Improvement of EMI filters performance by taking into account frequency-dependant magnetic material properties.

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Abstract — Traditional EMI filters (ElectroMagnetic Interference), used to reduce differential (DM) and common mode (CM) noise flowing from SMPS (switching-mode power supply) to aircraft power network, has become a major issue to reduce the volume of power electronics equipment. New EMI filters based on a single component and able to reduce the both modes are proposed. To study such components, we need to take care of the DO-160 standard which imposes attenuation level and magnetic material performance in a large frequency range (10 kHz to 100 MHz). To predict and optimize the behaviour of the filter, an original computation model is developed. It is based on lumped electric, geometric and magnetic parameters and can even take into account the complex permeability behaviour with frequency. This tool, should allow the EMI filters performance to be improved. with respect to the DO-160 standard.

I. INTRODUCTION

In aerospace applications, the DO-160 standard requires the mitigation of electromagnetic interference according to specific templates. Two distinct sources of disturbances exist: common mode (CM) and differential mode (DM) currents. In general, each type of disturbance requires an adapted filter because the frequency ranges are well separated. Each filter has an inductance designed with winding modes and materials well suited to every need. To reduce the volume of power electronics equipment, the final objective is to design a filter that achieves mitigation CM/ DM with a single component. Several structures exist [1,2] or could be imagined, but to determine the best component they should be studied and compared. Thanks to measurements, the frequency dependence of magnetic permeability of the materials can be determined. However, no circuit simulation software permits, as far as we know, today to design the filter considering this practical behaviour. In this article, a robust method is proposed to achieve that. In a first part, we present the need to use a circuit simulation to describe the whole system defined by the DO-160 standards. We introduce also a model to reproduce the magnetic behaviour of the magnetic material used in the filter. On the other hand, we use a Matlab program which permits to modify some parameters of the circuit netlist thanks to measurements in order to take into account the frequency behaviour of some magnetic properties.

II. CIRCUIT SIMULATION SOFTWARE RESTRICTION

A. *Criteria of the DO-160 standard.*

The DO-160 standard imposes attenuation level at the LISN (Line Impedance Stabilization Network) input, that's why the first step was to design an electric circuit which describes the whole system (Fig 1).

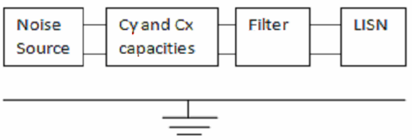

Fig. 1. Scheme of the filter characterization.

In the circuit simulation software, we described noise source, LISN as explained in DO-160 standard. Cx and Cy values are imposed by the Hispano-Suiza company. To describe magnetic materials, a dynamic flux tube model is used.

B. *Dynamic flux tube model.*

This model is based on the gyrator capacitor approach [3,4]. In this method, the mmf F is analogous to a voltage source, but the current corresponds to the *rate-of-change* of magnetic flux, $d\Phi/dt$. This quantity, which is called *the flux-rate*, is expressed in webers per second. For a given N turns winding, the coupling between electric and magnetic domains can be expressed by :

$$V = Nd\phi/dt \text{ and } I = \frac{F}{N} \qquad \text{(1) and (2)}$$

This can be easily represented by a gyrator. In the magnetic domain, the energy losses and storage can be related to R and C elements. R and C values are function of the geometric parameters of the core (cross section S, average length l), the pulsation ω, and the complex permeability

$$C = \frac{\mu_0.S.(\mu_{real}{}^2 + \mu_{imag}{}^2)}{\mu_{real}.l}. \qquad (3)$$

$$R = \frac{\mu_{imag}.l}{\mu_0.\omega.S.(\mu_{real}{}^2 + \mu_{imag}{}^2)} \qquad (4)$$

Thanks to this model, all the blocks are composed of resistors, inductors and capacitors. During an AC analysis simulation with circuit simulation software, each value (R, L, and C) are kept constant. This is a drastic limitation because material magnetic properties, like complex permeability, have a non-linear behaviour with frequency. However, no circuit simulation software, as far as we know, is able to make an AC analysis simulation with components or parameters that are frequency dependant. The solution, we propose here, consists in a co-simulation coupling the circuit software for the AC frequency resolution with a MATLAB® program which changes the netlist parameters.

III. CO-SIMULATION

A. *Principle*

Thanks to the circuit simulation software, we generate a netlist file which converts the scheme in a text file. In this file, we focus on the parameters that depend on frequency and replace the initial constant value by a variable. It is the case, for example, of the complex permeability. So the netlist should be modified for each frequency. This is achieved thanks to a developed MATLAB® program which updates the netlist for each frequency using measured data. Thus, at the end of the simulation, the real material or component characteristics were used.

B. *Test on a resonant circuit and a prototype.*

To test this method, we characterize two components separately with an impedance analyzer: an inductance and a capacitor. An L and C parallel circuit is created in the software and the netlist is generated. Then, the AC simulation is made using the measured L and C values. The impedance of the same circuit is also measured and the experimental results are compared to simulation. Another co-simulation is made using the flux tube model for the inductance and the three approaches are compared as shown in Fig. 2 The two simulation methods give the same results which constitutes a first verification of the flux tube model. A good agreement between the model and the measurement is noticed up to 1MHz. The divergence between the two resonance frequencies after 1MHz can be linked to the winding parasite capacitance and inductance. Indeed, at this frequency range, the capacitance is stable, so the variation of the second resonance frequency can be attributed to a parasite inductance (11nH).

In order to show the influence of the frequency on the effectiveness of the filter and the robustness of our method, we simulate the structure seen on Fig.1 by three different ways (see Fig.3). First, the filter is simulated with perfect coupled inductances, secondly, the filter is simulated with flux tubes associated with gyrators and constant permeability and the third way is the same as the second one except that the values of permeability change for each frequency. The values of the source noise are chosen so as to have equals repartition of the two modes. We noticed perfect agreement between coupled inductances system and flux tube model with constant permeability.

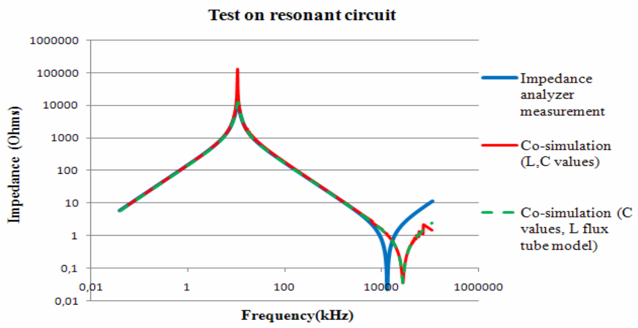

Fig. 2. Comparison between the impedance measurement and the result of the model.

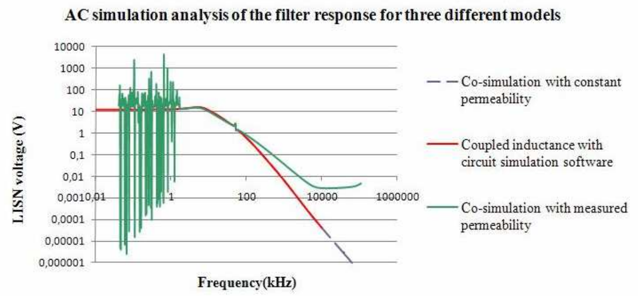

Fig. 3. Comparison between coupled inductance and non optimized EMI.

The third way shows that the LISN voltage is above the other ones (the filter is less efficient). This is due to the decreasing of the real permeability (the plateau after 1MHz corresponds to the very low values of the real permeability). More details about the model structure and the co-simulation will be given in the extended paper.

IV. CONCLUSION AND PROSPECTS

We developed an original computation model, based on lumped electric, geometric and magnetic parameters. Using this approach the complex permeability behaviour with frequency can be taken into account and the EMI filters performance with respect of the DO-160 standard can be improved. Indeed, with this kind of model, both geometric parameters and magnetic circuit can be optimized.

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V. REFERENCES

[1] Yamaguchi. Choke coil for eliminating common-mode noise and differential-mode noise, 1996.US patent 5,581,224
[2] Nan, L; Yugang,‘A Common Mode and Differential Mode Integrated EMI Filter’ 5th International Power Electronics and Motion Control Conference proceeding (2006) VOLS 1-3, Pages: 214-218
[3] D. Karnopp and R. Rosenberg, System Dynamics: A Unified Approach, 2nd Edition (Hardcover - Aug. 21, 1990)
[4] D.C. Hamill, “Gyrator-Capacitor Modeling: A Better Way of Understanding Magnetic Components’’, IEEE Trans. on Power Electronics, vol. 8, no. 2, pp. 97-103, Apr. 1993.