POWER DISTURBANCES AND COMPUTERIZED EQUIPMENT

Power disturbances are increasingly an EMI problem. Computerized systems are particularly susceptible to the noise and voltage fluctuations on power lines. Definitions, applicable documents and mitigation techniques are discussed.

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INTRODUCTION

For commercial and industrial computer and microprocessor based systems, interference problems generally fall into one of several categories: regulatory compliance (FCC/VDE/VCCI); radio frequency interference (RFI) due to high level electromagnetic fields; electrostatic discharge (ESD); or power line disturbances.

In too many cases, power disturbances are overlooked or ignored by the manufacturer in the hope that someone else -- the user or the power company -- will solve the problem. This is unfortunate, since interference problems related to power disturbances are increasing, as modern electronic systems incorporate embedded computers, microprocessors, and other complex solid-state devices. By their nature, these devices operate at low energy levels and high speeds, making them particularly susceptible to power line noise.

The primary responsibility to prevent and cure these problems is with the equipment designer and manufacturer, with a secondary responsibility with the installer or user. Blame can easily be placed on the power utilities and demands can be made that they provide "clean power," but the power company is usually not the culprit, nor does it have much control over the situation. In one recent study, over 85 percent of the power disturbances (such as impulses, surges and sags) were caused by customers, not the utilities. Simply stated, designers and EMC engineers need to address the problem first. Hopefully, this article can help.

DISTURBANCE MODES AND TYPES

One of the reasons power disturbances are difficult is the many variables involved. First, noise can be present -- either common mode or differential mode -- and second, disturbances can vary from short spikes to complete losses of power. Compounding the problem is a lack of clear, concise definitions with which everyone agrees. Nevertheless, some definitions will be presented for the purpose of this article.

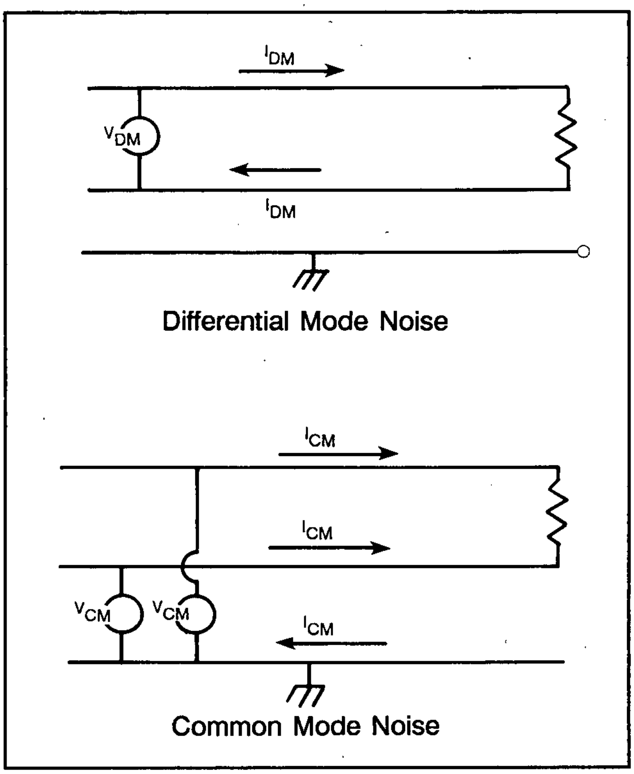


Figure 1. Common Mode vs. Differential Mode.

*See advertisement on page 316.

Common Mode vs. Differential Mode

The first crucial definitions regard the "direction" of the noise or disturbance on the power lines, as shown in Figure 1. Noise currents that all flow in the same direction (voltages in phase) are referred to as "common mode" or "longitudinal mode." Noise currents that flow in opposite directions (voltages out of phase with each other) are referred to as "differential mode" or "normal mode."

The mode often gives a clue to the source and/or coupling path. For example, differential mode noise suggests that the disturbance is on the same power circuit, while common mode noise suggests that the noise was coupled into the circuit by radiation or crosstalk.

A special case of common mode noise, where the noise is common mode on the phase conductors, but is differential with respect to the safety ground, is often seen in switching mode power supplies. It is the result of parasitic capacitive coupling to the cabinet, and is a common cause of FCC and VDE compliance failures. It can also cause problems to electronic equipment sharing the same power circuit.

A current probe offers an easy method by which to determine the mode. The probe is connected around each line individually, then around multiple lines. For example, if the current increases with two lines, the currents are flowing in common mode; if the currents decrease to zero with two lines, the current flow is in differential mode.

This distinction on modes is important, since common mode fixes may not work on differential mode problems, and vice versa. Both modes should be addressed; to do otherwise is to solve only half the problem.

Disturbance Types

The second set of definitions address the various types of disturbances on the power lines. At the present time, the terminology for

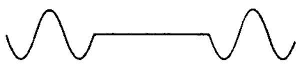
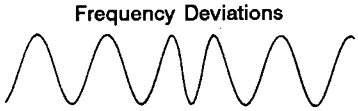
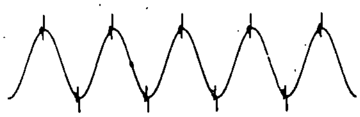
Types of Disturbance	Typical Origin
Sags 	• Lightning • Turn-On of Heavy Loads • Brownouts
Surges 	• Sudden Load Decreases • Incorrect Transformer Taps
Outages 	• Severe Weather • Transformer Failures • General Failures
Harmonic Distortion 	• Rectifier Loads • Switching Power Supplies • Variable Speed Drives
Frequency Deviations 	• Generator Instabilities • Regional Network Problems
Transients 	• Lightning • Power Line Feeder Switching • Power Factor Capacitor Switching • Turn-Off of Heavy Motors
Electrical Noise 	• Radar, Radio Signals • Arcing Utility and Industrial Equipment • Converters and Inverters

Table 1. Power Disturbance Types.

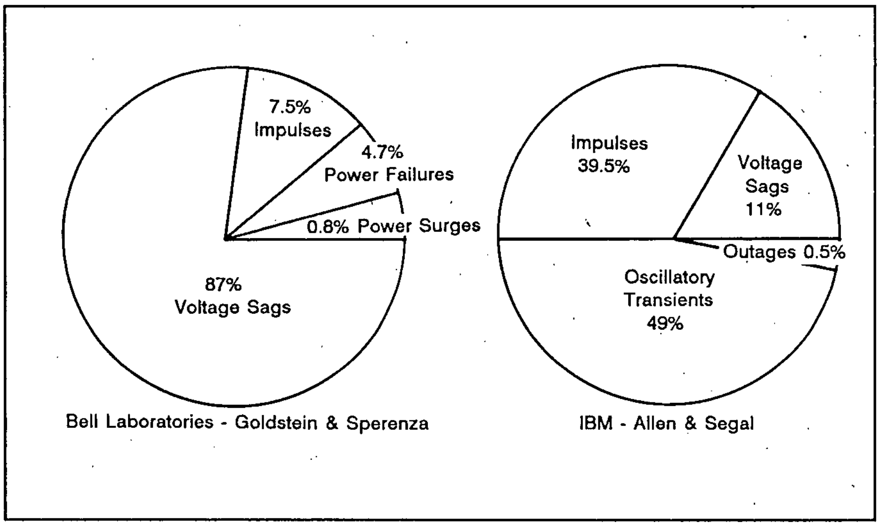


Figure 2. Results of Studies on the Effects of Power Disturbances on Computers.

power disturbances has not been formalized, but there are common terms in wide use.

Most classifications are based on duration and levels, and include voltage variations (sags, surges, outages) frequency variations, waveform distortion (voltage and current) continuous noise or "hash," and transients.

Table 1 provides an overview of these disturbances, and their most likely sources. Usually the source is not utility related, but due to nearby motors, radio transmitters, or non-linear devices such as switching mode power supplies or variable speed drives.

Effects on Computerized Equipment

Fortunately, not all of these disturbances cause problems for computerized equipment. In fact, only two are very serious threats -- short-term spikes and long-term sags. Spikes can be coupled into the system by crosstalk or even directly through the supply, causing false triggering of internal logic circuits. Sags can cause loss of memory or other volatile data. Other disturbances, such as minor overvoltages, harmonic distortion, or frequency deviations, are usually ignored by computerized systems.

Several studies have been made to determine the effects of power disturbances on computers. Three comprehensive and widely quoted studies were by IBM, AT&T and the U.S. Navy. Figure 2 summarizes two of those studies, Allen and Segal of IBM (1974) and Goldstein and Sperenza of AT&T (1982). While the IBM study shows most of the problems due to the transients, and the AT&T study shows most due to voltage sags, these discrepancies can be explained by different test thresholds. The third study, by Thomas Key of the U.S. Navy, summarized computer failures over a ten year period; undervoltages were the primary power line failure mode.

The key message is that long undervoltages/sags, and short transients/spikes are the principal power line disturbance failure modes for computerized equipment.

Harmonic Distortion: An Emerging Problem

Although computers are not generally affected by harmonic distortion, they are a major cause of this problem. The problem is not due to the computers or microprocessors themselves, but rather the power supplies. In this case, the victims are often adjacent motors, transformers, and even facility wiring.

Power supplies can represent "non-linear" loads to the power distribution system. Rather than taking current over the entire sine wave, the power supplies take a gulp of current at the peak of the cycle. This non-sinusoidal current (Figure 3) results in current harmonics, as well as voltage harmonics, if the current is high enough to distort the voltage waveform. These current harmonics can cause overheating of transformers, motors, and even neutral lines on three phase systems. The latter is due to the addition, rather than cancellation, of selected harmonics in the neutral.

If only a few non-linear loads exist in a system, the effects are negligible. In some facilities, however, over half of the loads may be non-linear due to computers and variable speed motor drives. In recognition of this new problem, the 1990 National Electrical Code now requires larger neutrals in distribution systems supplying non-linear loads. In addition, facilities designers are also using larger transformers and wire sizes for the same reason. In a sense, computers are "getting even" for all the noise they've been subjected to in the past.

GUIDELINES

Although there are no mandated

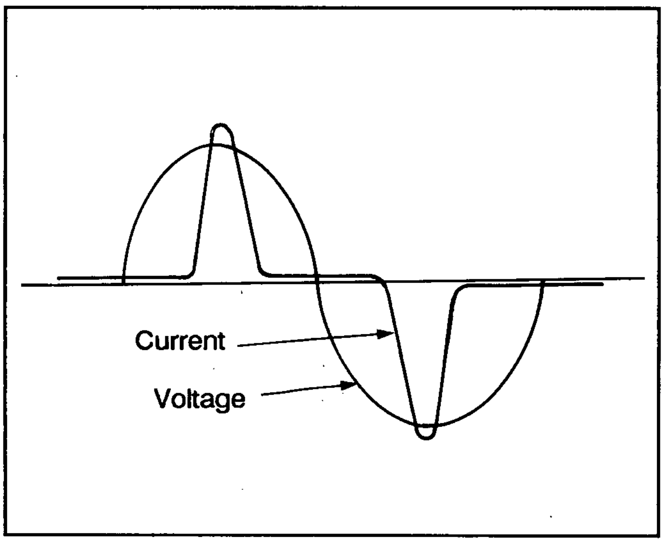


Figure 3. Example of Current Distortion Due to a Non-Linear Load.

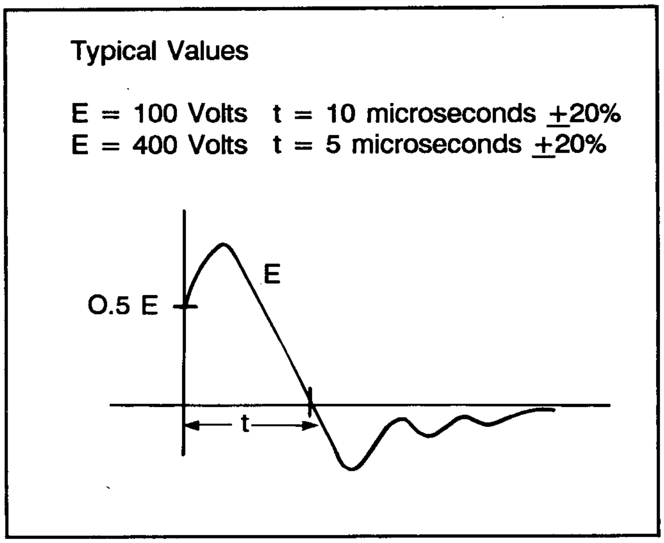


Figure 4. MIL-STD-461 Spike - Method CS06.

regulations for power disturbances, other than the relatively low level FCC/VDE conducted emissions limits, there are industry guidelines and specifications that address this area. In addition, most large computer companies today have internal power specifications to address this issue. Smaller computer companies, and manufacturers of related equipment like industrial controls would be well-advised to adopt similar internal standards.

MIL-STD-461

As the EMI standard for equipment procured for military applications, both emissions and susceptibility on the power lines are addressed in MIL-STD-461. Since this is a military standard, however, the applicability to the commercial and industrial environments is somewhat limited.

One MIL-STD-461 test limit that is common in commercial/industrial specifications is method CS06, the conducted spike test. This pulse, shown in Figure 4, is considered to be a good example of actual power transients, so it has been adopted by many as a test standard. Also, test equipment is readily available to perform this test.

ANSI/IEEE STD 446-1987

"IEEE Recommended Practice for Emergency and Standby Power," (also known as the "Orange Book") gives recommended power limits for computer manufacturers. This curve is shown in Figure 5, and has been adopted by many manufacturers. Computer equipment should operate with no power upsets within these limits. Note should be taken that it assumes a long-term sag of 13 percent, and a total short-term loss of voltage for up to 1/2 cycle. Spikes increase with shorter duration.

This curve also appears in FIPS PUB 94, "Federal Information Processing Standard Guidelines on Electrical Power for ADP Installations," an excellent guide for anyone installing

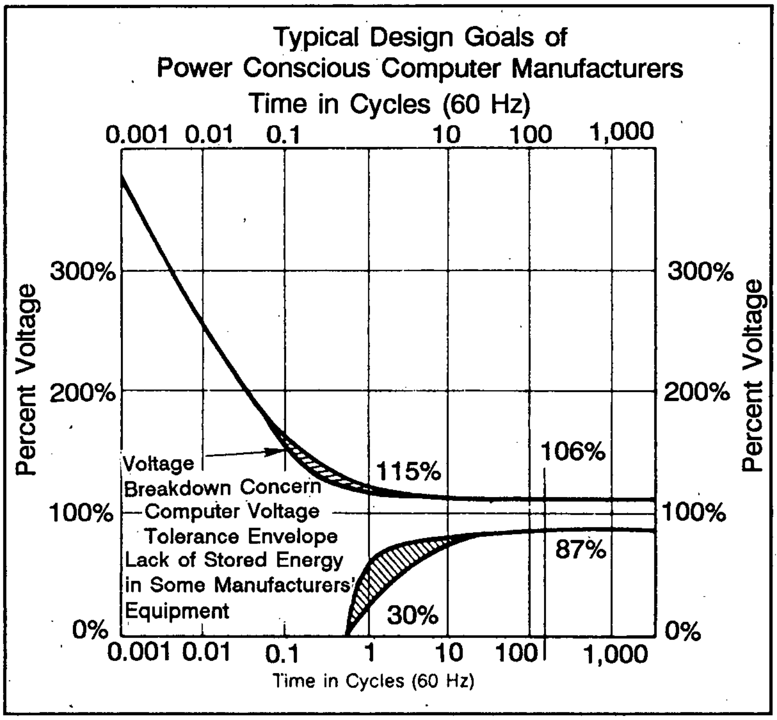
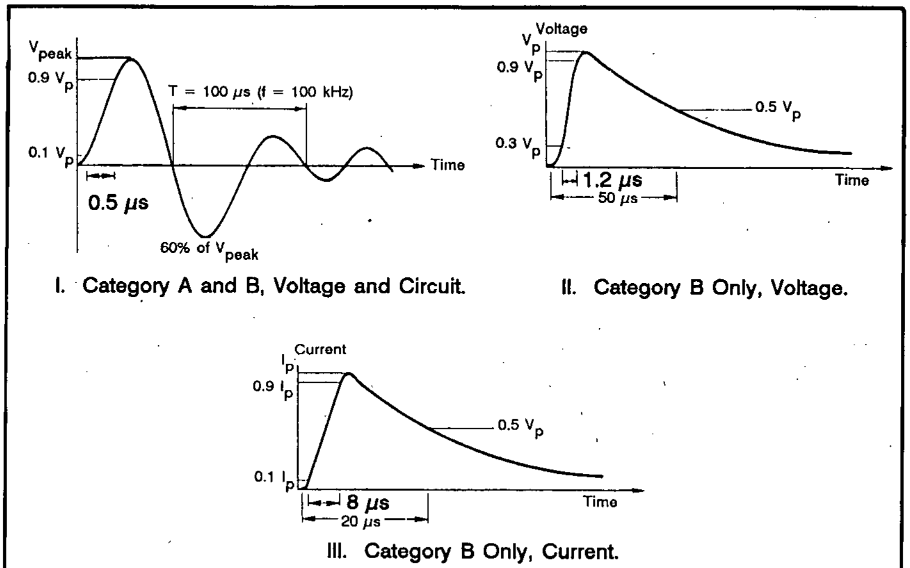


Figure 5. ANSI/IEEE-STD 446-1987 Recommended Power Limits.



Location Category	Waveform	Amplitude
A - Inside Bldg., Greater Than 10 M from Entrance	0.5 μs - 100 kHz (I)	6 kV 200 A
B - Inside Bldg., Less Than 20 M from Entrance	1.2 x 50 μs (II) 8 x 20 μs (III)	6 kV 3 kA
	0.5 μs - 100 kHz (I)	6 kV 500 A

Figure 6. ANSI/IEEE C62.41-1980 Recommended Transient Waveshapes.

computer systems. This curve is often referred to as the CBEMA curve, after the Computer Business Equipment Manufacturers Association.

ANSI/IEEE STD C62.41-1980

This document, "IEEE Guide for Surge Voltages in Low Voltage AC Power Circuits," is essentially a lightning damage specification. Formerly known as IEEE STD 587, it defines surge voltages and currents of up to 6000 volts and/or 3000 amps, and is based on empirical data gathered over many years.

Figure 6 shows these limits. Category A refers to equipment located more than 10 meters from the service entrance; Category B refers to any equipment within a building. Unless one can guarantee the location of equipment, however, the more stringent Class B limits should be used. These limits are considered damage levels, rather than upset levels. It is probably unrealistic to expect computer equipment to operate through these transients without an upset; the equipment should survive, however, without damage.

ANSI/IEEE STD 519-1981

This document, "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters," gives guidelines for allowable levels of harmonic distortion. It is often used as a reference by the power utilities and specifically states that it is not an EMI specification. Nevertheless, it is an important document regarding power line disturbances.

MITIGATION TECHNIQUES

There are a wide variety of devices and products available that can help to mitigate power line disturbances. These range from simple single component spike suppressors to complex automatic on-line uninterruptible power systems (UPS). In fact, a multi-million dollar annual business has grown up in recent years to address these problems.

The proper application of these products is as important as the proper selection. Improper application is a very common cause of power disturbance problems.

In addition, both coupling modes, common and differential, must be addressed. To only protect for one mode is to solve only half the problem, because to predict in advance which mode will predominate is difficult, and often both modes are present at the same time.

Ranging from simple to complex (and inexpensive to expensive), the devices and products which can help control power disturbance problems are summarized in Table 2.

Dedicated Circuits

A dedicated circuit is a single circuit with a single load. This is a simple, inexpensive, yet highly effective technique. It works best if the dedicated circuit originates at the main entrance panel, rather than a sub-feeder panel, since this provides the lowest common impedance.

As a variation, a single circuit feeding multiple pieces of computer equipment, with no "noisy" loads like motors or other machinery, can be used. The neutrals and ground wires must be properly sized, since most computers use switching mode power supplies.

Transient Suppressors

These devices divert energy above predetermined voltage levels. Included in this category are gas discharge tubes, metal oxide varistors (MOVs), and zener diodes. Some suppressors are hybrids of the above.

There are two classes of transient suppressors -- crowbars and clamps. The crowbar devices provide a short circuit above the threshold, while the

Dedicated Circuits

Transient Suppressors
- Crowbar - Arc Gap Devices
- Clamp - Zener Devices

Filters

Isolation Transformers
- Unshielded
- Faraday Shielded

Voltage Regulators
- Electronic
- Mechanical
- Ferroresonant

Power Conditioners
- Multipurpose

UPS/SPS Systems
- On-line vs. Off-line
- Electronic with Batteries
- Motor Generators

Table 2. Power Disturbance Mitigation Techniques.

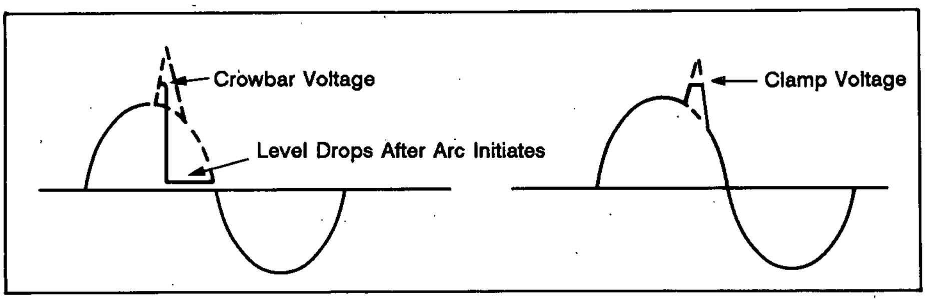


Figure 7. Crowbar vs. Clamp Transient Suppression.

clamp simply limits the voltage excursion at the threshold. The differences are shown in Figure 7.

The crowbar suppressors are usually arc gap devices, such as gas discharge tubes. When the gas ionizes, the voltage across the gap drops to a low level, and most of the energy is diverted. The response time of these devices is relatively low, so they do not work on fast transients. They are very well suited, however, for lightning transients.

The clamp suppressors are either zener diodes or metal oxide varistors (MOVs). These devices act by limiting the voltage at a preset level, and diverting the remaining energy. Since much of the energy is dissipated by the clamp, they are usually rated in joules of energy. A word of caution -- if this rating is exceeded, the device can be destroyed. The response time of these devices is much faster than the crowbar suppressors, with the zener diodes being faster than the MOVs.

Transient suppressors can be installed for either common mode (line-to-ground) or differential mode (line-to-line) transients. To protect for both modes, protectors should be installed as shown both line-to-line and line-to-ground.

Finally, the effectiveness of any transient suppressor depends on proper installation. Lead lengths should be kept as short as possible; transients behave like high frequencies, and lead length inductance can severely limit their performance.

Filters

Unlike transient suppressors, which are non-linear devices, power line filters are linear circuit elements combined to pass power frequencies and reject higher frequencies that contain electrical noise. They are most useful for removing lower levels of continuous energy, although they will reduce transients as well. (Since they are linear, however, filters reduce transients proportionally, and do not clamp to a fixed value like a transient suppressor.)

Most commercial power filters today address common mode and differential mode noise. Figure 8 shows a typical filter, having a common mode choke and common mode capacitors (line-to-ground) combined with differential mode chokes and differential mode capacitors (line-to-line).

A common trend today is to add a small choke in the safety ground lead, which helps with common mode filtering. This can be quite effective against common mode transients, such as lightning. This value must be kept small enough, however, to not interfere with the fault clearing capabilities at 60 Hz.

The effectiveness of filters depends on proper installation. At higher frequencies, filters must be installed in the cabinet bulkhead to prevent coupling around the filter. Also, the input and output wiring must be separated, or crosstalk can couple noise around the filter.

Finally, grounding of the filter is very important. Figure 9 illustrates the effects of poor grounding on a pi-network filter. In this case, the input and output capacitors actually bypass the inductor at high frequencies. Direct contact is best; even an

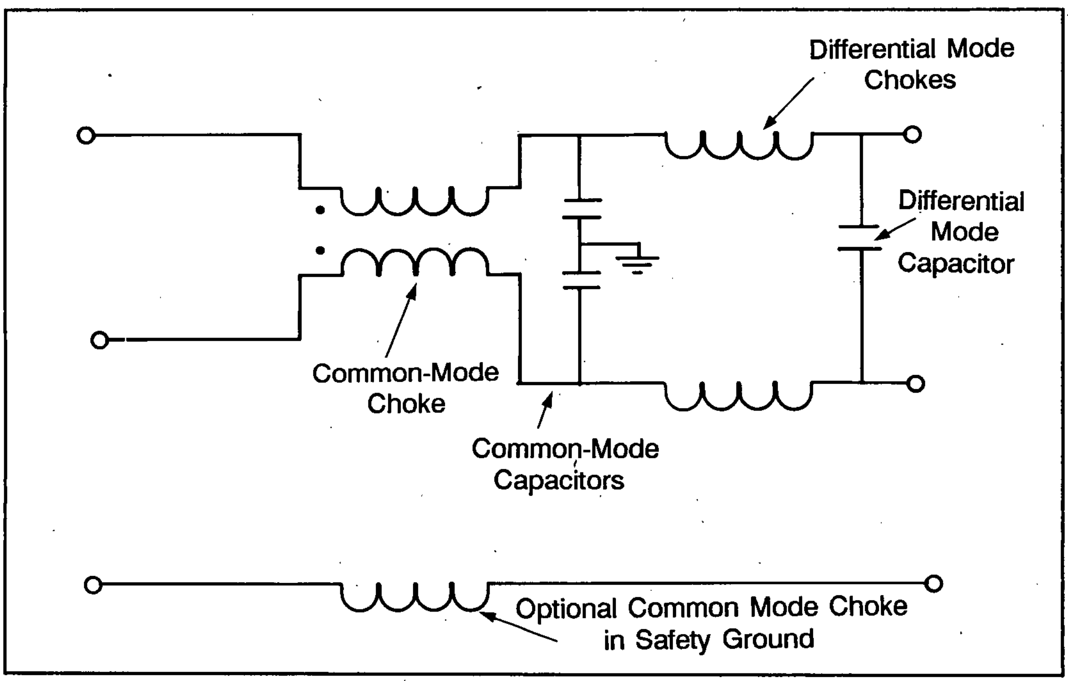


Figure 8. Common Mode and Differential Mode Filter.

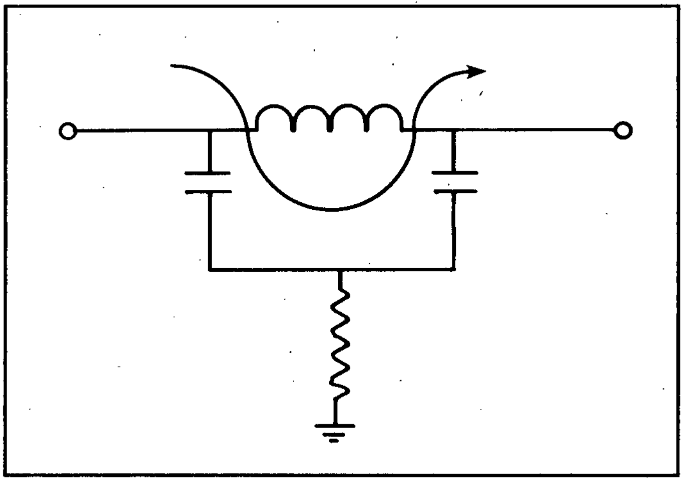


Figure 9. Poor Grounding of Filter.

inch of wire at high frequencies results in too much inductance.

Isolation Transformers

Isolation transformers are power transformers with no direct current connection between the primary and secondary. As a result, they provide isolation between input and output circuits, as well as a level of common mode shielding.

This isolation and shielding degrades with increasing frequency due to interwinding capacitance. To extend this operation to high frequencies, capacitive or "Faraday" shields are installed between the windings.

These shields can provide common mode or differential mode protection, depending on where the shield is terminated, as shown in Figure 10. For common mode, the shield should be connected to the ground, while for differential mode the shield should be connected to the neutral. The object is to provide a high frequency path for the noise.

If shielding is needed for both modes, two shields can be used -- one for common mode, and one for differential mode. As with filters, installation is important. The shield connections must be as short and direct as possible, or the shield will degrade at higher frequencies.

Isolation transformers work best at lower frequencies (under 1 MHz). Thus, for full frequency protection, filters may be needed as well. In fact, the combination of filters and isolation transformers offers a wide range of frequency protection with reasonable cost and component sizes.

Voltage Regulators

Standard isolation transformers do not offer protection against long-term voltage surges or sags. For these types of disturbances, some method of voltage regulation is needed.

A regulator's function is to maintain output voltage within a limited range with varying input conditions. Regulators can be active, using electronic circuits, or passive, such as autotransformers or ferroresonant transformers. Since computers are particularly susceptible to low voltage conditions, regulators are often needed to assure proper operation.

Ferroresonant regulators have enjoyed great popularity due to their simplicity and high reliability. Essentially a transformer on the verge of saturation, they exhibit small output voltage variations with large input voltage variations. They may cause problems, however, when used with switching mode power supplies, since ferroresonant transformers have a relatively large output impedance and switching power supplies need a low impedance. Ferroresonant regulators should be specifically designed for use with switching supplies.

Power Line Conditioners

Power line conditioners are usually used for products that provide several functions in one unit -- isolation, voltage regulation, and noise suppression. They generally do not provide protection against total power losses.

Power line conditioners can vary from hybrid transformer-filter-regulator units to motor-generator sets. They are often marketed in a package for computer operation, and are usually more cost-effective than buying individual protective devices.

UPS/SPS Systems

The ultimate in power protection is the uninterruptible power system (UPS), or its cousin, the standby power system (SPS). The distinction between the two is that the UPS is on-line, and continues to provide power without interruption to the load, while the SPS is off-line, and must be switched into the load circuit.

UPS/SPS systems typically employ batteries for short-term energy storage, and may employ gasoline or diesel generators for longer term energy needs. A UPS/SPS is the only way to protect critical loads for outages in excess of about 0.5 seconds.

Installation of UPS/SPS systems is very important. The system must be isolated from the utility power wiring. Otherwise, utility workers could be harmed, believing they were working on unenergized wiring. Installations should be performed and checked only by competent electricians and engineers who fully understand the safety issues. IEEE-STD-446, "IEEE Recommended Practice for Emergency and Standby Power" is an excellent guide in this area.

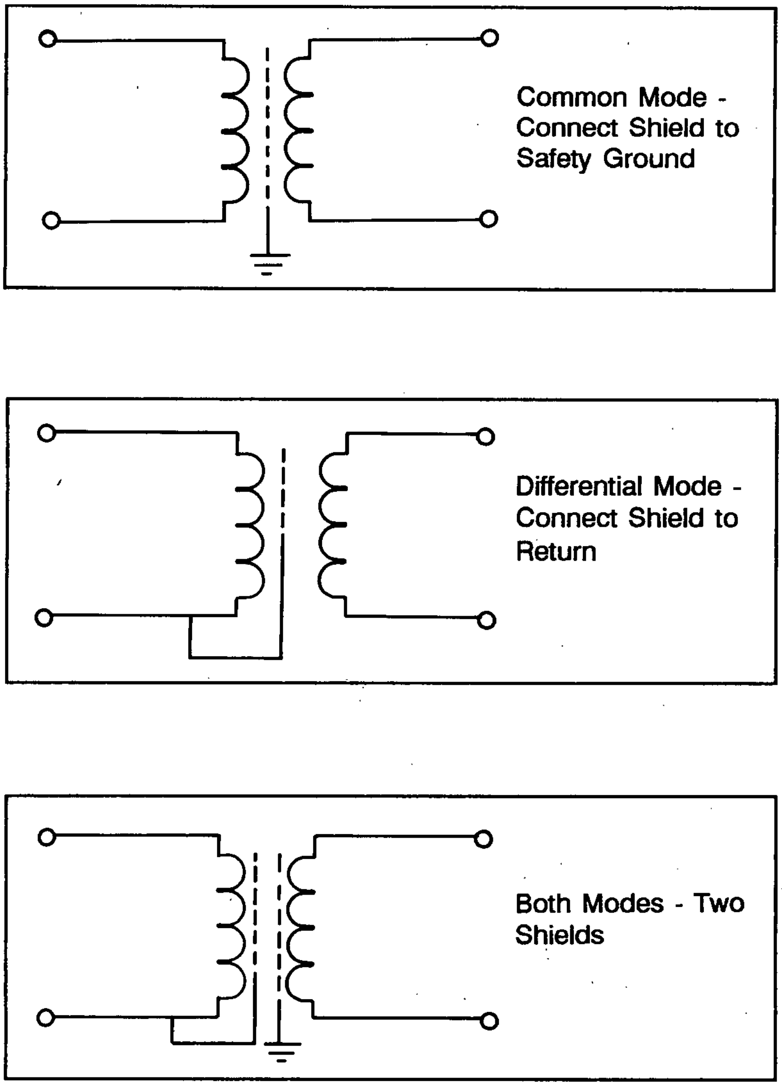


Figure 10. Isolation Transformer: Common Mode vs. Differential Mode.

SUMMARY

Power disturbances are increasing as an EMI problem, particularly with modern electronic systems. Computerized systems are very vulnerable to short-term voltage spikes and long-term voltage sags. An emerging problem is harmonic distortion, due to the proliferation of non-linear loads such as switching mode power supplies.

The primary responsibility with preventing and fixing these problems lies with the designer and user. There is little most utilities can do to help, since most problems are generated from within the user's facility. Most utilities, however, are willing to give guidance, and some even have "power quality" engineering groups dedicated to helping with these problems.

While industry guidelines for power disturbances do exist, at the present mandatory requirements do not, other than the relatively low level FCC or VDE limits. Conscientious companies should incorporate internal test standards for their own equipment.

A wide range of mitigation techniques and products are available to prevent and solve power disturbance problems. Proper selection and installation, however, are crucial for success. Both coupling modes (common and differential), must be addressed, and short connections are mandatory for high frequency protection. ■

BIBLIOGRAPHY

ANSI/IEEE Standard 446-1987, "IEEE Recommended Practice for Emergency and Standby Power," (The Orange Book), New York, NY: IEEE.

ANSI/IEEE Standard C62.41, "IEEE Guide for Surge Voltages on Low Voltage AC Power Circuits," (Formerly IEEE STD 587), New York, NY: IEEE.

ANSI/IEEE Standard 519-1981, "IEEE Guide for Harmonic Control and Reactive Compensation for Static Power Converters," New York, NY: IEEE.

"Filters and Power Conditioning," Gainesville, VA: Interference Control Technologies, Inc., 1988.

FIPS PUB 94, "Guide on Electrical Power for ADP Installations," Gaithersburg, MD: U.S. Department of Commerce.

"Power Quality Reference Guide," Toronto, Ontario: Ontario Hydro, 1989.