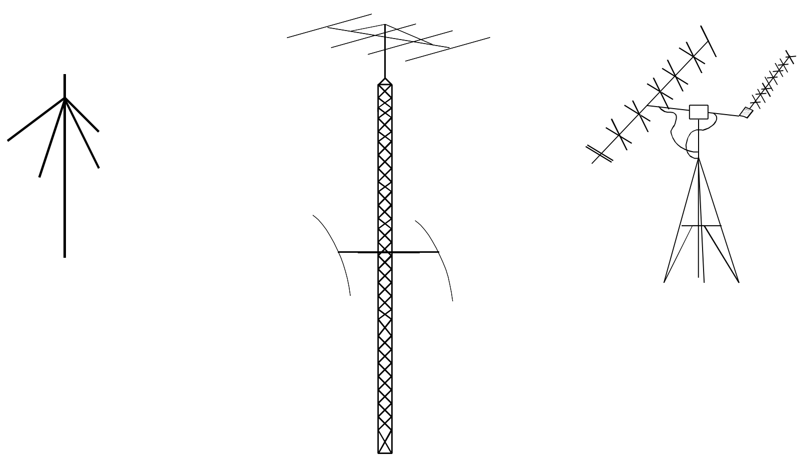
Federal Communications Commission
Office of Engineering & Technology

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Amateur Radio Stations



Supplement B
(Edition 97-01)
to
OET Bulletin 65 *(Edition 97-01)*

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Amateur Radio Stations

SUPPLEMENT B
Edition 97-01
to
OET BULLETIN 65
Edition 97-01

November 1997

AUTHORS
Jerry L. Ulcek
Robert F. Cleveland, Jr.

Standards Development Branch
Allocations and Standards Division
Office of Engineering and Technology
Federal Communications Commission
Washington, D.C. 20554

IMPORTANT NOTE

This supplement is designed to be used in connection with the FCC's OET Bulletin 65, Version 97-01. The information in this supplement provides additional detailed information that can be used for evaluating compliance of amateur radio stations with FCC guidelines for exposure to radiofrequency electromagnetic fields. However, users of this supplement should also consult Bulletin 65 for complete information on FCC policies, guidelines and compliance-related issues. Definitions of terms used in this supplement are given in Bulletin 65. Bulletin 65 can be viewed and downloaded from the FCC's Office of Engineering and Technology's World Wide Web Internet Site: http://www.fcc.gov/oet/rfsafety.

ACKNOWLEDGMENTS

The following individuals and organizations reviewed an early draft of this supplement. Their valuable comments and suggestions greatly enhanced the accuracy and usefulness of this document, and their assistance is gratefully acknowledged.

American Radio Relay League (ARRL) HQ staff and outside advisors:

Paul Danzer, N1II, ARRL Assistant Technical Editor
Walter L Furr III, K4UNC
Robert E. Gold, M.D., WB0KIZ, ARRL RF Safety Committee
Gerald Griffin, M.D., K6NN, ARRL RF Safety Committee
Arthur W. Guy, Ph.D., W7PO, ARRL RF Safety Committee
Ed Hare, W1RFI, ARRL Laboratory Supervisor
John Hennessee, N1KB, ARRL Regulatory Information Specialist
Tom Hogerty, KC1J, ARRL Regulatory Information Branch Supervisor
Howard Huntington, K9KM, ARRL Central Division Vice Director
Wayne Irwin, W1KI, ARRL VEC Assistant to the Manager
Bart Jahnke, W9JJ, ARRL VEC Manager
Zack Lau, W1VT, ARRL Senior Laboratory Engineer
Roy Lewellan, P.E., W7EL, ARRL Technical Advisor
Jim Maxwell, Ph.D., W6CF, ARRL Pacific Division Vice Director
Gary E. Myers, K9CZB, ARRL RF Safety Committee
William J. Raskoff, M.D., K6SQL, Chairman, ARRL RF Safety Committee
Peter Richeson, KA5COI,
Kazimierz Siwiak, P.E, KE4PT, ARRL RF Safety Committee
R. Dean Straw, N6BV, ARRL Senior Assistant Technical Editor
Larry Wolfgang, WR1B, ARRL Senior Assistant Technical Editor

Jay Jackson, Wireless Telecommunications Bureau, FCC
John B. Johnston, Wireless Telecommunications Bureau, FCC
Fred O. Maia, W5YI Group, Inc., and W5YI-VEC, Inc.
Professor Wayne Overbeck, California State University, Fullerton
Edwin Mantiply, U.S. Environmental Protection Agency

TABLE OF CONTENTS

Introduction

In 1996, the FCC adopted new guidelines and procedures for evaluating human exposure to environmental radiofrequency (RF) electromagnetic fields from FCC-regulated transmitters. The new guidelines replaced those adopted by the FCC in 1985 (the 1982 RF protection guides of the American National Standards Institute, ANSI).[1] The FCC's guidelines are used for evaluating exposure from fixed station transmitters and from mobile and portable transmitting devices, such as cellular telephones and personal communications devices, in accordance with FCC responsibilities under the National Environmental Policy Act of 1969 (NEPA).[2] These rule changes set new limits on maximum permissible exposure (MPE) levels that apply to all transmitters and licensees regulated by the FCC.

The FCC also revised its policy regarding transmitters, facilities and operations for which routine evaluation for compliance is required before granting an application. A routine evaluation is a determination as to whether the station conforms to the RF exposure requirements. For amateur stations, the new policy requires that the station be subject to routine evaluation when it will be operated above certain power levels. In the past, although amateur stations were expected to comply with the FCC's guidelines, routine station evaluation was not required.

In August, 1997, the FCC issued a revised technical bulletin, OET Bulletin 65[3], that provides assistance and guidance to applicants and licensees in determining whether proposed or existing transmitting facilities, operations or devices comply with FCC-adopted limits for human exposure to RF fields. Although Bulletin 65 provides basic information concerning evaluation for compliance, it is recognized that additional specific guidance and information may be helpful for certain specialized categories of stations and transmitters such as radio and television stations and amateur stations. Therefore, supplements to Bulletin 65 have been prepared to provide this additional information. Supplement A was developed for radio and television broadcasting stations and this supplement (Supplement B) has been prepared for amateur stations. Users of this supplement are also strongly advised to consult Bulletin 65 itself for complete information and guidance related to RF guideline compliance. It should also be noted that, although Bulletin 65 and this supplement offer guidelines and suggestions for evaluating compliance, they are not intended to establish mandatory procedures, and other methods and procedures may be acceptable if based on sound engineering practice.

---

[1] *See Report and Order*, ET Docket 93-62, FCC 96-326, adopted August 1, 1996, 61 *Federal Register* 41006, 11 FCC Rcd 15123 (1997). The FCC initiated this rule-making proceeding in 1993 in response to the 1992 revision by ANSI of its earlier guidelines for human exposure.

[2] See 47 CFR § 1.1301, et seq.

[3] To view and download OET 65, the website address is: http://www.fcc.gov/oet/

In general, the information contained in Bulletin 65 and in this supplement is intended to enable the applicant or amateur to make a reasonably quick determination as to whether a proposed or existing amateur station is in compliance with the exposure guidelines and if not, the steps that can be taken to bring it into compliance.[4] Bulletin 65 and this supplement include information on calculational methods, tables and figures that can be used in determining compliance. In addition, amateurs are encouraged to consult Section 4 of Bulletin 65 that deals with controlling exposure. In some cases, e.g., some multiple-emitter locations such as amateur repeater sites and multi-transmitter contest-style stations, measurements or a more detailed analysis may be required. In that regard, the part of Section 2 of Bulletin 65 dealing with multiple transmitter sites and, also, Section 3 of Bulletin 65 dealing with measurements and instrumentation provide basic information and references.

The new FCC limits for exposure incorporate two tiers of exposure limits based on whether exposure occurs in an occupational or "controlled" situation or whether the general population is exposed or exposure is in an "uncontrolled" situation. A detailed discussion of the guidelines and adopted limits are included in Bulletin 65.

As mentioned, in the FCC's recent *Report and Order,* certain amateur radio installations were made subject to routine evaluation for compliance with the FCC's RF exposure guidelines, effective January 1, 1997 (this date was later extended).[5] Section 97.13 of the Commission's Rules, 47 C.F.R. § 97.13, requires the licensee to take certain actions before causing or allowing an amateur station to transmit from any place where the operation of the station would cause human exposure to levels of RF fields that are in excess of the FCC guidelines. The licensee must perform the routine evaluation if the transmitter power of the station exceeds the levels specified in 47 CFR § 97.13(c)(1) and repeated in Table 1.[6] Amateurs may use the optional worksheet shown in Appendix B of this supplement to help in determining whether a routine evaluation is required.

All mobile amateur stations are categorically excluded from this requirement. Such mobile stations are presumed to be used only for very infrequent intermittent two-way operation. They are, however, required to comply with the exposure guidelines. Otherwise the operation is categorically excluded from routine RF radiation evaluation except as specified in Sections 1.1307(c) and (d) of the FCC's Rules.

---

[4] As is the case with all other FCC rules, an amateur station licensee or grantee is responsible for compliance with the FCC's rules for RF exposure.

[5] *See* para. 152 of Report and Order, ET Docket 93-62, (footnote 4). *See also*, 47 CFR 97.13, as amended. In the FCC's *First Memorandum Opinion and Order* in this docket, FCC 96-487, released December 24, 1996, the Commission extended the implementation date of the new guidelines for the amateur radio service to January 1, 1998. *See* 62 Federal Register 3232 (January 22, 1997).

[6] These levels were chosen to roughly parallel the frequency of the MPE limits of Table 1 in Appendix A of this supplement. These levels were modified from the Commission's original decision establishing a flat 50 W power threshold for routine evaluation of amateur stations (see *Second Memorandum Opinion and Order*, ET Docket 93-62, FCC 97-303, adopted August 25, 1997).

Table 1. Power Thresholds for Routine Evaluation of Amateur Radio Stations

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

***** Transmitter power = PEP input to antenna. For repeater stations ***only,*** power exclusion based on ERP (effective radiated power).

No station is exempt from ***compliance*** with the FCC's rules and with the MPE limits. However, many amateur stations are categorically exempt from the requirement to perform a ***routine station evaluation*** for compliance. Stations operating at or below the power levels given in Table 1, are not required by the FCC to perform a routine evaluation for compliance. Also, stations using mobile and portable (hand-held) transmitters (as defined by the FCC's rules) are not required to be routinely evaluated.[7] Amateur repeater stations transmitting with 500 W ERP or less whose antennas are not mounted on buildings, but rather on stand alone towers, and which are located at least 10 meters above ground are also categorically exempt from performing an evaluation. In the case of building-mounted repeater station antennas, the exemption applies regardless of height if the ERP is 500 W or less.

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 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. FCC rule parts 1.1307 (c) and 1.1307 (d) could require that in cases where a station is categorically exempt, the FCC can require additional action, including a station evaluation, be taken by the station licensee if the FCC believes there is reason to believe that the exposure levels are being exceeded.

Although not required by the FCC's rules, it is advisable that mobile stations also be considered for potential exposure 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 could also present problems in some cases. In general, it is recommended that in these higher powered 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 on a vehicle with a fiberglass roof. In general, mobile installations, even higher-powered ones, should not exceed the MPEs if sound installation guidelines are followed. The ARRL *Handbook* and ARRL antenna books, available from the ARRL, have additional material on mobile installations and antennas (see footnote 9).

[7] The FCC has defined "mobile" devices as those designed to be used in other than fixed locations and to be used in such a way that a separation distance of at least 20 cm is normally maintained between the transmitter's radiating structure(s) and the body of the user or nearby persons. The FCC defines "portable" devices as those designed to be used so that the radiating structure(s) of the device is/are within 20 cm of the body of the user. For example, this definition would apply to handheld cellular phones. Although amateur mobile and portable (handheld) PTT devices are categorically exempt from routine evaluation, users are cautioned to be aware that relatively high-powered mobile or portable devices can expose persons in their immediate vicinity to significant RF fields under conditions of relatively continuous transmission. An example might be a 100-110 W vehicle-mounted mobile antenna that is mounted in such a way (e.g., on a rear window) so that RF fields are created inside the vehicle. An example of this was noted in the FCC's measurement survey of typical amateur radio stations that is cited in Footnote 10.

Even if the regulations do not require an evaluation, there could be a number of reasons to conduct one anyway. At a minimum, such an evaluation would be good practice for the time when a station change is made that would require an evaluation. In addition, the results of an evaluation will certainly demonstrate to the amateur and his or her neighbors that the station's operation is well within the guidelines and is not a cause for concern. In the case of some of the unusual circumstances described earlier, the FCC's rules could require an evaluation of a station otherwise categorically exempt. In all cases, regardless of categorical exemption, the FCC's rules require compliance with the MPE limits. In most cases, the FCC will rely on amateurs to determine for themselves how the evaluation requirements apply to their stations, but under the rules, the FCC does have the flexibility to ask that an evaluation be performed on any transmitter regulated by the FCC.

The Commission's *Report and Order* instituted a requirement that amateur license examination question pools will include questions concerning RF environmental safety at amateur stations. Five questions on RF safety are required within each of the first three levels of written examination elements. Applicants for new amateur licenses must demonstrate their knowledge of the FCC Guidelines through the examinations prepared and administered by the volunteer examiners. The Commission also adopted the proposal of the American Radio Relay League (ARRL) that amateurs should be required to certify, as part of their license application process, that they have read and understand our bulletins and the relevant FCC rules. In addition, applicants for new, renewed and modified primary, club, military recreation and radio amateur civil emergency service (RACES) station licenses and applicants for a reciprocal permit for alien amateur licenses are also required to certify that they have read and understood the applicable rules regarding RF exposure.

When routine evaluation of an amateur station indicates that exposure to RF fields could be in excess of the limits specified by the FCC, the licensee must take action to correct the problem and ensure compliance (see Section 4 of OET Bulletin 65 on controlling exposure). Such actions could be in the form of modifying patterns of operation, relocating antennas, revising a station's technical parameters such as frequency, power or emission type or combinations of these and other remedies. For example, assume an amateur applicant or licensee determined that his or her station was in compliance at full power with all relevant FCC limits in all surrounding areas except for one corner of a neighboring property when a certain antenna was aimed in that direction. In such a case, one way of complying would be to simply avoid pointing the antenna in that direction when people are present at that location.

Amateur station licensees are also expected to follow a policy of systematic avoidance of excessive RF exposure. In its *Report and Order* the Commission said that it will continue to rely upon amateurs, in constructing and operating their stations, to take steps to ensure that their stations comply with the MPE limits for both occupational/controlled and general public/uncontrolled situations, as appropriate. In that regard, for a typical amateur station located at a residence, the amateur station licensee and members of his or her immediate household are considered to be in a "controlled environment" and as such are subject to the occupational/controlled MPE limits. All persons, with particular emphasis on neighbors, who are not members of an amateur station licensee's household are considered to be members of the general public, because they cannot reasonably be expected to exercise control over their exposure. In those cases, general population/uncontrolled exposure MPE limits apply. Similar considerations apply to amateur stations located at places other than a residence.[8]

To qualify for use of the occupational/controlled exposure criteria, appropriate restrictions on access to high RF field areas must be maintained and educational instruction in RF safety must be provided to individuals who are members of the amateur's household. Persons who are not members of the amateur's household but who are present temporarily on an amateur's property may also be considered to fall under the occupational/controlled designation provided that appropriate information is provided them about RF exposure potential if transmitters are in operation and such persons are exposed in excess of the general population/uncontrolled limits. As one example of educational materials, the 1998 *ARRL Handbook for Radio Amateurs* has a section on RF safety. The ARRL also publishes other materials on RF safety and RF exposure. Much of this material is available for viewing or downloading from the ARRL's World Wide Web site[9].

Amateur stations represent a unique case for determining exposure because there are many possible transmitting antenna types that could be designed and used for amateur service. However, several relevant points can be made with respect to analyzing amateur radio antennas for potential exposure that should be helpful to amateur licensees in performing evaluations.

First, the generic equations described in OET Bulletin 65 and in this supplement can be used for analyzing fields due to almost all antennas, although the resulting estimates for power density may be overly-conservative in some cases. Nonetheless, for general radiators and for aperture antennas, if the user is knowledgeable about antenna gain, frequency, power and other relevant factors, the equations in this section can be used to estimate field strength and power density as described earlier. In addition, other resources are available to amateurs for analyzing fields near their antennas. For example, as mentioned above, the ARRL provides excellent material available to help amateurs analyze their radio facilities for compliance with RF guidelines. Also, in 1996 the FCC released the final report of a 1990 study conducted by the FCC and the Environmental Protection Agency (EPA) of several amateur radio stations that provides a great deal of measurement data for many types of

---

[8] The definitions of these exposure criteria are discussed in more detail in OET Bulletin 65 and in the Commission's *Report and Order.*

[9] Contact: American Radio Relay League, Inc., QST Magazine, 225 Main St., Newington, CT 06111 Voice: 860-594-0200, FAX: 860-594-0294, Email: pubsales@arrl.org, Tech info: tis@arrl.org, Web Site: http://www.arrl.org/news/rfsafety/. The ARRL has developed the ARRL RF Exposure Package, and this material has been reproduced at the ARRL Web site. Paper copies are available from the ARRL Technical Information Service. In addition, recent articles have appeared in amateur publications that discuss amateur compliance with the FCC's RF rules. Two examples are: (1) *"The FCC's New RF-Exposure Regulations,* by Ed Hare, KA1CV, in *QST*, January 1997; and (2) *"Complying with the FCC's New RF Safety Rules*, by Wayne Overbeck, N6NB, in *CQ VHF*, January 1997. CQ Communications, Inc. 76 North Broadway, Hicksville, NY, 11801-2953. Tel: (516) 681-2922 FAX: (516) 681-2926 Email: CQVHF@aol.com; 72127.745@compuserve.com; cqcomm@delphi.com; Web Site: http://members.aol.com/cqvhf/ .

antennas commonly used by amateurs.[10] The FCC/EPA study concluded that, for most of the stations surveyed, RF protection guidelines were not exceeded in most accessible areas. However, the report also indicated that at higher power levels or with different facility configurations, higher exposure levels could not be completely ruled out.

This supplement contains information that should allow amateur licensees to predict RF field levels at their station site and determine distances that should be maintained from transmitting antennas in order to comply with the FCC's guidelines. The tables in this supplement represent the more commonly used types of amateur station antennas. For those types not covered by the tables, it may be necessary for the licensee to calculate the fields that are present by means of equations from this supplement, Bulletin 65, computer modelling, or direct measurements.[11] Material from the ARRL contains additional charts and tables developed with the same methods used to create the information in this supplement.

The FCC is relying on the demonstrated technical skills of amateurs to comply with these rules, select an evaluation method and to conduct their own station evaluations. The methods outlined in Bulletin 65 and this supplement can be used, but amateurs are free to select alternative methods as long as they are technically valid. If an amateur station is evaluated and found to be in compliance with the rules, no paperwork need be filed with the FCC, other than any required certifications as part of the Form 610 station application, and the station may be immediately put into operation.

Amateur radio organizations and licensees are encouraged to develop their own more detailed evaluation models and methods for typical antenna configurations and power/frequency combinations.[12] Such models and methods have been utilized in developing the material in this supplement. In addition, FCC staff will continue to work with the amateur radio community to assist licensees and applicants in evaluating compliance.

Information on RF safety issues is generally available at the FCC's World Wide Web Site. OET bulletins and supplements, such as this one, and other relevant FCC orders and documents can be downloaded from the specific web site for "RF safety." For example, information on the biological effects and potential hazards of RF radiation are discussed in an FCC publication (OET Bulletin 56), entitled "Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Radiation." This document can be downloaded from

---

[10] Federal Communications Commission (FCC), "Measurements of Environmental Electromagnetic Fields at Amateur Radio Stations," FCC Report No. FCC/OET ASD-9601, February 1996. FCC, Office of Engineering and Technology (OET), Washington, D.C. 20554. Copies can be ordered from the National Technical Information Service (NTIS), 1 800-553-6847 (Order No. PB96-145016), or the report can be downloaded from OET's Home Page on the World Wide Web at: http://www.fcc.gov/oet/.

[11] See Bulletin 65 for a discussion of measurement techniques and instrumentation.

[12] For example, a power density "calculator" has been developed by Kenneth Harker, KM5FA, and can be accessed at the following World Wide Web site: http://www.utexas.edu/students/utarc/. This program is based on a C version of a public domain BASIC program written by Prof. Wayne Overbeck that appeared in the January, 1997, issue of *CQ VHF*. The source code for this program may be downloaded at: ftp://members.aol.com/cqvhf/97issues/rfsafety.bas

the web site, or copies can be requested from the FCC's RF safety program. The FCC's home page address is: www.fcc.gov. The web site address for the RF safety program is: www.fcc.gov/oet/rfsafety. Information on RF safety issues can also be directed to the FCC's RF safety program at: (202) 418-2464 [FAX: (202) 418-1918] or by calling the FCC's toll-free number: 1 (888) CALL FCC [1 (888) 225-5322].

Section 1
What is Radiofrequency Radiation?

Radiofrequency (RF) energy is one type of electromagnetic energy. Electromagnetic waves and associated phenomena can be discussed in terms of energy, radiation or fields. Electromagnetic "radiation" can be defined as waves of electric and magnetic energy moving together (i.e., radiating) through space. These waves are generated by the movement of electrical charges. For example, the movement of charge in a radio station antenna (the alternating current) creates electromagnetic waves that radiate away from the antenna and can be intercepted by receiving antennas. Electromagnetic "field" refers to the electric and magnetic environment existing at some location due to a radiating source such as an antenna.

An electromagnetic wave is characterized by its wavelength and frequency. The wavelength is the distance covered by one complete wave cycle. The frequency is the number of waves passing a point in a second. For example, a typical radio wave transmitted by a 2-meter VHF station has a wavelength of about 2 meters and a frequency of about 145 million cycles per second (145 million hertz): one cycle/second = one hertz, abbreviated Hz.

Electromagnetic waves travel through space at the speed of light. Wavelength and frequency are inversely related by a simple equation: (frequency) times (wavelength) = the speed of light, or $f \times \lambda = c$. Since the speed of light is a constant quantity, high-frequency electromagnetic waves have short wavelengths and low-frequency waves have long wavelengths. Frequency bands used for amateur radio transmissions are usually characterized by their approximate corresponding wavelengths, e.g., 12, 15, 17, 20 meters, etc.

The electromagnetic "spectrum" includes all of the various forms of electromagnetic energy ranging from extremely low frequency (ELF) energy (with very long wavelengths) to all the way up to X-rays and gamma rays which have very high frequencies and correspondingly short wavelengths. In between these extremes lie radio waves, microwaves, infrared radiation, visible light and ultraviolet radiation, respectively. The RF part of the electromagnetic spectrum can generally be defined as that part of the spectrum where electromagnetic waves have frequencies that range from about 3 kilohertz (kHz) to 300 gigahertz (GHz). Figure 1 illustrates the electromagnetic spectrum and the approximate relationship between the various forms of electromagnetic energy. Further information on RF

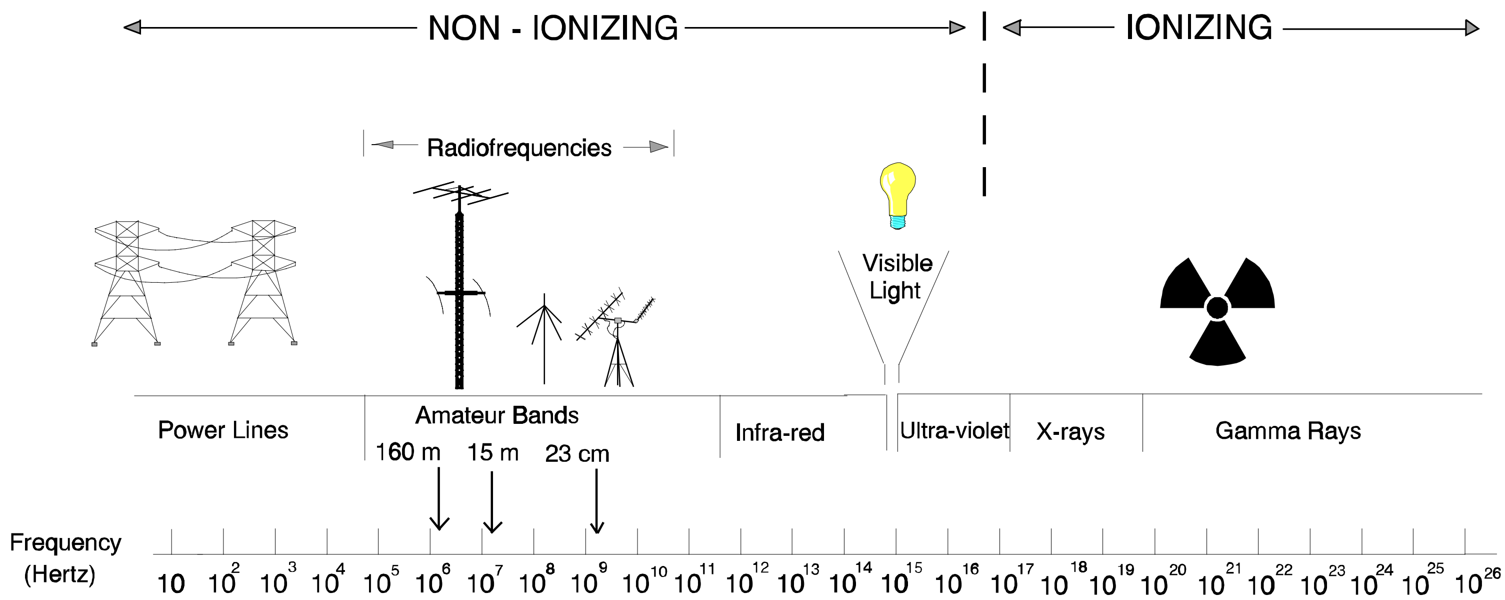


Figure 1. The Electromagnetic Spectrum

electromagnetic field exposure and potential biological effects can be found in the FCC's OET Bulletin 56.[13]

Section 2
FCC Exposure Guidelines and Their Application

The FCC's guidelines for Maximum Permissible Exposure (MPE) are defined in terms of power density (units of milliwatts per centimeter squared: mW/cm^2), electric field strength (units of volts per meter: V/m) and magnetic field strength (units of amperes per meter: A/m). In the far-field, *in free space* of a transmitting antenna, where the electric field vector (E), the magnetic field vector (H), and the direction of propagation can be considered to be all mutually orthogonal ("plane-wave" conditions), these quantities are related by the following equation.[14]

$$S = \frac{E^2}{3770} = 37.7H^2 \qquad (1)$$

where: S = power density (mW/cm^2)
E = electric field strength (V/m)
H = magnetic field strength (A/m)

In the near-field of a transmitting antenna, the term "far-field equivalent" or "plane-wave equivalent" power density is often used to indicate a quantity calculated by using the near-field values of E^2 or H^2 as if they were obtained in the far-field. As indicated in Table 1 of Appendix A for near-field exposures the values of plane-wave equivalent power density are given in some cases for reference purposes only. These values are sometimes used as a convenient comparison with MPEs for higher frequencies and are displayed on some measuring instruments.

---

[13] *"Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Radiation,"* OET Bulletin No. 56, Third Edition, January 1989. This bulletin can be viewed and downloaded at the FCC's OET World Wide Web site: http://www.fcc.gov/oet/rfsafety. Also, note that this bulletin is being revised, and a new version should be available in early 1998.

[14] Note that this equation is written so that power density is expressed in units of mW/cm^2. The impedance of free space, 377 ohms, is used in deriving the equation.

Exposure Environments

The FCC guidelines incorporate two separate tiers of exposure limits that are dependent on the situation in which the exposure takes place and/or the status of the individuals who are subject to exposure. The decision as to which tier applies in a given situation should be based on the application of the following definitions.

Occupational/controlled exposure limits apply to situations in which persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure. Occupational/controlled exposure limits also apply where exposure is of a transient nature as a result of incidental passage through a location where exposure levels may be above general population/uncontrolled limits (see below), as long as the exposed person has been made fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means. As discussed previously, occupational/controlled exposure limits apply to amateur licensees and members of their immediate household (but not their neighbors - see below). In general, a controlled environment is one for which access is controlled or restricted. In the case of an amateur station, the licensee or grantee is the person responsible for controlling access and providing the necessary information and training as described above.

General population/uncontrolled exposure limits apply to situations in which the general public may be exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure. Therefore, members of the general public always fall under this category when exposure is not employment-related, as in the case of residents in an area near a broadcast tower. Neighbors of amateurs and other non-household members would normally be subject to the general population/uncontrolled exposure limits.

For purposes of applying these definitions, awareness of the potential for RF exposure in a controlled or similar environment can be provided through specific training. Warning signs and labels can also be used to establish such awareness as long as they provide information, in a prominent manner, on risk of potential exposure and instructions on methods to minimize such exposure risk.[15]

Time and Spatial Averaging

A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the whole-body averaged specific absorption rate (SAR) that will result from the exposure and the

[15] For example, a sign warning of RF exposure risk and indicating that individuals should not remain in the area for more than a certain period of time could be acceptable. Bulletin 65 provides more information on warning signs.

MPEs specified in Table 1 of Appendix A are based on this concept. This means that local values of exposures that exceed the stated MPEs do not imply non-compliance if the spatial average of RF fields over the body does not exceed the MPEs. Further discussion of spatial averaging as it relates to field measurements can be found in Section 3 of Bulletin 65 and in the ANSI/IEEE and NCRP reference documents noted there.

Another feature of the exposure guidelines is that exposures, in terms of power density, E^2 or H^2, may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure. As shown in Table 1 of Appendix A, the averaging time for occupational/controlled exposures is 6 minutes, while the averaging time for general population/uncontrolled exposures is 30 minutes. It is important to note that for general population/uncontrolled exposures it is usually not possible or practical to control access or otherwise limit exposure duration to the extent that averaging times can be applied. In those situations, it would normally be necessary to assume continuous exposure to RF fields that would be created by the on/off cycles of the radiating source.

As an illustration of the application of time-averaging to occupational/controlled exposure (such as would occur at an amateur station) consider the following. The relevant interval for time-averaging for occupational/controlled exposures is six minutes. This means, for example, that during any given six-minute period an amateur or a worker could be exposed to two times the applicable power density limit for three minutes as long as he or she were not exposed at all for the preceding or following three minutes. Similarly, a worker could be exposed at three times the limit for two minutes as long as no exposure occurs during the preceding or subsequent four minutes, and so forth.

This concept can be generalized by considering Equation (2) that allows calculation of the allowable time(s) for exposure at [a] given power density level(s) during the appropriate time-averaging interval to meet the exposure criteria of Table 1 of Appendix A. The sum of the products of the exposure levels and the allowed times for exposure must equal the product of the appropriate MPE limit and the appropriate time-averaging interval.

$$\sum S_{exp} t_{exp} = S_{limit} t_{avg} \tag{2}$$

where:

S_{exp} = power density level of exposure (mW/cm^2)
S_{limit} = appropriate power density MPE limit (mW/cm^2)
t_{exp} = allowable time of exposure for S_{exp}
t_{avg} = appropriate MPE averaging time

For the example given above, if the MPE limit is 1 mW/cm^2, then the right-hand side of the equation becomes 6 mW-min/cm^2 (1 mW/cm^2 X 6 min). Therefore, if an exposure level is determined to be 2 mW/cm^2, the allowed time for exposure at this level during any six-minute interval would be a total of 3 minutes, since the left side of the equation must equal 6 (2 mW/cm^2 X 3 min). Of course, many other combinations of exposure levels and times may be involved during a given time-averaging interval. However, as long as the sum of the products on the left side of the equation equals the right side, the ***average*** exposure will meet the MPE limit. It is very important to remember that time-averaging applies to ***any*** t_{avg}. Therefore, in the above example, consideration would have to be given to the exposure situation both before and after the allowed three-minute exposure. The time-averaging interval can be viewed as a "sliding" period of time, six minutes in this case.

Another important point to remember concerning the FCC's exposure guidelines is that they constitute ***exposure*** limits (not ***emission*** limits), and they are relevant only to locations that are ***accessible*** to workers (or members of an amateur's household) or members of the public. Such access can be restricted or controlled by appropriate means such as the use of fences, warning signs, etc., as noted above. For the case of occupational/controlled exposure, procedures can be instituted for working in the vicinity of RF sources that will prevent exposures in excess of the guidelines. An example of such procedures would be restricting the time an individual could be near an RF source or requiring that work on or near such sources be performed while the transmitter is turned off or while power is appropriately reduced. Section 4 of Bulletin 65 should be consulted for further information on controlling exposure to comply with the FCC guidelines.

The concept of power averaging includes both on and off times, and the "duty factor" of the transmitting mode being used. Various modes of operation have their own duty factor that is representative of the ratio between average and peak power. Table 2 shows the duty factors for several modes commonly in use by amateurs. 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, e.g., a 6-minute period (the averaging time for controlled exposure) or a 30-minute period (the averaging time for uncontrolled exposure). This is an example of "source-based" time averaging.

For example, if a 1,500-watt PEP amateur single-sideband station (with no speech processing) transmits ("worst case") two minutes on, two minutes off then two minutes on again in any six-minute period (the averaging time period for controlled exposure), then for controlled exposure situations the effective power would be:

1,500 W X 0.2 (20% from Table 2) X ⅔ (4 of 6 minutes) = 200 W

For uncontrolled exposures the averaging time is 30 minutes and the total transmission time during any 30-minute period would be 20 minutes out of 30. The result would then also be:

1,500 W X 0.2 X ⅔ (20 of 30 minutes) = 200 W

On the other hand, if the transmission cycle were, say, 7 minutes on, 7 minutes off, the average power would be higher, since there would be continuous exposure over a six-minute period (controlled and uncontrolled time-averaging periods specify **any** six or thirty minute period, respectively). In this case the average power (for controlled exposure) becomes:

1,500 W X 0.2 X 1.0 (6 of 6 minutes) = 300 W

For uncontrolled/general population exposure average power becomes:

1,500 W X 0.2 X .53 (16 of 30 minutes) = 159 W

Another example might be a 500-watt CW station that is used in a DX pileup, transmitting 15 seconds every two minutes (45 seconds for six minutes) the result would be the same for either controlled or uncontrolled exposure:

500 W X 0.4 (40% from Table 2) X 0.125 (45 of 360 seconds) = 25 W (controlled)

500 W X 0.4 X 0.125 (225 of 1800 seconds) = 25 W (uncontrolled)

For the case of a 250-watt FM base station used to talk for 5 minutes on, 5 minutes off, 5 minutes on (worst case) calculated power becomes (since worst case is 5 minutes transmission during any six-minute period or 15 minutes during any 30-minute period):

250 W X 1.0 (100% from Table 2) X 0.833 (5 of 6 minutes) = 208.3 W (controlled)

250 W X 1 X 0.5 (15 out of 30 minutes) = 125 W (uncontrolled)

Table 2. Duty Factor of Modes Commonly Used by Amateurs

Mode	Duty Factor	Notes
Conversational SSB	20%	Note 1
Conversational SSB	50%	Note 2
Voice FM	100%	
FSK or RTTY	100%	
AFSK SSB	100%	
Conversational CW	40%	
Carrier	100%	Note 3

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: A full carrier is commonly used for tune-up purposes

Section 3
Methods of Predicting Human Exposure

Amateurs can select from a number of technically valid methods that can be useful in performing the required station evaluations. In general, it will be appropriate to use one of the following methods:

o Estimated compliance distances using tables developed from field-strength equations
o Estimated compliance distances using tables derived from antenna modeling
o Estimated compliance distances using antenna modeling (NEC, MININEC, etc.)
o Estimated compliance distances using field-strength equations
o Estimated compliance distances using software developed from field-strength equations
o Estimated compliance distances using calibrated field-strength measurements

In addition, methods for controlling exposure outlined in this supplement and in Section 4 of OET Bulletin 65 should be consulted for information on various means of ensuring compliance.

Tables Using Far-Field Formulas

Most amateurs will use various tables to estimate compliance distances for MPE limits. The simplest of these tables was developed using a far-field equation and assuming ground reflection of electromagnetic waves from the RF source. This model, although simplified, has been verified to be a reasonable approximation against a number of dipole, ground-plane and Yagi antennas, based on computer modeling (see later discussion) carried out by the ARRL. The ARRL reports that this model does not necessarily apply to all antenna types. Computer models of small HF loops, for example, yield RF fields very near the antenna that are much higher than the far-field formula predicts. In most cases, however, the tables derived from this far-field approximation give conservative results that over-predict exposure levels. Tables 4 a. and 4 b. are probably the easiest of the tables to use. They are followed by a number of tables based on specific antenna types.

The first step an amateur should take is to select the simple table that best applies to your station and determine the estimated compliance distance(s) for the relevant operating band(s). If a compliance distance is less than the actual distance to an exposure location, 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. Remember also, that the FCC's limits are ***exposure*** limits, not ***emission*** limits. Therefore, if high RF levels are present at a given location, but no one will be exposed at that location, this does not mean the station is out of compliance.

Tables Derived from NEC Modeling

In many cases, actual exposure below an antenna can be significantly less than that indicated by the tables based on far-field considerations. If a station "passes" using the far-field tables, this could be a moot point, although some licensees may still need to demonstrate actual predicted exposure levels. There are no easy answers to actual near-field predictions for actual antennas over real ground. The ARRL has, however, used Numeric Electromagnetic Code (NEC4) antenna modeling software to predict fields from a number of actual antennas and ground conditions. The results are summarized in a series of tables. These tables are located in Section 4 of this supplement, beginning with Table 18. Amateurs who desire a more accurate estimate of the RF fields expected near their antennas are encouraged to refer to this section. In many cases, a station that may not pass based on "worst-case" predictions could easily be shown to be in compliance using these tables. The ARRL tables offered in this supplement are only a few examples of a large number of tables prepared by that organization using this method.

Antenna Modeling

The same methods used to derive the NEC-modeled tables can be applied to any antenna situation. Amateurs are known to use many unique and varied types of antennas, and it is not possible to develop tables for every possible antenna type or combination. Some amateurs may want to evaluate the effect of multiple antennas or other conductors in proximity to their antennas in order to have a more accurate estimate of exposure than could be obtained from other calculational methods. For example, many amateurs may wish to use antenna-modeling software for this purpose.

Many antenna-modeling programs are based on NEC or MININEC analysis. These programs often yield very accurate results. An amateur enters his or her antenna dimensions and ground characteristics into the antenna model, and the program is then executed to calculate electric and magnetic field strengths near the antenna. These programs do require some amount of user skill, but the average amateur should not experience too much difficulty in using them. The ARRL Web page maintains a list of software vendors who sell antenna modeling software (http://www.arrl.org/news/rfsafety).[16]

---

[16] Note: Brian Beezley, K6STI, has made a scaled-down version of his Antenna Optimizer software available. Download NF.ZIP at: http://oak.oakland.edu:8080/pub/hamradio/arrl/bbs/programs/. Contact: Brian Beezley, K6STI, 3532 Linda Vista Drive, San Marcos, CA 92069, Phone: 619-599-4962, Email: k6sti@n2.net. Also, The equations used for the simple, far-field tables in this supplement have been used to develop a program written in Basic by Wayne Overbeck, N6NB. This program has been made available for downloading from ftp://members.aol.com/cqvhf/97issues/rfsafety.bas. It has also been rewritten into a power density calculator by Ken Harker, KM5FA, and can be accessed at http://www.utexas.edu/students/utarc/. Roy Lewellan, W7EL, sells ELNEC and EZNEC antenna modeling software, based on MININEC or NEC2. 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, Phone: 503-646-2885, Fax: 503-671-9046, Email: w7el@teleport.com, Web Site: ftp://ftp.teleport.com/vendors/w7el/

Prediction Methods and Derivation of Tables

The tables, figures and graphs provided in this supplement should allow most amateur station licensees and applicants to easily determine the steps necessary to ensure that their stations will comply with the FCC's guidelines. By using the appropriate table or figure for a given antenna type, the station licensee should be able to obtain the necessary compliance information. As an example, to ensure compliance for a station using a certain antenna type and transmitter power level, the minimum separation distance between a person and an antenna is given in the appropriate table. Since continuous exposure is assumed for convenience, and because time-averaging of exposure is allowed, these distances will be conservative (most amateur station transmissions are two-way and thus not continuous for significant periods of time).

The tables and figures are based both on far-field equations (see Bulletin 65) and also on data obtained from computer programs such as the Numeric Electromagnetic Code (NEC) and MININEC. Much of this information has been provided by individual amateur licensees and amateur radio organizations. When this is the case, the source of the table or information has been provided. The tables are provided for a sample of the most commonly-used amateur station antennas. For other antennas or system configurations, amateurs may have to perform their own calculations or other evaluation based on the information in Bulletin 65.

As discussed in Bulletin 65, calculations can be made to predict RF field strength and power density levels around typical RF sources. For example, in the case of a non-directional antenna, a prediction for power density in the far-field of the antenna can be made by use of the general Equations (3) or (4) below [for conversion to electric or magnetic field strength see Equation (1) above]. These equations are generally accurate in the far-field of an antenna but will over-predict power density in the near field, where it could be used for making a "worst case" or conservative prediction.

$$S = \frac{PG}{4\pi R^2} \qquad (3)$$

where: S = power density (in appropriate units, e.g. mW/cm^2)
P = power input to the antenna (in appropriate units, e.g., mW)
G = power gain of the antenna in the direction of interest relative to an isotropic radiator (dBi)
R = distance to the center of radiation of the antenna (appropriate units, e.g., cm)

or:

$$S = \frac{EIRP}{4\pi R^2} \qquad (4)$$

where: EIRP = equivalent (or effective) isotropically radiated power

When using these and other equations care must be taken to use the ***correct units*** for all variables. For example, in Equation (3), if power density in units of mW/cm^2 is desired then power should be expressed in milliwatts and distance in cm. Other units may be used, but care must be taken to use correct conversion factors when necessary. Also, it is important to note that the power gain factor, ***G***, in Equation (3) is normally ***numeric*** gain. Therefore, when power gain is expressed in logarithmic terms, i.e., dB, a conversion is required using the relation:

$$G = 10^{\frac{dB}{10}}$$

For example, a logarithmic power gain of 14 dB is equal to a numeric gain of 25.1. Table 3 gives factors that can be used for converting logarithmic and numerical gain.

Table 3. Gain Conversion

Gain (dBi)	Numeric Gain	Gain (dBi)	Numeric Gain
1	1.3	11	12.6
2	1.6	12	15.9
3	2.0	13	20.0
4	2.5	14	25.1
5	3.2	15	31.6
6	4.0	16	39.8
7	5.0	18	63.1
8	6.3	20	100.0
9	7.9	25	316.2
10	10.0	30	1000.0

In many cases, operating power may be expressed in terms of "effective radiated power" or "ERP" instead of EIRP. ERP is referenced to a half-wave dipole radiator instead of an isotropic radiator. Therefore, if ERP is given it is necessary to convert ERP into EIRP in order to use the above equations. This is easily done by multiplying the ERP by the factor of 1.64, the gain of a half-wave dipole relative to an isotropic radiator. Conversely, divide

EIRP by 1.64 to obtain ERP. For example, if ERP is used in Equation (4) the relation becomes:

$$S = \frac{EIRP}{4\pi R^2} = \frac{1.64\ ERP}{4\pi R^2} = \frac{0.41\ ERP}{\pi R^2} \qquad (5)$$

For a truly worst-case prediction of power density at or near a surface, such as at ground-level or on a rooftop, 100% reflection of incoming radiation could be assumed, resulting in a potential doubling of predicted field strength and a four-fold increase in (far-field equivalent) power density. In that case Equations (3) and (4) can be modified as follows to:

$$S = \frac{(2)^2 PG}{4\pi R^2} = \frac{PG}{\pi R^2} = \frac{EIRP}{\pi R^2} \qquad (6)$$

As discussed in Bulletin 65, for the case of FM radio and television broadcast antennas, the U.S. Environmental Protection Agency (EPA) developed models for predicting ground-level field strength and power density. The EPA model recommended a more realistic approximation for ground reflection by assuming a maximum 1.6-fold increase in field strength leading to an increase in power density of 2.56 (1.6 X 1.6). Equation (4) then becomes:

$$S = \frac{2.56\ EIRP}{4\pi R^2} = \frac{0.64\ EIRP}{\pi R^2} \qquad (7)$$

If ERP is used in Equation (7), the relation becomes:

$$S = \frac{0.64\ EIRP}{\pi R^2} = \frac{(0.64)(1.64)\ ERP}{\pi R^2} = \frac{1.05\ ERP}{\pi R^2} \qquad (8)$$

It is often convenient to use units of microwatts per centimeter squared ($\mu W/cm^2$) instead of mW/cm^2 in describing power density. The following simpler form of Equation (8) can be derived if power density, **S**, is to be expressed in units of $\mu W/cm^2$:

$$S = \frac{33.4\ ERP}{R^2} \qquad (9)$$

where: S = power density in $\mu W/cm^2$
ERP = power in watts
R = distance in meters

An example of the use of the above equations follows. A repeater station is transmitting at a frequency of 146.94 MHz with a total nominal ERP (including all polarizations) of 1 kilowatt (1,000 watts) from a tower-mounted antenna. The height to the center of radiation is 10 meters above ground-level. Using the formulas above, what would be the calculated "worst-case" power density that could be expected at a point 2 meters above ground (approximate head level) and at a distance of 20 meters from the base of the tower (e.g., at a neighbor's property line where the more restrictive general population exposure limits would apply)? Note that this type of analysis ***does not*** take into account the specific radiation pattern of the antenna, i.e., no information on directionality of propagation is considered. Use of actual radiation pattern data would likely significantly reduce actual ground-level exposures from those calculated below, but often this is unnecessary when using "worst case" approximations or for amateur stations where operating powers may not be that high (see Bulletin 65 for further discussion)

From simple trigonometry the distance **R** can be calculated to be about 21.5 meters [square root of: $(8)^2 + (20)^2$]. Therefore, using Equation (9), the calculated power density is:

$$S = \frac{33.4\ (1{,}000\ watts)}{(21.5\ m)^2} = about\ 72\ \mu W/cm^2$$

By consulting Table 1 in Appendix A, it can be determined that the limit for general population/uncontrolled exposure at 146.94 MHz is 0.2 mW/cm^2 (200 $\mu W/cm^2$). Therefore, this calculation shows that even under "worst-case" conditions this station would easily comply with the general population/uncontrolled limits at the neighbor's property line. Similar calculations could be made to ensure compliance at other locations, such as at the base of the tower where the shortest direct line distance, R, to the ground would occur and where worst-case exposure of the amateur's household members might occur.

Measurements

The equations and calculational methods described here and in OET Bulletin 65 have been used to develop the tables, figures and graphs in this supplement. In addition, direct measurement of RF fields can be performed, and this topic is also discussed in Bulletin 65. Bulletin 65 includes an extensive section on the topic of performing measurements of RF field strength and power density. However, in general, most amateurs will not have access to the appropriate calibrated equipment to make such measurements. The field-strength meters in common use by amateurs operators and inexpensive hand-held field strength meters do not provide the accuracy necessary for reliable measurements, especially when different frequencies may be encountered at a given measurement location. As discussed in Bulletin 65, repeatability and accuracy of more than a few dB is often difficult to achieve even with the best available instrumentation and expertise.

Section 4
Estimated Compliance Distances from Typical Transmitting Antennas

Tables Based on Far-Field Equations

The following tables are based on use of the far-field equations for power density given above (Equations 3 and following) assuming the reflection factor used by the EPA. These tables represent "worst case" estimates of the far-field equivalent power density. These tables should be used unless the exposure situation of interest is in the main beam or lobe of the antenna being considered. In the latter case, surface reflection would not necessarily be of major concern.

Tables 4-17 are not height-specific. To use these tables it is necessary to match the characteristics of the antenna in question as closely as possible to those of the appropriate table and locate the distance to the appropriate environment boundary. For example, for a 500 watt, 21 MHz, horizontal, half-wave dipole antenna refer to Table 7. In order to comply with the occupational/controlled environment, a line-of-sight distance of 2.8 meters would have to be maintained from the antenna for conditions of continuous transmission. The distance required to comply with the limit for the general public/uncontrolled exposure criteria distance would be a minimum of 6.3 meters for continuous transmission. If the antenna in question is operated with a power level in between two of the levels given in a table it is possible to interpolate the distance given between the actual power level and the next highest power level.

For example, consider the following situation. Using Table 5 it is desired to find the distance necessary to comply with the occupational/controlled limit for a three-element, tri-band Yagi antenna transmitting at approximately 14 MHz with 700 watts of power (peak envelope power or PEP). Since a specific entry for 700 watts is not given in Table 5, the appropriate distance must be determined from those given. There are two ways to do this. The first and simplest approach is to simply use the distance corresponding to the next highest power level. This approach will lead to a more conservative distance, but may not be a problem if the actual separation distance is more anyway. For this approach, using the entry for 1,000 watts results in a distance requirement of 4.5 meters in order to be assured of meeting the controlled/occupational criteria.

The second approach for this case is to interpolate between the entries for 500 watts and 1,000 watts, respectively. This requires solving for the value x in the following relation and adding the value obtained for x to the distance requirement for 500 watts (3.1 m). To set up this calculation, 200 watts is obtained from 700-500 watts, 500 watts is obtained from 1000 - 500 watts and 1.4 is obtained from 4.5 - 3.1.

Solving for x

$$\frac{200\ watts}{500\ watts} = \frac{x}{1.4}$$

Solving for x yields approximately 0.6. Adding this to 3.1 results in a value of about 3.7 m. Therefore, using this method, at 700 watts and 14 MHz, the required "worst-case" distance is determined to be about 3.7 meters from the antenna in order to comply with the occupational/controlled limit.

NOTE: Some of the tables in this section use the following abbreviations:

- ✓ **con = occupational/controlled exposure limit(s)**
- ✓ **unc = general population/uncontrolled exposure limit(s)**
- ✓ **f = transmitter frequency**
- ✓ **HAG = antenna height above ground level**
- ✓ **m = meter(s)**

TABLE 4a. (MF/HF Bands)
(Developed by Fred Maia, W5YI Group, working in cooperation with the ARRL.)

Estimated distances in meters 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") using typical antenna gains for the amateur service and assuming 100% duty cycle and maximum surface reflection. Chart represents worst case scenario.

Freq. (MF/HF) (MHz/Band)	Antenna Gain (dBi)	Peak Envelope Power (watts) 100 watts		500 watts		1000 watts		1500 watts	
		Con.	Unc.	Con.	Unc	Con.	Unc.	Con.	Unc.
2.0 (160m)	0	0.1	0.2	0.3	0.5	0.5	0.7	0.6	0.8
2.0 (160m)	3	0.2	0.3	0.5	0.7	0.6	1.06	0.8	1.2
4.0 (75/80m)	0	0.2	0.4	0.4	1.0	0.6	1.3	0.7	1.6
4.0 (75/80m)	3	0.3	0.6	0.6	1.3	0.9	1.9	1.0	2.3
7.3 (40m)	0	0.3	0.8	0.8	1.7	1.1	2.5	1.3	3.0
7.3 (40m)	3	0.5	1.1	1.1	2.5	1.6	3.5	1.9	4.2
7.3 (40m)	6	0.7	1.5	1.5	3.5	2.2	4.9	2.7	6.0
10.15 (30m)	0	0.5	1.1	1.1	2.4	1.5	3.4	1.9	4.2
10.15 (30m)	3	0.7	1.5	1.5	3.4	2.2	4.8	2.6	5.9
10.15 (30m)	6	1.0	2.2	2.2	4.8	3.0	6.8	3.7	8.3
14.35 (20m)	0	0.7	1.5	1.5	3.4	2.2	4.8	2.6	5.9
14.35 (20m)	3	1.0	2.2	2.2	4.8	3.0	6.8	3.7	8.4
14.35 (20m)	6	1.4	3.0	3.0	6.8	4.3	9.6	5.3	11.8
14.35 (20m)	9	1.9	4.3	4.3	9.6	6.1	13.6	7.5	16.7
18.168 (17m)	0	0.9	1.9	1.9	4.3	2.7	6.1	3.3	7.5
18.168 (17m)	3	1.2	2.7	2.7	6.1	3.9	8.6	4.7	10.6
18.168 (17m)	6	1.7	3.9	3.9	8.6	5.5	12.2	6.7	14.9
18.168 (17m)	9	2.4	5.4	5.4	12.2	7.7	17.2	9.4	21.1
21.145 (15m)	0	1.0	2.3	2.3	5.1	3.2	7.2	4.0	8.8
21.145 (15m)	3	1.4	3.2	3.2	7.2	4.6	10.2	5.6	12.5
21.145 (15m)	6	2.0	4.6	4.6	10.2	6.4	14.4	7.9	17.6
21.145 (15m)	9	2.9	6.4	6.4	14.4	9.1	20.3	11.1	24.9
24.99 (12m)	0	1.2	2.7	2.7	5.9	3.8	8.4	4.6	10.3
24.99 (12m)	3	1.7	3.8	3.8	8.4	5.3	11.9	6.5	14.5
24.99 (12m)	6	2.4	5.3	5.3	11.9	7.5	16.8	9.2	20.5
24.99 (12m)	9	3.4	7.5	7.5	16.8	10.6	23.7	13.0	29.0
29.7 (10m)	0	1.4	3.2	3.2	7.1	4.5	10.0	5.5	12.2
29.7 (10m)	3	2.0	4.5	4.5	10.0	6.3	14.1	7.7	17.3
29.7 (10m)	6	2.8	6.3	6.3	14.1	8.9	19.9	10.9	24.4
29.7 (10m)	9	4.0	8.9	8.9	19.9	12.6	28.2	15.4	34.5

Note: Multiply above distances by 0.707 if duty cycle is 50% - such as during a typical back and forth communications exchange. To convert from meters to feet multiply meters by 3.28. Distance indicated is shortest line-of-sight distance to point where MPE limit for appropriate exposure tier is predicted to occur.

Table 4b. (VHF/UHF Bands)
(Developed by Fred Maia, W5YI Group, working in cooperation with the ARRL.)

Estimated distances in meters 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") using typical antenna gains for the amateur service and assuming 100% duty cycle and maximum surface reflection. Chart represents worst case scenario.

Freq (VHF/UHF) (MHz/Band)	Antenna Gain (dBi)	Peak Envelope Power (watts) 50 watts		100 watts		500 watts		1000 watts	
		Con.	Unc.	Con.	Unc	Con.	Unc.	Con.	Unc.
50 (6m)	0	1.0	2.3	1.4	3.2	3.2	7.1	4.5	10.1
50 (6m)	3	1.4	3.2	2.0	4.5	4.5	10.1	6.4	14.3
50 (6m)	6	2.0	4.5	2.8	6.4	6.4	14.2	9.0	20.1
50 (6m)	9	2.8	6.4	4.0	9.0	9.0	20.1	12.7	28.4
50 (6m)	12	4.0	9.0	5.7	12.7	12.7	28.4	18.0	40.2
50 (6m)	15	5.7	12.7	8.0	18.0	18.0	40.2	25.4	56.8
144 (2m)	0	1.0	2.3	1.4	3.2	3.2	7.1	4.5	10.1
144 (2m)	3	1.4	3.2	2.0	4.5	4.5	10.1	6.4	14.3
144 (2m)	6	2.0	4.5	2.8	6.4	6.4	14.2	9.0	20.1
144 (2m)	9	2.8	6.4	4.0	9.0	9.0	20.1	12.7	28.4
144 (2m)	12	4.0	9.0	5.7	12.7	12.7	28.4	18.0	40.2
144 (2m)	15	5.7	12.7	8.0	18.0	18.0	40.2	25.4	56.8
144 (2m)	20	10.1	22.6	14.3	32.0	32.0	71.4	45.1	101.0
222 (1.25m)	0	1.0	2.3	1.4	3.2	3.2	7.1	4.5	10.1
222 (1.25m)	3	1.4	3.2	2.0	4.5	4.5	10.1	6.4	14.3
222 (1.25m)	6	2.0	4.5	2.8	6.4	6.4	14.2	9.0	20.1
222 (1.25m)	9	2.8	6.4	4.0	9.0	9.0	20.1	12.7	28.4
222 (1.25m)	12	4.0	9.0	5.7	12.7	12.7	28.4	18.0	40.2
222 (1.25m)	15	5.7	12.7	8.0	18.0	18.0	40.2	25.4	56.8
450 (70cm)	0	0.8	1.8	1.2	2.6	2.6	5.8	3.7	8.2
450 (70cm)	3	1.2	2.6	1.6	3.7	3.7	8.2	5.2	11.6
450 (70cm)	6	1.6	3.7	2.3	5.2	5.2	11.6	7.4	16.4
450 (70cm)	9	2.3	5.2	3.3	7.3	7.3	16.4	10.4	23.2
450 (70cm)	12	3.3	7.3	4.6	10.4	10.4	23.2	14.7	32.8
902 (33cm)	0	0.6	1.3	0.8	1.8	1.8	4.1	2.6	5.8
902 (33cm)	3	0.8	1.8	1.2	2.6	2.6	5.8	3.7	8.2
902 (33cm)	6	1.2	2.6	1.6	3.7	3.7	8.2	5.2	11.6
902 (33cm)	9	1.6	3.7	2.3	5.2	5.2	11.6	7.3	16.4
902 (33cm)	12	2.3	5.2	3.3	7.3	7.3	16.4	10.4	23.2
1240 (23cm)	0	0.5	1.1	0.7	1.6	1.6	3.5	2.2	5.0
1240 (23cm)	3	0.7	1.6	1.0	2.2	2.2	5.0	3.1	7.0
1240 (23cm)	6	1.0	2.2	1.4	3.1	3.1	7.0	4.4	9.9
1240 (23cm)	9	1.4	3.1	2.0	4.4	4.4	9.9	6.3	14.0
1240 (23cm)	12	2.0	4.4	2.8	6.2	6.2	14.0	8.8	19.8

Note: Multiply above distances by 0.707 if duty cycle is 50% - such as during a typical back and forth communications exchange. To convert from meters to feet multiply meters by 3.28. Distance indicated is shortest line-of-sight distance to point where MPE limit for appropriate exposure tier is predicted to occur.

The following tables (Tables 5 -17) give estimated distances to meet RF power density MPE limits in the ***main beam*** of typical amateur station antennas. These tables were supplied by Professor Wayne Overbeck of California State University, Fullerton, CA., Mr. Kai Siwiak, P.E., KE4PT, and by the FCC. These tables are based on the far-field equations discussed previously (and in Bulletin 65) and provide values that assume a surface reflection as an estimate of the ground reflection and other factors that surround most antenna installations.

It may be possible to obtain a more accurate assessment of the required compliance distances by using tables 18-31 found later in this section as they are based on computer modeling using the Numeric Electromagnetic Code (NEC 4). They will likely provide a more accurate analysis of antenna field patterns. However, a disadvantage to using the tables derived from computer modeling is that the antenna in question must match the approximate antenna height given in order for the values to be applicable. If the antenna in question is not located at the appropriate height, then tables 4-17 should be consulted, or other appropriate methods of determining compliance described in Bulletin 65 and this supplement should be used.

TABLE 5. Three-element "triband" Yagi assuming surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits						
	14 MHz, 6.5 dBi		**21 MHz, 7 dBi**		**28 MHz, 8 dBi**	
Power (watts)	con.	unc.	con.	unc.	con.	unc.
100	1.4	3.1	2.2	5	3.4	7.5
500	3.1	7	5	11.2	7.5	16.7
1,000	4.5	10	7.1	15.8	10.6	23.7
1,500	5.5	12.2	8.7	19.4	13	29

TABLE 6. Omnidirectional HF quarter-wave vertical or ground plane antenna (estimated gain 1 dBi) assumes surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits										
	3.5 MHz		**7 MHz**		**14 MHz**		**21 MHz**		**28 MHz**	
Transmitter power (watts)	con.	unc.	con.	unc.	con.	unc.	con.	unc.	con.	unc.
100	0.2	0.4	0.4	0.8	0.8	1.7	1.1	2.5	1.5	3.3
500	0.4	0.9	0.8	1.9	1.7	3.7	2.5	5.6	3.3	7.5
1000	0.6	1.3	1.2	2.7	2.4	5.3	3.5	7.9	4.7	10.6
1500	0.7	1.6	1.4	3.2	2.9	6.5	4.3	9.7	5.8	12.9

TABLE 7. Horizontal half-wave dipole wire antenna (estimated gain 2 dBi) assuming surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits										
	3.5 MHz		**7 MHz**		**14 MHz**		**21 MHz**		**28 MHz**	
Transmitter power (watts)	con.	unc.	con.	unc.	con.	unc,	con.	unc.	con.	unc,
100	0.2	0.5	0.4	0.9	0.9	1.9	1.3	2.8	1.7	3.7
500	0.5	1.0	0.9	2.1	1.9	4.2	2.8	6.3	3.8	8.4
1000	0.7	1.5	1.3	2.9	2.6	5.9	4	8.9	5.3	11.8
1500	0.8	1.8	1.6	3.6	3.3	7.2	4.9	10.9	6.5	14.5

TABLE 8. VHF 1/4 wave plane or mobile whip antenna at 146 MHz (estimated gain 1 dBi) assuming surface (ground) reflection

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure limit
10	0.5	1.1
50	1.1	2.5
150	2	4.4

TABLE 9. UHF 5/8 wave ground plane or whip antenna at 446 MHz (estimated gain 4 dBi); main beam exposure, assumes surface (ground) reflection

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure limit
10	0.6	1.3
50	1.3	2.9
150	2.3	5.1

TABLE 10. Seventeen (17) element Yagi on five-wavelength boom designed for weak-signal communications on 144 MHz (estimated gain 16.8 dBi); main beam exposure assuming surface (ground) reflection

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure limit
10	3.1	7
100	9.9	22.1
500	22.1	49
1500	38.2	85.5

TABLE 11. Seventeen (17) element Yagi on five-wavelength boom designed for weak-signal communications on 144 MHz (estimated gain 16.8 dBi); main beam exposure; this table does not assume ground reflection and can only be used if the antenna is pointed significantly above the horizon

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure
10	2	4.4
100	6.1	13.9
500	13.9	30.8
1500	23.9	53.5

TABLE 12. Eight 17-element Yagis with five-wavelength booms designed for "moonbounce"communications on 144 MHz (estimated gain 24 dBi); main beam exposure, assumes surface (ground) reflection

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure limit
150	27.7	62
500	50.6	113
1500	87.6	196

TABLE 13. Eight 17-element Yagis with five-wavelength booms designed for "moonbounce" communications on 144 MHz (estimated gain 24 dBi); main beam exposure; this table does not assume ground reflection and can only be used if the antenna is pointed significantly above the horizon

Transmitter power (watts)	Distance (m) to comply with occupational/ controlled exposure limit	Distance (m) to comply with gen. population/ uncontrolled exposure
150	17.4	38.7
500	31.5	70.7
1500	54.9	121.9

TABLE 14. HF Discone antenna (estimated gain 2 dBi); main beam exposure, assumes surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits								
	3.5 MHz		**7 MHz**		**14 MHz**		**28 MHz**	
Transmitter power (watts)	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0.1	0.3	0.3	0.6	0.5	1.2	1.1	2.4
100	0.2	0.4	0.4	0.8	0.7	1.7	1.5	3.3
250	0.3	0.7	0.6	1.3	1.2	2.6	2.4	5.3
500	0.4	0.9	0.8	1.9	1.7	3.7	3.3	7.5

TABLE 15. VHF/UHF Discone antenna (estimated gain 2 dBi) main beam exposure, assumes surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits								
	50 MHz		**144 MHz**		**220 MHz**		**440 MHz**	
Transmitter power (watts)	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	1.3	2.8	1.3	2.8	1.3	2.8	1	2.3
100	1.8	4	1.8	4	1.8	4	1.5	3.3
250	2.8	6.4	2.8	6.4	2.8	6.4	2.3	5.2
500	4	9	4	9	4	9	3.3	7.3

TABLE 16. Quarter-wave half-sloper antenna (estimated average gain 6.7 dBi); main beam exposure, assumes surface (ground) reflection

Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits								
	7 MHz		**14 MHz**		**21 MHz**		**28 MHz**	
Transmitter power (watts)	con.	unc.	con.	unc.	con.	unc.	con.	unc.
100	0.7	1.6	1.4	3.2	2.2	4.8	2.9	6.4
500	1.6	3.6	3.2	7.2	4.9	10.7	6.4	14.3
1000	2.3	5	4.5	10.2	6.9	15.2	9.1	20.2
1500	2.8	6.2	5.6	12.5	8.4	18.6	11.1	24.8

TABLE 17. (Submitted by Kai Siwiak, P.E., KE4PT) One meter diameter HF Loop, 150 W, assumes surface (ground) reflection

Frequency (MHz)	Distance (meters) from loop center for compliance with either occupational/controlled or general population/uncontrolled exposure limits	
	con.	unc.
7	2.0	2.8
10	2.1	2.8
14	2.1	3.2
18	2.3	3.5
21	2.3	3.7
24	2.4	3.9
28	2.4	4.2

Tables Based on Computer Modeling

The following tables were developed by the American Radio Relay League (ARRL). The information in these tables was created by use of the Numeric Electromagnetic Code (NEC4), a computer program developed by the Lawrence Livermore Laboratory.[17] The various heights listed for exposure represent different configurations in a typical residential building. For example, the 1.8-meter height was used to estimate ground-level or first-floor exposure. The 3.7 meter height represents the ceiling of a typical first floor or the lower part of a second floor. The 6.1 meter height represents the ceiling of a second floor, or the lower level of a third floor. The 9.1 or 4.6 meter heights represent typical exposure if someone were standing at the same height as the antenna in its main beam. This is a typical "worst-case" exposure for each antenna type. In addition, an 18.2 meter height was included to show how significantly the exposure would drop if antennas were placed at this height or above.

In modeling these antennas, a dielectric constant of 13.0 and a conductivity of 0.005 Seimens were assumed for all antennas. This is generally recognized as "average" ground. In general, the compliance distances would be a bit greater for better ground, such as might be found in rich farmland, or less for poorer ground such as rocky, dry soil. The NEC4 program automatically calculated the specific gain of the antenna dimensions modeled.

These tables should provide a more accurate estimate of actual exposure than tables 4-17 which are based on the far-field equation. However, in order to achieve this accuracy, it was necessary to model specific antennas. The following tables are based on computer modeling of antennas at various heights above average ground. They will likely provide a more accurate estimate of antenna fields at the specific compliance heights used in the tables. However, a disadvantage to using tables 18-31, is that the antenna in question, and its height, must match the table to be applicable. These tables are examples of a larger number of tables developed by the ARRL using the same methods.

If the antenna is located higher than the heights in these tables, *in general*, the exposure should be less than the predicted values. If these tables are not a good match for your particular installation, it may be necessary to use the previous tables or other evaluation methods described in Bulletin 65.

[17] Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, tel (510) 422-1100, http://www.llnl.gov/.

TABLE 18. Ten (10)-meter band, horizontal, half-wave dipole wire antenna, f = 29.7 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.8	1.7
100	0	0	0	0	0	0	1.1	2.4
150	0	0	0	0	0	0.9	1.2	2.9
250	0	0	0	0	0	2.7	1.7	3.8
500	0	0	0	0	0	4.9	2.4	5.5
750	0	3.8	0	6.9	0.9	6.3	2.9	6.7
1000	0	5.8	0	9.8	2.1	7.3	3.4	7.3
1500	0	8.2	0	12.8	3.4	9.5	4.3	8.8

The following example illustrates use of Table 18. Assume an antenna is mounted approximately 9 meters above ground and operates at 250 watts. Then at 1.8 m and 3.7 m above ground a person could safely occupy the area directly below the antenna. In other words, at a distance of 3.7 m above ground, a person would be approximately 5.4 m below the antenna and still be in compliance with both the occupational/controlled and general population/ uncontrolled exposure guidelines. However if a person were located 6.1 m above ground level, a distance of 2.7 m from the antenna would be required in order to comply with the general population/uncontrolled guidelines. As a "worst case," if a person were located 9.1 m above ground, in other words at the same height as the antenna, that person would have to be separated by at least 3.8 m from the antenna to be in compliance with the general population/ uncontrolled exposure guidelines or a distance of 1.7 m away to be in compliance with the occupational/controlled exposure limits.

Continuing to use Table 18, if a person lived in a neighborhood of single story residences, and an antenna was approximately 9.1 m above the ground, then the first column of the table (1.8 m) corresponds to the ground level exposure of a typical person. The data in the table indicates that a power of up to 1000 watts could be used and the antenna would still not cause a compliance problem at ground level. If, for example, a neighbor was working on his roof at a level higher than 1.8 m., say 3.7 m., the power would have to be scaled accordingly by the amateur so the appropriate distance would be met between the neighbor and the antenna. If the power were raised to 1500 watts, for example, a distance of 12.8 m. would have to be maintained from this antenna in order to ensure compliance with the uncontrolled limit at the 3.7 m. height.

TABLE 19. Ten (10)-meter band, three (3)-element Yagi antenna, f = 29.7 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	2.6	4.0
100	0	0	0	0	0	0	3.0	5.5
150	0	0	0	0	0	4.7	3.4	6.6
250	0	0	0	0	0	7.5	4.0	8.2
500	0	0	0	14.3	0	15.0	5.5	11.0
750	0	10.7	0	18.0	4.6	21.6	6.5	13.7
1000	0	14.0	0	20.7	6.4	25.3	7.3	18.3
1500	0	17.4	0	24.1	8.5	30.5	8.8	31.4

TABLE 20. Ten (10)-meter band, three (3)-element Yagi antenna, f = 29.7 MHz, HAG = 18.3 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**18.3**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	2.6	4.0
100	0	0	0	0	0	0	3.0	5.5
150	0	0	0	0	0	0	3.4	6.7
250	0	0	0	0	0	0	4.0	8.5
500	0	0	0	0	0	0	5.5	12.8
750	0	0	0	0	0	0	6.7	15.8
1000	0	0	0	0	0	0	7.6	17.6
1500	0	0	0	21.0	0	0	9.4	20.1

TABLE 21. Fifteen (15)-meter band horizontal, half-wave dipole wire antenna, f = 21.45 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.6	1.2
100	0	0	0	0	0	0	0.8	1.8
150	0	0	0	0	0	0	0.9	2.3
250	0	0	0	0	0	0.8	1.2	2.9
500	0	0	0	0	0	3.0	1.8	4.1
750	0	0	0	1.7	0	4.3	2.3	5.0
1000	0	0	0	4.6	0	5.2	2.6	5.8
1500	0	3.0	0	7.5	1.5	8.1	3.2	7.2

TABLE 22. Fifteen (15)-meter band, three-element Yagi, f = 21.45 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	3.2	3.8
100	0	0	0	0	0	0	3.4	4.4
150	0	0	0	0	0	0	3.5	5.2
250	0	0	0	0	0	3.0	3.8	6.4
500	0	0	0	0	0	7.8	4.4	9.0
750	0	0	0	8.2	0	12.5	5.2	11.4
1000	0	0	0	11.6	1.5	15.4	5.8	14.2
1500	0	11.1	0	14.8	4.3	19.4	7.0	20.7

TABLE 23. Twenty (20)-meter band horizontal, half-wave dipole wire antenna, f = 14.35 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground where exposure occurs (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.3	0.8
100	0	0	0	0	0	0	0.5	1.1
150	0	0	0	0	0	0	0.6	1.4
250	0	0	0	0	0	0	0.8	1.8
500	0	0	0	0	0	0	1.1	2.6
750	0	0	0	0	0	0	1.4	3.2
1000	0	0	0	0	0	1.2	1.5	3.8
1500	0	0	0	0	0	2.7	2.0	4.7

TABLE 24. Twenty (20)-meter band , three-element Yagi, f = 14.35 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	4.4	4.9
100	0	0	0	0	0	0	4.6	5.2
150	0	0	0	0	0	0	4.7	5.3
250	0	0	0	0	0	0	4.9	5.8
500	0	0	0	0	0	4.0	5.2	6.7
750	0	0	0	0	0	5.5	5.3	7.8
1000	0	0	0	0	0	6.7	5.6	8.8
1500	0	0	0	0	0	8.7	6.0	10.8

TABLE 25. Twenty (20)-meter band, three-element Yagi, f = 14.35 MHz, HAG = 18.3 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**6.1**		**18.3**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	4.4	4.9
100	0	0	0	0	0	0	4.6	5.2
150	0	0	0	0	0	0	4.7	5.5
250	0	0	0	0	0	0	4.9	5.8
500	0	0	0	0	0	0	5.2	6.9
750	0	0	0	0	0	0	5.5	7.8
1000	0	0	0	0	0	0	5.6	8.7
1500	0	0	0	0	0	0	6.1	10.3

TABLE 26. Forty (40)-meter band, horizontal, half-wave dipole wire antenna, f = 7.3 MHz, HAG = 4.6 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**4.6**		**6.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0.2	0.5	0	0
100	0	0	0	0	0.3	0.6	0	0
150	0	0	0	0.2	0.4	0.8	0	0
250	0	0	0	0.8	0.5	1.1	0	0
500	0	0	0	1.4	0.6	1.5	0	0.2
750	0	0	0.2	1.8	0.8	2.0	0	1.1
1000	0	0.9	0.6	2.1	0.9	2.1	0	1.5
1500	0	2.0	0.9	2.7	1.2	2.7	0	2.1

TABLE 27. Forty (40)-meter band, horizontal, half-wave dipole wire antenna, f = 7.3 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of antenna for compliance with occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.2	0.3
100	0	0	0	0	0	0	0.2	0.6
150	0	0	0	0	0	0	0.3	0.7
250	0	0	0	0	0	0	0.3	0.9
500	0	0	0	0	0	0	0.6	1.2
750	0	0	0	0	0	0	0.7	1.7
1000	0	0	0	0	0	0	0.8	1.8
1500	0	0	0	0	0	0	0.9	2.3

TABLE 28. Eighty (80)-meter band, horizontal, half-wave dipole wire antenna, f = 4 MHz, HAG = 4.6 m.

Power (watts)	Distance (meters) from any part of antenna for compliance with occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**4.6**		**6.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0.1	0.3	0	0
100	0	0	0	0	0.2	0.3	0	0
150	0	0	0	0	0.2	0.5	0	0
250	0	0	0	0	0.3	0.6	0	0
500	0	0	0	0.5	0.3	0.9	0	0
750	0	0	0	0.8	0.5	1.1	0	0
1000	0	0	0	1.1	0.6	1.2	0	0
1500	0	0	0	1.5	0.6	1.5	0	0.2

TABLE 29. Eighty (80)-meter band, horizontal half-wave dipole wire antenna, f = 4 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of antenna for compliance with occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.1	0.2
100	0	0	0	0	0	0	0.2	0.3
150	0	0	0	0	0	0	0.2	0.5
250	0	0	0	0	0	0	0.2	0.6
500	0	0	0	0	0	0	0.3	0.9
750	0	0	0	0	0	0	0.5	1.1
1000	0	0	0	0	0	0	0.5	1.2
1500	0	0	0	0	0	0	0.6	1.5

TABLE 30. 160-meter band, horizontal, half-wave dipole wire antenna, f = 2 MHz, HAG = 4.6 m.

Power (watts)	Distance (meters) from any part of antenna for compliance with occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**4.6**		**6.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0.1	0.2	0	0
100	0	0	0	0	0.1	0.2	0	0
150	0	0	0	0	0.2	0.2	0	0
250	0	0	0	0	0.2	0.3	0	0
500	0	0	0	0	0.3	0.5	0	0
750	0	0	0	0	0.3	0.5	0	0
1000	0	0	0	0	0.5	0.6	0	0
1500	0	0	0	0	0.5	0.8	0	0

TABLE 31. 160-meter band, horizontal, half-wave dipole wire antenna, f = 2 MHz, HAG = 9.1 m.

Power (watts)	Distance (meters) from any part of the antenna for compliance with either occupational/controlled or general population/uncontrolled exposure limits							
	Height above ground (meters)							
	1.8		**3.7**		**6.1**		**9.1**	
	con.	unc.	con.	unc.	con.	unc.	con.	unc.
50	0	0	0	0	0	0	0.1	0.2
100	0	0	0	0	0	0	0.2	0.2
150	0	0	0	0	0	0	0.2	0.2
250	0	0	0	0	0	0	0.2	0.3
500	0	0	0	0	0	0	0.3	0.5
750	0	0	0	0	0	0	0.3	0.6
1000	0	0	0	0	0	0	0.5	0.6
1500	0	0	0	0	0	0	0.6	0.9

Examples Using Models

The following two examples illustrate how tables such as Tables 24 and 26 can be used.

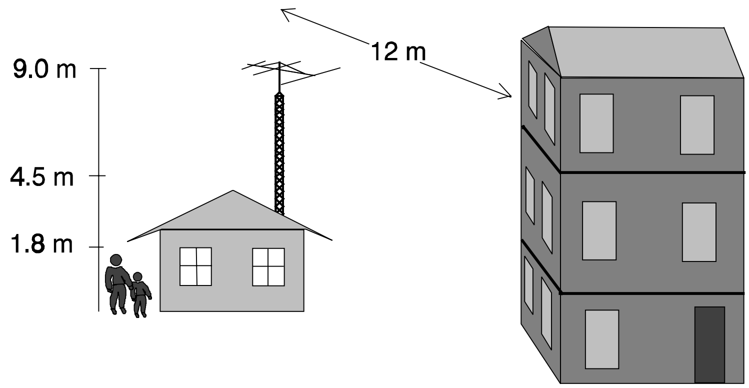


FIGURE 2. Illustration of use of Table 24.

In Figure 2, an amateur station located at a residence is transmitting using a three-element Yagi antenna (20 meter/14.35 MHz) that is located approximately 9 m above ground level. Maximum ***average*** operating power is 1,000 watts. From Table 24 it is apparent that a person standing at ground level (taken as the 1.8 meters level based on a person's height) would always be exposed below the guidelines, regardless of whether they are considered under the occupational/controlled or the general population/uncontrolled tiers of exposure limits. If only single story residences were located near this amateur station then the station would be assumed to be in compliance with FCC exposure guidelines. However, in the case shown in Figure 2 a three-story apartment building is located adjacent to the amateur station. People living in this building would have to be considered under the general population/uncontrolled exposure guidelines. Since the antenna is the same height (9 meters) as the third story of this building, the amateur would have to ensure that the transmitting antenna is at least 8.8 meters from the apartment building. Since the actual distance in this case is 12 meters, the amateur station can be assumed to be in compliance. However, if the distance were not at least 8.8 meters, the amateur station may not comply but there would still be several options for actions that could ensure compliance. These include (but are not necessarily limited to) raising the center of radiation of the antenna to an appropriate height above the apartment building, moving the antenna to the other side of his property, or possibly incorporating duty cycle considerations into determining exposure levels.

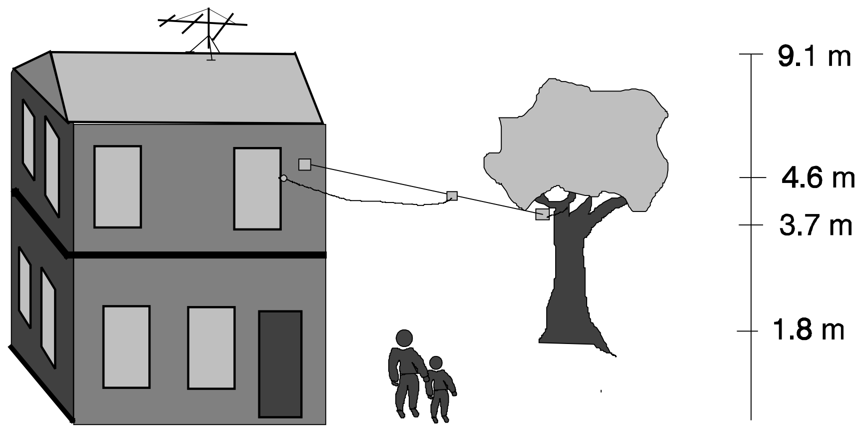


FIGURE 3. Illustration of use of Table 26.

In Figure 3, an amateur station is using a 40 meter/ 7.3 MHz horizontal half-wave dipole antenna that extends from outside a second floor window to a nearby tree. The antenna is approximately 4.6 meters off the ground, and average transmitter power is 1,500 watts. From Table 26 the station would be in compliance with FCC RF guidelines if the amateur or members of his/her immediate household (occupational/controlled exposure) remained directly below the antenna (see 1.8 m column in the table). However, in this example, a household member on the second floor of the house would have to maintain a minimum distance of 2.7 m from the antenna (see 3.7 m and 4.6 m columns for occupational/controlled exposure) in order to ensure compliance. Note also that from Table 26 compliance distances required for a height of 1.8 m are 2 m (general population/uncontrolled). Neighbors of the amateur or persons who do not fit the category of occupational/controlled must stay at least 2 m from the antenna, while at ground level, in order to ensure compliance for continuous exposure. Since the antenna is approximately 4.6 m. off the ground, a person of around 1.8 m. tall would be 2.8 meters from the antenna while they were standing at ground level. Therefore, this station would be in compliance with uncontrolled limits using the parameters listed above

Also, for the case shown in Figure 3, the amateur station is using a ten-meter, three-element Yagi antenna mounted on the roof of the house that is operated with 100 watts of average power. This power level was chosen because the second floor of the house is located between 3.7-6.1 meters above ground (see Table 19). Since the antenna is mounted approximately 9 meters above ground level, the amateur has decided to operate without any duty factor or time-averaging restrictions that might be necessary if higher power levels were used. As shown in Table 19, the station would be in compliance with the RF guidelines for both occupational/controlled and general population/uncontrolled categories for ground-level and 2nd floor (3.7 and 6.1 m. heights) exposure. If the amateur in this case were to choose to transmit using both antennas simultaneously it would be necessary to consider the total contributions of both antennas to field strength or power density levels at possible exposure locations. This topic is discussed in detail in Bulletin 65, Section 2 (multiple transmitter environments).

Section 5
Controlling Exposure to RF Fields

The FCC's guidelines for exposure to radiofrequency electromagnetic fields incorporate two tiers of limits, one for "general population/uncontrolled" exposure and another for "occupational/controlled" exposure. Amateurs and members of their immediate household are considered by the FCC under the "occupational/controlled" exposure limits. Neighbors, guests, people walking by on the street, delivery people, maintenance people coming to work on the property where an amateur station is located, etc., are normally considered to fall under the "general population/uncontrolled" exposure category. However, under some conditions persons transient through the station property may be considered under the occupation/controlled criteria as discussed in Bulletin 65.

In order for an amateur to perform an evaluation of his or her station for RF compliance, the following questions should first be asked:

(1) Which category of exposure applies at the location(s) in question?
(2) What type(s) of transmitting antenna is/are being used?
(3) What transmitting power levels will be used?
(4) How far is the area being evaluated from the antenna(s) in question?

The tables in this supplement can then be used to help determine compliance with exposure guidelines. If this supplement does not contain a table that is relevant to the particular station parameters, Bulletin 65 should be consulted for alternative methods of determining compliance (e.g., calculations, measurements, etc.)

After an evaluation is performed, if a determination is made that a potential problem exists, Section 4 of Bulletin 65 should be consulted for a discussion of recommended methods for reducing or controlling exposure. Such methods could include one or more of the following:

1. ***Restricting access to high RF-field areas***
2. ***Operating at reduced power when people are present in high RF-field areas***
3. ***Transmitting at times when people are not present in high RF-field areas***
3. ***Considering duty factor of transmissions***
4. ***Time-averaging exposure***
5. ***Relocating antennas or raising antenna height***
6. ***Incorporating shielding techniques***
7. ***Using monitoring or protective devices***
8. ***Erecting warning/notification signage***

Limiting access may be the easiest method to reduce exposure. If an antenna is in an area where access is generally restricted (such as a fenced-in yard) it may be sufficient to simply control access to the yard when transmissions are in progress (assuming exposure levels exceed the guidelines in the yard). An antenna could also be placed high enough on a tower or mast so that access to high RF levels is generally impossible.

Reducing transmitting power can also significantly reduce exposure levels. The power output of a transmitter has a linear relationship with the power density exposure level that could be experienced by a person near the transmitting antenna. For example, if power output is reduced by 20% then power density at a given location will also be reduced by 20%.

An often overlooked method of reducing exposure is by utilizing the inherent duty factor of the transmissions from an amateur station. The worst-case duty factor, 100%, occurs during continuous or "key down" transmissions. However, most amateur service two-way transmissions are more likely to be of the "key on, key off" type, resulting in more typical duty factors of, say, 50%.

Consider the following example. An amateur station transmits on-off keyed telegraphy emission type A1A on 28.05 MHz (10 Meter band). The station antenna is a half-wave dipole mounted outside a nearby window (about 9 meters above ground). The station transmits with 1,500 watts PEP. The amateur needs to know how far he or she should be from the antenna to comply with the RF safety guidelines. Table 18 indicates that there must be a distance of about 4.3 meters from the antenna during transmissions. However, the antenna is located closer than 4.3 m to the control point. Assume that with an emission type A1A transmission, the antenna would be energized about 50% of the time. In this case, first consider exposure of the station operator. In such a case limits for the occupational/controlled criteria apply, and the averaging time for occupational/controlled exposure is 6 minutes (see last column in Table 1, Appendix A). This means that the station operator can be exposed at or below 100% of the limit indefinitely. However, exposure in excess of 100% of the limits is permissible if the ***time-averaged*** exposure (over 6 minutes) is 100% or less of the MPE limit. For example, should the operator only send telegraph approximately 3 minutes out of every 6 minutes, compliance could be based on a 50% duty factor (50% reduction in power level used in determining exposure potential). This means that the distance values in tables such as Table 18 can be reduced by the multiplication factors shown in Table 32. In this example, the distance requirement for compliance for continuous exposure can be calculated to be:

(0.71)(4.3 meters) = 3 meters

Table 32. Duty Factor Conversion

Duty factor percentage	Multiplication factor
75%	0.87
66%	0.82
50%	0.71
33%	0.58
25%	0.5
10%	0.32

Conclusion

As of January 1, 1998, amateur licensees and grantees will be expected to routinely evaluate their stations for potential human exposure to RF fields that may exceed the FCC-adopted limits for maximum permissible exposure (MPE). If such an evaluation shows that potential exposure will exceed the MPE limits, the amateur licensee must take appropriate corrective action to bring the station into compliance before transmission occurs (see 47 CFR § 97.13(c), as amended.

The Commission has always relied on the skills and demonstrated abilities of amateurs to comply with its technical rules, and it will continue to do so. The Commission believes that amateur licensees and applicants should be sufficiently qualified to conduct their own evaluations and act accordingly. In OET Bulletin 65 and in this supplement we attempt to provide the amateur community with as much information as possible to accomplish these tasks. In addition, Commission staff will continue to be available to answer questions and provide further information if requested. The Commission will also continue to work with amateur organizations such as the ARRL to improve the usefulness, accuracy and inclusiveness of this supplement.

Future editions of this supplement (as well as of Bulletin 65) may be issued as needed to update the data and information provided here or to make any major corrections that may be necessary. In that regard, the Commission invites amateurs to provide input to FCC staff relating to evaluating RF exposure and the contents of the Bulletin 65 and its supplements. We also encourage the amateur community to continue its activities in developing its own methods and information for performing RF environmental evaluations. We believe that these efforts will result in an improved and safe amateur service that will benefit both amateur licensees and those persons residing or working near amateur facilities.

Appendix A
Exposure Criteria Adopted by the FCC

Table 1 lists the exposure criteria adopted by the FCC for various transmitting frequencies and for the categories of "controlled/occupational" and "general population/uncontrolled" exposures. The limits are defined in terms of electric field strength, magnetic field strength and power density. Intervals for time averaging of exposures are also given. For further information and more detail consult OET Bulletin 65.

Table 1. *FCC Limits for Maximum Permissible Exposure (MPE)*

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	$(900/f^2)$*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz   *Plane-wave equivalent power density

NOTE 1: ***Occupational/controlled*** limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure. These limits apply to amateur station licensees and members of their immediate household as discussed in the text.

NOTE 2: ***General population/uncontrolled*** exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure. As discussed in the text, these limits apply to neighbors living near amateur radio stations.

Appendix B
Optional Worksheet and Record of Compliance

This optional worksheet can be used to determine whether routine evaluation of an amateur station is required by the FCC's rules. It also can be used as an aid in determining compliance. However, use of this worksheet is not required by the FCC.

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

for Amateur Radio Stations

Instructions

Introduction. This optional worksheet is intended to be helpful when determining whether any particular combination of transmitting apparatus at an amateur radio station ("a setup") is in compliance with the FCC rules (47 C.F.R. § 1.1310) concerning human exposure to radiofrequency (RF) electromagnetic fields.

The purpose of the first section of this worksheet is to help determine, for any given setup of the amateur station, whether the routine RF evaluation prescribed by FCC rules (47 C.F.R. § 1.1307(b)) must be performed before the setup can be used for transmitting. In the event that a routine RF evaluation must be performed, that requirement may be satisfied by completing the second section of the worksheet, by using methods outlined in OET Bulletin 65 or by employing another technically valid method.

The person responsible for making the determination is the person named on the data base license grant as the primary station licensee or as the club, military recreation or RACES station license trustee, and any alien whose amateur radio station is transmitting from a place where the service is regulated by the FCC under the authority derived from a reciprocal arrangement. When completed, this worksheet may be retained in the station records so that if and when the setup is changed, it may more easily be re-evaluated. **Do not send the completed worksheets to the FCC.**

If the amateur station is to be operated on more than one wavelength band, or with several different antennas or combinations of apparatus, each is considered to be a separate setup. It might be helpful, therefore, to complete a separate worksheet for each setup. For an amateur radio station where two or more transmitters are used with the same antenna on the same wavelength band, it is only necessary to consider the setup that uses the highest power to the antenna input.

Top of each page. At the top of each page are blanks to fill in the amateur station call sign (item 1), the wavelength band under consideration (item 2), and a number or identifier that will identify the each setup (item 3). The purpose for repeating these items on each page is so that the various pages of a particular completed worksheet could be reassembled if they were to become separated. Additionally, at the top of Page 1 of the worksheet, there are blanks for the location of the station (item 4), the name of the person completing the worksheet (item 5), and the date (item 6).

Section I

Items 7 and 8. Fill in the manufacturer and model of the transmitter or transceiver and any RF power amplifier, or a brief description of these if they are home built.

Item 9. Fill in the Peak Envelope Power (PEP) output of the transmitter (use the PEP of the external amplifier, if one is to be used), in Watts (A). Many commercially manufactured transmitters and RF power amplifiers have a built-in power meter that 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, or a reasonable estimate, based on factors such as measured power input, the maximum capability of the final amplifier devices or the power supply, may be used.

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields for Amateur Radio Stations

Instructions

Check the PEP output against Table 1. Because the PEP input to the antenna (H) can't be more than the PEP output (A), it's worthwhile at this point to take a quick look at Table 1 on page 3 of Supplement B to OET Bulletin 65. If the PEP output (A) does not exceed the value listed for the wavelength band under consideration, neither will the PEP input to the antenna (H). If that is the case, a routine RF evaluation is not required for this setup, and it isn't necessary to complete the rest of the worksheet. Otherwise, continue as follows.

Item 10. Fill in the PEP output used in item 9, converted to dBW. The power unit dBW expresses the ratio of the power in question to 1 Watt, in deciBels. The following chart can be used to convert common PEP levels in Watts to dBW. For power levels that fall in between the levels given, use the next higher power.

Watts	dBW
1	0
2	3
3	5
5	7
10	10
15	12
20	13
25	14
30	15
40	16
50	17
80	19
100	20
150	22
200	23
500	27
1000	30
1200	31
1500	32

Alternatively, the following mathematical formula can be used to do the conversion:

$$power_{dBW} = 10 \times \log\,(power_{Watts})$$

Items 11 and 12. Fill in the feed line type and loss (attenuation) specification (C). The attenuation or loss of a feed line is higher for higher frequencies. Therefore, the wavelength band of operation must be taken into account when determining what the feed line loss specification is. Manufacturers of coaxial cables develop tables showing the attenuation of various types of cables at various frequencies. There are also graphs and charts showing feed line attenuation versus frequency in readily available amateur radio handbooks and publications. The conservative approximate loss specifications for commonly used feed line type, given in the table on the next page, can also be used. In terms of feed line loss, a "conservative" estimate means that the feed line is very unlikely to have a lower loss than the estimate, although it may easily have a higher loss than estimated.

Item 13. Fill in the length of the feed line in feet (D).

Item 14. Fill in the calculated feed line loss (E) in dB. Calculate the feed line loss (E) by multiplying the feed line loss specification (C) by the feed line length (D). Inherent feed line loss often increases as the feed line ages. Also, feed line loss is considerably larger if the antenna impedance is not matched to the feed line impedance (causing a high SWR). However, for the purposes of this work sheet, do not consider or rely upon any additional feed line loss attributable to feed line aging or mismatch.

Feed Line Loss Specification for Commonly Used Feed Lines (dB/100 feet)

Band	RG-58	RG-8X	RG-8A, RG-213	RG-8 Foam	"9913" & eqv	½" 50Ω "hardline"	"Ladder line"
160 m	0.5	0.4	0.3	0.2	0.2	0	0
80 m & 75 m	0.7	0.5	0.4	0.3	0.2	0.1	0
40 m	1.1	0.7	0.5	0.4	0.3	0.2	0
30 m	1.4	0.9	0.6	0.5	0.4	0.2	0
20 m	1.7	1.1	0.8	0.6	0.5	0.3	0
17 m	2.0	1.2	0.9	0.7	0.6	0.3	0.1
15 m	2.2	1.3	1.0	0.7	0.6	0.3	0.1
12 m	2.4	1.4	1.1	0.8	0.6	0.3	0.2
10 m	2.5	1.5	1.3	0.9	0.7	0.4	0.2
6 m	3.5	2.1	1.7	1.2	0.9	0.5	0.3
2 m	6.5	3.6	3.0	2.0	1.6	1.0	0.7
1¼ m	8.4	4.6	4.0	2.6	2.0	1.3	
70 cm	12	6.5	5.8	3.6	2.8	1.9	
33 cm	19	9.6	9.0	5.4	4.0	3.0	
23 cm	23	12	11	6.4	4.6	3.7	
13 cm		15	15	8.8	6.4	5.2	

This table provides conservative approximations 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. The term "hardline", as used above means commercial grade coaxial cable with a solid center conductor, foam dielectric, and solid or corrugated jacket. The term "ladder line", as used above, means 450Ω insulated window line with parallel conductors.

Instructions

Items 15 and 16. There may be other loss causing components in the feed line between the transmitter or external amplifier output and the antenna input. For example, there may be antenna switches or relays, directional couplers, duplexers, cavities or other filters. Usually the losses introduced by these components are so small as to be negligible. However, for setups operating in the VHF and higher frequency bands, the losses introduced by feed line components can be substantial. If this is the case, fill in a brief description of what these components are in item 15, and a conservative estimate of the total loss in dB in item 16, feed line components loss (F). Otherwise, write 0 (zero) in item 16. In terms of feed line component loss, a "conservative" estimate means that the feed line components are very unlikely to have a lower loss than the estimate, although they may easily have a higher loss than estimated. If the feed line component loss is not known, write 0 (zero) in item 16.

Item 17. Fill in the PEP input to the antenna, in dBW (G). Calculate this by subtracting the calculated feed line loss (E) and the feed line components loss (F) from the PEP output in dBW (B). Expressed as a mathematical equation, this is:

$$G = B - E - F$$

If G is less than 17 dBW, a routine RF evaluation is not required for this setup, and it isn't necessary to complete the rest of the worksheet. Otherwise, continue as follows.

Item 18. Fill in the PEP input to the antenna used in item 17, converted to Watts. The following table can be used to convert PEP levels in dBW to Watts. The entries in this table correspond to the power levels in Table 1 in OET Bulletin 65, Supplement B. For power levels that fall in between the levels given, use the next higher power.

dBW	Watts
17.0	50
18.5	70
18.8	75
20.0	100
21.0	125
21.8	150
23.0	200
23.5	225
24.0	250
26.3	425
27.0	500

Alternatively, the following mathematical formula can be used to do the conversion:

$$power_{Watts} = 10^{\frac{power_{dBW}}{10}}$$

Item 19. If the setup under consideration is an amateur radio repeater station, skip over this item and go directly to item 20. Otherwise, proceed as follows: Compare the PEP input to the antenna in Watts (H) to the power level listed in Table 1 in OET Bulletin 65, Supplement B, for the wavelength band to be used.

If the PEP input to the antenna in Watts (H) is less than or equal to the power level listed in Table 1 of OET Bulletin 65, Supplement B, for the wavelength band to be used, put a check mark in the first box. This means that the FCC rules do not require that a routine RF evaluation of the amateur radio setup be performed before it can be operated. It is not necessary to complete the rest of the worksheet.

On the other hand, if the PEP input to the antenna in Watts (H) exceeds the power level listed in Table 1 in OET Bulletin 65, Supplement B, for the wavelength band to be used, put a check mark in the second box. This means that a routine RF evaluation of this setup must be performed before it may be used to transmit. This requirement may be satisfied by completing the second section of the worksheet, by using methods outlined in OET Bulletin 65 or by employing any other technically valid method.

Note: Items 20 through 26 are only for amateur radio repeater setups.

Item 20. Fill in the manufacturer and model of the transmitting antenna for the amateur repeater setup, or a brief description of the antenna type (e.g. vertical collinear array).

Item 21. Check the appropriate box to indicate whether or not the repeater antenna is mounted on a building.

Item 22. Fill in the height above ground level of the lowest radiating part of the repeater antenna, in meters (I). One meter equals 3.28 feet.

Item 23. Fill in the maximum gain of the repeater antenna, in dBd (J). The term maximum gain means the highest antenna gain the antenna exhibits in any direction, not just in the direction of nearby places where people could be exposed to RF electromagnetic fields. The unit "dBd" means that the gain is expressed as a ratio between the power flux density ("pfd") that the antenna in question produces and the pfd that a lossless half-wave dipole antenna would produce in free space (when both antennas have the same input power. Antenna gain of commercially manufactured antennas mounted in various typical arrangements is generally measured by the manufacturer on an antenna test range. The manufacturer may specify maximum antenna gain in dBd or dBi or both. If the gain is specified in dBi, for the purpose of this item simply subtract 2.15 dB from the dBi specification to obtain the dBd. Take into account, if possible, any increase in the gain resulting from the mounting arrangement (e.g. if the antenna is side-mounted on a tower). If the it is a home built antenna, estimate the maximum gain likely to be realized for an antenna of that type. Although antenna gain includes antenna efficiency, assume the efficiency is 100% for the purpose of this item.

Item 24. Fill in the maximum effective radiated power (ERP), in dBW (K). Calculate this by adding the PEP input to the antenna in dBW (G) and the estimated maximum repeater antenna gain (J). Expressed as a mathematical equation, this is:

$$K = G + J$$

Item 25. Fill in the maximum ERP used in item 24, converted to Watts (L), using the same methods as in the instruction for item 18.

Item 26. If L is less than or equal to 500 Watts (or K is less than 27 dBW), a routine RF evaluation is not required for this amateur radio repeater setup. Furthermore, even if L exceeds 500 Watts (i.e. K equals or exceeds 27 dBW), provided that the antenna is not located on a building and is installed such that the lowest point of the antenna is at least 10 meters (33 feet) above the ground level, a routine RF evaluation of this amateur radio repeater setup is not required. In either case, put a check mark in the first box. This indicates that a routine RF evaluation of the amateur radio repeater setup is not required before it can be operated.

In all other cases, put a check mark in the second box. This means that a routine RF evaluation of this amateur radio repeater setup must be performed before it can be operated. This requirement may be satisfied by completing the second section of the worksheet, by using methods outlined in OET Bulletin 65 or by employing any other technically valid method.

Section II

Item 27. Fill in a brief description of the antenna. If it is a commercially made antenna, indicate the manufacturer and type.

Item 28. Fill in the height above ground level of the lowest radiating part of the antenna, in meters (M). One meter equals 3.28 feet.

Item 29. Fill in the antenna gain in dBi (N). The term "antenna gain" generally refers to the field intensity at a given distance radiated by the antenna with a given power input, relative to an ideal lossless reference antenna type such as a half-wave dipole (dBd) or an isotropic radiator (dBi), fed with the same power and measured at the same distance. Antenna gain is a result of the directivity (i.e. that more energy is radiated in some directions than in others) and the efficiency (that some portion of the energy is not radiated as electromagnetic fields, but is instead converted to heat as a result of electrical resistance in the antenna materials and its surroundings). For this item, consider only the directivity of the antenna. The efficiency factor is considered in items 35-36.

Check Table 4. At this point, refer to Table 4 in Supplement B to OET Bulletin 65 (the W5YI table). For the wavelength band indicated in item 2, and using the PEP input to the antenna (H) and the antenna gain (N) from the worksheet, find the minimum necessary separation distances in meters from the antenna for uncontrolled and controlled environments. Pencil these distances in item 38 as (T) and (U) respectively. For power levels and antenna gains between those provided in the table, use the next higher values. This table is for a worst case analysis. Proceed now to the instruction for item 39, understanding that, if the worst case distances derived using Table 4 are not met in reality, they can be erased from item 38 and the evaluation can then proceed into further detail with the next instruction.

Item 30. Fill in the emission type used (e.g. SSB, CW, FM, FSK, AFSK, etc.).

Item 31. Fill in an emission type factor (O). The following table may be used.

CW Morse telegraphy	0.4
SSB voice	0.2
SSB voice, heavy speech processing	0.5
SSB AFSK	1.0
SSB SSTV	1.0
FM voice or data	1.0
FSK	1.0
AM voice, 50% modulation	0.5
AM voice, 100% modulation	0.3
ATV, video portion, image	0.6
ATV, video portion, black screen	0.8

This emission type factor accounts for the fact that, for some modulated emission types that have a non-constant envelope, the PEP can be considerably larger than the average power. See also Table 2 in Supplement B of OET Bulletin 65 which provides examples of duty factors for modes commonly used by amateur radio operators.

Items 32 and 33. Fill in the transmit duty cycle and duty cycle factor. The duty cycle is the percentage of time in a given time interval (6 or 30 minutes) that the amateur radio station is in a transmitting condition, including instants where a transmission is in progress, but there is momentarily no power input to the antenna (e.g. the spaces between the "dits" and "dahs" of Morse telegraphy, the pauses between words of SSB telephony). The duty cycle factor is simply this percentage expressed in decimal form. For example, 20% becomes 0.2.

This transmit duty cycle is one of the parameters that is most easily controlled by the amateur radio station operator. As an example, with directed net or list operation, consideration should be given to whether the station is a net control station (relatively more transmit time) or a check-in (lots of listening time, relatively less transmission). When transmissions are carried through a repeater, the repeater timer may serve as a reminder to limit the length of continuous transmissions. With casual two way conversations, the transmit duty cycle could be approximated as 50%. A more detailed discussion, with examples, is contained in Supplement B to OET Bulletin 65 under the heading of "Time and Spacial Averaging".

Item 34. Fill in the average power input to the antenna (Q), in Watts. This is calculated by multiplying the PEP input to the antenna, in Watts (H), by the emission type factor (O) and the duty cycle factor (P). Expressed as a mathematical equation, this is:

$$Q = H \times O \times P$$

Check Tables 4-17 and/or 18-31. At this point, refer to Tables 4 through 17 (the Overbeck/Siwiak/FCC tables) and/or Tables 18 through 31 in Supplement B to OET Bulletin 65 (the ARRL tables). For the wavelength band indicated in item 2, and using the average power input to the antenna (Q) and selecting the appropriate table for the type of antenna, find the minimum necessary separation distances in meters from the antenna for uncontrolled and controlled environments. Note the limitations on appropriate use of these tables set forth in the bulletin. Write the distances found in item 38 as (T) and (U) respectively. For power levels and antenna gains between those provided in the table, use the next higher values.

Items 35 and 36. This item can be used for calculating the power flux density in accordance with the methods outlined in OET Bulletin 65, where antenna efficiency is a significant factor. Fill in the antenna efficiency and antenna efficiency factor (R). The antenna efficiency is the percentage of the input power that is radiated as electromagnetic energy. The antenna efficiency factor is simply this percentage expressed in decimal form. For example, 20% becomes 0.2. For most antennas, the efficiency is high enough to be negligible. For some antennas, however, particularly shortened vertical ground plane antennas, mobile whips, resistor broadbanded antennas, and small loops, the radiation resistance of the antenna may be so low that a significant portion of the energy is lost as heat in the antenna and it's ground system. Consult available amateur radio publications literature for more details. Otherwise, assume that the antenna efficiency is 100% and the antenna efficiency factor (R) is 1.0.

Item 37. Fill in the average power radiated (S). This is calculated by multiplying the average power input to the antenna (Q) by the antenna efficiency factor (R). Expressed as a mathematical equation, this is:

$$S = Q \times R$$

Item 38. This item is for filling in the distances, in meters, obtained from the various tables in Supplement B to OET Bulletin 65. It is also a good idea to jot the table number down next to this item so that the source of the distances indicated is known.

Item 39. Fill in the actual estimated, calculated or measured shortest physical distances, in meters, between the radiating part of the station antenna and the nearest place where the public or a person unaware of RF fields could be present, and the nearest place where a person who is aware of the RF fields could be present, (V) and (U) respectively.

Item 40. This item is a table where the evaluator may fill in calculated or measured power flux densities at locations where persons may be present. Power flux density may be calculated by methods outlined in Section 3 of Supplement B to OET Bulletin 65. If valid measurements are made at a reduced power level (that would comply with exposure guidelines), it can be assumed that these measurements may be adjusted proportionally to predict field levels at a higher power.

Conclusions Section

At the end of the work sheet is a page where the evaluator can indicate his or her finding that the evaluated amateur radio setup is in compliance with FCC rules. A setup that does not comply must not be used for transmission until it is brought into compliance.

The evaluator should check the boxes [ ] next to any and all statements that apply to the evaluated amateur radio setup. The blank lines can also be used to elaborate on circumstances that support the conclusion.

The first four check boxes are for the situation where, for any of various reasons, it is very unlikely or simply not possible for any person to be in a location where he or she would be exposed to radiofrequency electromagnetic fields that are strong enough to exceed the levels prescribed in the FCC Guidelines for Human Exposure. The second four boxes are for the situation where a person could be in a location where he or she could be briefly exposed to radiofrequency electromagnetic fields that are strong enough to exceed the levels prescribed, but that other considerations ensure that a person will not remain in that location long enough to receive exposure in excess of that allowed by the FCC Guidelines for Human Exposure.

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields for Amateur Radio Stations

1. Call sign: ___________ 2. Wavelength band: ___________ 3. Setup #: __________

4. Station location: ____

5. Evaluated by: ____________________________________ 6. Date: _____________

I. Initial Determination as to whether a Routine Evaluation is required by FCC Rule Section 97.13 for this amateur radio station setup.

7. Transmitter description: ____

8. External amplifier description: ____

9. Peak Envelope Power (PEP) output, in Watts: (A)_______Watts

10. PEP output, converted to dBW: (B)_______ dBW

11. Feed line type: _________ 12. Feed line loss specification: (C)_______ dB/100 feet

13. Feed line length: (D)_______ feet

14. Calculated feed line loss: (E)_______ dB

15. Other feed line components, if any: ____

16. Feed line components loss: (F)_______ dB

17. PEP input to antenna, in dBW: (G)_______ dBW

18. PEP input to antenna, converted to Watts: (H)_______ Watts

19. INITIAL DETERMINATION FOR STATIONS OTHER THAN REPEATERS:
(for repeater stations go to the next page)

[ ] Based on the peak envelope power input to the antenna (H) calculated above, **a routine evaluation is NOT required** by FCC rules for operation as described of this setup in the stated wavelength band. It is not necessary to complete the rest of this worksheet.

[ ] Based on the peak envelope power input to the antenna (H) calculated above, **a routine evaluation is required** by FCC rules for operation as described of this setup in the stated wavelength band. The licensee may satisfy the requirement for a routine evaluation by completing the rest of this worksheet.

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

1. Call sign: ___________ 2. Wavelength band: __________ 3. Setup #:_____________

---

20. Repeater antenna description: ____

21. Repeater antenna location: [ ] mounted on a building [ ] not on a building

22. Minimum repeater antenna height above ground level: (I) _______ meters

23. Estimated maximum repeater antenna gain: (J)________ dBd

24. Maximum Effective Radiated Power (ERP), in dBW: (K)_______ dBW

25. Maximum ERP, converted to Watts: (L)_______ Watts

26. INITIAL DETERMINATION FOR AMATEUR REPEATER STATIONS:

[ ] Based on the effective radiated power (L) calculated above and the antenna height (I) and location of the antenna, **a routine evaluation is NOT required** by FCC rules for operation as described of this amateur radio repeater station in the stated wavelength band. It is not necessary to complete the rest of this worksheet.

[ ] Based on the effective radiated power (L) calculated above and the antenna height (I) and location of the antenna, **a routine evaluation is required** by FCC rules for operation as described of this amateur radio repeater station in the stated wavelength band. The licensee may satisfy the requirement for a routine evaluation by completing the rest of this worksheet.

Reminders:

- A routine evaluation is not required for vehicular mobile or hand-held amateur radio setups. However, amateur radio operators should be aware of the potential for exposure to radiofrequency electromagnetic fields from these setups, and take measures (such as reducing transmitting power to the minimum necessary, positioning the radiating antenna as far from humans as practical, and limiting continuous transmitting time) accordingly to protect themselves and the occupants of their vehicles.

- The operation of each amateur radio setup must not exceed the FCC's guidelines for human exposure to radiofrequency electromagnetic fields, regardless of whether or not a routine evaluation is required.

- Although a particular amateur radio setup may by itself be in compliance with the FCC's guidelines for human exposure to radiofrequency electromagnetic fields, the cumulative effect of all simultaneously operating amateur radio setups (and any other operating transmitters in other services) at the same location or in the immediate vicinity must also be considered.

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

1. Call sign: ___________ 2. Wavelength band: __________ 3. Setup #:_____________

II. Routine Evaluation of amateur radio station setup.

27. Antenna description: ____

28. Antenna height above ground level: (M)_______ meters

29. Lossless antenna gain (directivity only): (N)________ dBi

30. Emission type: ________ 31. Emission type factor: (O)_______

32. Transmit duty cycle: _____% 33. Duty cycle factor: (P)_______

34. Average power input to the antenna: (Q)_______ Watts

35. Antenna efficiency: _____% 36. Antenna efficiency factor: (R)_______

37. Average power radiated: (S) _______ Watts

38. Minimum necessary distance from radiating part of antenna to place where:

- public may be present (uncontrolled): (T)_______ meters
- amateur radio operator may be present (controlled): (U)_______ meters

39. Actual distance from radiating part of antenna to nearest place where:

- public may be present (uncontrolled): (V)_______ meters
- amateur radio operator may be present (controlled): (W)_______ meters

40. Calculated power flux density:

Location	Power Flux Density

Optional Worksheet and Record of Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

1. Call sign: ___________ 2. Wavelength band: __________ 3. Setup #:_____________

CONCLUSIONS

Based on this routine evaluation, operation of this amateur radio station setup in accordance with the technical parameters entered above complies with the FCC's guidelines for human exposure to radiofrequency (RF) electromagnetic fields. The following statements provide the basis for this conclusion.

[ ] It is physically impossible or extremely unlikely under normal circumstances for any person to be in any location where their exposure to RF electromagnetic fields would exceed the FCC guidelines, because:

- [ ] the antenna is installed high enough on a tower or tree or other antenna support structure, such that it is not possible under normal circumstances for persons to get close enough to the antenna to be where the strength of the RF electromagnetic fields exceed the levels in the applicable FCC guidelines.
- [ ] fences, locked gates and/or doors prevent persons who are unaware of the possibility of RF exposure from normally gaining access to locations where the strength of the RF electromagnetic fields exceed the levels in the applicable FCC guidelines.
- [ ] ____

  ____

  ____

[ ] Although persons could normally be in location(s) where the RF fields from the evaluated setup exceed the guideline levels, the following factors ensure that FCC human exposure guidelines will not be exceeded:

- [ ] Signs have been installed that alert persons to the presence of RF electromagnetic fields and warn them not to remain for an extended period.
- [ ] The locations where RF electromagnetic fields may exceed the guideline levels are roadways or other areas where human presence is transient.
- [ ] ____

  ____

  ____