Accurate and efficient FEM simulations of circular spiral planar inductors

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Summary. In this paper an efficient methodology to simulate electromagnetic devices involving circular spiral planar windings is illustrated. The numerical simulations are carried out by means of 2D axisymmetric finite element (FE) analyses to solve electrostatic and magneto quasi-stationary (MQS) field problems taking into account all parasitic effects, in order to obtain accurate results with a reduced computational effort.

1 Introduction

One of the more pressing objective of technology is to improve performances of electrical and electronic devices reducing their dimensions, weight, power consumption and cost. To achieve this goal miniaturization of devices components, increase of signals frequency and easy manufacturing are mandatory.
Integrated planar electromagnetic devices are widely applied and, in particular, spiral planar windings can be used as integrated inductors for RF systems [1], as antennas for wireless transmissions, in RFID applications, as HF transformers [2], for contactless energy transmission systems or as EMI filters [3].
In this paper, the performances of coreless planar spiral windings (CPSW) used as integrated planar EMI filter for limiting conducted emissions are investigated by means of numerical simulations. The simulations where carried out by means of FE analyses following an efficient strategy, described in section 2, that allows to obtain accurate results with a reduced computational effort. A prototype was realized and comparison between simulated and measured results were made as shown in section 3.

2 Finite element strategy

Electromagnetic planar devices are affected by several parasitic effects that influence their operation and performances. The increase of signal frequency produce an increase of the windings resistance due to the skin effect and to

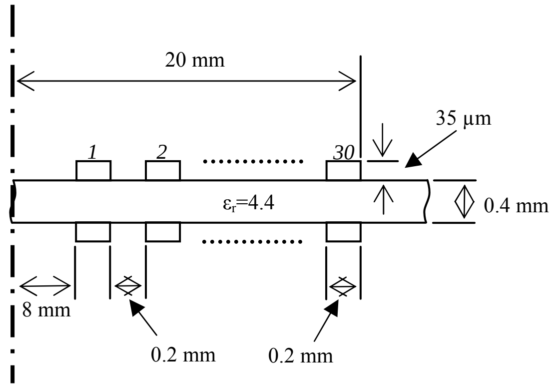

Fig. 1. Axisymmetric section of the prototype and geometric parameters.

the proximity of other conductors; the capacitive effects, that are negligible at low frequency, must be considered and they determines the frequency response of the device and its resonances.
In this work, a coreless EMI filter made by two circular spiral planar inductors drawn on a double face printed circuit board (PCB) is analyzed. To simulate the planar EMI filter, FE analyses were preferred to analytical models: since these models are often too simple and inaccurate especially to determine distributed turn-to-turn capacitances and the resistance in presence of skin and proximity effects. In order to consider all these effects, a full wave 3D FE analysis should be necessary but it requires a huge computational effort particularly if conductors must be discretized by means of a fine mesh.
In this work, authors present a strategy to carry out accurate FE simulations with an acceptable computational cost in terms of memory usage and CPU time.
This strategy consists in the following steps:

1) the real 3D geometry of the filter is approximated with an axisymmetrical one as shown in Fig. 1;
2) an electrostatic FE analysis is carried out by mean of FEM-DBCI [4] in order to calculate the matrix of capacitances [5] among all turns;

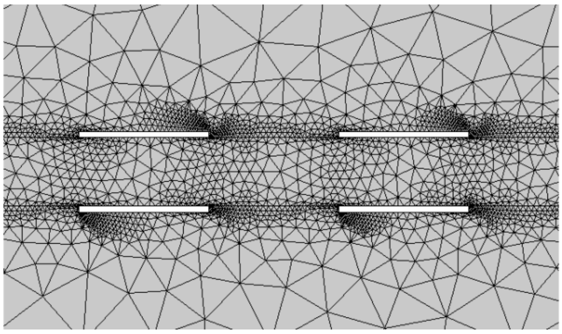

Fig. 2. FE mesh near conductors.

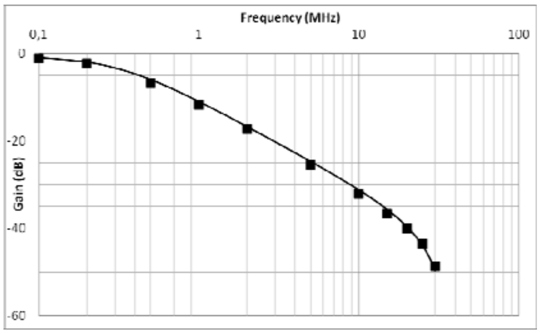

Fig. 3. Simulated (continuous line) and measured (marks) transfer gain for the CM filter.

3) MQS analyses [6] are then performed in the range 1÷30 MHz and the capacitive contribution is taken into account by means of concentrated capacitors connected between each couple of turns (circuit elements interface with finite elements).

Steps 2 and 3 were performed by means of a script that launched the FE analyses consecutively: first the electrostatic solution and then the MQS analyses in which all the capacitors are automatically inserted between each pair of turns.

3 Simulation results

Figure 2 shows a detail of the FE mesh for electrostatic analysis: in this case conductors are not discretized and a total of about 13,500 second order finite elements were used. In the MQS analyses conductors should be discretized according with penetration dept in order to have accurate results: to avoid the use of an adaptive meshing, the mesh with the right accuracy at 30 MHz was used for all the frequencies (a total of about 75,000 second order finite elements were employed).

All the computations were performed by means of ELFIN, an FE code developed by the authors [7]. The simulations runs on a PC (Pentium IV, 3,2 GHz, 4Gb RAM): they take about one hundred minutes. On the same machine it was impossible to complete a full wave 3D FE analysis of the real device, also using a coarse mesh inside conductors.

A prototype was realized on which several measures were performed.

Figure 3 shows a comparison between simulated and measured transfer gain for the CM filter: numerical results are in good agreement with measures.

Similar results were obtained for the DM filter.

More details and results will be given in the full contribution.

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