Potential Impact of DUT Directivity Characteristics on Electromagnetic Effects Testing

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Abstract - This paper examines the relationship between equipment level tests conducted using anechoic chamber and reverberation chamber test techniques. Comparative testing was conducted using a specially constructed generic test device referred to as the "Common Test Article" (CTA). Coupling investigations conducted on a purpose built shielded enclosure are also examined. The results show the aspect angle sensitivity of anechoic chamber measurements and the explores the relationship between the anechoic chamber and reverberation chamber methods.

Index Terms**—Component, reverberation chamber, anechoic chamber, electromagnetic susceptibility** *(key words)*

I. INTRODUCTION

Historically the default test method for electromagnetic effects testing is the anechoic or semi-anechoic chamber. Their ability to generate a uniform field under controlled conditions cannot be matched by any other method. However, the variability in directivity in devices that are not designed as antennas, can result in unacceptable uncertainties unless many aspect angles are evaluated [1,2]. In the 1970s, McDonnell Douglas measured the directivity pattern of a twisted pair [3]. The results, shown in Figure 1, typifies the variations that can be encountered in "real world" applications. So, to obtain a reasonable uncertainty in an anechoic chamber, a single aspect angle may be sufficient if the directivity of the device is known (ex. antenna) or the device is isotropic. However, if the device's characteristics are unknown and complex, like those depicted in Figure 1, then a significant number of aspect angles may be required to obtain reasonable uncertainty.

The US Navy began investigating reverberation chamber test techniques in the late 1970's and in 1982 the Naval Surface Warfare Center Dahlgren Division (NSWCDD) constructed the first purpose build large scale reverberation chamber test facility. The United States Airforce Rome Air Development Center (RACD) was also interested in reverberation chambers and together NSWCDD and RACD funded the National Bureau of Standards (NBS), later National Institute of Standards and Technology (NIST), to conduct a study on reverberation chambers. The resulting report, NBS Technical Report 1092, was the first of many reports that eventually resulted in reverberation chambers becoming accepted by the technical community. This acceptance was reflected in the technique being incorporate into several major standards such as RTCA DO-160 and MIL-STD-461. Eventually, a stand-a-lone standard was developed in the form of IEC Standard 61000-4-21. In the period between the publication of NBS TN 1092 and

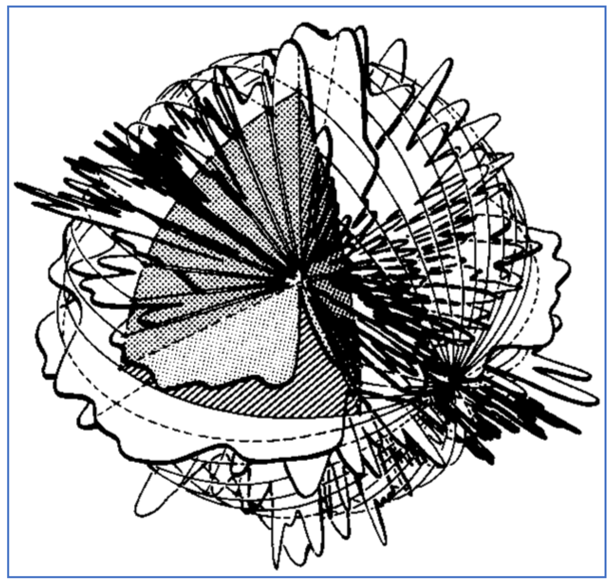

Figure 1 Directivity of a twisted pair

the acceptance of reverberation chambers by the technical community, numerous efforts were undertaken to relate the results of the reverberation chamber technique to the de facto standard anechoic chamber [4,5,6] some of which reported variations as much as 15 dB which were assumed to be a result of the directivity characteristics of the device under test (DUT) [6]. To better understand the effects of DUT directivity NSWSCDD, in cooperation with NIST, collected "high resolution" aspect angle resolution" data on a generic test device referred to as the "Common Test Article" (CTA) [4,5].

II. CTA TESTING

The CTA has been extensively tested in both the NSWC and NIST reverberation chambers as well as the NIST anechoic chamber. Data from these tests were previously reported at the Third Australasian Instrumentation and Control Conference held in Adelaide Australia during April of 1994 [4]. The anechoic chamber data presented at that time included only the upset threshold levels. The data presented demonstrated 1) that the uniformity of the electromagnetic environment (EME) in a reverberation chamber minimizes the impact of the differences in the cable configurations as the tests were conducted with no attempt to specifically replicate cable layout, box position or orientation, and 2) that the upset levels obtained using the anechoic chamber were 3 to 5 dB below those obtained using the reverberation chamber. At that time the difference was attributed to the failure of the reverberation chamber environment to preserve the directivity characteristics of the CTA. While this may still be the case, the data was collected early in the development of reverberation chambers and chamber calibration procedures and the resulting field strength estimates have changed [7,8] adding additional uncertainty to the estimated directivity.

In the next section the details of the anechoic chamber data collected on the CTA will be presented and the implications of sample size (number of aspect angles evaluated) when collecting data on devices with unknow directivity characteristics will be examined.

III. CTA ANECHOIC CHAMBER RESULTS

The aspect angle susceptibility characteristics of the CTA were evaluated using the NIST anechoic chamber. For these measurements, the CTA was mounted in a carboard construction tube using dielectric supports to secure boxes one and two and their interconnecting cables as shown in Figure 2.

For the evaluation, the tube was rotated 360 degrees in 6-degree steps and then rolled from 0 to 90 degrees in 10-degree increments resulting in a total of 600 aspect angles. The CTA was evaluated at five frequencies as shown in Table 1. As the data in Table 1 shows, the higher the test level was above the threshold, the more aspect angles resulted in upset. Figures 3 through 7 show the data obtained for 1500 MHz as the test level was varied up to 5 dB above threshold.

The test level was defined as the E-field at the center of rotation. Upset threshold was defined as an absence of upset at the aspect angle being evaluated for a 1 dB reduction in input power. i.e. the filled data points indicate the level at which an upset occurred and a 1 dB reduction in input power would result in no failure occurring at the aspect angle being evaluated.

Figure 2 CTA Mounted in NIST Anechoic Chamber

Table 1 Test level vs percentage of upsets

Rel to Threshold (dB)	600 MHz	1000 MHz	1500 MHz	1800 MHz	2000 MHz
0	28/600 (4.7%)	6/600 (1.0%)	5/600 (0.8%)	12/600 (2.0%)	8/600 (1.3%)
1	*	16/600 (2.7%)	13/600 (2.2%)	*	*
2	*	*	28/600 (4.7%)	*	*
3	*	*	55/600 (9.2%)	*	*
4	110/600 (18.3%)	25/600 (4.2%)	*	*	*
5	*	*	153/600 (25.5%)	*	*
	* DATA NOT COLLECTED AT THIS LEVEL				

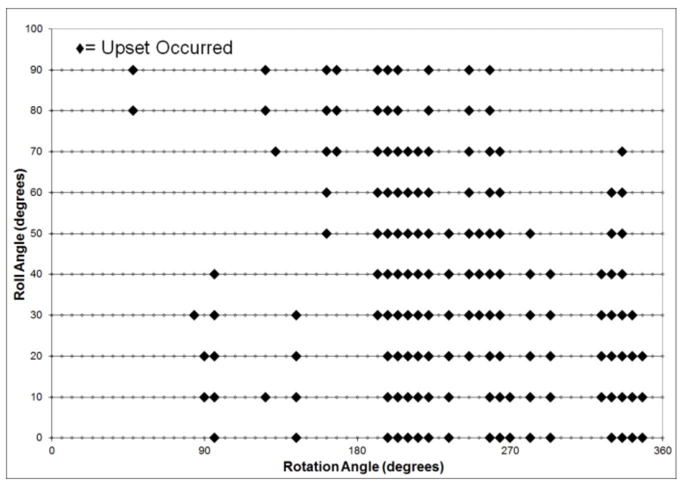

Figure 3 Data 5 dB above threshold, 25.5% of aspect angles tested resulted in upset

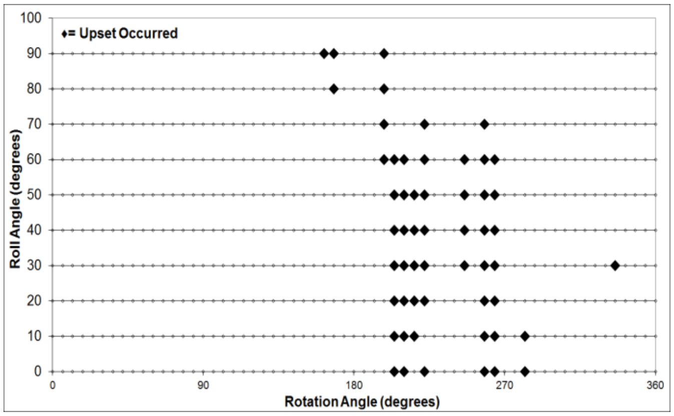

Figure 4 Data 3 dB above threshold, 9.2% of aspect angles tested resulted in upset

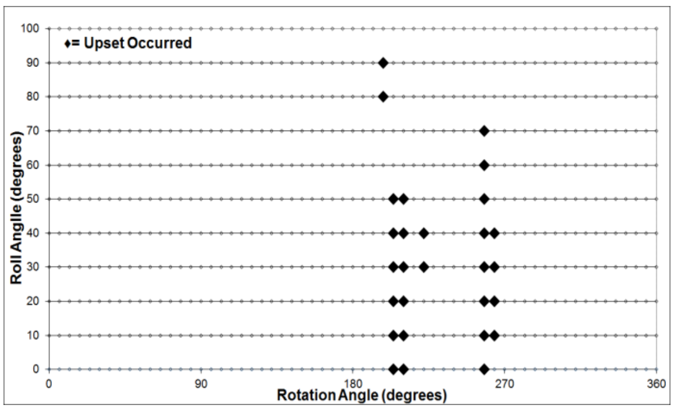

Figure 5 Data 2 dB above threshold, 4.7% of aspect angles tested resulted in upset.

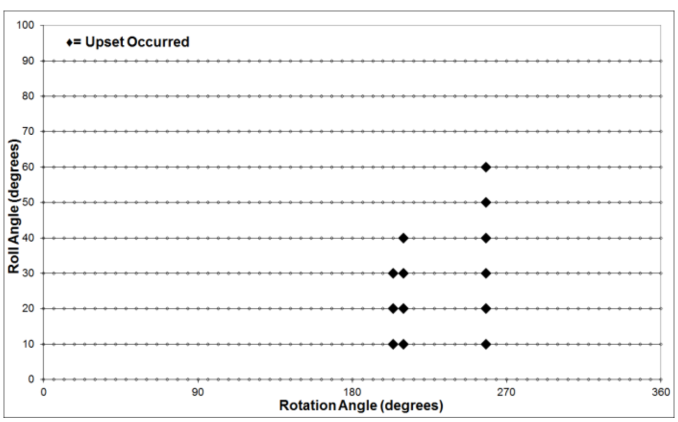

Figure 6 Data 1 dB above threshold, 2.2% of aspect angles tested resulted in upset

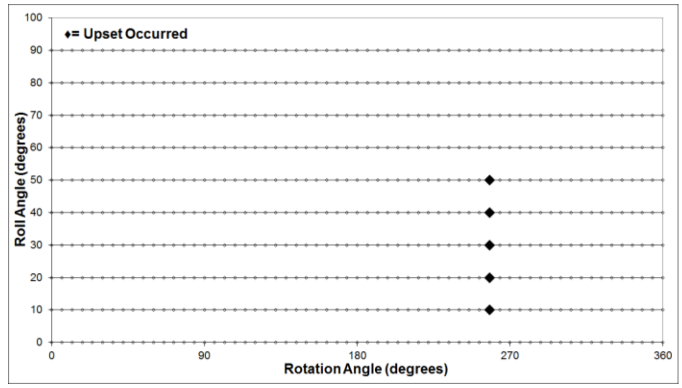

Figure 7 At threshold, 0.8% of aspect angles tested resulted in upset

To evaluate the sensitivity of the CTA for small variations in aspect angle, an additional test was conducted at the 30-degree roll angle, using one-degree increments of rotation. The susceptibility width of 5 degrees, indicates that the 6-degree rotation and 10-degree roll increments used in this evaluation were likely insufficient to ensure detection the true threshold level.

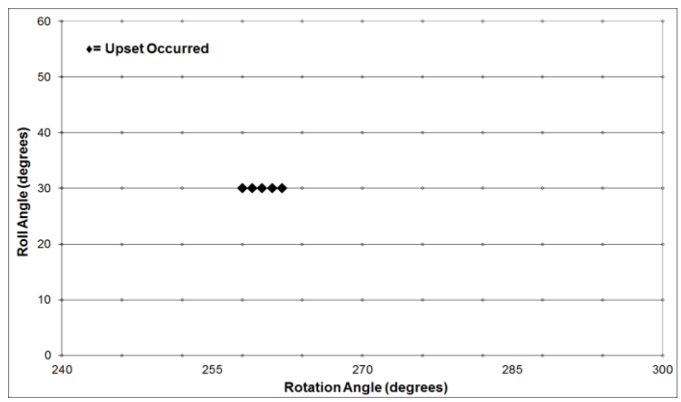

Figure 8 Threshold 1-degree rotation angle results

Initial perceptions of those attempting to compare reverberation chamber and anechoic chamber results were that the reverberation chamber over tested the devices being evaluated. This view was driven by the fact that most anechoic chamber tests were conducted at a low number of aspect angles which resulted in a low probability of finding the actual susceptibility level [2]. A typical anechoic chamber test would be conducted at two aspect angles and two polarizations, at angles perpendicular to the device being tested. For the CTA anechoic chamber data this would correlate to testing at 0, 90, 180, or 270 degrees rotation and 0 and 90 degrees roll. Upsets during anechoic chamber testing corresponding to one of these specific aspect angles occurred twice. Once at 600 MHz, (270 degrees rotation and 90 degrees roll) at 4 dB above threshold and once at 1500 MHz, (270 degrees rotation and 0 degrees roll) at 5 dB above threshold. The most upsets recorded during anechoic chamber testing was 153 out of 600 aspect angles

(25.5%) at 5 dB above threshold at 1500 MHz. From this data, it is easy to see how a much higher susceptibility level could be obtained using an anechoic chamber and that a reverberation chamber test would find a lower susceptibility level giving the impression that the reverberation chamber was an "over test"

IV. SHIELDED ENCLOSURE TEST RESULTS

In addition to the CTA, NSWCDD developed an enclosure for comparing shielding effectiveness measurements conducted using reverberation chambers to the results obtained using anechoic chambers. The enclosure is shown in Figure 9. Shielding data obtained in both the NSWCDD reverberation chamber and NSWCDD anechoic chamber are shown in Figure 10. Note that the RC data is a single value and that there is little change in shielding for the three elevations angles evaluated in the anechoic chamber while the enclosure was rotated 360 degrees. It should be noted that an internal mechanical tuner was rotating for both evaluations.

Figure 9. Shielded enclosure in NSWCDD reverberation chamber

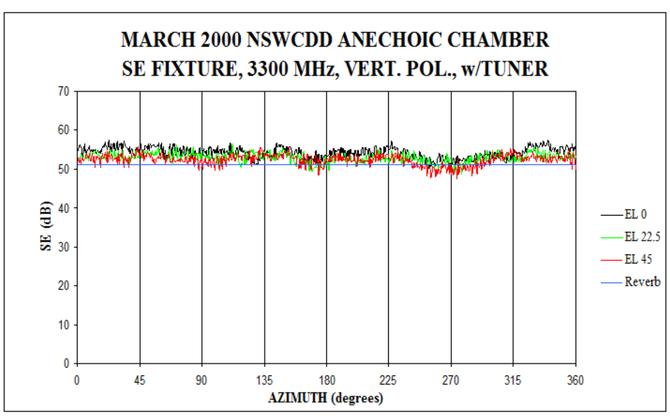

Figure 10 Enclosure shielding obtained using NSWCDD anechoic and reverberation chambers.

Following the evaluations at NSWC the enclosure was sent to NIST [2]. After it was verified that the shielding had not changed during shipment, fixture was modified by drilling holes in each face. Initially one 1.6 cm hole was drilled at a random location in each face. After evaluating the fixture with five holes, four additional 1.6 cm were drilled at random locations in each face (30 holes total). The shielding of the modified enclosure was evaluated using the NIST reverberation chamber. Shielding results obtained with five holes in each face are shown in Figure 11. As in the NSWC evaluations there was a mechanical tuner rotating within the enclosure during the reverberation chamber test. The fixture was also evaluated with the mechanical tuners in a fixed position as the enclosure was rotated 360 degrees in each of the three principal planes using the NIST anechoic chamber. The enclosure mounted in the NIST anechoic chamber is shown in Figure 12 and the results of this evaluation for 2 GHz and 4 GHz are shown in Figures 13 and 14. Close examination of the two plots shows that no significant coupling occurred at what are normally considered the standard test orientations, i.e. perpendicular to the face of the DUT.

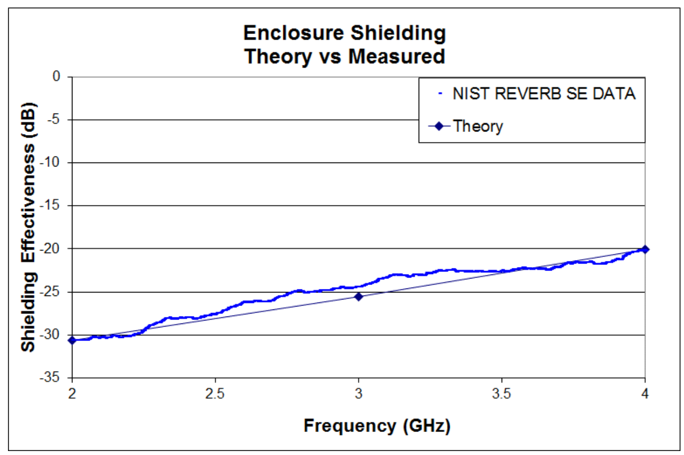

Figure 11 Shielding of modified enclosure from NIST reverberation chamber

Figure 12 Enclosure in NIST anechoic chamber

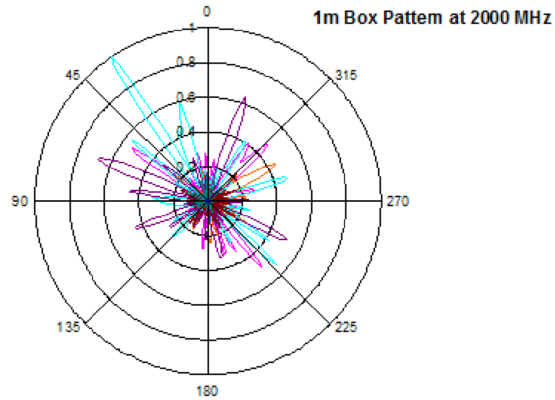

Figure 13 Enclosure pattern with fixed internal tuner for three principal planes at 2 GHz

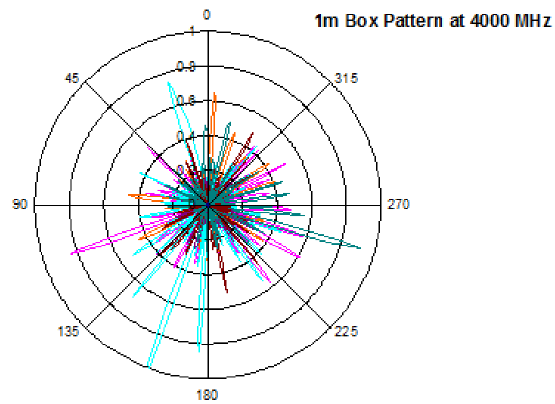

Figure 14. Enclosure pattern with fixed internal tuner for three principal planes at 4 GHz.

V. SUMMMARY

The anechoic chamber data from the CTA clearly shows that the susceptibility pattern is complex like that of the twisted pair shown in Figure 1. The CTA exhibited multiple narrow lobes of susceptibility indicating large variations exist in the transfer functions as a function of aspect angle for devices with low **"**overall**"** directivity. Anechoic chamber data for the shielded enclosure indicate similar, multiple, narrow lobe, coupling characteristics. When one considers that electronic components represented by the CTA are usually installed inside an enclosure, it is easy to see how a test conducted using an anechoic chamber at a low number of aspect angles could easily mischaracterize the susceptibility level. It should be noted that in many cases it is recommend, when possible, that a mechanical tuner be installed inside the enclosure or cavity being evaluated [9,10].

Statistical techniques currently under development to understand and exploit the complex characteristics of coupling and shielding [11, 12] should result in techniques that simplify the certification process while decreasing the uncertainty of such testing. Until such methods are developed the best approach to susceptibility testing may be a twostep process: 1) identify the susceptibilities using reverberation chambers, 2) characterize susceptibilities using anechoic chamber, GTEM cells or Open Area Test Sites as appropriate.

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REFERENCES

[1] Freyer, G.J., and Backstrom, M.G., "Comparison of Anechoic & Reverberation Chamber Coupling Data as a Function of Directivity Pattern", IEEE Int. Symposium on EMC, Washington, DC, August 2000.

[2] J.M. Ladbury, T.H. Lehman and G.H. Koepke, "Coupling to Devices in Electrically Large Cavities, or Why Classical EMC Evaluation Techniques are Becoming Obsolete"; IEEE Int. Symposium on EMC, Minneapolis, MN, August 2002

[3] "Electromagnetic Coupling to Aerospace Cables at Microwave Frequencies", McDonnell Douglas Aerospace Company, Report ATN 73-003, November 1973

[4] M.O. Hatfield and G.J. Freyer "Typical Results of Radiated Immunity Testing using Reverberation Chambers" Third Australasian Instrumentation and Control Conference, Adelaide Australia, April 1994

[5] M.O. Hatfield, J.L. Bean, G.J. Freyer and D.M. Johnson "Repeatability of Mode-Stirred Chamber Measurements", IEEE International Symposium on EMC Chicago IL, August 1994.

[6] L. Jansson and M Backstrom, "Directivity of Equipment and Its Effect on Testing in Mode-Stirred and Anechoic Chamber; IEEE Int. Symposium on EMC, Minneapolis, MN, August 2002

[7] J.M. Ladbury and G.H. Koepke," Reverberation Chamber Relationships: Corrections and Improvements or Three Wrongs Can (almost) Make a Right, IEEE International Symposium on EMC, Seattle, WA, August 1999

[8] M. Hatfield, "A Calibration Procedure for Reverberation Chambers", IEEE Int. Symposium on EMC, Washington, DC, August 2000.

[9] M.O. Hatfield, W.P. Pluim and W. Price, "Investigation into IN-SITU Shielding Effectiveness Testing of Transport Aircraft", IEEE International Symposium on EMC, Boston, MA, August 2003

[10] IEC 61000-4-21 Annex H

[11] C.E. Hager, J.D. Rison and G.B. Tait, "Electromagnetic Probability-of-Effect Assessment Tool for High-power Susceptibility Testing"; IEEE Transactions on Electromagnetic Compatibility, Volume: 58, Issue:4, August 2016

[12] M. Magdowski, "First Results for the Measured Directivity of Practical Devices Under Test from the DEBoRA Project", International Conference for Electromagnetic Compatibility, Düsseldorf, Germany, February 2018