High frequency model of EMI filter

Szymon Pasko and Boguslaw Grzesik

***Abstract*—The EMI filters are usually used for suppression of electromagnetic conducted interference of range 9 kHz-30 MHz. The efficiency of electromagnetic interference filter is described by attenuation characteristics. The value of attenuation of EMI filter depends on main parameters of filter's elements and its parasitic parameters. Therefore the high frequency model of electromagnetic interference filter is analyzed in this paper.**

***Index Terms*—Electromagnetic compatibility, EMI filter.**

I. Introduction

The EMI filters are usually used to suppress electromagnetic conducted interference of range 9 kHz - 30 MHz.

The EMI filter is inserted between main supply and devices which generates interferences (Fig. 1). The conducted interferences embrace common mode (CM) and differential mode (DM) interferences. The common mode (CM) interferences are propagated in both phases in the same direction and come back to the ground (Fig. 1). The differential mode (DM) interferences are propagated in one phase in one direction and come back via the second phase in opposite direction (Fig. 1). The direction of the interference is like the direction of respective current – i_{CM}, i_{DM} [1].

The structure of filter is selected so the impedance mismatch occurs. If impedance of main supply V_{AC} is big then the impedance of filter, seen from L, N terminals has to be low, and the same from devices side [1].

The CM interferences are suppressed by coupled coils L_0, and the capacitor C_{Y1}, C_{Y2}. The impedance of coupled coils is higher than impedance of capacitors C_{Y1}, C_{Y2} so that the CM interferences flow via capacitors C_{Y1}, C_{Y2} and PE conductor (Fig. 1). The DM interferences flow by capacitors C_{X1} and C_{X2}, because the impedance of AC supply is higher than the impedance of the filter, seen from L, N terminals. It results from mismatch impedance conditions [1]. The efficiency of EMI filter suppression is determined by its attenuation A_{dB}.

$$A_{dB} = 20\log\left(\frac{V_1}{V_2}\right) \quad (1)$$

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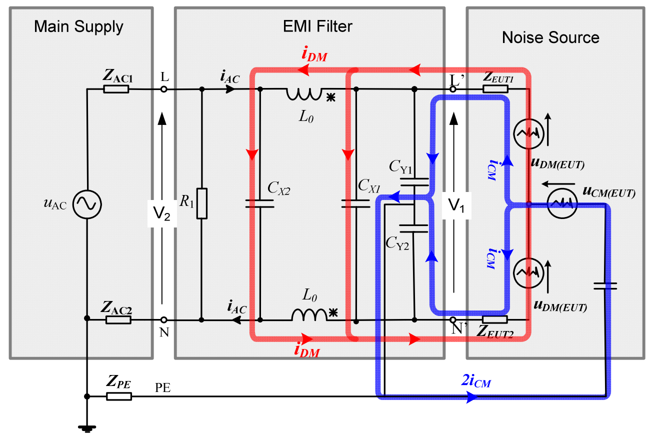

Fig. 1. Propagation of CM, DM interferences in EMI filter.

where V_1 is the voltage of source of interferences (V_{DM}, V_{CM}), while V_2 is the voltage at the output of the filter that is connected to the Noise' source [2], [3]. It is given in dB. The measured attenuation characteristic of FN2020 filter is depicted in Fig. 2.

II. High Frequency Model of Filter's Elements

The EMI filters consist of coupled coils L_0 and capacitors CX and CY (Fig. 1). The value of attenuation of EMI filter depends also on parasitic parameters of EMI filter elements. The value of parasitic parameters causes frequency resonances which reduces the attenuation of EMI filters.

The equivalent circuit of capacitors of EMI filters, e.g. C_{X1}, (Fig. 3b) is the series connections of: resistance R_{X1}, which represents the losses of the capacitor, inductance L_{X1}, which

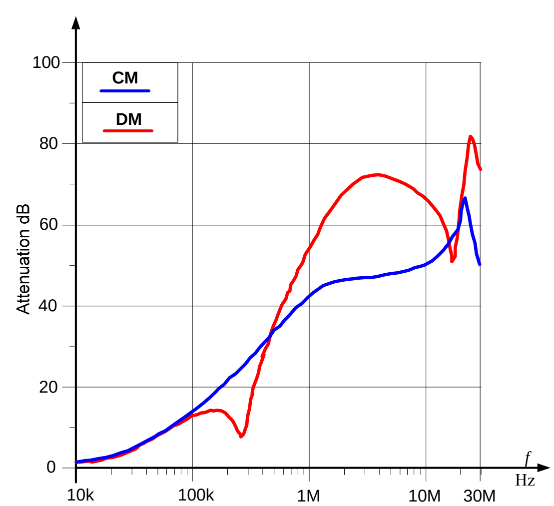

Fig. 2. The measured attenuation characteristics of FN2020 EMI filter.

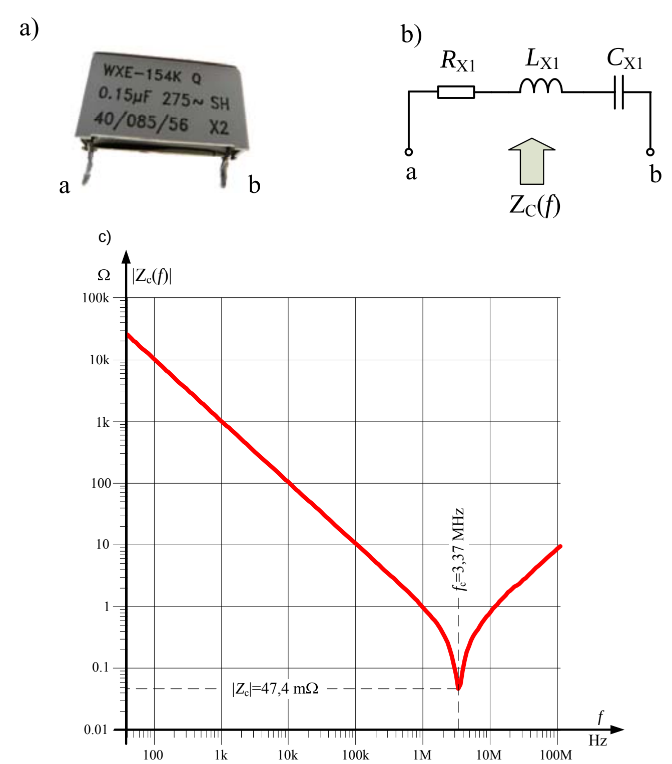

Fig. 3. The capacitor CX (0.15 μF) polyester capacitor WXE 154K: a) photograph, b) equivalent circuits, c) measured module impedance characteristic.

represents inductance of the capacitor and the actual capacitance C_{X1} of the capacitor C_{X1} Fig. 3a).

The parameters of filter's capacitors C_X, C_Y equivalent circuits are calculated basing on the modulus of impedance characteristics, which were measured by impedance analyzer Agilent 4294A [4], [5]. The measured impedance characteristic of capacitors C_X, is given in Figure 3c. The impedance $|Z_C(f)|$ of the capacitor decreases with increasing frequency, up to serial resonance frequency f_C. The value of C_X is proportional to $X_C(\omega)$ up to serial resonance frequency f_C. For the resonant frequency the impedance $|Z_C|$ is equal to the R_X, the series resistance capacitor. The impedance $|Z_C|$ increases above resonant frequency f_C. The capacitor equivalent circuit above the resonance frequency changes its character from capacitive to inductive. The parasitic inductance is calculated according equation (2).

$$f_c = \frac{1}{2\pi\sqrt{L_X C_X}} \qquad (2)$$

The parasitic parameters of capacitors depend on their construction. The majority of EMI filters are based on metalized polypropylene, polyester, paper and ceramic capacitors.

The ceramic capacitors have the lowest parasitic inductance. The parasitic inductance of metalized capacitors is also small. The greatest parasitic resistance has ceramic capacitors, while among the metalized capacitors the greatest value of the parasitic resistance has paper capacitors. Metalized capacitors have self-healing properties while ceramic ones are not. Therefore ceramic capacitors are not used as C_X capacitors. However, the metalized capacitors are characterized by larger volume and higher price in comparison with ceramic ones. [6]

The most important elements of EMI filter are coupled coils. These coupled coils are wound on toroidal core. The equivalent circuit (Fig. 4) of coupled coils consists of: L_0 inductances, leakage inductance L_r, ($L_r << L_0$), R_p resistance which represents the losses of the coil, R_w resistance which represents the resistance of the wire, $R_w << R_p$, C_1, C_2, C_3, C_4 parasitic capacitances of coupled coils.

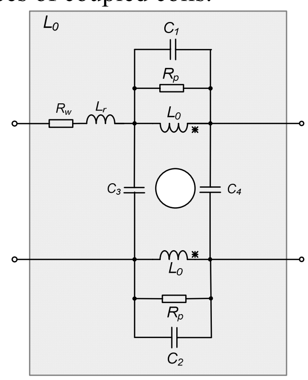

Fig. 4. The equivalent circuits of EMI filter coupled coils.

The C_1, C_2 represents parasitic capacitances of primary and secondary winding of the coupled choke. The C_3, C_4 represents the parasitic capacitances between primary and secondary winding.

The parameters of equivalent circuit of coupled coils are calculated basing on the modulus of impedance characteristics, which were measured by impedance analyzer Agilent 4294A. The calculation of parameters of equivalent circuit of coupled coils is more complicated than those of capacitor's one. The method is presented in details in [7].

The parasitic parameters filter elements have influence on attenuation characteristic of EMI filter. The value of choke parasitic parameters depends on design of coupled coils. The value of L_0 depends on core materials and number of turns. The core made of Mn-Zn ferrite is common practice in EMI filter. The initial permeability of Mn-Zn core is small in comparison with initial permeability of, e.g., nanocrystaline core. Therefore nanocrystaline materials offer significant advantage in attenuation performance. The high permeability permits to achieve the inductance L_0 5 times higher than for Mn-Zn for common mode case when the geometry and number of turns are similar [8]. It should be noted that inductance L_0 and resistance R_p are strongly depend on frequency. The inductance increases and resistance R_p decreases vs, frequency. The value of resistance also depends on type of core.

The value of parasitic capacitances depends on the way the winding is wounded and number of turns. The lowest value of parasitic capacitance is obtained in single layer windings (Fig. 5a) and in "bifilar" windings (Fig. 5b). The "bifilar" coupled coils however must be wounded with well-insulated insulated wires due to safety requirements. Moreover, the leakage inductance of L_r bifilar wound coils is minimal.

The single layer coils a larger core to achieve the larger inductance. Double layer windings increases the parasitic capacitances but can be decreases the dimension of the core [6], [8], [9].

The Actown Electrocoil Company has brought into market TIGHTpak toroidal coupled coils (Fig. 6). These are a single layer coils with wires flattened on the inner part of the core.

This manufacturing technique makes the higher number of turns in winding having the same length. This increases inductance L_0 without increasing core size [10], [11].

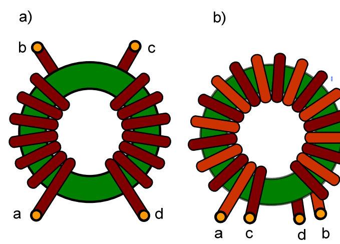

Fig. 5. EMI coupled coils: a) single layer, b) "bifilar" wound coupled coils.

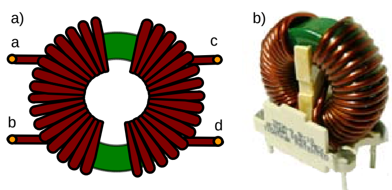

Fig. 6. TIGHTpak toroidal coupled coils.

III. High Frequency Model of EMI Filter

Basing equivalent circuits of filter elements its high frequency model is created – Fig. 7. The equivalent circuits of EMI filter for CM interferences takes the form shown in Fig. 8a.

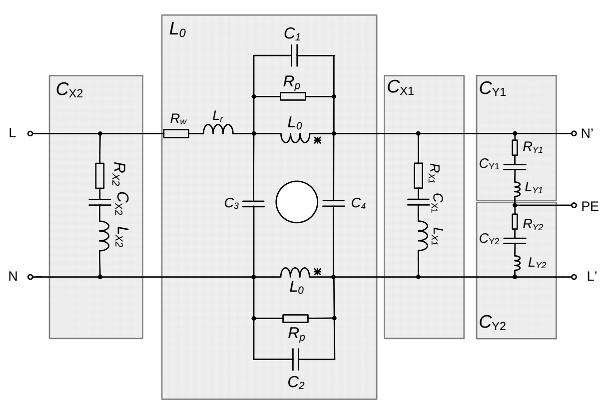

Fig. 7. The high frequency model of EMI filter.

The attenuation characteristic of CM noise depends on value of inductance L_0, resistance 0.5 R_p, and sum of winding parasitic capacitance C_1+C_2 and also parameters of equivalent circuits of C_{Y1}, C_{Y2}.

The parameters of C_{X1}, C_{X2} have no impact on attenuation characteristic for CM noise.

The differential mode (DM) interferences are propagated in one phase in one direction and come back via the second phase in opposite direction. Therefore the equivalent circuits of EMI filter for DM take the form shown in Fig. 8b. The attenuation characteristic of DM noise depends on value of leakage inductance L_r, resistance R_p, parasitic capacitance C_1, C_2, C_3, C_4 and also parameters of equivalent circuits of C_{Y1}, C_{Y2}, C_{X1}, C_{X2}.

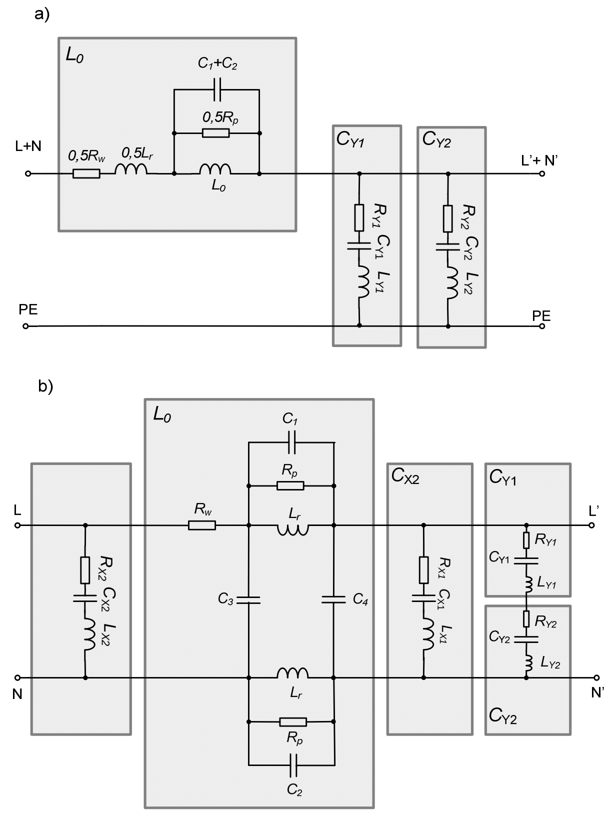

Fig. 8. The high frequency model of EMI filter for: a) CM conducted interference, b) DM conducted interference.

IV. Examples of Filter's Element Influence on EMI Filter's Attenuation

The parasitic parameters of filter's elements have predominated influence on attenuation characteristic of EMI filter. The parasitic parameters of filter's elements depend on its construction. As an example the value of L_0 depends on core materials, winding construction and number of turns. Therefore nanaocrystaline materials offer significant advantage in attenuation performance. The high permeability of nanocrystaline materials permits to achieve the inductance L_0 5 times higher than for Mn – Zn for common mode in case when the geometry and number of turns are similar. The comparison of EMI filter attenuation characteristic for common mode with nanaocrystaline (NC) and Mn-Zn (MnZn) materials is depicted in Fig. 9.

The value of L_0, also depends on number of turns. The number of turns yields to decrease value of inductance L_0 and also parasitic capacitance which reduce attenuation. Therefore the method of winding of coupled coils is most important. The "bifilar" wound coupled coils has the lowest parasitic capacitance and also leakage inductance L_r as opposed to the double layer coupled coils. Therefore the attenuation for filter with "bifilar" wound coupled coils is higher for CM noise and lower for DM in comparison on filter with double layer coupled coils. The comparison of attenuation characteristic for EMI filter with "bifilar" (BCc) wound coupled coils and double layer (DCc) one is depicted in Fig. 10.

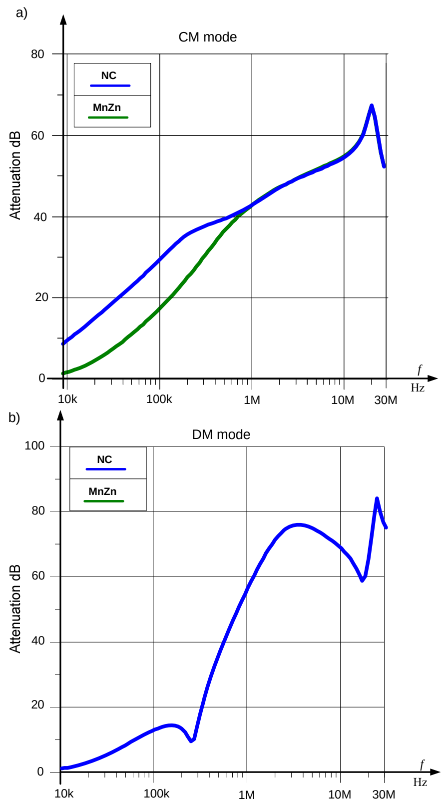

Fig. 9. Comparison of EMI filter attenuation characteristic of coupled coils with nanaocrystaline (NC) and Mn-Zn (MnZn) materials: a) attenuation characteristic for CM noise, b) attenuation characteristic for DM noise.

V. Conclusion

The parameters of EMI filter have influence on its attenuation performance for different frequency as was shown in Fig. 9, Fig. 10. The power electronics converters generate the conducted electromagnetic interference in different range of frequency. It results from its construction. Therefore to effective suppress electromagnetic conducted interference and EMI filter construction the high frequency model is indispensable.

The future work will based on creating FEM (finite elements method) model of EMI filter and check the proposed one.

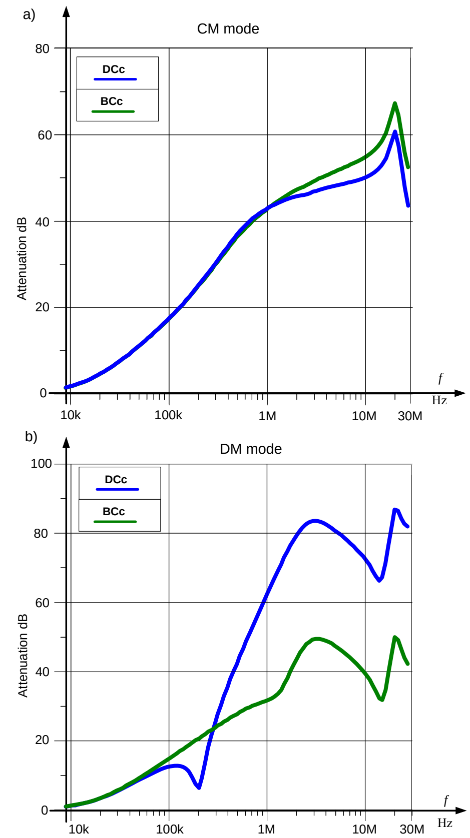

Fig. 10. Comparison of EMI filter attenuation characteristic for "bifilar"(BCc) and double layer (DCc) coupled coils: a) attenuation characteristic for CM noise, b) attenuation characteristic for DM noise.

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