A Survey of Common-Mode Noise

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ABSTRACT

This application report provides the results of research regarding common mode noise induced on cables of varying lengths in different environments. It also provides information on noise sources.

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1 Introduction

Noise generators are pervasive in today’s high tech world. Knowing the characteristics and understanding the behavior of noise sources is valuable to designers and users of electronic circuits. The first part of this report defines some fundamental concepts of noise; the latter portion demonstrates the effect of the noise induced on cables of different lengths.

2 Noise Sources

Noise is generally caused by electromagnetic interference (EMI), radio frequency interference (RFI), and ground loops.

2.1 EMI

Electromagnetic interference (EMI) can cause undesirable performance in a device or a system. Electronic equipment can be divided into two main EMI categories. The first category comprises intentional radiator devices such as radio and television transmitters, citizen's band and amateur radio transceivers, cellular telephones, radar and electronic navigation systems etc., wherever rf signals are being deliberately emitted.

The second category is composed of unintentional radiators such as computers, home television and stereo sets, office equipment—such as printers, copiers, fax machines, etc.—, fluorescent lights, power tools, and power lines. This category causes the most problems for systems, devices, and designers.

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

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

Most 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) wiring is a likely candidate for noise pickup. This is especially likely if there is an inadequate ground, or the cable is routed close to a noise source.

Conducted noise can still enter the system through the ground. If the ground wire contains electrical signals, they do not mysteriously disappear. They travel the path of least resistance and sometimes return to their point of origin—a device, ground, or even earth.

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

2.2 RFI

RFI is the propagation via radiation (electromagnetic waves in free space) and by conduction over signal lines and ac power distribution systems. There are two modes of propagation.

The first mode is radiated. 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 wave length for RFI frequencies present in digital equipment and switching power supplies.

The second mode, conducted, is induced over the ac power system in two ways. Common-mode (asymmetrical) RFI is present on both the line and 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.

2.3 Ground Loops

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

Grounding is primarily used to insure safety from fire and hazards. An important aspect of this protection is a reliance on multiple or redundant grounds. In this way if one ground is accidentally removed or disconnected the additional safety paths 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 provide shielding 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, and 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 from switching or inrush currents, for example the initial charge on the input capacitors in a switching power supply, the starting of a high inductive motor, and, of course, 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.

3 Common Mode Noise

The term common-mode noise is used in ac power management and in circuit design considerations. Both environments are 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 from 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 normal mode noise.

The amount of noise present on the power line can be surprising at any given time. The source of this noise is from the electrical distribution system external to the building and from the one within the building. It is the result of the power line's dynamic nature due to the ever-changing loads. Figure 8 shows typical noise found on a power line. This 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 frequency. This type of noise is common-mode signals found on the power line. Some type of motor driven device generally causes this type of noise. An oscilloscope left in infinite persistence mode would show random or asynchronous noise that is the result of loads being switched on and off, power utility switching, or some natural phenomena.

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

Common mode noise is often referred to as common mode voltage (CMV) which is present at both input leads of an analog circuit with respect to analog ground.

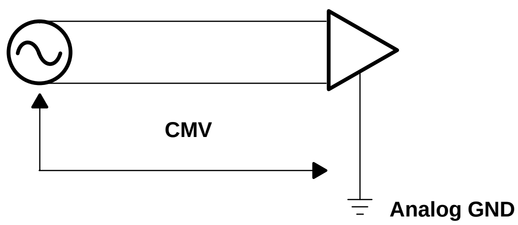

Figure 1. Common-Mode Voltage

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 of this 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 CMV. If the CMV is high enough, component failure is possible.

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

The radio frequency noise sources mentioned in the RFI section are common sources of common-mode noise. A poor ground system or an ungrounded analog signal cable can literally 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.

4 Common-Mode Rejection (CMR)

Common-mode rejection techniques exist to prevent common-mode noise from being converted to normal-mode voltage. This is the ability of an amplifier to reject the effect of voltage applied to both input terminals simultaneously. The common-mode rejection ratio is the ratio in dB of the differential voltage amplification to common-mode voltage amplification. CMR is often defined at an associated effective frequency with a maximum allowable input imbalance:

120 dB @ 500 Hz 1000 Ω

A common-mode rejection ratio of 120 dB means that a 1 V common-mode voltage passes through the device as though it were a differential input signal of 1 µV. This implies the higher the CMRR the better.

5 Experiment 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 report is to measure the effect effect of noise and not to characterize it, the decision was made to use an oscilloscope and view the noise in a time/voltage domain versus using a spectrum analyzer and viewing the data in a frequency domain. The latter could be an application report by itself.

Figures 2 through 12 show noise induced on cables of variable lengths. The transmission line used in each case was a 24 AWG solid bare copper wire, polyolefin insulated, twisted pairs, unshielded, with a PVC jacket. This is Beldon’s part #1588A, which is one of their most-sold cables for data transmission. This 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 above cable has two pairs of conductors. In each case the pair that was connected to the oscilloscope was terminated with 100 Ω at the load end of the cable. The oscilloscope used was a Tektronix TDS784C with termination on each channel set at 1 MΩ. 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.

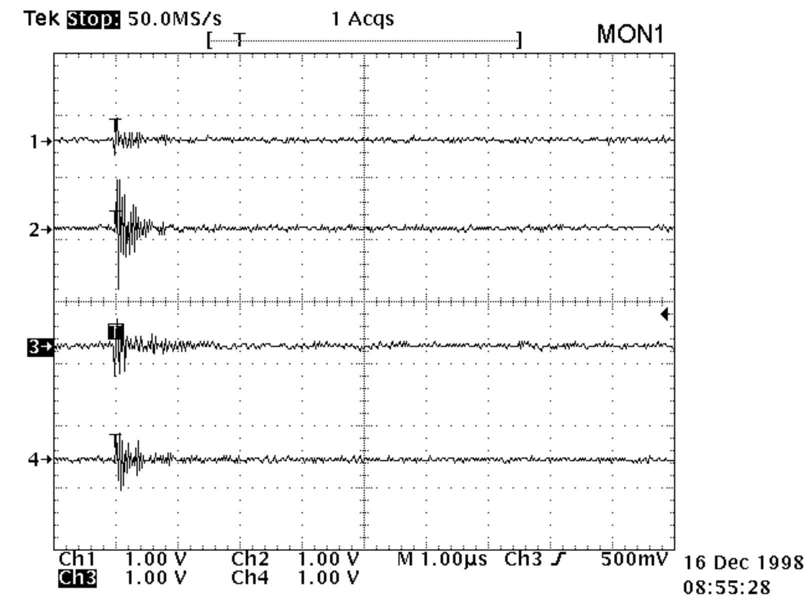

Figure 2. PC Monitor Power Switched On/Off (Scope Time Base at 1 µs)†

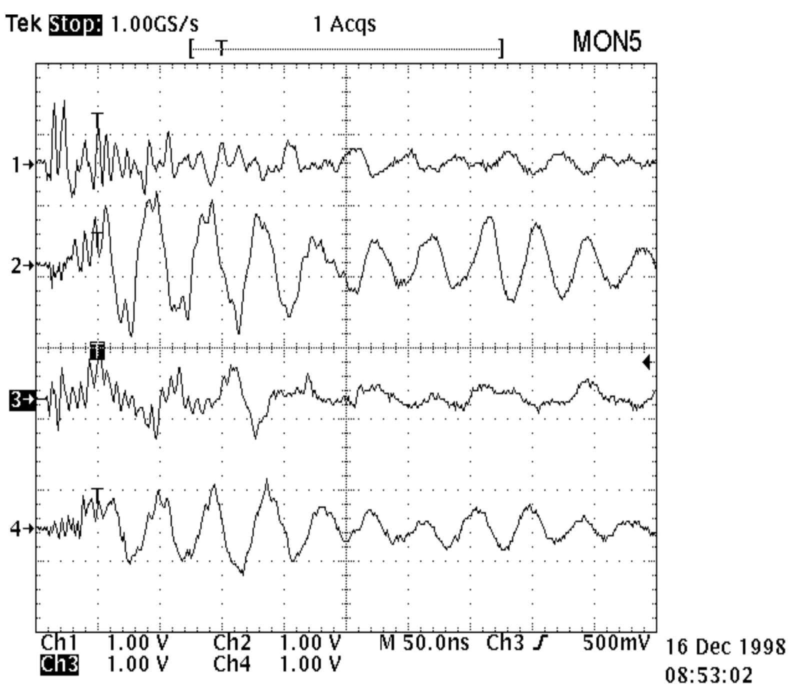

Figure 3. PC Monitor Power Switched On/Off (Scope Time Base at 50 ns)†

†Cable positioned 6 inches from the monitor

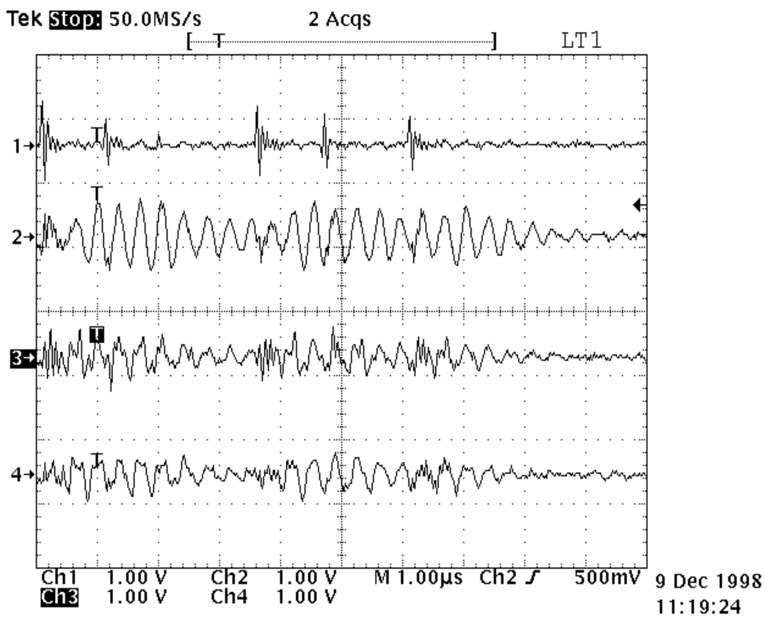

Figure 4. Fluorescent Light Switched On/Off (Scope Time Base at 1 µs)†

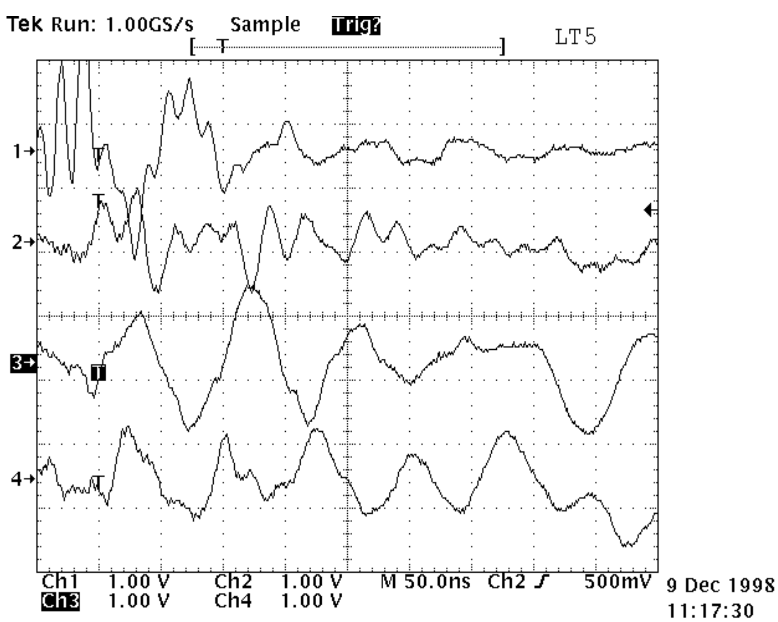

Figure 5. Fluorescent Light Switched On/Off (Scope Time Base at 50 ns)†

†Cable positioned 12 inches from the fluorescent light

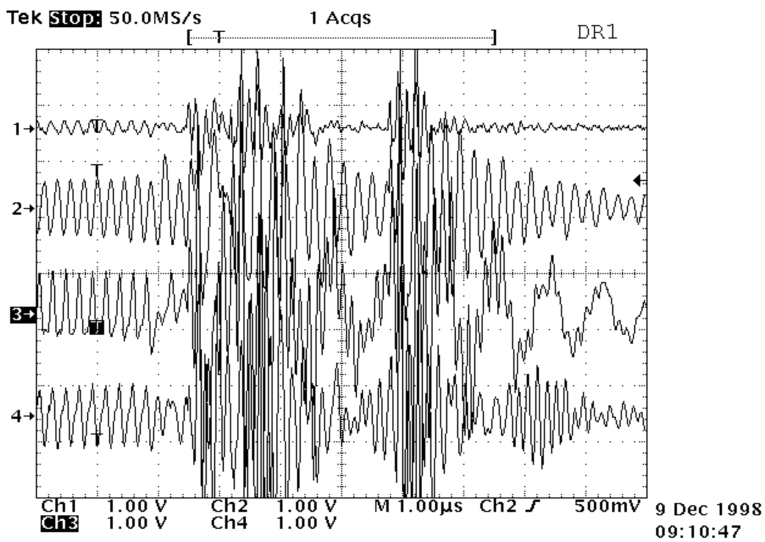

Figure 6. 110-V Drill Press Motor (Scope Time Base at 1 µs)†

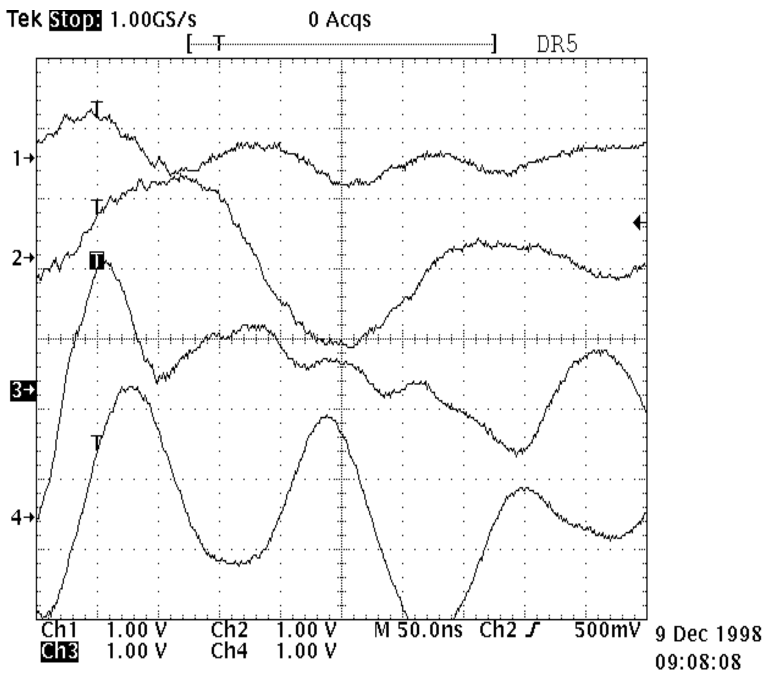

Figure 7. 110-V Drill Press Motor (Scope Time Base at 50 ns)†

†Cable positioned 10 inches from the drill motor

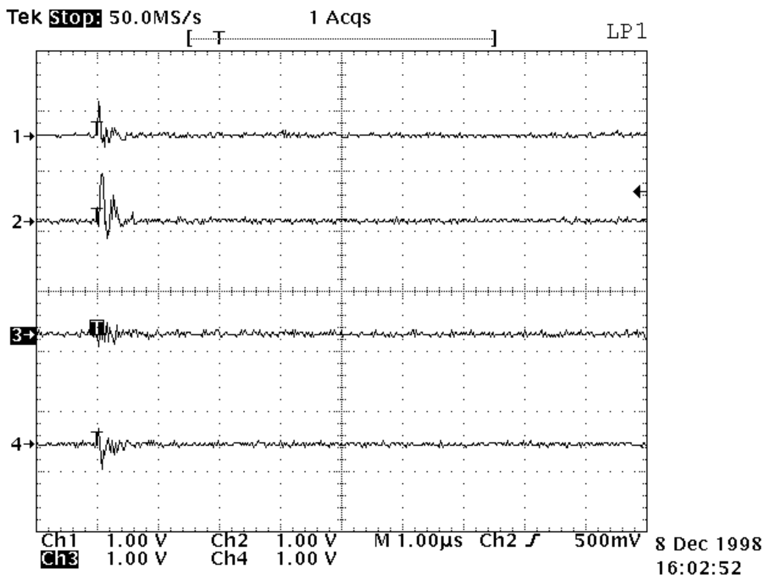

Figure 8. 208 VAC Power Line in Conduit (Scope Time Base at 1 µs)†

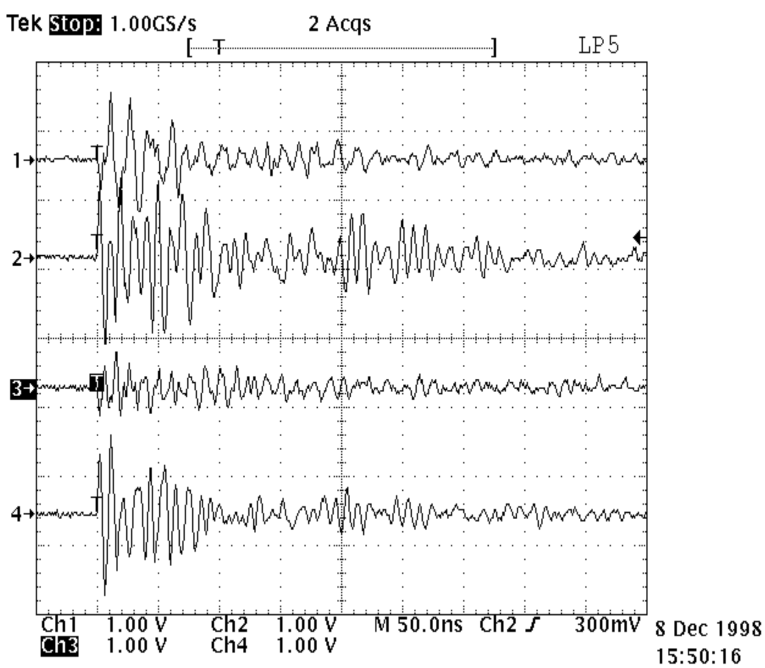

Figure 9. 208 VAC Power Line in Conduit (Scope Time Base at 50 ns)†

†Cable 1/4 inch from the power conduit

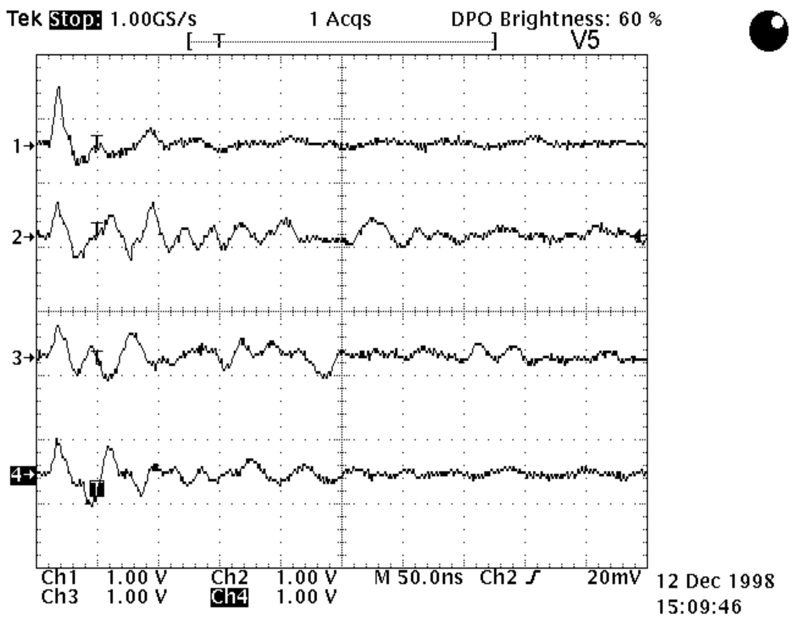

Figure 10. Cables Tied to Chasis Ground on a VLSI Logic Tester and Powered On/Off

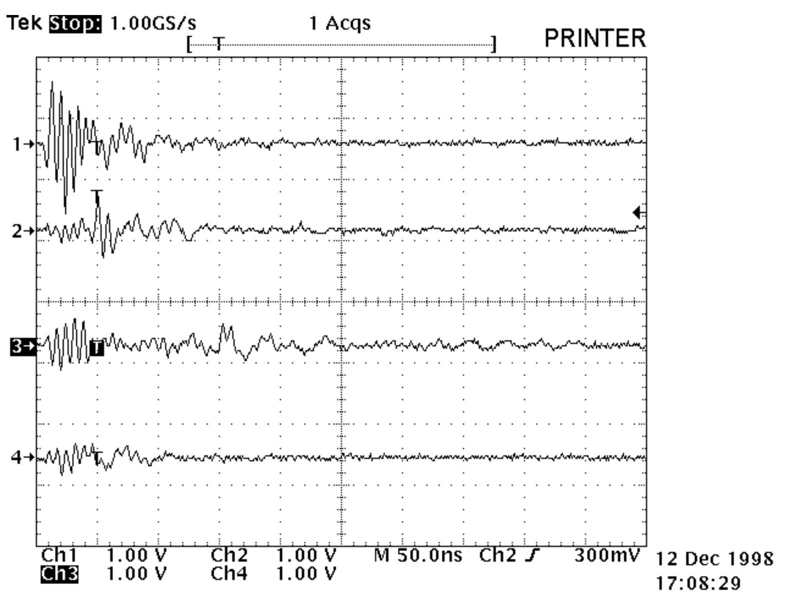

Figure 11. Cables Connected to a Networked Laser Printer Ground While Printing

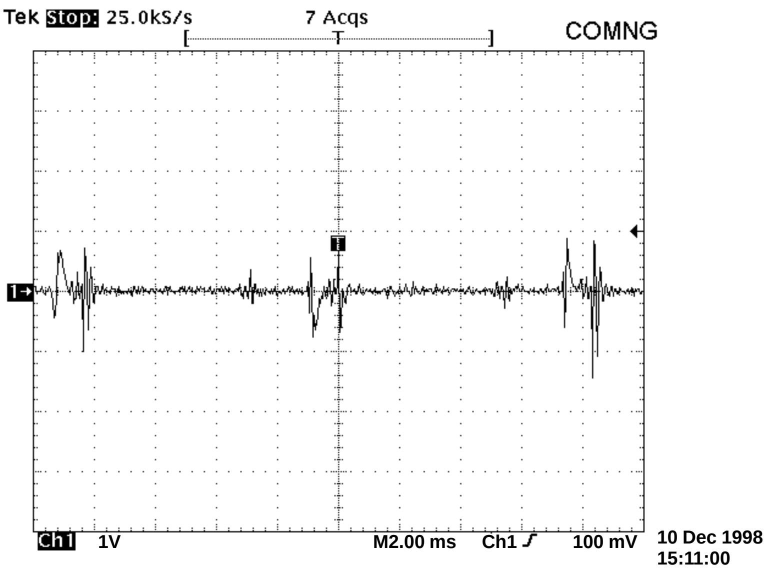

Figure 12. Common Mode Noise From Neutral to Ground

6 Summary

It appears from Figures 2 through 12 that cable length made very little difference on the induction of noise in the described environments. 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 measuring the drill motor EMI. The longer the cable, the better chance that high EMI fields can couple to it. It should be pointed out that if the same test were repeated, 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 Texas Instruments LVDS and LVDM products.

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