Solving Interaction Problems of a TEMPEST AC Power Filter and High Current Equipment

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INTRODUCTION

A traditional solution to the control of power line conducted (PLC) TEMPEST emanations from a shielded area is to install a standard 100-dB TEMPEST power line filter at the interface. However, most standard 100-dB TEMPEST filters use large in-line inductors to achieve their high levels of attenuation. This can sometimes result in unacceptably high ac wave distortions that can cause severe operational problems if high current drawing and/or pulsing equipment interacts with this filtered power. In these cases, a specially designed nonstandard low inductance TEMPEST filter can minimize ac wave distortion and solve the operational problems while still providing 100 dB of attenuation from 14 kHz to 10 GHz.

A low inductance TEMPEST filter can minimize ac wave distortion and solve operational problems.

PROBLEM DEFINITION: A CASE STUDY

In order to meet TEMPEST requirements imposed on a sheltered communications system, the power to the system needed to be heavily filtered. All parties agreed that if a 100-dB TEMPEST power filter was utilized at the shelter interface, PLC testing would not be required. In order to meet the proposed schedule, a TEMPEST filter needed to be selected before the first high current drawing device (HCD) was delivered. Standard high inductance TEMPEST power line filters were purchased for the system. The incompatibility between the TEMPEST filter and the shelter equipment could not be established until the shelter was completely integrated.

Normally, standard 100-dB ac power filters achieve their high level of isolation through the use of large in-line inductors instead of large capacitors to ground in order to minimize filter leakage current. A 100-dB filter that uses high values of capacitance-to-ground to attain its insertion loss exhibits a high level of leakage current, a major drawback to many energy-efficient systems. Fortunately, leakage current from the ac power filters was not a major concern on this shelter.

After three HCDs were installed in a sheltered system, HCD power output faults were frequently observed during integration tests (Figure 1). Each of the HCDs was previously qualified outside the shelter, with each HCD outputting high power into matched loads for several hours without exhibiting any problems. When the HCDs were subjected to the same conditions but powered from 3ø 208 VAC shelter power, they exhibited power faults on the average of one per hour while outputting continuously and three times per hour in the pulsed mode. The fault indicated a low voltage condition, causing the actual output to fall short of the commanded output and result in a major fault. Obviously this was a

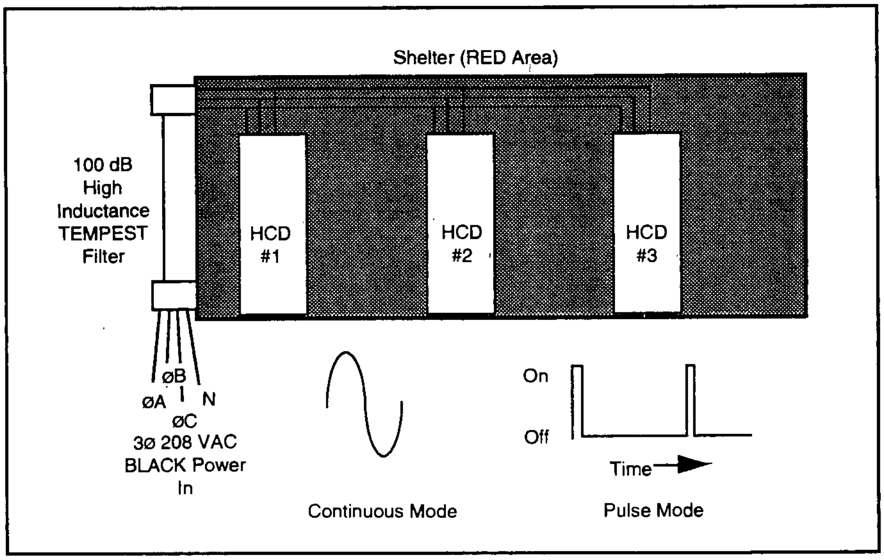

Figure 1. HCD Operational Configuration.

serious problem since it did not allow the system to operate reliably.

After each power phase was measured for distortion using a distortion analyzer, the problem was eventually traced to the shelter power. The ac waveform distortion was measured to be 20% while the HCDs were operating in continous or ready modes, and up to 30% while the HCDs were in the pulsed mode (Figure 2). The HCD vendor confirmed that ac power with that level of distortion could be expected to cause a major power fault depending on when the dc voltage was sampled (which explains why faults were seen anywhere from 5 to 60 minutes after HCD operations started).

The dips in the ac voltage waveform can be attributed to the large current draw by rectifiers in the HCD power supply interacting with the large in-line inductance in the TEMPEST filter. The rectifiers only drew current near the peaks and troughs of the ac waveform (Figure 3). The amplitude of the voltage dips was consistent with the rectifier circuit current draw and the rate of change of that current draw. The component of the dip due to the rectifier current draw is given by

$V = I*|Z| = 33A * 2* \pi * 120\ Hz *294\ \mu H$ (in-line inductance of the TEMPEST filter) = 7.39 V.

The component of the dip due to the rectifier current rate of change is given by

$$V = L*\frac{dI}{dt} \text{ approximated by } L*\frac{\Delta I}{\Delta t} = 294\ \mu H * \frac{33A}{0.00083 \text{ seconds}} = 11.69\ V.$$

Figure 2. *Observed AC Waveform Distortion.*

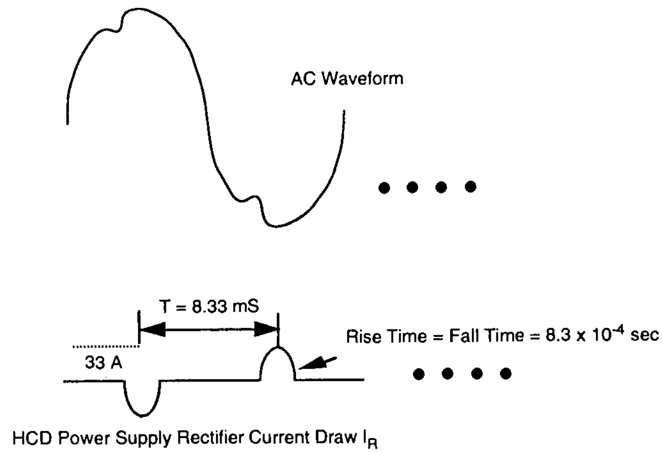

Figure 3. *Distorted AC Waveform Vs. Rectifier Current Draw.*

VERIFYING THE CAUSE OF THE PROBLEM

In order to verify that the high level of in-line inductance from the HCD back to its power source was creating the problems, the TEMPEST filter was bypassed (no RED processing or signal transmission was permitted during this time, of course) and each HCD was tested. Each HCD operated in both the pulsed and non-pulsed modes in the shelter for several hours without experiencing a single fault. AC waveform distortion on each phase was measured at 2% in the continuous and ready modes and 4% during the pulsed mode.

The number of faults of other selected equipment in the shelter (such as the signal generators) was also markedly reduced when the highly inductive filter was removed. This result was interesting because some other types of equipment in the same shelter showed no performance degradation resulting from high inductance filter interaction.

CREATING AND IMPLEMENTING A NEW FILTER DESIGN

In order to counteract the effects of the old high inductance filter, yet provide the required TEMPEST isolation, a new low inductance filter design had to be created. Using the SPICE modeling tool and some trial and error, a new filter design was developed that used 0.10 of the in-line inductance (30 µH) of the old filter design but was still predicted to meet NACSEM 5203 guidelines and provide 100 dB of isolation from 14 kHz to 10 GHz when tested in accordance with MIL-STD-220A. Figure 4 illustrates the resultant filter circuit (for each line element). Figure 5 shows the physical layout of the filter element used.

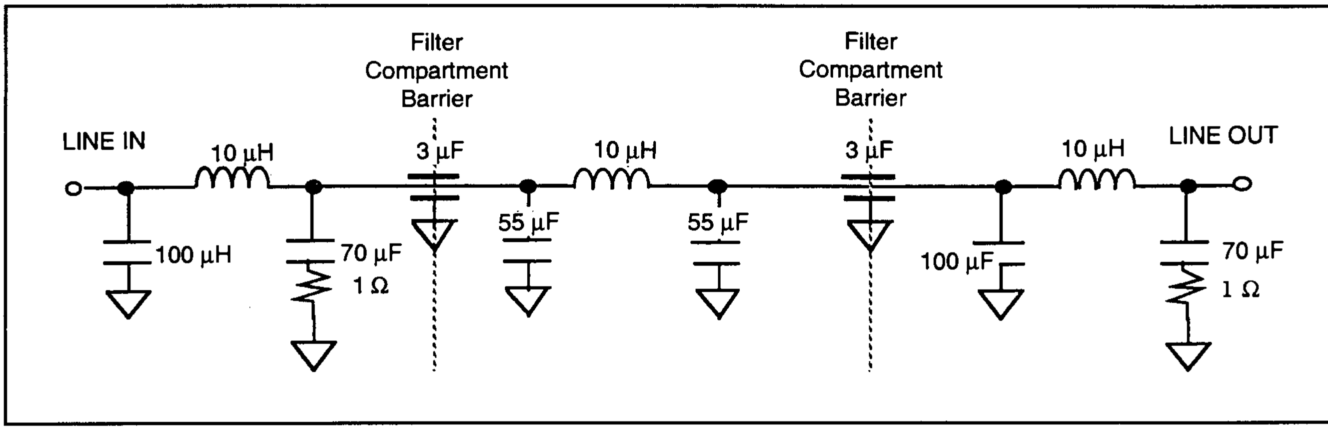

Figure 4. *Replacement Filter Schematic.*

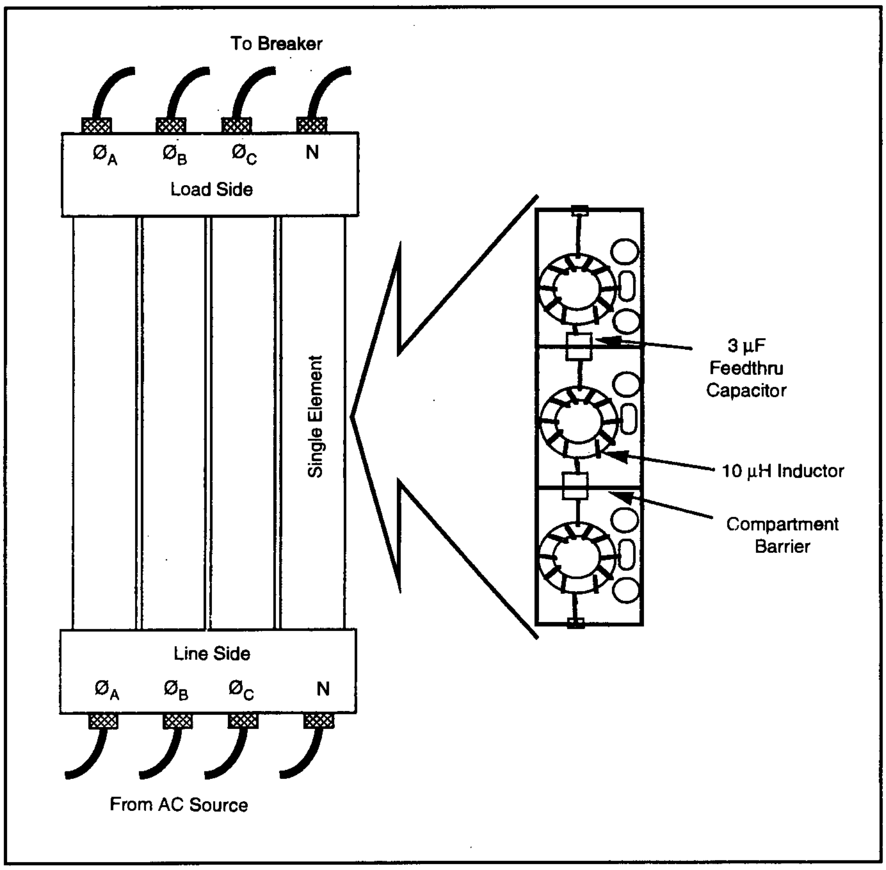

Figure 5. *Physical Configuration of the Replacement Filter.*

TEST RESULTS

The prototype filter element was constructed and tested for insertion loss (IL) in accordance with MIL-STD-220A (Figure 6). Despite some parasitic responses above 100 MHz, the attenuation levels proved to be sufficient to stop any conducted sensitive RED signals from escaping the shelter by way of the ac power lines.

Once its filtering capability was established, three other elements were constructed and the entire prototype filter was then installed on the shelter. Each HCD was operated in both the pulsed and continuous modes in the shelter for several hours without experiencing a single fault. AC waveform distortion on each phase was measured at 3% in the continuous and ready modes and 4.9% when two HCDs were operating in the pulsed mode. No additional operational problems were observed on any other piece of shelter equipment.

Since the design of this filter used a high level of capacitance, it was not surprising that it exhibited 20 amps of leakage current, even in a no-load condition. Fortunately this level of leakage current could be tolerated at the system level.

A specification control drawing (SCD) for deliverable filter elements which included the electrical schematic of the prototype was created. The SCD imposed safety requirements for bleeder resistors to be added to the deliverable filter. The filter schematic was modified so that the delivered filter achieved the 100-dB insertion loss from 14 kHz to 10 GHz, met the safety requirements and still caused no adverse interaction with any shelter equipment. The delivered filter elements met all environmental and reliability requirements.

SOME FILTER SELECTION GUIDELINES

Despite the fact that some high current drawing equipment was found to negatively interact with the standard power filter initially selected, many other types of equipment were found to be compatible. It is no more desirable to

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use a low inductance TEMPEST filter with its high leakage current with a system that doesn't require it than to use a standard high inductance TEMPEST filter with high current drawing equipment. Equipments found to be most susceptible to highly inductive filters are those which draw high currents for a short time, such as equipment which utilizes high current rectifier-based power supplies. The following guidelines were developed to aid the system engineer in avoiding the aforementioned type of interaction between filters and equipment:

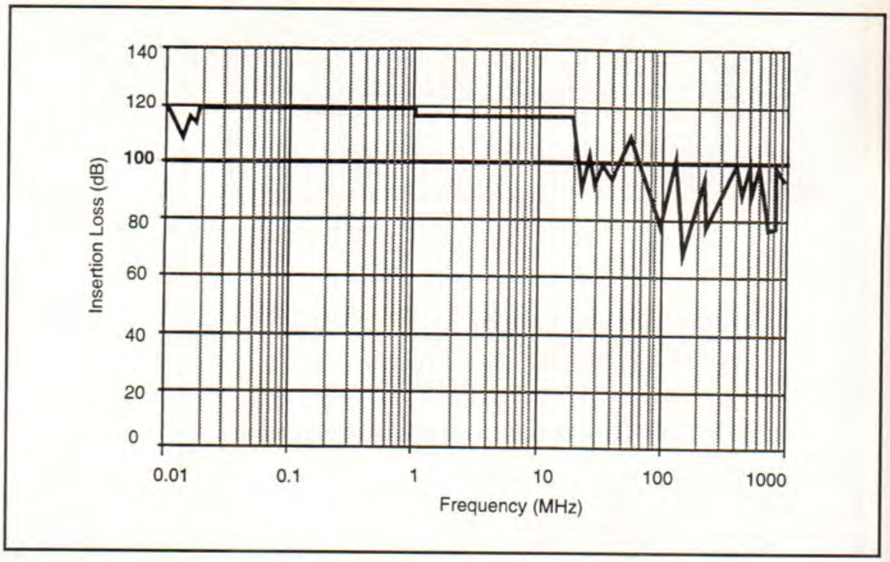

Figure 6. *Prototype Single Line Filter Insertion Loss.*

- Properly define the system TEMPEST EMI ac power attenuation requirements and educate the customer on them. In most cases customers will simply specify some defined standard and probably would be receptive to a derived system-specific attenuation requirement, especially if they were made aware of the risks and drawbacks of routinely using a 100-dB TEMPEST filter. Depending on the noise sources, a 100-dB filter may not be necessary to sufficiently address the TEMPEST ac power hazard. Do not specify a 100-dB filter if a 60-dB filter will do.
- If a 100-dB filter is necessary, carefully screen all the equipment powered from that filter for the limit of ac waveform distortion that it can tolerate. Address the equipment most likely to be affected first, and avoid specifying the filter requirements until after the facility equipment has been established. An applications engineer for that particular equipment can be contacted for that information. Query the engineer for knowledge of any interaction between equipment and a highly inductive filter. Select equipment with the most tolerance to ac waveform distortion.
- If equipment with a low ac wave distortion tolerance is necessary in the system, consider specifying a low inductance filter which meets the insertion loss requirements.

Unfortunately, following these guidelines does not guarantee compatibility between filters and equipment, but they can substantially reduce the risk of incompatibility. Operational testing of high current drawing equipment using the TEMPEST-filtered system should begin as early in the program schedule as possible to allow for any corrective action.

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