MV Echo

Echo Reduction Toolbox

White Paper

Echo Reduction by Modal Filtering Technique in Advanced Near Field Antenna Measurement

MVG
Microwave Vision Group

Spurious error signals from absorbers and other structures in the measurement set-up can significantly decrease the measurement accuracy in standard antenna measurement configurations.

When is echo reduction needed?

Most near field antenna measurements are performed in shielded anechoic chambers to simulate free-space conditions. High-quality absorbing materials are generally used on all surrounding surfaces that otherwise would interfere with the measurement by transmitting energy toward the test region through a combination of reflections and/or diffractions.

In the majority of measurement cases with well-designed anechoic chambers, the measurement uncertainty contribution from these additional error signals named echo(s) or echo pollution in the following discussion can be considered negligible [1]. However in special measurement conditions and/or when very high precision measurements are needed, the above consideration is no longer valid. Significant echo contributions can occur in the case of large angle of incidence even on absorber covered surfaces. Furthermore, if the anechoic chamber is used near or below the lower frequency limit of the absorbers, the quality of the test region is compromised by strong echo due to diminishing absorption properties of the absorbing material in these frequency ranges. Another source of test zone echo pollution is when the antenna under test is placed too close to the chamber walls or close to objects that cannot effectively be covered by absorbers.

An example of measurement situation where echoes or stray signal might be not negligible is shown in Figure 1 - Compact Payload Test Range (CPTR) at ESA-ESTEC *, where a Compact Range and a NF System share the same measurement environment.

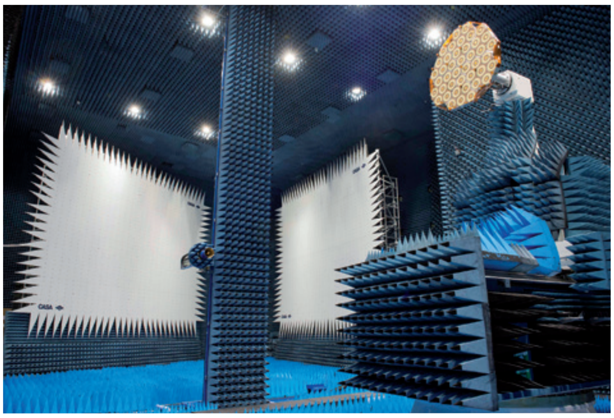


Figure 1 - Compact Payload Test Range (CPTR) at ESA-ESTEC* (Noordvijk, The Netherlands). A Compact Range and a NF System share the same measurement environment. Echoes and stray signals may occur while performing NF measurements.

What are the different solutions?

Common methods to reduce errors coming from echoes and stray signals present in the measurement environment are based on several approaches.

- **Modal Filtering:** The measured field is expanded over a set of orthogonal basis functions in which the scattered field components, being highly oscillating, are attributed to higher order modes that can be eliminated through a filtering of the spectrum.
- **Time-domain filtering:** The field measured in the frequency-domain is transformed to the time-domain through a Fourier Transformation (essentially by FFT) so that the components arising from the AUT are isolated from the echo contributions which have a longer time dependence.
- **Spatial filtering on AUT-aperture domain:** The measured field is projected on a plane tangent to the AUT aperture so that a space distribution containing equivalent sources is computed. The spatial filtering is then applied by "switching-off" those sources that are not associated with the aperture of the AUT.
- **Average of NF acquisitions separated λ/4:** Two (or more) NF acquisitions are performed at a distance of λ/4 (or multiple of λ/4) from the other(s) and combined with a proper phase correction term so that echo contributes cancel when the different NF acquisitions are averaged.

These techniques are described in detail in the IEEE standard test procedure for antennas [see reference notes 1-2] and also in [3], where an excellent overview of several methods is presented.

Most of the mentioned techniques require additional AUT measurements (e.g. Time-domain filtering, where data at several frequencies must be acquired) or can only be applied to certain types of antennas or measurement situations (such as Spatial filtering on AUT-aperture domain which is suited only for medium/high directive antennas).

(*) Courtesy of ESA-ESTEC

The modal filtering is a more flexible echo reduction approach purely based on intelligent post processing of measured data applicable to a wide range of antennas and measurements situations, such as Planar (PNF) Cylindrical (CNF) and Spherical Near Field (SNF), with no need for additional measurements or additional equipment.

MODAL FILTERING TECHNIQUE

Modal filtering can be seen as another type of spatial filtering in which the filtering is applied in a spectral (modal) domain. Such filtering takes advantage of the fact that the majority of the room scattering contributions are more highly oscillating than the direct contributions coming from the Antenna Under Test (AUT) on a surface enclosing the antenna itself. The technique is based on the expansion of the field over a set of orthogonal basis functions.

Among all the possible type of expansion bases (e.g. Spherical, Cylindrical, Plane Wave Expansion), the Spherical Wave Expansion (SWE) represents the one that can be applied to the majority of the measurement situations. Furthermore, the modal filtering performed in the spectrum computed by the SWE is based only on the knowledge of the physical extent of the Antenna Under Test (AUT). In fact, as described in [4-5], the maximum index of the significant Spherical Wave Coefficients (SWC) in the SWE is determined by the radius R_0 of the smallest sphere centered at the origin and enclosing the AUT (minimum sphere). As a consequence, the truncation index N can only be determined with the knowledge of the AUT size. More specifically, for an AUT corresponding to a minimum sphere of radius R_0 the coefficients of the spherical modes with index $n > N$ (with $N=kR_0+n_1$, where n_1 is an integer number depending on the size of the AUT) are expected to be negligible. On the other hand, echo contributions arising outside the AUT minimum sphere, since they are highly oscillating, are associated with modes of higher order with respect to the AUT modal distribution ($n > N$), and can be easily filtered out (see Figure 2).

It is worth noting that, since the physical extent of the AUT plays a key role in this type of filtering, any mathematical operation aimed at minimizing the AUT minimum sphere within the reference coordinate system, increases the modal separation between the AUT and the echoes enforcing the effectiveness of the method.

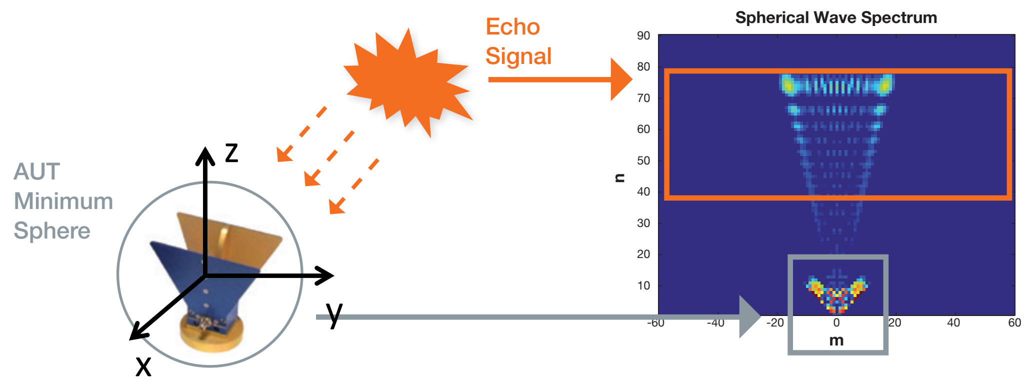


Figure 2 - llustration of spatial filtering capabilities of the SWE.

Application to SNF measurements

Due to the nature of the SWE basis function, the application of the modal filtering to Spherical NF (SNF) measurements is relatively straightforward. However, some additional considerations regarding the benefits coming from the acquisition of redundant SNF data (oversampling) can be pointed out.

BENEFITS FROM ACQUIRING REDUNDANT NF DATA (OVERSAMPLING)

In [6] it has been observed and proven through experimentation that if the near field acquisition is performed using a redundant set of data, i.e. having more samples than required by the Nyquist criteria, the expansion and successively modal filtering will improve the system Signal-to-Noise Ratio (S/N) with a ratio proportional to the square of the oversampling factor. This is due to the fact that random noise is completely uncorrelated so it is spread all over the computed spectrum. It is thus evident that the larger the computed spectrum (i.e. higher oversampling factor) is, the more improvements can be obtained by modal filtering. This fact is illustrated by the black dotted curve reported in Figure 3.

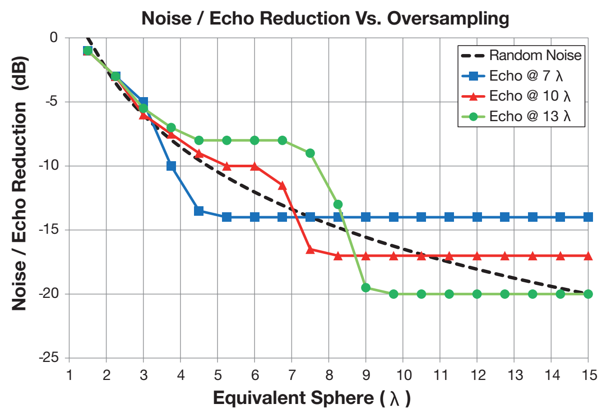


Figure 3 - Effectiveness of the modal filtering against noise and interferer placed at different distances varying the oversampling.

Intuitively, stray signals arising from a physical echo should be highly correlated to the wanted signals radiated by the AUT (especially if their source is relatively close to the AUT minimum sphere). Therefore it is not easy to know if oversampling (combined with modal filtering) can give rise to improvement in the estimation of the radiation pattern.

The effectiveness of having redundant data by varying the oversampling factor has been numerically investigated for echo signals located at different distances from the origin of the AUT minimum sphere. The results are reported in Figure 3 where a numerical AUT has been simulated in the presence of interferers located at different distances. For each configuration, different oversampling factors with respect to the AUT minimum sphere (see [4]) have been tested and the improvement after the application of the modal filtering has been reported similarly to what has been done for the random noise. It should be noted that, once a spherical (regular) sampling grid has been defined, choosing a certain oversampling, an equivalent sphere radius (ES) could be defined in terms of wavelengths by

$$ES \triangleq \frac{180}{StepDeg}\,\frac{1}{2\pi}$$

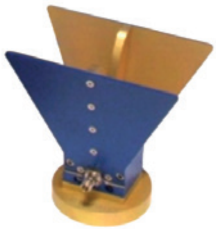
The equivalent sphere is thus directly linked to the oversampling factor. It has been used as the x-axes in Figure 3.

It is observed in [4] that if the equivalent sphere corresponding to the sampling includes both the AUT and the source of the interference in terms of echo or stray signals, then the modal filtering should be able to completely eliminate the disturbance. From the results in Figure 3, it can be seen that oversampling allows the improvement of the pattern estimation only to a certain limit. After this limit has been reached, no further improvement can be expected. It is worth noting that the farther the interferer is away from the AUT the better the possible improvements that can be achieved using modal filtering are. However, these improvements require further oversampling.

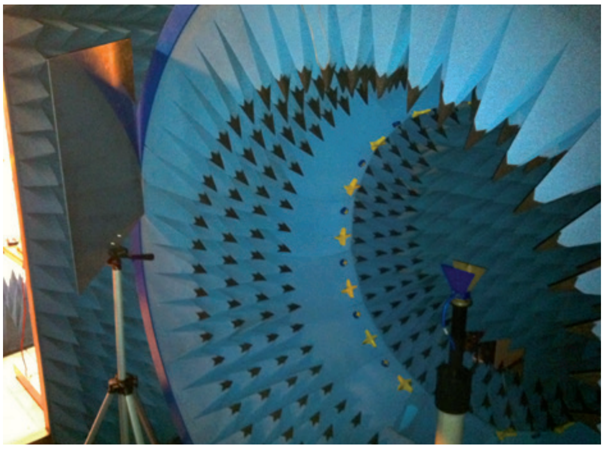
Furthermore, it is observed that the improvement threshold is reached before the equivalent sphere sampling corresponds to a particular interferer location. This means that there is no need to apply strong oversampling factors in order to include the interferer in the equivalent sphere and represent it with the spherical modes. Measurement time can thus be saved accordingly.

MEASUREMENT EXAMPLE: SH2000 + REFLECTING PLATE

To investigate the effectiveness of modal filtering in a spherical NF range, the MVG wideband horn reference antenna, SH2000 shown in Figure 4-a (operating at 6 GHz) is used in the measurement. The size of SH2000 is 105 mm x 61 mm x 104 mm and its gain at 6 GHz is approximately 9 dBi.



(a)



(b)

Figure 4 - MVG SH2000 (a); SH2000 + reflecting plate during measurement in StarLab (b).

The SH2000 is measured in the MVG StarLab (SL) multi-probe spherical system. The SNF setup used to measure the SH2000 is illustrated in Figure 4-b. The AUT is located in the center of the arch of the StarLab (i.e. reference of the coordinate system). To generate an echoic NF measurement scenario, a reflecting source (conducting plate) located in a known position has been introduced in the measurement setup. The reflecting plate has a size of 0.5 m x 0.5 m (10λ x 10λ @ 6 GHz) and it is placed outside the measurement sphere at 0.9 m from the origin of the coordinate system. Based on the considerations reported in the beginning of this section regarding the acquisition of redundant data, a five times oversampling with respect to the minimum needed has been adopted (sampling step of 2.25° both in azimuth and elevation).

The analysis performed with the modal filtering technique is reported in the following. The goal is to assess the antenna radiation pattern mitigating the effects of echo signals. In the comparison of results, the pattern measured without the reflecting plate is considered to be the reference pattern.

The comparison of Pn spectra @ 6 GHz is reported in Figure 5 for reference (blue curve) and perturbed measurement (red curve). The effect of the interferer is clearly indentifiable in the modal spectrum for higher order modes. The applied low pass modal filtering @ 6 GHz is $N_{filt} = M_{filt} = k*R_{min}$ (with R_{min} = 0.1 m) is illustrated by the black dotted filtering windows in Figure 5.

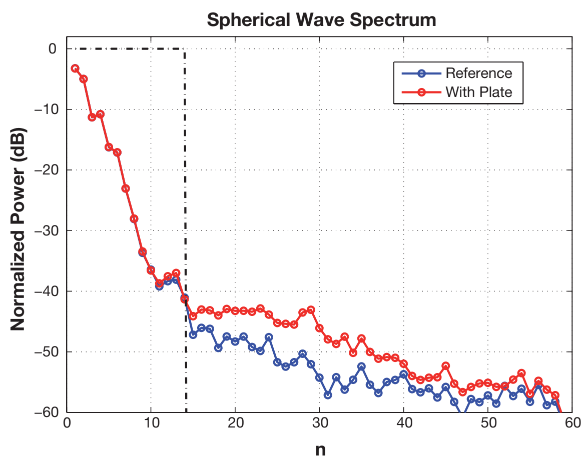


Figure 5 - Spherical Wave Spectrum of the SH2000 obtained with SWE of the FF data. Measurement w/o reflecting plate (Blue curve); measurement with reflecting plate (Red curve).

Comparison of E-plane and H-Plane pattern cuts are shown in Figure 6 for reference (blue curve), perturbed (red curve), Echo reduced (green curve) measurements.

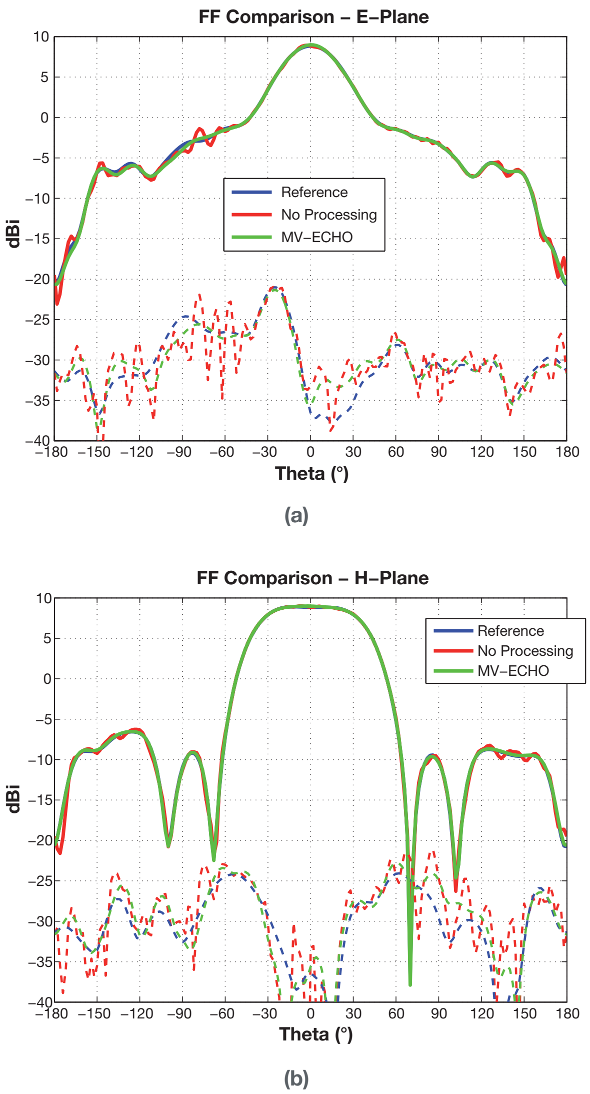


Figure 6 - Measured directivity, SH2000 in the StarLab. Solid lines show co-polar components, dashed lines show cx-polar components. E-Plane (a), H-Plane (b).

The improvement deriving from the application of modal filtering is appreciable. In particular, the FF ripple identified in the co-polar E-plane around θ = -75°, and caused by the interaction between the reflecting plate and the probe arch, is filtered out by the technique. Furthermore, as seen by the two cuts, the overall cx-polar performances have been improved. The reduction of the echo power level on the E-plane in Figure 7 also highlights the benefits of the application of the modal filtering technique.

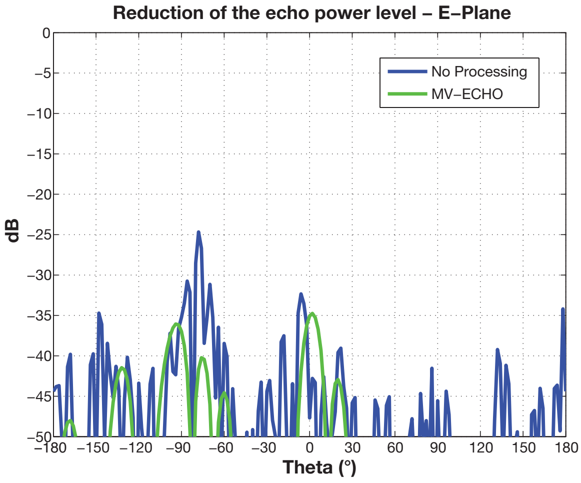


Figure 7 - Reduction of the echo power level in the Co-Polar E-Plane.

Such traces are the weighted difference of perturbed and reference pattern and are computed by the following formula:

$$e_i(\theta,\varphi) = \left|\frac{E(\theta,\varphi) - \tilde{E}(\theta,\varphi)}{E(\theta,\varphi)}\right| \frac{|\tilde{E}(\theta,\varphi)|}{|\tilde{E}(\theta,\varphi)|_{MAX}}$$

- $\tilde{E}(\theta,\phi)$ is the reconstructed pattern
- $E(\theta,\phi)$ is the reference pattern

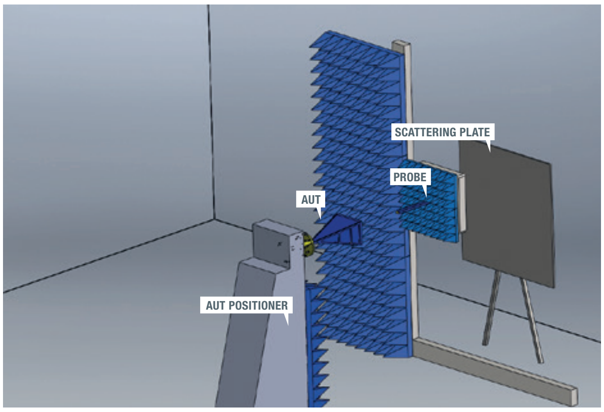
Application to PNF measurements

In PNF measurement, the AUT can be characterized following the same procedure applied for SNF measurement (data acquisition, expansion over set of orthogonal waves, FF computation). Once the FF has been computed it can be easily used as input to the modal filtering technique. Since the FF coming from PNF measurements is defined only in the forward hemisphere, a field manipulation has to be performed in order to compute the SWC. Typically, a zero-padding on the backward hemisphere is accomplished in order to create field distribution over the full 3D sphere.

MEASUREMENT EXAMPLE: SGH820 + REFLECTING PLATE

To investigate the effectiveness of modal filtering in a PNF range, the MVG Standard Gain Horn (SGH), SGH820 shown in Figure 8-a (operating @ 10 GHz), is used in the measurement. The size of SGH820 is: 195 mm x 148 mm x 353 mm and its gain @ 10 GHz is approximately 22 dBi.

(a)



(b)

Figure 8 - MVG SGH820 (a), Layout of the PNF measurement (b).

The layout of the PNF setup used to measure the SGH820 is illustrated in Figure 8-b. Like in the SNF measurements described in the previous section, a reflecting plate is introduced in the measurement setup.

The SGH820 together with the reflecting plate for the PNF measurement is shown in Figure 9. The reference system is located on the probe aperture (where the probe is positioned in the middle of the scanner), the z-axis is aligned with the AUT main axis. The reflecting plate is placed behind the scanner parallel to the wall and centered at $(x_0, y_0, z_0) = (-0.5$ m, -0.4 m, 1.8 m).The dimensions of the reflecting plate are 1.25 m x 1.25 m, approximately 41λ x 41λ at 10 GHz.

PNF measurements are performed considering an AUT-to-Scanner distance of 0.375 m, a scanner size of 1.5 m x 1.5 m (view angle of approximately 60°) and using a standard spacing of $\lambda/2$.

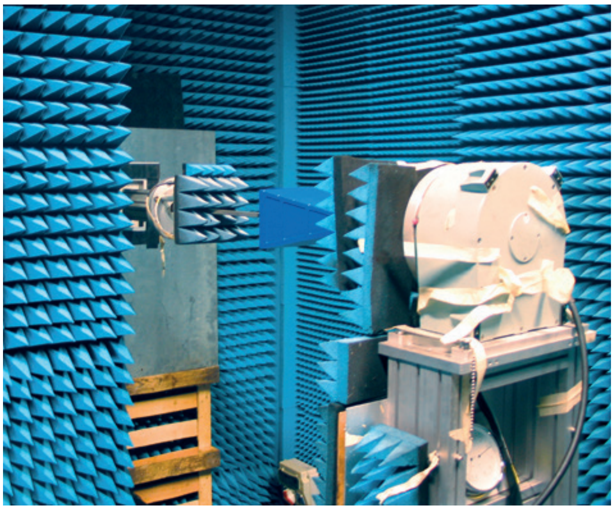
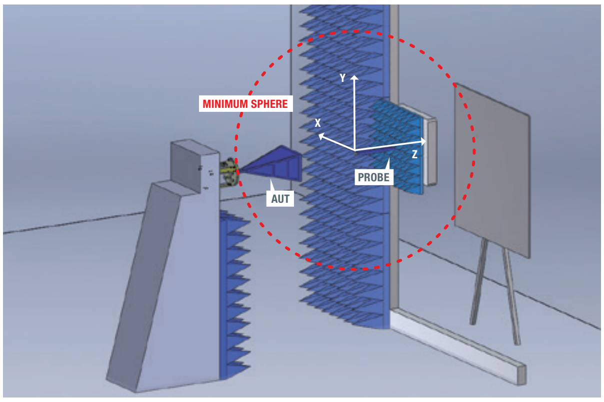
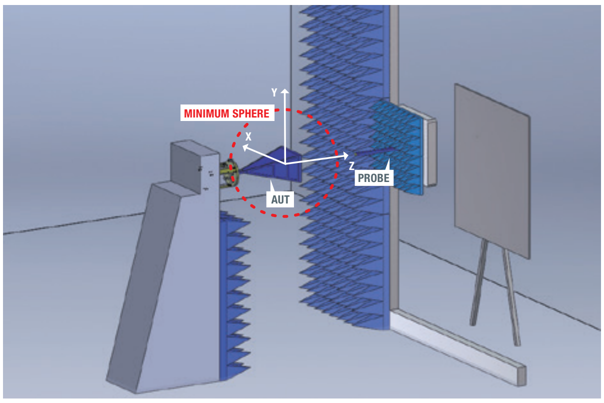


Figure 9 - SGH820 during NF acquisition in the MVG PNF range.

Reference and perturbed far field patterns are computed from the PNF measurement. The measured FFs are referenced to $z_0 = -0.375$ m (which is the AUT aperture location in the original coordinate system). The original and modified coordinate system is illustrated in Figure 10 together with the corresponding AUT minimum sphere.



(a)



(b)

Figure 10 - Illustration of original coordinate system (a) and modified coordinate system (b) and the corresponding AUT minimum sphere.

The origin of the FF coordinate system is moved to the AUT aperture resulting in a decrease of the AUT minimum sphere (r_0). A reduction of the size of r_0 ensures that the spherical modal spectrum distribution is concentrated in the lower possible order modes (i.e. low pass behaviour) as shown in Figure 11-a. As a result, the low pass filtering capabilities are more effective for the suppression of echo pollution characterized by higher order modes.

The perturbed modal spectrum, normalized at the peak value, after the modification of the reference coordinate system, is reported in Figure 11-a. The effects of the reflecting plate is evident for radial modes of order > 24. As depicted by the Pn spectra shown in Figure 11-b, the modification of the coordinate system ensures that the modal separation between the AUT and the disturbance increases and the peak associated with the interferer is clearly identified at higher order modes (approximately n = 85). The applied low pass modal filtering at 10 GHz is $N_{filt} = M_{filt} = k{*}R_{min}$ (with $R_{min} = 0.125$ m) is illustrated by the black dotted filtering windows in Figure 11-b.

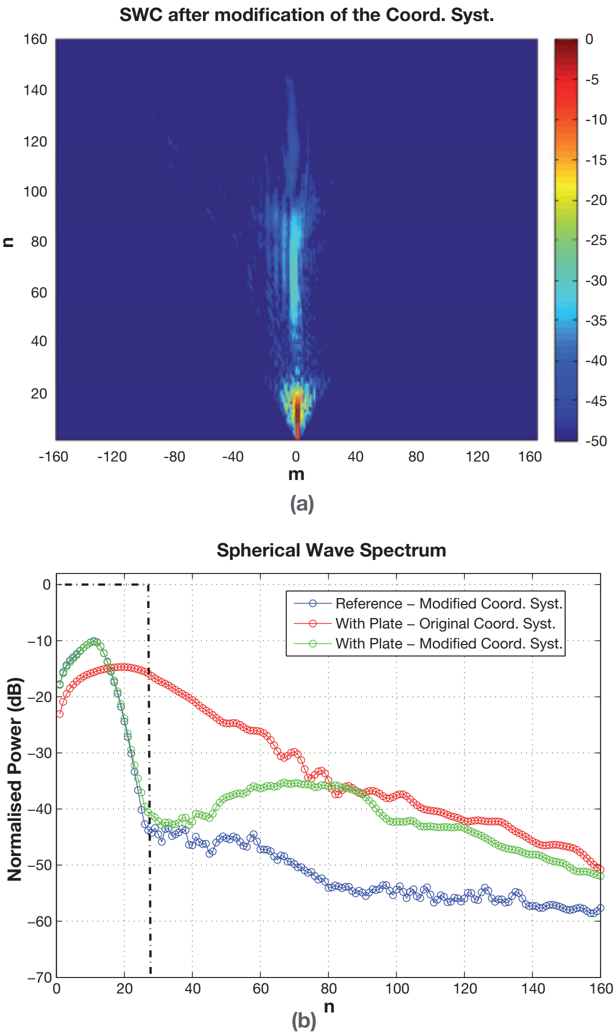


Figure 11 - SGH820: SWC after modification of the coordinate system (a); Pn Spectra (b).

The comparison of the E-plane and the diagonal plane (φ=135°) patterns are reported in Figure 12 showing far field reference: FF (blue curve), Perturbed (red curve), Echo reduced (green curve). The improvements coming from the application of MV-echo is appreciable in both the Co polar and Cx polar plots as well as in Figure 13 where the reduction of the echo power level is reported for the diagonal AUT plane. As can be seen, up to 20 dB, the mitigation of the errors coming from the presence of echo signals can be reached.

To further investigate the problem, Figure 14 shows the holographic maps on the aperture plane of both the perturbed (a) and echo reduced data (b).The effect of the reflecting plate is clearly visible in the Co polar map in Figure 14-a for negative y. The wide spot is supposedly associated to a re-irradiation of the field reflected by the plate from the antenna positioner. As seen in Figure 14-b, the effect of the reflecting plate is strongly attenuated by the modal filtering technique.

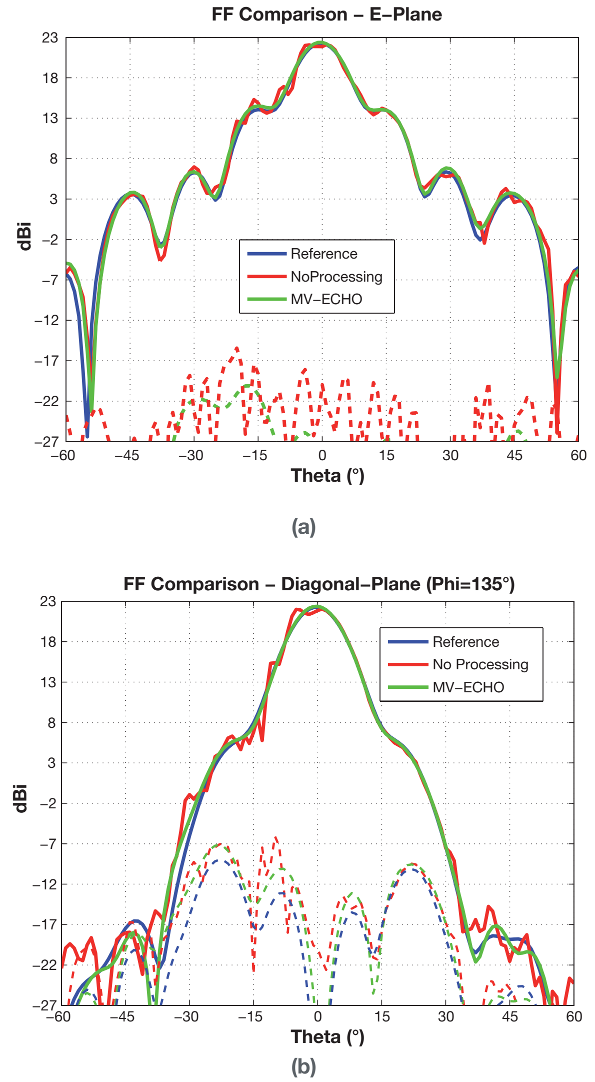


Figure 12 - Directivity pattern comparison for the SGH820 measured in the PNF system. Solid lines show co-polar components, dashed lines show cx-polar components. E-Plane (a), Diagonal-Plane, φ=135° (b).

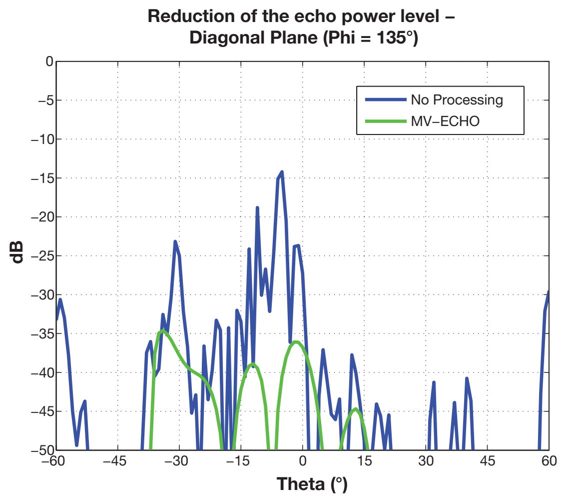


Figure 13 - Reduction of the echo power level in the Co-Polar Diagonal Plane, φ = 135°.

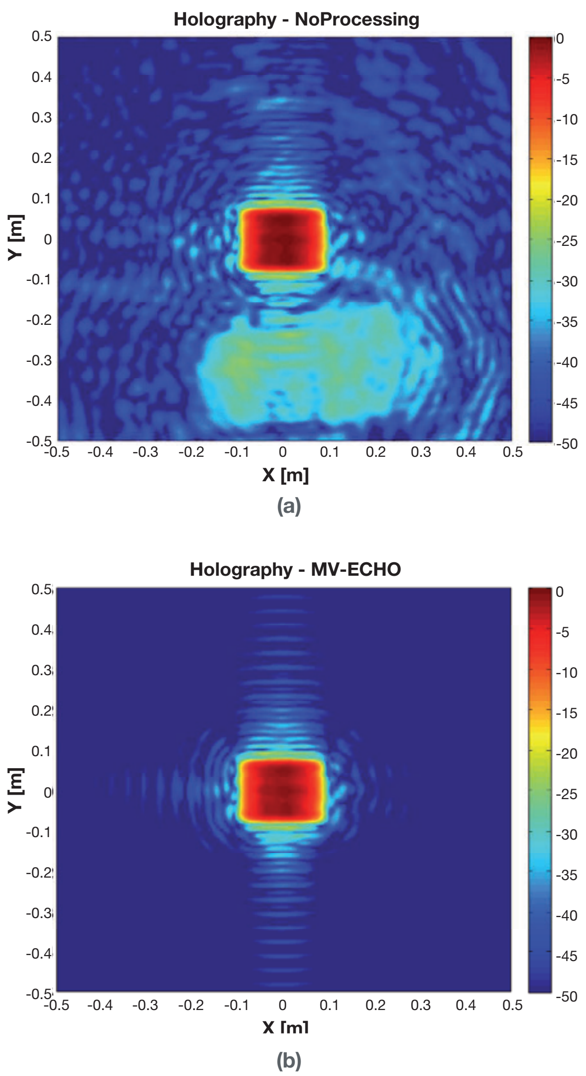


Figure 14 - Holography on the AUT aperture plane. Computed using non processed data (a); Computed using Modal filtered data (b).

Conclusions

The modal filtering technique presented in this paper is implemented in a MVG measurement post-processing tool called MV-Echo. MV Echo allows the reduction of echo pollution in a typical NF antenna measurement scenario (Planar, Cylindrical and Spherical NF). The technique implements spatial filtering (performed in the Spherical Wave Domain) that makes use of the band-limitless of the field radiated by the AUT and a priori information of the physical size of the AUT. The approach is purely based on intelligent post-processing of the measured NF that can be applied to a wide range of antennas and measurement scenarios with no need of additional measurements or additional equipment. In this paper, the main concepts of the modal filtering approach are explained. The application of the modal filtering to two measurement scenarios (Spherical and Planar Near Field) are presented. The measurements are performed in a controlled echoic environment using a reflecting plate. MVG wideband dual-ridge horn, the SH2000, and standard gain horn, the SGH820, have been considered as typical antenna measurement applications. The measurement results have demonstrated the remarkable effectiveness of the technique in the improvement of the antenna radiating pattern and the directivity estimation in a strong echoic NF measurement situation.

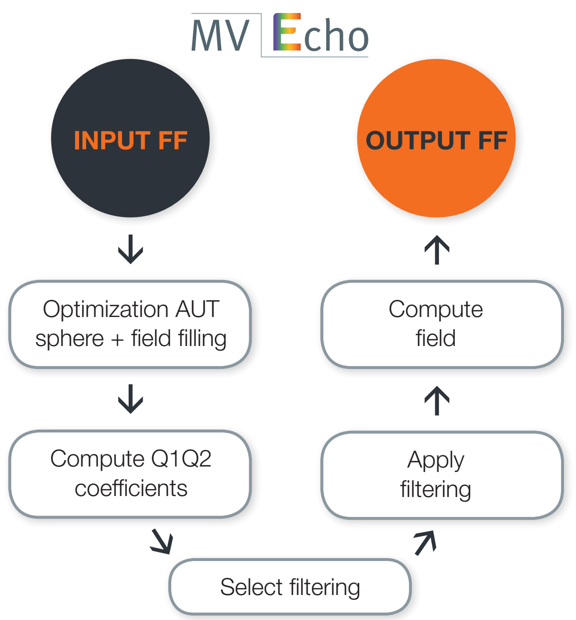


Figure 15 - Block diagram of MV-Echo algorithm.

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ABBREVIATIONS

- AUT → Antenna Under Test
- DUT → Device Under Test
- NF → Near Field
- FF → Far Field
- SWE → Spherical Wave Expansion
- SWC → Spherical Wave Coefficients
- NF-to-FF → Near Field to Far Field Transformation
- PNF → Planar Near Field
- CNF → Cylindrical Near Field
- SNF → Spherical Near Field
- S/N → Signal-to-Noise ratio

MVG - Meeting the Testing Challenges of a Fully Connected World

The Microwave Vision Group (MVG) has developed unique expertise in the visualization of electromagnetic waves. These waves are at the heart of our daily lives: smartphones, computers, tablets, cars, trains, planes - these devices and vehicles would not work without them. MVG expertise brings measurement solutions to R&D teams for the characterization of antennas and their performance within these devices, and chamber solutions for EMC testing. MVG innovation remains focused on supplying the world with the most advanced EMF measurement technology to date.

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