CATR Quiet Zone Depth Variation

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***Abstract*— The traditional characterization of the quiet zone for a CATR is to perform field probe scans perpendicular to the range axis at one or more depths of the quiet zone, usually front, middle and back. There is usually no attempt to compare the peak signals across the field probe scans. In recent years, users of CATRs have been using these devices at lower and lower frequencies, sometimes below the lowest frequency that provides the specified performance for the CATR. It is recognized that as a CATR is used at lower and lower frequencies compared to its optics, the quiet zone quality will degrade. The purpose of this study was to create a quiet zone depth variation model to characterize the variation, particularly for low frequencies. The model was to treat the CATR as an antenna aperture and apply a power density versus distance model. It is well known that the extreme near field of an aperture is oscillatory at distances up to approximately 10% of the far-field distance, at which point the power density begins to follow the Fraunhofer approximation. The optics of a CATR place the quiet zone well within the oscillatory zone, indicating that the field will vary through the depth of the quiet zone. This variation will decrease with increasing frequency as the far-field distance for the CATR increases with frequency. The model has been compared to a simulation in GRASP and experimental data collected on a CATR.**

I. Introduction

A Compact Antenna Test Range (CATR) consists of one or two large parabolic reflector sections driven by a feed at the focal point of the optical system. The CATR forms a "quiet zone" at a designated distance down range where the field quality in the zone meets specified characteristics in terms of amplitude taper, amplitude ripple, phase variation and cross-polarization isolation. These specifications are usually the same throughout the quiet zone.

Figure 1 shows the nominal layout for a single reflector, center-fed CATR.

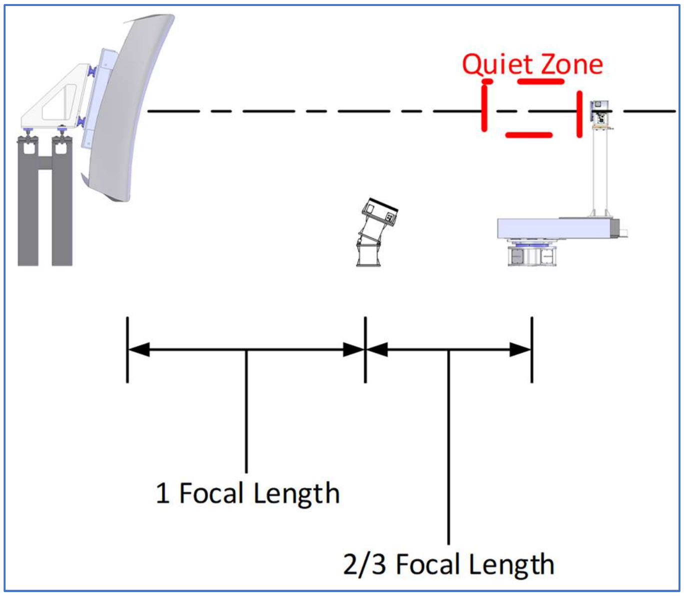

Figure 1. Geometry of a Center Fed Single Reflector CATR

The range feeds are at 1 focal length from the vertex of the offset-fed parabolic reflector. The center of the quiet zone, in depth, is usually placed from 2/3 to 1 focal length behind the range feeds.

Testing is usually performed using the field probe method [1] [2]. The normal data set consists of vertical and horizontal cuts at both range feed polarizations at one or more depth positions in the quiet zone. If the range includes a slide or offset arm long enough to cover the quiet zone, sets of field probe cuts are usually performed at the front, middle and back of the quiet zone. Some ranges do not have a slide or offset arm capable of down range motion, so these ranges may only perform field probe cuts at the center of the quiet zone.

It is usually time prohibitive to perform many cuts at a fine increment along the depth of the quiet zone since variation of the quiet zone with depth has traditionally not been a specified performance metric. The impetus of this study was to estimate the variation in quiet zone depth without investing in a significant test campaign, with the goal of having a tool that can provide an accurate prediction of this depth variation.

II. Power Density Based Model

Significant work has been performed on the power density from an aperture in both the near and far field [3], [4]. These references also cite many of the earlier works in this area.

Figure 2 [5] shows the normalized power density variations with distance for a circular aperture with uniform distribution, circular aperture with a tapered distribution, and a square aperture. Note that the x-axis is normalized distance as a fraction of the far-field distance.

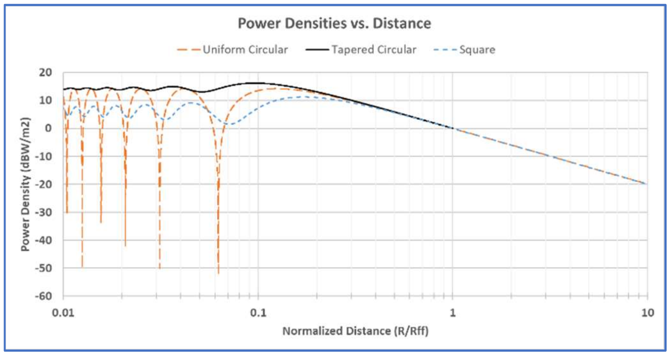

Figure 2. Power Density vs. Distance for Several Apertures

Notice the oscillatory nature of the curves to approximately 0.1 of the far-field distance for the circular apertures and 0.17 of the far-field distance for the square aperture. Beyond the peak oscillatory distances, all the apertures begin to follow the Fraunhofer square law for power density at a given distance. The vertical normalization has the power density of 0 dBW/m^2 at the normalized far-field distance of 1.

If the CATR (which is an offset-fed parabolic reflector) is considered like any other aperture, the power density versus distance for the CATR aperture can be calculated. Since the CATR is of a fixed size, the far-field distances for the reflector will increase with increasing frequency and will be relatively far away in terms of the CATR chamber size. In any case, the quiet zone location relative to the far-field distance will occur in the left third of Figure 2 at least. Figures 3 and 4 show the power density curves for the tapered-circular aperture for a low frequency relative to the compact range lowest operating frequency and a much higher frequency respectively.

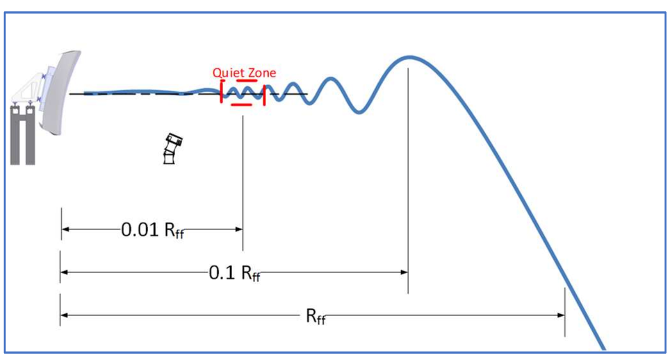

Figure 3. Power Density vs. Distance for a Low Frequency

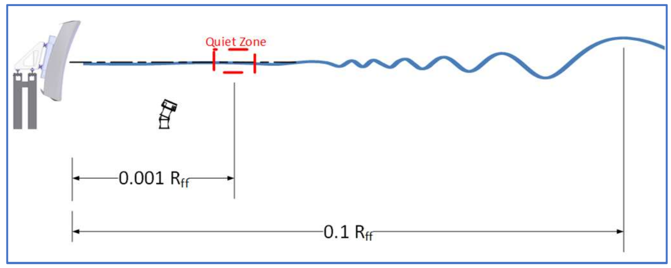

Figure 4. Power Density vs. Distance for a High Frequency

The observation is that the power density will vary within the quiet zone based solely on the aperture size, and the frequency and distance of the quiet zone. If a fixed-aperture antenna was to be scanned through the depth of the quiet zone, it would capture a power level versus distance that would follow the power density variation.

To show the order of magnitude of these variations, the power density equations are applied to a 1.2 m circular quiet zone reflector. The effective area of a reflector, 4.6 m wide by 4 m high, was used. The reflector is described further in Section IV. The aperture model used was a tapered illumination of a circular aperture where the circular aperture is the equivalent area of the reflector. The lowest specified frequency for the reflector is 4 GHz and the upper specification limit is 40 GHz. Figure 5 shows the variation over the quiet zone depth predicted by the power density model for several frequencies. As seen in the approximate plots, the lower the frequency, the more variation in amplitude, and the longer the periodicity of the variation.

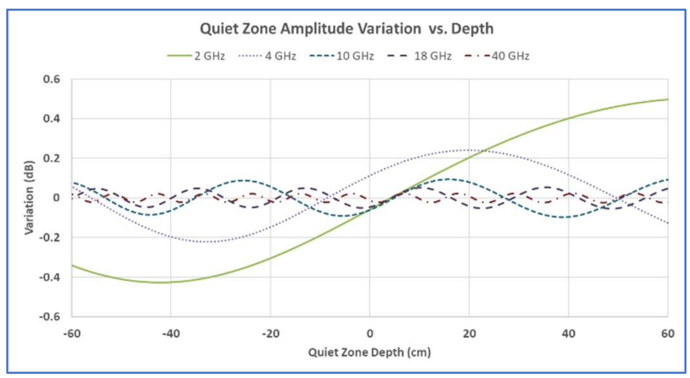

Figure 5. Quiet Zone Variation for Several Frequencies

III. Variation for the Far-Field Condition

The power density model predicts variation through the depth of the quiet zone. For a far-field range, variation in depth in the test zone is modeled by the change in space loss from the front of the test zone to the back of the test zone [1]. A comparison of the power density model with the accepted variation in depth of a far-field range is instructive. For the modeled reflector above, the true far-field distance would vary from 300 m for 2 GHz to almost 5400 m at 35 GHz. The equation for amplitude variation over the far-field test zone depth is [1][2]:

$$\Delta_{dB} = 20 * Log_{10}\left(\frac{R_{ff}+{}^{Depth}/_{2}}{R_{ff}-{}^{Depth}/_{2}}\right) \quad (1)$$

A plot of several frequencies for the variation in depth over the several far-field distances is shown in Figure 6, with negative distances toward the range antenna and positive distances away from the range antenna.

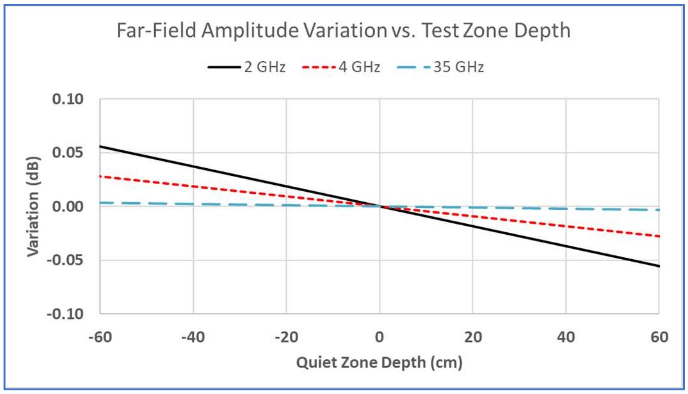

Figure 6. Far-Field Condition Variation

Note that the power density model CATR variation prediction is larger than the far-field variation from (1). However, it shows no front-to-back tilt. This is to be expected since the CATR quiet zone is in the near field of the reflector. This matches the standard concept that the transfer function of a CATR does not incur space loss once the energy has departed from the reflector [4]. This far-field "tilt" is not included in the model/data comparisons that follow but is provided for comparison purposes.

IV. Test Campaign

Measurements versus quiet zone depth were made on the NSI-MI Technologies CATR in Atlanta, Georgia. A photo of the reflector is shown below.

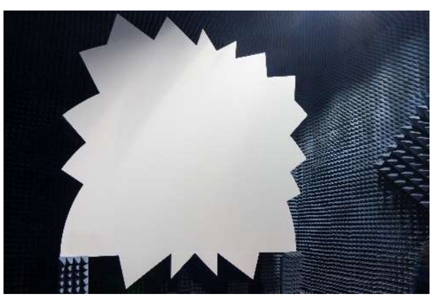

Figure 7. NSI-MI CATR Reflector

This reflector is a Scientific-Atlanta Model 5752, with a 3.66 m focal length, and a 1.2 m circular quiet zone with 1.2 m of depth. With edge treatments, the reflector is approximately 4.6 m wide and 4m high.

The reflector is approximately 35 years old but is probed annually for A2LA certification of the range. The range includes a roll-over-mast-over-azimuth-over-elevation-over-floor slide AUT positioner. In the configuration used, the floor slide provides ±0.4 m of travel along the range axis.

Characteristics of the test campaign:

- Measurements were made in S, C and X bands with standard gain horns (SGH) as the AUT. These relatively small probe apertures minimize the effects of horizontal taper variation from position to position.
- Wideband data was collected so that time-domain processing could be used to evaluate and reduce any stray signals. Time-domain processing and gating was used to eliminate a small variation caused by mechanical effects of scanning the floor slide.
- Scans were made forward and backward to average out any backlash in the floor slide.
- Scans were made with and without an additional 6 dB attenuator on the AUT port to possibly improve the matching of the AUT. Comparison would indicate if any mutual coupling between the AUT and the compact range feeds was occurring. The measurements with and without the additional attenuator were essentially the same, indicating little mutual coupling.

V. GRASP Simulation

NSI-MI uses a compact range performance software tool that is based on the TICRA GRASP package for serrated edge reflectors. The typical approach is to build a GRASP model from the design of a reflector, including the outline of the serrations used for edge treatment. The CATR used in the test campaign pre-dates the current methodology, so creating an accurate model would require a significant effort. As a first-order approximation, we modeled a standard reflector design that mimics the overall size of the actual CATR to help us approximate the correct near-field response.

The GRASP simulation was run for 2, 4 and 10 GHz. This provided data at ½ the lowest frequency for specified performance, at that frequency, and at 2.5 times the lowest frequency for specified performance.

VI. Results

The results of the test campaign, GRASP simulation, and the power density estimate are shown in Figures 8 through 10 for 2 GHz, 4 GHz and 10 GHz respectively.

All data sets are normalized to a central magnitude of 0 dB. The plots are also arranged such that a negative distance in the plot is toward the reflector with a positive distance away from the reflector.

VII. Conclusions

The following conclusions can be drawn from the test campaign and the simulations:

- The power density model and the GRASP simulation are not in exact agreement but show similar trends. They both show variation in amplitude, with quiet zone depth that increases with decreasing frequency.

- The power density model consistently shows a larger variation than the GRASP simulation. The actual data shows a trend that is between these two extremes.
- For a frequency that is one octave below the lowest specified frequency for the CATR, the variation can be significant (up to ±0.5 dB) over this 1.2 m quiet zone. While users that test below the lowest rated frequency of a CATR accept some degradation in the normal field quality metrics, the variation with depth will also be significant.
- For the lowest specified frequency, the variation with depth is approximately one half the normal specifications for amplitude ripple across the quiet zone.
- For higher frequencies, the amplitude variation drops to an insignificant value above twice the lowest specified frequency.
- The power density model may possibly be used as a worst case bound on the variation. Table I shows the power density model limits for the test campaign CATR.

TABLE I. EXAMPLE CATR VARIATION WITH FREQUENCY

Frequency (GHz)	**Min Variation (dB)**	**Max Variation (dB)**
2	-0.43	0.50
4	-0.22	0.24
8	-0.12	0.12
10	-0.10	0.10
12	-0.08	0.08
18	-0.05	0.05
26	-0.04	0.04
35	-0.03	0.03
40	-0.02	0.02

VIII. NEXT STEPS

The findings of this study indicate the possibility of quantifying downrange quiet zone variation with an analytical model. However, additional work is needed to validate the proposed model. The authors are planning another test campaign using modern reflectors with both serrated and rolled-edge treatments. A refinement of the power density model, presented here, as a valid error bound estimator is the goal.

ACKNOWLEDGEMENTS

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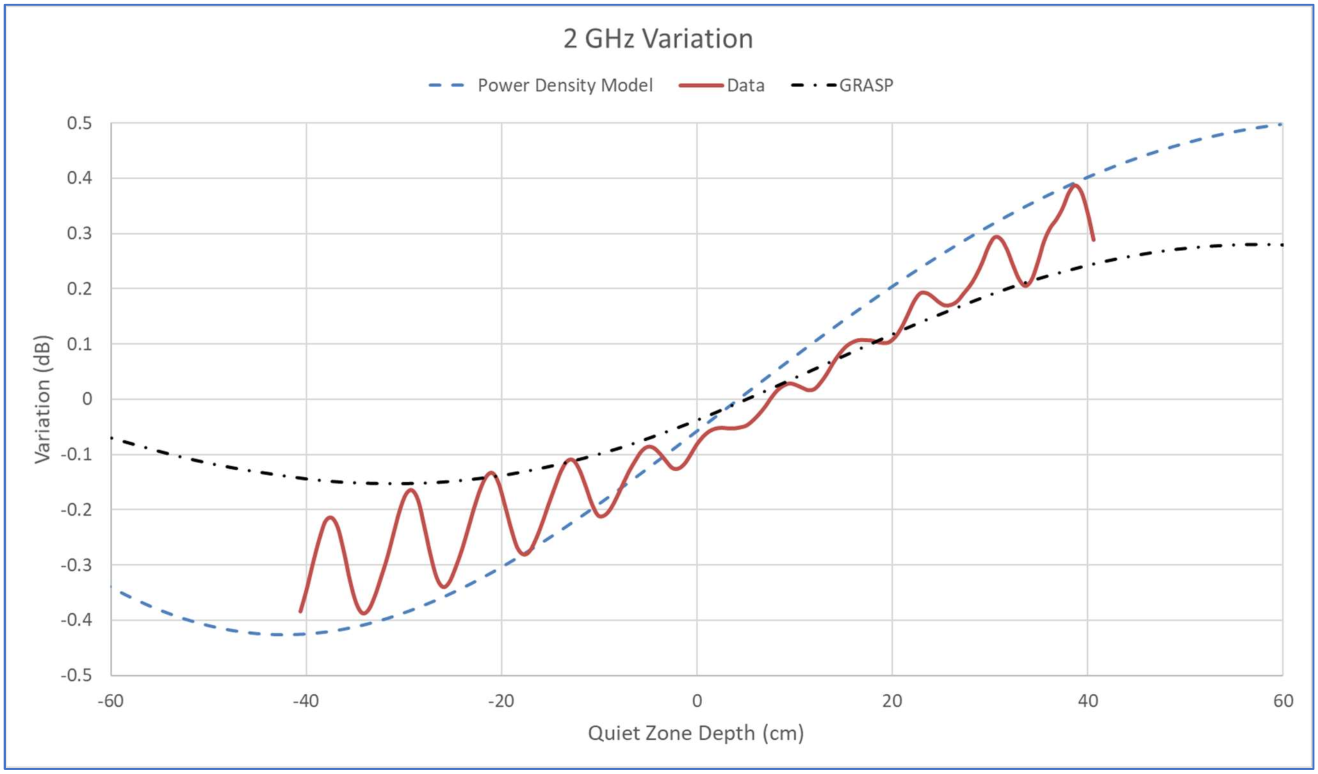

Figure 8. Test and Simulation Results for 2 GHz

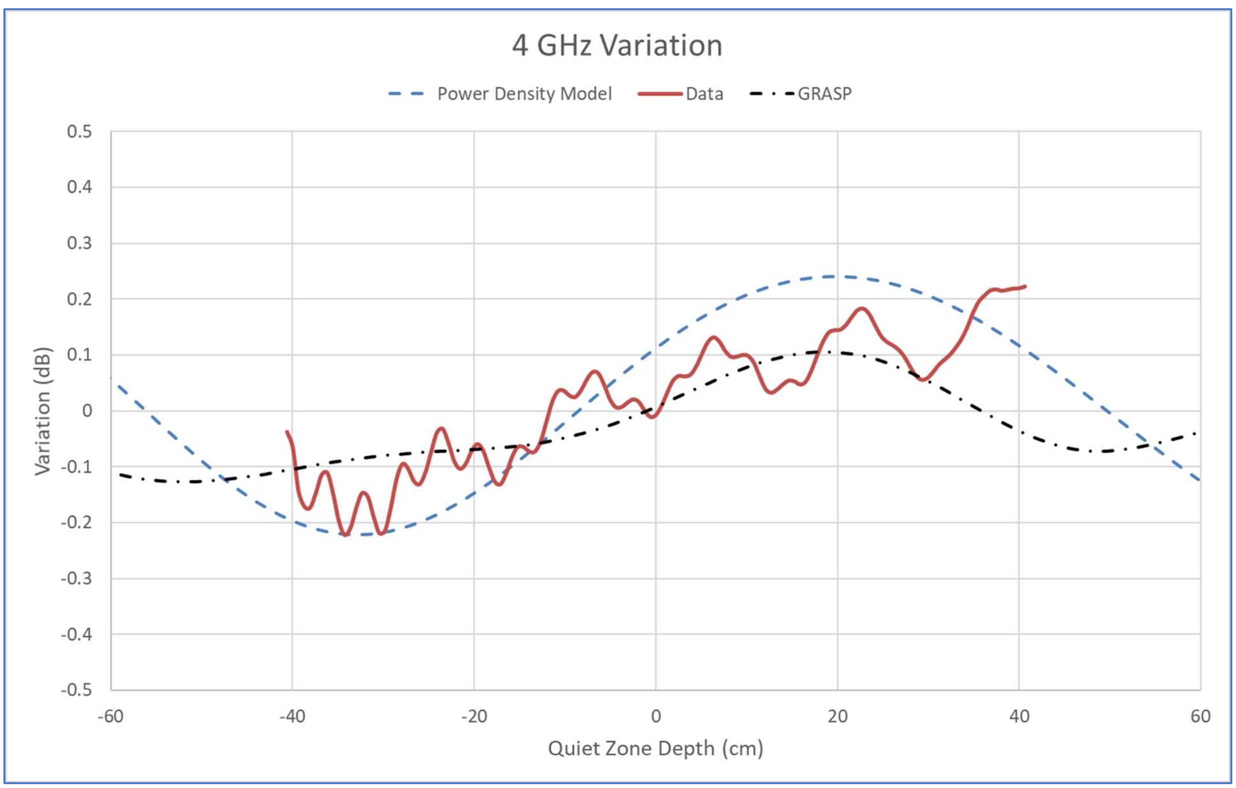

Figure 9. Test and Simulation Results for 4 GHz

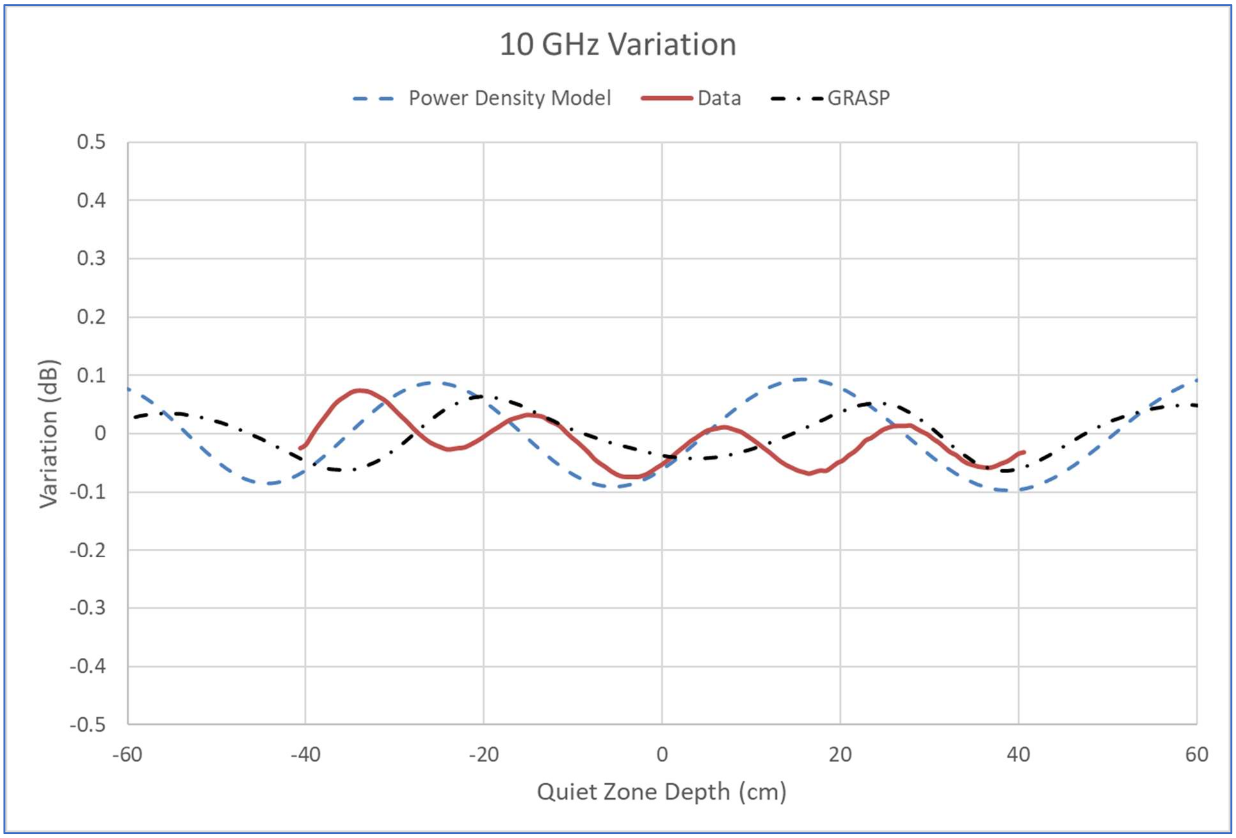

Figure 10. Test and Simulation Results for 10 GHz