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THE ANTENNA FACTOR

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In the world of electromagnetic compatibility (EMC) and electromagnetic interference (EMI) testing, a parameter known as "antenna factor" commonly is used. Antenna factor is not widely known in the cable industry, although it is built in to the calculations used for signal leakage measurements as the “0.021” and “f” (frequency) in the microvolts per meter-to-dBmV conversion formula. (For more on the mathematics of field-strength measurements, see my June 2008 column at www.cable360.net/ct/operations/bestpractices/30008.html).

Wikipedia defines antenna factor as “the ratio of the incident electromagnetic field strength to the voltage V (units: V or μV) on the line connection of an antenna. For an electric field antenna, field strength is in units of V/m or μV/m, and the resulting antenna factor AF is in units of 1/m: AF = E/V.

“The antenna factor for a given antenna is related closely to the load impedance Z0 connected to the antenna’s terminals.”
In other words, antenna factor is the ratio of the field strength of an electromagnetic field incident upon an antenna to the voltage produced by that field across a load of impedance Z0 connected to an antenna’s terminals. (Subsequent references to “antenna terminals” in this article assume those terminals are connected to a suitable load of the desired impedance Z 0).

The field strength can be calculated by multiplying the voltage at the antenna’s terminals by the antenna factor. Many prefer to work in the world of logarithms and decibels, and antenna factor commonly is expressed in decibel format rather than the previously discussed linear format. When antenna factor is stated in decibels, field strength in decibel-microvolts per meter (dBμV/m) is calculated by adding the signal level at the antenna terminals in decibel-microvolts (dBμV) to the antenna factor in decibel/meter (dB/m).

“Whoa!” you say. “We measure signal level in dBmV, not dBμV; and field strength in microvolts per meter (μV/m) rather than dBμV/m.” That’s true in North America, but much of the rest of the world uses dBμV and dBμV/m. Fortunately, it’s not that difficult to convert between dBμV and dBmV, or between dBμV/m and μV/m.

To convert a value in dBμV to dBmV, simply subtract 60 from the dBμV value. Going the other direction, adding 60 to a value in dBmV gives dBμV. For example, +117 dBμV is +57 dBmV, and 0 dBmV is +60 dBμV. Our familiar 20 μV/m signal leakage field strength limit is converted to dBuV/m using the formula:

20log10(value in μV/m)

20log10(20 μV/m)

20 * [log10(20)]

20 * [1.301]

26.02 dBμV/m

Converting from dBμV/m to μV/m is done with the formula μV/m = 10 (value in dBμV/m divided by 20).

Consider a signal-leakage measurement made at 121.2625 MHz (CEA Channel 14's visual carrier) using a resonant half-wave dipole. We can calculate the antenna factor for that dipole knowing the field strength and the signal level at the antenna terminals.

For instance, assume that the field strength produced by a leak is the previously mentioned 20 μV/m. (Note: When making a field strength measurement for the purpose of determining antenna factor, ensure that the measurement is in the far field as opposed to the near field; the antenna has been aligned to the same polarity as the electromagnetic field being measured; and that the antenna has been oriented to produce the maximum level at its terminals.) The signal level in dBmV at the antenna's terminals is found with the formula:

dBmV = 20log10[(E/0.021f)/1000]

where E is the field strength in μV/m and f is the frequency in megahertz.

dBmV=20log10[(20/0.021 * 121.2625)/1000]

= 20log10[(20/2.5465)/1000]

= 20log10[7.8539/1000]

= 20log10[0.0079]

= 20 * [log10(0.0079)]

= 20 * [-2.1049]

= -42.1 dBmV

Now, add 60 to -42.1 dBmV to get the level in dBμV: +17.9 dBμV. We already know that 20 μV/m equals 26.02 dBμV/m, so the antenna factor of our dipole is 26.02 dBμV/m – 17.9 dBμV = 8.12 dB/m. This antenna-factor value applies to this particular antenna at this frequency.

If we make a field-strength measurement at another frequency, the antenna factor will be different than what was just calculated for 121.2625 MHz. For example, if a leak produces a 20 μV/m field strength at 782 MHz, and we measure that field strength with a resonant half-wave dipole for the higher frequency, the level at the antenna's terminals will be -58.29 dBmV, or +1.71 dBμV. Knowing that 20 μV/m equals 26.02 dBμV/m, the antenna factor is 26.02 dBμV/m – 1.71 dBμV = 24.31 dB/m.

A couple of interesting things become apparent. First, the leakage field strength is 20 μV/m for both frequencies, yet the levels at the two antennas' terminals are quite different: -42.1 dBmV at 121.2625 MHz versus -58.29 dBmV at 782 MHz. The difference is 16.19 dB, which happens to be equal to the difference between the two antenna factors: 24.31 dB/m – 8.12 dB/m = 16.19 dB.

You've probably seen tables or charts that show resonant half-wave dipole antenna levels in dBmV versus frequency for a given signal-leakage field strength. For instance, 20 μV/m field strength produces dipole levels of -42.1 dBmV on Channel 14 (121.2625 MHz), -42.5 dBmV on Channel 15 (127.2625 MHz), -42.9 dBmV on Channel 16 (133.2625 MHz), -43.3 dBmV on Channel 17 (139.25 MHz) and so forth. The reason for the variation in the level at the antenna terminals versus frequency is because of the difference in antenna factor at different frequencies.

So far, I've been talking about measurements made using Z0 = 75 ohms impedance equipment (a dipole in free space has an impedance of approximately 73 ohms). EMC and EMI measurements usually are done using Z0 = 50 ohms impedance equipment, making antenna factor slightly different. Half-wave dipole antenna factor in 50 ohms impedance is calculated easily with the formula:

$$AF_{50\Omega} = 20\log_{10}(f) - 10\log_{10}(G) - 29.7707$$

where

AF50Ω is the antenna factor for a half-wave dipole connected to a load of Z0 = 50 ohms, f is frequency in megahertz and G is the dipole's numeric gain (1.64). 10log10(1.64) gives a dipole's gain in decibels, or 2.15 dBi. For the earlier examples of 121.2625 MHz and 782 MHz, a Z0 = 50 ohms impedance scenario's half-wave dipole antenna factors are 9.76 dB/m and 25.95 dB/m, respectively.

I've not seen a similar antenna factor formula for Z0 = 75 ohms impedance, but it's easy to sort out. I came up with the following, using Z0 = 73 ohms, a dipole's approximate free-space impedance:

$$AF_{73\Omega} = 20\log_{10}(f) - 10\log_{10}(G) - 31.4142$$

where

AF73Ω is the approximate antenna factor for a half-wave dipole, f is frequency in megahertz, and G is the dipole's numerical gain (1.64). This formula agrees closely with the earlier calculation, where an antenna factor of 8.12 dB/m was sorted out for 121.2625 MHz. Here it works out to 8.11 dB/m. If Z0 = 75 ohms is used, the formula changes very slightly to:

$$AF_{75\Omega} = 20\log_{10}(f) - 10\log_{10}(G) - 31.5315$$

As you can see, antenna factor for a given antenna is related closely to the load impedance Z0 connected to the antenna's terminals. In a real-world field-strength measurement, a dipole antenna will be connected to an instrument like a spectrum analyzer via a length of coaxial cable. There might be a bandpass filter or preamplifier in-line, too. One must account for the insertion loss of the coax and such devices as filters (or gain, in the case of a preamplifier) to come up with what the signal level would be at the antenna's terminals with the load directly connected to the antenna.

But back to the load impedance Z0: A spectrum analyzer might have an input return loss of around 20 dB with input attenuation switched in (it will be lower with the input attenuator set to 0 dB). That 20 dB return loss equates to a voltage standing wave ratio (VSWR) of 1.22:1, which means the actual load impedance Z0 "seen" by the antenna's terminals could be anywhere in the 61.36 ohms-91.67 ohms range (I'm leaving reactance out of the impedance discussion as well as the contribution of the coax to keep things simple). Using these two extremes of possible load Z0, the calculated antenna factors for a half-wave dipole at 121.2625 MHz work out to 8.8663 dB/m (Z0 = 61.36 ohms) and 7.1229 dB/m (Z0 = 91.67 ohms).

If an unknown field strength at 121.2625 MHz produces a level at a dipole's terminals of 17.9 dBµV (-42.1 dBmV), we get a range of possible field strengths of 17.9 dBµV + 7.1229 dB/m = 25.02 dBµV/m to 17.9 dBµV + 8.8663 dB/m = 26.77 dBµV/m. In our more familiar microvolts per meter, these values are 17.8 µV/m and 21.8 µV/m, respectively.

In practice, commercial antennas used for EMC/EMI purposes include antenna factor-versus-frequency data provided by the manufacturer.

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