Ground Loop Noise
and
Opto-Isolation

Outline

1. Ground Loops

2. Opto-Isolators

3. Mixed signal circuits: separating analog and digital circuitry.

Ground Loops

A ground loop occurs when two ground wires that are not quite at ground (0 Volts) are connected and a current flows between them. This current can produce a false signal.

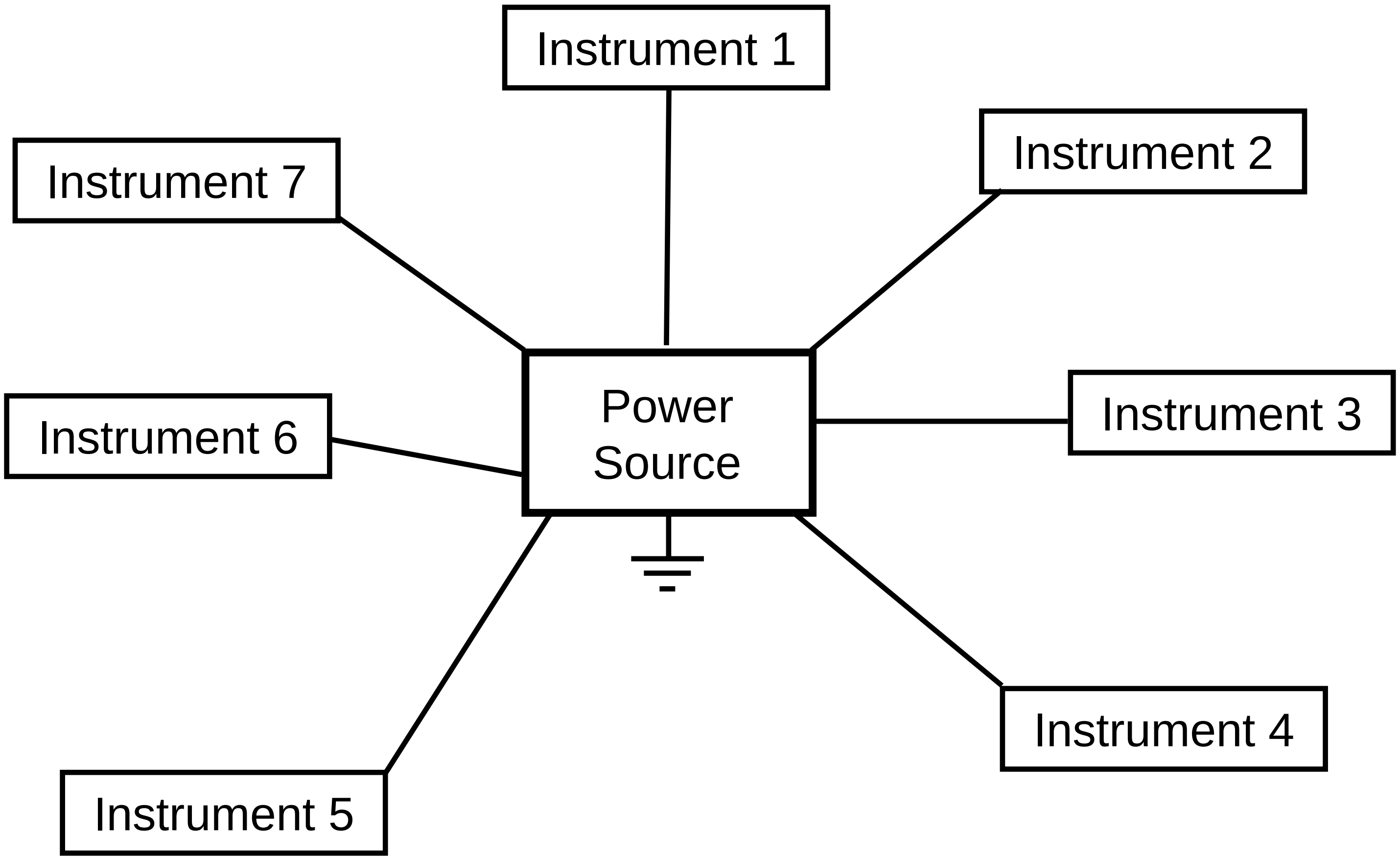
→ Most ground loop noise is at 60 Hz, but you also can get ground loops in the kHz and MHz ranges as well.

→ Ground loops are frequently observed when connecting two or more noise-free instruments.

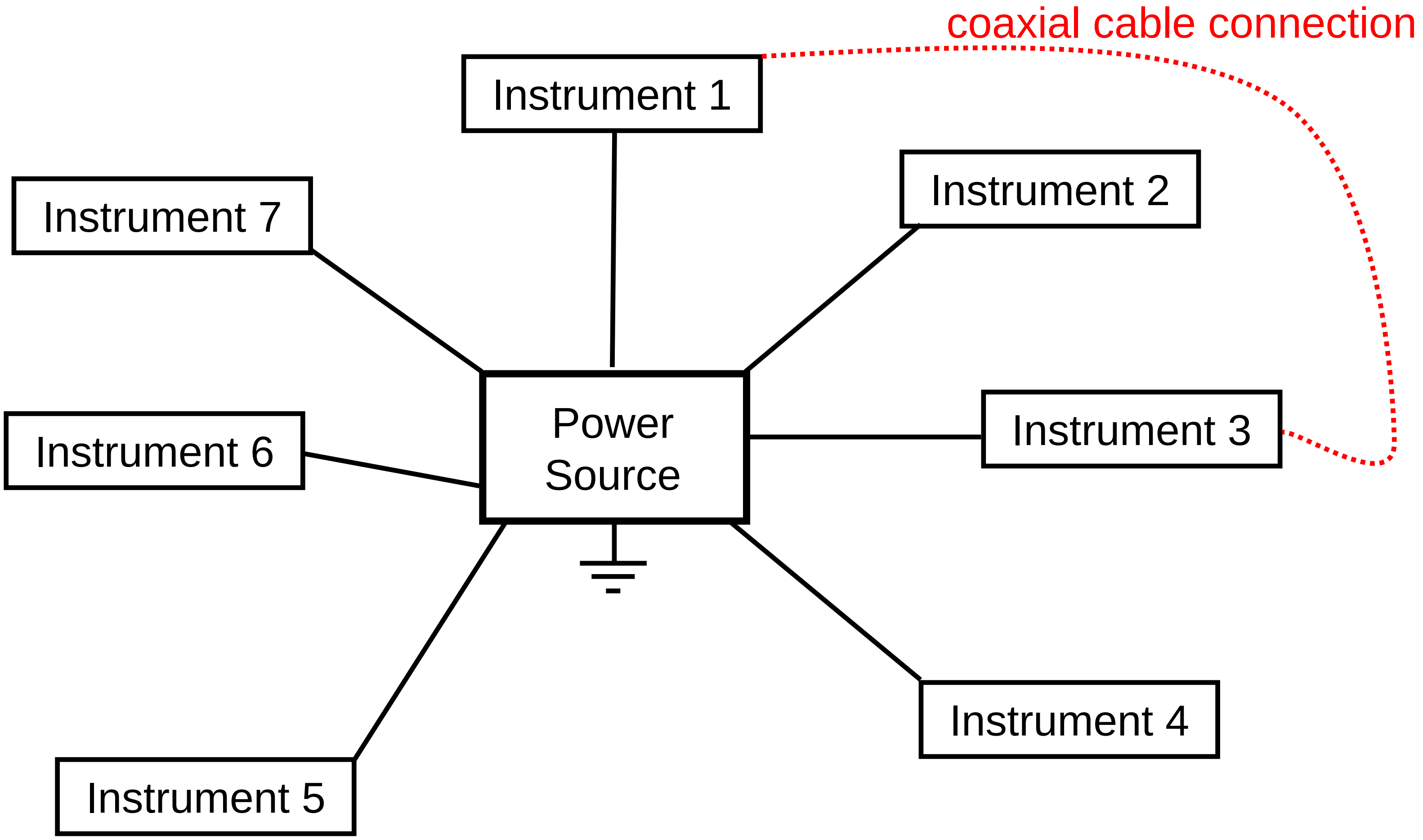
Causes:

1. Normal current in ground wires that are too thin produces a small but non-negligible voltage drop.
2. Magnetically induced currents in a ground wires with small but finite resistance.
3. Any noise at a specific frequency that is not understood is frequently relegated to "ground loop noise" status.

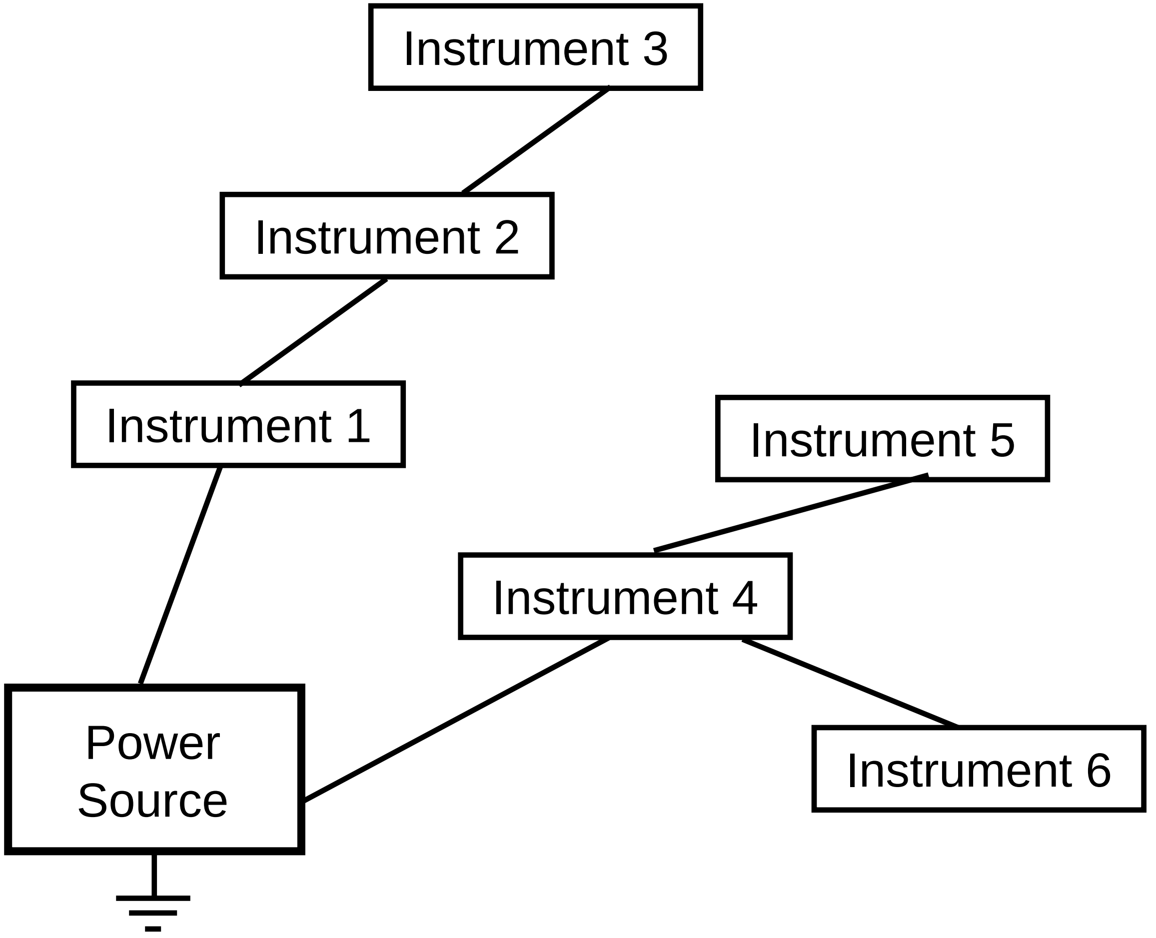
"Good" Grounding: Star Configuration



"Good" Grounding: Star Configuration



Bad ground architecture



Troubleshooting a ground loop

Generally hard, time consuming, frustrating, and you may start to doubt the laws of physics and causality.

Make sure that you use a floating oscilloscope for troubleshooting:

- Oscilloscope should not be grounded.

- Ideally, oscilloscope should be run off of a battery for guaranteed isolation.

Stranded Ground Wiring

→ Large cross-section reduces resistance of wire.

→ Multi-conductor stranded wire keeps resistance low at high frequencies (i.e. AC skin effect).

→ Tightly braided design means that the assembly can be used as a ground shield (like in a coaxial cable).

High Frequency Ground Loops

In practice, most ground loops are at 60 Hz, but at high frequencies they are also fairly easy to make, due to induced voltages and the AC skin effect:

Induced voltage is larger at high frequencies:

$$\Delta V_{induced} = -\frac{d}{dt}\phi = -\frac{d}{dt}\vec{B}\cdot\vec{A} = i\omega\,\vec{B}\cdot\vec{A}$$

→ this is why twisted pair or coaxial cable should be used whenever possible.

AC skin effect: Current flows at the edges of a wire in a region with a characteristic length scale of

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$, with ρ = resistivity and μ = magnetic permeability

60 Hz: δ = 8.5 mm; 1 kHz: δ = 2.1 mm; 10 kHz: 0.65 mm; 100 kHz: δ = 0.2 mm

1 MHz: δ = 65 μm; 10 MHz: δ = 21 μm; 100 MHz: δ = 6.6 μm; 1 GHz: δ = 2.1 μm

Know the Ground Layout in your Lab

Unfortunately, most buildings and labs have multiple ground networks (i.e. the wiring that is connected to the third pin on a power cord connector).

→ Never (ever) connect instruments that are on different ground networks. You are guaranteed to get ***ground loop noise***.

→ This is the most common source of ground loop noise.

For example, the electronics lab (Small Hall, room 148) has at least two ground networks

Use only one Ground

Disconnect the ground pin on some of the power cords of your instruments, so that only one instrument defines the ground for your multi-instrument circuit.

Amplify your Signal

If you can’t get rid of your ground loop noise, you can try to drown it out to a relative negligible level by amplifying your signal before sending it to another instrument.

Battery Power

If you power your circuits with batteries then it is easier to define ground yourself without worrying about the grounding network in your lab.

Go Digital

Digital signals are inherently less prone to noise than analog signals.

Grounding Examples (I)

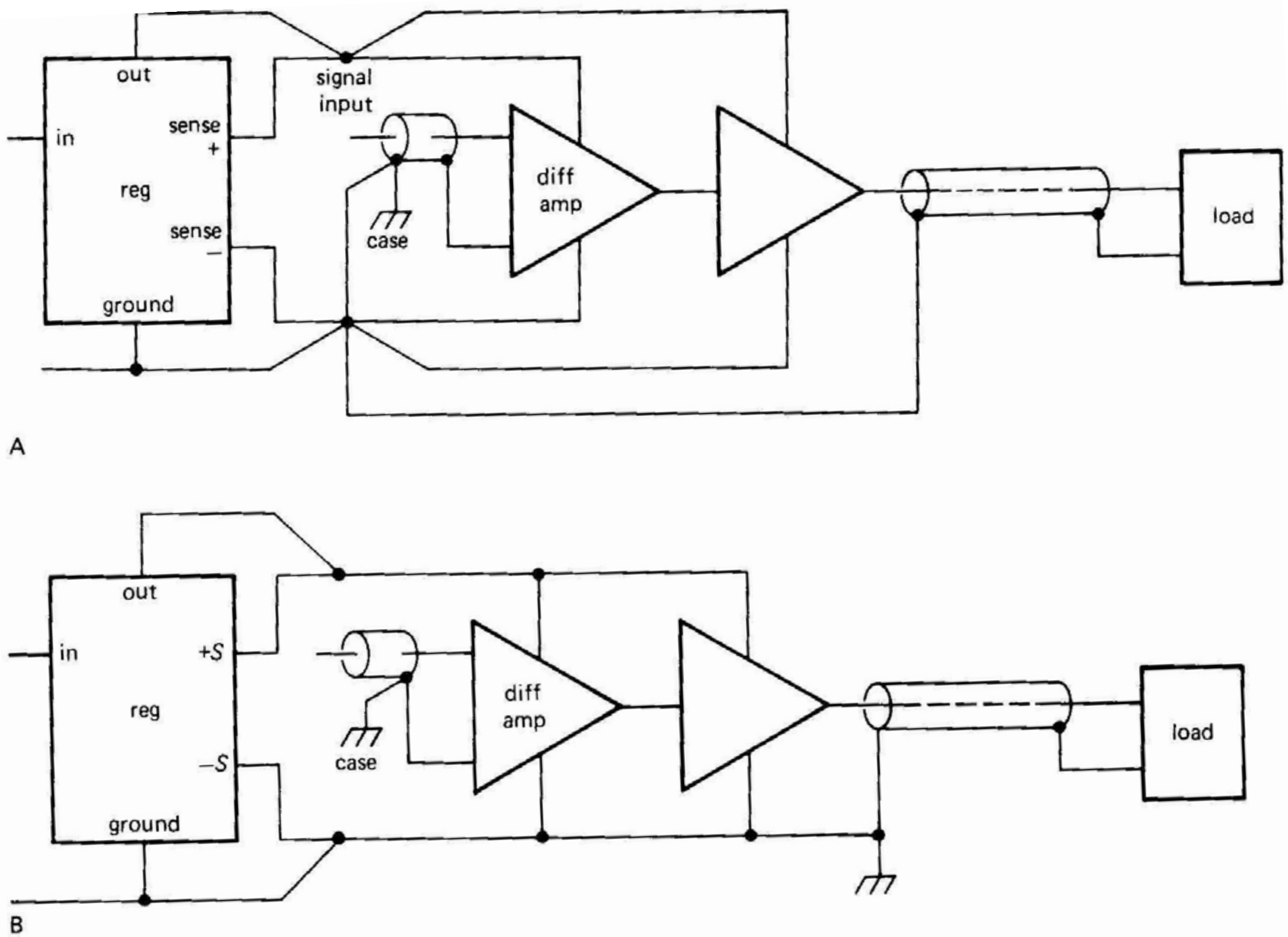


Figure 7.67. Ground paths for low-level signals.
A. Right
B. Wrong

[Figure from Horowitz and Hill, *The Art of Electronics*, p. 458]

Grounding Examples (II)

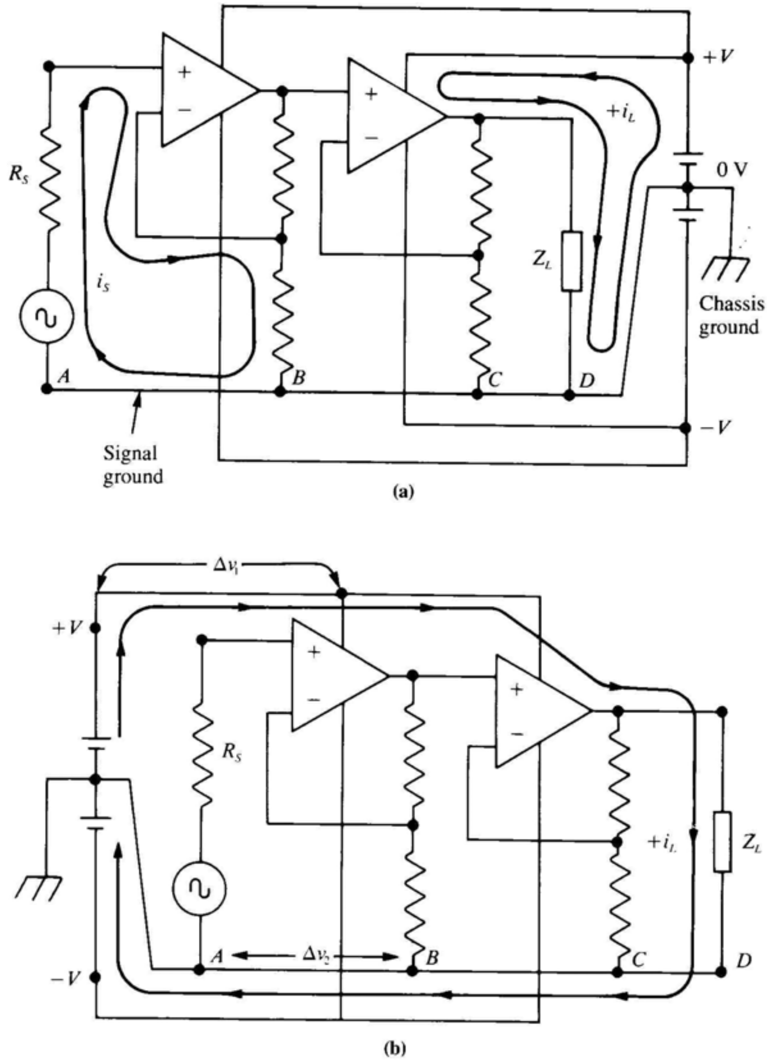


Figure 11.23 Proper attention to the high-current paths points up the difference between (a) good and (b) bad grounding techniques.

[Figure from Fortney, *Principles of Electronics*, p. 497]

Overkill Solution: Opto-Isolators

Opto-isolators are integrated circuits that transmit a signal between two devices by converting the electrical signal to a light signal and then back to an electrical signal.

The two sides of an opto-isolator are not electrically connected, thus providing perfect isolation, in principle.

Opto-isolation will get rid of almost any ground loop problem and is also useful for eliminating the possibility of ground loop noise.

Opto-Isolation Amplifier

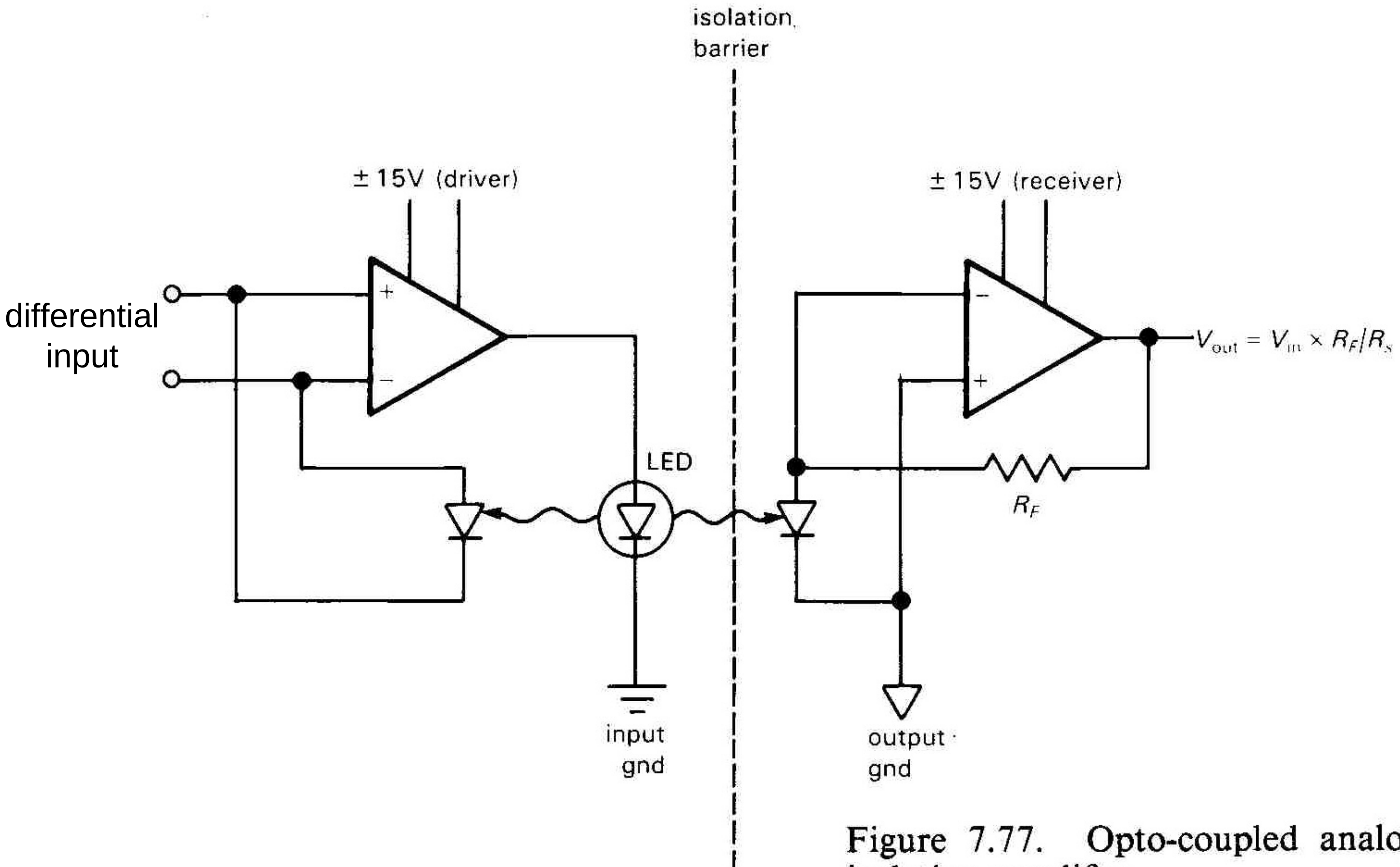


Figure 7.77. Opto-coupled analog isolation amplifier.

[Figure from Horowitz and Hill, *The Art of Electronics*, p. 463]

Opto-Isolation Amplifier

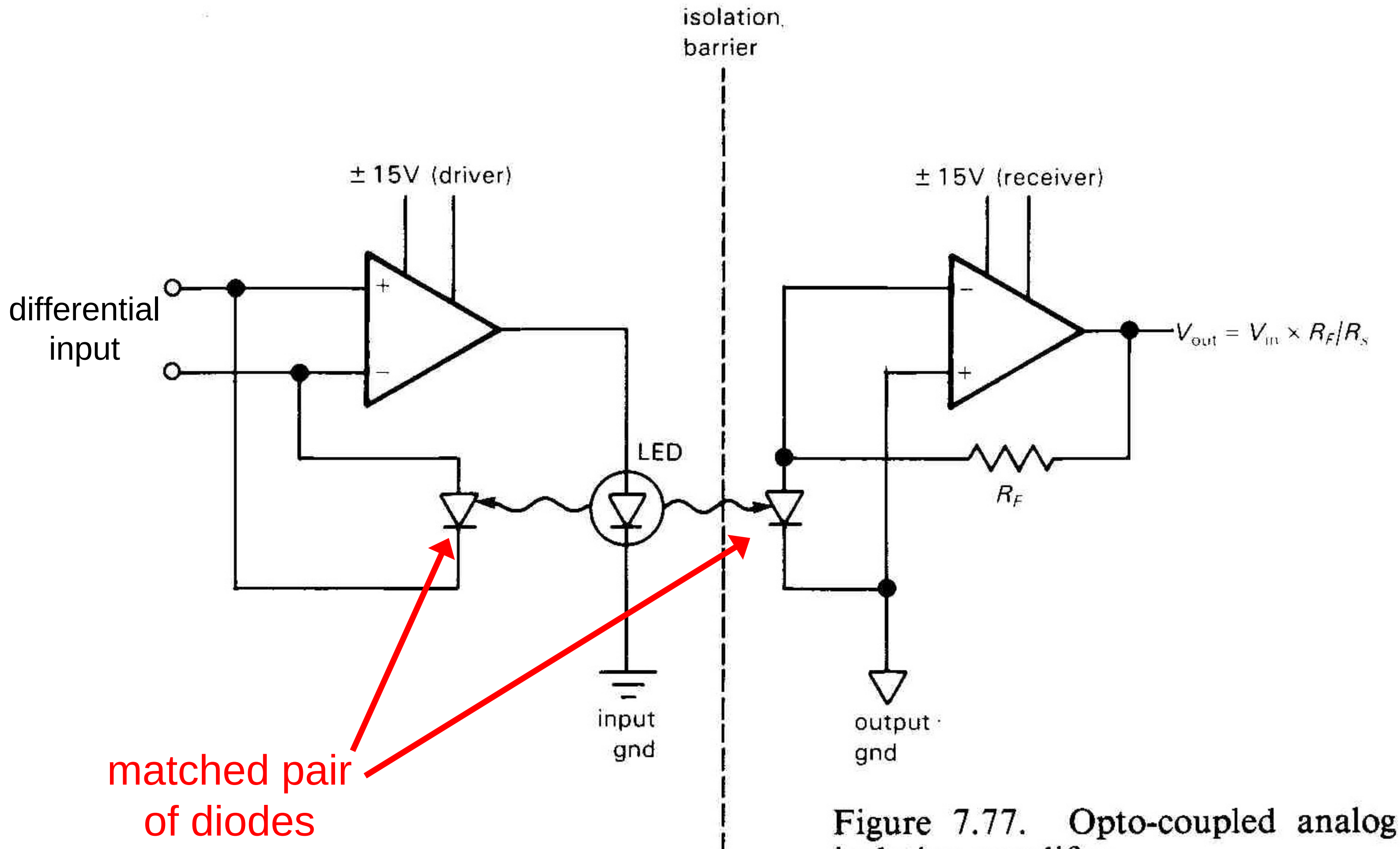
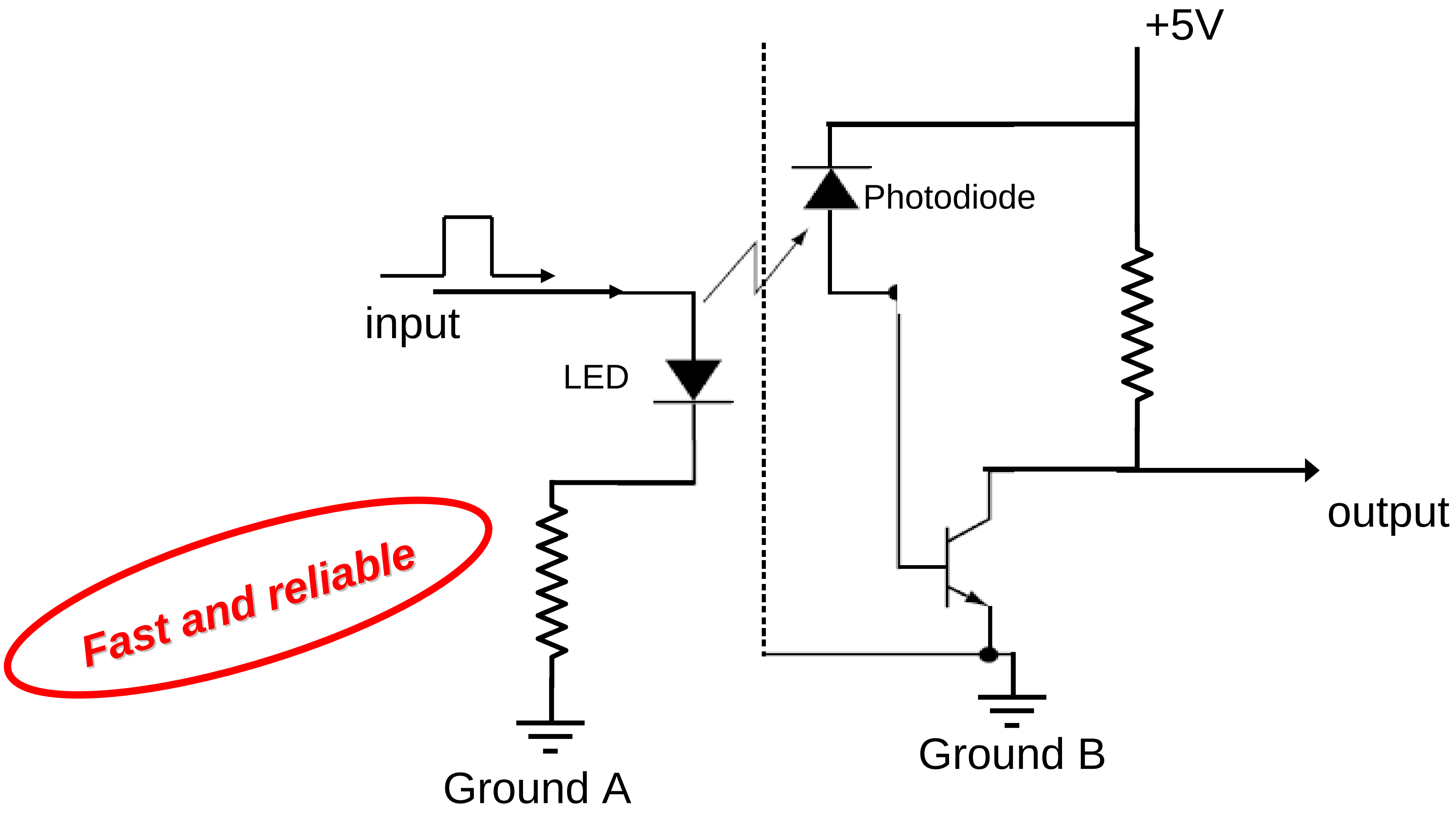


Figure 7.77. Opto-coupled analog isolation amplifier.

[Figure from Horowitz and Hill, *The Art of Electronics*, p. 463]

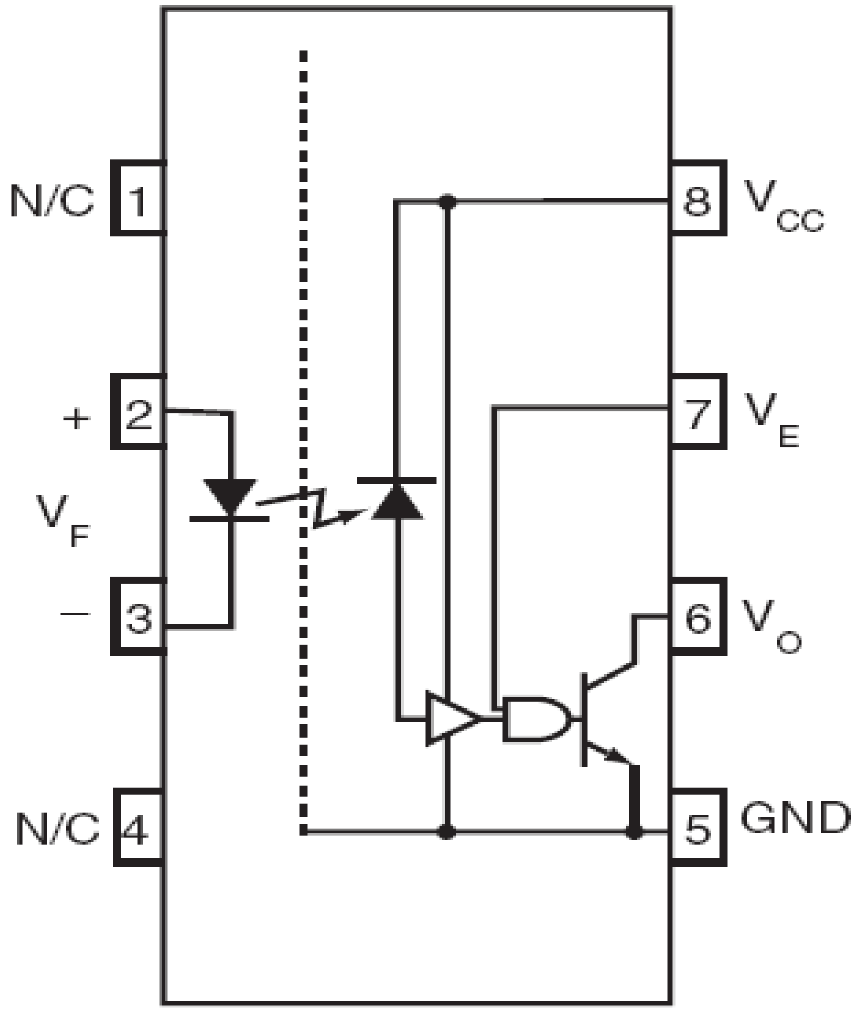
Digital Opto-Couplers (I)



[figure adapted from the Fairchild 6N135 datasheet]

Digital Opto-Couplers (II)

10-50 Mbits/s



[figure from the Fairchild 6N137 datasheet

Mixed Signal Circuits

Here are a few design tips for producing circuits which include both digital and analog components:

- Keep **analog** and **digital** circuitry as far **apart** as reasonable.

- Use **separate grounds** for analog and digital circuitry (i.e. make a double star configuration … you will have to connect the two ground together at some point though).

- Use **separate regulators** to power analog and digital circuitry.

- Generally, **digital circuitry will produce noise** in an analog circuit, but not vice-versa.

- **Use 100 nF bypass capacitors on all power connections of chips.**

- Use large ground wires.