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RESEARCH PAPER

# Analysis of time filtering techniques for echo reduction in antenna measurements

PILAR GONZÁLEZ-BLANCO AND MANUEL SIERRA-CASTAÑER

*This paper presents a review of filtering methods to eliminate echo in antenna measurements. Two different methods, fast Fourier transform and Matrix Pencil, are explained, compared, and simulated in a planar near field where other effects, such as aliasing, can and will be present if the simulation is not appropriately made and the parameters are not carefully chosen. Finally both methods are applied to real measurements of a dipole in a Microwave Vision Group multiprobe system and of a horn in a single-cut measurement. Other effects, such as window shift, may appear depending on the geometry of the system where the measurement is taken. These effects must be taken into consideration and carefully corrected.*

**Keywords:** Antenna design, Modeling and measurements, Microwave measurements

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## I. INTRODUCTION

During the last few years, the echo reduction in antenna measurements has been an important issue to validate the antenna measurements. This echo reduction is mostly achieved by improving the environment conditions (e.g. taking the measurement in an anechoic chamber). As sometimes fully anechoic conditions are not available, different techniques are applied to obtain the correct radiation patterns by removing or compensating the undesired effects.

The number of approaches to analyze and cancel the effects of unwanted contributions has increased in recent years. Methods such as time domain characterization, frequency decomposition, and compensation techniques have been employed and studied [1–8]. Other techniques consist in spatial filtering or diagnostic techniques [9–18]. Last but not least, time-gating techniques are employed to remove reflected contributions. Time-domain transforms such as Fourier transform (FT) and inverse FT (IFT) are used to separate the direct signal from the echoes [19–21].

In this paper, two efficient echo reduction techniques (time gating and Matrix Pencil) are used and compared. In Section II, we provide a theoretical introduction of the methods and carry out and compare some simulations. The simulations show aliasing due to the mutual couplings existing between a metallic Antenna Under Test (AUT) and the probe (Fig. 1), which could not be separated using spatial filtering because all the reflections are originated in the same direction. In Section III, a practical implementation is presented using both methods in different setups, filtering out diverse echoes, such as environment reflections. To conclude, in Section IV, we present some conclusions and final remarks.

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## II. FFT AND MATRIX PENCIL METHODS

### A) Theoretical introduction to the methods

The first approach we are presenting is the use of a fast Fourier transform (FFT) to pass from the frequency domain to the time domain. First, the samples measured at different frequencies are transformed to the time domain, via an inverse FFT. The echoes are then effectively filtered out in the time domain, and finally a new FFT is applied to reconstruct the field [21–25]. The time filtering principle is shown in Fig. 2.

This method requires a multifrequency measurement. The main drawback is that the fast algorithms used to compute the FT and IFT need a constant frequency step. Thus, when there are high-frequency regions where the field varies quickly, a small step has to be employed throughout the entire bandwidth to obtain a good characterization in those regions. This drawback can make the measurement time increase considerably.

A second approach for time filtering is based on the 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. This method works quite well both with uniform and non-uniform frequency samples [5–8, 22, 26]. The measured field is represented as a sum of complex exponentials multiplied by a residue. The Matrix Pencil gives the sharp values for the parameters of the problem: $M$ (the number of exponentials), $R_i$ (residues), and $z_i$ (exponential factors). These complex exponentials can be directly related to the different contributions of the signal measured at the probe (direct, reflected, and

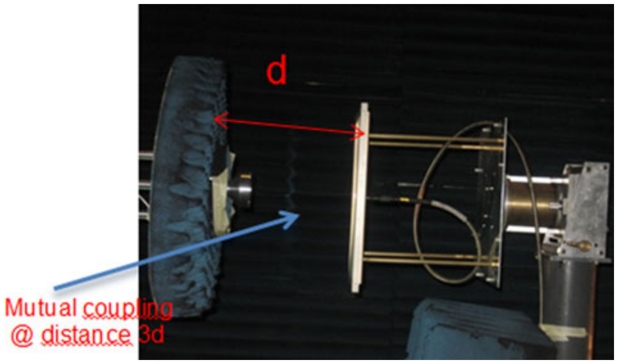


**Fig. 1.** Mutual coupling effect.

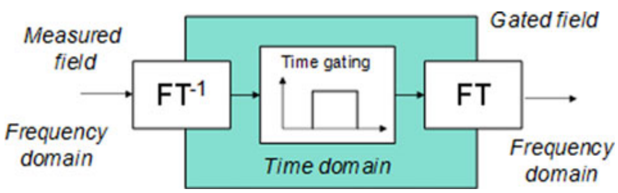


**Fig. 2.** FFT time filtering.

diffracted components):

$$y(kT_s) = x(kT_s) + n(kT_s) \approx \sum_{i=1}^{M} R_i \cdot z^k + n(t), \qquad (1)$$

where $z_i = e^{siTs} = e^{(-\alpha i + j\omega i)Ti}$ for $i = 1, 2 \ldots M$.

Once the measured signal is fitted as a combination of exponentials, the next step is to determine which term corresponds to the direct contribution, so the other contributions (reflections and diffractions) can be removed from the measured data, as shown in Fig. 3.

## B) Effect of aliasing

While simulating a signal and its echo, there will be a maximal distance at which the peaks coming from direct and reflected ray can be detected. This distance depends on the total bandwidth and the number of samples. This maximal distance is bounded by $c{\cdot}\Delta t{\cdot}N$, $N$ being the number of samples. If the bandwidth ($BW$) is very narrow, the different echoes cannot be distinguished, since $\Delta t = 1/BW$; if the signal or the echoes are present at a greater distance, they will be received in the next sweep, presenting an aliasing effect. Hence, for the simulation, the number of samples must be appropriately chosen in order to avoid aliasing.

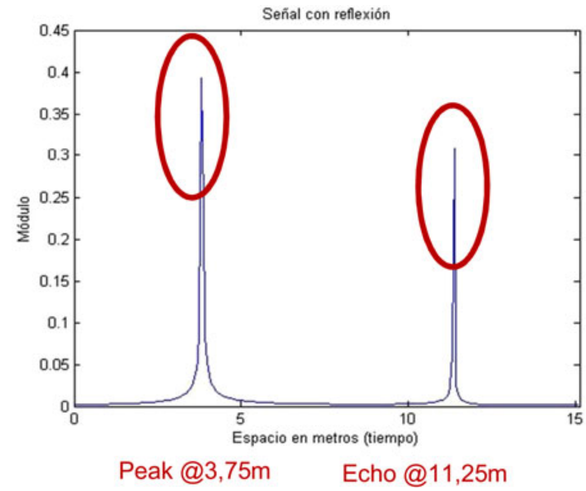


**Fig. 4.** Simulated signal and echo.

Next we present a simulation in the range from 0.8 to 6 GHz, where the distance between the AUT and the probe has been set, so that the signal appears at 3.75 m and the echo at 11.25 m as shown in Fig. 4. As $c^*\Delta t^*N > 3^*dist$ and $\Delta f < c/(3^*dist)$, taking $dist = 3.75$, $\Delta f$ should be at most 26.67 MHz.

As discussed above, a minimal step of 26.67 MHz is needed to avoid aliasing. This can be seen in the first simulation in Fig. 5. The echo appears correctly taking a step of 20 MHz. However, choosing 30 MHz, the echo appears in the next sweep.

## C) Comparison between FFT and Matrix Pencil method

The performance of both methods has been compared by simulating a signal (Fig. 6), the same signal with an echo (Fig. 7), filtering it with both methods (Fig. 8) and comparing with the simulated original signal without reflection (Fig. 6). In this simulation, the Matrix Pencil method has shown a better performance due to the distortion present in FFT method as a consequence of the windowing. In this direction, let us mention that, in stark contrast, in the real-life measurements presented in Section III, the FFT will prove to be a more reliable method.

# III. PRACTICAL ASPECTS TO BE CONSIDERED IN THE MEASUREMENTS

When the algorithms shown in previous section are applied to antenna measurements, some other difficulties appear. The

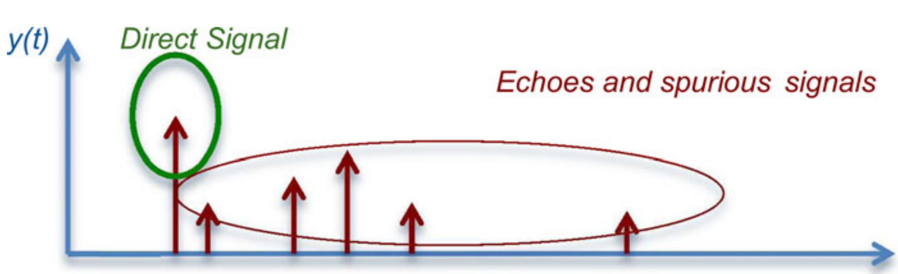


**Fig. 3.** Echoes to be suppressed with Matrix Pencil method.

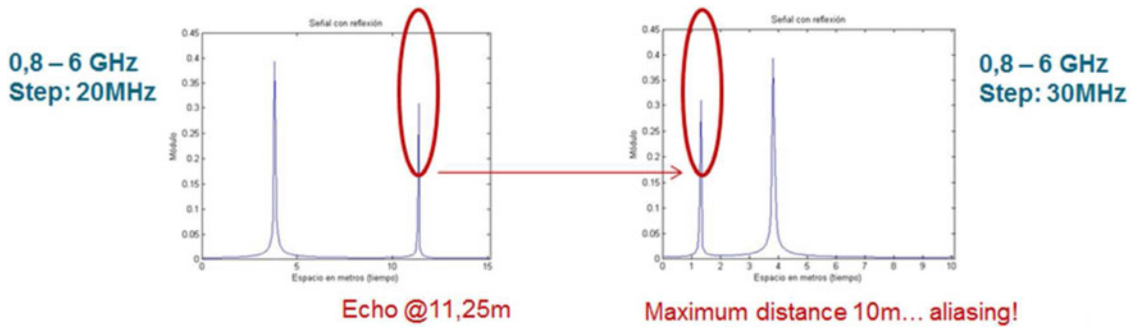


**Fig. 5.** Aliasing.

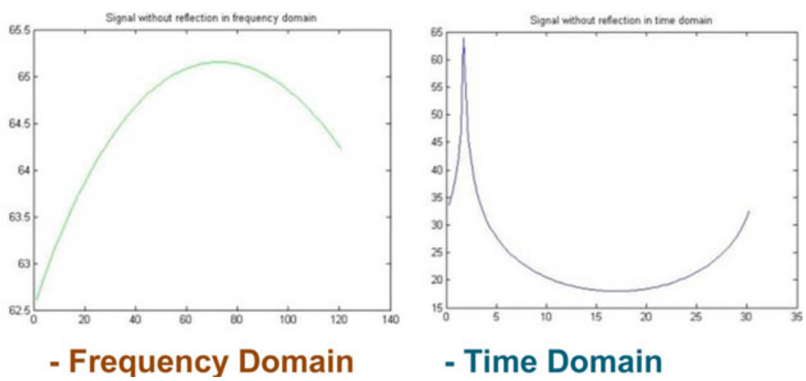


**Fig. 6.** Original signal without echo.

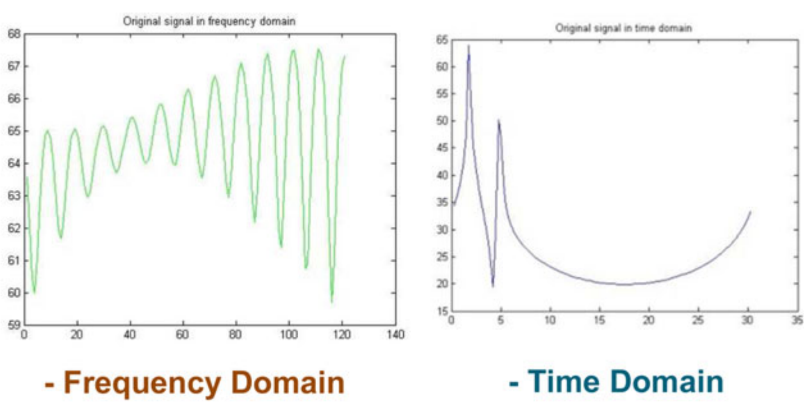


**Fig. 7.** Original simulated signal with reflection.

main problem is the need for multifrequency measurements. This introduces serious complications in some cases as in the classical near-field (NF) acquisition the measurement time can be very large. Of course, another aspect is the presence of noise. However, this is not often very serious because the signal-to-noise ratio in the main lobes is large.

In order to check the validity of the echo reduction techniques exposed in the previous section, different tests have been performed using different antenna measurement systems. First, a multiprobe system is used: in this case, the AUT is placed on the azimuth positioner, centered in the antenna system. Therefore, for each angle of arrival, the echoes and the signal get the receiver with the same time delay. In the second measurement system, an azimuth positioner is used for a single-cut measurement, but the phase center of the AUT is displaced and the offset has to be corrected during the process. Moreover, in this case another problem appears, as the distance between AUT and probe is different for each measurement point. This implies that the time gating has to be adjusted for each measurement point.

One advantage is that, since both the processes of NF to far-field (FF) transformation and time gating are linear, this time gating can be applied to the FFs. This simplifies the method and makes it independent of the antenna measurement system. These considerations will be discussed in detail in a future contribution.

Finally, one other important aspect that must be taken into account is that the filtering must be done using similar

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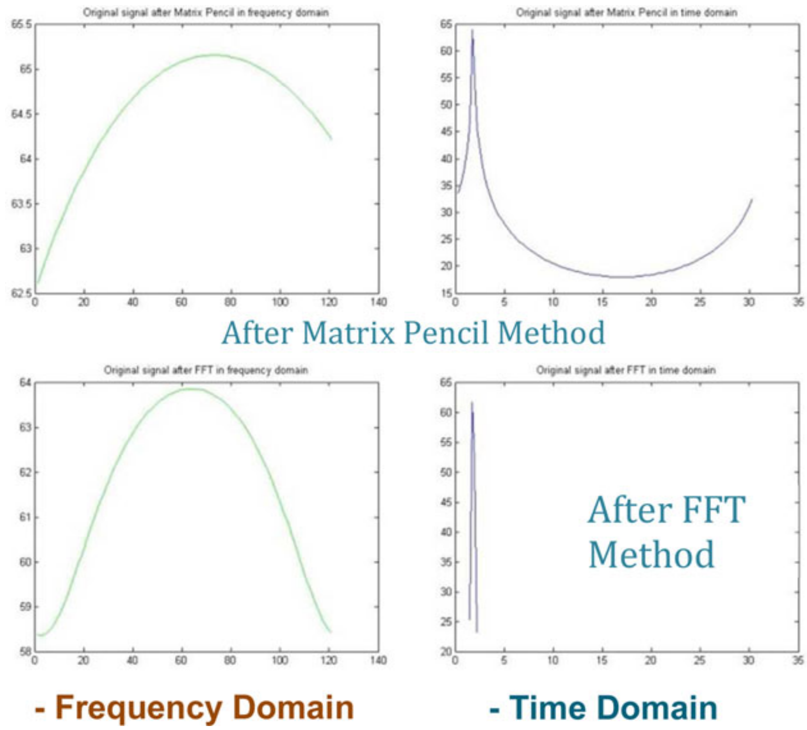


**Fig. 8.** Filtered signals with both methods.

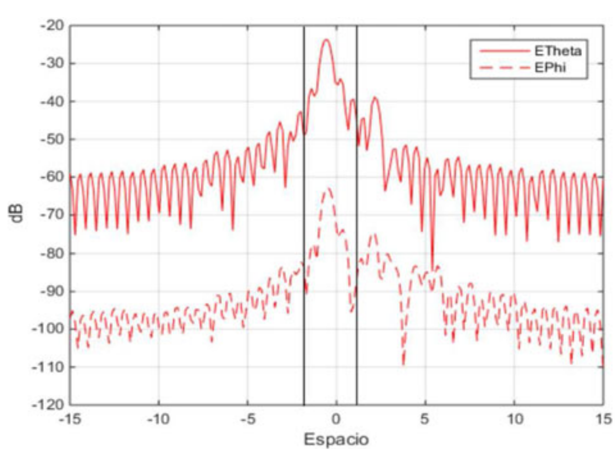


**Fig. 9.** Fictitious signals generated.

window widths for each sweep. Otherwise the received power would be different for each point and the result would be rather poor.

In this section, we will show some measurements and their time gating using different algorithms and methods.

## A) First setup: time gating without window adjusting

First of all, a Microwave Vision Group (MVG) multiprobe system has been used to measure a dipole featuring a reflection due to a metallic plate that was added to the setup. As the dipole has cylindrical symmetry with the same axis as the positioner and the dipole phase center coincides with the center of rotation, the same gating window can be used for all the measurements (see Fig. 9). This makes it unnecessary to adjust it in

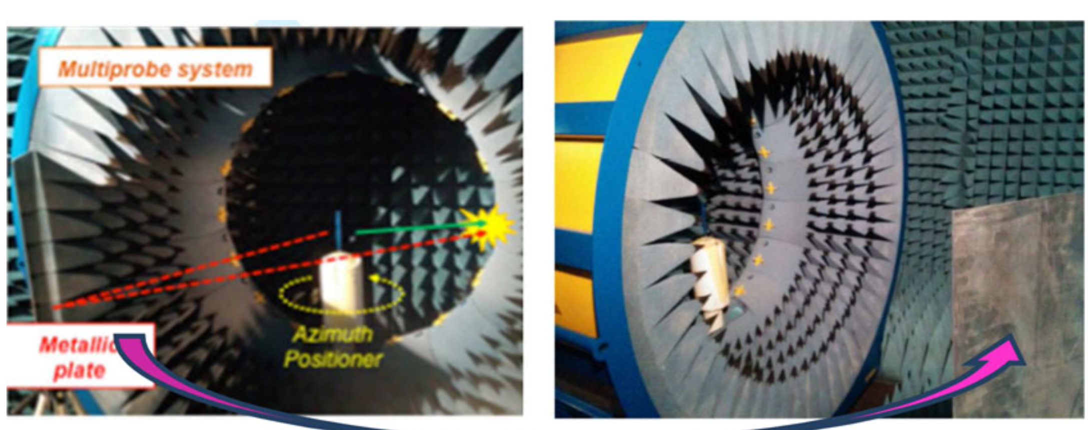


**Fig. 10.** Satimo multiprobe system.

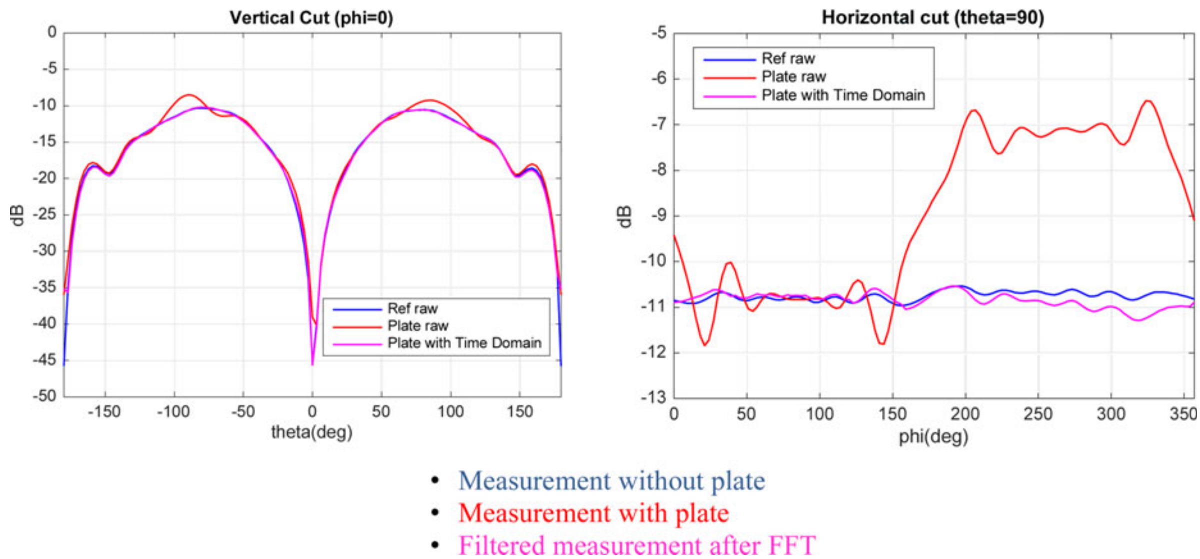


**Fig. 11.** Filtered signal with FFT method.

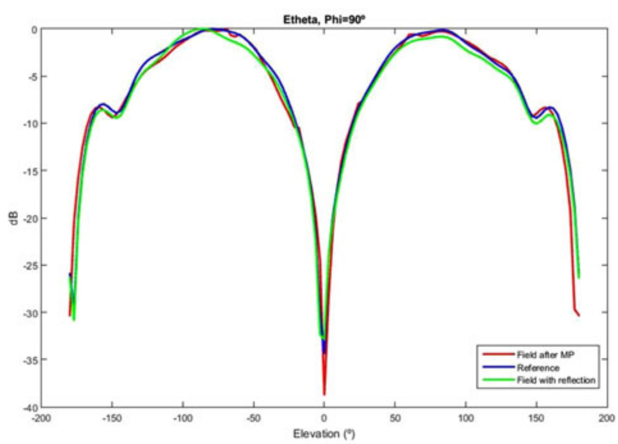


**Fig. 12.** Vertical dipole cut after Matrix Pencil method.

post-processing, making the filtering less involved. The setup of the measurement can be observed in Fig. 10. The measurements have taken place between 1.7 and 2.2 GHz with a 10 MHz step.

### 1) MEASUREMENTS AFTER FFT TIME GATING

After filtering the measures with FFT method, the results are very satisfactory, as shown in Fig. 11. Especially in the horizontal cut, the reflection is almost perfectly eliminated.

### 2) MEASUREMENTS AFTER MATRIX PENCIL

In this case, the performance of the Matrix Pencil method is much worse than that of the FFT method. The number of exponentials that we must take for the Matrix Pencil method varies dramatically in quite similar measurements. We have not found a rule of thumb to choose the optimal number of exponentials that should be taken when the reflection is large. The results are shown in Fig. 12 and the approximation with three exponentials of S21 component in Fig. 13.

## B) Second setup: time gating with window adjusting

A quadridge horn SH2000 was measured in a single-cut system in the facilities of the MVG in Italy (Fig. 14)

The measurement was carried out in the range from 6 to 10 GHz every 10 MHz. Measurements were performed in NF, in the range from 6 to 10 GHz every 10 MHz; the transformation to FF was carried out before and after the time gating, to compare results.

One difficulty of this system is that the antenna phase center is not the center of rotation. Therefore, one needs to shift the gating window for each measurement to correct the deviation. As there is a small difference between direct ray

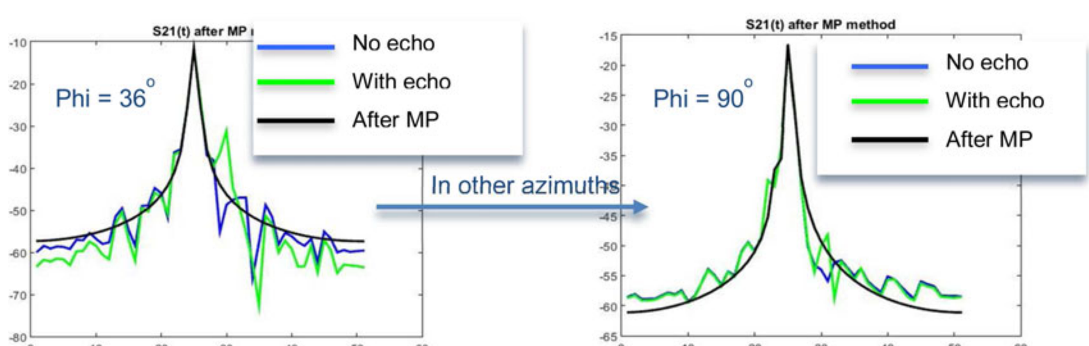


**Fig. 13.** S21 after Matrix Pencil method.

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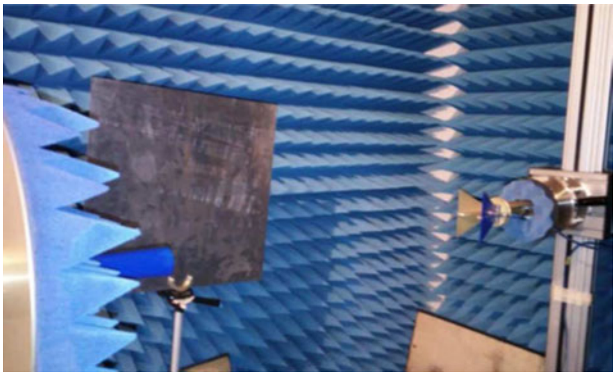

**Fig. 14.** Spherical near field setup.

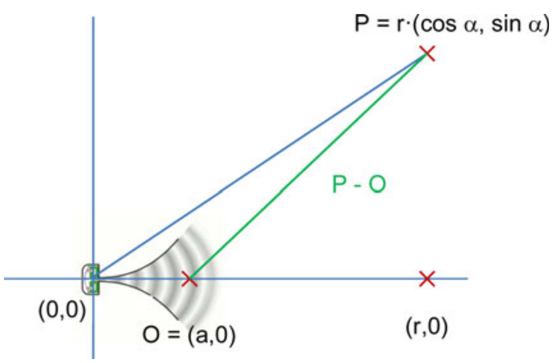


**Fig. 15.** Measurement correction.

and reflection, zero-padding is applied in the FFT transformation

### 1) Shift process in FF

Although the measurements have been made in NF, in this example we obtained FF data through a NF to FF transformation before filtering.

The phase shifting is corrected by aligning the maximum to the same point after the FFT transformation. As the reflection is sometimes greater than direct ray, the correction should be made by taking into account the effect of the distance between the antenna phase center ($O$) and the measurement point ($P$), as shown in Fig. 15.

This distance is given in FF by the expression:

$$|\vec{P} - \vec{O}| - r \approx \sqrt{r^2 - 2\,a r\cos\alpha} - r = r\left(\sqrt{1 - \frac{2\,a\cos\alpha}{r}} - 1\right) \approx -a\cos\alpha. \quad (2)$$

With this correction, the phase shifting works fine (Fig. 16) and then the filtering can be carried out in a satisfactory way for all frequencies. Results are shown in Fig. 17 for 6, 8, and 10 GHz.

### 2) Shift process in NF

In NF, the same algorithm as in FF has been applied. The distance cannot be approximated by a Taylor expansion, so the window alignment must be achieved using the formula

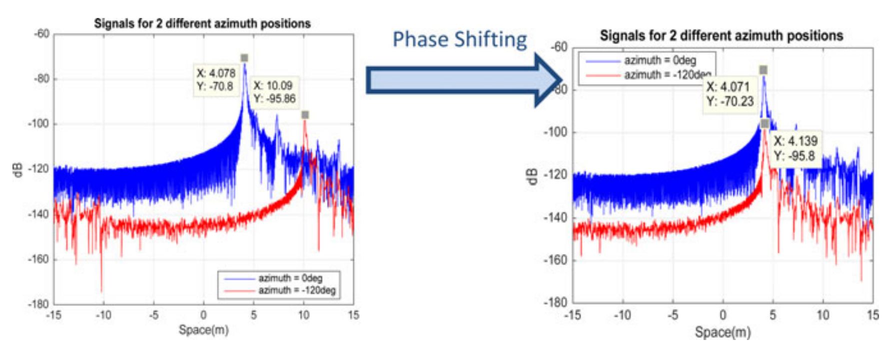


**Fig. 16.** Phase shifting for two different azimuth positions.

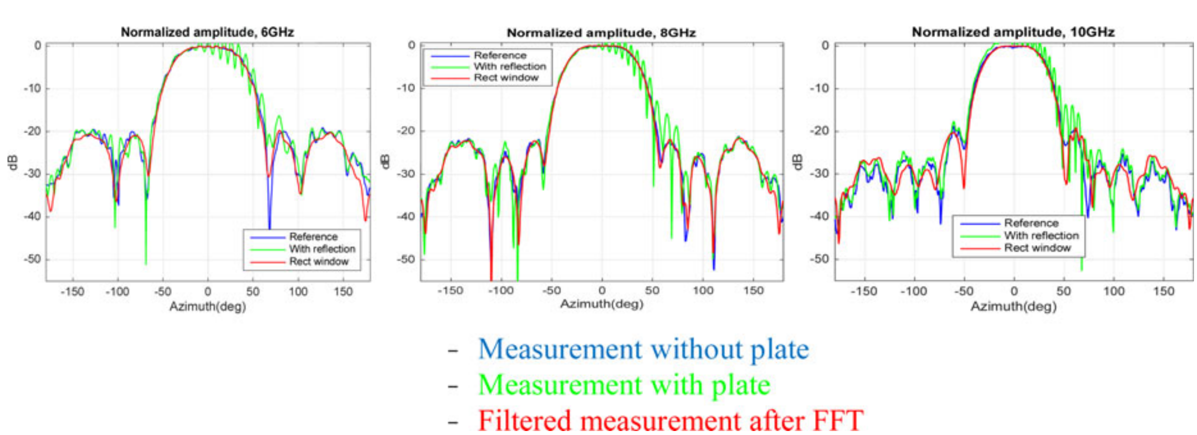


**Fig. 17.** Filtered measurements and comparison with no-echo measurements for 6, 8, and 10 GHz.

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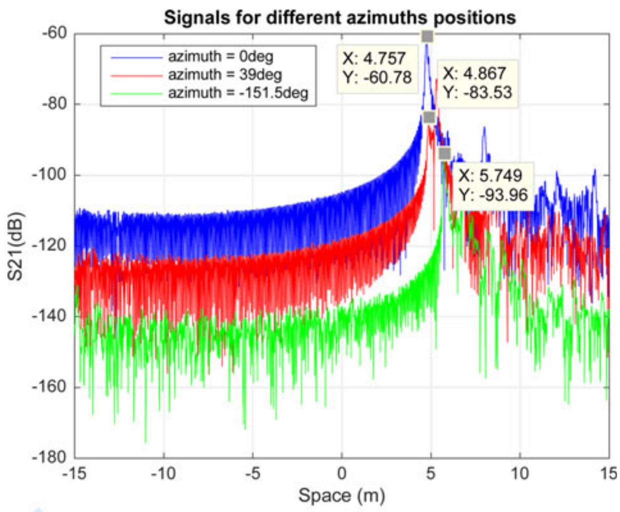


**Fig. 18.** Alignment of signals for different azimuths positions.

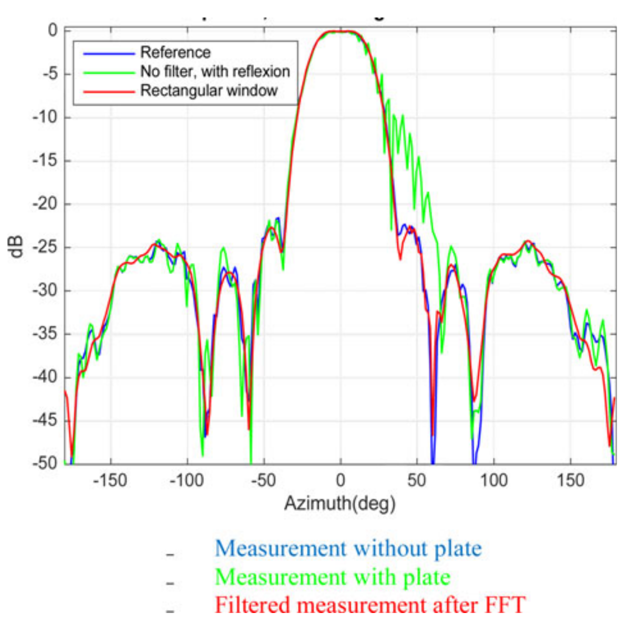


**Fig. 19.** Original signal, filtered signal, and reference.

$$\Delta s = \sqrt{r^2 - 2ra\cos\alpha + a^2} - (r - a), \tag{3}$$

where $\Delta s$ is the difference between direct and reflected path for NF. If we want to calculate the difference in the number

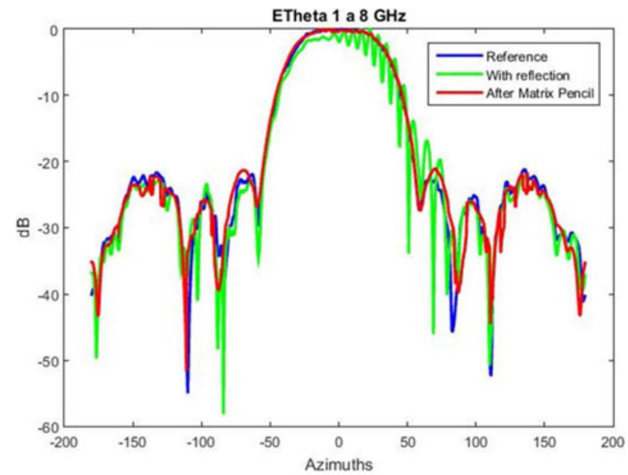


**Fig. 21.** Result after Matrix Pencil method.

of samples, we can use the equation

$$\Delta n = (\Delta s \cdot BW)/c,$$

where $BW$ is the bandwidth of the measurement and $c$ the speed of light.

The alignment in NF is shown in Fig. 18 and the filtered signal in Fig. 19.

### 3) Shift using Matrix Pencil

The Matrix Pencil method has also been applied to filter the measurements. Again the number of exponentials in the decomposition has been manually adjusted in each case, as we have not been able to find a general way to choose this number *a priori* in the filtering. The shift process using Matrix Pencil has to be performed the same way with the FFT method.

In this case, we have chosen a 20 exponential decomposition and a range of 0,43 in the phase of the exponentials. The validation was done in the transform domain (see Fig. 20), and the result is shown in Fig. 21. This result is clearly less satisfactory than that of the FFT method.

## IV. CONCLUSION

Time-gating techniques have proved to be efficient methods to eliminate noise in an antenna measurement, if the geometry of the system and of the AUT is appropriate. Comparing these techniques to the Matrix Pencil method, both advantages

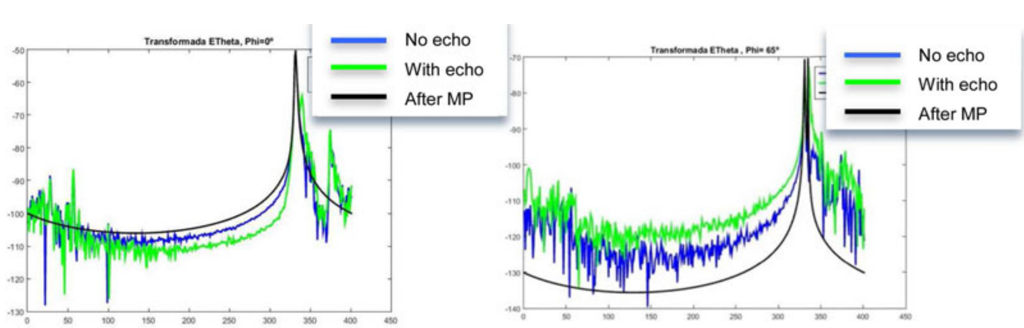


**Fig. 20.** Twenty exponentials for Matrix Pencil method.

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and disadvantages has been found. Matrix Pencil has shown much better performance for simulations and in the cases where the signal was significantly bigger than the noise and the reflections.

In the examples that we have considered, we have also introduced large reflection to analyze their effect. For these setups, the FFT method has proved to be the best and easiest way to filter a signal with echo and has the additional advantage that it can be performed either in NF or after the transformation to FF.

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