ANALELE UNIVERSITĂŢII
"EFTIMIE MURGU" REŞIŢA
ANUL XXI, NR. 3, 2014, ISSN 1453 - 7397

Adina Racasan, Calin Munteanu, Vasile Topa, Claudia Pacurar, Claudia Hebedean

Improving Filter Performances for Conducted Electromagnetic Interferences Suppression

Improving the performances of a filter for conductive electromagnetic interferences suppression involves two major directions of action: the first direction refers to the increase of attenuation at high frequency, while the second direction refers to the suppression of the parasitic effects in the constitutive devices. Thus, in this light, the paper presents the authors' contribution to the two major directions of actions mentioned above; in the first part, techniques for HF loss increase are presented, while in the second part techniques for minimizing the structural parasitic capacitance are shown. In the third part of the paper these techniques are applied simultaneously to an EMI filter made in planar electromagnetic technology in order to study its performance.

Keywords: electromagnetic interferences, structural parasitic capacitance, HF losses, planar electromagnetic technology, EMI filters

1. Introduction in EMI filters

The modeling, characterization, designing and optimization of filters used for conductive electromagnetic interference (EMI) suppression are research topics of high interest internationally. Lately there is a growing interest in the design and optimization of EMI filters [1]-[3].

These filters are placed between the power supply lines and the input of the converter, in order to attenuate the common mode (CM) switching noise [4], respectively the differential mode (DM) switching noise, as represented in the structure of a typical distribution power system (DPS) presented in Figure 1.

As it can be seen, a DPS consists of a device for power factor correction (PFC) and the converter itself. PFC converts the active voltage AC from the input to continuous voltage DC at the output, in this case from 400V, and the DC/DC converter decreases this voltage from 400 V DC to the voltage value of 48 V DC for the power load [5], [6]. In order to meet the requirements of the standard EMI EN55022, Class B, an EMI filter is used in front of the PFC in order to prevent CM and DM noise propagation from the PFC to the AC line.

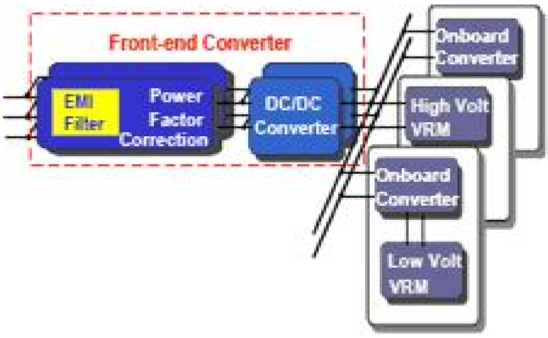
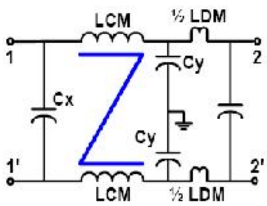
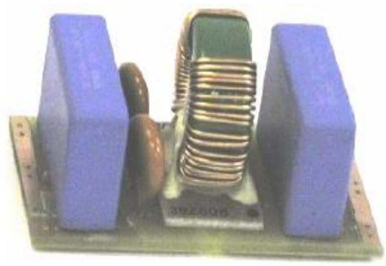


Figure 1. The structure of a distribution power system [5].

The scheme of a typical EMI filter realized in conventional manufacturing technology (often referred to in the literature as “discrete filters”) is presented in Figure 2(a). The image of such a prototype is shown in Figure 2(b). The EMI filter is made from a common mode (CM) coil, a differential mode (DM) coil, the common mode (CM) capacitors (so-called Y-caps) and two differential mode (DM) capacitors (so-called X-caps) [7].





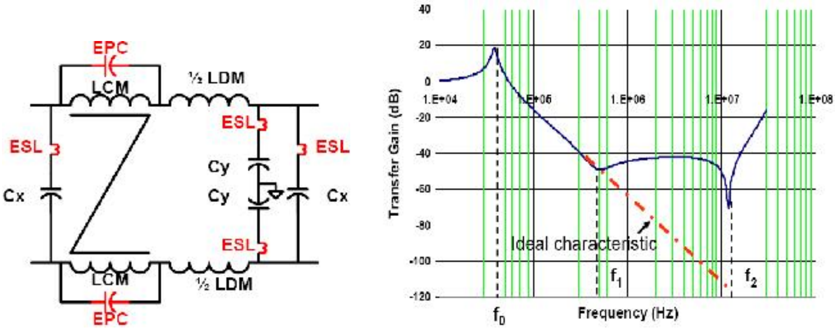
(a) equivalent electrical scheme (b) example of classical EMI filter

Figure 2. EMI filter realized in conventional manufacturing technology [8].

Inevitably all the EMI filters elements have parasitic parameters, such as the coil’s structural parasitic capacitances (SPC) and the capacitor’s equivalent series inductances (ESL). When the filter components are assembled on the plate and are connected with wires and routes, ESL and SPC will modify due to the electromagnetic coupling between the filter elements and the cable routes. Taken into account these parasitic elements, the first order approximation of the EMI filter equivalent circuit is presented in Fig. 3 [8].

In order to show the impact of the parasitic parameters on the HF characteristics of the EMI filter, the CM transfer functions of a discrete EMI filter is measured as it can be observed in Figure 3(b). On the measured CM transfer function graph presented in Figure 3, f_0 is the resonant frequency of the filter, determined especially by the CM inductance and the C_Y capacitance. Starting from the f_1 frequency, the curve of the measured transfer function differs from the ideal curve, variation caused by the appearance of the CM coil resonance, as an effect of the HF attenuation reduction. The HF attenuation is then lowered from the frequency f_2, where the phenomenon of resonance between the C_Y capacitances and their own ESL appears.

From the observations above we can conclude the fact that the HF characteristics of EMI filters are in fact essentially influenced by the parasitic parameters of the constitutive elements.



a) b)

Figure 3. The equivalent circuit of an EMI filter with parasitic parameters and the measured CM transfer function.

Thus, given the current requirements regarding limitation of the harmful emission driven in the supply network, the performance development of the EMI filters by introducing new implementation technologies able to remove the technological and performance barriers imposed by the devices used in conventional filters represents a current research theme of international importance.

The fundamental element of an EMI filter realized in planar electromagnetic technology is the integrated LC structure, more precisely the configuration type low-pass filter of it presented in Figure 4. Therefore, the improvement techniques of the EMI filter performances are first analyzed and developed on simple integrated LC structures in order to determine the optimum configuration of the structure which to stand at the basis of the EMI filter design.

2. Improving the performance of integrated EMI filter by increasing the HF conductor loss

For the accomplishment of the integrated EMI filters, great loss is sought for high frequency, and small loss for low frequency, respectively. To this end, the authors propose to use the technique of Conductor Nickel-plating, technique to be described below. Instead of using pure copper, the conductors can be made of metal layers. Figure 5 presents one of the configurations where a rectangular cross-section copper conductor is plated (metal-faced) with a thin nickel layer on its upper and lower surfaces.

Since the current always chooses the lowest impedance path, much of the current at work frequency will go through the copper layer, resulting in small losses at low frequency. For high frequencies, due to the skin and proximity effect, the common mode noise current (CM) and the differential mode noise current (DM) will go through the upper and bottom nickel layers. Conduction losses will practically grow exponentially with the growth of the thickness of the normalized conductor Δ = d/ δ. The penetration depth δ is given by the well-known relation:

$$¢ = \sqrt{\frac{1}{® f ±«}} \qquad (1)$$

where f is the signal frequency (Hz), σ is the conductivity (Sm^{-1}) and μ is the permeability (Hm^{-1}). Because nickel has a resistivity four times larger and permeability 100 to 600 times larger than copper, the penetration depth of the nickel is much smaller than the penetration depth of the copper for the same frequency [12].

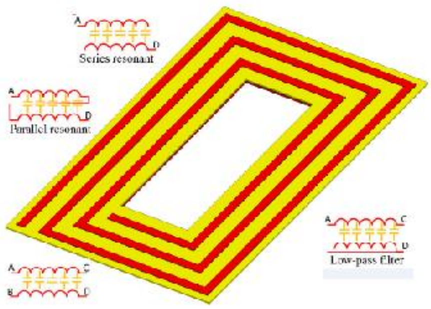


Figure 4. The fundamental element of EMI filter.

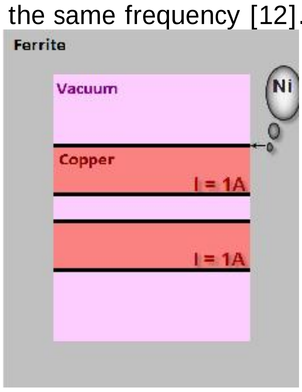


Figure 5. The model of two nickel-copper conductor coated s.

Thus, starting from these considerations, the nickel-plating technique tests for the conductors has been carried out on the simple model of the two conductors presented in Figure 5. Seven types of configurations were analyzed, each being tested for 9 frequencies with values between 100 kHz and 10 MHz; in total a number of 126 runs were made with the help of a numerical modeling program based on the finite element method. For an overview of all the configurations analyzed in Figure 6, a comparison between all the studied cases is presented [12].

From these representations it appears that the most efficient configuration for increased losses for the model consisting in two copper conductors positioned as shown in Figure 5 is the configuration in which the copper conductors are nickel plated on the inner surface of each conductor. Later on the present technology is to be extended to more complex structures.

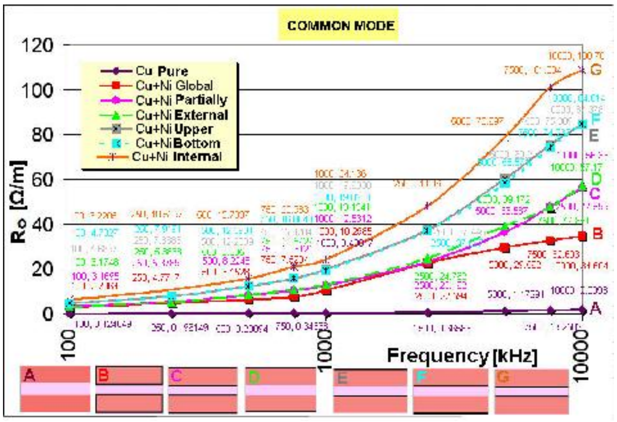


Figure 6. Graphs of variation of the high frequency losses.

Following the study of the literature and the conducted research made by the authors, in order to construct an EMI filter in planar magnetic technology, using an LC integrated structure with 3 turns on layer was considered. As follows, the results obtained after applying the nickel platting technique on the conductors on this structure, generically named Original Structure, is presented. This Original Structure consists on an integrated LC structure which contains a thick copper winding, a ceramic layer and a normal copper winding, respectively an auxiliary winding of copper as it can be seen in Figure 7. Every layer of winding is made up of 3 turns.

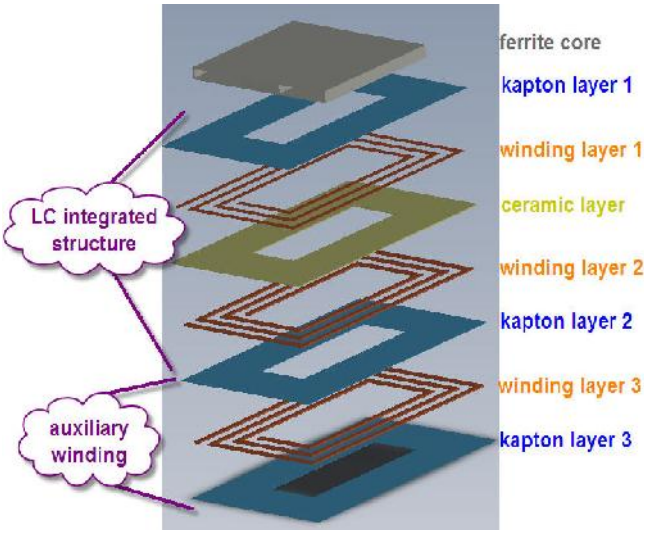
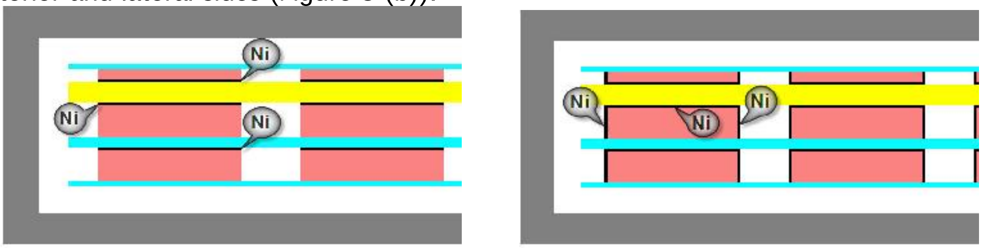


Figure 7. The Original Structure.

Taking into consideration the conclusions of the study on HF loss increase in the case of the model presented in Figure 5 for the case of two conductors [12], two strategies are proposed for the Original Structure, namely the method of nickel – plating the exterior surface of each conductor, and that of nickel – plating the exterior and lateral surface of each conductor. Consequently, in order to increase the HF losses, three types of configuration have been analyzed for the Original Structure, that is: pure copper conductors (Figure 7); nickel-plated copper conductors on the exterior side (Figure 8(a)); nickel-plated copper conductors on the exterior and lateral sides (Figure 8 (b)).



(a) nickel-plated copper conductors on the exterior side

(b) nickel-plated copper conductors on the exterior and lateral sides

Figure 8. Methods proposed for increasing the HF losses - Original Structure.

The total HF losses for each configuration of the simulated Original Structure are presented in Figure 9.

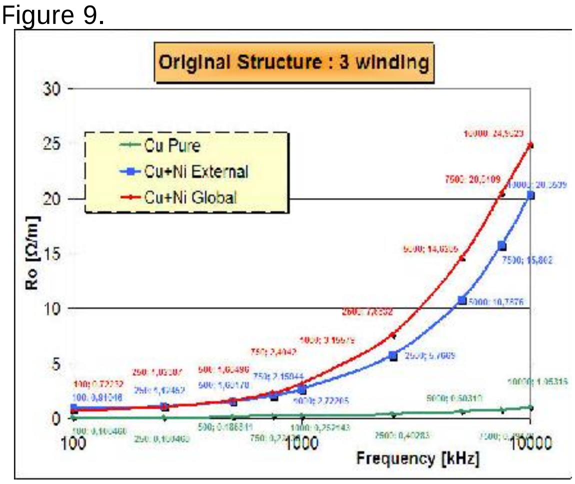


Figure 9. HF loss variation graph – the Original Structure.

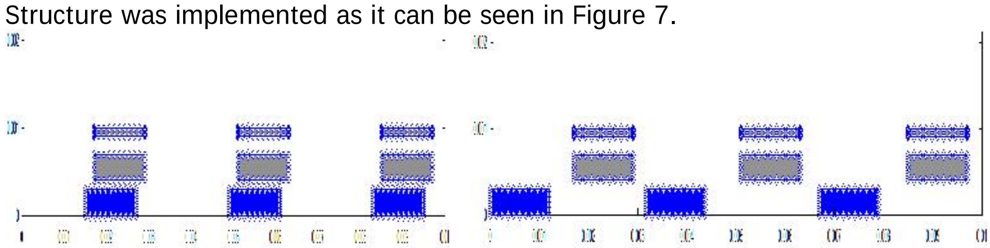
Looking at the graphical representation it can be observed that the most efficient method of nickel-plating of the copper conductor which constitute the Original Structure in order to increase the HF loss is represented by the method of nickel-plating the exterior and lateral surfaces of each conductor. Up to the frequency of 500 kHz there is no major difference between the two proposed methods, that is the method of nickel-plating of the exterior surface and the method of nickel-plating of the exterior and lateral surfaces, but once the frequency increases, the second method proves to be more efficient.

3. Improving the performance of integrated EMI filter by the suppression of the structural parasitic capacitance

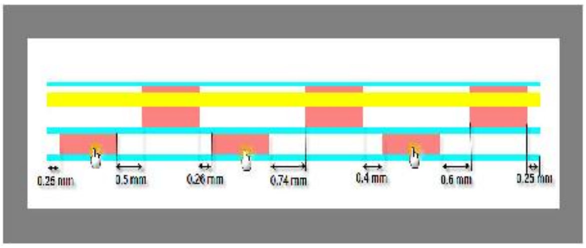
In what concerns the structural parasitic capacitance, dealing with structures of great geometric complexity, it can neither be defined through direct calculus relationships nor can it be localized in a certain device since it is practically distributed in the space between the coil windings which constitute the filter. Within the present paper, a new technique is proposed aiming at reducing the structural parasitic capacitance, namely that of applying an optimal geometric staggering between the coil windings. The optimum placement of the staggered coiling in the structure constitutes the subject of a study by means of optimal design using a specific numeric optimization algorithms created by the authors [13].

This program has been used for determining the optimal configuration of the Original Structure presented in Figure 7, a structure which, as was mentioned above, is to be used in the construction of the EMI Filters. Thus, in Figure 10(a) the bi-dimensional view of one half of the Original Structure is shown. This configuration has been introduced in the optimal design program implemented by the authors. Figure 10(b) shows the resulting optimal configuration. In order to highlight the optimum shifting of the conductors obtained from the use of the optimal design program developed by the authors, in Figure 10(c) a 2D view of a half of the Original Structure built in accordance with the optimal configuration obtained, clearly stating the optimal distances between any two conductors, is presented.

In order to test the obtained optimal solution (using the program implemented by the authors) and using partial capacitances, the model of the Structure with the shifted winding was forward implemented in a commercial 3D program for the numerical modeling of the electromagnetic field based on the finite element method. So, in Figure 11 the 3D view of this configuration is presented. In order to have a comparison term, in the same program the configuration of the Original Structure was implemented as it can be seen in Figure 7.



a) the initial configuration b) the optimal configuration



c) the optimal configuration - detail

Figure 10. Original Structure optimization for SPC minimization.

The obtained results following the numerical modeling of these two structures are presented in Figure 12. Comparing the two capacitance matrixes obtained following the numerical modeling of the two configurations, the efficiency of the optimal shifting of the windings and of course the efficiency of using the optimal design program implemented by the authors was observed.

So it can be stated that the optimum shifting of the winding leads to a decrease of the parasitic capacitance C_{33} which is approximately 7 times smaller than the value obtained for the Original Structure.

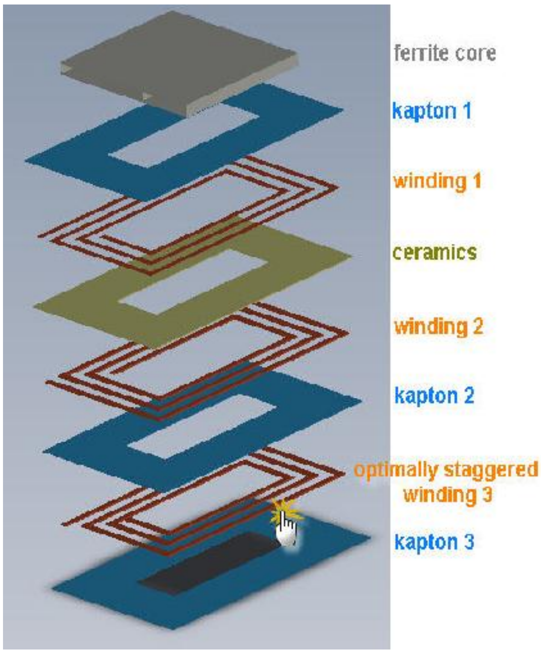
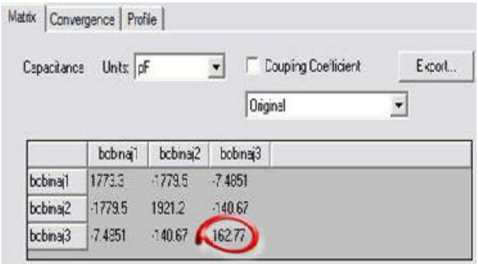
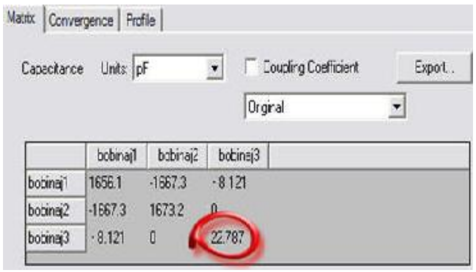


Figure 11. Explanatory structure with optimally position conductors.



a) Original Structure 3D (Figure 7)



b) Structure with optimally positions conductors 3D (Figure 11)

Figure 12. C_{33} results: analysis through parasitic capacitance.

4. EMI filters made in planar electromagnetic technology

The techniques of loss increase at high frequency and of SPC minimization respectively, proposed by the authors are finally applied in the case of the integrated EMI filters with a view to improving their performance.

The equivalent principle scheme of an EMI filter achieved by planar electromagnetic technology is presented in Figure 13. It contains necessary constructive elements described in paragraph 1, Figure 3, elements which will be indicated also in the actual technical solutions used and described as follows.

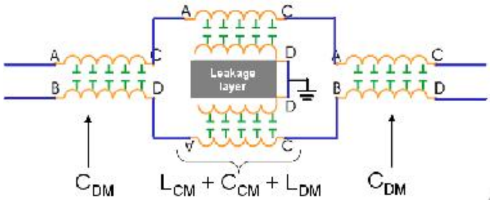


Figure 13. Explanatory_structure with optimally position conductors.

In order to highlight the efficiency of the techniques proposed by the authors on the EMI filter performance, a comparative study was carried out. With this purpose, two EMI filters have been constructed: one filter having the initial structure, the so called Original Structure as a fundamental element (Figure 14) and another filter based on the nickel-plated optimized structure proposed by the authors (Figure 15).

Comparing the matrices of the capacitances obtained as a result of the numeric modelling of the two proposed filters, it can be noticed that the structural parasitic capacitance corresponding to bobina_CM1 decreases from 219.4 pF, the value obtained in the matrix corresponding to the EMI filter based on the Original Structure, to 102.32 pF in the case of the EMI filter based on the nickel-plated and optimally staggered coiling. As for the structural parasitic capacitance corresponding to bobina_CM2, this decreases from 216.16 pF to 101.61 pF. The values of the partial capacitances of the structures called bobina_CM1 and bobina_CM2 containing multilayer spiral windings with and without optimum shifting are observed.

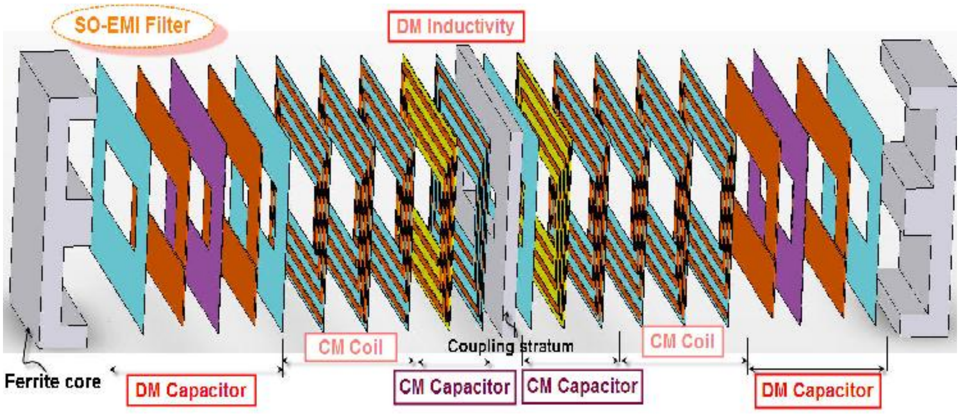


Figure 14. The EMI filter based on the Original Structure.

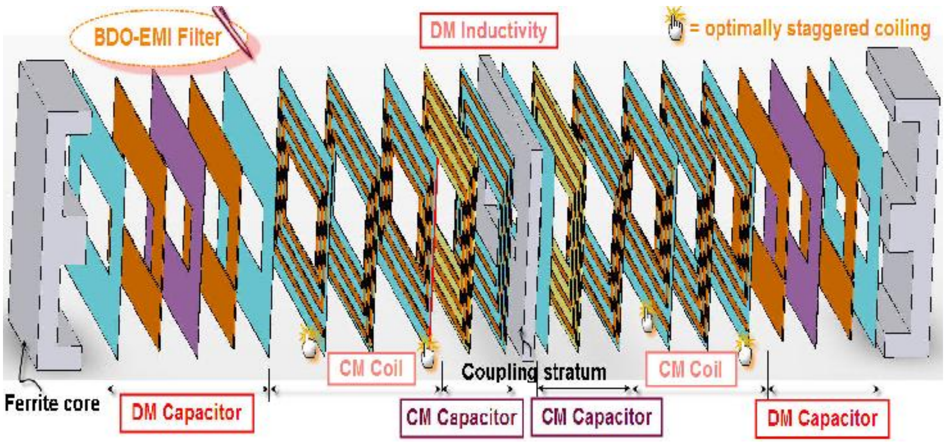
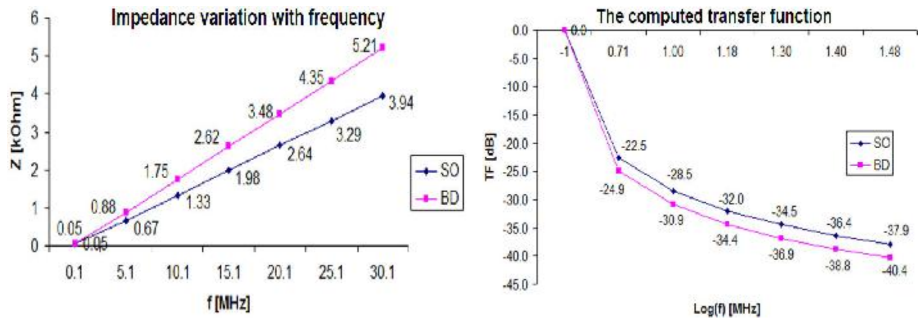


Figure 15. The EMI filter based on the optimized nickel coated structure.

The analysis of HF losses increase of the filter through nickel platting the winding conductors is achieved also through a comparative study of the two filters shown in Figure 14 and Figure 15. The impedance variation with the frequency at the input terminal of the filter closed on a 50 Ω load in the case of the two proposed structures is shown in Figure 16.



a) input impedance b) transfer function

Figure 16. The results of the comparative analysis of the variation with the frequency in case of EMI filters: SO – the original structure; BD – nickel plated, staggered coiling.

Looking at the results presented in Figure 16(a) and Figure 16(b) it can be seen that the nickel plated optimally staggered winding filter presents a 32% increased efficiency as compared to the original structure and an improved attenuation of 2.4 dB in terms of the transfer function – computed on the basis of the results of the numeric analysis.

5. Conclusions

In this paper the authors propose the use of a new technology for the EMI filter construction, namely the planar electromagnetic technology. For a better improvement of the EMI filter performances the conductor’s nickel-plating technique is proposed in order to increase the HF losses and the optimum staggering technique is proposed for the structural parasitic capacitance minimization. Comparing the obtained results through the numerical modeling of an EMI filter based on the classical structure with the ones obtained after the numerical modeling of the filter proposed by the authors, having nickel-plated and optimum staggered conductors, the efficiency of the proposed techniques is ascertained.

Acknowledgment

This paper was supported by the Post-Doctoral Programme POSDRU/159/1.5/S/137516, project co-funded from European Social Fund through the Human Resources Sectorial Operational Program 2007-2013.

References

[1] Nagel A., De Doncker R.W., Systematic design of EMI-filters for power converters, IAS 2000 IEEE, 2000, 2523-5.

[2] Rengang C., Wang Shuo, van Wyk J.D., Odendaal W.D., Integration of EMI filter for distributed power system (DPS) front-end converter, IEEE PESC 2003, 2003, 296-300.
[3] Kraemer J.G., S-parameter characterization for EMI filters, 2003 IEEE Symposium on Electromagnetic Compatibility, USA, 2003, 361-6.
[4] Electromagnetic compatibility (EMC)—Part 3: Limits—Section 2: Limits for harmonic current emissions , IEC 61000-3-2 Document, 1998.
[5] Gradski P.M., Lee F.C., Design of high-frequency hybrid power transformer, Applied Power Electronics Conference, 1988, 319-326.
[6] Lee F.C., Barbosa P., Peng X., Jindong Z., Yang B., Canales F., Topologies and design considerations for distributed power system applications, Proc. of the IEEE, June 2001, 939-50,.
[7] Violette Norman J.L., White D.R.J., Violette M.F., Electromagnetic compatibility handbook, New York Van Nostrand Reinhold, 1987.
[8] Wang S., Lee F.C., Odendaal G.W.,. Van Wyk J.D, Improvement of EMI filter performance with parasitic coupling cancellation, IEEE Trans. on Power Electronics, vol. 20, 2005.
[9] Strydom J.T., Van Wyk J.D., Volumetric limits of planar integrated resonant tranformes: A 1 mHz case study, IEEE Trans. Power Electr, 2003.
[10] Ott W.H., Noise reduction techniques in electronic systems," 2nd ed., New York: Wiley", 1988.
[11] Wang S., Lee F.C., Odendal W.G., Characterization and parasitic extraction of EMI filters using scattering parameters, IEEE Trans. Power Electronics, 2005.
[12] Răcăşan A., Munteanu C., Ţopa V., Pacurar C., Hebedean C., Antonescu O., HF Losses Increase of the Planar Integrated EMI Filters by Multi-Metal Metalization of the Windings, EPE2010, 2010, 83-86.
[13] Răcăşan A., Munteanu C., Ţopa V., Pacurar C., Hebedean C., Minimization of the Equivalent Parallel Capacitance in Planar Magnetic Integrated Structures, OPTIM 2012, 2012, 219 – 224.

Addresses:

- Lect. Dr. Eng. Adina Racasan, Technical University of Cluj Napoca, G. Baritiu Street, no. 26, Cluj Napoca, adina.racasan@ethm.utcluj.ro
- Prof. Dr. Eng. Calin Munteanu, Technical University of Cluj Napoca, G. Baritiu Street, no. 26, Cluj Napoca, calin.munteanu@ethm.utcluj.ro
- Prof. Dr. Eng. Vasile Topa, Technical University of Cluj Napoca, G. Baritiu Street, no. 26, Cluj Napoca, vasile.topa@ethm.utcluj.ro
  Lect. Dr. Eng. Claudia Pacurar, Technical University of Cluj Napoca, G. Baritiu Street, no. 26, Cluj Napoca, claudia.pacurar@ethm.utcluj.ro
- Assist. Dr. Eng. Claudia Hebedean, Technical University of Cluj Napoca, G. Baritiu Street, no. 26, Cluj Napoca Claudia.Hebedean@ethm.utcluj.ro