# Hard-less Common Mode Active EMI filter

D. Pérez, D. González, J. Mon, J. Balcells, J. Gago, P. Bogonez

Departament d'Enginyeria Electrònica. Universitat Politècnica de Catalunya.
daniel.perez-robles@upc.edu

***Abstract : Active EMI filters appear as an alternative to classical EMI filters based on passive components. Active EMI filters can provide more compact, cheaper and lighter solutions than passive approach. In this paper we present a theoretical analysis of the 4 possible configurations. Expressions of the transfer function and insertion losses considering impedances of mains and source of noise are presented. The voltage-current topology is identified as the more convenient solution. Finally, preliminary experimental results of a prototype capable to provide attenuation up to 100MHz are shown.***

***Keywords : Active EMI filter, power converters, conducted disturbances.***

## 1. INTRODUCTION

Specifications of power converters for on-board applications are a high specific power (W/cm$^3$, W/kg) and an excellent EMC performance. The classical way to fulfil the EMC requirements is the use of shielding and filtering techniques [1]. The commonly used EMI filters consist of bulky and heavy passive components (inductances and capacitors) that degrades the specific power of the converter+filter set. Some authors points that passive EMI filters represents about 20% of cost, weight and price of a power converter. Finally, the effective attenuation obtained with a passive filter is highly dependent of both the impedance of the mains and the source of noise.

Active EMI filters appear as a worthy alternative to the classical approach based in passive filtering. They can provide similar attenuations with less board space. On the other hand, the effective attenuation in a real application is less dependent of the mains and source of noise impedances. For this reason, it has been a subject of research in the last 10 years [2-7]. Nowadays some active EMI filters are commercially available [8]. Manufacturers claim for an attenuation above 20dB up to 30MHz.

On the other hand, common mode (CM) is very often the dominant mode of disturbances propagation in switched power converters. Therefore, most of the research on active EMI filters is focused in CM attenuation. Finally, EMC standards consider that conducted disturbances must be limited up to 30MHz. However, it is a well known fact that conducted disturbances exists above 30MHz and they are the origin of radiated disturbances up to frequencies of some hundreds of MHz.

Here we show preliminary results of our research addressed to obtain a hard-less CM active filter capable to provide noticeable attenuation of conducted disturbances up to 100MHz. The paper is organized as follows. In section 2, the theoretical analysis of the four feedback topologies is presented. Relationships among mains and source of noise impedances and both insertion losses (IL) and transfer function are obtained. Section 3 describes the prototype that has been built. Section 4 shows experimental attenuation results. In this section, the paper is summarized and future works are outlined.

## 2. THEORETICAL ANALYSIS

The general simplified common mode equivalent circuit is depicted in Figure 1.

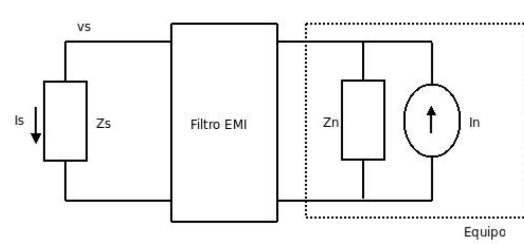


*Figure 1: General simplified equivalent CM circuit*

In Figure 1, $Z_s$ represents the mains impedance. In our research it was set equal to the LISN impedance. Current $i_s$ is the disturbing current that reaches the mains and should be attenuated as much as possible by the filter. The source of noise is represented by means of a Norton circuit that consists of a current source $i_n$ with an impedance $Z_n$ in parallel.

The transfer function, $FT(j\omega)$, of the active filter is calculated according to (1)

$$FT(j\omega)=i_s/i_n \qquad (1)$$

Insertion losses, IL$(j\omega)$, are calculated according to (2)

$$IL(j\omega)=v_s^{0}/v_s \qquad (2)$$

where $v_s^{0}$ and $v_s$ are the disturbing voltage at the mains side without and with the filter attached, respectively. The relationship between IL$(j\omega)$ and $FT(j\omega)$ is given by (3)

$$IL(j\omega)=\frac{Z_n}{Z_n+Z_s}\frac{1}{FT(j\omega)} \qquad (3)$$

Figure 2 shows the four possible topologies for feedback configurations.

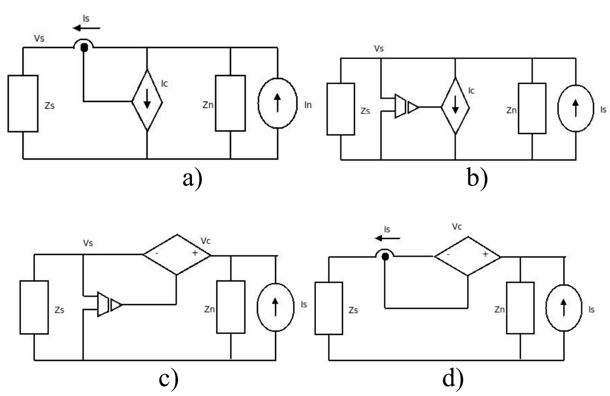


*Figure 2: Feedback topologies*

*a)I-I ; b) V-I; c)V-V; d)I-V*

The transfer function and insertion losses of these topologies are summarized in Table I and II respectively. In Table I and Table II, parameter $A$ represents the gain of the feedback loop. It is understood that $A$, $Z_n$ and $Z_s$ are frequency dependent functions.

**TABLE I. TRANSFER FUNCTION**

| Topology | *FT(jω)* |
|---|---|
| I-I | $\dfrac{1}{\frac{Zn+Zs}{Zn}+A}$ |
| V-I | $\dfrac{1}{\frac{Zn+Zs}{Zn}+A\cdot Zs}$ |
| V-V | $\dfrac{1}{1+(1+A)\cdot\frac{Zs}{Zn}}$ |
| I-V | $\dfrac{1}{1+\frac{Zs}{Zn}+\frac{A}{Zn}}$ |

**TABLE II. INSERTION LOSSES**

| Topology | IL*(jω)* |
|---|---|
| I-I | $1+A\cdot\dfrac{Zn}{Zn+Zs}$ |
| V-I | $1+A\cdot\dfrac{Zn\cdot Zs}{Zn+Zs}$ |
| V-V | $1+A\cdot\dfrac{Zs}{Zn+Zs}$ |
| I-V | $1+A\cdot\dfrac{1}{Zn+Zs}$ |

From results shown in Table I and in Table II the following conclusions can be derived regarding each topology.

- Current-Current (I-I): it is especially suitable in case that $Z_n$>>$Z_s$ and needs a high value of $A$.

- Voltage-Current (V-I): it provides a better $IL$ than topology I-I.

- Voltage-Voltage (V-V): it is especially suitable in case that $Z_s >> Z_n$ and needs a high value of $A$.

- Current-Voltage (I-V): it provides a better $IL$ than topology V-V.

## 3. FILTER DESCRIPTION

The filter prototype was implemented according to a voltage-current feedback topology, as it is shown in Figure 2b. This topology has several advantages in front of feed-forward topologies [9]. First of all the measurement and injecting stages are made with capacitors, which have a better frequency response than inductances. On the other hand, the volume, size and weight are also smaller than other options. Figure 3 shows the schematic of the implemented prototype.

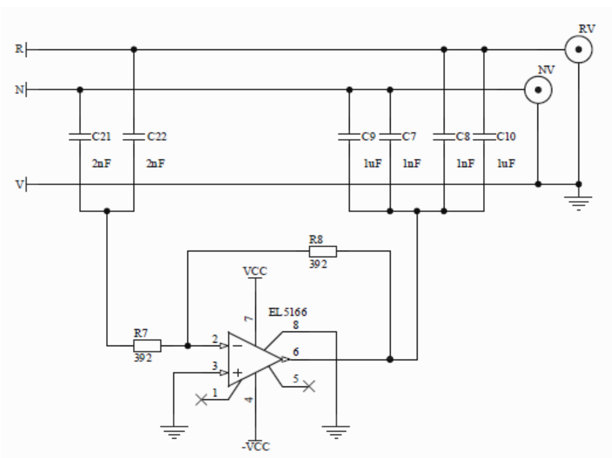


*Figure 3: Active EMI filter schematics*

The amplifier is a current feedback amplifier EL5166 from Intersil [10]. The gain of this stage is -1. It should be paid attention to the bandwidth and slew-rate of the amplifier. The values of these features are 1.4GHz and 6kV/µs, respectively.

The prototype is shown in Figure 4. A LISN has been implemented in the same board to guarantee the repeatability of the measurements.

Special attention has been paid to the PCB design in order to minimize stray inductances that could lead to a bandwidth reduction. The bottom plane of the PCB, which is connected to the middle point of the LISN, is the reference plane that is used to have a good coupling for CM disturbances. In this prototype, the amplifier was powered through external batteries in order to avoid stray couplings.

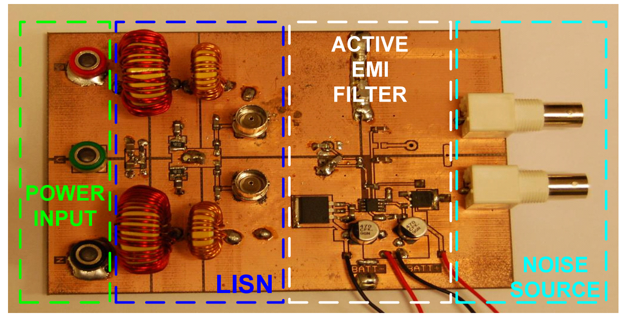


*Figure 4: Implemented prototype*

## 4. RESULTS AND FUTURE WORKS

Figure 4 shows the CM attenuation up to 100MHz.

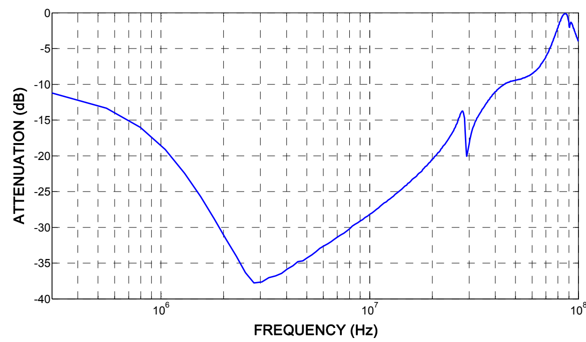


*Figure 4: Attenuation plot up to 100MHz*

The attenuation performance has been tested injecting a sinusoidal waveform between the two live wires and the ground plane. As it can be seen in Fig. 4, a minimum attenuation of 10dB is obtained up to 50MHz. The behaviour of the filter in the range from 50MHz up to 100MHz should be improved.

The next step in our research is to obtain a complete model of the active EMI filter. This model must consider all stray impedances of the prototype and a thorough description of the measuring and coupling sections of the filter and the amplifier as well in order to gain insight about the behaviour of the full system.


## ACKNOWLEDGMENTS

Authors would gratefully acknowledge the support of the Ministerio de Ciencia e Innovación in the frame of project TEC2011-25076.

## 5. REFERENCES


[1] Biela, J.; Wirthmueller, A.; Waespe, R.; Lobo, M.; Raggl, K.; Kolar, J. W.; “Passive and Active Hybrid Integrated EMI Filters”. Power Electronics, IEEE Transactions on, Vol. 24, No. 5, May 2009.

[2] Chen, W.; Zhang, W.; Yang, X.; Wang, Z.; “An Experimental Study of Common- and Differential-Mode Active EMI Filter Compensation Characteristics”. Electromagnetic Compatibility, IEEE Transactions on, Vol. 51 No. 3, August 2009.

[3] Hamza, D.; Jain, P. K.; “Conducted EMI Noise Mitigation in DC-DC Converters using Active Filtering Method”. Power Electronics Specialists Conference, PESC 2008, June 2008. p. 188-194.

[4] Mainali, K.; Oruganti, R.; “Design of a Current-Sense Voltage-Feedback Common Mode EMI Filter for an Off-line Power Converter”. Power Electronics Specialists Conference, PESC 2008, June 2008, p. 1632-1638.

[5] Mortenson, N.; Venkataramanan, G.; “An Active Common Mode EMI Filter for Switching Converters”. Industry Applications Society Annual Meeting, IAS 2008, October 2008, p. 1-7.

[6] Pairodamonchai, P.; Surapong, S.; Somboon, S.; “Design and Implementation of a Hybrid Output EMI Filter for High-Frequency Common-Mode Voltage Compensation in PWM Inverters”. Industry Applications, IEEE Transactions on, Vol. 45 No. 5, September/October 2009.

[7] Son, Y. C.; Liu, S. K.; “Generalization of Active Filters for EMI Reduction and Harmonics Compensation”. Industry Applications, IEEE Transactions on, Vol. 42 No. 2, March/April 2006.

[8] Picor Corporation, ”7 A Active EMI Filter for 24 Vdc Bus”. Application Note. 2008

[9] Zhu, M.; Perreault, D. J.; Caliskan, V.; Neugebauer, T. C.; Guttowski, S.; Kassakian, J. G.; “Design and Evaluation of Feedforward Active Ripple Filters”. Power Electronics, IEEE Transactions on, Vol. 42 No. 2, March/April 2006.

[10] Intersil Corporation, “EL5166 – EL5167 Datasheet” May 2007