Validation of electromagnetic numerical simulations through measurements for an efficient deployment of complex systems

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Abstract. A proper use of electromagnetic numerical simulations can lead to an efficient equipment integration and consequent successful deployment of complex systems and stations. In this paper, the level of accuracy attainable with modern numerical methods is discussed as a consequence of measurement campaign performed in complex systems and environments.

1. Introduction
Electromagnetic numerical simulations have become a standard tool for the design of RF and microwave devices and subsystems. The growing maturity of such techniques, together with available high power computing capabilities, allowed us to go several steps further in the design stage of complex systems so that a proper use of such techniques can lead to an efficient equipment integration and consequent successful deployment of complex systems and stations. In particular, the final goal of an interference-free system, maintaining, at the same time, the desired performance of each subsystem to be integrated, is a key issue.

The enormous recent development of numerical methods avoids costly trial and error procedures based on post factum verifications, providing a remarkable benefit: different engineered solutions can be tested in advance, with the great advantage of an early knowledge of the attainable performance; as a result, technical specifications of the overall systems, issued by buyers and stakeholders, can now be tailored to the available and cost-efficient technologies.

The above-mentioned issues pose different questions about a major concern, i.e., how far the numerical accuracy must be pushed to obtain meaningful results for a correct final deployment of complex systems/stations. Some results will be presented based on authors’ experience on numerical methods, and compared with real measurements obtained in practical cases, regarding satellite ground stations, military base with the simultaneous presence of communication and electronic warfare systems, top side arrangement of ships.

2. Early stage design: simulation methods

2.1. Setting up scenery
The first step to be taken before running any simulation is the construction of the scenario where sources and victims operate. Generally, we start from a model of the complex scenario (i.e. ship, airplane, helicopter) built for purposes other than those of electromagnetic analysis. Therefore, the first effort to be made is to adapt the mechanical model to the needs of the chosen numerical methods. The adaptation
takes place eliminating from the mechanical model all the details irrelevant for electromagnetic purposes and building a mesh of the object that respects the constraints of the chosen model. After having defined the geometry of the scenario it is necessary to characterize its parts with the type of material that compose them through its electrical properties. These properties can be found in literature or directly measured if unknown.

2.2. Characterization of materials

The description of the materials from the point of view of their electromagnetic properties is as important as the geometric description. The designer can face two situations: either the measurement data of the electrical properties of the materials in the band of interest are available or it is necessary to refer to data present in the literature. In the former case, the designer will have to consider the correctness of the method used to estimate the parameters to be employed in his model, whereas in the latter case, not all materials may be available in open literature so one may need to refer to similar experiences for the model to be realistic. Furthermore, it is not possible to characterize a material on a broad frequency band by using a single method and a single measurement setup. In the case of a waveguide measurement at a given band up to GHz, there will certainly be a need for more setups, i.e., as many setups as the number of waveguides necessary to cover the band of interest. If we are also interested in two polarizations, we must also multiply by two the measurement effort.

Among the methods based on the inversion of the Fresnel formulas expressing the reflection and transmission coefficients at the interface of a material layer by resorting to the wave impedance of the medium and its index of refraction, the method of Nicolson-Ross -Weir (NRW) is certainly one of the most used [1], cited and modified by engineers [2].

To characterize a material in the 4-18 GHz radar band, it is necessary to use a set of waveguides of different sizes in order to cover the whole band. Table 1 shows a possible choice of three waveguides for the band of interest and indicates the name, the dimensions of the long (a) and short (b) sides and the band covered by each guide: the waveguide with larger geometrical dimensions (WR187) corresponds to the narrower frequency band, whereas the smaller one (WR62) has the wider band.

| Wave Guide | a[mm] x b[mm] | Band [GHz] |
|------------|---------------|------------|
| WR187      | 47.54 x 22.14 | 3.95 - 5.85 |
| WR90       | 22.86 x 10.16 | 8.20 - 12.40 |
| WR62       | 15.79 x 7.89 | 12.40 - 18 |

**Table 1.** Size and frequency band of three waveguides used to characterize a plastic sheet

| Parameters | Band [GHz] |
|------------|------------|
| WR187      | 3.95 - 5.85 |
| WR90       | 8.20 - 12.40 |
| WR62       | 12.40 - 18  |

**Table 2.** Electric parameters of a plastic sheet estimated by using the Nicholson-Ross-Weir method

| Properties               | Plastic sheet |
|--------------------------|---------------|
| Dielectric relat. permittivity | 3.0 - 3.5   |
| Magnetic relat. permeability | 0.9 - 1.1   |
| Conductivity [S/m]        | 0.02 – 0.2   |

**Figure 1.** The waveguides WR187, WR90 and WR62.

**Figure 2.** Measured S11 and S21 parameters (setup shown in the inset) of a 0.65 mm thick plastic sheet.
It is therefore clear that investigating the lower portion of the band requires a greater number of guides than the upper portion 12-18 GHz, which is covered by the WR62 alone. Fig. 1 shows the three waveguides with a sample of plastic, a low loss dielectric material, and Fig. 2 the S11 and S21 parameters measured by using the setup shown in the inset of the figure. Table 2 shows the estimated dielectric permittivity, magnetic permeability and conductivity of the plastic sheet (minimum and maximum values).

2.3. Numerical simulations

Commercial software for calculating low-frequency electromagnetic propagation is based on numerical methods such as Method of Moments (MoM), Integral Equation Method and Finite Element Method or Finite Difference Time Domain. These methods estimate the exact solution of the Maxwell equations, but they need to discretize the objects of the scenario by a mesh whose size is of the order of one tenth of the wavelength. This causes an increase in the simulation time, more evident when the frequency increases, that has been partially overcome by the implementation of speed-up algorithms, such as the Multi-Level Fast Multipole Method or the Characteristic Basis Function method [3] for the MoM. Unfortunately, these full-wave EM computational techniques have proved unsuitable for simulating environments that exceed 100 wavelengths [4]. In these cases, the propagation of wireless electromagnetic signals is studied by using high-frequency techniques based on Geometrical Optics, the Geometric Theory of Diffraction and its uniform extension such as the Uniform Theory of Diffraction, because they show some advantages: no constraints on the size of the mesh, ray tracing algorithms can be used to compute the wave propagation in the inner side and the attenuations that rays suffer scenarios (reflections, transmissions and diffractions) are easily evaluated [5][6].

3. Measurements in complex systems and environments

In a complex system or platform, measurement campaigns are needed to verify both EMC issues (as the RADHAZ, HERE, HERO, HERF) and personnel exposure (HERP). It is necessary to compare the level of the electric field emitted by the sources (i.e. antennas) with the maximum level reported in the regulations (i.e. MIL-STD-461/464, STANAG 2345, ICNIRP). Considering that measurements can be performed both by broadband instrumentation (isotropic field sensors for E and H fields) and by narrow band instrumentation (by means of spectrum analyzer) they can be very expensive in terms of time and cost. To make the measurement process more efficient, we propose a working method based on the synergy of measures and simulations. Indeed, thanks to the simulations, the most critical measuring points can be identified and therefore limiting the measurements to only these points. Once the agreement between measurements and simulations has been verified at these points, simulations can be used instead of measurements to evaluate the electric field at any other point. Fig. 3 and Fig. 4 show some photos of measurements carried out for HERP and HERE purposes and the related simulated scenarios. Table 3 shows the comparisons between the measured and simulated electric field values due to a radar antenna and a VHF communication antenna.

It is worth mentioning that similar accurate results can also be obtained in terms of other meaningful parameters to system engineers, such as the delay spread or angle of arrival ([7][8]).

This kind of procedure (simulations and measurements both broadband and narrowband) has been carried out extensively during several projects in recent years ([6] [8] [9]). Therefore, it is possible to state that, if the scenario and the sources are faithfully characterized from an electromagnetic point of view, in rural scenarios (having large size and few obstacles) the error between simulations and measurements is about ± 1.5dB, while in complex scenarios (small size and many details, for example aboard ships) the error is about ±3dB.

4. Conclusion

In this paper, a discussion about the simulation accuracy attainable by current electromagnetic methods has been conducted with particular reference to the complexity of the system under investigation, [10]. Measurements performed after the deployment of the system show that a sufficient
accuracy can be obtained if the initial model contains the main features contributing to the propagation phenomena: obstacles and their material electric properties; exhaustive description of sources. Such a high degree of confidence allows designers to carefully plan in advance the layout of ICT equipment and subsystems for maximum performance [11] and interference-free functioning.

![Figure 3. Measurement and simulation for radar antenna.](image)

![Figure 4. Measurement and simulation for VHF antenna.](image)

### Table 3. Measurement and simulation comparison related to scenarios of Figure 4 and 5

| Scenario | Electric Field [V/m] | Measured | Simulated |
|----------|----------------------|----------|-----------|
| Radar    | 211                  | 215      |           |
| VHF      | 70                   | 80       |           |

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