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# 4.5m GTEM Characterization

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## Abstract

The Gigahertz Transverse ElectroMagnetic (GTEM) test cell propagates planar electromagnetic waves to illuminate a test object with radio frequency (RF) energy within a bounded structure. Once illuminated, the test object produces a response or a transducer measures a parameter inside the test object providing information for computing a transfer function. The transfer function informs a model or additional testing. This report documents the behavior and characterization of the GTEM. The characterization presented in this report uses measurements from electric field measurements spanning a frequency range between 100 kHz and 18 GHz. This report provides guidance for using these results to predict uncertainty of measurements conducted in the GTEM. The GTEM is slightly smaller than EMES (Electromagnetic Environment Simulator); hence, can accommodate objects almost as large as EMES. Sandia acquired the GTEM from ETS Lindgren. ETS Lindgren installed and performed the acceptance test per requirements set forth by Sandia. This document also reports some of the features of the GTEM including safety.

Weapons Systems Engineering Assessment Technology (WSEAT) commissioned this effort to provide support to Nuclear Weapons qualification in accordance with Realize Product Sub System (RPSS). Motivation for this effort stems from four qualification programs: B61 LEP, W88 ALT370, W80-4 LEP, and the Mk21 fuze program.

# ACKNOWLEDGMENTS

The authors would like to acknowledge support received in executing these measurements and performing a reviewer of this document. Reviewers for formatting and technical content include: Clare Amann, Mike Dinallo, Matt Halligan, Mark Jursich, Steve Glover, and Larry Warne.

Contents

# FIGURES

# NOMENCLATURE

| | |
|---|---|
| dB | decibel |
| DOE | Department of Energy |
| DUT | Device under test |
| EUT | Equipment under test |
| E-field | Electric field |
| EM | Electromagnetic |
| EMES | Electromagnetic Environment Simulator |
| EMP | Electromagnetic Pulse |
| EMR | Electromagnetic Radiation |
| GTEM | Gigahertz Transverse Electromagnetic |
| NW | Nuclear Weapons |
| RF | Radio Frequency |
| RPSS | Realize Product Sub System |
| SNL | Sandia National Laboratories |
| TDR | Time Domain Reflectometer |
| TEM | Transverse Electromagnetic |
| V/m | Volts per meter |
| W | Watt |

# 1. INTRODUCTION

The GTEM is a bounded structure allowing the free E-field RF illumination of test objects while confining all energy inside the boundary of the GTEM. This capability addresses the safety concern of subjecting personnel to RF energy and emissions that interfere with other systems while conducting radiated tests. Further, the facility provides a capability to test objects with high field strengths and remain compliant with rules set by the FAA and FCC. The metrics used to evaluate the performance of the GTEM, or other bounded test structure, evaluate the ability of the GTEM to simulate a free E-field environment. When RF propagates in a free-field environment, the electric and the magnetic fields are orthogonal to each other and to the direction of propagation. In a bounded structure, RF energy reflects off boundaries. The reflected energy vectorially adds to the injected energy. The consequences of these reflections are the electric and magnetic fields at any point are not necessary orthogonal or propagate in one direction. In the case of continuous wave testing, standing waves develop in the GTEM. These standing waves have peak intensity areas and low intensity areas. In some cases, reflection amplitudes are almost the same amplitude as the injected energy. When this occurs, significant energy can propagate in a direction unintended in the GTEM resulting in an environment not representative of a free space.

In this report, we document measurements that characterize the performance of GTEM in terms of free E-field performance. The major parameters used to characterize free E-field environment and the quality of GTEM are E-field uniformity and field purity. Section 5 ‘Test Requirements’ explains both uniformity and purity.

# 2. DESCRIPTION OF THE GTEM

Figure 1 shows a diagram of the GTEM. The facility is 20 meters long, 7 meters high, and 10 meters wide. The distance between the ground floor and the septum at the cones is 4.7 meters. The GTEM has one door for personnel access (1.2 by 2.1 meters) and a large equipment door (3.7 by 3.7 meters). The large equipment door design includes a zero height threshold permitting a forklift to transport heavy objects into the facility. The large hydraulically operated door is equipped with 'Bump-Guard Safety' to stop the door from closing if the door could crush an object or person. The chamber floor is capable of supporting 5080 kg.

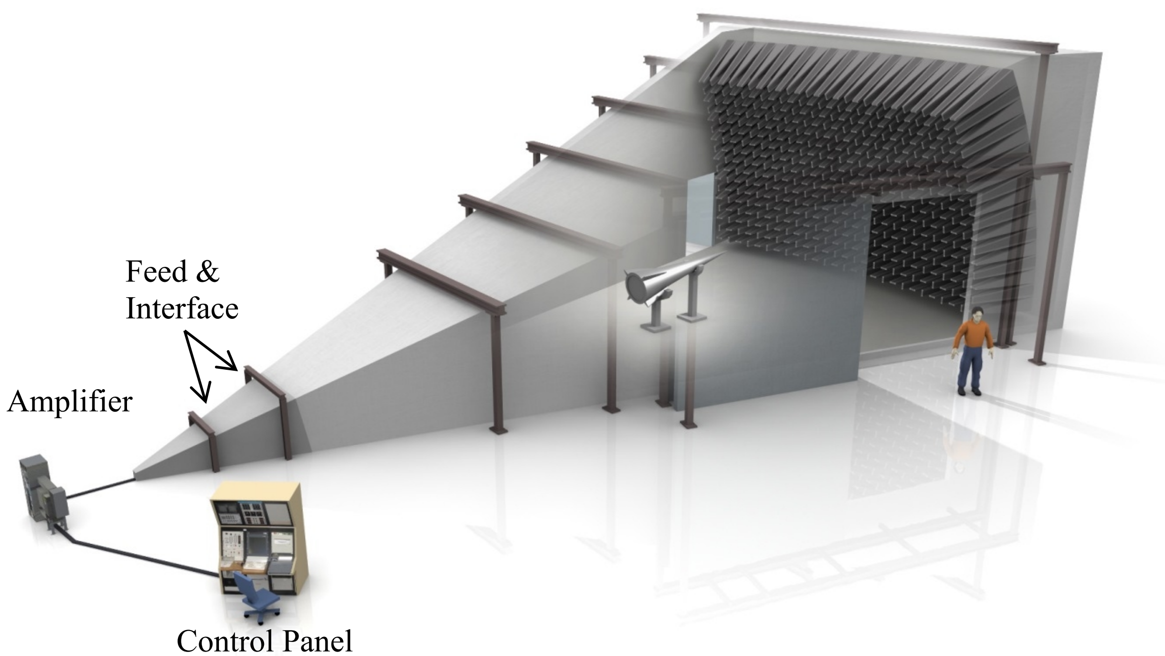



**Figure 1: GTEM Cutaway Diagram**

Kevlar straps suspend the septum from the ceiling. The straps allow adjustment of the septum height and angle. The septum angle is critical to feed placement and hence adjusted to match the high voltage feed at installation.

Safety features include interlocks on both entries. An Emergency-Stop button is located near the operator's console. Located inside the GTEM along each wall (Figure 2) are cables that activate the safety interlock when pulled. A VESDA aspirating smoke detection system detects smoke inside the GTEM. The smoke detection system interfaces the SNL fire protection system. Installation of the smoke detection system is an alternative to a fire suppression sprinkler system.

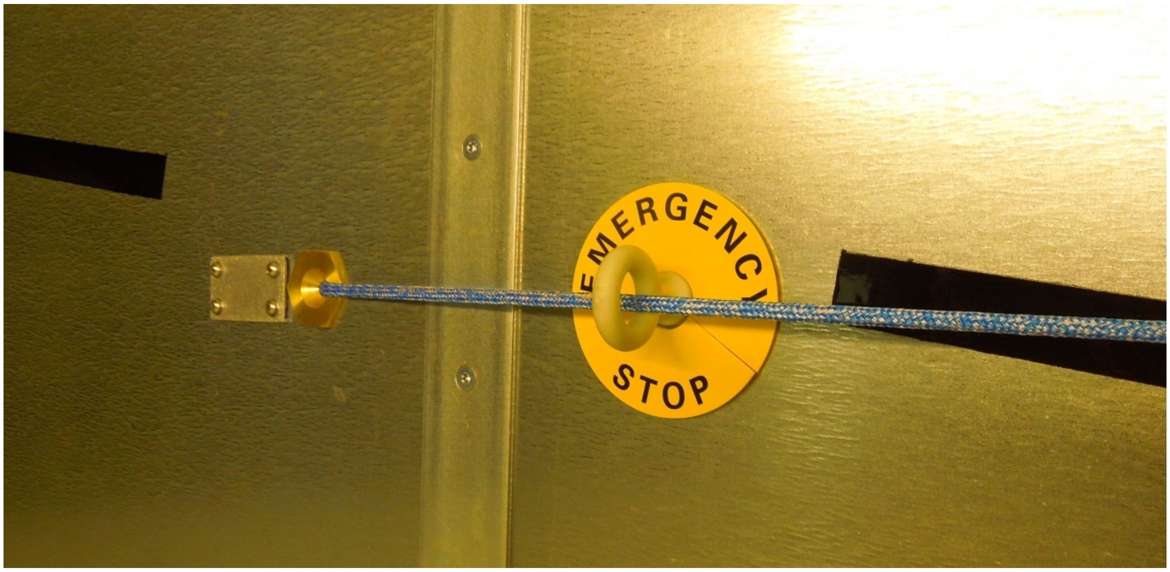



**Figure 2: Emergency Stop Located along the internal length inside each side**

## 2.1 Feed Structure

The GTEM's design includes multiple feeds to accommodate different test configurations. One feed design (Figure 3) is a continuous wave (CW) RF feed (7/16 DIN with adapter to Type N) for CW operation between DC and 18 GHz. Another, very similar RF feed rated for 5 kW, uses a 1-5/8" EIA connector and operates between DC and 250 MHz.

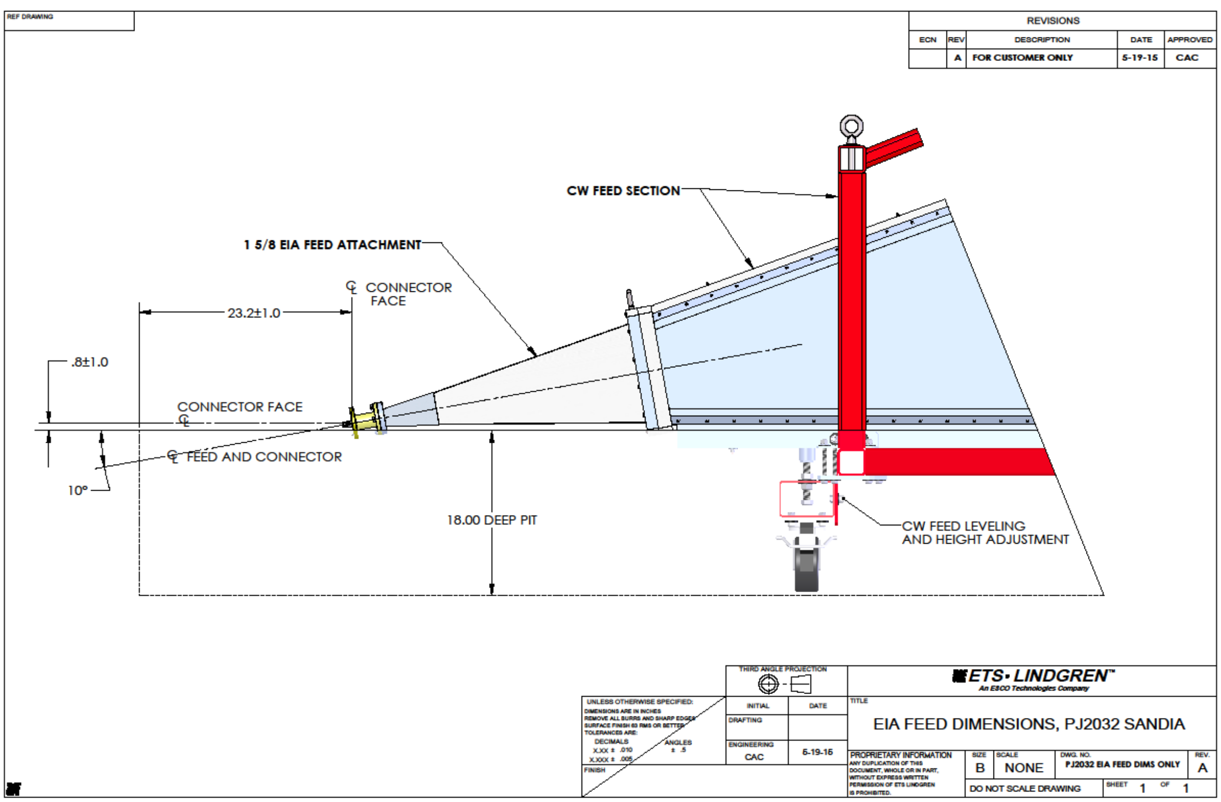



**Figure 3: Type 'N' Feed Structure**

Figure 4 shows the high voltage feed to the GTEM rated for 600 kV into 50 Ω. The high voltage feed contains 144 gallons of XIAMETER PMX-561 TRANSFORMER LIQUID from Dow Corning (silicone oil). The high voltage feed is for electromagnetic pulse (EMP) testing.

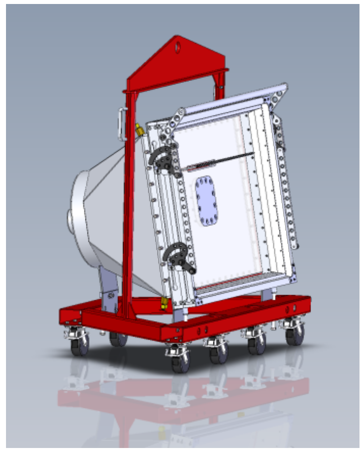


**Figure 4: High Voltage Feed**

## 2.2 Power Distribution

Two 208V / 3-phase / 30A outlets and two 110V / 20A outlets provide any equipment power needs both inside GTEM and support equipment outside the facility.

## 2.3 Ground and Isolation

A threaded brass ground stud with dimensions 1.3 cm by 12.7 cm is located near the HV feed interface. This ground stud attaches to building ground.


**Figure 5: Grounding Cable and Rod**

## 2.4 Penetration Panels

Three RF-shielded feed-thru connector panels (0.6 by 0.6 meters) accommodate diagnostic measurement equipment access to the test object and instrumentation needed to monitor the E field. The panels bolt onto the GTEM providing the capability of removal and replacement. Each panel employs the following removable bulkhead connectors: four precision N-type connectors, four SMA connectors, four APC 3.5 RF connectors, and one FiberPlex® WGF-6 18 GHz 6-channel fiber optic waveguide to support up to six LC, SC, ST, or FC connectors.

## 2.5 Termination

The GTEM employs a two element termination structures. The purpose of the structure is to absorb RF energy preventing reflections back into the GTEM thereby simulating a free E-field environment. A resistive network provides a matched termination at low frequencies. Figure 6 shows some of the 30 resistors along the end of the septum. Each resistor is a unique resistance value to optimize termination characteristic. Absorbing cones provides a match at high frequencies. Figure 7 shows the termination absorbers made of anechoic foam backed with ferrotiles. The ferrotile improve RF absorption at lower frequencies and improve cross over performance between resistors and cones.

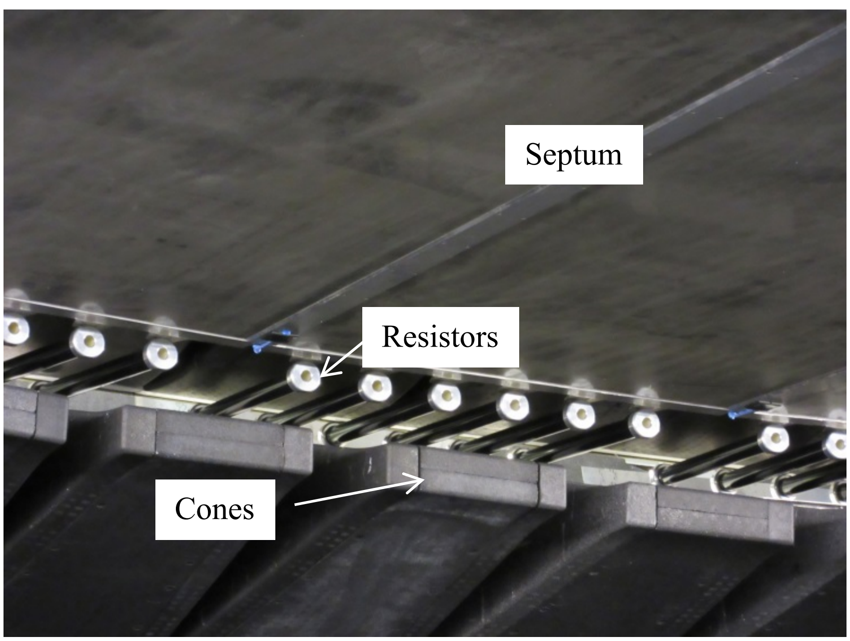



**Figure 6: Termination Resistors**

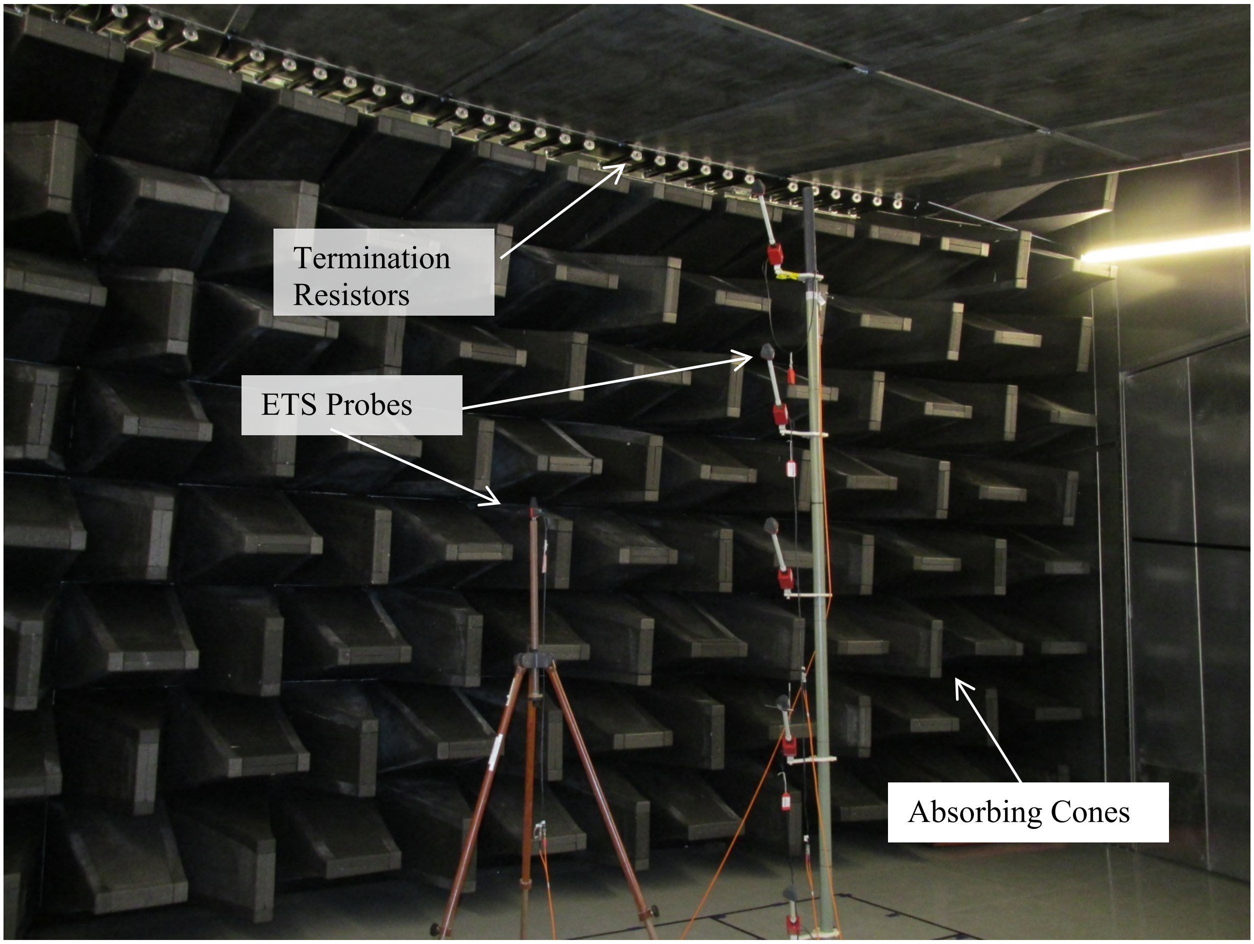



**Figure 7: Termination Absorbers**

## 2.6 Ventilation

The chamber uses eight honeycomb waveguide air vents. Each vent includes a 3 mm steel waveguide honeycomb structure. A steel frame fastens each waveguide to the chamber. The waveguides provide 100 dB of RF-shielding attenuation at 18 GHz.

**Figure 8 Air Vent**

# 3. TEST OBJECTIVES

The overall objective of this effort is to collect information in order to understand E field variations and quantifying the uncertainty of the E field. Corporate Procedure: CG100.6.20[1] Achieve Quality and Mission Success establishes requirements for a measurement assurance plan (MAP). The MAP requirement appears in Requirements Table “Integrate Quality Related Requirements into Workflows, Products, Processes, and Services” Step 2. These requirements are part of the Realize Product Sub System

To meet the overall objective this report provides a measure of the following parameters:

1. Uniformity
2. Purity

These parameters provide an understanding of measurement uncertainty in the GTEM. This document also reports VSWR at input to the GTEM. Although VSWR is not a metric of the E-field behavior, it does influence GTEM performance.

[1] https://info.sandia.gov/cps/corporate_governance/policy/processes/procedures/CG100.6.20.html

# 4. TEST SETUP

## 4.1 Test Grid Pattern

Figure 9 shows the grid pattern used to collect data. Test results are in a section later in this report. Five E field probes at different elevations recorded the E-Field at each position shown in the diagram. Paragraph 4.2 describes the probe configuration.

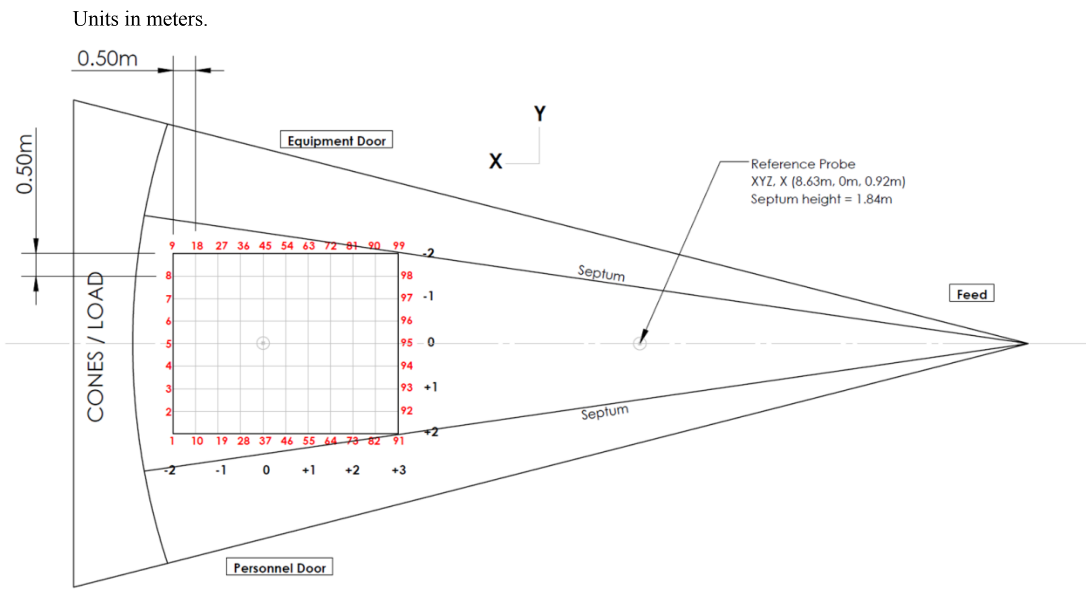



**Figure 9: Characterization Test Grid, dimensions are in meters, x is the radial direction**

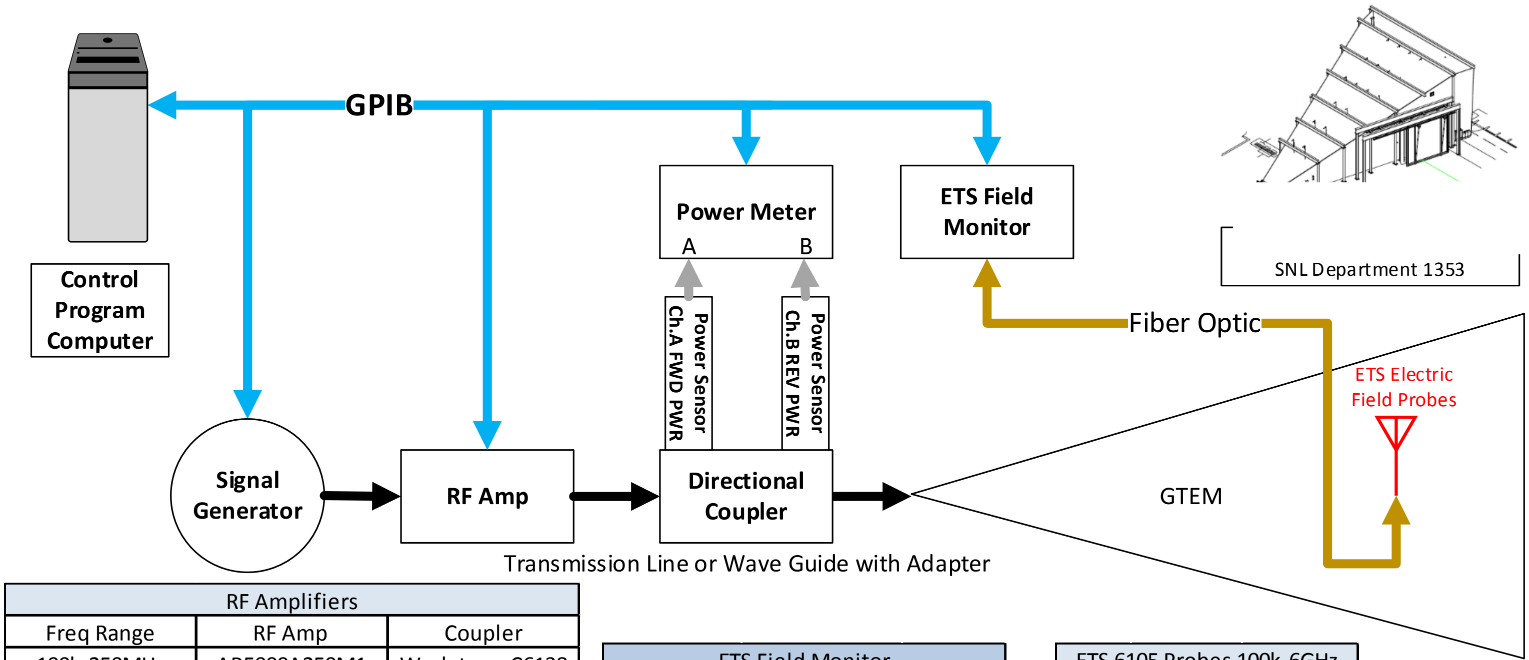
## 4.2 Test Equipment

Figure 10 shows the probe stand for high frequency testing. The HI-6153 probes collected E-field measurements for testing above 6 GHz. The low frequency probes, HI-6105 were on a similar stand for testing below 6 GHz. The probes heights divided the vertical dimension to achieve even distribution. The septum height is dependent on distance from the cones; hence, as the probe stand moved, each, probe height also moved to maintain evenly vertically spaced probes at each location. A reference probe close to the feed port provided a measure of the E-field at a single location for all test. The reference probe is the same as the other probes. The reference probe provided confirmation of consistent chamber operation over the numerous measurements taken.

ETS Probes

**Figure 10: HI-6153 Probe Stand**

Figure 11 illustrates the full instrument setup for the effort. Due to bandwidth limitations of the amplifiers, data acquisition divides into 6 bands. Although the GTEM operates down to DC, the amplifier limited the lowest frequency measured to 100 kHz.




| RF Amplifiers | | |
|---|---|---|
| Freq Range | RF Amp | Coupler |
| 100k-250MHz 5kW | AR5000A250M1 S/N 308776 | Werlatone C6138 S/N 11578 |
| 200M-1GHz 1kW | AR1000W1000BM1 S/N304641 | Werlatone C5044 S/N 11539 |
| 1-2.5GHz 1kW | AR1000W1G2BM4 S/N 305497 | Werlatone C5070 S/N 11934 |
| Low 2.5-4GHz 1kW | AR1000T2G8BM5 S/N 340232 | MEC R203-50-N S/N 111 |
| High 4-7.5GHz 1kW | AR1000T2G8BM5 S/N 340232 | MEC R203-50-N S/N 130 |
| 7.5-18GHz 1kW | IFIT188-1000-4 S/N S1768-1214 | MDC 12750-249 S/N 3398 |

| Agilent Power Meter / Sensor | | |
|---|---|---|
| Model | Serial | SNL Cal # |
| E4417A EPM-P | MY54336007 | 6662329 |
| E9304AH18 | MY5433002B | 6663956 |
| E9304A Opt. H18 | US3900766 | 6568732 |

| ETS Field Monitor | | |
|---|---|---|
| Model | Name | Serial |
| HI-6100 | Field Monitor | 200461 |
| H491273 | Ch1 Laser Mod | 202509 |
| H491273 | Ch2 Laser Mod | 2022801 |
| H491273 | Ch3 Laser Mod | 202748 |
| H491273 | Ch4 Laser Mod | 202754 |
| HI-6100 | Field Monitor | 200467 |
| H491273 | Ch5 Laser Mod | 200324 |
| H491273 | Ch6 Laser Mod | 202595 |

| HP/Agilent Signal Generator | | |
|---|---|---|
| Model | Frequency | Serial |
| 8648C | 9k - 3.2 GHz | 3847A4747 |
| E8257D | 250M - 50GHz | MY51501162 |

| ETS 6105 Probes 100k-6GHz | | |
|---|---|---|
| Z | S/N | SNL Cal # |
| 5 | 86893 | 6667407 |
| 4 | 69661 | 6661880 |
| 3 | 102910 | 6662169 |
| 2 | 192911 | 6666217 |
| 1 | 108304 | 6667408 |
| Ref. | 58601 | 6562418 |

| ETS 6153 Probes 10M-40GHz | | |
|---|---|---|
| Z | S/N | SNL Cal # |
| 5 | 161704 | 6665315 |
| 4 | 84500 | 6667409 |
| 3 | 104585 | 6668010 |
| 2 | 201426 | 6666417 |
| 1 | 110426 | 6658773 |
| Ref. | 161705 | 6665314 |

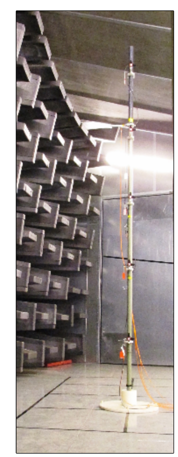

Probe Stand

**Figure 11: Instrumentation Setup**

## 4.3 Measurement Process

For each measurement, a LabVIEW™ program controlled all the instruments shown in . The test operator placed the probe stand at one location defined by the test grid of Figure 9. Five probes on the test stand divided the height of the septum into six even spaces. As the test stand moved from the cones to the feed, their height changed to maintain the equal spatial distribution between the floor and septum. The program set the forward power injected into GTEM and stepped through all the frequencies of one frequency band. When testing completed for a single point, the operator placed the probe stand at the next test location and restarted the LabVIEW program. This continued until the operator collected data from all test locations.

Due to the necessity to use more than one amplifier, the operator connected a different amplifier for the six different bands and repeated the actions describe in the previous paragraph.. In addition to amplifier changes, the operator used the appropriate E-field probe for each of the tests. The lower frequency probe (HI-6105) had a maximum capability of 6 GHz. The high frequency probe (HI-6153) had a low frequency capability of 10 MHz.

# 5. TEST REQUIREMENTS

There is no SNL instruction establishing testing requirements for the GTEM. In this effort, we use industry standard IEC 61000-4-20 (Electromagnetic compatibility (EMC) – Part 4-20: Testing and measurement techniques – Emission and Immunity) as a guide and source for good practices. Testing included three measurements: 1) uniformity 2) purity and 3) VSWR. The following describes these properties.

## 5.1 Field Uniformity

IEC 6100-4-20 defines field uniformity as follows. Uniformity[2] is the variance of $E_i$ for N test points in a given plane orthogonal to the intended direction of propagation. Using at least 75% of test points in the plane, the primary field component shall fall within a range of 6 dB. This is applied to the E-field uniformity equations (Equation 1) to give an expected standard deviation less than or equal to 2.61 dB.

$$\text{Mean: } \bar{E} = \frac{1}{N}\sum_{i}^{N} E_i$$

$$Variance: {\sigma_E}^2 = \frac{1}{N-1}\sum_{i}^{N}\left(E_i - \bar{E}\right)^2$$

$$\bar{E} - k\sigma_{\bar{E}} \leq E_i \leq \bar{E} - k\sigma_{\bar{E}}$$

$$k = 1.15\ corresponding\ to\ a\ probablity\ of\ 75\%$$

**Equation 1. Field Uniformity Calculation**

## 5.2 Field Purity

Using the same area definition for uniformity, purity[3] is a measure of the magnitudes of the secondary (unintended) E field components compared to the primary component of the E field (Equation 2). The secondary components are required to be 6 dB below the primary component, over at least 75 % of test points in the defined cross-section. The tested points are located in a cross-section of the TEM waveguide (perpendicular to the propagation direction). For the 75% test points, a primary E field component range greater than 6 dB up to +10 dB, or a secondary E field component level up to –2 dB of the primary field component, is allowed for a maximum of 5 % of the test frequencies, provided the actual tolerance and frequencies are stated in the test reports. The frequency range is 30 MHz up to the highest frequency of intended use of the waveguide. The first frequency step shall not exceed 1 % of the fundamental frequency and

[2] IEC 61000-4-20 (5.2.3.3)
[3] IEC 61000-4-20 (5.2.1)

thereafter 1 % of the preceding frequency between 80 MHz and 1000 MHz, 5 % below 80 MHz and above 1,000 MHz.

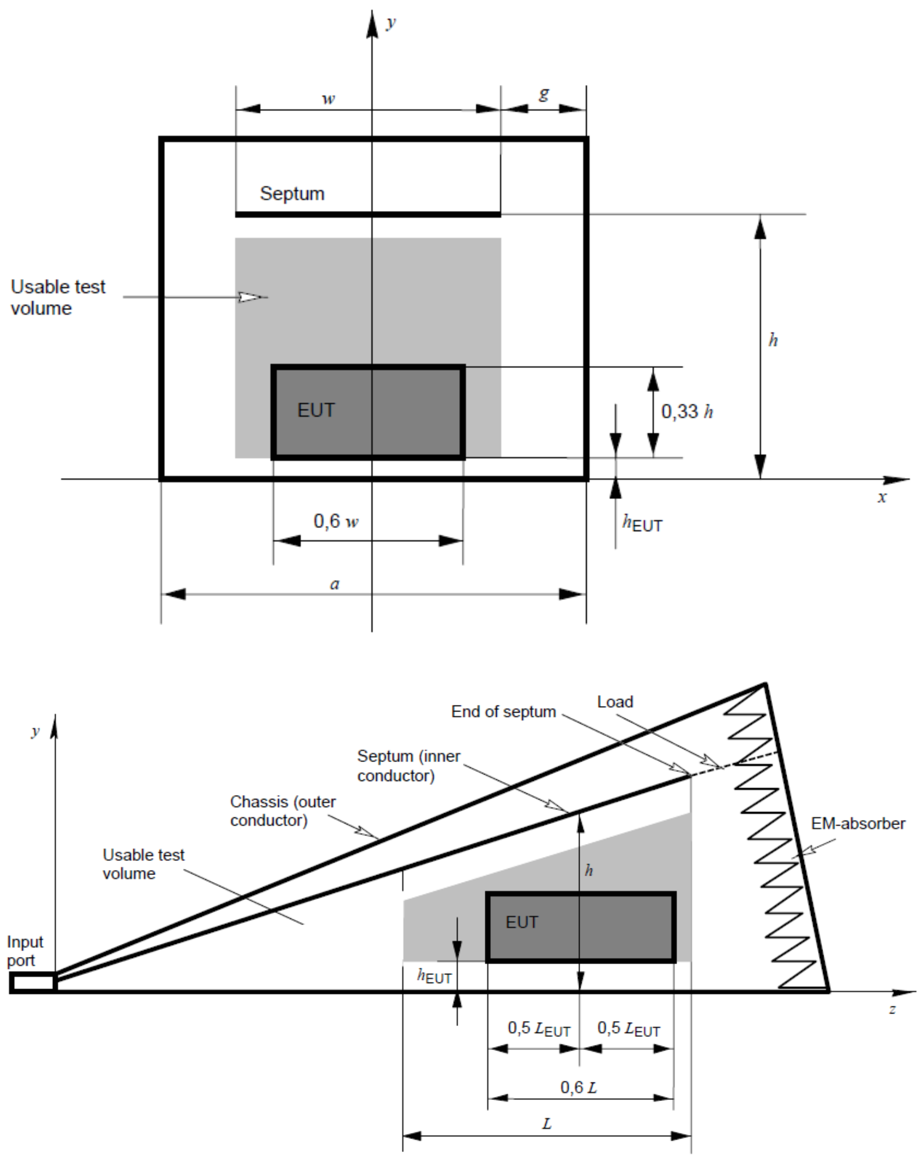
$$\text{Purity} = 20\log_{10}\left(\frac{E_{primary}}{E_{\text{secondary}}}\right)$$

**Equation 2. Field Purity Calculation**

## 5.3 Usable Test Volume

Usable test volume is a bit of a misnomer. What is really of interest is a ‘uniform area” which is a hypothetical area where variations of the E-field magnitude are acceptably small. However, an accumulation of the usable areas can define usable volume. The intended propagation direction is orthogonal to the uniform area (transverse plane). In the plane, the entire cross-section of the usable test volume has to fulfil the requirements of the uniformity criteria previously defined in this report. The minimum distance between the test object and each conductor or absorber of GTEM (see Figure 12 Useful Operating Volume extracted from [1]) is the distance between the boundary of the uniform area and the conductor. The distance between the test object and the floor of GTEM should be larger than 0.05 h (see Figure 12 Useful Operating Volume for h) to avoid a possible change of test object operational behavior due to close coupling between the test object and the floor conductor.

The usable test volume defines the maximum test object size. The test object shall be less than or equal to 60 % of the width of the septum and 60 % of the length of the septum. Note that the septum width is a function of position in the chamber. Therefore, if an object is close to the feed its allowed width is less than if the object is close to the termination. The maximum test object height is one—third the height of the septum. Again, the height depends on location along the length of the septum.




Test object label is EUT

**Figure 12 Useful Operating Volume**

## 5.4 VSWR

VSWR is a parameter used to characterize the impedance match between two objects at their interface. Historically VSWR arose from the availability of instrumentation used to execute measurements on waveguides. Ultimately, the important parameter is the quality of impedance matching, which influences the quality of energy transfer between two systems. To understand these relationships refer to the equation

$$Reflection\ Coefficient: |\rho| = \frac{VSWR - 1}{VSWR + 1}$$

**Equation 3. Reflection coefficient**

The amount of energy reflected back to the source from the load is the return loss defined by

$$Return\ loss:\ -20\log|\rho|$$

**Equation 4. Return Loss**

VSWR does not give an indication of the uniformity or purity, but it does indicate how well energy transfers from the power source and the GTEM.

## 5.5 TDR

An important consideration for any facility used for RF measurements is the amount of energy injected into the facility. Transducers require a minimum amount of energy to produce a signal strong enough for instrumentation to detect and produce a reliable and accurate representation of the parameter measured. The amount of power injected into the GTEM is a function of power available and power rejected. Power amplifiers primarily determine the RF power available. The impedance match between the amplifier and the GTEM determines how much of the available the GTEM rejects. Further, one can think of the GTEM as a transmission line. As such, one can quantify the return power from any location within GTEM. To accomplish this assessment, a Time Domain Reflectometer (TDR) measurement at the input to GTEM provides the amount and location of reflected energy. TDR results are in the result section of this report. There is no requirement associated with this parameter in the IEC standard. However, high reflection in the facility directly influences other parameters that are part of the standard.

# 6. RESULTS

This section presents results from the GTEM acceptance and characterization test series. The E-field at a point in the GTEM is a function of power injected and height of the septum at the point of the measurement (Equation 5). Equation 6 computes the normalized results in this report. Normalization reduces the effects of injected power variations across all measurements. This step is necessary to accommodate the large variation in forward power.

$$E\left(\frac{V}{m}\right) = \frac{\sqrt{P(W) * Z_o(\Omega)}}{h(m)},$$

$$\text{where } P \text{ is the injected power in watts,}$$
$$Z_o \text{ is characteristic impedance of the chamber,}$$
$$\text{and } h \text{ is the height of the septum at the point of the electric field}$$

**Equation 5. Expected E field for a given power and septum height**

$$\frac{E\left(\frac{V}{m}\right)}{\sqrt{P(W)}} = \frac{\sqrt{Z_o(\Omega)}}{h(m)}$$

**Equation 6. E field normalized to square root of net power**

The coordinate system and labels are as follows: vertical refers to the case where the electric field is vertical; horizontal is the case where the electric field is orthogonal to the vertical field and the length of the GTEM; and radial is orthogonal to both the vertical and horizontal directions and follows the direction along the centerline of the GTEM. The data presented in subsequent sections use slices of these data representing planes of propagation. The radial = 0 plane consist of 25 probe measurements each with three orthogonal components. On the first line of Figure 13 is all the data measured at each location. The second row of plots shows data normalized to input power reducing measurement variation caused by run-to-run input power differences. Note the improved flatness at the upper frequency range. Finally, the third row shows the mean normalized standard deviation of the normalized data. The intended vertical component shows much less variation than the horizontal and radial components. In particular, the horizontal component shows a significant spread. In the second row of plots, a reference line indicates the expected vertical E-field in a TEM cell centered between the septum and floor and centered across the width of the septum per Equation 6. In a true free field environment, the horizontal and radial E-fields values should be at least 20 dB less than the vertical value. All 25 vertical probe locations are close to the expected value across the full frequency range, although with greater variation at the higher frequencies[4]. Above 1 GHz, the normalized E-field plot for the vertical component fluctuates significantly. This results indicates it is important to monitor the actual E-field value above 1 GHz

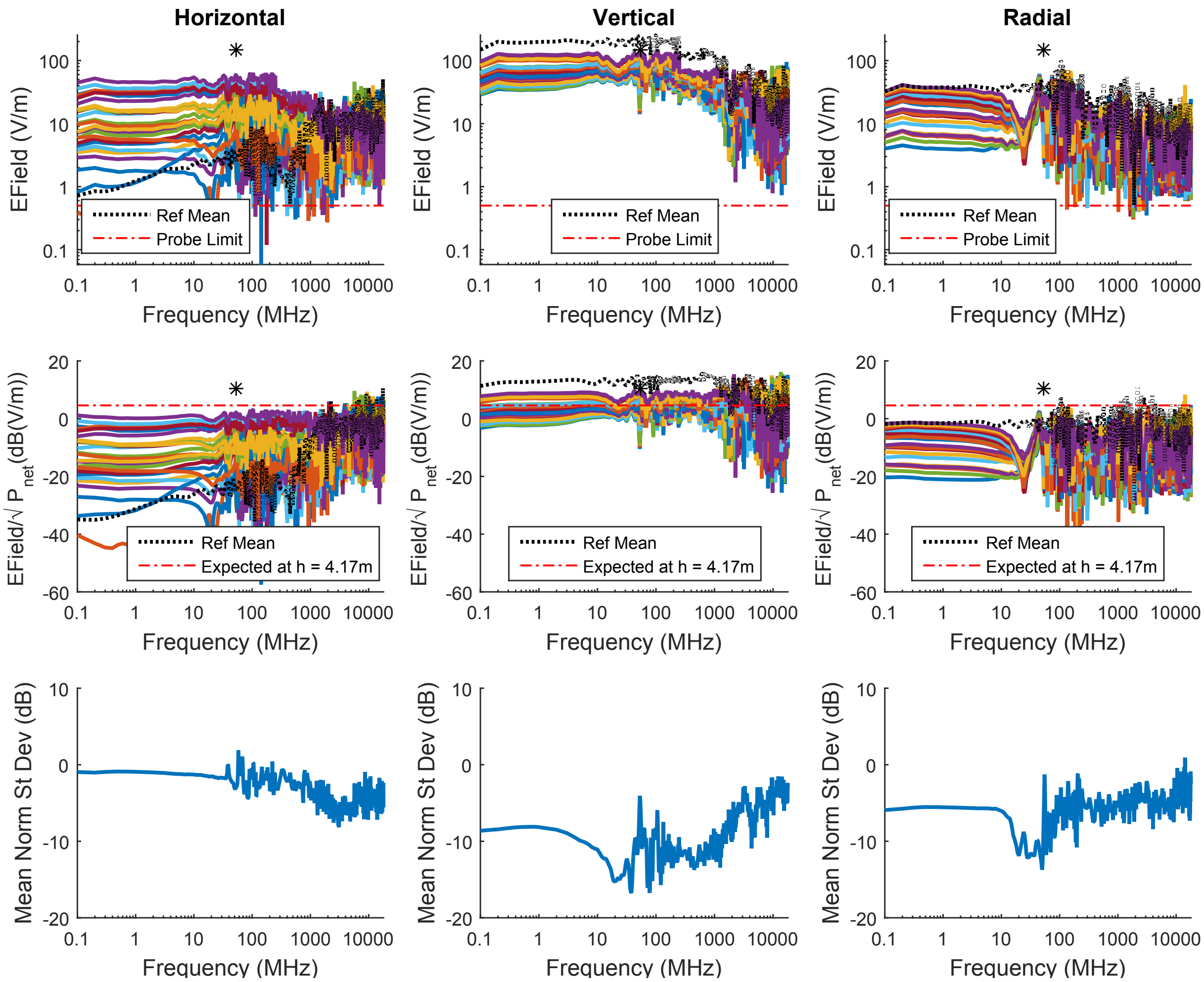



**Figure 13: All Measurements Taken in Radial = 0 Plane**

[4] The input power drops quite a bit at the high frequencies compared to the lower frequencies. The reason is twofold. The power available from the high frequency amplifies was less than the lower frequency amplifiers. The insertion loss into GTEM increased with increasing frequency.

As mentioned previously, a reference probe measured the E-field at a fixed location for every data run to verify run-to-run consistency. Figure 14 shows results in the same format as Figure 13. This data maintains a high level of consistency across the full frequency range, showing the variation between runs of the GTEM is very low. It is worth stating that this location, near the feed, also showed significant field variation above 1 GHz.

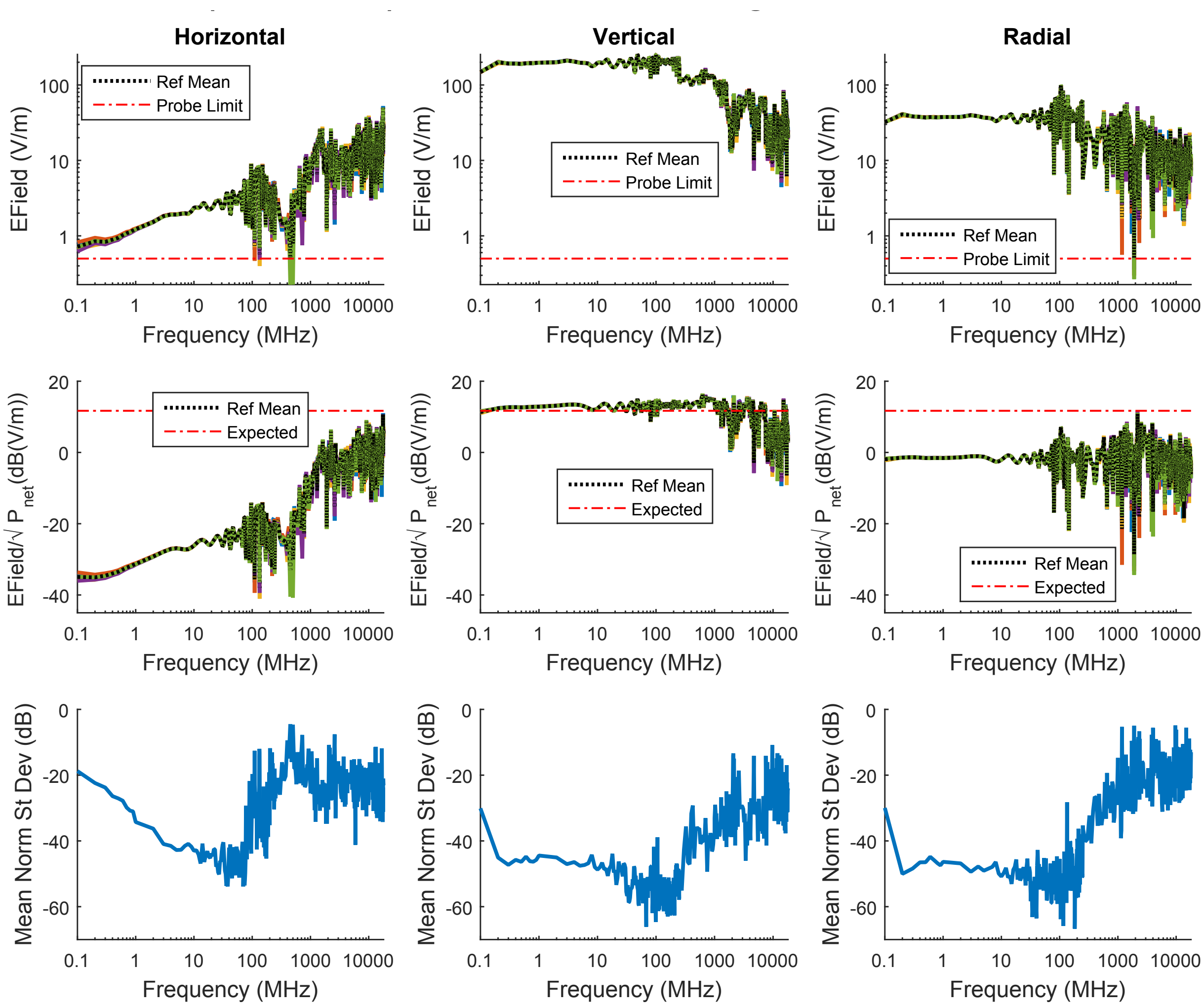



**Figure 14: Reference Probe Data for all Radial = 0 Measurements**

Figure 15 shows E-field distribution, at a single frequency, at individual points in plane radial = 0.. The top row of plots shows the reference probe data with a dot at the frequency of the data. The bottom row shows the individual measurements at each location for each component. The vertical component shown in the middle is dominant at all heights. The horizontal component is very low in the center, with increased fields towards the edges as the E-field curves around the septum. The radial component amplitude is consistently 12 dB less than the vertical component, between 100 kHz and 100 MHz. The different lines in the diagrams represent the reads take at a specific height. The dotted line at about $5\ dB\left(\frac{V}{m\sqrt{watt}}\right)$ is the expected E-field value.

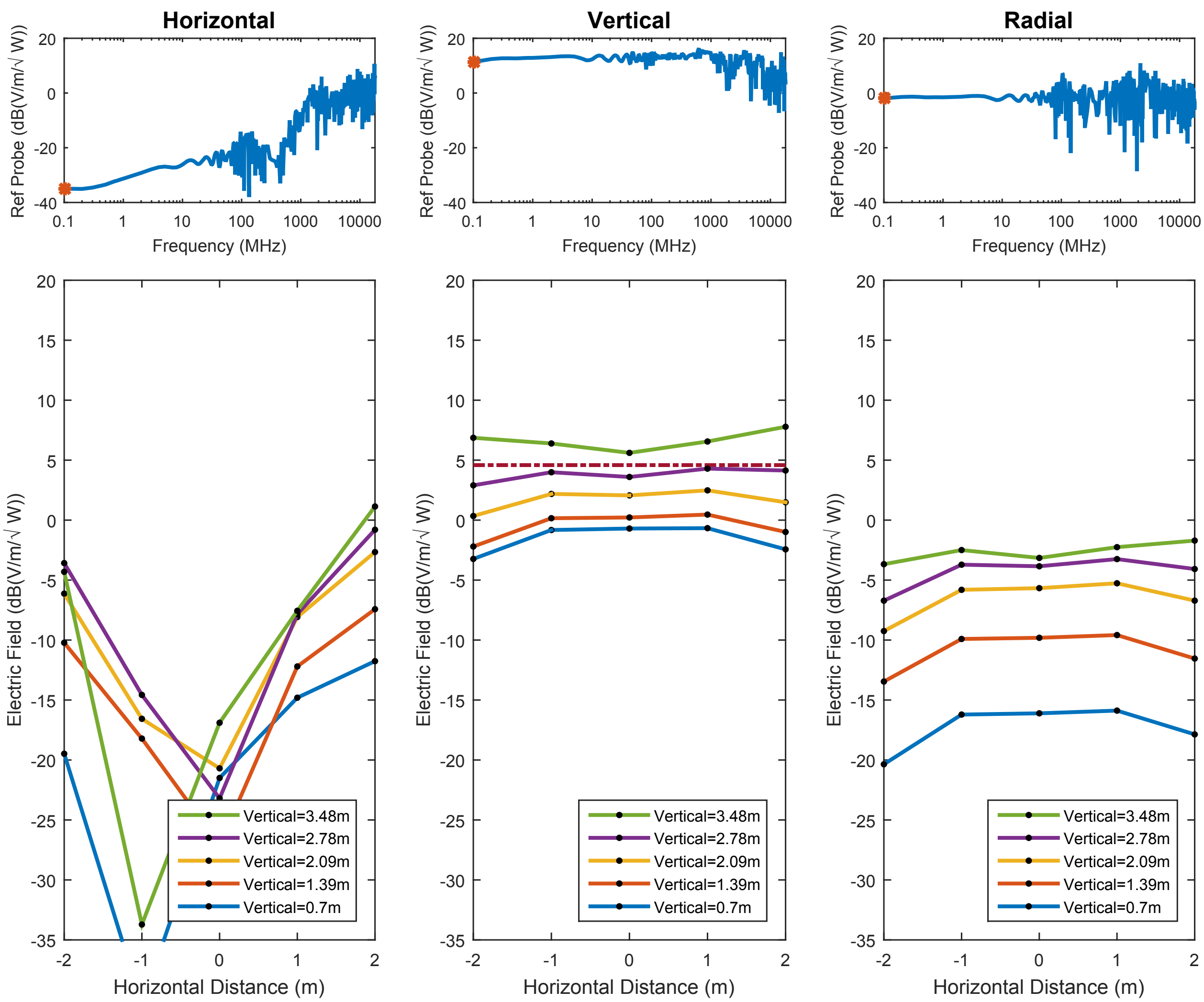



**Figure 15: Field Distribution across Large Area, Radial = 0 Plane at 100kHz**

Figure 15 shows a large spread in measurement results especially the horizontal component. These results demonstrate the significances of the test object size and placement in the chamber. The E-field at height 3.48 m is 7 dB higher compared to height 0.7 m. Later results will show that E-field variations are not nearly as pronounced as shown here for smaller volumes. The radial E-field component is in the direction between the feed and the termination. The horizontal E-field component is horizontal to the floor and orthogonal to the radial E-Field. Vertical components are orthogonally to the floor and radial component in the GTEM. The septum angle is about 15$^{o}$ relative to the floor. Hence, the vertical E-field is not exactly vertical to the floor except at the floor and is 15$^{o}$ relative to the floor at the septum. The E-field is spherical. The slight angle presents less than 4% error in expect vertical E-field at any height in the GTEM.

Figure 16 shows the cross polarization of the measured fields, the horizontal and the radial component, and the composite of the two. This shows that at about 40 MHz the radial field is equal to the intended vertical field. Recall this is for all the data in a single plane located at reference location radial = 0. At higher frequencies, the cross-polarization of the E-field may be greater than 20 dB above the intended vertical component.

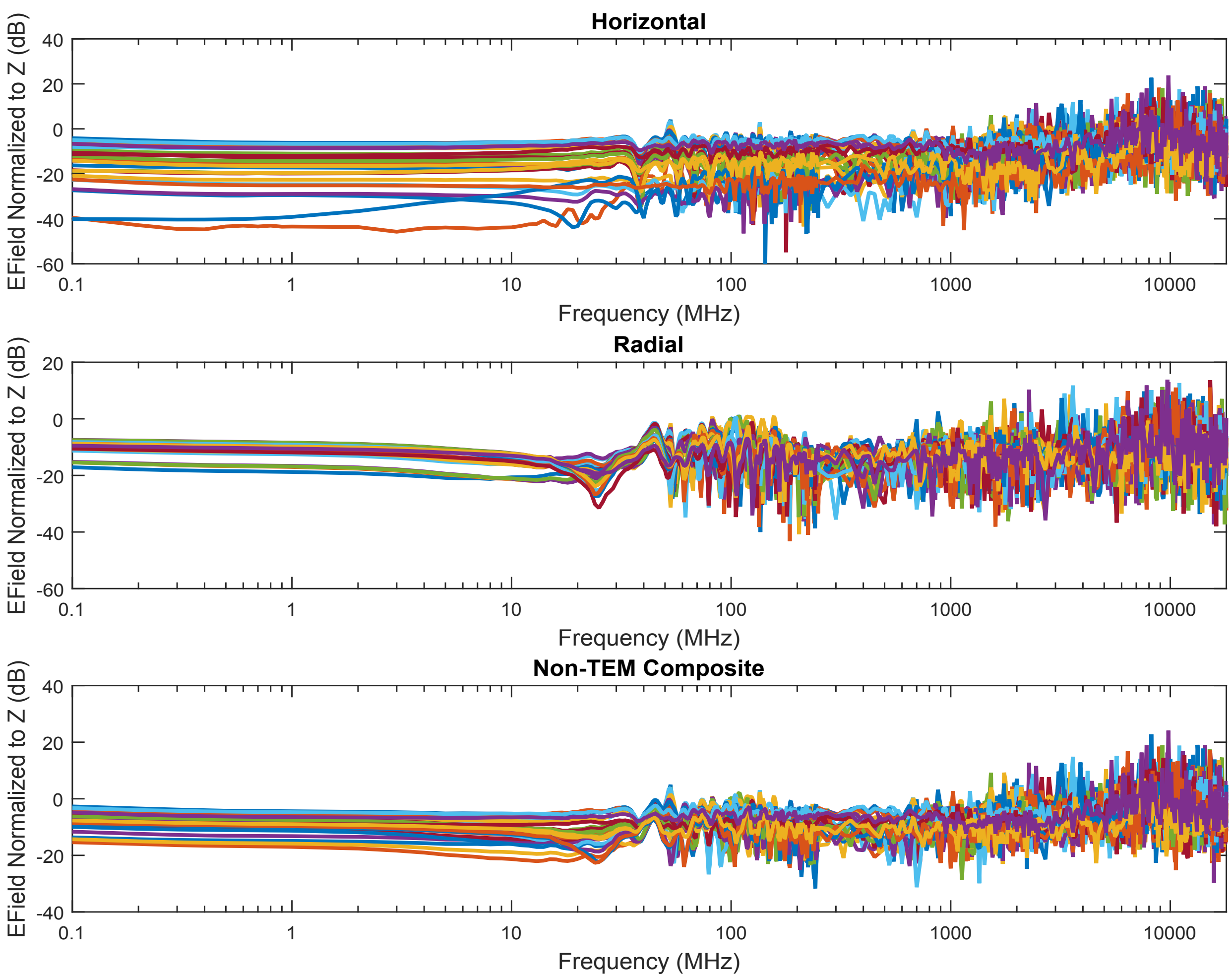



**Figure 16: Polarization of Data Taken in Radial = 0 Plane at 40 MHz**

## 6.1 Uniformity

A plane wave propagating in the radial direction illuminates the test article. Data processing divides the data into individual planes orthogonal to the intended radial propagation. This test series collected data for planes located at radial locations shown in Figure 9 (-1, 0, 1, and 2 meters from the absorbent cones). The size of the plane influences uniformity. This report presents two volumes. The large volume consists of five test points both horizontally and vertically in the plane at horizontal location -2, -1, 0, 1, and 2 and vertical locations dependent on the septum height, at heights of $\frac{1}{6}h$, $\frac{2}{6}h$, $\frac{3}{6}h$, $\frac{4}{6}h$, and $\frac{5}{6}h$. The smaller volume consists of three test points horizontally and vertically at horizontal location a -1, 0, and 1 and vertical locations at heights of $\frac{2}{6}h$, $\frac{3}{6}h$, and $\frac{4}{6}h$.

Figure 17 shows field uniformity plots for all large planes orthogonal to the radial direction. Per IEC 61000-4-20, 75% of the points (measured in dB (V/m)) shall lie within a range of 6 dB, allowing no more than 5% of the frequency points to exceed 6 dB but not above 10 dB. This is equivalent to calculating a standard deviation of all measured points within 2.61 dB (Equation 1). The standard deviation was calculated using all data points measured in dB (V/m). Per this metric, the GTEM is acceptable up to 50 MHz. We use the standard as a guide and have no requirement to meet this standard.

Figure 18 shows the same results as Figure 17 except for a smaller area. The difference between the two results illustrates the impact of volume size. The smaller area exceeds the standard requirement at about 130 MHz.

$$\text{Difference} = E_{max}\left[dB\left(\frac{V}{m}\right)\right] - E_{min}\left[dB\left(\frac{V}{m}\right)\right]$$

**Equation 7. Field difference calculation**

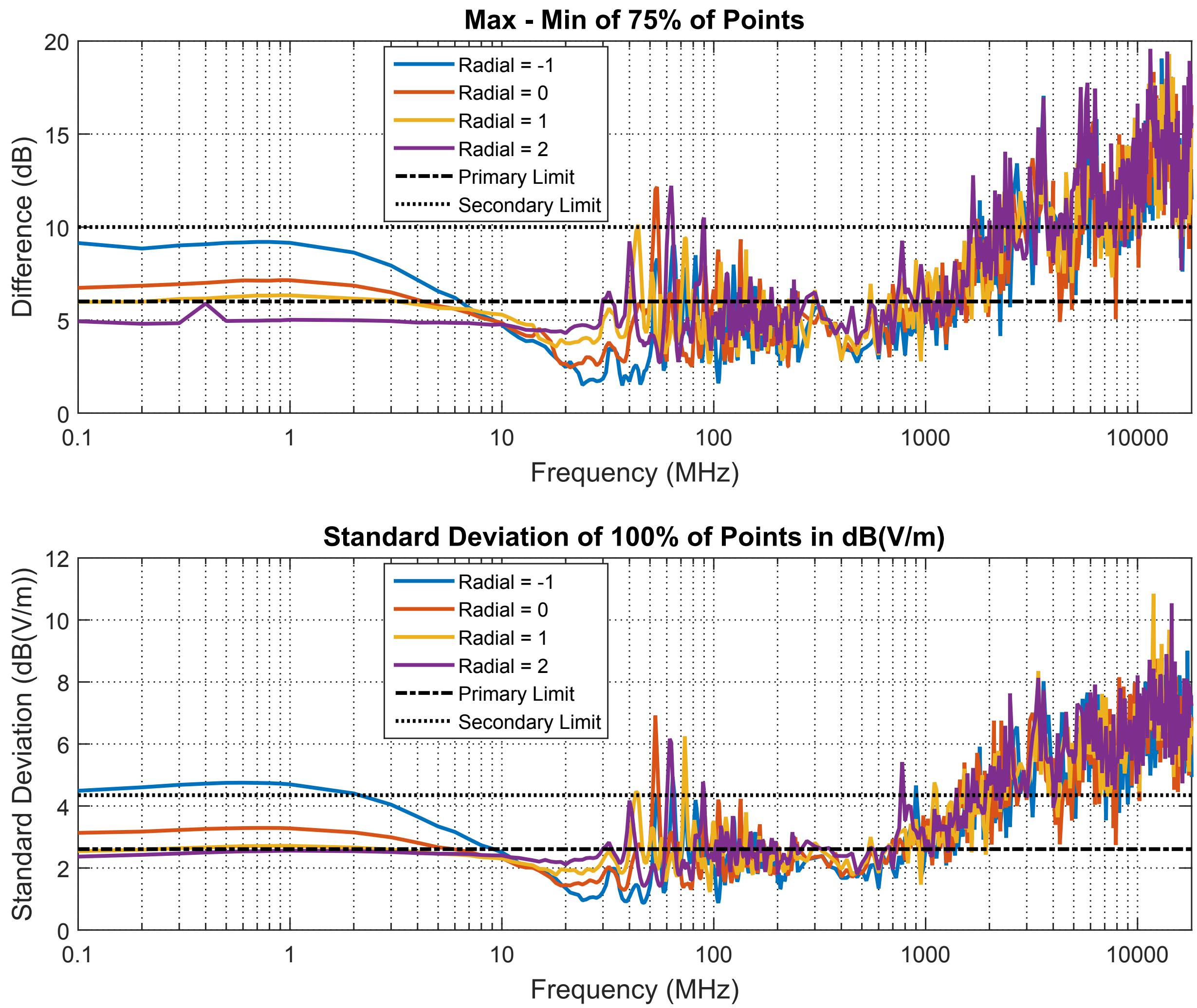
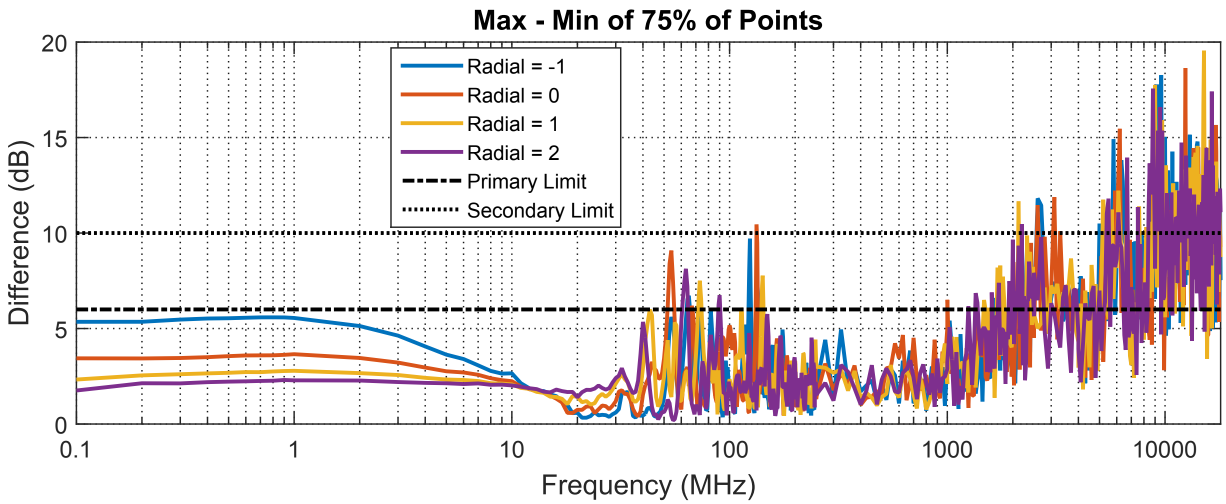



**Figure 17: Field Uniformity for Large Planes in GTEM**



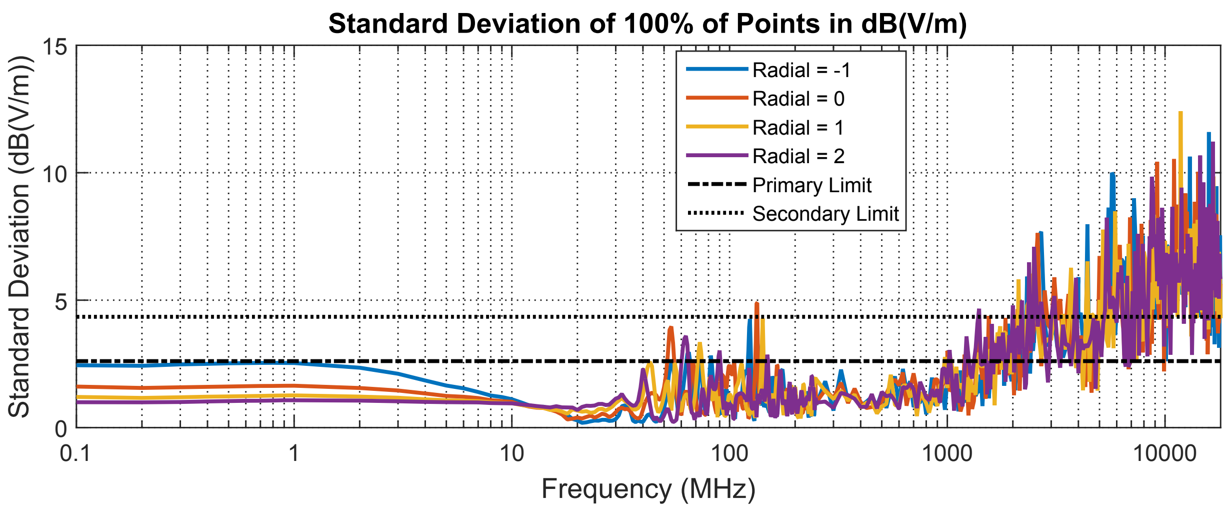




**Figure 18: Field Uniformity of Small Area**

## 6.2 Purity

Section 5.2 defines purity. The purity results not only quantify the uncertainty of GTEM for the purpose of RPSS, it also provided the information for acceptance of GTEM.

IEC 61000-4-10 states of the 75% of data, the secondary component should not exceed -6 dB of the primary component, with no more than 5% of frequency points up to -2 dB of the primary component. Figure 19 shows both the horizontal and radial components field purity per Equation 8. Per this metric, the GTEM meets the requirements up to roughly 40 MHz for the large area. Figure 20 shows purity results for a smaller volume. Comparing the two results illustrates the consequence of different volumes.

$$Purity = E_{secondary}\left[dB\left(\frac{V}{m}\right)\right] - E_Z\left[dB\left(\frac{V}{m}\right)\right]$$

**Equation 8 Field purity calculation**

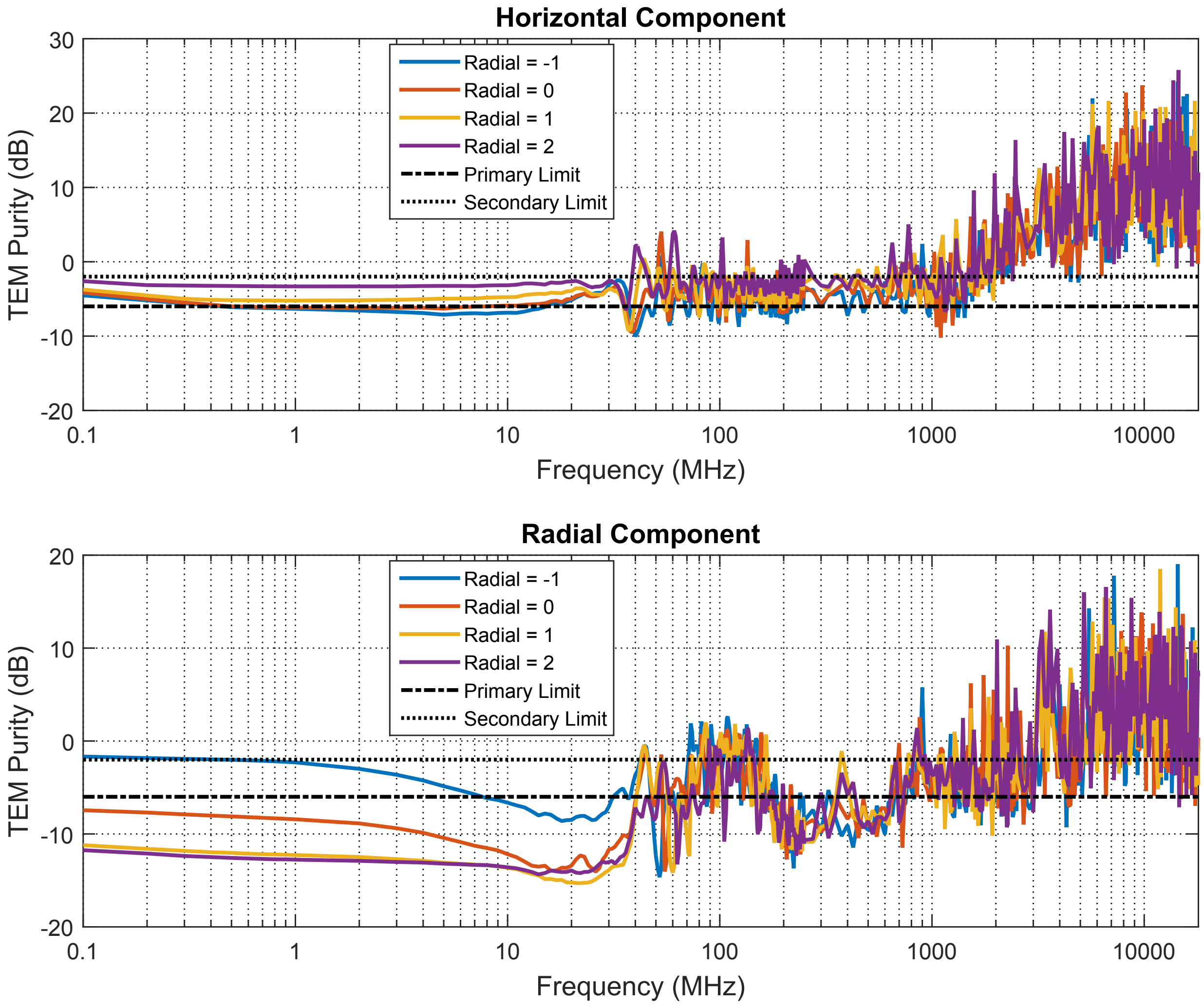



**Figure 19: Field Purity for Large Planes in GTEM**

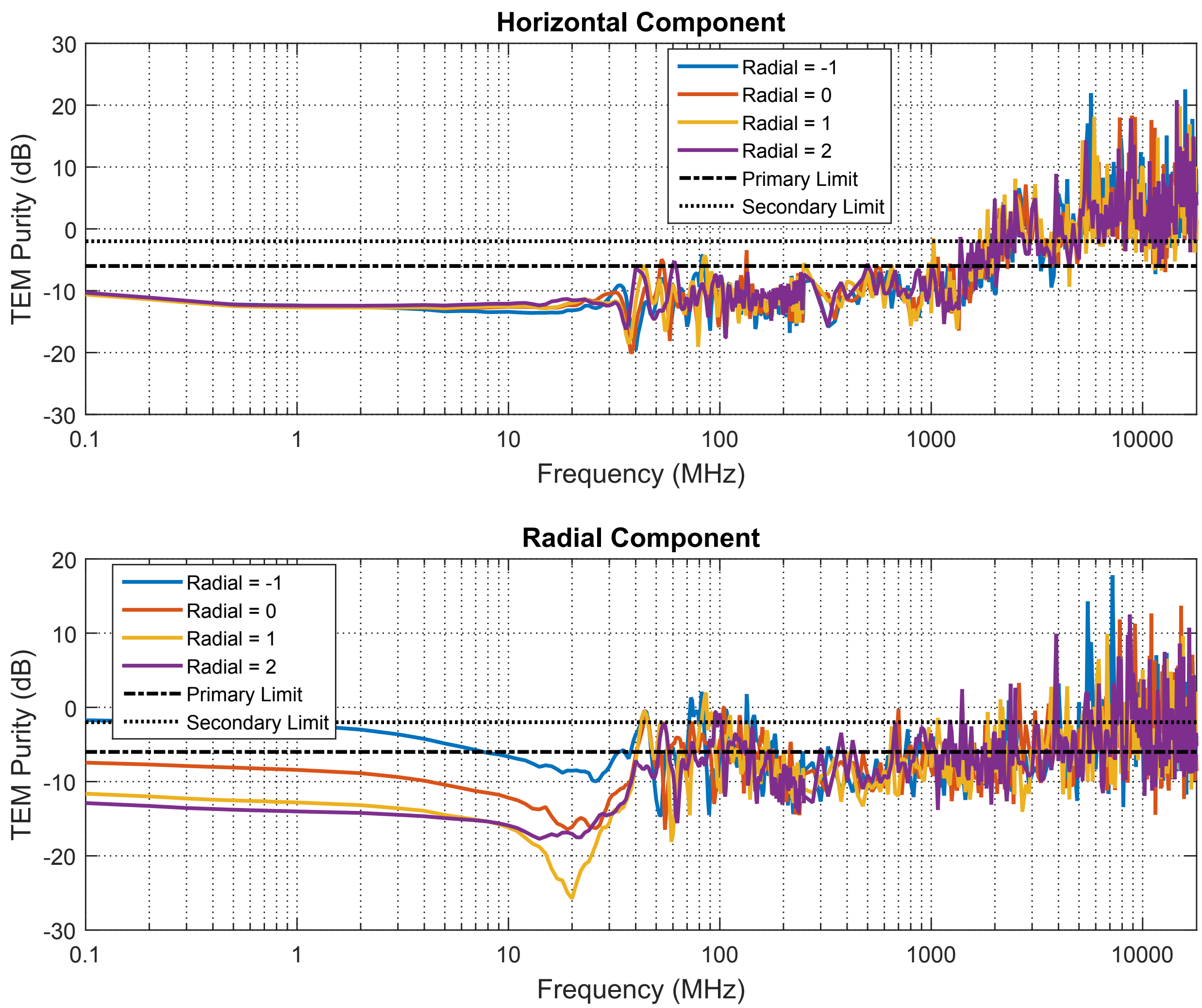



**Figure 20: Field Purity for Small Planes in the GTEM**

## 6.3 VSWR

VSWR is a unit less parameter indicating the magnitude of peak voltage to minimum voltage along the length of propagation into GTEM. Figure 21 shows a peak VSWR of ~1.38 occurs at 60 MHz and is the total VSWR at the GTEM input. Since this result is in the frequency domain, contributions along the length of GTEM contribute every point in this result. Figure 22 shows VSWR as a function of position in the GTEM. The reflection from a location in GTEM propagates at a fixed speed. Hence, the distance scale shown in the graph is a simple function of return time and the speed of the energy. The maximum value is ~1.2 at the feed of GTEM. There is also a significant (~1.1) contribution at the termination of GTEM. One expects discontinues at these locations. Recall that VSWR is a measure of maximum-to-minimum field strength and is an indicator of the quality of impedance matching.

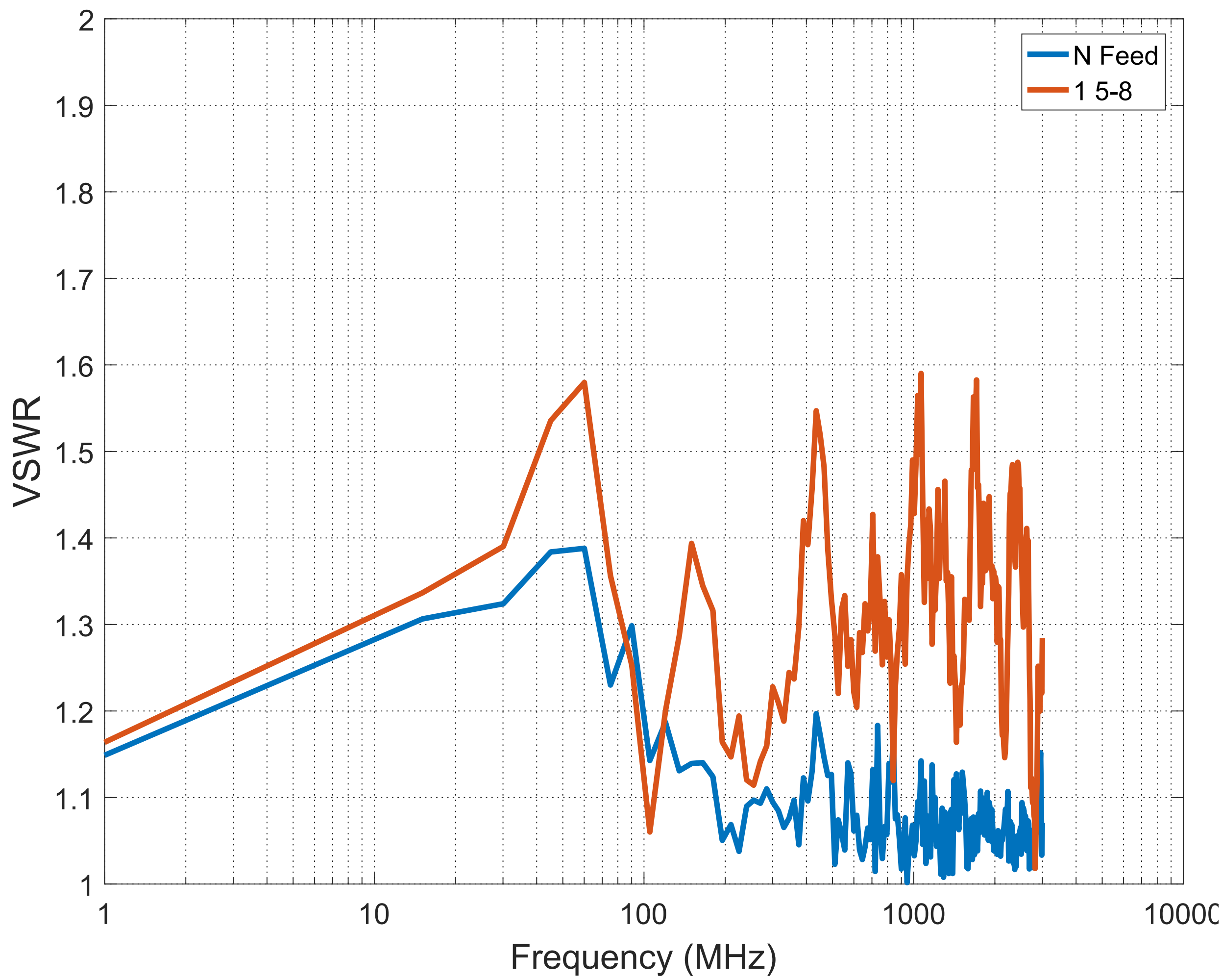



**Figure 21 GTEM VSWR Frequency Domain**

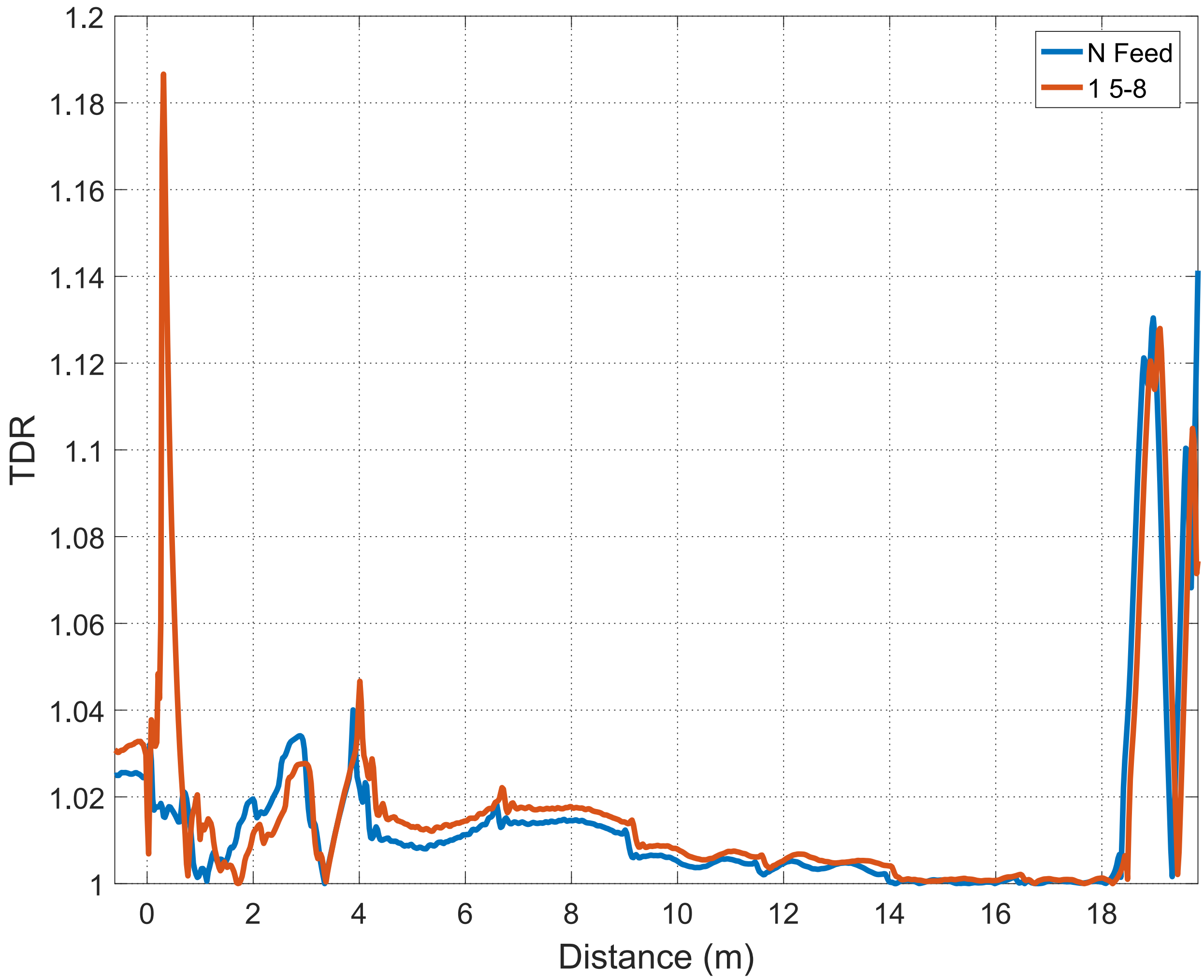



**Figure 22 GTEM VSWR Time Domain**

## 6.4 Summary and recommended application of this data

The purpose of this study was to characterize and record the performance of the GTEM for use by NW qualification programs. RPSS requires knowledge of the uncertainty of any measurement used to evaluate the qualification of a NW system or component. To meet this requirement, we measured the variation in field strength over the volume of a test object. The known variation in field strength informs the uncertainty of a measurement conducted in GTEM. . It should be noted that test objects placed in this facility will have an effect on the field structure. The size of the object and materials that it is created from will determine the significance of that impact.

These results provide a measure of the variation in field strength as a function of position, size of an area, and frequency. We used IEC 61000-4-20 to guide the measurements; however, this standard is not a requirement. The two results presented show that variations in E-field are less than 6 dB for most frequencies for a 2 m by 2 m area. This information is necessary for uncertainty assessment. Further, except for close proximity to the termination cones, the purity of the E-field is better than 6 dB. This information is also useful for uncertainty assessment. The total E-field is required to understand a test object response. In the case where the horizontal or radial field exceeds the value of the vertical field, one should consider these results the value of the E-field stimulus not the vertical component. Therefore, E-field probes should monitor the field near the location of the test object in all three axes.

# 7. REFERENCES

(Electromagnetic compatibility (EMC) – Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides, 2010)

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