Near Field Measurements with Radically Reduced Sampling Requirement through Numerically Defined Expansion Functions

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***Abstract*— We present an antenna measurement methodology requiring a radically reduced number of field samples than the standard Nyquist-based theory maintaining a comparable accuracy.**

Numerical simulations and partial knowledge of the geometry of the Antenna Under Test are combined to build a set of numerically defined expansion functions. The method uses basic knowledge of the antenna and the assumption that scattering from large surfaces can be predicted accurately by numerical tools. Areas of the antenna such as feeding structures are treated as unknown and represented by equivalent electric and magnetic currents on a conformal surface. In this way, the complexity, and thus the number of unknowns, is dramatically reduced with respect to the full problem for most antennas.

The method can be employed in standard sampling ranges. The methodology is validated with in spherical and in planar near field geometries considering a reflector antenna (the MVG SR40 fed by dual ridges horns) in single- and multi-feed configurations, respectively at 18 and 30 GHz. Patterns obtained with down-sampled fast approach are compared to standard measurements. Down-sampling factors up to 8 are achieved maintaining very high correlation levels with standard techniques.

I. Introduction

This paper presents a methodology to perform antenna measurement requiring a radically lower number of field samples than the standard Nyquist-based theory [1] maintaining a comparable accuracy.

The technique is based on numerically defined basis functions which can be built by combining simulations and partial knowledge of the geometry of the Antenna Under Test (AUT). Such combination is based on the partial knowledge of the AUT and on the assumption that scattering from large surfaces can be predicted accurately by numerical tools. The basis functions representing the full antenna are used to interpolate a radically reduced set of measured samples to a fine regular grid of Near Field (NF) samples in standard geometries. Regular NF to Far Field (FF) transformation techniques [2] are then employed to determine the FF. The sampling reduction is evaluated compared to a regular sampling on standard Nyquist-complaint grids.

In [3], asymptotic simulation tools were used to build the numerical basis. In this paper, methods based on Surface Integral Equations (SIEs) are used to compute currents and fields. The currents induced on the antenna structure by each elementary source are computed and used to evaluate the radiated field. Both electric and magnetic elementary sources are placed around the antenna. The SIE problems use a fast algorithm to evaluate matrix-vector products. In this way, the complexity, and thus the number of unknowns, is dramatically reduced with respect to the full problem for most antennas allowing to achieve a down-sampling factor.

The method can be employed in standard sampling ranges. The fast antenna measurement can be in fact performed on a regular grid which is undersampled with respect to the Nyquist criteria. The time reduction factor is the same as the down-sampling factor in case of stepped acquisition.

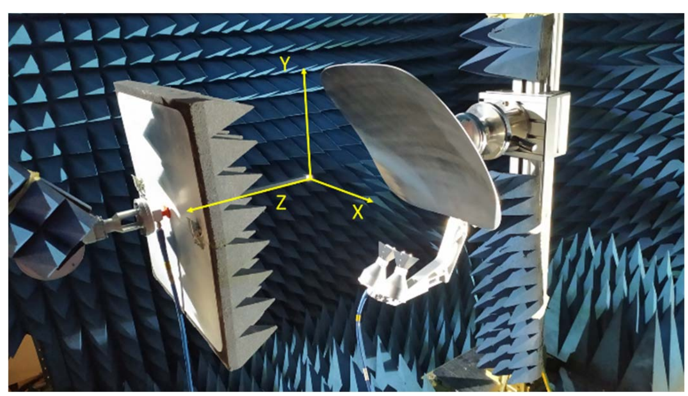

Figure 1. MVG SR40-A offset reflector in multi-feed configuration during PNF measurements in the multipurpose facility at MVI premises.

In this paper, we present the methodology and its validation with both Planar (PNF) and Spherical Near Field (SNF) acquisitions. A reflector antenna (MVG SR40) fed by a dual ridge horn (the SH4000) at 18 GHz is considered to validate the methodology in SNF geometry. The same reflector antenna in a multi-feed configurations (using two SH5000 dual-ridge horns) at 30 GHz is instead considered to perform the validation in PNF geometry (see Figure 1). The accuracy of the proposed fast methodology is presented comparing radiation patterns and computing the Equivalent Noise Level (ENL) wrt to traditional measurements. Down-sampling factors up to 8 are achieved maintaining very high correlation levels with standard techniques.

The paper is organized as follows: in Par. II, we give an overview of the methodology; in par. III the validation campaign is presented; in Par. IV the details of the numerical modelling are shown; in Par. V the results for PNF measurements are shown while the results for SNF acquisitions are shown in Par. VI; finally, the conclusions are summarized in Par. VII.

II. METHODOLOGY

We denote with $E(r)$, the field radiated by the antenna at point r. We call it *target field.* We want to express it as a linear combination of N basis function $f_n(r)$. With

$$\tilde{E}(r) = \sum_n \alpha_n f_n(r), \qquad (1)$$

we want

$$E(r) = \tilde{E}(r) \qquad (2)$$

Given L samples of the target field

$$E_l = E_l(r_l) \qquad (3)$$

we enforce (2) on these points

$$E_l = \sum_n \alpha_n f_n(r_l) \qquad (4)$$

and solve the linear system of equations resulting from (4) to determine to coefficients α_n . The linear combination determined solving (3) is called *reconstructed field*. As the basis functions are easy to evaluate at arbitrary points, once the coefficients have been established, the reconstructed field can be evaluated everywhereIf the basis functions are the vector spherical harmonics, the number of unknowns to be computed are approximately the same of the minimum sampling imposed by the Nyquist criteria, hence no down-sampling can be obtained [2].

In the proposed method, the basis functions are built considering a surface enclosing the main radiating part (i.e. the antenna feed) and evaluating numerically the field radiated by each elementary source in the presence of the reflector (see Figure 2).

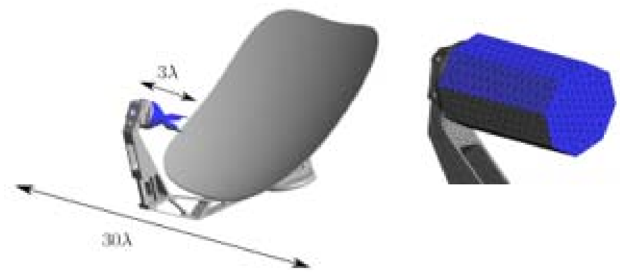

Figure 2. Example of reflector antenna where the feed (in blue, on the left) is enclosed in a surface (in blue, on the right) to generate the basis functions.

We apply the surface integral equation formulation (the Method of Moments) to compute currents and fields [4]. We generate triangular meshes on the surface surrounding the feed and on the one representing the reflector, to use classical Rao Wilton Glisson (RWG) functions [5]. We compute the current induced on the platform by each elementary source and use that to evaluate the radiated field. Both electric and magnetic elementary sources are placed around the antenna feed, and the MoM problems are solved with an iterative method (GMRES) coupled with a fast algorithm to evaluate matrix-vector products [6]. As the independent elementary sources are placed only on a surface enclosing the feed (not on the surface enclosing the whole antenna), some residual discrepancy between the target and the reconstructed field is unavoidable. These discrepancies will be analyzed in view of the reduced number of sample points.

III. VALIDATION CAMPAIGN

The AUT used for the validation is the MVG SR40-A offset reflector antenna. The SR40-A is a X/Ku/Ka-band high gain reflector antenna with a rim of 400x400 mm and a F/D of 0.5 [7]. It is precision machined with stiff and robust mechanical design.

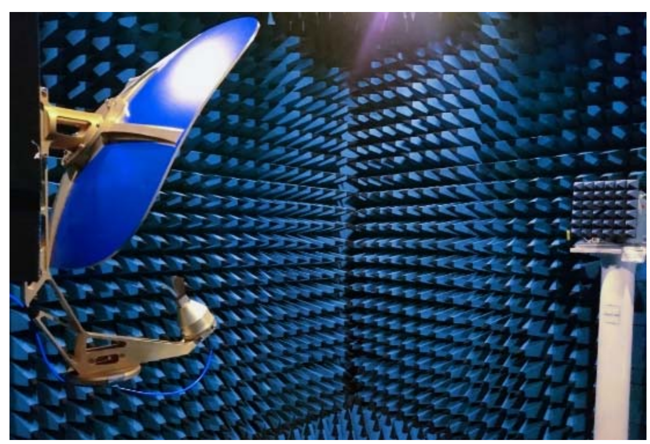

Figure 3. MVG SR40-A fed by a SH4000 dual-ridge horn in the SNF range at Politecnico di Torino.

The reflector has been measured at 18 GHz in single feed configuration, with an SH4000 dual ridge horn in the Spherical Near Field (SNF) range installed in the anechoic chamber of Politecnico di Torino, as visible in Figure 3. Planar measurements in multi-feed configurations, with two SH5000, have been performed at 30 GHz in the multipurpose NF measurement facility located at MVI premises in Pomezia, as shown in Figure 1. In such case the PNF acquisition have been performed with a 6-axis robotic arm.

In both systems, measurements have been performed in the standard Nyquist-compliant way and with the methodology proposed in this paper.

IV. Modelling and Down-Sampling factors

The technique requires a mesh of a box enclosing the feed and a mesh of the surface of the scattering region. To speed up the computation, we consider as the scatterer only the inner surface of the parabolic reflector SR40, discarding the supporting structure. This choice proved to give a good trade-off between results accuracy and computational burden.

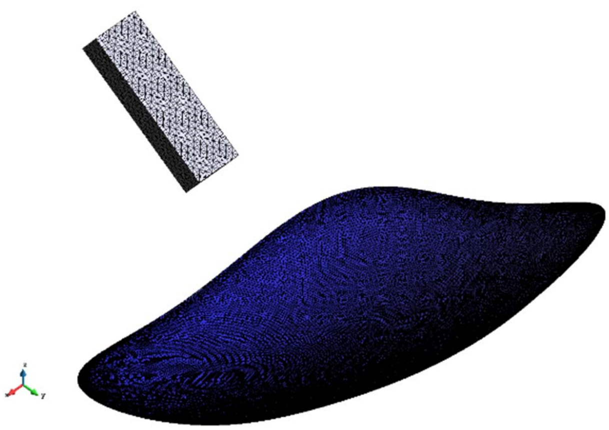

Figure 4. Meshes at 30 GHz of the surface enclosing the 2 feeds SH5000 (gray) and of the inner surface of the reflector (blue) for the PNF measurements.

In the computation, we consider as the scatterer only the inner surface of the parabolic reflector SR40, discarding the supporting structure. This choice proved to give a good trade-off between results accuracy and computational burden.

A. *Planar Near Field Measurements*

For the PNF measurements, where the reflector has been used at 30 GHz in multifeed configuration, the mesh of the feed has 3104 triangles, resulting in 9312 unknowns, while the mesh of the reflector has 62110 triangles as visible in Figure 4.

Two different decimated sets of the standard PNF measurements have been considered. In particular:

- Considering half of the samples along the x-axis (2x1downsampling, one every second sample is kept);
- Considering one third of the samples along the x-axis (3x1downsampling, one every third sample is kept).

B. *Spherical Near Field Measurements*

For the SNF acquisitions, where the reflector has been used at 18 GHz in single feed configuration, the mesh enclosing the feed has 1940 triangles, resulting in 5820 unknowns, while the mesh of the reflector has 22528 triangles, as shown in Figure 5.

Two cases have been analysed:

- Down-sampling factor of 6 (2x3): 2-time in θ (Δθ=2.0°) and 3-time in φ (Δφ= 3.0°);
- Down-sampling factor of 8 (2x4): 2-time in θ (Δθ=2.0°) and 4-time in φ (Δφ= 4.0°);

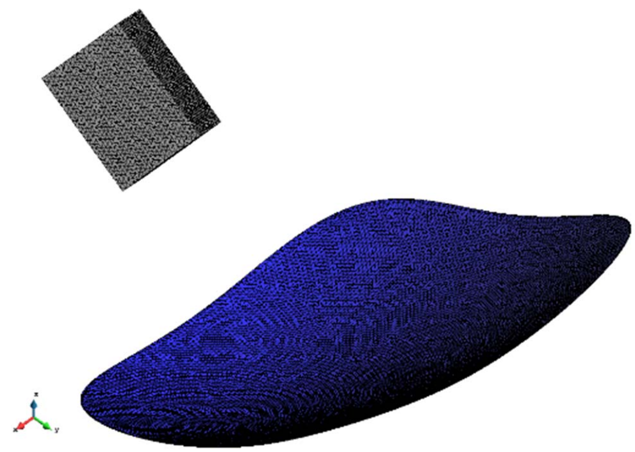

Figure 5. Meshes at 18 GHz of the surface enclosing the feed SH4000 (gray) and of the inner surface of the reflector (blue) for the SNF measurements.

V. PNF Measurements Results

This Section reports the results for PNF measurements considering a down-sampling factor of 2 and 3. Patterns are plotted in UV coordinates, at U=0.112 (Figure 6) and V=0 (Figure 7). The blue curves (Standard) represents the FF obtained with classical NF to FF transformation. The orange curves and green represent the FF obtained with the fast technique with down-sampling factor of 2 and 3, respectively. The agreement of the co-polar and cross-polar pattern in the main beam region is very good for both the presented cuts. In the V=0 plane the agreement outside the main beam region is also good, especially for the 2x1 decimated scenario. Some discrepancies are instead observed in the sidelobes of the U=0.112 cuts. These are probably due to truncation of the scanning area and/or simplification of the antenna modelling used to expand the measured down-sampled data.

Table I shows the comparison on the peak directivity and peak realized gain at 30 GHz for the standard measurement and the two decimated measurements processed with the fast methodology. The ENL [8], computed on all gain cuts on the full pattern corresponding to a θ cone ranging from –90° to 90°, is also reported in the same table. The reference pattern is represented by the standard measurement. The low values of ENL confirms the agreement visible in the radiation patterns.

Figure 6. PNF measurements: Vertical (U=0.112) co- (top) and cx-polar (bottom) gain pattern cuts comparison at 30 GHz.

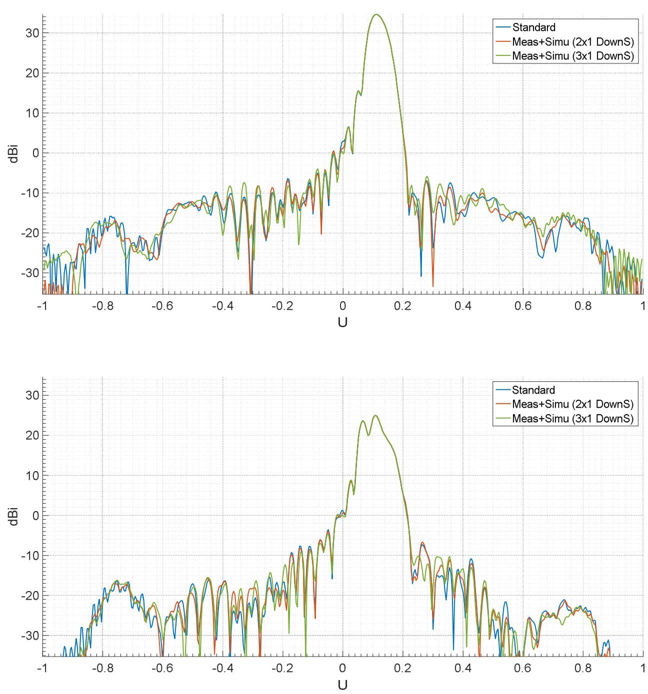

Figure 7. PNF measurements: Horizontal (V=0) co- (top) and cx-polar (bottom) gain pattern cuts comparison at 30 GHz.

TABLE I. PEAK REALIZED GAIN, DIRECTIVITY AND EQUIVALENT NOISE LEVEL AT 30 GHZ FOR THE PNF MEASUREMENTS.

Down-sampling	**Peak Realized Gain [dB]**	**Peak Directivity [dB]**	**ENL [dB]**
1 (Reference)	35.1	36.1	-
2	35.1	36.1	-61.3
3	35.1	36.2	-59.3

VI. SNF MEASUREMENTS RESULTS

This section reports the results for SNF measurements considering a down-sampling factor of 6 and 8 with respect to the Nyquist criteria.

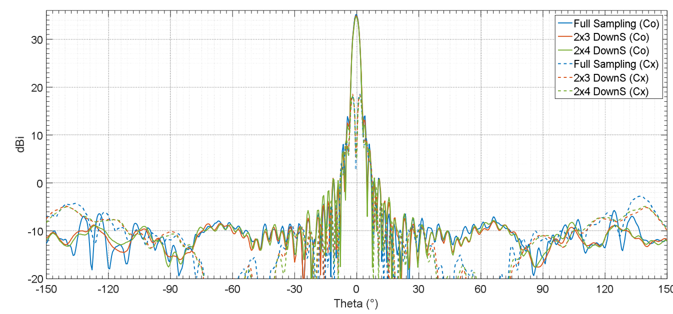

Figure 8. SNF measurements: horizontal gain pattern cut comparison; co- and cx-polar components at 18 GHz.

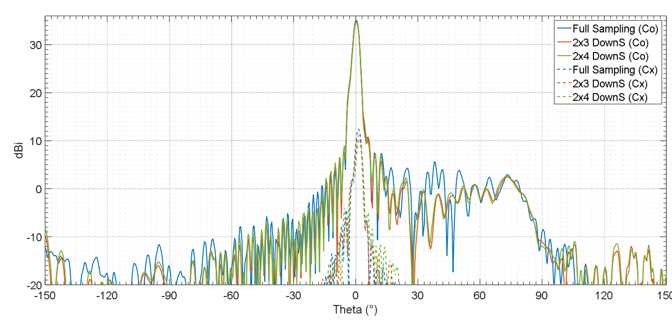

Figure 9. SNF measurements: vertical gain pattern cut comparison; co- and cx-polar components at 18 GHz.

Figure 8 and Figure 9 show the co- and cx-polar gain radiation pattern comparison at 18 GHz, respectively for the horizontal and vertical plane. The blue curves (full-sampling, reference) represents the FF obtained with classical NF to FF transformation. The red curves (2x3 DownS) represents the FF obtained with the fast technique with down-sampling factor=6. The green curve (2x4 DownS) represents the FF obtained with the fast technique with down-sampling factor=8. The agreement of the co-polar and cross-polar pattern in the main beam region is very good for both the presented down-sampled scenario. Some discrepancies are instead observed in the sidelobes of the pattern. These are probably due to simplification of the antenna modelling used to expand the measured down-sampled data.

Table II shows the comparison on the peak directivity and peak realized gain at 18 GHz for standard measurement and the two decimated measurements processed with the fast methodology. In the same table, the ENL computed on all gain cuts on the full pattern corresponding to a θ cone ranging from –180° to 180°, is also reported. The reference pattern is represented by the standard measurement. The low error levels confirms the agreement visible in the radiation patterns.

TABLE II. PEAK REALIZED GAIN, DIRECTIVITY AND EQUIVALENT NOISE LEVEL AT 18 GHZ FOR THE SNF MEASUREMENTS.

Down-sampling	Peak Realized Gain [dB]	Peak Directivity [dB]	ENL [dB]
1 (Reference)	35.1	35.6	-
6	34.8	35.6	-51.8
8	34.6	35.6	-47.5

Patterns obtained from the PNF measurements at 30 GHz with down-sampling factors of 2 and 3 show a very good correlation in the main beam region in both planes and, for V=0 plane, also outside the main beam region. The low values of ENL confirm the agreement visible in the radiation patterns and in the peak gain and directivity.

Similarly, patterns obtained from the SNF measurements at 18 GHz with down-sampling factors of 6 and 8 show a very good agreement in the main beam region for both the presented down-sampled scenarios. Some discrepancies are instead observed in the sidelobes of the pattern probably due to simplification of the antenna modelling used to expand the measured down-sampled data. Peak gain and directivity obtained with the fast methodology are very similar to results achieved with standard measurements. Equivalent noise levels are also in this case extremely low.

VII. CONCLUSIONS

In this paper an antenna measurement methodology requiring for a radically reduced number of field samples than the standard Nyquist-based theory maintaining a comparable accuracy has been shown. The methodology is based on the combination of numerical simulations and partial knowledge of the geometry of the AUT to build a set of numerical basis functions: areas of the antenna such as feeding structures are treated as unknown and represented by equivalent electric and magnetic currents on a conformal surface. In this way, the complexity, and thus the number of unknowns, is dramatically reduced with respect to the full problem for most antennas.

The methodology can be applied to any standard range and the reduction of samples corresponds directly to the time reduction in case of stepped acquisition. In case of combined stepped on-the-fly acquisition the time reduction factor might be lower than the down-sampling factor as the continuous motion already gives its own improvement

The paper reported the description and the validation of the methodology considering spherical and planar near field acquisitions performed at 18 and 30 GHz, respectively. The AUT was the MVG SR40-A reflector antenna in single feed (SH4000) and multi-feed (using two SH5000) configurations.

Good correlation with standard measurements has been shown achieving down-sampling factors up to 8.

ACKNOWLEDGEMENT

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