a varying 60-Hz magnetic field, then generates a proportionally opposing (nulling) cancellation field within a defined area (room or building) surrounded by cancellation coils. Ideally, when the two opposing 180-degree out-of-phase magnetic fields of equal magnitude intersect, the resultant magnetic field is completely canceled (nullified). This technology has been successfully applied in both residential and commercial environments to mitigate magnetic fields from overhead transmission and distribution lines, and underground residential distribution (URD) lines.

EMF Fundamentals - Rigid Magnetic Shielding

Rigid magnetic shielding is divided into two fundamental types based upon the magnetic properties of the materials: flux-entrapment shields and lossy shields. A flux-entrapment shield is constructed with highly permeable (μ), specially annealed ferromagnetic mumetal alloy composed of 80% nickel and 20% iron (Hipernom Alloy, CO-NETIC AA, Amumetal, AD-MU-80) which either surrounds (cylinder or rectangular box) or separates ("U" shaped or flat-plate) the victims from the magnetic source. Ideally, magnetic flux lines incident upon the flux entrapment shield prefer to enter the highly permeable (μ) material traveling inside the material via the path of least magnetic reluctance-U, rather than passing into the protected (shielded) space. The relative permeability (:r) of mumetal ranges between 350,000-500,000 depending on the composition and annealing process. Unfortunately, mumetal sheets are extremely expensive: a single fully annealed 30 x 120 inch sheet (0.04-inches thick) costs around $1,800 (prices are very volatile due to fluctuation in nickel costs).

Lossy shielding depends on the eddy-current losses that occur within highly conductive materials (copper and aluminum), and low permeable (:) materials that are also conductive such as iron, steel, and silicon-iron. When a conductive material is subjected to a time-varying (60-Hz) magnetic field, currents are induced within the material that flow in closed circular paths -- perpendicular to the inducing field. According to Lenz's Law, these eddy-currents oppose changes in the inducing field, so the magnetic fields produced by the circulating eddy-currents attempt to cancel the larger external fields near the conductive surface, thereby generating a shielding effect. It is often very effective and extremely expensive to shield with multiple layers composed of low permeable/conductive materials (silicon-iron sheets or 1010 annealed steel plates), highly conductive aluminum/copper plates, and highly permeable mumetal sheets.

Shielding factor (SF) is the ratio between the unperturbed magnetic field B_o and the shielded magnetic field B_i as expressed in: $SF = B_i / B_o$ or decibels $SF_{dB} = 20 \log 10 (B_i / B_o)$. The final shielding design depends on the following critical factors: maximum predicted *worst-case* 60-Hz magnetic field intensity (magnitude and polarization) and the earth's geomagnetic (DC static) field at that location; shield geometry and volumetric area; type of materials and properties -- con-

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ductivity (F), permeability (μ), induction and saturation which are a function of material thickness; number of shield layers; and, the spacing between sheet materials and layers.

Small, fully-enclosed shields for video display terminals, electronic equipment, and electrical feeders follow simple formulas that guide the design engineer through the process to a functional, but not necessarily optimal, design. After assembling a prototype, the design engineer measures the shielding factor (SF) and modifies the design (adds materials, additional layers, anneals bends, etc.) to achieve the maximum shielding requirements. This is a very iterative design process, from concept to final product. Unfortunately, magnetic shielding is more of an art than a science, especially when shielding very large areas and rooms from multiple, high-level, magnetic field sources. At this time there are no reliable design formulas or EMF simulation programs that offer design engineers practical guidelines for shielding large exposed areas from multiple, high-level, magnetic field sources.

EMF Fundamentals - To Shield or Not To Shield The Source?

It is usually not desirable, especially if office space is limited, to evacuate an entire room or several rooms exposed to very high magnetic field levels. So, when space is at a premium the only other alternative is magnetic shielding. To shield or not to shield the source? That is the question! Generally, when physically practical, source shielding is the most effective and least expensive alternative. However, if there are multiple magnetic field sources (i.e., parallel transformer vaults, network protectors, secondary feeders, etc.), it may not be economically feasible to separately shield each source. In that case, shielding the room, and consequently the victims, is the preferred solution. Call a professional 60-Hz magnetic shielding company for a detailed magnetic field survey, site evaluation, and estimate. Magnetic shielding is expensive, so don't be astounded by the quote to shield an entire 50' x 40' room (2,000 ft2 floor plus four walls 8 ft. high) to 10 mG or 5 mG and less, measured one-meter off the floor from 500-1,000 mG levels emanating from multiple transformer vaults, network protectors, secondary feeders, and switchgears located under, above or adjacent to the room. Finally, request a written 10 mG or 5 mG and less performance guarantee over 95% of the shielded room -- only Vitatech Electromagnetics, Llc. can achieve this demanding performance requirement using state-of-the-art shielding materials.

EMF Fundamentals - Magnetic Shielding Information

In 1994 the Electric Power Research Institute (EPRI)published a two volume set Handbook of Shielding Principles for Power System Magnetic Fields, April 1994, EPRI TR-103630-V1 & V2 for a mere $50,000 (510-934-4212). These two huge volumes provide an encyclopedic treatise on 60-Hz magnetic field mitigation; however, there are very few practical shielding design equations and useful examples. So, if you are a design engineer, first experiment with small shield designs using various ferromagnetic and conductive materials, read selected chapters in the EPRI Handbook, and call Vitatech Electromagnetics, Llc. (866-905-9400). Do not attempt any large-scale room shield designs. Only an experienced 60-Hz magnetic shielding engineer has the technical expertise to guarantee the design and successfully install complex shielding systems for offices, work areas, and apartments.

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References

Electric and Magnetic Fields Research and Public Dissemination Program (EMF RAPID) 1995. Questions and Answers About EMF Electric and Magnetic Fields Associated with the Use of Electric Power, pages 28-29. National Institute of Environmental Health Sciences and U.S. Department of Energy: GPO #DOE/EE-0040.

Lee, J., et al. 1993. "Electrical and Biological Effects of Transmission Lines: A Review," Electric and Magnetic Fields, pages 13-23. U.S. Department of Energy Bonneville Power Administration.

Office of Radiation Programs. 1980. "Evaluation of Health and Environmental Effects of Extra High Voltage (EHV) Transmission," Quantitative Description of Voltages and Currents Induced in Objects by the Fields, pages 37-69. U.S. Environmental Protection Agency: # ORP/SEPD 80-13.

Johnson, T., et al. 1993. "Magnetic Field Reduction Research," Basic Source Types, pages 4-7. Empire State Electric Energy Research Corporation (ESEERCO): EP90-48.

Clairmont, B., et. al. 1994. "Handbook of Shielding Principles for Power Systems Magnetic Fields- Volume 1," Basic Magnetic Field Principles, pages 2-15 to 2-19, Introduction to Shielding Principles, pages 3-1 to 3-8. Electric Power Research Institute (EPRI): EPRI TR-103630-V1

George, E., 1992. "MPR2: An Overview and Update," Ergonomics,

National Institute of Environmental Health Sciences (NIEHS) Working Group Report, 16-24 June 1998. “Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields”, Final Summary And Evaluation, section 5, pages 395-402.

National Institute of Environmental Health Sciences (NIEHS) Report, 4 May 1999. “Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields” (NIH Publication No. 99-4493), by Dr. Kenneth Olden, Director, Executive Summary & Conclusions And Recommendations, pages 37 and 38.

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