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ARRL on RF radiation safety

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RF Radiation Safety

Although Amateur Radio is basically a safe activity, in recent years there has been considerable discussion and concern about the possible hazards of electromagnetic radiation (EMR), including both RF energy and power frequency (50-60 Hz) electromagnetic fields. xtensive research on this topic is under way in many countries. This section was prepared by members of the ARRL Committee on the Biological Effects of RF Energy ("Bio Effects" Committee) and coordinated by Wayne Overbeck, N6NB. It summarizes what is now known and offers safety precautions based on the research to date.

All life on earth has adapted to survive in an environment of weak, natural low-frequency electromagnetic fields (in addition to the earth's static geomagnetic field). Natural low-frequency EM fields come from two main sources: the sun, and thunderstorm activity. But in the last 100 years, manmade fields at much higher intensities and with a very different spectral distribution have altered this natural EM background in ways that are not yet fully understood. Much more research is needed to assess the biological effects of EMR.

Both RF and 60-Hz fields are classified as nonionizing radiation because the frequency is too low for there to be enough photon energy to ionize atoms. Still, at sufficiently high power densities, EMR poses certain health hazards. It has been known since the early days of radio that RF energy can cause injuries by heating body tissue. In extreme cases, RF-induced heating can cause blindness, sterility and other serious health problems. These heat-related health hazards may be called thermal effects. But now there is mounting evidence that even at energy levels too low to cause body heating, EMR has observable biological effects, some of which may be harmful. These are athermal effects.

In addition to the ongoing research, much else has been done to address this issue. For example, the American National Standards Institute, among others, has recommended voluntary guidelines to limit human exposure to RF energy. And the ARRL has established the Bio Effects Committee, a committee of concerned medical doctors and scientists, serving voluntarily to monitor scientific research in this field and to recommend safe practices for radio amateurs.

Thermal Effects of RF Energy

Body tissues that are subjected to very high levels of RF energy may suffer serious heat damage. These effects depend upon the frequency of the energy, the power density of the RF field that strikes the body, and even on factors such as the polarization of the wave.

At frequencies near the body's natural resonant frequency, RF energy is absorbed more efficiently, and maximum heating occurs. In adults, this frequency usually is about 35 MHz if the person is grounded, and about 70 MHz if the person's body is insulated from ground. Also, body parts may be resonant; the adult head, for example, is resonant around 400 MHz, while a baby's smaller head resonates near 700 MHz. Body size thus determines the frequency at which most RF energy is absorbed. As the frequency is increased above resonance, less RF heating generally occurs. However, additional longitudinal resonances occur at about 1 GHz near the body surface.

Nevertheless, thermal effects of RF energy should not be a major concern for most radio amateurs because of the relatively low RF power we normally use and the intermittent nature of most amateur transmissions. Amateurs spend more time listening than transmitting, and many amateur transmissions such as CW and SSB use low-duty-cycle modes. (With FM or RTTY, though, the RF is present continuously at its maximum level during each transmission.) In any event, it is rare for radio amateurs to be subjected to RF fields strong enough to produce thermal effects unless they are fairly close to an energized antenna or unshielded power amplifier. Specific suggestions for avoiding excessive exposure are offered later.

Athermal Effects of EMR

Nonthermal effects of EMR, on the other hand, may be of greater concern to most amateurs because they involve lower-level energy fields. In recent years, there have been many studies of the health effects of EMR, including a number that suggest there may be health hazards of EMR even at levels too low to cause significant heating of body tissue. The research has been of two basic types: epidemiological research, and laboratory research into biological mechanisms by which EMR may affect animals or humans.

Epidemiologists look at the health patterns of large groups of people using statistical methods. A series of epidemiological studies has shown that persons likely to have been exposed to higher levels of EMR than the general population (such as persons living near power lines or employed in electrical and related occupations) have higher than normal rates of certain types of cancers. For example, several studies have found a higher incidence of leukemia and lymphatic cancer in children living near certain types of power transmission and distribution lines and near transformer substations than in children not living in such areas. These studies have found a risk ratio of about 2, meaning the chance of contracting the disease is doubled. (The bibliography at the end of this chapter lists some of these studies. See Wertheimer and Leeper, 1979, 1982; Savitz et al, 1988).

Parental exposures may also increase the cancer risk of their offspring. Fathers in electronic occupations who are also exposed to electronic solvents have children with an increased risk of brain cancer (Johnson and Spitz, 1989), and children of mothers who slept under electric blankets while pregnant have a 2.5 risk ratio for brain cancer (Savitz et al, 1990).

Adults whose occupations expose them to strong 60-Hz fields (for example, telephone line splicers and electricians) have been found to have about four times the normal rate of brain cancer and male breast cancer (Matanoski et al, 1989). Another study found that microwave workers with 20 years of exposure had about 10 times the normal rate of brain cancer if they were also exposed to soldering fumes or electronic solvents (Thomas et al, 1987). Typically, these chemical factors alone have risk ratios around 2.

Dr. Samuel Milham, a Washington state epidemiologist, conducted a large study of the mortality rates of radio amateurs, and found that they had statistically significant excess mortality from one type of leukemia and lymphatic cancer. Milham suggested that this could result from the tendency of hams to work in electrical occupations or from their hobby.

However, epidemiological research by itself is rarely conclusive. Epidemiology only identifies health patterns in groups--it does not ordinarily determine their cause. And there are often confounding factors: Most of us are exposed to many different environmental hazards that may affect our health in various ways. Moreover, not all studies of persons likely to be exposed to high levels of EMR have yielded the same results.

There has also been considerable laboratory research about the biological effects of EMR in recent years. For example, it has been shown that even fairly low levels of EMR can alter the human body's circadian rhythms, affect the manner in which cancer- fighting T lymphocytes function in the immune system, and alter the nature of the electrical and chemical signals communicated through the cell membrane and between cells, among other things. (For a summary of some of this research, see Adey, 1990.)

Much of this research has focused on low-frequency magnetic fields, or on RF fields that are keyed, pulsed or modulated at a low audio frequency (often below 100 Hz). Several studies suggested that humans and animals can adapt to the presence of a steady RF carrier more readily than to an intermittent, keyed or modulated energy source. There is some evidence that while EMR may not directly cause cancer, it may sometimes combine with chemical agents to promote its growth or inhibit the work of the body's immune system.

None of the research to date conclusively proves that low-level EMR causes adverse health effects. Although there has been much debate about the meaning and significance of this research, many medical authorities now urge "prudent avoidance" of unnecessary exposure to moderate or high-level electromagnetic energy until more is known about this subject.

Safe Exposure Levels

How much EM energy is safe? Scientists have devoted a great deal of effort to deciding upon safe RF-exposure limits. This is a very complex problem, involving difficult public health and economic considerations. The recommended safe levels have been revised downward several times in recent years--and not all scientific bodies agree on this question even today. In early 1991, a new American National Standards Institute (ANSI) guideline for recommended EM exposure limits is on the verge of being approved (see bibliography). If the new standard is approved by a committee of the Institute of Electrical and Electronic Engineers (IEEE), it will replace a 1982 ANSI guideline that permitted somewhat higher exposure levels. ANSI-recommended exposure limits before 1982 were higher still.

This new ANSI guideline recommends frequency-dependent and time-dependent maximum permissible exposure levels. Unlike earlier versions of the standard, the 1991 draft recommends different RF exposure limits in controlled environments (that is, where energy levels can be accurately determined and everyone on the premises is aware of the presence of EM fields) and in uncontrolled environments (where energy levels are not known or where some persons present may not be aware of the EM fields).

Fig. 20 is a graph depicting the new ANSI standard. It is necessarily a complex graph because the standards differ not only for controlled and uncontrolled environments but also for electric fields (E fields) and magnetic fields (H fields). Basically, the lowest E-field exposure limits occur at frequencies between 30 and 300 MHz. The lowest H-field exposure levels occur at 100-300 MHz. The ANSI standard sets the maximum E-field limits between 30 and 300 MHz at a power density of 1 mW/cm\2/ (61.4 volts per meter) in controlled environments--but at one-fifth that level (0.2 mW/cm\2/ or 27.5 volts per meter) in uncontrolled environments. The H-field limit drops to 1 mW/cm\2/ (0.163 ampere per meter) at 100-300 MHz in controlled environments and 0.2 mW/cm\2/ (0.0728 ampere per meter) in uncontrolled environments. Higher power densities are permitted at frequencies below 30 MHz (below 100 MHz for H fields) and above 300 MHz, based on the concept that the body will not be resonant at those frequencies and will therefore absorb less energy.

In general, the proposed ANSI guideline requires averaging the power level over time periods ranging from 6 to 30 minutes for power-density calculations, depending on the frequency and other variables. The ANSI exposure limits for uncontrolled environments are lower than those for controlled environments, but to compensate for that the guideline allows exposure levels in those environments to be averaged over much longer time periods (generally 30 minutes). This long averaging time means that an intermittently operating RF source (such as an Amateur Radio transmitter) will show a much lower power density than a continuous-duty station for a given power level and antenna configuration.

Time averaging is based on the concept that the human body can withstand a greater rate of body heating (and thus, a higher level of RF energy) for a short time than for a longer period. However, time averaging may not be appropriate in considerations of nonthermal effects of RF energy.

The ANSI guideline excludes any transmitter with an output below 7 watts because such low-power transmitters would not be able to produce significant whole-body heating. (However, recent studies show that handheld transceivers often produce power densities in excess of the ANSI standard within the head).

There is disagreement within the scientific community about these RF exposure guidelines. The ANSI guideline is still intended primarily to deal with thermal effects, not exposure to energy at lower levels. A growing number of researchers now believe athermal effects should also be taken into consideration. Several European countries and localities in the United States have adopted stricter standards than the proposed ANSI guideline.

Another national body in the United States, the National Council for Radiation Protection and Measurement (NCRP), has also adopted recommended exposure guidelines. NCRP urges a limit of 0.2 mW/cm\2/ for nonoccupational exposure in the 30-300 MHz range. The NCRP guideline differs from ANSI in two notable ways: It takes into account the effects of modulation on an RF carrier, and it does not exempt transmitters with outputs below 7 watts.

Low-Frequency Fields

Recently much concern about EMR has focused on low-frequency energy, rather than RF. Amateur Radio equipment can be a significant source of low-frequency magnetic fields, although there are many other sources of this kind of energy in the typical home. Magnetic fields can be measured relatively accurately with inexpensive 60-Hz dosimeters that are made by several manufacturers.

Table 3 shows typical magnetic field intensities of Amateur Radio equipment and various household items. Because these fields dissipate rapidly with distance, "prudent avoidance" would mean staying perhaps 12 to 18 inches away from most Amateur Radio equipment (and 24 inches from power supplies and 1-kW RF amplifiers) whenever the ac power is turned on. The old custom of leaning over a linear amplifier on a cold winter night to keep warm may not be the best idea!

Table 3

Typical 60-Hz Magnetic Fields Near Amateur Radio Equipment and AC-Powered Household Appliances

Values are in milligauss.

Item Field Distance

Electric blanket 30- 90 Surface
Microwave oven 10- 100 Surface (1- 10 at 12")
IBM personal computer 5- 10 Atop
monitor 0- 1 15" from screen
Electric drill 500-2000 At handle

Hair dryer 200-2000 At handle
HF transceiver 10- 100 Atop cabinet (1- 5 at 15" from front)
1-kW RF amplifier 80-1000 Atop cabinet (1- 25 at 15" from front)

(Source: measurements made by members of the ARRL Bio Effects Committee)

There are currently no national standards for exposure to low- frequency fields. However, epidemiological evidence suggests that when the general level of 60-Hz fields exceeds 2 milligauss, there is an increased cancer risk in both domestic environments (Savitz et al, 1988) and industrial environments (Matanoski et al, 1989; Davis and Milham, 1990; Garland et al, 1990). Typical home environments (not close to appliances or power lines) are in the range of 0.1-0.5 milligauss.

DETERMINING RF POWER DENSITY

Unfortunately, determining the power density of the RF fields generated by an amateur station is not as simple as measuring low-frequency magnetic fields. Although sophisticated instruments can be used to measure RF power densities quite accurately, they are costly and require frequent recalibration. Most amateurs don't have access to such equipment, and the inexpensive field-strength meters that we do have are not suitable for measuring RF power density. The best we can usually do is to estimate our own RF power density based on measurements made by others or, given sufficient computer programming skills, use computer modeling techniques.

Table 4 shows a sampling of measurements made at Amateur Radio stations by the Federal Communications Commission and the Environmental Protection Agency in 1990. As this table indicates, a good antenna well removed from inhabited areas poses no hazard under any of the various exposure guidelines. However, the FCC/EPA survey also indicates that amateurs must be careful about using indoor or attic-mounted antennas, mobile antennas, low directional arrays, or any other antenna that is close to inhabited areas, especially when moderate to high power is used.

Table 4

Typical RF Field Strengths near Amateur Radio Antennas

A sampling of values as measured by the Federal Communications Commission and Environmental Protection Agency, 1990.

Freq, Power, E Field, Antenna Type MHz Watts V/m Location

Dipole in attic 14.15 100 7-100 In home
Discone in attic 146.5 250 10- 27 In home
Half sloper 21.15 1000 50 1 m from base
Dipole at 7-13 ft 7.14 120 8-150 1-2 m from earth
Vertical 3.8 800 180 0.5 m from base
5-element Yagi at 60' 21.2 1000 10- 20 In shack 14 12 m from base
3-element Yagi at 25' 28.5 425 8- 12 12 m from base
Inverted V at 22-46' 7.23 1400 5- 27 Below antenna
Vertical on roof 14.11 140 6- 9 In house 35-100 At antenna tuner

Whip on auto roof 146.5 100 22- 75 2 m from antenna 15- 30 In vehicle 90 Rear seat
5-element Yagi at 20' 50.1 500 37- 50 10 m from antenna

Ideally, before using any antenna that is in close proximity to an inhabited area, you should measure the RF power density. If that is not feasible, the next best option is make the installation as safe as possible by observing the safety suggestions listed in Table 5.

It is also possible, of course, to calculate the probable power density near an antenna using simple equations. However, such calculations have many pitfalls. For one, most of the situations in which the power density would be high enough to be of concern are in the near field--an area roughly bounded by several wavelengths of the antenna. In the near field, ground interactions and other variables produce power densities that cannot be determined by simple arithmetic.

Computer antenna-modeling programs such as MININEC or other codes derived from NEC (Numerical Electromagnetics Code) are suitable for estimating RF magnetic and electric fields around amateur antenna systems. And yet, these too have limitations. Ground interactions must be considered in estimating near-field power densities. Also, computer modeling is not sophisticated enough to predict "hot spots" in the near field--places where the field intensity may be far higher than would be expected.

Intensely elevated but localized fields often can be detected by professional measuring instruments. These "hot spots" are often found near wiring in the shack and metal objects such as antenna masts or equipment cabinets. But even with the best instrumentation, these measurements may also be misleading in the near field.

One need not make precise measurements or model the exact antenna system, however, to develop some idea of the relative fields around an antenna. Computer modeling using close approximations of the geometry and power input of the antenna will generally suffice. Those who are familiar with MININEC can estimate their power densities by computer modeling, and those with access to professional power-density meters can make useful measurements.

While our primary concern is ordinarily the intensity of the signal radiated by an antenna, we should also remember that there are other potential energy sources to be considered. You can also be exposed to RF radiation directly from a power amplifier if it is operated without proper shielding. Transmission lines may also radiate a significant amount of energy under some conditions.

SOME FURTHER RF EXPOSURE SUGGESTIONS

Potential exposure situations should be taken seriously. Based on the FCC/EPA measurements and other data, the "RF awareness" guidelines of Table 5 were developed by the ARRL Bio Effects Committee. A longer version of these guidelines appeared in a QST article by Ivan Shulman, MD, WC2S (see bibliography).

QST carries information regarding the latest developments for RF safety precautions and regulations at the local and federal levels. You can find additional information about the biological effects of RF radiation in the publications listed in the bibliography.

Table 5

RF Awareness Guidelines

These guidelines were developed by the ARRL Bio Effects Committee, based on the FCC/EPA measurements of Table 4 and other data.

o Although antennas on towers (well away from people) pose no exposure problem, make certain that the RF radiation is confined to the antenna radiating elements themselves. Provide a single, good station ground (earth), and eliminate radiation from transmission lines. Use good coaxial cable, not open wire lines or end-fed antennas that come directly into the transmitter area.

o No person should ever be near any transmitting antenna while it is in use. This is especially true for mobile or ground-mounted vertical antennas. Avoid transmitting with more than 25 watts in a VHF mobile installation unless it is possible to first measure the RF fields inside the vehicle. At the 1-kilowatt level, both HF and VHF directional antennas should be at least 35 feet above inhabited areas. Avoid using indoor and attic-mounted antennas if at all possible.

o Don't operate RF power amplifiers with the covers removed, especially at VHF/UHF.

o In the UHF/SHF region, never look into the open end of an activated length of waveguide or point it toward anyone. Never point a high-gain, narrow-beamwidth antenna (a paraboloid, for instance) toward people. Use caution in aiming an EME (moonbounce) array toward the horizon; EME arrays may deliver an effective radiated power of 250,000 watts or more.

o With handheld transceivers, keep the antenna away from your head and use the lowest power possible to maintain communications. Use a separate microphone and hold the rig as far away from you as possible.

o Don't work on antennas that have RF power applied.

o Don't stand or sit close to a power supply or linear amplifier when the ac power is turned on. Stay at least 24 inches away from power transformers, electrical fans and other sources of high- level 60-Hz magnetic fields.

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