EXHIBIT B

7) Learn how to repair or replace the sensitive components of the radio equipment.

8) Use nonmetallic guy lines and antenna structural parts where possible.

9) Obtain an emergency power source and operate from it during periods of increased world political tension. The power source should be completely isolated from the commercial power lines.

10) Equipment power cords should be disconnected when the gear is idle. Or the circuit breaker for the line feeding the equipment should be kept in the OFF position when the station is off the air.

11) Disconnect the antenna lead-in when the station is off the air. Or use a grounding antenna switch and keep it in the GROUND position when the equipment is not in use.

12) Have a spare antenna and transmission line on hand to replace a damaged antenna system.

13) Install EMP surge arresters and filters on all primary conductors attached to the equipment and antenna.

14) Retain tube-type equipment and spare components; keep them in good working order.

15) Do not rely on a microprocessor to control the station after an EMP event. Be able to operate without microprocessor control.

The recommendations contained in this section were developed with low cost in mind; they are not intended to cover all possible combinations of equipment and installation methods found in the amateur community. Amateurs should examine their own requirements and use this report as a guideline in providing protection for the equipment.

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. Extensive research on this topic is underway 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, man-made 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.

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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.

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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

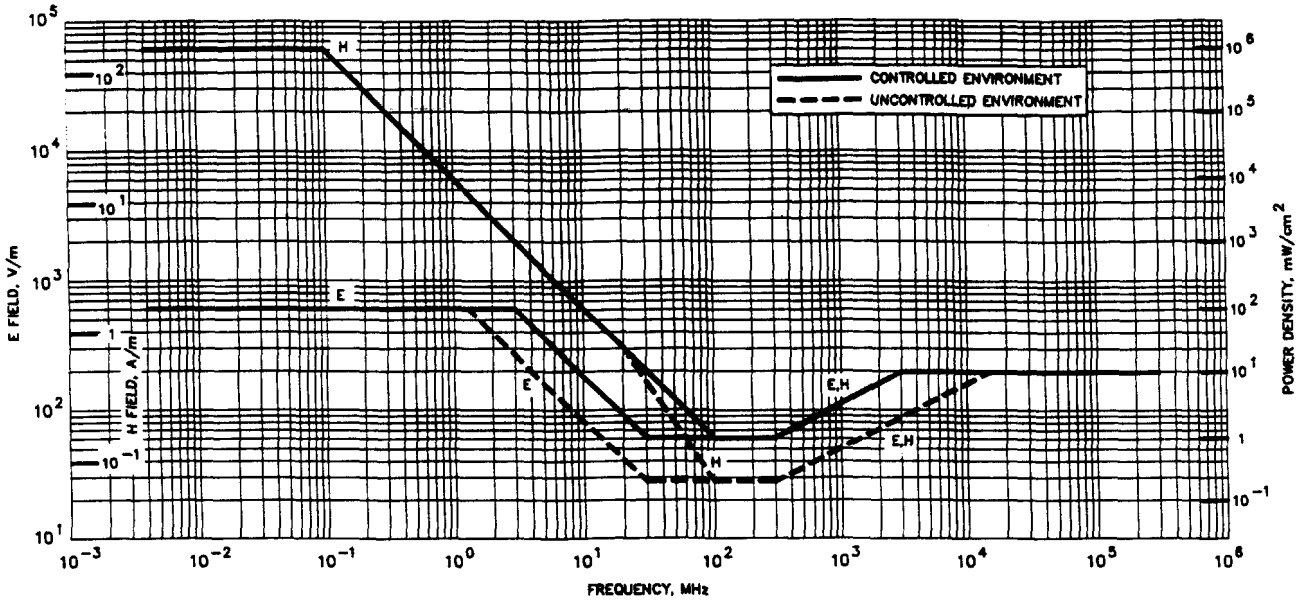

Fig 20—Proposed 1991 ANSI RF protection guidelines for body exposure of humans.

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.

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	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	15" from front
1-kW RF amplifier	80-1000	Atop cabinet
	1-25	15" from front

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

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!

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

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.

Antenna Type	*Freq, MHz*	*Power, Watts*	*E Field, 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 ft	21.2	1000	10-20	In shack
			14	12 m from base
3-element Yagi at 25 ft	28.5	425	8-12	12 m from base
Inverted V at 22-46 ft	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 ft	50.1	500	37-50	10 m from antenna

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.

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.

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.

- 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.
- 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.
- Don't operate RF power amplifiers with the covers removed, especially at VHF/UHF.
- 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.
- With hand-held 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.
- Don't work on antennas that have RF power applied.
- 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.

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.

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EXHIBIT C

station is covered in the Code. All conductors inside the building must be at least 4 inches away from conductors of any lighting or signalling circuit except when they are separated from other conductors by conduit or a nonconducting material. Transmitters must be enclosed in metal cabinets, and the cabinets must be grounded. All metal handles and controls accessible by the operator must be grounded. Access doors must be fitted with interlocks that will disconnect all voltages above 350 when the door is opened.

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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

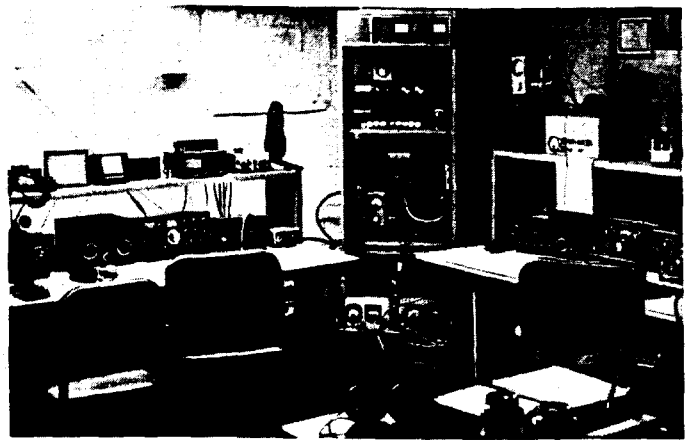

Fig. 2 — The basement makes a good station location if it is dry. This setup belongs to WB2NPE.

Fig. 3 — Some amateurs, like PP2ZDD, are fortunate enough to have a separate room available for their stations.

your style of operation. If possible, pick an area large enough for future expansion.

SAFETY

Although the RF, ac and dc voltages in most amateur stations pose a potentially grave threat to life and limb, common sense and knowledge of safety practices will help you avoid accidents. Building and operating an Amateur Radio station can be, and is for almost all amateurs, a perfectly safe pastime. However, carelessness can lead to severe injury, or even death. The ideas presented here are only guidelines; it would be impossible to cover all safety precautions. Remember: There is no substitute for common sense.

A fire extinguisher is a must for the well-equipped amateur station. The fire extinguisher should be of the carbon-dioxide type to be effective in electrical fires. Store it in an easy-to-reach spot and check it at recommended intervals.

Family members should know how to turn the power off in your station. They should also know how to apply artificial respiration. Many community groups offer courses on cardiopulmonary resuscitation (CPR).

AC and DC Safety

The primary wiring for your station should be controlled by one master switch, and other members of your household should know how to kill the power in an emergency. All equipment should be connected to a good ground. All wires carrying power around the station should be of the proper size for the current carried and be insulated for the voltage level involved. Bare wire, open-chassis construction and exposed connections are an invitation to accidents. Remember that high-current, low-voltage power sources are just as dangerous as high-voltage, low-current sources. Possibly the most-dangerous voltage source in your station is the 117-V primary supply; it is a hazard often overlooked because it is a part of everyday life. Respect even the lowliest power supply in your station.

Whenever possible, kill the power and unplug equipment before working on it. Discharge capacitors with an insulated screwdriver; don't assume the bleeder resistors are 100 percent reliable. In a transmitter, always short the tube plate cap to ground just to be sure. If you must work on live equipment, keep one hand in your pocket. Avoid bodily contact with any grounded object to prevent your body from becoming the return path from a voltage source to ground. Use insulated tools for adjusting or moving any circuitry. Never work alone. Have someone else present; it could save your life in an emergency.

National Electrical Code

The *National Electrical Code®* is a comprehensive document that details safety requirements for all types of electrical installations. In addition to setting safety standards for house wiring and grounding, the Code also contains a section on Radio and Television Equipment — Article 810. Sections C and D specifically cover Amateur Transmitting and Receiving Stations. Highlights of the section concerning Amateur Radio stations follow. If you are interested in learning more about electrical safety, you may purchase a copy of *The National Electrical Code* or *The National Electrical Code® Handbook,* edited by Peter Schram, from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

Antenna installations are covered in some detail in the Code. It specifies minimum conductor sizes for different length wire antennas. For hard-drawn copper wire, the Code specifies no. 14 for open (unsupported) spans less than 150 feet, and no. 10 for longer spans. Copper-clad steel, bronze or other high-strength conductors may be no. 14 for spans less than 150 feet and no. 12 for longer runs. Lead-in conductors (for open-wire transmission line) should be at least as large as those specified for antennas.

The Code also says that antenna and lead-in conductors attached to buildings must be firmly mounted at least 3 inches clear of the surface of the building on nonabsorbent insulators. The only exception to this minimum distance is when the lead-in conductors are enclosed in a "permanently and effectively grounded" metallic shield. The exception covers coaxial cable.

According to the Code, lead-in conductors (except those covered by the exception) must enter a building through a rigid, noncombustible, nonabsorbent insulating tube or bushing, through an opening provided for the purpose that provides a clearance of at least 2 inches or through a drilled window pane. All lead-in conductors to transmitting equipment must be arranged so that accidental contact is difficult.

Transmitting stations are required to have a means of draining static charges from the antenna system. An antenna discharge unit (lightning arrester) must be installed on each lead-in conductor (except where the lead-in is protected by a continuous metallic shield that is permanently and effectively grounded, or the antenna is permanently and effectively grounded). An acceptable alternative to lightning arrester installation is a switch that connects the lead-in to ground when the transmitter is not in use.

Grounding conductors are described in detail in the Code. Grounding conductors may be made from copper, aluminum, copper-clad steel, bronze or similar erosion-resistant material. Insulation is not required. The "protective grounding conductor" (main conductor running to the ground rod) must be as large as the antenna lead-in, but not smaller than no. 10. The "operating grounding conductor" (to bond equipment chassis together) must be at least no. 14. Grounding conductors must be adequately supported and arranged so that they are not easily damaged. They must run in as straight a line as practical between the mast or discharge unit and the ground rod. Adequate ground systems are covered later in this chapter.

Some information on safety inside the

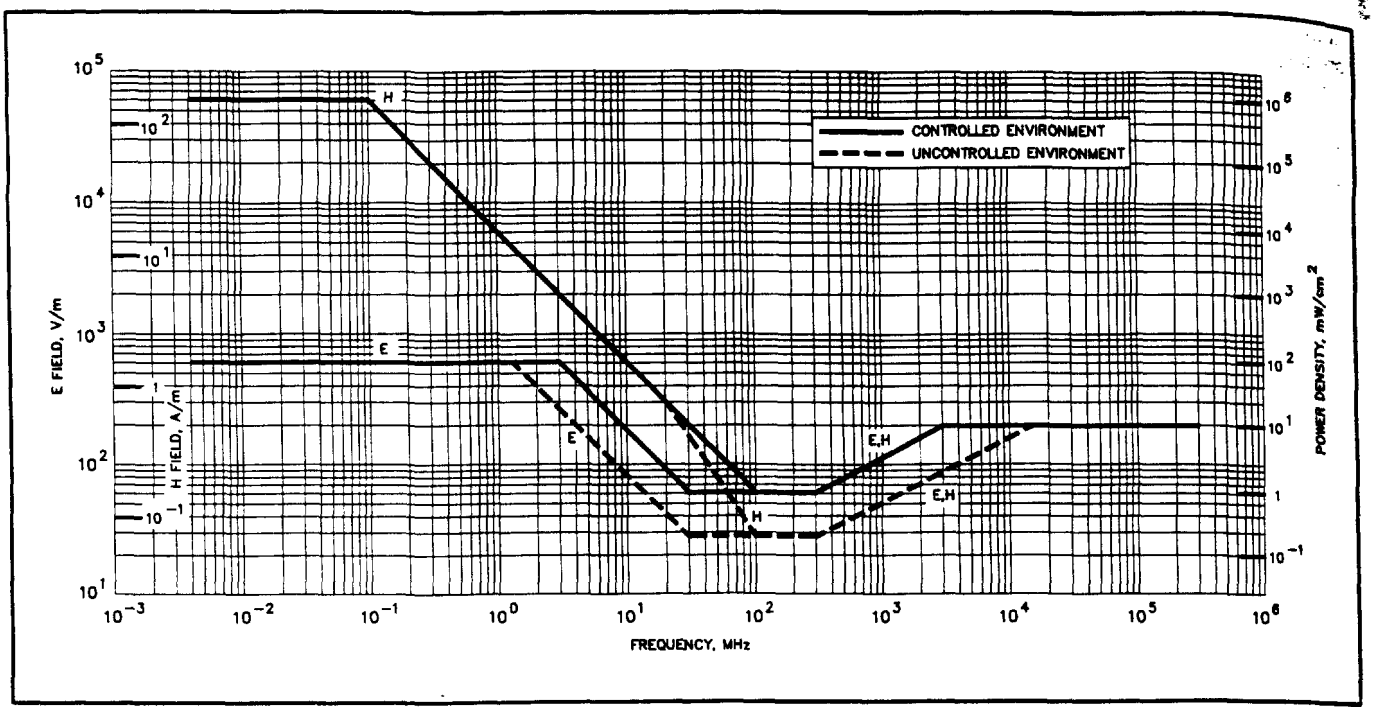

Fig. 4—Proposed 1991 ANSI RF protection guidelines for body exposure of humans.

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).

The graph in Fig. 4 depicts 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/cm² (61.4 volts per meter) in controlled environments—but at one-fifth that level (0.2 mW/cm² or 27.5 volts per meter) in uncontrolled environments. The H-field limit drops to 1 mW/cm² (0.163 ampere per meter) at 100-300 MHz in controlled environments and 0.2 mW/cm² (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

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	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	15" from front
1-kW RF amplifier	80-1000	Atop cabinet
	1-25	15" from front

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

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!

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 measure-

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.

Antenna Type	*Freq, MHz*	*Power, Watts*	*E Field, 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 ft	21.2	1000	10-20	In shack
			14	12 m from base
3-element Yagi at 25 ft	28.5	425	8-12	12 m from base
Inverted V at 22-46 ft	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 ft	50.1	500	37-50	10 m from antenna

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.

- 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.
- 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.
- Don't operate RF power amplifiers with the covers removed, especially at VHF/UHF.
- 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.
- 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.
- Don't work on antennas that have RF power applied.
- 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.

ments 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.

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.

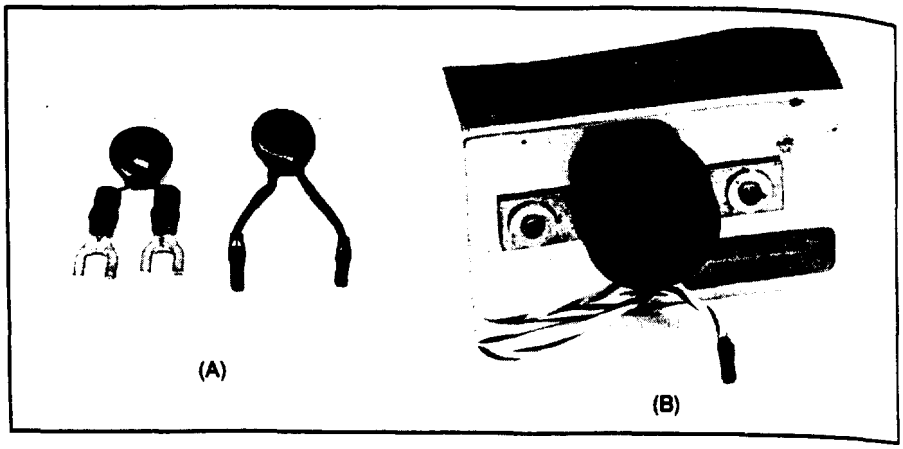

Fig. 5 — Typical LA series MOV protectors are shown at A with various connectors on the leads. A PA series MOV is shown at B as it might be mounted in a service-entrance box.

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.

Lightning Protection

The National Fire Protection Association (NFPA) publishes a booklet called *Lightning Protection Code* (NFPA no. 78-1983) that should be of interest to radio amateurs. Write to the NFPA at the address given in the previous section for information on obtaining a copy. Two paragraphs of particular interest to amateurs are presented below:

"3-26 Antennas. Radio and television masts of metal, located on a protected building, shall be bonded to the lightning protection system with a main size conductor and fittings.

"3-27 Lightning arresters, protectors or antenna discharge units shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins."

The best protection from lightning is to disconnect all antennas from equipment and disconnect the equipment from the power lines. Ground antenna feed lines to safely bleed off static buildup. Eliminate the possible paths for lightning strokes. Rotator cables and other control cables from the antenna location should also be disconnected during severe electrical storms.

In some areas, the probability of lightning surges entering homes via the 117/234-V line may be high. Lightning produces both electrical and magnetic fields that vary with distance. These fields can couple into power lines and destroy electronic components. Radio equipment can be protected from these surges through the use of transient-protective devices. The following information originally appeared in a February 1982 *QST* article by Gene Collick, W8LEQ and Ken Stuart, W3VVN.

Protective Devices

The General Electric Home Lightning Protector® is designed to prevent lightning surges (entering through the wiring) from damaging electrical wiring and/or appliances. The protector is a two-pole, three-wire device designed primarily for single-phase 117/234-V grounded-neutral service. It mounts via a ½-inch pipe-thread connection through a knockout in the service-entrance box preferably, or, at the weather-head or within the meter housing. The purpose of this device is to reduce the amplitude of large transients.

TransZorbs® are silicon devices manufactured by General Semiconductor Industries for transient suppression. They contain a large-area PN junction having integral heat sinks and are capable of handling short-duration, high-power pulses (typically 1500 watts for 1 millisecond and 100,000 watts for 100 nanoseconds). The TransZorb® protects by clamping transient voltages to a safe level, with sub-nanosecond reaction time.

A metal-oxide varistor (MOV) is a bulk semiconductor device whose resistance varies with the magnitude (but not polarity) of the applied voltage. At extremely low currents, a varistor acts like a linear resistor with a resistance that can exceed hundreds of megohms. At higher currents, the voltage-current relation is nonlinear, and at extremely high currents the device acts

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EXHIBIT D

Chapter 2

RF Safety Practices

By Dr David Davidson, W1GKM (SK)

The *ARRL Handbook* and some *QST* articles stress safety precautions in the ham shack during equipment alignment and maintenance, and while erecting or adjusting antennas. These admonitions concern preventing contact with electrical voltages and currents.

Another important safety concern is radio-frequency (RF) protection. This involves minimizing human exposure to strong RF fields that might occur near or around antenna structures. At VHF and above, this includes antenna feed systems and waveguide openings.

The biological effects of RF exposure have been studied for more than two decades. We now know a great deal about these effects in animals, particularly where the RF energy produces detectable tissue heating. There has been progress in translating these results to the case of human exposure, although there remain questions about bioeffects at lower RF field intensities.

Since 1979 there has been much activity in advancing RF-protection guides (RFPG) or standards. The US government has never had a formal RF-protection standard, either for occupational exposure or for exposure of the general population, although an advisory RFPG did exist for the work place until 1983.

In 1979 the Federal Communications Commission (FCC) initiated an inquiry into how RF protection should be provided through its licensing procedures. The National Environmental Protection Act (NEPA) requires the Commission to consider environmental issues. Since 1970, the FCC has been pursuing its NEPA obligation in the licensing of satellite Earth stations with antenna diameters of 30 feet or more.

By 1982, the American National Standards Institute (ANSI) had adopted a RFPG that recommended maximum permissible exposure levels (MPELs) for frequencies between 0.3 MHz and 100 GHz (Fig 1).[1] This RFPG recognized that in a uniform RF field, the human body absorbs RF energy more effectively at a frequency where body length is about 0.4 λ and the body's long axis is aligned with the incoming electric-field polarization. This condition is known as "whole-body resonance."

The ANSI guide aims to provide RF safety by limiting whole-body RF rate-of-energy uptake to no more than 0.4 watt per kilogram (W/kg), which provides a safety factor of 10 over the consensus threshold of RF hazard at >4 W/kg.[2] Additionally, the guide states that any "spatial peak value of the SAR would not exceed 8 W/kg over any one gram of tissue and over any time period of 0.1 hour." (ANSI C95.1-1982, paragraph 6.6, p 13; paragraph 6.11, p 15.) The ANSI guide also notes "Measurements...shall be made at distances 5 cm or greater from any object." (paragraph 4.3, p 10.) For example, for an average male adult weighing about 70 kilograms, and about 1.75 meters tall, the maximum RF energy uptake would be at about 60 MHz, close to TV channel 2, and not far removed from the 6-meter amateur band.

There is also a special ANSI exclusion for hand-held radios: "At any frequency between 300 kHz and 100 GHz, the protection guides may be exceeded if the radio frequency input power of the radiating device is seven watts or less." (paragraph 4.2(2), p 10.)

Most organizations commenting in the FCC inquiry recommended that ANSI's 1982 RFPG be followed until the US Environmental Protection Agency (EPA) issues a

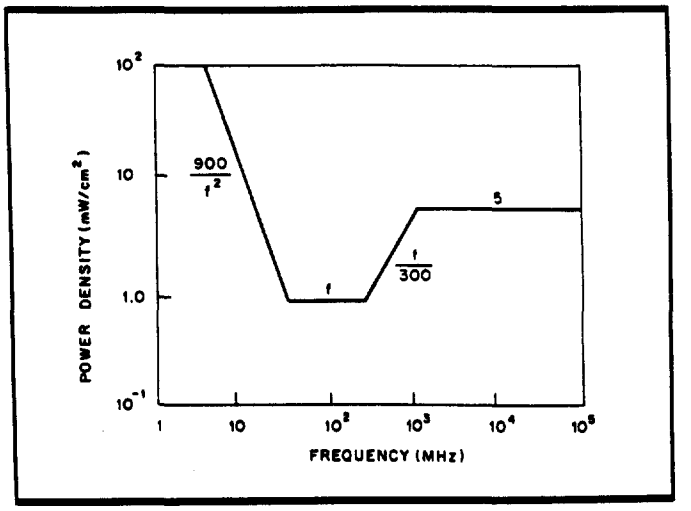

Fig 1—Maximum permissible RF power density (ANSI, 1982) for far-field exposure of human beings or animals, averaged over any six-minute period, and well insulated or isolated (more than 10 cm) from ground.

guideline for protection of the general population from RF energy. An EPA guideline would likely become obligatory for agencies of the federal government; it would likely become a *de facto* national standard. In the meantime, many states or localities have been proposing or enacting RF regulations, some of which are more stringent than ANSI's.[3] The ARRL has consistently maintained that Amateur Radio should be excluded from these regulations because of the intermittent nature of amateur transmissions; modulation or keying varies the instantaneous power, there are frequent pauses, much time is spent listening, and the RF power is low compared to the levels used in the broadcasting services. This thesis has not been accepted by all regulators, however.

In 1985, the FCC decided to accept the majority's recommendation by promulgating the ANSI RFPG as an *interim* standard, effective January 1986 for processing applications for broadcasting, satellite Earth stations and experimental stations. In early 1987, the FCC exempted Amateur Radio stations from "routine evaluation of their environmental impact due to human exposure to radio-frequency radiation."

The EPA pointed out that some amateur operations involve relatively high effective radiated power (ERP). The ARRL acknowledged that amateurs sometimes use high ERP, but recommended that amateurs comply by becoming "RF aware"—learning about the subject during preparation for FCC license exams, and by practicing self-regulation. ARRL recommended this course owing to (a) administrative reasons, (b) the long licensing term (10 years), and (c) the impossibility of predicting 10 years in advance which frequency bands amateurs would use.

Other countries, such as Canada, the Federal Republic of Germany, Sweden, and the USSR, all have protection guides (standards, or codes)—each of which is different—concerning the application, exclusions and MPELs at various frequencies. Many of the foreign standards have been undergoing changes. None of these countries seem to be concerned yet about amateur operation, possibly because the legal power limits are generally much lower than in the USA.

Regardless of US regulations and the practice abroad, it is prudent and responsible to examine those situations where high-level RF fields occur. The radio amateur must determine if access should be controlled, whether RF power should be limited or not, and what precautions need be taken—including a knowledge of what the RF power density levels are, should questions ever be raised. On this basis, a radio amateur can, and preferably should, choose to use more conservative RF power density levels than those in the ANSI RFPG.

Our knowledge of RF bioeffects will grow as more studies are made. Regulations may be changed accordingly. For example, in April 1986 a non-governmental body, the National Council on Radiation Protection and Measurements (NCRP), recommended that an RF-protection standard for public exposure be set at a power-density level 1/5 that of ANSI 1982. NCRP calculated this safety factor by noting that a worker spends 1/5 of his life on the job. However, NCRP allows an averaging period of one-half hour for the general public. The idea was to allow brief high RF exposure of the general public while passing a "civil telecommunications system."[4] And, in December 1986 the EPA solicited comments on three options for regulating the public's exposure. One is like ANSI's, a second like NCRP's, and the third is twice as stringent as NCRP's. Most respondents have urged adoption of option 2 or one close to it. Amateurs should know where they stand on this issue, so they can understand the consequences of changes in equipment, modes of operation, and antenna configurations with respect to levels of an adopted RFPG. More importantly, amateurs must realize the consequences of changes in RF exposure-protection standards.

Near- and Far-Field Antenna Zones

A convenient place to begin to appreciate the actual RF fields is well away from a transmitting antenna, in the *far-field* zone. Close to an antenna is the *near-field* zone, in which complicated RF fields exist. Beyond that zone in the far field, it is possible to estimate the magnitudes of the electric and magnetic fields, or the power density they develop, and relate these to the MPELs of an RFPG or standard. *If the estimate is lower than the MPEL, one knows that from that point outward, at the same bearing to the source, levels are of no concern.* A maximum limit can be computed by assuming: (1) the highest transmitter power level allowed, or that the licensee expects to employ, and (2) the highest antenna gain that might be used.

Power Density and Field Strength

A radio emitter in free space appears to be sending out a spherical wavefront. Radiated RF power is spread over the area of this imaginary sphere, centered on the source. Power measured per unit area (for example, per m^2) decreases as the distance increases (Fig 2). This reduction is proportional to the square of the distance from the source. If the source has a directional antenna, then at a constant radial distance the power-density level will depend on the bearing from the source. For examining a worst case, let's consider levels along the direction of maximum antenna gain.

The power density, S (in W/m^2), at an observation point, is proportional to the square of the electric field, E (in V/m). The proportionality constant in this relationship is the impedance of free space (377 ohms):

$$S = \frac{E^2}{Z_0} = \frac{E^2}{377} \qquad \text{(Eq 1)}$$

This relation between S and E (its RMS value) holds only in the far field, because $Z_0 = 120\pi = 377$ ohms is uniformly true there, being independent of position.

Similarly, the associated RMS magnetic field strength, H, is also related to S:

$$S = Z_0 H^2 \qquad \text{(Eq 2)}$$

because $Z_0 = E/H$ everywhere. This relationship characterizes transmission in free space, far from a source. Propagation of the E and H fields away from a source, therefore, represents a power flow outward. For RF-protection purposes in the far field at VHF, UHF and above, the quantity of interest is S, the average power flow per unit area, which we can compute if we know either E or H.

Near-Field Region

In the near field, the distances between an observing point and various parts of a source antenna differ greatly

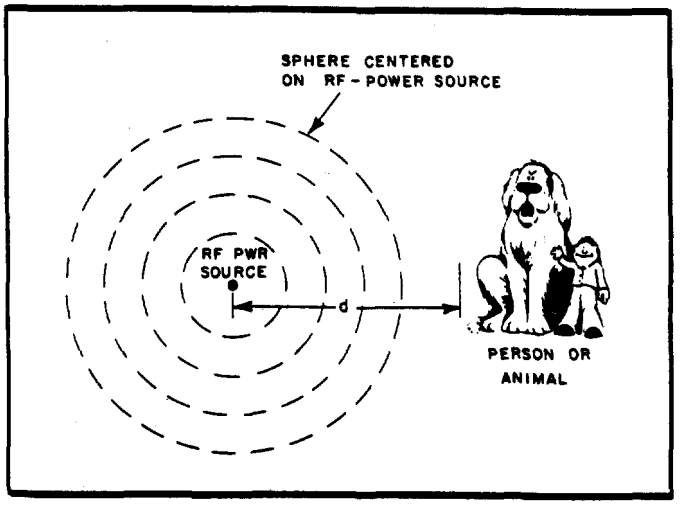

Fig 2—Radiation sphere that is centered on an RF-power source. If the source is isotropic, then at distance d the entire RF power, P, is distributed uniformly over the spherical surface ($4\pi d^2$), so the power density is $P/(4\pi d^2)$. If the source is not isotropic, the power density at d is $PG/(4\pi d^2)$, where G is the power gain in the direction of measurement.

from each other in terms of wavelength. The distance from the antenna to that point where the near field ends, or the far field begins, varies according to antenna type. When estimating power densities for RF-protection purposes, the nominal far-field boundary is a useful reference location. Within this distance, however, the E and H fields of the antenna are geometrically complicated; their size and spatial disposition relate to energy storage in and around the radiating system, and depend on how the voltages and currents are distributed on the antenna structure, too. In the near field the ratio, Z, of an E-field to an associated H-field component, no longer is equal to the impedance Z_0 of free space, but takes on values that vary markedly over relatively short distances near the antenna. In the near field, it is not always possible to uniquely define a power flow and hence a real power density.

As an example, the electric field in the far-field region of a ½-λ dipole is polarized in a direction parallel to the dipole axis, when viewed from a position on the perpendicular bisector. In the near-field region, the electric field strength having the same polarization as found in the far field is very small, while the magnetic field strength is large. Thus, the wave impedance $Z = E/H$ there is much lower than 377 ohms. (The H field can be calculated accurately for a point on the bisector by assuming it is caused by the antenna current flowing in a very long wire coincident with the dipole axis.)

Near the tips of a dipole antenna, the current is approximately zero. The magnetic field just outside the tips is very small, but the E field is very high, because this is the part of the antenna where electric charge is stored. Thus the wave impedance, Z, near the tips, can be high. The E field near the tip depends on shape. A thin, wire dipole will have high E fields near the ends, but if the antenna is thick or the ends have large knobs or spheres, the E field can be reduced dramatically, by a factor of 10 or more.[5] Thus, while the far-zone E field can be predicted without having much detail of the antenna structure, in the near-field zone specific information is required to achieve relatively accurate results, and advanced mathematical methods of evaluation must be employed.[6,7,8]

For amateurs working at VHF and above, it is interesting to compare the near fields of a simple straight-wire dipole and that of a helical dipole (comprising many turns of small diameter).[6,7] Although both would have equivalent far fields for the same radiated power, the near fields will be very different. Even two helical dipoles (or grounded helical monopoles), each with a different number of turns and diameter, will have different near-field configurations, and thus different local energy storage configurations.

Power Density

At UHF and above, RF power is often fed to the antenna by means of a waveguide. A waveguide appropriate for 10 GHz (WR90) has an inside cross section of 1.0 × 2.3 cm (0.4 × 0.9 in). From the open end of such a waveguide the average power density emerging, S, if power P is supplied, is

$$S = \frac{P}{ab} \qquad \text{(Eq 3)}$$

where a and b are the waveguide inner dimensions. The result for P = 1 W is

$S = 4347\ W/m^2$, or $435\ mW/m^2$

Although a mismatch would cause reflection of power back to the source, this is a very high power density—one that could cause a tissue burn close to the opening! This example illustrates why the care and handling of RF energy in the ham shack has to be taken seriously, and why with even a low-power source, dangerous levels can be developed if RF power flow is concentrated in a small area.

An open waveguide end is often used as a rudimentary antenna or feed system. Far from the opening, the power density falls off as the square of the distance (discussed earlier), but the region near such an opening should be made inaccessible during operation.

Far-Field Power Density

In the far-field region in free space, power density, S, falls off as the square of the distance.

$$S = \frac{PG}{4\pi R^2} = \frac{(EIRP)}{(\text{Area of sphere at R})} \qquad \text{(Eq 4)}$$

where

P = RF power supplied to the antenna
G = far-field, free-space antenna gain (numeric value), relative to an isotropic antenna
R = distance from the antenna

The product PG is called EIRP (effective isotropic radiated power), and is the term used at frequencies above 1 GHz. [Below this frequency, antenna gain is often referred to as the gain of a ½-λ dipole, which is 1.64 times the isotropic gain. In this case, the FCC uses the abbreviation ERP instead of EIRP.] For P we would use the *average power* supplied over some period, usually the averaging period found in the RFPG, which for the ANSI 1982 RFPG is six minutes. For CW keying *throughout an averaging period,* P would be around 50% of the average RF power supplied per RF cycle, because of the on/off duty cycle. For SSB, the average power would be much less because of the peak-to-average characteristic, including speech pauses. Together, these come to about 7 dB, or an average power of about 1/5 of the peak envelope power (PEP). For FM or RTTY, the carrier is always present during the sending interval and the power P to be used is 50% of PEP.

Most amateurs don't know the actual gain of their antennas. For RF protection we want an upper-bound or worst-case estimate, so we can use a textbook value for G for the type of antenna being used.[9] Generally this value is given in a table or a figure, and refers to the ideal case of a lossless antenna far from the influences of structures or ground. (Examples of how to use G in Eq 4 are given below.) In calculating power density for RF-protection assessment, one should start by determining the far-field power density associated with the main lobe.

Since all real antennas are elevated above Earth, reflections can occur through reinforcement by the image in the ground plane, via nearby reflective surfaces, or by field enhancements near metal objects. Although complete reinforcement would double the RF field and thus quadruple the power density, the FCC and EPA

RF Awareness: Protection Rules for the Radio Amateur

The following protection rules are suggested as a matter of prudence and good practice. They are worth observing whether or not a particular Amateur Radio operation is covered in the RF regulations enacted by the government.

1) Respect RF power.

2) Know the RF power input to your antenna.

3) Know approximately the directional properties of your antenna (for example, the gain, and the gain pattern).

4) If in doubt about how much power density you are generating nearby, reduce power output. Note, that for US amateurs, FCC rules require that "amateur radio stations shall use the minimum power necessary to carry out the desired communications."† Thus, if your signal is being received as 20 dB over S9, you can and should reduce power.

5) When using high power and high antenna gain, keep transmissions short, especially with high-duty-cycle modes (RTTY, FM, and so on), unless the antennas are isolated.

6) Keep the antenna parts away from people, especially if you are using full legal power or close to it, or are using a high-duty-cycle mode.

7) At high power levels, be sure the entire antenna is at least several meters away from persons who might be present for the RFPG averaging period. This is most important for vertical antennas!

8) With mobile rigs of 10 W or more, *do not* transmit if a person is standing one-half meter or less from the car antenna.

9) When using hand-held units, maintain at least 2.5 to 5 cm separation between your forehead and the antenna, especially if the RF power is close to 7 W. Observe the manufacturer's recommendations on use and placement.

10) Be sure RF power is *off* (and stays off) before climbing a tower to make antenna adjustments. Also, make certain all neighboring antennas are deactivated. *Never assume* RF power is off—check, and re-check!

11) In the SHF bands:

- Never look into the open end of a waveguide that is carrying power.
- Never direct the end of such a waveguide toward a person or animal.
- Never direct a powered horn or "dish" toward people or animals.
- Know the power being fed into your waveguide.
- Make sure all waveguide flanges and transitions are tightly secured, preferably with a torque wrench, to specifications. If in doubt, wrap the junction in metallic foil. Household foils may be used, but for this purpose several high-shielding, conductive foils are available commercially. (3M/Electrical Products Division, 225-4N 3M Center, St Paul, MN 55144.)

12) Make certain that all RF-power-stage-compartments in transmitters are closed tightly before operating the transmitter.

13) The lids or covers for RF-power-stage compartments or cavity panels should be secured tightly with numerous screws to prevent leakage at UHF and higher.

14) Never install an antenna so that the radiating elements can be reached by human beings, or so that the near-field radiation can be directed at people or animals.

15) Never work around radiating antennas in bare feet or flimsy footwear or permit others to do so.

†FCC Rules and Regulations, Part 97, Amateur Radio Service, Section 97.313(a). Government Printing Office, Washington, DC. Part 97 is reproduced in the ARRL publication, *The FCC Rule Book.*

recommend using 2.5S, where S is the power density calculated in Eq 4.[10]

Where Does the Far Field Begin?

Since S is highest for the least distance R, we need to know where the far field begins. The hint about where the far field begins is contained in Eq 4. This critical distance is the smallest for which the inverse-square law in that formula is still valid. It is determined for the kind of antenna used, by considering where, as the antenna is approached, the increase in S begins to slow down (the rate of change decreases), and the power density is no longer inverse-square-law dependent.

Table 1 lists the distances R_{ff} at which the far field can be considered to begin (for the purposes of this chapter).[11] The distance (column 3) is expressed in terms of some maximum or characteristic antenna dimension, such as the diameter. Column 2 identifies the characteristic dimension.

The formulas given here are to be used with practical units: power in watts, distances in meters, E fields in volts/meter and H fields in amperes/meter. Then S comes out in watts/square meter (W/m^2). [Some RFPGs express the MPEL in milliwatts/square centimeter (mW/cm^2). To convert a value in W/m^2 to one in mW/cm^2, simply divide by 10. Wavelength (λ) should also be in meters.]

To assure an upper-bound estimate, the free-space antenna gain should be used if the actual value is not known. A textbook value, as noted, will be useful because, among other things, antenna-system losses are either neglected or underestimated. Column 4 in Table 1 lists suggested antenna gains for each entry.

Column 5 gives the desired power density at R_{ff} for the antennas listed, expressed as the ratio, P/S, of the RF power P, applied to the antenna to achieve a specified power density S, such as the MPEL of an RFPG. (The dimension of P/S is area in m^2, being the hypothetical area through which the RF energy appears to flow at the point of observation.)

Example 1

A Yagi, $G' = 20$ (13 dBi), is mounted atop a 30-foot (9-meter) tower. The frequency is 430 MHz, $\lambda = 0.7$ meter. According to Table 1, the far-field reference location, measured along the axis of the beam (the "boresight"), is located at a distance R_{ff} from the Yagi end element

$$R_{ff} = \frac{2 \times (0.35)^2}{0.7} = 0.36 \text{ m} \qquad \text{(Eq 5)}$$

With the antenna 30 feet above local ground and the main lobe pointed into the right half-plane, let us find the maximum power density that could occur for RF power P, at a radius of 9 meters or 30 feet. According to Eq 4, the power density will be

Table 1

Far-field Location and RF Protection Parameters

Antenna Type	*Characteristic Dimension*	R_{ff}	*Antenna Gain*	*P/S at R_{ff}*
Parabolic dish	Diameter, D	$2D^2/\lambda$	$2\pi(D/\lambda)^2$	$8D^2$
Broadside array	Width, w Height, $\lambda/2$	$2w^2/\lambda$	$4\pi A/\lambda^2$ $A = w\lambda/2$	$8w^3/\lambda$
Waveguide (open end) Sides a, b ($a \geq b$)	a	$2a^2/\lambda$	$10ab/\lambda^2$	$5a^3/b$
Pyramidal horn, 60° angle, all edges L equal, $L = 2\lambda$	L	$2L^2/\lambda$	Gain $\cong 25$ (14 dBi)	$32\lambda^2$
Axial-mode helix	Turn diameter, D Circumference, $C \cong 1\lambda$ Spacing, s Turns, n	$2D^2/\lambda$	$15ns/C$	$\cong \lambda^3/(\pi ns)$
End-fire types:				
Yagi Boom length, B	$L = \lambda/2$; length of driven element	$2L^2/\lambda$	$G' = 5.8 + 11.1B$ $(0.3 \leq B \leq 2.5\ \lambda)$	$\cong \pi\lambda^2/G'$
Loop (quad)-Yagi Boom length, B	Max width, L, of loop (quad)	$2L^2/\lambda$	ditto	ditto
Stacked Yagi (vertically)	Stack spacing, W	$2W^2/\lambda$	2 (Yagi gain)	$4\pi W^4/(\lambda^2 G')$

Notes

Gains are numeric values; gain (dBi) = 10 log gain (numeric).
Waveguide & horn gains are based on text notes 12 and 13.
Axial-mode helix design formulas are taken from Kraus.[14]
G' is an approximation from the Yagi curves of Greenblum,[15] and is given with respect to an isotropic antenna, to be useful in Eq. 4.
(The following approximation fits values given in the *ARRL Handbook*, Chapter 33, for boom lengths between 0.4 λ and 4.2 λ:
$G' = 3.8 + 12.25B - 0.687B^2$)
Parabolic dish gain is based on 64% efficiency.
All dimensions are in meters.

$$S = \frac{PG'}{4\pi R^2}$$

where R = 9 meters (30 feet) and G′ = 20.

Since Eq 4 is for free space, we must figure in the possible contribution of the antenna image in the ground plane. At some positions above the ground plane there will be reinforcement and at others there will be almost complete cancellation.[12] At any maximum, the electric field will be no more than doubled, quadrupling the power density. Thus, a factor of 4 needs to be applied

$$P/S = \frac{4\pi R^2}{4G'} = \frac{9^2\pi}{20} = 12.86\ M^2$$

For protection in accordance with the ANSI standard, S should not exceed 1.4 mW/cm², or 14 W/m². Thus, the allowed RF power to the antenna would be

$$P = 12.86 \times 14 = 180\ W$$

This is allowed power expressed as the average over *any* six-minute transmission period. Notice, this is a worst-case estimate because a factor of 4, rather than 2.5, was used.

Suppose a future general-population standard is promulgated that follows NCRP's recommendations, in which all ANSI MPELs have been lowered by a factor of 5, while the averaging period has been lengthened by a factor of 5, to 30 minutes.[4,13] In the above example, P would come out as 180/5 = 36 W, to be the average over *any 30-minute period.* In Amateur Radio practice, the end result might be the same as with the ANSI standard when the type of modulation is taken into account. For example, if SSB is used a factor of 7 dB (numeric value of five) relates PEP to average power. In a six-minute transmission period under the ANSI standard, we could allow 5 × 180 W = 900 W PEP. Under the more stringent standard, 5 × 36 W = 180 W would seemingly be the limit. However, *provided* that each transmission never lasts more than six minutes and there are silent periods in between, the same 900-W PEP could be employed.

Example 2

The frequency of operation, f, is 10 GHz, so λ = 3 cm = 0.03 meter. A parabolic "dish" antenna is employed, diameter, D, = 2 feet = 0.6 meter. The start of the far field is

$$R_{ff} = \frac{2D^2}{\lambda} = \frac{2 \times 0.6^2}{0.03} = 24\ m$$

At R_{ff} the P/S ratio (from Table 1) is

$$P/S = 8D^2 = 8 \times 0.6^2 = 2.9\ m$$

Let us assume that the dish illumination is tapered, in order to minimize diffraction of the RF energy over the dish circumference. Fig 3 shows there is a location of axial reinforcement, or an RF "hot spot" located on axis at a point $R' = 0.1R_{ff}$ = 2.4 meters from the dish aperture. For a tapered dish illumination, the power density at R′ is *42 times* the value at R_{ff}. It is not necessary to invoke the RFPG for the hot spot *if* we know that *location R′ is inaccessible* when the RF power is on.

For f = 10 GHz, the ANSI MPEL is 5 mW/cm² = 50 W/m² for whole-body exposure. The maximum allowed RF power (six-minute averaging) without access to the area within a 24-meter radius of the antenna is

$$P = 2.9 \times 50 = 145\ W$$

The dish antenna has a half-power beamwidth of about 3.5°. Thus, at the distance R_{ff} from the aperture, but off-axis by 1.75°, the power density would be 25 W/m² = 2.5 mW/cm².

Example 3

The frequency remains at 10 GHz, but the antenna is open-ended WR90 waveguide. Assume that the area between the waveguide end and a point 1 meter distant is inaccesible. At a distance 1 meter from the antenna, RF-energy protection is desired according to the ANSI standard; therefore, S is not to exceed 5 mW/cm² or 50 W/m². What is the maximum power permissible under these conditions?

From Table 1, the gain of this antenna is

$$G = \frac{10\ ab}{\lambda^2} = 2.56$$

where a, b are the inside waveguide dimensions for WR90.

The far field begins at 4.5 cm, so Eq 4 can be used to compute the allowed RF power. Because the antenna is located near some flat surfaces, this time we include the EPA/FCC factor of 2.5 to protect spatially. Thus, at 1 meter

$$S = \frac{2.5\ PG}{4\pi R^2}, \text{ and } P = \frac{4\pi \times 1^2 \times 50}{2.5 \times 2.56} = 98\ W$$

This is the maximum average power that can be applied for any six-minute period.

Example 4

In this case, f = 1296 MHz, so λ = 23 cm = 0.23 meter. The antenna is an "optimum horn" with considerable flare-out, so that the edges are greater than 1 λ long. Let the dimensions for L be 46 cm (18 inches) and 51 cm (20 inches), so that one side is exactly 2 λ long. The gain of this horn, G, = 28, or 14.4 dBi.[14] Here,

$$R_{ff} = \frac{2 \times 0.51^2}{0.23} = 2.26\ m$$

ANSI's MPEL at this frequency is 5 mW/cm² = 50 W/m². From Eq 4 we have

$$S = \frac{GP}{4\pi R_{ff}^2} = \frac{28\ P}{4\pi \times 2.26^2} = 0.44\ P$$

and P = 50/0.48 = 115 W maximum average for any six-minute exposure. A similar result would be obtained for a 60° pyramidal horn, 46 cm (18 inches) on each edge.

In Westman,[15] the 10-dB beamwidth of the above

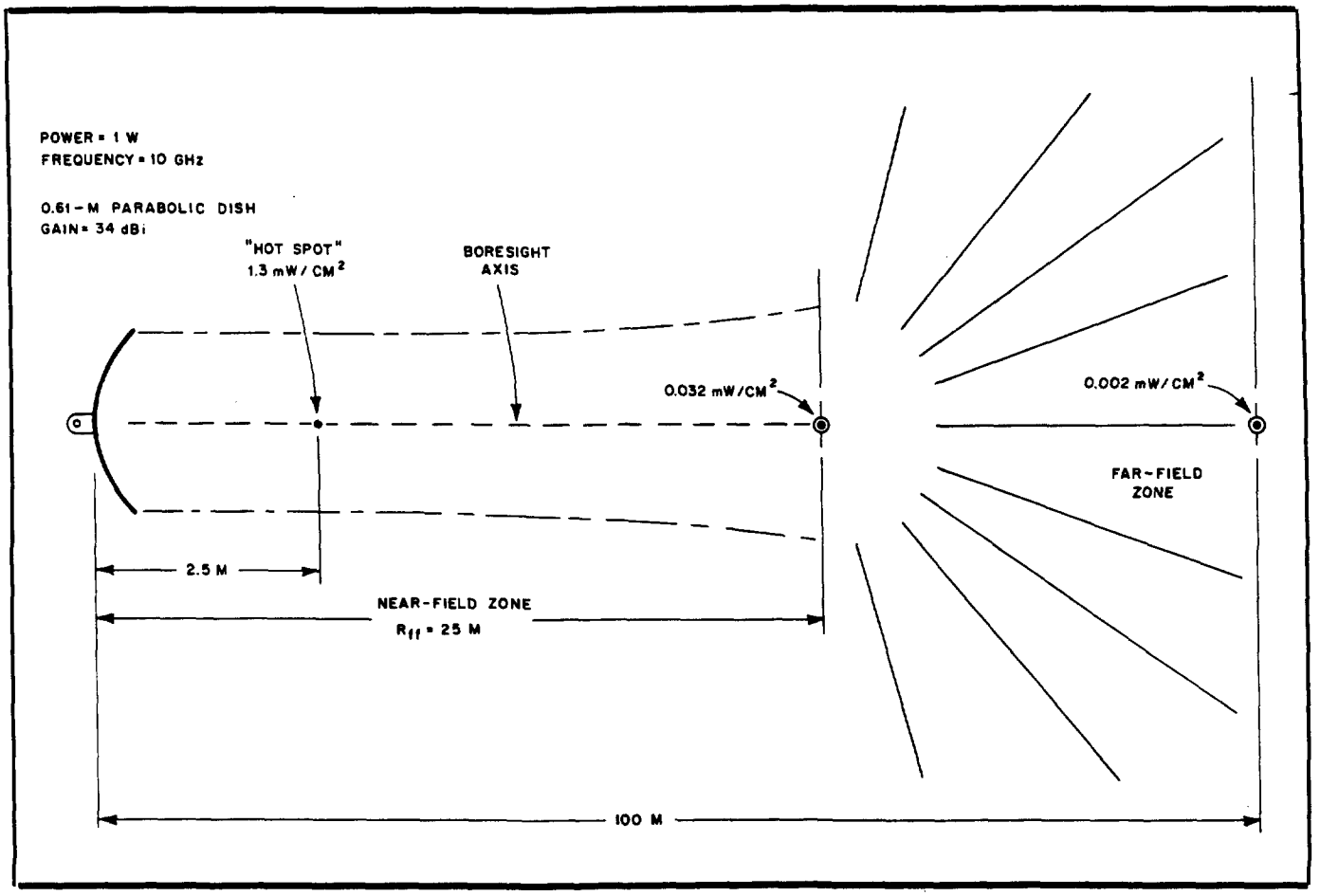

Fig 3—The zones around a parabolic antenna, showing RF power density levels at various positions along the boresight axis. Note that the R' "hot spot" is located 2.5 meters from the antenna.

horn (0.1 the power density) is given as 40°. If no access is possible at R_{ff} through an angle 20° above or below the boresight of this horn, the averaged RF power could be raised to 10 × 104 W/2.5 = 416 W, while safety is maintained as close as 2.26 meters from the antenna. Here the EPA/FCC factor of 2.5 was used.

In the above examples, the initial location of interest was R_{ff}, the start of the far field in the direction of maximum radiation. For antennas such as the parabolic dish, broadside array, and pyramidal horn, an upper limit of the power density can be found for distances as close as $0.3R_{ff}$ by increasing the power density found for R_{ff} by a factor of $(1/0.3)^2$, or approximately 10. At distances closer than $0.3R_{ff}$, scaling by the inverse square of the distance will lead to a gross overestimate of power density.

The National Bureau of Standards has provided the details of the power density levels in front of typical microwave circular parabolic antennas.[16] Fig 4 shows the results for one with diameter D = 16.2 λ, fed with 1 W RF power. (For f = 10 GHz, D = 1.6 feet.) The horizontal scale is distance away from the aperture in units of D^2/λ, or $R_{ff}/2$. The vertical scale is in units of the diameter. Tapered illumination by the feed was assumed.

Contours, separated by 2.5 dB, are in dB below 1 mW/cm² for 1 W input. Thus, if the RF power supplied is 10 W, the level 1 mW/cm² would be found approximately 2.4 meters (8 feet) in front of the aperture along the boresight axis.

Vertical Monopole and Polarization

In the VHF region (30 to 300 MHz), the human body may be close to 0.4 to 0.5 λ long, depending on age and build; at this wavelength the uptake of RF energy is greater than at others, particularly if the polarization (orientation) of the electric field is aligned parallel to the body axis. Radio-protection guides recognize this "resonance effect" by generally setting the lowest permissible maximum power density level in this frequency range. For amateurs, this suggests that the case of vertically polarized antennas, fed at the highest power levels, should be reviewed for power-density estimates. Tower-mounted, horizontally polarized antennas produce very little vertically polarized field at ground level near the antenna, assuming flat terrain around the antenna support.

For a vertical monopole over perfect ground, fed for more than six minutes with 1 kW of FM or RTTY at

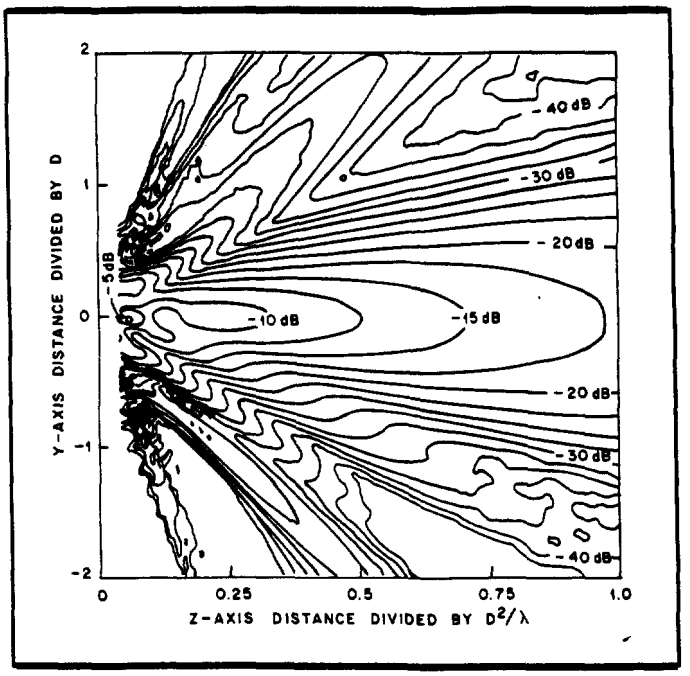

Fig 4—Calculated power density contours in the near-field zone of a parabolic antenna with diameter D = 16.2 λ. The contours are spaced 2.5 dB, and the levels are shown in dB below 1 mW/cm² for 1 W RF power input. The horizontal axis is in front of the aperture. This figure was adapted from reference 16.

30 MHz, the distance at which the power density meets the ANSI protection level of 1 mW/cm² is 5.2 meters. During transmissions, access should be denied within this radius.

Near-Field Exposure

As noted, the fields close to an antenna are complex and there are more spatial field components than in the far field. For a dipole there is not only an electric field oriented parallel to the antenna, but also a radially polarized field that may be the stronger, close to the antenna.[8] In this region, the parameter for checking RF-energy protection as provided in the ANSI standards (and most foreign standards) is the sum-squared electric field strength

$$(E_s)^2 = (E_1)^2 + (E_2)^2 + (E_3)^2 \qquad \text{(Eq 6)}$$

where E_1, E_2, and E_3 are three orthogonal E-field components, such as the x, y, and z components. A similar summing applies to the H field. This is the method used in most commercial RF-exposure meters.

Experiments have been performed at VHF/UHF using full-size models of human beings, known as phantoms, which have been filled with material simulating the electrical properties of tissue, muscle and bone at the chosen radio frequencies.[17] The results of one experiment at 350 MHz can be directly applied to Amateur Radio practice at 430 MHz. The energy-rate uptake, or SAR, was measured in the model by an internal field probe. In the far field of a dipole, with polarization aligned with the body upright (antenna axis parallel to body length), the measured SAR was in accord with the ANSI-intended SAR limit. This held true for both whole- and partial-body exposure, when the ambient power density was held to 1.2 mW/cm² (the ANSI MPEL for 350 MHz).

With the dipole center placed 2 to 3 inches from the neck and shoulder region, 6 W produced the same whole-body SAR as measured in the far-field exposure. However, for partial-body exposure, only 2 W produced the same SAR in the model's head as found in the far-field case. (In this test the dipole center was adjacent to the head.) Note that the far-field (MPEL) power density of 1.2 mW/cm² could be produced in free-space at a distance, d, of 1 meter, by feeding the dipole with 92 W of RF power.[18]

Making Measurements in the Far Field

As mentioned previously, the near field is extremely complex. This makes power-density measurement difficult in the near field.[19] A field-strength meter can be used to check far-field estimates. The meter's antenna should be oriented parallel with the ambient E field, which can be achieved by looking for the highest reading as the antenna is slowly rotated. A good meter is self-contained (battery operated) and well-shielded, and does not have drift problems or zero-setting errors. The reading is best taken without human presence near it, which is accomplished by setting the meter on an insulated stand, backing away and reading the indicator from a distance. A pair of binoculars can be helpful. (Some amateurs may be able to borrow a commercial power-density monitor for a short time.)

The power density, S, is represented by

$$S = \frac{E^2}{377}$$

where E is in V/m. A reading with transmitter off should also be taken, to assure no contamination from unidentified sources.

Notes

[1]American National Standards Institute (ANSI) paper C95.1, "American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz," Institute of Electrical and Electronic Engineers, Inc, 345 East 47th St, New York, NY 10017. This text includes the rationale for the RFPG.

[2]The rate of energy uptake is known as the *specific absorption rate*, or SAR. To relate SAR to the body's use of energy, note that for a resting adult the body's metabolic rate is about 1.3 W/kg, while for swimming, the rate is about 11 W/kg, and for running, about 18 W/kg. Rates in certain parts of the body (head, heart) are considerably higher. See: US Environmental Protection Agency, Health Effects Research Laboratory, "Biological Effects of Radio Frequency Radiation," *EPA-600/8-23/026F*, Sep 1984.

[3]The trend to more stringent protection levels has the following basis: The ANSI RFPG (Appendix) states, "Because of the limitations of the biological effects database, these guides are offered as upper limits of exposure, particularly for the population at large." There is also the problem of possible electric shock or startle effects with exposure to the full ANSI level below about 50 MHz, upon touching metallic objects without the feet being adequately insulated from ground.

[4]Commonwealth of Massachusetts, Department of Public Health, "Regulations Governing Fixed Facilities which Generate Electromagnetic Fields in the Frequency Range of 300 kHz to 100 GHz, and Microwave Ovens," *105 CMR 122.000*, Oct 1983. Department of Public Health, Boston, MA 02111. See also NCRP Report No. 86, "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," Apr 6, 1986, by the National Committee on Radiation Protection and Measurement, 7910 Woodmont Av, Bethesda, MD 20814. The Canadian government is considering promulgating a standard similar to these for public protection.

[5]R. King, *The Theory of Linear Antennas* (Cambridge, MA: Harvard University Press, 1956), Chapter 5, pp 575-576.

[6]Q. Balzano, et al, "The Near Field of Omnidirectional Helical Antennas," *IEEE Transactions on Vehicular Technology*, Vol VT-31, Nov 1982, pp 173-185.

[7]Ibid, "The Near Field of Dipole Antennas, Part 2: Experimental Results," *IEEE Transactions on Vehicular Technology*, Vol VT-30, Nov 1981, pp 175-181.

[8]A. Adams, et al, "Near Fields of Wire Antennas by Matrix Methods," *IEEE Transactions on Antennas and Propagation*, AP-21(5), Sep 1973, pp 602-610.

[9]See Chapter 16. Some useful references are: *The ARRL Antenna Book*, *The ARRL Handbook*, and Kraus (note 14). Gains measured by amateurs for a number of antennas at 1296 and 2304 MHz are given in *QST*, Jan 1986, p 96.

[10]"Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radio-Frequency Radiation," *OST Bulletin 65*, Oct 1985. Office of Science and Technology, Federal Communications Commission, Washington, DC 20554.

[11]Transition from the near field to the far field is not sharp. The value of R_{ff} given here is based on a fairly strict phase criterion, so that conventional far-field gains (G) may be used in Eq 4. With many antennas, such as the parabolic dish and broadside array, the inverse-distance-squared law (Eq 4) holds well for distances as small as $0.3R_{ff}$ for RF-protection estimating. See the later discussion.

[12]G. Hall, ed, *The ARRL Antenna Book*, 15th edition (Newington, CT: ARRL, 1988), Chapter 3.

[13]D. Cahill, "A Suggested Limit for Population Exposure to Radio-Frequency Radiation," *Health Physics*, Vol 45, Jul 1983, pp 109-126.

[14]H. Jasik, *Antenna Engineering Handbook* (New York: McGraw-Hill, 1961), Chapter 10, or E. C. Jordan, editor, *Reference Data for Engineers: Radio, Electronics, Computers and Communications*, 7th edition (Indianapolis, IN: Howard W. Sams Co, 1985) p 32-21, or J. Kraus, *Antennas*, 2nd edition (New York: McGraw-Hill, 1988).

[15]H. Westman, ed, *Reference Data for Radio Engineers*, 5th edition, (Indianapolis, IN: Howard W. Sams Co, 1969) pp 25-37.

[16]R. L. Lewis, A. C. Newell, "An Efficient and Accurate Method for Calculating and Representing Power Density in the Near-Field-Zone of Microwave Antennas," National Bureau of Standards, Dec 1985. Available as PB86-181963, from NTIS, Dept of Commerce, Springfield, VA 22161.

[17]M. Stuchly, et al, "Exposure of Human Models in the Near and Far Field—a Comparison," *IEEE Transactions on Biomedical Engineering*, BMI-12(8), Aug 1985, pp 609-615.

[18]The E field of a ½ λ dipole in free-space is $E = P/d$, where P is the power, and d the distance along the boresight. If E corresponds to the MPEL power density S_0, we must have $E^2 = 377S_0$. Therefore, the transmitter power, P, must be no more than $P = S_0d^2/0.13$.

[19]J. Coppola and D. Krautheimer, "Environmental Monitoring for Human Safety, Part 2: Radiation Monitors," *RF Design*, Apr 1987, pp 48-53.

EXHIBIT E

important aspect of generating RF energy at VHF and UHF: RF power hazards.

RF Power Safety

Amateur Radio is basically a safe activity, but accidents can always occur if we don't use common sense. Most of us know enough not to place an antenna where it can fall on a power line, insert our hand into an energized linear amplifier, or climb a tower on a windy day. RF energy is also a potential hazard. Large amounts can cause damage in people by heating tissues. The magnitude of the effect depends on the wavelength, incident energy density of the RF field, exposure duration and other factors such as polarization. It is therefore important to take steps to prevent overexposure.

At the frequencies of interest to satellite users—145, 435 and 1269 MHz—large power densities may be accessible. The most susceptible parts of the body, the tissues of the eyes and gonads, don't have heat-sensitive receptors to warn us of the danger before the damage occurs. Symptoms of overexposure may not appear until after irreversible damage has been done. The potential danger should be taken seriously. With reasonable precautions, however, operation at 145, 435 and 1269 MHz can be safe.

The primary aim of this section is to show where protection from RF energy may be necessary. Our emphasis is on the practical problems encountered by satellite operators; for a more comprehensive technical treatment, see the references that follow this section. The RF-protection problem consists of two parts: (1) determining safe exposure levels and (2) measuring or estimating the local RF levels produced by a given power and antenna at a particular location. If the actual RF power density levels are greater than or even roughly equal to the safe levels, protection or precaution is required by limiting access or some other means. We begin with the question of safe exposure levels.

Safe Exposure Levels: In recent years, scientists have devoted a great deal of effort to determining safe RF-exposure limits. As the problem is very complex, it's not surprising that some changes in the recommended levels have occurred as more information has become available. The American Radio Relay League believes that the latest "Radio Protection Guide of the American National Standards Institute (ANSI)" is the best available protection standard; it took nearly five years to formulate and had undergone repeated critical review by the scientific community. This 1982 guide recognizes the phenomenon of whole-body or geometric resonance and establishes a frequency-dependent maximum permissible RF exposure level.

Resonance occurs at frequencies for which a body's long axis, if parallel to the ambient field, is about 0.4 wavelength long. Because of the range of human heights, the resonant region spans a broad range of frequencies. The most stringent maximum permissible exposure level, the bottom of the "valley" (see Fig 9-17), is 1 mW/cm^2 for frequencies between 30 and 300 MHz. On either side of those "corner" frequencies the rise is gradual. At 3 MHz,

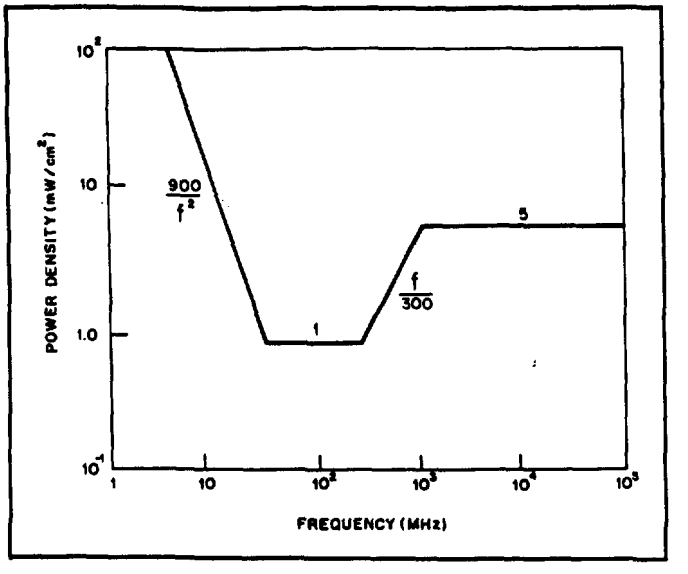

Fig 9-17—1982 ANSI RF Protection Guide for whole-body exposure of human beings.

the maximum permissible exposure level is 100 mW/cm^2; at 1500 MHz and above, 5 mW/cm^2. The valley region includes some active amateur bands (10, 6, 2 and 1¼ meters), as well as all FM, and some TV, broadcasting. The rationale for specifying a constant 5 mW/cm^2 above 1500 takes into consideration that with the extremely short wavelengths there is very little penetration into tissue. The levels specified refer to average power density allowed over any six-minute period. Until the Environmental Protection Agency (EPA) promulgates a general population standard, the ANSI Guide will likely be the most commonly accepted one.

Estimating Power Density: Our task is to determine the power density levels that could be produced at a given location by a specified antenna and power. Since most amateurs do not have the special equipment needed to measure RF electric fields accurately, power density will have to be estimated by calculations which involve approximations. While our estimates will always tend toward the conservative side, keep in mind that the results should be used only as a guideline for pointing out situations to avoid. The results should *never* be taken as *proving* that a particular setup is safe. For example, we consider only radiation from an antenna. Radiation can also take place directly from a power amplifier (if operated without proper shielding), from transmission lines (if poorly shielded, or if connectors are improperly installed) and in other situations. Take care to see that the only radiation from your station is at the antenna. Also, we'll be using a free-space propagation model to get a first estimate of power density. You may and should allow up to a 4- or 6-dB margin to provide for cases where a reinforcing reflection might occur.

Generally, antenna engineers divide the region around an antenna into a *far field* and a *near field*. At large dis-