# Correlation between the near magnetic field radiated by an EMI filter and its electric working

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***Abstract*—In this paper, the behavior in radiated mode of an EMI filter used in speed drives is analyzed. It was identified as one of the main sources of magnetic near field radiation. On one hand, the EMI filter is located upstream from the speed drive and is the victim of the other radiation sources of the speed drive. On the other hand, these sources excite its parasitic elements and create new resonance frequencies. By analyzing input impedance and transfer function and magnetic field measurements, we tried to link the resonance frequencies of the amplitude spectra of the radiated magnetic field and the one of the electric characteristics.**

## I. Introduction

Measurement techniques that are usually used for the characterization of radiated and conducted emissions of power electronics are mainly concerned by the compliance with EMC standards. Actually, near field techniques constitute also an efficient approach to characterize complex radiating systems [1], [2]. However, near field scanning over a power electronic device is not referenced in standards, but it can be useful to estimate the characteristics of radiations and to locate spatially the sources of electromagnetic fields. From magnetic near field scanning measurements over an industrial device, an adjustable speed drive (ASD), three main radiating sources were identified : the switching mode power supply (SMPS), the inverter and the EMI filter. Each source was studied separately and a methodology was developped for correlating the near magnetic field radiation of each source and its electrical working. Both first sources studies were the aim of some publications [3], [4]. In this paper, the results about the EMI filter are presented. However, the approach is some different in comparison to both other sources (inverter and SPMS) because the EMI filter is the victim of these two sources and a radiation source. In a first paragraph, the methodology for linking the amplitude spectrum of the radiated magnetic field with the electrical working is briefly recalled. Then, the studied EMI filter is described and the measurements of its transfer function and input impedance are shown. In a third paragraph, the results for the EMI filter are presented.

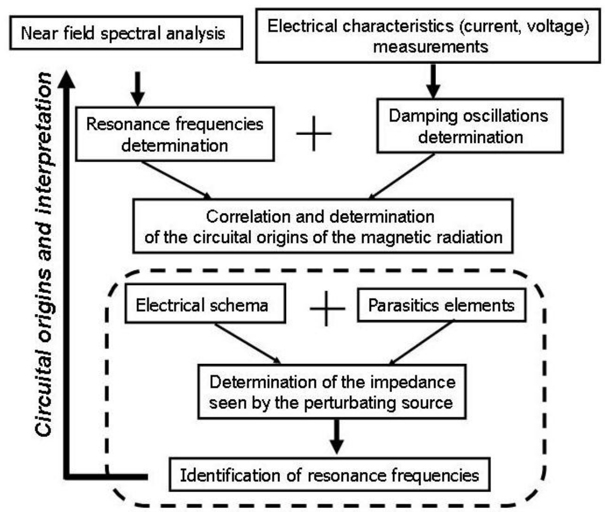


Fig. 1. Methodology

## II. Methodology

The followed methodology is shown on Fig. 1. In spectral domain, either the amplitude spectrum of the magnetic near field at a specific point over the ASD, either the near magnetic field at a specific frequency over all the ASD area can be measured [5]. From these measurements, the radiating sources can be located and the resonance frequencies, where the magnetic field amplitude is the highest, can be determined. In time domain, electrical characteristics, like currents and voltages, can be measured and the damping oscillations can be identified. By correlating these two kinds of measurements, the circuital origins (current) of the magnetic field by identifying the radiating current loop can be found. The second part of our methodology is to predict the resonance frequency. Indeed, from the electric schema and by integrating the parasitic elements, the impedance seen by the radiation source is

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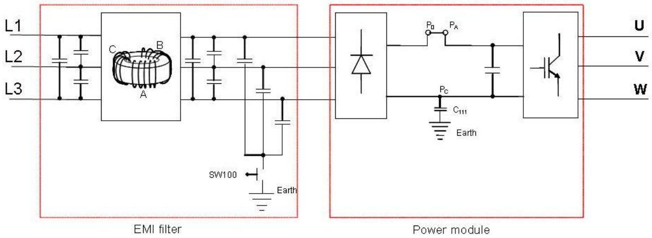


Fig. 2. Adjustable speed drive diagram

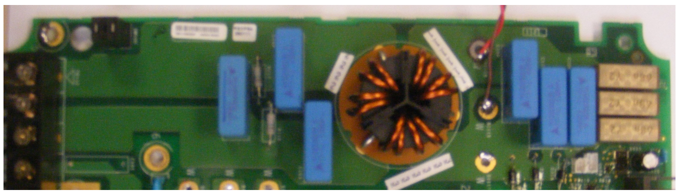

Fig. 3. Filter picture

calculated. The resonance frequency corresponds to a minimal impedance, then a maximal current and a maximal radiated magnetic field.

Both sources (SMPS and inverter) were studied by following this methodology. In both cases, the radiation differential current loop and some resonance frequencies were identified : 1.8 MHz and 4.5 MHz for the inverter, 450 kHz, 1.8 MHz, 4.5 MHz and 4.8 MHz for the SMPS.
In this paper, the application of this methodology on the EMI filter is presented, but only the part concerning the correlation between the radiated magnetic field and the electrical working. The part concerning the resonance frequency prediction is currently in progress.

## III. EMI FILTER DESCRIPTION

The studied EMI filter is inserted in the ASD, as it is shown in Fig. 2. It is a $\pi$-shaped EMI filter and it is constituted of six differential mode (DM) capacitors $C_x$, three common mode (CM) capacitors $C_y$ and a nanocrystalline CM inductor. All components are routed on a 4 layers PCB, one of the layer is a ground plane. To reduce the parasitic inductances of connections, the conductors are large, as it can be seen in Fig. 3. For economic reasons, the manufacturer has designed a three-phased filter, this topology is kept when the filter is used in a single-phased mains, which is our case; the third line is let open-circuited.

The EMI filter study is a little different in comparison to the study of the SMPS and inverter sources because it is the victim of these two sources. On Fig. 4, both sources are represented by a current source in parallel with a capacitor in the DM case and by a voltage source in series with a weak impedance in the CM case. These sources excite the parasitic elements of the filter and create new resonances, which will be analyzed. For this, both modes will be distinguished : common mode and differential mode.

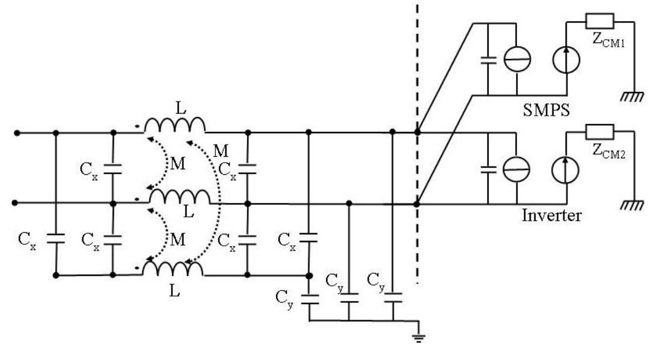


Fig. 4. EMI filter positioning regarding Flyback and inverter sources

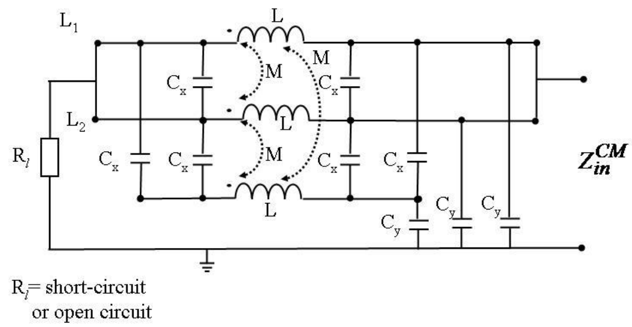


Fig. 5. Common mode input impedance measurement set-up

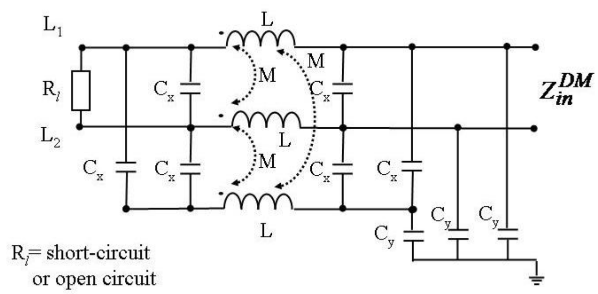


Fig. 6. Differential mode input impedance measurement set-up

## IV. RESULTS

### A. Electrical characteritics measurements

The EMI filter was characterized by measurements of its impedance and its transfer function. These measurements were achieved with the filter on the ASD, in order to take into account the PCB. The EMI filter was only disconnected it from the rest of the ASD. First, the input impedance of the filter seen by the sources by replacing mains supply by short-circuit and open circuit was measured. These measurements were performed for both modes, as it is shown in Fig. 5 and Fig. 6.

The modulus of the common mode impedance measured

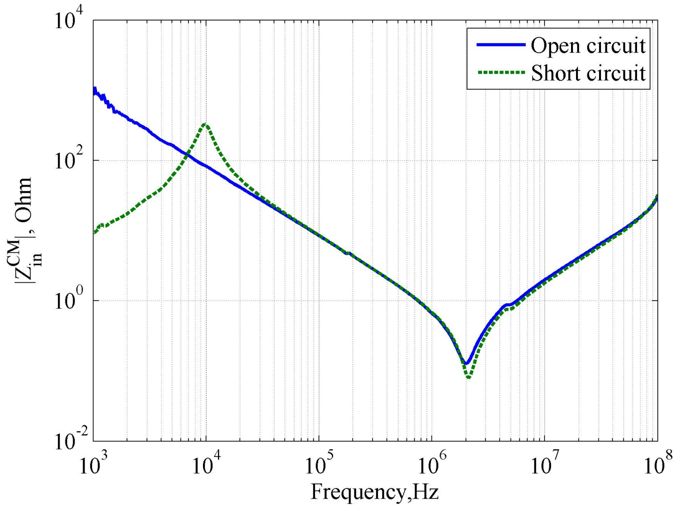


Fig. 7. Common mode impedance modulus of the EMI filter

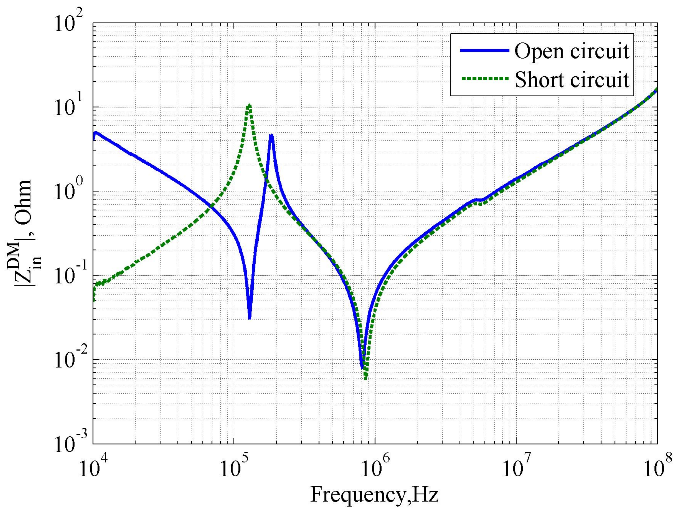


Fig. 8. Differential mode impedance modulus of the EMI filter

between the two phasis and the ground is presented in Fig. 7, as the modulus of the differential mode impedance measured between the two phasis is presented on Fig. 8. In common mode, a resonance at about 2 MHz is observed whatever the load configurations. In differential mode, a resonance at 130 kHz is noted when the filter is open circuited and a resonance at about 850 kHz, also present when the filter is short-circuited.

Secondly, the CM and DM transfer functions were measured as it is shown in Fig. 9 and Fig. 10. It has to be precised that the voltage $V_S$ is measured indirectly. In fact, the current in a 50 $\Omega$ load is measured by using a wide bandwidth current probe (Tektronix CT2), in order to ensure a good input/output decoupling. The voltage $V_s$ is deduced from the current measurement by correcting it with the probe factor $F_{probe}$. This method is an alternative to using balun.

The Fig. 11 compares the CM and DM transfer functions. The DM transfer function presents a resonance at about 130 kHz, found also on the input impedance. This can explain the

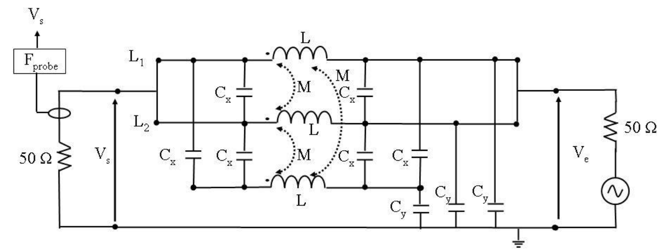


Fig. 9. Common mode transfer function measurement set-up

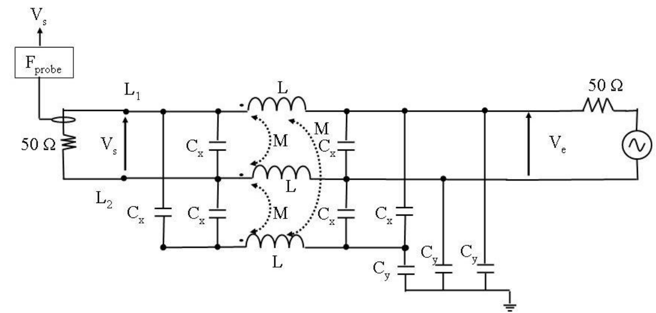


Fig. 10. Differential mode transfer function measurement set-up

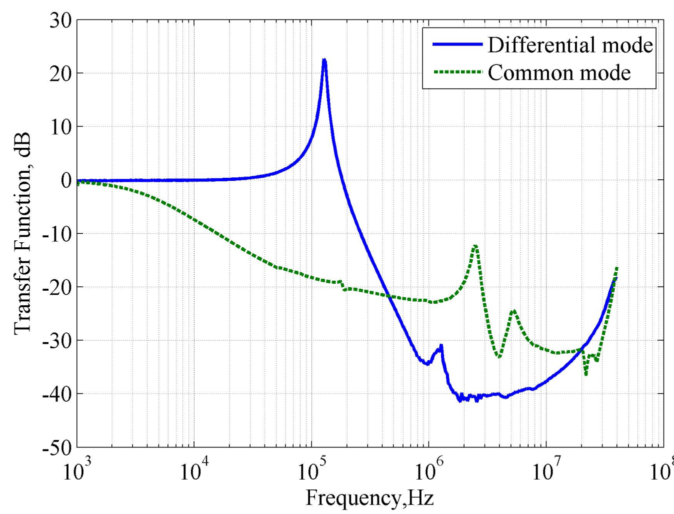


Fig. 11. CM and DM transfer functions comparison

decreasing of the filter efficiency in the standard frequency range. On the other hand, a decreasing of the CM attenuation due to the increasing of the impedance of the CM inductance can be observed. For the common mode like the differential mode, the EMI filter performance decreases with the frequency, because of its parasitic elements and the imperfections of its elements [6], [7].

### *B. Near field magnetic measurements*

At a distance of 1 cm on the vertical of the EMI filter, in the band [150 kHz-30 MHz], the magnetic field radiated by the ASD is measured for two configurations : first, the

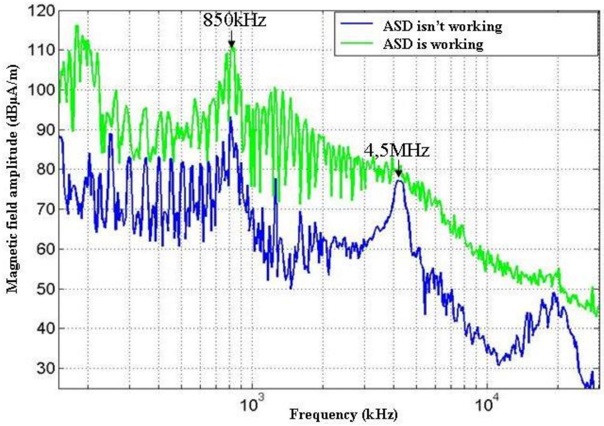


Fig. 12. Magnetic field spectrum

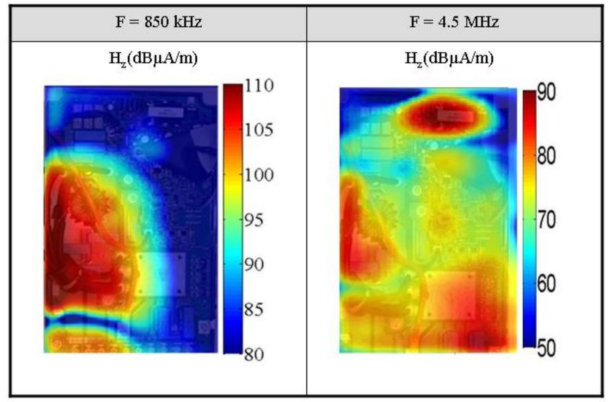


Fig. 13. z-component of the magnetic field $(dB\mu A/m)$

ASD is only supplied (the ASD isn't working) ; secondly, the ASD is working with a motor frequency $F_m$ equal to 50 Hz and an inverter switching frequency $F_d$ equal to 16 kHz. These two configurations allow us to distinguish both radiation sources : in the first case, only the SMPS source is active. The magnetic field spectrum of the component $H_z$, perpendicular to the plane of the ASD, is shown in Fig. 12.
Of course, an increasing of the amplitude of the magnetic near field is noted, when the inverter switches. On the low frequency band of the spectrum, when the ASD is only supplied, the spectrum lines linked to the SMPS switching can be seen. They become less visible, when the ASD is working, due to the inverter harmonics and switching noise, that mask the SMPS ones. The resonance at 4.5 MHz is an example of this phenomenon. On the other hand, the resonance at 850 kHz is strongly marked for the two configurations. This confirms that the origin of this peak is mainly in the EMI filter. It can also be supposed that the peak at about 150 kHz is linked to the filter too because it's a resonance frequency observed on the input impedance and the transfer function measurements.

Then, magnetic near field scannings were performed with our test bench at the identified frequencies : 850 kHz and 4.5 MHz. The surface scan is 16 cm x 28 cm to cover all the ASD surface and the near field probe height is settled on 3 cm, in order to be the nearest as possible the components over all the speed drive surface [2], [8]. The $H_z$ component of the magnetic field was measured and the obtained mappings are given in Fig. 13.

At 850 kHz, the magnetic field radiation is essentially concentrated over the EMI filter. The absence of radiation over the rest of scanning area allows us to conclude that this frequency is a frequency proper to the filter. The analysis of the input impedance of the filter in differential mode shows a resonance frequency at 850 kHz, that explains this behaviour.

At 4.5 MHz, the magnetic field radiation isn't anymore concentrated over the filter but over almost the whole scanning area. On the right bottom of the mapping, the radiation of a practically circular loop of 5 cm diameter, which corresponds to the dimensions of the resultant of the three switching cells of the inverter, can be noticed. It is a little distorted due to the motor cable radiation. On the right top of the mapping, the SMPS radiation, which switching frequency is equal to 50 kHz, is observed. And the radiation over the common mode choke and the $C_x$ capacitors of the EMC filter, located at the ASD input, is noticed. The EMI filter is victim of radiations due to the inverter and the SMPS. However, the quantification of this effect is complex to evaluate.

## V. Conclusion

A methodology for correlating the magnetic near field radiated by a power electronics device and its electrical working was developped. The study of an industrial ASD allowed us to identify three main magnetic radiation sources : the SMPS, the inverter and the EMI filter. The EMI filter study is different in comparison to the others because it is at the same time a radiation source and a victim of the other radiation sources. From input impedance and transfer function measurements, resonance frequencies were identified. Some of these frequencies appear also on the magnetic field amplitude spectra. Finally, magnetic field scannings at two representative frequencies have been shown : at 850 kHz, only the EMI filter radiates and at 4.5 MHz, the EMI filter is victim of radiations of the other sources. Our further work consists on predicting these resonance frequencies : from the electric schema of the EMI filter and by integrating the parasitics elements, the impedance seen by the radiation sources (SMPS and inverter) is calculated. The resonance frequency of this impedance should be the frequency where the magnetic field is the highest.

## References

[1] M. Hernando, A. Fernandez, F. Arias, F. Rodriguez, M. Las-Heras, "Radiated noise measurement system to estimate the EMI regulations compliance of a power electronic circuit",*Proceedings of IEEE International Symposium on Industrial Electronics*, on CD-ROM (2007).

[2] J. Aimé, J. Roudet, E. Clavel, O. Aouine, C. Labarre, F. Costa and J. Ecrabey, "Prediction and measurement of the magnetic near field of a static converter", *Proceedings of IEEE Symposium on Industrial Electronics*, Vigo, Spain, 2007.

[3] O. Aouine, C. Labarre, F. Costa and J. Ecrabey, "Modelling and Analysis of the Magnetic Field Radiated by a Switching Mode Power Supply", *Proceedings of IEEE International Conference on Industrial Electronics* , IECON 09, Porto, Portugal, 3-5 November 2009.

[4] C. Labarre, F. Costa, O. Aouine and J. Ecrabey, "Modelling and Analysis of the Magnetic Field Radiated by a Three Phased Inverter", submitted to IEEE International Symposium on Industrial Electronics , ISIE 2010, Bari, Italy, July 2010.

[5] O. Aouine, C. Labarre and F. Costa, "Measurement and modeling of the magnetic near field radiated by a Buck chopper", *IEEE Transactions on EMC*, vol.50, n$^\circ$2, pp 445-449, May 2008.

[6] H. Chen, Z. Qian, Z. Zeng and C. Wolf, "Modeling of Parasitic Inductive Couplings in a PI-Shaped Common Mode EMI Filter", *IEEE Trans. on EMC*, vol.50, n$^\circ$1, Feb. 2008.

[7] D.H. Liu, J.G. Jiang, "High Frequency Characteristic Analysis of EMI Filter in Switch Mode Power Supply (SMPS)", *Power Electronics Specialists Conference* , Volume 4, 2002 Page(s): 2039 - 2043.

[8] O. Aouine, C. Labarre, F. Costa, P. Baudesson and J. Ecrabey, "Identification of the radiated sources inside a variable speed drive from near field measurements", IEEE Symposium on embedded EMC, 2emc, Rouen 2007.