On the Disadvantages of Tilting the Receive End-Wall of a Compact Range for RCS Measurements

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***Abstract*— Tilting the receive end wall of a compact range anechoic chamber to improve Radar Cross-Section (RCS) measurements has been a tool of the trade used since the earliest days of anechoic chambers. A preliminary analysis using geometrical optics (GO) validates this technique. The GO approach however ignores the backscattering modes from the reflected waves from a field of absorber. In this paper, a series of numerical experiments are performed comparing a straight wall and a tilted wall to show the effects on both the quiet zone and the energy reflected back towards the source antenna. Two Absorber covered walls are simulated. Both walls are illuminated with a standard gain horn (SGH). The effects of a wall tilted back 20° are computed. The simulations are done for 72-inch long absorber for the frequency range covering from 500 MHz to 1 GHz. The ripple on a 10 ft (3.05 m) quiet zone (QZ) is measured for the vertical wall and the tilted wall. In addition to the QZ analysis a time-domain analysis is performed. The reflected pulse at the excitation antenna is compared for the two back wall configurations Results show that tilting the wall improves measurements at some frequencies but causes a higher return at other frequencies; indicating this method does not provide a broadband advantage.**

Keywords: ***Anechoic Chamber Design, Radar Cross Section Measurements, Geometrical Optics***

I. INTRODUCTION

The idea of tilting the receive end wall of an RCS chamber is not new. It is discussed by Hemming in [1]. The typical angle for the tilt is small, usually 5 to 8 degrees. A tilt of over 10 degrees is not usually seen [1]. Figure 1 shows an illustration of this approach. The theory behind the tilt is based on geometrical optics (GO). The absorber is treated as a solid layer of material having a lossy permittivity with a gradient as the position varies along the normal to the surface of the material. This is a common way to model absorber as presented in [2]. The variation of the permittivity is related to the average between the foam material and the surrounding air. The goal of the tilt is to send the reflected signal from the back wall above the body of the reflector where it will not be received by the feed, and the effects of the back wall will be reduced.

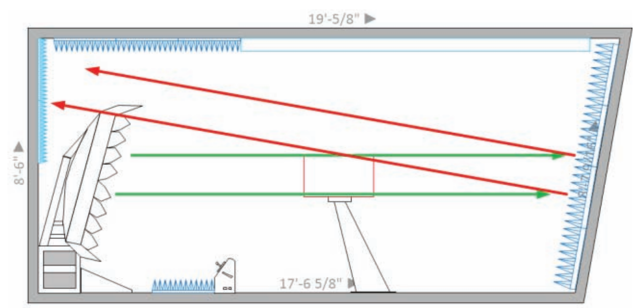

Figure 1. A RCS compact range with a 10-degree tilted wall.

This idea is good if we can assume that the pyramidal absorber behaves like these layers of material. For solid layers of material, the reflectivity follows Snell's law of reflection [3]

$$\theta_r = \theta_i \qquad (1)$$

Where θ_i is the angle of the incident ray and θ_r is the angle of the reflected ray. Tilting the wall does not seem to have any disadvantages due to the angle of incidence. As was shown in [4], the reflectivity at 10 degrees is equal to the reflectivity at normal incidence. The reflectivity of absorber of different electrical sizes versus angle of incidence is shown on Figure 2.

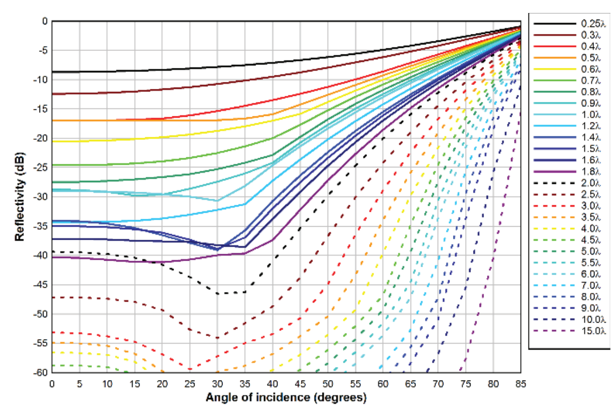

Figure 2. Bi-static reflectivity of pyramidal absorber of different thickness as reported in [4]

II. DISADVANTAGES OF THE TILTED WALL

Based on that simple GO analysis, tilting the wall is a valid approach to reducing backscattering effects. For X-band applications, the absorber on the receive end wall can be relatively small. Typical 8-inch pyramidal material is rated to lower that -50dB reflectivity by most manufacturers. At the bottom of the X band (8.2 GHz), the absorber is 5.55λ in height. If we use the Rodriguez Equations presented in [4] at the bottom of the X band (8.2 GHz), the absorber has a reflectivity of -54.23dB. The same equations will show that at an angle of 10 degrees (a back wall tilt of 20 degrees) the reflectivity is also about -55 dB.

This method of analysis assumes that the only reflected energy will be in the bi-static direction. However, as reported in [5], at frequencies where the tips of the absorbers are one wavelength away from each other, backscattering will occur in other directions, and a portion of the reflected energy will travel back towards the source of the incident ray, in this case, the reflector. For typical 8-inch absorber, the pyramids are placed 3 inches apart or 2.1λ apart at 8.2 GHz. However for frequencies below 3.9 GHz, the 3 inch separation is less than one wavelength. Therefore, there is no reflected energy heading back to the reflector. At those frequencies, the 8-inch absorber is 2.64λ and the reflectivity at that frequency is -47dB per the equations in [4] (-45dB for a 10 degrees of incidence). Manufacturers give a -45dB level at 4GHz so the absorber is good enough for reasonably good RCS measurements.

It is interesting that this issue of the back-scattering as reported in [5] is not usually mentioned in the literature, and [1] does not seem to address it in its discussion on RCS chambers. It is true that the back scattering is smaller than the bi-static reflectivity, but nevertheless it will be present. The back-scattering phenomena is known, since that is the main reason for using wedge absorber on the side walls of RCS chambers. However, for some reason it is not taken into account when looking at the back wall treatment when it is tilted.

In [6], a double tilted wall with the top half tilted 8 degrees and the bottom half tilted -8 degrees was studied, but this was all in the VHF band. Thus, up to 300MHz, the back-scattering phenomena does not occur for typical 72-inch and 48-inch pyramidal absorbers. These sizes are the common ones used down in the VHF band.

Let us concentrate now on the lower UHF band. At those frequencies, the same 72-inch and 48-inch pyramid is used. Typical 72-inch pyramidal absorber is manufactured with a base that is 24 inches by 24 inches. Typical 48-inch pyramids are usually 12 inches by 12 inches in base. These absorber geometries place the backscatter phenomena at 491.8 MHz for a wall treated with 72-inch material and at 983.6 MHz for a 48-inch pyramidal treatment. Manufacturers seem to disagree a bit more on the performance of these materials at 500 MHz. The following table shows their guaranteed levels versus the predictions of the Rodriguez Equations [4].

TABLE I. GUARANTEED AND CALCULATED PERFORMANCE FOR LONG PYRAMIDAL ABSORBERS.

Absorber	Manuf. A	Manuf. B	Manuf. C	Aver.	Rodriguez [4]
48-Inch	40	39	40	39.6	43.5
72-Inch	45	42	43	43.3	49.8

Given that the manufacturer's levels are guaranteed levels and that it is expected that most pieces will exceed that number, the predictions of [4] are good. Using [4], the bi-static reflectivity at 10 degrees of incidence is computed. The reflectivity levels for 48-inch absorber are -42dB. For the 72-inch material the reflectivity at 10 degrees of incidence is -48dB. It seems desirable to use the 72-inch absorber when the lowest frequency of interest is 500 MHz. Given the geometry of the pyramid, it is expected that certain level of energy will be transmitted back towards the source of the incident rays, that is, the reflector. This energy will be small compared with the bi-static, which will be the highest reflected level. However, the fact that there is a reflected back-scattering seems to take away the main benefit of tilting the back wall on a RCS range. The back-scattering may increase significantly as frequency increases, given the size of the flat surfaces of the absorber that are now facing more towards the source.

In Figure 3, we see the flat facets of the absorber that are seen by the reflector as we tilt 72-inch absorber. What are the effects of these facets at high frequencies? While it is true that the permittivity is reduced as we go to higher frequencies [4] and the wave may penetrate these facets easier, it is not an easy numerical problem to solve, and the effects of these on the high frequency performance of the range is unknown.

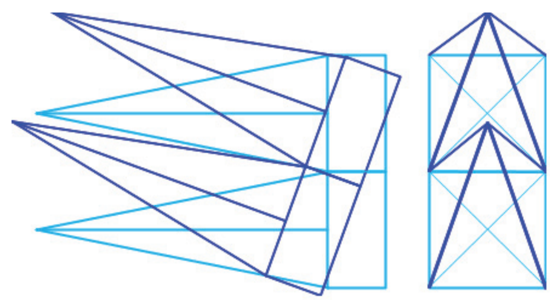

Figure 3. Side and front view of 72-inch regular pyramids with and without a 20-degree tilt.

To check any possible benefits of tilting the wall at the low frequencies, a set of numerical experiments were performed using CST Suite^{TM}. Figure 4 shows the two different set ups. A large standard gain horn (SGH) is used to illuminate a wall of absorber. On the top of Figure 4, is the standard wall, and on the bottom of Figure 4, there is a wall tilted back 20 degrees.

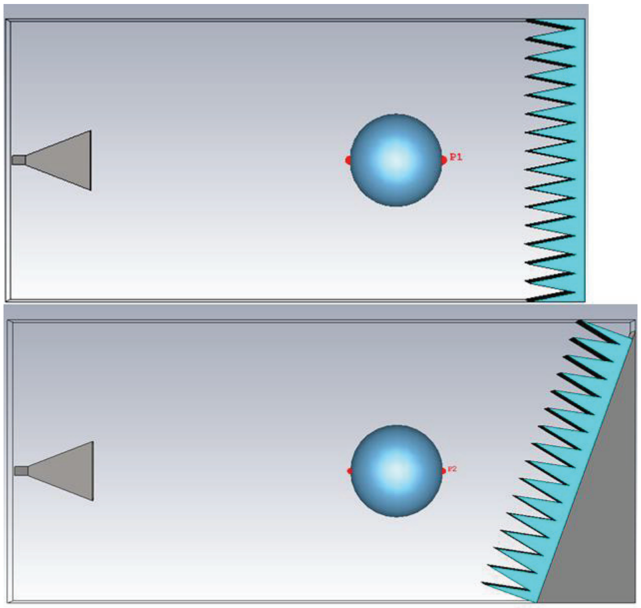

Figure 4. The two numerical experiments. The top is a SGH illuminating a standard wall of 72-inch pyramids, the bottom is the same SGH illuminating a tilted wall treated with the same 72-inch pyramids.

The horn is fed with a WR-1500 waveguide and the simulation is executed from 500 MHz to 750 MHz. In Figure 5, the field distribution is shown. The E-plane pattern of the horn can be observed in the two cases. For the simulations, the top, bottom and side walls of the computational domain, as well as the wall behind the SGH, are set as open boundaries (perfectly matched layers). The wall behind the absorber is set to a perfect electric conductor (PEC). For the tilted wall an additional block of PEC was inserted to provide a conductive backing to the absorber.

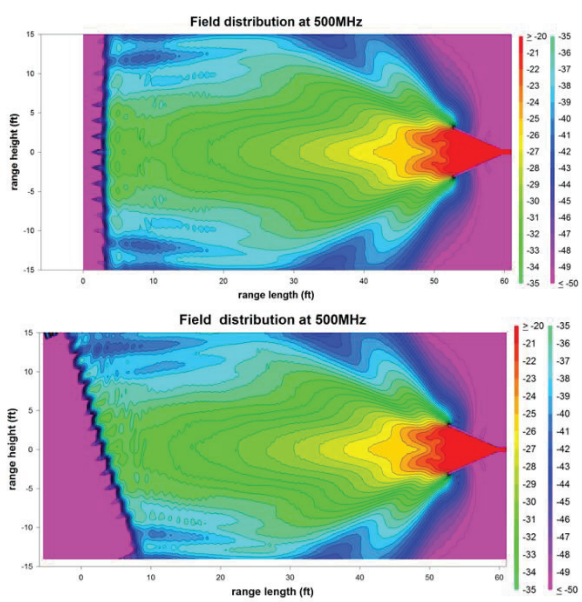

Figure 5. Field Distribution at 500 MHz for both the standard wall and the tilted wall.

The chosen quiet zone (QZ) is located between 15 ft and 25 ft away from the back wall. Figure 6 shows a scan of the electric field along the center of the QZ along longitudinal axis of the spherical QZ.

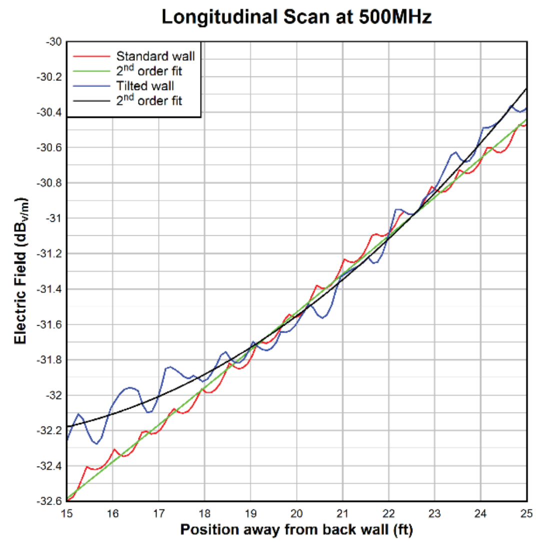

Figure 6. Longitudinal scans for the standard wall and the tilted wall. A second order fit has been added for analysis of the ripple.

The distribution along the center of the QZ is different for the two cases. A slight difference in the period of the ripple is shown. This is expected given the angle of the reflecting surface. For further analysis, the 2nd order fit curve is subtracted from the field distribution to get a better view of the ripple. Figure 7 shows the results of this subtraction.

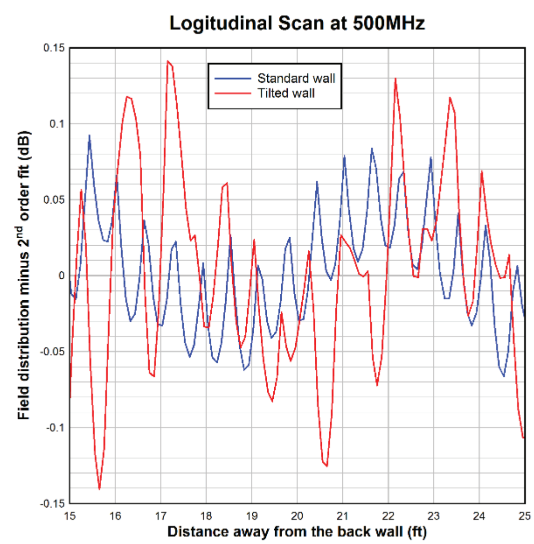

Figure 7. Distribution of the field in the QZ minus the 2nd order fit for the two cases being analyzed.

The results show the largest peak-to-peak ripple of 0.20 dB for the tilted wall. The standard vertical wall shows a peak-to-peak ripple of about 0.11 dB. This translates to a reflectivity of -44 dB for the standard wall and -39 dB for the tilted wall. Additionally, in Figure 5, no difference on the field distribution above the SGH can be appreciated. There does not seem to be any advantage to tilting the wall.

III. Analysis of the Reflected Signals

One could argue that the analysis of the QZ fields does not apply for RCS chambers. It was mentioned that the advantage of tilting the wall in RCS chambers was to direct the reflected energy away from the illuminating reflector. The performed numerical experiments do not have a reflector illuminating the QZ, but a large SGH. However, we can look at the signal that returns to the horn for each of the two cases.

Figure 8 shows the time domain signal of the power at the excitation port from 100 to 180 ns. This corresponds to a wave traveling about 100 to 180 ft. That roughly the distance from the excitation port to the wall and back to the excitation port for both cases being simulated. The standard vertical wall shows the modulated Gaussian pulse that was reflected from the back wall. The peak of the reflected pulse is at 130ns. The excitation signal peaks at about 15ns, so there is roughly a difference of 117 ns between the original excitation at the port and the reflected signal. Figure 5 shows about 60ft between the feed of the horn and the back wall.

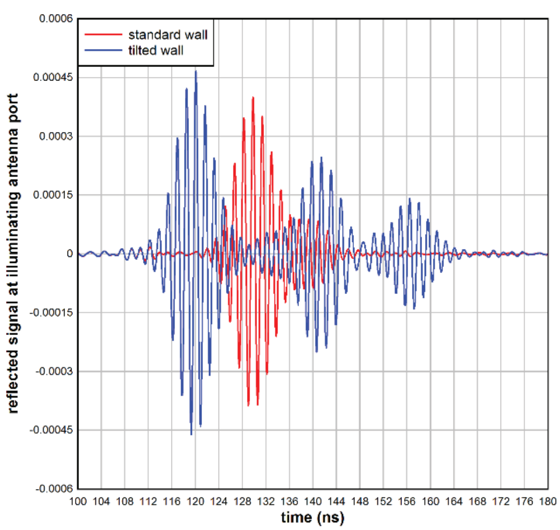

Figure 8. Time domain signals for the two cases.

So indeed, the pulse in Figure 8 is coming from the back wall. Figure 8 shows that for the tilted wall, the pulse is higher in magnitude, and it is spread over a longer time. There seem to be a total of 3 pulses with a much higher initial pulse followed by two additional pulses. If a FFT is performed on these time domain signals, their frequency behavior can be extracted. Figure 9 shows the frequency domain of the excitation signal as well as for the reflected signals.

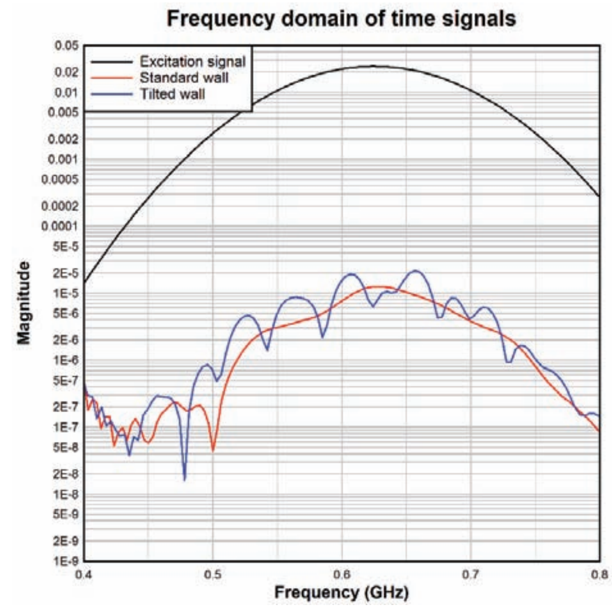

Figure 9. Frequency spectrum of the excitation and the signals reflected form the back wall at the excitation port.

From the data shown on Figure 9, it seems that for some frequencies the tilted wall has an advantage, but for others it does not. At the lowest frequency of interest (i.e. 500 MHz) the levels of the reflected signals compared to the excitation are -47.3 dB for the standard wall and -35.1 dB for the tilted wall. There is not a broadband improvement of the performance. There is an improvement at 478 MHz, at 542 MHz, 584 MHz. At the center of the band there is an improvement from 610 MHz to 640 MHz. Above that, there is an improvement at 674 and 727 MHz. In general, the improvement, at those frequencies where it does occur, appears to be about 3.5 dB. The highest improvement is at 478 MHz, where the difference between the two wall geometries is 10.5 dB

IV. CONCLUSIONS

Tilted walls have been used in RCS ranges for many years. The literature mentions their use in back walls of RCS chambers and provide an explanation for their advantage based on a geometrical optics approach. In this paper, we have shown that the geometrical optics analysis may be missing some of the effects that are present when a wall of absorber is illuminated. It has been shown that tilting the wall may provide a limited advantage at some frequencies. The advantage is not worth the additional cost of installation and the extra footprint required for the chamber. At other frequencies, the tilting of the wall does not provide any advantage. While more thorough analysis may be required to check issues at frequencies above 1 GHz, the author has shown that for RCS chambers operating down to 500 MHz, tilting of the wall does not provide any significant advantage over a broad band. Avoiding that back-scattered energy is the main reason for the tilting of the wall. The numerical exercises have shown that the backscatter may be larger over most of the frequency band when the wall is tilted. Thus, the use of tilted walls is not recommended. Users are better off using other techniques to reduce the effects of the backscattered energy such as time gating [7].

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