Numerical Study of Chebyshev RF Absorber Arrangements Versus Tilted RF Absorber Pyramids

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Abstract—Driven by economics, it is common to repurpose existing indoor antenna ranges for different applications such as hardware-in-loop (HWiL) testing of systems. If the range was originally intended to have a centered line-of-sight, using it for a different use may create reflected paths with high angles on incidence onto the lateral walls. These reflected paths have angles of incidence onto the absorber that are very large and cause for the absorber to perform poorly. Two different approaches are possible to improve the range performance. One of them is to use a Chebyshev approach. The second approach is to tilt the absorber blocks to change the angle of incidence to the incoming wave. In this paper numerical methods are used to study the difference between the two approaches to see their advantages and disadvantages.

Index Terms—RF Absorber, Anechoic range design, electromagnetic measurements.

I. INTRODUCTION (Heading 1)

It has been mentioned in the literature [1-5] that RF absorber is optimized for normal incidence, however, when using the RF absorber in the treatment of the walls for an anechoic range the incidence is at an angle that is far from normal incidence. These larger angles of incidence reduce the performance of the RF Absorber. The rules for sizing an indoor anechoic range given in [5] and [6] can help in reducing the effects of the poor performance of the absorber on the lateral surfaces of the range. However, it is becoming more common to repurpose existing ranges. This is driven by economics given the cost of the real estate required for a range and also to reuse existing shielded enclosures (if shielding is a requirement [5]) that were built for development programs that are no longer in progress. In the interest in checking the performance of RF absorber at large angles of incidence has sparked interest in developing methods to measure RF absorber at large angles of incidence [7, 8] and in analyzing different RF absorber approaches to improve the performance of the anechoic range.

Consider the range in Fig. 1. Let us assume that this range was designed to perform antenna measurements, and let us assume that the range antenna, as defined in [9] may have been set in the centerline of the range, at location A, to provide an angle of incidence onto the absorber of around 50°. A 50° angle of incidence was shown in [1] to provide -40 dB of absorption with pyramidal absorber that is between 2.5λ and 3λ in total height at the frequency of interest. However, if the new test setup calls for additional range antennas located at position B, as shown on Fig. 1, changing

the angle of incidence to about 64°, which as shown on [1] does change the reflectivity of 2.5λ and 3λ to levels of about -20 dB. A 20 dB reduction in range performance. The reduction in performance is a reason for looking at different absorber layout. A simple approach will be to double the size of the absorber to 5λ or more, but this longer absorber may block the direct path between the range antenna at B and the quiet zone (QZ), or the proximity may load the antenna and distort its pattern. There are two potential options for treating the lateral walls. Chebyshev arrangements as described in [10], and tilted or “dragon-tail” absorber as shown on Fig 2.
II. CHEBYSHEV TREATMENTS

As it was stated in [5], the Chebyshev absorber concept assumes that the reflection at each step is very small and that higher order interactions between the steps can be ignored. The theoretical improvement of a third order Chebyshev can be easily computed. However, this computation assumes that

\[ f_0 = f_3 = \frac{f_m}{2} \sec^2 \psi_m \]  \hspace{1cm} (6)

and

\[ f_1 = f_2 = \frac{f_m}{2} (3 \sec^3 \psi_m - 3 \sec \psi_m) \]  \hspace{1cm} (7)

We can then write an equation for the magnitude of the reflection coefficient of a Chebyshev arrangement which in dB becomes:

\[ |\tilde{\Gamma}(\psi)| (dB) = 10 \log_{10} \left[ \left( (f_0 + f_3) \cdot \cos 3\psi + (f_1 + f_2) \cdot \cos \psi \right)^2 \right] \]  \hspace{1cm} (8)

Where \( f_0 + f_1 + f_2 + f_3 = 1 \) and, as shown in equations (6) and (7) \( f_0 = f_3 \) and \( f_1 = f_2 \). These coefficients are the percentage of absorber in the period that is at a given step. Assume that \( f_0 = f_3 = 0.25 \) and \( f_1 = f_2 = 0.25 \), hence all the pyramidal heights have equal amounts of absorber. Let us assume a step for an incidence of 70°. Hence, \( d = \frac{\lambda}{4 \cdot \cos 70°} \) or 1.83 cm or a maximum step of 5.5 cm (2.2 inches). The theoretical improvement of the arrangement is shown in Fig. 4.

In the actual implementation of the Chebyshev the perfect cancellation will not be achieved since, as it was mentioned above, there is no perfect plane wave incidence and no infinite area covered with the absorber treatment. However, theoretically improvements of 10 dB are achievable over the standard absorber according to [10].

![Fig. 3. A Chebyshev arrangement showing a step d.](Image 54x620 to 264x696)

![Fig. 4. A Chebyshev arrangement improvement showing a step d = 1.83cm and equal coefficients.](Image 325x228 to 551x467)
III. TILTED ABSORBER

In reference [1], computed off-normal performance of absorber was presented. Figure 5 shows the performance of the absorber based on the results reported in [1].

![Graph of computed bi-static reflectivity vs. angle of incidence](image)

**Fig. 5.** Off-normal performance of pyramidal absorber as reported in [1]

Notice in Fig. 5 that a change in angle of incidence of 5°, from 65° to 60° for a 3λ pyramidal absorber provides a change from -21dB to -28dB in reflectivity, a 7 dB improvement. Thus, changing the angle of the pyramids on the piece by tilting the base could potentially improve the reflectivity of the absorber layout.

Then consider the absorber treatment shown in Fig 6. Where the pyramids have been tilted 22.6°

![Typical 18-inch (45cm) pyramidal absorber block with a 22.6 degree tilt](image)

**Fig. 6.** Typical 18-inch (45cm) pyramidal absorber block with a 22.6 degree tilt.

Theoretically, at 2 GHz, when 18-inch pyramidal absorber is 3λ, the improvement at 70 degrees of incidence would be about 26dB from -14.5 to -40.2 approximately.

This improvement is theoretically much larger than the improvement obtained from Chebyshev. Additionally, Chebyshev arrangements are frequency dependent, while tilting, from the data shown in Fig. 5, is frequency independent provided that the pyramidal absorber has a height larger than 2.5λ and for incident angles larger than 50° where the slope of the reflectivity barely changes as the electrical height of the absorber increases.

IV. COMPARISON OF COMPUTED RESULTS

To really settle the question a full wave analysis of a Chebyshev arrangement and of a tilted arrangement are compared. The frequency solver on CST Suite is used to compute the reflectivity of the absorber. The measured results using the methodology presented in [7] and [8] showed good correlation between the computed results and the measurements. The results of the measurements of 24-inch (61 cm) pyramidal absorber is shown on Fig. 7.

![Graph of measured vs. computed reflectivity](image)

**Fig. 7.** Measured and computed results for 24-inch pyramidal absorber at 82° of incidence.

Some of the difference between the computed and the measured results can be explained from the material properties used. The numerical model assumes a homogeneous absorber with the same material properties thought the pyramid. However, given the manufacturing process this is not the case. As the wet foam dries the wet carbon solution drifts pulled by the gravity causing different amount of carbon in different areas of the pyramid. This was already reported in the IEEE STD 1128-1998 [11] that provides guidance for RF absorber measurements. Data presented in [11] showed the potential variations in permittivity inside a piece of absorber. Figure 8 shows the data reported in [11].
The results in Fig. 7 seem to validate the numerical approach using the frequency domain solver in CST Suite when analyzing periodic structures using periodic boundaries and Floquet ports for large angles of incidence.

A. Full-wave analysis of Chebyshev arrangement.
Pyramidal absorber 18 inches (45 cm) in height was arranged in the Chebyshev arrangement discussed above (\(d=1.83\) cm) and equal weight. A single period of this arrangement is shown in Fig. 9.

![Fig. 8](image)

The analysis is performed when the period of the Chebyshev is cross-range, that is for \(\phi=90^\circ\) and for the period along the range or \(\phi=0^\circ\). In [10] it was suggested that the Chebyshev period variation should be across the range. The simulation is performed from 5 to 10 GHz, which the results in Fig. 4 showed would provide about 10dB of improvement. Results of the analysis from 5 GHz to 10 GHz are shown in Fig. 10. The results in Fig. 10 show that there is improvement from the Chebyshev arrangement for both polarizations of the incident field. However, the perpendicular polarization seems to exhibit a larger improvement. The results also validate what [10] mentioned that the cross-range arrangement provides better improvement. Additionally, it is shown that, between 8 GHz and 9.5 GHz the improvement is less than 10 dB and it is smaller than the improvement observed at 6 and 6.5 GHz which Fig. 4 shows are at a null or perfect absorption for the theoretical Chebyshev improvement.

B. Full-wave analysis of Tilted absorber.
The tilted absorber arrangement shown in Fig. 6 is analyzed over the same frequency range. The model view is shown in Fig. 11.

![Fig. 9](image)

The absorber is analyzed at 70 degrees of incidence as was the case with the Chebyshev arrangement. In this case the field is incident only from the direction that the tips of the pyramids are tilted.

In Fig. 12 the tilted pyramid performance is compared to the standard 18-inch absorber at an angle of incidence of \(\theta=70^\circ\).
The improvement of the tilted absorber decreases as the frequency approaches 1 GHz, this is 18-inch absorber so it is about 1.5λ. Notice in Fig. 5 that the performance improvement with angle of incidence changes is smaller the shorter the pyramidal material is. The results for the tilted absorber are plotted with the cross-range Chebyshev results modeled. The results show that for most of the 6 to 10 GHz simulated range the two approaches are very similar on the advantage that they provide.

The tilted absorber provides about 10 dB of improvement versus the Chebyshev at 5 GHz. At frequencies from 1 to 5 GHz, the tilted approach provides more improvement compared to the Chebyshev arrangement. The performance difference from 1 to 5 GHz seems to imply that the tilted approach may be a wider band approach than the Chebyshev arrangement.

V. Conclusion

The numerical results are not very conclusive regarding which approach is better to treat the lateral walls of a range to improve the performance when the angles of incidence are not ideal. Based on the presented data the tilted approach is a broader band approach than the Chebyshev approach.

REFERENCES


