MODEL OF EMI FILTER FOR ASYMMETRICAL MEASUREMENT SEPUT

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Abstract: In Introduction main problems of measurement of EMI filter are introduced. Reduced equivalent circuitries for EMI filter are shown. The spurious elements of filter in asymmetrical measurement setup are searched by nonlinear least-squares optimization routines. Insertion loss characteristics of several impedance conditions are compared.

Keywords: Insertion loss, EMI filter, spurious component, quasi-Newton method

1. INTRODUCTION

The main attributes of EMI filters are insertion loss characteristics. These characteristics are typically frequency dependant and they refer about the attenuation of the EMI filter. The measurement of insertion loss characteristics are complicated by several aspects. The first main problem of measurement insertion loss characteristics is the configuration of the input and output terminals of the EMI filter. Technical standards distinguish several types of measurement setups according to the interfering signals, which penetrate through the power supply network – e.g. the asymmetrical measurement setup and the symmetrical measurement setup [2].

The second main problem is represented by the non-defined impedance termination at the input and output sides of the filter. The harmonized technical standard ČSN CISPR 17 [1] distinguishes several methods: the standard one with 50 Ω impedances at the input and output terminals of the filter; the approximate method for the EMI filters with 0.1 Ω and 100 Ω at the input and output and vice versa combination, too. But any one of the mentioned method does not corresponded with the reality [2].

It is not possible to perform a lot of measurement of insertion loss characteristics with different impedance termination in several measurement setups due to the technical limits. This is the motivation for the creation of the models of EMI filters. These models will be able to compute insertion loss characteristics for a lot of different terminating impedances and different measurement setups. The components of the model are supposed to be searched by optimization routines.

2. MODEL OF EMI FILTER

The model of the EMI filter is based on the real circuitry of the EMI filter, which is shown for specific filter in figure 1. This basic circuitry has to be enlarged by the spurious components of the filter, which degrade insertion loss in high frequency range. Insertion loss characteristics above 100 kHz are changed with spurious components.

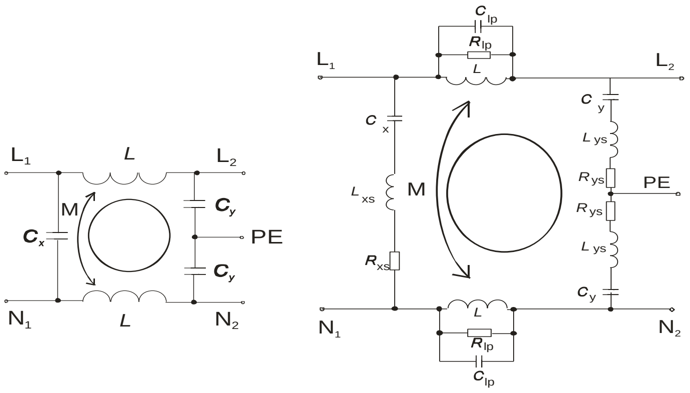
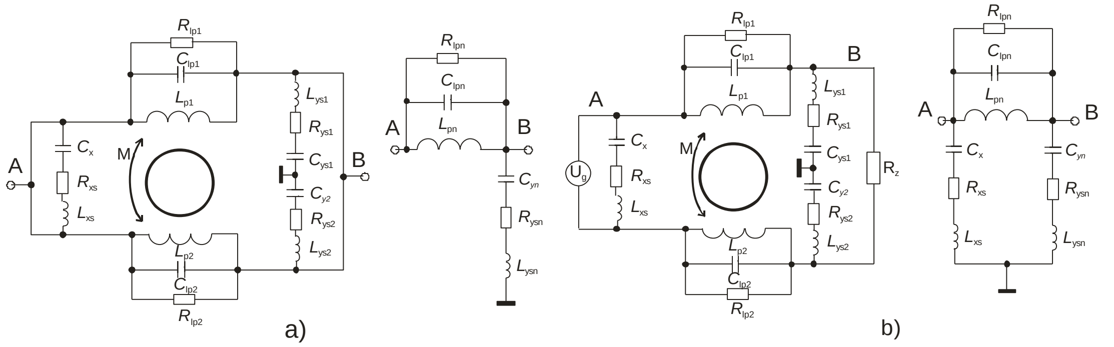


Figure 1: Real and enlarged circuitry of the EMI filter Shurter 5110.1033.1

The model of EMI filter that is created by the enlarged circuitry is shown in figure 1. The mathematical description is possible due to the six-pole parameters, e.g. admittance parameters. This way of description is very difficult and the formulas for computing the insertion loss are very large. For that reason six-pole description is unsuitable for using in iteration loop of optimization.

In figure 2a reduced equivalent circuitry in asymmetrical measurement setup is shown [3], in figure 2b symmetrical measurement setup is depicted. Significant advantage of reduced equivalent circuitry is four pole configuration, because input and output connections are connected according specific measurement setup. It is able to compute the insertion loss by system of non-linear equations obtained e.g. from snap or PSpice software.



a)

b)

Figure 2: Connection of clamps and reduced equivalent circuitry in asymmetrical measurement setup (a) and symmetrical measurement setup (b).

3. QUASI-NEWTON METHOD

The Matlab® function lsqcurvefit - nonlinear least-squares optimization routines was used The line search procedures used in conjunction with a quasi-Newton method are used as part of this function. In the least-squares problem a function $f(x)$ is minimized that is a sum of squares [4].

$$\min_{x} f(x) = \|F(x)\|_2^2 = \sum_i F_i^2(x) \qquad (1)$$

Problems of this type occur in a large number of practical applications, especially when fitting model functions to data, i.e., nonlinear parameter estimation. They are also prevalent in control where you want the output, $y(x,t)$, to follow some continuous model trajectory, $\varphi(t)$, for vector x and scalar t. This problem can be expressed as [4]

$$\min_{x\in\Re^n} \int_{t_1}^{t_2} (y(x,t)-\varphi(t)^2)dt \qquad (2)$$

where $y(x,t)$ and $\varphi(t)$ are scalar functions.

When the integral is discretized using a suitable quadrature formula, the above can be formulated as a least-squares problem [4]:

$$\min_{x\in\Re^n} f(x)=\sum_{i=1}^{m}(\overline{y}(x,t_i)-\overline{\varphi}(t_i))^2 \tag{3}$$

where $\overline{y}$ and $\overline{\varphi}$ include the weights of the quadrature scheme. Note that in this problem the vector $F(x)$ is [4]

$$F(x)=\begin{bmatrix}\overline{y}(x,t_1)-\overline{\varphi}(t_1)\\ \overline{y}(x,t_2)-\overline{\varphi}(t_2)\\ \ldots\\ \overline{y}(x,t_m)-\overline{\varphi}(t_m)\end{bmatrix} \tag{4}$$

In problems of this kind, the residual $\left\|F(x)\right\|$ is likely to be small at the optimum since it is general practice to set realistically achievable target trajectories. Although the function in LS can be minimized using a general unconstrained minimization technique, certain characteristics of the problem can often be exploited to improve the iterative efficiency of the solution procedure. The gradient and Hessian matrix of LS have a special structure.

Denoting the m-by-n Jacobian matrix of $F(x)$ as $J(x)$, the gradient vector of $f(x)$ as $G(x)$, the Hessian matrix of $f(x)$ as $H(x)$, and the Hessian matrix of each $F_i(x)$ as $H_i(x)$, you have [4]

$$\begin{aligned}G(x)&=2J(x)^T F(x)\\ H(x)&=2J(x)^T J(x)+2Q(x)\end{aligned} \tag{5}$$

where

$$Q(x)=\sum_{i=1}^{m}F_i(x)\cdot H_i(x) \tag{6}$$

The matrix $Q(x)$ has the property that when the residual $\left\|F(x)\right\|$ tends to zero as x_k approaches the solution, then $Q(x)$ also tends to zero. Thus when $\left\|F(x)\right\|$ is small at the solution, a very effective method is to use the Gauss-Newton direction as a basis for an optimization procedure.

In the Gauss-Newton method, a search direction, d_k, is obtained at each major iteration, k, that is a solution of the linear least-squares problem:

$$\min_{x\in\Re^n}\left\|J(x_k)-F(x_k)\right\|_2^2 \tag{7}$$

The direction derived from this method is equivalent to the Newton direction when the terms of $Q(x)$ can be ignored. The search direction d_k can be used as part of a line search strategy to ensure that at each iteration the function $f(x)$ decreases [4].

4. RESULTS

The real own elements values was determined by PSO optimization [5]. Insertion loss characteristic from both measurement setups (asymmetric and symmetric) was used for calculation of fitness function. For that reason was possible determine the mutual coefficient k. Determined values are written in table 1.

	L_p [mH]	C_y [nF]	k [-]
Catalogue	0,40	2,20	-
Real	0,35	2,40	0,998

Table 1: Values of own elements of EMI filter.

Spurious elements of EMI filter in asymmetrical measurement setup were obtained by nonlinear least-squares optimization routine, described in chapter 3. Reduced equivalent circuitry in asymmetrical measurement setup was used. The basic characteristic for fitting was measured insertion loss characteristics in asymmetrical measurement setup for impedance condition 50Ω/50Ω. This characteristic is sufficiently approximated by fitted characteristic, what is depicted in figure 3.Obtained values of spurious elements are described in table 2.

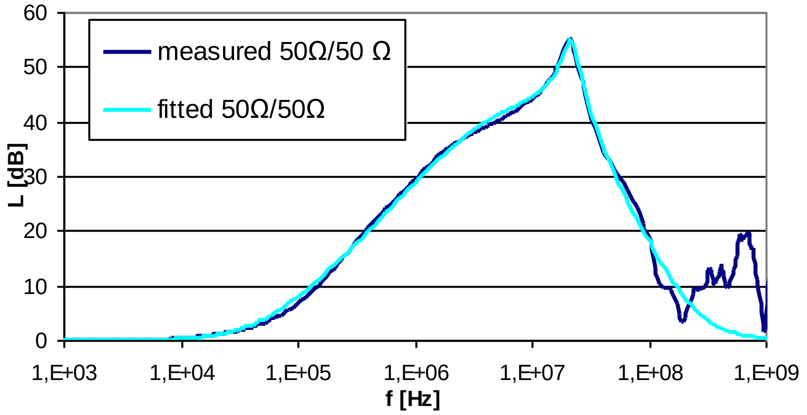


Figure 3: The result of optimization for filter Schurter 5110.1033.1 in asymmetrical measurement setup for impedance condition 50Ω/50Ω.

In figure 2 are characteristics in impedance condition 0,1Ω/100Ω and 100Ω/100Ω calculated from obtained own and spurious elements. It is depicted in contrast with measured characteristics in the same impedance conditions.

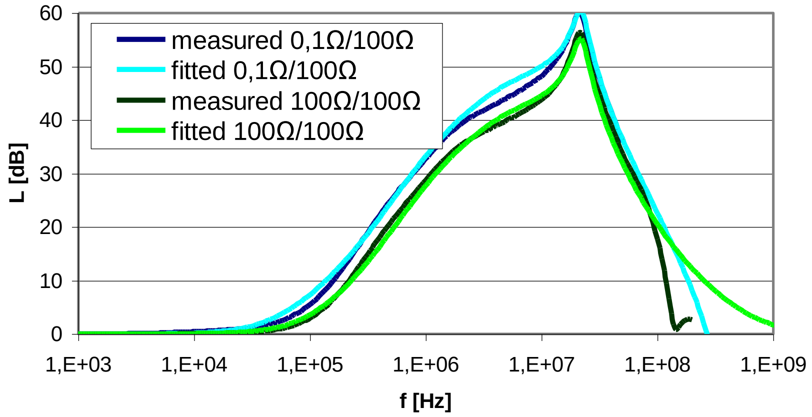


Figure 4: The result of optimization for filter Schurter 5110.1033.1 in asymmetrical measurement setup for impedance conditions 0,1Ω/100Ω and 100Ω/100Ω.

R_{lp} [Ω]	C_{lp} [pF]	R_{ys} [Ω]	L_{ys} [nH]
3353,8	8,53	0,789	21,7

Table 2: Values of spurious elements of EMI filter.

5. CONCLUSIONS

In introduction the main problems about EMI filter measurement were depicted. The equivalent circuits for the asymmetrical and symmetrical measuring systems were introduced. The real own elements values and the mutual coefficient k was determined by PSO optimization [5]. Nonlinear least-squares optimization routine is used for searching values of spurious elements of equivalent circuits for the asymmetrical measurement setup. The basic characteristic for fitting was measured insertion loss characteristics in asymmetrical measurement setup for impedance condition 50Ω/50Ω. Obtained values of own and spurious elements are used for computing another impedance conditions (0,1Ω/100Ω and 100Ω/100Ω) and was compared with measured characteristics in the same impedance conditions. The results show that model is useful for several impedance conditions. Validity of this model is in frequency range to 80 MHz. At higher frequency the spurious connection among elements of filter are important and change the insertion loss characteristics [6].

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