Xi'an Jiaotong-Liverpool University
西交利物浦大学

EEE220 Instrumentation and Control System

2018-19 Semester 2

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Lecture 6

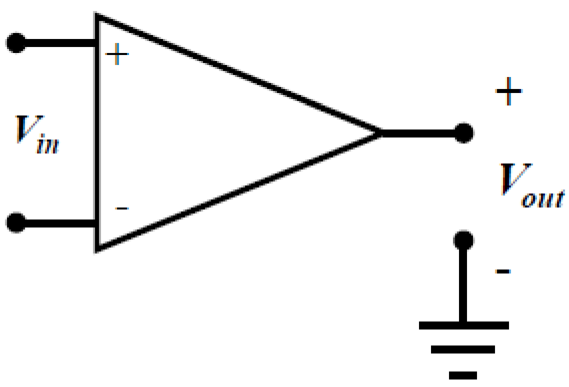
Outline

Signal Conditioning

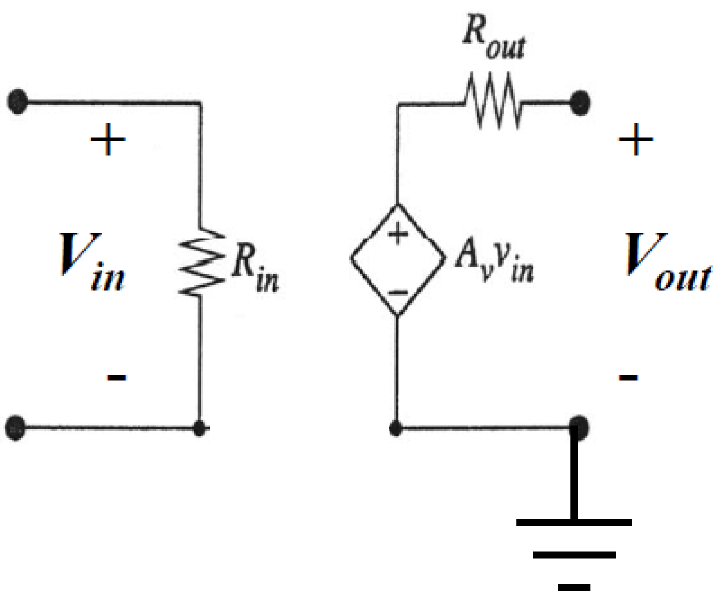
- ❑ **Amplifiers**
- ❑ **Interference and Noise**

The Operational Amplifier (Op-Amp)

Circuit Symbol



Model

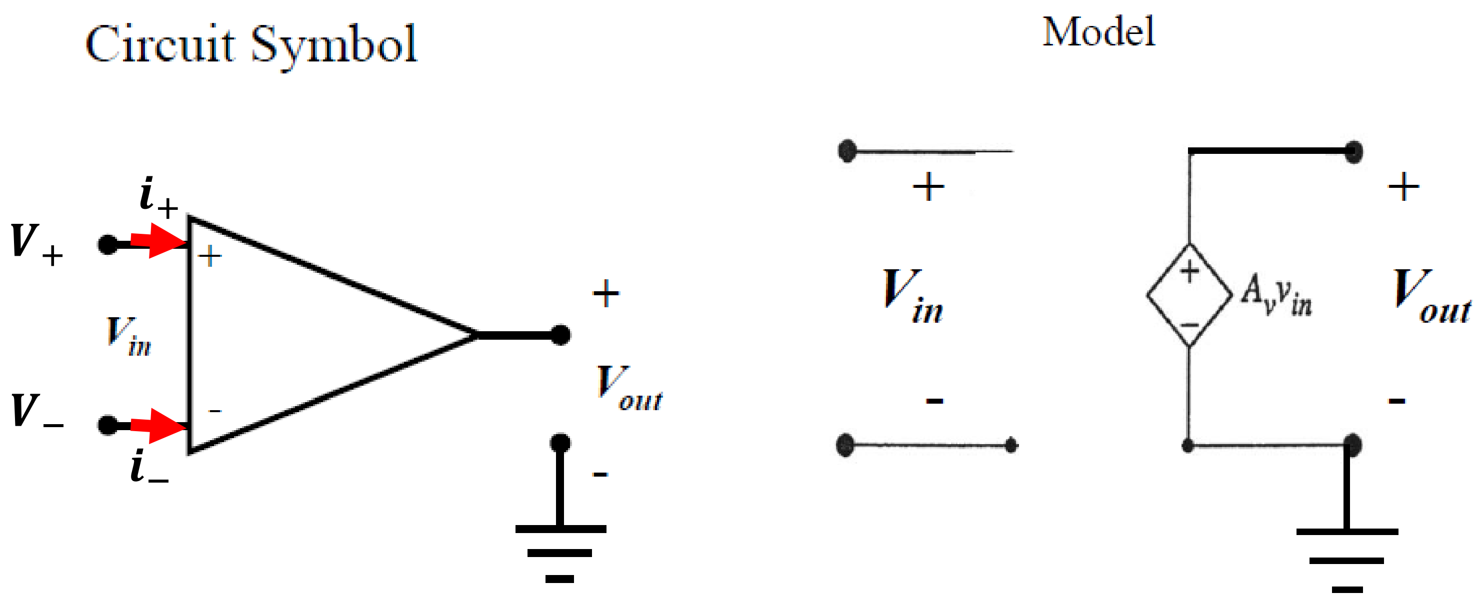


Ideal Operational Amplifier

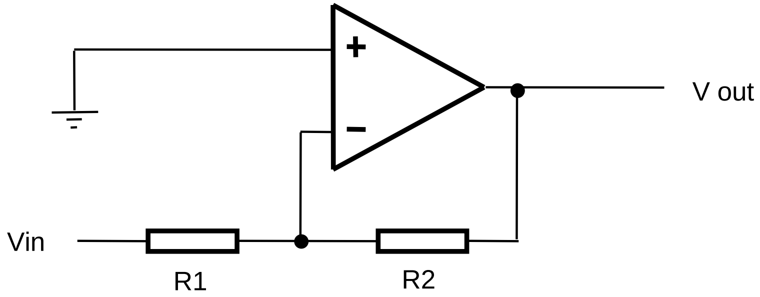
- R_{in} = Infinity;
- Voltage Gain: A_v=Infinity at all frequencies;
- $R_{out} = 0$;
- $i_+ = i_- = 0$;
- $V_+ = V_-$.

Infinite gain means that the device is useless without adding "Feedback" to control the overall gain to a finite value.

$$\boxed{\boldsymbol{V_{out} = A_v(V_+ - V_-)}}$$



Inverting Amplifier



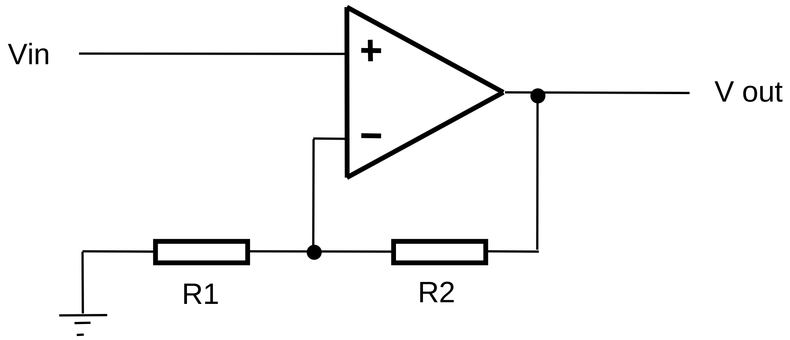
Voltage gain $= -\dfrac{R_2}{R_1}$

$$\frac{V_{out} - V_-}{R_2} = \frac{V_- - V_{in}}{R_1}$$

$$V_- = V_+ = 0$$

$$\frac{V_{out}}{V_{in}} = -\frac{R2}{R1}$$

Non-inverting Amplifier

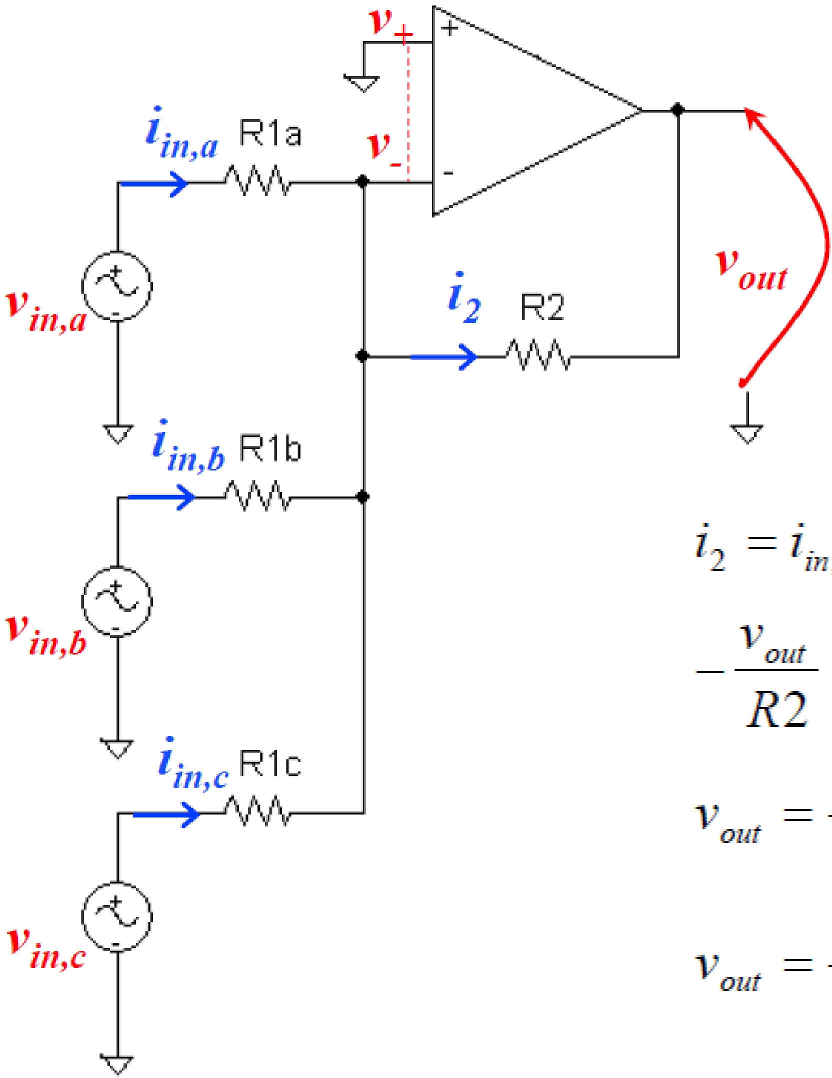


Voltage gain $= 1 + \dfrac{R_2}{R_1}$

$$\left.\begin{array}{c} \dfrac{V_{out} - V_-}{R_2} = \dfrac{V_- - 0}{R_1} \\[2em] V_- = V_+ = V_{in} \end{array}\right\}$$

$$\frac{V_{out}}{V_{in}} = \frac{R1 + R2}{R1}$$

Summing Amplifier



- Output is a scaled sum of inputs.
- Scaling can be controlled by ratios of resistors.

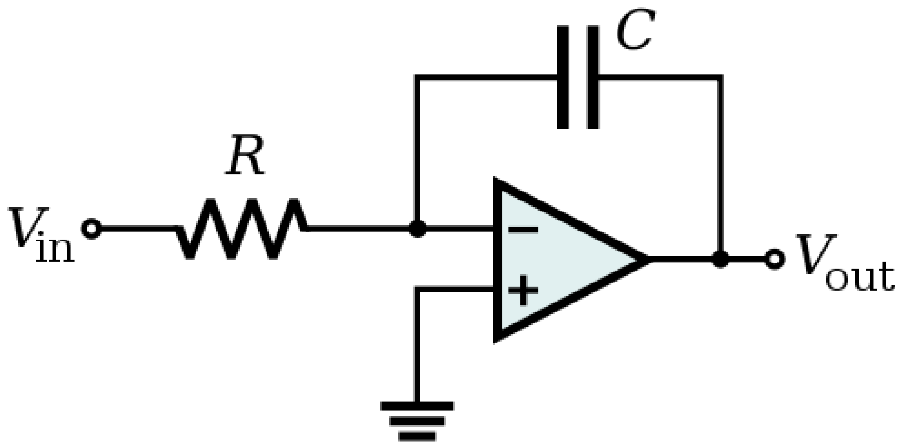
$$i_2 = i_{in,a} + i_{in,b} + i_{in,c}$$

$$-\frac{v_{out}}{R2} = \frac{v_{in,a}}{R1a} + \frac{v_{in,b}}{R1b} + \frac{v_{in,c}}{R1c}$$

$$v_{out} = -v_{in,a}\frac{R2}{R1a} - v_{in,b}\frac{R2}{R1b} - v_{in,c}\frac{R2}{R1c}$$

$$v_{out} = -\left(v_{in,a}\frac{R2}{R1a} + v_{in,b}\frac{R2}{R1b} + v_{in,c}\frac{R2}{R1c}\right)$$

Integrating Amplifier

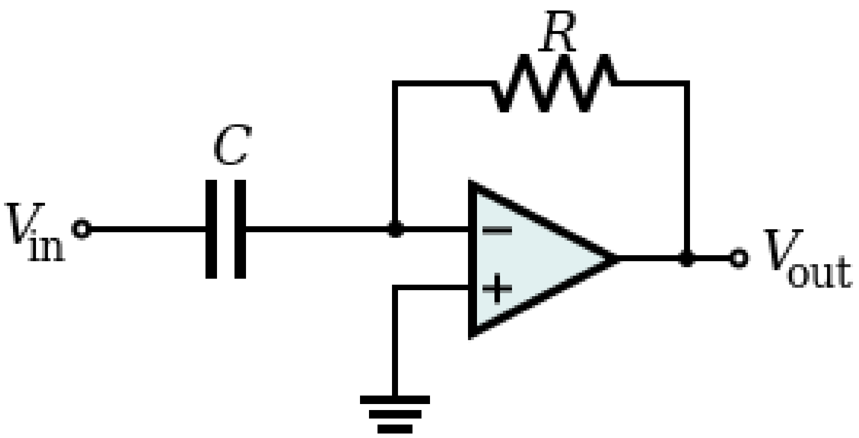


$$\frac{V_{in}-0}{R}=C\frac{d(0-V_{out})}{dt}=-C\frac{dV_{out}}{dt}$$

$$dV_{out}=-\frac{1}{RC}V_{in}\mathrm{dt}$$

$$V_{out}(t_2)-V_{out}(t_1)=-\frac{1}{RC}\int_{t_1}^{t_2}V_{in}\mathrm{dt}$$

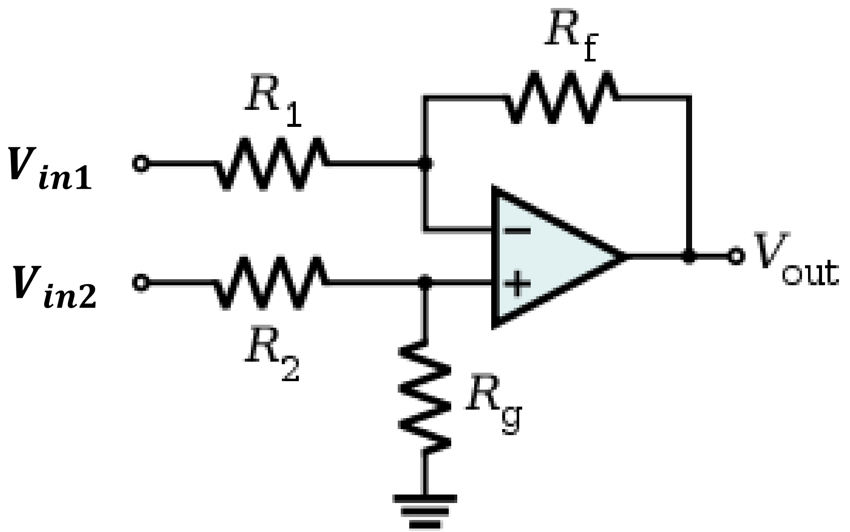
Differentiating Amplifier



$$\frac{V_{out} - 0}{R} = C\frac{d(0 - V_{in})}{dt} = -C\frac{dV_{in}}{dt}$$

$$V_{out} = -RC\frac{dV_{in}}{dt}$$

Difference Amplifier



$$\frac{V_{out} - V_-}{R_f} = \frac{V_- - V_{in1}}{R_1}$$

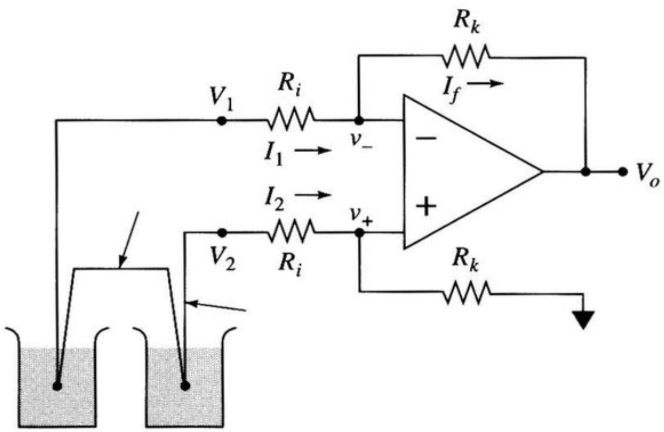
$$V_- = V_+ = V_{in2}\frac{R_g}{R_2 + R_g}$$

assume: $$\frac{R_1}{R_f} = \frac{R_2}{R_g}$$

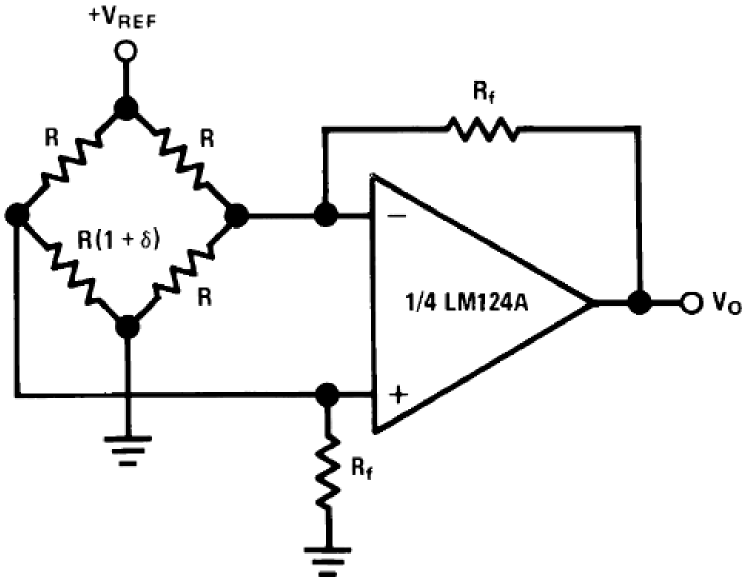
$$V_{out} = \frac{R_f}{R_1}(V_{in2} - V_{in1})$$

Typical Applications of Difference Amplifiers

- ❑ **Thermocouple**



- ❑ **Wheatstone Bridge**

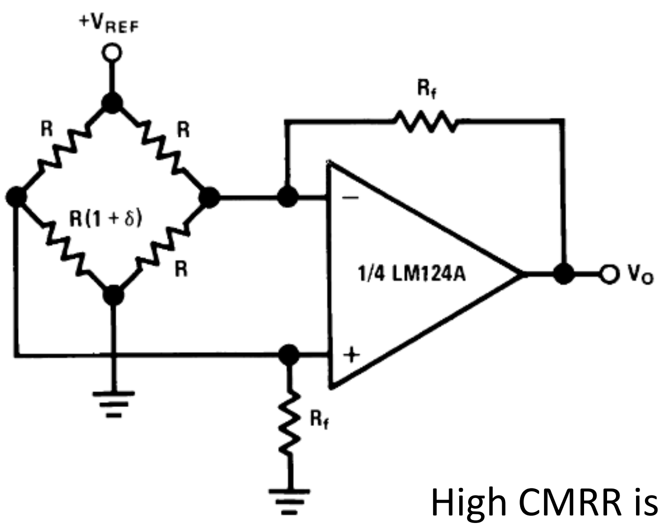


Common Mode Rejection Ratio (CMRR)

- The original voltage which is common to both inputs is termed:

Common Mode Voltage (V_{CM})

- Ideally, difference amplifier will only amplify the potential difference between two output terminals of bridge circuit;
- In practice, since the two input channels of the amplifier cannot be perfectly matched, V_{CM} will also be amplified. Thus, amplifier output voltage will not be perfectly proportional to the difference of two inputs.



$$V_{out} = G_d \Delta V + G_{CM} V_{CM}$$

where G_d is the gain for the voltage difference ΔV, G_{CM} is the gain for V_{CM}

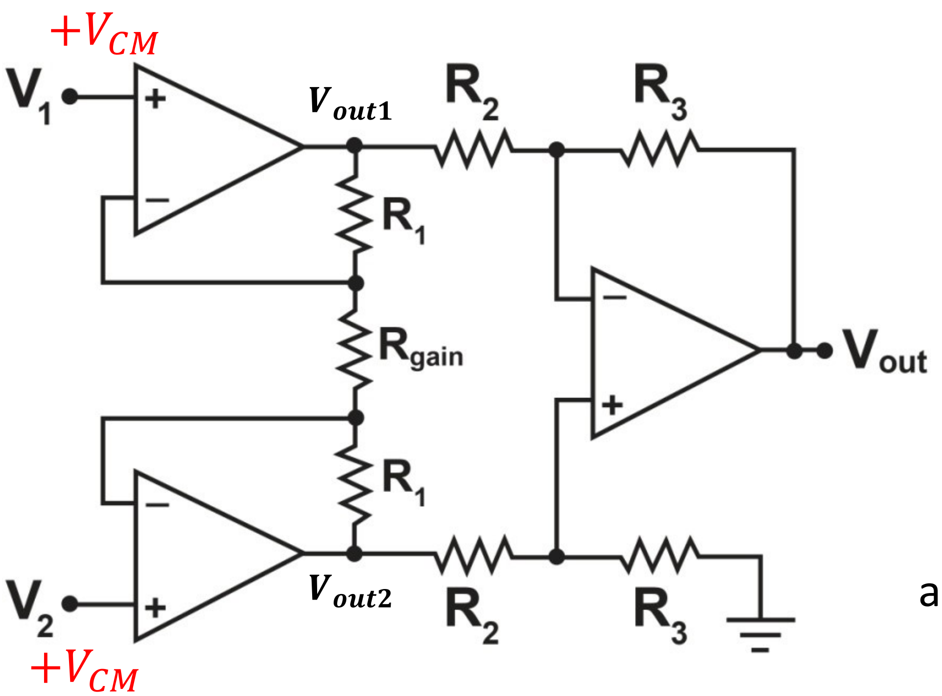
Common Mode Rejection Ratio (CMRR):

$$CMRR = 20\lg(\frac{G_d}{G_{CM}})$$

High CMRR is required, CMRR for a typical op-amp is about 80~100 dB.

How to Improve CMRR?

Instrumentation Amplifier



$$V_{out} = \frac{R_3}{R_2}(V_{out2} - V_{out1})$$

$$\frac{V_{out2} - V_{out1}}{2R_1 + R_{gain}} = \frac{V_2 - V_1}{R_{gain}}$$

$$\downarrow$$

$$V_{out} = \frac{R_3}{R_2}\frac{2R_1 + R_{gain}}{R_{gain}}(V_2 - V_1)$$

assume: $R_3 = R_2$

$$V_{out} = (1 + \frac{2R_1}{R_{gain}})(V_2 - V_1)$$

Normally, amplification gain is adjusted by adjusting R_{gain}.

- V_{CM} effects are reduced, CMRR ↑
- Provides high input impedance.

Interference and Noise

Transducers often produce only small amplitude signals that have to be connected to a display device some distance away from the point of measurement. This must be done with care to avoid 'picking up' unwanted noise signal (interference and natural noise) that can corrupt or obscure the required signal.

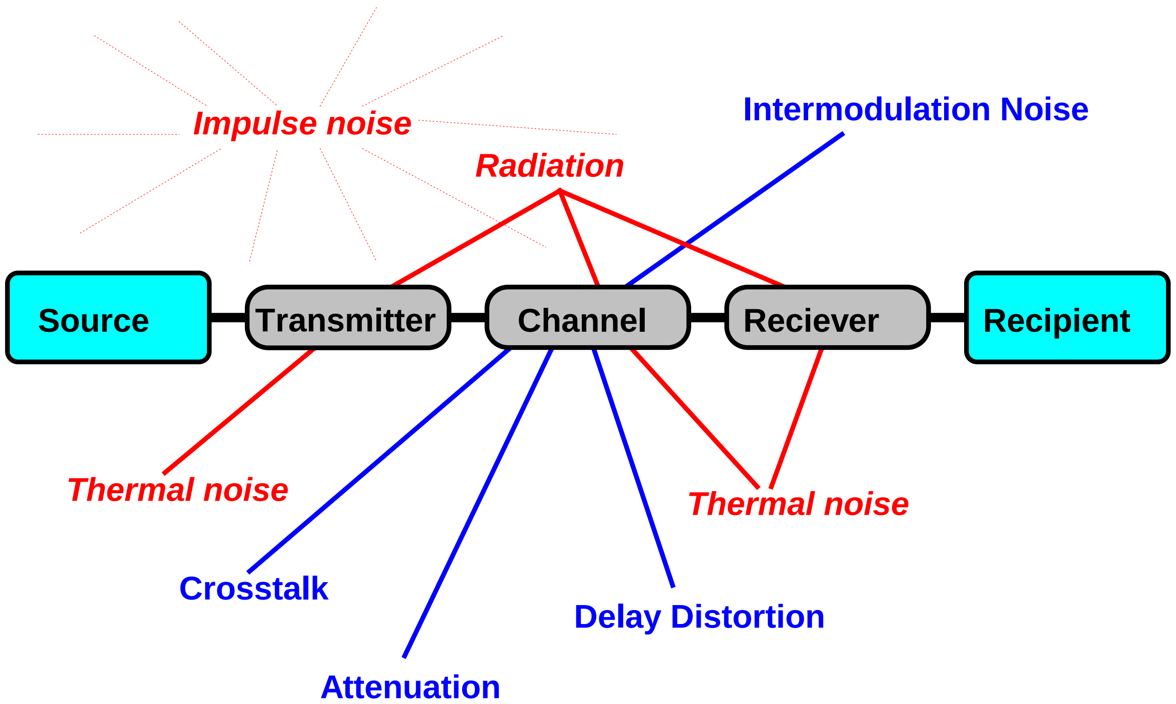
Signal-to-Noise Ratio:
SNR = Signal Power / Noise Power

It is better to prevent the noise being picked up than to try to eliminate it afterwards.

Signal processing techniques can be used to effectively to improve SNR:

- i.e., <u>signal averaging</u> is particularly useful when the required signal occupies a range of frequencies, but it works only if the noise is uncorrelated with the required signal.

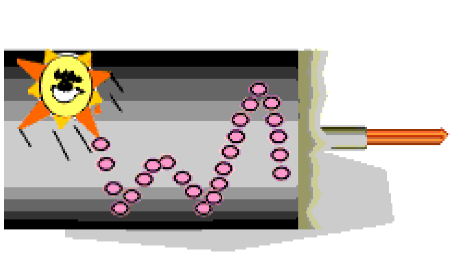
Sources of Noise

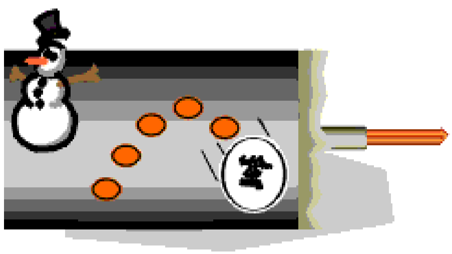


- Unwanted electric signals come from a variety of sources, generally classified as either human interference or naturally occurring noise.
- Noise (unlike distortion) is not correlated with the desired signal.
- Human interference: other electrical apparatus, channel crosstalk etc.
- Natural noise: atmospheric disturbance, extra-terrestrial radiation, random electron motion etc.

Thermal Noise

- Thermal noise is the noise produced by the random motion of charged particles (usually electrons) in conducting media.
- Thermal noise *can be reduced* by cooling the noise source (being applied in some radio receivers using cryogenic coolers, to improve the receiver sensitivity)
- *Cannot be eliminated.*



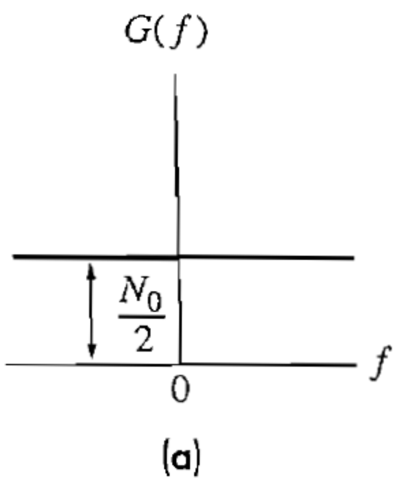


❖ Generally thermal noise can be modeled as a zero mean Gaussian WSS (wide-sense stationary) random process.

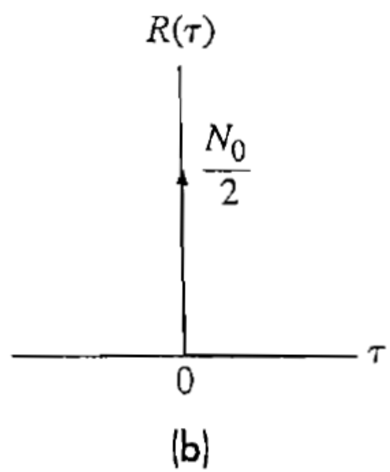
❖ The noise is called **White Noise** since all frequency components appear with equal power (white is used in white light for a similar reason).

Power Spectral Density (PSD) of White Noise

Power Spectrum



Autocorrelation function



$$G(f) = \frac{N_0}{2} \qquad \text{watts/Hz}$$

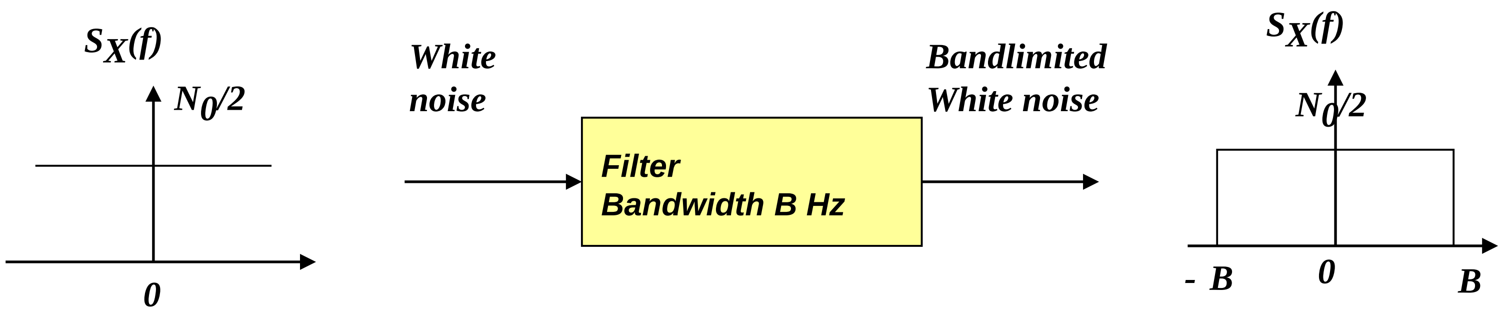
$$R(\tau) = \frac{N_0}{2}\delta(t)$$

$$\boxed{N_0 = KT \ \ (\text{watts/Hz})}$$

T=temperature of the resistor in Kelvins ($^oK=273+^oC$)
K=Boltzmann's constant $1.38\text{x}10^{-23}$ joules/K

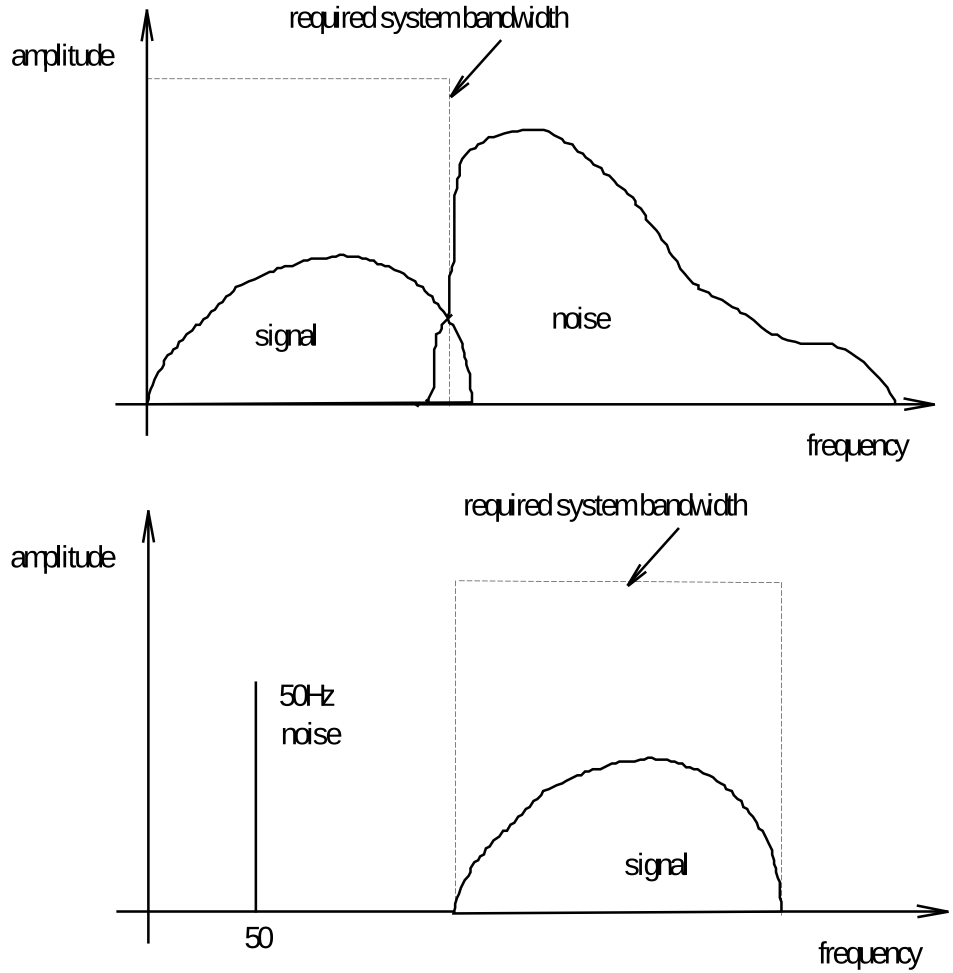
❖ It can be seen that $R(\tau)$ = 0 for $\tau \neq 0$, so any two different samples of a Gaussian white noise signal are uncorrelated and hence statistically independent.

- In baseband communication, we pass our message signals through a low-pass filter. The resultant noise is said to be bandlimited:



- The power of the bandlimited noise is ***N_0B.***

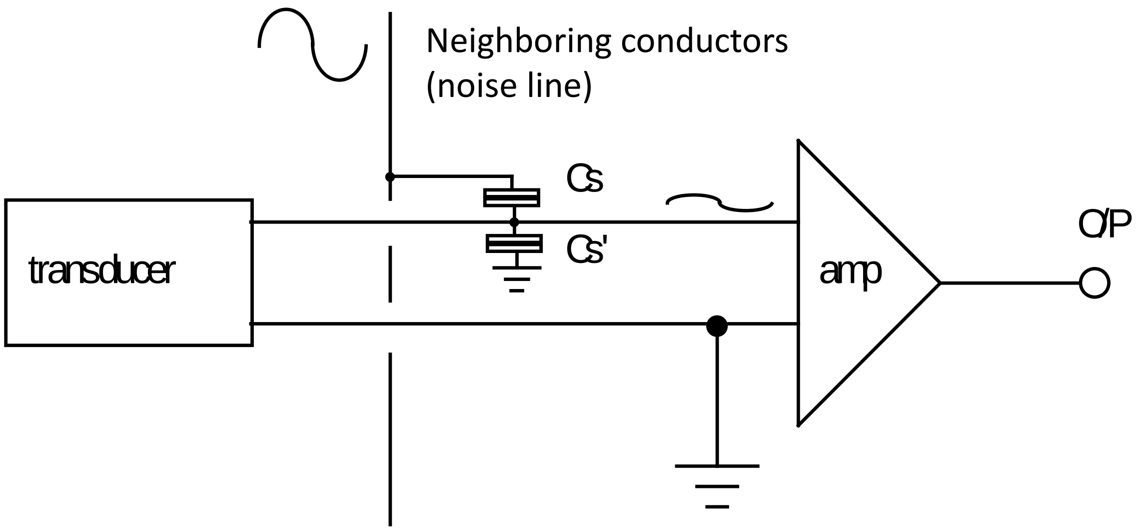
Noise Elimination – Bandwidth Limiting



Avoiding Noise 'pick-up'

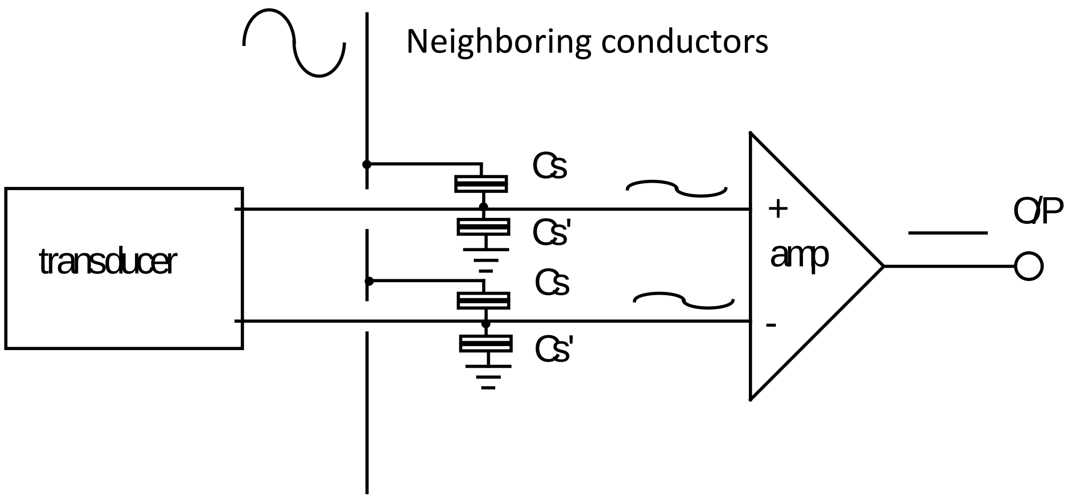
Noise is often inadvertently 'picked up' for three main reasons:

1) ***Noise pick-up by <u>capacitive coupling</u>***



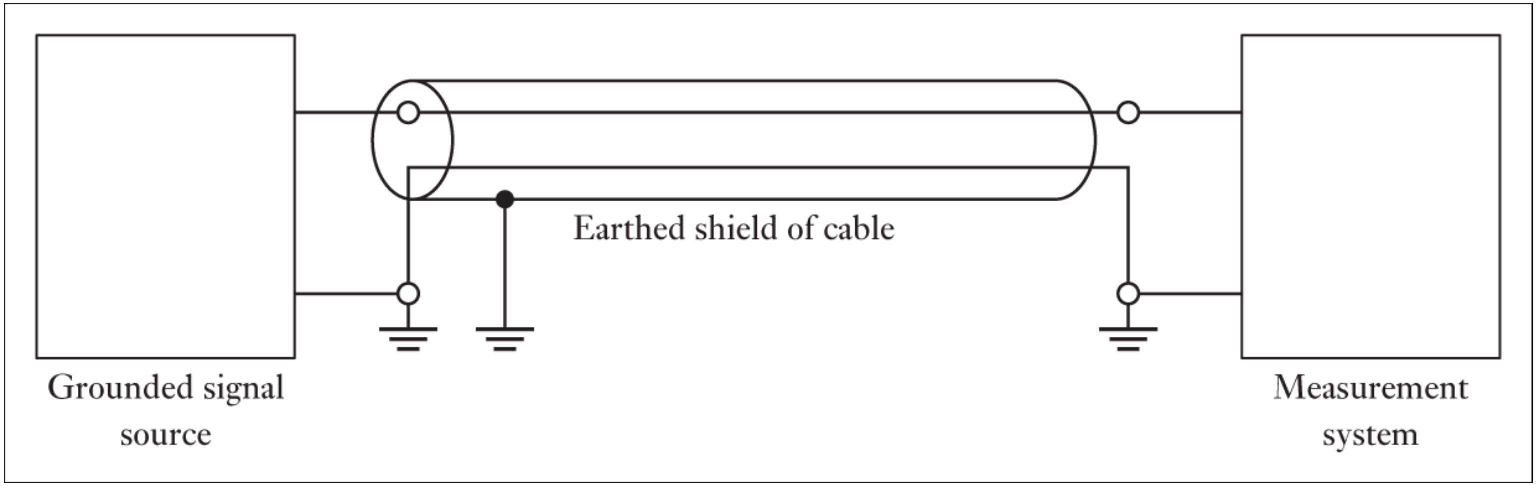
Avoid capacitive coupling – (i) balance the input

Minimise this problem by using a difference amplifier with high common mode rejection and with both input lines isolated from ground. Then the noise 'pick up' links equally to both inputs and cancels because the amplifier only amplifies *differential* signals and does not amplify common mode signals (ideally).

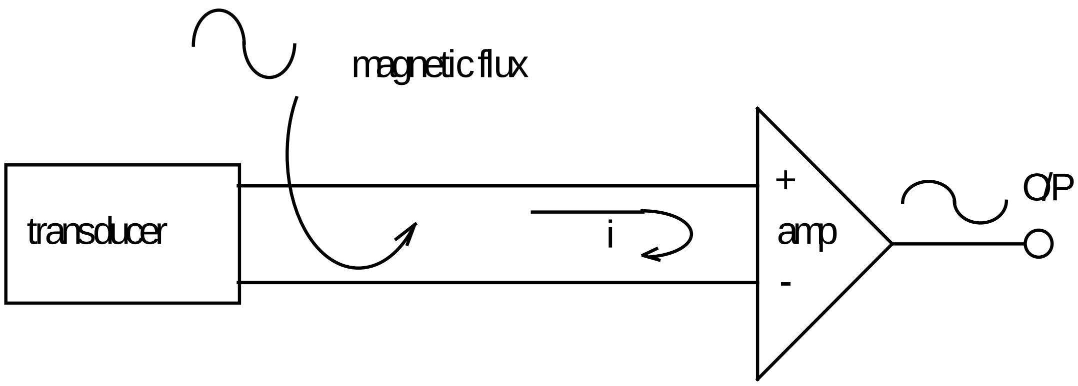


Avoid capacitive coupling – (ii) screen with co-axial cable

Alternatively use screened co-axial cable with the outer sheath grounded. This protects the inner cable from capacitively linking with the noise line.

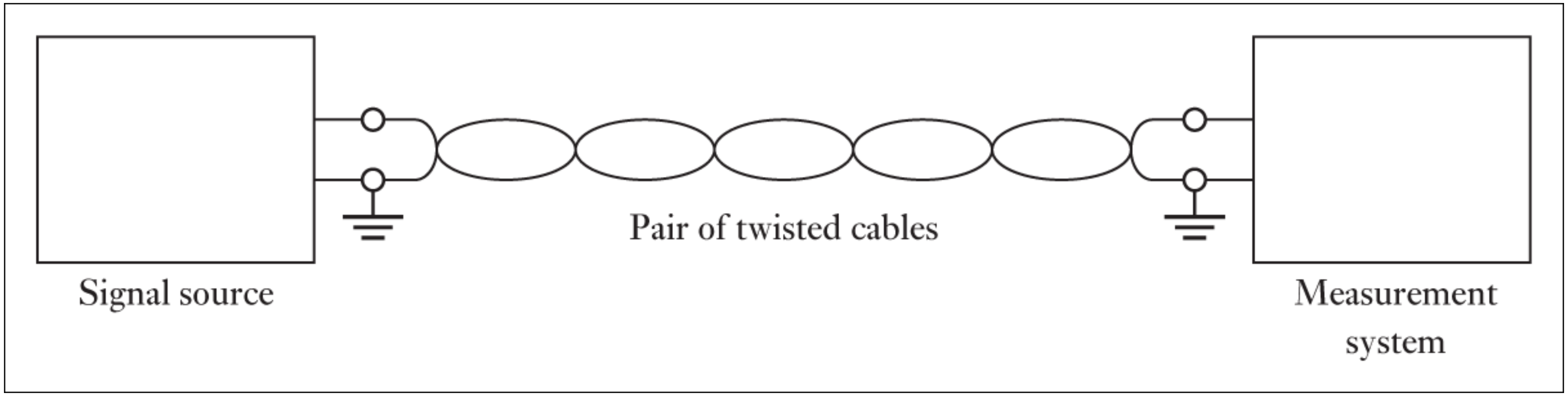


2) Noise pick-up by electromagnetic coupling



Avoid Electromagnetic coupling – twist the wires

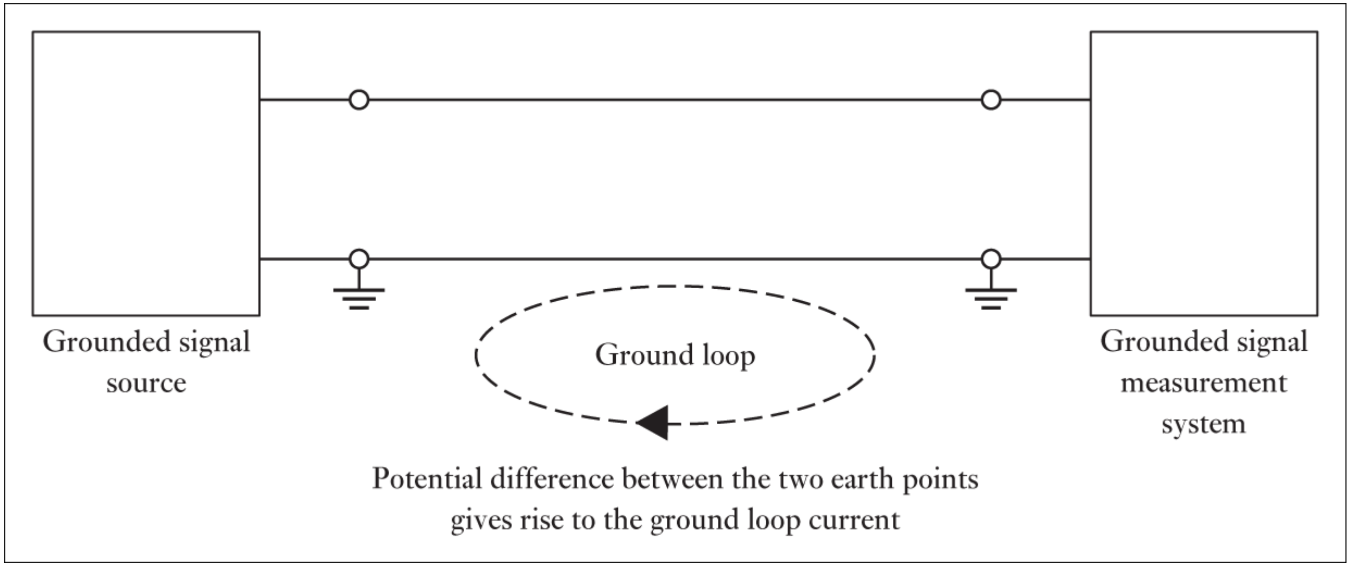
Minimise this pick-up noise by twisting the input lines together.



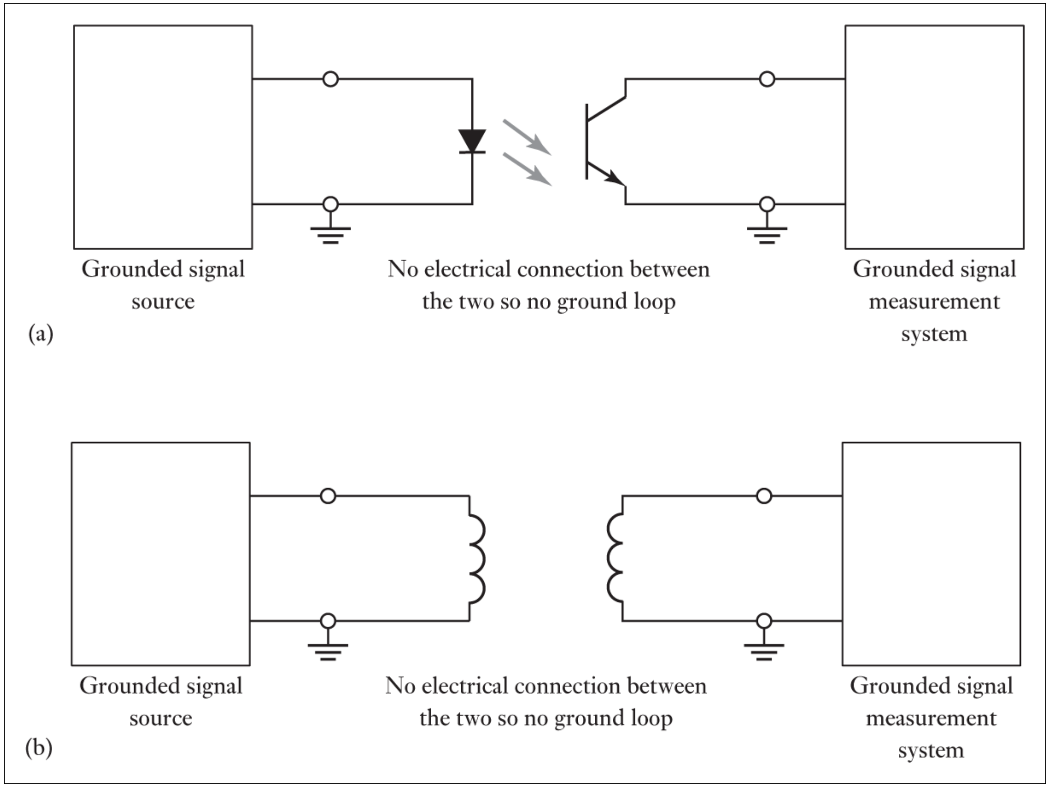
The induced voltages in each loop are reduced by the small area of each loop and are of opposite polarity in each loop and so cancelled.

3) Noise pick-up by Ground loops

Problems can arise with systems when a circuit has several grounding points. In a large system, multiple grounding is largely inevitable. Unfortunately, there may be potential difference between the two grounding points and thus significant currents (ground-loop currents) can flow between the grounding points through the low but finite ground resistance.



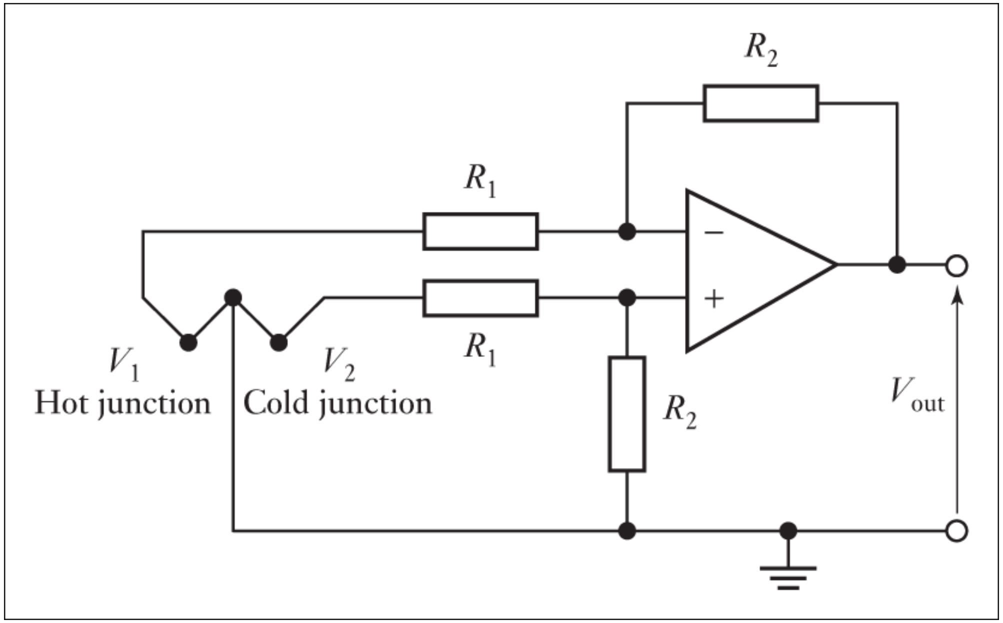
Avoid Ground loop coupling – electrical isolation



- ✓ Besides, ground loops from multiple point grounding can be minimized if the multiple earth connections are made close together and the common ground has a resistance small enough to make the voltage drops between the earth points negligible.

Quiz 6.1

A differential amplifier is used with a copper-constantan thermocouple sensor with sensitivity of $43\mu V/^{o}C$. Suppose $R_1 = 1k\Omega$ and $R_2 = 2.32k\Omega$, the temperature difference between the two thermocouple junctions is 100°C. Find the output voltage of the circuit.



Thank You !