Bob's TechTalk #6
by Bob Eckweiler, AF6C

RF Exposure Evaluation: (Party II of III)

Actual Example:

Last month the basics for evaluating your ham antenna to meet the FCC RF Exposure Guidelines were discussed. This month two antennas will be evaluated. The prime tools for the evaluation will be the tables in the ARRL book *RF Exposure and You*, referred to in the text as the "ARRL book". If you do not have a copy of this book I suggest you consider adding it to your ham library. Less extensive tables are available in Supplement 'B' of the FCC's OET Bulletin 65, Version 97-01 available on the FCC web site at:

http://www.fcc.gov/oet/rfsafety

Be sure to download the original document as well as supplement 'B' (Supplement 'A' relates to commercial broadcasting and is not needed.) If you use the FCC tables remember that the FCC tables measure distances in meters while the ARRL tables are in feet (One meter equals approximately 3 1/4 feet.)

Though there are many different ways of evaluating your antenna for RF exposure, the most sensible for the average ham is to use the tables supplied by the FCC and expanded by the ARRL. Three different sets of tables are available:

The first set of tables (starting on page 8.2 of the ARRL book) gives controlled and uncontrolled compliance distances based on antenna gain, power and frequency. The tables are based on the far-field equation over real-world ground conditions:

$$S = \frac{2.752PG}{4\pi R^2}$$

Where S is the power density in mW/cm2, P is the power in watts, G is the antenna gain over an isotropic antenna (dBi) expressed as a decimal number and R is the distance from the center of radiation of the antenna in feet. The calculation assumes the point is at the height of the antenna in the path of maximum gain. It offers a conservative answer.

The second set, comprised of 181 tables (starting on page 8.10 of the ARRL book) is based on the NEC 4.1 antenna modeling program. Separate tables are given for different antenna types, frequency band, and antenna height above ground. Controlled and uncontrolled compliance distances for different power levels are given at the antenna height as well as at 6', 12' and 20' above ground. The distance is measured horizontally from the nearest part of the antenna.

Evaluation Is Required

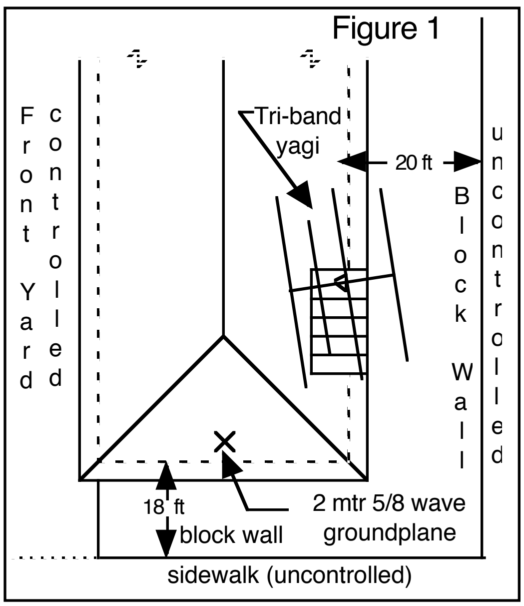
Band	if Power* (watts) Exceeds:
160 – 40 m	500 w
30 m	425 w
20 m	225 w
17 m	125 w
15 m	100 w
12 m	75 w
10 – 1.25 m	50 w
70 cm	70 w
33 cm	150 w
23 cm	200 w
13 cm & down	250 w

*PEP input to the antenna. (Repeater rules differ.)

Table One

The third set of tables (starting on page 8.75 of the ARRL book) are derived from the FCC Supplement 'B' tables. They give estimated distances to meet MPE limits in the main beam of antennas commonly used by amateur stations. As with the other tables ground reflection is taken into account.

Which table should you use? The choice is yours. My preference is the third set if your antenna type is included, then the first set which is quite conservative and finally the second set, which probably will give you the most accurate answer but is somewhat less conservative.



The process of evaluating an antenna can take on many forms. The procedure I'm going to follow here is to start using the most conservative method and add refinements that tend to be a bit less conservative (yet still meet the safety criteria) and offer more practical results for those of us living in less than ideal locations. Sometimes the most conservative method yields acceptable results, and since it's the easiest, that's as far as you need to go. If the results are unacceptable then you can refine your analysis and hopefully reach a point that is acceptable. Of course, you can start with the highly refined analysis, but that may add a lot of unnecessary work to your analysis.

Here is a path you can take:

1. See if your power is low enough to meet the requirements of Table 1. Even if it does you should continue to the next step to assure compliance.

2. Assume lossless coax, a 100% duty cycle and carrier down conditions. Use ARRL table set one and assume two-dimensions. (This gives very conservative results!)

3. Recalculate the distance using Pythagorean's Theorem if your antenna is above ground level.

4. Correct power for coax loss and duty cycle of the modulation. (See Table 2) and repeat the previous two steps.

5. Locate your antenna type in ARRL table set two (assuming it is there or approximated there.) Select heights depending on your surroundings and evaluate at both full PEP power and power corrected for modulation duty cycle.

6. As a last step you can take into consideration averaging time exposure as was discussed last month. This should be done last as it's hard to control if you are in the heat of a long QSO.

Remember, if you evaluate your station using modulation duty cycle and/or averaging exposure time, you must continue to operate your station within these conditions.

A Two-Meter Antenna:

Let's look at our first antenna, a two-meter Mosley Diplomat 5/8 wave ground-plane. The manufacturer claims a gain of 3.4 dBi. It is mounted on a six-foot pole attached to a roof vent pipe. The antenna base height is 18 feet above ground level. The antenna is fed through 50' of RG-8X mini-coax rated at 4.6dB loss per 100' at 144 MHz. The rig is a Yaesu FT-9100R that has a maximum output of 45 watts FM.

Forty-five watts is below the power level of 50 watts in Table 1 (repeated from last month's Tech Talk) so we can stop here. Instead, lets look at the power level to the antenna after taking into account the loss in the coax. This is usually significant at VHF and above unless you are using expensive feedline. Since the power levels in Table 1 are given as "power to the antenna", the loss due to the RG-8X can be included. The loss for 50' of coax is 2.3 dB or half of the stated 4.6 dB/100'. If we start with 45 watts, a 2.3 dB loss will result in only 26.5 watts of power at the antenna; that's way below the value in Table 1 and no further investigation is needed. (It also points out that there would be a benefit to using better coax!). Even though we've met the FCC criteria with this antenna, let's continue a bit further. A simple step would be to view the antenna layout in a two-dimensional sense. From Figure one, a layout of the area around this antenna, we note that the closest uncontrolled space is the sidewalk. It is located 18' horizontally from the antenna. Using the first set of tables* from the ARRL book we can interpolate for an antenna with a gain of 3.4 dBi to show the minimum safe uncontrolled distance for 100 watts is 15.5', close to our 18'. Since the field varies by the square of the distance, we can correct the power using the following equation to find the safe power for another nearby distance:

$$P_2 = P_1\left(\frac{D_2}{D_1}\right)^2$$

where Pn is the field measured at distance Dn. Solving for 18' shows that a power of up to 135 watts at the antenna would not exceed the MPE in the controlled sidewalk area. This assumes **100%** modulation duty cycle; valid for FM.

Above, we assumed only horizontal distances. The answer is very conservative. Let's look at the distances in three-dimensions. Since the antenna is up in the air, the distance is actually greater than 18'. For someone 6' tall standing in the uncontrolled sidewalk, the closest distance to the antenna is actually 21.6' [See side bar entitled "Pythagorean's Theorem" on page seven.] Correcting for this distance shows a power level of 194 watts to be within the MPE.

So far we have also assumed the direction we're measuring is in the same direction as the antenna's direction of maximum gain. Since a 5/8 wavelength groundplane antenna has its highest gain horizontally at the height of the antenna, the actual field will be even less at the six foot level. The ARRL table set two can be used to further refine the maximum power that meets the MPE in the nearest controlled area by taking the radiation pattern into account. To show how conservative the earlier measurements were, the bottom table on page 8.42 of the ARRL Book (Table set two) shows 1KW to be within the uncontrolled MPE if the antenna was raised another two feet to be 20' high.

What about the MPE in the controlled area? A similar process can be followed to show the areas within the controlled area where people would normally be during the operation of the radio are substantially below the controlled MPE at levels below a few hundred watts and would not be of any concern. However, if higher power operation is planned, common sense would dictate that the antenna be raised. It is more cost effective and results in stronger signals in both directions! Of course that RG8X has to go. There is a piece of LDF-4 coax waiting to replace it (0.83 dB loss/100' at 144 MHz).

Mode	Duty Factor
Carrier	100%
Conversational SSB	20%
Heavy Processor SSB	50%
Conversational CW	40%
FM	100%

Table 2

A Three Element Tri-Band Beam:

The second antenna we're going to look at is a Hy-Gain TH-4 tri-band beam (Specified gain is 11 dBi on 10 meters, 10.6 dBi on 15 meters and 10.1 dBi on 20 meters – [I wish!]). It is on a crank-up tower that allows the antenna to be raised from a low height of 26' up to 60'. The antenna is fed with 150' of LMR-400 coax (loss: 0.7dB/100' at 30 MHz). The radio is normally 100W PEP output. There is a 1500W PEP output linear amplifier that is used occasionally. Modes used are CW and SSB. Processed SSB is used only during DXing.

Table 3 shows the distances for this antenna in two dimensions as well as at 26 and 60 feet using ARRL table set one and full carrier. Distances are shown for both controlled (C) and uncontrolled (UC) space.

Even at 60 feet the results are not acceptable at the higher power. By using table set two from the ARRL book, (pages 8.50 to 8.55) which takes into consideration the antenna pattern below the antenna, results are more acceptable.

Some interpretation of the tables are needed since the antenna heights are given only at multiples of ten feet. However, operation with the antenna at 26 feet and 100 watts is unrestricted on all three bands. Results using 1500 watts are more interesting. On 20 and 15 meters operation is unrestricted if the antenna is at 60'. Operation on 10 meters would be restricted if there was a two story house within 66 feet of the end of the antenna, even with the antenna at 60' elevation. However the MPE would not be exceeded using conversational SSB (even with processing on) or CW. Tuning up for long periods, or full carrier modes would exceed uncontrolled second story MPE levels. Luckily, there are no two-story houses within 66 feet of the antenna. For this antenna MPE levels will not be exceeded as long as the antenna is raised prior to turning on the linear amplifier.

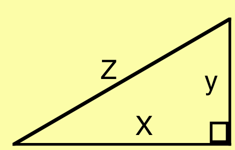
Pythagorean's Theorem:

Often the height and distance to a point is known and you want to know the slant angle. For instance if you're forty feet from the base of an antenna that's 30 feet in the air, how far are you from the antenna?

The problem is one of a right triangle (a triangle where two sides are perpendicular, or 90° apart.) A Greek named Pythagoras solved this many QSOs ago. The square of the longest side (aka. the hypotenuse) is equal to the sum of the squares of the other two sides.

$$Z^2 = X^2 + Y^2$$

$$Z = \sqrt{X^2 + Y^2}$$



Thus, in the example above the slant height is:

$$Z = \sqrt{(40 \bullet 40) + (30 \bullet 30)}$$

$$= \sqrt{1600 + 900} = \sqrt{2500} = 50$$

Band	Coax Loss	Ant Gain	Height: Xcvr Power	Two-Dim C	Two-Dim UC	@ 26 feet C	@ 26 feet UC	@ 60 feet C	@ 60 feet UC
				Distance ft					
20	0.7 dB	10.1 dB	100	6.3	14.1	0.0	0.0	0.0	0.0
20	0.7 dB	10.1 dB	1500	27.4	61.3	18.7	57.9	0.0	29.0
15	0.9 dB	10.6 dB	100	10.6	23.7	0.0	12.7	0.0	0.0
15	0.9 dB	10.6 dB	1500	41.0	91.7	35.8	89.5	0.0	74.1
10	1.1 dB	11.0 dB	100	16.4	36.8	0.0	30.9	0.0	0.0
10	1.1 dB	11.0 dB	1500	63.7	142.5	60.5	141.1	33.8	131.9

Table 3 - Triband Beam at Various Heights
C = Controlled Space
UC = Uncontrolled Space

Next month we'll look at another antenna as well as a software program for evaluating exposure. We will also refine operating and mode duty cycles further.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the June 2001 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.