SELECTION AND USE OF ANTENNAS FOR EMISSION TESTING OUTDOORS AND INSIDE A SHIELDED ENCLOSURE

Optimum antennas for emission testing inside a shielded enclosure are often those which exhibit performance similar to that experienced when used outdoors.

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INTRODUCTION

Antennas used for emission testing are selected based on frequency and bandwidth, test setup sensitivity and test setup dynamic range. Typically, emission testing includes the frequency range of 14 kHz to 10 GHz. Low frequency antennas are typically monopoles and exhibit rather high antenna factors which degrade the test setup sensitivity. Test setup sensitivity then can be improved by the use of active antennas which generally use an FET input amplifier constructed into the antenna. Since an amplifier is added to the test setup before the tuned receiver, the overall system sensitivity and dynamic range will be affected. The system sensitivity is often measured and recorded during ambient tests prior to starting emission testing. How often is the dynamic range measured when active antennas are used? How can the tester tell when the active antenna is saturated? How are the sensitivity, antenna factors and dynamic range influenced by a shielded enclosure? These questions were addressed recently while researching which antennas are best for use inside a shielded enclosure. "Best" as used here was defined as the antenna which could be used inside a shielded enclosure and exhibit performance similar to that experienced when used outdoors. During the effort, three antennas were developed, all broadband monopoles with ground planes. The variation in the three is the height: the tallest is 41", the next 24" and the smallest is 9" tall. Eventually the 24" monopole was dropped because it offered no benefit over the 41" and 9" monopoles. The antennas were designated FMA-41/A and FMA-9/A (for Fat Monopole Antenna). The antennas evaluated for comparison included a RAM-110A, SAS-1/D (both active receive-only antennas),a biconical dipole and a log spiral antenna, all standard EMI test antennas.

ANTENNA FACTORS

The intention at the outset of the antenna calibration test effort was to calibrate the new antennas in accordance with MIL-STD-461 and ARP-958 using the "two similar antennas method." The tests were performed outdoors on an aluminum ground plane over the frequency range of 10 kHz to 1 GHz. The data has been reduced and plotted and is shown in Figure 1. It was observed that the calculated antenna factors were approximately 17 dB from 10 kHz up until the test frequency approached a wavelength equivalent to far field. Since the antenna is passive, antenna factors of approximately 80 dB were expected at 10 kHz. ARP-958 was then examined in detail and found to apply only to far-field frequencies. ARP-958 was written for use in calibrating the two EMI log spiral antennas which cover the frequency range of 200 MHz to 1 GHz and 1 GHz to 10 GHz. The document has been used loosely or misused to include all EMI test antennas. ARP-958 derives the antenna factor equations and gain equations as follows (NOTE: taken directly from ARP-958):

The factor associated with any antenna of a given gain can be calculated as follows:

$$V = h_{eff}\, E/2 \qquad (1)$$

where

- V = voltage at input to a 50-ohm receiver
- E = field intensity in volts/meter
- h_{eff} = effective height of antenna in meters

The factor of 1/2 assumes that the voltage appearing at the antenna terminals divides by 1/2 when the 50-ohm receiver is placed across the antenna terminals.

$$h_{eff} = \sqrt{\frac{A_{em}\, R_r}{Z}} \qquad (2)$$

where

$$A_{em} = \frac{D\lambda^2}{4\pi} \qquad (3)$$

*See advertisement on page 185.

A_{em} = maximum effective aperture (aperture which would deliver maximum power to a matched load).
R_r = 50 ohms,
Z = 120π = 377 ohms,
D = directivity of the antenna.

Substituting (3) into (2):

$$heff = \lambda \sqrt{\frac{DRr}{\pi Z}}$$

If a zero loss 50-ohm transmission line is assumed between the antenna and the receiver and a zero mismatch is assumed, D = G. Therefore:

$$V = \frac{E\lambda}{2}\sqrt{\frac{G50}{\pi\, 377}} \quad (4)$$

$$= E\,\frac{\lambda}{9.76}\sqrt{G}$$

where

G = numeric power gain
λ = wavelength in meters

If a conversion from V to E is now desired, it can be seen from (4) that:

$$V\,\frac{9.76}{\lambda\sqrt{G}} = E \quad (5)$$

The antenna correction factor converting from a meter reading in volts to field intensity is then:

$$AF = \frac{9.76}{\lambda\sqrt{G}} \quad (6)$$

The far field begins at approximately $\lambda/2\pi$. For an antenna separation of one meter, λ = 6.28 meters, which corresponds to a frequency of 47.75 MHz. Therefore, the above equations would apply satisfactorily to the two log spiral antennas but theoretically not to antennas operating below 47.75 MHz. A graph of the wave impedance is shown in Figure 2. Also shown in Figure 2 is the wave impedance measured in the antenna calibration test setup.

The antenna factor measurements were repeated for the FMA-41/A, using the RAM and SAS as the reference antennas. The RAM is an active monopole physically similar to the FMA-41/A, and is calibrated for use from 10 kHz to 100 MHz. The SAS is actually a discone antenna when operated from 65 MHz to 1 GHz. The reference antennas were placed on the ground plane, one meter from one FMA-41/A, used as the transmit antenna. A calibrated input signal was applied to the transmit antenna from 10 kHz to 1 GHz and the resultant field strength was recorded from the reference antenna. The received signal amplitude was added to the RAM/SAS antenna factor to determine the actual antenna factor. The reference antenna then was removed and replaced with a second FMA-41/A antenna. The measurements were repeated, the received signal was recorded and subtracted from the reduced reference antenna data to determine the antenna factor which has been plotted and is presented in Figure 3. To further increase confidence in the test

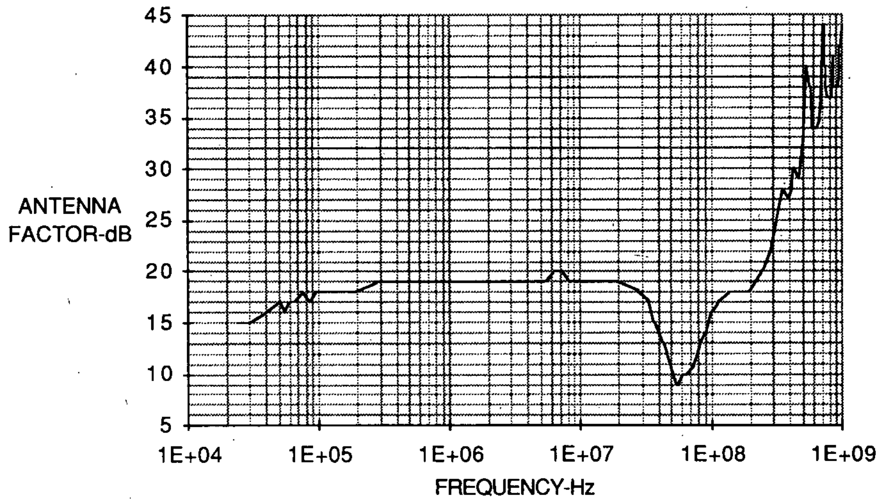

Figure 1. Antenna Factors for the FMA-41/A, Calculated per MIL-STD-461/ARP-958.

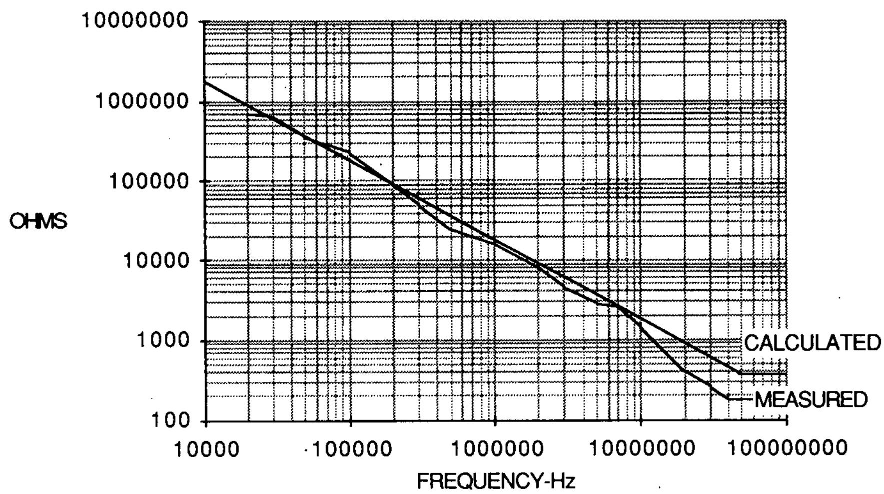

Figure 2. Graph of Theoretical and Measured Wave Impedance.

results, the three antennas i.e., FMA-41/A, RAM and SAS were configured on the ground plane and used to measure far-field emissions, radio stations, TV stations, etc. The data was reduced and compared favorably between the three antennas.

Goals were to: (1) Identify equations that would result in accurate antenna factors when calibrating antennas in the near field, using the "two identical antennas" method. (2) Achieve favorable comparison between calculated antenna factors using the "two identical antennas" method and antenna factors measured using the "reference antenna" method (assuming that the reference antennas are physically similar to those antennas being calibrated). ARP-958 was again reviewed. Equation (4) was modified to allow for a variable wave impedance as follows:

$$V = \frac{E\lambda}{2}\sqrt{\frac{G50}{\pi Z}} \qquad (4a)$$

$$= E\,\frac{\lambda}{2\left(\frac{1}{\sqrt{\frac{50}{\pi Z}}}\right)}\sqrt{G}$$

$$E = V\,\frac{2\left(\frac{1}{\sqrt{\frac{50}{\pi Z}}}\right)}{\lambda\sqrt{G}} \qquad (5a)$$

where

Z = Wave impedance

The antenna correction factor in going from a meter reading in volts to field intensity is then:

$$A.\,F. = \frac{2\left(\frac{1}{\sqrt{\frac{50}{\pi Z}}}\right)}{\lambda\sqrt{G}} \qquad (6a)$$

Antenna gain has been defined by ARP-958 to be:

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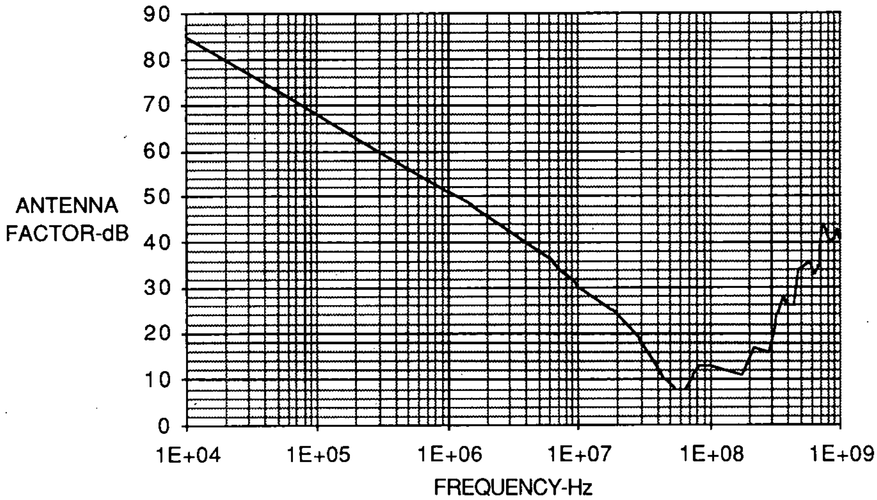

Figure 3. Antenna Factor for the FMA-41/A. Measured Using the Reference Antenna Method.

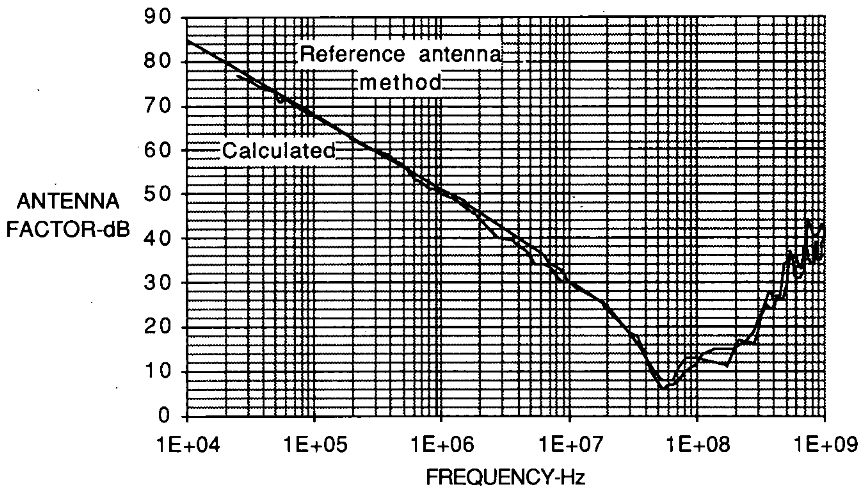

Figure 4. Antenna Factor for the FMA-41/A. Measured Using the Reference Antenna Method and Calculated.

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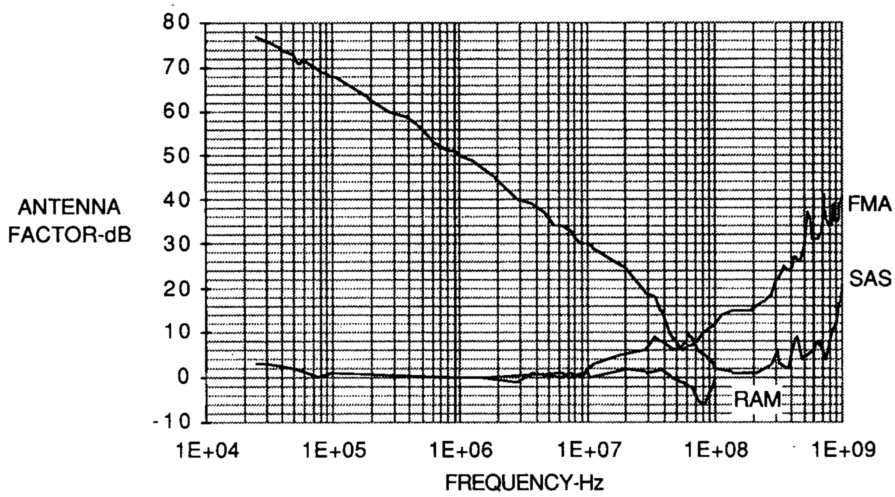

Figure 5. Antenna Factor Comparison, Performed Outdoors Over Ground Plane.

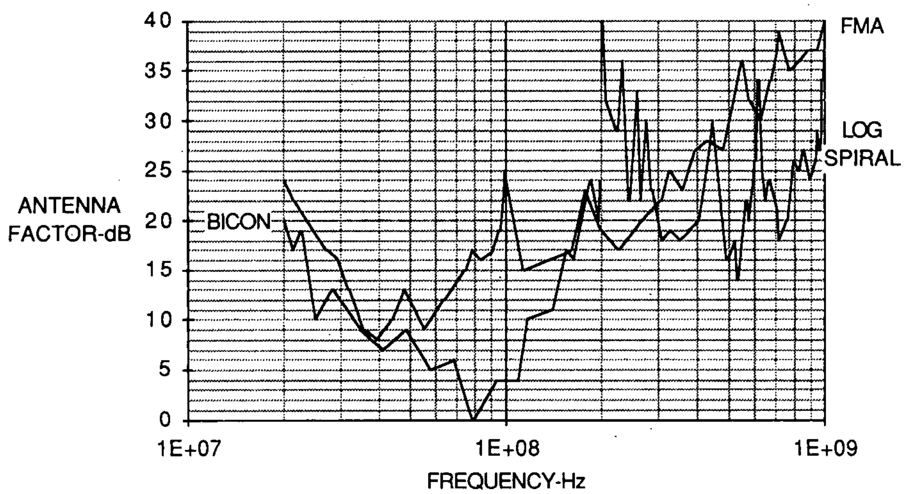

Figure 6. Antenna Factor Comparison, Performed Outdoors, 41" Over Ground Plane.

$$G = \frac{4\pi R}{\lambda} \bullet \frac{V_r}{V_t} \quad (7)$$

where

V_r = Received voltage.
V_t = Transmit voltage.

Since the antenna gain equations also are for far-field antenna measurements, it was necessary to modify Equation (7) to include the near-field wave impedance. The modifications to Equation (7) were determined empirically and result in the following expression:

$$G = \frac{4\pi R}{\lambda} \bullet \frac{V_r}{V_t} \bullet 2\left(\frac{377}{Z}\right) \quad (7a)$$

The test data resulting from the "two identical antennas" method was used to calculate the antenna factors using Equations (6a) and (7a). The resultant antenna factors have been plotted and are shown in Figure 4 with the antenna factors measured using the "reference antenna" method. The results are obvious; Equations (6a) and (7a) result in a favorable comparison of the two antenna calibration techniques. Therefore the following has been verified:

1. Since the measured wave impedance compares so closely with the theoretical wave impedance, the antenna factors for the RAM/SAS and H-field antennas have been shown to be accurate.
2. The antenna factors measured for the FMA antennas have been shown to be accurate.
3. Modified Equations (6a) and (7a) have been shown to be accurate.

Since the equations have been determined to be accurate they will be used for evaluating the antenna factors of the following antennas outdoors over a ground plane, with no ground plane, and inside a 12'

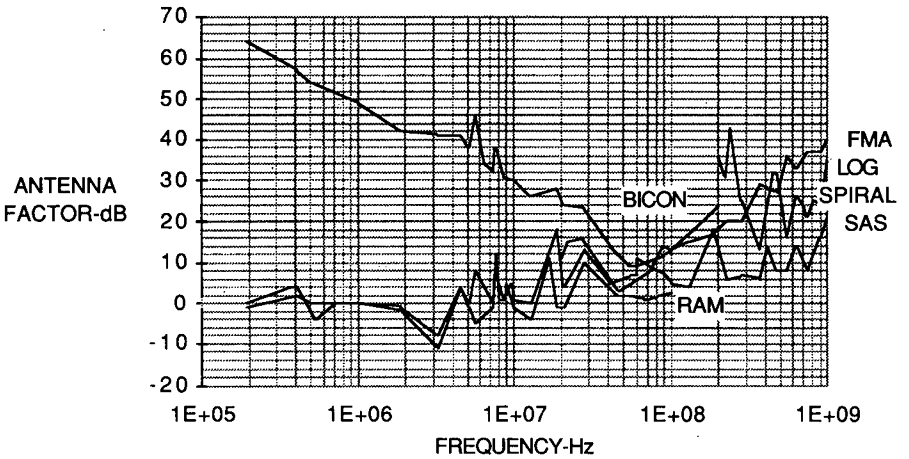

Figure 7. Antenna Factor Comparison, Performed Outdoors, No Ground Plane.

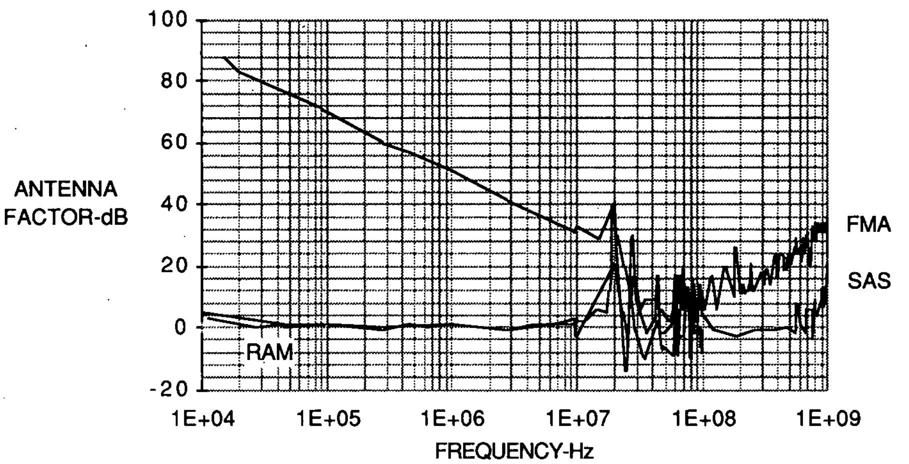

Figure 8a. Antenna Factor Comparison, in Shielded Enclosure.

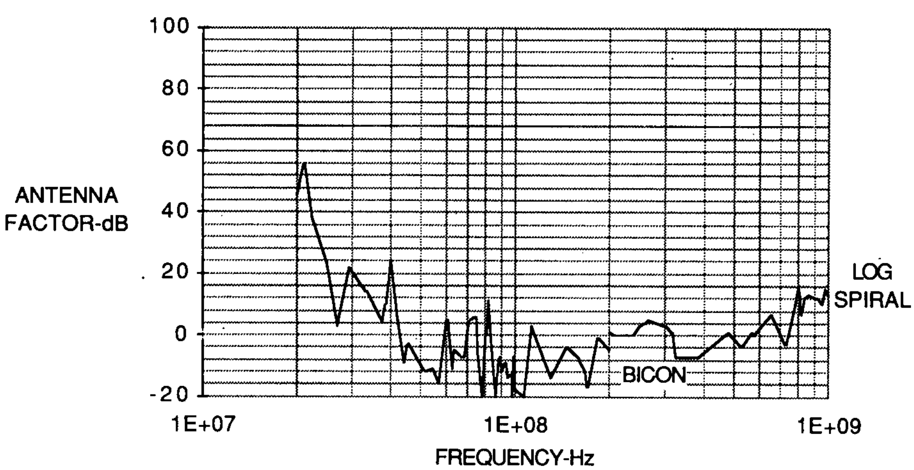

Figure 8b. Antenna Factor Comparison, in Shielded Enclosure.

x 20' x 10' high shielded enclosure, in a typical EMC emission test setup.

1. RAM-110A
2. SAS-1/D
3. Biconical dipole
4. Conical log spiral
5. FMA-41/A
6. FMA-9/A

Considerable data was collected, reduced and graphed during the research period described by this article. The antenna factor tests performed outside, and the antenna factor tests performed inside the shielded enclosure were actually performed two separate times to assure repeatability. Later during the test program, to increase confidence in the test data, the antennas were taken outside, placed over the ground plane and used to measure far-field signals. The data was reduced using manufacturers' antenna factors. The data compared favorably. The "threshold" of agreement between antennas occurred when the antenna which produced the lowest level signal and the antenna which produced the highest level signal differed by less than 8 dB, with a variation of ±4 dB at about the median amplitude.

ANTENNA FACTOR CALIBRATION TEST SETUP

The antenna factors for all of the antennas were measured for three test setups.

1. The antenna factors were measured by placing the antennas under test on a solid aluminum ground plane which measured 8'x 12'x .032" thick. Since the biconical and log spiral antennas could not sit on the ground plane like the monopoles, the FMA41/A antennas were recalibrated when raised 41" over the aluminum ground plane. These antenna factor test results then were used to calibrate the bicon and log

spiral antennas. The center of the bicon was actually about 53" above the ground plane, as was the center of the log spiral antenna.

2. The ground plane was removed and the antenna factors were measured by placing the antennas over earth ground.
3. The antenna factors were measured inside a 12" x 20" x 10" high shielded enclosure. The transmit antenna was placed directly on a copper ground plane which measures 39" wide by 8' long and 39" high. The receive monopole antennas were placed on a typical EMI type ground plane which measured 2' x 2' and was bonded to the transmit ground plane with an 18" wide solid copper strap. The receive ground plane was not used when testing the biconical and log spiral antennas. Both antennas were placed on a tripod.

All antenna factors were measured with the transmit and receive antennas separated by one meter. The antenna factors were measured for two FMA-41/A antennas using the "two identical antennas" method described in MIL-STD-461A and ARP-958 and using Equations (6a) and (7a). The remaining antennas were calibrated by removing the receive 41" FMA-1/B and replacing it with the antenna under test. All antennas were vertically polarized.

SENSITIVITY TEST SETUP

The sensitivity was determined by measuring the minimum discernable signal (MDS) of an AEL-2193 receiver with a low noise preamplifier. The manufacturers' correction factor was then added for passive antennas. For the active antennas, the antennas were placed inside a shielded enclosure, the noise level was calibrated, and the antenna factor was added to determine the radiated sensitivity.

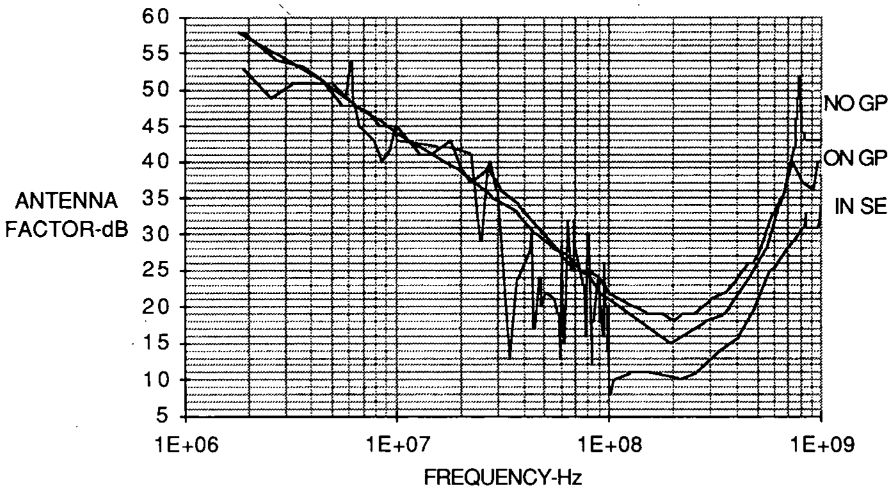

Figure 9. Antenna Factor Comparison for FMA-9/A Performed on Ground Plane, No Ground Plane, in Shielded Enclosure.

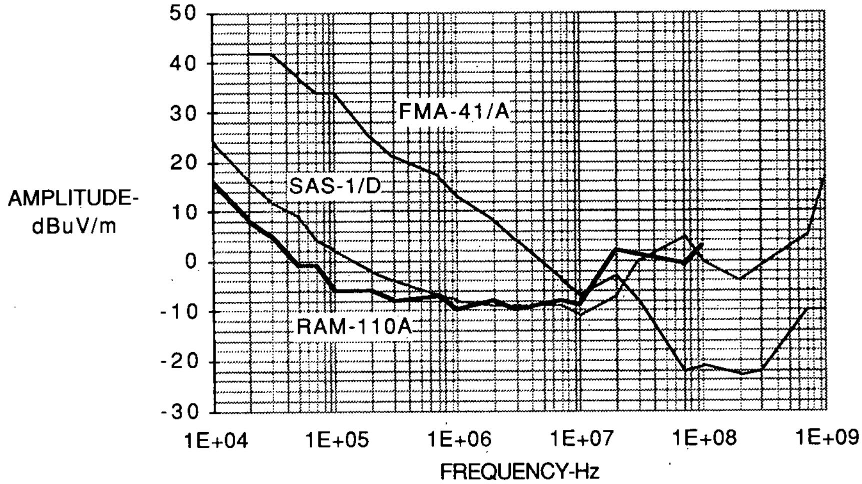

Figure 10. Sensitivity Comparison Using Manufacturers' Antenna Factors.

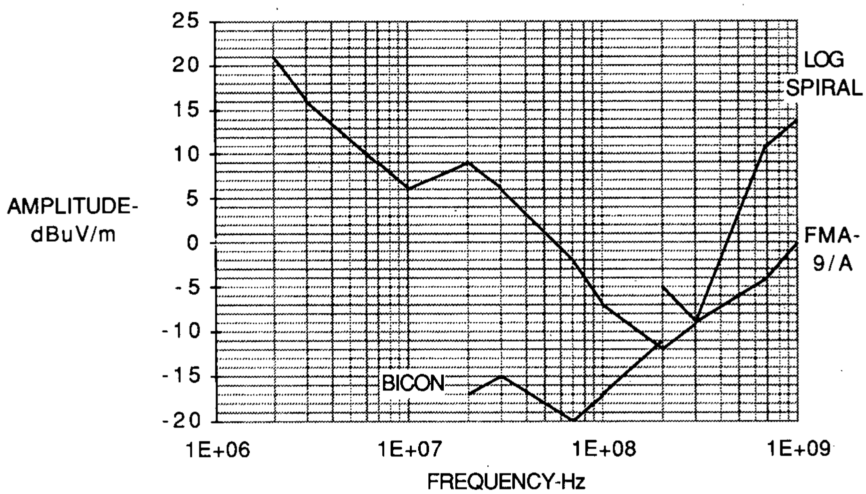

Figure 11. Sensitivity Comparison Using Manufacturers' Antenna Factors.

ANTENNA SATURATION AMPLITUDE

Only the saturation amplitude of the active antennas were evaluated. The saturation amplitude of a passive antenna, amplifier/receiver is practically limitless since an attenuator can be used between the antenna and amplifier/receiver. The saturation amplitude of the two active antennas were evaluated at discrete frequencies using a frequency synthesizer as the signal source. The broadband saturation amplitude was evaluated using an impulse generator as the signal source. Saturation amplitude as used here is defined as the amplitude where a 1 dB increase in transmit amplitude does not result in a 1 dB increase in receive amplitude. The tests were performed inside a shielded enclosure using the "two antennas method." Particular care was taken to ensure that the transmit power amplifier and receiver were not being saturated during the tests. Of course, the antenna dynamic range can be determined as the difference between the antenna saturation amplitude and the sensitivity measurements.

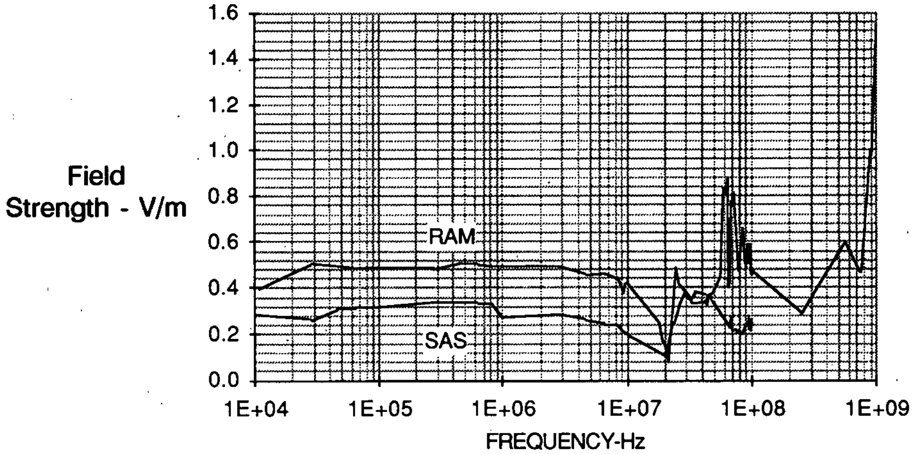

Figure 12. Comparison of CW Saturation Amplitude for Active Antennas.

RAM-110/A

Frequency MHz	System Sensitivity dbµV/MHz	Saturation Amplitude dBµV/MHz	Impulse Rep Rate kHz	Receiver BW kHz
1.0	41	93	.200	150
1.0	40	95	2	150
10.0	41	87	2	150
10.0	35	100	5	500
SAS-1/D				
33	53	90	5	500

Table 1. Active Antenna Saturation Amplitude When Subjected to Broadband Signals.

SUMMARY

The data presented in Figures 5 and 6 show the antenna factors for the referenced antennas as calibrated when placed on a ground plane. The FMA antenna was the FMA-41/A which was calibrated using the "two antennas method." The remaining antennas were calibrated using the "reference antenna" method. The FMA-41/A was the reference antenna. The correction factors measured for the RAM and SAS antennas were similar to the manufacturers' calibration data. The correction factors for the bicon and log spiral antennas differ from the manufacturers' data due to calibration techniques. The data is offered not to challenge the manufacturers' measurements but simply for consistency in the difference between the three measuring techniques reported herein, i.e., over a ground plane, no ground plane and inside a shielded enclosure.

Figure 7 shows antenna factors for the same antennas performed with the ground plane removed. These test results will vary as the antenna height above ground is varied.

Figure 8a shows the results of antenna factor calibration tests performed inside a shielded enclosure for the FMA, RAM and SAS antennas. Figure 8b presents the same test results for the bicon and log spiral antennas. Two graphs were provided for ease in reading. The test results for the FMA-41/A, RAM and SAS antennas from 10 kHz to 100 MHz are similar to the antenna factors measured outdoors over the ground plane. The shielded enclosure resonances become a dominant factor from approximately 10 MHz to 100 MHz. In this frequency range the antenna factors vary drastically with frequency. Another variable not pursued during the tests described herein is the position of the test antennas inside the shielded enclosure. This too will cause a variation of the antenna factors.

Figure 9 shows the results of the

three antenna factor tests performed on the FMA-9/A. The tests were performed from 1.9 MHz to 1 GHz. However the antenna is intended for use only from 100 MHz to 1 GHz. The antenna appears stable over the intended frequency range; i.e., the antenna factors do not change dramatically with frequency, but rather with use. The antenna factors decrease by approximately 4 to 6 dB when placed inside a shielded enclosure over the test results performed outdoors on a ground plane.

Figures 10 and 11 illustrate the receive system sensitivity when using low noise active antennas or passive antennas with separate low noise amplifiers between the antennas and the receiver. When evaluating radiated system sensitivity, the active antennas offer the lowest sensitivity from 10 kHz to approximately 10 MHz. The passive antennas offer the lowest system sensitivity above 10 MHz.

Figure 12 shows the active antenna saturation amplitude as measured at discrete frequencies from 10 kHz to 1 GHz. As stated previously, saturation was defined as the amplitude where a 1 dB increase in input amplitude failed to result in a 1 dB increase in output amplitude. It is obvious that the shielded enclosure resonances again become a factor from 10 MHz to 100 MHz. Table 1 shows active antenna saturation for broadband type signals. An impulse generator was used as the signal source.

CONCLUSION

EMI test facilities normally calibrate test equipment which is used to determine measured signal frequency and amplitude. Signal sources are calibrated for frequency and amplitude accuracy. Cables and attenuators are calibrated for amplitude accuracy. However, the detection device used for radiated emission testing is not calibrated for the application or environment in which it is used. Antenna calibration should become a part of an EMI test setup and should be performed every time the location of the test antenna is changed inside the shielded enclosure. Trained EMI engineers and technicians are certainly capable of performing the required tests and should have the required test equipment. The resultant correction factors should then be included in the EMI test report. The result would be more accurate emission testing and test results which should be repeatable from one test facility to another regardless of the dimensions of the shielded enclosure used to perform the EMI test program. This may also minimize the need to utilize anechoic material inside a shielded enclosure during emission testing.

Modern active antennas are beneficial to emission testing. They offer a convenient method to improve overall system sensitivity at low frequencies. Particular care must be taken prior to starting EMI testing to ensure that the active antennas are not being saturated by emissions generated by the equipment under test. This may not be a simple issue, since the amplifier saturation may be caused by high level narrowband signals or low level, broadband type signals. Saturation is a function of the amount of energy in the pass band. Active antennas should be designed with an input attenuator that could be controlled manually. This would permit the operator an opportunity to periodically check for saturation. Since active antennas need not be used above 10 MHz, the potential saturation problem can be limited by antenna selection. ■