OPTIMIZATION METHOD OF EMI POWER FILTERS AND ITS MEASUREMENT

J.Sedláček[1], Z.Szabó[2]

[1] UTEE BUT FEKT Brno, Czech Republic
Kolejní 2906/4, 612 00 Brno, tel.: +420 541 149 520, mail: sedlacj@feec.vutbr.cz

[2] UTEE BUT FEKT Brno, Czech Republic
Kolejní 2906/4, 612 00 Brno, tel.: +420 541 149 261, mail: szaboz@feec.vutbr.cz

Summary One of the most important problems solved nowadays is the improvement of the electronic systems immunity. This paper deals with the modelling and synthesis of EMC power filters. This is very important in the field of the electromagnetic compatibility and EMC filter design and optimisation. Various types of EMC filters are discussed. Idea of the synthesis and optimisation of EMC filters is illustrated on example. Results of our synthesis of EMC filter are shown at the conclusion.

1. INTRODUCTION

As the complexity of high-speed electronic system packages increase, engineers and designers are required to take control of more and more aspects of electrical and mechanical engineering early in the design cycle. In order to achieve the objective of faster time-to-market and to be cost effective one needs to be able to predict the electromagnetic radiated emission noises of the system design. [1]

Sensitivity of devices to electromagnetic disturbances is increasing in many industrial fields. For example in EMC modeling and simulation on chip level [2], automotive equipments EMC modeling [3] etc.. Due to the increasing amount of devices sensitive to electromagnetic disturbances solution of problems coupled with electromagnetic compatibility is very important. Problems with electromagnetic compatibility can be suppressed by using special circuit elements. In area of EMC (electromagnetic compatibility) are very often used EMI (electromagnetic interference) filters. Modeling and synthesis of EMI filters is described in this paper. The created model enables 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. 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.

2. EMI FILTERS

Text Electromagnetic interference (EMI) can be reduced to acceptable level using filter circuits usually referred as EMI or RFI filters. EMI filters are usually low-pass 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 low-pass filter configurations (LC ladder circuits). Because these filters are constructed for constant load and generator impedances, design and optimization of filters can be realized according known design and optimization procedures.

The second group of EMI filters is 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.

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 :

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

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

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

The requirement of insertion loss value must be fulfill 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.

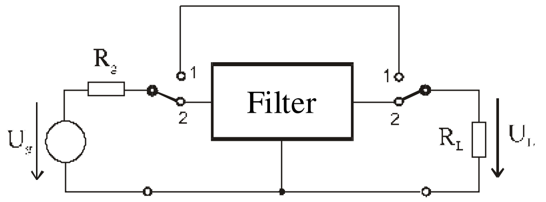

Fig.1. Insertion loss definition and measurement

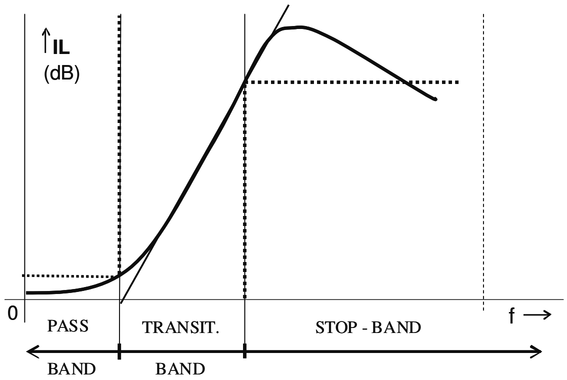

Fig.2. Typical frequency characteristic of EMI filter insertion loss

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. After determining the required insertion loss in the stop band-pass, 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 of power electronic EMC filter most often are used low-pass LC ladder filters in L, PI or T configurations. 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 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. The two – wire EMI filter should be studied as a six – terminal network. 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 specific impedance [7].

3. MODELING OF EMI POWER 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.

In present time PC technique enables to apply direct calculation method very easy. 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 models can be synthesized from the limited data available from manufacturers but also with measured data. 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.3). The approximate values of parasitic elements of most often used EMI filter elements (inductors and capacitors) are summarized in Table 1 [4].

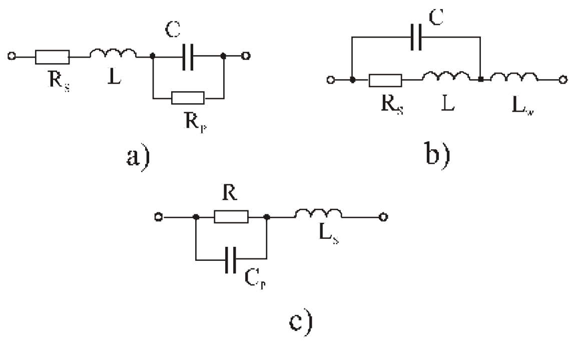

Fig.3. Equivalent circuits : a) of capacitor, b) of inductor, c) of resistor

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

Table1. Typical element values of real filter elements

4. SYNTHESIS OF EMI POWER FILTER MODEL

The model of the filter for three phase power FN 256 -64-52 is here presented as an example of EMC filter model synthesis and optimization. The first step of filter model synthesis was grown from known basic (from manufacturer's data sheet) filter topology (Fig.4).

In the second step the ideal basic elements (R, L,C) were replaced by real models for each of the tree lines. The initial filter value parameters were approximated. Using commercially available analyzers TINA and P-SPICE 9 the filter with equal load and generator resistors (50 Ω) was analyzed. Frequency curve of insertion loss was obtained from circuit analysis. It was compared with the frequency curve presented by the same measuring conditions in manufacturer's data sheet. Then the frequency curve the model of the filter was optimized using optimizer routines from analyzers. As the result of the optimization procedures the values of each element of the model of the filter were obtained. The resulting circuit diagram of the model of the filter with the values of its parameters is shown in Fig.5.

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

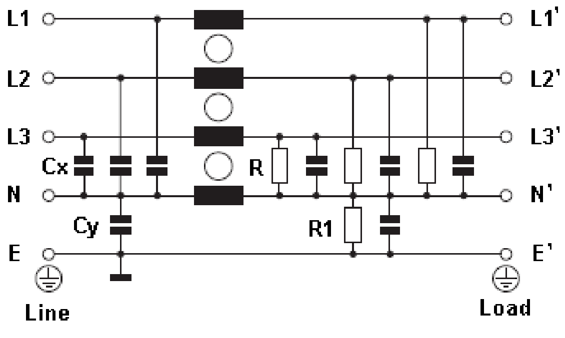

Fig.4. Typical electrical PI topology of power four – wire EMI filter

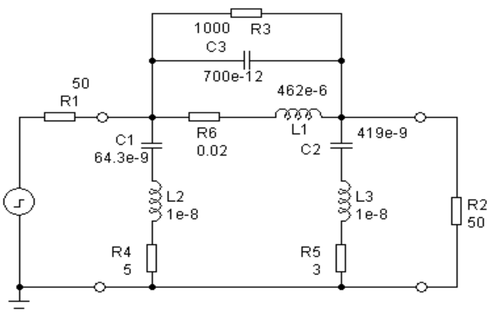

Fig.5. The resulting circuit diagram of filter model (filter FN 256-64-52)

We can see from Fig.6, that in real conditions must be taken into account not only resistances, but also inductances of loads and generators.

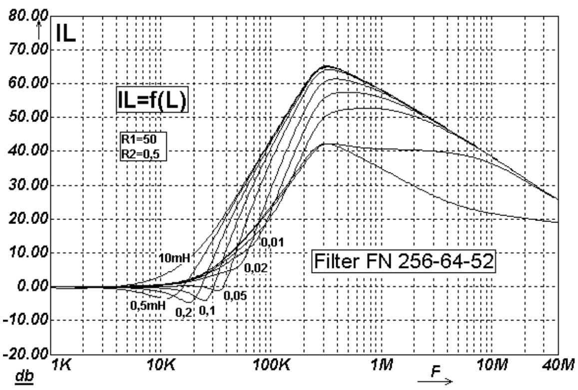

Fig.6. Insertion loss characteristics as function of load inductance

Using measuring chamber is shown on figures (Fig.7, Fig.8) the insertion lost characteristics of the EMC four wire power filter was measured. Results of the measurement were compared with the insertion lost characteristics obtained from the filter modeling.

5. CONCLUSION

The paper deals with the problems of modeling of optimization of EMC filters. The method of synthesis and optimization was described on example of EMC filter. The resulting circuit diagram of the model of the filter with its parameters and the insertion lost characteristics were shown. Influence of mismatched conditions of the insertion lost was investigated. Resulted characteristic from synthesis were compared with experimentally obtained characteristics. In the future the method decrypted in this paper will be improved and the method will be tested on various types of EMC filters.

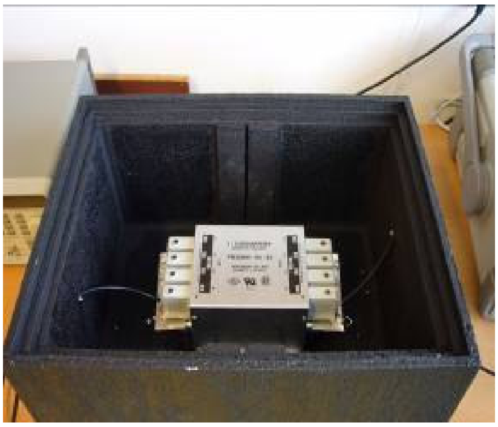

Fig. 7. Measuring chamber with EMC four wire power filter.

Fig. 8. Measuring place with measuring chamber and devices.

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