Analysis of complex environment effect on near-field emission

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Abstract. The article is dealing with uncertainty analyses of radiofrequency circuits electromagnetic compatibility emission based on the near-field/near-field (NF/NF) transform combined with stochastic approach. By using 2D data corresponding to electromagnetic (EM) field (X=E or H) scanned in the observation plane placed at the position \( z_0 \) above the circuit under test (CUT), the X field map was extracted. Then, uncertainty analyses were assessed via the statistical moments from X component. In addition, stochastic collocation based was considered and calculations were applied to planar EM NF radiated by the CUTs as Wilkinson power divider and a microstrip line operating at GHz levels. After Matlab implementation, the mean and standard deviation were assessed. The present study illustrates how the variations of environmental parameters may impact EM fields. The NF uncertainty methodology can be applied to any physical parameter effects in complex environment and useful for printed circuit board (PCBs) design guideline.

1. Introduction
The electromagnetic compatibility (EMC) and complexity are major factors susceptible to limit most of electronic system performances. So, relevant EMC emission analyses [1-3] were needed to predict the sources of the harmful perturbations especially during the electronic devices design phase. However, so far, few investigations were performed on the influence of emission near-field (NF) data accuracy for EMC applications. For certain use cases, slight design imperfections against severe EMC effects may involve drastic electrical degradations. Until now, not much existing work [4] was available for the inaccuracy investigation on planar circuit EMC emissions. In this paper, we are dealing with the consideration of potential uncertainties around relative electronic boards locations. We propose herein an uncertainty analysis based on the SC model introduced in [5] applied to planar EM data for the radiated EMC emission by using NF/NF transform [6-7]. To do this, the observation plane geometrical location is assumed as deterministic unknown with an infinite precision to assess the NF scanned data sensitivity analysis.

2. Theoretical methodology on the EM NF prediction and uncertainty estimation
To measure the electric (E-) and magnetic (H-) fields emission (denoted by \( X(x,y,z) \)) radiated by the circuit under tests (CUTs) supposed placed in \((Oxyz)\) Cartesian system coordinate, we use the NF scanner with synoptic overview presented in Fig. 1. However, the NF scanning can take more than one hour for sweeping observation surface with \( N_x \times N_y = 25 \times 40 \) samplings. Therefore, we intend to use the

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NF/NF transform $X(z)=f[X(z_0)]$ developed in [6-7] to extract the EM data $X(z)$ at any position $z$ from the given data $X(z_0)$ in the plane placed at $z=z_0$ in both the frequency- and time-domains.

2.1. Preliminary investigation on EMC NF emission

The NF/NF method exploited in this paper is based on the plane wave spectrum (PWS) theory [3]. The error vector magnitude (EVM) relative corresponding to an empirical example of this NF/NF transform are plotted in Fig. 2 for a CUT radiation in the observation plane placed from 2mm to 10mm. The EMC sensitivity analysis linked to this EVM was evaluated by using a stochastic model in function of the geometrical position whose mechanism and methodology are depicted in Fig. 3.

2.2. Mathematical approach for the uncertainty analysis under consideration

The proposed uncertainty analysis is fundamentally established with a polynomial approximation of given mapping data expressed by the variable $F$ which is supposed depending on a random parameter $Z=Z^0+u$ ($Z^0$ as initial value and $u$ as random variable (RV)). Firstly, we proceed with a $n$-order Lagrangian expansion of function $S \rightarrow F(Z^0,S)$:

$$ F(Z^0,S) = \sum_{k=0}^{n} F_k(Z^0) \cdot L_k(S), $$

with $L_k (k$ is a positive integer) is the Lagrangian polynomial and requiring $(n+1)$ SC points. Based on the demonstration in [5], this expansion can be defined with weighted coefficient $\omega_k$, set of points $S_m$. One of the most interesting properties of the Lagrangian basis relies on its reducing characteristic: $L_k(S_m)=\delta_{km}$ (Kronecker symbol) which justifies the parameter choice by greatly simplifying weights computing [5]. Hence, for instance, the mean and variance of mapping $F$ are written as follows:

$$ \langle F(Z^0,S) \rangle = \sum_{k=0}^{n} \omega_k \cdot F_k(Z^0) $$

$$ \text{var}(F(Z^0,S)) = \sum_{k=0}^{n} \omega_k^2 \cdot F_k^2(Z^0) - \langle F(Z^0,S) \rangle^2 $$

Table 1 addresses the calculated weights and collocation point coordinates for $n\{2,3,4\}$.

| SC order $n$ | Weights (no dimension) | Points (in mm) |
|-------------|------------------------|----------------|
| 2           | (0.277, 0.444, 0.277)  | (6.45, 8.00, 9.55) |
| 3           | (0.174, 0.326, 0.326, 0.174) | (6.28, 7.32, 8.68, 9.72) |
| 4           | (0.118, 0.239, 0.284, 0.239, 0.118) | (6.19, 6.92, 8.00, 9.08, 9.81) |

As figure of merit, the coefficient of variation (CV) is defined as the ratio between standard (std) and mean of EM field components. This approach relevance was checked with Matlab and use cases of EM scanned and simulated radiated data versus the observation plane positions.

3. Uncertainty analysis applications with experimental and simulation data

The Wilkinson power divider (WPD) operating at 1GHz and the arbitrary shaped microstrip line whose photo and HFSS 3D design are displayed, respectively, in Figs. 4(a) and 4(b) are considered as planar CUT1 and CUT2. The IRSEEM NF scanner monitored in Fig. 5 was used to generate the
measured scanned EM NF input data exploited in this investigation. It is worth noting that the NF/NF transform was validated experimentally and by EM computations with various structures [6].

3.1. Uncertainty Analysis of NF emission from the WPD

The numerical codes of the methodology shown in Fig. 3 was implemented and executed to provide a huge deterministic database with 6501 samples between \( z_0 = 2\) mm and 15 mm, step \( \Delta z = 2 \mu m \). Based upon computed NF data and in order to validate SC accuracy, we realised classical Monte Carlo (MC) simulations. By considering the stochastic modelling of random parameter \( z \) addressed in Table 1, we generate the first and second statistical moments of E-field components (same results without any additional cost for H-field) in Fig. 6 for \( z_0 = 2\) mm @ 1 GHz.

Table 2 summarizes the overview both of the convergence requirements (MC, SC) and SC precision considering relative differences of space averaged results over the entire scanning plan. In accordance with the relative gap existing between different MC realizations and various SC orders, the differences between means of E-fields are about 5\% by considering 10MC and 100MC simulations; they decrease of about 1.4\% averaging the results from 1000MC realizations. The good agreement between SC results (only 3 simulations needed with some ms computation time) and MC with 1000 realizations (relative gap around 0.05\%) demonstrates the SC accuracy and efficiency.

Table 2. Relative statistical (spatial mean value) gaps over entire \( E_x \) and \( H_z \) cartographies.

| Statistics from E-fields | MC10/100 | MC100 /1000 | SC3/MC1000 | SC3/SC5 |
|--------------------------|----------|-------------|-------------|--------|
| mean(\(E_x\))            | 5.71%    | 1.37%       | 0.05%       | 0.024% |
| std(\(E_x\))             | 5.20%    | 7.75%       | 0.67%       | 0.27%  |

The SC convergence of about 0.02\% is obtained by comparing data from SC orders \( n = 2 \) and \( n = 4 \) (SC3/SC5). Same remarks can be found from results for \( E_x \) and \( H_z \) std deviations, validating SC convergence for second statistical moment computing. Consequently, the accuracy results from Fig. 6 provide the system sensitivity, setting the focus on crucial locations. As expected, due to WPD radiation cartographies under consideration, most sensitive areas are centred around the WPD position.
3.2. Sensitivity analysis of microstrip line NF emissions

In this example, different cases showing how the SC may provide additional information are analysed. A set of deterministic results were computed over $z=5\text{mm}$ to $20\text{mm}$, $\Delta z=2\mu\text{m} @ 3\text{GHz}$. Without any lack of generality and in order to demonstrate the SC technique robustness, the uncertainty was modeled assuming a uniform distribution in Table 1. The SC precision remains very close to thousands of MC simulations with high convergence rate (relative gap between SC3 and SC5 around 1.5% depending on the EM components) and only 3 simulations are required to compute the mean value, std and CV. Fig. 7 provides the std and CV results for H-field, and lay emphasis on the most sensitive locations (due to random $z$-variations) with a quantitative assessment of expected effects. We can see that based on the cartography of the most sensitive areas which limits computing efforts, the H-field dispersion is around the mean value varies between 0.05A/m and 0.16A/m.

![Figure 7. Microstrip line (Fig. 4(b)) NF radiation analysis: H-field std (in top) and CV (in bottom) from SC3 @ 3GHz.](image)

4. Concluding remarks

A computational method of EMC emission uncertainty analyses established from NF/NF transform is investigated. The analytical approach illustrating the uncertainty model functioning principle is introduced based on the SC approach introduced in [6]. As application, non-intrusive, quick, precise and relevant sensitivity analysis of EM NF data radiated by microstrip circuits as WPD and interconnect line versus position are provided. This uncertainty analysis method is useful to check the geometrical inaccuracies influence on radiated EMC emissions during the design cycle.

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6. References

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