EMC Antenna Calibration Using the Standard Radiating Dipole Source

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INTRODUCTION

EMC measurements require the use of a number of different instruments to determine the equipment under test's (EUT) compliance with regulatory standards. Engineers and technicians can not make accurate measurements with spectrum analyzers that are not calibrated. Great care and precision is used to calibrate spectrum analyzers and cables to antennas. However, depending on the type of measurement facility, the calibration of the antennas themselves can range from almost accurate to incorrect.

This article describes EMC measurement errors caused by improper calibration of antennas. Real-world measurements show the magnitude of the error when using only the manufacturer's calibration data. When a standard radiating dipole source is used to calibrate the antennas, the results from the standard antennas become much better. This significant improvement is due to the calibration of the antennas in the environment in which they will be used.

Careful calibration of all antennas is important to insure consistency between test laboratories and various antennas.

STANDARD ANTENNA CALIBRATION

The technique used to calibrate an antenna is very important. Typically, manufacturers provide antenna correction factors based upon a far-field source (without any conducting ground planes). Often these supplied calibration factors are classified as typical, since the specific antenna factors are not determined for every antenna manufactured. Some manufacturers consider their calibration procedures secret. They strongly discourage visits to observe an antenna calibration, and so the true quality of the calibration ranges (as described) should be seriously questioned.

However, the real problem is more serious. Test sites usually use the manufacturer's published antenna factors to convert from the voltage reading at the spectrum analyzer's input to the electric field strength. If the calibration factors are not determined under the same measurement conditions as are used to characterize the EUT, then those calibration factors are wrong. Typically, calibration factors are determined for a far-field open environment. This environment is close to a fully anechoic room (at high frequencies where the far-field assumptions are correct), but it is quite different from an Open Area Test Site (OATS) used for FCC testing or a shielded room environment used for TEMPEST and MIL-STD EMC testing. Almost the only thing that can be said about far-field antenna factors when the testing is done in a shielded room is that they are inaccurate and not repeatable. The metal walls, floor and ceiling are all too close to the antenna and interact in unpredictable ways.

For years arguments have been made in the literature, both for and against testing in shielded rooms. This article certainly will not presume to settle those arguments. The bottom line is that shielded room testing will continue for the foreseeable future. The question should be: "What can be done to make this testing as accurate and as repeatable as possible?"

THE CURRENT STATE OF AFFAIRS

The antenna factor is assumed to accurately convert the voltage at the receiver (or spectrum analyzer) to the true value of the electric field at the point in space where the antenna is located. Whether the electric field at that point is truly due to only the EUT, or is some combination of the EUT and the shielded room's walls is not part of this discussion. Therefore, although different antennas might be used to cover the same frequency range, the proper electric field will be determined since the antenna

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factors will be different for each antenna.

As part of this effort to achieve accurate results, a dipole source antenna was set up at the Navy's EMI laboratory at Patuxent River, MD. Figure 1 shows the test setup geometry. Three different antennas were used to measure the field created from this source over a frequency range of 10 MHz to 600 MHz. The receive antenna position in the shielded room, generator level, etc. were all maintained constant throughout the test. Figure 2 shows the reported electric field results for the different antennas. As can be seen, the difference in the field levels varied significantly. The total deviation is plotted in Figure 3 and shows a deviation as much as 20 dB. From this data, it appears that the same EUT might be able to pass or fail a MIL-STD test depending upon which antenna was used. Clearly this is not acceptable.

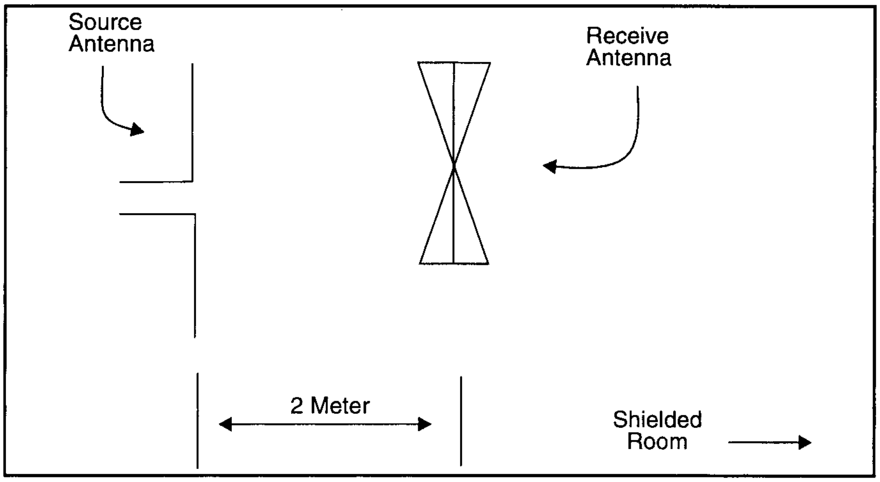

Figure 1. *Initial Antenna Measurement Setup.*

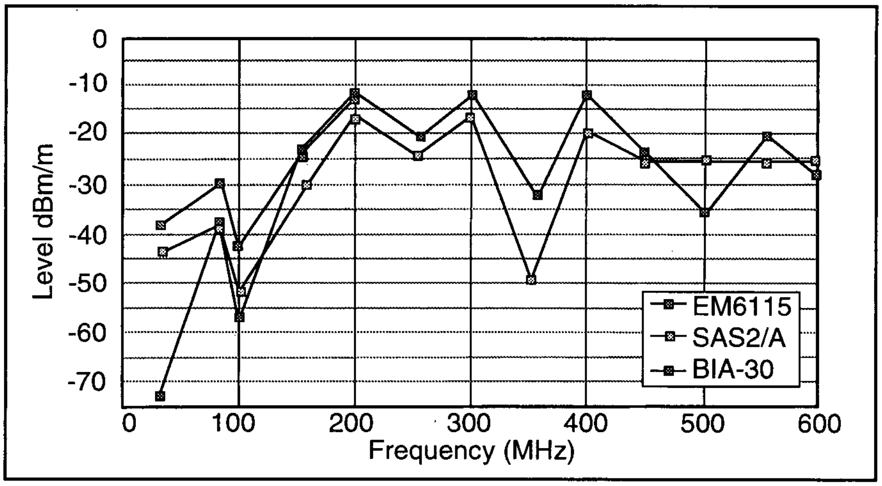

Figure 2. *Assessment of Three Antennas Measuring the Same Signals in a MIL-STD-461 Laboratory Shielded Room Using Antenna Factors Provided by Respective Vendors.*

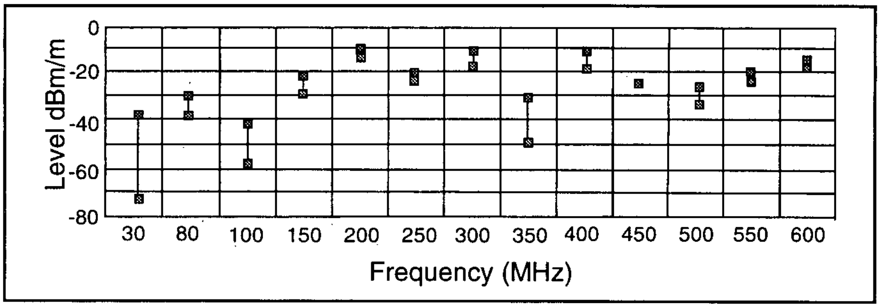

Figure 3. *Minimum/Maximum Readings from Three Antennas Measuring the Same Signals in a MIL-STD-461 Laboratory Shielded Room Using Antenna Factors Provided.*

SITE CORRECTION FACTORS

As mentioned earlier, the cause of this excessive deviation is due to the incorrect calibration factors. The antenna manufacturers cannot predict every possible use for their antennas, so they provide the antenna factors for the far-field open-space environment. The antennas really need to be calibrated in the environment where they will be used.

Research efforts have turned to how to perform this calibration in a shielded room. Obviously, a standard source is needed to provide the predictable electric fields at the desired distance. The source must be very repeatable so that the same electric field can be created whenever desired. The source must be physically small so that it will look as much like a point source as possible, and so its physical size will not be a factor during this calibration. Also the source should be physically repeatable so that once the source is placed in position, there will be no effect on coax cables, etc.

A standard radiating sphere is used to provide correction factors to the manufacturer's antenna factors. The test setup is shown in Figure 4. The standard radiating sphere is configured to provide a constant gap voltage at all frequencies, and the test is repeated for all antennas. The combination of the original antenna factors and the new correction factors creates the new antenna calibration factor for the shielded room environment shown in Figure 1.

FINAL RESULTS

The initial tests with an unknown dipole source are repeated, using both the manufacturer's antenna factors and the determined site correction factors. The agreement between the various antennas is now quite good, as can be seen in Figure 5. The deviation between the various antennas is shown in Figure 6. The maximum deviation is now reduced to 1 to 2 dB, a significant improvement over the initial uncertainty.

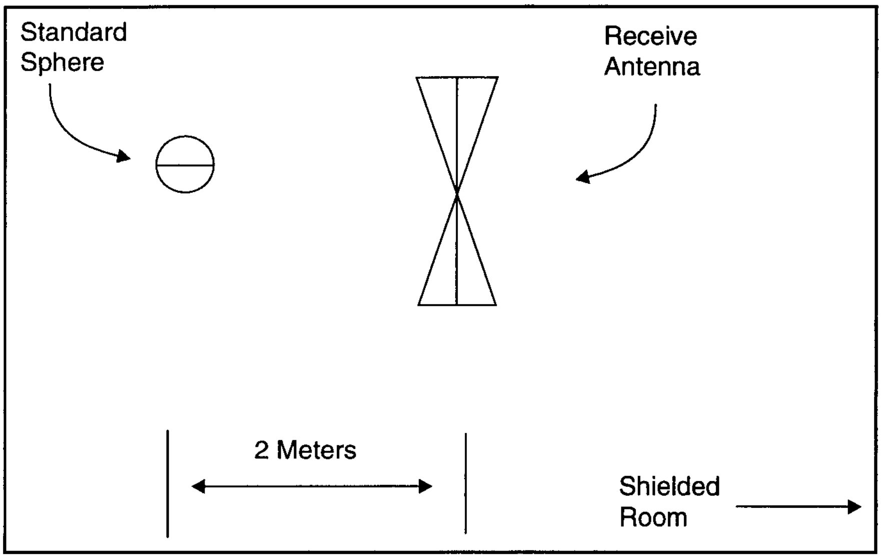

Figure 4. *Spherical Radiating Standard Setup for Antenna Calibration.*

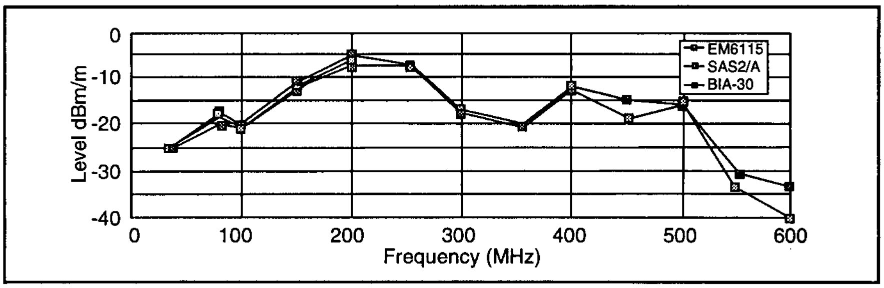

Figure 5. *Assessment of Three Antennas Measuring the Same Signals in a MIL-STD-461 Laboratory Shielded Room Using Spherical Radiating Standard Derived Antenna Factors.*

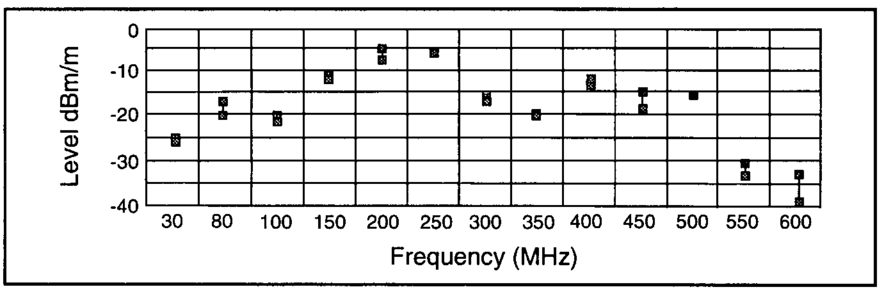

Figure 6. *Minimum/Maximum Readings from Three Antennas Measuring the Same Signals in a MIL-STD-461 Laboratory Shielded Room Using Spherical Radiating Standard Derived Antenna Factors.*

SUMMARY

Careful calibration of all antennas is important to insure consistency between test laboratories and various antennas. Without such calibration it is possible to allow the same EUT to pass or fail the MIL-STD test limits, depending upon which antennas are used to make the measurements. However, once the antenna calibration is performed for the shielded room (or whatever environment is used) this repeatability and consistency issue is resolved.

This article has shown the importance of properly calibrating antennas when they are used in any environment other than an open-space far-field environment. Using the manufacturer's calibration factors (determined for the open-space far-field case) significantly increases the measurement uncertainty unless a correction factor for the true test environment is also used. This article has also shown the usefulness of a standard radiating source as the calibration antenna.

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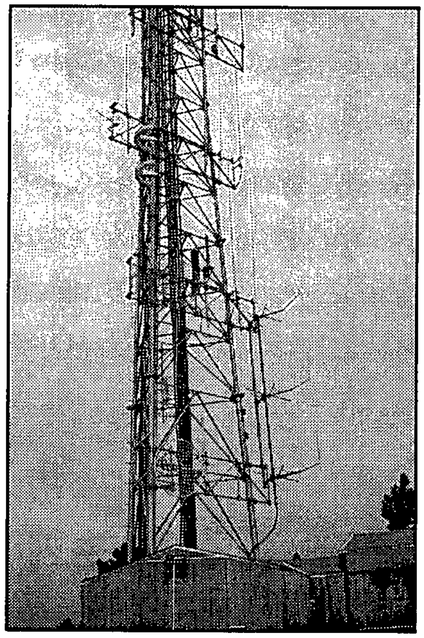

Figure 1. *Transmitter Tower and Equipment Building.*

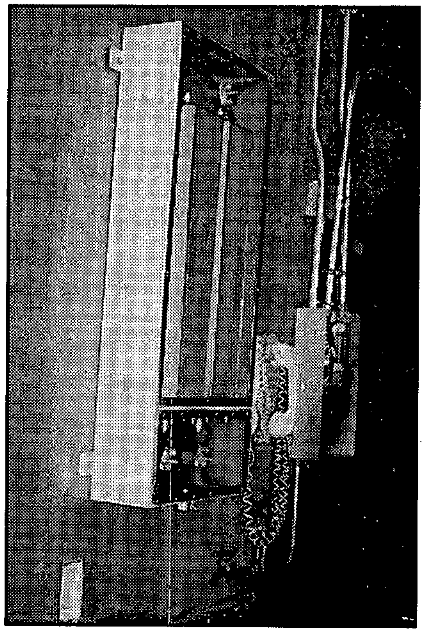

Figure 2. *Power Line Filters Mounted on Copper-Coated Wallboard.*

underground at a depth of approximately 42".

To reduce the RF radiation within the equipment room, a design goal of 60 dB of shielding effectiveness was used. In order to achieve this goal the equipment room was painted with two coats of copper paint. For power entering the room, power-line filters were utilized (Figure 2). These filters had filter attenuation characteristics of at least 80 dB between 100 kHz and 10 GHz. All telephone lines entering the building were filtered. The filters provided at least 80 dB of insertion loss between 30 kHz and 10 GHz.

The equipment room contained an exhaust fan and wall openings for ventilation purposes. These openings featured EMI dust filters plus a honeycomb filter for the exhaust fan. In addition, EMI gasket material was used around the door jamb and copper fingers were attached to the door bottom to create a metallic door threshold. Additional measures were taken to run incoming and outgoing cables through waveguide sleeves. Since completing the program, no transmitting/receiving problems have been noted due to interference problems.

PUBLISHING FACILITY

Another case involved a Virginia concern that was having a new facility designed to incorporate a computer center which would operate their newspaper plant through all stages of production, including printing. The computer center was to encompass an area of over 2000 square feet. The shielding design for the facility was done in conjunction with an architectural firm, while fabrication of the shielded area was accomplished by the contractor and a shielding consultant and coordinated with the computer equipment supplier.

The ultimate objective of shielding the computer center within the production facility was to prevent electromagnetic interference (magnetic and electric field) from disrupting the operation and printing of newspapers. Again, electric field shielding was provided by copper paint especially formulated for architectural applications. This copper paint was applied directly to the walls, ceiling and floor of the bare computer room. Magnetic fields were shielded by utilizing a sheet steel lining between the power room and the computer facility (0.125-inch steel was utilized). The steel shield covered one complete wall and overlapped onto the other four adjoining surfaces (ceiling, walls, floor). An uninterruptible power supply system required additional magnetic field shielding.

The radiated and conducted susceptibility criteria for the computer equipment was specified for both electric and magnetic fields. The criteria entailed a facility shielding effectiveness of approximately 60 dB. The susceptibility criteria underscored the need for power-line filters in conjunction with the shielding measures. The shielding measures also included the use of cooper mesh to shield viewing windows, gaskets and copper spring fingers for use with three doors. The project was completed and has been successfully operating for over two years.

SEMICONDUCTOR MANUFACTURER

A case relating to a semiconductor/chip manufacturer that utilizes electron microscopes in various stages during the manufacturing process is also illustrative. The manufacturer had built a new manufacturing facility in which the electron microscopes were located near or directly adjacent to power plant distribution areas. The manufacturer of the microscopes had specified that the microscopes be located in areas where ambient magnetic field levels were 0.5 milligauss or less. Measurements of magnetic field levels taken in the company's main lobby area exceeded 5 milligauss. Obviously the solution to the problem was to relocate the microscopes to areas where magnetic field levels were below 0.5 milligauss. Since the chip manufacturer insisted that relocation was impossible, shielding the areas became necessary. In order to achieve the degree of shielding necessary, an area fabricated from relatively high permeability steel had to be designed. The alternative would have been to design an area utilizing mu-metal material. Ultimately, steel sheets were incorporated within the microscope areas with great success. This solution to the magnetic field problem is currently being implemented at another semiconductor/chip manufacturer located in the southwestern part of the United States.

RADIO TELESCOPE

The Naval Radio Observatory giant telescope in the mountains of West Virginia offers a final example of architectural shielding being utilized in a somewhat unusualmanner. This particular project, as yet incomplete, has been given rather extensive media attention and deservedly so. The radio telescope is part of a structure larger than the Statue of Liberty. The structure will support a 100-meter (diameter) dish antenna.

In a support role, an operations building will house a large collection of electronic equipment that collects, reads, and analyzes the data collected by the dish. The data will consist of numerous low-level electronic signals and as such must be protected. The operations building will contain several completely shielded areas where the electronic equipment is housed.

There are other radio telescopes located at the Naval Observatory similar in nature but physically smaller than the 100-meter unit. Signals collected from these telescopes are low level. Due to the sensitive nature of these signals, no internal combustion engine vehicles are allowed on the base; transportation is either by base-owned diesel vehicles or bicycles. Knowing all this, it was quite important to carefully design the shielded areas housing the electronic equipment. The shielding system has been designed and consists of the following basic elements:

- Grounding of the building structure, including the shielded envelope and all systems with a low impedance system
- Shielding materials installed in walls, roof, door leaf, etc.
- Waveguide treatment of all duct penetrations
- Grounding, isolating, and RF sealing of all metallic pipe penetrations
- Feed-through boxes for alarm, signal, and telephone cable connections
- Ground provisions from shield to each electrode system
- Shielded doors, frames, thresholds, gaskets, windows
- Shielding materials to bond seams, joints, and interface points

Construction of the antenna structure has been started. Building construction will begin shortly. It is hoped that the entire system will be in operation by the end of 1995.

SUMMARY

Architectural shielding has become an integral part of many commercial building programs. The reasons for building and area shielding have not changed, but the need for the shielding has grown greatly. Current programs underway include several large buildings in New York City where magnetic fields emanating from power distribution units are causing computer upsets and distortion and safety concerns. Other programs involve a university physics building where research and development programs are being disturbed by a campus radio tower, and computer facilities in a Manhattan high-rise building which are being affected by the ambient noise levels present within the building in areas above the twenty-fifth floor. The problems continue to grow.

As recently as 10 years ago electromagnetic environmental effects (E^3) engineers knew that the shielding of structures was essential for the proper operation of sensitive electronic equipment and to protect sensitive information from falling into the wrong hands. What we didn't know was how far the needs would spread.

REFERENCES

1. Roy W. Bjorlin, Jr. and Frederick L. Helene, "The Use of a Copper Conductive Coating for Architectural Shielding Purposes," *ITEM Update* (1989), pp. 6-10.

***FREDERICK L. HELENE** has had over 20 years of engineering, management, teaching and consulting experience in the EMI/EMC field. In 1989, Mr. Helene formed his own company (F. L. Helene, Inc.) which specializes in consulting services relating to electromagnetic effects. Mr. Helene acts as a design consultant for many companies involved with the design and testing of complex electronic equipment, and acts as a design consultant for architectural programs involving the shielding of complex buildings and structures. Mr. Helene has authored articles, presented papers and taught courses dealing with EMI military standards, medical EMI, and architectural shielding. (203) 284-8303.*