5

How to Evaluate an Amateur Station

This chapter describes a number of techniques that can be used to evaluate single-transmitter installations, multiple-transmitter installations and repeaters. Most hams will elect to use the simple tables that show compliance distance at a glance.

THE ESSENCE OF THE RULES

There is an old saying: If a tree falls in the forest and there is no one there to hear it, does it make a sound? In radio, with regard to MPE limits, the answer is "No."

The FCC regulations cover *exposure* of people to RF energy, not the strength of RF energy where people are not being exposed. This principle applies to most aspects of a routine station evaluation. For example, if you find that exposure to the corner of a neighboring property is over the limit, it is only over the limit if someone remains in that area for an extended period. As another example, if you find that an area is at twice the limit, but you *know* that it is only occupied for 1 minute out of every hour, the exposure is below the limit.

The crux of the requirements of a station evaluation is found in *OET Bulletin 65*:

> Before causing or allowing an Amateur Radio station to transmit from any location where the operation of the station could cause human exposure to RF electromagnetic energy in excess of the FCC RF-exposure regulations, amateur licensees are required to take certain actions. A routine RF-radiation evaluation is required unless the station is categorically excluded from the requirement to perform a station evaluation.

This chapter deals exclusively with the actual evaluation, based on compliance with the MPE (Maximum Permissible Exposure) limits. Refer to the earlier chapters in this book for information on how these limits related to exposure, safety and specific absorption rates (SAR).

The Amateur Radio service is a lot more diverse than many radio services regulated by the FCC. If the FCC had to spell out the specific requirements of doing a station evaluation for every possible configuration in the rules, the rules would be larger than this book. Amateur Radio operators are licensed to use a wide range of frequencies and operating modes. Amateur Radio operation ranges from low-power (QRP) operation of a few milliwatts to 1500 watts PEP. Each operating mode has its own particular duty cycle and pattern of operation. Amateurs also use a wide range of antennas, from simple wires to tower-mounted gain antennas, to name just two. The diversity of Amateur Radio operation is one of its strengths, enabling amateurs to perform a wide range of technical investigations and operations under adverse conditions. The diversity, however, may require that amateurs choose from a number of methods to perform the station analysis and evaluation required by FCC regulations.

Certain Amateur Radio installations were made subject to a requirement that the station operator perform a routine analysis to establish that the station is being operated in compliance the FCC RF-Exposure regulations. The determination of just which stations need to be evaluated is based on power levels, frequency and the type of station.

The FCC is relying on the demonstrated technical skill of Amateur Radio operators to evaluate their own stations (although it is perfectly okay for an amateur to rely on another amateur or skilled professional to perform the evaluation). The FCC regulations do *not* require that an amateur perform field-strength measurements. In many cases, the evaluation can be accomplished by some relatively straightforward calculations or compari-

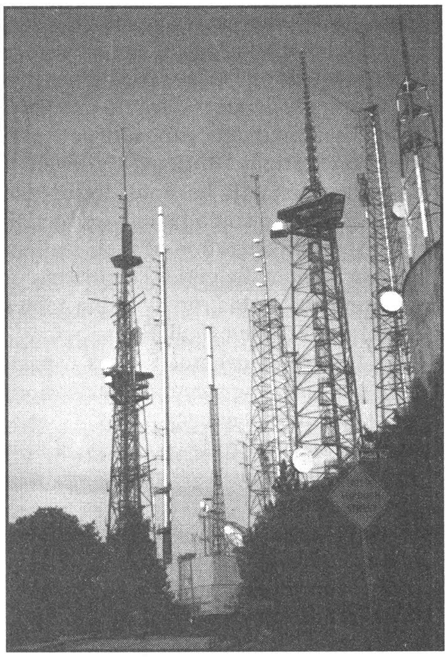

Figure 5.1—Some stations can be rather complex. There are a lot of possible power, frequency, mode and antenna combinations that could be associated with this commercial installation. *(photo courtesy Robert Cleveland, FCC Office of Engineering and Technology)*

sons between station operation and typical graphs developed by the FCC. Once an Amateur Radio operator has performed the required routine station evaluation, and determined that the station does not exceed the permitted MPEs, the Amateur Radio station may be placed into immediate operation. It is not necessary to secure FCC approval before operating.

WHAT IS A "ROUTINE RF ENVIRONMENTAL EVALUATION"?

The core of the requirements under these regulations is the MPE levels. However, the specific actions that need to be taken by Amateur Radio operators is to perform a "routine RF environmental evaluation" to establish that the station is being operated in compliance with the FCC RF-Exposure guidelines. This generally consists of a series of calculations to determine compliance with the MPE levels—including those derived from power-density formulas and those obtained with *NEC*- or *MININEC*-based antenna-modeling programs. A routine evaluation will generally need to be done for both controlled and uncontrolled exposure environments. However, if a ham determines that his or her operation meets the requirements for uncontrolled exposure in his or her own station, home and property, it will not be necessary to evaluate the same areas for controlled exposure.

A routine environmental evaluation is not nearly as onerous as it sounds! It is generally not difficult to do the necessary station evaluation. In general terms, the FCC requires operators of radio transmitters be *aware* of the RF exposure potential from their stations. In doing the evaluation, amateurs will be considering the ways that people could be exposed to RF fields from the operation of their station. This can be done by either calculating or measuring the fields, or by using tables derived from those calculations

The following general factors can all play a part in doing a routine evaluation:

- Transmitter frequency
- Transmit power
- Operating mode
- Transmitter duty cycle
- Antenna location
- Antenna gain
- Antenna pattern
- General station configuration
- The amount of time people are exposed

Most evaluations will not involve measurements, but will be done with comparisons against typical tables that have been developed by the FCC, individual amateurs and the ARRL. In many cases, the evaluation can be as quick and easy as looking at a table that represents your operation and determining that your antenna is far enough away from areas where people are located.

In most cases, hams will be able to use the table that best describes their station's operation to determine the minimum compliance distance for their specific operation. OET *Supplement B* (Chapter 7 of this book) contains a number of these tables (with the compliance distances converted to feet); additional tables are in Chapter 8 of this book, prepared using the same methods as were used for the *Supplement B* tables. The term *compliance distance* refers to the minimum distance one must be from an antenna to have the estimated fields be below the MPE limits.

Alternatively, hams could do relatively straightforward calculations of worst-case scenarios or computer modeling of near-field signal strength. The FCC encourages flexibility in the analysis, and will accept any technically valid approach.

WHO IS RESPONSIBLE FOR THE EVALUATION?

The rules generally require that the station licensee be responsible for ensuring that the evaluation is complete. If someone other than the licensee were acting as control operator, he or she also would also be responsible for the proper operation of the station under all FCC rules, including the rules on RF exposure.

WHERE CAN HAMS LEARN ABOUT DOING AN EVALUATION?

Hams could rely on their own personal technical expertise to know just what needs to be considered when doing an evaluation. However, for many hams, the whole topic is a "learning opportunity," because hams have never had *specific* requirements about RF exposure evaluations under the old RF-exposure rules and guidelines. Although most hams are enthusiastic about learning something new, they need some instruction and guidance.

The FCC didn't leave us out in the cold! Drawing on the resources of both their staff and the amateur community, the FCC has prepared two documents, *OET Bulletin 65: Evaluating Compliance With FCC-Specified Guidelines for Human Exposure to Radio Frequency Radiation* and *OET Bulletin 65 Supplement B: Additional Information for Amateur Radio Stations*. In this chapter, *Bulletin 65* generally refers to *both* documents together. These FCC materials explain a number of different ways that hams can complete the required evaluations.

WHO NEEDS TO DO AN EVALUATION?

The good news is that most amateur stations *do not* need to be evaluated. The following classes of amateur stations are exempt *from the evaluation requirement* because their power levels, operating duty cycles or station configuration are such that they are *presumed* to be in compliance with the MPE limits:

- Stations using the peak-envelope power (PEP) input or less to the antenna shown in Table 5.1
- Amateur repeaters using 500 W or less effective radiated power (ERP)
- Amateur repeaters with antennas not mounted on buildings if the antenna is located more than 10 meters above ground
- Amateur mobile and portable hand-held stations using push-to-talk or equivalent operation

Unlike the rules for maximum amateur power, which are expressed in PEP output from the transmitter, the rules for determining which stations need to be evaluated are expressed in PEP *input to the antenna.* Table 5.1 shows peak-envelope power to the *antenna* as the deciding factor. Factors such as feed line losses and losses in accessories such as wattmeters and antenna tuners can reduce the power from your transmitter to be some fraction of its original value at the antenna.

Bulletin 65 is Not Mandatory

Although the regulations are firm requirements, *Bulletin 65* is advisory in nature. To quote directly from the bulletin:

"This revised OET *Bulletin 65* has been prepared to provide assistance in determining whether proposed or existing transmitting facilities, operations or devices comply with limits for human exposure to radio frequency (RF) fields adopted by the Federal Communications Commission (FCC). The bulletin offers guidelines and suggestions for evaluating compliance. *However, it is not intended to establish mandatory procedures, and other methods and procedures may be acceptable if based on sound engineering practice.*"

The flexibility offered by this language especially applies to the Amateur Radio Service; the FCC is relying on the demonstrated technical ability of hams to select an appropriate method of analysis for the evaluation that may be required for their station.

Table 5.1

Wavelength Band	Evaluation Required if Power* (watts) Exceeds:
MF	
160 m	500
HF	
80 m	500
75 m	500
40 m	500
30 m	425
20 m	225
17 m	125
15 m	100
12 m	75
10 m	50
VHF (all bands)	50
UHF	
70 cm	70
33 cm	150
23 cm	200
13 cm	250
SHF (all bands)	250
EHF (all bands)	250
Repeater stations (all bands)	non-building-mounted antennas: height above ground level to lowest point of antenna < 10 m and power > 500 W ERP building-mounted antennas: power > 500 W ERP

* Power = PEP input to antenna except, for repeater stations only, power exclusion is based on ERP (effective radiated power).

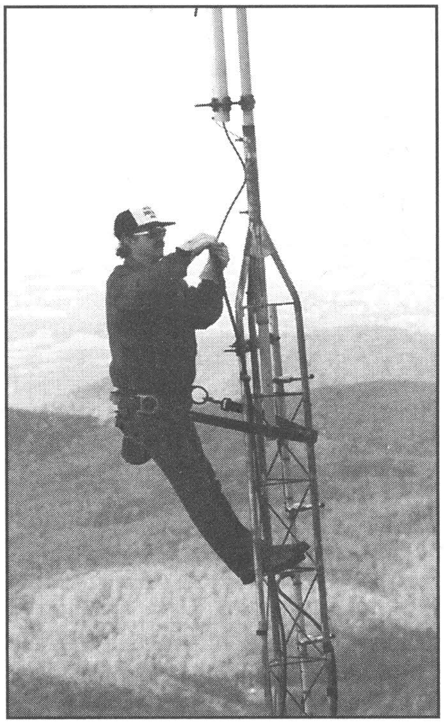

Figure 5.2—This repeater antenna is not mounted on a building and is located more than 10 meters above ground, so the operator of the repeater is not required to do a routine station evaluation.

The Rules chapter (Chapter 4) discusses the "letter of the law" about who needs to do a station evaluation. Many hams may find that they don't need to evaluate their station at all, because their power is low enough and their antennas are located far enough away from areas of exposure that they are not required to evaluate their stations. They are presumed to be in compliance with the MPE (maximum permissible exposure) levels. Those hams whose transmitter power is not more than the limits shown in Table 5.1 can stop right now; you do not need to do an evaluation, except perhaps in some rather unusual circumstances.

Note, too, that unlike the MPE limits, the levels in Table 5.1 are *not* average-power levels, but are peak-envelope powers (PEP), specified as power input to the antenna. If you transmit only one word per 30-minute period, and that word is transmitted at levels above those in the chart, you will still have to do an evaluation. When you do the evaluation, however, you can use average power. Admittedly, it sounds a bit complex, but it will be much more clear after you have read this chapter.

For the majority of amateurs, the power levels in Table 5.1 have virtually eliminated the need to perform station evaluations! Most HF transceivers are rated at 100-W PEP output; on 15 meters and below, stations using this power level need not be evaluated. Most VHF transceivers are rated at 50-W PEP or less; stations using this power level on VHF need not be evaluated. Statistically, most HF operators use "barefoot" rigs, typically 100-W PEP. Operators who wish to use 12 and 10 meters could either perform an evaluation for those two bands, or they could reduce power to the levels in Table 5.1 and forgo the evaluation altogether.

CATEGORICAL EXEMPTIONS

No station is exempt from the rules and the MPE levels, but many amateur stations are categorically exempt *from the requirement to perform a station evaluation*. Stations using the power levels in Table 5.1, or less, do not need to be evaluated. Mobile and portable (hand-held) stations using PTT operation do not need to be evaluated. Amateur repeaters using 500 W ERP or less also are categorically exempt from the requirement to evaluate.

News for Repeater Operators

The evaluation exemption for amateur repeater operation is determined by the *effective radiated power* (ERP) of the repeater. ERP is referenced to the gain of a half-wave dipole in free space (unlike equivalent isotropically radiated power, EIRP, which is referenced to an isotropic source). *Bulletin 65* describes how to calculate feed line losses and determine ERP for an amateur repeater.

All amateur repeaters using 500 W ERP or less generally do not need to be evaluated. This repeater exemption was added with an Erratum to the rules issued by the FCC in October 1997. Those that operate with more than 500 W ERP need to be evaluated if they have an antenna mounted on a building, or if any part of a non-building-mounted antenna is less than 10 meters (32.8 feet) above ground.

There is more information about calculating ERP later in this chapter, but to summarize, ERP is derived by multiplying the power to the antenna by the *numerical* gain of the antenna over a dipole (6 dBd, for example, represents a numerical equivalent of 3.98). This categorical exemption from evaluation covers many repeater stations.

Mobile and Portable (Hand-Held) Stations

According to *Supplement B*, all amateur mobile and portable hand-held operation is categorically exempt from the requirement to evaluate, although it is often a good idea to do so anyway. To clarify right up front, "portable" means something different to the FCC than it usually does to hams. To the FCC, a portable device is defined in the FCC rules as a non-fixed station customarily operated with its antenna within 20 cm of the body. Under the rules, mobile devices are evaluated to the MPE limits, while portable devices are generally evaluated to SAR limits. (See Chapters 1 and 2.)

As described in the FCC rules, there is no specific requirement that mobile and portable devices used under Part 97 (Amateur Radio) be evaluated. *Bulletin 65* explained that this applies particularly to amateur mobile operation using push-to-talk operation. Most Amateur Radio mobile or portable stations that meet these general criteria do not need to be evaluated.

They are not specifically mentioned in Table 5.1, but Section 1.1307(b)(2) of the FCC rules and the 1996 Report and Order cover portable and mobile devices. As described in Sections 1.1307 (b)(1), 1.1307 (b)(2), 2.1091 (c) and 2.1093 (c) of the FCC regulations, there is no specific requirement that mobile and portable devices used under Part 97 (Amateur Radio) be evaluated. The 1996 Report and Order announcing the rules further amplified that mobile and portable devices specifically using push-to-talk operation, as used by police, taxicab and *Amateur Radio*, generally need not be evaluated. This is because of the low power, low operating duty cycles generally employed and the expected shielding of the vehicle occupants by the vehicle body.

This is explained in *Bulletin 65* and *Supplement B. Bulletin 65* emphasizes that although this applies to all mobile and portable hand-held operation in the Amateur Radio Service, it is intended that this general categorical exemption apply to mobile or portable operation using push-to-talk (PTT) operation. In general, most mobile operation would be considered as being a controlled environment, as long as the operator and passengers were aware of the RF exposure.

The FCC has prepared another supplement to *Bulletin 65* that discusses evaluation of mobile and portable devices. While intended for evaluation of devices such as cellular telephones, this supplement may be of some passing interest to amateurs. It is known as *Supplement C to OET Bulletin 65*. It is available from the FCC or can be downloaded from the FCC web site.

If You Don't Need to Do an Evaluation

There is an exception to every rule, and this old adage could apply to stations that are categorically exempt from the requirement to evaluate. That exemption is not absolute. No station is exempt from the requirement not to exceed the MPE levels. There are some station configurations that could result in exceeding the limits, even for stations that are normally exempt.

If the regulations do not specifically require you to perform an evaluation, there could be a number of reasons to do one anyway. If nothing else, doing an evaluation now would be good practice for the day when you upgrade your station (by adding an amplifier or antenna, for instance) in such a way that makes an evaluation necessary. More importantly, the results of your evaluation will certainly

Figure 5-3—This station would technically be classified as a mobile station, although it is not likely that hams will duplicate it exactly.

Figure 5.4—Should this mobile installation be evaluated? The regulations are not a substitute for the RF-safety concerns that have been addressed in ARRL publications for years.

demonstrate to yourself, and possibly your neighbors, that your station is operating well within FCC guidelines and is no cause for concern. Finally, if you have an antenna that is located very close to people, you may be operating in excess of the MPEs. It's a good idea to evaluate and be on the safe side, just in case.

Many classes of amateur stations are categorically exempt from the need to do a station evaluation. This is because the circumstances under which exempt stations are usually operated are such that the station is presumed to be in compliance with the MPEs. Under some circumstances, such as an antenna that is located unusually near people or in some mobile installations, it is possible to exceed the MPE levels.

Sections 1.1307(c) and (d) of the FCC's rules stipulate that the Commission may require that a station that is normally categorically exempt from the requirement to perform a routine evaluation, perform such an evaluation—if the FCC determines that there is reason to believe that the station may be exceeding the MPEs allowed.

The FCC will generally handle these exceptions on a case by case basis. In addition, the FCC also will rely on amateurs to voluntarily consider whether any operating parameter of their stations also make it prudent to do a station evaluation—even in cases where the category of that station would otherwise make it exempt. If an antenna is located unusually close to people, such as an indoor antenna in a living space, or a balcony-mounted antenna a foot or so away from a neighbor's balcony, the FCC *could* require a station evaluation or take other action.

Mobile stations also should be closely considered before an amateur automatically applies the categorical exemption. As an example, a 500-watt, 10-meter mobile installation with a vehicle-mounted antenna would certainly merit a closer look. On VHF, the use of a high-power amplifier also could present problems in some cases. In general, it is recommended that in these higher power installations, the antenna be located such that the vehicle occupants will be shielded from the antenna during normal use. One good location is in the center of an all-metal roof. Locations to be avoided for high-power operation would be a trunk-mounted antenna, or installation in a vehicle with a fiberglass roof. In general, mobile installations will not exceed the MPEs if sound installation guidelines are followed. *The ARRL Handbook for Radio Amateurs*, *Your Mobile Companion, Your Ham Antenna Companion* and *The ARRL Antenna Book*, available from the ARRL, have additional material on mobile installations and antennas.

How to Calculate Peak Envelope Power to the Antenna

A number of hams are a bit confused about peak-envelope power. PEP is defined as the *average* power of a single cycle of RF at the modulation peak when the transmitter is being operated normally. See Figure 5.5 and the sidebar "What's Power?". A very good explanation of power is found in the *Lab Notes* column of the May 1995 issue of *QST*, page 88 (*Watt's It All About*, by Mike Gruber, W1DG).

Table 5.1 uses PEP input to the antenna as the threshold to trigger the need to do a station evaluation. This can easily be calculated. Because the PEP input to the antenna can't be more than the PEP output from the transmitter, the simplest way to calculate power to your antenna is not to bother with any calculations—you can assume that your transmitter power output and the power reaching the antenna are the same. This is, of course, a conservative estimate, but you are allowed (and perhaps even encouraged) to be conservative in doing your evaluation. If you assume that *all* the power from your transmitter is reaching your antenna, you can safely use that as the power that will determine if you need to do an evaluation. If you "pass," there would be no need to calculate other factors, such as feed line losses, etc. Most hams will easily pass their evaluation, so some of these steps may not be necessary.

Supplement B contains information and a worksheet about how to calculate power to the antenna. The worksheet makes use of a convenient tool: the decibel (dB). The convenient thing about doing this calculation using dB is that one can easily add and subtract to ultimately obtain a power level. See the worksheet in Chapter 1 of this book.

Doing the Calculation

To calculate PEP to the antenna, start with your transmitter's PEP output, or the PEP of an external amplifier, if you are using one. Many commercially manufactured transmitters and amplifiers have a power meter built in. These meters can provide a measurement of PEP with reasonable accuracy for this purpose. Also, commercially manufactured external PEP reading power meters are available for stations that use common coaxial cables as feed lines. If there isn't any capability to measure the PEP output, the maximum PEP capability specified by the manufacturer may be used. Another approach would be to use a reasonable estimate, based on factors such as measured power input, the maximum capability of the final amplifier devices or the power supply. If the PEP output of your transmitter is at the levels in Table 5.1 or less, you can stop right here: You don't need to do an evaluation. If your power is greater than the levels in Table

What's Power?

The peak envelope of an SSB or AM signal occurs at the highest crest of the modulation envelope. (The point at which PEP occurs has been labeled in Figure 5.5.) The easiest way to appreciate the meaning of PEP is to calculate it. Let's assume a 50-Ω load and a peak voltage at the modulation crest of 110 V.

$$PEP = \frac{(V_{peak} * 0.707)^2}{R} = \frac{(110 * 0.707)^2}{50} = 121\text{W PEP}$$

The peak envelope power calculation uses the peak voltage during the maximum RF cycle, and converts it to an RMS value by multiplying by 0.707. The instantaneous peak voltage during the maximum modulation crest is treated as if it were a complete cycle of a sine wave. This is why the terms "average" and "peak" are not mutually exclusive in this case. Although PEP is the peak power, it is averaged over one complete RF cycle as if it were a sine wave.

Wattmeters and PEP

To determine your power, you could, of course, measure that power with an accurate wattmeter. (Virtually any wattmeter with its scale in watts is accurate enough for this job.) If you do use a wattmeter, to determine power at the transmitter or at the antenna, *ensure that the wattmeter is capable of measuring PEP*, if you are measuring modes such as single-sideband or full-carrier, double sideband AM. If you are measuring CW or FM, the PEP is the same as the average power that will be measured by non-PEP-reading wattmeters. Remember, too, that most wattmeters are only accurate if they are measuring power in a 50-ohm resistive system. (If your SWR is 1.5:1 or better, you can safely assume that the wattmeter is reasonably accurate. If not, consult the owner's manual for your meter or consult with the meter's manufacturer.)

If you do accurately measure the power at the antenna, you can compare the result with the values in Table 5.1. If your power is at those levels or less, you do not need to do a station evaluation for that band at that power level.

5.1, you will need to calculate or determine the power input to your antenna.

Feed Line System Losses

The power at the transmitter will be reduced by any losses between the transmitter and antenna. This usually includes losses in the feed line and any external accessories such as power meters or antenna tuners. Most of the time, these losses are expressed in decibels (dB), either dB/100 feet for feed lines, or in dB for each accessory. In most cases, the published loss for feed lines is fairly accurate and it can be used directly in making your calculations.

To obtain an estimate of your feed line losses, refer to the graph of Figure 5.6. This graph provides estimates of feed line losses for common types of feed lines. It is not meant to represent the actual attenuation performance of any particular product made by any particular manufacturer. The actual attenuation of any particular sample of a feed line type may vary somewhat from other samples of the same type because of differences in materials or manufacturing. If the feed line manufacturer's specification is available, use that instead of the values listed in this table.

Feed line loses also vary with SWR. The higher the SWR, the higher the losses over and above the attenuation loss discussed above. For further information see *The ARRL Handbook for Radio Amateurs*, *Your Ham Antenna Companion* or *The ARRL Antenna Book*. You can ignore the additional losses caused by SWR for a conservative evaluation.

The graph gives the feed line loss in dB/100 feet. If your feed line is exactly 100 feet long, you already know your feed line losses. This is, however, unlikely, so you are going to have to multiply the loss in dB/100 feet by the ratio between your actual feed line length and 100 feet.

Other Losses

You can factor in other losses between the transmitter and the antenna, if you know them. Although the feed-line loss specification is reasonably realistic, the specifications for accessory items is often a "maximum" specification. The actual losses can be less. An antenna tuner might have a specification of 3 dB insertion loss, or loss of 50% of the available power, but this would be worst case—on most bands, the losses would be less. A conservative estimate on HF might be to assume that these components are lossless. On VHF and above, it would be reasonable to add 0.1 dB to the total losses for each accessory item that is connected between the output and the feed line going to the antenna. Do not include accessories that are between an exciter and the final amplifier. It would be conservative to assume that *connectors* have 0 dB loss.

Using Arithmetic

Decibels can only be added or subtracted with decibels. To obtain the power at the antenna, you will either have to convert your power to a form that is expressed in decibels or you will have to convert the decibel value to a number.

If you know the loss in dB, you can convert that to the percentage of loss using the following formula:

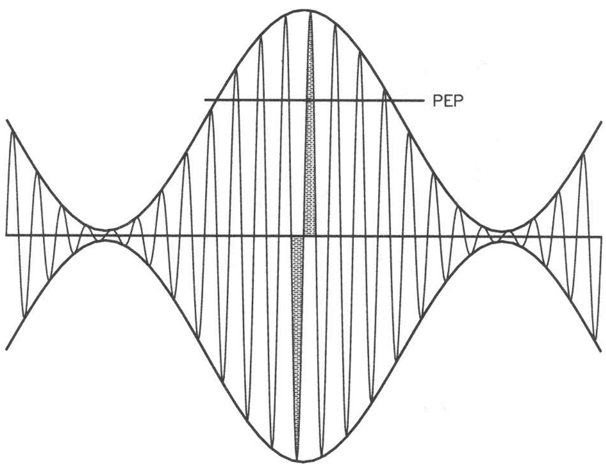

Figure 5.5—PEP is the average power of the single cycle highlighted in this graph. If the peak of the RF waveform is 100 volts and the resistance is presumed to be 50 ohms, the RMS voltage of the cycle is 70.7 and the power is 100 watts, using the classic formula, P = E^2/R.

Step by Step

Let's look at a hypothetical example of an amateur station and run through the evaluation steps. Assume that Al, N9AT, has the following station configuration:

• 80 meters, 100 W and 1000 W CW and SSB with a half wavelength dipole antenna 10 feet above ground. (This is a terrible height for an 80-meter dipole, but it serves as a worst case!)

• 40 meters 100 W and 1000 W CW and SSB with a half wavelength dipole antenna 10 feet above ground. (Ditto the height comments above!)

• 10 meters, 100 W and 1500 W CW and SSB with a 3-element beam 30 feet above ground, 8.5 dBi gain.

• 2 meters, 35 W FM, 100 W CW and SSB with a 4-element Yagi, 8 dBi gain 60 feet above ground.

Al first looks at Table 5.1 to see which operation requires a station evaluation. In this case, his 100-W 80- and 40-meter operation and his 35-W 2-meter FM operation do not need to be evaluated. (Al intends to evaluate them anyway, just to learn more about the subject.)

He could calculate his average power for the remaining operation, but this may not be necessary. Al first tries his evaluation with PEP, using Table 5.7 in this chapter in conjunction with Table 5.5. Rounding up to 3 dBi for the antenna gain, Table 5.5 estimates that on 80 meters at 1000 W his antenna needs to be located 2.8 feet from areas of controlled exposure and 6.2 feet from areas of uncontrolled exposure. The antenna is located about 10 feet from the property line and is attached to the house with 5-feet of rope, so this band would be in compliance for operation at a 1000-W continuous carrier level.

On 40 meters at 1000 W, Al first rounds his dipole gain up to 3 dBi. Table 5.5 shows 5.1 feet for controlled exposure and 11.4 feet for uncontrolled exposure. On this band the end of his antenna is located 5 feet from the property line and tied to the house with a 4-foot rope. It doesn't quite pass with full power. Al has a few choices. He can relocate the antenna, reduce power, or calculate his average power and try again or use the antenna-specific table at the same height. In this case, he calculates his average power and determines that he is using 133 W average power on SSB and 266 W average power on CW. Rounding up, he selects 500 W in Table 5-9 and determines that his antenna needs to be 3.6 feet from controlled exposure and 8.0 feet from uncontrolled exposure. He meets the requirements for controlled exposure, but the antenna would be located 6.4 feet from a person standing on the property line, so the station may still not be in compliance. Al decides to move the antenna 10 feet from the property line sometime next week. In the meantime, he will reduce his power on 40 meters.

On 10 meters, he is using a 3-element Yagi 30 feet in the air. Rounding his gain up to 9 dBi, using Table 5.5 he determines that his antenna needs to be 50.6 feet from controlled exposure and 113.2 feet from uncontrolled exposure. The tower is located 40 feet from the house, and solving for the hypotenuse of the distance between his residence and the tower (his one-floor house has the top of the first floor 12 feet above ground), he calculates that the antenna is located 43.9 feet from areas of controlled exposure. Thus there is a problem for full power, but not when he calculates his average power. The tower is 50 feet from the property line, for a total distance of 55.5 feet from ground level exposure *on the property line*. This does not pass for uncontrolled exposure. Al doesn't give up, though, he goes to Table 5.9 and determines that at ground level, the *NEC* model shows that the compliance distance needs to be 57.1 feet from the center of the antenna at 1500 W average power. He clearly cannot do 30 minutes of tune-up if his neighbor is on the property line. At 500 W average power, however, Al notes that his antenna could be built on the property line and ground-level exposure would be below the limits. He has met the requirements and does not need to make any changes to his station except to limit his tune-up time.

On 2 meters, his antenna has 8 dBi of gain. Rounding up to 9 dBi, he determines that at 100 W his antenna needs to be 13.2 feet from controlled exposure and 29.5 feet from uncontrolled. This antenna is at the top of his 45 foot tower, so he can run continuous power on 2 meters. Al gathers all the papers containing these calculations (along with his notes) and files them with his station records. Within 20 minutes he has completed his station evaluation!

$$\text{Loss\%} = 100 - \frac{100}{10^{\frac{\text{dB}}{10}}} \qquad \text{Eq 5.1}$$

Most electronic calculators have exponent functions (10^x) that can do this calculation handily. For those who don't want to do the mathematics, Table 5.2 handles the conversion in convenient steps. To be conservative, round the calculated feed line losses *down* to the next lowest step in this table. As you can see, if the losses are greater than a few dB, a *lot* of power is getting lost in your feed line. On the other hand, if your loss were 12 dB, about 94% of your power is lost as heat.

If you use the calculated feed line system loss in the above formula or table, multiply the power at the transmitter by the result of the above calculation percentage. This will give you the amount of power being lost in your feed line system. Subtract this power from the output of your transmitter and you will have calculated the amount of power being delivered to the antenna.

Table 5.2
dB to Decimal Number Loss Table

dB	*Loss%*	*dB*	*Loss%*	*dB*	*Loss%*	*dB*	*Loss%*
0.0	0.00	1.5	29.21	7.0	80.05	15.0	96.84
0.1	2.28	2.0	36.90	7.5	82.22	16.0	97.49
0.2	4.50	2.5	43.77	8.0	84.15	17.0	98.00
0.3	6.67	3.0	49.88	8.5	85.87	18.0	98.42
0.4	8.80	3.5	55.33	9.0	87.41	19.0	98.74
0.5	10.88	4.0	60.19	9.5	88.78	20.0	99.00
0.6	12.90	4.5	64.52	10.0	90.00	22.0	99.37
0.7	14.89	5.0	68.38	11.0	92.05	25.0	99.69
0.8	16.82	5.5	71.82	12.0	93.69	30.0	99.90
0.9	18.72	6.0	74.88	13.0	94.99	35.0	99.97
1.0	20.57	6.5	77.61	14.0	96.02	40.0	99.99

Using dBW

You also can convert your power into a decibel unit. This is the method generally used in the radio engineering field. This method is outlined in the FCC worksheet in *Bulletin 65*. The power unit dBW expresses

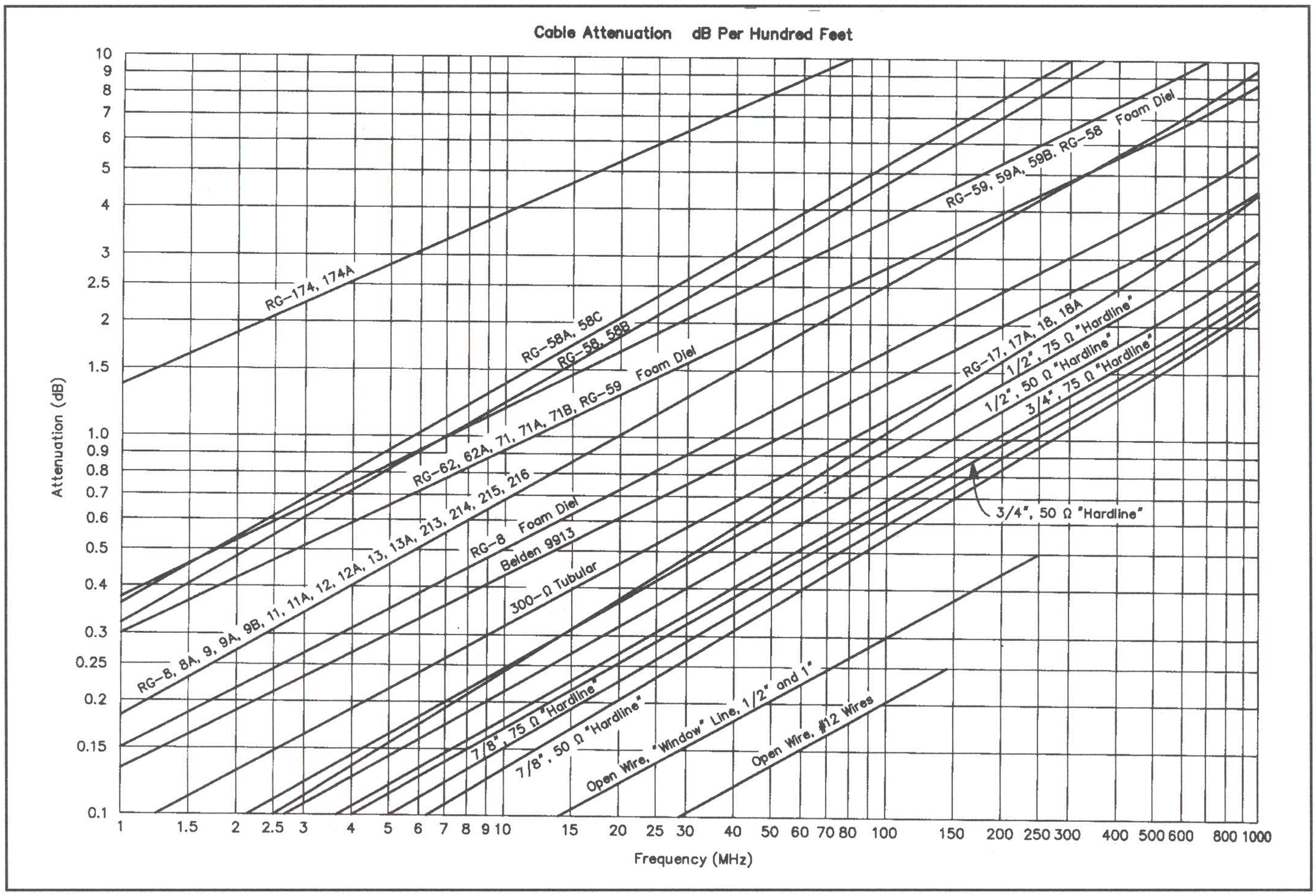

Figure 5.6—This graph shows the actual losses for many common feed lines.

the ratio of the power in question to 1 watt, in decibels. To obtain power in dBW, use the following formula:

$$\text{power}_{\text{dBW}} = 10\log_{10}\left(\text{power}_{\text{Watts}}\right) \qquad \text{Eq 5.2}$$

Table 5.3 gives the power in dBW for a number of power levels that will be useful to do this calculation. If you use this table, you will have to round up your actual transmitter power to the nearest value in the table. The power levels in this table were selected to correspond with various power levels that are part of the FCC RF-exposure rules, or that result from average power calculations of 1500 watt transmitters using various modes. This table can be used to convert dBW to watts, or watts to dBW. Ensure that any rounding up or down that you do with this table is in the "conservative" direction.

Working with the Decibel

Now that you have the power in dBW, you can easily subtract the feed line and other losses directly from the power in dBW, giving you power at the antenna in dBW. You can convert this back to power in watts, either using Table 5.3 (rounding up the dBW as required) or the formula:

$$\text{power}_{\text{watts}} = 10^{\frac{\text{dBW}}{10}} \qquad \text{Eq 5.3}$$

Practice converting power in watts to power in dBW, then from dBW back to watts. If you are doing the math correctly, you will end up with the same power you started with.

Table 5.3
Conversion of Power In Watts to dBW

Watts	*dBW*	*Watts*	*dBW*
1	0.00	125	20.97
2	3.01	150	21.76
3	4.77	200	23.01
5	6.99	225	23.53
10	10.00	250	23.98
15	11.76	300	24.77
20	13.01	400	26.02
25	13.98	425	26.28
30	14.77	500	26.99
40	16.02	600	27.78
50	16.99	750	28.75
70	18.45	1000	30.00
75	18.75	1200	30.79
100	20.00	1500	31.76

Once you have calculated power at the antenna using one of these methods, the power at the antenna can be compared to the power levels in Table 5.1 to see if you need to do a station evaluation. If you do, the peak-envelope power at the antenna will be used later in the evaluation to calculate average power and average exposure that will be used in doing your station evaluation. (It is a lot easier than it sounds!)

As an example, if you are running 100 watts PEP and have a feed line loss of 3 dB, you would convert 100 watts to 20 dBW, then subtract 3 dB. This would leave you with 17 dBW, which by using the table gives you 50 watts to the antenna. You could also look to Table 5.2 and determine that you are losing 50% of your power in the feed line. Follow the instructions on using Table 5.2 and you will calculate that you have 50 watts to the antenna. According to Table 5.1, this part of your operation would not have to be evaluated on any band.

PERFORMING AN EVALUATION FOR CONTROLLED AND UNCONTROLLED ENVIRONMENTS

In general terms, controlled exposure ap-

Multiple Evaluations

To comply with the requirements, an evaluation must be made for each transmitter, duty cycle and antenna. Different modes usually correspond to different duty cycles. In addition, where applicable, each combination has to be made of both controlled and uncontrolled areas. For the example in the text, each of the following modes and antennas will have to be evaluated twice—for controlled and uncontrolled spaces.

Band	*Mode*	*Power*	*Antenna*
146 MHz	FM	>50 W	Groundplane
146 MHz	FM	>50 W	5-element Yagi
144 MHz	SSB	>50 W	Groundplane
144 MHz	SSB	>50 W	5-element Yagi
222 MHz	FM	>50 W	Vertical collinear
222 MHz	SSB	>50 W	10-element Yagi

plies to you, your immediate household and property areas that you control. Uncontrolled exposure is a "general public" exposure, generally applied to neighboring properties and public areas.

A routine evaluation will generally need to be done for both controlled and uncontrolled exposure environments. However, if a ham determines that his or her operation meets the requirements for uncontrolled exposure in his or her own station, home and property, it will not be necessary to evaluate the same areas for controlled exposure. The definitions and scope of these terms are discussed in the Rules chapter.

Evaluation Must Be Done by Mode, Power, Antenna and Band

Amateur stations must be evaluated for each frequency, mode and station configuration used. Separate evaluations will probably need to be made for both controlled and uncontrolled environments, if it is possible that fields in these areas could exceed the MPEs. For example, if an amateur operates more than 50 W FM and/or SSB on 144 and 222 MHz, using one of two different antennas on 144 MHz and one antenna for each mode on 222 MHz, the evaluations shown in the "Multiple Evaluations" sidebar would have to be performed, including both controlled and uncontrolled environments:

Each mode has a specific duty cycle and each antenna has a specific gain and/or distance from areas of exposure, so each combination must be tested. In most cases, if an amateur uses two different transmitters with the same power for a single band and mode, the evaluation made for one will apply to the other. (This may not *always* be true, however. See the section on Duty Factor later in this chapter.)

One would find different average field strengths and resultant compliance distances for each mode, so it may be necessary to evaluate each mode separately. There are a few shortcuts, however. If a station meets the MPE requirements with a mode like FM with a 100% duty factor, it also will pass using a mode like SSB or CW with a smaller duty factor. In general, the compliance distance with a low-gain antenna such as the ground plane will be less than it will for the Yagi. Thus, if the station complies at a certain distance with the Yagi, the compliance distance with the ground-plane antenna will almost always be less.

How to Do an Evaluation

Most amateurs will probably select one or more of several calculation methods to perform their station evaluations. If appropriate, different methods may be applied to different station configurations. The selection of method is based on the needed accuracy, the specific factors that must be used to determine improvements from "worst-case," and the available tools.

General Methods Overview

Bulletin 65 outlines several ways that hams can evaluate their stations. However, hams may use any other technically appropriate methods. Many hams envision complicated measurements when they think about evaluating their stations. While precise measurements could be used, most hams will probably meet the requirements using one of the easier methods. The FCC notes, however, that some of these formula-based calculations and tables can give results that are *much* higher than would be actually encountered. In some cases, a more specific analysis, perhaps using computer modeling or the tables in Chapter 8 derived from computer modeling may help a ham prove compliance.

In general, you can estimate compliance by using:

- Tables developed from the field-strength formulas
- Tables derived from antenna modeling
- Antenna modeling software (*NEC*, *MININEC*, etc)
- Power-density and field-strength formulas
- Graphs made from power-density formulas
- Software developed from field-strength formulas
- Calibrated field-strength measurements

The First Step—Decide On a Method

Most amateurs will probably select one or more calculation methods to perform their station evaluations. The selection of method is based on the needed accuracy, the specific factors that must be considered and the available software, hardware or information "tools."

The first step in doing an evaluation is to determine in advance what method you will use. The list above shows some examples of the ways most hams will use for their evaluations. Once you have selected a method, you can either apply that method directly to your transmitter's output power as a shortcut, or you can determine the actual average exposure.

Average Exposure

FCC rules define maximum permitted amateur power in PEP output from the transmitter. They also define the threshold that triggers the need to do a station evaluation in PEP input to the antenna. The MPE limits, however, are based on *average exposure*, not peak exposure, using an average of the power density, or an average of the square of the electric or magnetic fields.

The concept of averaging RF exposure means that the total exposure for the averaging period must be below the limits. For example, someone could be at twice the MPE limit for half of the averaging period. As long as there was no exposure for that same amount of time before and after the exposure that was double the limit, you would meet the MPE requirements.

Another way of factoring in average exposure could be to determine the average transmitter power, and use that power in all your following calculations. Those who use the power-density formulas to calculate the power density to areas of exposure will probably find this method to be the most useful way of determining average exposure.

The easiest way to calculate average power is not to do the calculation. First use your transmitter's PEP output, or PEP to the antenna, and assume continuous exposure. You may meet the requirements. In that case, you don't need to calculate average exposure or average power at all!

Ground Reflections

A precise calculation in the near field is not very straight forward!

The presence of boundaries such as earth ground alters the wave impedance, so that electric and magnetic fields must be considered separately, even in the far field of the antenna. This is illustrated by considering the case of a horizontal dipole 15 m above the earth, operating at 29 MHz with 1,500 W supplied power. The electric and magnetic fields each obey the boundary conditions at the air-earth interface, and the magnetic field is enhanced, while the electric field is diminished. When normalized to the MPE of the 1996 FCC standard, the total magnetic field in decibels relative to the standard is shown in Figure A.

The total electric field contours similarly normalized are picture in Figure B. Ignoring the exposure averaging time in the standards, permissible general population exposure levels are the regions outside the "0 dB" contours. Significantly, the magnetic field contours of Figure A are substantially different from the electric field contours shown in Figure B. Magnetic fields peak at ground level while electric fields peak a quarter wavelength above ground. This is a consequence the ground reflection, and has nothing to do with whether the fields are near or far with respect to the dipole. The wave impedance evaluated on the total fields is simply not equal to the intrinsic impedance associated with the medium.

The exposure standard is written around the maximum of the either the electric or magnetic field limit. That quantity is pictured in Figure C. The "0 dB" contours represent the limits where either the electric or magnetic fields exceed the MPE level of the standard. If the power transmitted by the dipole were reduced by 5 dB, then the MPE limit contour would be represented by the "5 dB" contour in Figure C.

The figure illustrates that the determination field levels relative to MPE levels is complex, even for the very simple case of a dipole antenna in the presence of a single boundary—the ground.

Figures A - C show the fields near the ground. Those complicated contours make it awkward to specify a single distance as the compliance distance for this antenna and power combination. First, the electric or magnetic field alone produces different compliance contours, Figures A and B. We must comply with the worst case of both figures, which is represented by Figure C.

Even then, near ground level, the compliance distance along the ground is 7 m, as shown by point "A," whereas at a height ground of 7 m the compliance distance, point "B," is almost 11 m. This helps illustrate why the compliance distances in the ARRL compliance distance tables sometimes might appear to be unusual.—*Kai Siwiak, KE4PT*

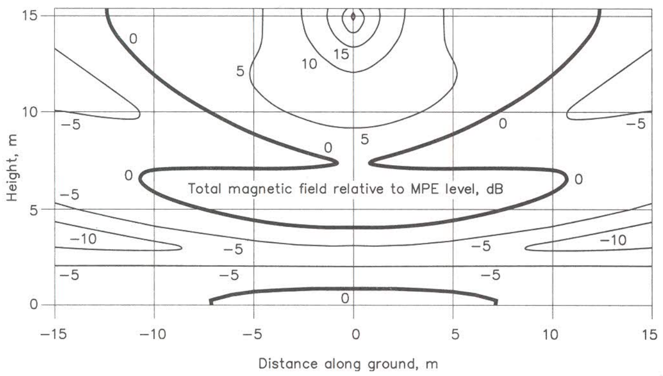

Figure A—Magnetic fields relative to MPE limits. The contours "0 dB" and greater are regions where the magnetic fields are not in compliance.

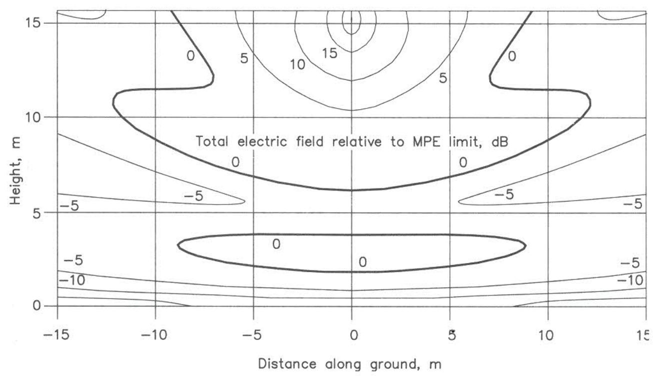

Figure B—Electric fields relative to MPE limits. The contours "0 dB" and greater are regions where the electric fields are not in compliance.

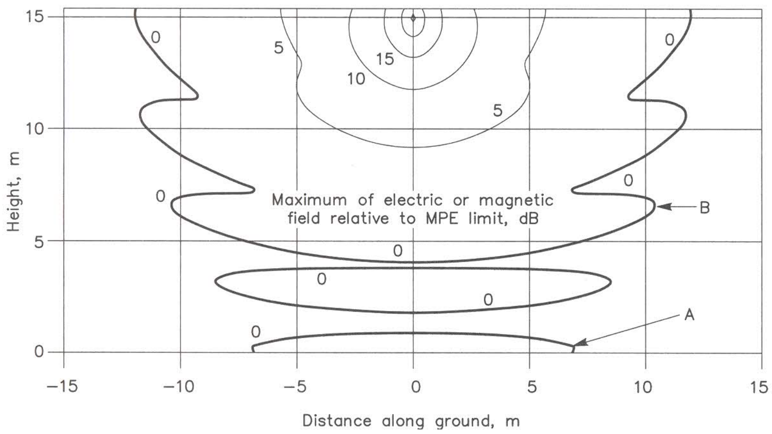

Figure C—Greater of the magnetic or electric fields relative to MPE limits. Any point outside the "0 dB" contours is in compliance with the FCC standards.

Table 5.4

Operating Duty Factor of Modes Commonly Used by Amateurs

Mode	*Duty Cycle*	*Notes*
Conversational SSB	20%	1
Conversational SSB	40%	2
SSB AFSK	100%	
SSB SSTV	100%	
Voice AM, 50% modulation	50%	3
Voice AM, 100% modulation	25%	
Voice AM, no modulation	100%	
Voice FM	100%	
Digital FM	100%	
ATV, video portion, image	60%	
ATV, video portion, black screen	80%	
Conversational CW	40%	
Carrier	100%	4

Note 1: Includes voice characteristics and syllabic duty factor. No speech processing.
Note 2: Includes voice characteristics and syllabic duty factor. Heavy speech processor employed.
Note 3: Full-carrier, double-sideband modulation, referenced to PEP. Typical for voice speech. Can range from 25% to 100%, depending on modulation.
Note 4: A full carrier is commonly used for tune-up purposes

Duty Factor

Duty factor is an expression between the peak-envelope power of a transmitter and its average power during the time it is on the air. It is usually expressed as a percentage, although it is not uncommon for it to be expressed as a decimal. It is sometimes called "duty cycle."

If all else is equal, some emission modes will result in less RF electromagnetic energy exposure than others. For example, modes like RTTY or FM voice transmit full power during the entire transmission (100% duty factor). On CW, you transmit at full power during dots and dashes and at zero power during the space between these elements. A single-sideband (SSB) phone signal generally produces the lowest exposure because the transmitter is not at full power all the time during a single transmission. The **duty factor** of an emission takes into account the amount of time a transmitter is operating at full power. Duty factor can either consider the time of a single transmission, or the time of a series of transmissions over a specific time period. The duty-factor tables and text in this section assume 100% transmission time. An emission mode with a lower duty factor produces less exposure for the same PEP output.

Lower duty factors, then, result in lower RF exposures. That also means the antenna can be closer to people without exceeding their MPE limits. Compared to a 100% duty-factor mode, people can be closer to your antenna if you are using a 40% duty-factor mode.

Duty factor is used as part of your calculation of average power. If you do want to determine your average power, you will need to know about how different modes have different average powers. *The MPE limits are based on exposures averaged over 6 minutes for controlled exposure or 30 minutes for uncontrolled exposure.* To obtain this average, we need to consider the mode being used, its duty factor and the total operating time.

Using a duty-factor correction for some modes, SSB, for example, would give an accurate MPE for conversational SSB. However, if the same transmitter were used for extended tune-up purposes on the air using a carrier, the MPE could be exceeded. If you apply duty factor to two different transmitters using the same mode, consider whether the speech processing, or CW keying characteristics might be different. This could result in a different duty factor and average power than would be obvious from the mode and power used.

Table 5.4 shows the duty factors of a number of modes in common use by amateurs. The actual PEP to the antenna can be multiplied by these values to yield a power level that has been corrected by the duty factor of the mode being used. The resultant average power can then be used in the various calculation methods described elsewhere in this bulletin. If so used, they are based on 100% operating "on" time for the mode described.

Determining Average Power

The concept of power averaging includes both on and off times and the "duty

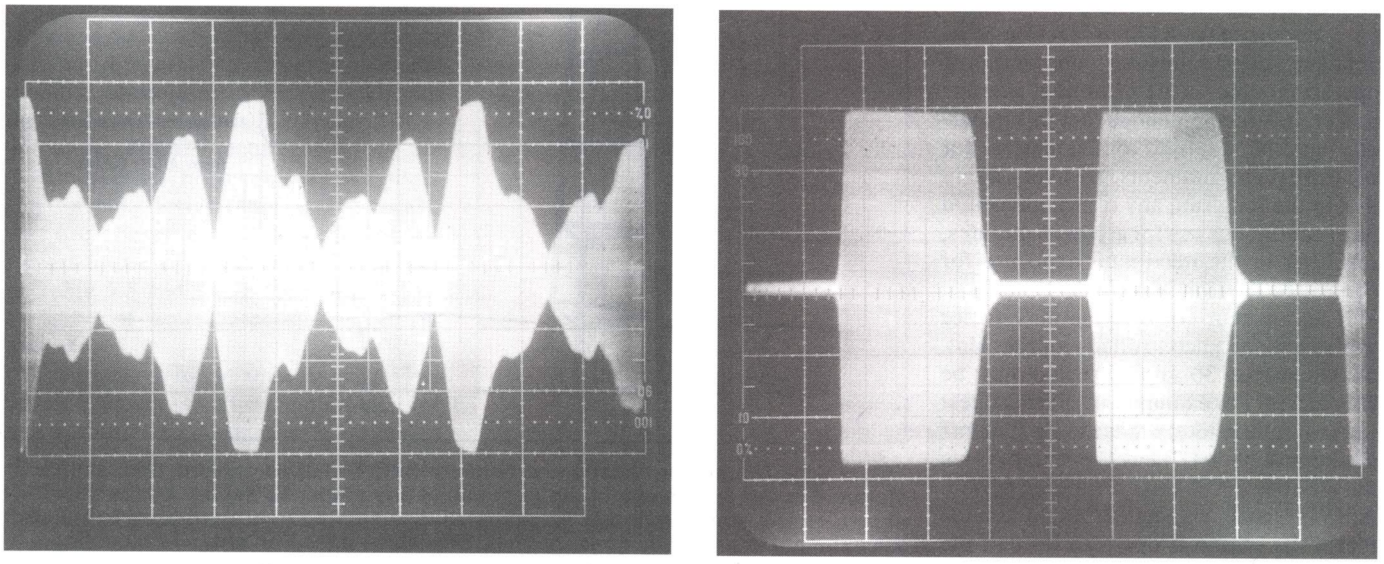

Figure 5.7—These two signals have different average power, but the same PEP.

factor" of the transmitting mode being used. Each mode of operation has its own duty factor that is representative of the ratio between average and peak power. Table 5.4 shows the duty factors for several modes commonly in use by amateur operators. To obtain an easy estimate of average power, multiply the transmitter peak envelope power by the duty factor. Then multiply that result by the worst-case percentage of time the station would be on the air in a 6-minute period for controlled exposure, or a 30-minute period for uncontrolled exposure.

For example, if a 1500-watt PEP amateur single-sideband station operates 10 minutes on, 10 minutes off, then 10 minutes on, this would be:

1500 W * 20% * (20 out of 30 minutes) = 200 watts for uncontrolled exposure

1500 W * 20% * (6 out of 6 minutes) = 300 watts for controlled exposure

A 500-watt CW station that is used in a DX pileup, transmitting 15 seconds every two minutes would be:

500 W * 40% * (15 out of 120 seconds) = 25 watts for controlled or uncontrolled exposure

A 250-watt FM base station used to talk for 5 minutes on, 5 minutes off, 5 minutes on, would be:

250 W * 100% * (5 out of 6 minutes) = 208 watts for controlled exposure

250 W * 100% * (15 out of 30 minutes) = 125 watts for uncontrolled exposure

The percentages (%) shown are taken from Table 5.4 for the mode used.

If the station might transmit for more than 6 minutes, one can assume continuous exposure in a controlled environment, so the average power for controlled exposure is 300 watts. Additional examples are shown elsewhere in this chapter under the "Step by Step" section. If an amateur does consider on and off operating time in determining average power, it is recommended that this generally not be applied to evaluation for controlled environments. It is very likely that in the long run, any one mode would be in continuous use for at least 6 minutes, resulting in the maximum exposure for controlled environments.

If an amateur corrects the duty factor for time for an uncontrolled environment, the worst-case 30-minute period must be considered. For example, in an HF contest operation, it is likely that the on time/off time could be 4:1. Thus the station is on the air 80% of the time for a long period. At first glance, an amateur might assume that if the station is operated for half the time, the duty factor correction is 0.5, but that is not always the case. For example, if a station were operated for 10 minutes on, 10 minutes off, then 10 minutes on, over the worst-case 30-minute period, the station would be on the air 67% of the time, resulting in a duty factor correction of 0.67.

Compliance Distance Tables

Most amateurs will use the tables in *Bulletin 65* to estimate their compliance with the MPE levels. The *Bulletin 65* tables do have advantages: they generally offer conservative estimates and they are easy to use. The tables in *Bulletin 65* are all formatted with distances in meters. These tables, plus a larger number created using the same methods as the FCC tables, are featured in Chapter 8, formatted in feet. These tables show the compliance distance—the minimum distance one must be from the antenna to be in compliance with the FCC rules for the frequency, antenna gain and average power involved. You can use PEP for the power levels shown in all the tables for a conservative estimate, or calculate average power for a more precise estimate.

Bulletin 65 contains three major sets of tables. The first features a list of antenna gains, frequencies and power levels, with the necessary compliance distance for each. The concept for this table was submitted to the FCC by the W5YI Group. The W5YI Group and the ARRL then worked together to expand the number of listings. Additional entries have been made to the version of this table featured in Chapter 8. The distances in these tables were derived using the far-field, power-density formula shown in Eq 5.7 later in this chapter. The tables assume that the exposure is taking place in the main beam, at the height of the antenna as a conservative estimate. This equation includes the "EPA" ground-reflection factor.

The second set of tables features specific antennas and transmitter powers, by frequency. These tables were supplied to the FCC by Wayne Overbeck, N6NB, Kai Siwiak, KE4PT, and the FCC staff. The tables assume that the exposure is taking place in the main beam, at the height of the antenna as a conservative estimate.

The third set of tables features specific antennas and transmitter powers, by frequency, modeled using *NEC4* at various heights above average ground. In these tables, the *horizontal* compliance distance was calculated from the center of radiation for various antenna heights, at heights

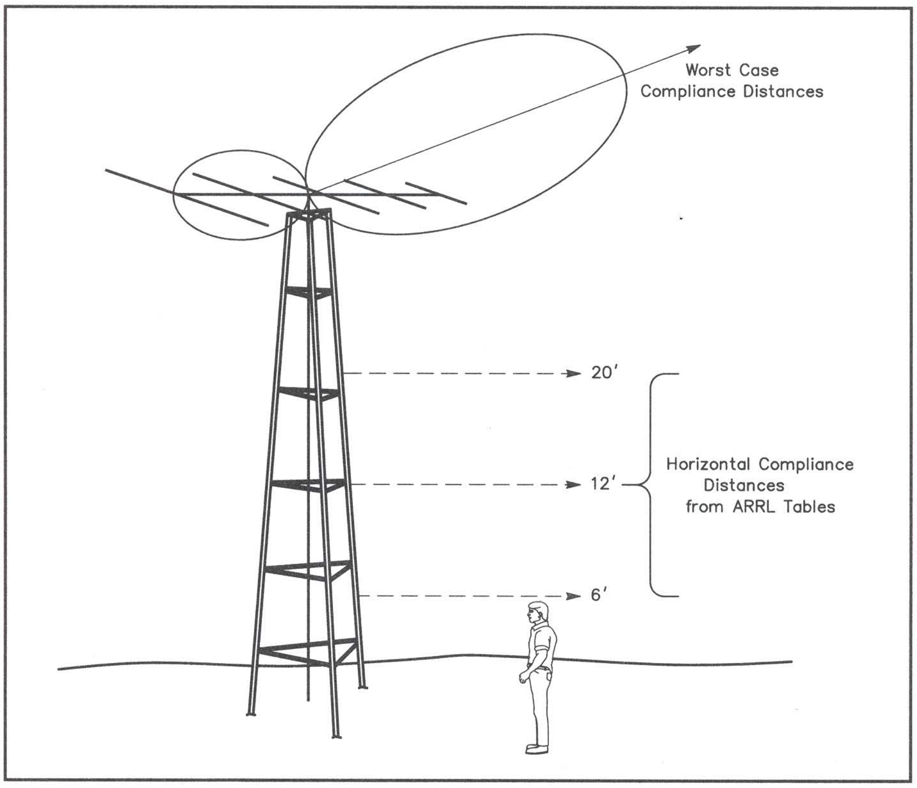

Figure 5.8—The power-density and field-strength formulas give the compliance distance in the main beam of the antenna, at any angle, as the uppermost line shown on this drawing. If this same distance is applied to ground-level exposure, the estimate is generally conservative. The tables based on antenna modeling have calculated the horizontal compliance distances at ground level, and at first and second story exposure levels.

where exposure occurs of 6 feet, 12 feet, 20 feet and at the height of the antenna. The 6-foot height estimates ground-level or first-story-level exposure. The 12-foot height represents the ceiling of a typical first-story exposure, or the floor of a second-story exposure. The 20-foot height represents the ceiling of a second story or the floor of a third story. These heights were chosen to accommodate different building structures. This is shown in Figure 5.8.

The tables calculate *actual* exposure at the various points being evaluated. The modeling process automatically includes the specific gain of the antenna and the actual ground conditions. These tables demonstrate that the exposure below an antenna is often much less than the exposure in the main beam. Figure 5.9 shows how these various tables and methods relate to the areas being evaluated.

Tables Developed from Far-Field, Power-Density Formulas

The easiest-to-use of these tables were developed from the far-field, power-density formula. They have been calculated with a "ground-reflection factor." This includes the "ground gain" of an antenna over typical ground. This allows hams to use manufacturer's antenna gain figures in dBi with confidence that the result represents a conservative real-world estimate. (Many antenna gains are expressed in decibels relative to a dipole. Add 2.15 dB to the gain in dBd to obtain dBi.) This model, although simplified, has been verified by the ARRL Laboratory staff using *NEC* antenna-modeling software against a number of dipole, ground plane and Yagi antennas modeled over ground. These tables do not necessarily apply to all antenna types. *NEC* models of small HF loops, for example, give fields near the antenna that are much higher than the far-field formula predicts. The table for the small loop was calculated using different, more accurate, techniques.

In most cases, however, the power-density-formula derived tables give results that are conservative. Examples of the easiest-to-use of these tables are shown in Table 5.5 and Table 5.6, followed by a number of tables based on specific antenna types.

The first step for an amateur is to select the simple tables that best applies to his or her station and determine the estimated compliance distance per band. *Bulletin 65* contains a number of these tables. If the compliance distance is less than the actual distance to the exposure, the station "passes" and the evaluation is complete. It can be that simple. Remember that these distances are for the absolute distance from the antenna *at any angle*. Figure 5.9 shows an example of how to determine the distance between an antenna and any point being evaluated.

This distance can be used with the tables derived from the power-density formula. The ARRL tables of modeled antennas use distance b or b' in Figure 5.9.

One shortcut is to use the highest power you use on each band. First, use your transmitter's PEP output to see if you are in compliance. Next select the table entry of antenna that represents your station configuration. Finally, look up your frequency and power and determine if areas where people might be exposed are farther away than the compliance distance in the table.

Tables Based on Antenna Gain

Tables 5.5 and 5.6 are derived from the method used in the tables in the FCC *Bulletin 65* submitted by the W5YI Group. They show the distances required to meet the power-density limits for different amateur bands, power and antenna gain, for occupational/controlled exposures (*con*), or for general population/uncontrolled exposures (*unc*). (All FCC tables give all the distances in meters; the tables in this article have been converted to feet.)

Tables 5.5 and 5.6 probably represent the *easiest* approach to doing a station evaluation. They can be conservatively applied to most antenna types. The frequency represents the "worst-case" for each band; the antenna gains are in dBi. (Some antenna gains are expressed in decibels relative to a dipole. Add 2.15 dB to the gain in dBd to obtain dBi.) Hams can use PEP or average power to obtain either a conservative or more precise estimate of compliance distances. Select the appropriate band and "round up" antenna gain and power to match the table. The distances are the minimum separation that must be maintained between the antenna and any area where people will be exposed. See Figures 5.8 and 5.9 for examples of how this distance applies.

To obtain a conservative estimate using Tables 5.5 and 5.6, hams should follow the following steps.

- Select the table entry for the frequency band being evaluated.
- Determine the estimated free-space antenna gain in dBi from the antenna manufacturer or from Table 5.7.
- First, assume full PEP and 100% operation, then look up the compliance distance on the chart. If the antenna is located at least this far from areas of exposure, either horizontally, vertically, or diagonally, the station "passes" on that antenna/band combination.
- If necessary, calculate average power,

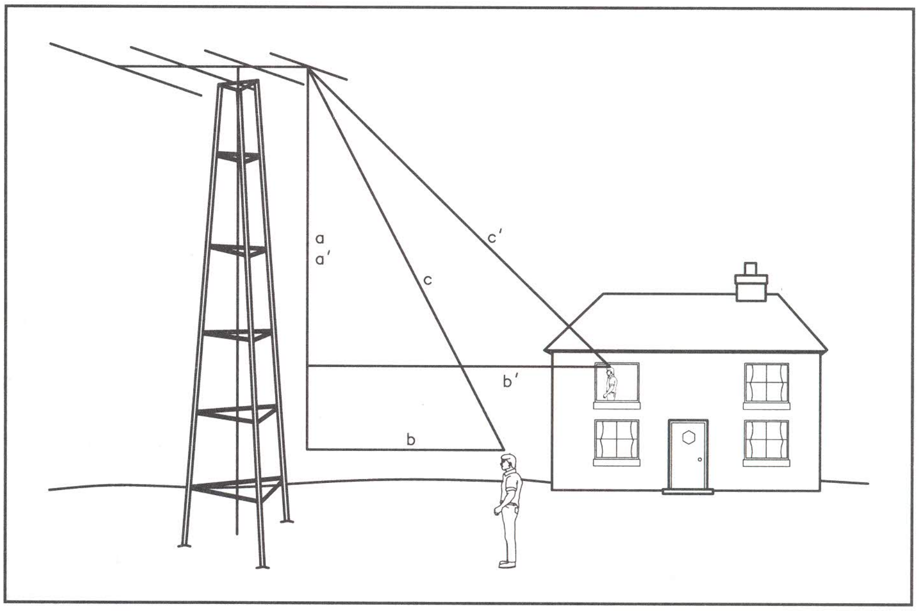

Figure 5.9— In calculating the actual worst-case horizontal compliance distances between the antenna and areas being evaluated, you must consider the antenna height, the height of the exposure and the horizontal distance between the antenna and the exposure point. This drawing illustrates exposures at ground and second-story levels. (Use the a´ and b´ for the second-story exposure.) From there, you can use the formula:

$$c = \sqrt{a^2 + b^2}$$

Table 5.5

Estimated distances from transmitting antennas necessary to meet FCC power-density limits for Maximum Permissible Exposure (MPE) for either occupational/controlled exposures ("Con") or general-population/uncontrolled exposures ("Unc"). The estimates are based on typical amateur antennas and assuming a 100% duty cycle and typical ground reflection. (The figures shown in this table generally represent worst-case values, primarily in the main beam of the antenna.) The compliance distances apply to average exposure and average power, but can be used with PEP for a conservative estimate. An expanded version of this table appears in Chapter 8.

		Distance from antenna (feet)							
Frequency (MHz)	*Gain (dBi)*	*100 W Con*	*100 W Unc*	*500 W Con*	*500 W Unc*	*1,000 W Con*	*1,000 W Unc*	*1,500 W Con*	*1,500 W Unc*
2	0	0.5	0.7	1.0	1.6	1.5	2.2	1.8	2.7
	3	0.7	1.0	1.5	2.2	2.1	3.1	2.6	3.8
4	0	0.6	1.4	1.4	3.1	2.0	4.4	2.4	5.4
	3	0.9	2.0	2.0	4.4	2.8	6.2	3.4	7.6
7.3	0	1.1	2.5	2.5	5.7	3.6	8.1	4.4	9.9
	3	1.6	3.6	3.6	8.0	5.1	11.4	6.2	13.9
	6	2.3	5.1	5.1	11.4	7.2	16.1	8.8	19.7
10.15	0	1.6	3.5	3.5	7.9	5.0	11.2	6.1	13.7
	3	2.2	5.0	5.0	11.2	7.1	15.8	8.7	19.4
	6	3.2	7.1	7.1	15.8	10.0	22.4	12.2	27.4
14.35	0	2.2	5.0	5.0	11.2	7.1	15.8	8.7	19.4
	3	3.2	7.1	7.1	15.8	10.0	22.4	12.3	27.4
	6	4.5	10.0	10.0	22.3	14.1	31.6	17.3	38.7
	9	6.3	14.1	14.1	31.6	20.0	44.6	24.4	54.7
18.168	0	2.8	6.3	6.3	14.2	9.0	20.1	11.0	24.6
	3	4.0	9.0	9.0	20.0	12.7	28.3	15.5	34.7
	6	5.7	12.7	12.7	28.3	17.9	40.0	21.9	49.0
	9	8.0	17.9	17.9	40.0	25.3	56.5	31.0	69.2
21.45	0	3.3	7.5	7.5	16.7	10.6	23.7	13.0	29.0
	3	4.7	10.6	10.6	23.6	15.0	33.4	18.3	41.0
	6	6.7	14.9	14.9	33.4	21.1	47.2	25.9	57.9
	9	9.4	21.1	21.1	47.2	29.8	66.7	36.5	81.7
24.99	0	3.9	8.7	8.7	19.5	12.3	27.6	15.1	33.8
	3	5.5	12.3	12.3	27.5	17.4	39.0	21.3	47.7
	6	7.8	17.4	17.4	38.9	24.6	55.0	30.1	67.4
	9	11.0	24.6	24.6	55.0	34.8	77.7	42.6	95.2
29.7	0	4.6	10.4	10.4	23.2	14.7	32.8	18.0	40.1
	3	6.5	14.6	14.6	32.7	20.7	46.3	25.4	56.7
	6	9.2	20.7	20.7	46.2	29.3	65.4	35.8	80.1
	9	13.1	29.2	29.2	65.3	41.3	92.4	50.6	113.2

Table 5.6

		50 W Con	*50 W Unc*	*100 W Con*	*100 W Unc*	*500 W Con*	*500 W Unc*	*1,000 W Con*	*1,000 W Unc*
50, 144, 222	0	3.3	7.4	4.7	10.5	10.5	23.4	14.8	33.1
	3	4.7	10.5	6.6	14.8	14.8	33.1	20.9	46.8
	6	6.6	14.8	9.3	20.9	20.9	46.7	29.5	66.1
	9	9.3	20.9	13.2	29.5	29.5	66.0	41.7	93.3
	12	13.2	29.5	18.6	41.7	41.7	93.2	59.0	131.8
	15	18.6	41.6	26.3	58.9	58.9	131.7	83.3	186.2
	20	33.1	74.0	46.8	104.7	104.7	234.1	148.1	331.1
420	0	2.8	6.3	4.0	8.8	8.8	19.8	12.5	28.0
	3	4.0	8.8	5.6	12.5	12.5	28.0	17.7	39.5
	6	5.6	12.5	7.9	17.7	17.7	39.5	25.0	55.8
	9	7.9	17.6	11.2	24.9	24.9	55.8	35.3	78.9
	12	11.1	24.9	15.8	35.2	35.2	78.8	49.8	111.4
	15	15.7	35.2	22.3	49.8	49.8	111.3	70.4	157.4
1240	0	1.6	3.6	2.3	5.2	5.2	11.5	7.3	16.3
	3	2.3	5.1	3.3	7.3	7.3	16.3	10.3	23.0
	6	3.2	7.3	4.6	10.3	10.3	23.0	14.5	32.5
	9	4.6	10.3	6.5	14.5	14.5	32.5	20.5	45.9
	12	6.5	14.5	9.2	20.5	20.5	45.8	29.0	64.8
	15	9.2	20.5	13.0	29.0	29.0	64.8	41.0	91.6

based on duty cycle and on/off times. See the Power Averaging section of this chapter or, as a rough rule of thumb, for CW or SSB you can use 40% of your output power as a conservative estimate of average power.

- In the unlikely event that your station still doesn't pass, you should refer to the more precise tables of antennas over ground in Chapter 8 , use some of the other methods for estimating compliance or follow some of the steps described in this chapter under Correcting Problems.

Tables for Specific Antenna Types

Bulletin 65 also contains tables for specific antenna types. Table 5.8 is an example of those supplied *for Bulletin 65* by Wayne Overbeck, N6NB. These tables have been reproduced, with distances in feet, in Chapter 8. It shows the estimated compliance distance *in the main beam* of a typical specific three-element Yagi HF antenna. These tables also are based on the far-field, power-density equations, with the frequency identifying the amateur band, the antenna gains in dBi. Hams can use PEP to obtain a conservative estimate of compliance distance or use average power to obtain a more precise estimate. Select the appropriate band and "round up" antenna gain and power to match the table. The distances are the minimum separation that must be maintained between the antenna and any area where people will be exposed.

To obtain a conservative estimate using these tables, hams should follow the following steps

- Select the correct table entry for the frequency band and antenna being evaluated
- First, assume full PEP and 100% operation, then look up the compliance distance on the chart. If the antenna is located at least this far from areas of exposure in any direction, the station meets the requirements on that antenna/band combination. Figure 5.9 shows how to determine the actual distance to the antenna.
- If necessary, calculate average power, based on duty cycle and on/off times. See the Power Averaging section of this chapter or, as a rough rule of thumb, for CW or SSB you can use 40% of your output PEP as a conservative estimate of average power.
- In the unlikely event that your station still doesn't pass, you should refer to the tables of antennas over ground in Chapter 8, use some of the other methods for estimating compliance or follow some of the steps described in

Table 5.7

Typical Antenna Gains in Free Space

	Gain in dBi	*Gain in dBd*
Quarter-wave ground plane or vertical	1.0	−1.1
Half-wavelength dipole	2.15	0.0
2-element Yagi array	6.0	3.9
3-element Yagi array	7.2	5.1
5-element Yagi array	9.4	7.3
8-element Yagi array	13.2	11.1
10-element Yagi array	14.8	12.7
17-element Yagi array	16.8	14.7

Note: Use the number of active elements on each band.

this chapter under Correcting Problems.

These simple tables give conservative estimates of compliance. They estimate the required distance one needs to be from the antenna *in the main beam of the antenna* (see Figures 5.8 and 5.9).

Like many tables, the ones shown in this article and *Bulletin 65* paint with a broad brush. They provide conservative answers to generalized conditions. If you want to bolster your confidence by using more precise evaluation methods, those are certainly available to you as well.

Tables Derived from NEC Modeling

The tables just described are all fairly easy to use. In many cases, however, exposure *near* an antenna in some areas can be much less than that indicated by the far-field tables. If a station "passes" using the simple tables, this could be a moot point. Even so, some hams may find it useful to use other methods to demonstrate that the exposure from their station is much less than what the rules allow.

A number of antenna-modeling programs (see the sidebar, "Available Software") will give much more accurate estimates of field strength in the near field of an antenna. However, many hams do not have the necessary experience to use them.

The ARRL Laboratory staff came up with a solution, but it involved considerable work on their part. To provide tables for specific antennas modeled at various heights over real ground, they selected the *NEC4* software package. Using *NEC4* they modeled a number of antennas, heights and power levels and calculated the compliance distances at ground level, first story and second story exposure points. (My personal 75-MHz Pentium PC had to chew on some of these calculations for as long as four hours!—*Ed.*) The antennas were modeled over "average" ground, with a conductivity of 5 milliseimens and a dielectric constant of 13, considered as being average ground by most antenna experts. Although the regulations permit whole-body exposure averaging, these tables are generally more conservative, calculating the field strength only at specific points.

The results were distilled into tables like Table 5.9, showing the 10-meter Yagi from Table 5.8, modeled 30 feet over average ground. Figures 5.8 and 5.9 show how these tables relate to the areas being evaluated. In many cases, a station that does not pass "worst-case" can easily be demonstrated to be in compliance using these tables.

Tables such as Table 5.9 provide a more accurate estimate of actual exposure than tables such as Table 5.8, derived from the far-field power-density formula. However, the antenna and its height must match the table to be applicable. (If the antenna is located higher than the heights in these tables, the exposure should be less than the predicted values.) The ARRL offered a number of these tables to the FCC for inclusion in *Bulletin 65. Supplement B* features a number of these antennas at heights of both 30 feet *and* 60 feet, helping to demonstrate that "higher is better"! In addition to the tables originally printed in *Supplement B*, Chapter 8 of this book contains a number of tables prepared using the same method as the tables in *Bulletin 65*.

To obtain a conservative estimate using these tables, hams should follow the following steps:

- Select the correct table for the frequency band, antenna and antenna height being evaluated
- First, assume full PEP and 100% operation, then look up the compliance distance on the chart. If the antenna is located at least this far from areas of exposure, either horizontally, vertically or diagonally, the station "passes" on that antenna/band combination. Figure 5.10 shows how to determine the actual distance to the antenna.
- If necessary, calculate average power, based on duty cycle and on/off times. See the Power Averaging section of this chapter or, as a rough rule of thumb, for CW or SSB you can use 40% of your output power as a conservative estimate of average power.
- In the unlikely event that your station still doesn't meet the more precise requirements, you should refer to the tables of antennas over ground in Chapter 8 , use some of the other methods for estimating compliance or follow some of the steps described in this chapter under Correcting Problems.

You will have to use these tables to look up the compliance distance for ground level, first story and second story exposures, if applicable. The distance shown is the *horizontal* distance at the exposure height, from the center of the antenna. This is shown in Figures 5.8 and 5.9. It was calculated using *NEC4*, in the direction of the main beam of the antenna. If you are calculating worst-case exposure in the main beam, you can assume that this distance is from the tower to the exposure point. If you are calculating exposure in areas other than where the antenna is pointing, a conservative approach is to assume that these distances are from any part of the antenna.

Let's Compare

Tables similar to Table 5.8 can be used for a conservative estimate of compliance; tables like Table 5.9 show compliance under specific "real-world" conditions. Let's look at the differences between these tables.

In both tables, the maximum distances are similar. The 1500-watt distance for the 10-meter Yagi in Table 5.8 corresponds closely with the 1500-watt distance at the height of the antenna in Table 5.9. This is to be expected; Table 5.8 calculates the estimated distance in the main beam of the antenna and the *NEC4* calculation at 30 feet is in the main beam of the antenna. It can be seen in Table 5.9 that the exposure at 20 feet above ground also is in the same ballpark.

Table 5.9, however, represents a model

Table 5.8

Estimated distances (in feet) to meet RF power density guidelines in the main beam of a typical three-element "triband" (20-15-10 meter) Yagi antenna assuming surface (ground) reflection. Distances are shown for controlled (con) and uncontrolled (unc) environments.

	14 MHz, 6.5 dBi		*21 MHz, 7 dBi*		*28 MHz, 8 dBi*	
	con	**unc**	**con**	**unc**	**con**	**unc**
100	4.7	10.4	7.4	16.5	11.0	24.6
500	10.4	23.1	16.5	36.8	24.6	54.9
1000	14.7	32.7	23.3	51.9	34.8	77.7
1500	17.9	40.1	28.5	63.6	42.6	95.1

Available Software and Freeware

The calculations used to create the far-field tables have been written in BASIC by Wayne Overbeck, N6NB, and made available for download from the Web at **ftp://members.aol.com/cqvhf/97issues/rfsafety.bas**. This software also has been written into a Web-page calculator by Ken Harker, KM5FA. It can be accessed at **http://www.utexas.edu/students/utarc**.

Brian Beezley, K6STI, has made a scaled-down version of his *Antenna Optimizer* software available. Download *NF.ZIP* from the Web at **http://oak.oakland.edu:8080/pub/hamradio/arrl/bbs/programs/.** These programs are based on *MININEC* and will generally give the same results as you can obtain from using the tables derived from *NEC4* modeling. Contact Brian Beezley, K6STI, 3532 Linda Vista Drive, San Marcos, CA 92069; Telephone 760-599-4962, e-mail **k6sti@n2.net**.

Roy Lewallen, W7EL, sells *ELNEC* and *EZNEC* antenna-modeling software. *ELNEC* is based on *MININEC*, but does not have near-field capability. *EZNEC* is based on *NEC2* and can be used to predict the near-field strength. This software is available from W7EL Software, PO Box 6658, Beaverton, OR 97007; Telephone 503-646-2885; fax 503-671-9046; e-mail **w7el@teleport.com**; **ftp://ftp.teleport.com/vendors/w7el/**.

NEC2 and documentation is available from the "NEC Home—Unofficial" at **http://www.dec.tis.net/~richesop/nec/index.html**. Beware, however, that "native" *NEC* is *not* a user-friendly program. These are used best in the hands of experienced antenna modelers.

of a real antenna. In real-world conditions, the fields under an antenna do not vary smoothly. In many cases, the field directly under an antenna is *not* the maximum field to be expected! That maximum often occurs some distance away from the antenna. As the power is lowered, the level of the maximum also lowers in proportion. When the maximum field at a particular height drops below the MPE level, the compliance distance will suddenly go to 0.0 feet! This can be seen in several of the entries in Table 5.9. In comparing a number of the entries in both tables, it can be seen that Table 5.8 indicates that one must be more distant from the antenna under some circumstances than what is shown in Table 5.9.

Note that the requirements for this real model shown in Table 5.9 are in many cases much less difficult to meet than the worst-case requirements shown in Table 5.8. As you can see, things are difficult to predict in the near field. In several cases, the table takes some pretty wild jumps, as noted between 600 watts and 750 watts at the 6-foot compliance point level. This is due to the distribution of fields under the antenna; the field is actually less right under the antenna than it is some distance away. Chapter 2 has additional information about what effects can be found in the near field of an antenna.

Table 5.9

10-meter band horizontal, 3-element Yagi, Frequency = 29.7 MHz, Antenna height = 30 feet

Horizontal distance (feet) from any part of the antenna for compliance with occupational/controlled or general population/uncontrolled exposure limits

Height above ground (feet) where exposure occurs

Average Power	*6 feet*		*12 feet*		*20 feet*		*30 feet*	
(watts)	*con*	*unc*	*con*	*unc*	*con*	*unc*	*con*	*unc*
10	0	0	0	0	0	0	8	9
25	0	0	0	0	0	0	8.5	11
50	0	0	0	0	0	0	9	13.5
100	0	0	0	0	0	0	10.5	18.5
200	0	0	0	0	0	21.5	12.5	25
250	0	0	0	0	0	25	13.5	27.5
300	0	0	0	0	0	28.5	14.5	30
400	0	0	0	39	0	35	16.5	34
500	0	0	0	47	0	48	18.5	37.5
600	0	0	0	52.5	0	59.5	20	40.5
750	0	36	0	59	16.5	70.5	22	45.5
1000	0	46.5	0	67	21.5	82.5	25	61.5
1250	0	53	0	73.5	25	91.5	27.5	95.5
1500	0	58.5	0	79	28.5	99	30	108

Antenna Modeling

In *Bulletin 65*, the FCC suggests that *NEC*, *MININEC* and other computer modeling can be used to satisfy the requirements of the regulations. The software used to create the tables in Chapter 8 can model virtually any antenna system. Hams sometimes use some exotic antennas and it is not practical to create a table for each one. Some hams may want to evaluate the effect of multiple antennas or other conductors in proximity to their antennas to have a more accurate answer than can be derived from any other calculation method. In these cases, many hams will elect to use antenna-modeling software.

To use antenna-modeling program calculations, the amateur must first accurately model the antenna systems associated with his or her station. This generally requires that the location of the antenna conductors be entered into the computer program as rectangular coordinates (the horizontal and vertical positions of the end of each conductor). It is generally agreed that computer modeling using *NEC* or *MININEC* code yields accurate results under most conditions *if the model entered is accurate.* The latter point is important because this usually requires that the antenna and *all nearby conductors* be entered into the model. This would include the antenna, tower, guy wires and conductors such as electrical and telephone wiring.

A specific evaluation of RF fields in the near field of an antenna is not a simple issue. The relationship between the E and H fields is not constant in the near field, being determined mainly by the characteristics of the radiating element. Some antennas exhibit more E field than H field close to the antenna; others radiate more H field and less E field. (As these fields propagate away from the antenna, the ratio of the E to H fields converges toward the far-field value of 377 ohms.) There are a number of factors that affect the specific value of the E or H field in the near field.

These factors do not follow the classic "inverse square" law that applies to the far field of a spherical wave. Both the near field and far field additionally may contain components due to direct fields and to those that are scattered and reflected from objects and surfaces near the observer. The presence of these scatterers (both conducting and non-conducting) will affect both the near- and far-field calculations or measurements. All field values can be perturbed by nearby scatterers and surfaces, such as guy wires, power and telephone wiring inside the home of the operator or his or her neighbors.

These points are made because no *simple* calculation can yield an *exact* answer in the near field. Specific near-field calculations often require a lot of work. This is where antenna modeling comes in! The sophisticated software used in most antenna-modeling programs considers all these factors, often using computer methods just past what could reasonably be done with a human and a calculator.

Modeling programs do require some amount of user skills, although they should not be too difficult for the average ham. A list of software vendors is found in the "Software" sidebar. The ARRL Web page also maintains a list of software vendors who sell antenna modeling software. See **http://www.arrl.org/news/rfsafety/**.

General Considerations

Once you have selected an appropriate antenna-modeling program, you can consult the users manual and/or the vendor for specific applications information. In general terms, using antenna-modeling software is relatively easy. First enter the parameters for your antenna. This will include the location of all conductors in your antenna, element diameter, feed point, loading coils and traps, etc. As discussed in the section "Real World Considerations," you may want to include nearby conductors (tower, guy wires, telephone and electrical wiring, etc) in the model to have the most accurate possible estimate. You should be able to use the program to verify that the model is accurate. If you see an antenna pattern and antenna gain and feed point SWR or impedance that is reasonable for the antenna type, you have probably done it right. Most of the programs come complete with example models for common antenna types. Of course, this will not help with some of the unusual antennas hams are known to use, although they will serve as good examples of how to model antennas in general.

When you have the model right, use the program's "near-field" capability to calculate the electric (E field) and magnetic (H field) in those areas you want to evaluate. Input the *average* power of your station in a 6-minute period for controlled exposure, and in a 30-minute period for uncontrolled exposure. (See the discussion under "Average Exposure" earlier in this chapter.) In most programs, this is done by specifying a line and calculating the field along that line in the increments you specify. For a Yagi antenna, calculating the near field, starting at a point directly below the antenna in a horizontal direction in the main beam would probably be most useful. This can be done at various heights above ground, to determine ground level exposure and the exposure to nearby buildings.

The near-field analysis capability of most of these programs shows the field value for each of the points and increments you have specified. You can then compare these results with the MPE limit. It is safe for people to remain indefinitely in all areas that are below the MPE limit for the operating mode, power and on/off times you used to determine your average power. The ARRL tables in *Supplement B* show the *farthest* compliant distance. For some antenna configurations, however, it is possible that some areas *closer* to the antenna might be in compliance. An example of this is shown in Figure 5.10. The only way to know exactly what areas are above or below the limit is to use the near-field model.

Measurements

While amateurs are not required to specifically measure the field strength from their station operation, the FCC would consider accurate measurement to be a valid method of complying with the regulations. However, most amateurs will not need to make measurements to perform a routine station evaluation.

Some hams, however, might *choose* to make actual measurements of the electric and magnetic field strengths around their antenna while they are transmitting a signal. If you happen to have a calibrated field-strength meter with a calibrated field-strength sensor, you can make accurate measurements. Unfortunately, such calibrated meters are expensive and not normally found in an amateur's tool box.

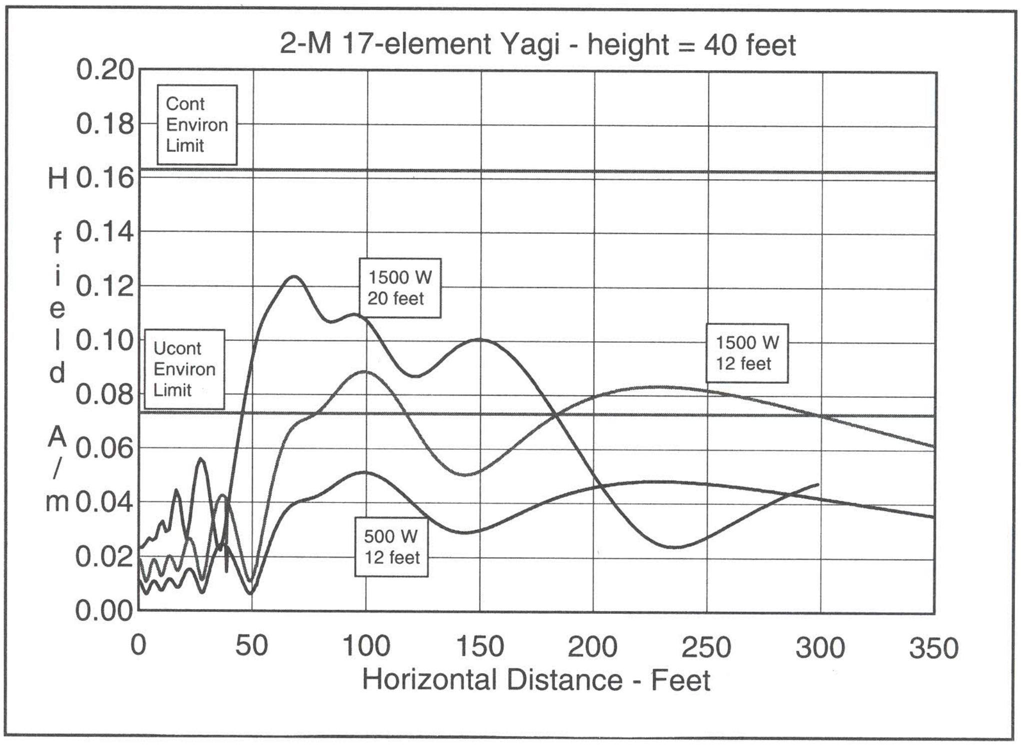

Figure 5.10—This plot shows the way the H field varies under an antenna. The X axis represents the horizontal distance from the center of the antenna in the main beam. Note that the field reaches a peak some distance in front of the antenna.

The relative field-strength meters many amateurs use are not accurate enough to make this type of measurement.

Making field-strength measurements, especially in the near field of an antenna, can be tricky. Measurements require accurate calibrated equipment, calibrated E and H-field probes and a sound understanding of the proper use, and limitations, of the equipment involved. Fortunately, the FCC regulations do not require actual field-strength measurements.

Measurements are one way to perform an analysis, but they're very tricky. With calibrated equipment and skilled measuring techniques, ±2 dB error is pretty good. In untrained hands, errors exceeding 10 dB are likely. A ham who elects to make measurements will need calibrated equipment (including probes) and knowledge of its use. Many factors can confound measurements in the near field. In most cases, various calculation methods, especially computer antenna modeling, can give results that are more accurate—if the model is right.

Usually you need to use a calibrated field-strength meter to make accurate measurements. These come in two varieties—tuned and wideband. Most of the instruments available are broadband devices. A broad-bandwidth instrument used to measure RF fields is calibrated over a wide frequency range, and responds instantly to any signal within that range. The nice thing about a wide-bandwidth instrument is that it requires no tuning over its entire operating range. Broad-band instruments offer some significant advantages—one can enter an RF environment and not have to carefully adjust the instrument for a peak response. They can be tricky to use in other ways, though, because the response of the probes used often varies with frequency, so one would have to have some knowledge of the signals present. In multiple-transmitter environments, it may not be possible to obtain an accurate measurement with some broad-band instruments. Other, more sophisticated instruments have compensation networks built in, tailored to match the frequency variation of any particular standard or regulation. With these instruments, you get a reading in a multiple-transmitter site that does not need to consider the frequencies involved. The instrument automatically compensates, and expresses the reading as a total of the permitted MPE level.

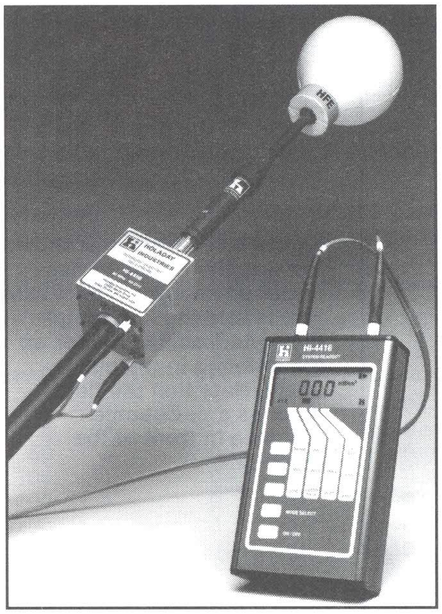

Figure 5.11—This calibrated field-strength meter and probes can be used to make measurements of the fields near a radio transmitter. *(Photo courtesy of Holaday Industries, Inc.)*

A narrow-bandwidth instrument, on the other hand, may be able to cover a wide frequency range, but would have a bandwidth of perhaps only a few kilohertz at any instant. You have to tune the instrument to the particular frequency of interest before making your measurements. Narrowband, tunable instruments can overcome some of the problems inherent with simple broadband instruments, although they are often a bit more complex to use. In essence, these are calibrated receivers. If the characteristics of the probe are known, the field-strength level can be determined directly for each frequency being measured.

All these instruments are used in conjunction with calibrated E-field, H-field or power-density probes. E-field probes generally consist of multiple short dipoles, mounted at right angles to each other to read E fields of any polarity. An H field-probe similarly consists of multiple small loops, mounted at right angles to read H fields of any polarity. A well-designed E- or H-field probe will have the response of the "wrong" field that is at least 20 dB less than the desired response. Power-density probes are usually thermocouple devices. One significant disadvantage of thermocouples is that they can be damaged by fields that are significantly higher than what they are designed to measure. They can sometimes be damaged even if the measurement instrument is not turned on, so they are generally used only in those areas where the test engineer has some knowledge of the strength of the RF energy.

To use most of these instruments, one needs to consider the overall accuracy and frequency response of the instrument, the accuracy and frequency response and orientation of the probes, and the interaction of the fields with nearby objects, the test equipment or the test engineer. Some test engineers have cited accuracy and repeatability of 6 dB as being typical. Others have noted that with "heroic" precautions taken, it is possible to obtain an accuracy of 1 dB. But this often consisted of taking and averaging multiple readings, setting the instrumentation on a small table and having the operator walk away and look at the reading through a pair of binoculars!

Even if you do have access to a laboratory-grade calibrated field-strength meter, you must be aware of factors that can upset your readings. Reflections from ground and nearby conductors (power lines, other antennas, house wiring, etc) can easily confuse field-strength readings. For example, if the measuring probe and the person making the measurement are located in the near-field zone, they can both interact with the antenna fields. In addition, you must know the frequency response of the test equipment and probes, and use them only within the appropriate range. Even the orientation of the test probe with respect to the test antenna polarization is important.

Why should we be concerned with the separation between the source antenna and the field-strength meter, which has its own receiving antenna? One important reason is that if you place a receiving antenna very close to an antenna when you measure the field strength, *mutual coupling* between the two antennas may actually alter the radiation pattern from the antenna you are trying to measure.

Actual measurements are best left to the professionals. In untrained hands, the errors can mount up fast. Some instruments just do not have the needed accuracy and consistent frequency response. If a ham, or the neighbor of a ham, uses these "instruments" to do field-strength measurements, the results are apt to be so far off as to cause undue alarm, of give a false sense of security.

It should be mentioned that many of the field-strength meters, especially the inexpensive ones, give only a relative field-strength measurement. Many of them have probes with a response that varies with frequency and is non-linear with power level. Most of these inexpensive instruments measure either the relative E field or H field. Although they may be calibrated in power-density units, they are really reporting the approximation of power density represented by equivalent plane-wave power density, usually for just one field component. For purposes of complying with these regulations, uncalibrated field-strength meters should be avoided.

Formulas

Most of the methods that hams will use to complete their station evaluations involve some form of calculation. The results of these calculations can be compared with the MPE limits. The tables published in Chapter 8, *Bulletin 65* and *Supplement B*—were derived from various calculational methods. Even the tables derived from computer modeling involved calculations, except in that case, the calculations were done by the computer. Fortunately, for those hams who want to "homebrew" their own evaluation, the equations involved are all quite straightforward. A knowledge of square roots and simple algebra is all that is required.

While most hams will probably prefer to use one of the table or software methods to estimate compliance, the power-density equations contained in *Bulletin 65* may be useful in some cases. The "basic" power density equation in *Bulletin 65* is shown in Eq 5.4:

$$S = \frac{PG}{4\pi R^2} \qquad \text{Eq 5.4}$$

where S = the power density, G = the numerical gain of the antenna in dBi expressed as a decimal number, R = the distance from the center of radiation and P = power input to the antenna. This is the equation for power density *in free space*. It will give the power density for areas located "R" distance away from the center of the antenna, in the main beam of the antenna. It assumes that all areas being considered are in the far-field region (see Chapter 2), a reasonable *approximation* for estimating compliance for most antenna types.

S, P and R must be expressed in the same units. S is the power density per square unit. If S is in milliwatts per square centimeter, then P must be in milliwatts and R must be in centimeters. G is the gain of the antenna, expressed as a decimal, not in dB. To convert the gain in dBi to a decimal number, use Eq 5.5 or consult Table 5.10.

$$G = 10^{dB/10} \qquad \text{Eq 5.5}$$

where G is the numerical gain of the antenna whose gain is expressed in dBi.

Most antennas are not in free space; they are located above ground. Placing an antenna above ground modifies the pattern such that the main beam of the antenna contains more energy than it would in free space. This is known as *ground gain*.

If an antenna is placed over a perfect ground, Eq 5.6 can be used to calculate power density. This formula assumes 100% reflection of the E and H fields from an infinite, perfect ground plane under the antenna.

$$S = \frac{PG}{\pi R^2} \qquad \text{Eq 5.6}$$

where S = the power density in mW/cm^2, G = the numerical gain of the antenna in dBi expressed as a decimal number, R = the distance from the center of radiation in centimeters and P is the power input to the antenna in milliwatts.

In reality, however, actual surface reflections are never 100% efficient. Various factors and losses reduce the actual reflection. The Environmental Protection Agency has made a recommendation that Eq 5.7 be used to estimate actual ground reflections under real-world conditions:

$$S = \frac{0.64\,PG}{\pi R^2} \qquad \text{Eq 5.7}$$

where S = the power density in mW/cm^2, G = the numerical gain of the antenna in dBi expressed as a decimal number, R = the distance from the center of radiation in centimeters and P = power input to the antenna in milliwatts.

If you know the power to your antenna, the gain of your antenna and the distance to any area for which you want to know the power density, these formulas can give a reasonable estimate. They tend to be conservative in the near field of an antenna, where one might be close to only part of the antenna.

As an example of the use of these formulas, assume a 1000 watt transmitter is operating into an antenna system with 3 dBi of gain. (To keep it simple, assume the feed line is lossless.) If you want to know the exposure at a point that is 20 feet from the center of the antenna, expressed in mW/cm^2, with the EPA ground-reflection factor, use Eq 5.7. First convert the 1000 watts to 1,000,000 milliwatts, convert 20 feet to 609.6 centimeters and convert 3 dBi gain to 2.0. The solution then is:

$$S = \frac{0.64 * 1{,}000{,}000 * 2.0}{3.14 * 609.6^2} = 1.097\,mW/cm^2$$

Feet!

All this converting from feet to meters can get tedious. Here are a few variations on the equations, expressing P in watts, R in feet, using the ground-reflection factor of Eq 5.7. In the equations that follow, all the conversion, square root and π factors have been considered in simplifying the formula.

$$S = \frac{0.219\,PG}{R^2} \qquad \text{Eq 5.8}$$

Eq 5.8 will give the power density in mW/cm^2 if P is in watts, R is in feet and G is the antenna gain expressed as a decimal number.

Perhaps the most useful derivation of these equations is one that tells you how far away from a particular antenna and power people must be for a given power density S.

$$R = \sqrt{\frac{0.219\,PG}{S}} \qquad \text{Eq 5.9}$$

where S = the power density in mW/cm^2, G = the numerical gain of the antenna in dBi expressed as a decimal number, R = the distance from the center of radiation in feet and P = power input in watts.

Another variation on this theme is shown in Eq 5.10. This formula lets you input your antenna gain (G), the distance to the antenna (R) and the power-density limit and determine the maximum allowed *average* transmitter power.

$$P = \frac{SR^2}{0.219\,G} \qquad \text{Eq 5.10}$$

where S = the power density in mW/cm^2, G = the numerical gain of the antenna in dBi expressed as a decimal number, R = the distance from the center of radiation in feet and P = power input in watts.

Eq 5.8, 5.9 and 5.10 can be helpful in a number of ways. If you run 500 watts average power and have a 10-meter dipole (2.15 dBi, G = 1.64) located 20 feet from

Table 5.10
dB to Decimal Number Gain Conversion Table

dB	*Gain*	*dB*	*Gain*	*dB*	*Gain*
0.0	1.00	5.5	3.55	12.0	15.84
0.5	1.12	6.0	3.98	13.0	19.95
1.0	1.26	6.5	4.47	14.0	25.12
1.5	1.41	7.0	5.01	15.0	31.62
2.0	1.58	7.5	5.62	16.0	39.81
2.5	1.78	8.0	6.31	17.0	50.12
3.0	2.00	8.5	7.08	18.0	63.10
3.5	2.24	9.0	7.94	19.0	79.43
4.0	2.51	9.5	8.91	20.0	100.00
4.5	2.82	10.0	10.00	22.0	158.49
5.0	3.16	11.0	12.59	25.0	316.23

an upstairs bedroom in your neighbor's home, you can use Eq 5.8 to calculate that the power density is 0.49 mW/cm^2. Unfortunately, the uncontrolled MPE limit on 10 meters is 0.2 mW/cm^2, so this is not in compliance for 500 watts of average power. You can then use Eq 5.9 to calculate that you would be in compliance if you move your antenna 30 feet away. You also could use Eq 5.10 to calculate that if you reduce your average power to 222.7 watts, you are in compliance.

Last but not least, because the MPE power-density level is frequency dependent, equations can be derived that include the frequency. For MF/HF *only*, the following formula can be used to calculate the required compliance distance in feet:

$$R = 0.03049 \sqrt{PG} \qquad \text{Eq 5.11}$$

Where R = the required minimum distance from the antenna in feet, P = power input to the antenna in watts and G = the gain of the antenna in dBi expressed as a decimal number. This formula has been simplified to remove all the feet-to-centimeter conversions, the watts to milliwatts conversions, π and square roots of fixed numbers.

All these formulas generally give conservative results. They are assuming that the distances involved are in the main beam of the antenna. In the examples given, the actual exposure could well have been in areas below the antenna, which generally give less exposure than areas at or slightly above the antenna. Although these examples showed the proper and easy use of the formulas, a better alternative might have been to use the antenna-over-ground tables in Chapter 8. FCC *Bulletin 65* features a number of variations on some of these formulae. Figures 1 and 2 in *Bulletin 65* show these formulas graphically. The formulas and graphs are reprinted in Chapter 6.

E to H to Power Density Formulas

The MPE limits in the regulations are called out in E-field, H-field and power density or plane-wave equivalent power density. The formulas above, however, all manipulate the power-density, distance, transmitter power and antenna gain. There is a relationship between power density and the two fields that applies perfectly in the far field, and may apply reasonably well in the near field. (This is discussed in more detail in the Antenna Fundamentals chapter.)

Once S has been calculated, the E and H fields can be determined. E can be calculated in volts per meter (V/m) by the formula:

$$E = \sqrt{3770S} \qquad \text{Eq 5.12}$$

where E is in V/m and S is in mW/cm^2

H can be calculated in amperes per meter (A/m) by the formula:

$$H = \sqrt{\frac{S}{37.7}} \qquad \text{Eq 5.13}$$

where H is in A/m and S is in mW/cm^2

The values of S, E and H, if applicable, can be compared to the values in the MPE limit tables in the rules.

This calculation is only valid in the far field of the antenna. In the near field the relationship is not this simple. This calculation may prove useful to you as you analyze your station for compliance with the FCC MPE limits. If you know the E or H field strength at some point in the far field then you can calculate the other value at that same point.

If a steady carrier level were used in all these formula evaluations, the station being evaluated at that power level and frequency can be operated into the antenna used in the calculation at 100% duty cycle (CW key down). It will have the MPE calculated at the distance used for the calculation. Any points more distant than this point also will be in compliance with the regulations. If PEP is used in the calculations, no additional calculations need to be made for this frequency, power level, antenna and exposure locations, assuming that the point has been calculated for the nearest points of exposure. This calculation is good for any operating mode for an indefinite exposure. Repeat this calculation for other bands, power levels and antennas, assuming that the points being calculated are in the far field of the antenna in question.

The formulas also can be used for average exposure, using power averaged over the appropriate averaging time, as described elsewhere in this chapter. *Bulletin 65* contains additional formulas, including a number of them for parabolic reflectors and other aperture antennas. These formulas have *not* been reproduced in the condensation of *Bulletin 65* that appears in Chapter 6. Contact the FCC for information about how to obtain a full copy of *Bulletin 65*, or go to their Web page at **http://www.fcc.gov/oet/info/documents/bulletins/#65**.

Using Graphs to Evaluate RF Exposure

It is possible to create graphs of field strength or power density based on computer analysis or other calculations. Figure 5.13 shows one such graph. The Novice and Technician class question pools contain questions about such graphs. The figure represents a beam antenna, such as a Yagi, that you might use with your amateur station. Some people might find it easier to read such graphs than search through the data in a table or use formulas. Each antenna type requires its own graph, so you still may have to search through many drawings to find the one that best describes your station. Graphs such as these have been included in *Bulletin 65*.

The power density of Figure 5.13 represents the signal in the main beam of this antenna. It is expressed for various levels of effective radiated power (ERP). ERP takes the antenna gain into account. For example, if you are using an antenna with 10 dBd of gain, and your transmitter produces 100-watts PEP output, then you would use the 1000-W ERP line. If you use only 10-watts PEP output with this antenna then you would use the 100-W ERP line.

Suppose you want to know the power density at a point 10 meters from your antenna when you have 1000-W ERP. Point 1 on this graph conveniently locates the 10-meter distance on the 1000-W ERP line of the graph. Now look to the axis along the left edge of the graph and read the power density. If you judged the value to be about 0.35 mW/cm^2 you would be pretty close.

Of course your evaluation is not complete at this point. Now you will have to determine the MPE limits for controlled and uncontrolled environments at your operating frequency. For a signal in the VHF range (30 to 300 MHz), the controlled environment power density limit is 1.0 mW/cm^2, so the power density at 10 meters is below this limit. For an uncontrolled environment, however, the power density limit is 0.2 mW/cm^2, so you will have to increase the distance to meet this limit.

To find the distance for this uncontrolled environment limit, you should find 0.2 mW/cm^2 on the power density axis, and look across to the right until you come to the 1000-W ERP line. You should come to point 5 on this graph. Now look down to the distance axis, and you should estimate that at about 15 meters you will meet the uncontrolled limit.

As you can see, a graph like this one can be quite helpful in evaluating the RF exposure from your station at various distances and ERP levels. They have been reproduced in Chapter 6 of this book, the partial reprint of *Bulletin 65*.

Antenna Patterns

All the evaluation methods discussed so far evaluate exposure in the main beam of the antenna, either at the height of the antenna as a worst-case, or at specific

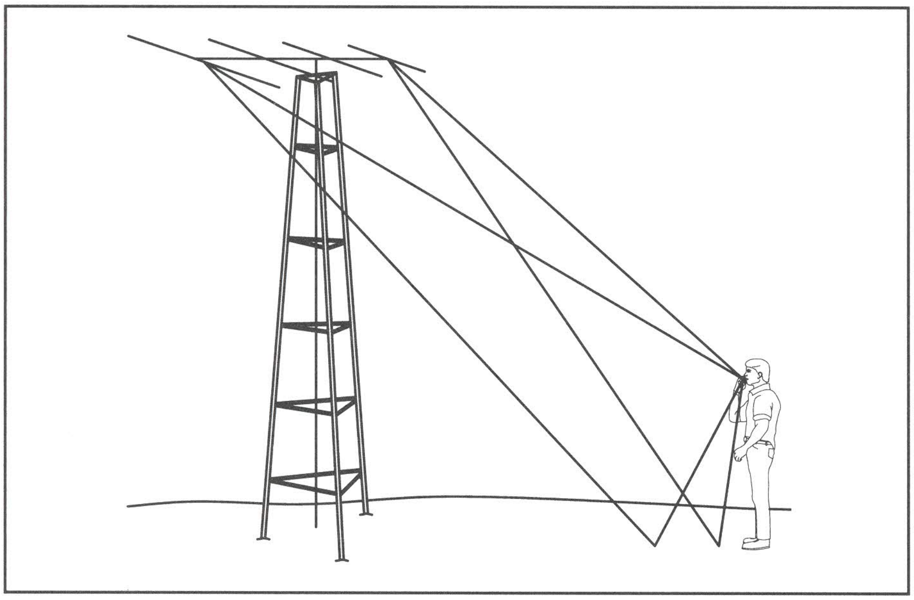

Figure 5.12—The signal on the ground results from a combination of all the signals arriving at the observer. In this case, signals from different parts of the antenna arrive directly, along with signals reflected from the ground. Each arrives in a phase relationship dependent on the relative lengths of the paths involved. These signals can add or subtract to varying degrees an any particular point.

heights in the direction the antenna is pointing. The actual field strengths will be maximum in the main beam of the antenna, and less in other directions. In most cases, amateurs will evaluate either simple antennas, such as dipoles, that are more or less omnidirectional, or rotatable antennas that can be pointed in any direction. In either case, evaluating in the main beam of the antenna is appropriate.

In other cases, though, especially with non-rotatable antennas, it may be helpful to consider how the fields vary near an antenna with the pattern of the antenna. This may help determine that a particular area has fields that are below the applicable MPE limit.

You can use the published pattern of an antenna to some degree when calculating exposure. Figure 5.14 shows the free-space radiation pattern of a 3-element Yagi antenna. At first you might believe that you should use the "above ground" pattern to evaluate the exposure potential of an antenna above ground. Unfortunately, this is not valid. Antenna patterns are derived in the far field—very far away from the antenna. At great distances, the rays from various parts of the antenna, reflected off ground, add up in or out of phase to form a pattern when the signal strength is plotted on a graph. Things are not nearly so precise in the near field, where one can be much closer to one element in an array than another. In this case the angles between the antenna and ground, and the observer and ground, are much different than they are very far away from the antenna. The far-field pattern of that antenna would indicate that there is *no* energy below the antenna at all, a conclusion that is not borne out by computer modeling of the near field.

The free-space pattern of Figure 5.14 does demonstrate that *some* energy is directed downward. Figure 5.12 shows that an observer on the ground will "see" two signals from the antenna—a direct signal and one reflected off ground. Depending on the relative path length of the two signals, they could arrive at the observer in or out of phase. If they are in phase, they will add—the reason that a *ground reflection factor* was included in all the tables. It can be seen, however, that the pattern shows that the amount of signal directed downward is not as much as is found in the main vertical lobe of the antenna. This pattern can be used with some reliability to predict the amount of energy directed downward.

Most antenna patterns use a decibel scale. The reference level is usually set to the point of maximum gain, and is usually set at 0 dB. You can look at the pattern and determine by how much the energy is reduced in a particular direction, and apply that to the evaluation process. For example, the point marked "A" on Figure 5.14 or 5.15 is about 12 dB less than it is in the main beam. If you want to evaluate exposure *in that direction,* you can reduce the amount of power used in the calculation by that amount and use the tables or formulas to estimate compliance. You can use the formulas and tables featured earlier in this chapter to determine how much to reduce the power for any particular reduction in dB. Some antenna patterns may have a decimal number scale instead of a dB scale, so look carefully.

This process does have its limitations,

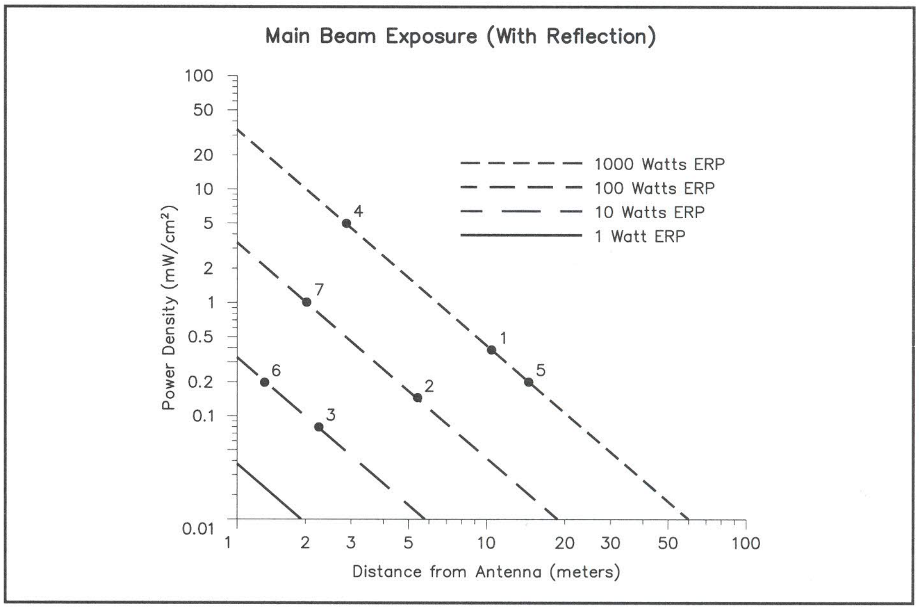

Figure 5.13—Using computer analysis or other calculations, it is possible to crate a graphical display of the field strengths and power densities for various antennas and transmitter power levels. This graph represents the power density in the main beam of an antenna such as a Yagi. Various effective radiated power (ERP) levels are given. ERP takes the antenna gain into account, referenced to a halfwave dipole in free space.

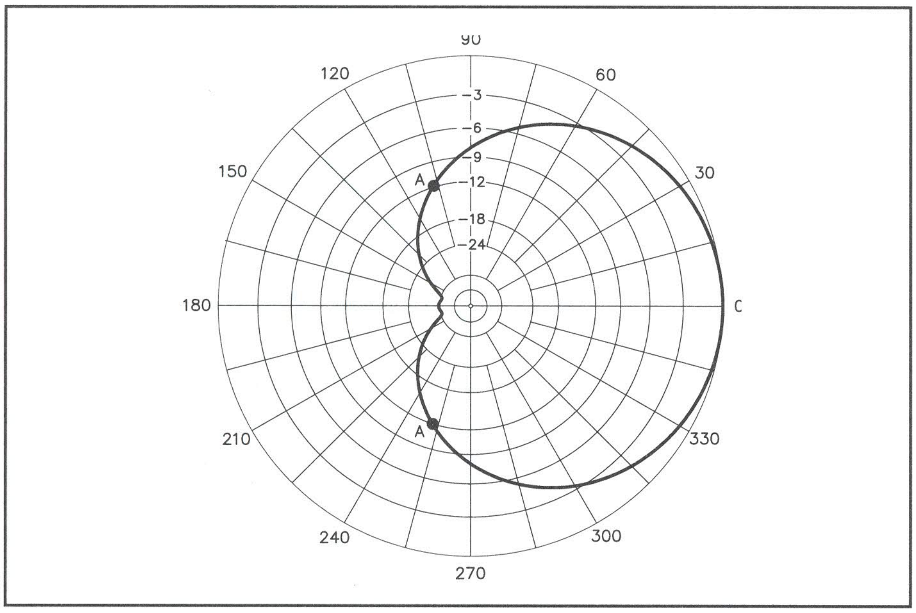

Figure 5.14—This is the free-space elevation pattern of a typical Yagi antenna. Less energy is directed downward toward the ground than in the main beam of the antenna. This is looking at the antenna from the side.

however. The patterns are derived from a far-field analysis that doesn't apply perfectly in the near field. This is especially true for the deep nulls that exist in some antenna patterns; you really can't count on their being present to that extent in the near field. Even the other areas of the pattern do not apply perfectly in the near field. However, according to the FCC in *Bulletin 65*, the patterns can be used with some degree of confidence. A good rule of thumb is that pattern nulls exceeding 15 dB or so are suspect, and probably should not be used without some modification.

Multi-transmitter Sites

The term "multi-transmitter site" applies to multi-transmitter amateur stations, such as are used in some contests, and to commercial sites, such as the mountaintop location of some amateur repeaters. Some amateur stations use multiple transmitters, such as an HF DX or contest station that also accesses a VHF PacketCluster. Other stations might be located at sites also occupied by transmitters in other radio services. Two or more transmitters could be operating at the same time, each adding to the exposure level. In these cases, the operators must take steps to ensure that the *total* exposure does not exceed the MPE level.

The rules are intended to ensure that operation of transmitters regulated by the FCC doesn't result in exposure in excess of MPE limits. It is fairly easy to make this determination for single transmitters when there are no other sources of RF to complicate things. However, many transmitters operate in proximity to other transmitters. It is entirely possible for two or more transmitters to be below their own limits, but the total exposure from all operating together to be greater than the permitted MPEs.

The FCC regulations cover this very likely situation. In most cases, all the significant RF transmitters operating at multi-transmitter sites generally must be considered when determining if the site's total exposure is in compliance. All significant emitters are jointly responsible for overall site compliance. The antenna tables elsewhere in this article cannot be used to determine actual power-density levels, as will be required to evaluate most multi-transmitter sites. The field-strength formulas in this article and in *Bulletin 65* or various antenna-modeling programs can be used instead.

At multi-transmitter sites, all significant contributions to the RF environment should be considered—not just those fields associated with one specific source. To this end, the FCC has determined that any transmitter that operates at an exposure level greater than 5% of the power density *permitted to its own operation* is jointly responsible *with all the other operators within its exposure area* who also exceed 5% for site compliance. In those areas where the exposure from the transmitter is less than 5% of the MPE level, the operator is not jointly responsible. Note that this is *not* the same as 5% of the total exposure power density, which could sometimes be unknown to any single transmitter at the site. This actually covers a lot of small stations like amateur repeaters, although a station evaluation may be required to demonstrate that the exposure is below the 5% threshold.

Categorical Exemptions Again

The FCC doesn't expect all low-power transmitters necessarily be responsible for site compliance at sites where they contribute only a tiny fraction of the total RF energy. The rules limit the responsibility of some operators at the site. In those areas where the exposure from a transmitter or system is less than 5% of the MPE level permitted to that transmitter, the operator

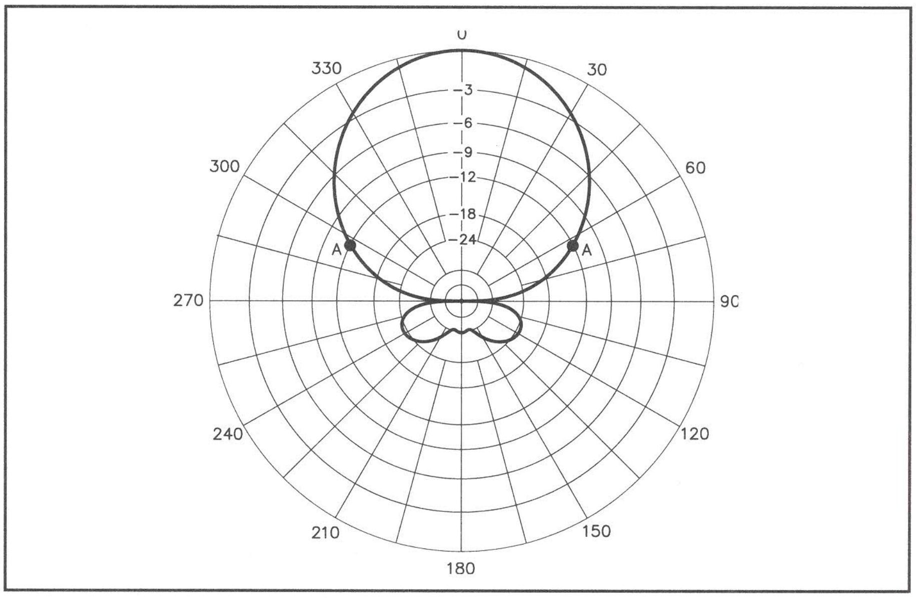

Figure 5.15—An azimuth pattern of a typical Yagi antenna. This is a bird's-eye view of the antenna.

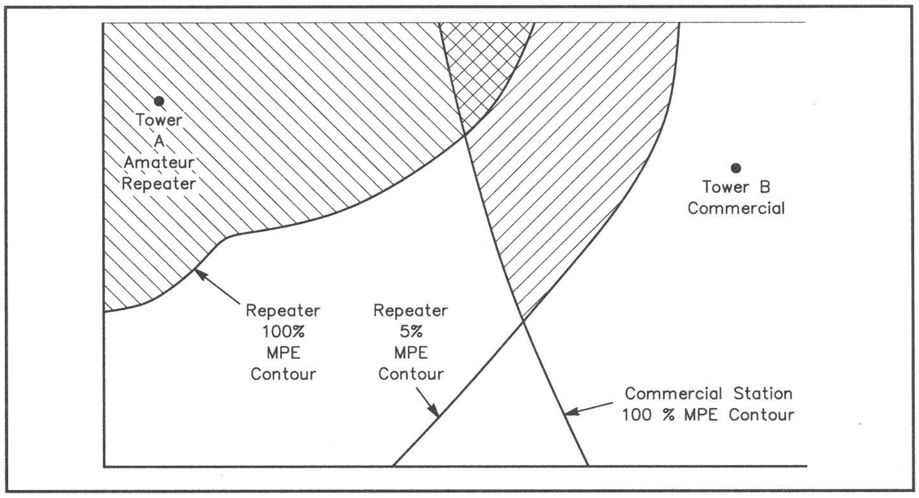

Figure 5.17—A bird's eye view of a rooftop installation. The line marked "5% contour" shows the area in which the exposure exceeds 5% of that permitted to the amateur repeater located on tower "A." The "100% contour" shows the area that is above the MPE limit for either the repeater or the transmitter on the adjacent tower "B." Under these circumstances, the amateur operator is solely responsible for the area with the diagonal cross hatch because it exceeds the MPE limits for the repeater station. The areas within the other 100%-contour boundary are out of compliance for the transmitter on tower "B." The amateur operator is, however, also jointly responsible for the overall compliance within the area with the double cross hatch because the repeater's contribution to overall exposure is greater than the 5% permitted to the repeater.

is generally not jointly responsible with the other operators on the site for overall site compliance.

For example, the controlled power-density MPE limit for a 146-MHz transmitter is 1.0 mW/cm^2. If that transmitter were operating alone, the operator would have to ensure that no one was exposed to a power density greater than that, averaged over 6 minutes. (A controlled environment was selected for this example because most repeater sites are not open to the general public.) This exposure would normally occur only close to the antenna, with rooftop exposure being considerably less than this. Let's assume that the exposure on the rooftop near the amateur antenna's tower is 0.1 mW/cm^2, well within the limits. Twenty-two feet away from the tower base, the power density from the amateur repeater drops to 0.05 mW/cm^2. This is 5% of the exposure permitted for a 146-MHz transmitter.

However, if another transmitter starts operating at the site, things may change. Let's assume that three different 156-MHz commercial stations also share the site. The controlled limit for this frequency also is 1.0 mW/cm^2. Let's assume that the rooftop exposure for each station is 0.98 mW/cm^2. This also is just within the MPE limit, as long as only one transmitter is on at a time. If one transmitter and the amateur station are transmitting for the full 6-minute exposure period (likely with an amateur repeater), the total field would be 1.08 mW/cm^2. This is over the MPE limit *if people are present on the rooftop.* In this case, the amateur licensee, even though the repeater is only contributing a small part of the field, would be responsible for site compliance in all areas of the site where the repeater exceeds the 5% MPE level, or 0.05 mW/cm^2. In this case, the amateur licensee would be responsible for areas up to 22 feet from the tower base, under the conditions stipulated in the previous paragraph. Even if other transmitters on the site made the areas farther away even more non-compliant, each licensee is responsible only for their 5% areas.

Calculating Total Site Exposure Levels

The example just cited was an easy one; both transmitters operated between 30 and 300 MHz, where the controlled MPE limit is constant at 1.0 mW/cm^2. In this case, one can simply add up the MPE levels and obtain the total exposure. In many cases, though, the involved transmitters could be operating on frequencies with different MPE limits, such as an amateur repeater used in the earlier example on 146 MHz sharing a site with a TV transmitter on 600 MHz. In this case, the controlled MPE limit for the 146 MHz transmitter is 1.0 mW/cm^2; the controlled MPE limit for the 600 MHz transmitter is 2.0 mW/cm^2. (The MPE limit increases for frequencies higher than 300 MHz.)

Even in cases where transmitters are operating on different frequencies, with different MPE limits, it is relatively easy to calculate total exposure at multi-transmitter sites. The antenna tables elsewhere in this article cannot be used to determine actual power-density levels. The field-strength formulas in this article and in *Bulletin 65* or various antenna-modeling programs can be used instead. For any point being evaluated, determine what percentage of the permitted MPE will actually be encountered for each transmitter. Then, add up the percentages for any transmitters that could be in operation simultaneously. If the total percentage exceeds 100%, the site is not in compliance. For example, if a 2-meter transmitter creates exposure at 40% of what is permitted on that frequency, and a simultaneous transmission is occurring by a 1.5-GHz commercial transmitter at the same site at 70% of the limit, the total is 110%. This site is out of compliance, even though each transmitter is being operated below its own limit.

To determine overall exposure when different frequencies are involved, first convert the exposure to a percentage. In the case of the 146-MHz repeater and the 600-MHz TV station, assume that at the base of the tower, the 146-MHz exposure is 10% of its permitted MPE. If the TV station creates an exposure of 1.9 mW/cm^2 at the base of the tower, this is 95% of the permitted MPE for that transmitter. If you add up the two percentages, you have the total exposure. In this case, the total is 105%, and the area below the tower is not compliant if both transmitters are on *and* people remain in that area for the 6-minute controlled environment averaging period. The 146-MHz MPE in the area next to the

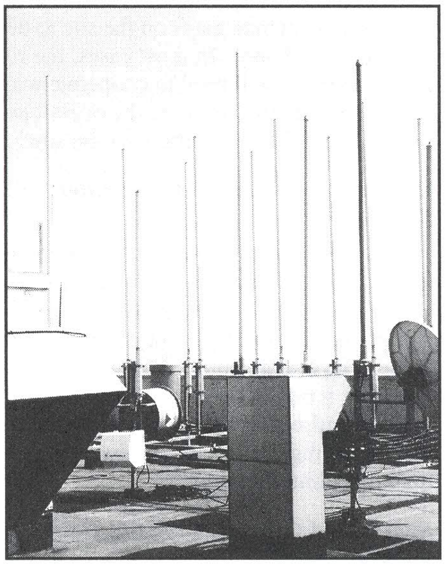

Figure 5.16—This multiple-transmitter site can be difficult to evaluate! *(Photo courtesy Robert Cleveland, FCC Office of Engineering and Technology)*

tower is 10% of what is permitted on 146 MHz. This exceeds 5%, so the repeater operator is jointly responsible for site compliance.

This would be equally true even if the 600-MHz TV transmitter were creating a power density of 10 mW/cm^2, which would be at 500% of the permitted limit. The 146-MHz transmitter operator would still be responsible for areas where its own MPE was greater than 0.05 mW/cm^2—5% of the MPE permitted to a 146-MHz transmitter. If in this case the repeater was operating on a 1.2 GHz repeater with a power density of 0.1 mW/cm^2 at the base of the tower, the MPE from the 1.2 GHz repeater is 2.5% of the MPE level permitted at that frequency. Strictly speaking, only the TV station operator is responsible for site compliance. The amateur should certainly help out, if possible. If a site were missing compliance by only a few percent and the amateur could move the repeater antenna higher up the tower, that would certainly be a "neighborly" gesture. Likewise, the amateur should share the results of the station evaluation with other operators on the site, to help them determine if the overall site is not in compliance.

Not Included

In general, all major emitters at a site should be considered when determining overall site compliance. However, the FCC has clarified that in most cases, those stations whose MPE levels are less than 5% of the permitted level need not be considered when determining overall site compliance. Likewise, those stations that are categorically exempt from evaluation generally do not need to be considered, either. In both cases, the stations that are exempt, or less than 5%, are *presumed* not to be a factor.

In the case of the 146-MHz repeater discussed earlier as an example, the power density from the repeater does not need to be considered past 22 feet from the base of the tower. At this point the exposure level drops below 5% of the MPE level permitted on 146 MHz. In the case of the 1.2 GHz repeater, its exposure does not need to be included in any calculations on the rooftop, because its exposure level is below the 5% level.

However, some types of stations, such as amateur repeaters using less than 500 W ERP, do not need to be evaluated. In addition, however, those stations that are not required to be evaluated generally are *presumed* not to be responsible for site compliance. Amateur repeaters using less than 500 W effective radiated power (ERP) and those whose antennas are not mounted on buildings and are located 32.8 feet (10 meters) or higher above ground, generally do not need to be evaluated. These stations are not usually included in determining overall site compliance.

These exclusions, however, must be considered in the overall context of the FCC's main goal—that people not be exposed to RF energy above the limits. If there were 20 stations all operating at 5% of the limit on a particular site, and another operating at 10% of the limit, the total would be 110%. If each of the "5%" stations was not considered, and the 10% station claimed that the site was at 10%, the error would be quite large. Although the specifics of the rules would indicate that no one is responsible, other parts of the rules do permit the FCC to require stations that are otherwise exempt to conduct evaluations. Amateurs should consider carefully whether circumstances might make it helpful to evaluate an operation that is otherwise categorically exempt.

Keep in mind, too, that although some of our examples show that rooftop exposure was below 5%, as one gets closer and closer to an amateur antenna, the 5% threshold (and the MPE limit threshold) sooner or later may be crossed. In most cases, an amateur repeater will have *some* areas of responsibility on any site, even if that responsibility extends only to areas on the tower. In many cases involving an Amateur Radio transmitter, only a very small area would be encompassed by that 5%. Joint responsibility might only exist in the immediate vicinity of the amateur antenna.

A repeater trustee, for example, might have that 5% level extend only to those areas up to 10 feet below the antenna, and thus be responsible for overall site compliance only to that area. In this case, the responsibility may be only to radio service personnel climbing the tower, and generally a controlled exposure environment would apply. However if tower maintenance people (who may or may not be trained about RF exposure) are present, an uncontrolled environment may be more appropriate.

The FCC can require any operator to conduct an evaluation if they believe that there could be a problem. *Bulletin 65* clarifies that these stations are presumed to be in compliance with their own individual MPE limits and generally do not need to be included when calculating overall site compliance. These are generally presumed not to be jointly responsible for site compliance. However, these are *not* ironclad assumptions. FCC rules, in Section 1.1312(a) stipulate that the FCC can require that any station file an Environmental Assessment (EA) or conduct a routine environmental evaluation to demonstrate that it is not necessary to request an EA—even those covered by specific categorical exemptions.

The FCC will make these determinations on a case by case basis, but in cases where a station that is categorically exempt from evaluation, or a station that is creating exposure that is less that 5% of what is permitted to it, the FCC could determine that the particular station needs to share responsibility for site compliance. Clearly, if an amateur station shares space with a high-power broadcast station, the "5% rule" is pretty straightforward, but if a number of low-power transmitters share a site, even minor emitters might have to make changes to their station if the overall site compliance is more than the MPE limits allow. It is quite possible for some sites to have literally hundreds of transmitters, most of which are operating below the 5% level, even though the overall site's RF exposure could be greater than the MPE limits. The best approach is to err on the side of caution and cooperate with other operators on the site, if there is a compliance problem. There is, of course, no substitute for your own good judgment; use it as it appears to be appropriate in "gray" areas. This may prevent the FCC from having to make a case out of your station.

The Unknowns at Multitransmitter Sites

In some cases, amateurs may not be able to obtain full information about the other transmitters on the site. If you find yourself in this situation, you should attempt to secure information from the site owner. If that isn't available, make the best estimates possible of other transmitter powers and antenna gains on the site to determine compliance. In most cases, the repeater operator will need to cooperate with other site users to determine the overall exposure of all the transmitters on the site.

Bulletin 65 and Multi-Transmitter Sites

While *Bulletin 65* does not include simple tables for hams to use to evaluate their stations, it does have an extensive section on compliance at multiple transmitter sites. Hams who operate multi-multi contest stations (or repeater operators) may want to read the entire bulletin, to get a head start on understanding the issues involved at multiple transmitter sites.

Real World Considerations in Doing Evaluations

Of course, the real world is not quite as neat as the formulas and tables would like it to be! Ground has slope, antennas have nearby conductors changing their patterns, feed lines sometimes radiate and Murphy can strike: Things do go wrong. Knowing how and when to apply these factors sometimes requires the sound technical judgment of the station operator!

Nearby Conductors and Antennas

Antennas can and do interact with nearby conductors. Conductors located near an antenna can usually pick up and reradiate some of the signal, which can complicate analysis. Such nearby conductors can sometimes conduct signals away from the antenna and reradiate them closer to areas of exposure. An example of the latter phenomenon would be an antenna, located within several feet of the phone line, running back into the operator's house. In cases where the phone line is located very close to areas of exposure, the MPEs could be exceeded under some circumstances. Such nearby conductors can be an unintended integral part of the antenna system. This can complicate antenna modeling, because these nearby conductors should be accurately entered into the model.

If you have a considerable safety margin in your evaluation, there is little risk that additional reradiation from nearby conductors will result in local fields that are higher than the permitted MPEs. You may want to consider whether tower structures, guy wires, nearby utility wires or large metal objects could be affecting your results. In general, those objects near the antenna, or near the area being evaluated, will have the greatest potential effect.

Grounding, Feed Line Radiation, Transmitter Leakage

In a well-designed station, virtually all the RF energy is radiated by the antenna. The formulas, tables and modeling software described in *Bulletin 65* all assume that all the power comes from the antenna system. In most cases, this is a reasonable assumption. Even the operator of the station probably receives more energy from the antenna than that inadvertently radiated from other sources. This is virtually certain to be true for most situations, where the people being exposed are not *much* closer to the source of incidental radiation than they are to the antenna. However, it is possible in some circumstances, especially for the operator, that people could be very close to the feed line or some other source of incidental radiation.

However, short of making actual field-strength measurements (with all the inherent problems in doing so), this incidental radiation can be virtually impossible to predict. Neither the FCC regulations nor *Bulletin 65* can fully address this possibility. All the evaluation methods consider only the RF coming from the antenna. Normally, these incidental radiators will not be considered during a routine evaluation. They cannot, however, be completely ignored.

Incidental radiators will not be evaluated quantitatively, but subjectively. Amateurs should be familiar with the circumstances under which excessive incidental radiation can occur and ensure that those circumstances are not present in the well-designed amateur station. The following problems can result in excessive incidental RF radiation:

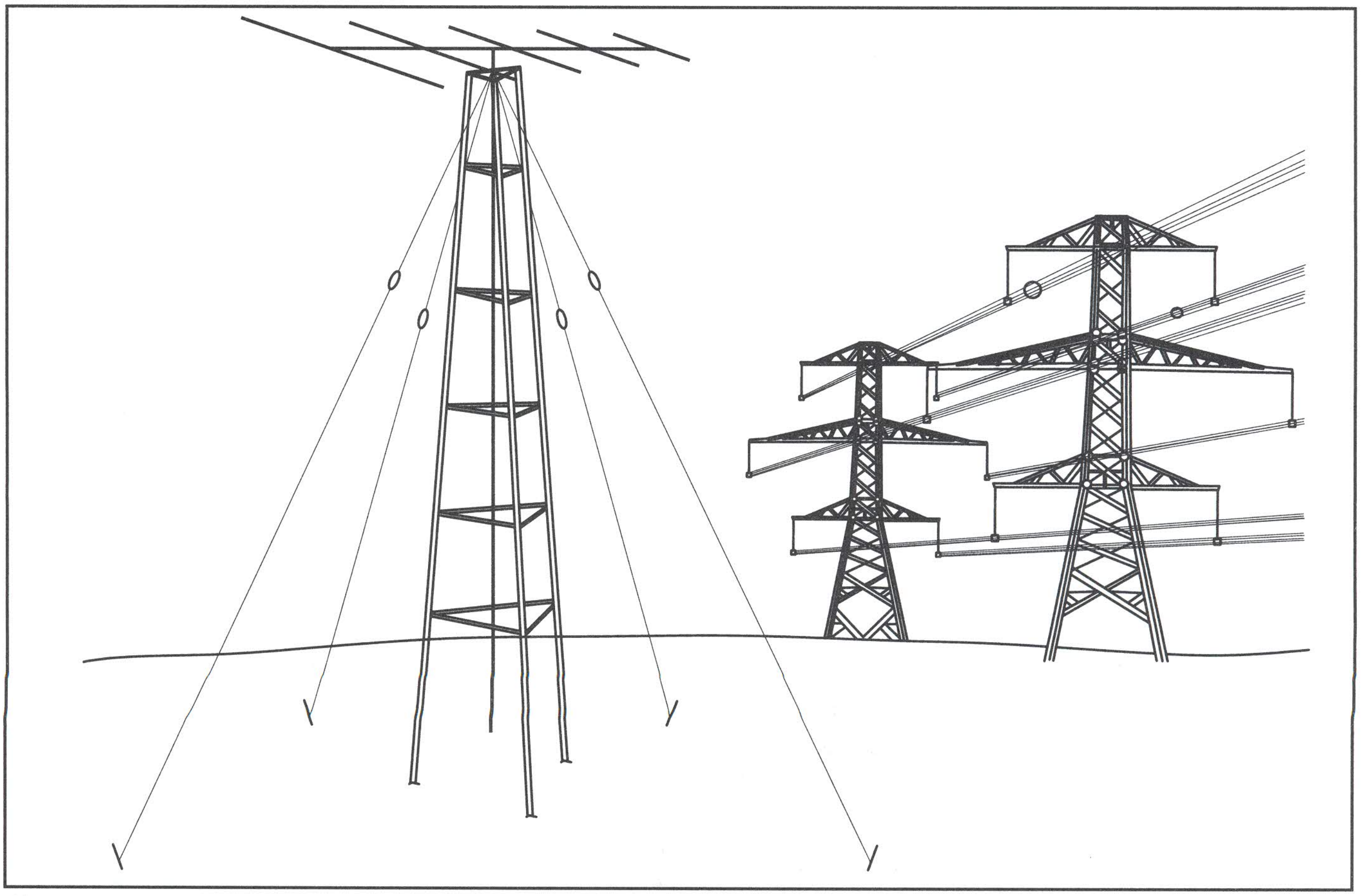

Figure 5.18—The tower, guy wires and utility wires near this antenna can affect the level of the fields near the antenna and the other conductors.

- End fed antennas whose connection occurs directly in the shack
- Feed line radiation caused by antenna-system imbalance
- Excessive feed line leakage caused by broken or missing shield connections on coaxial cables
- Excessive feed line leakage caused by inferior grade coaxial cables
- Improper grounding of station equipment
- Improper shielding of station equipment
- Improperly fastened or damaged wave-guide connectors
- Other "RF in the shack" problems

Many of these station problems can be traced to defects in the installation or maintenance of the station. These problems should normally be corrected as a routine part of designing and operating an effective and safe amateur station.

A poorly designed antenna system may have an unbalanced feed line connected to a balanced antenna, a feed line that runs at an acute angle to the antenna (see Figure 5.19), an inferior grade of coaxial cable that results in excessive feed line leakage or some defect or problem with the shield integrity on a coaxial cable.

A full discussion of grounding is beyond the scope of this book. However, properly grounding a transmitting installation can minimize problems with "RF in the shack," an unpleasant situation where small RF burns can be felt whenever the operator touches any station apparatus. RF in the shack is usually caused by antenna-system defects. The most effective cure is to locate the cause of the problem, but RF in the shack can sometimes be cured with station grounding. *The ARRL Handbook for Radio Amateurs* and *Radio Frequency Interference: How to Find It and Fix It* (also published by the ARRL) both feature information about grounding.

In a well-designed transmitter, all the RF energy is contained inside the transmitter until it is sent out of the output connector to the antenna. The transmitter chassis is usually well shielded, with RF bypass leads keeping the RF where it belongs. If you are using a commercial transmitter, the chances are excellent that it is *not* the source of unwanted RF emissions. However, things can sometimes go wrong. Bypass components can fail, or shielding can be removed. (If you service your transmitter and remove a shield cover with 47 separate sheet-metal screws, it may be tempting to use only 4 screws to put it back together, but this will probably decrease the effectiveness of the shield.)

Near the End!

One other factor to consider is that the total RF energy radiated from the ends of the conductors used in antennas like dipoles or Yagi arrays is generally less than the energy radiated from the center. This is because by the time the RF energy gets to the end, some of the energy has been radiated away. If you are doing exact modeling, you will be able to determine that you can generally be closer to the ends of an antenna than you can be to the center, or the "hot" end of a longwire. This could be especially helpful to evaluate an antenna like an inverted V, where you could be closer to the end than the center.

Figure 5.20 shows the electric field directly under a half-wave dipole that is 30 feet in the air. The graph shows the field in the axis of the wire at ground level, as if the person being exposed were starting at the center and walking toward the ends.

Attenuation by Buildings

It is difficult to estimate the amount of attenuation of the transmitted field strength that may result from buildings, vegetation, etc. The amount of attenuation will depend on factors such as frequency and the construction material used. A conservative evaluation generally does not include additional attenuation for buildings. However, *Bulletin 65* does conclude that for most rooftop installations, 10 to 20 dB of attenuation by the building might be expected for people located on lower floors.

PAPERWORK

Once an Amateur Radio operator determines that a station complies by doing the station evaluation (or determines that no evaluation is required), the station may be put into immediate operation. There's no need for FCC approval before operating. The FCC does not require you to keep any records of your routine RF radiation exposure evaluation. However it is a good idea to keep them. They may prove useful if the FCC would ask for documentation to demonstrate that an evaluation has been performed. The Commission recommends that each amateur keep a record of the station evaluation procedure and its results, in case questions arise.

Other than a short certification on Form 610 station applications, the regulations do not normally require hams to file proof of evaluation with the FCC. The FCC will ask you to demonstrate that you have read

Figure 5.19—This feed line is very asymmetrical with respect to the antenna. This configuration could result in excessive feed line radiation—possibly a problem for the station operator or persons located near the feed line.

and understood the FCC Rules about RF-radiation exposure by indicating that understanding on FCC Form 610 (Reprinted in Appendix C of this book) when you apply for your license.

Actually, the regulations do contain a provision that would allow an amateur to file an Environmental Assessment (EA) with the Environmental Protection Agency, however, the costs and time delays associated with an EA are usually prohibitive, especially for an amateur station. The Commission expects that it is highly unlikely that an amateur will be taking such an action. EAs are *not* normally required for amateur stations. An EA is required for any station that wants to continue to operate even though they exceed the MPE limits. It is not likely that an amateur would choose to file an EA in lieu of making changes to his or her station, to be in compliance with the MPE limits. The regulations will require that hams affirm on their station applications that they have read the regulations and that they are in compliance with them.

CORRECTING PROBLEMS

An antenna that is higher and farther away from people also reduces the strength of the radiated fields that anyone will be exposed to. If you can raise your antenna higher in the air or move it farther from your neighbor's property line you will reduce exposure.

A half-wavelength dipole antenna that is only 5 meters above the ground would generally create a stronger RF field on the ground beneath the antenna than many other antennas. For example, a three-element Yagi antenna or a three-element quad antenna both have significantly more gain than a dipole. Yet at a height of 30 meters both of these antennas would produce a smaller RF field strength on the ground beneath the antenna than would the low dipole. As a general rule, place your antenna at least as high as necessary to ensure that you meet the FCC radiation exposure guidelines.

When routine evaluation of an Amateur Radio station indicates that the RF radiation could be in excess of the FCC-specified limits, the station licensee must take action to bring the station operation into compliance with the regulations. The vast majority of stations will pass their evaluations handily. But some stations whose antennas are close to areas of exposure may not meet the MPE limits.

The FCC gives amateurs considerable flexibility in correcting problems. They are relying on the demonstrated technical ability of amateurs and their familiarity with their own stations and operating environments to make the appropriate changes to their stations or their operation to be in compliance with the MPE limits.

The following list offers some guidance on the types of changes that could be made to a station. It is not intended to be all inclusive:

- Relocate transmitting antennas to result in less exposure to people
- Choose a different antenna type to result in less exposure to people
- Control the pointing of directional antennas to reduce exposure to people
- Reduce transmitter operating power to reduce exposure
- Use a different operating mode that results in lower average transmitter power and exposure
- Reduce operating time to reduce average transmitter power and exposure
- Change the operating frequency to use a frequency where the MPE limit is higher
- Controlling access / signs
- Combinations of some or all of these

Relocating Antennas

This can be one of the easiest and most effective changes to make. In general, if you can locate your antenna farther away from people, their exposure will be less. Because an RF field diminishes rapidly with increasing distance between the measurement point and the source of RF energy, relocating the station's antenna(s) can reduce the field strength below the MPE limits. An antenna that is high and in the clear is usually going to have a field that is much reduced from a low antenna located near areas of possible exposure. Relocating a low antenna so that it is high and in the clear will have a second benefit; it will usually improve the DX performance of your station, giving you more low-angle radiation for HF DXing or VHF.

Antennas that have gain usually result in a concentration of energy, even in the near field. This can be an advantage or disadvantage. If the antenna can be located such that the gain is primarily away from areas of possible exposure, either in the horizontal or vertical plane, this could provide another means of meeting the regulations.

Moving a vertical antenna farther away from a house or nearby property also can significantly reduce exposure. Those pesky indoor and apartment-balcony antennas are particularly troublesome; if you can move them away from the building, they will work better for you and result in less exposure.

You must always take care to position your amateur antennas in a manner so they cannot harm you or anyone else. The simplest way to do this is to always install them high and in the clear, away from buildings or other locations where people might be close to them. To prevent **RF burns** you must be sure no one can touch the antenna while you are transmitting into it. It doesn't matter what type of antenna it is, or how much power you are running. If you or someone else can touch the antenna, it is

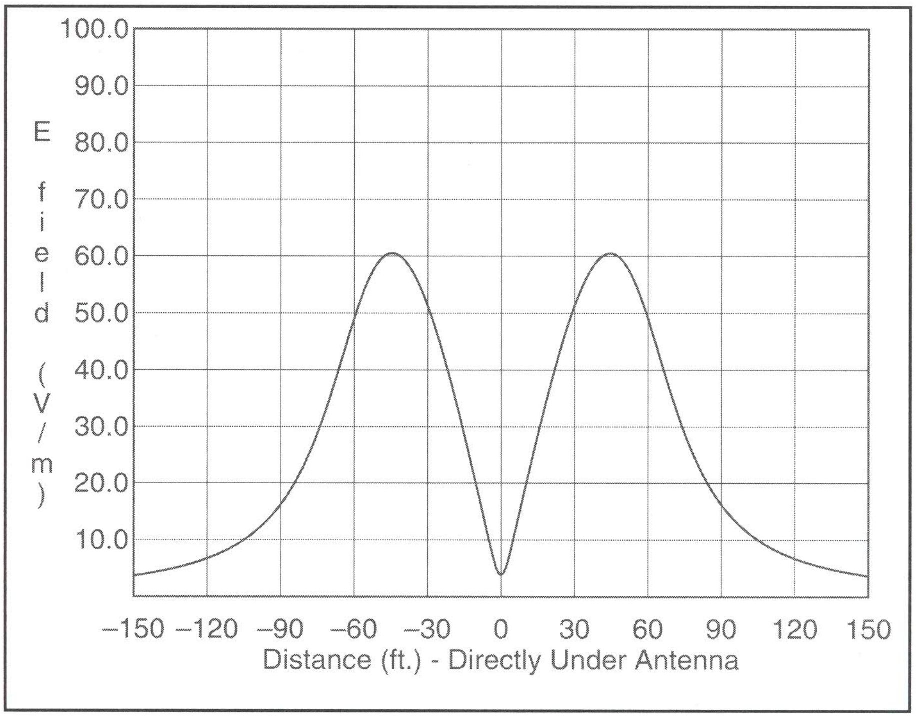

Figure 5.20—This plot shows the electric field directly under a wire dipole antenna.

too close.

Of course the one exception to this is the antenna on a hand-held radio. You aren't likely to receive an RF burn from touching the antenna on your hand-held radio because the transmitter power is quite low. You should still keep the antenna as far from you or anyone else as possible, to minimize your exposure to the RF electromagnetic fields from the radiated signal.

Choose a Different Antenna Type

There is no magic antenna that will solve all your RF-exposure woes, but the selection of an antenna can influence exposure, in both directions. In general, a large antenna usually results in a smaller field at any particular near-field point than a small antenna! This is because if one is near a small antenna, one is near the *entire* antenna, where with a large antenna, portions of the antenna may be far away.

A directional antenna, such as a Yagi array, can minimize exposure to areas off the sides and back. This comes with a price; exposure in the direction the antenna is pointing is often higher than it would be with an antenna with less gain. End-fed wires worked against earth ground almost always result in more exposure in the shack or nearby rooms than would an antenna located farther away, fed with feed line. On VHF and UHF, high-gain vertical antennas located up high often result in less exposure on the ground than would result from a simple ground plane at the same height.

In general, most gain antennas (such as Yagi arrays) radiate most of their energy toward the horizon or at low angles above the horizon as seen at the height of the antenna on the supporting tower.

The RF field at ground level is usually less (and sometimes much less) than the energy in the main beam of the antenna. This general rule usually does not apply to vertical antennas located at ground level.

It is Not Polite to Point

This old adage serves to remind us that the exposure from a gain antenna is maximum in one (or more) directions and minimum in others. It sounds too good to be true, but it is true; if you determine that your station exceeds the MPEs in a particular direction toward a particular house, the FCC considers it perfectly acceptable that you, as control operator, do not point your antenna at full power in that direction if someone is present in that direction at the time. You also can use the directional patterns of antennas to good effect; locate the antenna such that the nulls in the pattern fall toward areas where people are present, especially on the higher bands.

For example, if an amateur were to determine that his or her station was in compliance at full power to all surrounding uncontrolled areas except for one corner of a neighboring property when the antenna was aimed in that direction, one way of complying would be to avoid pointing a directional antenna in that direction if people are present on that part of the neighboring property.

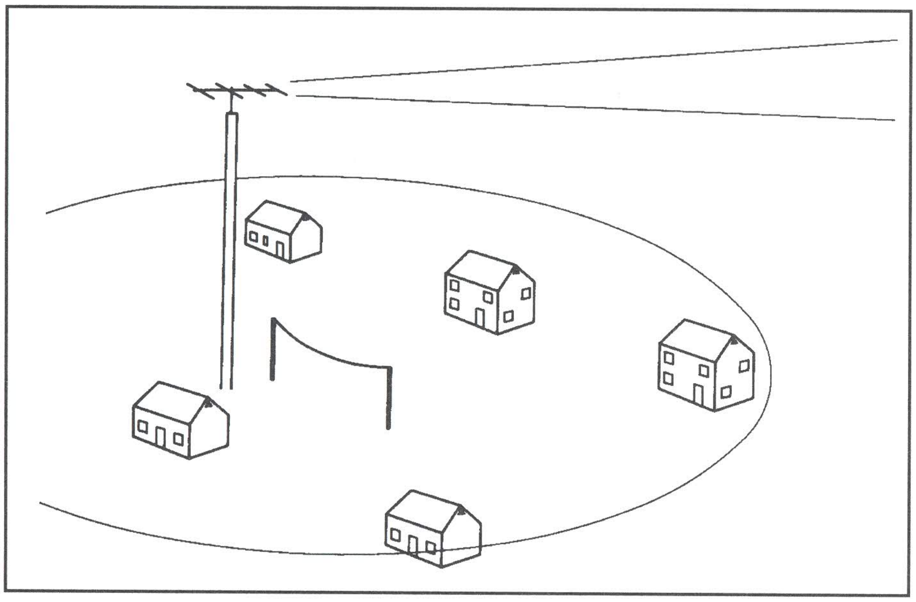

Figure 5.21—Antennas that are located up high are generally located far away from people. To the untrained, it may appear that the small antenna located between the houses will create less RF nearby than the big tower, but the antenna that is up in the air will create a smaller field on the ground.

In addition to using the free-space pattern of your antenna to calculate exposure (this was discussed earlier), you also can use the radiation pattern of the antenna to your advantage in controlling exposure. For example, if you position your dipole antenna (with maximum radiation off the sides of the antenna and minimum radiation off the ends) so the ends are pointed at your neighbor's house (or your house), you will reduce the exposure. A beam antenna can have an even more dramatic effect on reducing the exposure. Simply do not point the antenna in the direction where people will most likely be located.

QRP, Modes and Time

ARRL is not recommending that all stations run QRP (although there are a few avid QRPers on the ARRL staff, along with avid DXers, avid big-gun and little-pistol contesters), but reducing power is certainly an option. Higher transmitter power will produce stronger radiated RF fields. So using the minimum power necessary to carry out your communications will minimize the exposure of anyone near your station. Reducing power is one effective way of meeting the FCC MPE limits. You may find that you are not in compliance at 1500 watts, but at 1100 watts, you are just under the limit.

Some modes result in more average power than others. FM, RTTY or other digital modes have a duty factor of 100%, Morse CW has a duty factor of about 40% and voice SSB ranges from 20% to 40%. If you are running 1000 watts on RTTY and choose to use SSB instead, your average power during the time you are transmitting will drop from 1000 watts to about 200 watts. This can make a *big* difference in your exposure and the necessary compliance distances.

You also can adjust your on and off operating times to reduce your average power during the averaging period. For example, if an amateur were to discover that the MPE limits had been exceeded for uncontrolled exposure after 25 minutes of transmitting, the FCC would consider it perfectly acceptable to take a 5-minute break after 25 minutes. Thus, if necessary, an amateur may tailor the operating pattern of the station (on/off times) to meet the MPE requirements. It will then be the responsibility of the control operator and station licensee to ensure that the maximum time used for these calculations is not exceeded at any time during station operation if people could be exposed. It would be easy to forget during a long ragchew that no more than 4 minutes out of any 6-minute period are allowed, as an example—for controlled exposure.

Frequency

Even your choice of operating frequency can have an affect. Humans absorb less RF energy at some frequencies (and the MPE is higher at those frequencies). You can reduce exposure by selecting an operating frequency with a higher MPE.

The MPE limits vary with frequency. If your operation on 160 through 10 meters resulted in 0.4 mW/cm^2 uncontrolled exposure, you would have to reduce your average power on 10 meters by half, but you could use full power on 15 meters!

Controlling Access

Amateurs may be able to exercise control over access to areas that might have exposure that exceeds the MPE. As examples, if an amateur has authorized control over a private area, such as his or her own backyard, the areas that might have excessive exposure could be fenced in, or signs could be posted that indicate that the area may contain RF energy and is not authorized for entry for the general public, although this may invite more questions than some amateurs want to answer. Access can be controlled with fences, locked doors or any other reasonable means. Controlling access to areas where high RF energy may be present is probably the easiest method of controlling exposure.

It is important to note that for general population/uncontrolled exposures it is not often possible to control access or otherwise limit exposure duration to the extent that averaging times can be applied. In those situations, it is often necessary to assume continuous exposure to whatever exposure duration could be expected to occur with the on/off cycles of the transmitter.

Signs

The FCC accepts posted signs as a means of controlling exposure. If an amateur repeater were located on a rooftop and the exposure exceeded the MPEs after three minutes of continuous operation, a sign could be posted that indicates that RF is present and that it is not permissible to remain in the area for more than three minutes. This applies easily to occupational exposure areas.

Suitable signs are available from a number of sources. The National Association of Broadcasters, EMED Co., Inc. and Richard Tell Associates all sell such signs. See Appendix E, Resources, for contact information.

The Magic Combination

These various solutions can be combined. One could relocate an antenna and reduce power in combination to bring the exposure into compliance. One could reduce operating times whenever necessary, perhaps when a neighboring dwelling is known to be occupied.

EVALUATIONS AND THE FCC

The FCC has always relied on the Amateur Radio Service to follow the rules. Although Amateur Radio does have a few bad apples, overall, hams can be very proud of our rules-compliance record. The FCC expects that most hams will follow the requirements of these rules, too. For the most part, they expect that they will not need to become involved in the day-to-day management of individual amateur stations. The FCC may receive inquiries from neighbors of radio operators about the RF exposure from that station. In that case, it is possible that radio operators will receive an informal "inquiry" from the FCC in response. This inquiry will ask about the station, its frequency, power, modes and antennas. They also will ask if the station required an evaluation and ask for a summary of the results. For the most part, the FCC will assume that the evaluation was done correctly, and inform the inquiring neighbor that the station is operating in accordance with FCC rules. Although the FCC does retain the right to show up at your door and measure your fields, this would normally not be done, except under unusual circumstances. An example might be the ham who indicates that his 1500-watt CW station with a five-element, 10-meter band Yagi 10 feet from a neighbor's second-story bedroom window was in compliance at full duty cycle. (This unlikely sounding station was described to an ARRL employee by an FCC staffer!)

The FCC Worksheet

The FCC has included a worksheet in *Supplement B*. This optional worksheet has instructions on how to include the various factors necessary to do a station evaluation and provides a handy way to maintain a record of the evaluation. It runs step by step through the procedures outlined in this article, using the methods outlined in *Supplement B*. The worksheet describes the methods to calculate power to the antenna using feed line losses, and how to calculate ERP using both feed line losses and antenna gain. This is another example of how the FCC has made the evaluation process as clear and easy as possible for the Amateur Radio Service.

ARRL Worksheet

The FCC worksheet is comprehensive, guiding hams through a number of steps for evaluation thresholds for single transmitters and repeaters, and a comprehensive evaluation procedure. The ARRL has

Why Should We Even Bother?

No doubt many of you are shaking your heads and muttering, "Why should I even bother to do an evaluation? The FCC will never enforce these rules. This is a waste of time!"

There are a number of important reasons why amateurs should follow *all* FCC rules, including these. The Amateur Radio Service has a tradition of compliance with FCC regulations; Part 97 is our bible! The ARRL has worked hard to help the FCC fine tune these rules for the Amateur Radio Service. If we hope for more cooperation in the future, we must set the best example possible. The FCC (and our Amateur Radio supporters on Capitol Hill) must be assured that the majority of hams follow all the rules "by the book."

Safety also is a concern. While RF energy isn't known to cause major health problems, the research is still continuing. The levels that have been set by various standards bodies and the FCC are our best assurance that no ill effects on human health are expected from the normal operation of radio transmitters. Being in compliance buys peace of mind for you and your family. As the old saying goes, "better safe than sorry."

Your neighbors may also have questions and concerns. (The ARRL has already received quite a few questions on this subject from neighbors of hams.) Many of these concerns can be easily addressed by explaining the requirements to your neighbors and showing them the results of your station evaluation. The new rules even offer us a significant advantage; if our neighbors do have concerns, we are much better off being able to demonstrate that there are rules governing our conduct and that we have done what the rules require.

In most cases, these evaluations are not hard! They can usually be done by looking at a table, or spending a few minutes with some free software or a calculator. There is not much to lose, and a lot to gain. So, hams should complete their station evaluations and point to them with pride!—*Chris D. Imlay, W3KD, ARRL General Counsel* developed a simplified worksheet and instructions that will be helpful for amateurs that only need to do some parts of the evaluation. See Chapter 1 of this book for a copy of this worksheet.

RFX AND RFI

Radio Frequency Interference and Radio Frequency Exposure are *not* the same. One concerns interference to or from electronics equipment; the other concerns human exposure to RF energy. The topics are worlds apart, although hams have been overheard talking about the new "RFI" rules. The levels involved are generally worlds apart, too. Most consumer electronics equipment has immunity to fields of about 3 volts per meter. The *lowest* level of exposure in the new rules is a level of 27.5 volts per meter, about 20 dB higher than the level that causes RFI! The highest permissible exposure level is a whopping 614 volts per meter—some 46 dB higher! This often gives us a clear indication that we are not exceeding the MPE levels in neighboring homes—most neighbors of hams do not have RFI problems, indicating that the fields are not substantially greater than about 3 volts per meter.

CONCLUSION

This chapter told you how to do the required station evaluation. But much like the provisions of the National Electrical Code and house wiring, the provisions of the law are not intended to replace safety and common sense. In addition to the RF-exposure provisions in Part 97, hams should continue to practice RF-safety techniques. The earlier chapters of this book discussed the principles of "prudent avoidance." Don't let your enthusiasm for learning about your station evaluation cause you to skip the important fundamentals in the earlier chapters.

Overall, these regulations are not difficult for the Amateur Radio Service. Most hams don't have to do an evaluation at all. Most of those who are required to do an evaluation can do so using relatively easy methods. Once the evaluation is complete, hams can go back to their favorite hamming, answering their own questions about RF exposure and hopefully addressing any neighbors' concerns. All in all, it seems like it is not a bad trade-off.