

An Analytical and Experimental Comparison of Radiated Emissions Test Facilities

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ABSTRACT

Radiated Emissions measurements are usually required to be performed on a facility that meets the Normalized Site Attenuation (NSA) and receive antenna scan height requirements of ANSI C63.4 and CISPR 22. However, often times preliminary measurements for the purpose of frequency identification or engineering and troubleshooting are performed at fixed scan height indoor semi-anechoic facilities or free space facilities. Free Space facilities, in particular, have been put forth as a possible future alternative standard to OATS for certification measurements. An analytical and experimental comparison of the relative merits of these different types of facilities is presented.

INTRODUCTION

The benefits of a utilizing a free space test environment to reduce measurement uncertainty for radiated immunity tests are largely acknowledged in the revision of IEC 1000-4-3 (IEC 801-3, Second Edition).^[1] Previous work has fully detailed the benefits of a fixed height free space environment compared to the fixed height semi-anechoic for maintaining field uniformity during immunity testing.^[2] It has been suggested that the improved field uniformity of a free space environment may also yield improvements in measurement uncertainty and test repeatability for radiated emissions tests^{[3],[4],[5],[6],[7]} and such facilities may be used at present for certification testing of intentional radiators in accordance with ETSI standards^[8]. The purpose of the analysis and experiments detailed in this paper is to compare three commonly used types of test facilities and promote an understanding of the fundamental characteristics inherent to each for FCC Part 15 or CISPR 22 type radiated emissions tests : 1) An ideal open area test site (OATS) utilizing a 1-4m receive scan height, 2) a fixed-height semi-anechoic facility, and 3) a fixed-height free space facility.

BACKGROUND

Previous works have produced detailed models for Equipment Under Test (EUT) employing both loop and dipole radiators for the free space environment^[9]. The Effective Free Space Distance model selected for use in this present paper was specifically chosen to maintain consistency with the model for Normalized Site Attenuation (NSA) as it appears in ANSI C63.4 Tables 1 and 2.^[10] The concept of using effective free space distance to model Normalized Site Attenuation (NSA) over a ground plane was suggested in [4] and the models employed for this paper produce exactly the same results as Tables 1 and 2 of ANSI C63.4 (1992) when the same geometries are assumed.

On an OATS site, the maximum signal received by an antenna scanned from 1-4 meters occurs at the point of minimum effective free space distance (before consideration of mutual coupling effects). The following equations can be used for the computation of effective free space distance on an OATS :

For Horizontal polarity, this effective distance is given by :

$$D_{eff} = \frac{D_1 D_2}{\sqrt{D_1^2 + D_2^2 + 2 D_1 D_2 \cos[\mathbf{p} - \mathbf{b} (D_2 - D_1)]}} \quad (1)$$

For Vertical polarity, the effective free space distance on an OATS is as follows :

$$D_{eff} = \frac{D_1^3 D_2^3}{R^2 \sqrt{D_1^6 + D_2^6 + 2 D_1^3 D_2^3 \cos[\mathbf{b} (D_2 - D_1)]}} \quad (2)$$

where D_1 and D_2 are the direct and indirect path lengths in meters, and $\beta = 2\pi/\lambda$. In Free Space, the effective free space distance is equal to D_1 , the direct path length. These equations for effective distance appear in inverse form in [11] and are based on the field pattern of an electrically short dipole radiator.

The equation for Normalized Site Attenuation (NSA) that produces the same results as contained in ANSI C63.4 Tables 1 and 2 is as follows :

$$NSA = \frac{R_s \cdot R_L}{R_s + R_L} \cdot \frac{I \cdot D_{eff}}{Z_0} \quad (3)$$

where λ is the wavelength in meters, D_{eff} is the minimum effective free space distance, R_s and R_L are the source and load impedances of the measurement system (usually 50 ohms), and Z_0 is the characteristic impedance of free space (approximately 120π ohms).

ANALYSIS OF NSA OVER TEST VOLUME

For the analysis presented below, the EUT test volume is constructed around an assumed 2 meter diameter turntable. The source of emissions from the equipment is analyzed from 0.4m below the table top height to 0.7m above the table top height. Note that on an OATS site this corresponds to transmit heights between 0.4m and 1.5m above ground since the table top is usually located at 0.8m above ground. The heights are stated referenced to the table top for consistency because in the free space model considered, there is no ground plane.

The following heights and positions were included in the analysis in an effort to bound the front half of the volume that would be occupied by the EUT :

NSA Analysis Positions :

- Front Position : 3 meters from Receive Antenna
- Middle Position : 3.5 meters Receive Antenna
- Side Position : 4.123 meters from Receive Antenna

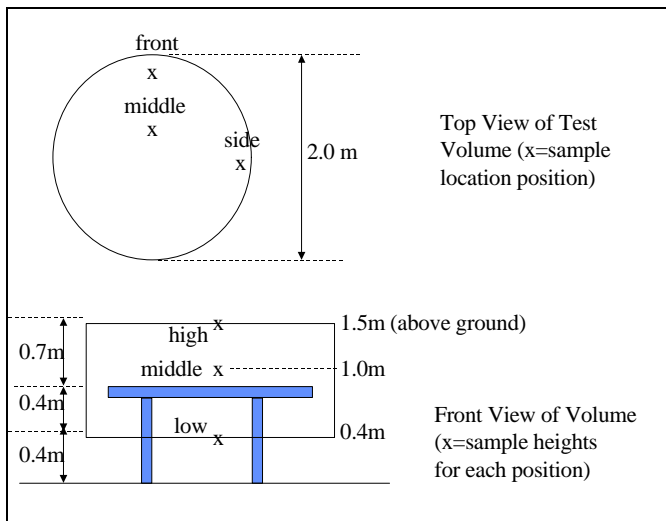
NSA Analysis Heights:

- 0.4m below table top (0.4m above ground)
- 0.2m above table top (1.0m above ground)
- 0.7m above table top (1.5m above ground)

Note that only the front half of the EUT volume is considered since an EUT would normally be rotated during the performance of the measurements and it is assumed that any emissions from the back half of the turntable would be maximized when the EUT is rotated to the front half. Also, note that the exact center position is not considered since this distance (4m) is very close to the same distance obtained from the side positions for the small turntable considered (4.123m).

Figure 1 Illustrates the construction of the Normalized Site Attenuation model.

FIGURE 1 : NSA MODEL CONSTRUCTION



ANALYSIS RESULTS

The above described analysis was performed by the use of an Excel spreadsheet to perform the multiple calculations. The results are presented to compare the range of possible results obtained at the receive antenna based on the different source locations within the test volume. The baseline values (0 dB) on these charts are the ideal isotropic 3 meter free space result. Each of the following plots contains nine traces, one for each of the analyzed positions and heights. However, all traces may not be visible due to the scale of the plots and the fact that some traces may lay over others. The primary purpose of this presentation is to illustrate the minimum to maximum range of possible results obtained over the relatively small test volume analyzed.

DISCUSSION OF ANALYSIS

Analysis of Normalized Site Attenuation suggests that the fixed height free space environment (Figure 2) most closely bounds the range of possible results over frequency, polarity and emissions source locations within the EUT volume. This would suggest that lower measurement uncertainty and better test repeatability would be achievable in a standard free space environment than with the existing OATS standard. The tighter bound of possible results means that the maximum emissions obtained will be less sensitive to placement of equipment under test, variation of cable location, and operator introduced errors such as improper variation of scan antenna height over all turntable angles, frequencies and polarities to be investigated. With respect to the common present day practice of using a fixed height semi-anechoic chamber to generate a frequency list for further full scan height investigation, the analysis suggests that this practice could introduce potentially large additional uncertainty due to the use of the fixed height to perform the pre-scan and frequency selection (Figures 5 and 6).

It is important to note that in order to achieve the theoretical quality of full 1-4m scan height measurements indicated in Figures 3 and 4 it is necessary to vary antenna height for every frequency. In practice, this would require test methods on the OATS to set the turntable to small incremental angles and perform a full height scan and frequency investigation at each table angle, then collate and reduce the results to report the maximum signals obtained. In practice, this is rarely done due to the length of time required to make such measurements, and thus even on full scan height capable facilities it is much more common to set the antenna height to a pre-determined "theoretical height" for initial investigations, and then produce a frequency list for further investigation later. It is observed that this more common test practice will not necessarily result in obtaining the theoretically achievable quality of full scan height measurements as indicated in Figures 3 and 4, but something in between the fixed height analytical results shown in Figures 1 and 2 and the full scan height results of Figures 3 and 4.

FIGURE 2 : RANGE OF POSSIBLE RESULTS BASED ON ANALYSIS OF NORMALIZED SITE ATTENUATION FIXED (1.5m) FREE SPACE CHAMBER 3 METER TEST DISTANCE, 30 MHz - 1000 MHz VERTICAL OR HORIZONTAL POLARITY

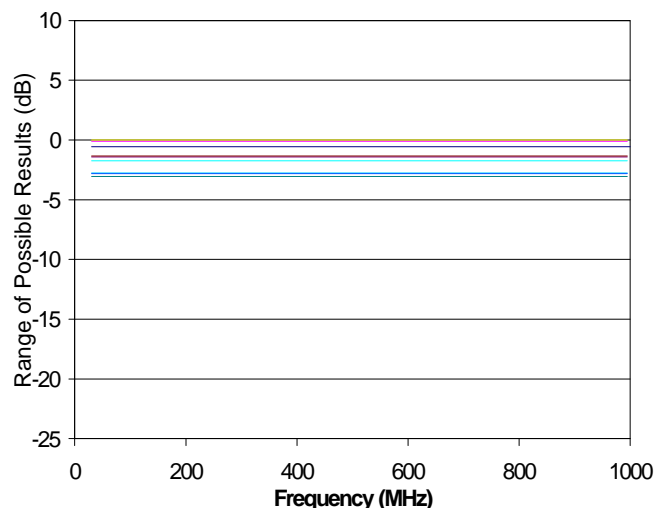


FIGURE 3: RANGE OF POSSIBLE RESULTS BASED ON ANALYSIS OF NORMALIZED SITE ATTENUATION OATS SITE, 1-4m RECEIVE SCAN HEIGHT 3 METER TEST DISTANCE, 30 MHz - 1000 MHz VERTICAL POLARITY

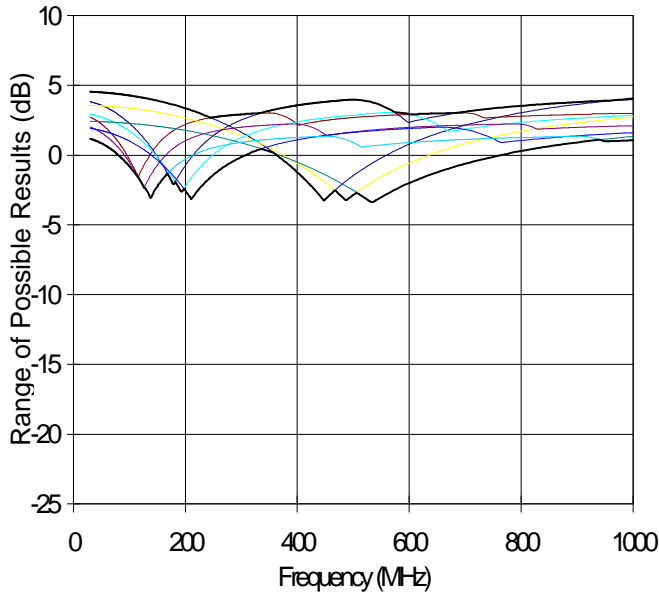


FIGURE 5: RANGE OF POSSIBLE RESULTS BASED ON ANALYSIS OF NORMALIZED SITE ATTENUATION FIXED 1.5M RECEIVE HEIGHT SEMI-ANECHOIC 3 METER TEST DISTANCE, 30 MHz - 1000 MHz VERTICAL POLARITY

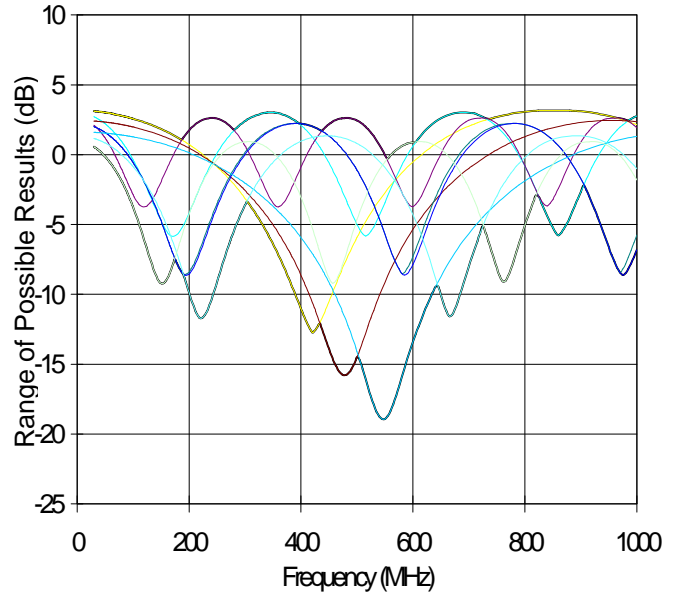


FIGURE 4: RANGE OF POSSIBLE RESULTS BASED ON ANALYSIS OF NORMALIZED SITE ATTENUATION OATS SITE, 1-4m RECEIVE SCAN HEIGHT 3 METER TEST DISTANCE, 30 MHz - 1000 MHz HORIZONTAL POLARITY

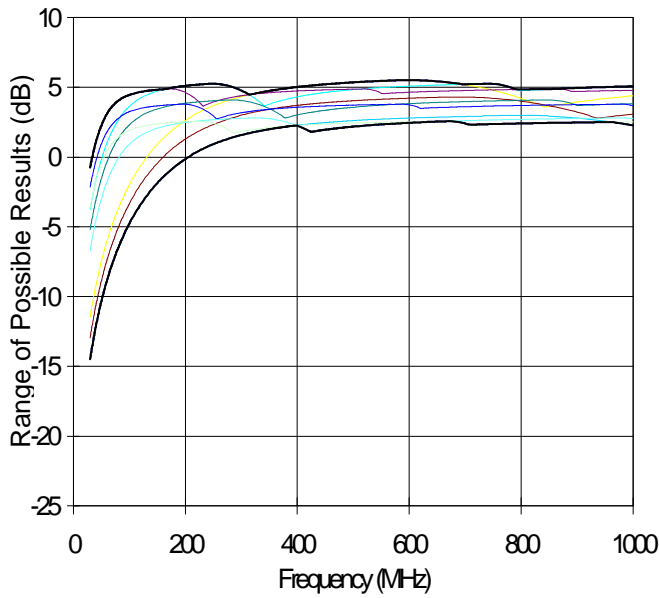
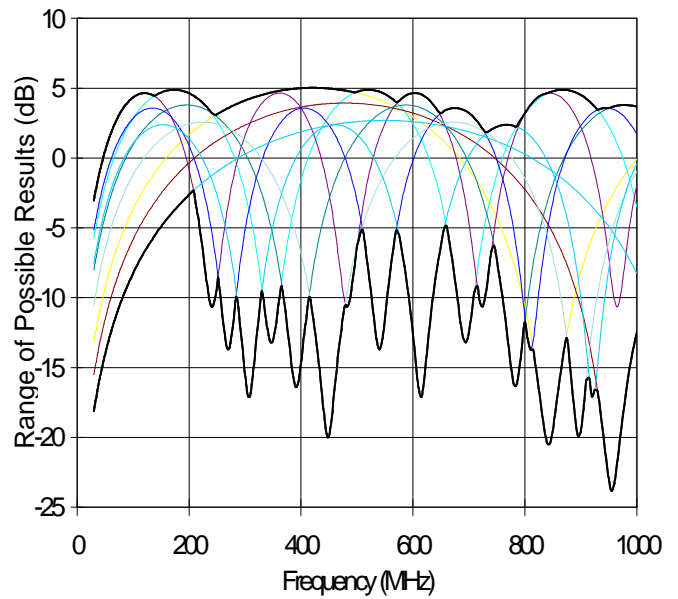


FIGURE 6: RANGE OF POSSIBLE RESULTS BASED ON ANALYSIS OF NORMALIZED SITE ATTENUATION FIXED 1.5m RECEIVE HEIGHT SEMI-ANECHOIC 3 METER TEST DISTANCE, 30 MHz - 1000 MHz HORIZONTAL POLARITY



EXPERIMENTAL VERIFICATION OF ANALYSIS

An experimental verification of the analysis presented in this paper was performed using five frequencies chosen by the authors based on inspection of charts 3-6. The frequencies selected were : 50 MHz, 200 MHz, 300 MHz, 450 MHz and 500 MHz. The choice of these five frequencies was somewhat arbitrary and intended to illustrate the principles of the analysis rather than to provide exhaustive and definitive proof of the concept. For convenience and consistency between laboratories, a small and portable source capable of generating these frequencies was chosen. Each laboratory was equipped with appropriate and comparable equipment to perform electric field strength measurements at these five frequencies with reasonable repeatability and accuracy, so only the source was transported between facilities. It was observed that illustration of the concepts described in the analysis only depend on a comparison of the range of results obtained within each type of facility, so the absolute measurement uncertainty of the instrumentation used does not affect the conclusions, only the repeatability of the instrumentation used and the emissions source.

Emissions Source For Experiments

The source selected was a comb generator device that has been used at the Hewlett Packard Vancouver Facility for several years. The device is typically used before and after Radiated Emissions Measurements are taken to increase confidence that all measurement equipment functioned properly during the entire measurement process. The source has been measured many times at several facilities and found to be an amplitude and frequency stable electric field source. The source is completely self contained and is constructed from a comb generator circuit originally used in the Hewlett Packard 85685A Tracking Preselector. Regulated power is supplied by sealed Lead-Acid batteries, and the source is equipped with a “low-battery” shutdown feature. The source is housed in a 15cm by 20 cm by 25 cm utility box with a 48 cm diameter plate mounted to the top. In the center of this plate is a modified type ‘N’ connector into which has been fitted a 48 cm antenna of 6 mm diameter. This antenna is a reasonably effective radiator at frequencies between 50 and 500 MHz. In the experiment, this antenna is intended to represent a source of radiation typical of a cable or slot of an ITE system.

The Test Facilities

The first facility selected was to use to simulate the Semi-Anechoic Chamber (SAC) and OATS environments of the analysis performed in Figures 3-6. The chamber selected was lined with standard carbon loaded pyramidal Polyurethane foam absorber of up to 1.5m on all surfaces except the conducting floor. The exterior dimensions of this shielded room are 8m (wide) by 12.3 m (long) by 6.5m (tall) to accommodate full 1-4m scan height measurements in accordance with CISPR 22 and ANSI C63.4 at a 3 meter test distance. This facility has been used for about 10 years in combination with an Open Area Test Site (OATS) to test the DeskJet Printer products designed and manufactured at Hewlett Packard’s Vancouver Site. This facility is considered a better quality facility than many laboratories use for 3m preliminary measurements in support of OATS testing because of the capability to perform a full scan height and the large pyramid absorber. The second facility selected was to represent the “free space” or “fully anechoic” environment. The free space facility measured 6.0m x 8.5m x 3.0m (w,l,h) nominal dimensions and is operated by KKC Laboratories, Inc. in Hillsboro, Oregon. This chamber has ferrite tile lining the interior walls, ceiling and the floor. This type of chamber is used regularly for Radiated

Immunity testing in accordance with IEC 1000-4-3 as well as for Radiated Emissions measurements in accordance with European draft standard prEN50147 Part 3 and European Telecommunications Standards (ETS) measurements for low power intentional radiators. Each of these facilities is equipped with Hewlett Packard spectrum analyzers and quasi-peak adapters as well as preamplifiers and antennas for use in the 30-1000 MHz frequency range. Each facility also has a turntable and power outlets, etc. to facilitate product testing.

Test Setup Geometries

The authors attempted to physically locate the emissions source at each of the nine positions described in Figure 1 for both Vertical and Horizontal Polarizations. Note that all locations were not directly achievable due to the finite size of the source and the EUT test tables in each facility but each of the nine positions were available within a tolerance of about +/- 2 cm. Care was taken to use the same mounting equipment at both facilities, so the residual effects of these practical considerations could be minimized for the comparison.

MEASUREMENT RESULTS

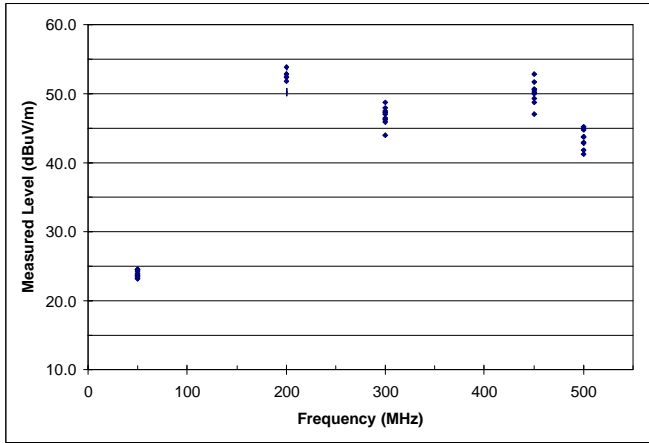
Figures 7-12 show the resulting field strength measured in each position for the fixed height Free Space chamber, Fixed height Semi-Anechoic chamber, and full 1-4m scan height semi-anechoic chamber. Table 1 summarizes these results for each type of facility. In general, the measurement results confirmed the effects predicted by the NSA analysis at the frequencies measured, showing substantially greater variations in measured field strength in the fixed height semi-anechoic case, and similarity between the fixed height free space and full scan height OATS results.

**TABLE 1 : EXPERIMENTAL RESULTS :
RANGE AND STANDARD DEVIATION OBTAINED AS A
FUNCTION OF SOURCE LOCATION WITHIN EUT
VOLUME**

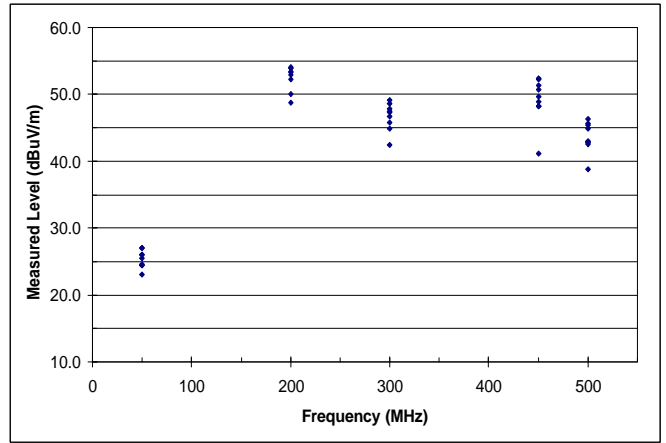
Frequency (MHz) Polarity	Fixed Height Free Space		Fixed Height Semi-Anechoic		Full Scan Height Semi-Anechoic	
	Range (dB)	s (dB)	Range (dB)	s (dB)	Range (dB)	s (dB)
50 Horiz	4.1	1.3	10.8	3.4	9.6	3.5
200 Horiz	5.2	1.8	7.7	2.4	5.3	1.9
300 Horiz	6.8	2.1	14.8	4.6	3.8	1.3
450 Horiz	11.3	3.4	24	7.5	7.6	2.5
500 Horiz	7.5	2.3	10.4	3.6	7.3	2.8
50 Vert	1.4	0.5	5.5	1.9	6.1	2.0
200 Vert	3.9	1.3	17.1	5.2	3.9	1.5
300 Vert	4.6	1.3	16.4	5.6	8.1	3.1
450 Vert	5.8	1.7	5.4	1.5	3.9	1.3
500 Vert	4.0	1.4	10.5	3.8	4.2	1.3
<i>Average</i>	<i>5.46</i>	<i>1.71</i>	<i>12.3</i>	<i>3.95</i>	<i>5.98</i>	<i>2.12</i>

Note : Range (dB) = Max (dB) - Min (dB)
s = standard deviation (dB)

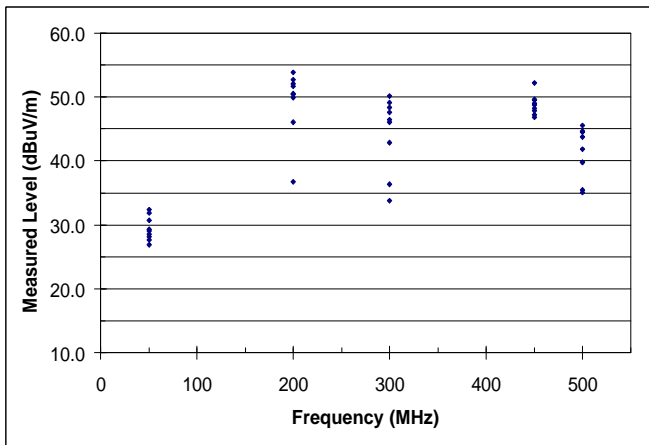
**FIGURE 7: EXPERIMENTAL RESULTS
FIXED HEIGHT FREE SPACE CHAMBER
VERTICAL POLARITY**



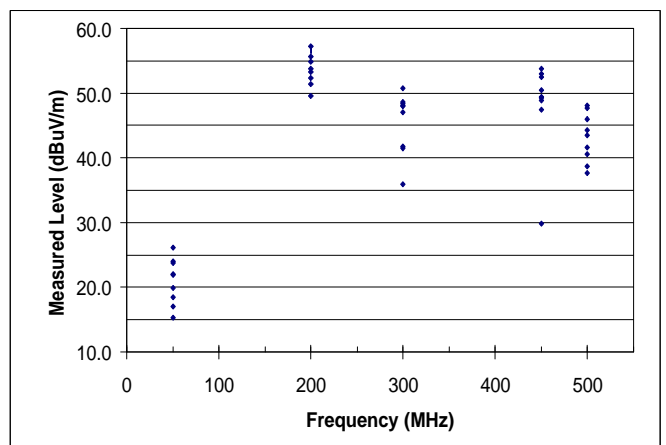
**FIGURE 8: EXPERIMENTAL RESULTS
FIXED HEIGHT FREE SPACE CHAMBER
HORIZONTAL POLARITY**



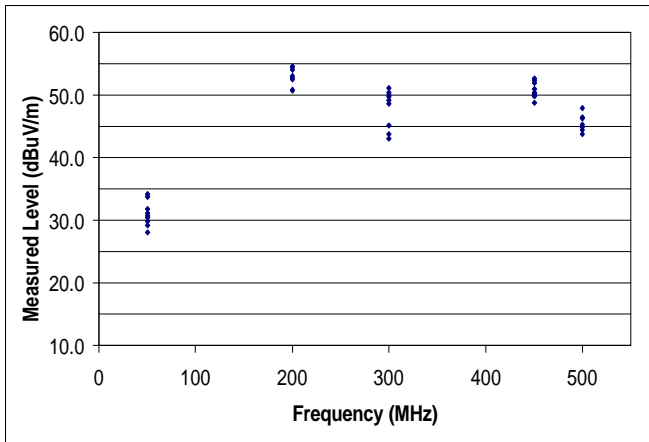
**FIGURE 9: EXPERIMENTAL RESULTS
FIXED HEIGHT SEMI ANECHOIC CHAMBER
VERTICAL POLARITY**



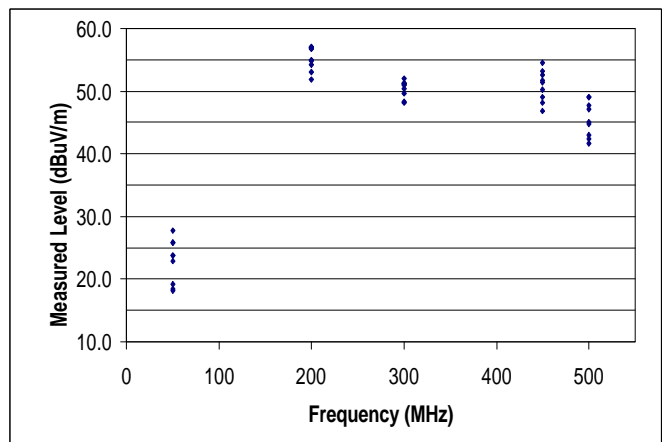
**FIGURE 10: EXPERIMENTAL RESULTS
FIXED HEIGHT SEMI ANECHOIC CHAMBER
HORIZONTAL POLARITY**



**FIGURE 11: EXPERIMENTAL RESULTS
OATS or SEMI-ANECHOIC 1-4M SCAN HEIGHT
VERTICAL POLARITY**



**FIGURE 12: EXPERIMENTAL RESULTS
OATS or SEMI-ANECHOIC 1-4M SCAN HEIGHT
HORIZONTAL POLARITY**



CONCLUSIONS:

It is generally understood that the free space environment and resulting improvements in field uniformity are advantageous for repeatability and reduced uncertainty of radiated immunity tests such as detailed in previous works and IEC 1000-4-3. This paper demonstrates that these same advantages also apply to radiated emissions measurements. The analytical and experimental methods show that using a fixed receive antenna height over a ground plane yields a large variation in the reported field strength once the source spatial location of the emissions source is considered over even a relatively small EUT volume. Since "fixed height" measurements over a ground plane are often used to select frequencies for further investigation using a proper full scan height, large errors can be presented since the difference between the fixed height results and full scan height results can vary by over 25 dB depending on the location of the emissions source. This is viewed as a significant problem for facilities that use fixed height semi-anechoic measurements to determine a frequency list for further investigation on an OATS, and a lesser but still present problem for full scan height OATS facilities since most practical OATS measurement procedures fix the antenna height during part of the investigation (such as to the theoretically predicted receive height which is based on consideration of a single source location). By contrast, a fixed height free space measurement can achieve approximately the same results as achievable by the ideal theoretical full scan height OATS, without the need to vary the scan antenna height. This suggests that free space emissions measurement techniques as described in standards such as ETS 300 series and prEN50147 part 3 present an opportunity to improve test repeatability beyond present day OATS practices. In part this is because industry has compromised the true theoretical quality of the full scan height OATS by the practical necessity of a fixed height for part of the OATS test, or the use of indoor, fixed height pre-scan facilities to generate frequency lists for further investigation.

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