DuPage
Amateur Radio Club
Step By Step
RF Safety Evaluation

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DuPage Amateur Radio Club
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Table of Contents:

Table of Contents: 2
Introduction: 3
    Why Should We Even Bother? 3
    Definitions: 4
First Time Through 5
    Before you start: 5
    Step 1 – Determine if you need to evaluate: 5
    Step 2 – Determine your Power Output and Antenna Gain: 5
    Step 3 – Determine your Distance data: 5
    First Time Through Examples: 6
    First Time Through Examples continued: 7
    What If I didn't Pass the First Time Through? 7
    Work Sheet (First Time Through Examples) 8
Second Time Through 9
    Step 4 – Estimate transmitter on time per averaging period: 9
    Step 5 – Determine your favorite emission mode(s): 9
    Step 6 – Convert the information: 9
    Step 8 – Check your Antenna Distance Calculation: 11
    Step 9 – Examine Table 8: 11
    Second Time Through Examples: 12
    Work Sheet (Second Time Through Examples) 15
When All Else Fails! 16
Documentation 16
Tables 17
    Table 1 – PEP Maximum Power per Band 17
    Table 2 – Typical Duty Factors 17
    Table 3 – Typical Antenna Gains in Free Space 17
    Table 4 – Standard Antenna Gains for Table 8 18
    Table 5 – Standard Power Levels for Table 8 18
    Table 6 – Power Gain to dB Conversion Factors 18
    Table 7 – Loss per 100 Ft. for Typically used Coaxial Cables 18
    Table 8 – Estimated Safe Distances 19
    Table 8 Continued… 20
References 21
Contact Information 21

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Introduction:

This document was prepared to assist hams in determining if their stations meet FCC RF Exposure Regulations. ALL amateur stations must be in full compliance with the FCC Rules on RF Exposure by September 1, 2000. The information herein was excerpted from ARRL publications on this subject and as published on their web site: www.arrl.org. The steps detailed here are designed to give a quick analysis of your station. Conservative methods were employed to generally ensure that you will not exceed safety standards. This approach should suffice for most installations but if you find that you are exceeding safety limits after following all the steps detailed here you should take a more exacting approach to your analysis.

To keep things simple, this document does not go into detail regarding the FCC regulations nor does it describe the full analysis process. However, it is important that you familiarize yourself with them. Please see references at the end of this document for more information about how to obtain various materials.

By the time you finish the steps you will have evaluated your station, determined what steps, if any, need to be taken to bring the station into compliance, and documented your efforts for your station files. Note that while the FCC does not require you to document that you have performed an evaluation of your station, having such documentation does show that the evaluation was done.

Remember, you must stay informed about RF safety regulations. Do not assume that once you have completed this evaluation your station will be in compliance *forever*. Evaluate as often as needed, using the most current methods, to ensure continued compliance with the changing state of the art.

Why Should We Even Bother?

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

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

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

Your neighbors may also have questions and concerns. (The ARRL has already received quite a few questions on this subject from neighbors of hams.) Many of these concerns can be easily addressed by explaining the requirements to your neighbors and showing them the results of your station evaluation. The new rules even offer us a significant advantage; if our neighbors do have concerns, we are much better off being able to demonstrate that there are rules governing our conduct and that we have done what the rules require. In most cases, these evaluations are not hard! They can usually be done by looking at a table, or spending a few minutes with some free software or a calculator.

There is not much to lose, and a lot to gain. So, hams should complete their station evaluations and point to them with pride! -- *Chris D. Imlay, W3KD, ARRL General Counsel*

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Definitions:

MPE – Maximum Permissible Exposure. This is the maximum RF energy level that can be present *where and when* people are being exposed. The maximum level varies with frequency and exposure time and is based on average exposure.

Controlled Environment. Defined as an area where people are aware of their exposure and have the ability to control it. A controlled environment includes areas where you control access and all persons entering the area have been given instruction in RF exposure and safety. Typically this includes your house, yard, and family. In the following tables, this environment is labeled **Con**.

Uncontrolled Environment. Defined as an area where people are *unaware* of their exposure and consequently are unable to limit or avoid it. This includes areas surrounding your property and your neighbors. In the following tables, this environment is labeled **Unc**.

Target Environment. This may be either a Controlled or Uncontrolled environment and is the area we are examining for exposure level.

Averaging Period. Since MPE limits are based on average exposure time in a given environment, representative “averaging periods” were determined for Controlled and Uncontrolled environments. In a Controlled environment the exposure is averaged over a (6) six minute period. This represents the thinking that someone in this environment would attempt to limit their exposure. Six minutes was selected as a reasonable value. In an Uncontrolled environment the exposure is averaged over a (30) thirty minute period. This presumes that someone in this environment would *not* attempt to limit their exposure.

Operating Duty Factor. Exposure time is an important factor in MPE calculations and the *duty factor* (length of time that an RF emission is at full power) of the RF emission contributes to exposure time. Unmodulated carrier, FM, FSK/RTTY, AFSK are all 100% duty cycle modes because the carrier power does not vary significantly over time. SSB and CW are lower duty factor (20 – 40%) modes because the RF amplitude varies considerably with time which affects the total time that the emission is at full power.

Antenna Gain. For MPE calculations this is expressed in dBi (Decibels over Isotropic) **not** dBd (Decibels over Dipole). ***Caution:*** *Do not use dBi and dBd interchangeably – despite what you may have heard, they are* ***not*** *the same.* If you have a dBd figure you may convert that to dBi by adding 2.15 dB to the dBd figure. Example: 3 dBd + 2.15 dB = 5.15 dBi. It is OK to add and subtract plain, unreferenced dB from any referenced form of dB such as dBi or dBd. In fact, this is the way all gain and loss calculations are done.

PEP (Peak Envelope Power). This is the average power developed by a transmitter during one RF cycle the crest of the modulation envelope. In other words, this is the maximum power developed by a transmitter when fully modulated. Example: An AM transmitter develops 6dB (4 times) more PEP power than it does carrier power so a 375 Watt AM transmitter would generate 1500W PEP when fully modulated.

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

First Time Through

<u>Before you start:</u>

You may wish to make a few copies of the Worksheet at the end of this packet. Several copies may be needed for your evaluation and it would be good to keep a few extras for future evaluations. You may wish to use pencil so you can make changes easily. You may also wish to separate the Table section beginning on Page 17 so that you can refer to the tables easily.

<u>Step 1 – Determine if you need to evaluate:</u>

Look at the PEP/Continuous Power column of **Table 1** to see if your operation requires a station evaluation. Use PEP for amplitude modulated signals (i.e., AM, SSB) and carrier power for non-amplitude modulated signals (i.e., CW, FM). *If your power <u>exceeds</u> the PEP/Continuous Power limits in this table for the bands you use, you <u>must</u> evaluate your station for the band(s) on which the limit is exceeded.*

If you must perform an evaluation, enter just the bands you need to evaluate in Band column of the **Distance Calculation** section of the Work Sheet (one band per row) then proceed to Step 2. If you *<u>do not exceed</u>* the power limits on the bands you use, go to **Documentation.**

<u>Step 2 – Determine your Power Output and Antenna Gain:</u>

a) Compare your *actual* power output with the values in **Table 5**. Enter the corresponding Table 8 value in the **Power in Watts (Table 5)** column of the **Distance Calculation** section of the Work Sheet.

b) Now look at **Table 3** for typical Antenna Gains in Free Space. Find the antenna that best matches the type you have. If you have a published dBi figure for your antenna you may use that instead of the typical value in **Table 3.** If you have a dBd figure you *must* convert to dBi by adding 2.15 dB to the dBd figure.

c) Look up your actual antenna gain(s) in **Table 4** and enter these in the **Antenna Gain in dBi (Table 4)** column of the **Distance Calculation** section of the Work Sheet.

<u>Step 3 – Determine your Distance data:</u>

a) Measure or estimate as accurately as possible the distance from your antenna to the nearest, inhabitable parts of your home and the nearest part of your neighbor's property. Enter the distance from your antenna to the nearest inhabitable part of your home in the **Measured Distance to Controlled in Feet** column and the distance from your antenna to the nearest part of your neighbor's property in the **Measured Distance to Uncontrolled in Feet** column.

b) **Table 8** shows the estimated distances from transmitting antennas for various frequencies, power inputs, and antenna gains for the two population types. Cross reference power to your antenna gain at all frequencies you wish to evaluate. Check the "**Con**" and "**Unc**" distances and write these in the **Minimum Distance to Controlled (in feet)** and **Minimum Distance to Uncontrolled (in feet)** columns. Compare these distances to your measured distances. If your antenna is no closer than *Minimum* distances to the appropriate population, proceed to **Documentation**. If your antenna is closer than either recommended distance proceed to **<u>Second Time Through</u>**.

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

First Time Through Examples:

Please refer to the **(First Time Through Examples)** Worksheet as you go through these examples. We've entered all four examples on one worksheet for convenience.

1) Joe really enjoys 160 Meter operation and has gone all out to put a whopper signal on the top band. He usually runs 375 Watts AM (1500W PEP) shunt loaded into his 100 foot tower that is located 15 feet from his house. Joe's closest neighbors live about 30 feet away from his tower. On all other bands, Joe runs less than 50 Watts.

Step 1 – Joe's power exceeds the 500W PEP limit for the 160 Meter band (from **Table 1**) so he enters 160 in the **Band** column and proceeds to Step 2 to evaluate only the 160 Meter station. No evaluation will be done for the other bands because Joe's power is at or below the permissible limit.

Step 2 – Joe now references his power output (he uses the PEP value because his signal is amplitude modulated) to Table 5 and finds, not surprisingly, that he should use 1500 Watts as his power level. He enters this value in the **Power in Watts (Table 5)** column. Joe's tower is not quite a quarter wave but per the convention of this exercise we round up. **Table 3** shows the gain to be 1 dBi for a quarter wave vertical. Joe then looks at **Table 4** to determine the antenna gain to be used and finds that he should use 3dBi. He enters this in the **Antenna Gain in dBi (Table 4)** column.

Step 3 – Joe enters the distance measurements *he made* in the **Measured Distance** columns section of the Worksheet. He then looks at **Table 8** which shows that for a 1500 Watt transmitter at 2 MHz running into a 3dBi gain antenna the minimum permissible distances are 3.8 feet for an Uncontrolled environment and 2.6 feet for a controlled environment. He enters these in the **Minimum Distance** columns.

Joe easily passes with this setup. Because Joe's antenna gain is actually less than 3dB he has a good "safety margin" since his actual power is lower than what he was able to simply look up in **Table 8**. Joe now goes on to **Documentation**.

2) Louise is a CW contest and DX operator whose favorite band is 20 Meters. She doesn't bother operating on other bands. Last year she bought and installed a 1500 Watt amp, a 3 element 20 Meter mono-band Yagi, and a roof mount that puts the antenna 12 feet above her roof. Louise lives in a housing division where her nearest neighbor is 40 feet away and dead east from the turning radius of her antenna. Unfortunately, the neighbor's second story is about the same height as Louise's antenna.

Step 1 – Louise's power is unquestionably above the 225 Watt limit for 20 Meters from **Table 1** so she knows that she has to fully evaluate her station. She enters 20 in the **Band** column.

Step 2 – Table 5 shows that Louise should use 1500 Watts as her power level so she enters that in the **Power in Watts (Table 5)** column. Louise's Yagi antenna has a 7.2 dBi gain according to **Table 3**. **Table 4** shows that Louise should use 9dBi as her antenna gain. She enters this in the **Antenna Gain in dBi (Table 4)** column.

Step 3 –Looking at **Table 8** Louise finds that for a 9dBi antenna gain she must have her antenna mounted at least 54.7 feet away from her neighbor and 24.4 feet away from her house in order to run 1500 Watts. She enters these values in the **Minimum Distance** columns. She also enters her measured distances in the **Measured Distance** columns. Since both measured Controlled and Uncontrolled distances are closer than the minimum distances Louise will need to do more evaluation work. Stay tuned.

First Time Through Examples continued:

3) Jack prefers working grid squares on 6 and 2 meter SSB so he invested in a 50 foot tower, 150 Watt transceiver, an 8 element Yagi for 6 meters and a 17 element Yagi for 2 Meters. He also has a 450 Watt amplifier for 2 Meters. The antennas are stacked with 10 feet between them so that the 2 Meter Yagi is actually at 65 feet and the 6 Meter Yagi is at 55 feet. Jack's nearest neighbor's house is 70 feet away from the tower that is side mounted to Jack's 30 foot tall, two-story house.

Step 1 – Jack exceeds the **Table 1** power limits for both 6 and 2 meters so an evaluation is necessary. He enters 6 and 2 in the **Band** column.

Step 2 – Consulting **Table 5**, Jack finds that he should use 500 Watts as his power level. He enters 500 for both 6 and 2 meters in the **Power in Watts** column. Jack then looks up his antenna gains in **Table 3** and finds that the 8 element Yagi has a gain of 13.2 dBi and the 17 element Yagi has a gain of 16.8 dBi. The antenna manufacturer rates the antennas at 11dBd and 14.5dBd so Jack believes the dBi figures from the table to be correct. **Table 4** shows that 15 dBi and 20 dBi should be used for the 6 Meter and 2 Meter antennas respectively. He enters these in the **Antenna Gain in dBi** column.

Step 3 – Jack enters his measured distances in the **Measured Distance** columns and then turns his attention to **Table 8** which shows that the 6 Meter antenna (15 dBi) if fed 500 Watts must be mounted 58.9 feet away from a Controlled environment and 131.7 feet away from an Uncontrolled environment. The 2 Meter antenna (20 dBi) if fed with 500 Watts would need to be 104.7 feet away from a Controlled environment and 234.1 feet away from an Uncontrolled environment. He enters these figures in the **Minimum Distance** columns.

Since the measured distances are much closer than the Minimum distances Jack will also need to do additional evaluations.

4) Don runs 100 Watts RTTY on all HF bands and is concerned about the lower power limits on 12 and 10 Meters. His antenna is a folded dipole, 30 feet high but located almost directly above his lot line and attached to his chimney so it extends about 10 feet above the roof. Don's neighbor is approximately 10 feet horizontally away from the antenna.

Step 1 – Since Don exceeds 75 and 50 Watts (from **Table 1**) on 12 and 10 Meters respectively, these two bands will have to be evaluated. He enters 12 and 10 in the **Band** column.

Step 2 – From **Table 5**, Don finds that he should use 100 Watts as his power level and he enters this in the **Power in Watts** column for both the 12 and 10 meter band entries. Don's antenna is approximately equal to a half-wave dipole and therefore has an estimated gain of 2.15 dBi. **Table 4** shows that Don should use 3dBi as his antenna gain so he enters this in the **Antenna Gain in dBi** column.

Step 3 – Don enters his measured distances in the **Measured Distance** columns and then looks at **Table 8** which shows that with 100 Watts into the antenna his neighbors should be no closer than 12.3 feet if Don is operating 12 Meters or 14.6 feet if Don is operating on 10 Meters. He enters these values in the **Minimum Distance** columns and sees that he's OK for the controlled environment but may have a problem with his neighbors.

At first look, Don's antenna may be a bit too close to the neighbors but we haven't taken height into consideration. Don should take a second look at how antenna height may affect his calculations.

What If I didn't Pass the First Time Through?

Louise, Jack, and Don did not pass on the first try. We'll examine them a bit closer in **The Second Time Through.**

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Work Sheet (First Time Through Examples)

↓ ***Start Here on the First Time Through*** ↓

Distance Calculation – Use Pencil

Band	Power in Watts (Table 5)	Antenna Gain in dBi (Table 4)	Minimum Distance to Controlled in feet (Table 8)	Minimum Distance to Uncontrolled in feet (Table 8)	Measured Distance to Controlled in feet	Measured Distance to Uncontrolled in feet
160	1000	3	2.1	3.1	15	30
20	1500	9	24.4	54.7	**12**	**40**
6	500	15	58.9	131.7	**25**	**70**
2	500	20	104.7	234.1	**35**	**70**
12	100	3	5.5	12.3	10	**10**
10	100	3	6.5	14.6	10	**10**

If Measured Distances are equal to or greater than Minimum Distances the station should be in compliance with FCC Emissions Safety Rules. *The entries in* **BOLD** *represent distances that are too close to the antenna under examination and where RF exposure levels may be excessive.*

↓The following sections are NOT used the First Time Through.↓

Duty Factor Calculation

Band	Transmit Power in Watts	Transmitter On time in Percent	TX On Time Average Power in Watts	Duty Factor Percent	Average Power in Watts	Standard Power in Watts (Table 5)

Gain and Round Up Corrections

Band	Actual Antenna Gain (in dBi)	Total Feedline Loss (in dB)	Antenna Gain Adjusted for Line Loss (in dBi)	Power Rounding Gain (in dB)	Corrected Antenna Gain (in dBi)	Standard Antenna Gain in dBi (Table 4)

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Second Time Through

If all your evaluations worked out OK in the first pass you may safely ignore the next steps. However, if your antennas appear to be too close to a Controlled or Uncontrolled environment you should proceed to Step 4. Use a new worksheet for this evaluation. DO NOT fill out the **Distance Calculation** table until you are instructed to do so.

Step 4 – Estimate transmitter on time per averaging period:

a) Enter the bands that you need to evaluate further in the "Band" columns of the **Distance Calculation, Duty Factor Calculation** and **Gain and Round Up Corrections** tables of the Worksheet.

b) Enter your *actual* transmit power levels, after any amplifier, into the **TX Power (in Watts)** column of the **Duty Factor Calculation** table for each band. **DO NOT** use **Table 5** values here.

c) Now think about when you would be transmitting most – your heaviest use operating period. To many, a contest or Field Day operation represents this type of situation. Next, estimate how much Transmitter On ("key down") time you would have during one hour of that activity[1]. This represents your average transmitting time. Enter these as percentages in the **Transmitter On Percent** column of the **Duty Factor Calculation** table.

Step 5 – Determine your favorite emission mode(s):

a) CW? SSB? RTTY? What mode(s) do you use most of the time? You may want to list all of the modes you might use during the heavy operating period you defined in Step 4. At minimum, pick a mode you use that has the highest percentage duty factor. This will give you a worst-case figure. Now look at **Table 2** and check the notes regarding the various duty factors. This is your Duty Factor Correction.

b) Enter these (including any that may be 100%) in the appropriate **Duty Factor Percent** spaces of the **Duty Factor Calculation** table.

Step 6 – Convert the information:

In Steps 4 and 5 you collected information that will now be used to calculate your *average power*. This will then be used to reference Table 8. First we'll work on the **Duty Factor Calculation** table.

a) Multiply each **Transmit Power** entry by its corresponding **Transmitter On time in Percent** entry and enter the result in the corresponding **TX On Time Average Power** space. Example: 100 Watts X 50% = 50 Watts

b) Multiply each **TX On Time Average Power** entry by the corresponding **Duty Factor Percent** and enter the result in the appropriate spaces in the **Average Power** column. Example: 50 Watts X 40% = 20 Watts

c) Examine **Table 5** to get the Standard Power Levels and enter these values in the spaces in the **Standard Power in Watts (From Table 5)** column. Also enter these values in the **Power in Watts** column of **the Distance Calculation** table. Example: 20 Watts should be entered as 0 (zero) Watts.

[1] A good rule of thumb for casual operating is that you spend 2/3 of your time listening and 1/3 transmitting. If so, you spend 33% of your time transmitting.

Step 7 – Make Gain and Round-up Corrections:

In this step we will correct for possible feedline losses and eliminate round-up errors. Feedline losses are often insignificant on HF but as frequency increases so do the losses. You should factor in these losses for VHF and UHF operations, especially if you are using an antenna with 3 or more dBi of gain. The round-up losses could be significant on any band, especially if you had to round-up power quite a bit. All entries for this step will be made in the **Gain and Round Up Corrections** table. If you have not already done so, enter the band(s) you are evaluating in the **Band** column.

a) Enter your ***actual*** antenna gain(s) in the **Antenna Gain in dBi** column. These may *not* be the same values you originally used in the **Distance Calculation** table**. DO NOT** use **Table 4** values for these entries**.**

b) Determine your feedline loss – especially if you are running more than 50 Watts on VHF or UHF. Coaxial cable always has more loss per foot than other types of line. To factor in this loss, determine the length of the coax "feedline" from your transmitter or amplifier to the antenna. Since manufacturers specify cable loss in dB per 100 feet divide your measured cable length by 100 to convert it to a percentage of 100 feet. Example: If you have 73 feet of coax running from your shack to your antenna divide 73 by 100 to get 0.73. This is your length of cable expressed in hundreds of feet.

c) Look up the dB loss per 100 feet at your operating frequencies in the cable manufacturer's literature or use the standard values from **Table 7**. Most manufacturers don't list all possible frequencies but typically show loss for 1, 10, 50, 100, 200, 400, etc., MHz. Select the frequency closest to the band in question. Multiply the loss per 100 feet by feedline length in hundreds of feet to get the total loss in dB. Enter this number in the **Total Feedline Loss in dB** column. Example: The 73 feet of coax from the previous step is known to have a loss of 3.2dB per 100 feet at 150 MHz. The loss for 73 feet can be found by multiplying 3.2dB times 0.73 which equals 2.34dB. It is OK to round to the nearest tenth dB so you would enter 2.3 dB in this example. **Note**: If you don't know and can't find the loss figures for your cable use 0 (zero) dB.

d) First calculate the **Antenna Gain Adjusted for Line Loss** by taking the **Antenna Gain in dBi** and subtracting the corresponding **Total Feedline Loss in dB**. Enter the results in the **Antenna Gain Adjusted for Line Loss** column.

e) Now we'll calculate the **Power Rounding Gain in dB**. We do this by dividing the **Standard Power in Watts** entries by the **Average Power** entries, both from the **Duty Factor Calculation** table. Example: If your **Average Power** is 120 Watts the **Standard Power in Watts** value should be 500 Watts (from **Table 5**). Convert this difference to the power ratio by dividing 500 by 120. This equals a power ratio of 4.17.

f) Compare each of the power ratio values you just calculated to the **Power Gain Multiplier** columns of **Table 6**. Pick the range that includes the number you calculated. Enter the **Gain in dB** value in the appropriate space in the **Power Rounding Gain in dB** column of the worksheet. Example: Our 4.17 ratio is in the range of 3.98 to 5.01 which corresponds to 6.0dB of gain.

g) Subtract the **Power Rounding Gain in dB** values from their corresponding **Antenna Gain Adjusted for Line Loss (in dBi)** values and enter the differences in the **Corrected Antenna Gain in dBi** column. It is OK if this value is less than zero.

h) Compare your **Corrected Antenna Gain** values to the **If your Actual Antenna Gain is:** values in **Table 4**. Enter the corresponding **Use this as your Antenna's Gain** entries in the **Standard Antenna Gain in dBi** column. Also enter these values in the **Antenna Gain in dBi** column of the **Distance Calculation** table.

Step 8 – Check your Antenna Distance Calculation:

Your antenna's height may factor into its total distance to the nearest Controlled and Uncontrolled environments. Except in cases where the antenna is at ground level or someone is directly in the main beam (i.e., looking almost directly into the antenna) the height should be factored into the total distance.

This is done by the formula: $a = SQRT(b^2+c^2)$ where a = total distance in feet to target environment, b = measured distance in feet from the base of the tower or antenna support to the area in question, c = measured height of the tower in feet, less any height above ground at the area in question. We'll solve for a.

a) Measure the horizontal distance from the base of your antenna support to the target environment. This is the distance value you used in the First Time Through. This is value "b". Square this and save it for future use. Example: We measure 12 feet. 12 squared = 144.

b) Measure or accurately estimate the height of your antenna above ground.

c) Measure or accurately estimate the height of your target environment (Your neighbor's second story for example). Subtract this from the height of your antenna. This result is value "c". Square this and save it for future use. Example: Your antenna is 30 feet high and your neighbor's second story bedroom is 20 feet high. Therefore c = 30 – 20 or 10. 10 squared = 100

d) Calculate the actual distance to the target environment. Add the squared values you calculated in Steps 8a and 8c then take the square root of the result. This is the actual distance from your antenna to the target environment. Example: 144 + 100 = 244. The square root of 244 = 15.62. It's OK to round to one decimal place so we will use 15.6 as the distance to the target environment in feet.

e) Enter the distance you just calculated in the appropriate **Measured Distance** column of the **Distance Calculation** table.

f) Repeat the above steps as necessary for all bands and all Controlled and Uncontrolled environments as needed.

Step 9 – Examine Table 8:

Just as you did on the First Time Through, cross-reference the average power level(s) and antenna gain(s) you just entered to **Table 8** values and determine the new minimum acceptable distance from your antenna. If your antenna is no closer than those distances to the appropriate population, proceed to **Documentation (Page 14)**. If your antenna is *still* closer than either recommended distance, proceed to **When All Else Fails.**

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Second Time Through Examples:

We will revisit the stations of Louise, Jack, and Don to see if the **Second Time Through** calculations help them enough to pass.

1) As you recall, Louise operates CW on 20 Meters with 1500 Watts into a 3-element mono-band Yagi on a roof mount 12 feet above her roof. Louise's nearest neighbor is 40 feet away, dead east from the turning radius of her antenna, and looks almost straight into the antenna from his second story window.

We found in the First Time Through that Louise must have her antenna mounted at least 54.7 feet away from her neighbor in order to run 1500 Watts with the beam pointed at her neighbor's house. Since the neighbor is closer than 50 feet, Louise may have a problem. To find out, Louise decided to go a **Second Time Through**.

Step 4 – Louise knows from her contesting experience that she spends about 50% of her time listening and 50% transmitting. She enters this information in **Transmitter On Percent** column of the **Duty Factor Calculation** table.

Step 5 – Louise never uses any mode but CW so she consults **Table 2** and finds that CW has a Duty Factor of 40%. She enters this information in the **Duty Factor Percent** column of the **Duty Factor Calculation** table.

Step 6 – Louise now converts the information she entered in the **Duty Factor Calculation** table and finds that her **TX On Time Average Power** is 750 Watts and that her **Average Power** is 300 Watts. She enters these in appropriate columns. Louise looks up the 300 Watt power level in **Table 5** and enters 500 Watts in the **Power in Watts** column of the **Duty Factor Calculation** table and in the **Standard Power in Watts** column of the **Distance Calculation** table.

Step 7 – Louise turns her attention to the **Gain and Round Up Corrections** table and enters her *actual* antenna gain (7.2dBi) in the **Actual Antenna Gain** column. She decides not to bother with correcting for feedline loss because she only has 50 feet of RG-8 coax and the loss on HF is so low as to not be a significant factor. She writes 0 in the **Total Feedline Loss** column and her actual antenna gain in the **Antenna Gain Adjusted for Line Loss** columns. She now calculates the **Power Rounding Gain** from the entries she made in the **Duty Factor Calculation** table by dividing 500 Watts by 300 Watts to get a power ratio of 1.67. **Table 6** shows this to equal 2.0 dB so Louise enters this in the **Gain and Round Up Corrections** table. She subtracts this value from her **Antenna Gain Adjusted for Line Loss** and finds her **Corrected Antenna Gain** to be 5.2dB. She consults **Table 4** and finds that 6.0 dB is her gain figure. She enters this in the **Standard Antenna Gain in dBi** column and in **Antenna Gain** column of **the Distance Calculation** table.

Step 8 – Louise now looks at **Table 8** and discovers that with her 7.2dBi antenna (corrected to 6dBi as a result of the gain and round up corrections) and 500 Watts, her neighbor needs to be only 22.3 feet away. Since the neighbor is 40 feet away, Louise is OK for the Uncontrolled figure. Louise also notes that the Controlled figure is 10.0 feet and that this is less than the distance from her antenna to her second floor ceiling. Louise's problem is solved and her family won't have to vacate the second floor of their house when she's contesting. She goes on to **Documentation.**

2) Remember that Jack runs 150 Watts on 6 meter and 450 Watts on 2 meter SSB into an 8 element Yagi for 6 meters and a 17 element Yagi for 2 Meters. The antennas are stacked with 10 feet between them so that the 2 Meter Yagi is actually at 65 feet and the 6 Meter Yagi is at 55 feet. Jack's nearest neighbor's house is 70 feet away from the tower that is side mounted to Jack's 30 foot tall, two-story house. Jack enters 150 Watts and 450 Watts into the **Transmit Power in Watts** column of the **Duty Factor Calculation** table.

Step 4 – Jack decides that his operation is pretty casual so he adopts the 2/3 listen, 1/3 transmit "rule" so he transmits only 33% of each hour. He enters this information in the **Transmitter On Percent** column of the **Duty Factor Calculation** table.

Step 5 – Jack always uses a speech processor to improve his modulation and average power output so his duty factor from **Table 2** is 40%. He also enters this in the **Duty Factor Percent** column of the **Duty Factor Calculation** table.

Step 6 – Jack now converts the information he entered in the **Duty Factor Calculation** table and finds that his Average Power is 19.8 Watts for 6 Meters and 59.4 Watts for 2 Meters. He enters these in **the Average Power in Watts** column. Jack looks up his Average Power values in **Table 5** and enters 0 Watts in the **Standard Power in Watts (From Table 5)** column of the **Duty Factor Calculation** and **Distance Calculation** tables for his 6 Meter station and 100 Watts in those columns for his 2 Meter station. Since his 6 Meter station now averages below 50 Watts no further evaluation is necessary so Jack does not enter anything for the 6 Meter station in the **Gain and Round Up Corrections** table. The 2 Meter station does need further work so Jack continues to Step 7.

Step 7 – Jack decides to correct for feedline loss because he was using cable that had 2.1dB loss per 100 feet at 145 MHz. He had 70 feet on the tower and easily another 30 feet running from the tower to his shack. He writes his *actual* antenna gain, 16.8dBi in the **Actual Antenna Gain** column and 2.1dB in the **Total Feedline Loss** column. He subtracts the Total Feedline Loss from the Actual Antenna Gain and writes 14.7dBi in the **Antenna Gain Adjusted for Line Loss** columns of the **Gain and Round Up Corrections** table.

He now calculates the **Power Rounding Gain** by calculating the power ratio from the entries he made in the **Duty Factor Calculation** table (100W/59.4W) and comparing the ratio (1.68) to the entries in **Table 6**. He enters 2 dB as the **Power Rounding Gain** value. He subtracts this value from his **Antenna Gain Adjusted for Line Loss** and finds his corrected gain to be 12.7dBi. He consults **Table 4** and finds that 15dBi is his standard gain figure. He enters this in the **Antenna Gain** column of **the Distance Calculation** table and **the Corrected Antenna Gain in dBi (From Table 4)** column of the **Duty Factor Calculation** table.

Step 8 – Jack thinks his numbers look good enough now so he decides to skip recalculating his distances. He reasons correctly that with his tower height the distance to his neighbors or his house should be great enough to not be a problem.

Step 9 – **Table 8** shows that Jack's 2 Meter antenna (15 dBi corrected gain) fed with 100 Watts would need to be 26.3 feet away from a Controlled environment and 58.9 feet away from an Uncontrolled environment. Remember, Jack did not have to reference **Table 8** for his 6 Meter station because the corrected power is below 50 Watts and therefore does not need evaluation.

Jack is now OK on both 6 and 2 Meters for both Controlled and Uncontrolled environments. He goes on to **Documentation.**

3) Don is running 100 Watts RTTY into a folded dipole at 30 feet located almost on his lot line.

Step 4 – Don knows that when he is having his usual RTTY ragchew he often is transmitting at least 50% of the time. He enters this information in the **Transmitter On Percent** column of the **Duty Factor Calculation** table.

Step 5 –RTTY has a 100% duty factor per **Table 2** so Don sees no reduction in average power as a result of the modulation method. He enters 100% in the **Duty Factor Percent** column of the **Duty Factor Calculation** table.

Step 6 – Don now converts the information he entered in the **Duty Factor Calculation** table and finds that his **TX On Time Average Power** is 50 Watts (100 Watts X 50%) as is his Average Power. He enters this power in both the **Transmitter On Time Average Power** and **Average Power in Watts** columns. Don looks up the Average Power (50 Watts) in **Table 5** and enters 100 Watts in the **Power in Watts (From Table 5)** column and in the **Power in Watts** column of the **Distance Calculation** table. Note: In this example, Duty Factor calculation did not really affect Don's calculated power output. This is not uncommon because of the way the tables are constructed. Don't worry. Don still has more work to do.

Step 7 – Don decides not to bother with correcting for feedline loss because he only has 60 feet of RG-8 coax and the loss on HF is so low as to not be a factor. He writes 0 in the **Total Feedline Loss** column and his actual antenna gain (2.15dBi) in the **Antenna Gain Adjusted for Line Loss** columns of the **Gain and Round Up Corrections** table. He now calculates the **Power Rounding Gain** from the entries he made in the **Duty Factor Calculation** table (100/50 = 2.0), looks up the **Power Gain Multiplier** (2.0 which falls between 1.99 and 2.51) in **Table 6** and enters the **Gain in dB** (3dB) in the **Gain and Round Up Corrections** table. He subtracts this value from his **Antenna Gain Adjusted for Line Loss** and finds his corrected gain to be –0.85dBi (a negative value is OK here). He consults **Table 4** and finds that 0dBi is his gain figure. He enters this in the **Antenna Gain** column of the **Distance Calculation** table.

Step 8 – Don takes a quick look at **Table 8** and sees that he is still a bit too close to his neighbor if he uses his original 10 foot distance number. He decides to recheck his distance and account for antenna height. Don's neighbor's house is 10 feet away from his house and the antenna is 30 feet above the ground. Don determines that his neighbor's house is 20 feet high so Don calculates that the actual distance from his antenna to top floor of his neighbor's house by the following method: b = 10 ft. (horizontal distance to neighbor's house), c = 10 ft. (Antenna height above ground minus height of neighbor's house). Therefore the distance (a) will be: $a = SQRT(10^2+10^2)$ or 14.14 ft. Don enters this distance in the 12 and 10 Meter rows of the **Distance Calculation** table.

Step 9 – **Table 8** shows that Don's antenna (0dBi corrected gain) fed with 50 Watts (corrected) must be mounted 3.9 feet away from a Controlled environment and 8.7 feet away from an Uncontrolled environment on 12 Meters and 4.6 feet away from a Controlled environment and 10.4 feet away from an Uncontrolled environment on 10 Meters. Don's station now passes easily so he goes on to **Documentation.**

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Step By Step RF Safety Evaluation

Work Sheet (Second Time Through Examples)

Distance Calculation

Band	Power in Watts (Table 5)	Antenna Gain in dBi (Table 4)	Minimum Distance to Controlled in feet (Table 8)	Minimum Distance to Uncontrolled in feet (Table 8)	Measured Distance to Controlled in feet	Measured Distance to Uncontrolled in feet
20	*500*	*6*	*10.0*	*22.3*	12	40
6	*0*	*9*	*N/A*	*N/A*	25	70
2	*100*	*15*	*26.3*	*58.9*	35	70
12	*100*	*0*	*3.9*	*8.7*	10	*14.14*
10	*100*	*0*	*4.6*	*10.4*	10	*14.14*

If Measured Distances are equal to or greater than Minimum Distances the station should be in compliance with FCC Emissions Safety Rules. *Italicized numbers have changed from the first time through.*

↓ ***Start Here on the Second Time Through*** ↓

Duty Factor Calculation

Band	Transmit Power in Watts	Transmitter On time in Percent	TX On Time Average Power in Watts	Duty Factor Percent	Average Power in Watts	Standard Power in Watts (Table 5)
20	1500	50	750	40	300	500
6	150	33	49.5	40	19.8	0
2	450	33	148.5	40	59.4	100
12	100	50	50	100	50	100
10	100	50	50	100	50	100

Gain and Round Up Corrections

Band	Actual Antenna Gain (in dBi)	Total Feedline Loss (in dB)	Antenna Gain Adjusted for Line Loss (in dBi)	Power Rounding Gain (in dB)	Corrected Antenna Gain (in dBi)	Standard Antenna Gain in dBi (Table 4)
20	7.2	0	7.2	2.0	5.2	6
6						
2	16.8	2.1	14.7	2.0	12.7	15
12	2.15	0	2.15	3.0	-0.85	0
10	2.15	0	2.15	3.0	-0.85	0

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Step By Step RF Safety Evaluation

When All Else Fails!

You are here either out of curiosity or because you've gone through every step and your emissions are still greater than the MPE in some area. Here are some thoughts about how to deal with this.

- **Is reducing power an option?** Remember that cutting your power in half translates to a 3dB drop. Since an "S" unit represents 6 dB, cutting your power in half only causes a ½ "S" unit drop at the receiver. However, this drop may make all the difference in your distance limitation. You may also consider only running higher power if you are unable to make or keep a contact. Remember to limit your transmit times when running at the higher power levels.
- **Can you reduce you duty factor?** Remember that exposure is time related. If you drop your duty factor you decrease your average power over time. A simple thing as turning off your speech processor drops duty factor from 40% to 20%. Switching from RTTY to one of the TOR modes reduces your duty factor to about 50%.
- **Can you relocate your antenna?** While not always practical this may be your best alternative.
- **Factor in Antenna Directivity.** Antenna gain comes from concentration of the radiated signal in a desired direction. This causes an equivalent reduction in signal in an undesired direction. Any antenna with a published gain figure greater than 0dBi will show some directivity. For instance, a Yagi radiates less signal above, below, and to the back and sides, than it does toward the front. Acquire a field intensity chart for your antenna that shows gain (or loss) in all directions and factor that in as your antenna gain in the desired direction. This could show that signal at ground level from a tower mounted Yagi is much lower than predicted from the simple modeling shown in our examples. **Important Note**: An antenna has both near-field and far-field directivity characteristics. You must take these into account when examining the antenna's directivity. This topic is beyond the scope of this evaluation sheet so please investigate other sources for further information.
- **Did you factor in cable loss?** If you bypassed this step and you are using small cable (RG-58) or long lengths you REALLY ought to factor this loss in. This is especially true if you are operating on VHF and above and are otherwise fairly close to passing your station. For instance, if your antenna only needs to be a few feet further away to pass.
- **Still in trouble?** Try checking your calculations again. It's easy to have things go wrong, particularly with the Gain and Round Up corrections. If you have questions, you can send them via email to: INFO@W9DUP.ORG

Documentation

If you followed all of the procedures, your documentation is complete. Simply file the completed Work Sheet with your station records.

If you did not need to evaluate your station because your power levels were below the maximums listed in **Table 1**, simply note that your power levels were below the limit and keep a record in your files.

IMPORTANT: If ***at any time*** you make changes to your station's RF setup you ***must*** evaluate the effect those changes had on your MPE levels. Keep a few blank copies of the Work Sheet for future calculations.

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Step By Step RF Safety Evaluation

Tables

Table 1 – PEP Maximum Power per Band

Band HF	PEP/Continuous Power in Watts	Band VHF/UHF	PEP/Continuous Power in Watts
160 Meters	500	6 Meters	50
80 Meters	500	2 Meters	50
40 Meters	500	220 MHz	50
30 Meters	425	440 MHz	70
20 Meters	225	900 MHz	150
15 Meters	125	1.2 GHz	200
12 Meters	75	2.3 GHz	250
10 Meters	50	Above 2.3 GHz	250

Repeaters:

Non Building Mounted Antenna:
If the distance between ground level and the lowest point of the antenna is less than 10 meters *and* the power is greater than 500 W ERP.

Building Mounted Antenna:
If the power exceeds 500 W ERP.

Table 2 – Typical Duty Factors

Mode	Duty Factor	Notes
Unprocessed Voice SSB	20%	Normal Voice Modulation – No processing.
Processed Voice SSB	40%	Normal Voice Modulation. Moderate Speech Processing in use.
FM	100%	Any modulating signal.
FSK/RTTY/AFSK/PSK	100%	
TOR Connected Modes	50%	i.e., ARC
TOR FEC Modes	100%	
Conversational CW	40%	
Continuous Carrier	100%	No Modulation – Tuning up

Table 3 – Typical Antenna Gains in Free Space

Antenna Type	Gain in dBi	Antenna Type	Gain in dBi
Quarter Wave Ground Plane or Vertical	1.0	5-element Yagi	9.4
Half Wave dipole	2.15	8-element Yagi	13.2
2-element Yagi	6.0	10-element Yagi	14.8
3-element Yagi	7.2	17-element Yagi	16.8

Table 4 – Standard Antenna Gains for Table 8

If your Actual Antenna Gain in dBi is:	Use this as your Antenna's Gain in dBi	If your Actual Antenna Gain in dBi is:	Use this as your Antenna's Gain in dBi
Less than 1	0	9 to 12	12
1 to 3	3	12 to 15	15
3 to 6	6	15 to 20	20
6 to 9	9		

Table 5 – Standard Power Levels for Table 8

If your HF Power Level is:	Use this as your HF Power Level	If your VHF/UHF Power Level is:	Use this as your VHF/UHF Power Level
Less than 50 Watts	0 Watts[2]	Less than 50 Watts	0 Watts[2]
50 to100 Watts[2]	100 Watts	50 Watts	50 Watts
100 to 500 Watts	500 Watts	50 to 100 Watts	100 Watts
500 to 1000 Watts	1000 Watts	100 to 500 Watts	500 Watts
1000 to1500 Watts	1500 Watts	500 to 1000 Watts	1000 Watts

Table 6 – Power Gain to dB Conversion Factors

Power Gain Multiplier	Gain in dB	Power Gain Multiplier	Gain in dB	Power Gain Multiplier	Gain in dB
1.00 – 1.26	0	2.51 – 3.16	4.0	6.31 – 7.94	8.0
1.26 – 1.58	1.0	3.16 – 3.98	5.0	7.94 – 10.00	9.0
1.58 – 1.99	2.0	3.98 – 5.01	6.0	10.00 – 12.59	10.0
1.99 – 2.51	3.0	5.01 – 6.31	7.0	12.59 – 15.85	11.0

Table 7 – Loss per 100 Ft. for Typically used Coaxial Cables

Cable Type	HF (1 MHz)	HF (30 MHz)	VHF (50 MHz)	VHF (145 MHz)	VHF (220 MHz)	UHF (440 MHz)
RG-58	0.4dB	2.4dB	3.3dB	5.9dB	7.5dB	12.0dB
RG-8	0.2dB	0.9dB	1.3dB	2.1dB	2.9dB	4.3dB
Belden 9913 & LMR 400	0.1dB	0.7dB	0.9dB	1.4dB	1.9dB	2.8dB

[2] Power Levels below 50 Watts do not require evaluation.

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Step By Step RF Safety Evaluation

<u>Table 8 – Estimated Safe Distances</u>

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

Distance from the Antenna in Feet - HF

		100 Watts		500 Watts		1000 Watts		1500 Watts	
Frequency MHz	**Gain dBi**	**Con**	**Unc**	**Con**	**Unc**	**Con**	**Unc**	**Con**	**Unc**
2.0	0	0.5	0.7	1.0	1.6	1.5	2.2	1.8	2.7
	3	0.7	1.0	1.5	2.2	2.1	3.1	2.6	3.8
4.0	0	0.6	1.4	1.4	3.1	2.0	4.4	2.4	5.4
	3	0.9	2.0	2.0	4.4	2.8	6.2	3.4	7.6
7.3	0	1.1	2.5	2.5	5.7	3.6	8.1	4.4	9.9
	3	1.6	3.6	3.6	8.0	5.1	11.4	6.2	13.9
	6	2.3	5.1	5.1	11.4	7.2	16.1	8.8	19.7
10.15	0	1.6.	3.5	3.5	7.9	5.0	11.2	6.1	13.7
	3	2.2	5.0	5.0	11.2	7.1	15.8	8.7	19.4
	6	3.2	7.1	7.1	15.8	10.0	22.4	12.2	27.4
14.35	0	2.2	5.0	5.0	11.2	7.1	15.8	8.7	19.4
	3	3.2	7.1	7.1	15.8	10.0	22.4	12.3	27.4
	6	4.5	10.0	10.0	22.3	14.1	31.6	17.3	38.7
	9	6.3	14.1	14.1	31.6	20.0	44.6	24.4	54.7
18.168	0	2.8	6.3	6.3	14.2	9.0	20.1	11.0	24.6
	3	4.0	9.0	9.0	20.0	12.7	28.3	15.5	34.7
	6	5.7	12.7	12.7	28.3	17.9	40.0	21.9	49.0
	9	8.0	17.9	17.9	40.0	25.3	56.5	31.0	69.2
21.45	0	3.3	7.5	7.5	16.7	10.6	23.7	13.0	29.0
	3	4.7	10.6	10.6	23.6	15.0	33.4	18.3	41.0
	6	6.7	14.9	14.9	33.4	21.1	47.2	25.9	57.9
	9	9.4	21.1	21.1	47.2	29.8	66.7	36.5	81.7
24.99	0	3.9	8.7	8.7	19.5	12.3	27.6	15.1	33.8
	3	5.5	12.3	12.3	27.5	17.4	39.0	21.3	47.7
	6	7.8	17.4	17.4	38.9	24.6	55.0	30.1	67.4
	9	11.0	24.6	24.6	55.0	34.8	77.7	42.6	95.2
29.7	0	4.6	10.4	10.4	23.2	14.7	32.8	18.0	40.1
	3	6.5	14.6	14.6	32.7	20.7	46.3	25.4	56.7
	6	9.2	20.7	20.7	46.2	29.3	65.4	35.8	80.1
	9	13.1	29.2	29.2	65.3	41.3	92.4	50.6	113.2

Table 8 Continued…

		Distance from the Antenna in Feet VHF - UHF							
		50 Watts		100 Watts		500 Watts		1000 Watts	
Frequency MHz	**Gain dBi**	**Con**	**Unc**	**Con**	**Unc**	**Con**	**Unc**	**Con**	**Unc**
50 - 222	0	3.3	7.4	4.7	10.5	10.5	23.4	14.8	33.1
	3	4.7	10.5	6.6	14.8	14.8	33.1	20.9	46.8
	6	6.6	14.8	9.3	20.9	20.9	46.7	29.5	66.1
	9	9.3	20.9	13.2	29.5	29.5	66.0	41.7	93.3
	12	13.2	29.5	18.6	41.7	41.7	93.2	59.0	131.8
	15	18.6	41.6	26.3	58.9	58.9	131.7	83.3	186.2
	20	33.1	74.0	46.8	104.7	104.7	234.1	148.1	331.1
420	0	2.8	6.3	4.0	8.8	8.8	19.8	12.5	28.0
	3	4.0	8.8	5.6	12.5	12.5	28.0	17.7	39.5
	6	5.6	12.5	7.9	17.7	17.7	39.5	25.0	55.8
	9	7.9	17.6	11.2	24.9	24.9	55.8	35.3	78.9
	12	11.1	24.9	15.8	35.2	35.2	78.8	49.8	111.4
	15	15.7	35.2	22.3	49.8	49.8	111.3	70.4	157.4
1240	0	1.6	3.6	2.3	5.2	5.2	11.5	7.3	16.3
	3	2.3	5.1	3.3	7.3	7.3	16.3	10.3	23.0
	6	3.2	7.3	4.6	10.3	10.3	23.0	14.5	32.5
	9	4.6	10.3	6.5	14.5	14.5	32.5	20.5	45.9
	12	6.5	14.5	9.2	20.5	20.5	45.8	29.0	64.8
	15	9.2	20.5	13.0	29.0	29.0	64.8	41.0	91.6

References

The FCC Office of Engineering and Technology Web page has all the FCC information on RF exposure. See http://www.fcc.gov/oet/rfsafety/. Paper copies of OET Bulletin 65 are available from:
National Technical Information Service, Springfield, VA 22161
Telephone: 800-553-6847
e-mail: orders@ntis.fedworld.gov
Web: http://www.ntis.gov Product Search for OET 65

Ed Hare, KA1CV, "The FCC's New RF-Exposure Regulations," QST, Jan 1997, p 47.

Ed Hare, W1RFI, "What's New About the FCC's New RF-Exposure Regulations," QST Oct 1997, p 51.

A copy of all applicable QST articles, and links to all FCC material and RF-exposure rules can be found on the ARRL Web at http://www.arrl.org Search RF Exposure

Greg Lapin (N9GL) has written many excellent articles regarding RF exposure. These provide a sanity check for an often insanely argued topic. Find these articles on-line at: http://www.arrl.org Search RF Safety or N9GL

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Notes

DuPage Amateur Radio Club
Step By Step RF Safety Evaluation

Work Sheet

Distance Calculation

Band	Power in Watts (Table 5)	Antenna Gain in dBi (Table 4)	Minimum Distance to Controlled in feet (Table 8)	Minimum Distance to Uncontrolled in feet (Table 8)	Measured Distance to Controlled in feet	Measured Distance to Uncontrolled in feet

If Measured Distances are equal to or greater than Minimum Distances the station should be in compliance with FCC Emissions Safety Rules. Power levels of 50 Watts or less do not require evaluation.

Duty Factor Calculation

Band	Transmit Power in Watts	Transmitter On time in Percent	TX On Time Average Power in Watts	Duty Factor Percent	Average Power in Watts	Standard Power in Watts (Table 5)

Gain and Round Up Corrections

Band	Actual Antenna Gain (in dBi)	Total Feedline Loss (in dB)	Antenna Gain Adjusted for Line Loss (in dBi)	Power Rounding Gain (in dB)	Corrected Antenna Gain (in dBi)	Standard Antenna Gain in dBi (Table 4)

Station Call Sign: ________________________________

Date: ___________________________ Licensee’s Name: ____