Potential Worst-case System for Testing EMI Filters Tested on Simple Filter Models

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Abstract. *This paper deals with the approximate worst-case test method for testing the insertion loss of the EMI filters. The systems with 0.1 Ω and 100 Ω impedances are usually used for this testing. These systems are required by the international CISPR 17 standard. The main disadvantage of this system is the use of two impedance transformers. Especially the impedance transformer with 0.1 Ω output impedance is not easy to be produced. These transformers have usually narrow bandwidth. This paper discusses the alternative system with 1 Ω and 100 Ω impedances. The performance of these systems was tested on several filters' models and the obtained data are depicted, too. The performance comparison of several filters in several systems is also included. The performance of alternate worst-case system is discussed in the conclusion.*

Keywords

Electromagnetic compatibility EMC, EMI mains filter, insertion loss, impedance termination, filter model, modified nodal voltage method, current compensated inductors.

1. Introduction

Electromagnetic compatibility branch is little bit specific from other electromagnetic and measurement branches. The main difference consists in the measuring or searching for the "worst-case" values of measured quantities, especially in electromagnetic compatibility area. On the other hand, the electromagnetic and measuring disciplines usually work with the immediate values of measured quantities, which have been taken in specified time. The electromagnetic interference penetrating from the devices under tests is always measured by specified techniques, by which the worst-case values of measured quantities are obtained. The measuring techniques are specified by authorized international standards. The same principle is applied for performance measuring of the EMI filters. The performance of these filters is usually given by insertion loss characteristics. The insertion loss of the EMI filter depends on the impedance terminations of the input and output terminals of the EMI filters. The insertion loss of the filter, which circuitry is depicted in Fig. 1, could be calculated by using the cascade parameters [1] and [2]:

$$
\begin{aligned}
L &= 20 \cdot \log \left| \frac{U_{20}}{U_2} \right| = \\
&= 20 \cdot \log \left| \frac{Z_\mathrm{L}}{Z_\mathrm{S}+Z_\mathrm{L}} \cdot \mathbf{A}_{11} + \frac{1}{Z_\mathrm{S}+Z_\mathrm{L}} \cdot \mathbf{A}_{12} \right| = \qquad (1) \\
&= 20 \cdot \log \left| \frac{Z_\mathrm{S} \cdot Z_\mathrm{L}}{Z_\mathrm{S}+Z_\mathrm{L}} \cdot \mathbf{A}_{21} + \frac{Z_\mathrm{S}}{Z_\mathrm{S}+Z_\mathrm{L}} \cdot \mathbf{A}_{22} \right| .
\end{aligned}
$$

U_2 is the voltage at the output of the EMI filter on the loading impedance Z_L, U_{20} is the same voltage, but the filter has been unplugged. $\mathbf{A}_{11}$, $\mathbf{A}_{12}$, $\mathbf{A}_{21}$ and $\mathbf{A}_{22}$ are cascade parameters of the EMI filter. These parameters are complex. Z_S is the impedance of the source of interfering signal or signals.

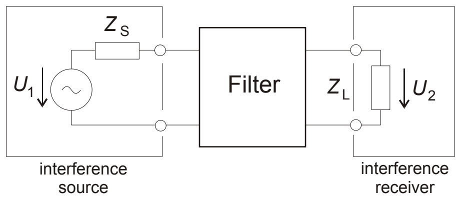

Fig. 1. The EMI filter as a ideal two-gate circuit.

The insertion loss of the filter depends on the input and output terminating impedances, and on the frequency of the interfering signal. It is necessary to change or tune, in the same time, the frequency, input and output impedances for obtaining the worst-case insertion loss of the filter. These conditions result from previous analysis. The identification of the worst-case by the mentioned test setup will be precise, but in fact this method could be realized in limited frequency bandwidth. The testing and measuring of the worst-case insertion loss characteristics are usually done in accordance with the authorized standards. There are several standards, e.g. ČSN CISPR 17 [3] Czech national standard which is in accordance with the international standard CISPR 17. The MIL-STD-220B [4] is similar. This standard is defined by the Department of Defence of the United States of America.

The above described measurement method is discussed in these standards, but the measurements are not carried out by this way in practical testing in addition. These standards also define the approximate method for the EMI filters. The EMI filters are tested in impedance systems with the terminating impedances 0.1 Ω/100 Ω and vice versa. The measurement setup of this method is depicted in Fig. 2.

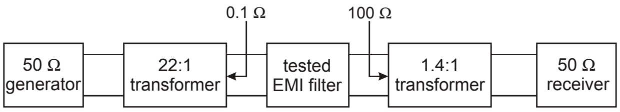

Fig. 2. The approximate method for the EMI filters.

The approximate test method requires using of two impedance transformers. These transformers transform the characteristic impedance of the measuring system to the impedances of 0.1 Ω and 100 Ω. These values are required by the technical standard [3]. The impedance transformers could transform asymmetrical input to symmetrical output etc. Operating frequency band of these transformers is usually reduced to two decades. This fact limits the wide-band measuring. Especially the design of the 0.1 Ω transformers is really critical. The value of the output transformed impedance usually rapidly increasing with the increases frequency. These transformers have usually only several coils of a secondary winding. The technique for winding several coils was discussed in [5]. Thus the biggest problem is in large transformation ratio from 50 Ω to 0.1 Ω. This problem could be fixed by similar test setup, by which the same values of the insertion loss of the EMI filters will be reached.

2. Alternative Worst-case Test Setup

The "intended" worst-case measuring system should respect the approximate test method for the EMI filters, but the 0.1 Ω should be replaced by another impedance value. The testing of intended test system could not be carried out only by producing several different impedance transformers and just simply measuring the insertion loss of the filters. This setup will be very time consuming and also not so much effective. The mathematical simulations on accurate EMI filters' models can offer more effective solution. These models were discussed in [6] and [7]. An alternative test system could be chosen from several systems with different terminating impedances, but the performance of tested EMI filters have to be the same or in specified limits. These tolerance limits should be under several dB which is usually uncertainty of the whole measurement. These conditions could be fulfilled for example by the system with 1 Ω/100 Ω and vice versa. This system was tested on several models of EMI filters: Schurter 5110.1033.1, Schaffner FN 321 1/05, FN 2020-16-06, FN 2070-10-06, Elfis 1ELF16V, 1ELF16VY-4 and Filtana TS 800 1006. The potential performance of Schurter 5110.1033.1, Schaffner FN 2070-10-06, and Elfis 1ELF16V filters is depicted in the following figures. The systems 1 Ω/100 Ω and 100 Ω/1 Ω were chosen as a compromise between the 0.1 Ω system, which is required by the CISPR standard [3], and the frequency bandwidth of the applied impedance transformers. The transformers with transformation ratio from 50 Ω to 1 Ω will accurately operate in the wider frequency range than the transformers with 0.1 Ω output impedance. The right presentation of obtained data from approximate worst-case system with impedances 0.1 Ω and 100 Ω is discussed in [8].

The system 1 Ω/100 Ω and vice versa system were tested on the mentioned EMI filters' models. The performance of each filter was tested in asymmetrical, symmetrical and in "non-symmetrical" measuring systems. The Schurter filter data are depicted in Fig. 3, 4 and 5. It should be also mentioned that the model works pretty well in the frequency range up to 10 MHz. This fact is caused by neglecting the spurious parameters of passive parts of the filter. This problem was discussed in [7].

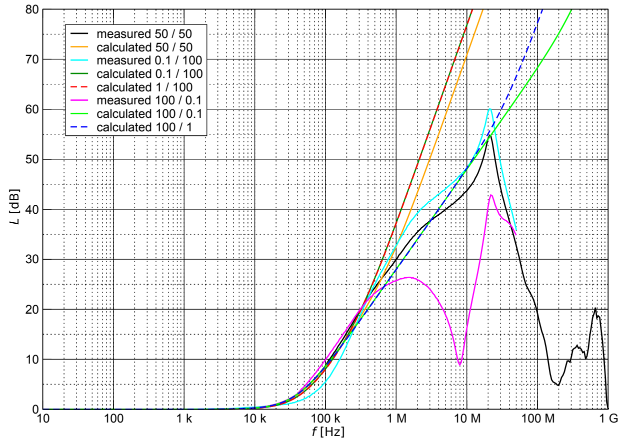

Fig. 3. The insertion loss of the Schurter 5110.1033.1 in asymmetrical systems.

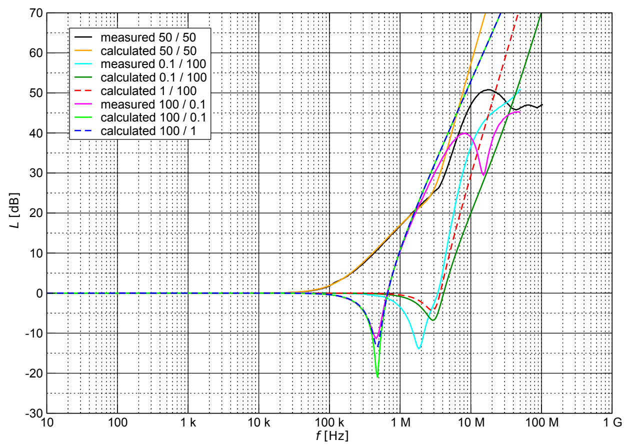

Fig. 4. The insertion loss of the Schurter 5110.1033.1 in symmetrical systems.

The examples of insertion loss characteristics of other EMI filters which were tested are depicted in Fig. 6, 7, 8, 9,

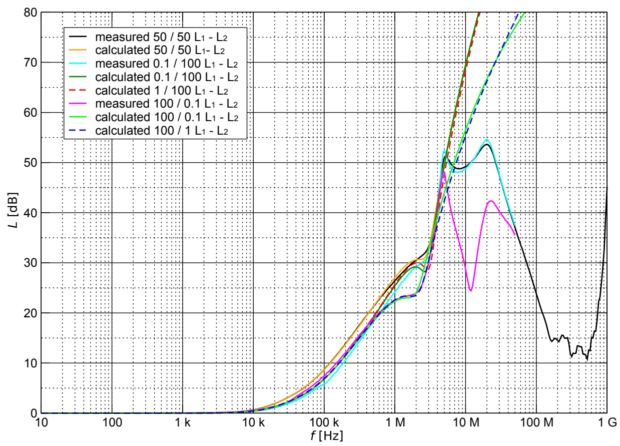

Fig. 5. The insertion loss of the Schurter 5110.1033.1 in "non-symmetrical" systems.

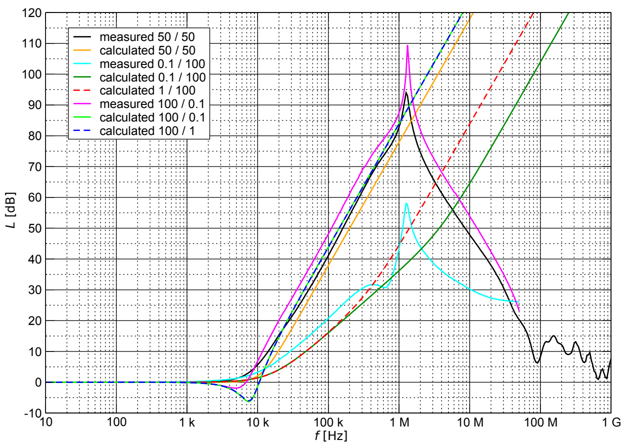

Fig. 6. The insertion loss of the Elfis 1ELF16V in asymmetrical systems.

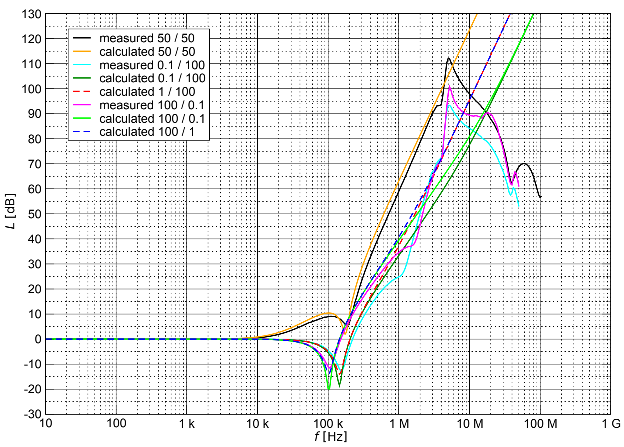

Fig. 7. The insertion loss of the Elfis 1ELF16V in symmetrical systems.

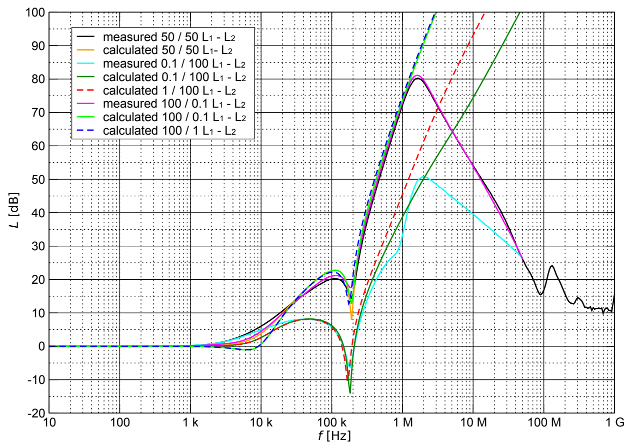

Fig. 8. The insertion loss of the Elfis 1ELF16V in "non-symmetrical" systems.

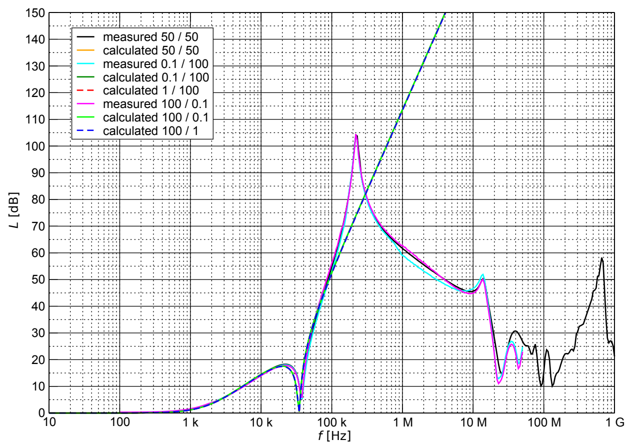

Fig. 9. The insertion loss of the Schaffner FN 2070-10-06 in asymmetrical systems.

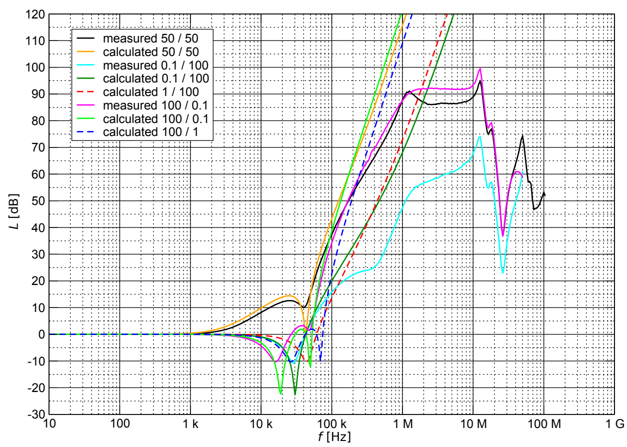

Fig. 10. The insertion loss of the Schaffner FN 2070-10-06 in symmetrical systems.

10, and 11. There were filters Elfis 1ELF16V and Schaffner FN 2070-10-06. The filters Schurter and Elfis contain only a single current compensated inductor, but on the other hand, the Schaffner FN 2070-10-06 contains two current compen-

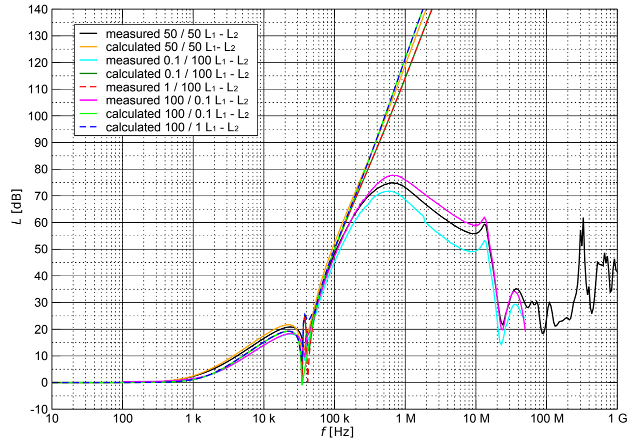

Fig. 11. The insertion loss of the Schaffner FN 2070-10-06 in "non-symmetrical" systems.

sated inductors. The performance of alternative worst-case system could be directly compared with approximate worst-case method, these data are shown in figures.

3. Conclusions

The performance of the alternative worst-case test method for EMI filters was compared with the approximate test method which is required by the international CISPR 17 standard [3]. The alternative test method used transformers with the 1 Ω output impedance and the approximate method used 0.1 Ω. The data for approximate method have been taken by measuring and by simulations on simple EMI filter's models. On the other hand the data for alternative worst-case method were taken only by using the simple models. The differences between these two systems are obvious from the presented figures. The absolute inaccuracy of the alternative test method is less than 3 dB in the frequency range up to 3 MHz, but at some cases only up to 100 kHz. In this frequency range the simple models work pretty well. This fact was discussed in [7]. The advantage of the alternative method might be in an easier design of the impedance transformers. These transformers will cover a wider frequency band with a stable output impedance. These advantages will be bought out by the several dB of the error according to the approximate method. The potential of the alternative method should be proved by the measuring of the insertion loss of real EMI filters in this new impedance system with 1 Ω. These measurements will be next steps in further work. The corresponding transformers should be designed and produced. Their performance should be checked by several measurements.

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