# FEM Computation in the Time Domain for Calibration of Electromagnetic Near-Field Scanning Technique

Susanne Bauer[1], Oszkár Bíró[1], Gergely Koczka[1], Andreas Gleinser[2] and Gunter Winkler[2]

[1]Institute of Fundamentals and Theory in Electrical Engineering, Graz University of Technology, 8010 Graz, Austria
susanne.bauer@tugraz.at
[2]Institute of Electronics, Graz University of Technology, 8010 Graz, Austria

**Near-field scanning techniques constitute an important procedure for the characterization of electromagnetic emission and immunity of integrated circuits (ICs) and printed circuit boards (PCBs). They pose a useful method to pinpoint areas of radiation or susceptibility which could influence the performance of devices nearby or the device under test itself. The electric- and magnetic-field probes used to gather the radiated near-field have an influence on the radiated field and therefore a calibration of the setup is necessary. This is done via a 3D-FEM-wave simulation in the time domain, stimulated with a Gaussian pulse, to gather the near-field behavior over the frequency range of interest. The numerically derived results can be used in the post processing to eliminate the probe influence on the measured results.**

***Index Terms*—electromagnetic compatibility, electromagnetic modeling, near-field scan, TD-FEM**

## I. Introduction

Techniques to improve the behavior regarding electromagnetic compatibility (EMC) of integrated circuits constitute a topic that becomes increasingly important since the operating frequency and the number of integrated transistors rises significantly.

Measurement techniques for scanning the radiated near-field of ICs or PCBs make it possible to identify areas of significant radiation that could lead to reduction of performance or even performance failures of the device itself or other devices in close vicinity.

A standardized method for this evaluation setup is proposed in [1] and [2]. A more detailed description is given later on.
For the measurements, different proposals for the electric- and magnetic-field probes are known but they can vary in the implementation. Therefore the influence of the used probes is not known per se and a calibration routine should be applied to gather reliable results. This can be done by the use of a three-dimensional finite element (3D-FEM) computation in the time domain. This is a useful tool to obtain results for the field components over the desired frequency range.

## II. The Surface Scan Method

Part 3 of IEC 61967 [1] provides a standard test procedure regarding the measurement of electromagnetic emissions of ICs.

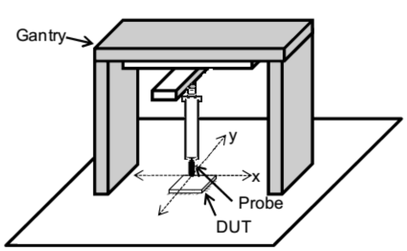


Fig. 1. Setup for surface scan measurement

It proposes a method for measuring the electric near-field distribution and the magnetic near-field distribution. The measurement setup is depicted in Fig. 1.

The probes can move in the *x*- and *y*-direction and the near field of the device under test (DUT) is scanned in a grid-like manner. The suggested probes used for measurements are shown in Fig. 2.

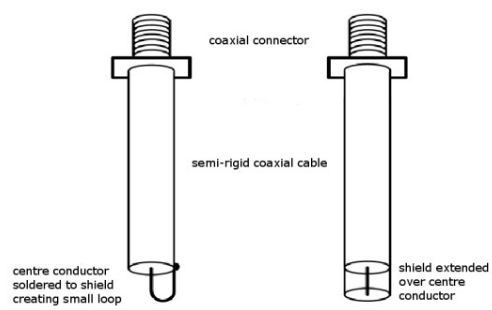


Fig. 2. Magnetic- and electric field probe construction

This procedure is capable of providing the detailed pattern of radio frequency (RF) sources internal to the IC.

The DUT for this calibration setup is a micro-strip line as proposed in [1]. The distance between the probe-tip and the micro-strip line is given with 1 *mm.*

## III. FEM Computation

The radiation characteristics of the given DUT are evaluated in a frequency range up to 1 *GHz*. For this purpose, a TD-FEM computation is carried out since the knowledge of the transient behavior enables the description of the desired frequency range. The frequency-components the signal consists of can be determined from this transient information by post-processing it via time-frequency analysis.

### A. *Maxwell Equations*

Ampere’s law in the time domain is given as:

$$\nabla \times \mathbf{H} = \mathbf{J} + \mathbf{J_0} + \frac{\partial \mathbf{D}}{\partial t} \tag{1}$$

where $\mathbf{H}$ is the magnetic field density, $\mathbf{J}$ is the current density and $\mathbf{J_0}$ is the impressed current density and $\mathbf{D}$ is the electric flux density.

Faraday's law of induction has the form

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{2}$$

with the electric field density $\mathbf{E}$ and the magnetic flux density $\mathbf{D}$. Gauss's law is given as:

$$\nabla \cdot \mathbf{D} = \rho \tag{3}$$

with the free space charge density $\rho$. Gauss's law for magnetism

$$\nabla \cdot \mathbf{B} = 0 \tag{4}$$

states, that the magnetic flux is solenoidal. Material relationships between the field quantities are given as:

$$\mathbf{B} = \mu \mathbf{H} = \frac{1}{\nu}\mathbf{H} \text{ and } \mathbf{J} = \sigma \mathbf{E}, \mathbf{D} = \epsilon \mathbf{E} \tag{5}$$

*B. **A**,v-Formulation*

A magnetic vector potential and an electric scalar potential are introduced as

$$\mathbf{B} = \nabla \times \mathbf{A} \tag{6}$$

$$\mathbf{E} = -\frac{\partial}{\partial t}\mathbf{A} - \nabla V = -\frac{\partial}{\partial t}\mathbf{A} - \frac{\partial}{\partial t}\nabla v \ . \tag{7}$$

The resulting second order hyperbolical partial differential equations for (1) and (2) are:

$$\nabla \times v \nabla \times \mathbf{A} + \frac{\partial}{\partial t}\sigma(\mathbf{A} + \nabla v) + \frac{\partial^2}{\partial t^2}\varepsilon(\mathbf{A} + \nabla v) = \mathbf{J_0} \tag{8}$$

$$\frac{\partial}{\partial t}\nabla \cdot \sigma\left(\mathbf{A} + \nabla v\right) + \frac{\partial^2}{\partial t^2}\nabla \cdot \varepsilon\left(\mathbf{A} + \nabla v\right) = 0 \tag{9}$$

The solution of the Galerkin equations by time-stepping is derived by the Newmark method and it leads to a system of equations of the form

$$[A]\{a_k\} + [B]\{\dot{a}_k\} + [C]\{\ddot{a}_k\} = \{b_k\} \tag{10}$$

Additionally the algorithm requires the displacement and velocity updated as

$$\{a_k\} = a_{k-1} + \Delta t_k\{\dot{a}_{k-1}\} + \left(\frac{1}{2} - \beta\right)\Delta t_k^2 \ddot{a}_{k-1} + \beta \Delta t_k^2\{\ddot{a}_k\} \tag{11}$$

$$\{\dot{a}_k\} = \{\dot{a}_{k-1}\} + (1-\gamma)\Delta t_k\{\ddot{a}_{k-1}\} + \gamma \Delta t_k\{\ddot{a}_k\} \ . \tag{12}$$

*C. Numerical simulation: time- frequency analysis*

The transient behavior of the system enables the description of the system behavior over a wide frequency range. For this purpose, a Gaussian pulse is used as an input stimulus. It is defined in the frequency domain and is then transformed into the time domain.

The required frequency range is assumed between $f_1$ and $f_2$. The central frequency $f_M$ and the bandwidth $f_W$ are derived as :

$$f_M = \frac{f_1 + f_2}{2} \ and \ f_W = | f_2 - f_1 | \tag{13}$$

The maximum amplitude in the center of the interval is 1 and the value on the boundaries is p.

Taking all conditions into consideration, the Gaussian-like pulse in the frequency domain is given as

$$U(f) = p^{-\left(\frac{2(f-f_M)}{f_W}\right)^2} \tag{14}$$

and the needed input function for the time domain computation can be retrieved by inverse transformation:

$$u(\mathrm{t}) = \int_{-\infty}^{\infty} U(f) \cdot cos(2\pi f(t - t_0))df \tag{15}$$

An example of the input function derived in this way is given in Fig. 3.

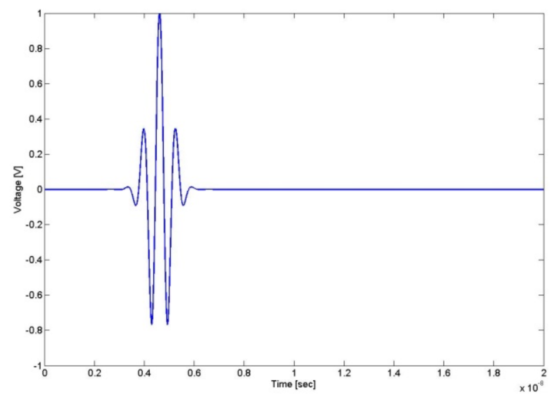


Fig. 3. Gauss-pulse in the time-domain

The obtained results are then post-processed with Fast Fourier Transform (FFT) to obtain the broadband spectrum of the radiated fields.

## IV. SUMMARY

The calibration of the used measurement setup is an important procedure to distinguish between the effectively measured field quantities and the actually radiated field quantities of interest without the distortion produced by the probes used. The full paper will present the evaluation and comparison of the computed and measured data.

## REFERENCES


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