A statistical survey of common-mode noise

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Introduction

In today's high-tech world, one does not have to look very far to find some sort of noise generator, whether in the home or office. Knowing the many different sources of noise and its behavior in an electronic circuit is very valuable to the designer and user. The first part of this article defines some fundamental concepts of noise, while the latter part demonstrates the effect of noise induced on cables of different lengths.

Noise sources

EMI

Electromagnetic interference (EMI) is a signal that can cause undesirable performance in a device or system.

Electronic equipment can be divided into two main categories. The first consists of devices from which RF signals are deliberately emitted, such as radio and television transmitters, citizens' band and amateur radio transceivers, cellular telephones, radar and electronic navigation systems, etc. The second category is composed of devices that emit unintentional RF signals, such as computers, home television and stereo sets, fluorescent lights, power tools, power lines, and office equipment such as printers, copiers, fax machines, etc. It is this category that gives us the most grief.

There are, of course, natural sources of EMI such as lightning, cosmic radiation, solar radiation, and nuclear decay. These are unique and require special consideration that is beyond the scope of this article.

High-impedance circuits are most susceptible to capacitive coupling from nearby circuits with rapid and large voltage swings and to inductive coupling from nearby circuits with rapid changes in large currents. These transients are momentary changes in voltage and current that can be measured from milliseconds to nanoseconds. Often this transient is called a voltage or current spike.

Most respectable electronic equipment has an EMI filter on the front end of the power supply. The FCC requires this filter to stop most noise conducted from the power lines through the supply. Unfortunately, noise can find other paths into the device. EMI may be radiated and can couple into the system through the metallic enclosures or through the data lines. Unshielded twisted pair (UTP) is a likely candidate for coupled noise. This is especially true if there is an inadequate ground or the cable is routed close to a noise source.

Conducted noise still can enter the system through the ground. If the ground wire contains electrical signals, they will travel the path of least resistance and sometimes return to their point of origin—a device, ground, or even earth.

Many computer problems have electrical or magnetic origins. Monitor problems, for example, often are caused by nearby magnetic fields, neutral wire harmonics, or conducted/radiated electrical noise. Intermittent lockup of computers often is caused by ground loops. An electrical wall outlet improperly wired or grounded also causes many problems.

RFI

There are two modes of radio frequency interference (RFI): via radiation (electromagnetic waves in free space) and via conduction over signal lines and ac power distribution systems.

One of the most significant contributors to radiated RFI is the ac power cord. The power cord is often a very efficient antenna, since its length approaches a quarter wavelength for RFI frequencies present in digital equipment and switching power supplies.

Conducted RFI is induced over the ac power system in two ways. Common-mode (asymmetrical) RFI is present on both the line and the neutral current paths with reference to the ground or the earth path. Differential (symmetrical) RFI is present as a voltage between the line and neutral leads.

Ground loops

One of the most difficult types of power problems to understand, diagnose, and resolve is the ground loop. All types of equipment are susceptible to this type of problem, whether medical, industrial, or data processing. Ground loops can cause data errors, component failures, lockups, and even—in the worst case—safety hazards.

Grounding is used primarily to insure safety from fire and hazards. An important aspect of this protection is a reliance on multiple or redundant grounds. If one ground is accidentally removed or disconnected, the additional safety paths still exist. This redundancy has one major side effect—it can create ground loops.

Grounding is also used to terminate the shield on transmission lines and to prevent radiated emissions from getting in or out.

When ground loops are formed, the current that flows in the system ground is very unpredictable. This ground current can be caused by voltage differences, induction from other cables or devices, wiring errors, ground faults, or normal equipment leakage. The currents can be dc, 60 Hz, or very high-frequency.

Ground loops can cause specific equipment problems in three ways:

1. Low-energy currents in the grounds generate voltages that can cause data errors. These can be low-frequency, such as a 60-Hz hum, or high-frequency, classified as electrical noise.
2. High-energy transients choose data grounds instead of power grounds to clear to earth. These transients can

be caused internally by switching or inrush currents, such as the initial charge on the input capacitors in a switching power supply; or externally by the starting of a high-inductive motor or by lightning. These transients can cause equipment damage to drivers, receivers, microprocessors, and almost any electrical component if the surge is high enough.

3. Ground loops are one cause of common-mode noise between phases, neutral, and ground in a power distribution system. This noise is injected into the power supplies, which in turn pass it on to the electronic components.

Common-mode noise

The term “common-mode noise” is used in both ac power management and in circuit design considerations. Both environments will be discussed.

Common-mode noise in terms of ac power is the noise signal between the neutral and the ground conductor. This should not be confused with normal-mode noise, which is referenced between the line (hot) and the neutral conductor.

Common-mode noise impulses tend to be higher in frequency than the associated normal-mode noise signal. This is to be expected since the majority of the common-mode signals originate from capacitively coupled normal-mode signals. The higher the frequency, the greater the coupling among the conductors, line, neutral, and ground. Electronic equipment is 10 to 100 times more sensitive to common-mode noise than to normal-mode noise.

We would probably be surprised at the amount of noise present on the power line at any given time. The source of this noise is both the electrical distribution system outside the building and the one inside the building. The noise results from the power line’s dynamic nature of the ever-changing loads.

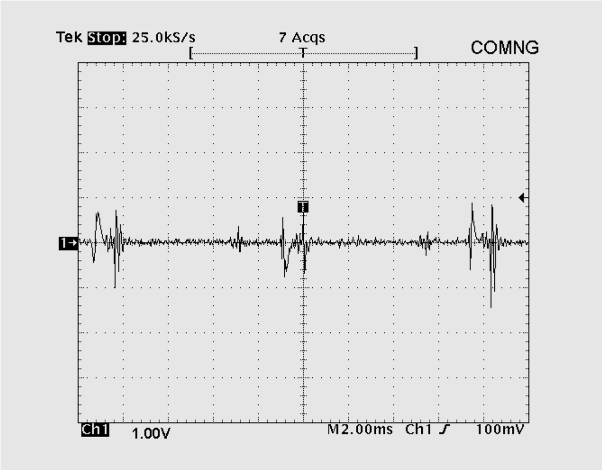
Figure 1 shows typical noise found on a power line. The noise was taken from unconditioned house power inside an IC characterization lab. Some of the signals occur at a regular repetition rate related to the 60-Hz power line frequency. This type of noise is common-mode signals found on the power line and is generally caused by some type of motor-driven device. If the oscilloscope were left in infinite persistence mode, we would see random or asynchronous noise from loads being switched on and off, power utility switching, or some natural phenomenon.

Conventional power transformers and isolation transformers will not block normal-mode noise impulses, but if the secondaries of these transformers have the neutral bonded to ground, they serve to convert normal-mode noise to common-mode noise. From the standpoint of microelectronic circuits, common-mode noise is even more potentially harmful than the normal-mode noise.

Common-mode voltage (CMV) identifies a voltage (noise) present on both input leads of an analog input with respect to analog ground (see Figure 2).

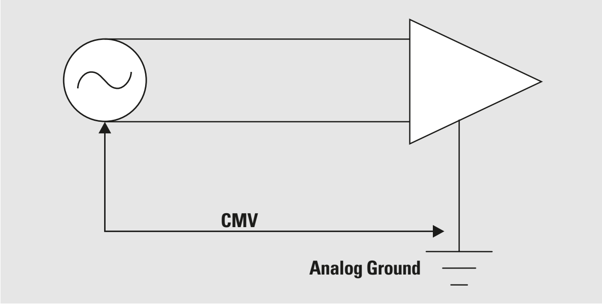
The biggest source of common-mode noise is the difference in potential between two physically remote grounds. This is often the case when dealing with networked computer equipment where ground loops can occur. Typical effects can be intermittent reboots, lockups, and bad data transfer. Network interface cards, serial ports, parallel ports, and modems are prime targets for some form of failure due to high CMV. If the CMV is high enough, component failure is possible.

Figure 1. Common-mode noise from neutral to ground



A line noise interface instrument from ONEAC was used.

Figure 2. Common-mode voltage



The second most significant common-mode noise source is the potential due to ungrounded sources. Such problems can occur when a separate power supply is used to power the field device remotely and the remote power supply is left ungrounded.

RFI noise sources provide ample opportunity to induce common-mode noise. A poor ground system or an ungrounded analog signal cable can act as an antenna, gathering the induced voltage and applying it on the analog input. The most common methods of treating common-mode noise lose their effectiveness as the frequency of the common-mode noise increases.

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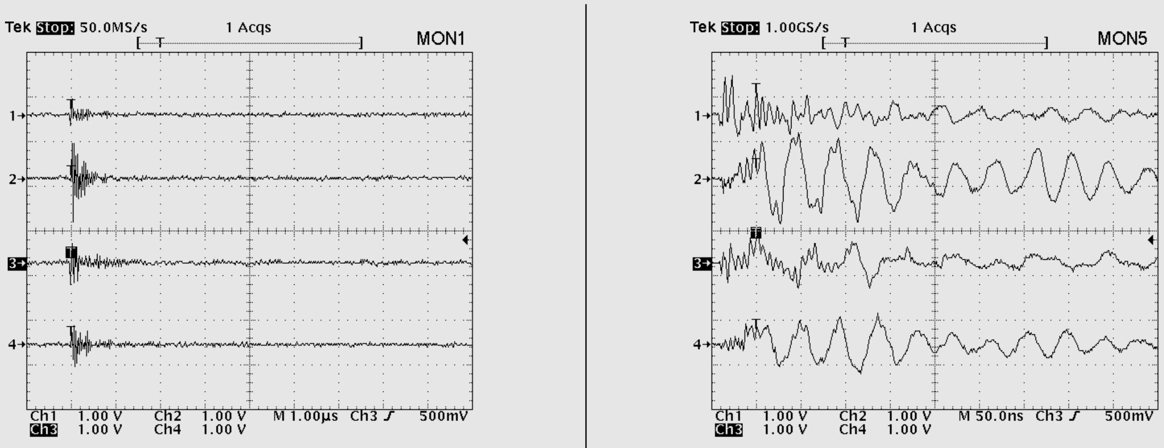
Common-mode rejection

Common-mode rejection (CMR) techniques exist to prevent common-mode noise from being converted to normal-mode voltage. These techniques relate to the ability of an amplifier to reject the effect of voltage applied to both input terminals simultaneously. The CMR ratio (CMRR) is the ratio in dB of the differential voltage amplification to CMV amplification. CMR is often defined at an associated effective frequency with a maximum allowable input imbalance such as 120 dB @ 500 Hz 1000 ohms. A CMRR of 120 dB means that a 1-V CMV passes through the device as though it were a differential input signal of 1 µV. This implies that the higher the CMRR, the better.

Experimental setups

There could be a big debate on which technique would provide the best data for measuring noise induced on a cable. Since the purpose of this article is to measure the effect of noise and not to characterize it, an oscilloscope was used to view the noise in a time/voltage domain

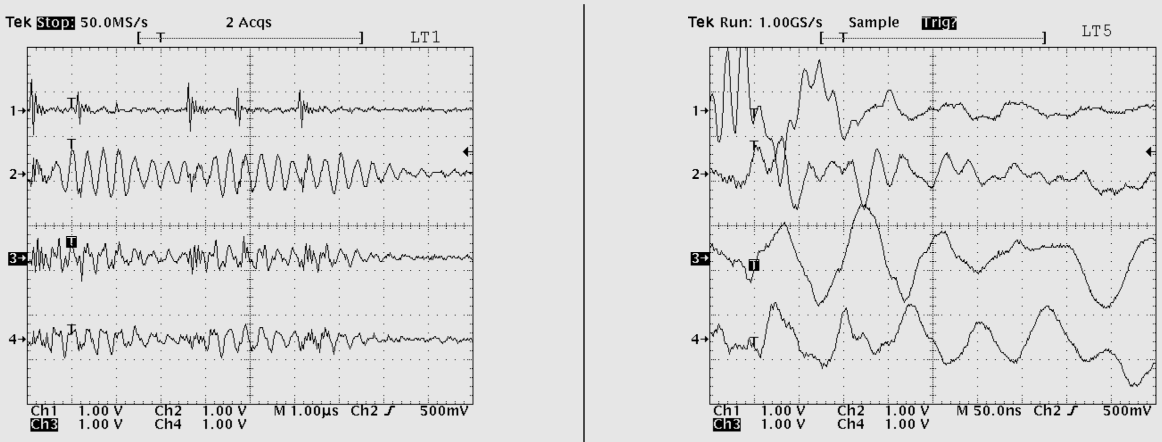
Figure 3. PC monitor power switched on/off with cables 6 inches from the monitor



(a) Time scale: 1 µs/div

(b) Time scale: 50 ns/div

Figure 4. Fluorescent light switched on/off with cables 12 inches from the light



(a) Time scale: 1 µs/div

(b) Time scale: 50 ns/div

instead of using a spectrum analyzer to view the data in a frequency domain. The latter method could fill an application note by itself.

Figures 3–8 represent views of noise induced on cables of various lengths. The transmission line used in each case was an unshielded, 24-AWG, solid bare copper wire with polyolefin insulation, twisted pairs, and a PVC jacket. This line is Belden part #1588A, one of Belden's most-sold cables for data transmission. It is a standard category-5 cable. The lengths used on channels 1–4 of the oscilloscope were 3 ft., 30 ft., 100 ft., and 800 ft., respectively.

The cable mentioned has two pairs of conductors. In each case, the pair that was connected to the oscilloscope was terminated in 100 ohms at the load end of the cable. The oscilloscope used was a Tektronix TDS784C with termination on each channel set at 1 Mohm. The 30-, 100-, and 800-foot cables were coiled with the exception of a 6-foot length on each end. The coiled sections were placed 6 feet from the noise source.

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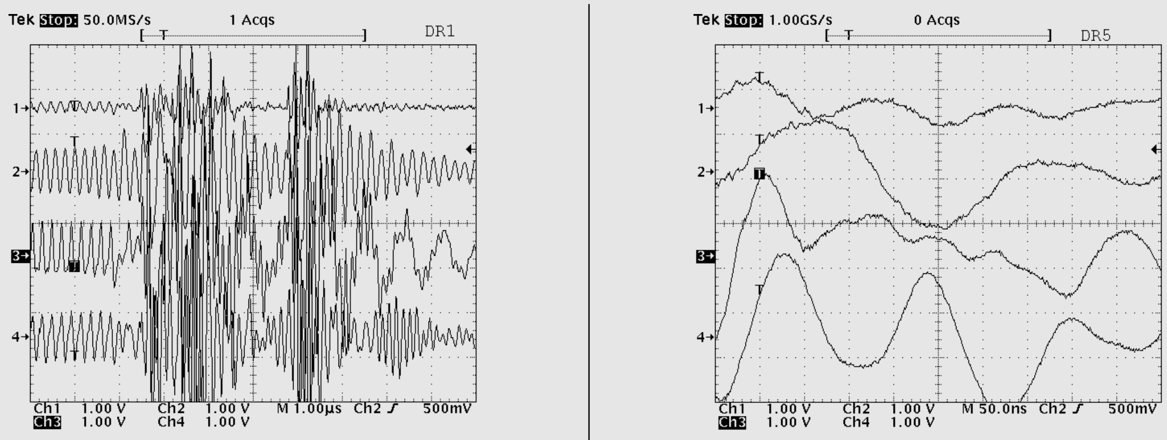
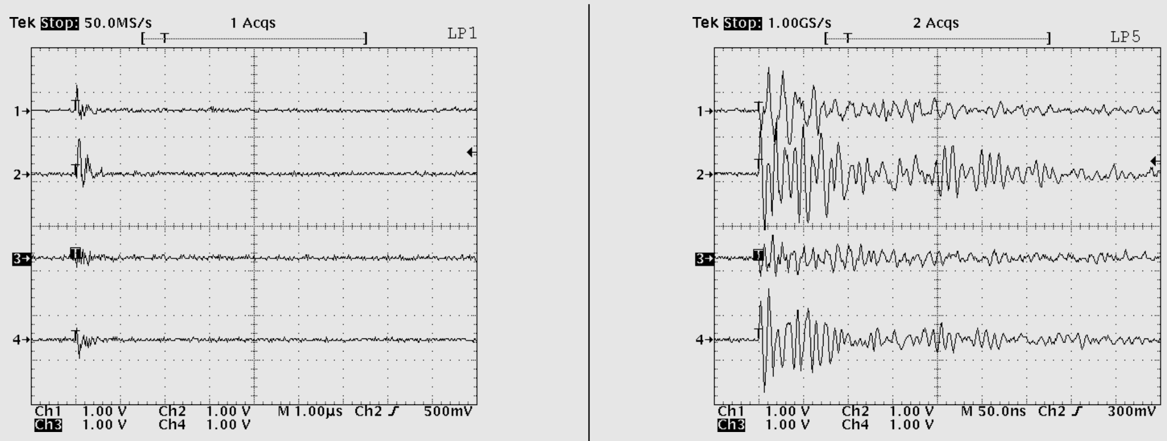
Figure 5. 110-V drill press motor with cables 10 inches from the motor



(a) Time scale: 1 µs/div

(b) Time scale: 50 ns/div

Figure 6. 208-V ac power line in conduit with cable insulation touching conduit



(a) Time scale: 1 µs/div

(b) Time scale: 50 ns/div

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Conclusion

It appears from Figures 3–8 that cable length made very little difference on the induction of noise in the environments described. There was some noticeable attenuation on the longer cables that could be attributed to the dc resistance of the cable and normal line loss factors. This was not always the case when the drill motor EMI was measured. The longer the cable, the greater the chance that high EMI fields will couple onto it. It should be pointed out that if the same test were done today, the results would be different because the noise level varies constantly. The noise was very unpredictable in all cases. We will never be able to eliminate all the noise in our environment. A good defense for common-mode noise would be to choose components that have a very high CMRR and a high common-mode operating range, such as the Texas Instruments LVDS and LVDM products.

Related Web site

interface.ti.com

Figure 7. Cables tied to chassis ground on a VLSI logic tester and powered on/off

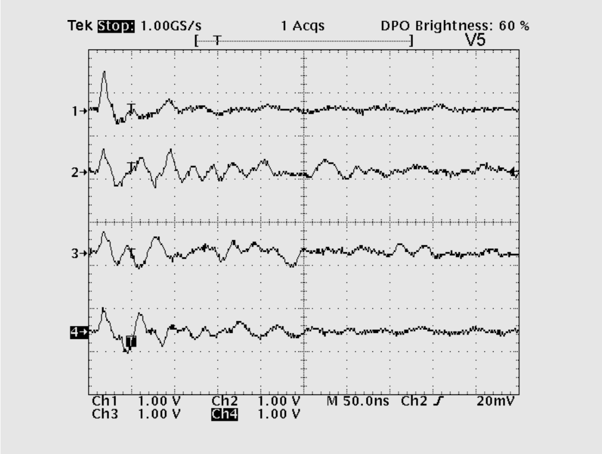
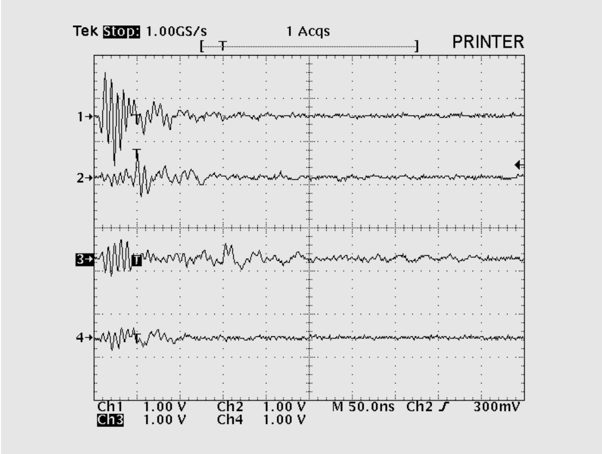


Figure 8. Cables connected to a networked laser printer ground during printing



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