Free Space Antenna Factor Computation Using Time Domain Gating and Deconvolution Filter for Site Validation of Fully Anechoic Rooms

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***Abstract*—An alternative method to compute the free space antenna factor using time domain transformation and deconvolution filter for pulse compression is proposed. The deconvolution filter helps in compressing the time domain pulse to distinguish the direct wave from the reflected wave and help evaluate the free space antenna factor for site validation of fully anechoic rooms. The antenna pair of ETS-Lindgren Model 3110C and 3180C antennas, simulated with NEC, is subjected to the proposed method with deconvolution filter and Wiener filter. The proposed method is implemented over the measured results of the antenna pair and used for the site validation of a fully anechoic room, based on the simulation results. The Free Space Normalized Site Attenuation Results comply with the ±4 dB specification.**

***Keywords*—Free space antenna factor, pulse compression technique, time domain transformation.**

I. INTRODUCTION

Fully Anechoic Rooms (FAR) are shielded enclosures with absorbers, absorbing the electromagnetic energy in the frequency of interest, lined on all the internal surfaces of the enclosure [1]. These rooms are intended to stimulate a free space like environment with only the direct wave from the transmitting antenna or EUT received by the receive antenna with zero to minimal reflections from the chamber walls. The site validation techniques to validate the Fully Anechoic Rooms, as per the CISPR 16-1-4:2010 standard, are, the Reference Site Method and the Normalized Site Attenuation Method. The Normalized Site Attenuation Method is the preferred method, for measurement distances between the two antennas to be equal to or greater than 5m and the Reference Site Method is required to be used for less than 5m measurement distances between the two antennas and can also be used for distances equal to or greater than 5m. For accurate site validations, dedicated antenna pairs of antennas are used to compute the site reference. A quasi-free space test site, as shown in Figure 1, is utilized. The height of the antennas are chosen per Equation 1 depending on the measurement distances between the two vertically polarized antennas to suppress the influence of the ground plane. The same antenna pair is later used for the site validation measurement tests in the Fully Anechoic Rooms.

$$h \geq d * \frac{8}{3} \tag{1}$$

where, h = the height of the antennas
d = antenna separation distance

As per Equation 1, the height of the antennas are, 8m for the measurement distance of 3m, 13.33m for measurement distance of 5m and 26.67 m for measurement distance of 10m. Constructing towers of 8m height can be a very expensive affair and not many testing laboratories can afford and/or are equipped with such infrastructure. In addition, constructing towers up to 30m is not feasible. Although placing the antennas at 8m height reduces the ground plane uncertainty but increases the uncertainty due to the wind and other factors. Hence, it is important to understand the rationale for Equation 1.

II. EFFECT OF GROUND PLANE ONLY

An antenna pair consisting of ETS-Lindgren's 3110C [2] and 3180C [3] were simulated in NEC [4-5]. The 3110C antenna is a biconical antenna operating from 30 MHz to 300 MHz and the 3180C antenna, with the cage elements, is a broadband mini-bicon antenna operating from 30 MHz to 1 GHz. These vertically polarized antennas were placed at 8m height above the ground plane and separated by 3m distance as recommended by the standard and Equation 1. The same antenna pair were then simulated without the ground plane. The responses of both the simulations were compared to compute the uncertainty due to ground plane as shown in Figure 2. Similarly, the vertically polarized antennas were placed at 13.33m above the ground plane with 5m separation distance and were simulated with and without the ground plane to study the corresponding uncertainty as shown in Figure 3.

As seen from Figures 2 and 3, the uncertainty due to ground plane only for measurement distances 3m and 5m are ± 0.4 dB and ± 0.25 dB respectively, but the antennas have to be placed at 8m and 13.33m above the ground plane to realize these small uncertainties. As mentioned earlier, the uncertainty due to the wind or any other factor may increase for antennas placed at 8m and 13.33m. Hence, it is not conclusive if the overall uncertainty would be held constant, better or worse. In addition, the construction of 8m, 13.33m and 30m antenna towers are very expensive and not feasible.

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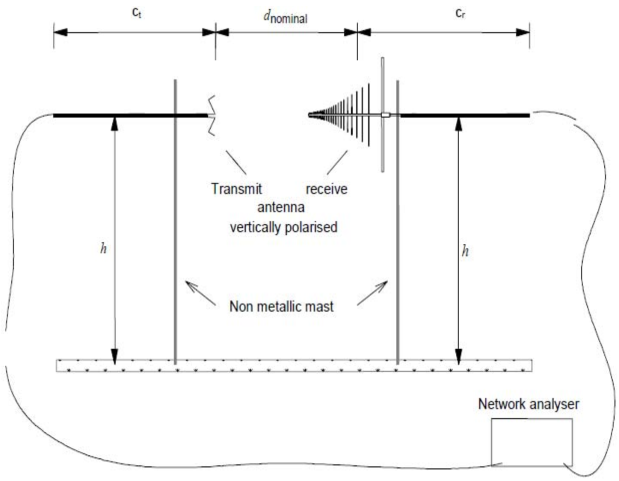

Figure 1. Free-space reference site attenuation measurement test setup

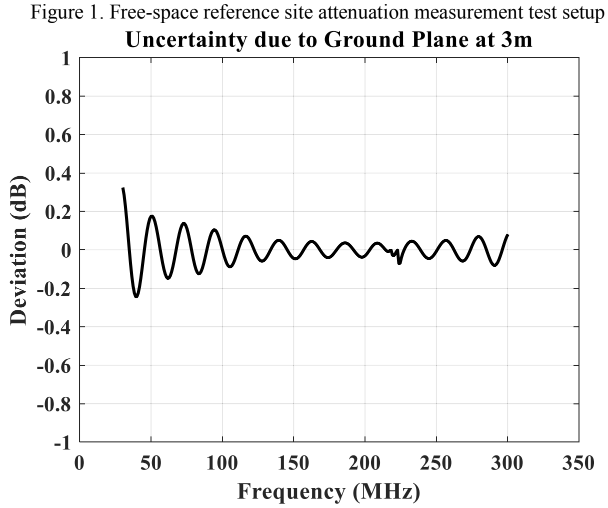

Figure2. Simulated Uncertainty due to ground plane only at 3m separation distance

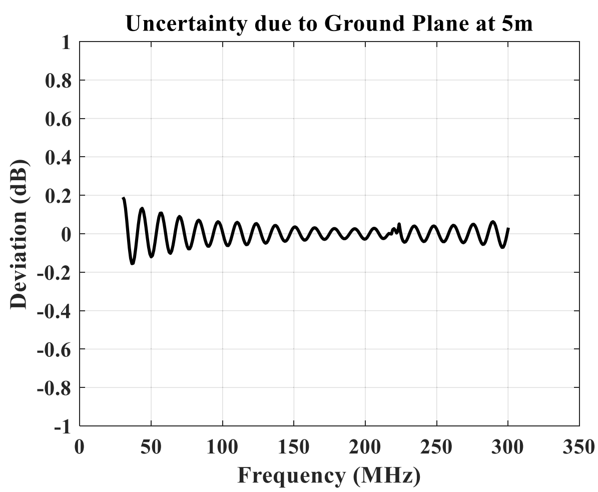

Figure3. Simulated Uncertainty due to ground plane only at 5m separation distance

III. Proposed Method

Most of the testing laboratories are equipped with 5m antenna towers to scan the antenna from 1m to 4m heights. Due to this limitation, the antenna cannot be placed higher than 5m. Based on Equation 1 and the height of 4m, the separation distance of the antennas will be 1.5m to have negligible ground plane effects. Hence, there will be ground plane effects included in the antenna pair response for separation distances of 3m and 10m. These ground plane effects can be suppressed by pulse compression and time domain gating techniques.

The frequency domain response of the antenna pair is transformed into time domain by inverse Fourier transform. The time domain response consists of the two pulses, first being the direct antenna-to-antenna response and the later pulse is the reflection from the ground plane. Time gating is applied to gate out the ground plane pulse. This gated time domain response is then transformed back to frequency domain by forward Fourier transform. However, for separation distances of 3m and 10m between the antenna pair, when placed at 5m height, there is not enough resolution to separate out the ground plane pulse from the direct antenna-to antenna response pulse. Due to this, pulse compression technique is required to improve the resolution to compress the pulses, and separate the direct and reflected pulses. Previous researchers have proposed pulse compression techniques using Wiener filter [6-8]. The Wiener filter, as mentioned in Equation 2, consists of a factor, η, which represents the additive noise corrupting the unknown signal. When this factor equals to one, the filter is reduced to the deconvolution filter. Comparative results show that the Deconvolution filter is optimal compared to the Wiener filter.

$$W(w) = \frac{E^*(w)}{E_0} \cdot \frac{1}{\eta \,|\, E^*(w) / E_0 \,|^2 + (1-\eta)} \tag{2}$$

where, $E^*(w)$ = complex conjugate of the unknown signal
E_0 = maximum magnitude of $E^*(w)$
η = signal to noise ratio parameter

The algorithm with pulse compression technique and deconvolution filter is described below:

- Two vertically polarized antennas are placed at a height of 4m above the ground plane with a separation distance of 1.5m. The height is chosen to be 4m as typical testing laboratories will be equipped with 5m antenna towers and the separation distance is based on Equation 1. The frequency domain response is recorded as $S_{21A}(w)$.
- The same antenna pair is placed at 5m above the ground plane with separation distance of 3m. The frequency domain response was recorded as $S_{21B}(w)$.
- The Deconvolution filter, $D_{filter}(w)$, was computed as per Equation 3.

$$D_{filter}(w) = \frac{S^*_{21A}(w)}{max(|S^*_{21A}(w)|)} * \left| \frac{max(|S^*_{21A}(w)|)}{S^*_{21A}(w)} \right|^2 \tag{3}$$

- The deconvolution filter was applied to the response $S_{21B}(w)$ using Equation 4.

$$S_{21B,filtered}(w) = D_{filter}(w) * S_{21B}(w) \tag{4}$$

- The filtered response $S_{21B,filtered}(w)$ was then transformed to time domain by inverse Fourier transform, $S_{21B,filtered}(t)$.
- Time Domain Gating is applied on the $S_{21B,filtered}(t)$ response to extract out the ground plane influence. The gated time domain response is then transformed back to frequency domain by forward Fourier transform, $S_{21B,filtered,gated}(w)$.
- The gated frequency domain response, $S_{21B,filtered,gated}(w)$ is then divided with the filter response to get the final response back as per Equation 5.

$$S_{21B,final}(\mathrm{w}) = \frac{S_{21B,filtered,gated}(w)}{D_{filter}(w)} \tag{5}$$

- The response $S_{21B,final}(w)$ is the response with minimal ground influence.

IV. Simulation and Measurement Results

A. Simulation Results

The antenna pair of vertically polarized 3110C and 3180C were simulated in NEC at 3m measurement distance and placed 5m above the ground plane. Time domain transformation was applied on the $S_{21}(w)$ response of the antenna pair and is shown in Figure 4. As seen from Figure 4, the pulse width of the direct wave of antenna response in time domain is very wide and it overlaps the pulse of reflected wave of the antenna response. This is due to the intrinsic property of the antenna response itself and due to the geometry of the test setup. As per the test setup's geometry, the direct wave is received at 10.71 ns and the reflected wave is received at 35.71 ns. However, the pulse width of the direct wave continues until 47.62 ns thereby overlapping the reflected wave. Thus, time gating cannot be applied to gate out the reflected component. Hence, pulse compression techniques are required to compress the direct and the reflected wave pulses and gate out the ground plane influence.

The proposed method algorithm was applied on the NEC simulations for the 3110C-3180C antenna pair. The vertically polarized antenna pair were simulated at 4m height above the ground plane with a separation distance of 1.5m. The response was recorded as $S_{21A}(w)$. The same antenna pair was then simulated at 5m height above the ground plane and a separation distance of 3m. The response was recorded as $S_{21B}(w)$. The deconvolution filter, $D_{filter}(w)$, filtered response $S_{21B,filtered}(w)$ were computed as per Equations 3 and 4 respectively and subjected to time domain transformation by Inverse Fourier transform. The time domain response of the filtered response $S_{21B,filtered}(t)$ is shown in Figure 5. Comparing Figures 4 and 5, it can observed that the filter helps to compress the time domain pulses and the direct wave and the reflected wave are easily distinguished. Time domain gating is applied to gate out the influence of the ground plane and transformed back to frequency domain, $S_{21B,filtered,gated}(w)$ by forward Fourier transform. This frequency domain gated filtered response is divided by the filter response as per Equation 7 to compute the final $S_{21B,final}(w)$ response. The comparison between $S_{21B,final}(w)$ response with the response of the antenna pair without any ground plane and separated by 3m, is shown in Figure 6. As seen from Figure 6, the uncertainty due to the ground plane only, at 3m is ± 0.5 dB using the proposed method.

Figure 7 shows the time domain response $S_{21B,filtered}(t)$ with Wiener filter instead of the proposed deconvolution filter. Comparing Figures 5 and 7, the time domain pulses are not compressed enough to separate out the direct antenna-to-antenna response and the ground plane response. Figure 8 shows the frequency domain response, $S_{21B,filtered,gated}(w)$ for 3m separation distance with and without time gating. As seen from Figure 8, the chosen gate cuts into the antenna-to-antenna response at the low frequency end. The Wiener filter with the signal to noise ratio parameter value of 0.9 [6-8] does not provide enough resolution at 3m antenna separation distance to distinguish between the direct antenna-to-antenna response and the ground plane response. Hence, the proposed deconvolution filter is better suited for 3m distances.

Figures 9 and 10 show the comparison between the time domain response with and without the pulse compression technique for the separation distance of 5m. As seen from Figures 9 and 10, the proposed method helps in compressing the time domain pulses and thereby improving the resolution to distinguish between antenna-to-antenna response and the ground plane response. Hence, the proposed method is implemented over separation distance of 5m as well. The response at 1.5m separation distance is recorded as the $S_{21A}(w)$ response and the response at 5m is recorded as the $S_{21B}(w)$ response. The uncertainty due to the ground plane only at 5m with the deconvolution filter is ± 0.5 dB as shown in Figure 11. Figure 12 shows the Wiener filtered response, $S_{21B,filtered,gated}(w)$ for 5m separation distance, with and without time gating. As seen from Figure 12, the Wiener filter with the signal-to-noise ratio factor value of 0.9 does not provide enough resolution to differentiate the antenna-to-antenna response with the ground plane response at 5m separation distance as well. Hence, the deconvolution filter is better suited for 5m distances as well. Similarly, the proposed method with deconvolution filter can be extended to separation distance of 10m.

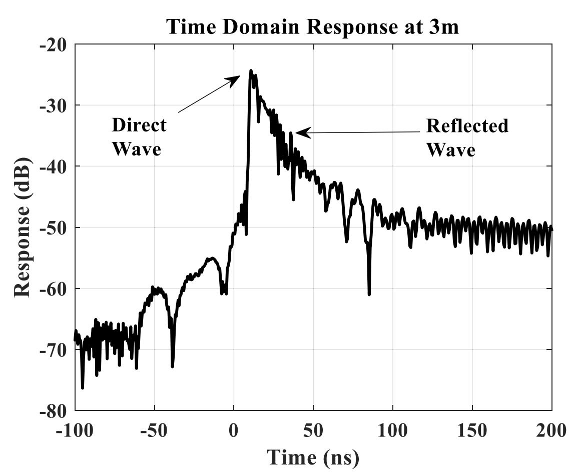

Figure 4. Simulated Time Domain Response at 3m measurement distance. Reflected wave overlapped with direct wave.

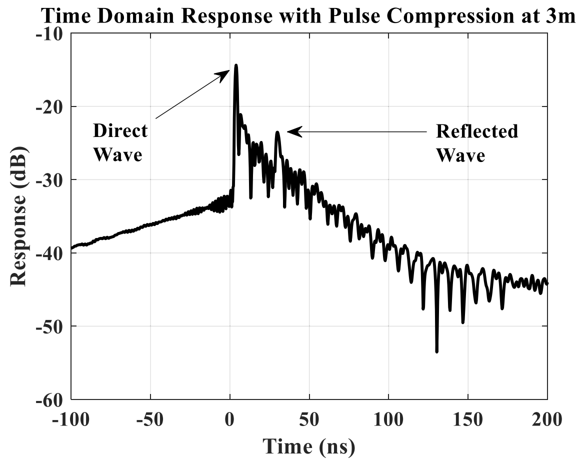

Figure 5. Simulated Time Domain Response with Pulse Compression at 3m measurement distance. Direct wave isolated from reflected wave.

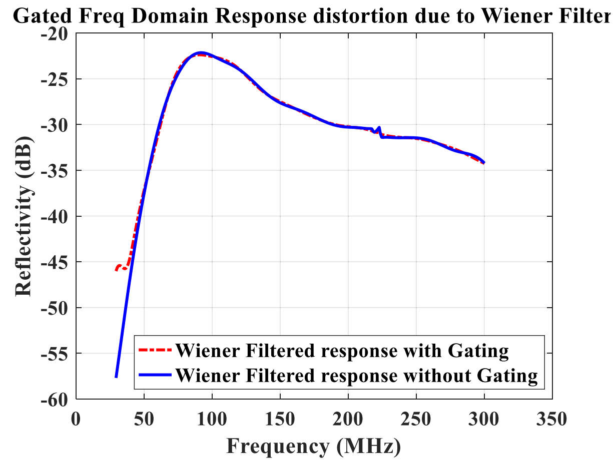

Figure 8. Frequency Domain response comparison for Wiener filter pulse compression with and without time gating at 3m separation distance

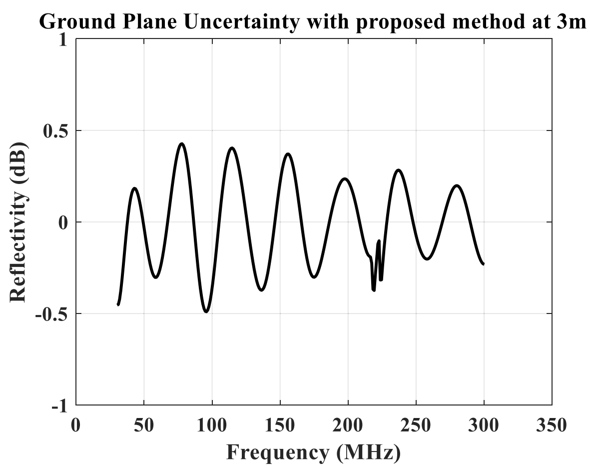

Figure 6. Simulated Uncertainty due to ground plane only with proposed method at 3m measurement distance

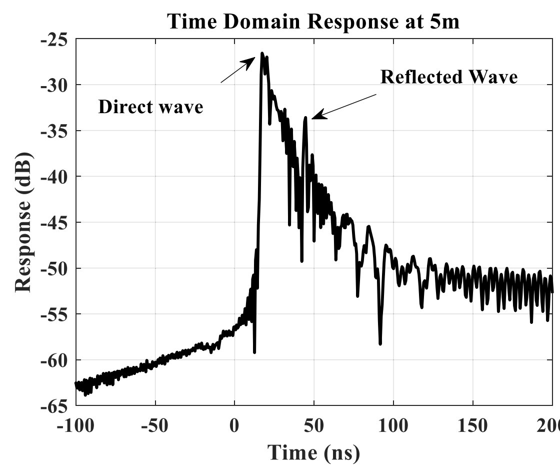

Figure 9. Simulated Time Domain Response at 5m measurement distance. Reflected wave overlapped with direct wave.

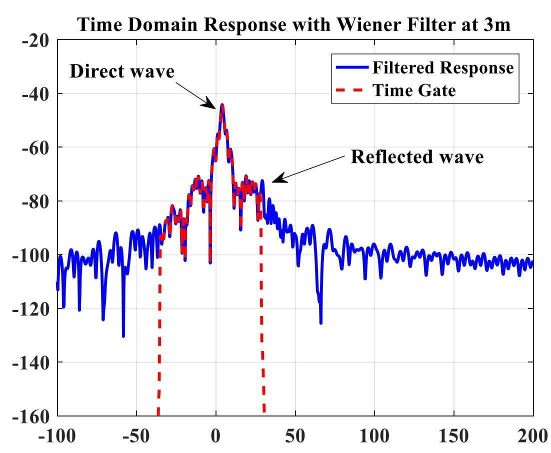

Figure 7. Time Domain Response with Wiener filter at 3m separation distance with time gate

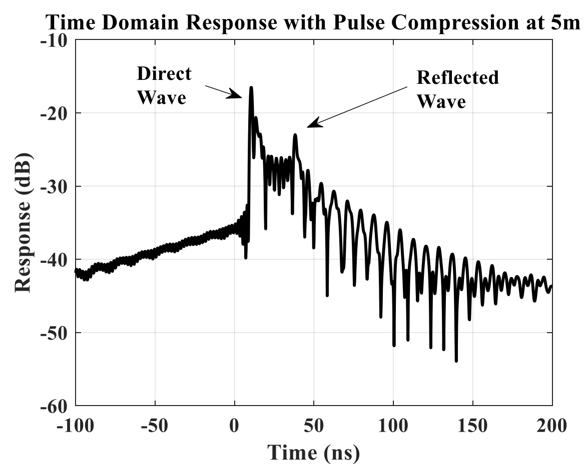

Figure 10.Simulated Time Domain Response with Pulse Compression at 5m measurement distance. Direct wave isolated from reflected wave.

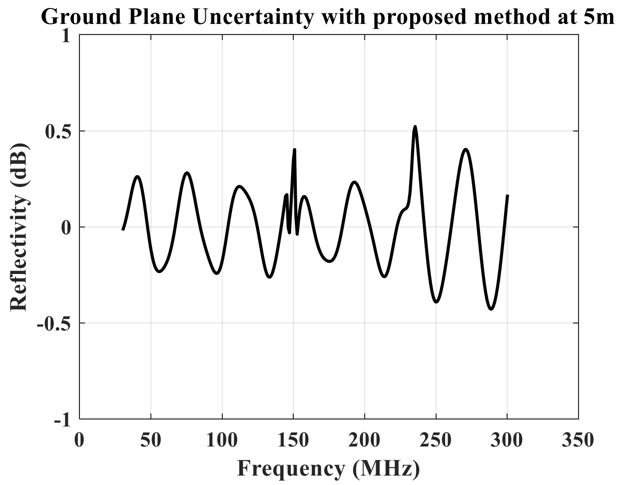

Figure 11. Simulated Uncertainty due to ground plane only with proposed method at 3m measurement distance

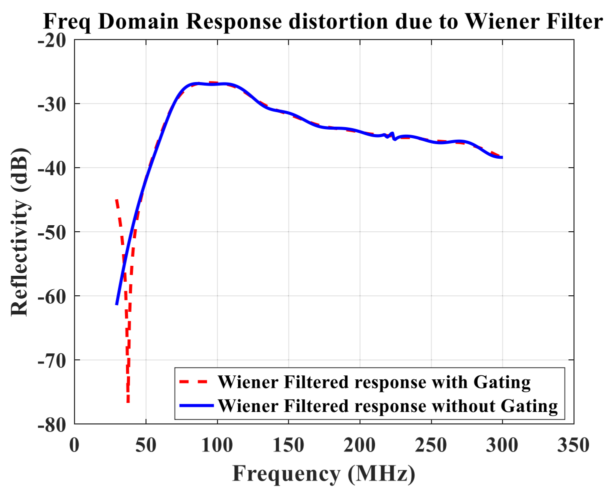

Figure 12. Frequency Domain response comparison for Wiener filter pulse compression with and without time gating at 5m separation distance

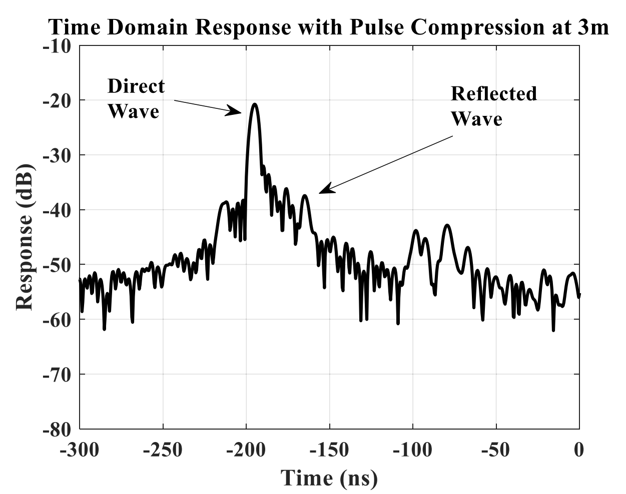

Figure 13.Measured Time Domain Response with Pulse Compression at 3m measurement distance. Direct wave isolated from reflected wave.

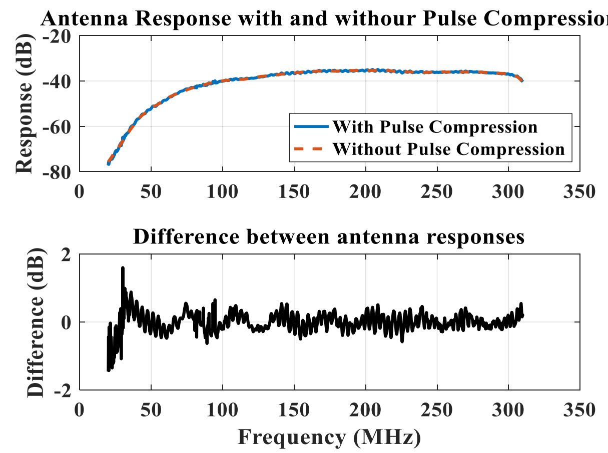

Figure 14. Comparison between antenna response at 3m measurement distance with and without the Pulse Compression

B. Measurement Results

Based on the analysis on simulations' data, the proposed method with deconvolution filter was implemented on the measured responses of the antenna pair. The antennas 3110C and 3180C were used for the response measurement and the corresponding site validation measurement. The vertically polarized antenna pair were placed at 4m height above the ground plane with a separation distance of 1.5m and the response was recorded. The same antenna pair were then placed at 5m above ground plane with a separation distance of 3m and the response was recorded. The proposed method algorithm was implemented on the two measured responses. Figure 13 shows the time domain response of the filtered response and Figure 14 compares the 3m response with and without the pulse compression algorithm implemented. Similarly, the antenna pair were placed at 5m height above the ground plane with a separation distance of 5m and the response was recorded. Using the response measured at 1.5m and 5m distances, the pulse compression algorithm was implemented to extract the final 5m response. Figures 15 represent the time domain response of the filtered response. This antenna pair response at 5m was then used to compute the Free Space Antenna factors and a Fully Anechoic Room site validation. Figure 16 and 17 show the FSNSA test result with and without the implementation of the proposed method at 5m separation distance for horizontal and vertical polarization respectively. As seen from Figures 16 and 17, the fully anechoic room complies with the FSNSA specification of ± 4 dB with the proposed method.

V. CONCLUSION

The site validation techniques recommended by the CISPR 16-1-4:2010 standard were laid out. Based on the standard's recommendation, the Reference Site Attenuation method can be used for site validation for measurement distances between the antennas to be less than, equal to or greater than 5m per Equation 1 to suppress the influence of the ground plane. Constructing towers as high as 30m might not practical for many testing laboratories and can have higher uncertainties associated from wind and other factors while reducing the ground plane influence.

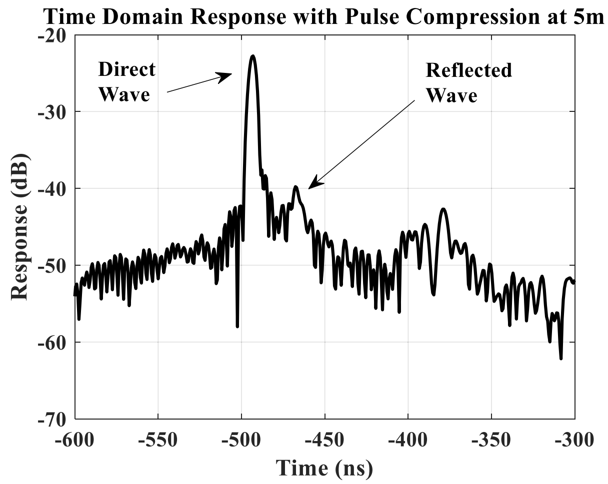

Figure 15.Measured Time Domain Response with Pulse Compression at 5m measurement distance. Direct wave isolated from reflected wave.

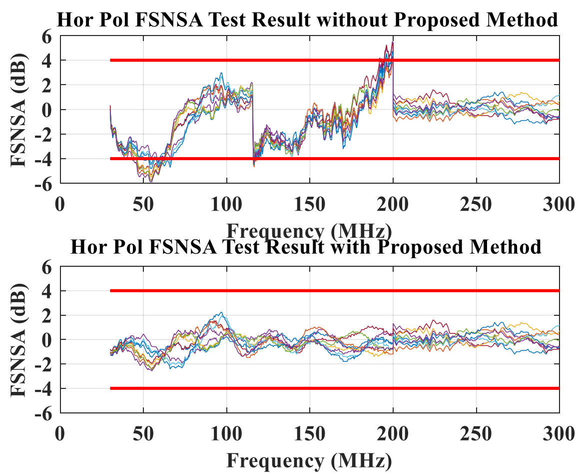

Figure 16. FSNSA Test Result for Horizontal Polarization with and without the Proposed Method

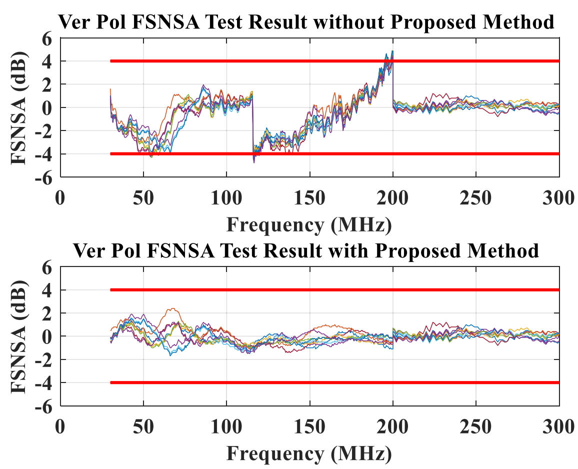

Figure 17. FSNSA Test Result for Vertical Polarization with and without the Proposed Method

Simulations were performed with ETS-Lindgren 3110C and 3180C antennas in NEC to better understand the rationale for Equation 1. Although, the uncertainty due to ground plane only at 3m and 5m measurement distance were shown to be ±0.4 and ±0.25 dB respectively, there may be additional multiple factors contributing to the overall uncertainty for antennas placed at 8m and 13.33m heights above the ground plane.

An alternative method using time domain transformation and deconvolution filter for pulse compression is proposed. The same antenna pair were simulated at 1.5m, 3m and 5m separation distances, and the proposed method was implemented. It was shown that the deconvolution filter could be used for pulse compression thereby distinguishing the direct wave and reflected wave in the time domain transformation. On implementing the proposed method over the antenna responses, the uncertainty due to ground plane only were shown to be ± 0.5 dB for 3m and 5m measurement distances. The pulse compression with deconvolution filter provides better resolution to distinguish the antenna-to-antenna response and ground plane response compared to the Wiener filter. Based on the results, the same method can be extended to compute the 10m free space response as well. The proposed technique was implemented on the measured results of the antenna pair. Graphs showing the pulse compression results and the improvement in the antenna responses were presented. These improved responses were then used as the free space antenna response and applied to the site validation of a fully anechoic room. The Free Space Normalized Site Attenuation results of the chamber comply with the ± 4 dB specification.

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