



NOVEL EMI SUPPRESSOR COMPRISING A BUNDLE OF FERRITE TUBES AND A SECONDARY EM COUPLING/INTERFERENCE REACTION

N.V.Blaž, M.D.Luković*, M.V.Nikolić*, O.S.Aleksić*, Lj.D.Živanov, L.S.Lukić**

University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

* Institute for Multidisciplinary Research, Belgrade, Serbia

** Institute Iritel, Belgrade, Serbia

Abstract: A novel EMI suppressor was formed using a bundle of soft ferrite tubes and two secondary coils wound in opposite directions to interfere the pulses in the bundle core. A power cable as a half turn primary coil was placed in the hole on the main axes while the secondary coils were placed on periphery tubes in the holes or between them. The impedance and EMI filter insertion loss were measured in the frequency range of 1M-500MHz for three different EMI suppressors with an EM coupling/interference reaction made of ferrite bundles. The results obtained were compared mutually and with the best literature data for cable core ferrite filters (sleeve cores). Complex values of magnetic permeability were measured in frequency range from 300kHz to 500MHz. From complex permeability graph we can determinate the frequency where the maximum suppression occurred.

Key Words: EMI suppressor, Ferrite bundle, EM coupling and interference

1. INTRODUCTION

Ferrite power EMI suppressors for cables are made as cylinders and toroids or split cores with a central hole designed for a single wire cable or triple wire cable in a half turn pass through it [1-3]. This type of EMI suppressors are produced worldwide and applied on cables with power electronic equipment such as telecommunication equipment, LAN, TV, PC, DC-DC power converters and other power devices [4-6]. Both MnZn and NiZn ferrites are used for EMI core production although MnZn ferrites are applied mainly in the kHz-MHz range and NiZn in MHz range [7-8]. The permeability of MnZn ferrites decreases from the order of magnitude of 10^3 to much lower values after 10 MHz, while NiZn ferrite permeability is of the order of magnitude of 10^2 and decreases after 200-300 MHz to the level of 10 or less [9-10]. Relative dielectric permittivity is also not constant, but a function of

frequency with similar behavior to the magnetic permeability.

The main idea was to utilize the advantages of MnZn ferrite and apply a bundle of ferrite tubes round a power cable as an EMI suppressor instead of large split cores. The second idea was to introduce short circuits as secondary coils through the bundle holes to invert the EMI pulses and interfere them magnetically.

2. EXPERIMENTAL AND RESULTS

EMI filters based on ferrite bundles act in a similar way to multi aperture cores but they have much larger dimensions to suppress high power noise. They can be used as chokes with opposite windings (direct and inverted EM signals) to interfere EMI pulses or to perform noise interfering by two opposite wound secondary coils that are EM coupled with a power cable placed on the main axis as a primary (half turn) coil, figure 1.

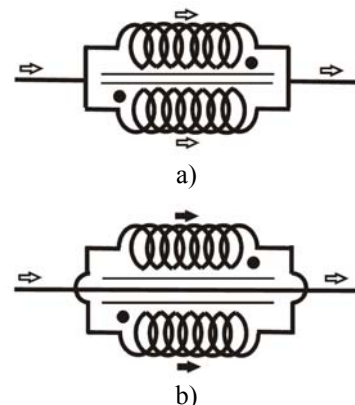


Fig. 1. Principle of ferrite bundle EMI suppression: a) inverting half of the EM field with opposite wound coils for interfering pulses, and b) EM coupling primary wire placed on the main axis with secondary coils and interfering of transformed pulses in a secondary circuit by opposite wound coils.

The bundle core construction is given in figure 2, while the EM field distribution is given in figure 3 for a single wire placed on the main axis in the bundle.

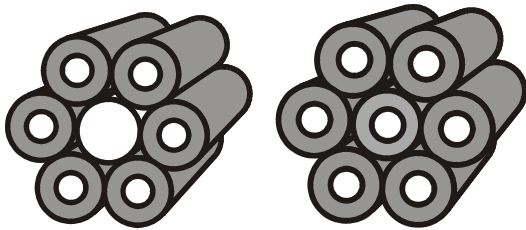


Fig. 2. Ferrite bundle core L-6 and L-7

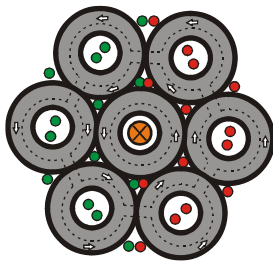


Fig. 3. EM induction in a ferrite bundle generated by a wire placed on the main axis (X) - the direction of EM induction B is designated by arrows and the flux by dashed lines. •• - vacancies suitable for coil placement and coils wound in opposite directions (combinations with 3 to 6 turns).

The ferrite grade used was commercial M-30 [IHIS Ferrites, RS] (complex $Mn_{0.6}Zn_{0.4}Fe_2O_4$ with excess Fe_2O_3) that gives high temperature stability [11-12].

For high frequency measurements of complex permeability, E5071B Agilent Technology vector network analyzer has been used with short ended coaxial sample. The coaxial sample holder (with and without sample) is connected to the calibrated network analyzer through the 50 Ω coaxial cable, figure 4.

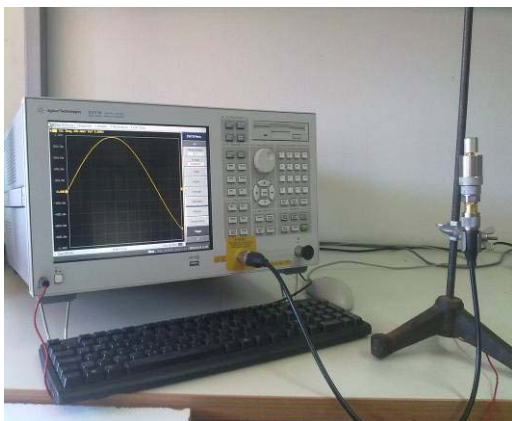


Fig. 4. Measurement setup for complex permeability measurement

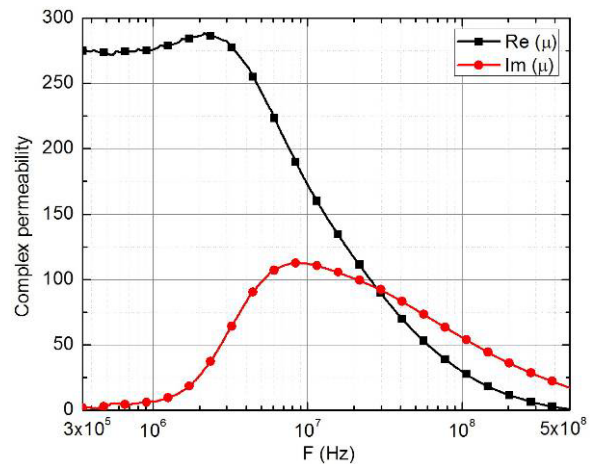


Fig. 5. Complex ferrite magnetic permeability of $Mn_{0.6}Zn_{0.4}Fe_2O_4$ $\mu'_r(\omega)$ i $\mu''_r(\omega)$ in the EMI range. Test sample sintered at 1280 °C/2h.

The reflection coefficient is measured, permitting the determination of the input impedance of the cell with sample. Equation for determination of the complex permeability of the holder equipped with the test sample is derived in [13, 14]. Real and imaginary parts of $Mn_{0.6}Zn_{0.4}Fe_2O_4$ permeability are depicted in Figure 4.

The bundle impedances in the range up to 500 MHz were measured by a HP 4191A impedance analyzer, figure 6.



Fig. 6. Measurement setup for measuring bundle impedances using HP 4191A impedance analyzer

At first a L-7 bundle suppressor was wound like a large multi-aperture core e.g. using one pass of the wire through 7 holes (7 times $\frac{1}{2}$ turns connected in series). Then the same bundle suppressor was wound by 7 separated wires e.g. 7 times $\frac{1}{2}$ turn connected in parallel. The first serial connection was aimed to serve as a low current bundle suppressor and the parallel connection as a very high current bundle suppressor. Their impedance vs. frequency diagram is given in figure 7.

After that the ferrite bundle was wound using two coils with 3 turns in opposite (3:3) (inverting principle in figure 1a). The main current of the bundle suppressor was split in two halves like in chokes and EM was inverted and interfered.

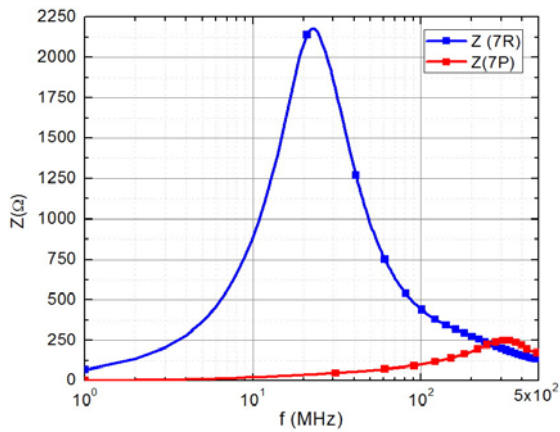


Fig. 7. Impedance vs. frequency for L-7 ferrite bundle: $Z(7R)$ - 7 times $\frac{1}{2}$ turns in series (left) and $Z(7P)$ - 7 times $\frac{1}{2}$ turns in parallel (right). Ferrite tube dimensions $\Phi=10/4$ mm, $l=40$ mm

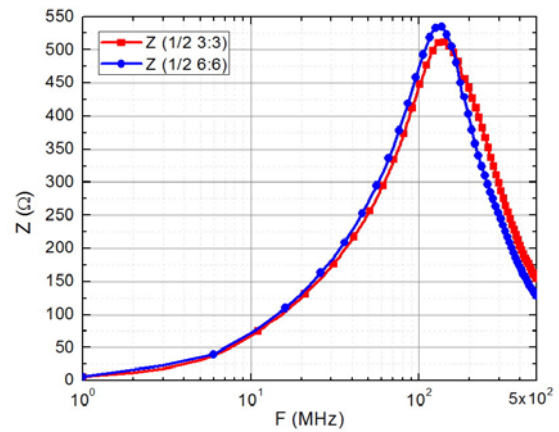


Fig. 9. Combined effects of primary and secondary coils in the bundle suppressor: electrical scheme 1b-coupling/inverting. Primary $\frac{1}{2}$ turn, secondary 3: 3 and 6:6 x $\frac{1}{2}$ turn, ferrite tubes $\Phi=10/4$ mm, $l=40$ mm.

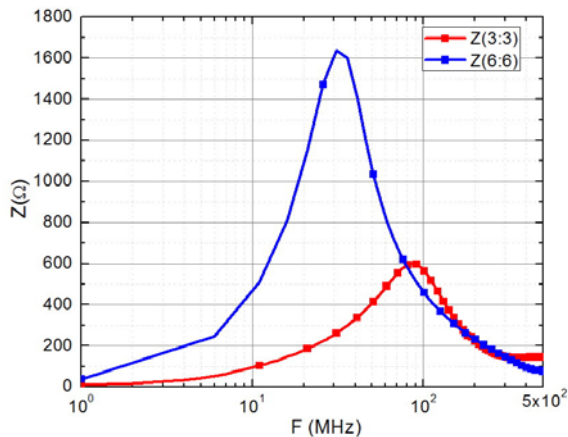


Fig. 8. Impedance of the opposite coils in a bundle suppressor with the inverting principle - electrical scheme 1a. Coils as 3:3 and 6:6 x $\frac{1}{2}$ turn, ferrite tubes $\Phi=10/4$ mm, $l=40$ mm.

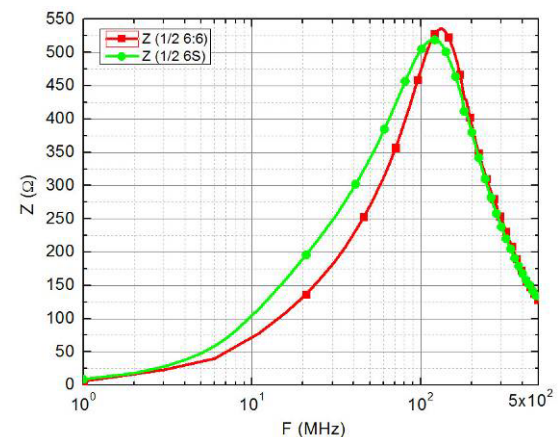


Fig. 10. Combined effects of primary and secondary coils in the bundle suppressor: electrical scheme 1b-coupling/inverting. Primary $\frac{1}{2}$ turn, secondary 6:6 and 6s x $\frac{1}{2}$ turn in series, ferrite tubes $\Phi=10/4$ mm, $l=40$ mm.

Then the number of coils was increased to 8 to form configuration (6:6) and increase the impedance. Their impedance vs. frequency change is given in figure 6 for smaller and larger numbers of turns.

Another configuration wound on a L-7 ferrite bundle was based on the coupling/inverting principle in a secondary circuit as given is given in figure 1b. A power cable ($\frac{1}{2}$ turn) was placed in the central hole of the bundle and the same opposite coils were used as previously. The impedance vs. frequency change for the combined effect ferrite bundle suppressor is given in figure 9.

Finally the impedance of the same ferrite bundle was measured for magnetic coupling with a primer ($\frac{1}{2}$ turn) and a new secondary coil (6s) with 6 turns in series and short cut ends to close the secondary coil and act as a load. The results obtained in measuring impedance vs. frequency $Z(1/2 6s)$ were compared with previous measuring $Z(1/2 6:6)$ as given in figure 10.

Coils, number of turns and winding directions were selected using the criteria of maximum coupling with primary ($\frac{1}{2}$ turn) and maximum interference in the secondary short circuit.

3. DISCUSSION AND CONCLUSION

An EMI ferrite bundle suppressor is a new construction aimed to serve in high power electronics as filters and suppresses pulse noise from IGBT-s, triacs, thyristors, DC-DC converters and other switching devices. It acts as a suppressor combining effects of primary and secondary coils placed in the bundle core like a large multi-aperture coil. The transforming principle (given in figure 1b) is suitable for very high currents passing through the main cable placed in the central hole in the bundle.

The copper wire in secondary coils is much thinner in diameter but it is enough for pulse noise (impulse current) transformed to secondary coils and interfered (maximum several percents of DC energy).

The Mn-Zn bundle core does not reach saturation with the main current due to local loops as given in figure 3. The L-6 bundle with a larger hole in the middle is suitable for three wire cables (F, O, G) while the L-7 bundle is suitable for a single wire cable. Both L-6 and L-7 configurations exhibit relatively high impedance of

500 Ω (figures 8-10), which is sufficient for EMI suppressing. The impedance of the bundle depends on the number of windings, winding configuration (arrangement), and frequency.

Relative permeability $\mu'_r(\omega)$ of the material M30-MnZn ferrite chosen for the tubes (figure 5) shows a drop at frequencies above 3MHz and rise of the dissipation factor $\mu''_r(\omega)$. Effective magnetic permeability was defined as

$$\mu_r(\omega) = \sqrt{\mu'_r(\omega)^2 + \mu''_r(\omega)^2}. \quad (1)$$

Imaginary part of complex permeability, $\mu''_r(\omega)$ have maximum value at 9MHz. The skin effect also contributes significantly to the effective impedance value, while the inter-coil capacitance affects the impedance less after 500 MHz, which is the limit for most MnZn ferrite EMI applications.

The results obtained for the ferrite bundle suppressor were compared with commercial components such as ferrite round core suppressors [1-4] with similar dimensions and in the same frequency range. It can be noticed that the values of impedances obtained for bundle cores are also similar, although producers used NiZn ferrite mostly in EMI/RFI applications. The ferrite bundle suppressor is significantly better on lower frequencies, than EMI suppressors made of NiZn ferrites.

Other advantages of the ferrite bundle suppressor are the use of higher currents and separating pulses from the main current by transforming them into secondary, inverting and interferring by opposite wound secondary windings.

The ferrite bundle core presented in this paper can be made in different ways: pressing and sintering, extruding, ferrite feedstock injecting – powder injection molding (PIM) [15-16]. This technology enables shaping a whole ferrite bundle as a complex geometry by MnZn ferrite feedstock injection in the mold like a very large multi-aperture ferrite core.

Finally it could be concluded that there are two ways to improve the ferrite bundle suppressor: the first, introducing MnZn nano-powders and nano-structured sintered bundle cores to spread the frequency range, and the second, introducing a PIM technology in bundle production. In the near future it is expected that bundle ferrite suppressors will be applied in power electronics as a new solution for EMI protection.

4. REFERENCES

- [1] Kemitron, *EMC Ferrites, Round cable cores, Catalogue* 2011, pp. 1-16.
- [2] Murata, *Ferrite core for EMI suppression, Catalogue No.063E-8, 2008, pp.1-23.*
- [3] TDK, *Ferrites for EMI suppression-for Round cable, Catalogue* 2011, pp.1-3.
- [4] Kitagawa Co., *EMC ferrite core products, Round cable ferrite cores (split cores, clamps), Catalogue* 2006, pp1-10.
- [5] Magnet-technologie GmbH, *Comparison of soft magnetic materials, 08/2008/ WS, pp1-15.*
- [6] J. Moulin, Y. Champion, J. M. Greneche and F. Mazaleyrat, "Magnetic properties of Mn-Zn ferrite with ultra fine grain structure", *Journal of Magnetism and Magnetic Materials*, vol.254-255, pp 538-540, 2003.
- [7] T. Sun, A. Borrasso, B. Liu and V. Dravid, "Synthesis and characterization of nanocrystalline zinc manganese ferrite", *Journal of the American Ceramic Society*, Vol. 94 (5), pp.1490-1495, 2011.
- [8] H. Li, Z. Li, B. Zhang, W. K. S. Tang and W.A. Halang, "Suppressing electromagnetic interference in direct current converters", *IEEE Circuits and Systems Magazine* Vol. 9 (4), pp 10-28, 2009.
- [9] L. Yong-Sheng, Z. Yun-Bo, Z. Jin-Cang, G. Min-An, Y. Zheng-Long, R. Zhong-Ming, "Crystalline and Magnetic Enhancement of Nanocrystalline MnZn Ferrites Fabricated under a High Magnetic Field", *Chinese Physics Letters*, Vol. 26, No. 8 pp 1-3, 2009.
- [10] D. Arcos, R. Valenzuela, M. Vazquez, and M. Vallet-Regi, "Chemical Homogeneity of Nanocrystalline Zn-Mn Spinel Ferrites Obtained by High-Energy Ball Milling", *Journal of Solid State Chemistry*, Vol. 141, pp 10-16, 1998
- [11] F. Z. Peng, H. Li, G. J. Su, and J. S. Lawler, "A new ZVS bidirectional dc-dc converter for fuel cell and battery application", *IEEE Trans. Power Electron.*, vol. 19, no. 1, pp. 54-65, 2004.
- [12] IHIS Ferrites, *Soft ferrites, Round cable cores, Catalogue* 2000, pp 1-21.
- [13] V. Radonić, N. Blaž, and Lj. Živanov, "Measurement of complex permeability using short coaxial line reflection method", *Acta Physica Polonica*, Vol. 117, No. 4, 820-824, 2010.
- [14] N. Blaz, A. Maric, G. Radosavljevic, L. Zivanov and G. Stojanovic, "Modeling and Characterization of Frequency and Temperature Variation of Complex Permeability of Ferrite LTCC Material", *Progress in Electromagnetic Research B*, Vol.23, 2010, pp. 131-146.
- [15] B. S. Zlatkov, N. S. Mitrovic, M. V. Nikolic, A. M. Maricic, H. Daninger, O. S. Aleksic, E. Halwax, "Properties of MnZn ferrites prepared by powder injection molding technology", *Materials Science and Engineering B: Solid State Materials for Advanced Technology*, vol. 175, No.3, pp 217-222, 2010.
- [16] B. Zlatkov, H. Loibl, H. Danninger, A. Maricic, N. Mitrovic, "The influence of thermal treatments on magnetic properties of MnZn ferrites prepared by PIM technology", *YUCOMAT, Herceg Novi* 31.08-04.09.2009, (Book of abstracts), P.S.B-25.