Time and Spatial Filtering for Echo Reduction in Antenna Measurements

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Abstract— **During the last years, new algorithms, based on time filtering, spatial or modal filtering, have been designed for echo reduction techniques applied to antenna measurements. These algorithms have been used for different applications where the effect of the echoes is important, as far field system, VHF or UHF applications, automotive systems, small antennas, etc. The authors, in previous papers, have analysed the effect of different algorithms: time filtering (fft, non uniform dft or matrix pencial), modal filtering based on Spherical modes (MV-Echo) and spatial filtering based on Integral Equations (Insight) and holographic techniques (fft and dft) to cancel the effect of the reflections. This comparison has been applied to the measurements of a dipole antenna (SD1900) using a StarLab system. It is observed that each of the algorithms is better for different situations, depending on the source of the echo. For instance, time filtering techniques are good for reflections coming from different distances with respect the direct ray, but not so good for close reflections. In addition hey need a large frequency band to work properly. Spatial algorithms can correct the effect of positioners or other structures close to the antenna under test, but they are better for planar near field acquisitions and worse for classical single probe spherical near field where the antenna is rotated and probe is fixed (e.g. roll-over-azimuths systems). Moreover, they require extra information of the AUT geometry.**

This paper presents first a comparison of each algorithm and then, a combination of time and spatial techniques based on uniform or non-uniform DFT to take advantage of the benefits of each algorithm for different origins of the reflections.

I. Introduction

In antenna measurement, well-established procedures for echo reduction have been shown during the previous years. These methods can be divided in different families. In this paper, the authors focus on three different families of methods: time gating, modal filtering and spatial filtering algorithms.

The first ones consist on measurement of a set of frequencies, transformation from frequency domain to time domain and filtering. There are different methods for performing this filtering, and, in this paper, the authors have used the well known Fourier Transform, explained in [1]. Other techniques have been applicated, as the Matrix Pencil method [2-3] for cancelation of echoes in antenna tests.

The second set of methods is based on modal filtering. In this case, the acquired field is transformed to spherical or cylindrical modes (typically, this step is necessary for the near to far field transformation). The modes that cannot correspond to the radiation from the antenna under test are identified and filtered. There are different commercial approaches of this method, as MARS® [4-5], from NSI; Isofilter® [6], from MI-Technologies or MV-Echo® [7-8], from Microwave Vision Group.

The third family of studied methods is based on spatial filtering. In this case, the sources on the AUT are calculated and the ones that are out of the antenna area or volume are filtered out. These methods require a source reconstruction technique. The classical one is the holographic technique [9], where the fileds on an aperture are calculated from the Plane Wave Spectrum (PWS). This method has been used to cancel the reflections in [10]. Other method is the use of the integral equation for the calculation of the sources on a volume surroinding the AUT. This is a more general method, and more accurate than the holographic technique. The theory of different implementation of these techniques can be found in [11-12]. MVG has applied the theory shown in [12] to the software INSIGHT® [13]. Another commercial product is DIATOOL®, from TICRA [14].

Of course, there are also other implementations for the reduction of the echoes. During the last years, DTU and TICRA investigated on a method based on the Spherical Wave Expansion to Plane Wave Transformation [15, 16]. Finally, Technical University of Munich, in [17, 18] showed a technique where the near to far field base functions were expressed in plane waves. In this case, the echoes were modelled with equivalent scattering centres, and could be filtered out.

This paper presents an introduction to the algorithms used in this work in Section 2: time gating using Fourier Transform, Matrix Pencil method, MV-Echo®, Holographic Technique for spatial filtering and INSIGHT.

Section 3 shows the application of some of the algorithms to Planar Near Field Simulations and Section 4 the application to measurements of a dipole antenna (SD1900) in a MVG StarLab® multiprobe system. In both cases, simulations and measurements, a combination of different methods has been shown. Section 5 corresponds to the main conclusions of the study.

II. Introduction to Echo Filtering Methods

This section explains briefly the fundamentals of each of the echo reduction techniques shown in the paper: time gating through Fourier Transform and Matrix Pencil, modal filtering through MV-Echo®, and spatial filtering of the equivalent currents on the antenna through holographic techniques and integral equations methods.

A. Time gating through Fourier Transform

The classical time gating method is based on the Fourier Transform from frequency domain to time domain. Each sample (for different positions of AUT and/or antenna probe) is acquired at several frequencies. Then, for each point, a Fourier Transform is applied and the information in time domain is gated. In this case, we studied different windows and a Hamming window was chosen as the best option. Finally, the signal is transformed to frequency domain again. The process is shown in Figure 1. After this process, a classical near to far field transformation (depending if a planar, cylindrical or spherical acquisition is performed) is applied to obtain the filtered far field. However, the process can also be applied to far field, since the important aspect is the relative distance between the rays. This technique is very useful when the different rays come from different distances, as mutual coupling between AUT and antenna probe, or reflections in walls or floor. If the FFT algorithm is used, the samples have to be equispaced. However, if non uniform DFT (NDFT) is used this algorithm can be applied for non uniform samples. However, in this case, the speed of the algorithm is drastically reduced, and the accuracy of the results depends on the samples.

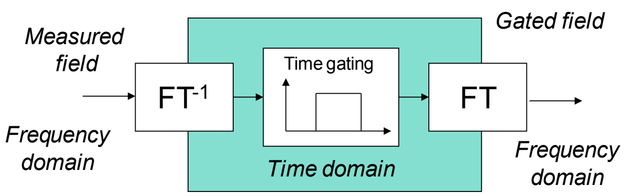

Figure 1. Echo cancellation using time gating technique.

B. Time gating through Matrix Pencil

A second approach for time filtering is the use of Matrix Pencil algorithm. The Matrix Pencil is a linear method to approach the problem of finding the best estimates of a signal from the noise-contaminated data. As it is customary, a signal will be represented as $y(t) = x(t) + n(t)$, where y(t) is the observed time response, x(t) is the signal and n(t) is the noise of the system. After sampling, the time variable t can be replaced by kT_s (T_s being the sampling period) and the signal can be written as $x(kT_s) = \sum_{i=1}^{M} R_i z_i^k$ for k=0,…,N-1, where R_i are the residues and $z_i = e^{s_i T_s} = e^{(-\alpha_i + j\omega_i)T_s}$ for i=1,2,…,M, where α_i are the damping factors and ω_i the angular frequencies. The Matrix Pencil gives the optimum solution for M, R_is and z_is. This method works pretty well with uniform and non-uniform frequency samples.

In both cases, the main disadvantage is that the acquisition has to be multifrequency to be able to apply these algorithms.

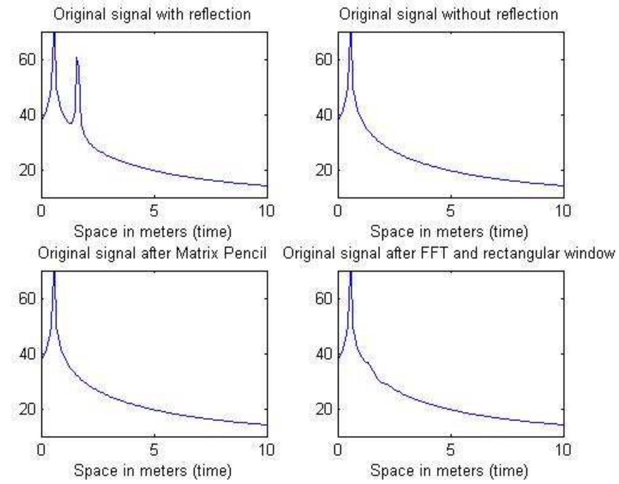

Figure 2. Echo cancellation using time gating.

C. Modal Filtering using MV-Echo®

The method is based on the Spherical Wave Expansion (SWE) of the measured field taking advantage of the a-priori information of the size of the AUT. The maximum index of the Spherical Wave Coefficients (SWC) in the SWE depends on the radius (Rmin) of the smallest sphere centered at the origin and enclosing the AUT (minimum sphere).

$$E(r) = \frac{k}{\sqrt{\eta}} \sum_{s=1}^{2} \sum_{n=1}^{\infty} \sum_{m=-n}^{n} Q_{smn}^{(3)} F_{smn}^{(3)}(r)$$

The echoes contribute arising outside the AUT minimum sphere, since they are highly oscillating, they are associated to modes of higher order respect to the AUT modal distribution. Therefore, they can be easily filtered out (see the example shown in Figure 3).

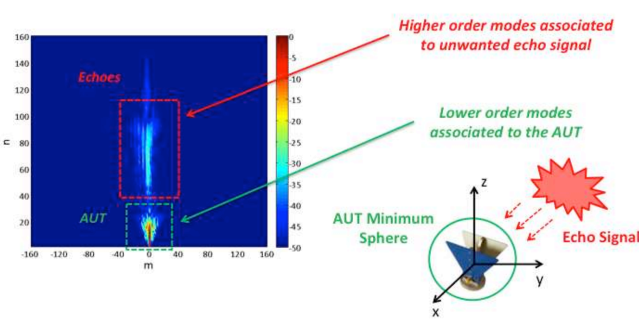

Figure 3. Echo cancellation using MV-Echo®.

D. Spatial Filtering using Holographic Technique

Spatial filtering methods are called to those ones where the near of far field pattern is transformed to the domain of the antenna under test through a source reconstruction technique. A Fourier Transform to the Plane Wave Spectrum in order to transform from k_x/k_y domain to x/y domain in the proximity of the AUT. If the reconstruction is done on a surface much larger than the AUT, the echoes can be detected and filtered out. The main advantage of the method is the speed (since it uses interpolations, FFT and plane wave propagation). The main disadvantage is that the reconstructed field is limited to a plane, due to the fact of using the Fourier Transform. This is useful for aperture or planar array antennas, but not for general cases. Also, if the source of reflection is not well established, and the surface where the sources are calculated is not large enough, the FFT produces aliasing and the echoes are not suppressed. Figure 4 shows the application of this technique to a RADAR antenna in a cylindrical outdoor range (ITM-CEAR cylindrical near field system in Guadalajara-Spain). The field is reconstructed on a large surface, and the sources coming from the AUT can be separated from the sources coming from the reflection in the ground (right part of the Figure 4). In the lower Figure 4, it is observed the improvement in the result of the radiation pattern.

This technique can be also applied with NDFT. In this case, instead of taking samples from the PWS (uniform in k_x/k_y domain), the samples can be taken directly from the far field (uniforms in θ/ϕ). This makes the process more general, and the interpolation from angular domain to spectral domain is avoided. Also, the filtering can be intrinsically applied to the specific surface of the AUT, without the need of calculating the fields on the whole surface (including potential echoes).

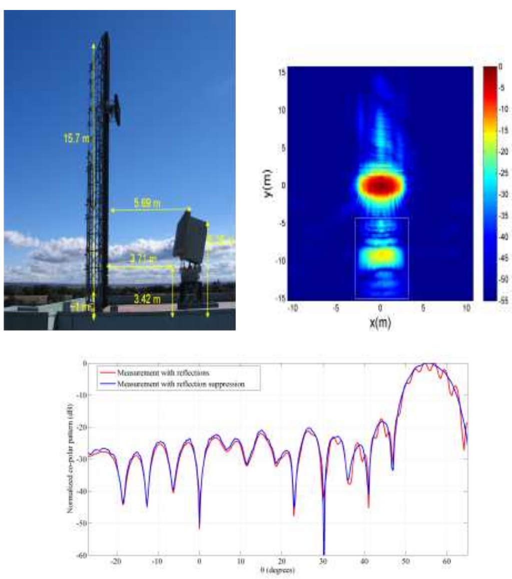

Figure 4. Application of Holographic Technique to a RADAR L-band Antenna.

E. Spatial Filtering using INSIGHT®

INSIGHT is based on the equivalence principle: all radiators and/or scatterers within a volume are substituted by equivalent electric and magnetic currents (J, M) that lie on an enclosing surface ΣR and radiate the same field on ΣM. Dual integral equation enforcing the boundary condition of zero internal field to determine the two unknown currents J/M on the surface conformal to the antenna. Then, the integral equation is solved efficiently with inverse Method of Moments.

This technique is not only applied to echo reduction, but also for providing in-depth understanding of antenna radiation characteristics, for antenna diagnostics, for data extrapolation, for detection of spurious radiation and for near to far field transformation. Figure 5 shows the measurement of a horn antenna, and the calculation of the sources on a volume. The echoes are intrinsically filtered out since they would appear out of that volume enclosing the AUT. The main advantage of this method is that other spurious signals (leakage, effect of positioners…) are also filtered out. The main disadvantage is the speed of the integral equation method.

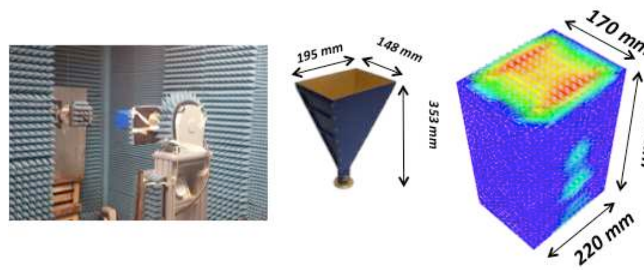

Figure 5. Application of Holographic Technique to a RADAR L-band Antenna.

III. Application to Planar Near Field Simulations

In order to validate and to compare the different algorithms, two exercises were done. The first one is the simulation of a planar near field acquisition with extremely strong reflections in one wall and floor, and/or a strong mutual coupling effect between AUT and antenna probe. For simulating the AUT, an array of ideal dipoles has been used (assuming they radiate in the whole frequency band). For the cancellation of the echoes coming from the mutual coupling, a time domain filtering based on FFT or Matrix Pencil has been applied. Here, we show the results with the FFT, and the Matrix Pencil results are similar. For this simulation 521 frequencies in a bandwidth 0.8 -6 GHz are simulated. The acquisition plane is supposed to be at 2 meters distance, and time gating is applied. Figure 6 shows the hamming window and the results of the simulations. The ideal and the filtered signals within the valid angular range are almost identical.

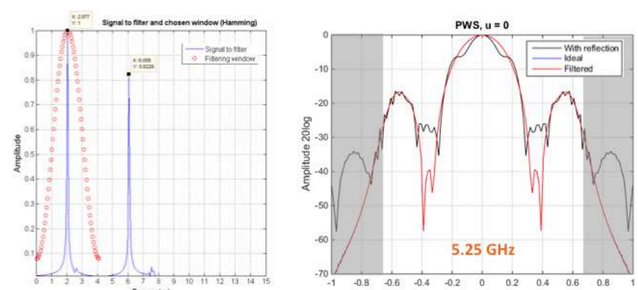

Figure 6. Simulations of a strong coupling between AUT and antenna probe.

For the cancellation of the echoes in the wall and ground, a spatial filtering through holographic technique has been applied. Figure 7 shows the effect of an artificial strong echo and the effect of the spatial filtering algorithm. The reconstructed PWS is almost identical to the ideal one.

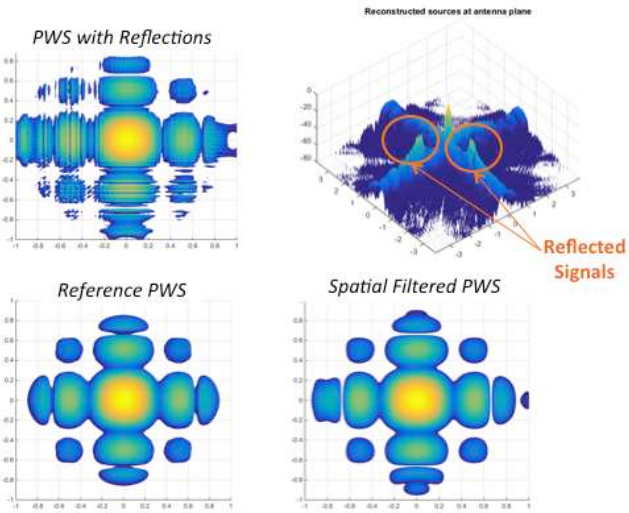

Figure 7. Simulations of a strong echo in left wall and ground.

Finally, a third set of simulations was performed. In this case, both kind of reflections were included, and the different algorithms were applied to examine the effect of the reconstruction. As can be seen in Figure 8. time domain filtering is more effective to mitigate the coupling effect between AUT-Probe, while spatial filtering works better for the ground and side reflections. This is due to the fact that the time gating solves much better the cases of large difference in time of the rays, while the spatial filtering requires that the fields were focused on different areas of the reconstructed surface. Applying both algorithms (red trace) a very good agreement is obtained.

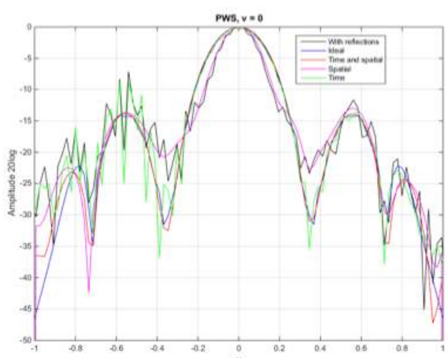

Figure 8. Simulations of reconstruction with both effects: strong coupling and echo in wall and ground.

IV. MEASUREMENTS

The previous methods have been applied to the measurement of the dipole antenna SD1900, working at 1900MHz. The dipole has been measured in a StarLab system where a square plate of side dimension of 50 cm has been placed on one side of the StarLab as shown in Figure 9 in order to create a strong echoic environment. The dipole has been chosen due to the omni-directional radiation pattern, a worst case for the analysis of reflections. Time filtering has been used from measurements in the frequency band 1.7 GHz to 2.2 GHz with a step of 10 MHz. Time filtering has been applied to near field data and to far field data. Spatial (INSIGHT) and modal filtering (MV-Echo) have been applied to the central frequency measurements (1.9 GHz).

Left plot of Figure 10 shows the results for the vertical pattern of the dipole and while right plot shows the results for the horizontal pattern. In these cases, time filtering has been applied before the near to far field transformation. The reference is considered the raw data without plate.

It is observed in the vertical plane that time filtering works very well in general. However, it cannot correct some effects due to the positioner and other reflections coming from the probes. Modal filtering works better in the angular range close to -180 degrees. INSIGHT works pretty well in the areas close to -180 and 180 degrees, since it is able to correct some effects not due to reflections in the plate, but the measurement set-up (filtering of currents flowing the cable and reduction of truncation errors). In the horizontal plane, time filtering works better than modal or spatial filtering. This is due to the fact that in the planes orthogonal to the arch, since the antenna is rotating, the reflections cannot be considered as an image; and therefore, the spatial or modal filtering techniques do not work in the appropriate way.

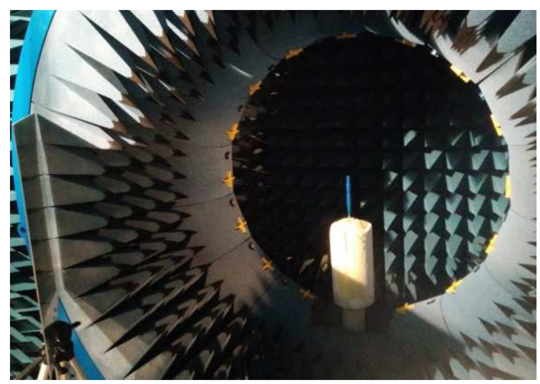

Figure 9. StarLab System with a reflector. Measurement of the SD1900 dipole.

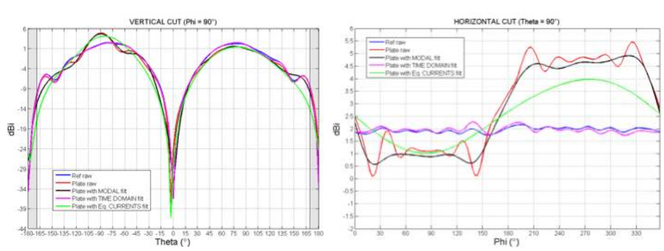

Figure 10. Measurement results for the vertical and horizontal planes. Processing from near field data.

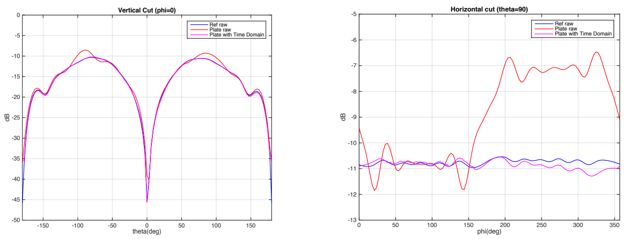

Figure 11. Measurement results for the vertical and horizontal planes. Processing from far field data.

Finally, in Figure 11, it is observed that time filtering can also be applied to the far field; even it is supposed to apply a time gating. The reason is that the near to far field transformation algorithm maintains the relative phase of the direct ray and echoes.

In any case, the best option is a combination of the different techniques, since each of them solves different sources of errors.

V. CONCLUSIONS

Different echo reduction techniques have been analysed in this work. They have been applied to two different cases: simulations with planar near field acquisitions and measurements in a spherical multiprobe system. The main conclusion is that different algorithms solve different problems of echoes, depending of the angle of arrival of the source. A detailed study of each case is necessary to optimize the performance of these algorithms, and the best option is the combination of the different techniques. Obviously, the main advantage of modal or spatial filtering techniques is that they can be applied to single frequency measurement. This is extremely important in classical spherical near field measurement systems, since the acquisition is very time consuming. Another important conclusion is the limitation of modal or spatial filtering techniques. They work very well in planar near field systems. In cylindrical or multiprobe systems, they work very well in the plane of the probes (or tower), but they do not reduce the echoes in the other plane. In classical single probe spherical systems (where the AUT is rotated and the probe is fixed), they have problems in both planes (although they can reduce the effect of the echoes in some cases). However, these techniques can mitigate the effect of positioners, towers and so on. This is not possible with time gating techniques since it is extremely difficult to separate in time the desired signal from the spurious contributions. This paper has shown that a combination of different techniques is the best option for improving the quality of the measurements.

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