Chapter 8: Ground loops and opto-isolation

Overview

In a research laboratory, one of the main technical difficulties you will face as a physicist is eliminating or suppressing noise. This is particularly true when using analog circuit, but occasionally it can also be a problem with digital circuits. Frequently, ground loop noise will appear when you connect two separate and relatively noiseless circuits. In this chapter, we will explore the nature of such noise and ways to avoid it.

I. Ground loops

A ground loop occurs when several circuit elements which should be at ground (i.e. 0 Volts), but are not quite at ground, are connected. Generally, a ground is constructed by connecting a wire to a central point which is defined as the "official" ground. Unfortunately, all wires have some resistance which is generally fairly small, but which can produce a significant voltage drop if enough current is flowing. There are three common causes of ground loops:

1. Normal current produces unexpected voltage drop

If the ground wire is too thin or is poorly connected, then it will have a significant resistance. Any current flowing through the wire will produce a significant voltage drop across the wire, according the Ohm's law (V=IR). If this ground wire is connected to another ground wire (with or without the same problem), then since the two "ground" wires are not both at ground (0 V), then a current will flow between them and mimic a signal.

2. A time-varying magnetic field induces a current in a looped ground wire

A time-varying magnetic field cannot induce a current or voltage between the outer conductor and the central conductor of a coaxial cable (and with difficulty between the conductors of a twisted pair). However, a current can be induced along the ground shield of a coaxial cable if the cable forms a loop. Generally, this current can be ignored, since the inner conductor will have the same current (and cancel it), but if the ground has finite resistance, then a voltage difference will be produced which will mimic a signal.

3. Technical noise (at some specific frequency) that you don't understand

Frequently, researchers will accuse a ground loop for any technical noise (at specific frequency) that they don't understand and are having trouble eliminating.

One of the most common ground loops (type 1) is between two pieces of relatively noiseless equipment that are connected to two different electrical outlets that do not share the same ground (i.e. the third pins on the two plugs are only remotely connected through the electrical grid). Separately, the two pieces of equipment work fine, but when you connect them you develop a ground loop. Most ground loops are at 60 Hz, but they can also show up in the kHz and MHz ranges. At high frequencies, circuits and instruments whose grounds are not physically connected by a wire can still be grounded together by stray capacitive or inductive coupling.

Here are some tips to help you minimize ground loops and their effects:

a. Star configuration for ground
You should connect all your instruments to the same set of power receptacles and avoid making a daisy chain of power bars and extension cords. As much as possible, all the power for your instruments should come from a central point.

b. Multi-conductor ground wire
Since the voltage drop in a ground loop depends on the resistance of wires involved, you should try to make their resistance as small as possible. This means that the cross-section of the ground wire should be a large as possible. Since at high frequencies, most of the current travels close to the surface of a wire (i.e. skin effect), you should also maximize the surface area of your ground wire by using stranded, multi-conductor wire.

c. Determine the ground layout in your lab
You should identify which power sockets in your work environment are connected to a common ground. The electronics lab, Small Hall room 148, has at least two separate grounds which differ by a several tens of volts. You should only connect instruments which share a common ground.

d. Disconnected ground
When connecting two instruments, you should consider disconnecting the ground on the power cord, so that only one instrument defines the ground – the ground of the "ungrounded" instrument is defined by the coaxial cable shield connecting the two instruments. Alternatively, you can connect the cable shield to only one of the instruments – this frequently done with tri-axial cable (twisted pair inside a coaxial cable.

e. Amplify your signal
If you cannot eliminate your ground loop, you can amplify your signal enough that the ground loop noise contribution to it becomes negligible.

f. Digital transmission
Digital signals are much less prone to ground loop noise, so you should consider sending your signal digitally. However, the clock signal timing of a digital signal can be affected by ground loop noise.

g. Debugging tip: use a multimeter or a floating oscilloscope
Finding the source of your ground loop noise can be very difficult (days can spent searching). The difficulty of this task is compounded by the fact that oscilloscopes are always grounded to some degree (even if you do not connect the ground pin on the power cord). This means that by attaching the oscilloscope to your multi instrument

circuit, you are actually changing the current path of the ground loop noise. Instead, you should either use a multimeter (it does not have its own ground since it runs on batteries) or use a floating oscilloscope that truly is not connected to the grounds of your circuit. You can float an oscilloscope by using an isolation transformer or, even better, a UPS battery back-up supply. In fact you can also float some of the instruments participating in your apparatus with battery power.

h. The cure-all: opto-isolators

If you must absolutely eliminate all ground loop noise, then you should consider using opto-isolators to connect several separate instruments and circuits together.

II. Opto-isolators

Opto-isolators are integrated circuits for transmitting signals and information between two separate circuits without ever connecting them electrically. As their name implies, opto-isolators transmit signals between two circuits with light. An LED converts the electrical signal to light, while a photo-detector with separate power and ground converts the light signal back into an electrical signal. Opto-isolators are primarily used for transmitting digital signals, but they are also available for analog signals.

The popular 6N137 digital opto-coupler can transmit data at a rate of 10 Mbits/s, though speeds of up to 50 Mbits/s are now possible with more recent opto-couplers. On the analog side, the ISO100 optical isolation amplifier by Burr-Brown (now Texas Instruments) has a bandwidth of 60 kHz, though the more recent HCNR200 opto-isolator by Avago technologies (formerly Hewlett-Packard and Agilent) boasts a bandwidth of 1 MHz.

Opto-isolators are useful for eliminating ground loop noise, but are also used to connect devices that operate at vastly different voltages. For example, opto-isolators are used to exchange data with a device that is floated to several thousands volts as is frequently the case in particle accelerators. Also, medical instruments which connect to humans must be isolated from the wall power by mandatory isolation circuits.

There exist other isolation technologies, such as transformer isolation and capacitive isolation, but these do not isolate as well as opto-isolators, since electrical noise can still get through a capacitor or a transformer. Light conversion can potentially provide total isolation between two circuits because there is no capacitive or inductive coupling at optical frequencies.