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QST Issue: Jun 1999
Title: RF Safety at Field Day
Author: Gregory D. Lapin, N9GL

By Gregory D. Lapin, N9GL

RF Safety at Field Day

A case study of Field Day 1998 with the North Shore Radio Club (NSRC) in Village Green Park, Northbrook, Illinois.

By now, we should all be aware of our responsibility to keep the public, and ourselves, safe from excessive exposure to RF energy. On January 1, 1998, new FCC regulations dealing with this issue went into effect for the Amateur Radio service. The specific wording can be found in the FCC Rules and Regulations,[1] Sections §1.1307b, §1.1310, §2.1093, §97.13c, and §97.503. At home, many of us are not required to assess RF exposure from our stations, as described in the table of exclusions listed in §97.13c. At the power levels listed in this table, it is highly unlikely that a situation can arise in which a person is exposed to unsafe levels of RF energy.

Field Day presents a different problem for RF safety. At a contest, we can reasonably expect more transmitting than would be done in usual operations. Since a Field Day site is temporary, it is likely that antennas will not be mounted as high as we would normally put them. Many Field Day sites operate two or more transmitters simultaneously. Field Day sites are often set up in public places, where it is possible for passersby to come in close proximity to actively transmitting equipment. Thus, a certain amount of preparation is necessary to ensure that a Field Day site will be operated safely and legally.

The "Exclusion"

Let's first examine the exclusion to performing a routine RF environmental evaluation. Section §97.13(c)(1) of the FCC Rules and Regulations states: "The licensee must perform the routine RF environmental evaluation prescribed by §1.1307(b) of this chapter, if the transmitter PEP exceeds the following limits." In the table that follows this text, the 160-40 meter bands have limits of 500 W, the 20 meter band has a 225 W limit, the 15 meter band has a 100 W limit, the 10-1.25 meter bands have limits of 50 W, and the 70 cm band has a 70 W limit.

The wording of this regulation could be interpreted to mean that if an amateur transmits less than the amounts of power listed in the table, it is not necessary to worry about RF safety. *This is not the case!* FCC OET Bulletin 65[2,3] clarifies this:

"No station is exempt from *compliance* with the FCC's rules and with the MPE limits. However, many amateur stations are categorically exempt from the requirement to perform a *routine station evaluation* for compliance. Stations operating at or below the power levels given in Table 1, are not required by the FCC to perform a routine evaluation for compliance..."

"...Under some circumstances, such as an antenna that is located unusually near people ... the FCC could require a station evaluation or take other action."

We, as responsible Amateur Radio operators, should not wait for the FCC to act, but rather should perform an RF safety evaluation if we suspect that people will be in proximity to our antennas. Field Day is one such case.

General Elements of the RF Safety Evaluation

In performing an RF safety evaluation, we are concerned that the total RF exposure remains below recognized safety limits, as required by the FCC Rules and Regulations.[1] The FCC has based the RF exposure levels that they consider to

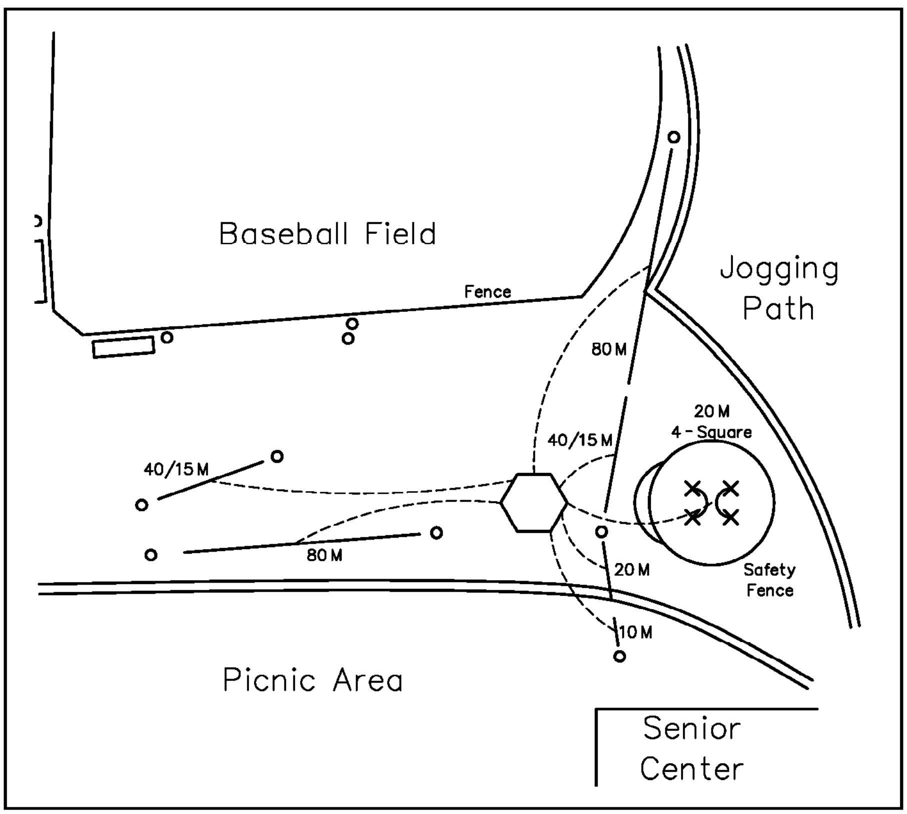

Figure 1—Map of the NSRC Field Day site. Antennas are labeled. Dashed lines indicate coaxial cable. All dipole antennas are at a 40-foot (12.3-meter) height. The 4-square antenna is the only one that requires a line delimiting the MPE threshold for the General Population. Notice the extension of the MPE threshold region adjacent to the 80-meter, 40/15-meter and 20-meter dipoles.

[1]Notes appear on page 51.

be safe on standards developed by scientific experts at the IEEE[4] and the NCRP.[5] RF exposure is affected by the following factors:

- Amount of RF power transmitted.
- Type of modulation.
- Duration of transmissions.
- RF power loss in the feed line to the antenna.
- Antenna pattern.
- Distance between antennas and people.
- The number of antennas near one location.
- The amount of time a person might be in that location.

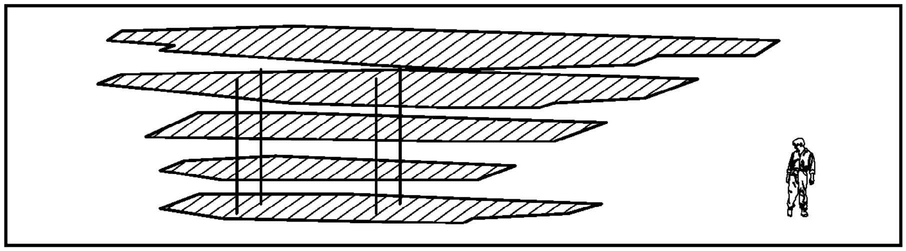

Figure 2—Three-dimensional representation of 4-square antenna near-field radiation pattern. Crosshatched regions represent horizontal planes where power density is greater than the MPE for the General Population. These regions are calculated at 5-foot (1.7-meter) intervals above the ground. The figure of a person represents a 6-foot (1.8-meter) tall individual. Since the pattern can be switched to four different directions, this represents one possibility. Inaccessible areas are defined by drawing a circle around the antenna with a radius equal to the farthest point above MPE.

RF Transmissions

The following text discusses some of the factors that go into accurately deciding the RF safety implications of your Field Day station. It is very difficult to exactly calculate the RF exposure; many values are estimated, with any estimation errors tending to overestimate the power. This is based on the principle that it is better to err on the side of safety.

After seeing the complexity of some of these calculations, you may not want to go to the trouble. In reality, most stations do not need to do so. The simplest calculations are to assume that every station transmits its full power to the antenna 100% of the time. While not realistic, if your station is deemed to comply with Maximum Permissible Exposure (MPE) limits while making this simplification, there will be no chance of excessive exposure. The only time that it is necessary to perform the more complex calculations is when you find, using the simple method, that your station does not meet the requirements for safe operation. Refining the calculations may then show that it actually is within the proscribed limits.

Modulation

Modulation affects the percentage of average power that is transmitted. Although subjective, the differences are minor for the purposes of estimating RF safety. A CW signal transmits only during key-down. The ratio of transmit to non-transmit time depends on speed and keying style. For practical purposes, an estimate of 50% key down during a transmission in a contest is reasonable. The relationship between PEP and average power in SSB transmissions is dependent on voice characteristics, speech patterns, and audio processing. Generally, estimating average power as 25% of PEP is accurate, but in a contest situation, 50% may be more realistic. RTTY and FM use 100% average power during transmission.

Duration of Exposure

Biological effects of RF energy depend on both the absorbed power density and the duration of the exposure. While there is a continuous relationship between these, the FCC Rules and Regulations are simplified by basing safety calculations on 6 minutes of continuous exposure for the Occupational Population or 30 minutes for the General Population. The Occupational (or Controlled) Population consists of people who know they are being exposed to RF and can do something about it. Hams and their families are considered to be part of this group. The General (or Uncontrolled) Population consists of people who do not know they are being exposed or cannot control their exposure, and consists of everyone else.

The transmit/receive duty cycle can further decrease the average continuous power transmitted. If this cycle time is less than 6 minutes for the Occupational Population and less than 30 minutes for the General Population, the power can be multiplied by the transmit/receive ratio. For instance, if you actually only transmit for 50% of the time and listen for the other 50%, your average power transmitted can usually be decreased by half. In a contest, such as Field Day, this is a valid approximation.

In a situation where long-winded rag chewing takes place, the actual portion of the 6 or 30 minute averaging interval during which the transmitter is active must be used. For example, if you talk for 6 minutes, and then listen for the next 6 minutes, you would use 100% of a 6-minute averaging period even though your transmit/receive duty cycle is still 50%.

Average Power Arriving at the Antenna

The time-averaged power from your transmitter is the output power level multiplied by the modulation factor and the transmit/receive duty cycle. For example, CW on a 100 W transmitter emits an average of 50 W during transmissions. With a short (< 3 min) 50% transmit/receive duty cycle, the average is further decreased to 25 W.

Power is lost as heat in antenna feed lines and does not affect RF exposure, so average power transmitted from the radio should now be corrected for feed line loss. As an example, 200 feet (62 meters) of RG-58U coax used on the 20 meter band has approximately 3 dB of loss, or a loss factor of 0.5 (Loss factor = $10^{-dB/10}$). So now the transmissions from a 100 W transmitter tuned to 14.030 MHz, modulated with CW and fed through this feed line appear at the antenna as 12.5 W of average power.

Types of Antennas

Field Day antennas are typically different than those used at base stations. Rarely is it practical to erect a tall tower and mount a beam on top of it. Rather, Field Day sites use many dipoles and ground mounted verticals. When it is possible to mount a beam, it is not usually very high above the ground. There are several ways of determining the power density near an antenna. The most accurate is to model the antenna near-field pattern. Since we generally use only a few different antenna types, these have already been characterized and reasonable estimates can be made.

For most HF antennas, the near-field pattern best describes the antenna radiation pattern at distances up to 10 wavelengths away from the antenna. For example, for a 10 meter band half wave dipole, the pattern is in the near field until about 100 meters away. At that distance, power densities are usually low enough that biological exposure is not a concern. The near-field pattern does not always resemble the far-field pattern. For many common antennas, the near field patterns are standard, based on antenna height above ground, and can be found in tables and in books[2,3,6]. Near-field patterns can also be calculated using one of the many antenna-modeling programs that use either *NEC2* or *MiniNEC*.

MPE Is Based on Frequency and Time of Exposure

At HF frequencies, with f in MHz, locations that have power densities $\geq 900/f^2$ for the Occupational Population, or $\geq 180/f^2$ for the General Population, are not safe for those groups, assuming that a person from the Occupational group remains in that area for at least 6 minutes, or a person from the General Population remains for at least 30 minutes. If it can be shown that people will remain in these areas for less time, the exposure can be adjusted down by the fraction of the amount of time spent in the area divided by the averaging time for the group. However, if this consideration is used to make an antenna comply with MPE, it is important to ensure that people do not remain there for a longer period.

Total Transmitted Power Density Is Important

A biological organism is affected by the total energy density to which it is exposed. At any location, there can be RF energy emanating from many different sources. Signals that are transmitted far away have power densities that are orders of magnitude lower than safety thresholds and it is not necessary to consider them. However, for every antenna that is within about 25 meters of a location, the power density could be high enough that, when added to the components from other antennas, it affects RF safety. Field Day is one time that this becomes an issue.

The calculation of total RF exposure at every location in three-dimensional space is a task that is beyond most of our computing means. The job can be simplified by disregarding all places where people cannot be found, for example, at elevations above 2 meters (unless the terrain contains hills or structures that allow people to approach an antenna at a higher elevation). Any location that is more than 25 meters from any antenna-radiating element can also be disregarded. The remaining places should be analyzed for their total power density.

Combining Signals at Different Frequencies

Resonance effects complicate biological exposure. This is why the MPE curves used by the FCC are not flat across frequency. The human body is more susceptible to damage from some frequencies because the energy is better absorbed due to resonance relationships between wavelength and the size of the organism.

At each location, the average power density of each frequency should be divided by the MPE for that frequency and the fractions should be added. If the result is greater than 1.0 (100% of MPE), that location is considered unsafe. For example, if an 80 meter vertical has an average power density of 7.2 mW/cm^2 at a location, and there is a 10 meter dipole overhead with an average power density of 0.15 mW/cm^2 at that point, the total fraction of MPE for the General Population is $[7.2 / (180/3.7^2) + 0.15 / (180/28.5^2)]$, which is equal to 1.22. This location is unsafe for a person from the General Population to remain for 30 minutes, even though the power density from each antenna alone is well below the MPE limit.

The FCC discusses a number of ways that areas, in which exposure exceeding MPE, can be marked to insure that RF safety is not compromised[2-3]. In particular, marking areas with safety signs and making unsafe areas inaccessible are preferred methods.

The NSRC Field Day Site

The North Shore Radio Club has participated each year in Field Day as NS9RC from Village Green Park in Northbrook, Illinois. This site has been ideal for the purposes of Field Day: The park was actively used, with playground equipment, a senior citizen center, picnic areas, and a baseball field. A large gazebo was the site of Field Day operations, with room for five stations (operating 3A plus a Novice-Tech station and a VHF/satellite/packet station). The site contained a number of relatively tall trees that made excellent antenna supports.

Unlike past Field Days, where 100 W transmitters were used and all of the antennas were dipoles, in 1988 two of the three main stations were equipped with 500 W linear amplifiers and a directional vertical phased array was constructed for operation on 20 meters. With the 7-dB increase in power and transmissions from ground level on 20 meters, additional care was necessary to insure that the public using the park was safe from RF transmissions.

Figure 3—Karl, AA9MN, designer of the NSRC 4-square antenna, standing in front of it. The area in which MPE limits can be exceeded has been made inaccessible by orange plastic safety fencing.

Mapping the Field Day Site

The first step in the process of modeling exposure was to map the site (see Figure 1). On the map, the important points of interest were the locations of the operating stations, the locations of all antennas, and the places that the public was likely to frequent. We assumed that all places on the map were equally accessible to hams and to the General Population, so only the more restrictive MPEs were considered.

Calculating Average Power at Each Antenna

The next step was to determine how much power was delivered to the feed point of each antenna. All calculations were based on worst-case approximations. The feed line loss was obtained from standard coaxial cable data, expressed in dB, and converted to a loss factor, as described earlier. All stations were used for both SSB and CW so the 50% modulation duty cycle was used. Also, the 50% transmit/receive duty cycle was used. The fractions of the two duty cycles (percent / 100) were multiplied by the feed line loss factor, which was then multiplied by the transmitter output power. The results represented the average power delivered to each antenna.

Determining Antenna Patterns

Near-field patterns for all of the antennas were calculated with the *NEC2* method-of-moments algorithm, in a software package called *NEEDS*. The modeling package considered power delivered to the antenna and generated power densities at different points in space around the antenna. This software, like most, separated the EM field into components, giving results for the E field (in V/m) and the H field (in A/m). The product of these values at each location, divided by 10, gave the power density in mW/cm^2. The three-dimensional results were converted to two dimensions by taking the maximum power density of each point in the horizontal (XY) plane, between ground level and 2 meters above ground, and using that to represent the power density for that point on the map.

Determining RF Safety Areas

Once the power density patterns of the

antennas were determined, the lines representing the MPE thresholds were marked on the map. Since all dipole antennas were erected 40 feet (12.3 meters) above the ground, only the 80 and 40 meter antennas were less than 1/4 wavelength high. However, the modeling showed that from ground level to 2 meters high, MPE limits were not exceeded at those frequencies.

Next it was necessary to look for areas with appreciable exposure from more than one antenna. At the NSRC site, the region between the 20 meter 4-square antenna and the 80, 40/15 and 20 meter dipoles fell into this category. We assumed that all of these antennas would radiate simultaneously and exposure of a person in an area between them was the sum of the exposures from each antenna. It was necessary to return to the antenna models to look for points in that region where the sum of fractions of MPE for all of these antennas exceeded 1.0, as discussed previously. Based on these calculations, the radius of the protected area on one side of the 4-square antenna was increased.

Ensure that RF Safety is Maintained

At the NSRC site, we decided against warning signs since we felt that the general public would not correctly understand this. Rather, we made areas inaccessible by erecting an orange plastic safety fence around the 4-square antenna (Figures 1 and 3). Based on modeling, this was the only area that exceeded MPE. This type of fence was inexpensive, easy to erect, and easily seen.

It helped to have someone at the site at all times who had the responsibility of Field Day Safety Coordinator. The Safety Coordinator did not perform any other tasks while keeping an eye on the safety aspects of the Field Day site, observing the antennas to make sure no one entered a safety restricted area.

Some Basic RF Safety

After the evaluations were performed and the proper barriers erected, it was still important not to forget about basic, everyday RF safety. No radio equipment should be operated with the covers removed from the high power amplifier sections. No transmitter should be active without an adequate load. No one should be working around antennas with transmitters operating. Since Field Day tends to be a frenetic activity, with many people working on different things at once, it was easy to violate this last rule. Anyone who needed to work on antennas during Field Day operations arranged transmission stoppages with the Safety Coordinator, who made sure no one sat down at the idle station and started transmitting while the work was being performed.

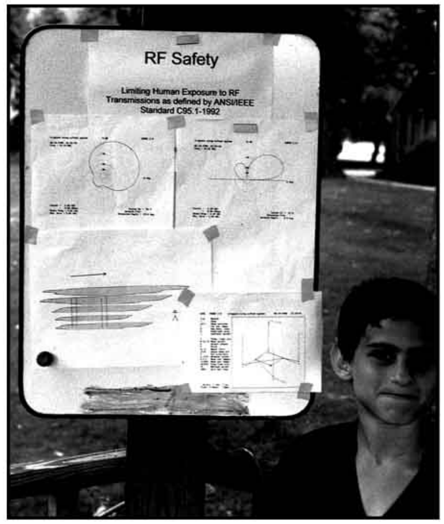

Figure 4—The NSRC RF safety display overlooking the 4-square antenna. Joel, a concerned citizen, learns about RF safety at Field Day.

Be Prepared to Discuss RF Safety

After making the effort to ensure that your Field Day site is safe, you should also make sure that the public knows it. At the NSRC site, a bulletin board was posted (Figure 4), displaying some of the modeling of the 4-square antenna. The site's Safety Coordinators were prepared to discuss RF safety with anyone who asked about it. The FCC has a good publication containing answers to commonly asked questions about RF safety.[7]

Conclusion

With a few precautions, Amateur Radio is an inherently safe activity. At the Field Day site, there is more potential for RF exposure above accepted safe limits and it is necessary to understand where such situations can arise. In particular, the most likely sources of overexposure are ground-mounted verticals, horizontal or sloping antennas that are less than one quarter wavelength above people, antennas in the upper HF and VHF ranges, and areas with concurrent exposure from more than one antenna.

Field Day is Amateur Radio's annual opportunity to show off to the public what we do. Many of the people in the General Population know very little about RF signals and tend to distrust this unseen energy that is often referred to as "radiation." Field Day presents a perfect forum to show the public that we understand the implications of transmitting RF signals and are able to deal with ensuring that no one is harmed by our transmissions. Spend a little time to perform RF safety evaluations of your Field Day site and then display the results publicly. The good will that you generate will go a long way toward enhancing our hobby for the future.

Gregory D. Lapin, PhD, PE, N9GL, is chairman of the ARRL RF Safety Committee. You can contact Gregory at 1206 Somerset Ave, Deerfield, IL 60015; **g.lapin@ieee.org**.

The ARRL RF Safety Committee

The ARRL maintains a volunteer committee of experts on the biological effects of electromagnetic energy—the RF Safety Committee. The committee is made up of scientists, physicians and engineers who are knowledgeable about interactions between electromagnetic energy and biological tissue. Many committee members participate in RF bioeffects activities outside of Amateur Radio. In addition to writing and maintaining the RF-safety related text that appears in ARRL publications (such as the *Handbook*, the *Antenna Book*, *License Manuals* and *RF Safety and You*), and reviewing RF-safety related questions in the Amateur Radio question pools, the RF Safety Committee has helped the FCC edit its recently enacted environmental exposure regulations.

Members of the committee monitor the scientific and popular press for new developments related to electromagnetic bioeffects. The committee advises the ARRL Board of Directors about all RF safety issues. The members of the RF Safety committee are Robert E. Gold, MD, WB0KIZ; Gerald D. Griffin, MD, K6MD; A. William Guy, PhD, W7PO; Gregory D. Lapin, PhD, PE, N9GL; Gary E. Myers, MS, CIH, K9CZB; William J. Raskoff, MD, K6SQL; and Kazimierz Siwiak, PE, PhD, KE4PT. Ed Hare, W1RFI, and Jim Maxwell, W6CF, are ARRL committee liaisons.

Notes

[1]Federal Communications Commission: Rules and Regulations. Title 47, US Code of Federal Regulations, Chapter 1, 10-1-97 Edition.

[2]Cleveland, R F Jr, Sylvar, D M, Ulcek, J L: *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields.* Federal Communications Commission, Office of Engineering and Technology. OET Bulletin 65, Edition 97-01, August 1997.

[3]R. F. Cleveland, Jr, J. L. Ulcek: *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields: Additional Information for Amateur Radio Stations.* Federal Communications Commission, Office of Engineering and Technology. OET Bulletin 65, Supplement B, Edition 97-01, November 1997.

[4]ANSI-IEEE Standard C95.1-1992: Safety *Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.* The Institute of Electrical and Electronics Engineers, New York, 1992.

[5]NCRP Report No. 86*: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields.* National Council on Radiation Protection and Measurement, Bethesda, MD, 1986.

[6]E. F. Hare: *RF Safety and You.* American Radio Relay League, Newington, CT, 1998.

[7]OET Bulletin 56: Questions *and Answers About Biological Effects and Potential Hazard of Radiofrequency Radiation.* Third Edition, Federal Communications Commission, Office of Engineering and Technology, January 1989.

References 2, 3 and 7 can be obtained on the Web at **http://www.fcc.gov/oet/info/documents/bulletins**.