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Development of an electrical model for integrated magnetic inductors

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Abstract. Nowadays, the current trend consists in the development of new technologies with the aim of reducing volume, weight as well as production cost. With the aim of decreasing occupied component area, it will be interesting to use magnetic materials to confine the fields. Therefore, our works concern the modeling and the characterization of magnetic planar inductors. The proposed model is detailed for inductors fabricated with one magnetic layer. The model can take into account, the capacitance between turns and the capacitance between the last turn and the ground plane, the magnetic permeability, the skin and proximity effects of the conductors according to the frequency. The structure of optimization developed to extract the parameters of the model will be presented. Results of extracted parameters are compared with the simulation parameters. A good correlation is observed on Y_{11} and Y_{12} parameters on all the broad band frequency.

1 Introduction

Nowadays, the current trend consists in the development of new technologies with the aim of reducing volume, weight as well as production cost.

A solution to decrease the size of components would be to use magnetic materials to confine the field. Many authors were already undertaken in this direction [1-5].

By confining the field, new phenomena are necessary to take into account for the definition of an electric model [6-8].

The objective of this paper is to develop a model allowing to taking into account the Joule effect, the skin and proximity effects of the conductors, the coupling between windings and the magnetic permeability in order to extract the inductance value.

This paper is decomposed into three parts. First of one concerns the inductor process, then the developed model and the optimization algorithm are presented. The last part concerns results obtained by the model which were compared with the simulation results.

2 Magnetic inductors realization

Inductors are constituted by a magnetic substrate and a thin metallization layer. Inductors are realized using magnetic substrate of yttrium iron garnet (YIG). The YIG thicknesses varied between 100 µm to 1000 µm.

The metallization have been realized in copper by using an RF sputtering deposition. The thickness of the copper layer is equal to 5 µm. In order to obtain the design of inductor (figure 1), a photolithography process has been used.

To finish the inductor realization, a bonding is necessary to connect the central pad to the outside pad (figure 2).

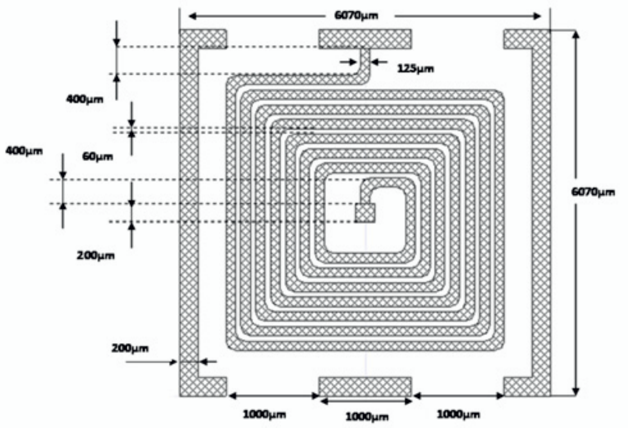

Fig. 1. Design of the magnetic inductor

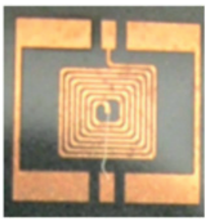

Fig. 2. Inductors realized with one magnetic layer

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3 Magnetic inductors modeling

In order to extract the device properties, it will be need to define an electrical model. Many authors [5-9] used an RLC model in order to take into account losses in the winding, the capacitive coupling and the effect of the substrate.

With the aim of improving this model, modifications are brought in order to take into account joule effects, skin and proximity effects in the conductors, the effect of capacitive coupling between turns of the winding and between the ground plane and the winding, and the effect of the magnetic permeability.

To achieve our goals the model shown in Fig. 3 has been developed. This model is composed of two RL inductors (L_1 in series with R_1 and L_2 in series with R_2). These two resistors represent Joule losses in the winding. The two parallel capacitors C_1 and C_2 represent the coupling between turns and the two capacitors C_m represent capacitive coupling between the coil and the ground plane.

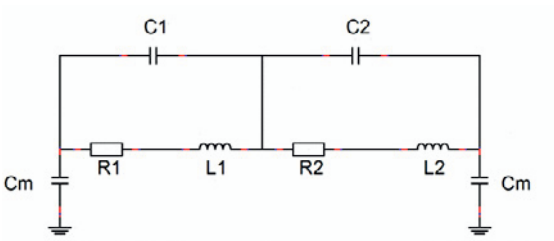

Fig. 3. Developed model

As the numbers of parameters are more important than equations, an algorithm optimization was set up.

This optimization is performed by comparison between the simulated (HFSS software) or measured values of impedance and admittance parameters (Y_{ij} and Z_{ij}) and the calculated values.

Simulations are realized by using the HFSS software based on the finite element method (FEM). This tool provides 3D electromagnetic field simulation and is well suitable to study high frequency components. This software generates a mesh for simulation according to geometry, material properties and some parameters that have been specified by the user. The simulation results are expressed as S_{ij} parameters. To analyze the simulation results, we use intermediate relations to obtain admittance or impedance parameters [10].

Measurements are realized by using a vector network analyzer (Rhode & Schwarz ZVA67) and a probing system with a prior OSTL calibration. S_{ij} parameters are obtained and intermediate relations are use as in simulation condition.

The optimization diagram of the program is shown in Figure 4:

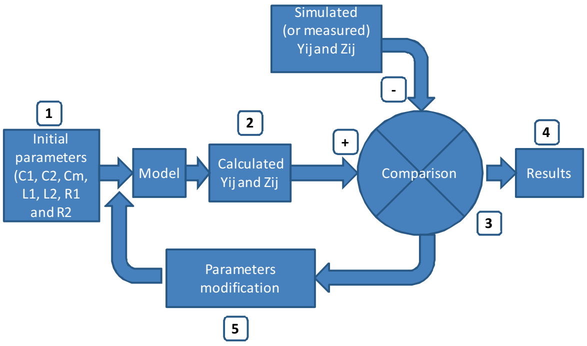

Fig. 4. Optimization algorithm diagram

The developed algorithm steps are the following:
Step 1: For each frequency the R_1, R_2, L_1, L_2, C_1, C_2 and C_m parameters are initialized.
Step 2: The software calculates the Y_{ij} and Z_{ij} parameters
Step 3: Simulated and calculated values Y_{ij} and Z_{ij} parameters are compared
Step 4: If the results are close enough, these values are retained for the given frequency
Step 5: If the results are unsatisfactory, the same cycle is repeated with slightly different parameter value.

4 Results and discussion

The develop algorithm allows for every frequency point to extract the different parameters of the electrical model. So to verify the good correlation between simulated and extract values, a comparison of Y_{ij} parameters are realized and represented figure 5 for an inductance constituted by a 500 µm YIG substrate. According to these results, a good extraction of Y_{11} and Y_{12} parameters are notified on all the frequency range (10 MHz – 1 GHz).

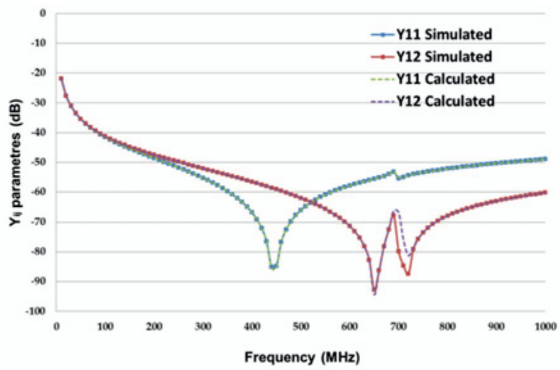

Fig. 5. Comparison of simulated and calculated Y_{ij} parameters

According to the table 1, the extraction of inductive parameters (L_1 and L_2) shows a decreasing value due to the magnetic permeability. In fact the magnetic permeability decreases when the frequency is superior to 100 MHz. At lower frequency, the magnetic permeability is equal to 45 and it reaches to 1 at higher frequency (1 GHz).

The resistive parameters (R_1 and R_2) increase according to the frequency due to the skin and proximity effects of the conductors consideration.

The capacitance parameters (C_1, C_2 and C_m) are constant on all the broad band frequency.

Table 1. Parameters extraction according to the frequency

Frequency (MHz)	L_1 (nH)	L_2 (nH)	R_1 (Ω)	R_2 (Ω)	C_m (fF)	C_1 (fF)	C_2 (fF)
10	86.3	99.6	1.1	4.8	480	790	190
100	86.2	99.6	4.5	23.1	480	790	190
300	85.6	99.5	81	42.7	480	790	190
500	84.6	99.4	10.74	56.2	480	790	190
800	82.2	99.1	13.6	72	480	790	190
1000	80.2	98.9	15.3	80.9	480	790	190

5 Conclusion

The objective of this work is to define a new electrical model allowing to taking into account the skin and proximity effects of conductors as well as the modification of the magnetic permeability according to the frequency.

An algorithm is performed, in order to extract all parameters of the model for every frequency point. A good correlation between extract and simulated values are observed.

These works open the way for study concerning magnetic components which present strong field as inductors constituted with two magnetic layers.

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