Measurement procedure for EMI estimation of Assembled and Stacked Sources

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Abstract

The aim of this work is to provide an outlook on the development of a novel measurement workflow, specifically suited to predict the radiation coming from a stacked assembly of electromagnetic sources. This task is achieved in a two-steps approach by firstly measuring experimentally the radiation characteristics of each single source independently and then by using the spherical wave expansion theory, typically applied to antenna measurements, properly combined with a suitable estimation technique of the EMI from the combined and stacked sources. Such a procedure has been previously validated by using, in place of real measurements, the values coming from accurate numerical models. Therefore, this work attempts to translate the simplified aspects inherent to a simulation scenario into a practical workflow for reliably applying the proposed estimation procedure to experimental measurements. All steps required to acquire the data concerning the single sources and the combined sources, as well as to process the measured data are described and analyzed in details. Moreover, an overview of the main relevant aspects concerning the measurement steps and physical constraints of the measurement facilities is also provided.

1 Introduction

Nowadays, in many modern practical applications, it is required to accurately evaluate the radiation coming from cumbersome aggregate sources of EMI. They can be from time to time very complex and custom-designed digital systems, such as the motherboard of a rack-mounted server unit (namely server "tray"), or more standard RF apparatuses. In effect, it is fairly evident that very often many challenging newborn EMI issues are linked with the radiated emissions coming from a set of stacked sources composed in turn by other complex structures. Actually, this fact makes the evaluation of the overall radiation viable only by specific measurements, this is the case for instance of most current server racks.

However, measuring the radiation of each rack, and estimating the level of interaction and interference among close systems, is a time consuming and challenging task. To overcome these limitations a proper estimation method has been proposed in [1], based on the Spherical Wave Expansion (SWE) theory [2], that is typically used for other purposes such as antenna measurements [3,4]. The method is suitable to characterize the radiation of the entire rack with the need to measure only single trays. Once the radiation of all possible tray types is acquired their spherical wave coefficients can be assembled to estimate the overall rack radiation. The paper recalls first the theoretical background of the proposed SWE-based estimation method together with its validation by numerical modeling. The second part of the paper deals with the practical experimental implementation of the proposed method, by highlighting and discussing the major aspects that need to be taken into account to reliably apply the proposed estimation technique.

2 EMI Estimation Method

According to what discussed in [1], it is possible to estimate the radiation coming from a stacked assembly of sources through the application of the SWE technique and a suitable estimation algorithm. The SWE technique enables to express the radiation coming from a generic source in terms of spherical waves, thus determining its spherical wave representation through a set of proper coefficients. Once the expansion coefficients are known, the SWE technique can also be used to reconstruct the electromagnetic (EM) field at an arbitrary distance. The suggested workflow associated to the proposed estimation method is described by the diagram reported in Figure 1.

Basically, the EM field data characterizing each source is gathered through a proper measurement process (that is the main topic of this paper) and then, by applying the SWE technique, the spherical wave expansion coefficients (a pair of matrices, namely Q_{1mn} and Q_{2mn}) related to each source are computed. After this stage, the collection of all the computed SWE coefficients is mathematically combined to calculate the final coefficients associated with the radiation of the entire assembly. From them the total EM field is then computed.

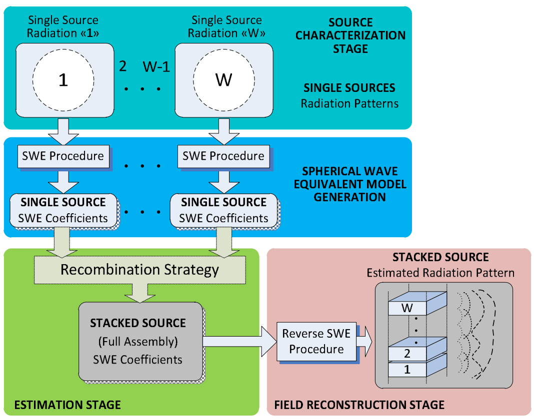

Figure 1. Principle scheme of the estimation method.

The recombination strategy of the SWE coefficients consists in the element-wise summation of the complex-valued matrices constituting the SWE coefficients of each single source, according to (1), where Q^{i}_{1mn}, Q^{i}_{2mn} stand for the pair of SWE coefficients obtained for the generic source indexed by i, with $i = 1,...,W$. W is the total number of stacked sources.

$$\begin{aligned} Q^{Tot}_{1mn} &= Q^{1}_{1mn} + \cdots + Q^{W}_{1mn} \\ Q^{Tot}_{2mn} &= Q^{1}_{2mn} + \cdots + Q^{W}_{2mn} \end{aligned} \tag{1}$$

The input data of the proposed methodology consists on the tangential electric (or, by duality, magnetic) field components E_ϑ and E_φ detected on a spherical surface at a given distance from the source. This distance, corresponding to the spherical surface radius, can be in the radiating near-field zone [5]. The procedure for measuring each source should be done using a spherical scanning and using a proper gridding of the spherical angle, i.e. angular step-size, in order to catch a suitable number of modes to have an accurate equivalent SWE representation of the radiation, as described in [1]. In particular the required number of modes can be calculated using the relationship (2), which relates N, the total number of spherical modes, to the physical dimensions of the source (the minimum measurement sphere radius r_0, and the propagation vector k associated to the frequency of interest); n_1 is usually set to be 10 according to [2]. The number of spherical modes N corresponds to the steps to divide the entire 0°-180° θ axis.

$$N = k \cdot r_0 + n_1 \tag{2}$$

Following the proposed estimation workflow presented in Figure 1 and referring to [1], a simulation case study can be taken as reference to provide a preliminary assessment of the effectiveness of the proposed estimation technique. The considered scenario refers to the prediction of the radiation coming from two sources, representative of generic server machines, when they are stacked together into an overall assembly mimicking a server rack.
The two sources considered consist of two types of different radiating structures, as sketched in Figure 2. One source is a simple microstrip running on a printed circuit board (PCB) having the geometry detailed in Figure 2a), it is indicated as "Source-M"; another kind of source is the one described in Figure 2b), consisting of a patch antenna designed to have 50 Ω input impedance and resonance at 8 GHz ("Source-P"). Both PCB sources have been enclosed in a metal shielding with only one open side, toward the positive y-direction, trying to represent the real metal structure of a server tray. The two sources can be assembled in the structure depicted in Figure 2 c), d) which is an attempt to mimic a simplified rack structure, it is referenced in the following as "Full Assembly".
The results coming from the application of the estimation technique proposed in [1] are the ones reported in Figure 3, where the three dimensional (3D) radiation pattern obtained from the numerical simulation of the entire rack-like structure (reference field), by using a commercial 3D EM Solver [6], is compared to the one that has been predicted applying the strategy resumed in Figure 1.

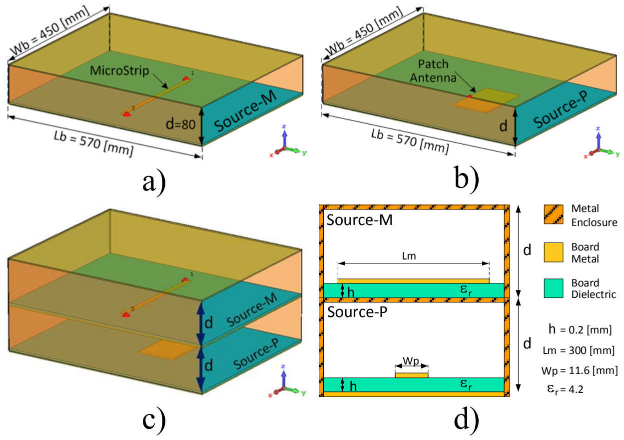

Figure 2. Structural details of the sources of interest: a) Source-M, b), Source-P, c), Full Assembly and section,d).

The E-Field data characterizing the radiation of each single independent source (i.e. standalone Source-M/Source-P) have been numerically computed simulating a virtual measurement process, whereas the radiation of the Full Assembly has been predicted through the proposed methodology in Figure 1.
As can be seen from Figure 3a) and b), the overall shape of the 3D radiation pattern is caught quite accurately, as well as the values assumed by the maxima. However, some differences are present in terms of spatial distribution of the local maxima, as highlighted from Figure 3c), d), where two main RP slices have been plotted for θ = 90° (equatorial plane XY), and ϕ = 90° (YZ). It is worth to note that, differently from the SWE application for antenna characterization, the prediction of EMI radiation does not require a very high precision, therefore few dBs of uncertainty can be acceptable.

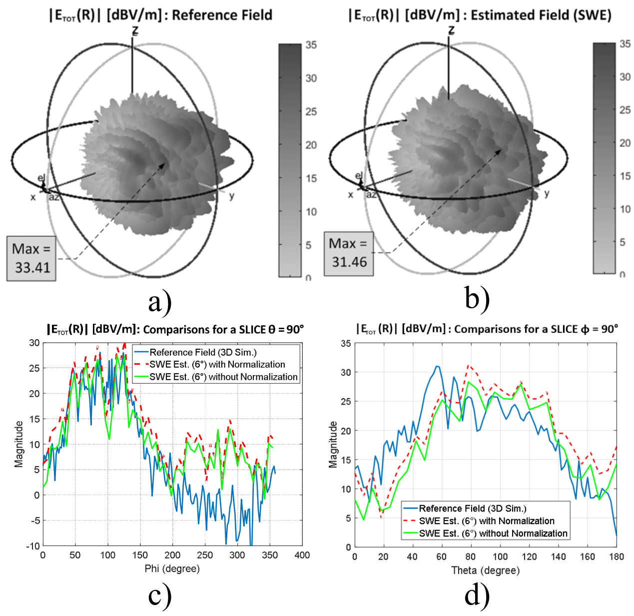

Figure 3. Radiation patterns of the Full Assembly: a), computed from 3D EM simulation, b), estimated from the proposed technique. Comparison of the reference E-Field versus the estimated one with and without coefficients normalization for two slices: c), θ=90° d) ϕ=90°.

According to the source dimensions in Fig. 2, and the frequency if interest (8 GHz) considered in [1], the spatial gridding to be used accounts for angular steps of 2 degrees, which can be fairly unfeasible for the practical implementation of the real measurements required by the estimation technique (16200 measurement points).
Because of this, a further study has been done to evaluate the impact of reducing the required number of samples.
The reduction of the number of measurement points corresponds to a lower number of modes caught). The results obtained for a downsampling from 2° to 6° has been reported in Figure 3c) and d), where it is compared to the original case ($\Delta\phi=\Delta\theta=2°$).
However, when reducing the number of angular samples the fast spatial field variations are not caught anymore, thus some high-order spherical modes are ignored; moreover, the largest radiation peaks may be missed, with a consequent error in the amplitude associated to each spherical mode. A solution to the latter problem is to properly rescale the SWE coefficients obtained from each single source. The scaling coefficient must be computed based on the measured Total Radiated Power (TRP).
This normalization step is based on the relationship between the SWE coefficients and the TRP, according to (3), as in [2].

$$\sum_s \sum_m \sum_n |Q_{smn}|^2 = |\upsilon|^2 = 2 \cdot \mathrm{TRP} \qquad (3)$$

Therefore, it is possible to rescale the SWE coefficients to obtain a new pair of coefficients $\tilde{Q}^i_{1mn}, \tilde{Q}^i_{2mn}$, for which the TRP value is maintained unaltered.
In the sub-panels c) and d) of Figure 3 the values of the E-Field calculated on 2 cutting planes have been reported, based on an angular step of 6° and with/without the proposed normalization.

3 Proposed Step-by-Step Measurement Procedure

The results obtained in [1], briefly recalled in Section 2, come from computer simulations as an attempt to achieve a virtual measurement procedure. However, in real experimental scenarios, there are plenty of issues coming from the implementation of real field scanning through a practical measurement setup.
By virtue of the normalization procedure introduced so far, the feasibility of real measurements has been brought to a concrete plausibility, strongly reducing the number of measurement points.
From a procedural point of view the following step-by-step measurement workflow can be proposed:

1. to measure the radiated field of each single source on a spherical surface in an Anechoic Chamber (AC), as reported in Figure 4; the probe has to be oriented coherently with the E-Field component to be recorded, i.e. E_ϕ and E_θ, and it has to be properly calibrated such that the probe factor can be readily removed from the measured raw data for getting the E-field values; alternatively, if the probe should be characterized in terms of its receiving coefficients, to be able to apply the more complex probe-calibrated SWE technique [7].
2. To measure the TRP of each single tray using a Reverberation Chamber (RC): it is required for accuracy enhancement in the case of large angular steps are required, compared to the ideal step from (2).
3. Application of the proposed EMI estimation method, as schematically illustrated in Figure 5.

Regarding the first step, supposing that a spherical scan has to be realized, if the AC will have the capability to implement cylindrical scans only, it is still possible to gather the data required by the proposed estimation technique. This can be done by applying the workarounds suggested in [1] (section 4.1: cylindrical-to-spherical scan transformation) but provided that the measurement setup possesses the so-called boresight capability, i.e. the probe is always pointing to the center of the radiation sphere.
Moreover, it is very important that the tray source is placed at the same position (elevation) that it has inside the full rack assembly (indicated in Figure 4 as Z_i, $i = 1,...,W$) during the spherical (or cylindrical) scanning .
In addition to this, there are also some other aspects that should be addressed, in particular: each single tray under measurement has to be actively working as if it was included into the full rack, the radiated emission has to be detected through a spectrum analyzer in order to record the EMI in a wide frequency range.

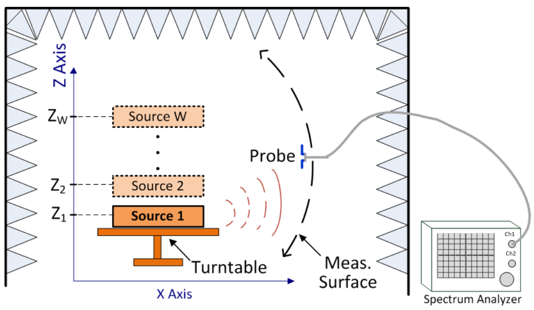

Figure 4. Measurement of the E-Field radiation using an anechoic chamber.

4 Steps for the Experimental Validation of the Estimation Method

Finally, the proposed estimation method can be validated also from an experimental point of view. In order to obtain such a kind of validation, it is required to execute the following two actions:

1. measure the radiated field on a spherical surface of the assembled sources (entire rack);
2. compare the results to the outcome of the EMI estimation method.

It is almost straightforward that the first point has to be executed taking into account what already highlighted in the previous section 3 regarding the measurement of the stand-alone sources. Furthermore, here we have to take care of assembling all the sources at the exact elevation used for stand-alone measurements and to operate the entire rack as if it was working in its nominal conditions, also the measurement points has to be maintained the same of the stand-alone measuring stage (number of points and position on the measurement surface).

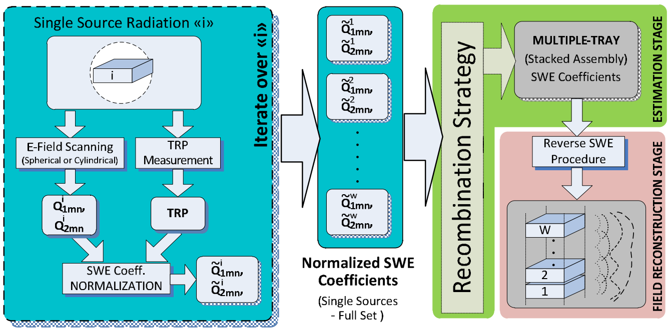

Figure 5. Complete Step-by-Step measurement procedure workflow.

5 Specific aspects for accurate Experimental Validation

In order to implement the proposed approach in reality, it is required to face some other measurement issues, which can have a relevant impact either on the accuracy of the method or on the feasibility of the workflow in Figure 1.
First of all, the execution of the measurements in the AC (either for the stand-alone sources or for the full assembly) by cylindrical scan shows the issue of missing data. In fact, due to the inherent positioning limits of the tower carrying the probe, the E-field dataset is inherently incomplete for low values of the elevation angle θ (toward the poles of the equivalent sphere). As discussed in [1], a possible solution to overcome this limitation is to complete the missing information with a zero-padded field in the region corresponding to the missing data (i.e. in proximity to the poles). This corrective action does not determine a loss of accuracy in the procedure, since the amount of field radiating in the Z direction is always very small by virtue of the metal enclosure surrounding the sources.
Another drawback is constituted by the difficulties in the acquisition of the correct phase information of the E-field measured in different spatial points at different times. In effect, the input of the SWE procedure is the complex-valued E-Field data (for both the two components E_ϕ and E_θ), since the phase relationship between two scanned points on the sphere is relevant. One methodology to solve this second kind of problem is to use a measurement setup accounting for two separate probes, a first movable one suited for the usual measurement scopes, plus another one, fixed, used as the reference for triggering purposes, as discussed also in [8].

6 Open Issues and Future directions

The estimation procedure recalled in this paper has been analyzed to set the base for its experimental validation. The most relevant aspects concerning the practical implementation of the SWE-based estimation methods have been discussed, and the most feasible solutions are proposed to make this methodology readily usable.
Once validated, the method can be extremely relevant to radiation prediction. To this aim, an extensive measurement campaign should be carried out to quantify the radiation from all possible types of tray, depending on their programmed functionalities. This allow to effectively apply the proposed method for a quick estimation of the radiation, and its minimization, while system engineers attempt to stack together the trays for filling up the whole rack.

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