"Antenna Factor Calculations

and Deviations"

INTRODUCTION

In recent years, the use of a term call "Antenna Factor" in EMC and spectrum pollution work has become very important. There has been a great need for measuring field intensity and/or power density as accurately and conveniently as possible.

Classically in RFI/EMI measurements, the use of antenna factors is very common. These antenna factors were, by definition, the conversion of two-terminal receiver voltages to field intensity. This is a very convenient term, particularly when expressed in decibels, and the receiver measures in dB above one millivolt. Historically, antenna factors were supplied by equipment manufactures, or in some cases, designated in military specifications. In many cases, these factors were used incorrectly because the user did not understand fully the mathematical significance of the antenna factor. It is the purpose of this paper to establish the relationship of antenna factor and antenna gain.

Antenna gain is a common term utilized by antenna design engineers as well as communication electronic system designers. The gain is the ratio of the power density produced by antenna, at a certain range in a certain direction, to the average power density at that range.

The recent deployment of computer controlled receiving systems with analysis capable capabilities has added a new need for examining the antenna factor. The desired data output from such systems is usually a field intensity expressed in volts per meter as a function of frequency. From the standpoint of strictly application of antenna factors it would seem an easy test to store the antenna factor as a "look up table" in the computers core memory; however as we shall see, it may not necessaryily be the most cost effective or the best utilization of computer memory.

ANTENNA FACTOR CALCULATIONS

Antenna Factor A_F is used in EMC/EMI testing to convert received voltage V_R to the radiated field intensity E_D. Depending on the type of test that antenna may include factors such as:

- Loss due to mismatch of impedance between the antenna output connector and transmission line.

- Loss due to attenuation of the transmission line.

- Loss due to VSWR at the antenna and/or the receiver.

- Gain due to a preamplifiers located at the antenna.

- Loss due to the mismatch of impedance at the input of the receiver.

Although all of the above factors are very real losses of received signal, they may be treated separately and independently. They may be calculated, measured, or obtained from published charts. If any of the above factors are included in an antenna factor, it should be stated so as to avoid misinterpretation.

Let us assume a condition where the antenna is so designed that the above five factors are negligible, that is, well-matched antenna output/cable/receiver, short low loss cable, no preamplifier gain, low VSWR.

From the radio engineers handbook, the rated power density is:

$$Po = \frac{Pr}{Ar} \qquad\qquad 1$$

where:

P_O = Power Density in watts/meters^2
P_r = Receiver Power
A_r = Effective area in meters^2

However,

$$Ar = \frac{G\lambda^2}{4\pi} \qquad\qquad 2$$

where:

G = Antenna gain(numeric)
λ = Wavelength

Combining Equations. 1 and 2:

$$Po = \frac{Pr}{G\lambda^2/4\pi}$$ 3

Again, from the radio engineers handbook:

$$Po = \frac{Eo^2}{Zo}$$ 4

Eo = Field intensity
Zo = Impedance of radiating media
  (120 π for free space)

The power at the receiver is

$$Pr = \frac{Vr^2}{Zr}$$ 5

where:

Vr = Voltage at the receiver
Zr = Receiver input impedance

Substituting the expressions for P_O and P_R of equations 4 and 5, respectively, into equation 3 yield:

$$\frac{Eo^2}{Zo} = \frac{Vr^2/Zr}{G\lambda^2/4\pi}$$ 6

Rearranging terms

$$\frac{Eo^2}{Vr^2} = \frac{Zo/Zr}{G\lambda^2/4\pi}$$ 7

Converting to decibels:

$$10\log\left(\frac{Eo^2}{Vr^2}\right) = 10\log\left(\frac{Zo/Zr}{G\lambda^2/4\pi}\right)$$ 8

$$20\log Eo - 20\log Vr = 10\log\frac{Zo}{Zr} - Gdb - 20\log\lambda + 10\log 4\pi \qquad\qquad 9$$

By definition, the ratio (expressed in dB) of the field intensity to the received voltage is the antenna factor F_A. Therefore,

$$A_F = 10\log\frac{Zo}{Zr} - Gdb - 20\log\lambda + 10\log 4\pi \qquad\qquad 10$$

Equation 10 is the general form of the antenna factor as a function of source and load impedance, and antenna gain.

Many practical applications of antenna factors are in "free space" environment. This is, in general, true for antennas used outside which are directive and are not pointed with low grazing angles.

When ground effects are to be considered, the source impedance Zo must be modified.

For free space (377 ohm) and a 50-ohm receiving system, we have the impedance ratio expressed in dB as follows:

$$10\log\frac{Zo}{Zr} = 10\log\frac{377}{50} = 10\log 7.54 = 8.8\,dB \qquad\qquad 11$$

And 4π expressed in decibels is as follows

$$10\log 4\pi = 10\log 12.56 = 11\,dB \qquad\qquad 12$$

Substituting into equation 10 the expressions obtained in equations 11 and 12, we have

$$A_F = 8.8 - G_{dB} - 20\log\lambda + 11\,dB \qquad\qquad 13$$

$$A_F = 19.8 - G_{dB} - 20\log\lambda \qquad\qquad 14$$

Equation 14 is the more useful form of the antenna factor which is a function of antenna gain and wavelength.

Many EMC engineers prefer to use frequency rather than wavelength because the measurement instrumentation is calibrated in frequency.

$$-20\log \lambda = -20\log \frac{C}{f}$$

$$= -20\log C + 20\log f$$

$$= -20\log 3*10^8 + 20\log f$$

$$= -9.5 - 160 + 20\log f$$

$$= -169.5 + 20\log f \qquad\qquad 15$$

Where:

C = Propagation velocity

Substituting the results of equation 15 into equation 14 we have

$$A_F = 19.8 - G_{dB} - 169.5 + 20\log f \qquad\qquad 16$$

$$A_F = 20\log f - G_{dB} - 149.7 \qquad\qquad 17$$

Equation 17 is the reduced form of antenna factor for an ideal antenna as a function of antenna gain and frequency.

APPLICATIONS TO COMPUTER PROCESSING

If you want to calculate and display field intensity from a real-time data collection system, it is important to have the value for antenna factor available in the computer for field intensity calculations. Since the receivers in the system are controlled by the computer, the frequency is always known. If we examine equation 17, we see that if the receiving antenna were designed to have a constant gain over a band width of interest the only variable would be frequency. Thus, by utilizing a constant gain antenna, no lookup table is required and the computer simply makes three additional additions to compute field intensity. The result is that practically no computer core is utilized and a calculation is simple.