# Examining the True Effectiveness of Loading a Reverberation Chamber

## How to Get Your Chamber Consistently Loaded

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*Abstract*—In this paper we explore how placing the same amount of absorber in different locations within a reverberation chamber can have different loading effects. This difference can have a significant impact on measurement reproducibility, both for measurements in the same chamber and measurements between chambers (i.e., round robin style testing). We begin by discussing some of the theories behind this and show some experimental results from different absorber placements in a reverberation chamber. We conclude with some suggestions to ensure absorber is placed consistently.

*Keywords-Reverberation Chambers, RF Absorber, Power Decay Time, Wireless Deivce Testing*

## I. INTRODUCTION

As the use of reverberation chambers expands to experiments and measurements involving loaded setups, we explore the realistic effectiveness of absorber loading. Large pieces of absorber are being used routinely in a variety of measurements (for a variety of applications) to lower the Q, decrease the power decay time, and alter the shape of the power delay profile (PDP) [1, 2].

Reverberation chambers are designed to create a consistent test environment with a statistically uniform field throughout the chamber. Many applications have taken advantage of this key principle. For certain applications (i.e., emissions), the original, highly reflective, reverberation chamber is useful. However, applications finding new use of the reverberation chamber are modifying this environment slightly by loading the chamber with RF absorbing materials. An example of this is the use of chambers to test wireless devices [1, 3]. The cell phone industry is beginning to use reverberation chambers for product testing. For the reverberation chambers to be useful for their application, the chamber is loaded to simulate a given insertion loss and power decay time that is representative of a real-world communications channel [4].

Many measurements require the chamber loading to recreate a particular environment. Experiments indicate that the absorber must be within the working volume, but do not specify exact absorber placement. This raises the questions of: Does it matter *where* in the chamber the absorber is placed? Is there an optimal configuration for the antennas and absorber? These are the questions we hope to address.

We address these questions by conducting a series of experiments whereby we measure the relative effectiveness of a fixed quantity of RF absorber placed at different locations within a reverberation chamber. Comparison of measurement results will show the effect of absorber placement within a reverberation chamber.

There are many different parameters we could measure to test our hypothesis. The results could be expressed in terms of power decay time or S-parameters. For this application we choose to display our results in terms of S-parameters. This allows our results to be easily extended to power decay time [1, 2].

## II. OUR HYPOTHESIS AND IT'S IMPLICATIONS

We expect small measureable differences as a result of absorber location in the chamber. Absorber will be placed in a corner (between two walls and a floor), along the wall (between one wall and the floor), in the center of the chamber (sitting on floor) and at various positions elevated off the floor.

The volume inside the chamber, where the average field is statistically uniform, is referred to as the "working volume." The boundaries of the working volume are defined to be some distance away from any metallic surfaces in the chamber. The IEC 61000-4-21 standard defines this distance as $\lambda/4$ from any wall, floor, tuner and/or antenna [5]. Other research indicates that field uniformity begins to diminish within $\lambda/2$ of the walls [6]. It is a reasonable assumption that absorber placed within the statistically uniform field of the "working volume" will have a greater loading effect than absorber placed on the floor or next to the walls.

Testing our hypothesis can be accomplished by measuring $S_{21}$, the insertion loss of the chamber. If our predictions are correct, we should see a change in $S_{21}$ as the absorber is moved around the chamber. The fully exposed absorber in the working volume will absorb more energy than that which is only partially exposed near the floor and walls.

When our measurement results are presented, they will be in the form of $<|S_{21}|^2>$. This can easily be thought of in terms of power using the following equation from [7]:

$$P_{rec} \propto <|S_{21}|^2> \qquad (1)$$

where the proportionality constant is $P_{trans}$. Thinking in terms of power, we predict that the amount of received power will depend on placement of absorber. The power transmitted into the chamber will be constant for each measurement, leaving $<|S_{21}|^2>$ the only variable.

As long as the insertion loss ($S_{21}$) or similar parameter (power decay time, etc.) is measured before each measurement, any problems with absorber placement can be resolved. We intend to show the outcome of a situation where absorber is moved around *after* the insertion loss is measured. Absorber might be moved around after the insertion loss measurement to make room for a device under test (DUT) or for easier access to parts of the chamber or antennas.

## III. MEASUREMENT SETUP

All measurements were conducted inside a reverberation chamber consisting of two paddles (one floor to ceiling and one wall to wall). The dimensions of the chamber are approximately 4.2 m long, 3.6 m wide and 2.9 m tall. The two paddles are identical in shape and have a width of 0.7 meters. Figure 1 shows the chamber used in our measurements.

Measurements were conducted using a pair of dual-ridged horn antennas (assumed to be identical) mounted on a pair of non-metallic tripods that are 1.3 meters tall. The antennas were connected to a vector network analyzer. Data were acquired at 16,001 discrete points between 800 MHz and 10 GHz and then averaged over 100 discrete paddle steps. When we display our data, we will only show results from 1 GHz to 10 GHz. We discard data below 1 GHz because the antenna mismatch becomes an issue.

The single piece of pyramidal absorber used in these measurements (seen in Figure 1) measures 0.6 m long, 0.6 m wide and 0.6 m tall (to the top of the cones). For the measurements where the absorber is elevated off the floor, styrofoam blocks were used to support the absorber.



Figure 1.        Reverberation chamber used in the measurements  with the absorber in position 10.
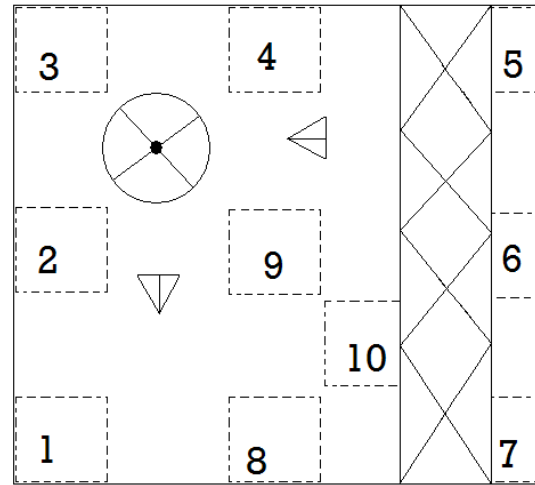


Figure 2.    Locations of absorber (dotted lines) in the chamber. One paddle is shown as a circle, and is mounted floor to ceiling while the other paddle outlined (rectangular box) is mounted wall to wall. Positions 5, 6, 7 and 10 are partially under the paddle.

To test our hypothesis that proximity to chamber surfaces affects the loading, absorber was placed in 10 different locations around the reverberation chamber and insertion loss ($S_{21}$) was measured at each location. The diagram in Figure 2 shows the locations of the absorber in the reverberation chamber. Note that this diagram shows a top down view of the absorber placement.

For positions 1-8, the absorber was placed on the floor of the chamber, up against and touching the wall or corner. In positions 2, 4, 6 and 8, the center of the absorber was placed in the center of the wall. While the absorber was at position 9, data were taken while the absorber was on the floor, and again after the absorber was raised to the height of the antennas (approximately 1.3 meters). This elevated position is referred to as "9A." In position 10, the absorber was at a height of 0.6 meters.

Regardless of the position of absorber, the antennas remained in the same position and orientation (cross-polarized).

## IV. MEASUREMENT RESULTS AND ANALYSIS

At each of the locations shown in Figure 2, $S_{21}$ was measured in phasor form at 100 discrete paddle positions. We computed the squared magnitude of $S_{21}$ at each paddle position, then computed the ensemble average (denoted as < >) to end up with a single $<|S_{21}|^2>$ value at each frequency. In addition to this, we measured the insertion loss of the chamber in an empty configuration as a reference.

We start our look at the measurement results with the reference measurement in Figure 3. Here, the chamber had no absorber in it, that is, there is 0 dB of intentional loading. The losses evident in Figure 3 are due in large part to the wall losses of the chamber. The rippling effect seen at the lower end of the frequency range is due to antenna mismatch. Since the same antennas are used in all of our experiments, any mismatch effects should be constant from measurement to measurement and thus unimportant for our comparisons.
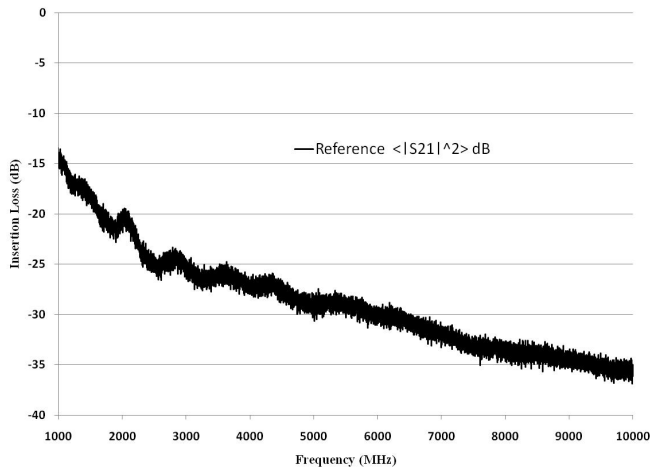
Figure 3. Reference measurement taken with no absorber in the chamber. Insertion loss is shown as $<|S_{21}|^2>$ dB.



Figure 4. Measured $<|S_{21}|^2>$ dB values for positions 1, 3, 5 and 7 as compared to the reference. No moving average has been applied.

Next, we examine the measurement results for the locations where absorber was placed in the corners of the chamber: positions 1, 3, 5 and 7. In these locations, the absorber should be least effective because it is not fully exposed on 3 sides. Figure 4 shows the four corner locations compared to the reference measurement (Figure 3).

An analysis of Figure 4 shows that each of the four corner absorber positions yields very similar results; so close that the curves are indistinguishable on the plot. To reduce the effects of measurement noise and aid our future analysis, a 101 point moving average is applied to the data. In addition to the moving average, we will compare our results directly to the reference measurement by defining "Absorber effectiveness."Absorber effectiveness is simply the difference between the reference insertion loss (unloaded chamber) and the insertion loss measured at the given location. Mathematically, we define absorber effectiveness as:

$$A.E. = <|S_{21}|^2>_{ref} - <|S_{21}|^2>_{pos.n} \qquad (2)$$

where "*pos.n*" is the given position number.

By calculating A.E. and applying a moving average to the results from positions 1, 3, 5 and 7, we can refine the results of Figure 4 to those of Figure 5 to show that a single piece of absorber in any corner of the chamber adds about 5 dB to the insertion loss measurement.

Figure 5 shows that after reducing the noise (using a moving average) each corner location shows a consistent amount of absorber effectiveness regardless of which corner it is.

The consistency of the corner locations (numbers 1, 3, 5 and 7) can also be seen in the mid-wall locations (numbers 2, 4, 6 and 8). In the mid-wall positions, only two sides of the absorber are not fully exposed. Figure 6 shows these results, with the same moving average applied. Absorber in these locations more effectively loads the chamber than the absorber located in the corners of the chamber.
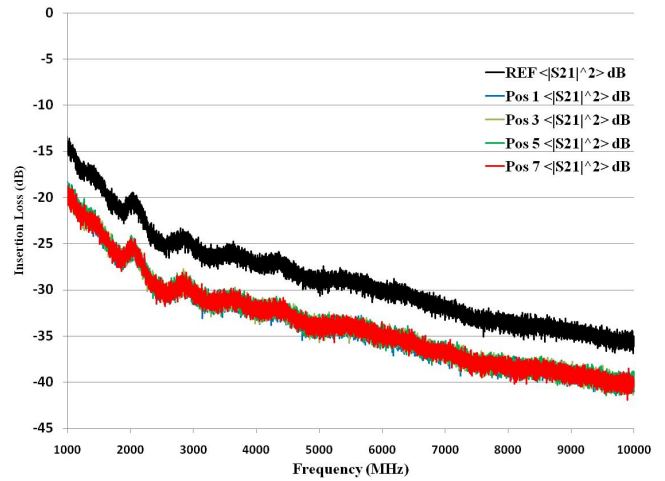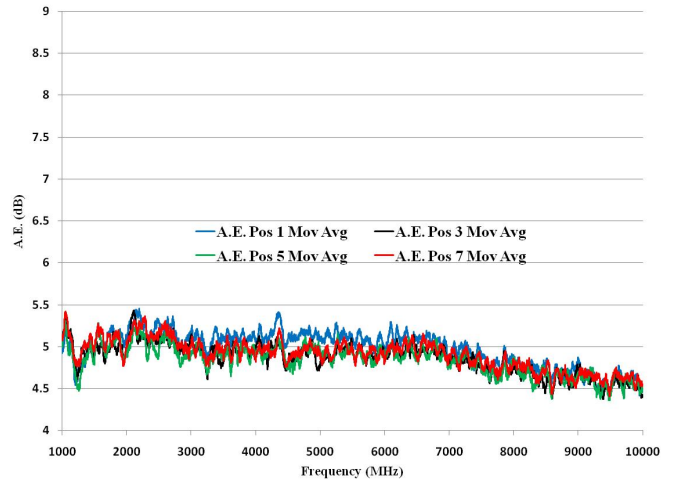


Figure 5. Absorber Effectiveness data for positions 1, 3, 5 and 7. With a 101 point moving average applied.
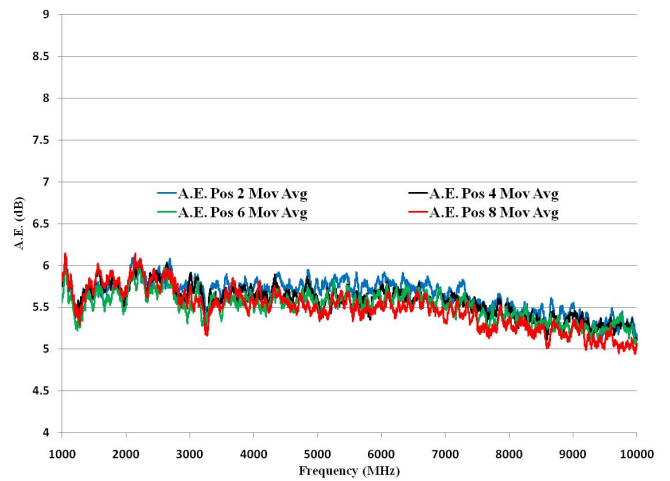


Figure 6. Absorber Effectiveness data for positions 2, 4, 6 and 8 with a 101 point moving average applied.
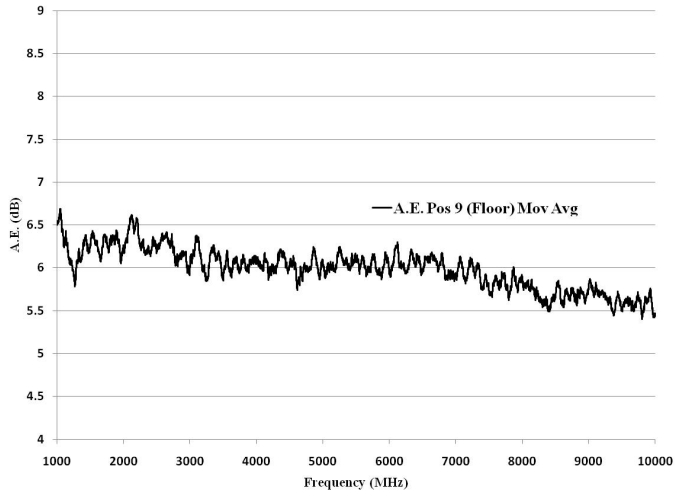
Figure 7.  Absorber effectiveness data for position 9 with a 101 point moving average applied.

Next, the absorber was placed in the center of the chamber, on the floor. In this location, the absorber has only one side that is not fully exposed. Therefore, we expect increased absorber effectiveness compared to all previous positions. Figure 7 shows the A.E. of position 9.

In addition to testing a single piece of absorber on the floor at position 9, we did an additional test with the absorber elevated to the height of the antennas (1.3 m). At position 9A, the piece of absorber is totally within the working volume of the chamber and should be fully exposed on all sides. At this position, we would expect that the absorber has reached it's maximum effectiveness.  However, as our hypothesis stated, any absorber placed anywhere in the working volume should provide the same amount of effectiveness. To test this, we placed the piece of absorber at position 10 at a height of 0.6 m above the floor. Figure 8 shows that the results from positions 9A and 10 are nearly identical (to within 0.3 dB).
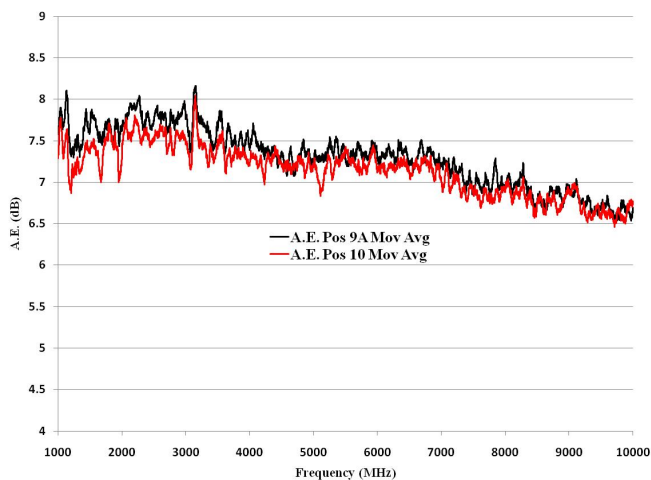


Figure 8.  Absorber effectiveness data for positions 9A and 10 with a 101 point moving average applied.
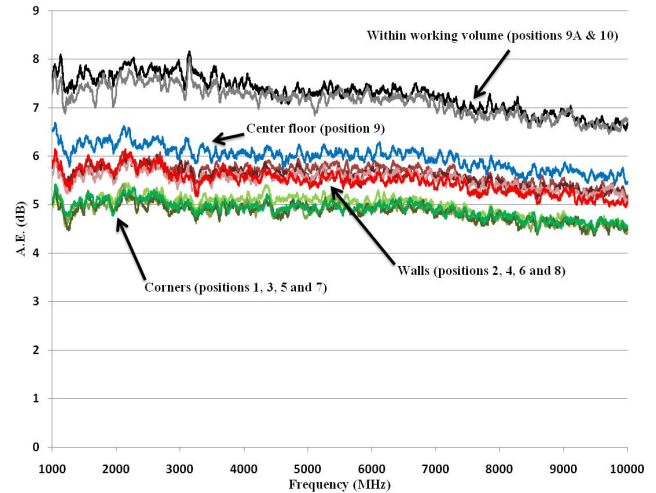


Figure 9.  A summary of the absorber effectiveness results showing all 11 configurations tested.

To better compare the differences that arise from placing absorber different locations, Figure 9 shows all 11 configurations on the same plot. On this plot we can see that the absorber placed in the corner of the chamber has a reduced effectiveness of almost 3 dB compared to the most effective location (elevated off the floor). This is most likely due to all sides of the absorber not being fully exposed. Similarly, absorber placed against the wall is approximately 2 dB less effective than if placed well within the working volume (position 9A and position 10).

## V.    MEASUREMENT UNCERTAINTIES

Uncertainty for these measurements can be quantified after first identifying the contributing factors. The uncertainty from the statistical processing of the measurements is the largest contributor. This initial uncertainty can be reduced through additional averaging, but cannot be eliminated completely. The second factor to be considered is the system drift as the temperature fluctuates throughout the measurement process.

It is important to note that this uncertainty analysis is restricted to those factors which impact *relative* measurements only. Some uncertainties that would usually affect absolute measurements need not be considered here. For example, uncertainties that manifest themselves as an offset would impact *both* measurements being considered in (2). Uncertainties of this type would not affect the relative measurement because they apply to both measurements equally.

The initial statistical uncertainty can be quantified by the standard deviation of the original measurements, before a moving average is applied (i.e. those shown in Figure 4). With no reference measurement subtracted, the data in each absorber configuration has a standard deviation of approximately 0.4 dB. Computing the absorber effectiveness using (2) increases this uncertainty by approximately 40% ($\sqrt{2}$) to 0.6 dB. To reduce this uncertainty we apply a moving average to the data. This will reduce the uncertainty by the following factor:

$$U_{stats} = \frac{0.6}{\sqrt{N_f}} \qquad (3)$$

where $N_f$ is number of independent frequency samples. This can be determined by calculating the bandwidth of the chamber using the measured Q of the chamber. In the worst case, our measurements have a bandwidth of about 1 MHz. In other words, we must sample at frequency intervals of 1 MHz or more in order to get a statistically independent sample. Given the frequency spacing of our initial measurements, and the size of our moving average window, we have about 50 independent frequency samples in each moving average window. This results in a final $U_{stats}$ of approximately 0.08 dB.

The second contributor to our final uncertainty number is the result of system drift largely due to temperature ($U_{temp}$). These measurements were taken over three days (two separate system calibrations). Over this period, the system has an estimated drift of about 0.1 dB.

To compute the cumulative uncertainty (also known as the Combined Standard Uncertainty), we combine these two factors by computing the root-sum-of-squares as shown in [8]:

$$U_{comb} = \sqrt{(U_{stats})^2 + (U_{temp})^2} \ . \qquad (4)$$

Inserting the terms we determined above, we obtain a combined uncertainty of 0.13 dB. After calculating $U_{comb}$ we can select a coverage factor. We choose a coverage factor of 2, which is common practice [8]. This coverage factor is multiplied with ($U_{comb}$) to obtain our final measurement uncertainty of 0.26 dB. This value applies to all relative measurements (including absorber effectiveness calculations) presented here.

## VI.  DISCUSSION

Our measurements to this point seem to coincide with our hypothesis that placing absorber in a corner or against a wall makes it less effective than if it were within the working volume. To more conclusively validate our hypothesis we duplicated the measurements at positions 9A and 10. However, this time we placed a metal plate underneath the piece of absorber. In this configuration, the absorber should be less effective because the metal plate is preventing all sides of the absorber from being exposed. We expect our results to look similar to the difference between positions 9 and 9A; placing a plate under the absorber should simulate the piece of absorber sitting on the floor. However, because the size of the plate is much smaller than the size of the floor, we don't expect the results to be identical. Figure 10 shows the original position 9 and 9A results with the addition of the results from position 9A with a metal plate.
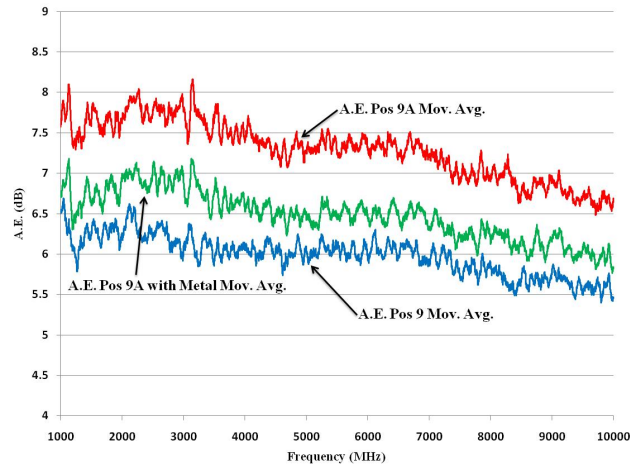


Figure 10. Comparison between Positions 9, 9A and 9A with a metal plate. A 101 point moving average has been applied.

Figure 10 shows that when the metal plate is used, results are within 0.5 dB of position 9. The remaining difference between the two configurations is likely due to the fact that the metal plate used was the exact same size as the bottom of the absorber. When placed on the floor (position 9), the absorber is effectively on a metal plate that is much larger and blocks *all* energy coming from underneath the absorber. With the metal plate, absorber in position 9A can still interact with energy reflected off the floor.

We also placed a metal plate under the absorber in position 10 to show that the result is independent of the absorber location (as long as it is within the working volume). In this configuration, we still expect the result to be close to position 9. Figure 11 shows the original position 9 and 10 data with the addition of the results from placing a metal plate under the absorber in position 10.

As with the metal plate in position 9A, using a metal plate in position 10 yields results that are within 0.5 dB of where we expected to be – equivalent to position 9. The reasoning here is also similar; the floor acts as a much larger metal plate than was actually used in positions 9A and 10.
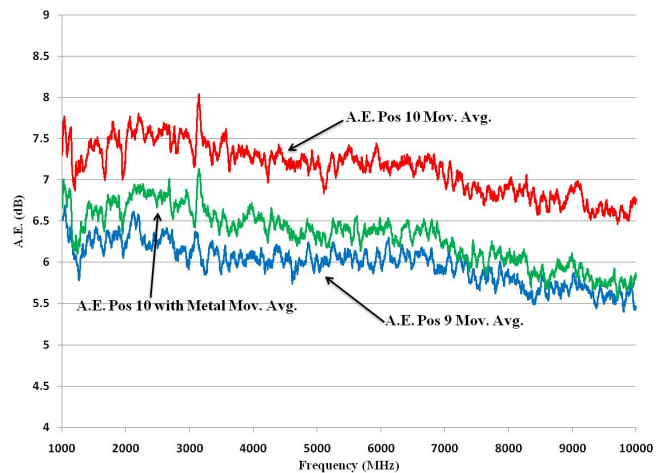


Figure 11. Comparison between Positions 9, 10 and 10 with a metal plate. A 101 point moving average has been applied.

## VII. CONCLUSIONS

We have shown that placing a fixed amount of absorber at different locations inside a reverberation chamber can impact the insertion loss of the chamber (and thus the "effectiveness" of the absorber). By placing a single piece of absorber at 11 different locations we showed that as long as all sides of the absorber are fully exposed and within the working volume of the chamber, maximum effectiveness is achieved. Because of this effect, we encourage others to measure the insertion loss of their chamber – in its test configuration – prior to other measurements and to avoid moving absorber once this measurement has been completed.

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