New Designs for a Feed Fence to Reduce the Direct Coupling to the Quiet Zone on Compact Ranges

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***Abstract*— Absorber fences have been used on compact ranges since their first implementations. The purpose of this fence is to hide the feed positioner and reduce the direct coupling between the feed and the device under test (DUT). A known problem caused by such a fence is that it diffracts the plane wave generated by the reflector, creating an interfering ripple on the illumination of the DUT in the quiet zone. Traditionally, fences have serrated edges to direct this diffracted signal away from the quiet zone. However, this redirection is not always achievable or even repeatable from one facility to the next. Often low frequency requirements drive absorber physical size, leading to very large absorbing surfaces that cannot be optimized to reduce this interfering signal. In this paper, the fence design presented in a recent publication [1] is further optimized by modifying its shape and absorbing material parameters. The performance of this new design is compared with traditional fences.**

I. Introduction

Recently, a Higher-Order Basis Function Method of Moments (HOBFMoM) was used to analyze compact ranges including the feed and feed fence effects [2]. Since the HOBFMoM approach provides data on the potential effect of the feed fence on the quiet zone (QZ) metrics, a paper was recently presented [1] where a new geometry for a feed fence was introduced. Reference [1] presented data for this new geometry for a specific material with complex permittivity ε_r. The present paper continues the work presented in [1] and studies other fence geometries as well as looking at different ε_r values for the fence materials. Additionally, the fence is analyzed at higher frequencies than those presented in [1]. The compact range reflector is the same rolled edge geometry analyzed in [2]. The rolled edge reflector has a projected width and height of 6.1 m (240") by 6.1 m (240”) with a focal length of 6.7 m (264”). The center of the 1.82 m (72”) diameter by 1.82 m (72”) long cylindrical QZ is located 11.18 m (440”) downrange from the vertex of the reflector.

Figure 1 shows the geometry of the range. The enclosure is not modeled and thus it is assumed that the range has perfect absorber on the range walls. Symmetry is used to reduce the numerical solution requirements and solve at higher frequencies with the available resources. The overall range geometry remains the same, but the effect of various fence geometries and material properties are analyzed.

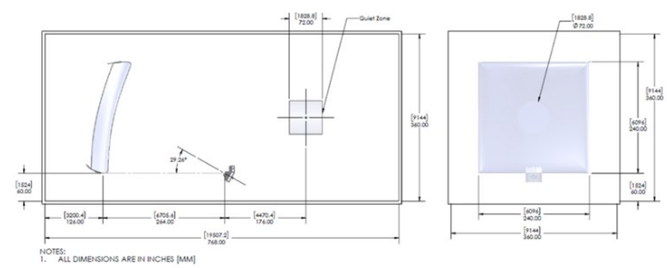

Figure 1. Dimensions of the compact range geometry

II. Fence Designs

The igloo or Romanesque apse presented in [1] is revisited. Figure 2 shows the model of the igloo or apse design presented in [1] and the slightly simplified model without the rounded edges in the front. This design is defined as “Design 0” in the present paper as we try to optimize its shape and location with respect to the focal point.

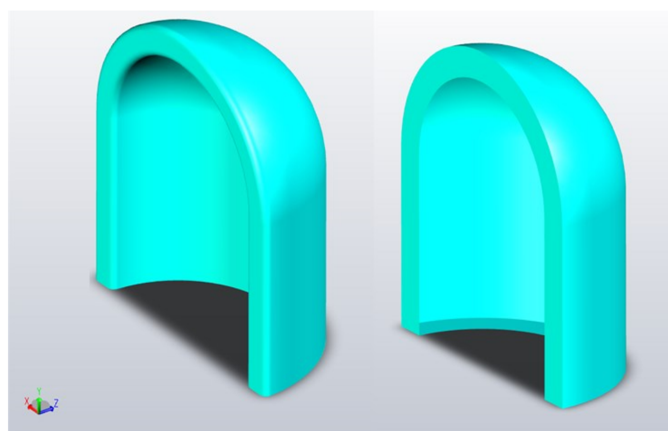

Figure 2. The fence design from [1] and the simplified model analyzed in the present paper.

Design 0, shown in Figure 2, consists of a half annular cylinder of height 1.22 m (48”) with an inner diameter of 1.42 m (56”) and an outer diameter of 1.82 m (72”). Thus, the thickness of the annulus is 20 cm (8”). The annular cylinder is capped with a quarter of a spherical shell 8 inches in thickness with the same inner and outer diameter as the annular cylinder. Thus, the total height is 2.13 m (84”). The front of the fence is located 23 cm (9”) behind the focal point plane.

A. Design 0 analysis

To compare the performance of the different fences, the QZ metrics are compared. The QZ metrics used are the ones defined in IEEE STD 149-2021 [3]. The chosen metrics are amplitude taper, amplitude ripple, and phase variation. These are evaluated at each frequency at the front, center, and back of the QZ, for the two principal polarizations and along the vertical and horizontal cut across the QZ for a total of 12 separate values per frequency for each metric. This is the same approach used in [1].

A quick analysis of the QZ metrics for the simplified design, presented in Figure 3, shows that the results are equivalent to the original rounded edge design. The results for the sharp edge Design 0 are shifted in the x axis for clarity, but they were analyzed at the same 1, 2, and 3 GHz frequencies. Thus, the sharp edge of the front of the fence seems to have very little effect on the QZ metrics, which are calculated following the same process used in [1].

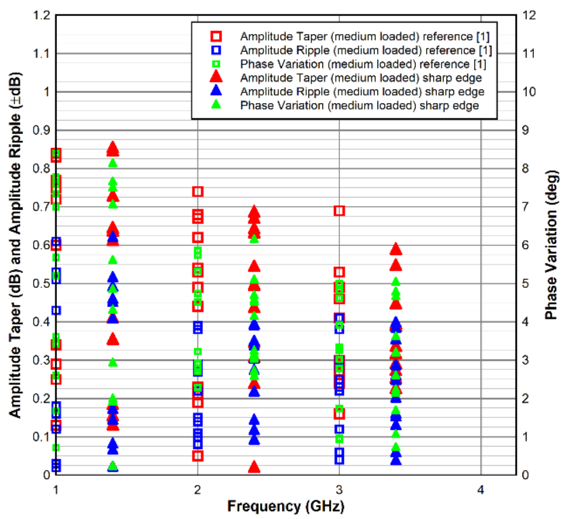

Figure 3. QZ metrics for the fence presented in reference [1] and for the simpler sharp edge model used here.

In reference [1] it was shown that different absorber material properties had limited to no effect on the QZ metrics for the traditional fence. Based on the results for the traditional fence using different absorbing foam properties the new design presented in [1] was only analyzed for a single type of absorber, which was described as “medium loading”[1].

The materials are the same as those used for the traditional fence in [1] and they correspond to a heavily loaded polyurethane foam-based absorber, typically used to build pyramidal absorber smaller than 30 cm (12”) in height, a moderately loaded foam typically used for pyramidal absorbers 45 cm (18”) in height, and a lightly loaded foam that corresponds to the loaded foam used in manufacturing pyramidal absorbers that are larger than 61 cm (24”) in height. The complex permittivity for these materials at different frequencies is presented in Table 1.

TABLE I. Dielectric permittivity used for absorber foam

Loading type	Freq (GHz)	ε_r'	ε_r''
High	1	3.24	6.01
	2	2.28	3.41
	3	1.94	2.48
Medium	1	2.22	4.04
	2	1.72	2.28
	3	1.57	1.61
Low	1	1.53	1.43
	2	1.37	0.80
	3	1.33	0.55

The values in Table I show that the real part of the permittivity at 1 GHz for the high loading is 46% higher than the real part for the medium loading at 1 GHz. At 2 GHz the difference is reduced to 32.5 % and at 3 GHz 23.5%. Hence, as the frequency increases the difference between the real part of the permittivity decreases. Figure 4 shows the QZ metrics for the various materials for Design 0. The biggest difference is seen at 1 GHz, where the materials are much different in magnitude of the real and imaginary parts of the dielectric permittivity. At 1 GHz, the heavily loaded (high loading) material has a bigger effect on the amplitude taper, potentially indicating that it is affecting the beamwidth of the feed antenna since the amplitude taper improves when lightly loaded absorber is used. For the high loading absorber, the worst amplitude taper is 1.01dB at the center and back planes of the QZ for the horizontal polarization and vertical scan. Whereas, for the absorber with low loading, the worst amplitude taper is 0.67 dB for the vertical polarization and horizontal scan.

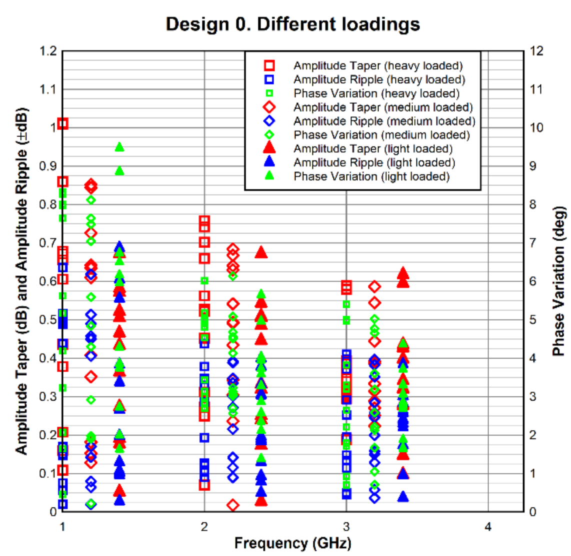

Figure 4. QZ metrics for Design 0 for different loadings

B. Design 1

A second version of Design 0 was analyzed. This version, named Design 1, is half of an annular cylinder with an inner diameter of 1.52 m (60”) and an outer diameter of 1.93 m (76”), making the thickness of the wall 20 cm (8”). The cylinder height is 1.27 m (50”) and the half dome that sits on top has the same thickness of 20 cm (8”)and the same inner and outer diameters. Thus, the height at the apex of the dome is 2.23 m (88”). The design is analyzed for the medium load and the QZ metrics are presented in Figure 5. The results for Design 1 are worse than for Design 0. The amplitude taper is worse, and analysis of the data shows that the higher amplitude taper is for the horizontal polarization and horizontal scan. The ripple is also larger, and it is related to the horizontal polarization and vertical scans.

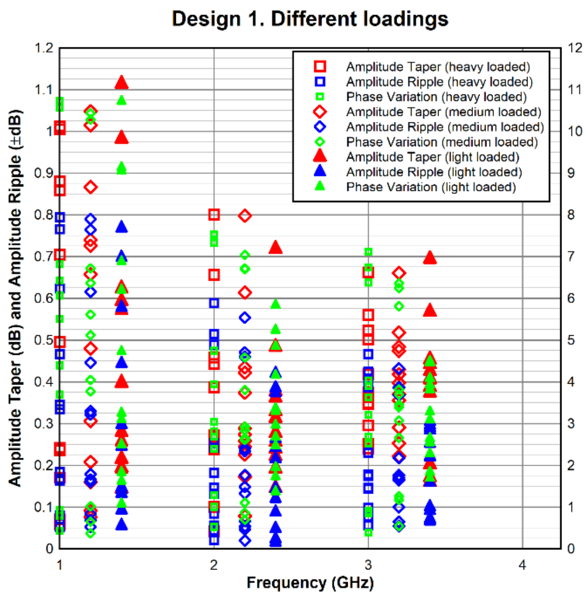

Figure 5. QZ metrics for the Design 1 fence

In addition to the QZ metrics, the period of the ripple on the scans can be used to check the direction of the interfering wave. Equation (1) can be used to find the direction the wave causing the ripple is arriving from. This equation can be found in [3] and [4].

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right) \qquad (1)$$

Where d is the period of the ripple, and λ is the wavelength in free space. Equation (1) was used to analyze the ripple on the vertical line at the front of the QZ for both the vertical and horizontal polarizations. The angle of arrival for each full period of the ripple present in the QZ is calculated. Figure 6 shows the results of this exercise. The direction of the ripple is on these vertical scans, which corresponds to the largest ripple, points towards the top of the fence. The source of this ripple could be either the feed spillover or the reflection & diffraction of the plane wave emanating from the reflector.

The fact that the slightly smaller Design 0 has a smaller ripple seems to point to interaction of the fence with the incoming wave from the reflector, since Design 0 is about 10cm shorter than Design 1 and therefore not as strongly illuminated.

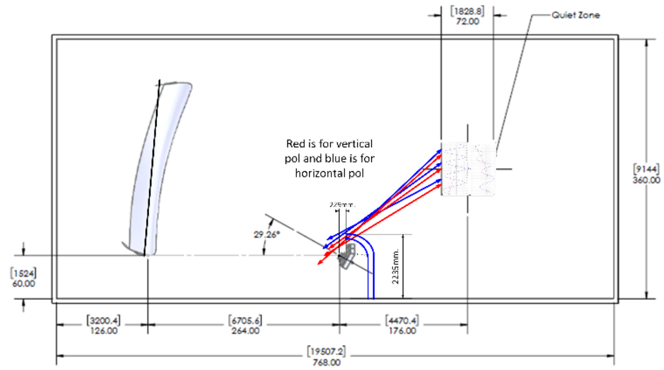

Figure 6. Direction of arrival of the interfering waves at 1 GHz, at the front of the QZ for Design 1

C. *Modifications to Design 1*

Two other variations of Design 1, which is in effect a larger Design 0, were studied. Design 1a, maintained the same dimensions as Design 0 except for the height of the half annular cylinder, which remained at 1.27 m (50”).

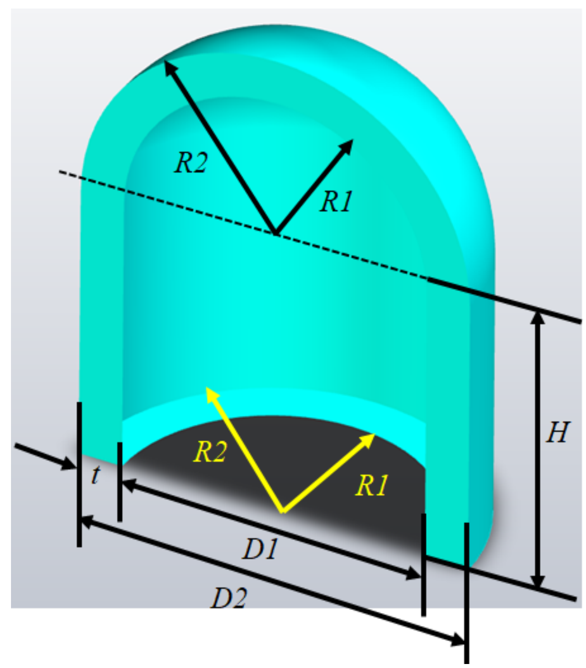

Figure 7. Geometry of Design 0, 1, 1a, and 1b.

Figure 7 shows the general geometry of the Igloo model with specific dimensions shown in Table II.

TABLE II. Igloo geometries

Design	H	D1	D2
Design 0	122 cm (48”)	142 cm (56”)	182 cm (72”)
Design 1	127 cm (50”)	152 cm (60”)	193 cm (76”)
Design 1a	127 cm (50”)	142 cm (56”)	182 cm (72”)
Design 1b	127 cm (50”)	132 cm (52”)	173 cm (68”)

The various quiet zone parameters are presented for the different variations of the structure. The only parameter that is not changed is the thickness (t) of the absorber, which is left fixed at 20 cm (8”) This is done for achieving proper mechanical stiffness to make the fence self-supporting. The radii of the dome are effectively half of the base diameter, hence: *R1*=*D1*/2 and *R2*=*D2*/2.

The QZ metrics for Design 1a are shown in Figure 8. The results were calculated for the three different loadings for the absorber foam. For Design 1a, the results show that lighter loading may be the best approach.

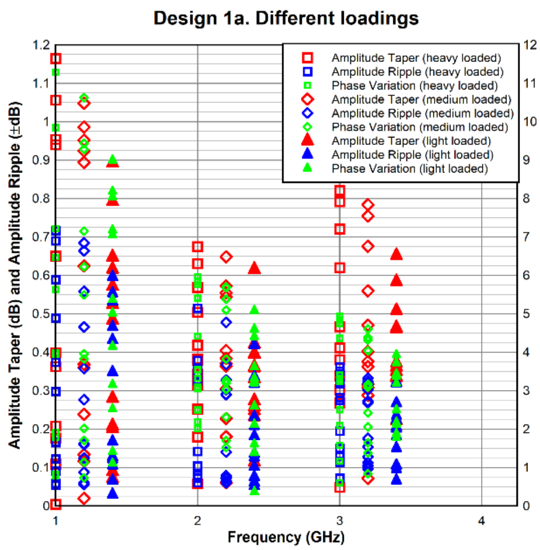

Figure 8. QZ metrics of Design 1a for different loadings

Analysis of the data for the lighter loading showed that the highest ripple is ±0.6 dB at 1 GHz for the horizontal polarization and vertical scan, occurring at the front of the QZ. For this frequency, polarization, and scan direction, there is a ripple of ±0.53 dB at the center of the QZ. At higher frequencies, the light loading and medium loading present amplitude taper better than 0.8 dB and amplitude ripple smaller than ±0.48 dB. The total phase variation is less than 6°.

Design 1b is, overall, the shortest and narrowest fence design. The QZ metrics for this design are shown in Figure 9. Comparing Figure 9 with Figure 4, a lot of similarities are found. The maximum ripple, taper, and phase variations for each loading are very similar for both geometries, but the values for each of the different scans do vary. For the 2 and 3 GHz calculation, the medium and lighly loading absorber provide excellent QZ metrics.

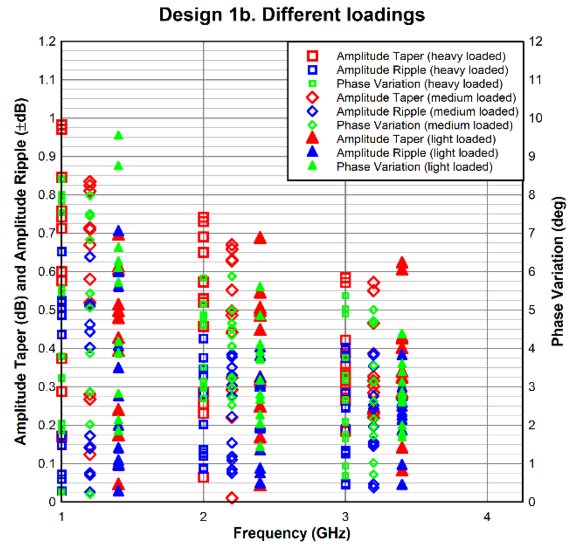

Figure 9. QZ metrics for Design 1b for all loadings

D. Design 2.

The next design explores the shaping of the top of the fence. The idea is to check if a more pointed fence will reduce the diffraction and divert it away from the QZ, thus reducing the ripple along a vertical scan line. The new design also explores a different shape that may be easier to implement.

Design 2, shown in Figure 10, consists of an annular cylinder of height 1.22 m (48”) with an inner diameter of 1.42 m (56”) and an outer diameter of 1.82 m (72”). Thus, the thickness of the annulus is the same 20 cm (8”) as that of Design 1. The annular cylinder is capped with a half conical top. The cone sides have a 45° angle to the vertical making the subtended angle 90°. Hence, it has an inner height of 71.12 cm (28”)) and an outer height is 0.91 m (36”) for an overall 2.13 m (84”) height for the fence. The design was analyzed at 1, 2, and 3 GHz. Figure 11 shows the QZ metrics for Design 2, the scale of the vertical axis was changed to plot all the results.

Figure 10. Design 2 for the fence

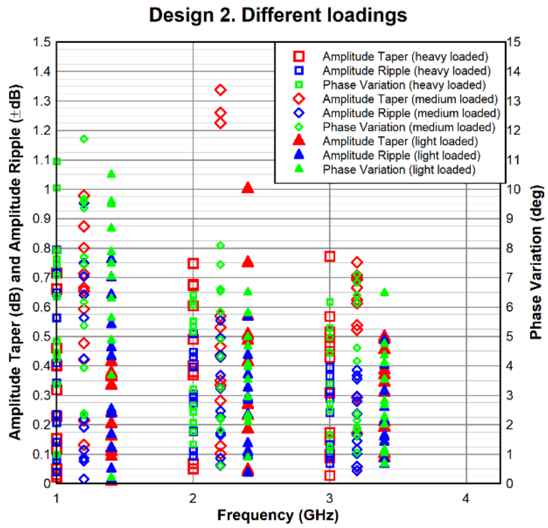

Figure 11. QZ metrics for Design 2 for all loadings (notice the broader range for the y axis)

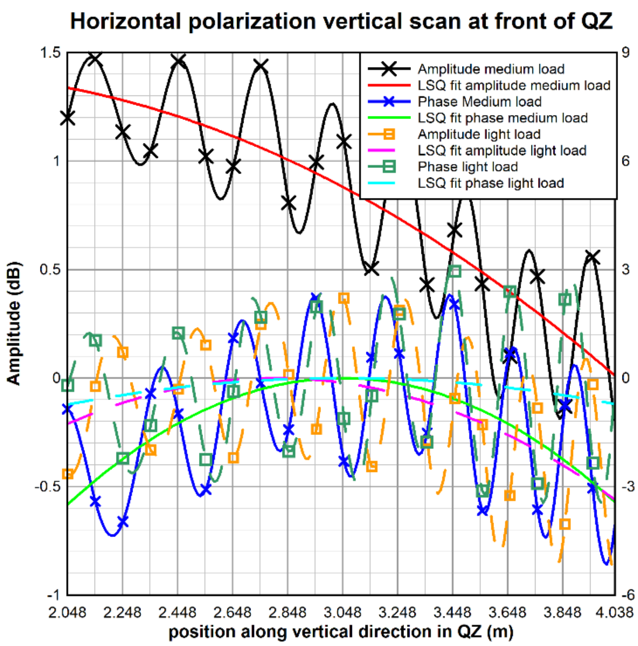

Figure 12. Amplitude and phase distributions for horizontal polarization on the vertical line at the front of the QZ for the medium and light loaded Design 2

Design 2 showed big variations with loading. Somehow this geometry is a bit more sensitive to variations in the loading, even for 2 GHz and 3 GHz, where the igloo variations seem to have smaller differences. The amplitude taper is severely affected. The horizontal polarization, vertical scan results exhibited amplitude taper of more than 1.2 dB. The horizontal polarization and vertical scan amplitude and phase for the medium and light loading are shown in Figure 12. The feed beam direction seems to be affected at 2 GHz and the amplitude taper is really tilted, but the phase indicates a correct propagation. For this Design 2 geometry, the higher loaded absorber seems to provide a better performance.

III. Additional Analysis of Results

The data available can be analyzed in more detail. If the QZ metrics for Design 0 are plotted where the metrics for each of the planes on the QZ are plotted separately, a better understanding of the performance can be obtained. Figure 13 shows the metrics for Design 0 for all different material properties plotted at three different planes of the QZ.

Figure 13 shows that for all frequencies and material properties, the phase variation improves further back in the QZ. The amplitude ripple, in general, is smaller at the back of the QZ. This is clearly the case at 1 GHz. The amplitude taper does not seem to follow that trend to provide exact information as to how the feed fence is affecting the performance.

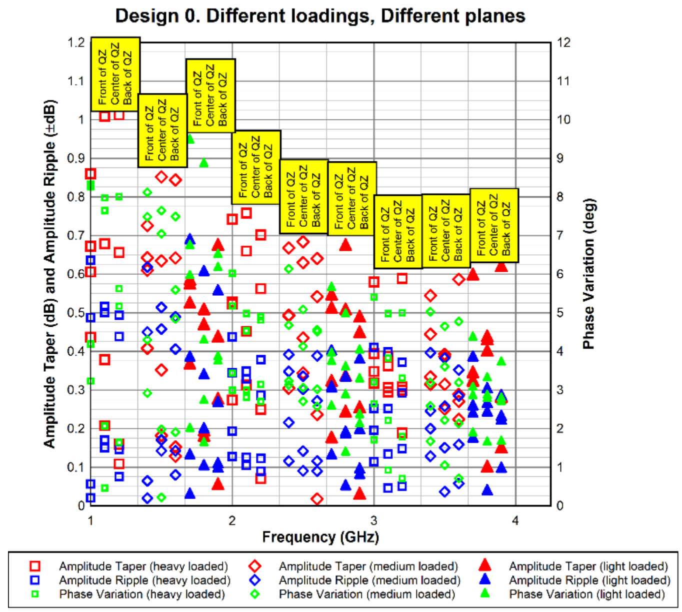

Figure 13. QZ metrics for Design 2. The different materials and planes of the QZ are shifted on the x for clarity

Since the back of the QZ is better behaved, an analysis is performed where the QZ is shifted to be centered at 13.4 m (528") instead of 11.17 m (440"). That is, the QZ center is changed from 5/3 focal length horizontally to twice the focal length horizontally from the virtual vertex of the reflector paraboloid. The values are based on typical QZ locations for compact ranges. While moving the QZ may increase the range length, sometimes it is necessary to do this to accommodate the AUT positioner. Additionally for RCS ranges, it is common to place the QZ at two focal lengths from the vertex [5].

The results for the QZ metrics presented in Figure 14 show that the amplitude ripple improves at all frequencies, but most importantly at 1 GHz, where the maximum amplitude ripple drops from ±0.62 dB for the original QZ to ±0.48 dB. This is lower than the typical ±0.5 dB that is an industry standard for accepted QZ ripple. In general, the phase variation increases slightly, but still stays below 10° maximum.

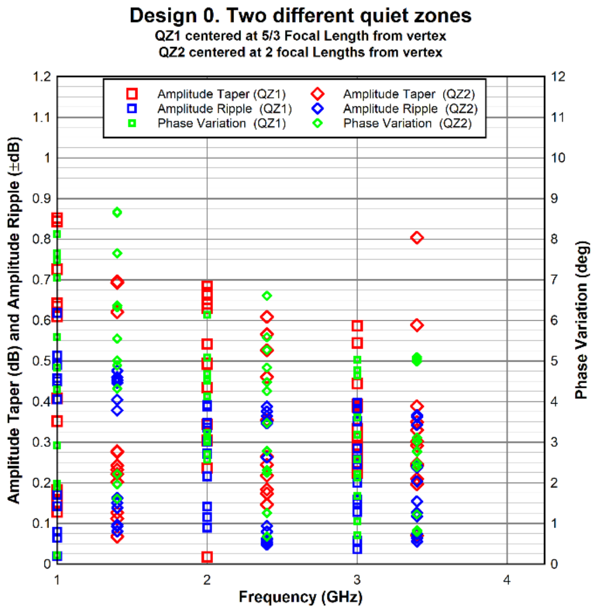

Figure 14. QZ metrics for two QZ locations for a medium loaded Design 0

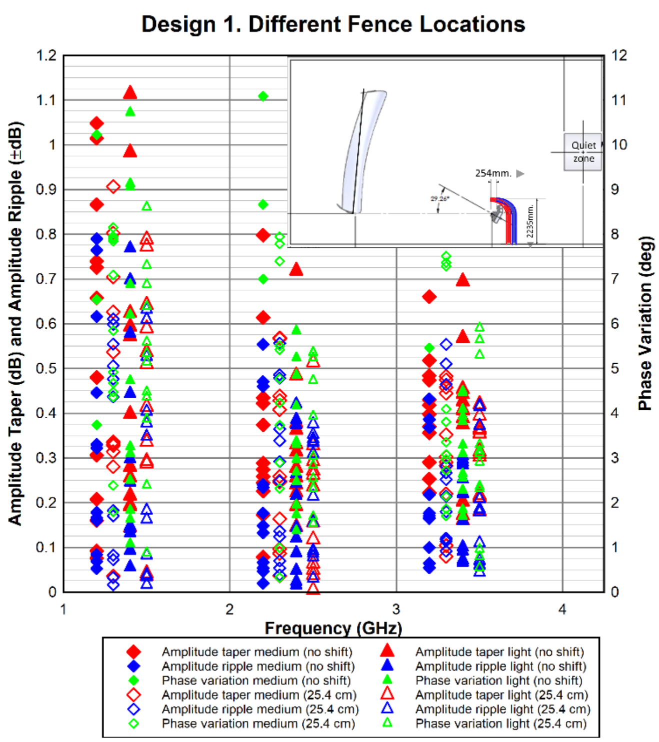

Figure 15. Shifting the design 1 feed fence by 25.4 cm (10") towards the reflector for the medium and low loadings

Another numerical experiment was conducted. The goal was to see if moving the fence forward towards the reflector would improve the QZ metrics. This was done for Design 1, which is the tallest design. The reason was to determine if the ripple seen for this geometry was due to a reflection from the reflected plane wave or diffraction from the feed illumination. Moving the feed fence forward 25.4 cm (10") covered the feed and reduced the direct coupling to the quiet zone. The resulting QZ metrics are shown in Figure 15. The shifted fence results show improvement for the maximum amplitude taper, and at 1 GHz for the amplitude ripple. There is also some improvement for phase variation across the frequency range.

IV. Conclusions

In this paper, a series of new compact range feed fence concepts have been explored. The goal was to design an improved fence that can be produced reliably. While some improvement has been achieved versus the results presented in [1], the most important conclusion is that a method has been presented to analyze the potential impact of the fence on the reflector illumination. The new fence design exhibits a lot of potential as it was shown in [1]. It has also been shown here that improvements to the QZ performance can be made by shifting the location of the fence. It has also been shown that since the QZ metrics improve as we move away from the reflector in the QZ, that shifting the QZ itself further back in the range can provide suitable performance at the lower frequencies. The ability to model these fences *a priori* will reduce the risk during implementation of the range itself. It is also possible to design fences for existing ranges to improve the QZ parameters. Future work will include looking at the potential of these fence designs for RCS ranges.

Acknowledgement

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References

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