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Use of Antenna Factors in EMI Measurements
AN-106 AF

There are various technical parameters associated with antennas which are commonly studied and defined; including gain, directivity, beamwidth (or beam area), aperture, antenna pattern, antenna temperature, and antenna radiation resistance. The *antenna factor* is rarely included as one of the basic parameters of an antenna, as it is used almost exclusively in EMI testing when making radiated electric field strength *(E-field)* measurements. E-field measurements are necessary for determining compliance with most electromagnetic interference requirements/standards, such as FCC Part 15, CISPR 22, EN 55022, etc. Many engineers starting new in the EMC field may find the concept of antenna factor and its explanation useful.

This application note defines the antenna factor and explains how this concept simplifies the measurement of E-field using an EMC antenna. Also included in this discussion are the basic parameters of other measurement system components typically used along with the antenna for making E-field measurements. Finally, some practical limitations of this concept are discussed along with precautions to be taken.

Antenna Factor Definition:

Antenna factor is defined as the ratio of the electromagnetic field incident on the antenna to the voltage output at its output terminal (connector). This is a linear definition expressed in volts per meter (V/m). So, in linear terms, the field strength is equal to the voltage output multiplied by the antenna factor. In practice, a logarithmic expression for the ratio is much simpler to apply, and is more commonly used. The advantage of using log terms is that instead of multiplying the two numbers, you simply add. So, the antenna factor normally has a dimension of dB/m, and is added to the voltage measured at the antenna output terminal (in dB microvolts) to determine the actual e-field level in dBμV/meter.

For example, let’s say an antenna is present in an electromagnetic field equal to 60 dBμV per meter (1 mV/m, or 1000 μV/m). If the voltage measured at its output connector is 40 dBμV (100μV). Then its antenna factor, logarithmically, would be equal to the difference between two, which in this case is 20 dB/m (60 minus 40), or in linear terms, 10/m (1000/100). Keep in mind that the factors vary with respect to frequency, so the appropriate factor must be applied, based on the frequency of the signal being measured.

Calculation of the E-field Level:

To determine the actual radiated emission level, you simply add the antenna factor (corresponding to frequency being measured) to the measured voltage level at the antenna terminal.

So, if 40 dBµV is measured at the antenna output connector, and the antenna factor at the frequency of measurement is 12 dB/m, the value of the E-field is determined as follows:

E = 40 dBµV + 12 dB/m
= 52 dB µV/m

Generally, the actual measurement system will include other components along with the antenna, which also must be accounted for in determining the actual E-field level. In order to achieve the overall sensitivity of the measurement system, a preamplifier is typically used boost the signal level at the output of the antenna, so the gain of this amplifier needs to be subtracted from the measured level. Also, the system components will typically be connected to each other via two or more 50-ohm coaxial cables. One or more of these cables is usually quite long, as the measurement equipment is usually located some distance away from the test site, so as to not interfere with the measurements. The cabling may have significant attenuation (known as cable loss).

So, the output at the antenna connector is amplified by the preamplifier and attenuated by the cables before reaching the receiver. Therefore, the E-field value is calculated by subtracting the amplifier gain and adding the cable loss (along with the antenna factor) to the receiver reading. In the above example, if the cable loss is 2 dB and the amplifier gain is 28 dB, the actual value indicated on the receiver would be 54 dBµV. This corresponds to the actual value at the antenna output (40), plus the preamp gain (28), minus the cable loss (2), minus the antenna factor (12).

In practice, the process is reversed. We get the measurement on the receiver, and apply the above "correction factors" to determine the actual field strength level. So, we get the corrected E-field level (E):

$$E = R_{reading} - P_{gain} + L_{cable} + AF$$

where: $R_{reading}$ = *Receiver reading*
L_{cable} = *Cable loss*
P_{gain} = *pre amplifier gain*
AF = Antenna Factor

Finally, the actual E-field measured at individual frequencies is compared with the applicable field strength limits. The following is typical of what would be seen on a radiated emissions data sheet for a FCC Part 15 test:

Freq. MHz	Meter Reading dBuV	Preamp Gain dB	Cable Loss dB	Antenna factor dB/m	E-Field Level * dBuV/m	FCC Limit dBuV/m	Delta R-L ** dB
50.0	50.0	28.0	2.0	12.0	**36.0**	**40.0**	**-4.0**
120.0	50.0	28.0	3.0	14.0	**39.0**	**43.5**	**-4.5**
250.0	50.0	28.0	4.0	16.0	**42.0**	**46.0**	**-4.0**

E-field level = Meter Reading – Preamp Gain + Cable Loss + Antenna Factor
Delta = E-Field level – FCC Limit

Limitations of Antenna Factors:

The antenna factor definition assumes that the incident field is uniform over the entire body of the antenna. In practice, this assumption is not valid most of the time. Therefore, the antenna is integrating the effect of the field over its entire body. The voltage reading at its terminal is dependent on how the field is distributed throughout the body of the antenna. The field distribution in turn, is dependent on the source of the field.

Antenna Calibration Methods:

In general, there are two acceptable antenna calibration methods; the two antenna (or reference antenna) method, and the three-antenna method. For the two-antenna method, one calibrated "reference" antenna is needed. At each calibration frequency, a signal is transmitted by a transmitting antenna, and the level of the signal is measured using the reference antenna. The reference antenna is then replaced by the antenna to be calibrated (or unknown antenna), and the difference between the two measurements is applied to the actual antenna factor of the reference antenna to determine the factor of the unknown antenna. For instance, at a given frequency, the reading with the reference antenna is 80 dBμV, the reading with the unknown antenna is 82 dBuV. If the antenna factor of the reference antenna at that frequency is 12 dB, then the unknown antenna has an antenna factor of 10 dB at that frequency.

In the three-antenna method of calibration, three data sets are collected using three uncalibrated antennas used in three transmit/receive (Tx/Rx) pair combinations (1/2), (1/3) and (2/3). The three unknown antenna factors are calculated based on these three sets.

In either case, the source of the field is a transmitting antenna and the field distribution is dependent on the distance of the transmitting antenna. Therefore, the antenna factors may be somewhat different than those obtained at a different distance. If the calibration distance of the antenna factor is not considered during its use, one is likely to get some error. The best way to judge the error magnitude is to compare the antenna factors at the two distances.