Numerical Analysis of Techniques to Improve Oblique Incidence of Absorber

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***Abstract*— Financial impacts often drive decisions to repurpose existing ranges instead of procuring new measurement facilities. These existing ranges have fixed geometries (height, width and length) that were set when the range was originally constructed and often are designed for a different purpose. The inability to set the geometry precludes the range designer from using the range geometry to improve measurement performance. Thus, the performance of the range is mostly dependent on the Radio Frequency (RF) absorber and the range antenna directivity. In rectangular-shaped ranges for example, the lateral surfaces, side walls, ceiling and floor, are the critical surfaces to address in RF absorber arrangement.**

In this paper, numerical analyses of Chebyshev arrangements as well as dragon tail or tilted absorber are studied. This paper also analyzes the performance of Chebyshev absorber for normal incidence and for oblique incidence along with the proper arrangement of the Chebyshev period. While certainly these have been discussed previously in the literature, this paper consolidates the previous information and illustrates it with numerical examples to help the reader understand the best approach to use when repurposing a range.

***Keywords*— RF Absorber, Range Design**

I. Introduction

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. As shown in [1], the larger the angle of incidence, the worse the performance of the RF absorber. References [5] and [6] provide some guidance in reducing the effects of the poor performance of the absorber on the lateral surfaces of the range by sizing the range accordingly. However, it is becoming more common to repurpose existing ranges. Financial concerns typically drive these decisions given the cost of the real estate required for a range. Another reason is to reuse existing shielded enclosures (if shielding is a requirement [5]) that were built for development programs that are no longer in progress. The repurposing of ranges takes away the ability of the range designer to use the geometry of the range to improve the performance. In many cases, absorber is the only way to achieve the desired electromagnetic environment in the range.

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. In reference [9], the use of a Chebyshev arrangement was presented to improve the performance of RF absorber at oblique incidence. In reference [10], the approach of tilting the absorber was analyzed and compared to the Chebyshev approach as a technique to improve the performance of RF absorber at oblique incidence. In this paper we look further into these two approaches and provide limits to their application.

II. Frequency Band of Improvement

It is important to remember that there is not a Panacea, a cure-all, that will provide improvement at all angles of incidence and for all frequencies from the low MHz to the THz range. This is however not a problem, as typically we are trying to improve the reflectivity of the specular reflections [5], which exist at only one particular angle of incidence. Hence, it is not necessary to have a very broad improvement over a wide range of angles on incidence. Similarly, since the bi-static reflectivity of absorber improves as the absorber becomes electrically larger [1], it is only necessary to provide the improvement at some frequency band where the absorber is not sufficiently large in terms of wavelengths. Chebyshev arrangements, as discussed in [9], provide improvement over a band that is a function of the step of the Chebyshev. While there is a periodicity such that as we increase the frequency, the theoretical Chebyshev improvement repeats itself. Typically the RF absorber performance also improves with frequency. Hence, the additional Chebyshev improvement is typically not necessary.

Figure 1 shows a theoretical improvement for a third order Chebyshev arrangement for angles of incidence around $\theta=70°$. The step is 1.83 cm and the weights on the polynomial are equal, that is, there are the same number of pyramids with no step to those with one, two and three steps. It is clear that the improvement occurs over a band and the bandwidth and center frequency can be calculated as shown in [9], [5], and [10].

The other approach is to tilt the absorber such that the pyramids point to the angle of arrival of the specular ray. This is not typically possible, so at least the approach is to tilt the absorber to reduce the angle of incidence.

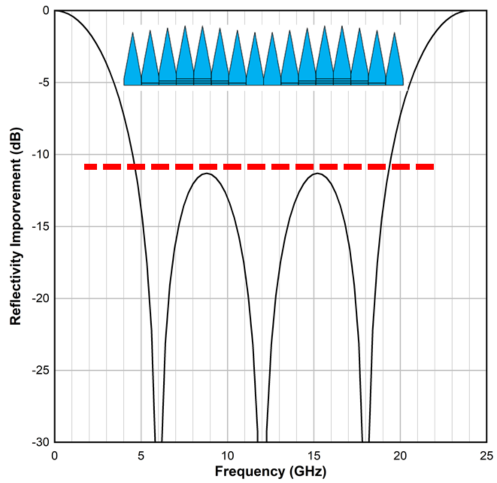

Figure 1. Theoretical improvement of a Chebyshev arrangement with a 1.83 cm step and equal weights for an angle of incidence of 70° off normal incidence.

As shown on Figure 2, reducing the angle of incidence will improve the performance of the RF absorber significantly. The improvement, however, is not unlimited across all frequencies and does not mean that this is an improvement over a wide range of frequencies. Notice in Figure 2 that given the typical behavior of pyramidal absorber at oblique incidence as reported in [1] for electrically large RF absorber over 10λ, there is no change in performance for angles of incidence such that $\theta \leq 65°$ (where $\theta=0°$ is normal incidence). Similarly, as the RF absorber gets electrically smaller, the improvement from tilting the pyramids is less pronounced than for pyramids that are larger than 2λ.

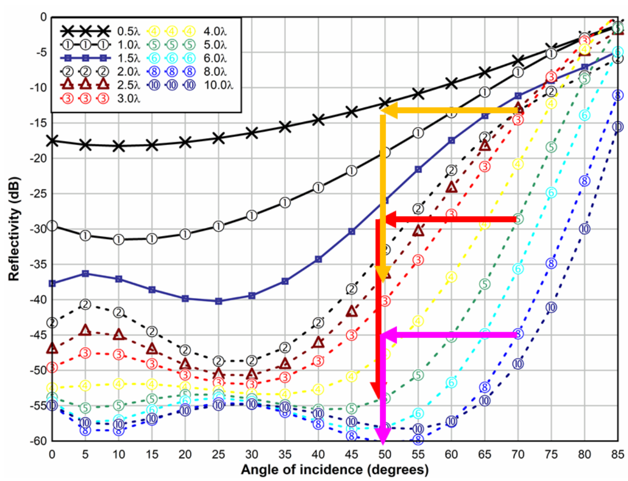

Figure 2. Bi-static reflectivity of RF absorber versus angle of incidence for different electrical sizes of RF Absorber. Showing the performance improvement by reducing the angle of incidence by 20°.

Additionally, as the frequency is reduced and the absorber becomes electrically smaller, the incoming wave does not "see" the absorber features, but rather a series of layers of effective permittivity. It has been shown in [11] that when the spacing between the pyramids is smaller than λ, only the bi-static reflectivity propagates, that is, there is no backscattering (assuming an infinite field of absorber). This is the reason that RF absorber can be modeled using a series of layer of effective permittivity that simulate a periodic pyramidal structure as was shown on [5] and [12]. Thus, as the absorber becomes electrically small, the incoming waves sees a series of effective permittivities as shown on the right on Figure 3. The permittivity profile created by the tilted pyramid at low frequencies may not provide any improvement and it may be detrimental to the performance of the absorber when compared to standard pyramids of equivalent height. Depending on the tilt angle of the pyramid, the overall height of the absorber may increase as shown in Figure 4. In Figure 4, a typical 18-inch high pyramidal absorber is tilted by about 22°. As it is shown, the overall height of the absorber increases from 18 inches to almost 27 inches. This means that, for example, at 4 GHz, the 18-inch absorber is about 6λ, while 24-inch absorber is 8λ. That change of size can provide up to 10dB of improvement at some angles of incidence, as shown in Figure 2, without having to use a customized cut that may be more costly than a standard sized pyramid.

Thus, neither approach will provide a solution that provides an improvement across an entire range of frequencies nor it will be ideal for all angles of incidence.

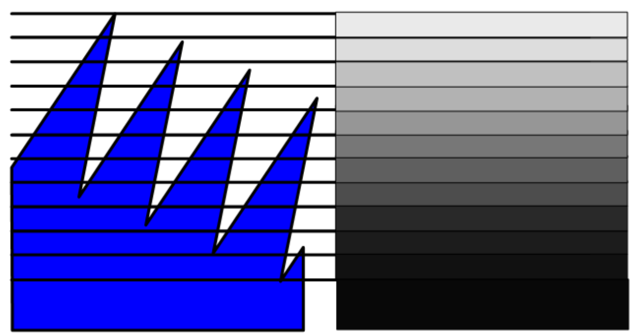

Figure 3. The tilted pyramid at "low frequencies" becomes a series of layers of effective permittivity that fail to provide any improvement and may be detrimental.

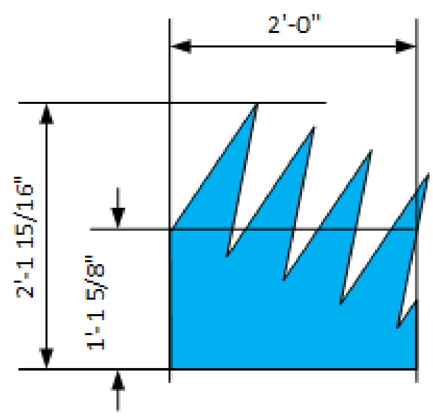

Figure 4. 18-inch typical pyramidal absorber tilted 22°

III. Numerical Results

In this section, we look at the improvement of each approach discussed in the previous section. A commercially available package was used to solve for the bi-static reflectivity of the absorber arrangements. A finite element method (FEM) with periodic boundary conditions was used. Results from the method and the package have been compared to measured results previously in [7]. The results are computed for the incoming wave arriving at θ-70°. Additionally, two different azimuth angles of arrival are tested, ϕ=0° and ϕ=90° as shown in Figure 5. Hence, what is being modeled is the wave arriving from two different directions so that in one case the spatial period of the Chebyshev is across the range, and in another is along the range. This is done to show that the recommendation from [9], to have the arrangement cross range, is the proper approach. It shows that having the Chebyshev arrangement spatial period along the range fails to provide any significant improvement compared to the same pyramid height without the Chebyshev arrangement. This should be obvious as the Chebyshev approach is based on phase cancellation of the reflected energy. For oblique incidence, if the arrangement is done along the range, then there will be a phase difference for the incident plane wave as it arrives onto the pyramids in the arrangement. If the arrangement is cross range, at a given distance from the source, the phase of the incident wave is the same as it hits the different pyramids in the arrangement.

Figure 5 shows the results of the numerical model. Clearly, the results show an improvement of about 10 to 15 dB when the spatial period of the Chebyshev is cross range, that is, ϕ=90°. The simulated results also show that as we go to lower frequencies, below 3 GHz, there is no improvement from the Chebyshev compared to the 18-inch absorber by itself.

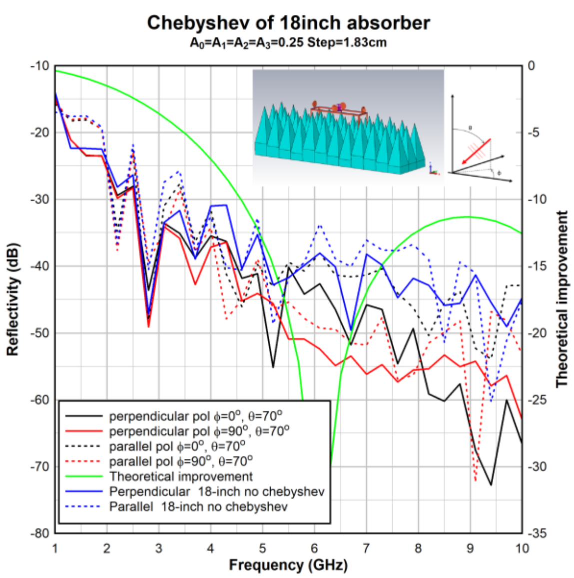

Figure 5. Results for the bi-static reflectivity for standard 18-inch, and a Chebyshev absorber arrangement across and along the propagation direction.

The other approach is the tilted absorber. The geometry shown on Figure 6 is analyzed. In this case, the analysis is only done at φ=0° since the pyramids are tilted towards the incoming wave (see Figure 6).

Figure 7 shows the results for the tilted absorber. The results show a similar improvement to the improvement seen with the Chebyshev arrangement technique, but it also shows that the

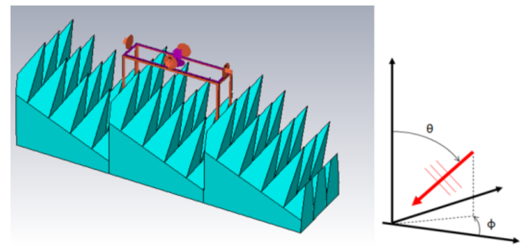

Figure 6. Model of the tilted absorber showing the angles of arrival.

improvement is slightly better for the tilted for the lower frequencies. There is an evident improvement to frequencies as low as 2.5 GHz.

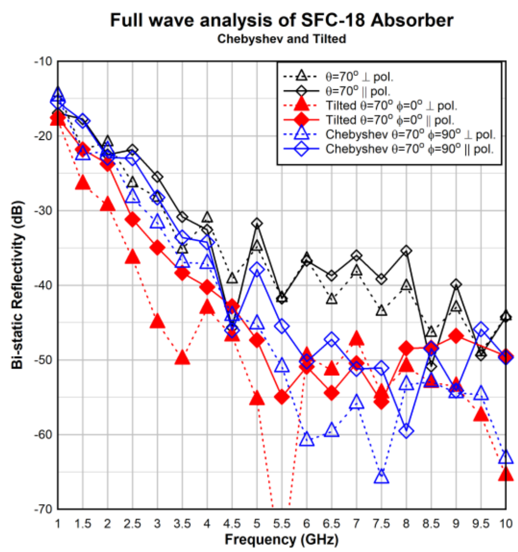

Figure 7. Results for the tilted absorber reflectivity at 70° of incidence compared to the standard 18-inch absorber and to the Chebyshev.

IV. Conclusion

A series of numerical analyses were performed to check two different approaches to improve the performance of ranges by means of improving the absorber performance at large angle of incidence. The two techniques have been shown to provide improvement over a limited range of angles and for a given band of frequencies. The limitations of these techniques are not critical, as typically the improvement is necessary for the specular ray and, also for the lower frequencies of the intended operational range of the anechoic chamber. While the results suggest that the two approaches are equivalent in improvement, the tilted absorber may have a slightly wider bandwidth than the Chebyshev approach presented. Guidance is also given on the proper Chebyshev arrangement by providing data that illustrates the difference between the cross range and down range layouts.

The cross-range arrangements are the ones that provide an improvement for the reflectivity.

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