VARIATION OF POWER LINE FILTER PERFORMANCE RELATIVE TO LOAD IMPEDANCE

INTRODUCTION

Two filters with differing catalog attenuation characteristics, one high-performance and one low-performance, behave differently in real applications. Sometimes, the low-performance filter does a better job in an application than the high-performance filter. As all engineers know, the power line filter performance is not equal to the attenuation as measured in a 50 ohm system. The development engineer usually selects the filter by the published data, assuming that a higher insertion loss gives better noise attenuation in the actual application.

This article shows and explains the variation of filter performance relative to load impedance variation. It explains why engineers should also look at the circuit diagram of a filter when choosing one for their equipment.

TYPICAL INSERTION LOSS MEASUREMENT

Insertion loss is the ratio (expressed in dB) of the signal voltage transferred from source to load when the filter is inserted. The insertion loss data published by the various filter manufacturers is typically based on MIL STD 220A. This means that the measurement circuit has a source and load impedance of 50 ohm resistive.

To achieve consistent results, it is important that the measurement circuit be precisely defined. In particular, when comparing insertion loss data of electrically "equal" filters from different manufacturers, it must be remembered that there may be variances because of a different measurement setup.

For power line filters, two different insertion loss modes are plotted.

Common mode (CM)	**Differential mode (DM)**
Signals from phase and neutral referenced to ground (Figure 1)	Signals from phase referenced to neutral (Figure 2)

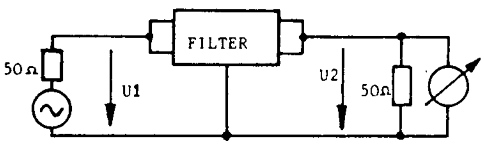


Figure 1. Common mode measurement.

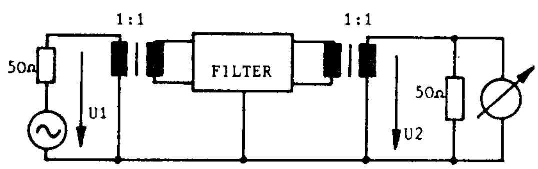


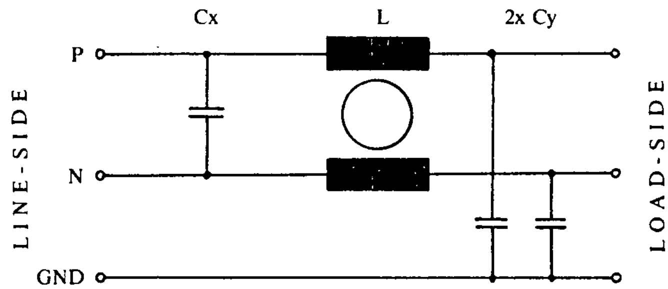
Figure 2. Differential mode measurement.

As other articles also point out, there are many factors which influence the performance of a filter in actual use:

- The physical dimensions of the inductor core;
- The operating current and frequency;
- The environment (ambient temperature and stray fields from other components);
- The temperature rise in the filter;
- The impedance (discussed in this article).

Impedance of line and load have a major influence in the filter performance. In general, one can say the greater the impedance mismatch, the better the attenuation of the filter. In other words, if the line and load impedances are low, the input and output impedances of the filter should be high to achieve a good mismatch, and therefore an acceptable attenuation for the interference spectrum.

A typical one-stage filter (Figure 3) was developed to demonstrate the difference between load impedance, match, or mismatch in performance of a filter.



Parameter	Filter
L	12.3 mH
Cx	0.22 uF
Cy	3.3 nF
Lstray	120 uH
Rcu	200 mOhm

Figure 3. Test filter circuit.

THE MEASUREMENTS AND RESULTS

The 50 ohm insertion loss curves

Figure 4 shows the recorded common mode and differential mode insertion loss curves.

Effective insertion loss under various load impedances

Effective insertion loss means the real effect a filter has in a particular piece of equipment. Conducted interference measurements are taken, one with, another without, the filter in the power line. The difference between these two curves is the effective insertion loss. This effective insertion loss is the real performance of the filter in that particular equipment. And with this effective insertion loss filters from different manufacturers can be compared.

An interference simulator (NSG 222A) was used as a reproducible noise source (Figure 5) and the interference spectrum was recorded for common and differential modes without a filter but with the various loads installed (dotted lines in Figures 8, 9, 10 and 11).

The test loads are: — 105 ohm resistor
— 3.5 mH choke
— 1.0 uF capacitor

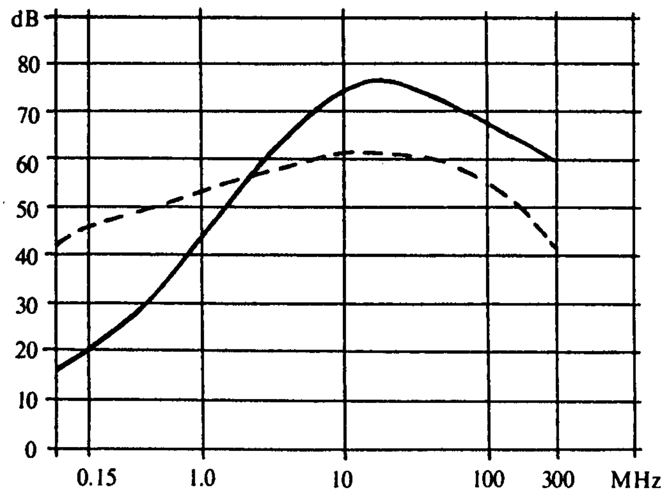


Figure 4. Differential mode (full) and common mode (dashed) insertion loss.

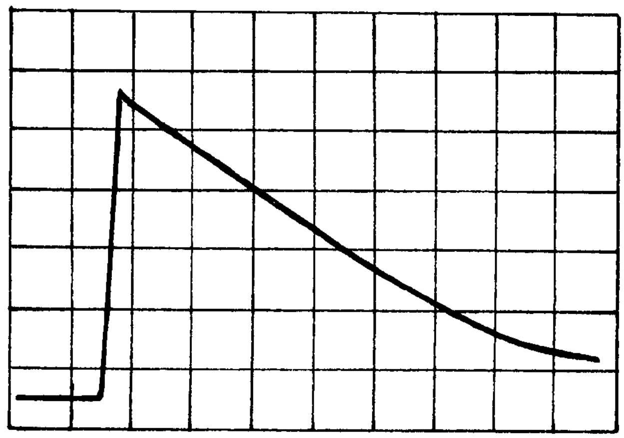


Figure 5. Interference pulse.
rise time — 5 ns
pulse width — 80 ns
amplitude — 1 kVp
repetition rate — 50 Hz

The current flow through the filter should not saturate its choke, so that only the variation in attenuation is measured, caused by the change in load impedance.

To simulate all the "good and questionable combinations" (Figure 7), the filter was used either "forwards" or "backwards" (Figure 6). In other words, the filter was reversed:

— "Forwards" = the line-side of the filter was connected to the NSG.

— "Backwards" = the load-side of the filter was connected to the NSG.

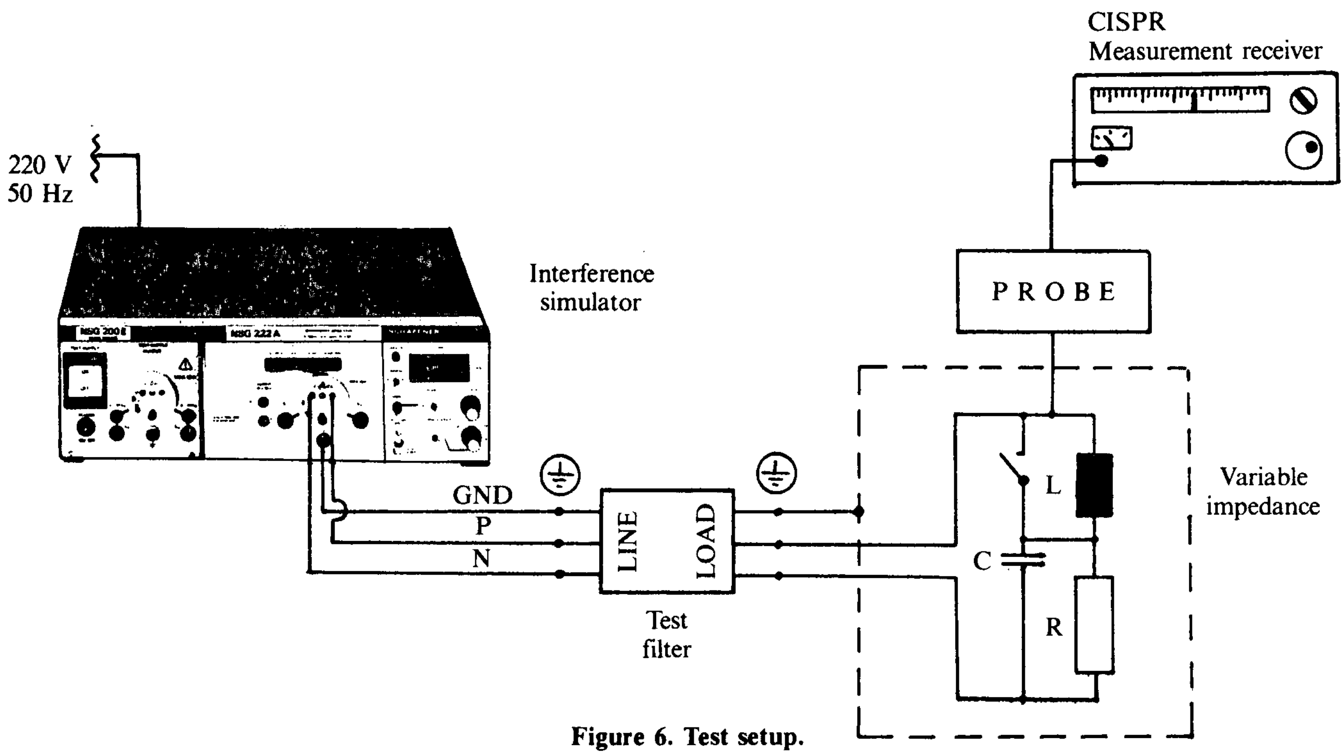


Figure 6. Test setup.

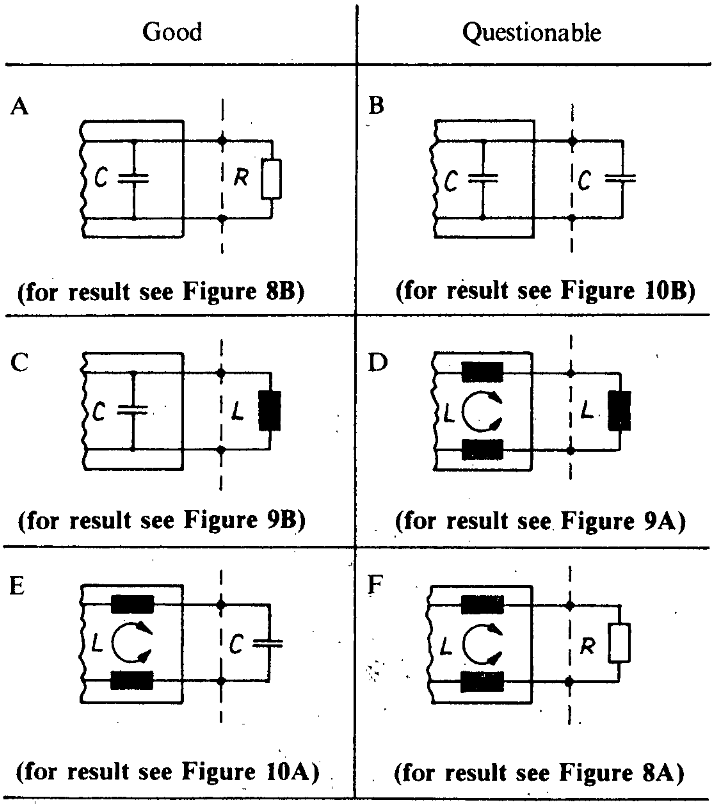


Figure 7. Impedance mismatch at filter output to load.

To assure a high impedance mismatch on the load-side of the filter is a difficult task. The input impedances of the various possible loads are usually unknown by the filter manufacturers. The user must select the filter which promises the best mismatch.

For example: A switching power supply has a low input impedance (looking in). That means that the filter load-side should have a high impedance.
Every power supply with a transformer input has a high input impedance; the filter load-side should, in this case, have a low impedance.

The effective insertion loss is the difference between the measured interference spectrum of the noise simulator, recorded first without the test filter, then with the test filter inserted (compare dotted with dashed and full line on Figures 8, 9, 10 and 11). For convenience, only the interference spectrums are shown in Figures 8, 9, 10 and 11, not the effective insertion loss. One can easily see that the overall lowest curve must correlate to the best impedance mismatch.

Discussion

Measurement:
- Without a filter, the interference spectrum of the interference source and a resistive load should be measured (Figure 8C).
- The filter should be put "forwards" in the power line which means the impedance condition will be as shown in Figure 7F. A measurement curve should be taken, as indicated in Figure 8A.
- The filter should be turned for "backwards" operation. The impedance condition is shown in Figure 7A. A measurement curve should be made as shown in Figure 8B.

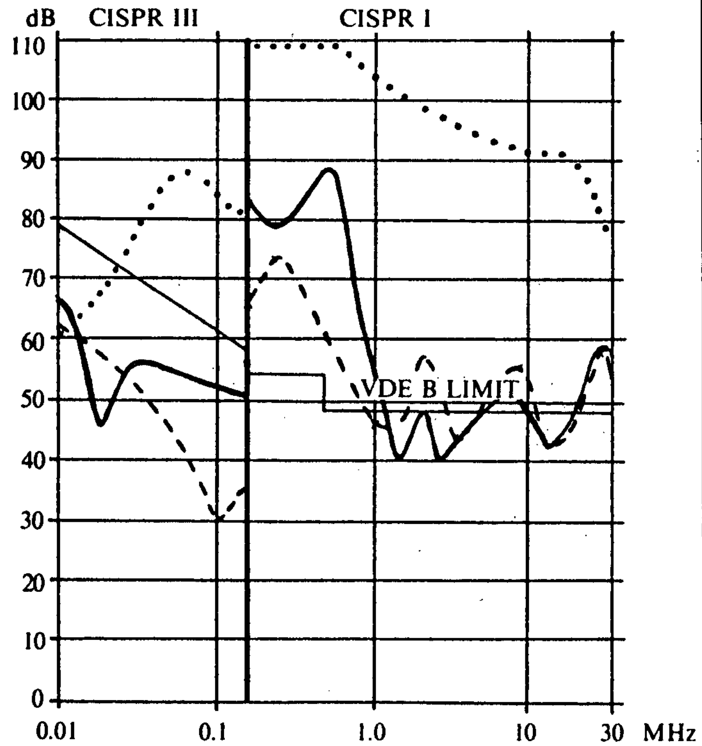


Figure 8. Differential mode interference spectrum with resistive load.
A) full: with filter "forwards"
B) dashed: with filter "backwards"
C) dotted: without filter

A resistive load is always a load with a relatively high impedance. It is apparent that, with a capacitor on the output of the filter, a better attenuation of the interference is achieved, especially in the lower frequency range. The better effective insertion loss is given with the better impedance mismatch.

For Figure 9 (DM with inductive load), an inductive load requires a capacitor on the filter output or load-side (for load condition, see Figure 7C).

For Figure 10, a capacitive load requires an inductive (high impedance) filter output or load-side (for load condition see Figure 7E).

An impedance mismatch on the line side of a filter is easier to achieve, because the line is known as an impedance of 50-150 ohm with a parallel inductive portion of approximately 50 μH. Therefore, the input impedance of a filter is usually much higher (series-inductance) or much lower (parallel capacitance) to achieve a good impedance mismatch.

In general, one can say that the y-capacitors (capacitors between line and ground) should be located on the load-side of the filter, because the input impedance of an equipment for common mode is given by its "capacity" to earth; this capacity is always very low (few pF), therefore high in impedance for the frequency below 30 MHz.

The y-capacitors are always relatively low in impedance. Therefore mismatch is guaranteed (Figure 11).

The interference source (NSG 222A) is set at common mode for this test. As can be seen in Figure 11A, this "forwards" filter impedance condition results in the best effective insertion loss. "Forwards" in the case of y-capacitors means that they are on the load-side of the filter.

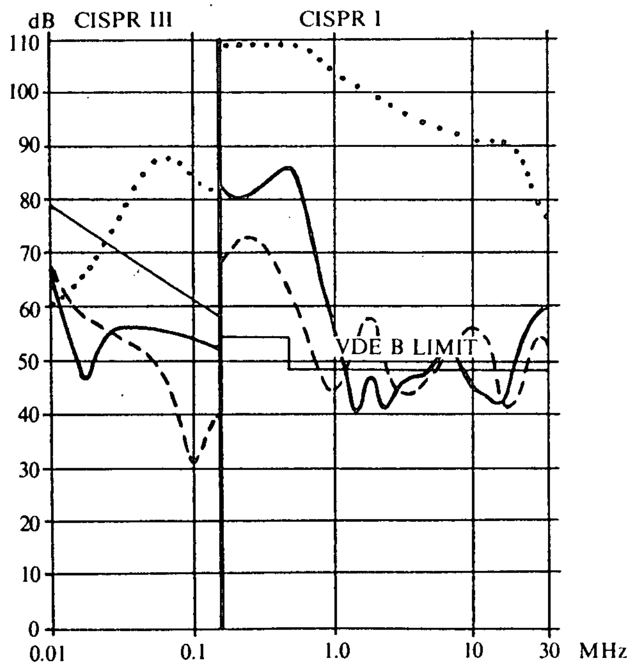


Figure 9. Differential mode interference spectrum with inductive load.
A) full: with filter "forwards"
B) dashed: with filter "backwards"
C) dotted: without filter

CONCLUSION

This study shows clearly that the 50 ohm insertion loss measurement does not give a valid indication of the effective attenuation of a power line filter. The article gives examples of how important a good impedance mismatch can be for better effective insertion loss. A bad impedance mismatch leads to a substantial reduction in the effective attenuation. Particularly with capacitive loads, resonance points can occur which may lead to an amplification of the noise signal. In any particular system (power line-filter-load) this resonance point must occur in the lower frequency range. As other authors have pointed out, this test does not save one from the final measurement for compliance when the filter is installed in the equipment under test.

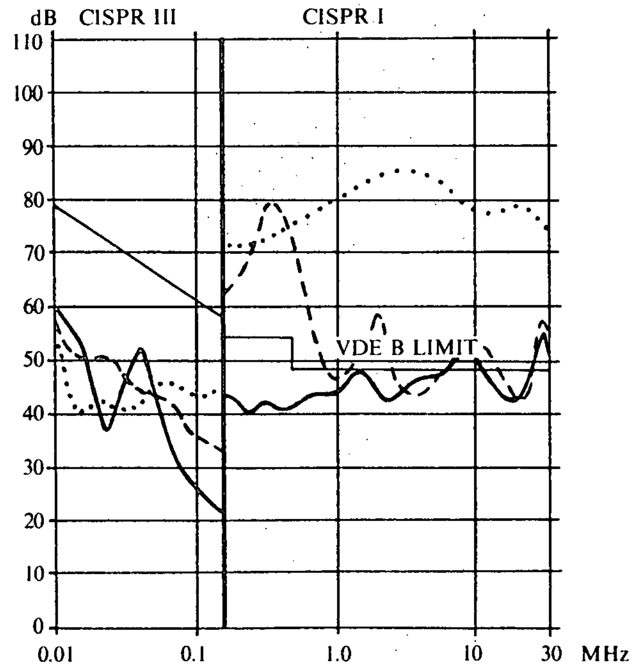


Figure 10. Differential mode interference spectrum with capacitive load.
A) full: with filter "forwards"
B) dashed: with filter "backwards"
C) dotted: without filter

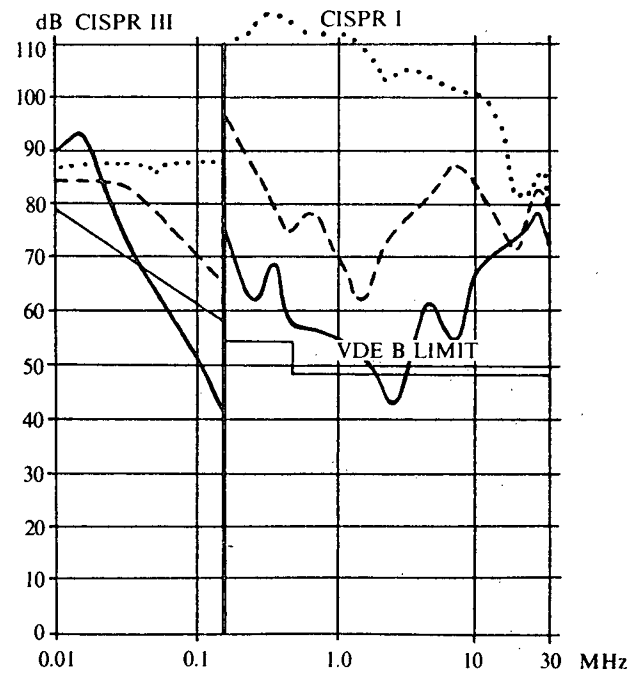


Figure 11. Common mode interference spectrum with resistive load.
A) full: with filter "forwards"
B) dashed: with filter "backwards"
C) dotted: without filter

This article was written for ITEM 85 *by Thomas Wacker, Schaffner EMC Inc., Union NJ, and Heinz Grueter, Schaffner Elektronik AG, Switzerland.*

SEE ADVERTISEMENT ON PAGE 71