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MODELING OF EMI FILTERS

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Abstract: *Nova days one from very important solved problems in practise there is an increasing of immunity of electronic systems. The paper deals with method of model synthesis, which is useful in area of EMC frequency filter design and optimization. Different types of EMC equivalent models here are discussed. The method of synthesis and optimization of equivalent model with required transfer response is declared in example of EMC power filter. The resulting influence of mismatched conditions on filter performance in entire working frequency range is discussed in some details.*

Key words: *Electromagnetic compatibility, interference, immunity, EMC, EMI filters, design, optimization, synthesis, model, frequency*

INTRODUCTION

In present time the world is becoming more densely populated with devices that are increasingly sensitive to electromagnetic disturbances. In industrial spheres, electronic control systems, data processing equipment and other sensitive devices play an increasingly important role. Therefore solution of problems coupled with problematic of EMC (electromagnetic compatibility) is very important. In electrical engineering practice now are used many new circuit elements for electromagnetic interference (EMI) suppression. We can observe, that in area of EMC are growing different requirements to solve problems of electromagnetic emissions and electromagnetic susceptibility.

In area of EMC there are very often used EMI filters. Their using can be differed to solution of two different problems. At first it is the essential decreasing of undesirable electromagnetic pollution, on the other hand are used to increase electromagnetic immunity of any electrical equipments.

In telecommunications adequate methods for computing and solving EMC problems have been developed over the last years. Unfortunately, many of these methods cannot be applied directly to power electronics, which has it own peculiarities[1].

1 EMI FILTERS

Electromagnetic interference (EMI) can be reduced to acceptable level using filter circuits usually referred as EMI or RFI filters. EMI filters are usually lowpass filter circuits with serial choke coils and parallel capacitors. These filters can be generally divided to two different groups. First group are named as data filters - are used namely in telecommunication systems. EMI data filters are performed as well known lowpass filter configurations (LC ladder circuits) and their design and optimization can be realized according known design and optimization procedures.

The second group of EMI filters are filters used in power electronic. In comparison to EMI data communications filters EMI power filters operate typically under mismatched impedance conditions. This
major problem of EMI filter design for power electronic equipment is caused by the arbitrary generator and load impedances. These impedances are really arbitrary because neither their value can be known, filters are installed in different equipments and supply network.The design of power EMI filters is different then well known procedures of classical filter design and requires some special view and procedures[1].

EMI filters are generally two - ports characterized by insertion loss (IL) rather then voltage attenuation. An insertion loss definition and measurement method is clear from Fig.1. The difference between the measured voltage appearing beyond the insertion point before (switch position1) and after the filter insertion (switch position 2) can be expressed as :

$$IL = 20\log\left(\frac{U_{L1}}{U_{L2}}\right) . \qquad (1)$$

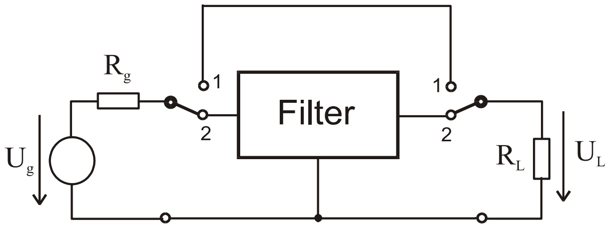

Fig.1: Insertion loss definition and measurement

The voltage U_{L1} can be expressed using resistances of load and generator , then insertion loss is given :

$$IL = 20\log\left(\frac{U_g}{U_{L2}}\frac{R_L}{R_g + R_L}\right). \qquad (2)$$

Assuming that the resistance of generator R_g and load R_L are in practice most often identical, the value of the insertion loss can be simplified as :

$$IL = 20\log\left(\frac{U_g}{2U_{L2}}\right). \qquad (3)$$

The requirement of insertion loss value must be fulfil in wide frequency range from DC to frequencies about hundred MHz. Thus analysis and measurement of the insertion loss must be made by filter design process in wide frequency range for many frequencies. Such a measurement procedure is not highly desirable in practical engineering. The chart in Fig.2 presents typical frequency characteristic of insertion loss of EMI filters. In the pass band insertion loss must be negligible, from cut-off frequency f_c it monotonically increases. At the stop frequency f_s reaches insertion loss required value, up the stop frequency f_s due to parasitic effects exhibit curve some imperfections and usually decreases.

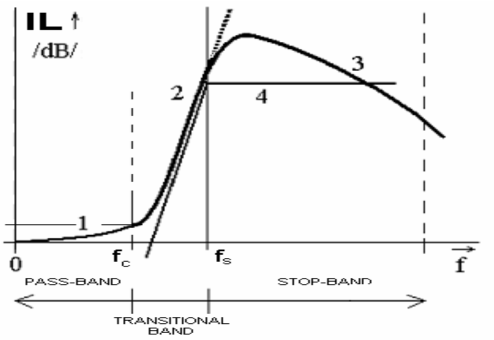

Fig.2: Typical frequency charakteristic of EMI filter insertion loss

After determining the required insertion loss in the stop bandpass, the next step of filter design is to choose a circuit configuration. Important factors may include a limitation on capacitive current for grounded equipments or the acceptable voltage drop across power line filters. For stringent suppression requirements must be also consider the mismatched impedance conditions. In area off of power electronic EMC filter most often are used lowpass LC ladder filters in L, PI or T configurations (see Fig.3). For high – performance applications are used also multistage LC circuits with higher number of basic sections. In power engineering practice, multistage filters having more then four stages are not very common.

To suppress EMI on all wires, filter prototypes from Fig.3 must be inserted in every wire of power lines. Thus power filter network becomes more complex with an increase in the number of wires to be filtered.

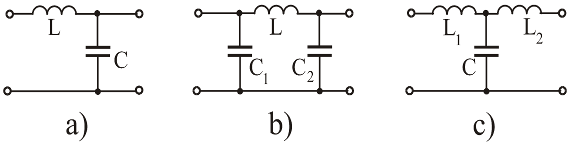

Fig.3: Basic EMI low pass filter configurations: a) L circuit, b) PI circuit, c) T circuit

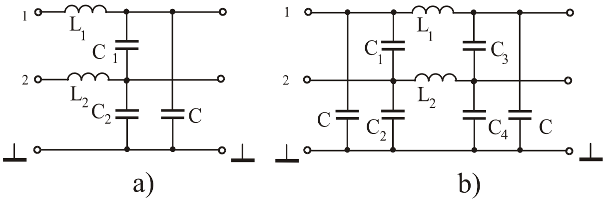

Fig.4: Filter topology - common and differential mode components a) L , b) PI circuit

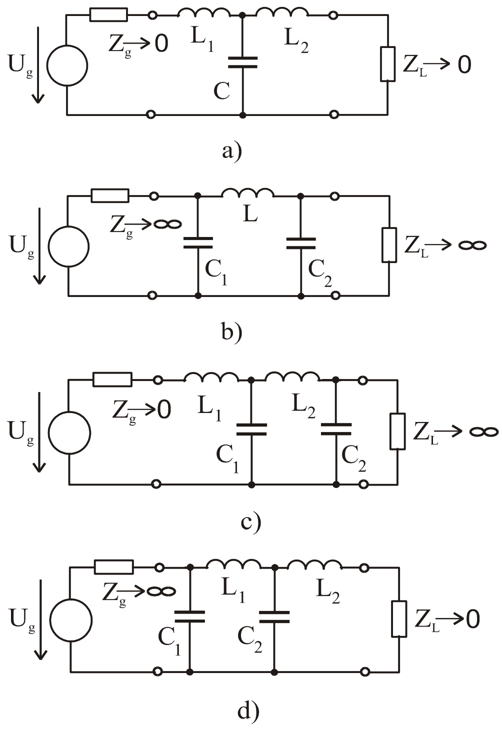

Fig.5: EMI filter configurations for extreme impedance mismatches

The two – wire EMI filter should be studied as a six – terminal network, as shown in Fig. 4, where examples of L and PI topology for two – wire filters are drawn EMI power filters are inserted most often in three phase main supply lines and then must be filtered each wires including neutral. The complexity of EMI filters then significantly increases. The measurement of insertion loss in this case must be realized separately for all terminal pairs. According of used measurement system (symmetric, asymmetric or non – symmetric) the unused terminal pairs must be connected together to obtain the lowest insertion loss value. These specifications require the unused terminals to be grounded, ungrounded, or linked to ground through a specific impedance [4].

To improve EMI filter performance under mismatched impedance condition, multistage filter configurations are applied. In a case that absolute value of the source and load impedances can be approximated, the use of following filter configurations from Fig.5 is recommended.

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2 MODELING OF EMI FILTERS

The synthesis of proper filter models (equivalent circuits) including function elements as well as parasitic elements is one from important parts of successful EMI filter design and optimization. Using modeling techniques can be analyzed the effects of parasitic phenomena and impedance mismatch. Three major modeling techniques for passive components including their parasitic effects have been developed: direct calculation, engineering approximation and analytical approximation.

In present time PC technique enable very easy to apply direct calculation method. The direct calculation method is also the simplest approach for generating a complete EMC filter model. This modeling method is based on equivalent filter circuit synthesis by means of built - in filter elements. The applicability of a particular modelling technique may depend on the type of component data available in manufacturer's catalogues and data sheets. The models can be synthesized from the limited data available from manufacturers but also with measured data.

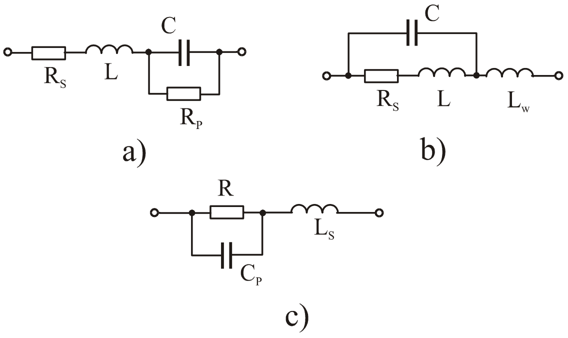

Fig.6. Equivalent circuits : a) of capacitor, b) of inductor, c) of resistor

The goal of filter model synthesis is usually equivalent filter circuit which exhibit required frequency curve of insertion loss in required frequency range. The EMI filter models can be synthesized using basic filter elements. To express filter performance in required wide frequency range, the basic filter elements must be assumed not ideal. Basic electrical element must be replaced by equivalent circuit including their parasitic elements. (Fig.6) In the engineering practice, the HF characteristics of real EMI filter **capacitors** are examined by means of the equivalent circuit shown in Fig.6a. While parallel resistance Rp is generally so high, that it need not be considered, resistance Rs depend on manner of working technology (there is great difference between electrolytic, paper, polystyrene and ceramic capacitors). The serial parasitic inductance is result of three inductances - the inductance of the wound structure, internal leads and inductance of connecting wires. The parasitic inductance plays significant role namely at higher frequencies. **Choke coils** can be well characterized in wide frequency range by the equivalent circuit seen in Fig.6b.The resistance in the circuit represents the losses . Parasitic effects on higher frequency, resulting from the stray capacitances between turns, cannot be neglected. The parallel connected concentrated capacitor provides a suitable approximation. HF parameters of various types of **resistors** which are used in filters are greatly different, generally the equivalent circuit diagram from Fig.6c can be given for studying the HF characteristics. The value of capacitor C is in range 0.1 to 10 pF. The value of the serial inductance depends on the construction of the resistors. The approximate values of parasitic elements of most often used EMI filter elements (inductors and capacitors) are summarized in Table 1 [1].

Table1. Typical element values of real filter

C	$L_{parasitic}$	Remark
< 10 nF	10 - 20 nH	feedthrough type capacitors in orders lower then 1/10 values
10 nF - 1 μF	40 nH	
>1 μF	30 - 100 nH	
L	R_S	$C_{parasitic}$
< 10 μH	1,5 mΩ	2 pF
50 μH - 200 μH	10 mΩ	5 pF
>200 μH	0,5 Ω	10 - 30 pF

The synthesis of proper filter models (equivalent circuits) including function elements as well as parasitic elements is one from important parts of successful EMI filter design and optimization. Using modeling techniques can be analyzed the effects of parasitic phenomena and impedance mismatch. In present time PC technique enable very easy to apply direct calculation method. This modelling method is based on equivalent filter circuit synthesis by means of built - in filter elements. The goal of filter model synthesis is usually required wide frequency range, the basic filter elements must be assumed not ideal. Basic electrical element must be replaced by equivalent circuit including their parasitic elements.

3 SYNTHESIS OF EMI POWER FILTER MODEL

As an example of EMC filter model synthesis and optimization a filter model for three phase power FN 256 -64-52 EMI filter is here presented. The first step of filter model synthesis was grown from known basic (from manufacturer's data sheet) filter topology (see Fig.7). In the second step the given topology with ideal basic elements was for each from three lines replaced by real models of each (R,L,C) filter elements. The initial filter value parameters was approximated and filter with equal generator and load resistors (50 Ω) was analyzed

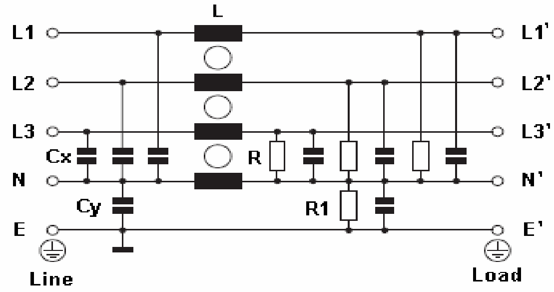

Fig.7: Typical electrical PI topology of power four – wire EMI filter

using commercially available TINA and P-SPICE analyzers. Using optimizer routines from analyzers was processly optimized frequency curve of filter model. As result of optimization procedures the values of each filter model were obtained. The resulting circuit diagram of filter model with their parameter values is shown in Fig.8.

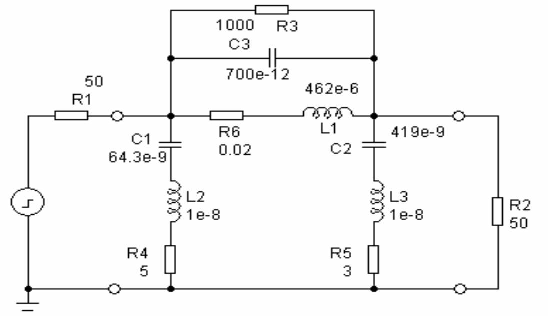

Fig.8: The resulting filter model (FN 256-64-52)

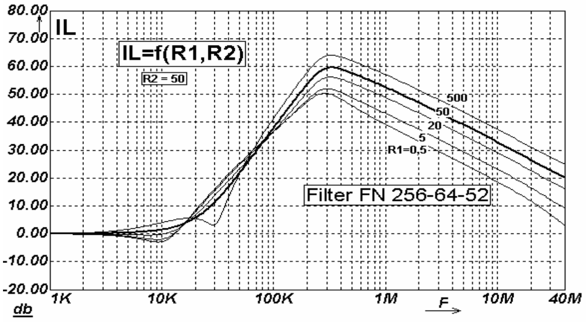

Fig.9: Insertion loss characteristics as function of generator resistance R_1

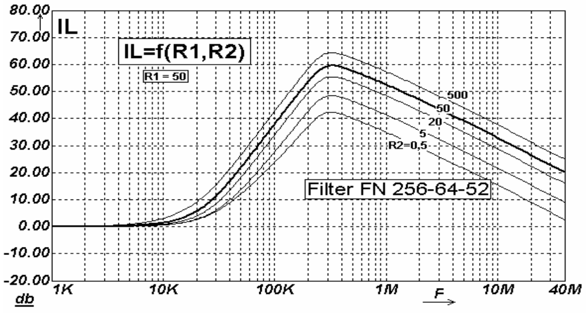

Fig.10: Insertion loss characteristics as function of load resistance R_2

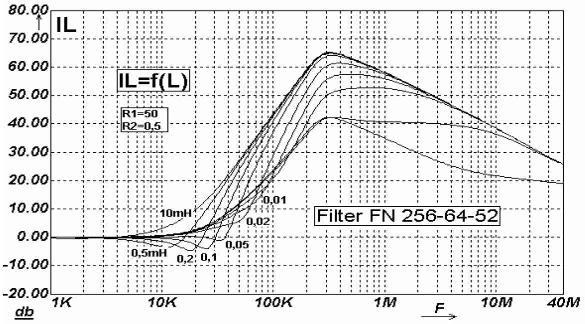

Fig.11: Insertion loss characteristics as function of load inductance

Using created filter model an influence of resistance of generator R_1 and resistance load R_2 on insertion loss of filter was investigated to determine worst case of operation. How it is seen from curves (Fig.9,10), effect of mismatch conditions in worst case can decrease initial insertion loss about 20dB in entire working frequency range what must be by filter design assumed.

We can see from Fig.11, that in a practice operating filter conditions must be to mismatch conditions, which are leading to worst case operating stage of filters taken in account not only resistances, but also inductances of loads and generators.

4 CONCLUSION

In the paper was shortly discusses problems of power EMC filter design and optimization. In a practical example of the power EMC filter was prescribed a synthesis method which enable to set and optimise equivalent filter model including their element value parameters. The created model enable to investigate influence of mismatched condition very quickly without measurement of filter. The great advantage of optimization method is that enable to optimize resulting filter model parameters by usage of usually accessible software for network analysis without requirement of special numerical programs what brings new possibility for many designers in area of EMC filter design and optimization.

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