FE-Simulation of Stochastic Coupling of HPM-Pulses into Cables

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Abstract**—**This paper introduces a method to determine the coupling of high power microwave (HPM) signals into shielded cables based on the finite element method (FEM). The cables are considered to be exposed to pulses with randomly distributed parameters.

I. INTRODUCTION

To harden a device against backdoor coupling, e.g., in the context of intentional electromagnetic interference (IEMI) by HPM-signals [1], it is important to know how signals couple into electric cables. Hence, the purpose of this work is to identify the coupling of HPM-pulses into shielded cables by simulation. The goal is to determine the probability distribution of failure for single components. To this end, the following equations for the magnetic vector potential A

$$\nabla \times \frac{1}{\mu} \nabla \times A = \begin{cases} -\kappa \left(\frac{\partial A}{\partial t} + \nabla \varphi \right), \\ -\varepsilon \left(\frac{\partial^2 A}{\partial t^2} + \nabla \frac{\partial \varphi}{\partial t} \right), \end{cases} \tag{1}$$

with the Coulomb-Gauge and the electric scalar potential φ

$$\nabla \cdot A = 0, \qquad \Delta\varphi = 0 \tag{2}$$

are solved. Here, μ is the material's permeability, ε its permittivity, and κ its specific conductivity. The first part of (1) is the eddy current equation, which is valid inside the cable. The lower part is used outside the cable. As long as no currents are imprinted in the cables, the electric scalar potential can be set to zero. With this formulation, even ferromagnetic shields can be computed. These equations are numerically solved for pulsed waves with randomly distributed parameters incident on the considered cable.

II. METHOD

A. Discretization

The spatial domain is discretized using an edge-based FEM [2], which ensures tangential continuity between discretized elements and divergence free cell interiors. This part is implemented using the software package oFEM [3], an implementation of the FEM in MATLAB. The resulting system of ordinary differential equations is then discretized using the Newmark-beta method [4], yielding a fully discretized time stepping scheme.

B. Stochastic methods

The random HPM-pulses are parameterized by quantities describing their shape, amplitude, and direction. The multivariate joint probability density function (pdf) of these parameters is assumed to be known at least approximately. The resulting distribution of the induced current is determined by two different methods. First a Monte Carlo [5] simulation is applied to determine a reference by a well-known and established method. The second method aims at solving the problem deterministically. Here, the parameter space is partitioned with the help of a mesh, and for each simplex of the mesh the probability that a parameter combination belongs to it is computed. Finally, the FEM is solved for every grid point as input parameter to determine the domains of the interesting quantity corresponding to each cell in the parameter space.

III. DISCUSSION

The proposed methods are well suited to determine failure probabilities of individual components. While the Monte Carlo method converges stochastically with $\mathcal{O}(N^{-1/2})$, $N \to \infty$, where N is the number of model evaluations, we can show that the second method converges faster. Additionally, the experiments need not be repeated, since the pdf converges deterministically. This reduces the computational cost significantly. It is planned to implement techniques based on polynomial chaos expansion [6, 7], which should lead to faster computations in the context of a linear partial differential equation.

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