Investigation of Echo Suppression Effeciency in Spacecrafts Near Field Measurement Scenarios

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***Abstract*— Measurement post-processing techniques based on spatial filtering have been presented as promising tools for the mitigation of echo's deriving from the measurement environment in regular Near Field (NF) measurement scenarios [1]-[2]. The adaptation of these tools into standard measurement procedures depends on the possibility to demonstrate the real effectiveness in a given measurement scenario. The standard validation approach is to introduce a known disturbance into a measurement scenario and show the efficiency of the techniques in attenuating this disturbance. While highly effective as a functional demonstration of this approach the benefit of the echo reduction on an actual measurement scenario should still be evaluated on a case by case basis.**

A hybrid Near Field (NF)/Far Field (FF) system has recently been installed in the existing dual reflector Compact Payload Test Range (CPTR) of ESTEC [3]-[4]. The installed system has been designed to perform spherical, cylindrical and planar NF measurements in the broad band of frequencies going from 400 MHz to 50 GHz. Despite the design effort to optimize the NF system position in the chamber some interaction with the dual reflectors in the range were expected for the PNF system in particular [5]-[6].

During the hybrid system acceptance at low frequency, measurements have been performed on the space array antenna intended as part of the European Navigation System GALILEO. The antenna is a pre-development model flying on the In-Orbit Validation Element, GIOVE-B satellite, developed by EADS-CASA Espacio [7]-[8]. This L-band antenna was particularly important test case for ESTEC since the PNF system has been later used in the final testing at space craft level on the GALILEO Satellites.

This paper presents the preliminary finding of the MV-Echo post processing validation for PNF measurements in the hybrid range. The GALILEO array antenna has been measured in different configurations and results with and without echo reduction processing are compared. The purpose of the activity was to quantify the benefits of the MV-Echo processing in a real case. Since the array is working in circular polarization it was possible to identify the major echo contributions as 2'nd order reflections.

I. Introduction

In any antenna measurement scenario, echoes and/or stray signals can arrive from signals scattered by absorbers or other structures in the measurements chamber [1]. As presented in previous papers [1]-[2], echo-reduction techniques based on spatial/modal filtering of the measured field, are promising tools that allows to mitigate the errors coming from the presence of echo and/or stray signal in the measurement environment.

In this paper the results obtained applying the commercially available echo-reduction software called MV-Echo on a realistic NF measurement will be presented. Measurements have been performed in the new hybrid NF system at ESA/ESTEC [3]-[4] shown in Fig. 1. As can be seen a dual reflector compact range (Compact Payload Test Range - CPTR) and a NF system (Spherical, Planar and Cylindrical) share the same environment. Despite the design effort to optimize the NF system position in the chamber, some echoes originated by the interaction with the dual reflectors and the NF system may occur especially when performing NF measurement in planar geometry.

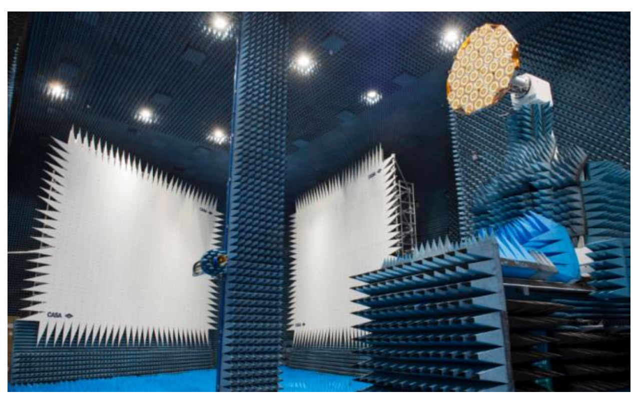

Figure 1. Compact Payload Test Range (CPTR) at ESA-ESTEC. A Compact Range and a NF System share the same measurement environment.

The MV-Echo post-processing software allows the user to apply suppression of unwanted signals in general NF antenna measurement scenarios using Spherical (SNF), Cylindrical (CNF) and Planar (PNF) scanning geometry. The main input of the echo reduction algorithm is the resulting Far Field data (FF) obtained transforming NF acquisition, including probe correction when applicable.

The antenna considered in this paper is a pre-development model flying on the In-Orbit Validation Element, GIOVE-B satellite, developed by EADS-CASA Espacio [7]-[8].

II. MV-ECHO

The spatial filtering implemented within the MV-Echo software for the mitigation of the errors arising from the echo signals is based on the expansion of the measured field over a set of orthogonal spherical wave modes (SWE) [9]. Such an expansion is then combined with a modal filtering based on the knowledge of the physical extent of the Antenna Under Test (AUT).

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) [9]-[10]. As a consequence, the truncation index N can be determined on the basis of the knowledge of the AUT size. More specifically, it is known that 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 a number depending on the size of the AUT and on the position of the measurement sphere) are expected to be negligible. On the other hand echoes contributes arising outside the AUT minimum sphere, since are highly oscillating, are associated to modes of higher order respect to the AUT modal distribution (n>N), that can be easily filtered out.

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, increase the modal separation between the AUT and the echoes enforcing the effectiveness of the method.

In Planar-NF measurements the reference system is in fact located on the probe aperture (when the probe is in the center of the scanning plane) thus the AUT results to be offset in the reference system as illustrate on Fig. 2 (left). As a consequence the AUT minimum sphere is bigger wrt an onset configuration thus echo's and AUT contribution results to be entangled in the corresponding spherical wave domain as illustrated in Fig. 2 (right).

Within MV-Echo the AUT minimum sphere can be minimized by properly modifying the reference coordinate system as shown in Fig. 3 (left). The optimization of the AUT minimum sphere separates the contributes associated to the AUT from those associated to the echoes (see Fig. 3 - right) allowing the application of the modal filtering.

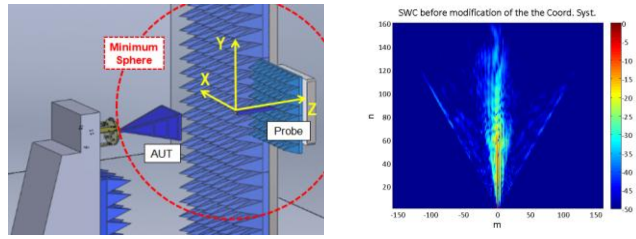

Figure 2. Illustration of original coordinate system of a PNF system (left) and corresponding SWC (right).

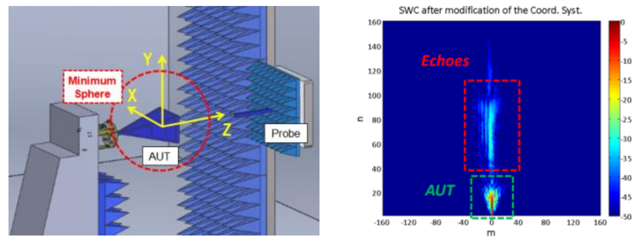

Figure 3. Illustration of modified coordinate system of a PNF system (left) and corresponding SWC (right) – i.e. optimization of AUT min. sphere.

III. APPLICATION TO PLANAR-NF MEASUREMENT OF GIOVE-B ARRAY ANTENA

The antenna considered in the processing is the GIOVE-B array antenna. It consists of 42 stacked patches on a regular grid within a 1.3 m diameter envelope, corresponding to 5.2λ @ 1192 MHz. The antenna has an iso-flux pattern, covering an angular domain of +/- 13 deg, corresponding to the Earth view angle from a Medium Earth Orbit (MEO). The antenna is right hand circularly polarized [8].

The antenna has been measured in the new hybrid NF system at ESA/ESTEC both in Spherical-NF and Planar-NF configuration.

Figure 4. The GIOVE-B array antenna during measurements in the new near field upgrade of the ESTEC CPTR system.

In the hybrid system, Spherical-NF measurements are performed rotating the AUT both in azimuth and roll (Roll/Az) while the probe is kept fixed. On the contrary, Planar-NF measurements are performed moving the probe along two orthogonal linear axes (X- and Y- axis) maintaining the AUT fixed.

In the analysis presented in the following, Far field data coming from the Spherical NF acquisition have been used as reference, not having access to raw data of measurements performed at CASA premises. It should be noted that, even those reference data may be affected by errors. Nevertheless, since in Spherical-NF configuration the AUT is moved along both the scanning axes, the effect of echoes and/or stray signals is expected to be much lower wrt Planar-NF configuration where the AUT is kept fixed.

Planar-NF measurements have been performed considering an AUT-to-Scanner distance of 2.15m and a scanner size of approximately 8m x 8m (valid view angle of approximately 57°). Measurements have been performed using a standard spacing of λ/2 between the near field acquisition points. Far field patterns have been computed from the Planar-NF using a standard Planar NF-to-FF transformation, including probe corrections for the open ended waveguide used. Such FF data have then been used as input to the MV-Echo software.

MV-Echo has been applied first referring the FF to the aperture of the AUT (i.e. optimization of the AUT minimum sphere) by moving the reference system of 2.15m (probe-AUT separation) toward the AUT and then applying a modal filtering considering a minimum AUT radius of 0.65m. The applied low pass modal filtering @1.192GHz is $N_{filt} = M_{filt} = k{*}R_0 + n_1 = 27$ (with $R_0 = 0.65$m and $n_1 = 10$).

The comparison between FF coming from spherical-NF measurement (reference, blue trace), FF coming from Planar-NF without application of MV-Echo (red trace) and FF coming from Planar-NF with application of MV-Echo (green trace) along φ = 0° and φ = 45° are reported respectively in Fig. 5 and Fig. 6 for both co-polar (RHCP) and cx-polar (LHCP) components (shadowed areas indicates regions outside the validity angle). A zoom on the main beam of the antenna is also illustrated in Fig. 7.

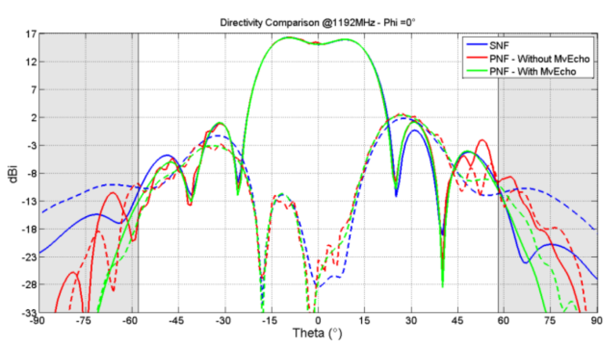

Figure 5. Directivity pattern comparison along φ = 0°. Solid lines show co-polar (RHCP) components, dashed lines show cx-polar (LHCP) components.

As can be seen the non-processed FF curves presents ripples caused by unwanted effects occurred during the Planar-NF measurement. It should be noted that the origin of such interfering signal may be due the combination of more unwanted effects such as the presence of echoes and/or stray signals (as mentioned above) and truncation errors. This last type of error are caused by the truncation of the scanning area thus are quite typical in Planar-NF measurement [11]. It is worth noting that, independently on the origin of the interference signals, the ripples are strongly attenuated by the spatial filtering implemented in MV-Echo.

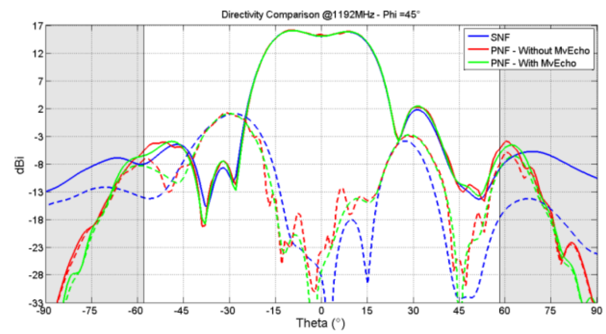

Figure 6. Directivity pattern comparison along φ = 45°. Solid lines show co-polar (RHCP) components, dashed lines show cx-polar (LHCP) components.

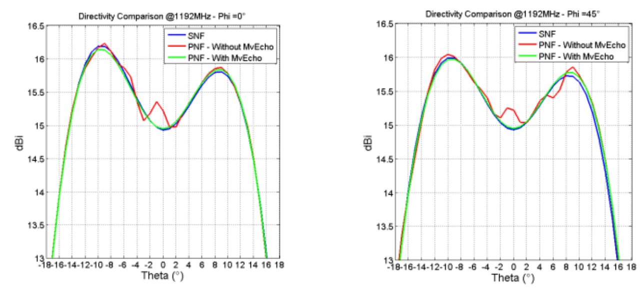

Figure 7. Zoom on the main lobe of the AUT. Comparison along φ = 0° (left), comparison along φ = 45° (right).

Fig. 8 and Fig. 9 show the reduction of the echo power level for the cut along φ = 0° and φ = 45° respectively. Such a quantity has been evaluated applying the below formula (eqn. 1) both to the co-polar components (top part of the figures) and to the cx-polar components (bottom part of the figures)

$$e_i(\theta,\phi) = \left| \frac{E(\theta,\phi) - \tilde{E}(\theta,\phi)}{E(\theta,\phi)} \right| \cdot \frac{\left|\tilde{E}(\theta,\phi)\right|}{\left|\tilde{E}(\theta,\phi)\right|_{MAX}} \qquad (1)$$

where

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

$E(\theta,\phi)$ is the reference pattern.

As can be seen, significant improvements in the mitigation of the errors are obtained both in the co-polar (RHCP) and cx-polar (LHCP) components and in both shown cuts. In particular, a relative high error, most probably caused by a 2^{nd} order reflection, where present in co-polar (RHCP) main beam area, before the application of the MV-Echo (error level around -30/-35 dB). Such error level has been lowered up to approximately -50 dB after the application of the MV-Echo software.

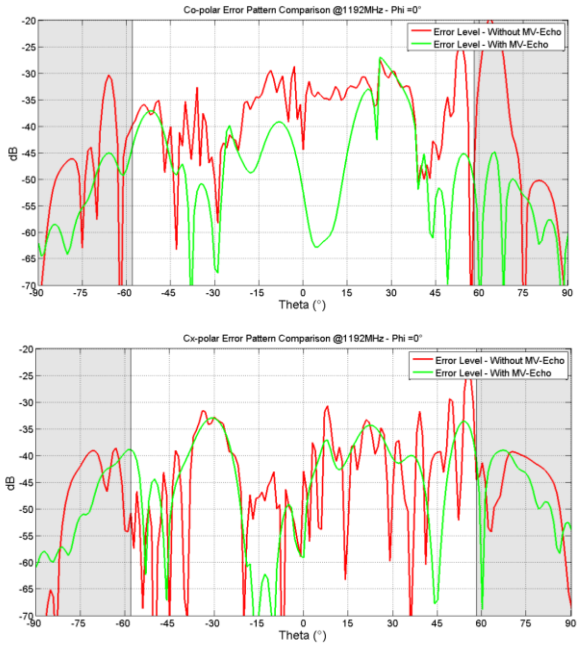

Figure 8. Reduction of the echo power level along φ = 0°. Co-polar (RHCP) component (top); Cx-polar (LHCP) component (bottom).

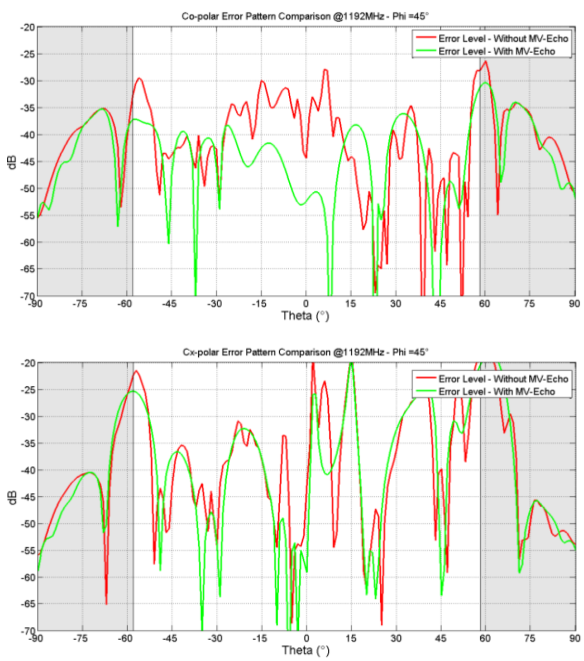

Figure 9. Reduction of the echo power level along φ = 45°. Co-polar (RHCP) component (top); Cx-polar (LHCP) component (bottom).

IV. Application to GALILEO FOC Measurements

In January 2014, the first flight model of the new generation of GALILEO satellites (Full Operational Configuration (FOC)) developed by OHB Bremen has been tested in Planar Near Field in the same facility at ESA-ESTEC. The objective of the test was to assess any possible deformation on the Navigation antenna introduced by any other antenna/instrument on board. The challenge was in this case to eliminate echoes and/or stray signals, without removing real pattern disturbances coming from the spacecraft topology. Also in this case the effectiveness of MV echo was shown, making possible to conclude that the pattern was only minimally affected by the antenna surrounding. Unfortunately, these measurements cannot be shown due to confidentiality issues.

V. Conclusion

In this paper the preliminary finding of the MV-Echo post processing validation for Planar-NF measurements in the hybrid range at ESA/ESTEC have been presented. The hybrid system hosts a dual reflector Compact Payload Test Range (CPTR) and a NF system (Spherical, Planar and Cylindrical). Despite the design effort to optimize the NF system position in the chamber, some echoes originated by the interaction with the dual reflectors and the NF system may occur especially when performing NF measurement in planar geometry.

The purpose of this paper was to quantify the benefits of the MV-Echo processing applied to a realistic test case without introducing known interferers as typically done to validate the effectiveness of echo-reduction techniques in attenuating such interferers. To do that, a space array antenna working at L-Band in right hand circular polarization has been used as test case. Such antenna is a pre-development model flying on the In-Orbit Validation Element, GIOVE-B satellite, developed by EADS-CASA Espacio.

Comparative results between FF data obtained with and without the use of MV-Echo have shown the remarkable capabilities of the software in the attenuation of the errors coming from the presence of unwanted signals. It has been observed that ripples present in the non processed FF pattern may be due both to the presence of echoes and/or stray signal and truncation errors. Independently on the origin of the interference signals, the ripples have been strongly attenuated by the spatial filtering implemented in MV-Echo.

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