



SPD/TVSS and Power Line Filtering

Background

Filtering has become an issue in the SPD marketplace primarily driven by questionable attenuation specifications and testing practices. For example, certain filter attenuations are derived using lengthy conductors (>100'). These supplement overall attenuation because of inductive effects at higher frequencies.

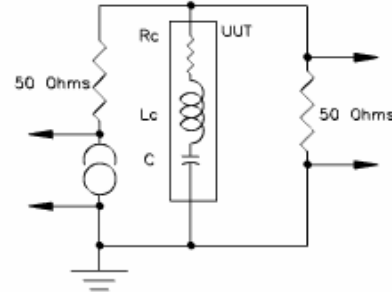
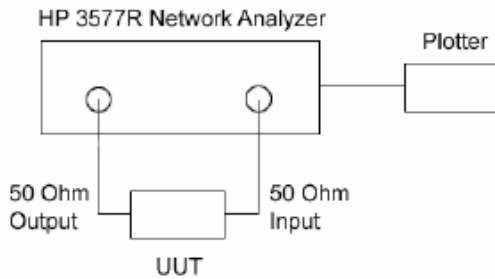
Filtering in a SPD System

A SPD is designed to effectively protect a facility against transients. Although this is sometimes thought of as power line filtering, filtering is not the primary function of a SPD device. Filtering does however provide some benefit in a suppressor; therefore, the issue of how much filtering should be included in the system. The factors to consider are effectiveness, cost, size, and weight. The filter must not adversely affect these factors or its value diminishes. Studies have shown that the only practical filter to include in a SPD system is a simple, first order capacitive filter (as parallel capacitor). Nearly all parallel SPD manufacturers provide this type of filter and most recognize that power line filtering is a separate issue from surge protection.

Our filtering provides some high frequency attenuation (10kHz to 10MHz; -50dB @ ~100kHz) and is effective in removing noise and low energy transients. Due to the practical limitations of a parallel capacitive filter such as; leakage, internal resistance, internal inductance, and the inductance of the wires that connect the SPD system to the distribution equipment, all filters of this type will have essentially the same performance. (This is not to say that using several parallel RC networks would not look good on the 50 Ohm insertion loss plot under ideal circumstances; but rather the effectiveness is diminished after installation of the device due to the limitations listed above.) Following is a derivation of a filter model and an evaluation of filter performance in MathCAD. It will demonstrate that our filtering approach is the most practical for a standard parallel SPD system. Additionally, it will confirm that the unrealistic filter specifications found in some manufacturers prototype specifications and literature, are not possible to attain with the filter that they employ. In conclusion, a technical presentation of actual laboratory data is provided. This information is provided to assist Consulting Engineers in specifying filtering for their projects.

Case "A", is an investigation of the typical filtering used by all major SPD manufacturers. Measurements are made and compared to simulation results with a "reasonable" model and the ideal capacitor. Results are plotted showing the insertion loss in dB as defined in MIL-STD-220B. A competitors filter is measured and simulated and shows that the filtering does not meet the published specification (see Case A below). This was also found to be true (identical) for several other products. Finally, performance of the filter is evaluated with 2' and 4' connecting leads (4' and 8' total length respectively: see Case B below). This completes the demonstration of how the limiting factors in this type of filter design such as: internal resistance, internal inductance, and the inductance of the wires that connect the SPD system to the distribution equipment will hamper the filters performance and essentially make all filters of this type perform equally.

Test Setup and Simulation Model using MathCAD



The UUT model used here is simply a capacitor model that reflects the internal resistance and inductance. The inductance of the connecting leads can be lumped together with L_c to account for the effects of lead length in the model. Leakage is neglected and for all practical purposes, negligible. The derivation of the attenuation is as follows:

Definitions and Constants

$$j := \sqrt{-1} \quad \Omega := 1 \quad \mu\text{F} := 1 \cdot 10^{-6} \quad \mu\text{H} := 1 \cdot 10^{-6} \quad \text{kHz} := 1 \cdot 10^3 \quad \text{MHz} := 1 \cdot 10^6$$

$$L_m := 4 \cdot \mu\text{H} \quad \text{Inductance per meter of connecting lead wire.}$$

$$L_f := L_m \cdot 0.305 \quad \text{Inductance per total foot of connecting lead wire.}$$

Reactance Magnitude of the Filter

$$X_c(f, C, R_c, L_c) := \left| R_c + \frac{-j}{2 \cdot \pi \cdot f \cdot C} + j \cdot 2 \cdot \pi \cdot f \cdot L_c \right|$$

Impedance Magnitude of the Output

$$Z(f, C, R_c, L_c) := \frac{X_c(f, C, R_c, L_c) - 50}{X_c(f, C, R_c, L_c) + 50}$$

Attenuation in dB

$$\text{dB}(f, C, R_c, L_c) := -20 \cdot \log \left(\frac{50 + Z(f, C, R_c, L_c)}{Z(f, C, R_c, L_c)} \right)$$

Attenuation Ratio (Insertion Loss)

$$\text{Atten}(f, C, R_c, L_c) := \frac{50 + Z(f, C, R_c, L_c)}{Z(f, C, R_c, L_c)}$$

Case A: Comparison of Known Filter to Published Specification

The following plot is a comparison of the measured filter to the specifications for the same unit. As a matter of fact, the specification is the same for all models from this particular manufacturer. One exception is the perceived "System" performance that quotes attenuation numbers so large that it's hard to believe (see the final discussion in the inclusion section). The following is a summary of the filter attenuation values:

	1kHz	10kHz	100kHz	1MHz	10MHz	100MHz
Published Spec			-34dB	-51dB	-54dB	-48dB
Measured		-5dB	-22dB	-55dB	-26dB	-8dB
Simulated		-10dB	-28dB	-55dB	-32dB	-17dB

Evident in the data above, and emphasized by the plots below, the published specification is not representative of what was measured. Actually, the published specification does not provide enough information to conclusively determine what it represents and since no attenuation plots are available, it will have to suffice to state that the specification does not match the measured values or fit a typical simulation.

Simulation for 8 μ F Filter - "Actual vs Specification"

Plotted Frequency Range
(1kHz to 100MHz, 10 kHz Steps)

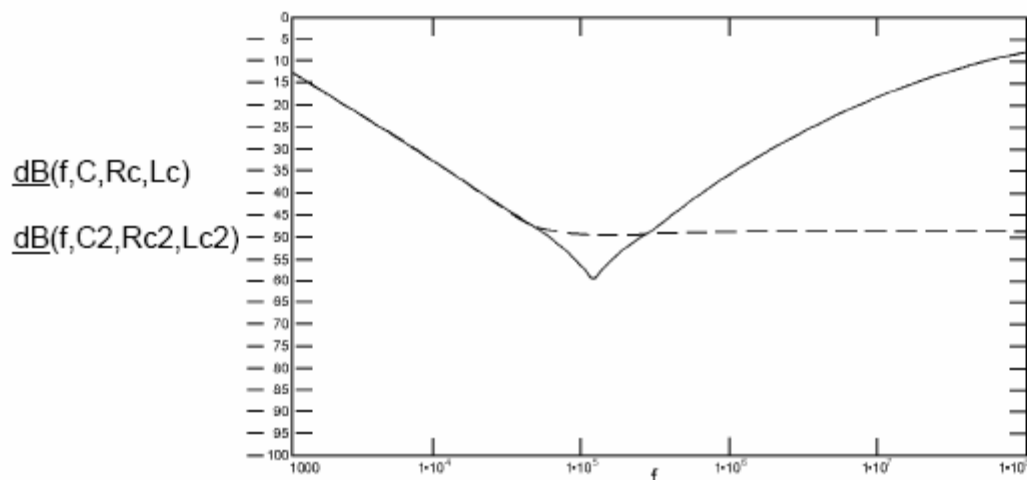
$f := 1000, 10000..100 \cdot 10^6$

Simulation of **Measured** Filter

$R_c := .06 \cdot \Omega$ $L_c := .2 \cdot \mu H$ $C := 8 \cdot \mu F$

Simulation of **Specified** Filter

$R_{c2} := .15 \cdot \Omega$ $L_{c2} := .0002 \cdot \mu H$ $C_2 := 8 \cdot \mu F$



Attenuation in dB for 6 Frequencies – "Actual vs Specification" $i := 1..6$

Measured	$f_i :=$	$dB(f_i, C, R_c, L_c)$	Specified	$f_i :=$	$dB(f_i, C_2, R_{c2}, L_{c2})$
-5	1-kHz	-13.1		1-kHz	-13.1
-22	10-kHz	-28.7		10-kHz	-28.6
-55	100-kHz	-54.5	-34	100-kHz	-46.1
-26	1-MHz	-31.5	-51	1-MHz	-50.4
-8	10-MHz	-15.5	-54	10-MHz	-50.5
	100-MHz	-7.6	-48	100-MHz	-48.2

Case B: The effects of Lead Length on Filter Performance

The following attenuation plot is a simulation of the measured filter with 8' of connecting wire compared to zero lead length. The following is a summary of the filter attenuation values:

	1kHz	10kHz	100kHz	1MHz	10MHz	100MHz	Peak
Measured -0'	-3dB	-21dB	-60dB	-38dB	-22dB		-66dB
Measured -8'	-3dB	-21dB	-23dB	-6dB	-1dB		-53dB
Simulated -0'	-13dB	-29dB	-53dB	-35dB	-18dB	-8dB	-62dB
Simulated -8'	-13dB	-29dB	-40dB	-19dB	-8dB	-6dB	-57dB

The added lead length manifests itself as added inductance in the filter as can be seen in the data above and the plot below.

Simulation for 8uF Filter with 0' to 8' Lead Length

Plotted Frequency Range
(1kHz to 100MHz, 10kHz Steps)

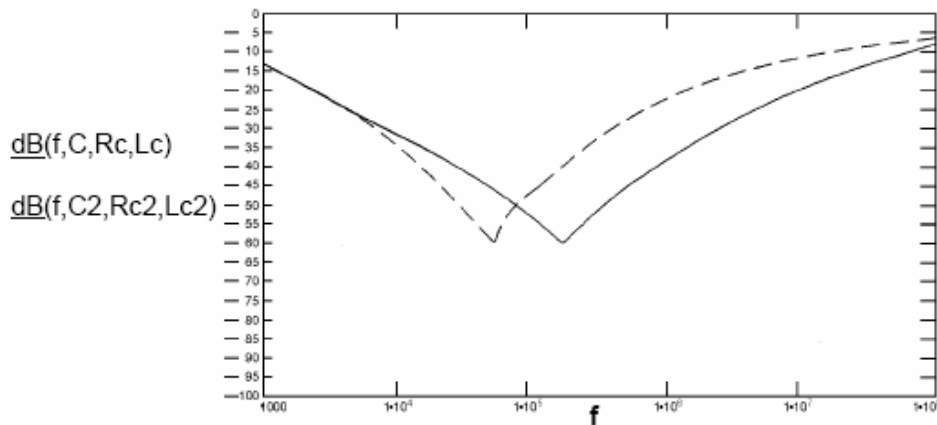
$f := 1000, 10000..100 \cdot 10^6$

Simulation for **0' Length**

$Rc := .05 \cdot \Omega$ $Lc := .15 \cdot \mu H + 0 \cdot L_f$ $C := 8 \cdot \mu F$

Simulation for **8' Total Length**

$Rc2 := .05 \cdot \Omega$ $Lc2 := .15 \cdot \mu H + 8 \cdot L_f$ $C2 := 8 \cdot \mu F$



Attenuation in dB for 6 Frequencies – 0' vs 8' $I := 1..6$

0' Length	$f_i :=$	$dB(f_i, C, Rc, Lc)$
-3	1.kHz	-13.1
-21	10.kHz	-28.7
-60	100.kHz	-52.7
-38	1.MHz	-35.0
-22	10.MHz	-17.3
—	100.MHz	-8.1

$f_i :=$	$dB(f_i, C2, Rc2, Lc2)$
1.kHz	-13.1
10.kHz	-29.0
100.kHz	-40.0
1.MHz	-19.2
10.MHz	-8.6
100.MHz	-6.3

Conclusion

It has been shown how the limiting factors in this type of filter design such as: internal resistance, internal inductance, and the inductance of the wires that connect the SPD system to the distribution equipment will hamper the filters performance and essentially make all filters of this type perform equally. Consider these limitations when evaluating a parallel SPD filter specification, it can be seen that the “System” filter specification mentioned in Case A (which lists the following attenuation values) is not possible.

100kHz	1MHz	10MHz	100MHz
-54dB	-71dB	-94dB	-120dB

These values are based on using two standard SPD systems, separated by 100 feet or more of conducting wire. The main point here is to show how performance can be misrepresented; it is not possible to attenuate to the values listed above except in a simulation.

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