Methods for Reducing Interference in Instrumentation

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Introduction

This note deals with methods of connecting signals and correct use of shielding to reduce the pickup of undesired signals. Interference can be coupled to a signal via an improper ground connection. There is a common tendency to "ground everything" for surely ground is your ally in interference problems. A brief discussion of what is ground can help to understand the problems caused by "grounding everything" and how to intelligently use ground as an ally in fighting interference. For this discussion, interference will be defined as some man-made signal such as 60 Hertz power or radio-frequency that causes problems when summed with a signal of interest.

What is ground?

Ground can be generally defined as the node in a circuit with the lowest absolute potential difference with respect to a nearby large conducting body such as earth. When earth is not convenient, the body of a motor vehicle, the hull of a ship, the body of a plane or satellite, etc. is then referred to as ground. Voltage measurements and signal sources are generally with respect to ground. One of the worst assumptions that can be made in industrial instrumentation applications is that "ground is ground" – i.e. all grounds are at the identical potential. Although all pieces of equipment are connected to ground, this does not mean that all pieces of equipment have zero potential difference between them. On paper, ground is generally thought of as an impedanceless conductor. In the real world, ground has resistance, inductance, and mutual inductance and capacitance to adjacent conductors. Thus, ground current causes a potential difference between various circuits connected to ground. Those potential differences become signal sources for undesired signals. Also, through mutual inductance, potential differences can be induced between two circuits connected to ground.

Ground loops

A ground loop is formed if an auxiliary connection is made across the potential difference between two circuits connected to ground. Although the potential difference between the two circuits may be reduced, ground loop currents can induce additional interference into the desired signal. In some instances, ground loop currents can be large enough to melt the auxiliary wire. Ground loops also act as an antenna and can be a major problem if they happen to resonate at the frequency of an interfering signal. Because a ground loop is a closed loop, any nearby dynamic magnetic field (such as from a transformer or motor) will induce a current in the closed loop and thus voltage differences around it. Ground loops are always undesirable. Often, ground loops are inadvertently introduced into a system.

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Signals

The first problem in instrumentation is that a signal measured with respect to one ground in a system is different when measured with respect to another ground in the system. The second problem is that the greater the distance between where a signal is generated and used, the more likely the signal becomes corrupted by interference. Both of these problems can be minimized by proper design.

The cable that connects a signal source to an amplifier is of three common types as shown in Figure 1. Each of the three types is subject to both inductive and capacitively coupled interference. Interference picked up by the cable has two components, differential and common-mode. Although it is desirable to minimize the interference in the absolute sense, it is more desirable that the interference picked up be exactly the same in both signal conductors – i.e. that the interference appear as common-mode. Common mode interference is not difficult to remove where as differential mode interference is nearly impossible to remove. The three common types of signal cables are discussed as follows.

Parallel or twisted pair connections (Figure 1a)

This is the cheapest form of signal cable. Note that both the inductively and capacitively coupled interferences are approximately equal on both wires. Thus, the interference is mostly a common-mode signal that can be rejected by an amplifier with high common-mode rejection. Twisting the wires improves the equality between M_{01a} and M_{02a} and between C_{1a} and C_{2a} thus reducing any differential interference signal pickup.

Coaxial cable (Figure 1b)

This cable consists of a center conductor surrounded by a cylindrical outer conductor of either foil or braid construction. Note that braid covers the center conductor by 85 to 95 percent where as foil provides practically 100 percent covering. Although the capacitively coupled interference to the outer conductor is about the same as that for any wire of the twisted pair approach, the capacitively coupled interference to the center conductor is reduced substantially. The inductively coupled interference to both center and outer conductors is about the same as in the case for twisted pair. Frequently in coaxial cable installations, each end of the cable is connected to ground thus forming a ground loop. Coaxial cable is fundamentally unbalanced and thus the primary problem with coaxial cable is that it may be difficult to get the interference to appear only as a common mode signal. Coaxial cable is very useful when the length is short, there is little or no potential difference between the grounds at each end, and a differential amplifier is not available. Note also that if the frequency spectrums of the signal and interference do not overlap, then frequency selective techniques can be applied to the amplifier to remove the interference. Coaxial cable works best when all of the return current is through the outer shield – i.e. no ground loops.

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Shielded twisted pair (Figure 1c)

This is the most expensive and the best way to connect a signal source to an amplifier over a long distance. The cable is made by wrapping a braid or foil shield around a twisted pair of wires. The shield is connected to ground at preferably only one end (the source end is usually the best) in order to prevent ground loop currents from inducing interference voltages in the twisted pair.

Signal reception

Figures 2a through 2g show various ways that a signal source can be connected to an amplifier some distance away. The problems or merits of each approach are discussed below. The amplifier in each case is an instrumentation amplifier. In Figures 2a through 2c, the amplifier is connected to emulate a conventional non-inverting operational amplifier. This is done to illustrate the disadvantage of not receiving the signal differentially. Vg is the difference between the two grounds. Vm is the inductively coupled interference voltage on the signal wires. Vc is the capacitively coupled interference voltage on the signal wires.

Figure 2a shows the worst possible way to connect a signal source to an amplifier. This connection assumes that "ground is ground" and that there are no sources of interference. All of the interfering sources add directly to the signal.

The twisted pair connection shown is Figure 2b is not much better. The attempt here is to "short circuit" the voltage difference between the two grounds. The ground loop thus formed will induce a fraction of the ground interference into the signal wire. The "short circuit" may help in some random situations (thus falsely leading to a conclusion that that is a good thing to do) although there is still a potential difference between the two grounds because of finite resistance. The "short circuit" does help to reduce inductively coupled pickup on the signal wires because the induced voltages add in an opposing manner.

In Figure 2c, the twisted pair cable is replaced by a coaxial cable. The only improvement is that the coaxial cable shields the signal wire from capacitively coupled interference.

In Figure 2d, a twisted pair cable connects the signal source to an instrumentation amplifier. The high common mode rejection of the amplifier greatly reduces the effect of Vg, Vm, and Vc. This approach may be satisfactory in cases where the signal is not extremely small and the common mode signal pickup does not exceed the limits of the amplifier.

In Figure 2e, the twisted pair cable is replaced by a coaxial cable. Because interference picked up on the shield is not the same as that picked up on the center conductor, some of the interference becomes a differential signal and will not be rejected by the amplifier.

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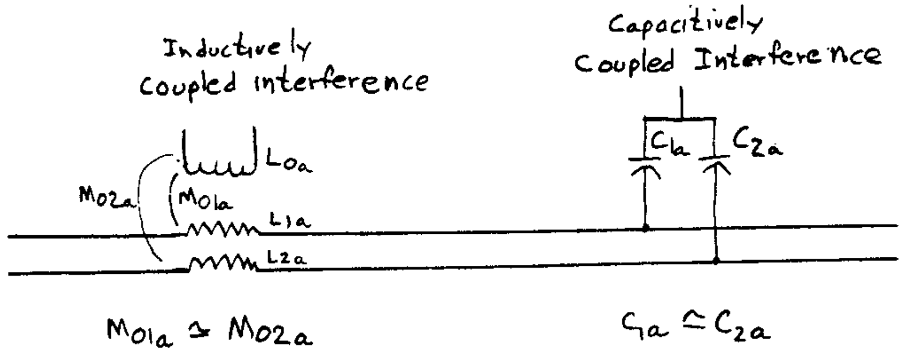
A shielded twisted pair cable is used in Figure 2f. This connection reduces the amplitude of capacitively coupled common mode interference on the twisted pair. Unfortunately, the shield is connected to ground at each end thus forming a ground loop. This ground loop can induce a portion of Vg into the twisted pair. While most of the induced voltage is common mode, some is differential due to variations in the cable.

In Figure 2g, the shield is connected only at the amplifier end. This removes the ground loop and maximizes the signal to interference ratio. Although seemingly excellent on paper, this approach will work very poorly if the interfering sources are of high amplitude. If the ground difference voltage, Vg, exceeds the common mode limits of the amplifier, then not only will the signal be interfered with but the amplifier could also be destroyed. This approach does not reduce the amplitude of inductively coupled common mode pickup on the twisted pair. It is not inconceivable that in some instances that inductive pickup could be so large as to cause problems.

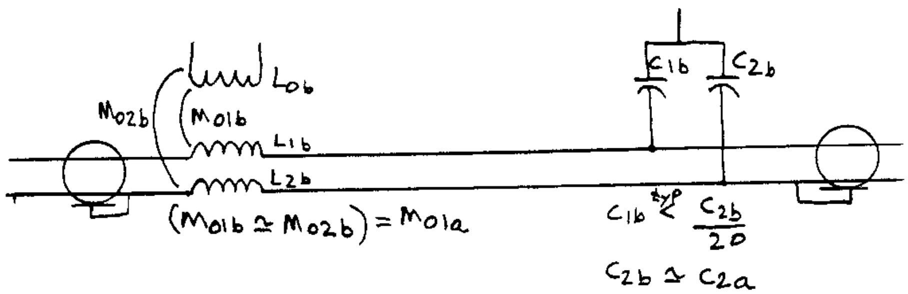
Conclusions

Transmitting a tiny signal in the presence of high amplitude interference is a challenge and takes considerable understanding and thought to properly address. Brute force methods such as using wide braid and other strapping only adds ground loops. It may magically help in some situations but is not the preferred approach.



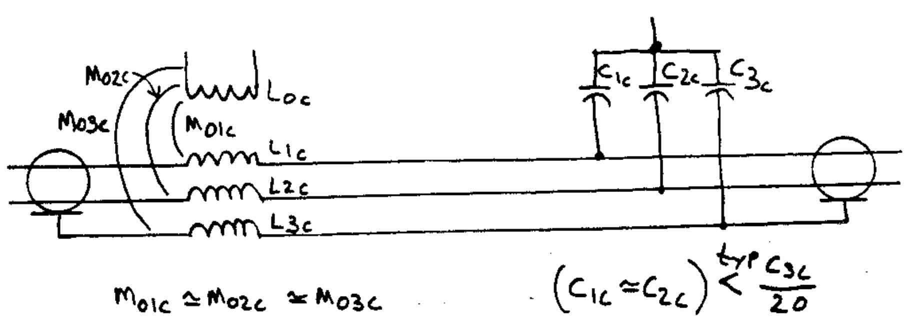
PARALEL OR TWISTED PAIR

Figure 1a



COAXIAL CABLE

Figure 1b



SHIELDED TWISTED PAIR

Figure 1c

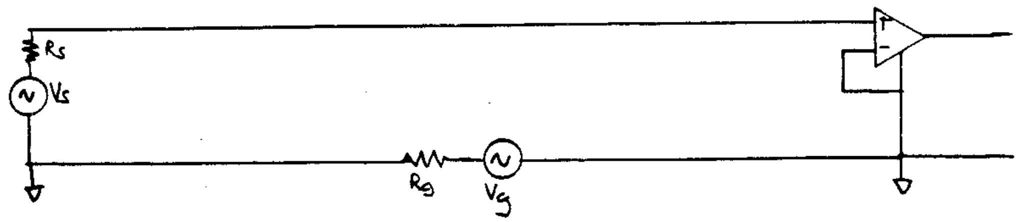


Figure 2a single-ended

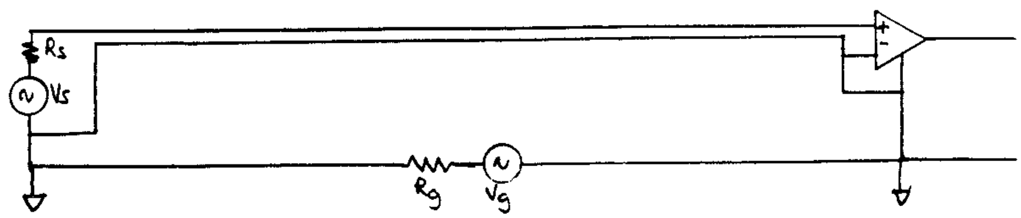


Figure 2b - ground loop

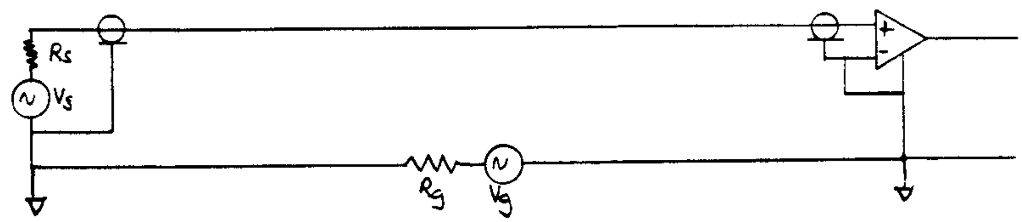


Figure 2c ground loop

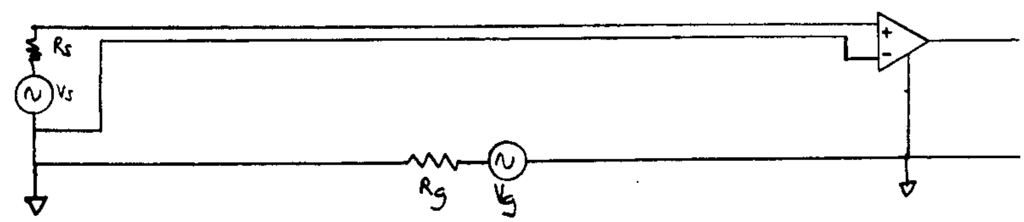


Figure 2d differential - twisted pair

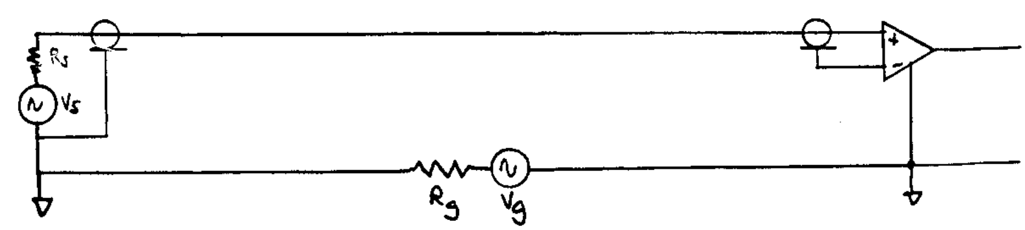


Figure 2e differential - coaxial

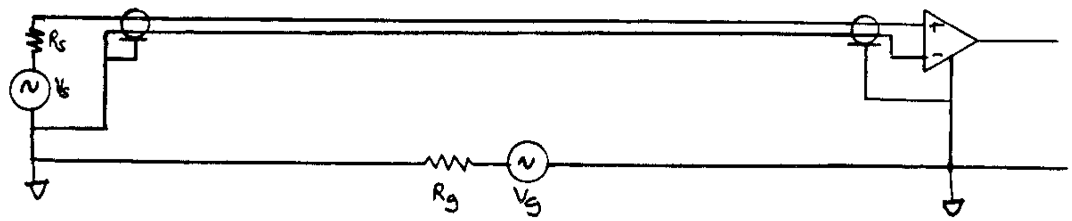


Figure 2f two conductor in shield - ground loop

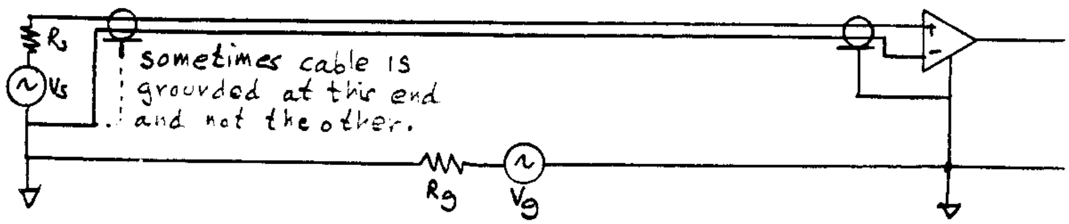


Figure 2g two conductor in shield