Numerical Study of the Effects of Absorber Permittivity Variations on Quiet Zone Illumination of Tapered Chambers

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***Abstract*—Tapered chambers use the reflections from the surfaces adjacent to the range antenna to illuminate the quiet zone (QZ). Polyurethane substrate is the preferred and most widely used radio frequency (RF) absorber in these chambers, due to its ability to be cut into complex shapes to conform to the tapered sections. Unfortunately, this type of absorber always presents slight differences in permittivity related to the manufacturing process.**

To analyze the effects of the permittivity of the lossy foam on the QZ illumination in a tapered chamber, a series of numerical experiments using a full wave analysis technique are executed. The results are mainly obtained for frequencies under 1 GHz. The upper frequency of the simulation is limited by the electrical size of the problem and by the available information on the material permittivity. However, frequencies below 1 GHz is where the tapered chambers are superior to other methods for indoor antenna measurements.

Magnitude and phase are recorded over a 1.82m diameter spherical QZ to show the effects of the different absorber on the illumination. Results show that a variation on the absorber around the range antenna will deviate the illumination and skew the amplitude taper across the QZ. The amplitude distribution peak can be shifted by as much as 3.5 degrees from boresight. The effect on the phase taper is smaller with a negligible change in phase.

I. Introduction

Tapered chambers have been the workhorse for indoor antenna measurements for over 55 years [1]. The tapered range behavior can be explained with different theories [2], but all off them point to the fact that the chamber illumination and the field across the quiet zone (QZ) is dependent on the RF Absorber in the tapered region and around the feed.

While in reference [3] the author pointed the limitations of trying to predict chamber behavior using numerical methods based on full wave analysis such as finite elements (FEM) and finite different time domain (FDTD), these methods can be use to show potential areas of the range that are critical to its operation. Using one commercially available computational electromagnetics package, the effects of changes to the RF absorber properties that were discussed in [3], are shown. A tapered range is analyzed and then changes to the complex dielectric properties of the absorber in the tapered region as well as in the region around the feed are modeled to show what the potential effect of these variations are to the QZ illumination.

The tapered chamber being analyzed is 4.9 m by 4.9m by 14.2 m, while physically large it is still possible to analyze the chamber up to 1 GHz. The range (shown on Figure 1) is described as a cubical section 4.9 m by 4.9 m by 4.9 m, with a tapered section having a subtended angle of 27.8° for a taper section length of 9.3 m per section for a total length of 14.2 m. The chamber quiet zone (QZ) is a 1.82 m sphere located 3.35

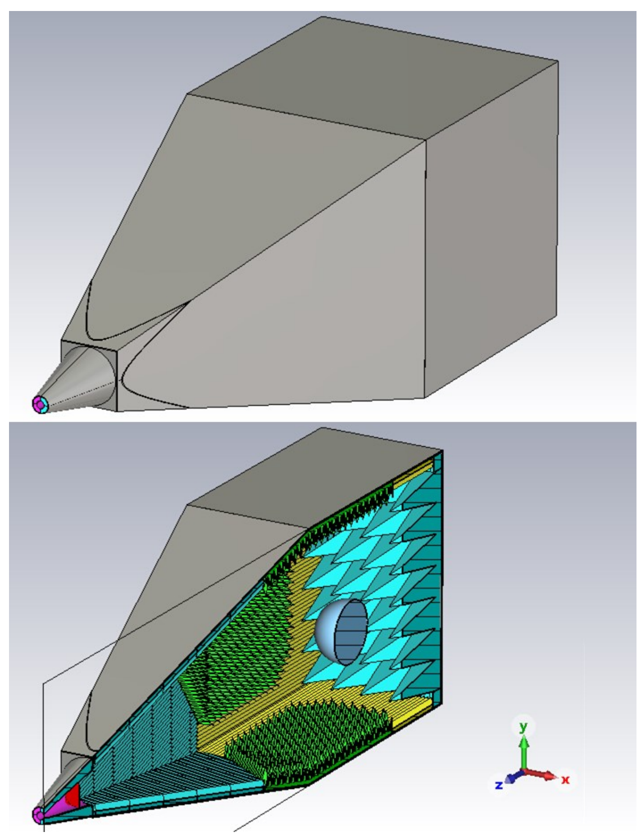

Figure 1. Geometry of the tapered range showing the location of the QZ (Sphere in the cubical section).

m from the end wall. The absorber treatment is 1.82 m pyramidal absorber on the end wall. The pyramid is 1.52 m tall with a square base 0.61cm by 0.61 cm. The pyramid sits on a hexahedral base 0.30m tall by 0.61m by 0.61m. The lateral areas of the cubical section are treated with 46 cm pyramidal absorber. The pyramids of this absorber are 40 cm in height with a square base with dimensions 15.2cm by 15.2 cm. the pyramid sits on a base that is 6cm in height. the balance of the cubical section as well as the taper sections are treated with 21.6 cm tall wedge absorber. The triangular cross section of the wedges is 16.51 cm high by 7.62 cm. the wedges sit on a base that is 5 cm tall.

The conical feed section is treated with a conical sleeve of absorber that ranges from a 21.6 cm thickness at the interface with the taper section to 7.62 cm thick at the apex.

The material properties for the different absorbers are shown in Figure 2.

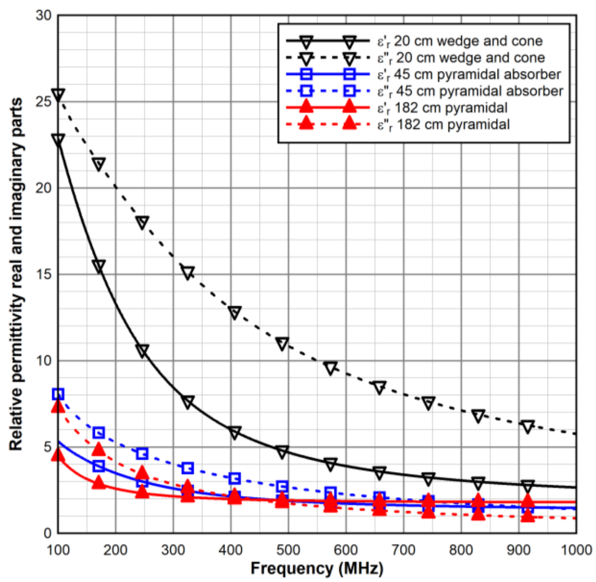

Figure 2. Material properties of the tapered range absorber.

For simplicity, the feed is set as a circular port in the conical feed section. While this may not be a physically implementable feed, specially at lower frequencies it does provide an excitation to the structure. As the frequencies increase this feed is similar to an open circular waveguide, thus it could be implemented.

II. Numerical Exercises

A series of numerical exercises were executed to evaluate the effect on the QZ illumination of absorber that is not properly loaded or that its permittivity has deviated from the standard expected value. The first simulation assumes that all the absorber is perfectly loaded and that the absorber permittivity for the different types of absorber used is that shown on figure 2. The other two cases look at the effects of wrong loading on the feed section or clamshell and at the wrong loading on the taper section as shown on figure 3. For the case where the conical feed section is improperly loaded, the material properties on Figure 2 for the cone material were

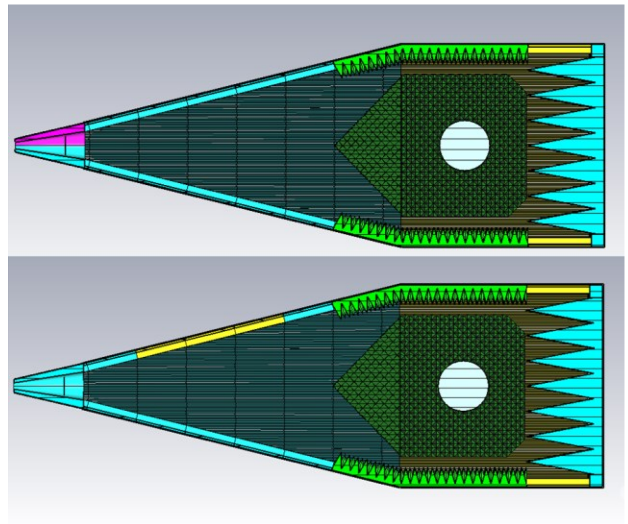

Figure 3. The two cases with improperly loaded absorber. the top has the feed section improperly loaded, the bottom case, the wedge material on the later section is not properly loaded.

reduced by 15% for both the imaginary and the real parts. Effectively this models a piece of foam with a lower content of carbon. For the case where the taper wedge is improperly loaded a more drastic change in material properties is modeled. In this case the wedge material is loaded like the 45cm pyramid.

A. *Case 1. Perfect chamber*

The perfect case assumes that all the absorbers in the chamber are perfectly loaded and have constant permittivity. The range also has no perturbations dues to lights, vents, and walk-on absorber. This is done to minimize the complexity of the model and to be able to model the structure up to 1 GHz. Symmetry is used when possible to allow for the model to run. For the perfect case the instantaneous field distribution is plotted at four frequencies. 100 MHz, 400 MHz, 800 MHz and 1 GHz. The resulting plots are shown on Figure 4. The data show that there is very little discernable ripple across the QZ. It also shows the propagation of the wave slowing down in the lossy material that lines the walls of the chamber. This is expected and it demonstrates that the model is providing the expected results.

However, the plots on Figure 4 do not provide a lot of quantitative information. So the field amplitude of the vertical polarization and phase across the transverse horizontal axis of the QZ are shown in figures 5 and figure 6, respectively. It is observed that the amplitude taper changes from 0.75dB at 1 GHz to 2.25 at 200 MHz, at several frequencies the amplitude taper across the 6 ft QZ is 1dB. The variation in amplitude

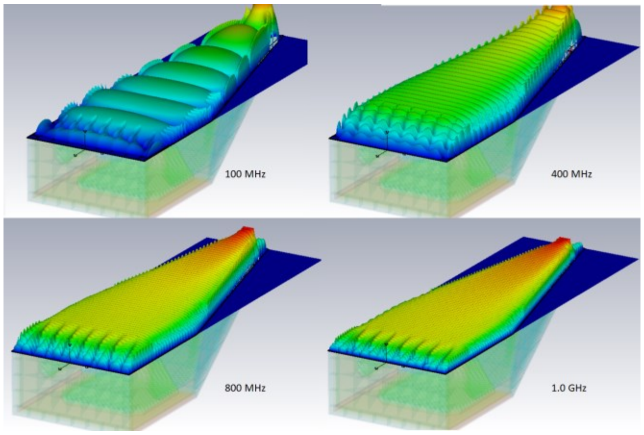

Figure 4. Instantaneous field amplitude at (clockwise from top left) 100 MHz, 400 MHz, 1 GHz, and 800 MHz. Notice the plane wave behavior across the QZ

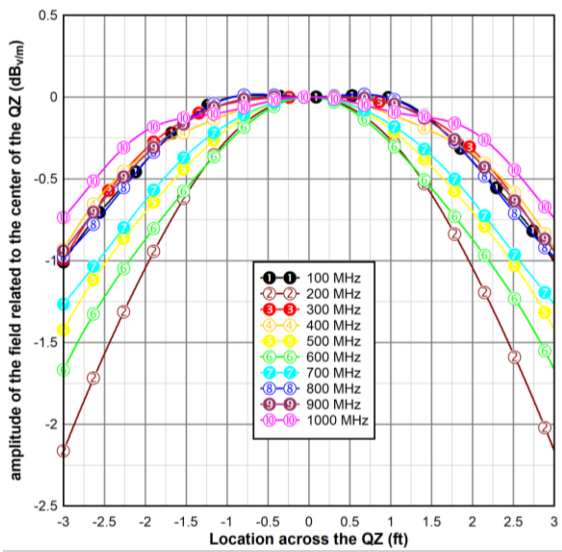

Figure 5. Amplitude taper. vertical polarization horizontal transverse scan. Perfect case.

taper is related to the pattern of the circular aperture. The phase taper shows the size of the usable, far field illuminated QZ. The phase shows that the size of the far field illuminated QZ (phase taper less than 22.5°) gets smaller as the frequency increases. Similar plots can be obtained for the vertically polarized field along a vertical axis of the QZ. Studying the phase taper for these two orthogonal QZ axes, the far field illuminated QZ size is plotted in figure 7. It can be seen from the data plotted in Figure 7 that the far field illumination of a tapered chamber QZ follows the far field equation as was presented in [2]. In references [2] and [4] the far field behavior of the tapered range was shown using measured data from different ranges. In this

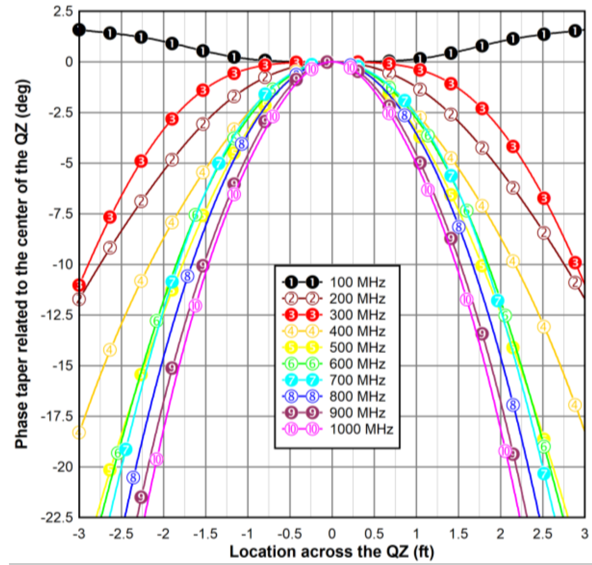

Figure 6. Amplitude taper. vertical polarization horizontal transverse scan. Perfect case.

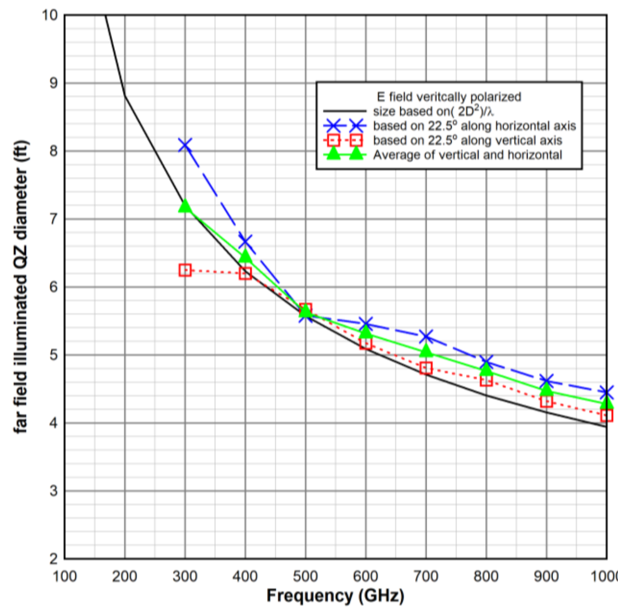

Figure 7. Far field illuminated QZ size

paper numerical methods are used to present the same conclusion.

B. *Case 2: Wrongly Loaded Absorber on the Conical Section*

The first of the two cases where the absorber is intentionally loaded as a defective part is the one where the conical section around the range antenna is misloaded. As stated above the absorber permittivity is reduced by 15% for both the imaginary and real parts. This simulates a lighter loading. Since typically these sections are treated with lossy foam block the material is not tested by the manufacturer and there is not a good way to ensure that the loading is correct. This is therefore a very plausible scenario. In this case we are looking at the worse-case where half of the clamshell is treated with correct loading and the other half with the lighter loading. The chances of this occurring are low, but the purpose of the numerical exercise if to show the potential effect of this misloaded pieces at the feed section of a tapered chamber.

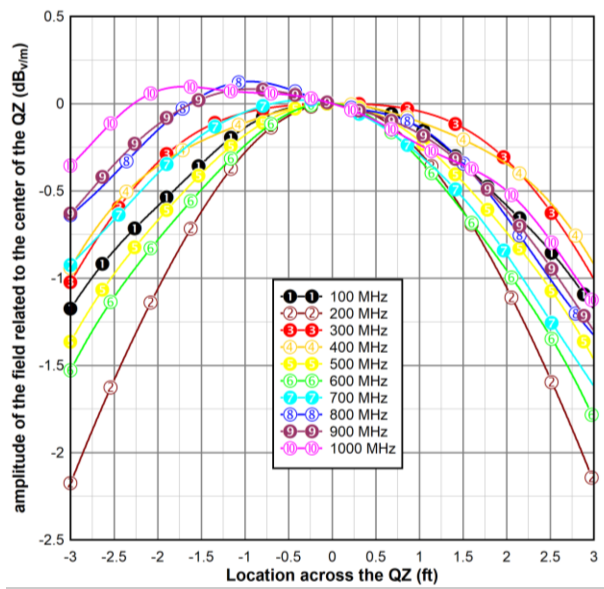

Figure 8. Amplitude taper. vertical polarization horizontal transverse scan. 15% reduction on ε'+jε".

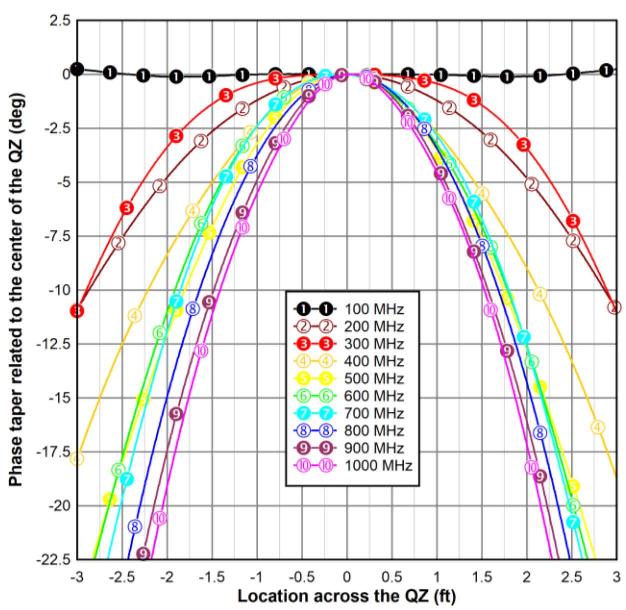

Figure 9. Phase taper. vertical polarization horizontal transverse scan. 15% reduction on ε'+jε".

Figures 8 and 9 show the case of the vertically polarized field and the horizontal transverse axis scan for amplitude and phase respectively. The effect on the amplitude is very clear, with the frequencies above 600 MHz being clearly affected by the asymmetry of the absorber treatment. The effect on the phase taper is not that clear. There is a slight asymmetry. At 1 GHz, the phase is 10 degrees less than at the center of the QZ at x=-1.41 ft on one side and at x=1.53 ft on the other side of the center. The difference is about a tenth of a wavelength at 1 GHz.

Figure 10 shows the difference between the defective absorber case and the perfect case. This shows in a better way what the effect of the small variation on the permittivity is on the QZ illumination. The plot shows the asymmetry of the illumination caused by the absorber difference in the feed

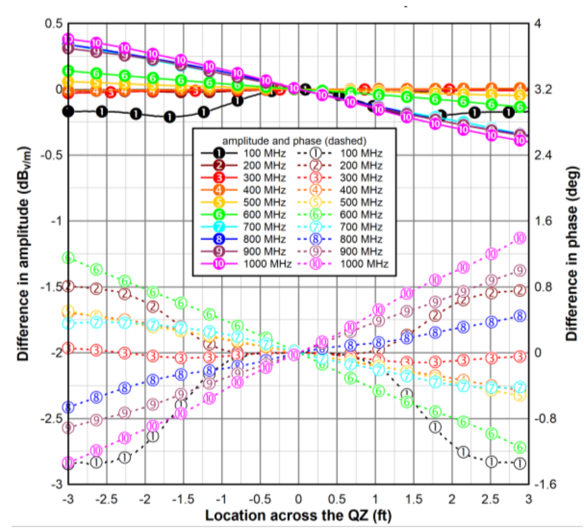

Figure 10. Difference of defective clamshell illumination compared to perfect case for the vertical polarization horizontal scan.

section versus the perfect case. We see effects of less than 0.5dB and less of the 1.2 degrees across the valid QZ. In the next case the clamshell or feed section is perfect, but the loading on some of the pieces of the taper section is not correct.

C. Case 3: Defective Absorber on the Taper Section

The last case to be analyzed is an extreme case where some pieces of the taper section are misloaded and uses a very different loading. In this case the 20 cm wedge is loaded like the 45 cm pyramid material. In this case not the entire side wall of the taper is treated with the defective absorber but only some pieces on the center of the wall. Figure 11 shows a view of the absorber from the outside of the chamber. The left wall (looking from the range antenna to the QZ) has three pieces of the 20cm wedge measuring 61cm by 122 cm that are not loaded properly.

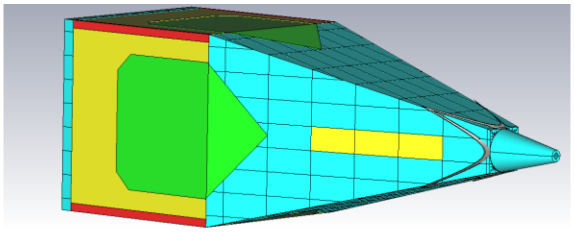

Figure 11. view of the absorber treatment showing the three pieces on the taper with the wrong loading

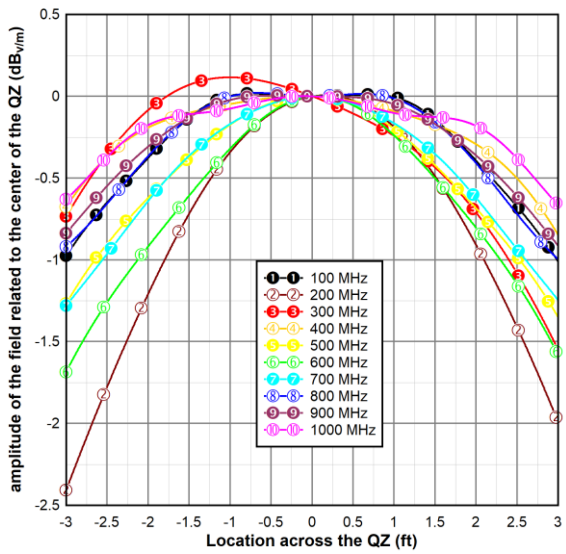

Figure 12. Amplitude taper. vertical polarization horizontal transverse scan. Figure 11 case.

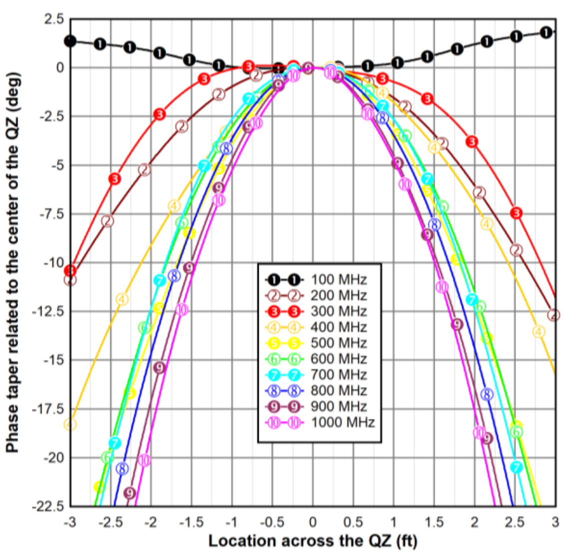

Figure 13. Phase taper. vertical polarization horizontal transverse scan. Figure 11 case.

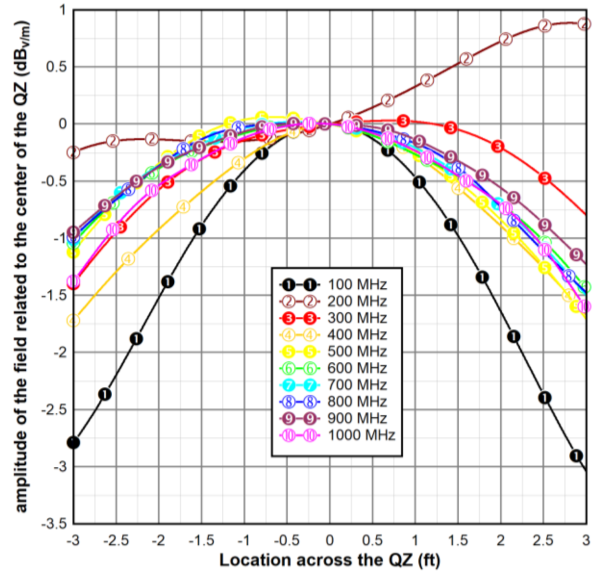

Figure 14. Amplitude taper. Horizontal polarization horizontal transverse scan. Figure 11 case.

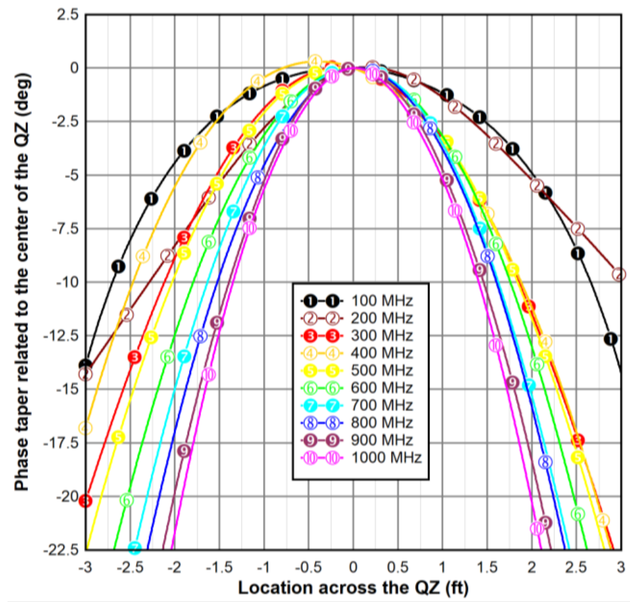

Figure 15. Phase taper. Horizontal polarization horizontal transverse scan. Figure 11 case.

As in the previous cases the amplitude and phase of the vertical field along transverse horizontal axis of the spherical QZ is computed. Figures 12 and 13 show the amplitude and phase respectively for the vertical polarized field along a horizontal scan. In addition to those results the other polarization, the horizontal polarized field along the horizontal transverse axis of the spherical QZ is also reported. Figure 14 shows the amplitude taper, and Figure 15 show the phase distribution.

This case shows that the absorber in the taper has still an effect on the illumination. Data in Figure 12 and 14 shows that the asymmetry is depending on the polarization as expected. The effect appears to be larger at lower frequencies compared to the higher frequencies. This can be explained by the pattern of the illuminating antenna. Given that the aperture is the same, at higher frequencies we have a narrower beam that is less affected by the lateral absorber.

It is interesting that the skew on the illumination changes with frequency and with polarization.

III. CONCLUSION

Unlike rectangular chambers where the reflections from the lateral walls are being minimized by absorbing them with the RF absorber treatment, in tapered chambers the reflections from the lateral walls are not reduced but used to create the illuminating wave. Because the illumination depends highly on the RF absorber treatment it has been show that small variations on the absorber can have significant effects on the symmetry of the illumination.

Results show that even small variations on permittivity of less than 20% which can be found from batch to batch of absorber (due to the drying process or the density of the substrate foam among other factors) will affect the symmetry of the illumination. Results also show that this asymmetry will change with frequency.

The results obtained also show that the tapered chamber is a far field illumination method and that the size of the usable QZ is reduced with increasing in frequency verifying some of the measured data available from actual implemented tapered ranges.

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