COMPENSATING FOR SHIELDED ENCLOSURE EFFECTS ON RADIATED EMISSIONS MEASUREMENTS

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ABSTRACT

This paper compares the differences in Open Area Test Site (OATS) derived antenna factors to those derived for a specific location of a shielded enclosure as well as compare the resultant E-field's of a Simulated - Equipment Under Test (S-EUT) using each. It will also show that using position specific shielded enclosure derived antenna factors not only produces excellent agreement on the resultant E-field for measurements made in two enclosures, but also to the predicted E-field of the S-EUT.

INTRODUCTION

The primary problems associated with EMI measurements made in a shielded enclosure arises from the enclosure's effects on the amplitude of the test item's radiated emissions and its effects on the receive antenna due to the relatively close proximity of the many reflective surfaces. When a test item radiates in a shielded enclosure, the field strength of an emission becomes relevant only to the dimensions of the enclosure and the geometrys of the measurement set-up. This not only produces irrelevant measurements but makes any correlation among test facilities, even within the same organization, impossible. This lack of correlation is well documented by the National Institute of Standards and Technology's (NIST) Internal Report entitled "Screened-Room Measurements on NIST Standard Radiators" [1].

Antennas calibrated on an Open Area Test Site using ANSI 63.5 [2] or SAE ARP-958 [3] will do the shielded enclosure test engineer little good in determining emissions field strength in her/his measurement environment. This is not because of any fault of the calibration facility, but because the effects on the radiated signal and measurement antenna attributed to the shielded enclosure's metal walls, ceiling, floor, size and geometry are so severe that the antenna calibration factors are now only a small factor in the transition from free space to the 50 ohm port of the antenna. There is a solution to this problem. Calibrating test antennas in shielded enclosures, while replicating the exact geometry of the test set-up, would allow the shielded enclosure's effects to be imbedded into the antenna's factors [1]. In order to accomplish these calibrations it is imperative that the calibration source be predictable, stable, accurate and repeatable. This can be accomplished with a Standard Spherical Dipole Source (SSDS) [4], which was designed and developed by the National Institute of Standards and Technology's Electromagnetic Fields Division. The SSDS used for calibrating antennas for this paper was a commercial version calibrated by NIST[5,6]. Using such a source allows the EMI test engineer to derive hybrid antenna factors that take on the responsibility of compensating for both the shielded enclosure's, and the antenna's frequency responses.

MILITARY STANDARD 461 REQUIREMENTS

MIL-STD-461C [7], Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, requires that emissions measurements be performed in a shielded enclosure with one meter of separation between the equipment under test and the measurement antenna. This Military Standard also requires that the measurements be made from 14 kHz to as high as 18 GHz. The measurements made in this paper follow the guidance of MIL-STD-461C over the frequency range of 30 to 200 MHz. A frequency span that benefits very little from the RF absorber requirements of the latest version of MIL-STD-461 [8]. It is also important to note that none of the MIL-STD-461 versions require correlation to a controlled environment.

CALIBRATION SOURCE

The Standard Spherical Dipole Source used in these shielded enclosure, position specific, antenna calibrations was a predictable standard source capable of .55 dB repeatability over the frequency range of 30 to 1000 MHz at all but one frequency where the repeatability was .93 dB [5]. This performance is possible through the unique design of the SSDS [5,6]. The SSDS is a system comprised of two sections, a battery powered radiating element and a control unit. The radiating portion is a sphere with a 10 cm diameter and a visible equatorial gap. Functionally it is a dipole antenna with each element made of a gold plated brass hemisphere separated by a 3 mm Teflon equator. Each hemisphere is hollow and contains a geometrically centered post feed designed to mate with the corresponding output of the balanced to unbalanced (balun) transformer. The inside edge of each hemisphere is threaded and mates with the corresponding threads of the Teflon equator. The balun transformer, batteries, and all other components are mounted to both sides of a printed circuit board occupying the area of the circle created by the equator. This radiating element is interfaced with the control unit by fiber optic lines that carry the radiating element's operational information . The control unit contains a 1300 nm laser source which is modulated by a calibrated RF synthesizer. When this modulated light reaches the radiating element it is demodulated. The resultant RF signal is amplified , fed through the balun transformer, to the feed posts, and then to the hemispherical elements where it is radiated. The RF voltage level is monitored at the input to the balun by a diode detector circuit and returned via fiber to the control unit where it is displayed. This monitored voltage is empirically correlated to the voltage across the 3 mm gap which can then be used to calculate the radiated field. Due to the operator's control and monitoring of the balun input voltage and the absence of any perturbing connections to the SSDS, the radiated field is constant each time the balun input voltage for a discrete frequency is reproduced. This repeatability has been empirically proven and documented by NIST for at least two variations of the SSDS system [4,5]. From this point forward, the use of the abbreviation SSDS will refer to the radiating element portion of the system.

SHIELDED ENCLOSURE ANTENNA CALIBRATION METHODOLOGY

After a measurement is made in the shielded enclosure, the Simulated EUT is removed and replaced with the NIST calibrated SSDS while maintaining the identical set-up as during the measurements. In each case, the observation antenna is supported at a specific height by a non-conducting tripod while the calibrated SSDS is elevated to the same height by non-conducting blocks. The process of imbedding the effects of the enclosure into the antenna factor is inherent to the calculation described by equation (1). This calculation produces a ratio of the predicted free-space field level to what is actually measured at the antenna's 50 ohm port. Any deviation from this predicted field level is attributed to the cavity like effects of the shielded enclosure [1] and "lumped" in with the standard losses presented by the antenna to the incident field.

$$AFe_{hybrid} = (20\log\frac{E_C}{E_M}) - L_{SSDS} - L_{cable} \qquad (1)$$

Where...

AFe_{hybrid} is the position specific antenna factor in dB (1/m).

E_C is the calculated free-space spherical dipole field level in volts at a discrete frequency, specific equatorial gap voltage, and a one meter separation.

E_M is the measured voltage at the spectrum analyzer 50Ω input terminal.

L_{SSDS} is the empirically derived transfer function, in dB, for the SSDS's display of the balun input voltage related to the voltage across the 3 mm gap.

L_{cable} cable loss in dB.

The process of resolving the field solutions for a spherical source comes from a program created by NIST [4] allowing one to input the spherical source's dimensions, equatorial gap voltage, and the observation point.

TEST METHODOLOGY

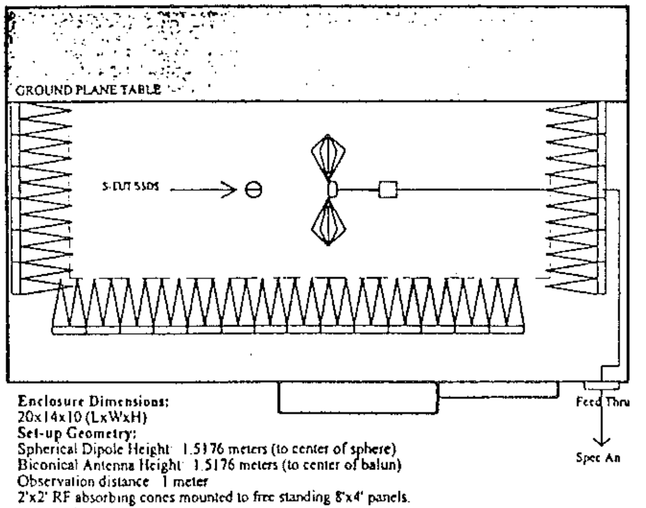
Eighteen repeatable discrete signals (30, 40, 50,...200 MHz) were radiated at the same level and measured from the S-EUT in two positions each of two shielded enclosures. Each measurement was resolved using OATS derived and shielded enclosure, position specific, derived antenna factors. A position specific derived antenna factor was calculated for each measurement frequency. The OATS derived antenna factors, provided by the antenna manufacturer for this specific antenna, were also at the measurement points. Interpolation was not required in either case.

The S-EUT was a Standard Spherical Dipole Source built by NIST for the United States (US) Department of Navy. The purpose of using an SSDS for the S-EUT stems from its ability to provide repeatable E-fields based on the displayed balun input voltage. It was also chosen because its E-field could be calculated and used to gauge the measurement results. A commercially built, NIST calibrated, SSDS was used for the position specific calibration process. For each position in both enclosures the same biconical receive antenna, cables, spectrum analyzer, and set-up geometry's were used to make the measurements, thus isolating differences due only to the measurement positions and environments. The time between measurements made in one enclosure to the next was 17 days.

RESULTS

In Enclosure A, the S-EUT and receive antenna were set-up as shown and described in figure (1). The 18 measurements were made and recorded without yet considering antenna factors. The S-EUT was removed and replaced by the calibrated SSDS, horizontally polarized, and in the exact location. The calibration process, as described previously, was performed and the resultant antenna factors recorded. These and the OATS derived antenna factors are compared in figure (2). It is already obvious that there will be disagreement in the resultant E-field calculations.

Position 1 of Shielded Enclosure A



Enclosure Dimensions:
20x14x10 (LxWxH)
Set-up Geometry:
Spherical Dipole Height 1.5176 meters (to center of sphere)
Biconical Antenna Height 1.5176 meters (to center of balun)
Observation distance 1 meter
2'x2' RF absorbing cones mounted to free standing 8'x4' panels.

Figure 1

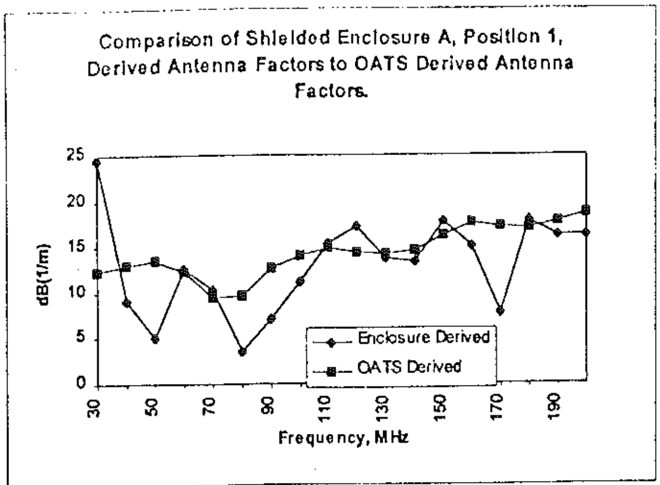
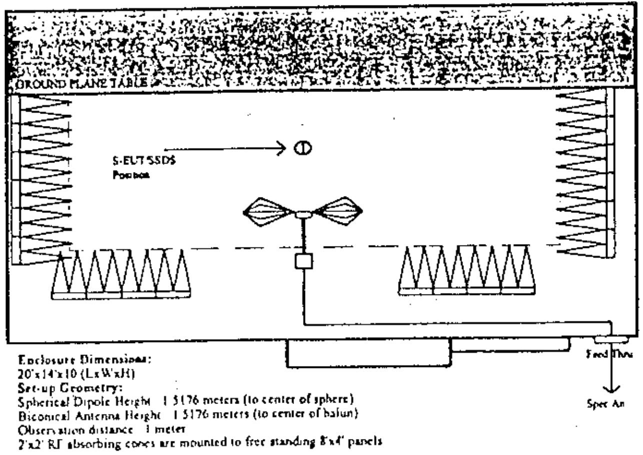


Figure 2

The set-up was relocated in this enclosure without changing any of the set-up parameters. These set-up parameters are height, separation, and polarization. This new position, Position 2, is illustrated in figure (3). This time the position specific antenna calibration was performed first, followed by the measurement of the 18 signals produced by the S-EUT. Figure (4) graphically presents the antenna factors derived in each position. These results illustrate differences in antenna factors due simply to position within an enclosure.

Position 2 of Shielded Enclosure A



Enclosure Dimensions:
20'x14'x10 (LxWxH)
Set-up Geometry:
Spherical Dipole Height 1.5176 meters (to center of sphere)
Biconical Antenna Height 1.5176 meters (to center of balun)
Observation distance 1 meter
2'x2' RF absorbing cones are mounted to free standing 8'x4' panels

Figure 3

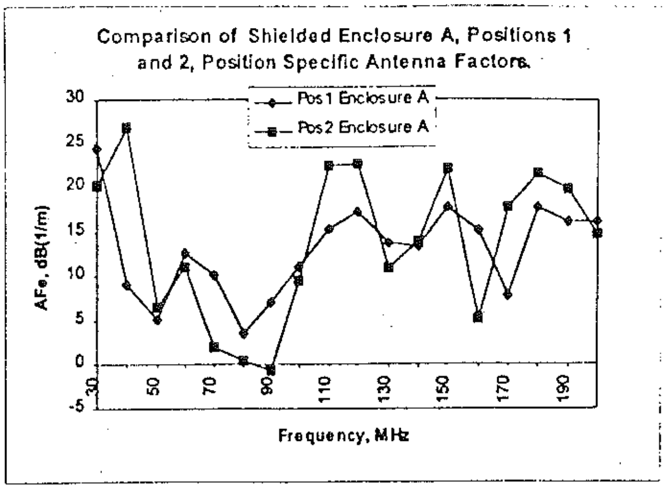


Figure 4

Figure (5) graphically presents the differences in the S-EUT measurement results using OATS derived antenna factors to calculate measurements made in positions 1 and 2 of Enclosure A.

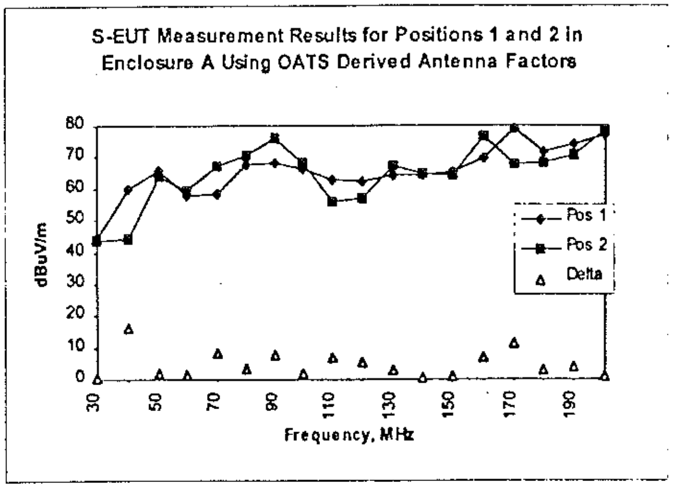


Figure 5

As seen in the graph of figure (5), using OATS derived antenna factors to resolve the S-EUT's emissions in two positions of a shielded enclosure, while holding all other measurement parameters equal, is questionable simply due to disagreement in the results.

The following graph, figure (6), shows the same measurements shown in figure (5) calculated using position specific antenna factors.

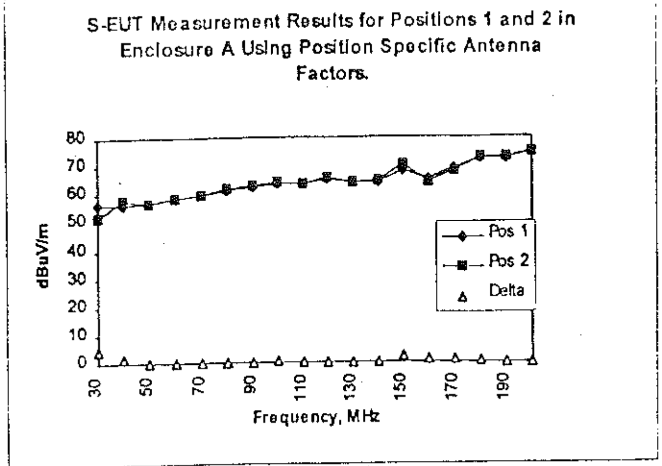


Figure 6

At a glance the agreement between the two positions is obvious. The worst disagreement in these results was 4.76 dB and occurred at 30 MHz.

Seventeen days after these measurements were made, the entire set-up including measurement equipment, was moved to the laboratory's second enclosure, Enclosure B. The observation antenna tripod's height, S-EUT/SSDS support height and separation distance were maintained identical to the previous set-up dimensions by a custom built mobile wooden supporting frame. Enclosure B's dimensions are similar to Enclosure A with the only difference being an increase in the width by one foot. The 2'x2' anechoic cones in this enclosure are affixed to the enclosure walls. As in enclosure A, there is no absorbing material on the ceiling or floor. It is important to note that the internal configurations, such as lighting detents and wiring conduits, are different for each enclosure. These configuration differences are not detailed in the illustrations, but are worth noting due to their potential contribution to the enclosure's effects on the measurements. Figure (7) details the set-up for Position 1 and figure (8) details Position 2. Although they are not presented, the variances between OATS derived factors and those derived in each of these positions are very different. For both of these positions, the process of S-EUT measurements, followed by position specific antenna calibrations was accomplished. What is to be examined next are the differences between position specific antenna factors derived for Position 1 of both enclosures. Looking back at figure (1), and forward to figure (7), one can see the similarities between the set-up location in each enclosure. Figure (9) graphically compares the factors derived in Enclosure A, Position 1, to those derived in Position 1 of Enclosure B. Regardless of the fact that the enclosure's dimensions are similar, and that the positions are in similar locations, the position specific antenna factors differ. Remember: The relationship between the SSDS and the observation antenna is identical for each case.

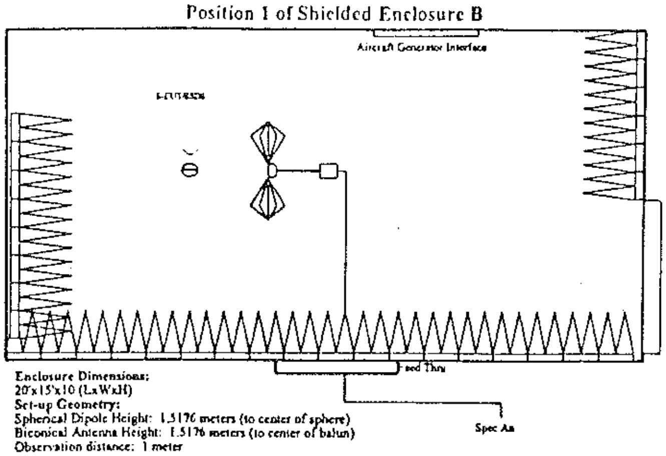


Figure 7

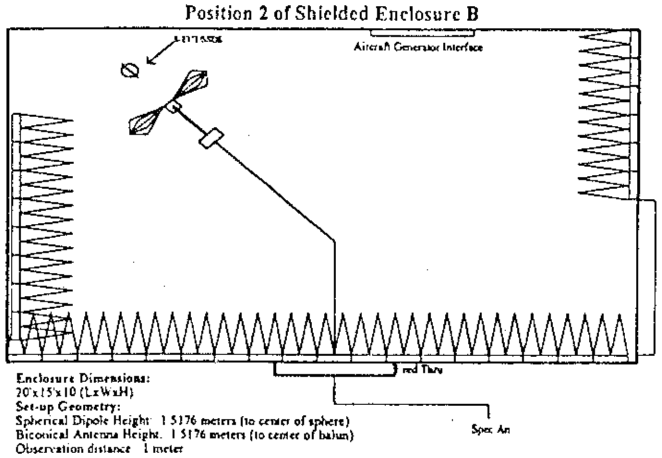


Figure 8

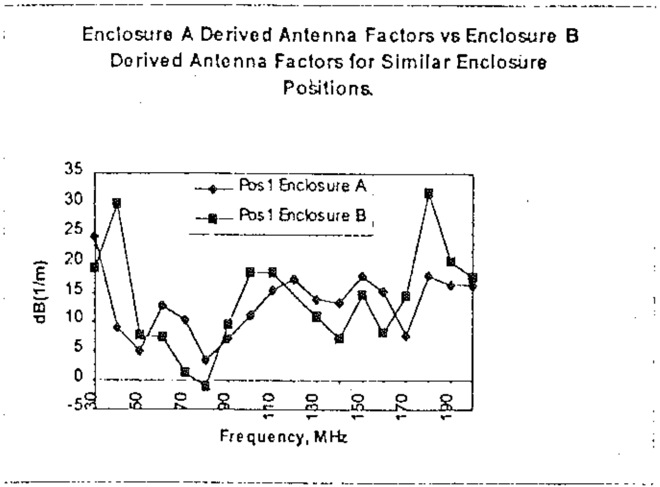


Figure 9

This next graph, figure (10), presents the resultant measurements of the S-EUT for Position 1 of each enclosure using OATS derived antenna factors.

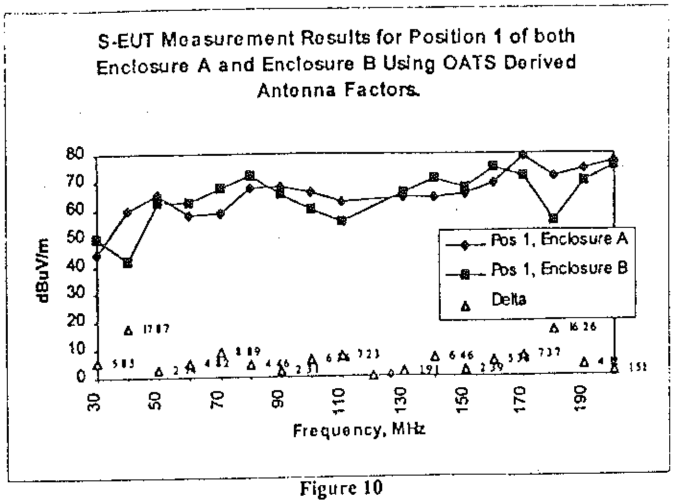


Figure 10

As can be seen in the graph, two measurements differ by as much as 17.87 dB and 16.26 dB. Nine of the measurements disagree by 5 dB or more while the remaining fall between 1.51 dB and 4.82 dB. It is obvious through these results that a test item's compliance or non-compliance to radiated emissions specifications could be determined simply by the enclosure in which it is tested.

This next graph, figure (11), presents the resultant measurements of the S-EUT for Position 1 of each enclosure using position specific derived antenna factors.

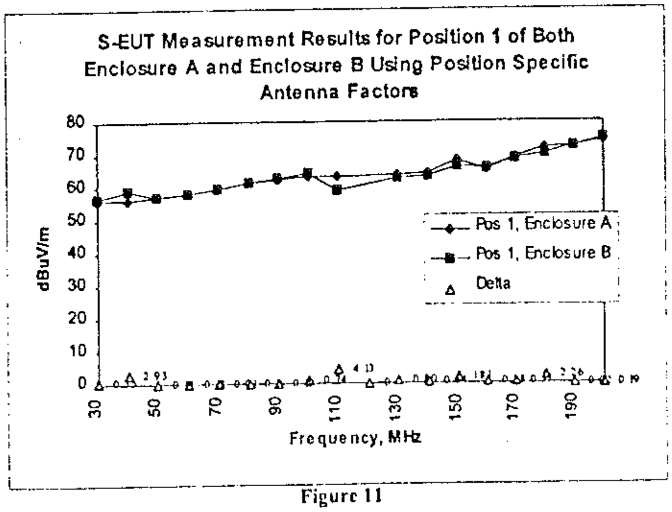


Figure 11

Summarizing these results we find that four measurements differ by 1.81 dB, 2.26 dB, 2.93 dB, and 4.13 dB. Reviewing the remainder of the measurements we find that none differ by more than .89 dB with nine of these agreeing by .35 dB or better.

Does agreement among measurements of the same quantity insinuate accuracy while disagreement inaccuracy? Because accuracy is the extent to which a measurement agrees with a standard value [9], we must show that this condition exists. It is feasible that one set of the OATS derived data may agree with this standard while all of the position specific derived measurements do not. Or that the OATS derived data is closer to this standard. Being that the S-EUT is a SSDS it is possible to predict what the incident E-field strength at the observation antenna was for these measurements. This is possible by resolving the SSDS field solutions [1] based on the indicated balun input voltages and set-up geometrys used during the measurements. Applying the empirically derived gap transfer function to these calculations provides the field strength at the observation antenna. Figure (12) is a graph containing all of the OATS calculated S-EUT measurements weighed against the predicted output of the S-EUT. The largest delta from the calculated output of the S-EUT and any one of the measurement results is also included on this graph. Table (1) tabulates this information.

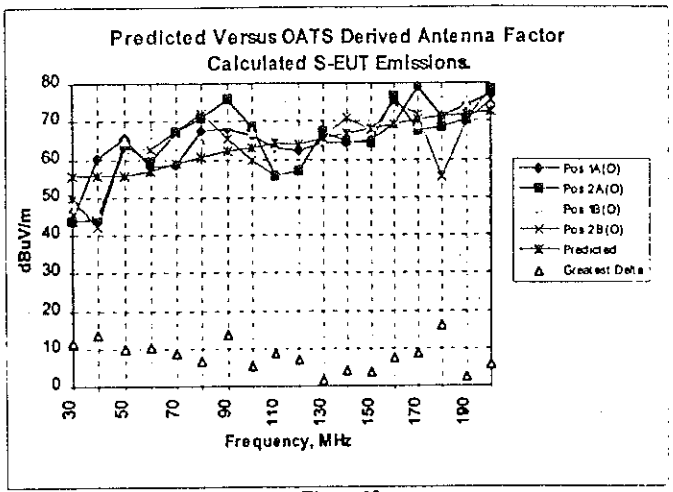


Figure 12

S-EUT Measurement Results using OATS Antenna Factors Versus Predicted E-field.

	Enclosure A		Enclosure B		E-field /	Greatest
Frequency	Pos 1A(O)	Pos 2A(O)	Pos 1B(O)	Pos 2B(O)	Predicted	Delta
30	44.14	43.77	47.6	49.99	55.52029	11.75029
40	60.07	44.09	46.01	42.2	55.61816	13 41
50	65.57	63.85	65.14	62.83	55.46454	10.1
60	58.01	59.53	67.13	62.83	57.01832	10.11168
70	58.63	67 08	65 28	67.52	58 84493	8.67507
80	67.51	70.74	65.35	71.97	60.64131	6 62
90	68.02	75 99	69.5	65 71	62.45456	13.53544
100	66.27	68.35	67.36	59 91	62.95368	5.39632
110	62.89	55.78	63.67	55 66	64.29875	8.63875
120	62.34	57.11	*	*	64.03021	6.92021
130	64.15	67.02	64.69	66.06	65.40403	1.61597
140	64.41	64.94	67.6	70.67	66.77137	4.09863
150	65.32	64 43	69.03	67.71	68.03923	3.60923
160	69.47	76.57	70.65	74.85	69.22136	7.34864
170	79.04	67.55	69.3	71.67	70.32894	8.71106
180	71.46	68.34	74.53	55.2	71.47113	16.27113
190	74.32	70 63	74.49	70 2	71.85555	2.63445
200	77.17	78.34	75.07	75.66	72.42856	5.91144

* not calculated.

Table 1

Evaluating each measurement point for the single largest measurement deviation from the predicted field we find the following. At four frequencies the delta lies between 1 and 5 dB, eight fall between 5 and 10 dB, while the remaining six differ by more than 10 dB. The worst case being 16.27 dB.

Figure (13) is a graph containing all of the position specific calculated S-EUT measurements weighed against the calculated output of the S-EUT. Table (2) contains the same data tabulated.

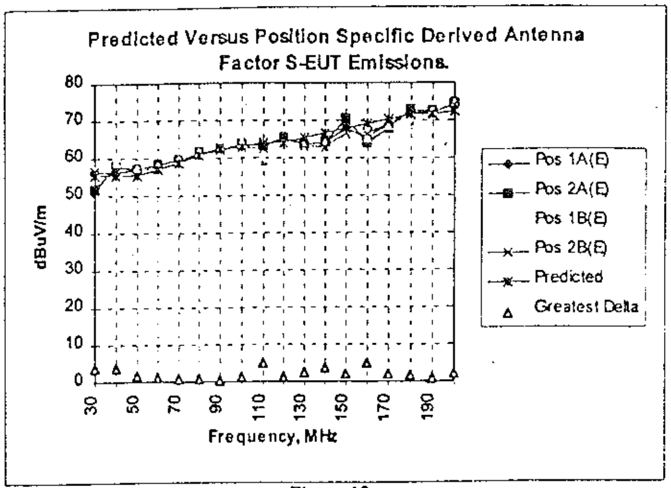


Figure 13

S-EUT Measurement Results Using Position Specific Antenna Factors Versus Predicted E-field

	Enclosure A		Enclosure B		E-field /	Greatest
Frequency	Pos 1A(E)	Pos 2A(E)	Pos 1B(E)	Pos 2B(E)	Predicted	Delta
30	56.40209	51.73209	56.75209	56.86209	55.52029	3.7882
40	56.29996	58.01996	59.22996	55.83996	55.61816	3.611
50	57.05634	56.93634	56.91634	56.52634	55.46454	1.5198
60	58.28012	58.30012	58.10012	57.30012	57.01832	1.2818
70	59.48673	59.53673	59.47673	58.93673	58.84493	0.6918
80	61.30311	61.53311	61.46311	60.74311	60.64131	0.8918
90	62.51636	62.68636	62.70636	61.89636	62.45456	0.5582
100	63.44548	63.92548	64.18548	62.73548	62.95368	1.2318
110	63.23055	63.42055	59.10055	62.31055	64.29875	5.1982
120	65.16201	65.45201	*	*	64.03021	1.4218
130	63.73583	63.80583	62.84583	63.37583	65.40403	2.5582
140	64.10317	64.33317	63.56317	62.89317	66.77137	3.8782
150	67.92103	70.23103	66.11103	66.53103	68.03923	1.9282
160	65.31316	64.11316	65.59316	66.49316	69.22136	5.1082
170	69.15074	68.06074	68.58074	69.21074	70.32894	2.2682
180	72.09293	72.77293	69.83293	71.96293	71.47113	1.6382
190	72.46735	72.69735	72.46735	72.05735	71.85555	0.8418
200	74.52036	74.69036	74.71036	74.32036	72.42856	2.2818

* not calculated.

Table 2

Evaluating each measurement point for the single largest measurement deviation from the predicted field we find the following. At four frequencies the largest delta is less than 1 dB, six fall between 1 and 2 dB, while the remaining eight miss the predicted value by greater than 2 but less than 5.2 dB. Two points deviated by 5.2 dB.

CONCLUSIONS

When the same E-field quantity was measured in two enclosures over the frequency range of 30 to 200 MHz, without compensating for the shielded enclosure's effects, not only were there significant disagreements between the measurements but also to the predict E-field level. Some of the differences from measured to the predicted E-field fell well above 10 dB. When the enclosure's effects were compensated for in the measurement process through shielded enclosure, position specific, hybrid antenna factors, the disagreement between enclosures and to the predicted E-field was greatly improved. The largest deviation from the predicted E-field in this case was 5.2 dB. Consideration of shielded enclosure effects must be considered in the process of radiated emissions measurements, specifically in frequency ranges where there is limited or no benefit from absorber material.

The work presented in this paper has shown an ideal, yet critical approach to the very complicated task of making meaningful measurements in shielded enclosures. Critical, in that it clearly exposes the degree of error attributed only to the enclosure's effects on radiated emission measurements, as well as providing a practical way of considering these effects in the measurement process. Ideal, in that the equipment under test, unlike the unintentional antennas representative of most equipment under test, was simulated by a characterized standard electromagnetic source. Also, unlike typical test conditions, the measurement equipment and set-up geometrys were constant throughout all of these measurements. A very difficult task under typical conditions. Results from a three laboratory study, conducted by NIST's Fields and Interference Metrology Group and the Naval Air Warfare Center Aircraft Division's EMI Laboratory in 1995, incorporating the process of position specific shielded enclosure antenna calibrations into present measurement methods, indicates that the hybrid antenna factors will prove to be an integral part of a solution containing many pieces.

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