

Practical Procedures in Determining the Differential Mode Characteristics of EMI Power Supply Filters

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Abstract—There are virtually no electronic products today that can comply with the conducted emission regulatory requirements without the use of some form of power supply filter being inserted where the power cord exits the product. Sometimes, properly designed transformers can provide inherent filtering, and so can obviate the need for an “intentional” filter. Mains EMI (electromagnetic interference) filters carry potentially high currents at dangerously high voltages, so care is essential in their choice. The working voltage and current rating of components can be decided once the specification is known. The basic specification should also include mechanical details such as the enclosure size, and the limit of weight. The electrical specification should include the voltage and current rating. In addition the EMC performance and the allowable leakage current should be specified. The electrical specification must also comply with national safety standards. In the Electrical Equipment Laboratory of the Technical University from Cluj-Napoca, we have made studies on several types of EMI filters and have performed procedures for determining their main differential mode characteristics, presented in the paper for a study of case.

Index Terms—EMI, insertion loss, conducted emissions, frequency analysis, attenuation

I. INTRODUCTION

Electromagnetic interferences (EMI) represent perturbations exceeding the maximal values allowed by standards. EMI filtering represents basically countermeasures meant to mitigate conducted interferences, i.e. perturbations transmitted by conductors (supply lines, data lines or signal conductors).

There is a main distinction between classical wave filters and EMI filters. If classical wave filters are conceived for impedances match in order to assure a maximum power transfer in the frequency band-pass and dissipate the perturbations energy inside the filters, EMI filters work mainly on large discontinuities in impedances, reflecting perturbations which dissipate their energy elsewhere in the system.

Most manufactured EMI filters are low-pass and band-stop filters, other types of conventional design being very rarely adopted. EMI and conventional filters technologies also differs greatly.

EMI filter design is less restrictive compared to the conventional filters design. EMI filters component values are flexible, so standardized values can be used. The main concern consists in achieving the specified insertion loss, assuming the rest of the specification is met. Although the power source may have harmonics, the actual power

supplied to the device through the filter is restricted to the fundamental frequency. So, flat frequency response, low phase distortion, or low peak-to-peak ripple across the filter band pass is not an issue here. These power line harmonics furnish no power to the load, so the EMI filter designer is not concerned with them.

To summarize, the requirements of the conventional, or wave filters are entirely different from EMI filters requirements. The conventional, or wave filter component values are critical and often requires tuning, operation which in the case of EMI filters represents an exception.

II. INSERTION LOSS

The characteristic value of EMI filters is the insertion loss IL , defined as the ratio between the power consumption on the load in a reference circuit before and after the filter insertion (Fig. 1).

$$IL = 10 \cdot \lg \frac{P_1}{P_2} = 20 \cdot \lg \frac{V_1}{V_2}, \quad (1)$$

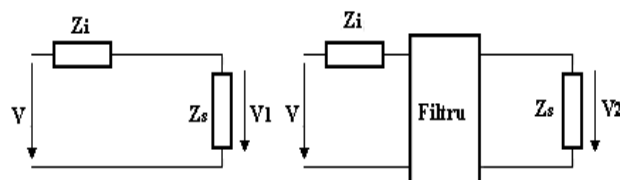


Figure 1. EMI filters insertion loss.

In the case of a ferrite core, inserted on signal lines, equation (2) is applied (Fig.2):

$$A[dB] = 20 \lg \frac{Z_i + Z_F + Z_s}{Z_i + Z_s} \quad (2)$$

The insertion loss introduced by a ferrite depends on the impedances of the circuit. For high values of source and load impedances, the specified insertion loss is obtained by increasing the number of the coil turns or by using a ferrite of higher volume.

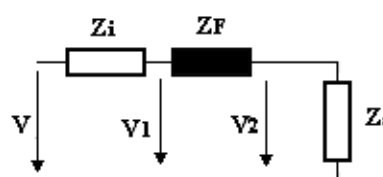


Figure 2. Insertion loss in the case of a ferrite.

In Fig. 3 is presented the typical variation of the modulus of the impedance of a ferrite for different number of turns.

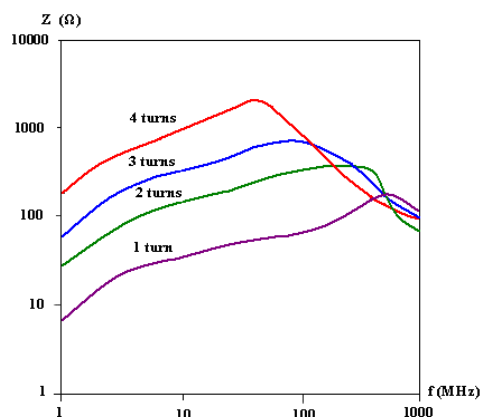


Figure 3. Typical variation of the impedance modulus in the case of a ferrite.

One can notice the growth of the impedance, along with a shift of the maximal value in lower frequencies range.

The most part of the manufacturers give the insertion loss of EMI filters or EMI ferrites versus frequency for a 50Ω source and load impedances. The 50Ω value represents also the standardized value for EMC emission tests and represents in the same time the LISN (line impedance stabilization network) impedance.

Obviously, this is not the situation in practical applications. Adopting this convention allows a direct comparison of the filters, but calculating the insertion loss based on these assumptions is in general optimistic compared with the performance of the filter inserted in specific equipments.

Inductances present certain frequencies of resonance, determined by the undesired inter-turns capacitances of the coil; capacitors also resonate because of the undesired inductances of the conductors. High values resistors are also susceptible of presenting stray capacitances while low values resistors present stray inductances.

The performances of the capacitors and inductors of a filter depend critically on the resonance frequencies and on the source and load impedances.

In order to have reasonable values for the filters and amplifiers impedances, the characteristic impedance of the cables must have an intermediate value.

Low value impedances may cause troubles in the design of the amplifiers.

For the coaxial cables, used in RF systems, the most common value of the impedance is 50Ω. Its geometry confers to coaxial cable, for maximum power transfer, a characteristic impedance value around 30Ω. In the same time for maximum power efficiency the value of the characteristic impedance is situated around 77Ω. That is why 50Ω represents a reasonable compromise between the two optimal values.

Another reason for the choice of the 50Ω characteristic impedance value is that monopole antennas have approximately the same characteristic impedance value, which guaranties an optimum match to the cable.

However, because a 75Ω coaxial cable presents the best power efficiency, the CATV companies have imposed this type of cable in TV signal distribution.

III. CONDUCTED EMISSIONS TEST

The conducted emissions conformity is usually tested using EMC receivers optimized in the 150kHz-30MHz frequency range. EMC receivers are superior in performances than spectrum analyzers, mainly because of the following characteristics:

- a higher sensitivity, which allows a better discrimination of the signals from the noise inside the standardized emission limits;
- a higher resistance of the input circuits to overload;
- a better accuracy in amplitude and frequency.

Spectrum analyzers, cheaper than EMC receivers, are widely used in rapid diagnosis techniques and are very suitable for the visualization of the frequencies and the nature of the aggressive emissions.

On another hand, the combination of a spectrum analyzer and a tracking generator is very useful to verify the circuit response in the frequency range.

In order to measure the voltages of the conducted emissions at the supply low voltage port, a line impedance stabilization network is used. The LISN assures definite radio-frequency impedance in a test point, in the same time creating the coupling possibility to the test instrumentation along with the isolation of the test circuit from the undesired interference signals incoming from the low voltage network.

The most utilized type of LISN is the one defined in CISPR 16-1 and presents an equivalent impedance of 50Ω in parallel with a 50μH inductance between each supply line and the PE conductor. Other types of LISN were also defined, but the 50Ω/50μH version became a standard.

In the Electric Equipments Laboratory of the Technical University from Cluj-Napoca, for test setups, we have used the spectrum analyzer and the built-in tracking generator HM 5014 and the line stabilization network HM 6050-2 (Hameg Instruments).

The spectrum analyzer HM 5014 has the following technical characteristics:

- continuous range of frequency between 150kHz - 1050MHz
- amplitudes between -100dBm and +13dBm (7dBμV to 120dBμV), 80dB on screen;
- bandwidth resolutions of 9kHz, 120kHz, 400kHz;
- dynamic range without inter-modulations of 75dB.

The essential characteristic of this spectrum analyzer is represented by its extended capacity for EMC measurements, having the possibility of representing the maximal, peak and quasi-peak values.

The HM 5014 spectrum generator includes a tracking generator, which can be successfully used to evaluate the frequency characteristics of the quadripoles.

The spectrum analyzer works under the firmware SW 5012E-V147, on the serial interface RS-232.

The test procedure respects the following conditions:

- Emissions generated by the electric equipment and conducted on the supply lines can be checked using a line impedance stabilization network and a spectrum analyzer/EMC receiver.

- The EUT (equipment under test) must be connected directly to the line impedance stabilization network.

Inside the LISN, the voltage lines are terminated on defined impedances with respect to PE.

Basically, the line impedance stabilization network is a filtering network, the EUT being connected to the mains ports by a low-pass filter (Fig.4).

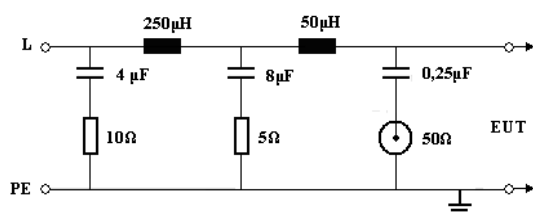


Figure 4. LISN between L and PE.

The determining components for the network impedance are the 50 μH inductance and the 50 Ω resistor. The rest of the components serve to decouple the low voltage supply. A supplementary high-pass filter between the line impedance stabilization network output and the spectrum analyzer/EMC receiver may be used. This high-pass filter cuts the frequencies under 9 kHz, in order that the receptor should be not affected by the high order harmonics of the supply network.

Obviously, this filter should maintain a 50 Ω impedance value and present a very low insertion loss in the measured range of frequencies (preferably 0 dB).

In order of performing tests with the spectrum analyzer/EMC receiver, the EMC signal is available after passing through the high-pass filter. The noise asymmetric signals emitted on the supply lines L1 and N of the EUT are given by two line impedance stabilization identical networks. The signals can be selected for being available in turn at the output port of the HM 6050-2.

In order to protect its inputs, when measurements are performed with a spectrum analyzer/EMC receiver, it is strongly recommended the use of a transient voltage limiter.

The LISN does not discriminate between differential and common mode perturbations.

The tests, carried out with the described equipments, refer to the conducted emissions according the standard EN 55011. According to this standard, the perturbation voltages in the frequency range from 150 kHz to 30 MHz are measured using a 50 Ω/50 μH line impedance stabilization network. The point of high frequency signal was connected to the spectrum analyzer, the series of measurements being compared with the standard average and quasi-peak limits, according to the Fig.5

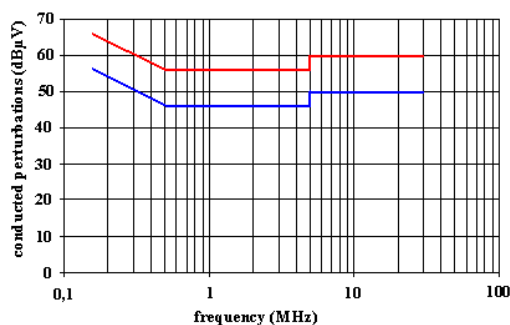


Figure 5. Average (blue) and quasi-peak (red) EN 55011 standard limits

Insertion loss may be measured either in common and differential mode, using a tracking generator and a spectrum analyzer. The test setup needs a correction calibration (Fig.

6) which takes into account the components interposed between the two equipments.

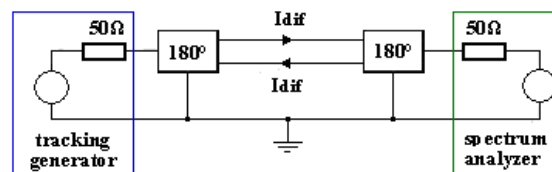


Figure 6. Calibration Setup.

Fig. 7 presents the insertion loss measurement setup for EMI mains filters in differential mode.

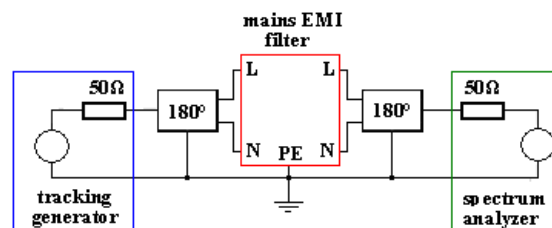


Figure 7. Measurement setup for the insertion loss in differential mode for the mains EMI filters.

The test setup used in the Electric Equipments Laboratory of the Technical University from Cluj-Napoca, is presented in Fig. 8. The connection cables are coaxial cables with 50 Ω characteristic impedance, RG 58/U type.

Normally, the measured values for the insertion loss of filters, must match with the manufactures specification.

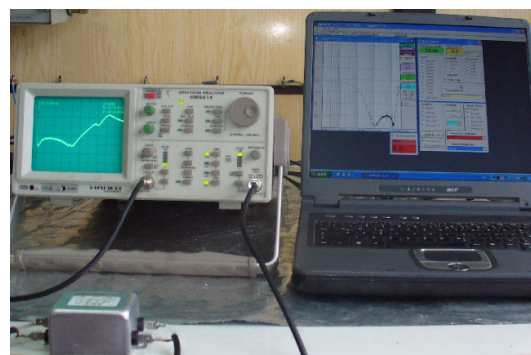


Figure 8. Test setup for the insertion loss of the EMI filters.

IV. EXPERIMENTAL RESULTS

Measurements were performed using the EMI filter F.A1.D-2330.ZA, manufactured by Arcotronics Ltd., 10A/230V a.c., whose electric circuit is presented in Fig. 9 and whose components are: $C_x=0,033\mu\text{F}$ (class X2), $C_y=2\times 2200\text{pF}$ (class Y2), $L=2\times 0,5\text{mH}$, leakage current $IL=2\times 0,2\text{mA}$; temperature range -25°C to $+85^\circ\text{C}$.

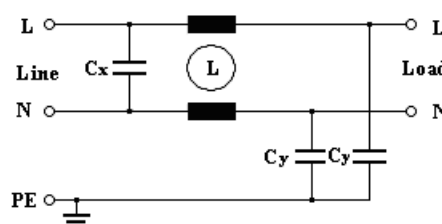


Figure 9. The F.A1.D-2330.ZA EMI filter electric circuit.

In Fig. 10 it can be seen the insertion loss curve in differential mode (interrupted line), respectively the insertion loss curve in common mode (solid line).

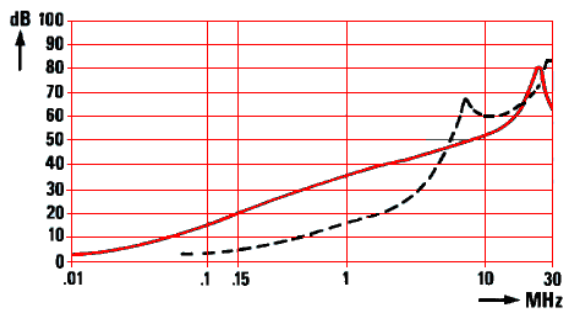


Figure 10. Insertion loss of the F.A.I.D-.2330.ZA, EMI filter in logarithmic scale.

The transfer characteristic of the F.A.I.D-.2330.ZA, EMI filter in differential mode in logarithmic and linear scale for the frequency are presented in Fig. 11 and 13.

Fig. 12, the reversed insertion loss characteristic, represents the attenuation characteristic of the filter and permits the direct comparison with the manufacturer's specifications (value and shape of the attenuation curves in the frequency range from 150kHz to 30MHz).

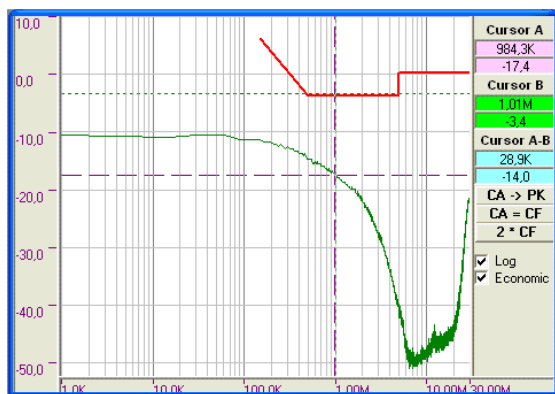


Figure 11. The direct transfer characteristic measured in differential mode

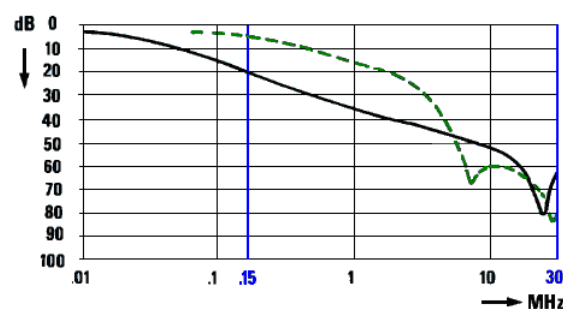


Figure 12. The attenuation of the F.A.I.D-.2330.ZA, EMI filter in logarithmic scale.

Comparing the measured characteristic with the catalogue characteristic (the interrupted green curve from Fig. 12), two major amendments result:

- the maximal measured attenuation does not exceed 50dB, while in the catalogue the maximal attenuation is around 67dB (in both cases this maximal attenuation occurs around the frequency of 7.5MHz)
- beyond the value of 7.5MHz the measured attenuation drops until 27MHz, while the catalogue attenuation continues to raise from 10MHz to 27MHz.

In other words, the maximal catalogue attenuation is not confirmed by the measurements; it results a 17dB difference of the maximal attenuation and beyond 10MHz the behavior of the filter is inverse. Furthermore, the measured attenuation at 150kHz is better than the attenuation indicated by the catalogue.

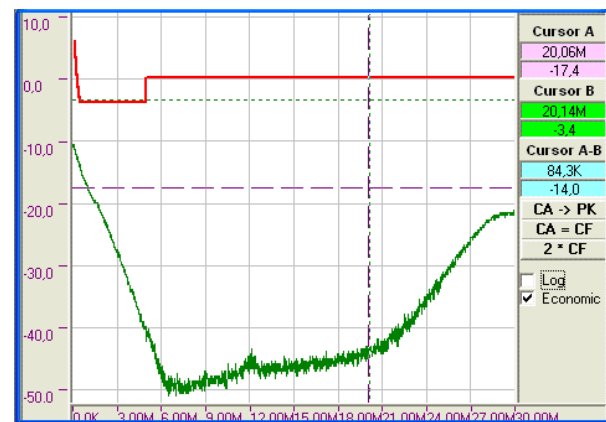


Figure 13. The attenuation characteristic in differential mode (linear scale for the frequency)

The measured characteristics in average values (blue curve) and maximal values (red curve) in logarithmic scale for the frequency (Fig.14) respectively in linear scale for the frequency (Fig.15) are very closed one to the other, which reveals a very good uniformity of the filters behavior.

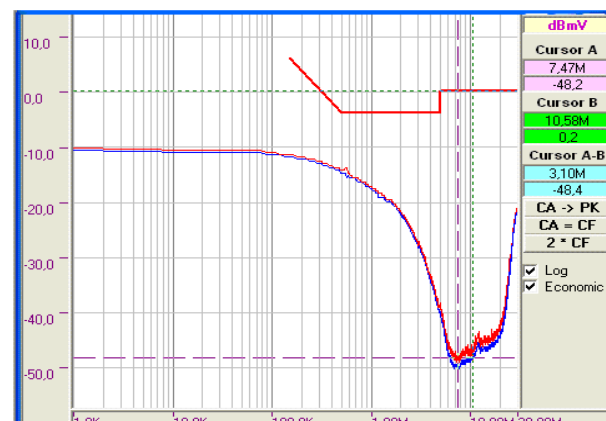


Figure 14. The attenuation characteristics in differential mode in average values (blue curve) and maximal values (red curve) (logarithmic scale for frequency).

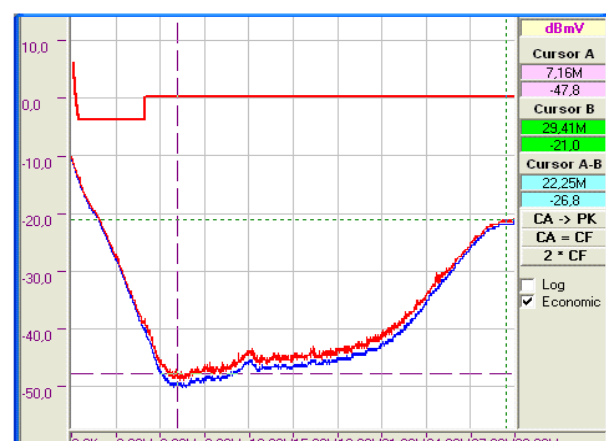


Figure 15. The attenuation characteristics in differential mode in average values (blue curve) and maximal values (red curve) (linear scale for frequency)

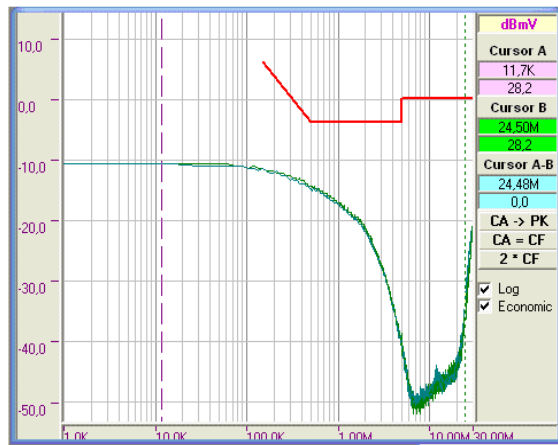


Figure 16. The attenuation characteristics, direct transfer (blue curve) and inverse (green curve) (logarithmic scale for frequency).

A comparative representation of the direct (blue curves) and inverse (green curves) transfer characteristics reveals a very good symmetry of the coils (Fig. 15 and 16), the filter fulfilling the theoretical reciprocity condition.

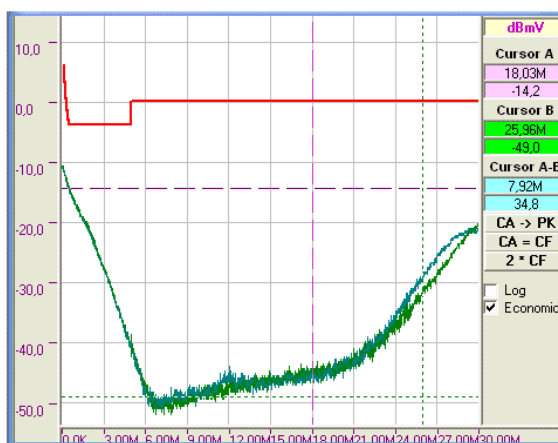


Figure 17. The attenuation characteristics, direct transfer (blue curve) and inverse (green curve) (linear scale for frequency).

V. CONCLUSIONS

The measurements reveal that the EMI filter F.A1.D-.2330.ZA, is meant for a quite low frequency range. It begins to attenuate around 1MHz (where attenuation is more or less 52dB) and lasts until around 12MHz (the upper limit for conducted emissions is 30MHz).

Comparing the measured characteristic with the catalogue characteristic four major amendments result:

- the maximal measured attenuation does not exceed 52.6dB and appears at 1MHz, while the maximal catalogue attenuation is around 70dB and appears at 3MHz

- the minimal measured attenuation is 9.2dB and appears at 25MHz, while the minimal catalogue attenuation is 40dB and appears also at 25MHz.

- the measured attenuation drops until 43dB between 3MHz and 6MHz, then grows again to 47dB at 12MHz; beyond 12MHz the measured attenuation drops constantly until 25MHz, while the catalogue attenuation drops until 25MHz;

- at 150kHz, the measured attenuation is 12dB, while the catalogue attenuation is 27dB;

To summarize:

- the maximum catalogue attenuation is not confirmed by the measurements

- the shape of the attenuation characteristic is slightly different from the catalogue one

- the similitude between the attenuation characteristics measured in average and maximal values reveals a very good uniformity of the filter in the whole range of frequencies, from 150kHz to 30MHz.

- the comparative representation of the direct (blue curves) and inverse (green curves) transfer characteristics reveals a very good symmetry of the coils, the filter fulfilling the theoretical reciprocity condition.

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