

# Feasibility and Accuracy of Antenna Placement Analysis based on Measured Sources and Commercial Numerical Tools

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**Abstract**—Computational Electromagnetics (CEM) solvers are important engineering tools for supporting the evaluation and optimization of antenna placement on larger complex platforms. Due to the conclusiveness and high reliability of actual measured data, antenna measurements are required for the final validation of most systems containing an antenna. Numerical modeling is increasingly used in the initial stages of antenna placement investigation, optimization and to ensure that the final testing, often a complex procedure, is successful. In some cases, the full-wave representation of the antenna is unavailable in the format required by the CEM solver. This is often the case if the antenna is procured from third party. To overcome such problem, an equivalent computational model of the antenna must be constructed. Recently, accurate representative electromagnetic models of measured antennas based on INSIGHT™ processing have been demonstrated [1-4]. The processing is based on the expansion of the measured field using equivalent currents [5-10]. From INSIGHT™ the electromagnetic model can be exported to a number of commercial CEM solvers [11-15]. In applications with flush-mounted antennas the measurement and subsequent INSIGHT™ processing has to be carefully performed. This paper discuss the source antenna measurement, post processing and successive link to commercial CEM solvers for simulation of the antenna within the complex environment.

## I. INTRODUCTION

Equivalent sources or currents implemented in the commercial tool INSIGHT™ have been adopted as an efficient diagnostics and echo reduction tool in general antenna measurement scenarios as discussed in [5-10]. The INSIGHT™ processing of measured antenna data was initially developed as a numerical representation of antennas in complex environment analysis for Computational Electromagnetics (CEM) solvers [3-4]. The main obstacle for widespread use of this method was the handling of the proprietary format of the equivalent currents.

Commercial CEM providers are currently investigating and implementing domain decomposition techniques based on the near field description of the local domain. This development also provides a direct link between INSIGHT™ processing of measured antenna data and numerical simulation. This link opens a range of interesting applications for using measured antennas in commercial numerical simulation tools as discussed in [1-4].

## II. FLUSH MOUNTED ANTENNA VALIDATION SCENARIO

The use of flush mounted, measured antennas in numerical simulation of larger complex structures is illustrated by an example of a small antenna mounted directly on a larger structure as shown in Fig.1. The purpose of this investigation is to quantify the achievable accuracy of using measured sources in numerical computation using commercial CEM solvers and thus validating the link.



Fig. 1. Validation structure during measurement in the MVG Spherical Near Field antenna measurement system, StarLab18GHz [16].

To minimize additional error sources not directly related to the validation of the measurement/simulation link, such as measurement uncertainty and the numerical computation errors of the environment itself, a simple rectangular plate of roughly  $5\lambda \times 10\lambda$  has been used. The source antenna is a simple mono-cone antenna mounted in a corner of the plate positioned  $1.5\lambda$  and  $2\lambda$  distance from the nearest edges. The validation structure is shown in Fig. 1.

Errors due to mechanical machining and material properties of the plate and mono-cone antenna are considered as negligible uncertainty contributors in this test case. Errors due to the measurements truncation and the PVS positioner will however affect the measurement accuracy.

The accuracy of the measurement/simulation link is estimated by comparing different results of the radiation pattern for this structure:

- 1) Direct measurement of the flush mounted mono-cone antenna on the rectangular plate using the MVG Spherical Near-Field measurement system (MEAS).
- 2) Full wave simulation of the flush mounted mono-cone antenna on the rectangular plate based on FDTD shown in Fig. 2 (SIMU).
- 3) Full wave simulation of the rectangular plate using a near field source representation. The source is derived from INSIGHT™ processing of the mono-cone antenna measured in a smaller environment locally similar to the final antenna placement (LINK).

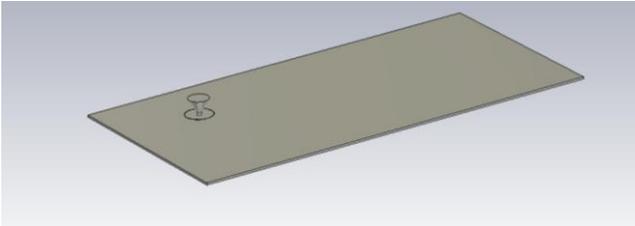


Fig. 2. CST Full wave numerical simulation – antenna system.

The measurements MEAS are performed in the MVG Spherical Near-Field antenna measurement system, StarLab18GHz [16]. The numerical computations in the SIMU and LINK cases are based on the Finite Difference Time Domain (FDTD) technique and the near field source representation implemented in the CST STUDIO SUITE® software [11].

The pattern comparison between measurement (MEAS, red trace) and full-wave simulation (SIMU, blue trace) is reported in Fig. 3 for  $\varphi = 0^\circ$  (top) and  $\varphi = 90^\circ$  (bottom) cuts. The equivalent error level computed with the weighted difference reported in eqn. 1 is as well reported in the plots (green traces). Such formula has been applied considering MEAS as reference field.

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

where

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

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

The equivalent error level averaged over the pattern cut is -32.0dB along  $\varphi = 0^\circ$  and -33.3 dB along  $\varphi = 90^\circ$ . It should be noted that these equivalent error levels take into account all the differences that are present between measurement and simulation of the entire radiating system (measurement accuracy/numerical computation errors). Thus, the equivalent error levels expected comparing the measurement with the proposed method should be comparable with the above values.

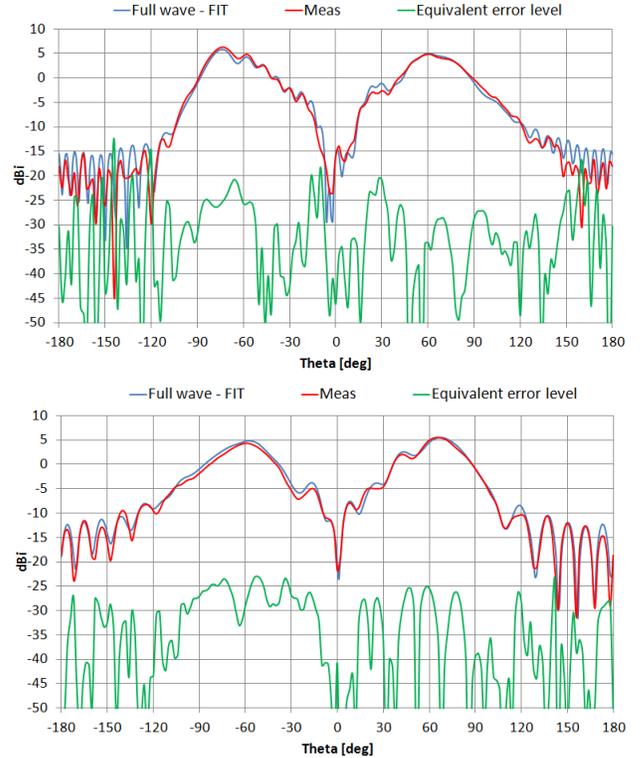


Fig. 3. Comparison between CST full-wave simulation (blue trace) and SL measurement (red trace) of antenna system along  $\varphi = 0^\circ$  (top) and  $\varphi = 90^\circ$  (bottom).

### III. PREPARATION AND USE OF THE MEASURED NF SOURCE

The preparation of the measured source for flush mounted problems is more tricky wrt to situation where the antenna is detached from scattering structure, thus it has to be carried out with particular attention. In fact, in flush mounted situation, the proximity of scattering modifies the current distribution on the antenna structure itself. The consequence is that the stand alone antenna cannot be considered in the measurement unless a proper boundary condition is reproduced.

In a ideal situation, an infinite ground plane boundary condition should be considered on the side of the antenna which is going to be placed on the final structure. Obviously, such an ideal condition cannot be directly obtained on a realistic measurement situation, but it can be properly

reproduced considering the measurement of the source antenna on a finite ground plane and a specific processing of the measurement able to emulate an ideal infinite ground plane condition. Such a processing can be performed with the so called SDE (Source Edge Diffraction Extraction) filter [17] which removes the diffractive contributions from the edge of finite ground plane creating the wanted infinite ground plane boundary condition.

The measurement of the mono-cone antenna performed in the StarLAB18GHz considering a circular ground plane of approximately  $7\lambda$  diameter is illustrated in Fig. 4.

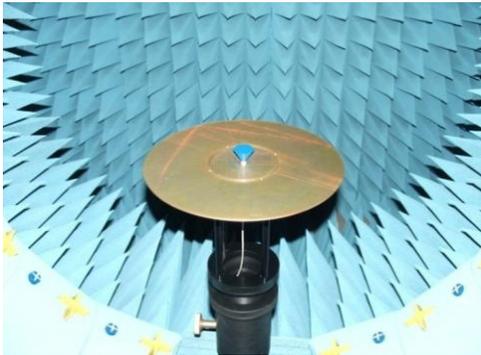


Fig. 4. Measurement in the MVG StarLab – antenna source.

Once the measurement has been performed and the SDE filter applied on the measured data, the Equivalent Current associated to the source can be evaluated with INSIGHT™. It should be noted that, since an infinite ground plane condition is considered, the image of the source antenna has to be first included in the computation of the Equivalent Currents and then removed when placed on the final structure.

The Equivalent Electric and Magnetic Currents associated to the measured mono-cone antenna with infinite ground plane boundary condition are illustrated in Fig. 5.

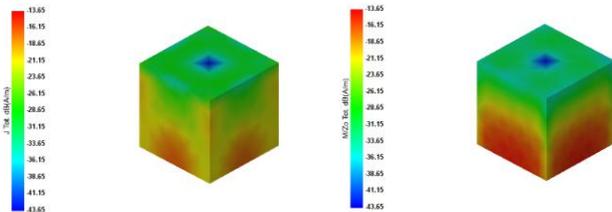


Fig. 5. Equivalent Electric (J) and Magnetic currents (M) of the monocone antenna computed with Insight.

#### IV. MEASUREMENT – SIMULATION LINK

Once the Equivalent Currents associated to measured source has been computed with the procedure described in the previous section, they can be used inside the full-wave simulation software.

An illustration of the source mono-cone antenna described by mean of the Equivalent Current mounted on the rectangular plate inside CST plugged inside CST STUDIO SUITE® is shown Fig. 6.

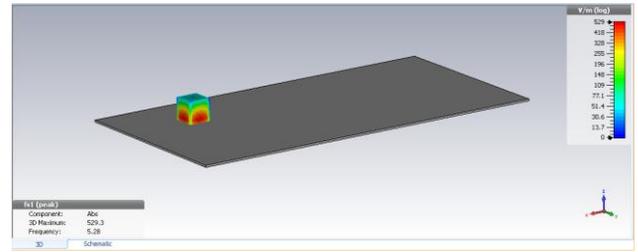


Fig. 6. CST numerical simulation using the measured antenna source (INSIGHT EQC).

Pattern results obtained with the proposed method (red trace) has been first compared with the pattern obtained with the full-wave simulation (blue trace). Such a comparison is reported in Fig. 7 for  $\varphi = 0^\circ$  (top) and  $\varphi = 90^\circ$  (bottom) cuts. The equivalent error level computed with the weighted difference reported in eqn. 1 is as well reported in the plots (green traces). The equivalent error level averaged over the pattern cut is  $-35.0\text{dB}$  along  $\varphi = 0^\circ$  and  $-42.5\text{ dB}$  along  $\varphi = 90^\circ$ . It should be noted that these two scenarios differ only by the source representation. Therefore, the corresponding error levels are directly associated to the accuracy of the use of the measured source. The different level of agreement in the two cuts is mainly due to grid dispersion effects in the numerical method.

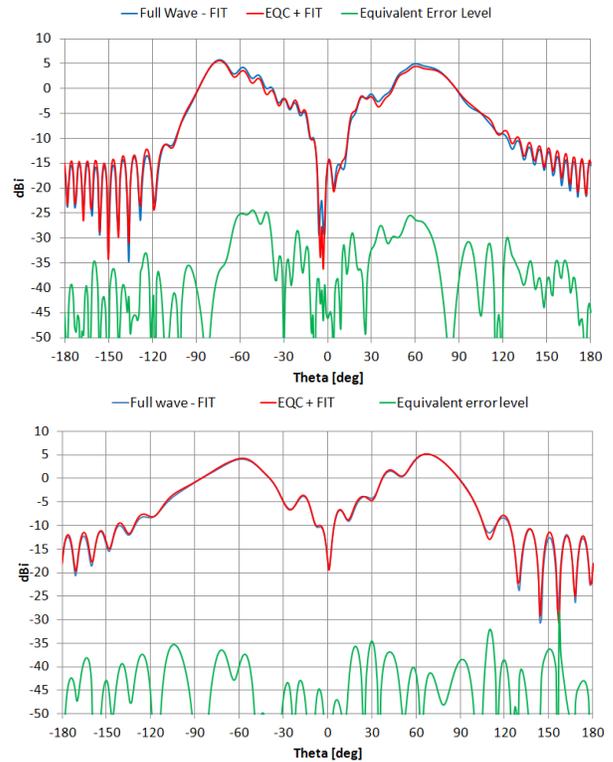


Fig. 7. Comparison between CST full-wave simulation (blue trace) and proposed EQC + FIT method (red trace) of antenna system along  $\varphi = 0^\circ$  (top) and  $\varphi = 90^\circ$  (bottom).

The resulting pattern obtained with the proposed method have then been compared with the measured pattern. Similarly to the previous plots, Fig. 8 shows the comparison between measured pattern (red trace) and measured source combined

with numerical CST simulation (blue trace) for  $\phi = 0^\circ$  (top) and  $\phi = 90^\circ$  (bottom) cuts. The equivalent error level computed with the weighted difference reported in eqn. 1 is as well reported in the plots (green traces).

The equivalent error level averaged over the pattern cut is -30.2dB along  $\phi = 0^\circ$  and -33.2 dB along  $\phi = 90^\circ$ . As expected, these equivalent error levels are comparable with the error levels obtained comparing the measurement and full-wave simulation (see Fig. 3). Therefore, the pattern deviation is primarily due to the measurement uncertainty and the accuracy of the numerical computation, rather than associated to the proposed method.

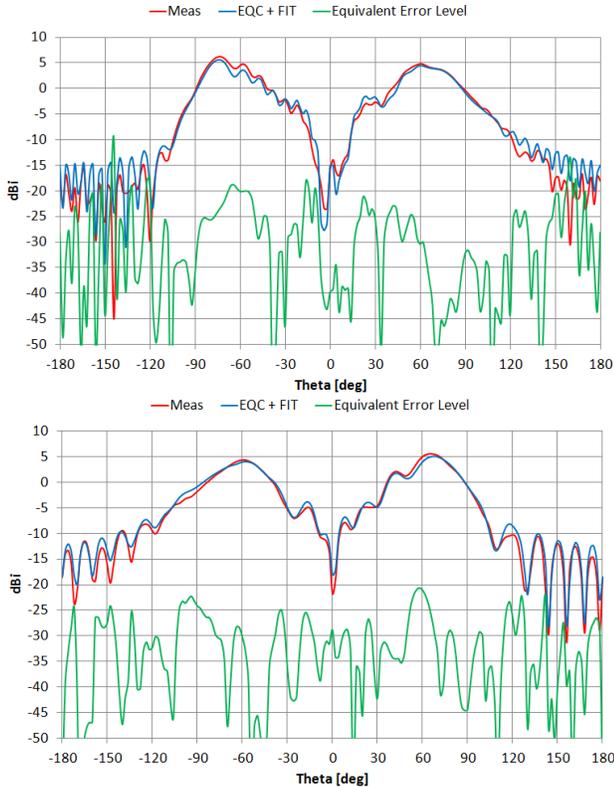


Fig. 8. Comparison between SL measurement (red trace) and proposed EQC + FIT method (blue trace) of antenna system along  $\phi = 0^\circ$  (top) and  $\phi = 90^\circ$  (bottom).

## V. FLUSH MOUNTED ANTENNA ON A CURVED SURFACE

In order to further validate the proposed method with a more realistic and complex scenario, a flush mounted antenna on a curved structure has been investigated using a small monopole-like antenna mounted directly on the back of a space plane as shown in Fig. 9. The purpose of this investigation is to quantify the error derived from the flat ground plane approximation used in the measurement and processing of the measured source in a curved scenario. To isolate this effect, the measured source has been derived from a simulation of the small antenna on a ground plane, similar to the measurement setup shown in Fig. 4. The measured source simulation has been processed using INSIGHT<sup>TM</sup> for import in the numerical tool. The space plane including the numerically derived measured source is shown in Fig.10.

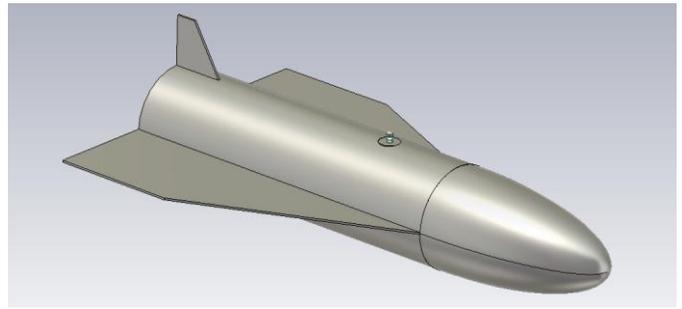


Fig. 9. CST Full wave numerical simulation – antenna system, small monopole antenna on a mockup of a space plane.

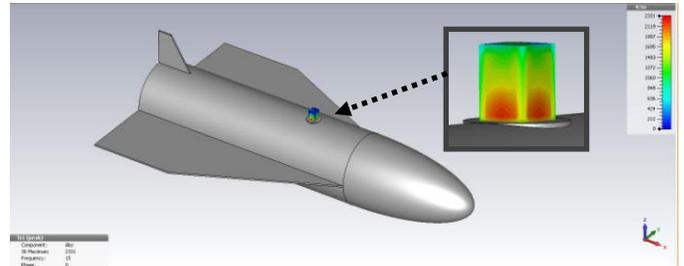


Fig. 10. CST numerical simulation using the antenna source based on INSIGHT<sup>TM</sup> processing.

The pattern comparison between source antenna in the numerical simulation (EQC + FIT, blu trace), full-wave simulation (Full wave - FIT, red trace) is reported in Fig. 11 for  $\phi = 0^\circ$  (top) and  $\phi = 90^\circ$  (bottom) cuts.

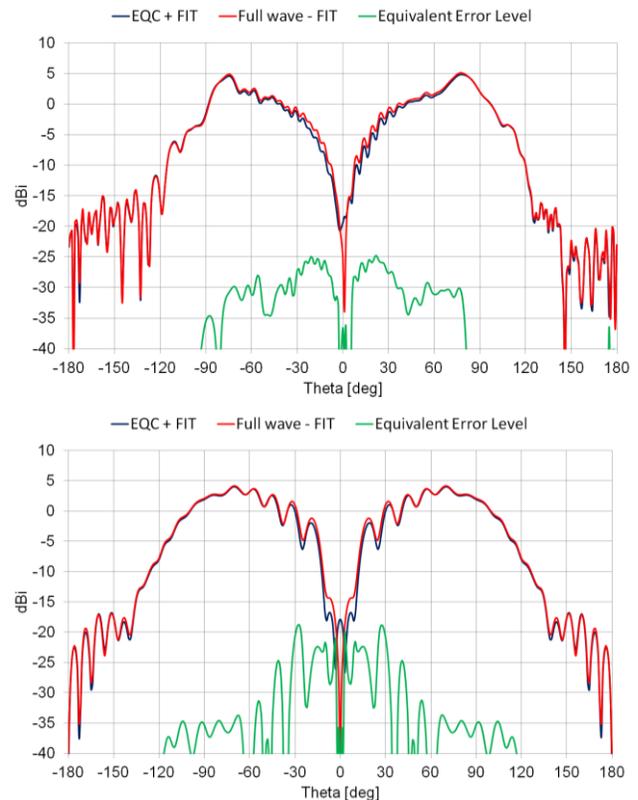


Fig. 11. Comparison between the proposed EQC + FIT method (blu trace) and CST full-wave simulation (red trace) of antenna system along  $\phi = 0^\circ$  (top) and  $\phi = 90^\circ$  (bottom).

The equivalent error level computed with the weighted difference reported in eqn. 1 is as well reported in the plots (green traces). The equivalent error level averaged over the pattern cut is -35.6dB along  $\varphi = 0^\circ$  and -33.9 dB along  $\varphi = 90^\circ$ . From this investigation it is shown that the measured source approach is an accurate approximation also when the source is flushed mounted on a curved structure. Next step will be to use the measurement of the antenna source to be included in the numerical simulations.

## VI. CONCLUSION

A new method has been proposed as the missing link between numerical simulation and antenna measurements. As an illustration of the capabilities, the method has been applied to the case of flush mounted antennas in antenna placement on complex structure scenarios. Using INSIGHT™ processing, an accurate numerical model of the flush mounted antenna can be derived from measurements of the antenna on a limited ground plane. The processed measurements can be used in commonly used commercial numerical simulations tools with no apparent limitation on simulation approach.

The method has been validated on a practical test case of flush mounted antennas using CST STUDIO SUITE® as simulation tool. The first validation was based on a simple mono-cone antenna mounted in the corner of a rectangular plate at  $1.5\lambda$  and  $2\lambda$  distance from the edges. Different comparisons between measurement, full-wave simulation and proposed method have been carried-out to determine the accuracy of the measured source method.

The agreement between full-wave simulation and the measured source method is roughly within -40dB equivalent error level. The differences are mainly due to measurement errors of the source antenna, limited size of the ground plane and numerical simulation errors. However, such agreement is considered sufficient for most antenna placement applications. The agreement between the proposed measured source method and measurements of the source antenna on the full structure is roughly within -33dB equivalent error level. The increased differences are primarily due to the measurement uncertainty of the test case and the accuracy of the numerical computation, rather than associated to the proposed method.

The proposed method has also been applied to a more realistic and complex scenario involving a monopole antenna mounted on the curve surface of a mock-up of a space-plane. From the numerical investigation of this scenario it has been shown that the measured source approach is an accurate approximation even when the source antenna is flushed mounted on a curved structure.

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