High frequency model of EMI filter

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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 $A_{dB}$.

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

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 $C_X$ and $C_Y$ (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

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

\[
f_c = \frac{1}{2\pi \sqrt{L_X C_X}}
\]

(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, \( R_e \) resistance which represents the resistance of the wire, \( R_e<<R_p \), \( C_1 \), \( C_2 \), \( C_3 \), \( C_4 \) parasitic capacitances of coupled coils.

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

![Fig. 4. The equivalent circuits of EMI filter coupled coils.](image)
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].

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.

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 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 $C_{Y1}$, $C_{Y2}$, $C_{X1}$, $C_{X2}$.

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 nanocrystalline materials offer significant advantage in attenuation performance. The high permeability of nanocrystalline 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 nanocrystalline (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 nanaocrystalline (NC) and Mn-Zn (MnZn) materials: a) attenuation characteristic for CM noise, b) attenuation characteristic for DM noise.

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.

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.

REFERENCES