Power Line Disturbances And Their Effect On Computer Design and Performance

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One of the earliest and continuing problems with computer systems is ac power line disturbances on customer premises. The computer manufacturer is becoming increasingly concerned about the ac line transient and grounding environment that a computer system is subjected to at a customer site.

The resolution of problems caused by ac power disturbances requires characterization of the ac power source and determination of the computer system's sensitivity to such anomalies. The effect of any possible solution on the manufacturer and the customer must be evaluated. If the manufacturer incorporates devices to protect the computer against all of the possible ac disturbances the initial cost of the computer increases significantly. A dilemma arises if, to keep purchase costs low, this is not done. In the purchase of any computer system, the cost of ownership must also be considered. The customer wants and should expect maximum use with a minimum of maintenance and downtime. If the computer is unable to handle power anomalies, the downtime and maintenance can become excessive and the cost of ownership increases dramatically.

Therefore, some compromise is required to minimize the overall cost to the customer. The customer should help by improving the environment for the computer system installation. The manufacturer should correctly and economically specify the environment required and educate the customer about this specification in addition to incorporating economical design features that improve the computer system's resistance to ac power line disturbances.

CHARACTERIZATION OF POWER SOURCES

Improving the immunity of a computer system to electrical noise requires adequate characterization of the ac power source. The terms frequently used to describe power line anomalies are discussed at the back of this paper. The noise present on an ac line can be generated by conditions unique to the customer's environment and by variations typically found on any power line supplied by a public utility. Wiring codes developed by regulatory agencies to insure the safety of the user are often in conflict with line configurations designed for noise reduction.

Computer manufacturers and users cannot influence or change these facts significantly. To place these conditions in proper perspective, note that statistics show that computer systems and other sensitive control loads represent less than 0.01% of the total utility load. Consequently, it is understandable that a utility will not try to prevent power disturbances affecting computers. Wiring codes are also generated with respect to the general consumer. Generally wire sizes and grounding specifications are based on electrical loads associated with major appliances and heavy electrical machinery, and do not take into consideration the low impedances that are required when computer systems are switching at millisecond speeds.

Factors describing the quality of an ac power line are nominal line voltage, service voltage, utilization voltage, statistical distribution of transients generated by the utility and the customers, and regulatory body specifications. In the U.S.A. there are national standards developed by American National Standards Institute (ANSI), and these specifications are typically used by U.S. utilities to permit better networking and interchange of power.

Nominal line voltage is the level close to the average value expected during normal operation. This value, measured at the outlet, varies with geographic location.

The most important parameter that the utility must adhere to is the service voltage — the voltage supplied to the customer's meter. In the San Francisco Bay area it is 114 volts minimum to 126 volts maximum. For three-phase-wye distribution, it is 197 volts minimum to 218 volts maximum. Generally speaking, the three-phase line voltage will be lower than the nominal 208 volts, but the power company is still within specifications as long as the line voltge does not go below the minimum service voltage.

The utilization voltage (at the wall outlet) is 110 volts minimum to 125 volts maximum. For three-phase-wye distribution, it is 191 volts minimum to 216 volts maximum. Herein lies a difficulty. The building owner is responsible for all internal wiring within the building from the meter to the wall outlet. Therefore, if there is a problem with the voltage, it is of little value to a user to have the power company measure voltage at the wall outlet because they have no control over the internal wiring of a building.

To compound the problem, there are some studies being made by U.S. utilities to change generating voltages to conserve energy. The federal government is strongly suggesting to the utilities that there be a conservation voltage reduction. This is a systematic lowering of distribution voltages to reduce energy consumption by customers. The minimum service voltage would remain the same but the maximum would be lowered. Suggested ranges would be either 114 to 118 volts or 114 to 120 volts. When the generating margin narrows, the utilities are forced to do more load switching. The result is more transients.

It is impossible to quantize transients caused by utilities switching loads during peak demand hours, or by breaker action during some fault condition. A model can be developed, but it is a function of such parameters as line impedance, circuit breaker size, fault current, and other widely varying factors. Obviously, the computer installer and customer should be fully aware of possible problems when the computer system is installed near a utility substation or switchyard.

CUSTOMER SITE CHARACTERISTICS

Noise on the power line can be generated in many different ways at the computer user's site. Electric clock systems signal-modulate the power distribution within a facility once an hour to update all electric clocks. Flicker (momentary voltage dip due to the starting of a large appliance) can occur typically 10 times per hour and the duration can be from 160 to 670 ms. The maximum amplitude of a transient is directly proportional to the velocity with which a contact opens, and is independent of power consumption. a 400-hp motor (with large slow-moving contacts) produces transients with one-tenth the amplitude of those produced by an electric clock motor. Fluorescent light switching can cause an extended transient of 2-MHz, 500V oscillations lasting for 20 microseconds. Power characteristics of an installation change with time even though good site preparation is done initially. Vending or copy machines can be added inadvertently to circuits and grounding that were initially wired exclusively for computer systems.

The most common customer problems associated with ac power are nonisolated grounds and improper conductor sizes. These occur even when the grounding and wiring are done according to code.

Two categories of ground systems must be considered:

1. Safety (dc conduction) — the electrical power grounding system which includes all ac power, distribution and utility service power used for lighting, equipment power, et cetera.
2. EMI (RF conduction) — signal circuit grounding which includes all electronic and electrical control circuits associated with a computer system.

In the first category, all neutral and ground line distributions are wired on separate buses and connected together at the main power transformer entrance to the building, making a single-point ground.[1] In the second category, the ground from the electronic equipment is connected to the nearest steel structural beam to make a multipoint ground (see Figure 1) from a facility viewpoint.

Because computer systems typically use earth ground as a reference within each cabinet and the entire system is connected to the facility earth ground, it is very important that the computer system be connected to an EMI grounding system. Figure 2 shows the system power and interface cable hookups and points where common-mode noise (voltage between both lines and ground) can exist. The net voltage difference between any two points on the ground network usually will be small (1 to 3 volts). However, the current through certain network paths can be on the order of 3 to 5 amperes with occasional currents of 10 to 15 amperes.

For typical building wiring, electricians use water pipes and conduit as ground. For safety and minimal shock hazard, this is legal from an electrical code viewpoint. For EMI suppression it is inadequate because lighting loads, vending machines, and other types of office equipment are connected to the same grounding system. Another common contributor to stray ground currents within a facility is the connection of the ac neutral line to earth ground inside the branch panel. Then the ground network becomes a part of the ac return line to the main building service entrance. The line current will divide between the neutral line and the ground return network in inverse proportion to the impedance of the two paths.

Because instantaneous power surges are required by a computer system during turn-on and normal operation, wire sizes must be large enough to keep the voltage from sagging. For example, during computer turn-on, switching power supplies can require currents peaking at 150A and decaying exponentially to 20A in less than 30 ms. If the wire size is inadequate, the input voltage can sag below the required input voltage tolerance of the computer for a period of 100 ms, causing the power-control circuitry to detect a powerfail, thus shutting the system off. Wire sizes specified by typical code requirements are usually at least one size smaller than required for computers. Such code requirements make it difficult for the computer manufacturer to convince the customer and electrician that larger wire sizes must be used if the computer system is to operate satisfactorily.

COMPUTER SYSTEM SENSITIVITY

Circuits used in a modern computer system are extremely fast and more vulnerable to noise than circuits used a few years ago. Because there is the same high-frequency sensitivity in a peripheral as in the mainframe, the same design parameters are used to immunize the total system from outside disturbances. For software, data integrity is protected from power line transients by using various error correction codes (ECC) in the transmittal of data between parts of a system, and "disc retrys" are used on disc drives when errors occur. Therefore, power line noise can be masked by using software error-correction techniques.

IMPACT ON CUSTOMER AND MANUFACTURER

Making positive determination that a computer installation problem is caused by power line disturbances can be very difficult. The occurrence may be random, and the effects on the system may be different depending on the state of the electronics at the precise time of the disturbance. Symptoms of such problems overlap with those that may be caused by intermittent electrical connections, electrostatic dischange (ESD) either directly to the computer or indirectly via other objects in the immediate vicinity, or even software program bugs. If intermittent ac disturbances are suspected, isolating them may require expensive monitoring equipment that is installed for a period long enough to detect the next occurrence.

The time required to analyze and repair an ac line disturbance problem can be several times the duration required for analysis and repair of other service problems. During the process of diagnosis machine time is lost and the service engineer may have to visit a site several times before proper remedies can be made. In the case of ac power transients, which can be random and are unpredictable, direct correlation of cause and effect is extremely difficult to obtain.

DETECTION OF A NOISE PROBLEM ON-SITE

The service engineer's objective is to prevent power line disturbances from reaching the computer by discerning their characteristics, and then either remove the source or isolate the computer from the source. A comprehensive set of site preparation guidelines is sent to the customer prior to delivery of a computer system. If the guidelines are followed, the likelihood of power line disturbance problems is minimized. The service engineer may participate in site preparation with the customer. Whether during a site preparation or installtion, or in troubleshooting an installed system, a service engineer may proceed through the following steps:

- Look outside the customer's site. Check for major industries in the area that consume large amounts of electricity. Their operation can cause voltage variations or transients to be propagated to other users sharing the same output of the utility company's substation transformer.

- Look within the customer's site for heavy electrical equipment. A transient source within the site may affect the computer installation more severely than a distant source because nearby transients, especially fast-rise-time pulses, do not dissipate significantly in the short distance before they reach the computer.

- Note local weather conditions. Electrical storms may cause transients by direct lightning hits on utility lines or induced coupling through nearby earth strikes. Besides the transients, the utility company's hardware is sometimes affected, causing voltage variations or powerfails.

- Check the wiring from the building's utility power connection to the outlets in the computer room. Feedback from HP's systems specialists in the field indicates that improper site wiring is often the major cause of power line disturbance problems. With the help of an electrician who is aware of local codes, check the building's electrical layout and look for load distributions that overload any circuits, or branch circuits that allow other electrical devices to use the same circuit breaker as the computer. Distribution and breaker panels must have solid electrical connections, and breakers and wire capacities must equal or exceed the computer's demand.

- Check equipment layout at the computer installation. All devices must be plugged into their own wall outlets. Extension cords with multiple outlet boxes must not be used. If possible, avoid extension cords altogether. Check especially for grounding of all devices by having the electrician confirm that the ground wire is continuous back to the building's service entrance. A computer system can pollute its own power if these procedures are not observed.

Up to this point all checks have been visual. If no answers are obvious, measurement equipment is required. Tools for analyzing ac power become progressively more complicated and expensive as the problem becomes more difficult. First, wall outlets can be checked for proper polarity of the lines and ground, and for existence of ground by a receptacle-circuit tester. At the same time, a ground loop impedance tester (GLIT) can be used to test the integrity between the neutral line and ground. However, it only checks impedance at the line frequency, not at high frequency or RF.

When intermittents occur, the cost of the tool goes up significantly and requires the user to have some skill and training in its operation. Such a tool is a power line monitor which can be left at a customer's site for several days and will measure and record voltage surges, sags, frequency variation, powerfails, and transients. Measurements are logged on a printout with their times of occurrence.

Throughout the measurement process, the service engineer notes the nature of the disturbance and checks it against factory-supplied specifications for the computer.

After these checks are completed, a solution is likely to be evident. It may be one of two types: 1) the problem source is identified and can be removed, or 2) the source cannot be removed or cannot be identified, but the nature of the disturbance has been characterized and a device to isolate the computer can be specified.

ISOLATION DEVICES

Isolation devices are available with a variety of features to match the needs of the problem site. Manufacturers offer product lines with varying degrees of protection and power handling capabilities. A qualitative summary of features is given in Table I.

Isolation devices must be installed with full knowledge of their capabilities in mind. Large computer sites set up through subcontractors place no burden of installation (other than financial) on the customer. Customers doing their own installation, however, must work with the service engineer to fulfill the prerequisites before successful operation can happen. Isolation transformers and line conditioners, in particular, are not panaceas that are merely uncrated and connected between the computer and the wall outlet. These devices have their own input and output specifications that must be met, or else a new set of problems will emerge to replace the old ones. All devices in the computer system should be isolated. Otherwise, as shown in Figure 3, an unprotected system component can receive a transient on its ac input and couple the noise to its chassis. Then the noise is coupled to an I/O cable leading to the chassis of the "protected" computer.

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Table I
Features of ac Line Protection Devices

Device	Description	Voltage Variation Protection	Frequency Variation Protection	Powerfail Protection	Normal-Mode Transient Protection	Common-Mode Transient Protection
Shielded isolation transformer	A transformer with isolated, electrostatically shielded primary and secondary windings.	Input/output ratio can be manually selected by jumpering windings.	None	None	Low. Transformer windings may limit bandwidth, but pulses get through.	High. 120 dB CMR specifications are available.
Tap-switching line conditioner	A shielded isolation transformer regulating output voltage by automatically switching additional secondary windings in or out.	Good. For a broad input range (≈40% tolerance), the output is kept within a ≈15% range.	None	None	Low to medium. Additional filtering may be provided by filter capacitors.	High. 120 dB CMR specifications are available.
Ferroresonant line conditioner	A shielded isolation transformer using a saturated core to clamp voltage to a set-level, and reconstructing the ac sine wave in the secondary.	Good. For a broad input range (≈30% tolerance) the output is kept within a ≈2% range.	None, and will itself malfunction if frequency varies by more than a few Hz.	Low. Energy storage in the core may help if the duration is less than one cycle.	High. Saturated core clamps all pulses. 120 dB NMR specifications are available.	High. 120 dB CMR specifications are available.
Uninterruptible power source (UPS)	Either a motor-generator set, with a diesel engine backup, or a solid-state inverter powered by dc from storage batteries.	High. Alternate power source cuts in if ac line is insufficient.	High. Alternate power source cuts in if ac line is insufficient.	Very good. Duration protection is a function of engine fuel reserve or battery capacity.	Total isolation.	Total isolation.

Definitions: ac Power Anomalies

Power line disturbances may be classified into several types (see Fig. 1):

Voltage variation: The supplied voltage deviates from the prescribed input range. Input below the range is a sag, above is a surge. Sags can be caused by deliberate utility cutbacks (brownouts) to lower power consumption, by customer loads for which the utility cannot compensate, or by an excessive inrush starting current to powered-up equipment. Surges originate from utility line malfunctions or sudden changes in power demand (removal of heavy loads) which cannot be corrected instantaneously.

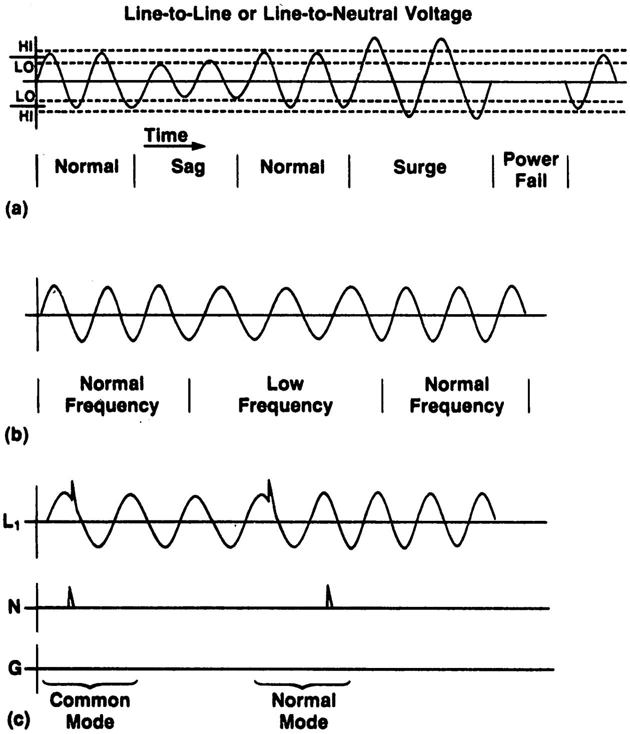

Fig. 1. *Graph of the ac line voltage under (a) normal, sag, surge, and powerfail conditions, (b) normal and abnormal frequency conditions, and (c) with common-mode and normal-mode transients.*

Frequency variation: The frequency of the power line voltage deviates from the prescribed input range. Sudden changes in load to the utility, switching of power between utility companies, or generator malfunction can cause such variations.

Powerfail: Total removal of the input voltage to the computer for at least 5 ms. Switching of power by utilities, either for the purpose of redistributing loads or correcting short circuits, will produce power failures from a few cycles to several seconds. Power equipment failure can result in outages of minutes to hours.

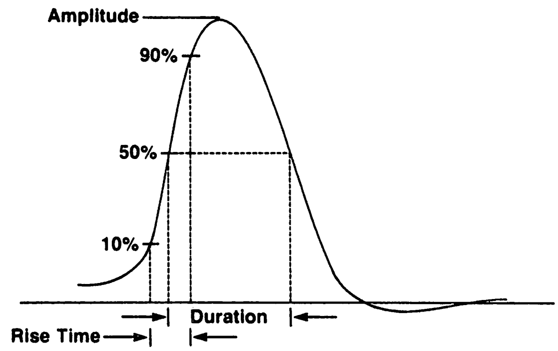

Fig. 2. *Characteristics of transient noise on an ac power line.*

Transient: A disturbance of less than 5 ms duration. The amplitude, rise time, duration, resultant oscillation (if any) and repetition rate (see Fig. 2) determine the effect on the computer's operation. We can classify transients into three types, distinguishing them by their sources.

Transients from nearby sources (within 50 feet of the computer) have very fast rise times (nanoseconds) rich in high-frequency content. The power cord becomes a transmission line, and the propagation of the transient is influenced by distance, conduit, adjacent conductors (into which these transients may be coupled), flatness of the cord against the floor, and socket connections. Because of high-frequency coupling between the conductors in the cord, these transients are usually common-mode by the time they reach the computer. Sources of this type of transient are anything with mechanical breaker contacts, such as coffee pots, electric typewriters, and clock motors.

Transients produced by distant sources will have slower rise times (microseconds) and longer durations than the first type. They are generated by any electrical device that produces enough transient energy to propagate through the device's circuit breaker and distribution panel back to the circuit breaker feeding the computer. Elevator motors, industrial machinery (either on the premises or a block away), and air conditioners are possible sources. These transients are normal-mode or common-mode.

Other transients with rise times similar to those of distant-source transients and with a common-mode structure can be produced by utility distribution faults and resultant arcing, or by lightning, direct or induced, on the utility power pole.

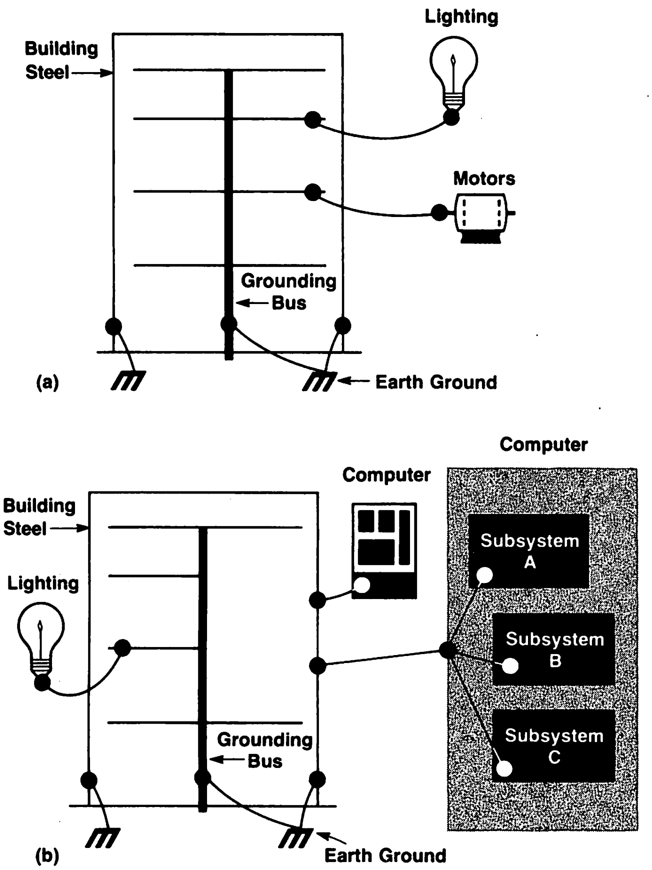

Fig. 1. *The grounding within a building can consist of both (a) single-point (used for lighting, motors, and appliances) and. (b) multipoint (used for computer systems) ground bus systems.*

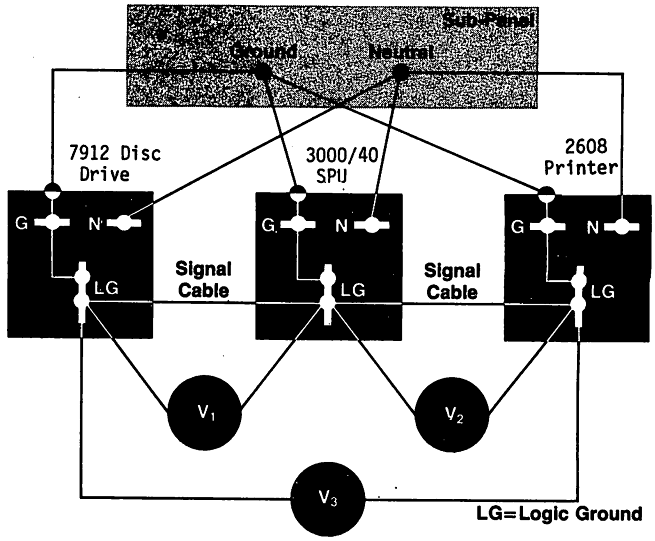

Fig. 2. *Voltage differences between the logic grounds of interconnected computer units can exist if ground impedances and power needs differ between any two units.*

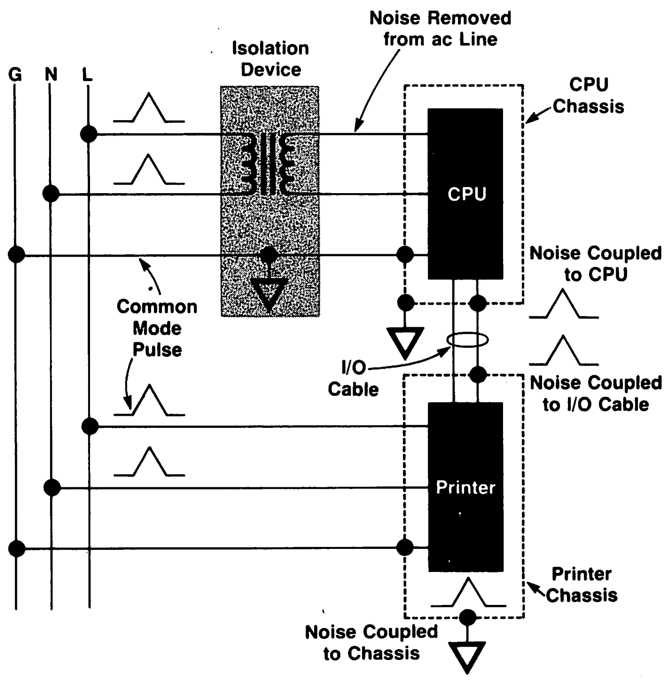

Fig. 3. *All units in a computer system must be isolated from the ac power line. Otherwise, an unisolated unit, the printer shown here, can couple noise to an isolated unit, the CPU here, via the I/O interconnections.*