Full Characterization of Installed Antennas on Complex Platforms from Isolated Source Measurement

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Abstract—Any radiating system, of a practical electrical size, consisting of a small radiating device either positioned directly on or in close proximity to a larger scattering structure, like small antennas on satellites, planes, cars etc. can be completely characterized using different antenna measurement technologies [1]. A practical limit, to the full characterization of the radiating system by means of antenna measurements, is imposed on the maximum allowable physical dimensions and/or mass of the radiating system by the available measurement system.

A viable solution to characterize electrical large systems is to apply a domain decomposition technique in which only part of the system containing the actual antenna is determined by measurements. The remaining part of the entire system is determined by numerical modeling. In the case of small antennas and large scattering objects like reflectors and their feeds, the feed can be represented very efficiently using a spherical wave expansion, that can be derived from measured data or from modeling by a full wave solver and the entire system can be solved very accurately using MoM, PO or UTD modeling of the reflector [2]. The spherical wave expansion method as a domain decomposition technique is a very efficient technique when the scattering object is outside the minimum sphere surrounding the source. This restriction, poses a limit to this technique to a very small sub class of realistic problems.

An alternative domain decomposition technique is based on the equivalent current expansion of the measured isolated sources [11-12]. The advantage of the equivalent current technique over the spherical wave representation of the source is the freedom to have the source mounted more freely in any position and orientation wrt the large scattering structure.

This paper reviews the underlying techniques in conducting the measurements on the isolated source antennas and preparing the source data for accurate numerical representation.

Keywords— Near Field, Antenna Measurements, Spherical Wave Expansion, Inverse Problem, Equivalent Source, Verification.

I. Introduction

In order to overcome practical limits for the characterization of electrical large radiating system, such as physical dimensions, mass and time consumption, a domain decomposition technique can be adopted in which only the source region is characterized by actual measurements [2-10]. SatSim, is a commercially available implementation of a domain decomposition approach in which the numerical solver is based on fast ray-tracing. This approach has been proposed, implemented and validated in [3-9]. In the past implementation of this technique, the source have been represented by a spherical wave expansion of the measured antenna in stand-alone/isolation configuration. This approach has been shown to be very accurate when the scattering object is lying outside the minimum sphere of the source region.

In this paper, the source representation in SatSim has been extended so that the source antenna can be represented also by mean of an expansion based on equivalent currents (EQC) [11-12]. The accuracy of the numerical modeling has also been improved by introducing the grazing diffraction (or creeping waves) in the formulation. These modification allows the source antenna to be mounted more freely in any position and orientation wrt to the complex environment. The advantages of the EQC source representation is illustrated by measurements on a small source antenna on an electrically large satellite [6].

II. Antenna Measurements and Modelling of the Environment

SatSim provides an user-friendly way to accurately evaluate the behavior of an antenna in its final operational environment as a post-processing step of the actual measured antenna in stand-alone/isolation configuration. This can be achieved by combining numerical modeling of the environment based on ray-tracing in the form of fast Astigmatic Beam Tracing (ABT) and full sphere, Near-field or Far-field, measurements of the stand-alone real antenna. Hence, SatSim allows the user to assess the antenna interaction with a complex environment without resorting to extensive measurement campaign of the complete environment. The software can be seen as an efficient extension to the fast measurement capabilities of the MVG spherical near field measurement systems.

The Satsim software combines a real measurement of a source antenna with a numerical modeling of a complex environment where the antenna is going to be installed. In order to do that, the code is divided in two units:

- A first part, in which the propagation from the source location to the observation point is modeled by mean of an fast ray-tracing approach taking into account only the geometrical properties of the problem.
- A second part in which the final radiated field (associated to the source antenna in the complex environment) is evaluated starting from the source model of the antenna and the previously computed rays tracing. In this part the electromagnetic properties of the source (and material properties of the environment) are taken in to account.

It should be noted that the above working procedure allows to evaluate the behavior of different antennas with different characteristic or antennas operating at different frequencies (like wide band antenna) based on the same output from the first part. This is a direct consequence of the fact that only the geometrical properties of the structure are taken into account in the computation of rays in the first part.

A brief explanation of the propagation and source modeling is reported in the following paragraph.

A. Propagation Modeling

Ray tracing methods combined with Geometrical Optics (GO) and Uniform Theory of Diffraction (UTD) are frequently exploited to accurately and efficiently model the electromagnetic field propagation in electrically large and complex environments.

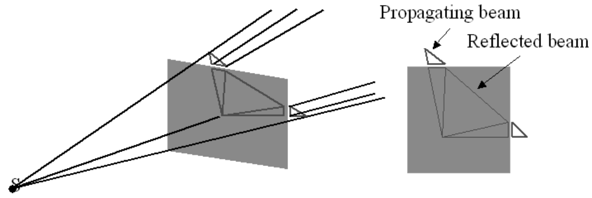

Figure 1. Beam division. The interaction of a beam with a obstacle create smaller beams and additional beams of reflections and diffractions.

The numerical ray tracing approach adopted within SatSim is based on the novel and computationally efficient Astigmatic Beam Tracing (ABT) method [4] and [5]. ABT is a forward ray tracer algorithm based on a complete partition of the 3-D space using beams. A beam is conceived as a bundle of rays that originate from a caustic. Beams generated from the source interact with the environment while they propagate. Each beam is divided in smaller beams and additional beams of reflections and diffractions when partly illuminating an obstacle as illustrated in Fig. 1.

This forward beam tracing implementation allows to model an unlimited number of diffractions and reflections from objects represented by polygonal flat surfaces with unprecedented speed and high accuracy [4]. A beam is propagated from the source until one of the three following conditions are met:

- The maximum order of interaction (determined by the user) is reached,
- The beam has left the computational domain,
- The beam hits the observation domain.

This implementation is well suited for parallel computation and has proven to be much faster and more accurate than conventional backward propagating ray tracer algorithms since the time consuming solution of non-linear equations is avoided.

During the forward beam propagation in the environment a beam-tree is generated and the pertinent information gathered in a data structure as shown in Fig. 2. From this data structure, the ray path is simply obtained by exploring the beam-tree from a leaf to the root. It should be noted that in the recent release of SatSim the grazing diffraction [13] has been introduced in order to improve the accuracy of the results. This is particularly important if the source is very close to the complex structure, like when the antenna is placed directly on the structure.

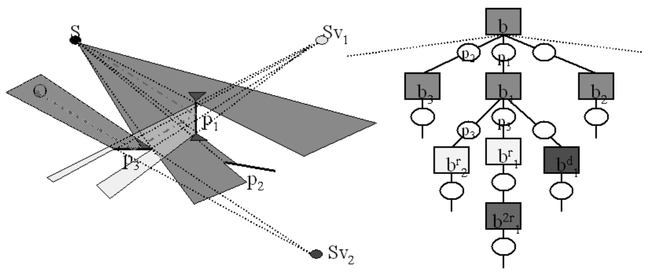

Figure 2. Beam tracing principle and beam tree structure. A new branch is added when a beam interacts with the structure.

B. *Source Modeling*

The real measured source can be represented within Satsim in two different ways:

- Spherical Wave Expansion (SWE);
- Equivalent Current expansion (EQC).

The spherical wave expansion is an efficient mathematical tool which allows to represent the field radiated by a source antenna outside its minimum sphere [10]. As a consequence it cannot be used if the source is too close to structure, thus it can be applied only to a limited number of practical test cases.

The equivalent current expansion (EQC) is an alternative way to represent a certain source antenna that allow to evaluate the radiated field even in the very proximity of the antenna surface. In this way the source antenna can be mounted more freely in any position wrt to the large structure. Furthermore, the EQC expansion can be used also as a spatial filter [12] in order to include only the desired contribution from the measured source filtering out possibly scattered and echo signals present in the measurement environment.

As described with more detail in [11] the equivalent current expansion is an implementation of the inverse source technique [14]. Such an expansion is currently used within another MVG software package called INSIGHT [15]. Starting from the measured NF or FF data, the equivalent electric (J) and magnetic (M) currents can be computed on an arbitrary shaped reconstruction surface. INSIGHT is a powerful multipurpose tool which can be used for antenna diagnostic, NF-to-FF transformation, measurement data extrapolation and interpolation, filtering/echo reduction (spatial filtering [12]) and, as in the present paper, in a post-processing step to create the source for numerical modeling.

III. VALIDATION CAMPAIGN

A comprehensive measurement campaign has been performed on a scaled model of a complete satellite including solar panels and reflectors, as shown in Fig. 3, in order to demonstrate the pertinent features and accuracy of the SatSim software on a realistic application example. The outcomes of the initial measurement campaign and numerical processing based on the spherical wave expansion representation of the source was reported in [6]. In the present paper the measurements performed have been reused in order to appreciate the improvements coming from the novel source modeling and last updates made to the software.

The modular satellite breadboard has been designed to obtain a multitude of different configurations by positioning different elements on the satellite body to emulate realistic scenarios of varying electrical complexity. The breadboard is shown in Fig. 3 during measurement in the SATIMO SG-64 multi-probe spherical near field range.

The Far Field of the source antenna measured in the SATIMO SG-64 is shown Fig. 5 for the main pattern cuts. Two configurations of the satellite breadboard have been considered for this validation as shown in Fig. 6.:

- Source centered on the satellite body (Test Case #1 – see Fig. 7);
- Source close to a corner of the satellite body (Test Case #2).

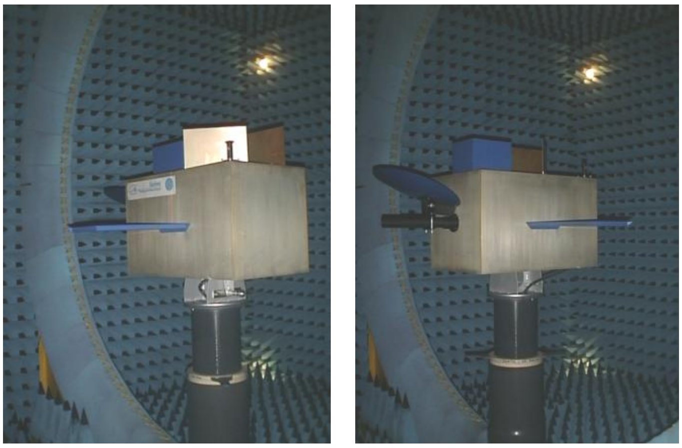

Figure 3. Modular satellite breadboard in the SG-64 facility during the validation measurement campaign.

The radiating element for the validation measurements is a dual linear polarized square patch antenna operating at 5GHz shown in Fig. 4. The patch is printed on a dielectric substrate having a thickness of h=1.524 mm. The ground plane is a square plate of 30x30 mm and the radiating element is a square metallization of 14.6x14.6 mm.

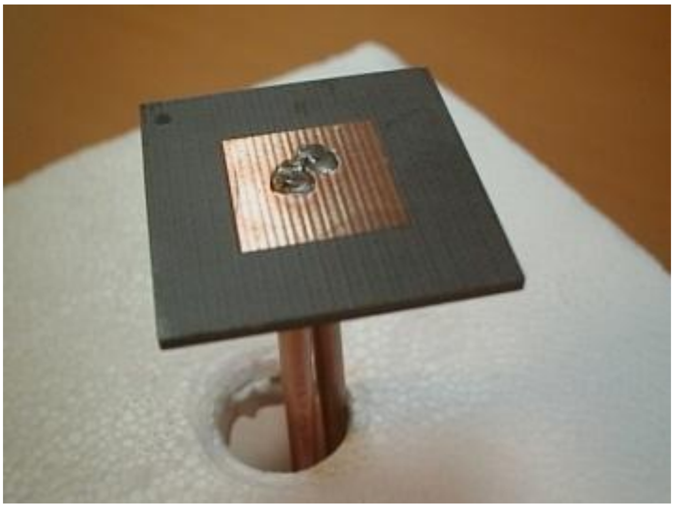

Figure 4. Dual polarised square patch antenna used as source in the validation campaign.

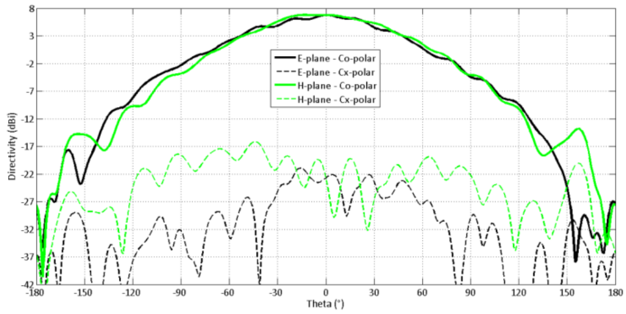

Figure 5. Measured principal plane farfield cuts of the Patch antenna in isolated configuration.

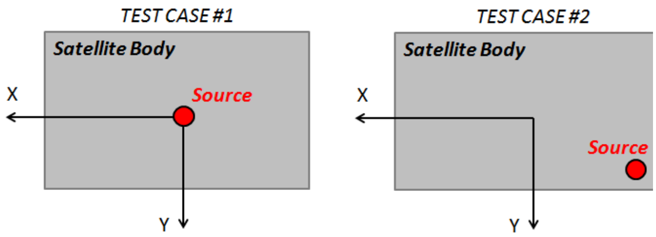

Figure 6. Layout of the two test cases considered in the validation.

As performed in the previous validation campaign, reference data of the global problem have been obtained by a measurement of the entire system (satellite body with source) in the SG-64 multi-probe system. The model of the stand alone patch antenna have been obtained from a measurement of the antenna in isolation and used within SatSim together with geometry of the structure in order to reconstruct the behavior of the antenna on the considered structure.

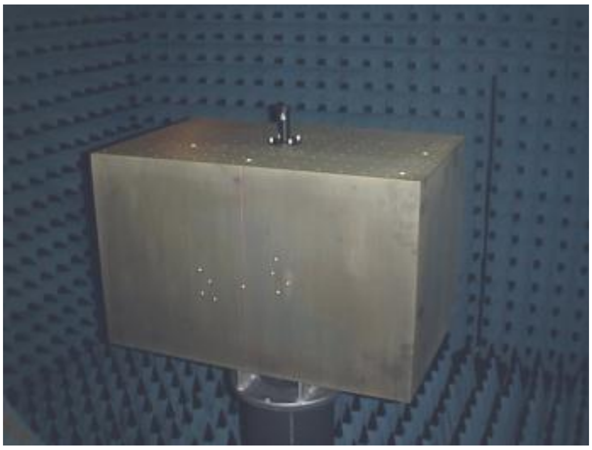

Figure 7. Illustration of patch source antenna mouted centtrally on the satellite body (Test Case #1) during measurement.

A. *Equivalent Current Representation of the Source*

For both test case configurations the patch source antenna has been represented using the equivalent current expansion. In the application of the equivalent current techniques, a box of size (60 x 60 x 15) mm with a mesh step of λ/15 @5.28GHz has been considered as reconstruction surface enclosing the source antenna. The reconstructed J and M currents on the defined equivalent surface fully enclosing the antenna are illustrated in Fig. 8.

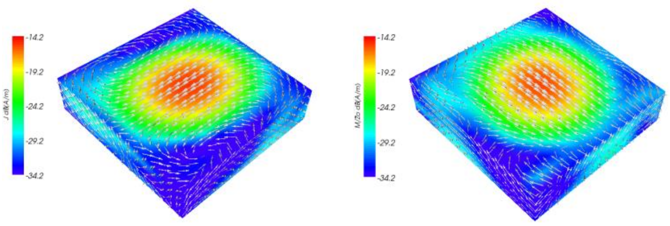

Figure 8 Equivalent J (left) and M (right) currents associated to the patch antenna in stand-alone configuration.

Fig. 9 shows the FF computed from the equivalent currents. As can be seen equivalent current expansion acts as a spatial filter [12]. In fact, the ripples that were present on the measured FF shown in Fig. 5, are strongly attenuated and the resulting pattern is smooth as can be expected from a small radiator. The FF ripple in the measurement were likely caused by radiation from the feeding cable. The cable radiation is an integral part of the antenna pattern although not completely intentional as source of radiation and as such should be represented in the source modeling. In the final computation results a full source representation has been used, including the cable currents.

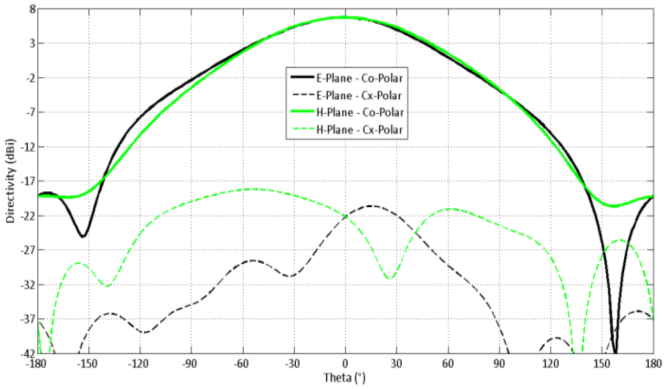

Figure 9. FF of the Patch antenna in isolated configuration computed from equivalent J and M currents.

B. *Source Centered on Satellite Body*

The comparison of reference measurement (blue lines) and predicted results (red lines) for the patch source antenna centered on the satellite body are shown in Fig. 10 and Fig. 11 for ϕ=0° and ϕ=90° cuts respectively. As can be seen, a very good agreement has been observed for the Co-polar component. In particular, the ripples present around θ = +/-70° are much better reconstructed using the equivalent current expansion of the measured source rather than the spherical wave expansion. Similarly, further improvements are observed also in the reconstruction of the Cx-polar component.

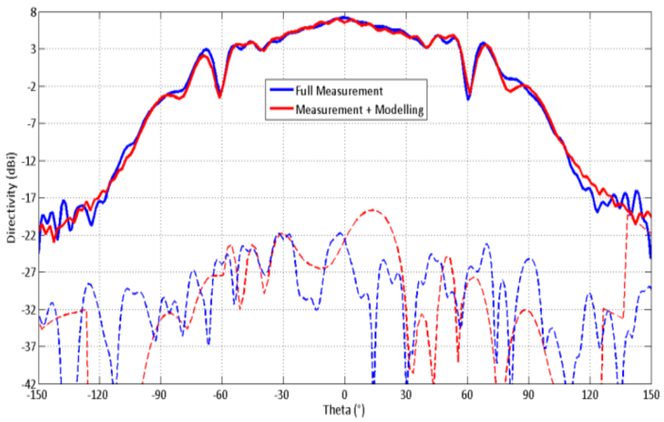

Figure 10. Comparison of measured and predicted results.Source antenna centered on the satellite body, ϕ = 0°.

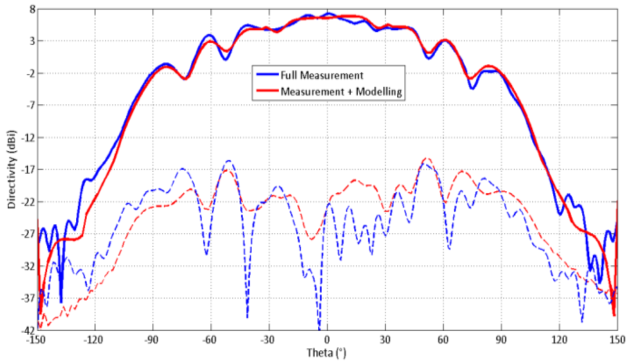

Figure 11. Comparison of measured and predicted results. Source antenna centered on the satellite body, ϕ = 90°.

C. Source close to a Corner of the Satellite Body

The comparison of reference measurement (blue lines) and predicted results (red lines) for the patch source antenna located close to a corner of the satellite body are shown in Fig. 12 and Fig. 13 for ϕ=0° and ϕ=90° cuts respectively. In this case a very good agreement has been observed between the FF envelope coming from the reference measurement and the one obtained with the SatSim predictions, particularly for the Co-polar field component. It should be noted that in both pattern cuts the highly oscillating ripple is not reproduced by the technique. This ripple is most probably caused by the multiple interactions between the source structure and the satellite breadboard. Such interactions create an additional contribute that is currently not accounted in the implementation of the software. Such additional contribute will be studied and introduced in the next release of the software.

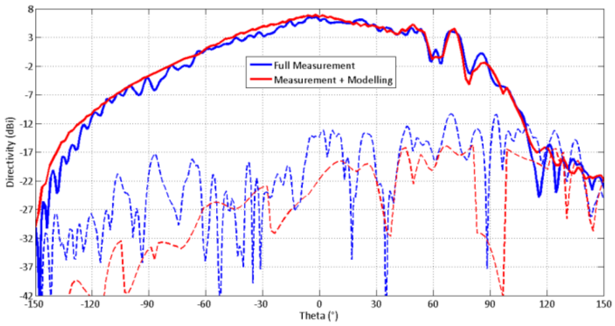

Figure 12. Comparison of measured and predicted results. Source antenna close to a corner of the satellite body, ϕ = 0°.

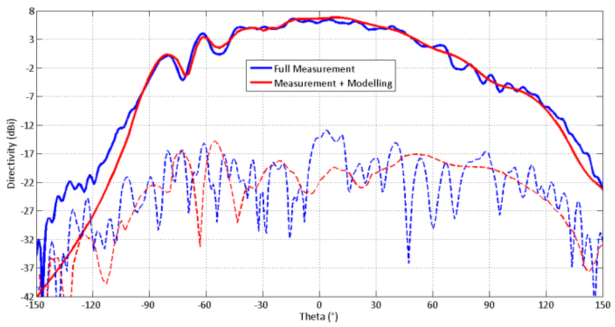

Figure 13. Comparison of measured and predicted results. Source antenna close to a corner of the satellite body, ϕ = 90°.

IV. Conclusions

In this paper, an efficient and accurate technique which allows the characterization of small antennas on electrically large structures has been presented. The method is based on a domain decomposition technique in which only a limited part of the electrically large structure containing the actual antenna is determined by measurements. The full pattern of the complete structure is determined by numerical modeling based on fast ray-tracing techniques and the measured local source is represented by equivalent current (EQC) or Spherical Wave expansion. In this procedure, only the geometry of the large structure and material properties needs to be known and no information about the actual antenna is needed.

The equivalent current expansion is better suited as source representation than the spherical wave expansion technique in the case of stronger interaction between the antenna and the complex structure. It also adds additional freedom to locate the source in close proximity to the structure.

The validation measurements performed on a satellite breadboard during the validation campaign reported in [6] has been used to show improvements from the innovative source representation features added to the MVG, SatSim ray-tracing software [15]. Good agreement has been observed between the measurement of the full system and the predictions. In particular, significant improvements have been observed using a source representation based on equivalent current expansion rather than a spherical wave expansion.

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