White Paper

Finding the "Missing Link"

Bringing Together Numerical Simulation and Antenna Measurement to Understand Deployed Antenna Performance

MVG Microwave Vision Group

EXECUTIVE SUMMARY

The analysis of deployed antenna performance in complex scenarios can prove to be problematic due to the realistic details to be taken into account in the investigation. In these cases, both measurements and numerical modeling are fundamental tools to evaluate the antenna performance.

The numerical modeling created with Computational Electromagnetic (CEM) tools requires a particular representation of the source antenna. This can be achieved by knowing the exact characteristics of the antenna. However, in many practical cases, a full-wave representation is unfeasible or unavailable. This is where recent antenna measurement techniques are proven effective.

In this paper, you will learn of tools and techniques that overcome the limitations due to unknown source model characterization and the complexity of the environment to be measured. The approach, based on the equivalent current representation of an antenna, links measurement equipment/techniques with commercially available numerical computational tools to provide measurements of source antennas for simulations in the most complex of test environments.

Intro

For the placement of a radiating device upon a large structure, such as an antenna on a satellite, a radar on an aircraft, or a sensor on a car, investigation and optimization of the scenario is necessary. While full measurements are still required for final validation of deployed antenna performance due to the conclusiveness and high reliability of measured data, numerical modeling is increasingly used in the initial stages of antenna placement investigation and optimization.

Due to the increasing complexity of test scenarios, Computational Electromagnetic (CEM) simulation tools are implementing the Domain Decomposition Technique (DDT). In some cases, when implementing an antenna supplied by a third party, the mechanical and electronic characteristics needed for a full-wave representation of the antenna may be unavailable, particularly in the format required by the CEM tool. To overcome this problem, the radiating antenna can be characterized by a true radiating measurement.

Figure 1 - Radiating measurement of a shark blade antenna in isolation; determining the correspondent EQC model.

From the measured radiation pattern, an Equivalent Current (EQC) representation of the measured source antenna in near field can be determined and this can be imported into the CEM tool for simulations. The obtained EQC model is an electromagnetic complete representation of the radiation pattern of the antenna and can be used as an equivalent black box based on a Huygens' formulation in simulations on the basis of the DDT [1-5].

The Domain Decomposition Technique (DDT) allows operators to divide a scenario under test into smaller more manageable chunks, optimizing and reducing the computational cost. Applying the DDT in a complex antenna placement problem means, in a practical sense, that the characterization of the radiating antenna is to be obtained separately as a sub-problem then integrated into the final full scenario.
In the past, the use of DDT was strictly limited to simulated problems where different numerical methods had to be used to solve the various sub-problems. This limitation has recently been overcome. New technology developed in MVG's Insight software allows true measurements to characterize the sub-problems using the DDT.

BLACK BOX REPRESENTATION OF DEVICES RADIATING INTO 3D SPACE

While the development of black box electrical representation of microwave components has revolutionized the design of integrated circuits, the development of an equivalent black box representation of devices radiating into 3D space, such as antennas, has been much less successful. The black box representation of a microwave device is based on the definition of physical ports on the device and the relationship between incoming and outgoing waves defined by S-parameters. The device details are often unknown to the user since the S-parameters representation, fully characterizing the device, can only be obtained by measurements, simulations or provided by the vendor.

Similar to what happens with S-parameters of microwave components, a radiating device into 3D space can be fully characterized by a Near Field (NF) source data set. In this case it is defined as an equivalent black box based on a Huygens' formulation which represents the radiation pattern of the device [6].

INSIGHT [7] is software by MVG that creates accurate representative electromagnetic models of measured antennas based on the expansion of the measured field using Equivalent Currents (EQC) [8-14]. From INSIGHT, an EQC representative model can be imported by a number of commercial CEM tools for simulation and testing in full, complex scenarios.

INSIGHT provides the "Missing Link", bringing together numerical simulation and antenna measurement to understand deployed antenna performance.

The radiation pattern (near field and/or far field) of the horn in isolation is to be initially measured. The measured data is then post-processed to obtain an equivalent black box based on a Huygens' formulation. The equivalent black box can then be installed on the reflector for the simulation with different CEM tools.

The equivalent current representation of the source antenna also allows accurate results when the antennas are in close proximity or mounted directly on complex structures. The procedure is general and can be used with any antenna in complex environments of arbitrary shape and complexity [1-5].

Defining the Link

The Link is the intersection between antenna measurement equipment, CEM numerical modelling and an EQC model of an NF measurement of the source antenna suitable for the CEM solver. To illustrate the procedure, let's consider as an example a reflector system fed by a dual ridge horn. This system can be divided in two parts: the horn (source antenna) and the reflector, as is shown in Figure 2.

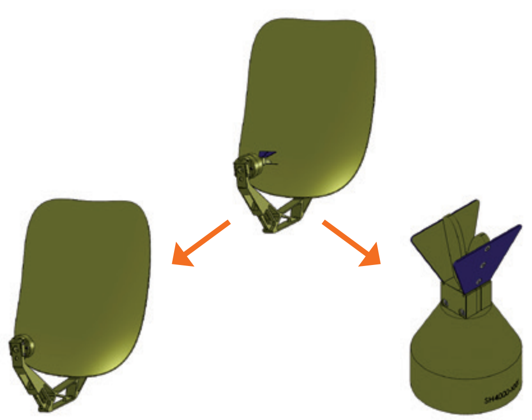

Figure 2 - Reflector system: The MVG SR40-A reflector fed by the MVG SH4000 Dual ridge horn.

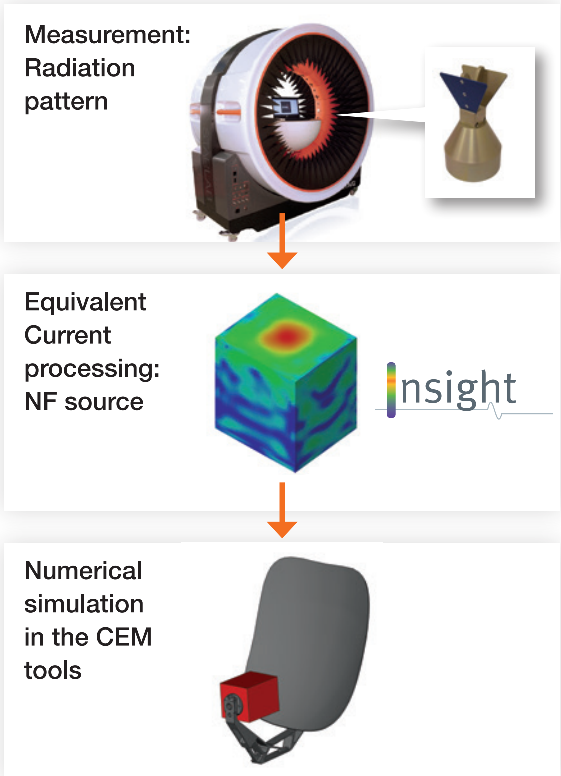

Figure 3 - The link.

ANTENNA MEASUREMENT EQUIPMENT

A near field or a far field measurement of the antenna radiation pattern, over a spherical, cylindrical or planar scan surface, is equally applicable in the preparation of the EQC representation to be used in a CEM simulation. Measurements of the isolated antenna in many cases do not necessarily require large measurement equipment and compact near field measurement ranges can be used to perform accurate and efficient measurements of the source antenna. Compact and portable measurement systems are in fact quite favorable in this case as, like other instrumentation in the EM laboratory, they can be easily used in combination with and in proximity to the platforms where the simulations are carried out. In addition, if the system is a multi-probe system, measurement time can be proportionately reduced.

Measurements presented in this paper and used for validation of the Link have been performed by the compact and portable MVG StarLab measurement system [15] shown in Figure 4.

Figure 4 - MVG StarLab 18 GHz spherical near field multiprobe system [15].

EQUIVALENT CURRENT PROCESSING: NF SOURCE MODELING

An Equivalent Current representation of the isolated antenna is to be proposed as a measured near field model to represent the source antenna in a CEM tool. Equivalent current representations can be computed from measured data by INSIGHT [7] by application of the inverse-source or equivalent current/source method (EQC) [8-10]. The key in using the inverse-source method is in its capability to reconstruct the EQC on arbitrary or generic 3D surfaces enclosing the antenna under test (AUT). For this reason, the method can be applied to all antennas without limitations of type or shape. An example of equivalent current reconstruction for a dual ridge horn is shown in Figure 5.

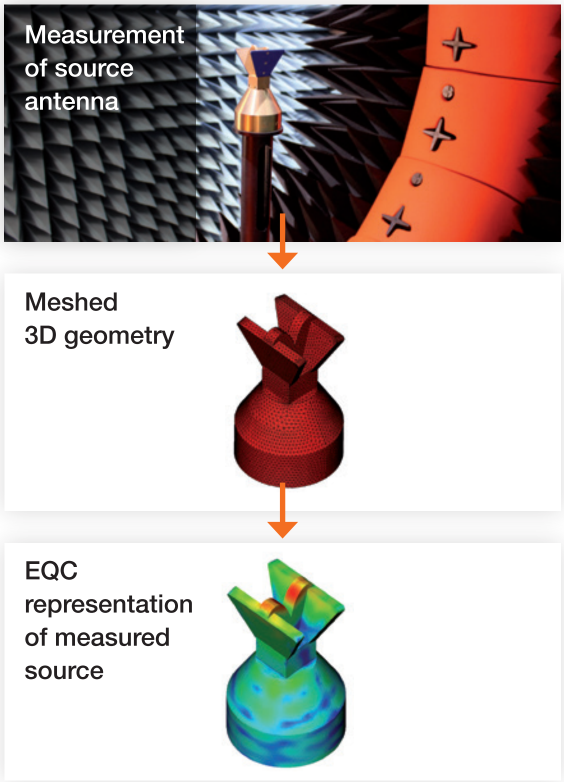

Figure 5 - Equivalent current reconstruction from a measured radiation pattern of a dual ridge horn for diagnostic purposes.

Since the EQC can produce a form fitting representation of the antenna surface, the source antenna can be mounted more freely in any position on any large structure (final scenario). This method is recommended as opposed to spherical wave expansion. In spherical wave expansion, only the field radiated outside the minimal sphere of the source antenna can be computed [16]. This sphere of minimum radius fully enclosing the source antenna must not be intersected by the structure, therefore the source antenna cannot be installed too close to the structure. As a result, this approach can be applied only to a limited number of practical test cases. When equivalent current processing is applied to measured data for numerical modelling, an equivalent black box based on a Huygens' formulation, enclosing the antenna provides enough accuracy for the procedure. An example of a EQC representation of the dual ridge horn as an equivalent black box is shown in Figure 6.

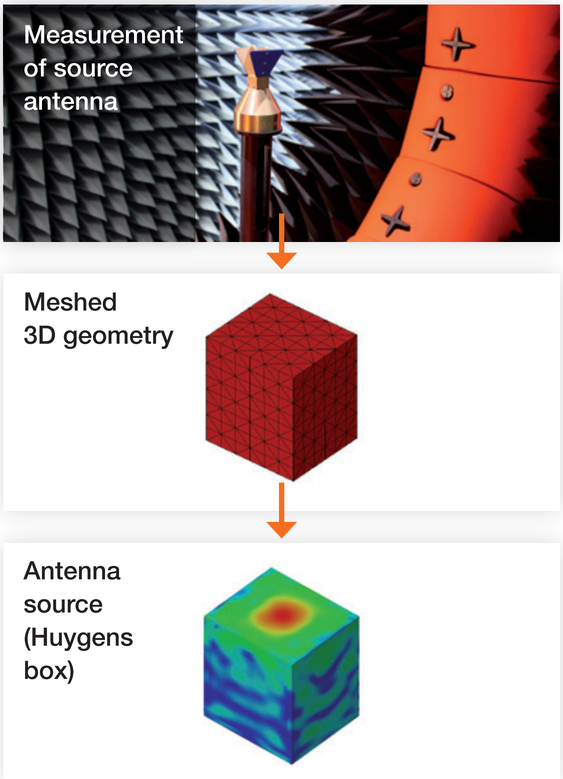

Figure 6 - Equivalent currents reconstruction from a measured radiation pattern of a dual ridge horn using INSIGHT software.

NUMERICAL SIMULATION IN THE CEM TOOLS

Once the equivalent black box of the source antenna has been created in INSIGHT, it can be implemented into a number of CEM tools. The CEM solver will consider it as a full representation of the antenna in any scenario required for simulation. Applying the black box approach, the simulation is carried out with no more additional information. The advantages: no modifications to the source files are necessary and the EQC representation can be used in any scenario to be tested, even the most complex. The equivalent current representation model computed in INSIGHT can be imported by a number of commercial CEM solvers [17-22], see Figure 7.

Figure 7 - INSIGHT's EQC source model is exportable to several commercially available CEM tools.

An example of a simulated far field radiation pattern [17] obtained using the Link between measurements, INSIGHT, and a CEM simulation tool (Figure 3) is shown in Figure 8.

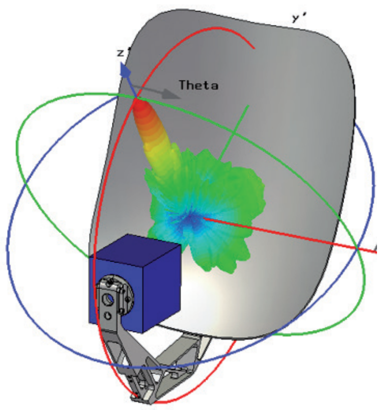

Figure 8 - Simulated 3D far field pattern obtained by the Link (measured source installed on the reflector @ 8 GHz) [17].

Validating the link: Proven data and results

To validate the Link between antenna measurements and CEM simulations, different case scenarios have been tested (see figure 9). The objective was first to prove the accuracy of the technique, and second to show its flexibility in application in several of the different commercially available computational electromagnetic simulation tools.

3 test cases were considered for the validation:

a) Reflector antenna fed by a horn antenna;
b) Flush mounted monocone antenna and open ended waveguide on a flat structure;
c) Flush mounted monopole antenna on a curved structure.

The equivalent current representations of the antennas previously measured in isolation, were given to 6 CEM tool vendors. Comparisons were made between the results from the various vendors and against the reference measurements of the final scenario. The reference measurements consist of the antenna radiation patterns in the full final scenarios determined entirely in the measurement system.

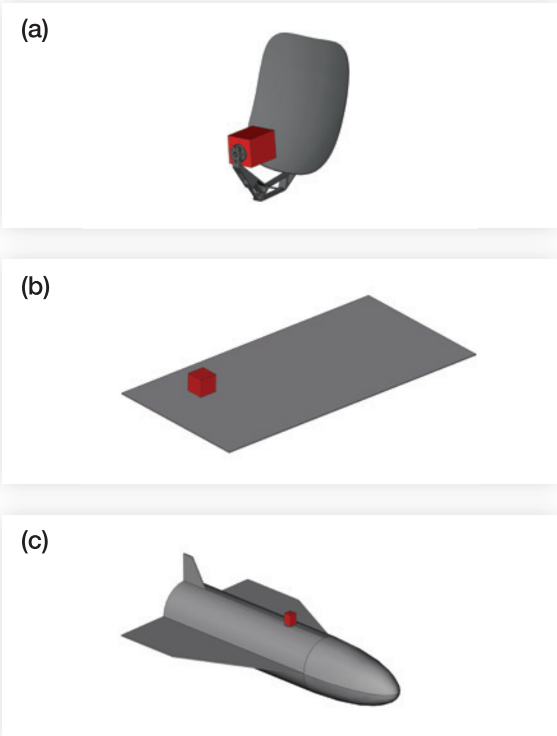

Figure 9 - Test cases for the validation campaign of the Link between measurements and simulations. Reflector antenna fed by a horn (a); Flush mounted monocone antenna and open ended waveguide on a flat structure (b); Flush mounted monopole antenna on a curved structure (c). Equivalent Current representations appear as red boxes.

The same information (an equivalent black box based on a Huygens' formulation modelling the source antenna) were provided to the 6 SW vendors. In order to preserve the spirit and effectiveness of the validation campaign, no numerical results of the simulations were exchanged among SW vendors during the entire campaign.
Only the example of the flush mounted monocone antenna on a flat structure is demonstrated in this paper.

VALIDATING THE TEST [SCENARIO/STRUCTURE]

The validation structure consists of a flush mounted monocone (MVG SMC2200) antenna on a flat structure. A simple ground plate of 30 x 60 cm has been chosen as the initial validation scenario to minimize errors not directly related to the validation of the measurement/simulation Link (see Figure 10). The monocone antenna has a low directive radiation pattern with the polarization orthogonal to the ground plane [1-5], causing relevant interaction with the plate.
The source antenna is mounted in a corner of the plate, positioned at a distance of 1.5λ and 2λ from the nearest edges (at the validation frequency). Figure 10 shows the validation structure during measurements in the MVG StarLab 18 GHz spherical near field multi-probe system.

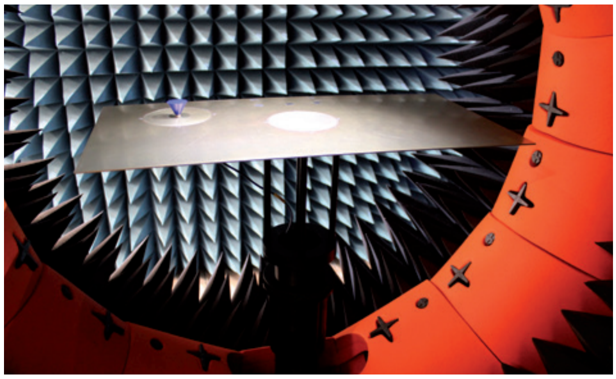

Figure 10 - Rectangular ground plane validation structure – Measurement of SMC2200 monocone antenna in the MVG StarLab18 GHz.

THE SIMULATION USING THE NF SOURCE

The evaluation of the EQC representation of the source antenna in a flush mounted application is much more complex than the evaluation of a source model detached from a structure that may be a source of scattering; in this case the plate. The proximity of scattering structures modifies the current distribution on the antenna itself. An infinite ground plane boundary condition is a good approximation of the correct boundary conditions; however, it cannot be directly obtained in a realistic measurement scenario. This condition can be emulated from measurements of the source antenna installed on a finite ground plane, together with measurement post-processing [1-5]. The measurement set-up is shown in Figure 11.

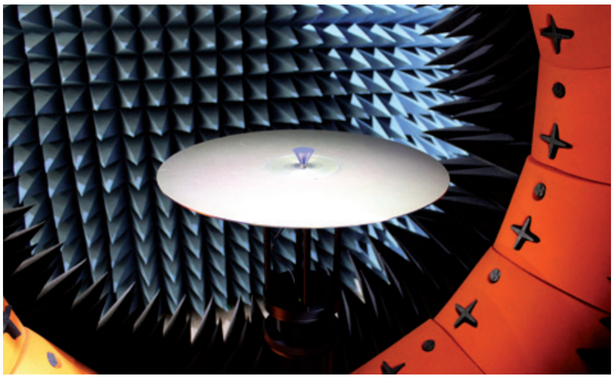

Figure 11 - Measurement of the monocone antenna on a limited ground plane in the MVG, SL18GHz spherical near field multi probe system.

The post-processing of the measured data removes the diffractive contributions from the edges of the finite ground plane creating the wanted infinite ground plane boundary conditions [23]. A circular ground plane with minimum 2λ radius is considered adequate for most measurement source antennas. This procedure is shown in Figure 12.

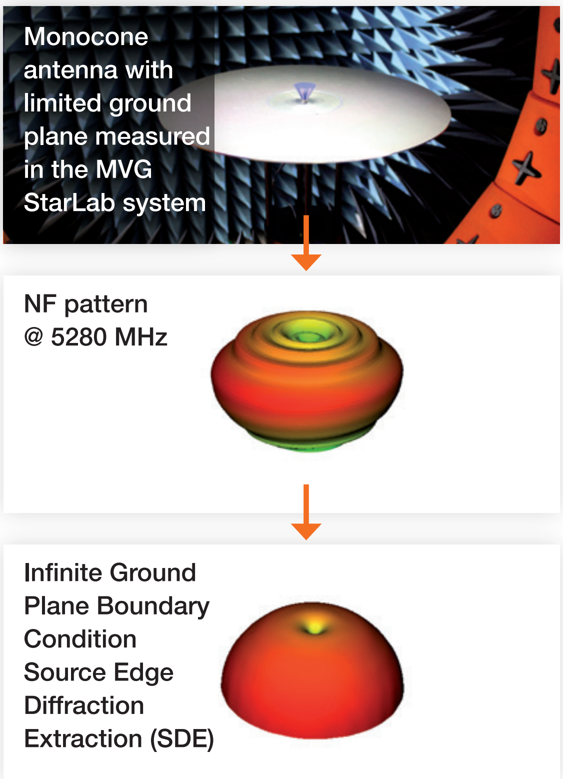

Figure 12 - Post processing in INSIGHT by MVG of the measured data to remove the diffractive contributions from the edges of the finite ground plane creating the wanted infinite ground plane boundary conditions [23].

In the validation example, the antenna has been measured on a circular ground plane of diameter 7λ (at the test frequency of 5.28 GHz). After post-processing to eliminate edge diffraction, the 3D electromagnetic model is created by the Equivalent Current technique of INSIGHT.

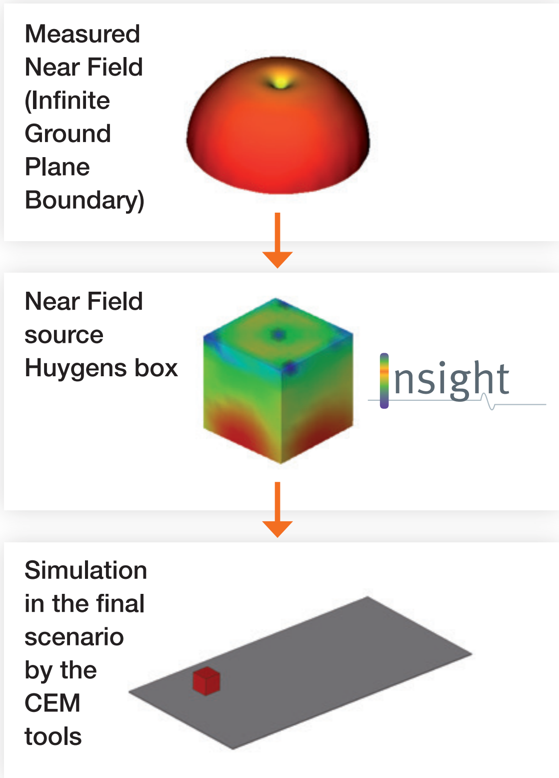

Figure 13 - Preparation of the near field source and placement in the final scenario.

It should be noted that, since an infinite ground plane condition is assumed, the image of the source antenna is initially included in the equivalent current computation and then removed when determining the equivalent black box representation of the measured source.

RESULTS

The final pattern of the monocone antenna in its full test scenario (set on the rectangular plate in Figure 10), is a result of the measured monocone antenna computed as an equivalent black box and imported into the CEM simulation software. The measured and simulated peak directivities @ 5.28 GHz of the rectangular plate with the monocone antenna have been reported in Table I. « MEAS » is the reference measurement. The results of the simulations have been computed by the different CEM tools [17-22] using the same Huygens' box. Very good agreement between measurements and simulation can be observed.

	MEAS	CST	Savant	FEKO	ADF	HFSS	WIPL-D
Peak Directivity [dBi]	6.2	5.7	5.9	5.8	6.0	5.5	5.8

Table I - Peak Directivity @ 5.28 GHz – SMC2200 on plate.

Directivity radiation patterns over the principal cut planes at the investigated frequency are shown in Figure 14. The agreement between simulation and measurements is very good despite an approximation due to the feed representation and uncertainties arising from measurement, manufacturing and simulation.

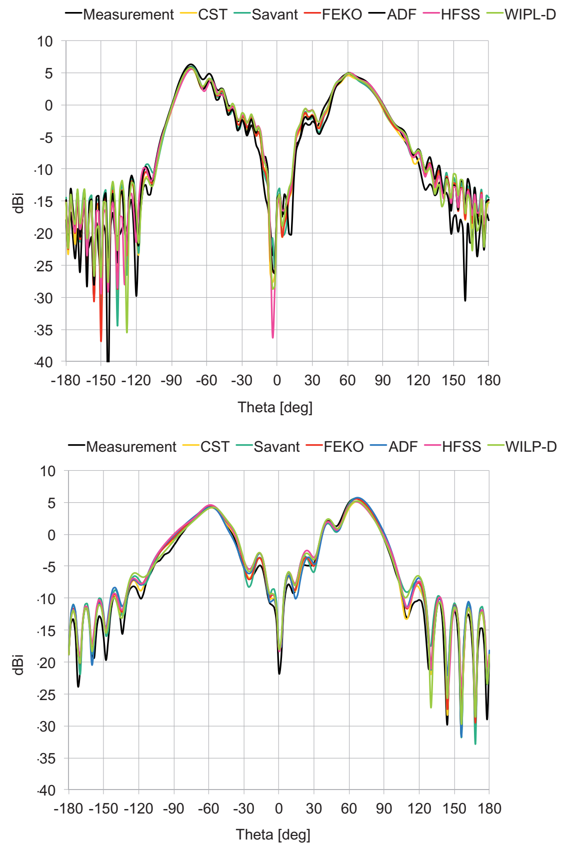

Figure 14 - Directivity pattern of SMC2200 monocone antenna on rectangular plate @ 5.28 GHz; phi=0° plane (top), phi=90° plane (bottom). Measurement and simulation using measured source: CST [17], Savant [18], FEKO [19], HFSS [20], ADF [21], WIPL-D [22].

The validity of the Link as a result of correlation between measurements and simulations has been evaluated in terms of the weighted difference [5] between the measured and simulated fields. The measured far field is considered the reference field. An overlay of the weighted difference for each simulation tool with the measured patterns @ phi = 0° and @ phi = 90° in the forward hemisphere is shown in Figure 15.

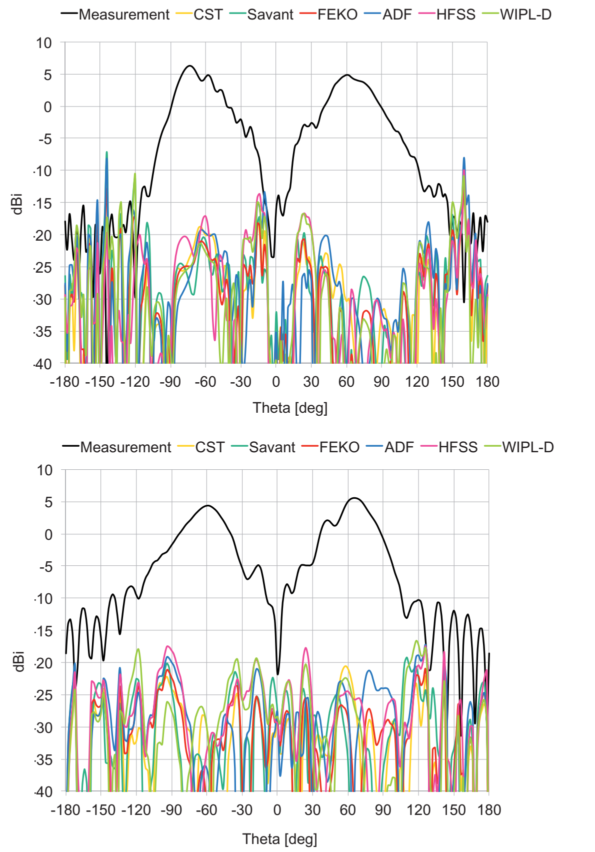

Figure 15 - Weighted difference of simulation and measurements, phi=90° plane. Simulation using measured source: CST [17], Savant [18], FEKO [19], HFSS [20], ADF [21], WIPL-D [22].

The medium value of the weighted difference has been calculated and represents the correlation in a single value as shown in Table II.

	CST	Savant	FEKO	ADF	HFSS	WIPL-D
Phi=0° plane [dB]	-30.2	-30.1	-30.5	-28.7	-30.17	-31.02
Phi=90° plane [dB]	-33.2	-32.4	-33.4	-30.5	-30.79	-31.63

Table II - Mean weighted difference with measurement monocone antenna SMC2200 on rectangular plate.

The average correlation between simulations and measurements is ~30 dB, which is similar to what is obtainable with classical full-wave simulations of the antenna.
This positive result confirms the accuracy and the validity of the technique and the Link between measurements and CEM simulation tools.

Conclusions

In many practical electromagnetic analyses of complex antenna scenarios, a full-wave representation of the physical antenna is unfeasible or unavailable in the format required for application in a certain computational electromagnetic (CEM) tool. This occurs particularly when antennas are supplied by a third party and/or are protected by intellectual property.

In such situations both measurement and simulation is a necessity. The proposed solution takes root in the Domain Decomposition Technique and measures the radiation pattern of the physical antenna in isolation to create an equivalent representation that can be imported into commercially available CEM simulation tools. A principal advantage of this technique is that no additional modifications to the source files are necessary in the implemented working procedure. The EQC model can therefore be used as a near field source in multiple and /or complex simulation scenarios.

This equivalent model of the measured source antenna, is based on the black box theory, and consists of an EQC representation in the form of an equivalent black box based on a Huygens' formulation. It is created by the MVG software INSIGHT using the inverse-source method. Today, INSIGHT is capable of exporting the EQC model to several CEM solvers: CST [17], Savant [18], FEKO [19], HFSS [20], ADF [21], WIPL-D [22].

The Link between measurements and simulations has been validated proving the accuracy of the measured near field source representation and its application to the different CEM tools and numerical methods. The results demonstrate the remarkable effectiveness of the Link in the characterization of antennas radiating in various and complex scenarios.

The practical applications of this technique delivers much more flexibility in testing of large or complex equipment particularly when source antenna characteristics are unknown. It's a useful piece in the antenna designer's toolkit and should serve its purpose well facing the testing requirements of our increasingly electronic world.

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ABBREVIATIONS

- EQC → EQuivalent Current
- CEM → Computational ElectoMagnetic

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To learn more about INSIGHT software and how it links antenna measurement and numerical CEM Tools, visit:
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