RF RADIATION HAZARDS

Introduction

This article presents for EMC engineers a brief overview of various types of radiation hazards (RADHAZ) due to high-level RF emissions. Three broad RADHAZ categories are considered:

1. Personnel: direct biological effects and indirect effects resulting from the performance of cardiac pacemakers.
2. Explosives: both munitions and other applications (blasting caps, seat ejectors, etc.), primarily those utilizing electro-explosive (EED) devices.
3. Fuel: ignition due to RF-induced sparks.

RF Radiation Hazards To Personnel

Biological Effects

Biological hazards to personnel due to whole-body radiation are measured by incident power density or energy flux, respectively, in milliwatts or millijoules per square centimeter. Biological damage to living tissue is known to be caused by the heating effect on the tissue. (Some other reversible effects are known or suspected, but are not considered here.) Skin burns, eye cataracts, and overheating of delicate body organs can be caused by radio-frequency (RF) radiation.Organs with limited circulation to dissipate heat, such as the lungs, testicles, and liver, may be damaged by RF radiation. Until recently, the generally accepted threshold level in the United States is a time-averaged power density of 10 milliwatts per square centimeter (10 mW/cm²), for a limited duration of 6 minutes during any hour period, over the frequency range from 10 MHz to 100 GHz.

The new revision to ANSI C95.1[1] decreases the level, presents it in terms of the square of field strength (electric and magnetic), and makes it a function of frequency. These proposed changes are particularly significant since they are likely to be adopted widely by military and civilian organizations. The new limits for ANSI C95.1 are shown below, and plotted in Figure 1.

All values averaged over 0.1-hr. period.

f (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	P (mW/cm^2)
0.3 - 3	400,000	2.5	100
3 - 30	$4{,}000(900/f^2)$	$0.25\ (900/f^2)$	$900/f^2$
30 - 300	4,000	0.025	1.0
300 - 1,500	4,000 (f/300)	0.025 (f/300)	f/300
1500 - 100,000	20,000	0.125	5.0

Note that for 300 kHz$<$f$<$100 GHz, values may be exceeded provided average whole-body specific absorption rate (SAR)$<$0.4 W/kg, and peak spatial SAR$<$8 W/kg averaged over 1 g of tissue.

Some foreign countries identify more stringent limits for continuous exposure to RF radiation. For example, the Academy of Medical Sciences of the USSR specifies 0.01 milliwatt per square centimeter as a level for continuous exposure.[2]

The purpose of the ANSI standard is to recommend maximum radiation levels to prevent harmful effects in human beings exposed to electromagnetic fields. These recommendations are intended to apply to non-occupational, as well as occupational, exposures. The recommendations are not intended to apply to the purposeful exposure of patients under the direction of practitioners of the healing arts.

The proposed standard has several definitions which are of critical importance. There are as follows:

RADIO FREQUENCY PROTECTION GUIDES (RFPG) FOR PERSONNEL EXPOSURE TO RF/MICROWAVE RADIATION

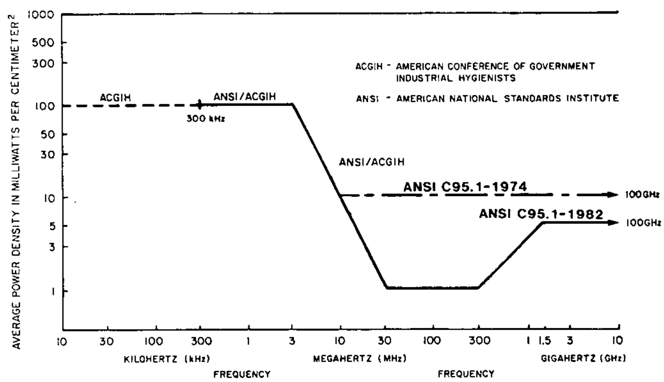

Figure 1.

Radioprotection Guide (RFPG). The radio frequency field strength or equivalent plane wave power density should not be exceeded without (1) careful consideration of the reasons for doing so, (2) careful estimation of increased energy disposition in the human body, and (3) careful consideration of the increased risk of unwanted biological effects.

Specific Absorption Rate (SAR). The time rate at which radio frequency electromagnetic energy is imparted to an element of mass of a biological body.

For human exposure to electromagnetic energy of radio frequencies from 300 kHz to 100 GHz, the Radio Frequency Protection Guide, in terms of equivalent plane wave free-power density is as follows:

FREQUENCY RANGE (MHz)	POWER DENSITY (mW/cm^2)
.03 - 3	100
3 - 30	$900/f^2$
30 - 300	1.0
300 - 1500	f/300
1500 - 100,000	5.0

For mixed or broadband fields consisting of a number of frequencies for which there are different values of radio frequency protection guide, the fraction of the radio frequency protection guide incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed the unity.

At all frequencies between 300 kHz and 100 GHz, the protection guide may be exceeded if the exposure condition can be shown by laboratory procedures to produce specific absorption rates (SAR) below 0.4 w/kg, as averaged over the whole body, and spartial peak SAR values below 8 w/kg, as averaged over any 1 gram of tissue. Furthermore, at frequencies between 300 kHz and 1 GHz, the protection guide may be exceeded if the radio frequency input power of the radiated device is 7 watts or less.

Both for pulsed and non-pulsed fields, the power density and the values of SAR or input power, as applicable, are averaged over any 0.1-hour period. The time-average values should not exceed either the power densities given above or in the exclusions. Measurements to determine adherence to the recommended protection guides shall be made at a distance of 5 centimeters or greater from any object (refer to ANSI C95.3-1979 for radio frequency measurements).

ANSI also publishes recommended measurement practices in ANSI C95.5[6]. The latest guide, approved on March 16, 1981, is stated to be useful over the frequency range of approximately 1 MHz to 100 GHz. The standard points out that no single measurement or instrumentation arrangement is valid over the wide frequency range covered by the standard. In general, measurement techniques and instrumentation developed for use in the microwave range (primarily above 1 GHz) are not suitable for use at lower frequencies and vice versa. Furthermore, most older instruments were not designed specifically for hazards purposes and are incapable of performing the accurate near-field measurements required to evaluate hazardous situations. For instance, below 300 MHz field strength measurements within one wavelength of the source are commonly required, and older instruments were designed primarily for far-field measurements. Radiation leakage from electronic equipment presents special problems because the source of energy may not be clearly defined *a priori.* It could be coming from a crack in the shielding cabinet, or from poorly bypassed connecting cables. The polarization of the electromagnetic field and the location of the leak are not generally known ahead of time. This is a special case of the general near-field situation and the same problems can exist for all near-field measurements, whether the emitted fields are intentional or accidental. A completely general theoretical treatment of the leakage problem is very difficult.

The survey techniques differ from those associated with the radiation fields from antennas of radars and communication equipment. In the leakage case, the location of the source is found by trial and error. A nondirectional, nonpolarized detector is desirable in order to probe in the immediate vicinity of the equipment where directive pickup antennas would give poor readings because of their inability to respond to multipath signals and because of innaccurately known gain-reduction factors in the near field. However, a somewhat directive system consisting of a waveguide probe, thermistor, attenuator, and power meter is easy to assemble, and may be useful for locating a source of leakage when accurate knowledge of the level is not required.

The reactive near-field region of a given equipment exists close to the equipment where energy storage fields are important. In this region of space immediately surrounding the equipment, reactive components of the field predominate over the radiating near-field and radiating far-field components. Although the extent of the reactive region varies for different equipment, the practical outer limit is of the order of a few wave-lengths. For example, at a distance of three wavelengths from an ideal dipole, all reactive components are less than 10% of the radiating components and the measurement error due to the reactive components would be less than 1 dB. Although the reactive components do not contribute to the net flow of radiated energy, they can couple into material and thus effect energy absorption. Consequently, it is important that the reactive field be measured in many situations. Furthermore, both electric and magnetic fields must be measured to fully evaluate the hazard since both are absorbed by biological subjects.

In the near field, three orthogonal components of the electric field with arbitrary relative phases and amplitudes exist. Similarly, there are three orthogonal components of the magnetic field with arbitrary phases and amplitudes. The electric field is elliptically polarized in an arbitrary plane and the magnetic field, in general, is elliptically polarized in another plane. Consequently, in the near field, measurements of the phase and amplitude of each of the three components of the electric field give no information about the magnetic field at the point. Thus, use of instruments capable of measuring either the electric or the magnetic field and which respond to any arbitrary polarization is indicated.

When characterizing hazardous em fields, a distinction should be recognized and made between emission levels and exposure levels. An emission standard specifies the maximum field strength or power density at specified (usually small) distance from an emitting source; whereas an exposure standard generally specifies the maximum field strength or power density to which personnel should be exposed as a function of exposure duration. In most cases where an emission standard applies, the sources are small apertures, for example, localized leakage around the periphery of a microwave oven door. In these situations the radiated fields follow approximately an inverse-square reduction of power density with distance or an inverse dependence of field strength with distance. Such inverse-distance dependence has been verified for leakage emission from microwave ovens for distances of 5 cm to several feet. The rapid decay from emission levels to acceptable exposure levels at a distance of several feet from the typical microwave oven may not apply if the leakage source consists of a large radiating aperture (for example, *leaking* viewing window).

In general, the potential level of exposure to personnel will not be equivalent to the emission level. Furthermore, it is expected that the exposure area will decrease as personnel approach the source. Thus, as the source is approached, a plane must be scanned by personnel surveying a leakage field to determine the location of the localized leakage radiation beam.

Cardiac Pacemakers

Personnel with implanted cardiac pacemakers are exposed to an additional hazard, indirectly, from RF emissions interfering with the operation of cardiac pacemakers. Cardiac pacemakers, especially the widely-used demand type, are sensitive to RF emission, not necessarily limited to high-power-density emitters. A low-energy transient voltage can give the pacemaker a false trigger, causing a change in rate or suppression of output. (In less direct fashion, interference with the operation of diagnostic medical equipment can result in responses that lead to a false diagnosis, with subsequent danger to a patient.)

The leads of a pacemaker act as antennas to receive undesired signals.† In addition, there may be interference resulting from case penetration. With a sensitivity of 0.2-1 mV, these devices have been interfered with by transient emissions from household appliances, such as electric mixers and electric razors. From such incidents, it is apparent that the modulation of the emitter becomes a factor in addition to field strength.

Safe levels and criteria for pacemakers in RF fields have not yet been established, although several research groups have generated values for specific emitters (not available in the open literature).

RF Radiation Hazards To Ordnance

Electroexplosive devices (EEDs) are electrically initiated primers used in initiating explosives. They may be used in a demolition charge or may be incorporated in a complex weapon system. The EED is the most sensitive link in the system whose susceptibility to RF emissions is based on receiving enough energy to detonate or cause dudding. (AF Regulation 127-100 identifies 50 mW as the minimum fire power for this situation.[4]) The wire leads of the EED may act as a dipole, or as a loop antenna when the ends are shorted. The most stringent hazard criteria in the ARM 127-100 are based on the "worst-case" configuration of the EED, and are given as a function of frequency for three situations: transport or storage, exposed, and on taxiing aircraft.

The basic problem in determining an ordnance-system susceptibility to RF radiation lies in evaluation of the antenna-like couplings that exist between illuminating fields and the various EEDs employed in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin. RF energy may also be conducted into the weapon by the firing leads or other wires that penetrate the weapon enclosure. The precise probabilities of EED actuation are relatively unpredictable, being dependent upon variables of frequency, field strength, geometric orientation, environment, and metallic or personnel contact with the ordnance or the ordnance platform (aircraft, ship, vehicle, etc.). The most susceptible periods are during assembly, disassembly, loading, unloading, or testing in electromagnetic fields. The most likely effects of excessive RF energy are dudding, reduction of reliability, or propellant ignition.

Each of the U.S. military services has published documents specifying safe radiation levels for its particular weapon systems.

RF Radiation Hazards To Fuel

The probability of ignition of fuel vapors by RF-induced arcs is based upon a minimum-length spark containing sufficient energy to cause ignition occurring in a flammable fuel-air-mixture environment.

In an idealized laboratory setup with the above (worst-case) conditions existing, a peak power density of 5 W/cm^2 or less is considered safe.[5]

A power-density criterion of the emitter identifies the amount of radiated power available. The configuration of the refueling operation determines how much of this available power is received. The size and shape of an aircraft, for example, on a carrier, and its orientation with respect to the emitters and the refueling equipment used will determine the voltage and power that is available between the nozzle and the fuel filler to ignite fuel vapors.

References

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4. *Explosives Safety Manual,* AFM 127-100, U.S. Air Force, December 1971 (Revised 1974), and Change 1, 31 March 1978.
5. *Electromagnetic Radiation Hazards,* T.O. 31Z-10-4, U.S. Air Force, 1 August, 1965, and Change 3, 10 February 1978.
6. Recommended Practice for the Measurement of Hazardous Electromagnetic Fields — RF and Microwave. Standard C95.5-1981, American National Standards Institute, New York.

†The leads may be as long as 54 cm and unshielded.[3]

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