Antenna Factors, their Derivation…and the FCC

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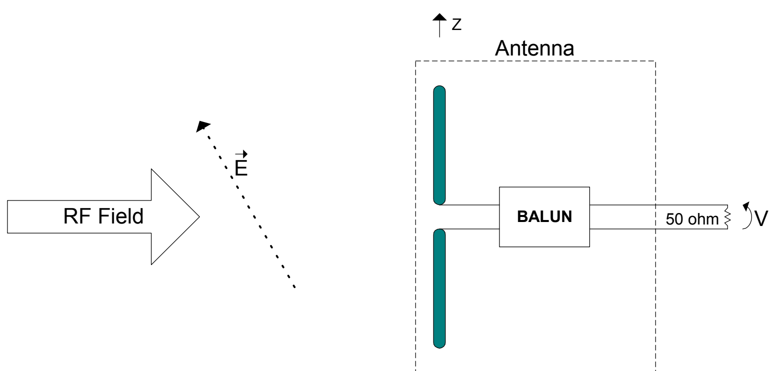
OVERVIEW:

In the document I start with the definition of antenna factor (AF). Next I give a short history of what led to "antenna factors". This will provide much-needed insight into why these factors are so widely accepted and used. I also provide the answers to these most common questions:

- "What does antenna factor mean?"
- "How does one derive antenna factor from antenna gain?
- "What is the antenna factor for a dipole?"
- Lastly I provide the derivation of several related charts used with antenna factor.

DEFINITION:

The definition of antenna factor is the ratio of incident electric field strength [upon an antenna] to the voltage that is produced at the antenna's terminals—into a 50 ohm load. A visual picture of this definition is provided:



$$\text{Antenna Factor (ratio)} = \frac{|\vec{E} \cdot z|}{V}$$

If one is talking strictly a ratio, the dimensions are in "reciprocal-distance"—i.e. for meters this is "1/m". Most labs use the logarithmic version because it turns succeeding calculations into an addition problem; in this case the units are dB/meter.

Be aware that there is no such measurable quantity as an "antenna factor"—the term more rightly should be classified as a "conversion factor for antennas". Even that definition is lacking. I know I will get some arguments from those who will say, "Well you're wrong as we measure these numbers all the time…how do you think we supply the table?!" I'll illustrate this best by analogy. For example: In analogy the number 2.54 is a conversion factor from inches to centimeters and vice-versa; one does not measure the conversion factor—one measures in inches or centimeters.

THE BACKGROUND:

The FCC needed a methodology for determining compliance within the rules and regulations promulgated by the FCC.

> *Note to the Astute: Be aware that the rules and regulations commonly called Code of Federal Regulations are NOT the law; the law is contained prima-facie in the Title code [i.e. USC] and is not too surprisingly lacking--as the limitation of the federal government not on federal land is to the state governments… and a little interstate commerce. The rules and regulations merely tell government agencies how to interpret the law--primarily for their own usage. If you understand this advanced lawful concept, you will understand why the FCC seeks compliance over enforcement. Can you understand why the methodology for "compliance" is so nebulous....in application to the private sector? Further, you will understand why the FCC will never answer the question, "What is legal?" They will instead simply state what is compliant within the CFR…for example CFR Part 15.*

Back to the measurement issue…The problem with the FCC Part 15 rules and regulations is the limits are expressed in terms of field strength. This is highly dependent on ground terrain and subject to measurement error via the form of measurement. The ground terrain issue was solved by prescribing a standard metal "hardware cloth" ground plain for test sites—now anywhere someone measured, the ground reflection effects should be the same. The measurement error was reduced by using a dipole as the reference antenna. Enter Wilmar Roberts of the FCC!

Wilmar Roberts "standardized" the antennas into what became known as "Robert's Antennas." These are essentially sets of dipole antennas with simple coaxial baluns. [FYI: People give Wilmar too much credit for having *invented* a dipole with a nice balun; actually the balun was reported by Marchand—I believe in a 1940's Electronics Magazine.] In any case, the FCC now had a standard for antennas between say 30 and 1000 MHz [FYI: Even above 1000 MHz the FCC will acknowledge the standard is a dipole antenna.] Many manufactures build these antennas commercially—but the astute person can easily construct a set from telescoping rod and RG-58 coax. This was the major contribution of Roberts in my opinion: (1) a standardized antenna, (2) with "close-enough-for-government-work" repeatable results (3) easily constructed (4) well documented and (5) can be made by anyone at low cost.

So how does all this nice history relate to antenna factors? You have to understand that most FCC measurement people—say test labs—are NOT antenna engineers. Most simply take calibrated antennas, calibrated equipment, a unit under test, move it 3 meters [or 10 meters] back in distance and measure it for compliance. Antenna factors make the “fudge factor” easy in converting from say a spectrum analyzer reading to an actual field strength. In addition be aware that these antenna factors came into being in the early days—slide rules and calculators were the norm instead of an Excel Spread-sheet of ease. So you can think of antenna factors in the same way of the original usage of logarithms: i.e. they take something of multiplication complication and turn it into simple addition.

How does one use these antenna factors “in the real world”? First understand that the factor is a “given” by the manufacturer of the FCC test antenna—in other words it is a published calibration factor dependent on frequency. Manufacturers characterize the antennas and provide the factors in table form. For example, the antenna factor at 120mhz might be 15 dB/m whereas at 40mhz it might be 10 dB/m. Usually one gets a published “curve” or table of antenna factors vs. frequency.

The easiest way to see the usage-ease of these factors is via example. Let’s say at 120 MHz you measured a spike in spectrum due to your unit-under-test when your test antenna was 3 meters away. You want to know if you are “compliant with FCC 47 CFR Part 15”. With your calibrated antenna and on your spectrum analyzer you read say -50 dBm on the display marker. From your antenna-manufacturer chart you read the antenna factor as +15 db/m (at that frequency). You would add the -50 to the 15 and get -35 dBm/m. [If you have cable loss simply add-in that number as a positive quantity; for example 5db of cable loss gets added as +5 to the -35dBm/m number yielding -30dBm/m.] From another conversion chart—or equation [see below]—you could convert this -35 dBm/m number to 3980uV/m. Since the FCC regulations are expressed in terms of this number, you could then determine compliance. The usage of antenna factors is even easier if one sets the measuring device to “dBuv”; in this case one needs no odd-ball conversion table.

The equation to convert from dBm/m to uv/m is really as simple as converting from dBm to uv. The equation for P dBm/m to E uv/m is:

$$E_{[\text{as uv/m}]} = 5^{1/2} \times 10^{\{(100+P)/20\}}$$

Or…

$$E_{[\text{as uv/m}]} = (2.236 \times 10^{5}) \times 10^{(P/20)}$$

For example if P= -35dBm/m then E would be 3980 uv/m.

A few last comments on background:

- “It’s electric!” The antenna factors I described are based on electric fields; there are also magnetic field antenna factors and even complex antenna factors. However since most field strengths are listed in rules and regulations in terms of volts per meter, the electric version predominates.

- The RF engineer might see this as similar to another factor—noise. For noise one has the pure ratio described as “noise factor” and its logarithmic cousin, “noise figure”, expressed in dB. Unfortunately there is no such ease of identification for antennas for in analogy the pure ratio would be described as ‘antenna factor” while its cousin expressed in dB would be called “antenna figure”. One must be careful to note whether the numbers simply called “antenna factor” are expressed as pure ratios or as dB. In most cases I find the dB/m numbers are provided by manufacturers; in opinion these really are “antenna figures”. But that might lead to other confusions…

BOTTOM LINE:

As one can tell, the usage of antenna factors makes compliance into a game of addition and table look-ups. No one need be aware of antenna gain or know anything about the antenna. Simply place the test antenna 3 meters away, orient it horizontally or vertically for peak and then move up and down for peak, take the reading, add the dB/m version of antenna factor, convert the number and you’re done! It is for this reason they are so popular—even though the purists will state, “I can’t measure a conversion factor of dB/m.”

DERIVATION OF ANTENNA FACTOR FROM ANTENNA GAIN

There is a longer derivation I can provide via contact with the author but this shorter derivation—or rather I should say—conversion between gain and antenna factor is simpler. Since usually this is expressed in db/m, I will show the logarithmic version as the final result. To answer the question of dipole AF is simply a matter of inserting the dipole Gain of 1.64 [make sure ratio form!] into the equation and inserting the frequency desired.

This is the simpler derivation based on a parameter defined in antenna books called antenna “effective area.”:

Referring to the picture above….An incident electric field (E) will produce a Power Density (P_d) in space. It also leads to a power (P) in the 50 ohm load (Z) attached to the load of any antenna within that space of power density. The power (P) results in a voltage V across the load via simple $P=V^2/Z$ where Z=50 ohms As E is the incident field strength magnitude and V is the voltage produced across the 50 ohm load termination, the antenna factor (AF) we desire is simply AF=E/V. [In dB it would be 20 log (E/V)]. Other than above, there are 4 antenna equations one needs to know--as the result we seek are simply manipulations of these:

- $P=V^2/Z$….this is the power in the load of Z=50 with E across the load as a voltage.
- $P_d= E^2/(120\pi)$….this is the relation between electric field strength and the power density that produced-it.
- $A= P/ P_d$.....this is the definition of antenna effective area.
- $A=(\lambda^2 G)/(4\ \pi)$….another definition of effective area (G is gain)

From these we have all we need:

[1] $P_d=P/A$

[2] $P_d=(4\pi P)/ (\lambda^2 G)$…via substitution

[3] $P_d=(4\pi)\ V^2/ (\lambda^2 GZ)$…where Z=50…another substitution

[4] but…$E=(P_d 120\ \pi)^{1/2}$

[5] Substitution of equation 3 into 4 and more manipulation and collection of numbers yields:

$$\mathbf{AF_{[as\ a\ ratio\ with\ G\ as\ a\ ratio]}=E/V=(9.73)/\ (G^{1/2}\ \lambda)}$$

The above is the RATIO version with the dimensions of 1/m (Note: Gain (G) is a ratio in the above equation and NOT dB…so for example use G=1.64 for a dipole).

The more commonly used logarithmic version with the dimensions of dB/m is:

$$\mathbf{AF_{[as\ dB/m\ with\ G\ as\ ratio]}=\ 20\ Log\ [9.73)/\ (G^{1/2}\ \lambda)]}$$

Derivable from the above are some other commonly seen versions of the equation (Note F is in MHz and G is a ratio):

$$\mathbf{AF_{[as\ dB/m\ w/\ F\ in\ MHz,\ G\ as\ ratio]}=\ 20\ log\ F - 10\ log\ G - 29.77}$$

Of course if your antenna gain is expressed in dB, the 10logG term is simply that number of dB.

Remembering that F is in MHz for the next equation, for an ideal DIPOLE with a gain of G=1.64 this equation reduces to:

$$\mathbf{AF_{[as\ dB/m\ for\ an\ ideal\ dipole\ with\ F\ in\ MHz]}=\ 20\ log\ F - 31.9}$$

Note: There is some loss associated with the balun and as an average a lot of manufacturers prescribe a +0.5dB difference for antenna factor to account for the non-ideal balun loss.