Paradigm of sensitivity analysis in EMC stochastic enclosed environments

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Abstract

The aim of this contribution is to present a whole experimental methodology to assess the effects of uncertainties for a classical EMC issue. To this end, a cabinet was designed and achieved with controlled geometrical parameters including moving external slot and internal plate, an inner rotating unit embedded with stirrer and cable. From industrial expectations, the experimental setup and the theoretical basis will be described briefly. Then, the validation (convergence, accuracy and robustness) of the proposed stochastic methods will be obtained facing Monte Carlo (MC) measurements including three random parameters. Finally, the combination of stochastic techniques with sensitivity study will improve the global process.

1. Physical and industrial contexts

In the ElectroMagnetic Compatibility (EMC) literature, designing electronic large systems is mostly based upon “worst” cases approaches. In accordance with standards, this mainly sets two problems: the need for precise and efficient tools to quantify more realistic EMC margins, jointly with trustworthy reliability levels. Non-exhaustive state-of-the-art EMC stochastic issues contain different philosophies to integrate this problem for instance involving Printed Circuit Boards (PCBs) [1], cable coupling [2-3] and effects of uncertain High Intensity Radiated Fields (HIRFs) [3].

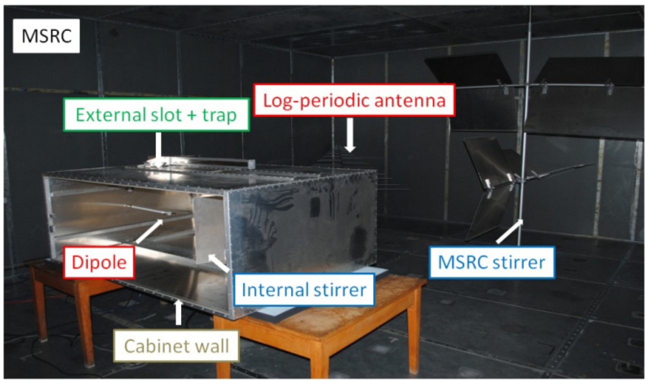
2. Materials and methods

2.1 Overview of stochastic measurements setups

The study presented in [4] detailed the design and achievement of a box including different geometrical parameters acting as Random Variables (RV). The governing idea was to manufacture a device providing mechanically various and precise configurations of the equipment. This allows defining different EMC classical setups involving different devices and outputs. Indeed, as depicted respectively in Fig.2-A and Fig.3-A, slots and inner volume modifications are allowed, and a rotating unit enables modifications around the location of different equipment (cable for instance). First, a spectrum analyzer Anritsu MS 2663C (bandwidth 9kHz-3GHz) has been used for power measurement (Figure 2). Then, S_{12} parameter (Figures 1 and 2) between emission and reception antennas is measured by a network analyzer Rohde & Schwarz ZVB 8 (bandwidth 300kHz-8GHz). A common strategy has been defined since the measurements were achieved in one go (no break); this has required a whole automation of the process (especially for MC treatments). Due to the similarity of the MC and Stochastic Collocation (SC) approaches (details in section 2.2), the statistical treatments required only to use the chosen points from this database.

2.2 Stochastic theory and sensitivity analysis needs

According to the SC foundations [4], the technique is close to MC philosophy since it only requires a smart sampling of input data and to straightforward apply the deterministic setup (numerical and/or experimental) from this set of points. The theoretical details and some chosen examples of SC weighted points sets may be found in [5] where the limitations of the method were presented. Due to the complexity inherent to EMC systems, many random parameters may be involved to precisely describe their global behavior. It could be quite inconvenient, time consuming or even impossible to access to large sets of data for multi-RV problems. That is the reason why Sensitivity Analysis (SA) (jointly with SC technique) should provide first qualitative results with a reduced cost comparatively to MC experiments. In this paper and from [5], we focused on Morris screening formalism (Fig.1-B) where the relative effect from each considered RV is computed regarding their mean $\langle\mu^*\rangle$ and standard deviation σ impacts. This allows to separate RV between stochastically important and negligible ones as described in Fig.1-B involving 4,000 measurements (Fig.1-A). In the following, the whole methodology (SA+SC) will be validated from MC experiments.



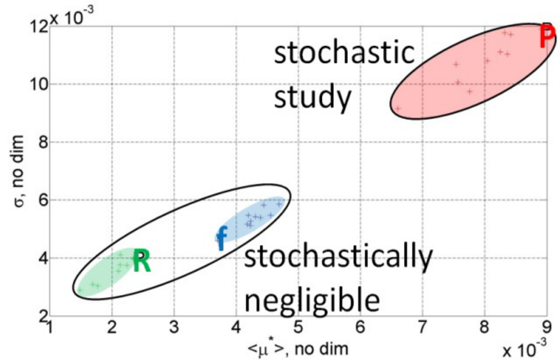


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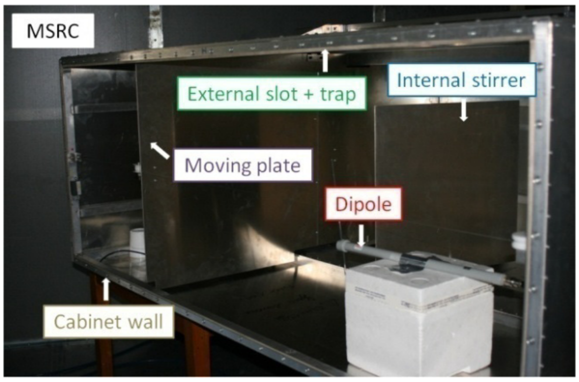
Fig.1: -A- Embedded box inside Pascal Institute (PI) MSRC with 3 random parameters: external trap (P), internal stirrer (R) and source frequency (f). -B- Ranking RV from screening design [5] and Fig.1-A setup.

3. Measurements and stochastic 1-RV results

This part will describe the "stochastic" experiments led in Pascal Institute (PI) laboratory (received power P_r and S_{12} parameter).

3.1 A first example: power variations inside cabinet due to moving plate (1-RV)



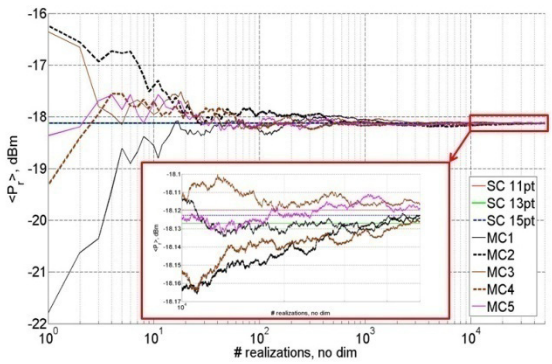


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Fig.2: -A- Inner view of the cabinet embedded with moving plate. -B- SC/MC comparison according to $\langle P_r \rangle$ inside the box (5mm uniformly distributed uncertainty around the 200mm-initial plate position) at 778.6MHz.

In the Fig.2-B, the results coming from different SC approximation orders (n) are given jointly with MC data. From a technique to another, different number and sets of points are needed to compute the mean value of the received power P_r according to experimental setup given in Fig.2-A. The efficiency and accuracy of AS for 1-RV case appear clearly since the convergence is achieved with 13 (SC order n=12) realizations comparatively to the 5 different MC sets obtained from 50,000 measurements. In the following, we will consider S_{12} parameter as a random output.

3.2 Measurements from random cable (1-RV) locations

The Fig.3-A describes the considered experimental setup: the precise location of an unshielded cable is controlled from rotating unit (the moving plate is placed at its initial position). The stochastic 1-RV model provides the mean and standard deviation dispersion according to different SC approximations (n=2, 4, 6, 8, 10). As described in Fig.3-B, 9 measurements are necessary to compute 1st and 2nd statistical moments from S_{12}. The standard deviation provides a quick but quantitative view of the model sensitivity: greater dispersion (2dB) around resonances frequency.

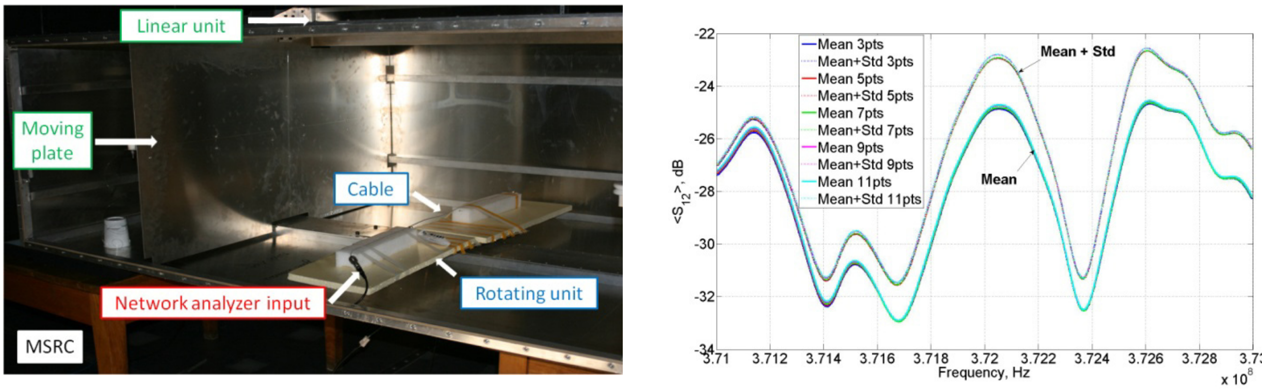

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Fig.3: -A- Stochastic box with moving plate and rotating cable. –B- SC results from $\langle S_{12}\rangle$ assessments inside the cabinet (2.5° uniformly distributed uncertainty around the 2.5° initial cable location) from 371 to 373MHz.

4 From sensitivity analysis to multi-RV model reduction

In this part, the model includes 3 random parameters according to Fig.1-A: rotating stirrer location (R), external trap opening (P) and source frequency (f). From [5], these data are stochastically modeled following

$$R = R^0 + \hat{u}_1^0, \qquad P = P^0 + \hat{u}_2^0, \qquad f = f^0 + \hat{u}_3^0, \tag{1}$$

with $R^0 = 15°$, $P^0 = 250\text{mm}$, $f^0 = 276.41\text{MHz}$ respectively the stirrer, trap and frequency central (mean) values. The RV $\hat{u}_1^0$, $\hat{u}_2^0$ and $\hat{u}_3^0$ are given a priori and without any loss of generality, they are uniformly distributed with zero mean following respectively U[13; 17] (in degrees), U[225; 275] (in mm) and U[276.40; 276.42] (in MHz).

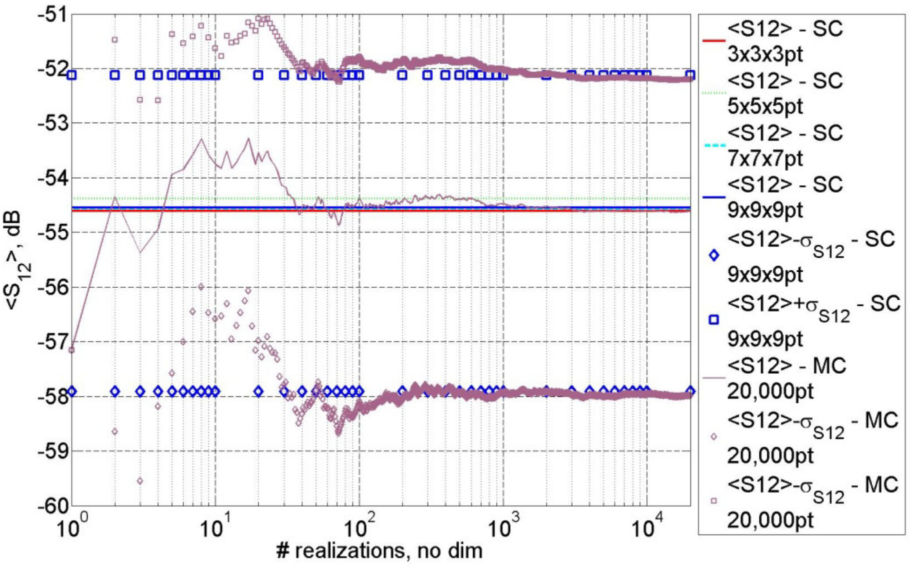

Fig.4: SC/MC convergences (S_{12} 1st and 2nd statistical moments) for "entire" random modeling (3-RV) from (1).

The Fig.4 shows the great agreement between SC results (including 729 measurements) and 20,000 MC data regarding the averaged value $\langle S_{12}\rangle$. Without any supplementary measurements, the SC and MC dispersions around $\langle S_{12}\rangle$ including ± one standard deviation are in accordance and provide a precise assessment of margins. Despite all, we may improve EM analysis of system from SA.

Consider now the results obtained from Morris model (Fig.5-A) including a weaker number of measurements (481) than in complete 3-RV modeling (Fig.4). Even if it is quite difficult to precisely separate random parameters, we may propose to reduce the models to the two interacting variables: P and f. The Fig.5-B show the results obtained considering $R = R^0$ in relation (1). In comparison with Fig.4, the mean and standard deviation of S_{12} fit very well, justifying the lower impact of RV1. The finer results obtained from Morris with 4,000 data confirmed this assumption (Fig.1-B). Moreover, a simple view of the problem may consist in regarding the S_{12} measurements obtained from extreme values of the random parameters and from their mean values (R^0, P^0, f^0). In Fig.5-B, these data are given respectively by pink, cyan and black curves. Obviously, these results may be relevant for this model given two hypotheses: the output mapping (S_{12} measurement) is linear and monotonic (which is rarely the case, especially regarding resonating issues) .It should be noticed that the use of previous straightforward model may lead to noticeable differences. Indeed, the average value obtained from mean input data shows a gap with SC/MC computing greater than 2dB. Finally, the margins given (Fig.5-B) by input low (pink) and up (cyan) boundaries are underestimated in comparison with calibers from $\langle S_{12} \rangle$ more or less three standard deviations (blue squares and diamonds).

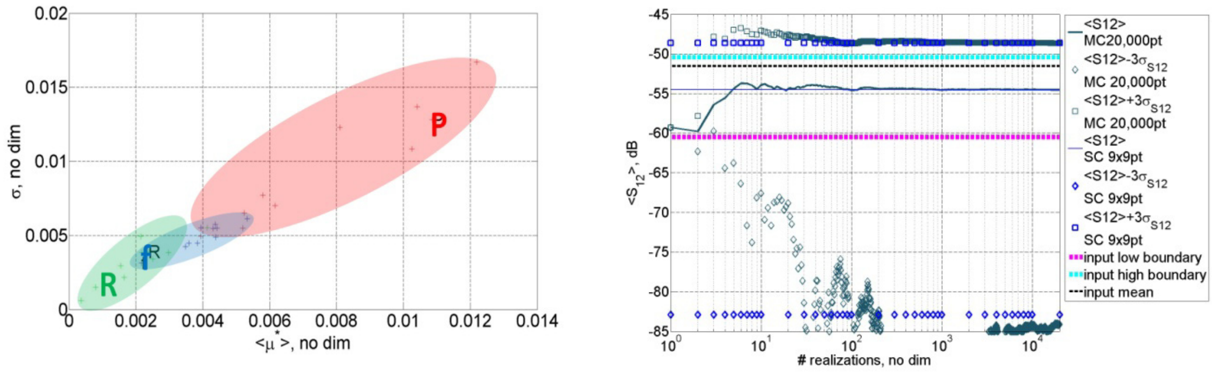

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Fig.5: -A- Ranking RV from "weak" Morris design. –B- SC/MC convergences (S_{12} mean and standard deviation caliber) for "reduced" 2-RV model.

5. Conclusion

In this paper, classical EMC problems were considered experimentally regarding random variations of geometrical and sources parameters. If integrating the randomness of parameters in simulations becomes a widely spread need in EMC community (academic and industry), the experimental assessment of uncertain variables requires the use of non intrusive techniques. The joint use of SC method and SA presented in this paper brings a smart solution improving MC requirements. Obviously, this remains one approach among many others (experimental design, unscented transform method, polynomial chaos, principal component analysis…) but the simplicity and efficiency of the proposed methodology made it very interesting to provide a probabilistic model useful for EMC reliability.

6. References

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