Computer Grounding

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INTRODUCTION

Computer grounding is a much misunderstood subject surrounded by a host of myths and folklore. Cranky computers often cause people to throw science and engineering principles out of the window, and substitute black magic.

Computers and their peripherals in many military, commercial and industrial installations have been damaged or disrupted by transients or EMI/RFI. Whenever computers malfunction in this way, a "dirty" or "noisy" ground is usually blamed. In response, the users may implement a number of innovative schemes to "clean up" the ground. These often include one or more of the following:

- Driving ground rods through the floor next to the computer.
- Cutting the safety green wire electrical connection.
- Installing insulating bushings in metal conduits.
- Installing isolation transformers with floating secondaries.
- Mounting the computer on insulators.
- Installing isolated ground receptacles.

Most of these practices are outright dangerous and a violation of the National Electrical Code (NEC). None of them make engineering sense or make computers work better. Sometimes temporary success may be achieved, but the problem resurfaces later, often in a more serious way.

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The truth is that none of these popular measures works because they do not address the most important problem experienced with computers: momentary differential ground voltages. Sometimes called ground skews, these are differences in the potential of the local ground with respect to ground at some other point in the building, and they occur in all buildings to a greater or lesser extent. Computer problems arise when these voltages (or resulting currents) are applied to data and control lines, causing disruption or damage. Large facilities, with many large frequently switched loads and multiple power sources with separate grounds, are particular problems. Additionally, computers are being used increasingly to control or monitor processes in electrically noisy environments and are, therefore, very susceptible to interference through their data or control lines.

Before these problems and their solutions are discussed, some fundamentals regarding power systems and computers and why they are grounded at all must be addressed.

WHY GROUND?

First, it must be stated that computers do *not* need to be grounded for them to work. Two computers serve as examples to prove this assertion. One is a laptop, which continues to function satisfactorily in aircraft flying at 35,000 feet (including through thunderstorms, with sparks leaping from the wingtips). It is never grounded to anything, but it works just fine. The other example is a 40 MHz, 386 IBM clone installed in a home office. The home is 30 years old and the office wiring is the standard two-wire type, without a grounding conductor (no green wire). The two-wire outlet is replaced with a GFI outlet (in accordance with NEC recommendations) in order to connect the computer's three-prong plug. The computer works like a champion, but it is not grounded!

So if computers work just fine without being grounded, why bother at all? There are two reasons:

- **Safety & Electrical Code Requirements** - To provide safety when connected to a power system and to meet the requirements of national, state or city electrical codes.
- **Signal Reference** - To provide a common signal reference for interconnected computers and peripherals.

The laptop, being battery powered and stand-alone, needs no ground. The home office computer is ac powered, but safety and NEC compliance is assured by the GFI. It is connected to a printer via a serial data cable, but the printer ac cord is plugged into the same GFI outlet and thus shares the same signal reference (but it is not ground).

Ground is chosen for these two functions because of tradition and for convenience. Unfortunately, grounding for safety and to meet code requirements does not ensure that a high-quality signal reference ground exists, and vice-versa. The requirements of both need to be fulfilled by a practical grounding scheme.

GROUND LOOPS AND DIFFERENTIAL GROUNDING: GROUNDING PRINCIPLES

SAFETY GROUNDING

The return path for the flow of electric current in the event of insulation breakdown or equipment failure is necessary to minimize voltages and to ensure the safety of personnel. Since the introduction of the first power systems in the last century, standard practice has been to use ground as a safety return path. This is only natural, since most power stations, transmission lines and substations are fixed to the earth. Use of an earth electrode is a convenient and inexpensive alternative to running an extra non-current-carrying conductor. Inside buildings, a non-current carrying conductor connected to the power supply earth electrode and to the chassis of electrical equipment has become standard to perform the same function.

Unfortunately, grounding for safety and to meet code requirements does not ensure that a high-quality signal reference ground exists, and vice-versa.

A low-voltage building power system thus consists of two or more current-carrying conductors and a non-current-carrying safety grounding conductor. In some circumstances, one of the current-carrying conductors may also be grounded. This grounded conductor is usually referred to as a neutral. In the U.S., the National Electrical Code sets standards for the sizing and connection of line, neutral and grounding conductors, and grounding techniques.

The main function of a safety ground is to equalize voltages when power-frequency currents flow, and this requires a low resistance connection. The actual value of resistance depends on the available fault current. Low inductance is not a requirement, as frequencies involved are usually not more than a few hundred hertz. The effectiveness of a safety ground can therefore be defined by ohmic voltage drop under stated low frequency currents. Safety ground effectiveness can readily be measured with simple test equipment.

SIGNAL REFERENCE GROUNDING

Computers communicate internally by using sequences of digital voltage pulses synchronized by an internal clock. These pulses generally use a 0 state of close to 0 volts, and a 1 state of 3 to 5 volts. These voltage pulses are referenced to a circuit board ground plane which, together with the dc power source, is usually connected to the computer chassis. Clock speeds vary from a few megahertz up to about 50 MHz. Circuit elements which communicate with each other therefore need a common signal reference ground which offers a low impedance at these frequencies. As long as communication is internal to the computer, the actual voltage of the chassis and signal ground is irrelevant (that's how laptops survive). Difficulties may arise when communications are carried outside the computer chassis on a data line to a remote peripheral or to another computer.

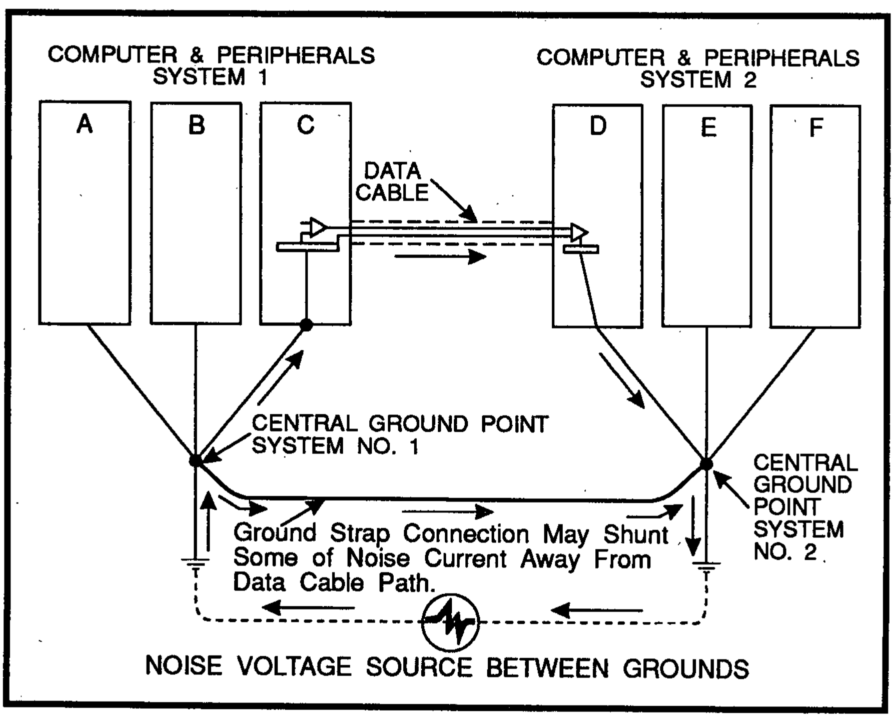

FIGURE 1. *Noise Induced by Differential Ground Voltage.*

In these cases, high-frequency electrical noise or transients can be induced on the data line by differences in ground voltages at the two locations (Figure 1). Unshielded cables may also be susceptible to radiated interference (EMI/RFI). Momentary noise or transient voltages as low as one or two volts may cause data disruption. Transient voltages between 30 to 50 volts will destroy many transceiver chips. Two major solutions are possible:

- Locate the computer and its peripherals close together and connect to a zero-impedance reference grid, typically on a subfloor (Figure 2).
- Provide electrical isolation of the data or communications line and limit the voltage rise of any conducting data line by using communication suppressors (Figures 3a and 3b).

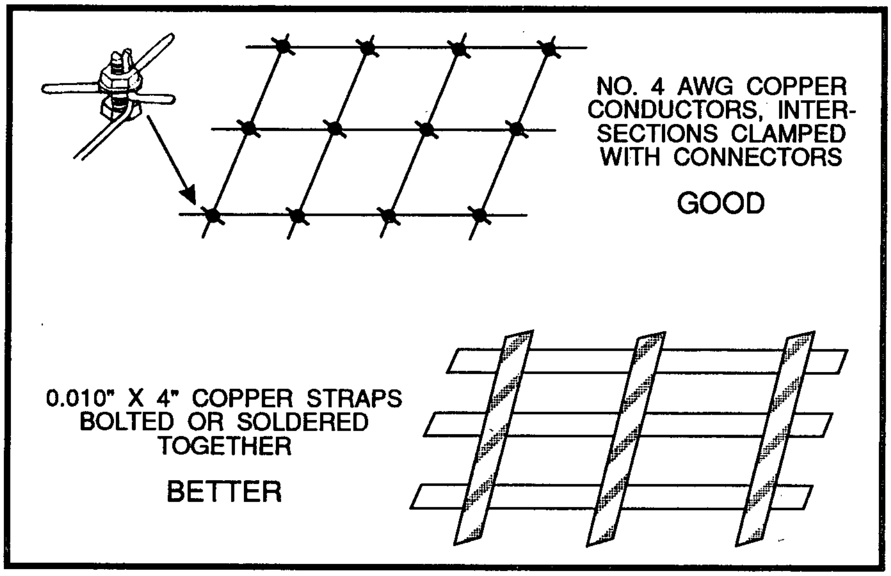

FIGURE 2. Zero or Low-impedance Signal Reference Grid.

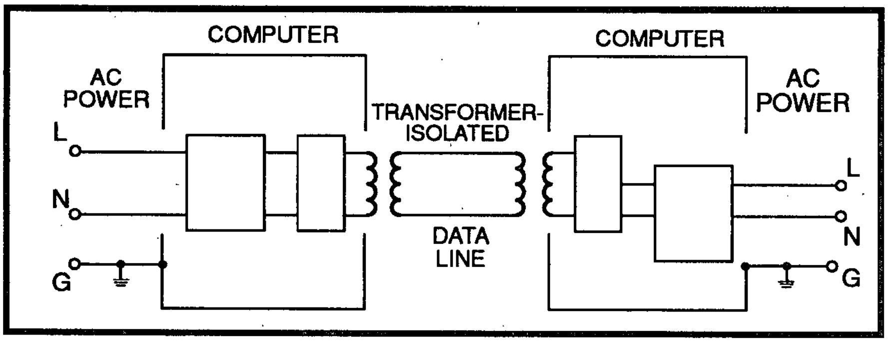

FIGURE 3a. Data-line Isolation.

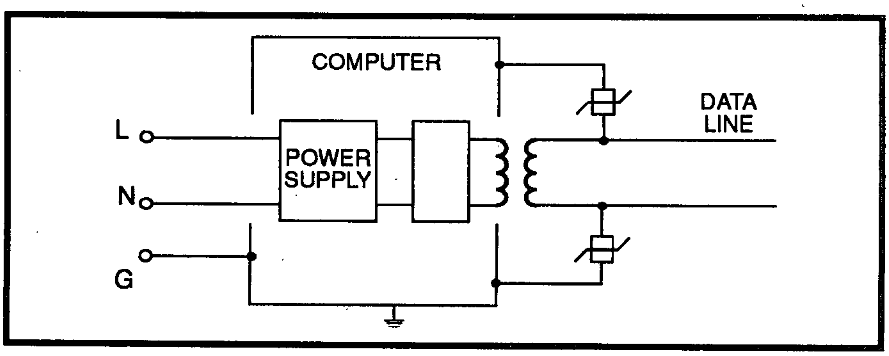

FIGURE 3b. Data-line Isolation and Suppression.

To be successful in equalizing potentials, a zero-impedance reference grid must have low inductance as well as low resistance. Hence many short, parallel paths (as in a traditional computer room floor) are necessary. Isolated grounding conductors will act like a long antenna, and will show both high and low impedances at different frequencies (Figure 4). The use of an isolated grounding receptacle to power computer equipment, even when done in accordance with NEC recommendations, may not meet the necessary requirements of low impedance at high frequencies, and therefore usually will be ineffective.

Similarly, the application of isolation transformers cannot offer a solution to low-impedance reference grounding, although they are commonly misapplied in this way.

SIGNAL ISOLATION

To communicate between remote locations, some isolation of the data communications will generally be essential, as it is physically impossible to equalize potentials at separate locations. It takes about a tenth of a microsecond to communicate between points about 30 feet apart.

The susceptibility of computers to data line interference depends on the signal level and on the degree of isolation between the transceiver and the data line itself. The most problematic differential ground voltages will appear as a common-mode signal between all data line conductors and chassis. Provided that the common-mode voltage is below the damage or disruption level, no problems will occur. Unbalanced directly-connected communications lines (such as RS-232) will be the most susceptible to problems.

Balanced communications (such as RS-422) will be less susceptible. Balanced isolated systems (such as Ethernet 10Base-T) are very immune to noise problems. Table 1 shows approximate damage and susceptibility levels of several popular communications systems.

NOISE AND TRANSIENT PROTECTION

AC POWER SYSTEMS

Power line filters, voltage regulators, isolation transformers and surge suppressors have been applied for many years to protect computers from disturbances on the ac power system. This is another area rife with myths, unscientific practice and innovative marketing schemes which prey on the fear of the unknown.

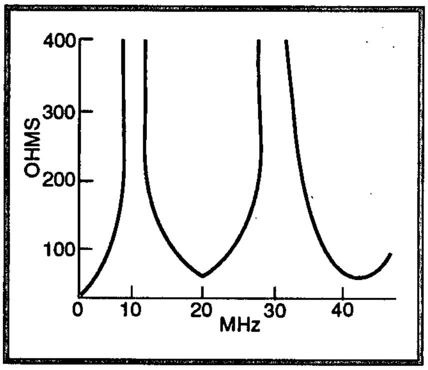

FIGURE 4. Impedance of 22 ft. of No. 4 AWG Isolated Ground Conductor, Grounded at One End Only.

Several manufacturers state in marketing literature that computers are sensitive to noise or transient voltages as low as one or two volts between neutral and ground conductors, and that these voltages will "disrupt the logic." Fear of common-mode noise is often used to justify isolation transformers. Surge suppressor manufacturers vie with each other to claim the lowest possible normal-mode transient let-through voltages, 300 V being an often quoted level needed to protect modern computers.

Laboratory measurements, using ANSI C62.41-1991 standard transient waveforms, have shown few computer power supplies unable to withstand transient voltages of 500 V in any mode, and significant feed-through to the low-voltage dc bus has rarely been measured. Recent data show that this coupling mode is possible, but only significant at very high frequencies. Disruption of computer logic with transients incident on the ac power supply in modern well-designed circuitry is a lot tougher than most people imagine.

A common statement is, "Everyone knows that computers are very sensitive to transients, particularly neutral-to-ground." However, published data does not support that position. A major manufacturer of high-end computer workstations recently stated that their computers were able to withstand transient voltages of 4 kV in all modes without causing damage or disruption.

Another argument can easily show the absurdity of the neutral-to-ground sensitivity myth. It is common practice in several countries, as well as onboard U.S. Navy and many commercial ships, to use power systems with two line conductors and no neutral. In Navy usage, the "neutral" has 60 V rms on it, and all standard U.S. computers work perfectly well. If the circuit design of a typical power supply is examined, it is clear that both line conductors are electrically isolated from the dc output (Figure 5). Neither normal mode nor common mode disturbances have an easy coupling path to the dc supply, and there is no significant propagation mode for either noise or transients, except perhaps at very high frequencies (>1 MHz).

Most modern computer power supplies are quite tough, and can withstand surprisingly large transient voltages. Normal mode transients will damage either the input filter capacitors or, more commonly, the rectifier diodes. Common mode transients will damage either the input filter or the high frequency transformer. Even the cheapest components usually have a withstand voltage in excess of 500 volts (1.2 x 50 μs), with 1 kV being common. The well-known workstation manufacturer mentioned earlier said that it was "not difficult" to obtain a 4 kV withstand. Therefore any reputable manufacturer of a computer for industrial applications would be expected to design its power supply to withstand a minimum of 1 kV, perhaps 3 or 4 kV. The ANSI C62.41-1991 Category A2 Ringwave (4 kV, 130 A, 100 kHz) would be a good test to use for power supply durability testing.

DATA SYSTEM	DISRUPTION VOLTAGE	DAMAGE VOLTAGE
RS-232	5	30
RS-422	30	50
Ethernet Thinnet	50	500
Ethernet 10BASE-T	500	3,000
Modems	1,000	4,000
Fiber	∞	∞

TABLE 1. Damage and Susceptibility Levels.

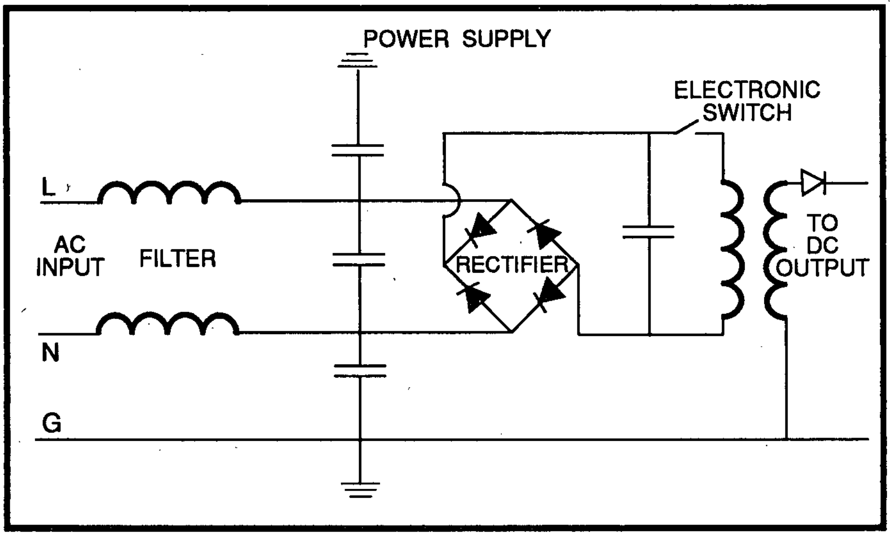

FIGURE 5. *Input Circuitry of Typical Switch-mode Power Supply.*

EFFECTIVE INSTALLATION PRACTICES

COMPUTER SPECIFICATIONS

The effective protection of computers must start with the specifications of the unit themselves. In the absence of any transient or EMI/RFI immunity specifications, it is impossible to coordinate protection devices. These specifications, together with suggested values are:

- The acceptable range of input voltage and frequency (nominal + 20 % - 30%).
- Power supply hold-up time (30 ms at full load).
- Withstand capabilities to ac transients without damage or disruption (ANSI C62.41-1991 Category A1 or A2: 2 kV or 4 kV).
- Withstand capabilities to transients on data or communication ports (ANSI C62.41-1991 Category A1 or A2).

AC GROUNDING AND POWER CONDITIONING

Safety Grounding. All computers and their peripherals should be solidly grounded to the ac power ground and any building steel. Ground connections should be made intentionally, and no reliance should be placed on conduit or incidental grounding connections.

Power Conditioning. AC power at each computer should be protected by an all-mode surge suppressor capable of attenuating ANSI C62.41 Category A3 transients to a level 25 to 30 percent lower than the susceptibility level of the computer.

Incoming ac power to the facility should be protected by a service-entrance suppressor or lightning arrester capable of attenuating ANSI C62.41 Category C3 transients to a reasonably low level (1.5 kV or less). Similarly, internal transients should be intercepted close to the sources (typically large motors) or at branch distribution panels by panel mount suppressors capable of attenuating ANSI C62.41 Category B3 transients to a level which the point-of-use suppressors can safely handle.

DATA LINE GROUNDING AND PROTECTION

Reference Grounding. Computers using directly-connected data media (such as RS-232 lines) must be grounded to a low impedance reference grid. Computers which are physically separated in a building cannot be referenced well enough for reliable and safe operation and should be provided with isolated data lines. These could include opto-coupled data lines, modems and systems using data isolation transformers or fiber-optic cable.

Transient Protection. Metallic data lines run over long distances should be protected at each end by a suppressor which can reduce transient overvoltages to a level 25 to 30 percent below the insulation withstand of the isolation medium. Use of shielded cable, with the shield grounded at each end, is recommended.

CONCLUSION

Computer grounding requires an understanding of two separate functions: performance and safety. Techniques must be used which address both of these important areas.

Integral with the correct grounding is the use of suitable power-conditioning devices on the ac power supply as well as surge protection on any vulnerable data or control lines.

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