Reduced Sampling in NF Antenna Measurement Using Numerical Defined Expansion Functions

M. A.Saporetti[1,] F. Saccardi[1], L. J. Foged[1], J. Zackrisson[2], M. Righero[2], G.Giordanengo[2], G. Vecchi[4], D. Trenta[5]

[1] Microwave Vision Italy SRL, Via dei Castelli Romani,59,
Pomezia (RM), Italy, (maria.saporetti, francesco.saccardi,
lars.foged)@ mvg-world.com

RUAG Space AB,
SE-405 15 Göteborg, Sweden
Jan.Zackrisson@ruag.com

[3] Istituto Superiore Mario Boella, Via Pier Carlo Boggio,
61, 10138 Torino (TO), Italy, (righero,
giordanengo)@ismb.it

[4]Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129
Torino (TO), Italy, giuseppe.vecchi@polito.it

[5]European Space Agency, ESTEC, The Netherlands, Damiano.Trenta@esa.int

***Abstract*— This paper presents an advanced RF test methodology for time efficient antenna testing. The measured field is projected over precomputed basis functions obtained with simulations of the antenna platform using fast ray-tracing methods [1], [2]. The source antenna is treated as a black box and no material or dimensional information is needed. As the number of basis functions is significantly reduced with respect to the Nyquist criteria, the number of NF measurement points is equally reduced, or down-sampled, leading to a significant saving in overall measurement time. The methodology is particular efficient for relatively small antennas installed on large platforms. The new methodology performs faster antenna measurements, while maintaining a certain level of confidence. It can be directly implemented, without hardware changes in existing spherical near field (SNF) measurements range.**

In this paper we introduce the new methodology for the first time. The method has been validated using actual measurements of a small X-band antenna on a large satellite mock-up. The achievable measurement accuracy is investigated by determining the correlation with traditional measurements through the calculation of the Equivalent Noise Level (ENL). The new methodology achieves a sampling reduction, or down sampling factor of 5-9 in the tested scenarios, maintaining good accuracy levels with respect to standard measurement. The new methodology is highly applicable for verification testing due to the significant measurement time savings, with a moderate trade-off on measurement accuracy.

***Index Terms*—antenna, spherical near field, simulations, measurement.**

I. INTRODUCTION

The increasing complexity and stringent performances required in RF instruments and payloads demand more and more that RF functional verification be performed on the integrated satellite under the most realistic operational conditions. Near field (NF) methods are very attractive techniques for such testing. However, in standard NF testing of small antennas on large platforms, the minimum number of samples is determined by the size of the entire platform. This requirement leads to very long testing times even for smaller antennas.

In this paper, we present an advanced RF test methodology that aims at minimizing the duration and the cost of both preliminary preparation and test campaigns. The time efficiency with respect to traditional measurements is achieved through the exploitation of measurements and simulations combined together. The methodology allows to perform fast antenna measurements in the target environment applicable to Antenna Integration and Test Verification in a generic testing scenario in traditional near field measurements ranges while maintaining a certain level of confidence with respect to a standard measurement.

The background of this activity is represented by ESA project "Innovative RF Testing approaches for reduced antenna/payload AIT/AIV" ([3][4]). The antenna was numerically modelled to build an expansion basis; a robotic arm "sniffer" system was used to sample the radiated near field of the Antenna Under Test (AUT); a model-based interpolation algorithm was developed to reconstruct both Near and Far Field from heavily under-sampled near-field data. The approach was iterative with an optimal sampling to determine the "hot" field points with the maximum significance for the expansion.

The workflow of this new activity is presented in Fig.1.

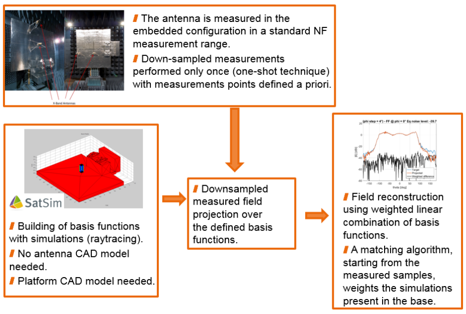

Fig. 1. Workflow of the fast test methodology

The down-sampled measurements can be performed in traditional spherical NF (SNF) measurement ranges. The measured field is projected over precomputed basis functions obtained with simulations based on raytracer methods [1] using SatSim SW [2]. No electromagnetic (EM) or mechanical information about the design of the antenna is needed but only an approximate CAD model of the platform. The reduced number of measured points are used to compute the weighting coefficients to reconstruct the complete field using weighted linear combination of basis functions. Such coefficients are determined imposing matching between the reconstructed field and the field radiated by the AUT.

Based on the considerations underlined above, the methodology proves to be particularly suitable for relatively small antennas installed on large platforms. It has been validated using actual measurements of a small X-band antenna on a large satellite mock-up.

The paper is organized as follows: in Par. II, we give a brief overview of the method; in par. III the validation with actual measurements is presented; finally, in par. IV conclusions are drawn.

II. METHOD OVERVIEW

The radiating source is modelled using a small number of EM sources placed on a volume enclosing it. No electromagnetic (EM) or mechanical information about the design of the antenna is needed, avoiding any intellectual property issues. No sources are located inside the box. The best trade-off between computational time and results accuracy, is obtained placing, with a spacing equal to λ/2, 4 sources on each point: 2 short electric dipoles and 2 short magnetic dipoles. The box dimensions include the antenna envelope plus a small margin (λ/2). The dipoles are oriented along the tangential directions; there are no dipoles oriented along the orthogonal direction. That means that, for example, on the upper face of the box (i.e. external normal pointing towards increasing Z), for each point there will be:

- 1 electric dipole oriented along X axis;
- 1 electric dipole oriented along Y axis;
- 1 magnetic dipole oriented along X axis;
- 1magnetic dipole oriented along Y axis.

The scattering part is analyzed with raytracing methods (SatSim software) on an approximate CAD model of the platform. Full-wave methods (e.g. Method of Moments [5]) have been also analyzed to compute the basis and compared with raytracer, but have been discarded since the increase in computational time, even using fast solvers [6], is too large with respect to the achieved improvement in the accuracy results.

For each elementary source (small dipole), say $n, n = 1, \dots, N$, we evaluate the radiated field both on a grid of the measurement surface where NF samples will be acquired in the measurement phase, ψ_n^{NF}, and in the FF, ψ_n^{FF}.

The NF fields radiated by each elementary source are linearly combined to fit the few NF measured samples $E^{meas}(r_m)\ m = 1, \dots, M$, in a least square sense.

$$\sum_{n=1}^{N} a_n \psi_n^{NF}(r_m) = E^{meas}(r_m)\ m = 1, \dots, M$$

The weights a_n determined with this NF fitting are then used to linearly combine the FF fields radiated by each elementary source, ψ_n^{FF}, and the resulting combination approximates the FF radiated by the antenna mounted on the platform.

The whole procedure amounts then to a NF to FF transformation, which experimental tests prove to work also with data undersampled with respect to the Nyquist criterion. Best results are obtained when the different measured polarizations are threated independently.

III. VALIDATION

The methodology has been validated with actual measurements of a small X-band antenna installed on a large satellite mock-up, shown in Fig.2 and performed by RUAG. This test case has been chosen in order to show the advantage of the proposed methodology in scenarios including small antennas installed on large platform where, with traditional measurements, the minimum number of samples is determined by the size of the entire satellite. The mock-up maximum dimension (diagonal) is equal to 85 λ at 8.2 GHz resulting in a very small sampling step with standard measurements (i.e. fulfilling Nyquist criteria) equal to 0.5°leading to a large number of measurement samples.

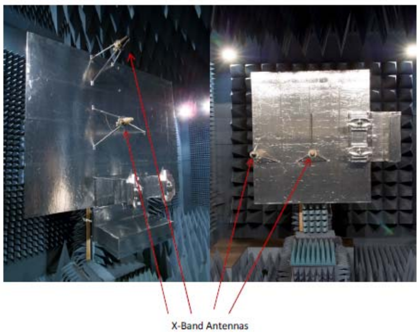

Fig. 2. Test case used for the validation: X-band antennas installed on large mock-up satellite

The X-band antenna dimensions are shown in Fig.3, while in Fig.4 the set-up for the basis functions building using SatSim SW is shown: radiating source on the approximate CAD model of the mock-up. The number of basis function is equal to 1920 and raytracer takes 1.5 min for each source, while Mom would take 9 min per source.

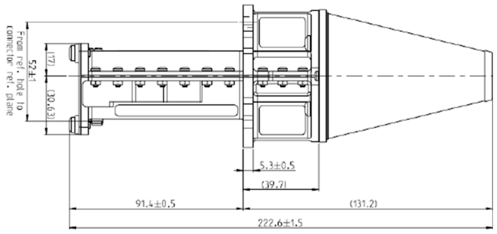

Fig. 3. X-band antenna dimensions

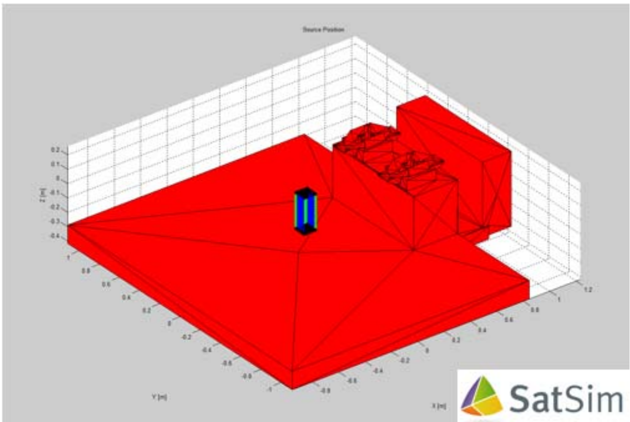

Fig. 4. Basis function building set-up for SatSim SW

Different down-sampling rate, with respect to Nyquist-compliant measurements, has been applied on different directions. In fact, the down-sampling along a certain axis can be more convenient than along the other direction depending on the characteristics of the measurement system. In a stepped φ-axis and "on-the-fly" ϑ-axis measurement system, the test time is proportional to number of φ cuts while the number of samples in each φ cut does not add a lot of extra time. The contrary results for a stepped ϑ -axis and "on-the-fly" system.

The reconstruction accuracy has been investigated by comparison of Far-Field patterns, achieved by standard Nyquist-compliant measurements, and by calculation of the Equivalent Noise Level (ENL).

In the following plots, the standard measurement is shown as "target", blue line, and the field obtained with the proposed methodology is shown as "projected", red line. The black curve is a weighted difference between the two patterns. The RMSE of the weighted difference is the Equivalent Noise Level [], also shown in the images.

Standard measurement time of such scenario is equal to 8.8 hours.

A. *Downsampling on φ-axis*

The results obtained applying a down-sampling factor of 9 on φ-axis, corresponding to a sampling step in φ equal to 4.5°, are shown in this section. Fig.5 and Fig.6 show, for the cuts φ=0° and φ=90°: the amplitude and phase of the right copolar component, standard measurement and field obtained with the proposed methodology; the weighted difference; the Equivalent Noise Level. The time needed for the down-sampled measurement, in a ϑ stepped system, would be equal to 4 hours, resulting in a time reduction of about 2.

B. *Downsampling on ϑ -axis*

Similarly to the previous section, for the cuts φ=0° and φ=90°, Fig.7 and Fig.8 show the results applying a down-sampling factor of 5 on ϑ -axis, corresponding to a sampling step in ϑ equal to 2.5°. The time needed for the down-sampled measurement, in a ϑ stepped system, would be equal to 1.7 hours, resulting in a time reduction of 5.

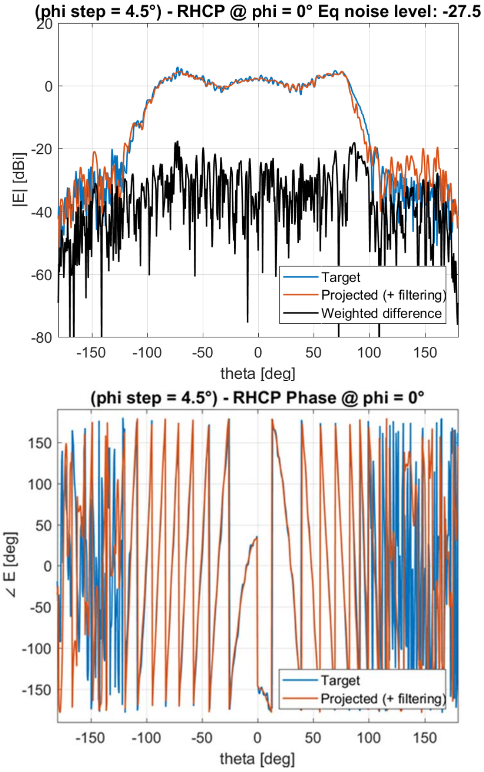

Fig. 5. Copolar component (RHCP) at phi=0°, amplitude and phase. "Target": standard measurements, "Projected": reconstruction using a sampling step in φ =4.5°, down-sampling φ factor equal to 9.

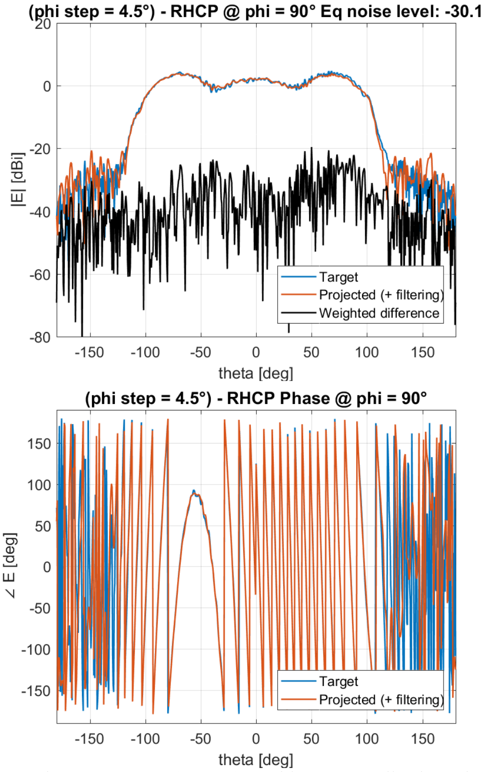

Fig. 6. Copolar component (RHCP) at phi=90°, amplitude and phase. "Target": standard measurements, "Projected": reconstrcution using a sampling step in φ =4.5°, down-sampling φ factor equal to 9.

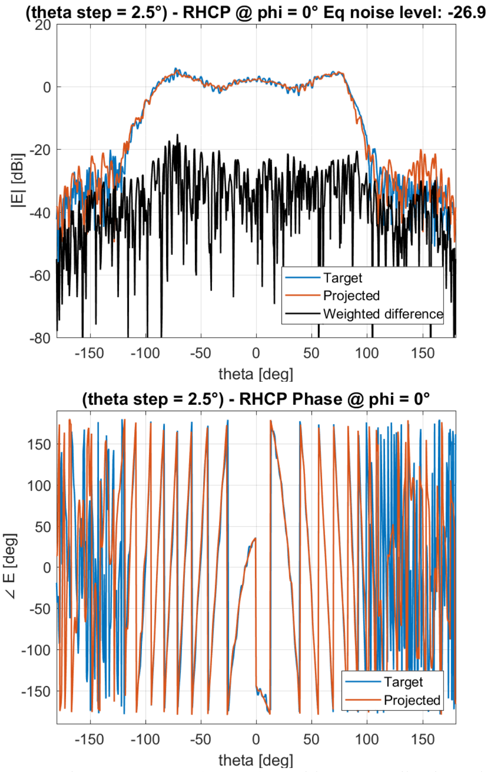

Fig. 7. Copolar component (RHCP) at phi=0°, amplitude and phase. “Target”: standard measurements, “Projected”: reconstrcution using a sampling step in ϑ =2.5°, down-sampling ϑ factor equal to 5.

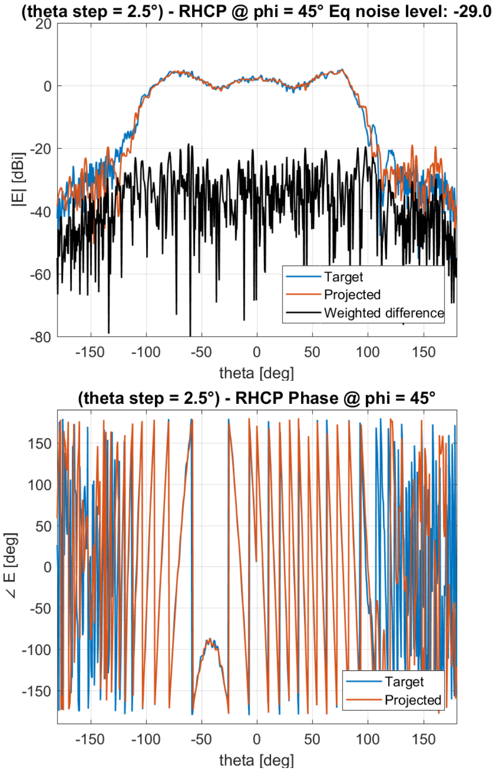

Fig. 8. Copolar component (RHCP) at phi=90°, amplitude and phase. “Target”: standard measurements, “Projected”: reconstrcution using a sampling step in ϑ =2.5°, down-sampling ϑ factor equal to 5.

IV. CONCLUSIONS

An advanced RF test methodology for time efficient antenna testing based on proper combination of numerical simulations and spherical NF down-sampled measurements has been presented. Measurements can be performed in traditional SNF measurements ranges with no additional hardware.

The down-sampled measured field is projected over precomputed basis functions obtained with simulations based on fast forward ray-tracing methods as implemented in SatSim SW. An accurate CAD model of the source antenna is not required, avoiding intellectual property issues. The methodology has been validated on a small antenna installed on a large satellite mock-up. Traditional techniques (fulfilling Nyquist criteria) have been compared to the new measurement methodology in terms of time and accuracy. The achieved down-sampling factor is 9 with a corresponding time reduction factor of 5 using the proposed methodology. A reasonable level of accuracy with respect to standard measurement has been achieved. The average correlation between traditional measurements and the proposed met methodology, determined as the Equivalent Noise Level is around -28 dB. This value is considered acceptable, also considering that it contains the measurement uncertainty of both methods. The significant measurement time saving at the expense of decreased accuracy makes the proposed met methodology highly suitable for verification testing.

A possible improvement to the method is an automatic procedure such as laser tracking or other optical system to determine the platform dimension. This is currently under investigation.

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