Computing Required Antenna RF Input Power for a Given E-Field Level at a Given Distance

JOHN D. M. OSBURN
EMC Test Systems, Austin, TX*

Developing a practical, realistic estimate for required input power requires a more complex evaluation than is sometimes recognized.

Introduction

Computing the value required for RF input power to an antenna to develop a specific E-field level at a given distance from the antenna is often more difficult than expected. Incomplete calculations produce input power values that are lower than required to achieve the desired E-field level in actual practice. This paper explains a method for the calculation of input power to an antenna to achieve a specific value of E-field for immunity or susceptibility testing at a specific distance from the antenna.

Calculations

This section describes one of several methods for calculating the RF input power required for a given E-field value as a function of frequency at a given distance from the antenna. Inherent assumptions are:

- Bore-site alignment exists from the antenna to the point where the E-field is evaluated.
- Near ideal propagation conditions exist. The method is based on the Friss Transmission Formula.

Input power to an antenna to develop specified E-field value is readily accomplished, given a combination of the following characteristics of the antenna:

- Antenna numerical gain, (G_i), *or*
- Antenna gain in dB, G_i, (dB), *or*
- Antenna factor, AF (dB m^{-1}), *and*
- Distance from the transmitting antenna reference point,
- Frequency, and
- Required E-field level.

Note that the antenna gain, gain in dB and antenna factor vary as a function of frequency. If one of these parameters is known, the others may be determined from the expressions in Table 1.

Sample values for these variables used in an example calculation are:

- Numerical gain over an isotropic antenna, G_i, = 2.05
- Gain in dB of the antenna, G_i, (dB) = 3.1 dB
- Antenna Factor, AF (dB m^{-1}) = 7.1 dB m^{-1}

Figure 1 shows the geometry assumed for the calculations. In Figure 1, note that the reference point for calibration is different for the two standards normally applied for calibration of E-field generating antennas. The Society of Automotive Engineers' Aerospace Recommended Practice 958 is applied for calibration of antennas used in MIL-STD testing, for a spacing of 1 meter, tip-to-tip. The American National Standards Institute C63.5 is applied from the feed point for biconical dipole antennas, and, as shown, from

FROM: \ TO COMPUTE:	AF (m^{-1})	G_i	G_i (dB)
AF (m^{-1})		$20 \times \log\left(\frac{9.73}{\lambda \sqrt{G_i}}\right)$	$20 \times \log [f(\text{MHz})]$ $-29.79 - G_i$ (dB)
G_i	$\left(\frac{9.73 \times (3 \times 10^8)}{f \times 10^{\frac{AF}{20}}}\right)^2$		$10^{\frac{G_i(\text{dB})}{10}}$
G_i (dB)	$20 \times \log [f(\text{MHz})]$ $-29.79 - \text{AF}$ (m^{-1})	$10 \times \log (G_i)$	

Table 1. *Expressions for Computing G_i, G_i(dB) and AF(dB $^{m-1}$), Given a Value for One Parameter.*

*See advertisement on back cover.

the mid-point of all elements of a log periodic antenna's element array. These reference points are important because they define the point in free space, when the computation of input power is complete, that defines the value of the E-field at that distance.

These calculations are valid for estimates of input power when testing will be conducted in an anechoic chamber. The ARP and ANSI calibration methods produce a value for AF that is referred to as the "equivalent free space antenna factor." This means that the effects of the calibration environment are removed from the antenna factor, and that the numerical values are close to that which would be measured if the antenna had, in fact, been calibrated under true free space conditions.

BASIC CALCULATION OF INPUT POWER

A variant of the Friss transmission formula is:

$$E\ (V/m) = \frac{1}{r\ (m)}\ \sqrt{30 \times P_t\ (W) \times G_t}$$

It relates the E-field [E (V/m)] produced at a distance [r (m)] due to net input RF power [P_t (W)] being applied to an antenna with known gain, [G_i], (Figure 1).

Solving for input power gives:

$$P_t = \frac{E^2 r^2}{30 \times G_t}$$

As a sample calculation, suppose that a 10 V/m field was required at 3 meters for immunity testing. If the antenna chosen has a gain of 2.05 at 100 MHz, the input power required is:

$$P_t = \frac{(10.0)^2 \times (3)^2}{30 \times 2.05} = 14.63\ W$$

The value of almost 15 watts seems to indicate that the amplifier required would conservatively be about 20 or 25 watts output RF rating.

Other Factors in Determining Amplifier RF Output Power

Other adjustments for sizing the input amplifier include the antenna input voltage standing wave ratio (VSWR). As shown in Figure 1, when RF power is applied to the input of an antenna, some fraction of the power is actually radiated to generate the electromagnetic field. This fraction is what is computed above. Another, hopefully much smaller, fraction is reflected back to the amplifier. The amount reflected is described by the antenna parameter, the input voltage standing wave ratio, VSWR.

When some antennas are used at the extreme edge of their designed operating range, their input VSWR can be quite high. The correction value for these conditions is shown in Figure 2. Input VSWR data should be available from the antenna manufacturer.

As an example, for input VSWR of 2:1, allow an extra 1 dB of amplifier output to compensate for the power reflected from the input terminals of the antenna. As a side note, it is not uncommon for required input power evaluations to be made solely based on radiated power requirements, totally neglecting the effect of VSWR. In some cases, when the input VSWR is high, more than 20:1, an order of magnitude more input power is required than would be estimated on the basis of radiated power alone.

Most EMC amplifiers are rated at a minimum gain for a fixed level input, usually 0 dBm. The output levels are given in:

- CW watts, minimum (of saturated power, the condition where an increase at the input will give no increase at the output), and
- CW watts, linear, at the 1 dB compression point (e.g., a 4-dB increase of input signal will provide a 3-dB increase of output signal).

For consistent test results, the amplifier must be operated in its linear operating range, preferably at least 1 dB below the 1-dB compression point.

In addition, no amplifier running close to or at maximum rated power is as reliable as it is at reduced power. Thus, for continued long-term operation, an allowance for rating to assure that the amplifier is running at about 90 % of rated power will produce almost indefinite operation. This adds approximately another 1 dB to the required output power rating.

The ANSI calibration distance for measurement of the antenna factor (AF) for log periodic antennas (at the center of the element array) is different than the distance where the immunity test calibration is performed (measured from the tip of the antenna). The ratio of these distances, in dB, should be added to the power amplifier rating to closely estimate the required power input level. For one model, this difference in distance is just under 1 meter. If the calibration distance is 3 meters from the tip of the antenna, the correction would be $20 \bullet \log_{10} [4m \div 3m] = 2.5$ dB. Other physically smaller antennas would need a lesser allowance. Note that no distance correction is needed for a 1-meter measurement, as for this case, the antenna is calibrated for MIL-STD measurements from the tip.

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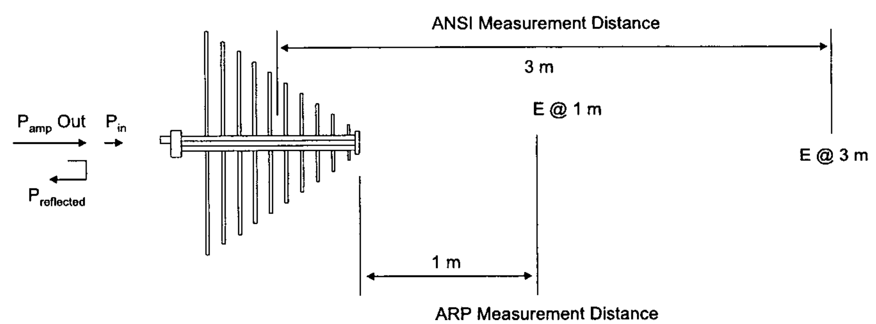

Figure 1. *Geometry for the Calculation of Input Power for a Given E-Field.*

With respect to sizing the amplifier for use with a given antenna, remember that normally, the calibration measurements per the most recently published specification are conducted with continuous wave (CW) excitation of the antenna. When actual testing is accomplished, it is usually accomplished with amplitude modulation (AM). The most recently published specification requires 80 % AM with a 1-kHz sine wave. This requires an amplifier with 1.8 times the linear output range of the CW signal. This, it turn, requires the amplifier output to be $(1.8)^2$ larger than for the CW case, since power input increases as the square of the input voltage. This means that the power amplifier gain will need to be $10 \cdot \log_{10} [(1.8)^2] = 5.1$ dB greater than needed for the CW case.

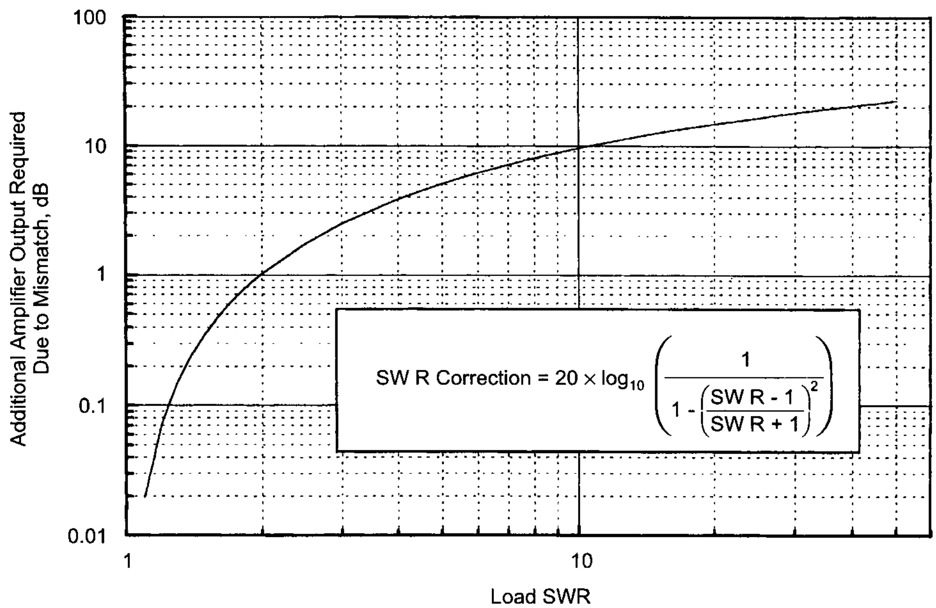

Figure 2. *Correction for High VSWR.*

A summary of these factors is given in Table 2.

FACTOR	ALLOWANCE (dB)
VSWR (Input VSWR 2:1)	1.0
True Linear operation	1.0
Calibration distance	2.5
Modulation allowance	5.1
TOTAL	9.6

Table 2. *Summary of Input Power Allowances for Sizing an Amplifier.*

Thus, any amplifier input level computed for use on a CW basis may actually need to be at least 9.6 dB higher rating for proper continuous operation when other effects, including modulation are considered. This implies that selection of an amplifier, when based on a CW computation, can be too low by almost an order of magnitude. Failure to take these factors into account has led to unsatisfactory results in the past, when the amplifier was operated well past the linear region to attempt to reach the desired level with AM modulation present.

If a factor of 10 dB is applied to the 15 watts determined by calculation in the first section, it is seen that the actual rating of the amplifier needed is closer to 200 watts than to 20 watts.

Summary

The computed value of RF input power is based on the nominal conditions of "free space" testing, i.e., testing in an anechoic chamber, to contain the fields generated. They are useful estimates for other conditions, but engineering judgment must be applied to the selection of amplifiers in all cases.

In the above development, no mention has been made of RF losses in the coaxial cables connecting the amplifier and the amplifier. These losses should not be neglected. If longer than several meters, the cable connections from the amplifier output to the antenna input can amount to several dB at 1 GHz. Selection of high-power, low-loss cables for this application will minimize this source of loss and the resultant reduction in developed field intensity.

Developing a practical, realistic estimate for required input power requires a more complex evaluation than is sometimes recognized. Choosing an amplifier based on the minimum power required to achieve the desired level without consideration of VSWR, antenna calibration setup, the effect of modulation on the amplifier rating, etc, can provide too low a rated value for the amplifier. Most EMC amplifiers are rated at minimum output (or gain) for a specified maximum input level, and have sufficient reserve gain to accomplish the test over a portion of the frequency range. There will be regions in the frequency spectrum to be tested where the desired level cannot be reached. Only by understanding the entire nature of the test setup and the interaction of the antenna with the amplifier can adequate estimates be made of required amplifier output.

JOHN D. M. OSBURN *is the principal EMC Scientist for EMC Test Systems. He is a member of the IEEE EMC Society and the Society of Automotive Engineers, and is an active participant in the EMC standards development of ANSI, the IEEE and SAE. John has 30 years experience as a lead EMC engineer, and has worked on projects ranging from single equipment to major systems with operating frequencies from 3000 sec/cycle to 34 GHz. He graduated from the University of Texas in Austin in 1964 with a BSEE and the University of Southern California with a MSSM in 1985. (512) 835-4684, ext. 669.*