Sensitivity Analysis of Fast Non-Redundant NF Sampling Methodologies with Probe Positioning Errors

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***Abstract*—The Planar Wide-Mesh Scanning (PWMS) methodology is based on Non-redundant scanning schemes allowing faster measurements than classical Nyquist-compliant acquisitions based on denser, regular, equally spaced Planar Near Field (PNF) sampling. The methodology has no accuracy loss and has been validated at different bands and with different antennas. The effectiveness of the PWMS technique has always been proven in error-free (or quasi-error-free) scenarios, assuming that possible errors introduced by the technique itself are independent on the typical sources of measurement uncertainty.**

In this paper, we investigate for the first time the sensibility of the method wrt one of this error source included in the 18-terms lists considered by the measurement community as an exhaustive list of the NF errors: X and Y probe positioning errors. Such errors are typically unknown and random and are associated to the mechanical vibrations and/or backlash of the system. The investigation has been done considering actual measurements of a multi-beam reflector antenna with approximately 35 dBi gain. The test was performed at 22-33 GHz introducing uniformly distributed random errors in the range [0-1] mm, corresponding to λ/10 at 30 GHz.

I. INTRODUCTION

Planar Wide-Mesh Scanning (PWMS) [1]-[2] methodology can enable much faster measurements than standard implementations of Planar NF (PNF) technique based on dense, regular and equally-spaced NF sampling fulfilling Nyquist criteria [3]. PWMS instead is based on a non-redundant sampling scheme and is thus without loss of accuracy. An example of PWMS sample grid [4] is shown in Figure 1: meshes becomes wider and wider with the increase in their distance from the center of the scanning plane. The scanning grid can be defined based simply on the dimensions of the antenna.

The PWMS approach has been applied to different types of antennas, such as telecommunication Ku-band antennas [4] and V band Standard Gain Horn [5]. The non-redundant scanning has been validated also for spherical measurements [6] with a Galileo navigation antenna [7]. In [8], the echo reduction benefits of the optimal sampling interpolation expansion have been applied to PNF measurements. In the above-mentioned examples, the effectiveness of the PWMS technique has always been proven in error-free (or quasi-error-free) scenarios, where it was assumed that possible errors introduced by the technique itself are independent on the typical sources of measurement uncertainty.

In this paper, the sensibility of the method with respect to one particular error source included in the 18-terms lists [9], considered by the measurement community as an exhaustive list, is investigated for the first time. The considered error source is the X and Y probe positioning errors which are random and depends on the mechanical vibrations and/or backlash of the system. Although in same cases such positioning errors can be retrieved, in the majority of the cases they are unknown. The investigation is carried out considering actual measurements of a multi-beam reflector antenna with approx. 35 dBi gain (MVG SR40-A offset reflector fed by two SH5000 dual ridge horns).

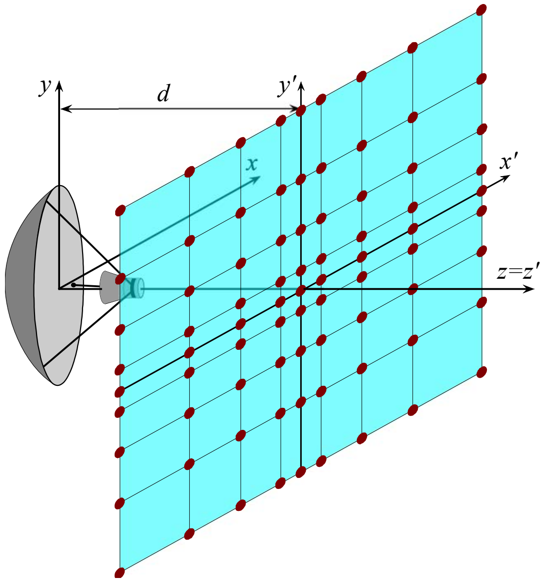

Figure 1. Example of PWMS acquisition grid

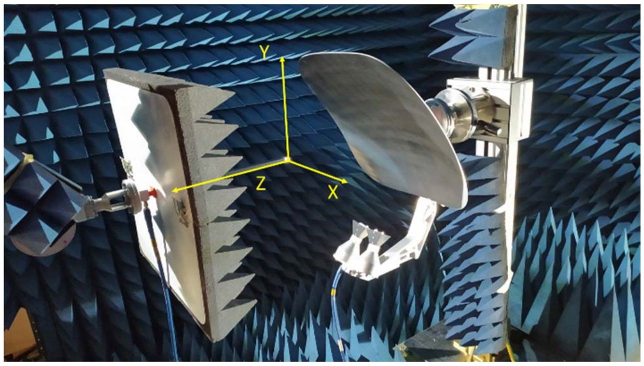

Figure 2. MVG SR40 offset reflector antenna fed by 2 SH5000 in the multipurpose NF facility at MVI premises. Robotic arm used for PNF acquisitions.

The AUT has been measured in a planar geometry implemented by a 6-axis robotic arm. The test is performed in the 22-33 GHz frequency range. A set of measurements has been performed introducing a uniformly distributed random error in the range [0-1] mm, corresponding to λ/10 at 30 GHz. Errors are considered unknown.

The paper is organized as follows: in Par. II, the description of the measurements is provided; in Par. III, the results of the investigation are shown; finally, the conclusions are summarized in Par. IV.

II. MEASUREMENT SCENARIO

A. *AUT and measurement set-up*

The AUT is the MVG SR40 offset reflector antenna in multifeed configuration, fed by 2 MVG SH5000 dual ridge horns. The SR40 is a X/Ku/Ka-band high gain reflector antenna, linearly polarized with high polarization purity and with low return loss. It is precision machined with stiff and robust mechanical design. The feeds are 2 dual ridge horn SH5000 characterized by stable gain performance and low VSWR. Figure 2 shows the AUT measured in the multipurpose NF measurement facility located at MVI premises (Pomezia, RM). As can be seen, a 6 axes Staubli robot is used to perform the planar NF acquisition. The scanning area is 700 x 700 mm in the X-axis (width) and in the Y-axis (height) while the distance from the aperture of the probe to the uppermost termination of the AUT is 131 mm. The frequency band is [22-33] GHz. Measurements have been performed using an Open-Ended Waveguide MVG OEW2200 (WR34) as probe and with stepped acquisition both in X and in Y axes. In this particular test case, the PWMS allows to achieve a down-sampling factor of 1.33 wrt standard measurements.

B. *Measurements with XY Probe positioning Errors*

The probe position errors are unknown and random and are associated to the mechanical vibrations and/or backlash of the system. This kind of error belongs to the 18-terms lists [9], considered by the measurement community as an exhaustive list of the NF errors. A set of measurements have been performed to emulate the presence of such errors to evaluate the robustness of the method. To this purpose, a uniformly distributed random positioning error in the range [0-1] mm, corresponding to λ/10 at 30 GHz, has been included in the measurements. The errors have been introduced on both traditional Nyquist-complaint standard grid (λ/2 sampling step) and on the non-redundant grid defined with the PWMS methodology. Errors are considered unknown.

III. RESULTS

As a first step, the influence of the XY probe positioning errors has been evaluated on the standard PNF measurements, as reported in par. A. Then, the effect in case of PWMS has been analysed, in terms of radiation patterns, peak gain, Equivalent Noise level (ENL) and iso-level contours, as shown in par. B.

A. *Standard acquisition*

The influence of the XY positioning errors on the standard acquisition is shown in Figure 3 and Figure 4 where the two main gain pattern cuts intersecting the peak of the main beam are shown in UV coordinates, at 30 GHz. The blue traces (Standard) are the FF obtained from the standard measurement without the positioning errors. The orange traces (Standard Repeat) are the FF obtained from the repetition of the standard measurements to evaluate the repeatability of the measurement after 4 days, without realignment and without RF drift correction of the instrument. Finally, the green traces (Standard XY errors) are the FF obtained from the standard measurement with the XY positioning errors.

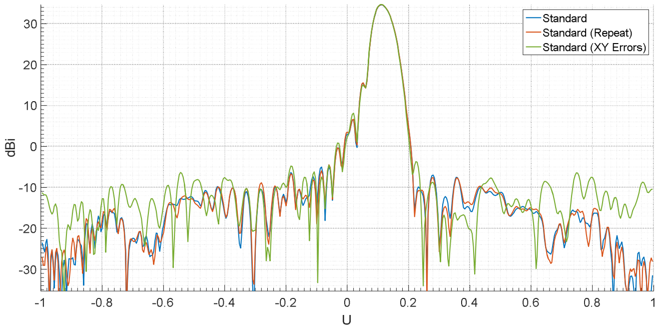

Figure 3. Comparison of copolar gain pattern cut at V=0 at 30 GHz (standard acquisition).

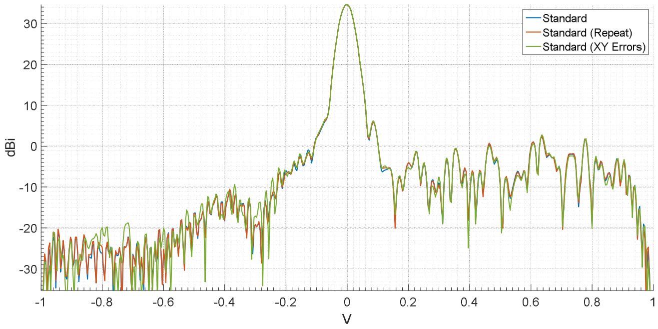

Figure 4. Comparison of copolar gain pattern cut at U=0.112 at 30 GHz (standard acquisition).

The agreement of the repeated measurement with the first one is very good, meaning that the alignment of the system is maintained, and no additional positioning errors are introduced. The effect of the intentionally introduced positioning errors is clearly visible in the sidelobes especially in the FF cut where the beam is tilted (V=0). The main beam is instead not affected by the introduced errors.

B. *PWMS acquisition*

The effect of the XY positioning errors is evaluated below in case of PWMS. As in the previous comparison, Figure 5 and Figure 6 shows the two main UV gain pattern cuts intersecting the peak of the main beam at 30 GHz obtained with the wide-mesh scanning. The blue traces are the patterns from the wide-mesh acquisition without positioning errors while the orange ones are the patterns from the wide-mesh acquisition with XY positioning errors.

The probe XY positioning errors introduce disagreements on the sidelobes in the cut V=0. These errors are comparable to what happens in the standard measurement. Neither in this case, the main beam is affected by the introduced errors.

Figure 7 shows the comparison on the boresight realized gain over frequency for each performed measurement. The agreement is very good for all cases confirming the agreement on the main lobe seen in the radiation patterns shown in the previous paragraph.

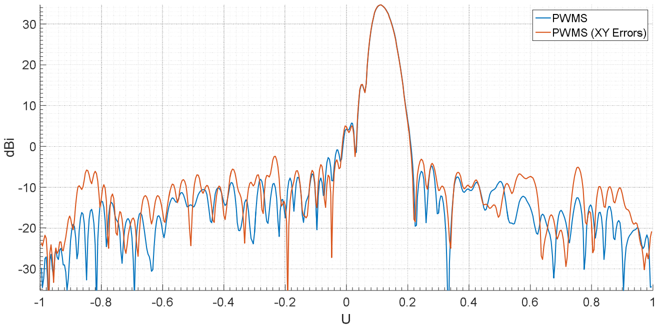

Figure 5. Comparison of copolar gain pattern cut at V=0 at 30 GHz (wide-mesh acquisition).

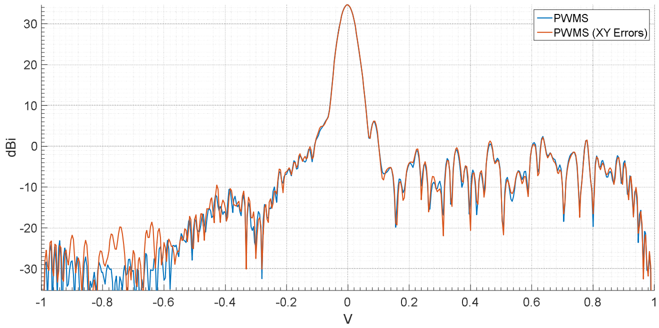

Figure 6. Comparison of copolar gain pattern cut at U=0.112 at 30 GHz (wide-mesh acquisition).

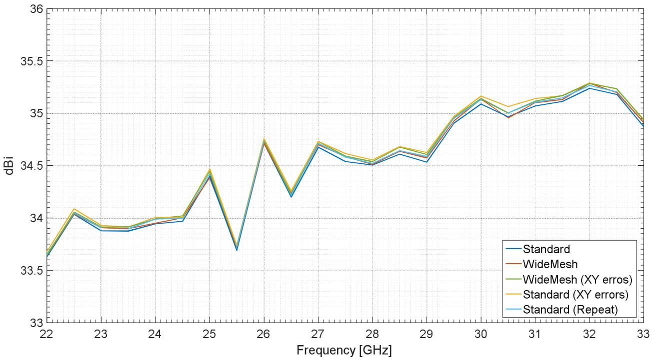

Figure 7. Comparison of peak realized gain over frequency for each performed measurement (standard and PWMS).

The effect of probe positioning error has been evaluated also computing the Equivalent Noise Level (ENL) [10] defined by the following equation

$$ENL = 20\log_{10}\left(RMSE\left|\frac{E(u,\mathrm{v}) - \tilde{E}(u,\mathrm{v})}{E(u,\mathrm{v})_{MAX}}\right|\right)$$

where $E(u,\mathrm{v})$ is the reference pattern and $\tilde{E}(u,\mathrm{v})$ is the test pattern. Different ENLs obtained by comparing different pattern on the whole hemispherical gain pattern are shown in Figure 8. The ENL shown in orange is obtained considering the standard PNF measurement as reference and the repeated standard measurement as test. The very low value confirms the good repeatability of the measurements (e.g. possible positioning errors, not intentionally introduced, are negligible). In the ENL shown in green, the reference is still standard PNF measurement and the test is the standard measurement with the introduced positioning errors. These error levels are approx. 5 to 9 dB higher than the ones obtained in the repeatability test. Finally, the ENL shown in yellow is obtained considering the wide-mesh measurement without and with positioning error respectively as reference and test patterns. As can be seen, the error level obtained with the perturbed wide-mesh acquisition is comparable with the one obtained with the perturbed standard acquisition. It can be concluded that the PWMS technique is robust against the XY positioning errors.

Figure 9 shows the isolevel contour shapes at 30 GHz, at different levels, for the co-polar and cx-polar components in UV coordinates for the standard acquisition (blue traces) and wide-mesh acquisitions without and with XY positioning errors (orange and green traces respectively). The good agreement shown in these plots further confirms the robustness of the method.

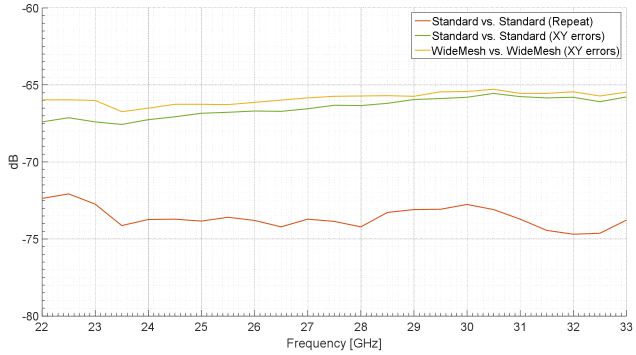

Figure 8. Comparison of the ENL computed on the gain pattern over 22-33 GHz band.

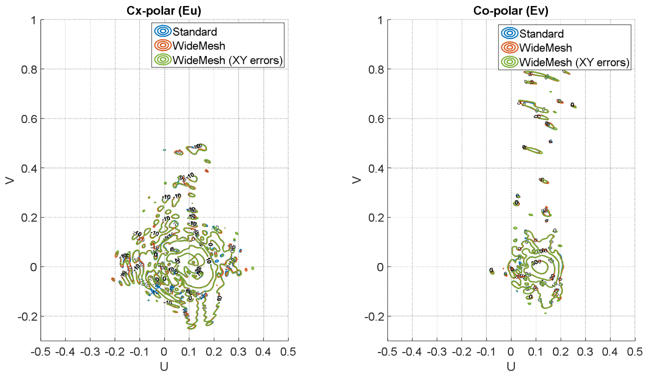

Figure 9. Comparison of isolevel contours for the co-polar (right) and cx-polar (left) components at 30 GHz.

IV. CONCLUSIONS

The planar wide-mesh scanning (PWMS) methodology is based on non-redundant scanning schemes allowing faster measurements than classical Nyquist-compliant acquisitions. In previous activities, it has been experimentally verified that the methodology has no accuracy loss. In this paper, we have investigated for the first time the sensibility of the PWMS wrt X and Y probe positioning errors. Such errors are unknown and random and are associated to the mechanical vibrations and/or backlash of the system. The investigation has been done considering actual measurements of a multi-beam reflector antenna MVG SR 40 with approximately 35 dBi gain at 22-33 GHz, introducing a uniformly distributed random error in the range [0-1] mm, corresponding to λ/10 at 30 GHz. It has been shown that both in the classical and PWMS approaches the main beam is basically not affected by the introduced errors. The sidelobes are instead affected by such errors especially in the pattern cut where the beam is tilted. Such error levels obtained with the classical approach are comparable to those obtained with the PWMS approach, meaning that the latter is stable wrt such type of perturbations.

ACKNOWLEDGEMENT

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