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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4 March, 2019

Lecture 5

Outline

Signal Conditioning

- ❑ **What is Signal Condition**
- ❑ **Wheatstone Bridge**
  - Basics
  - Temperature Compensation
- ❑ **Protection Circuit**
- ❑ **Filters**

What is Signal Conditioning?

The output signal from the sensor of a measurement system has generally to be processed in some way to make it suitable for the next stage of the operation. The signal may be, for example,

- too small and have to be amplified,
- contain interference,
- be non-linear and require linearization,
- be analogue and have to be made digital,
- Be a resistance change and have to be made into a voltage change etc.

All these changes can be referred to as **signal conditioning**.

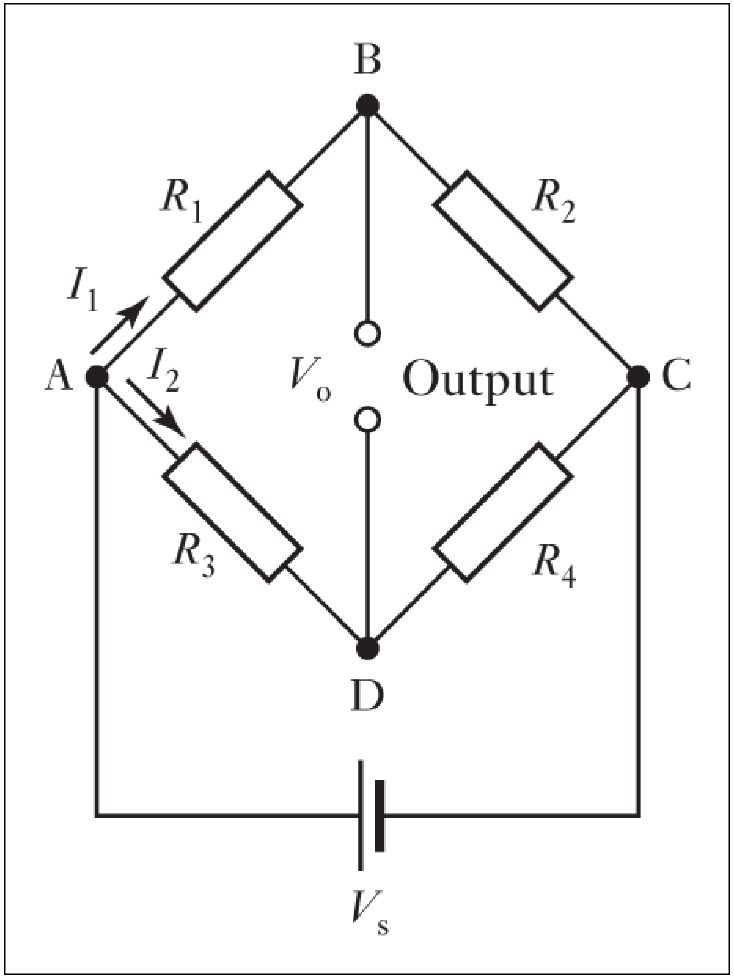
Signal Conditioning Elements

Signal conditioning can involve protection to prevent damage to the next element in a system, getting a signal into the form required, getting the level of a signal right, reducing noise, manipulating a signal to perhaps make it linear.

Commonly used signal conditioning elements are:

- *Wheatstone bridge*
- *Protection elements*
- *Filters*
- *Operational amplifiers*
- *Signal modulators*

Wheatstone Bridge



The **Wheatstone bridge** can be used to convert a resistance change to a voltage change and can detect very small changes in resistance.

The bridge is said to be balanced if:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

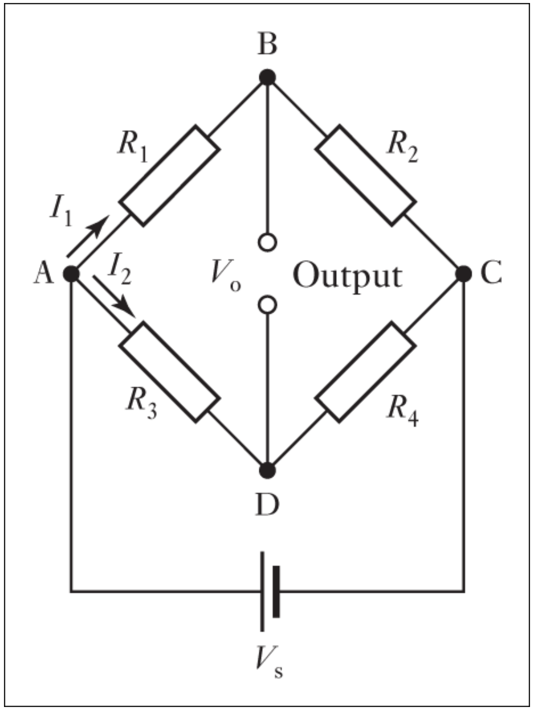
Then the output voltage

$$V_o = V_{AB} - V_{AD} = V_s\left(\frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right)$$

$$= 0.$$

Wheatstone Bridge Application

Consider R_1 to be a sensor which has a resistance change. A change in resistance from R_1 to $R_1 + \delta R_1$ gives a change in output from V_o to $V_o + \delta V_o$:



$$V_o + \delta V_o = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right)$$

$$\delta V_o = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_1}{R_1 + R_2}\right)$$

If δR_1 is much smaller than R_1, then the above equation approximates to:

$$\delta V_o \approx V_s\left(\frac{\delta R_1}{R_1 + R_2}\right)$$

With this approximation, the change in output voltage is thus proportional to the changes in the resistance of the sensor (when there is no load resistance across the output. If there is such a resistance then the loading effect has to be considered).

Bridge Balancing

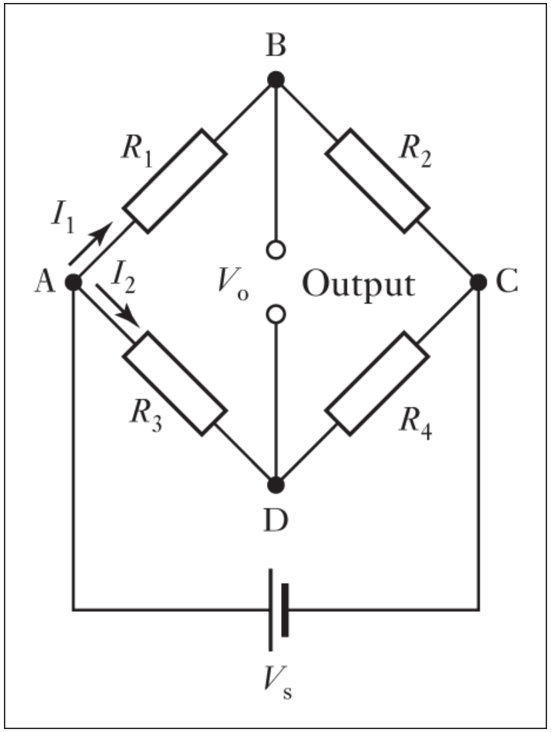
When a bridge is installed, it is very unlikely that the bridge will output exactly zero volts when no strain is applied. Rather, slight variations in resistance among the bridge arms and lead resistance will generate some nonzero initial offset voltage.

There are a few different ways that a system can handle this initial offset voltage:

- **Software Compensation**: compensates for the initial voltage in software. If the offset is large enough, it limits the amplifier gain that can be applied to the output voltage, thus limiting the dynamic range of the measurement;
- **Offset-Nulling Circuit**: uses an adjustable resistance, or potentiometer, to physically adjust the output of the bridge to zero;
- **Buffered Offset Nulling**: a nulling circuit adds an adjustable DC voltage to the output of the instrumentation amplifier.

Example 5.1

Consider a platinum resistance temperature sensor which has a resistance at 0°C of 100 Ω and forms one arm of a Wheatstone bridge (supply voltage: 6.0 V). The bridge is balanced, at this temperature, which each of the other arms also been 100 Ω. If the temperature coefficient of resistance of platinum is 0.0039/K, what will be the output voltage per degree change in temperature if the load across the output can be assumed to be infinite?



The variation of the resistance of the platinum with temperature:

$$R_t = R_0(1 + \alpha t)$$

Thus change in resistance caused by per degree change in temperature is:

$$R_t - R_0 = R_0 \alpha t = 100 \times 0.0039 \times 1 = 0.39\ \Omega/\mathrm{K}$$

Since the resistance change is small compared with the 100 Ω, the approximate equation can be used, hence:

$$\delta V_0 \approx V_s \left(\frac{\delta R_1}{R_1 + R_2} \right) = \frac{6.0 \times 0.39}{100 + 100} = 0.012V$$

Temperature Compensation for Strain Gauge

Recall of **Strain gauge**: sensor used to measure very small strain.

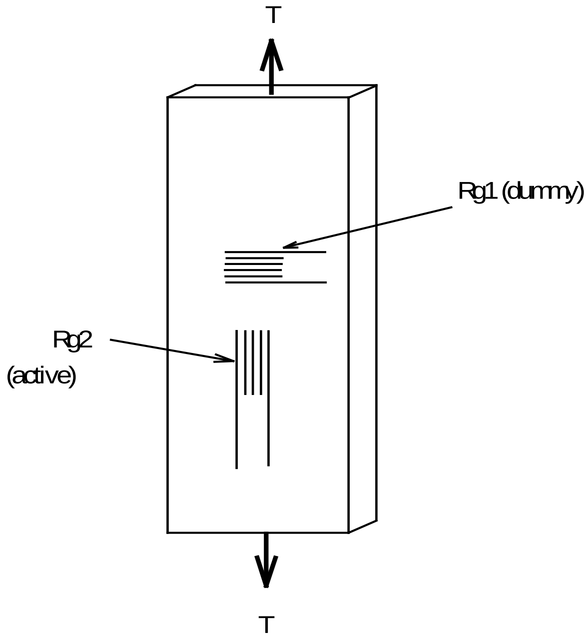
The major **problem**: gauge resistance changes not only with stain, but also with temperature. Especially for semiconductor strain gauges, which have a great sensitivity to temperature.

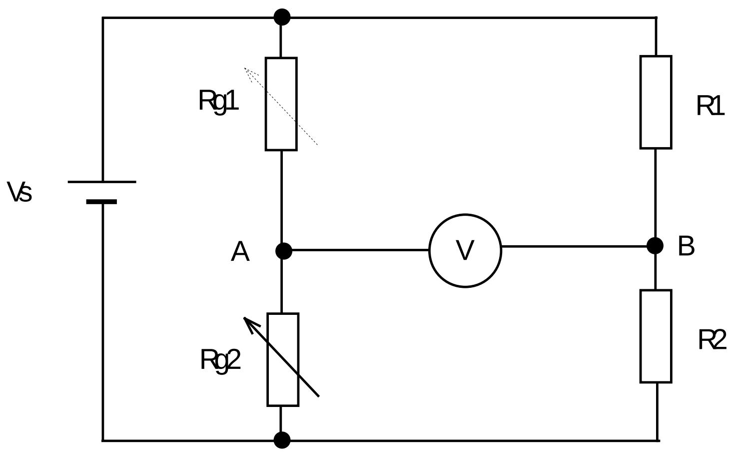
One way of eliminating the temperature effect is to use a **dummy** strain gauge.

- This dummy strain gauge is identical to the one under strain, i.e., the active gauge, and is mounted on the same material but is **NOT** subject to the strain.
- The dummy strain gauge is positioned close to the active gauge so that it is suffered from the same temperature change.
- The active gauge is mounted in one arm of the Wheatstone bridge, and the dummy gauge in the other arm, so the effects of temperature-induced resistance changes cancel out.

Single active gauge plus one 'dummy' gauge

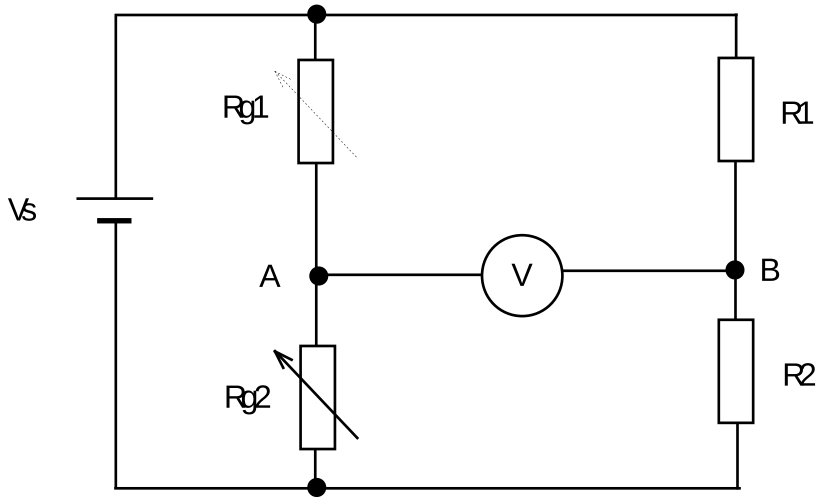
Used to measure tensile strain and provide temperature compensation





Note that temperature changes affect both gauges but this does not affect the bridge balance. Longitudinal strain however, only affects $Rg2$ and this produces an out of voltage from the bridge.

Analysis



$$V_{out} = V_A - V_B$$
$$= V_s\left(\frac{Rg2}{Rg1+Rg2} - \frac{R2}{R1+R2}\right)$$

$= 0$ at original balance.

Note that a temperature change will cause the same fractional change to both Rg1 and Rg2 so that the ratio $\frac{Rg2}{Rg1+Rg2}$ is unaffected.

However, when subjected to strain, only Rg2 becomes:

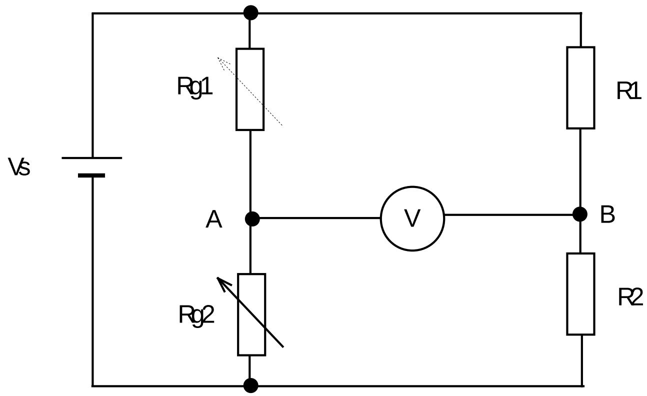
$$Rg2 + \Delta Rg2 = Rg2\left(1 + \frac{\Delta Rg2}{Rg2}\right) = Rg2(1 + G\varepsilon)$$

Therefore,

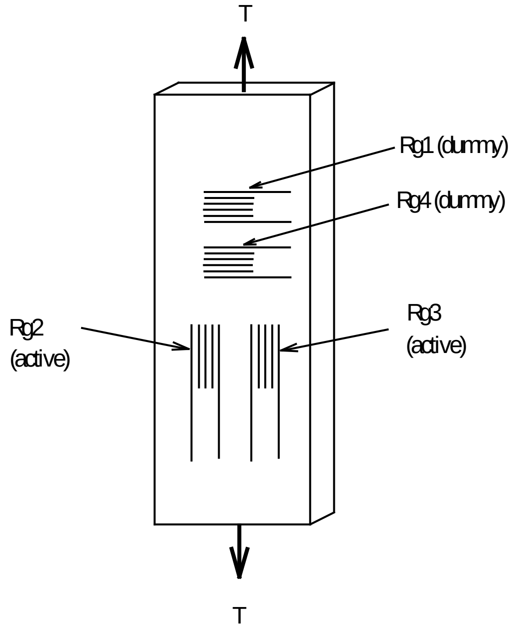
$$V_{out} = V_s\left(\frac{Rg2(1 + G\varepsilon)}{Rg1 + Rg2(1 + G\varepsilon)} - \frac{R2}{R1 + R2}\right)$$

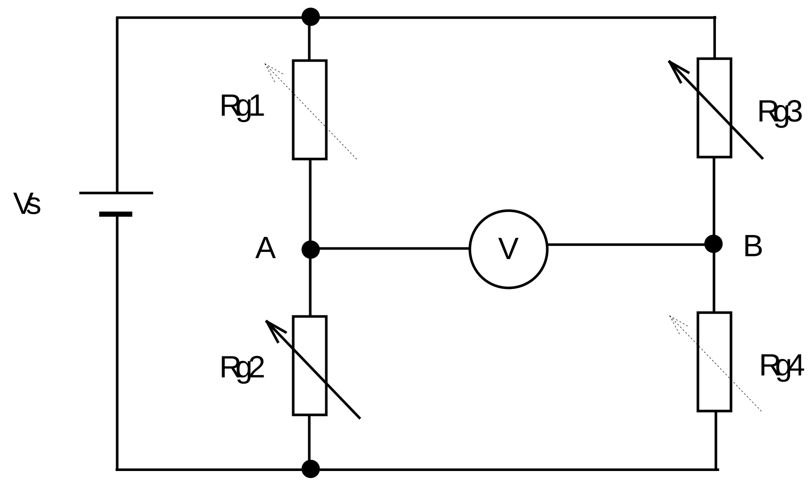
so if $Rg1 = Rg2 = Rg$ and $R1 = R2$, then

$$\begin{aligned} V_{out} &= V_s\left(\frac{Rg(1 + G\varepsilon)}{Rg + Rg(1 + G\varepsilon)} - \frac{1}{2}\right) \\ &= V_s\left(\frac{(1 + G\varepsilon)}{1 + (1 + G\varepsilon)} - \frac{1}{2}\right) \\ &= V_s\left(\frac{G\varepsilon}{2(2 + G\varepsilon)}\right) \approx V_s\frac{G\varepsilon}{4} \end{aligned}$$



Two active gauges and two 'dummy' gauges





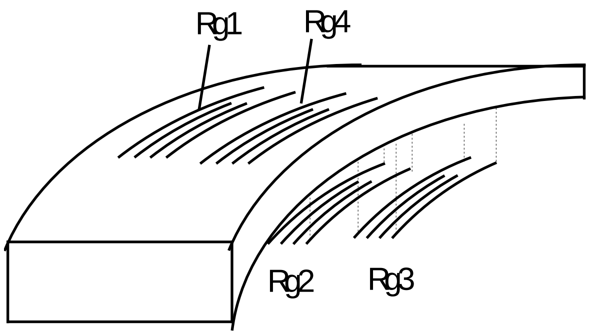
Note the position of the gauges in the bridge are chosen so that :

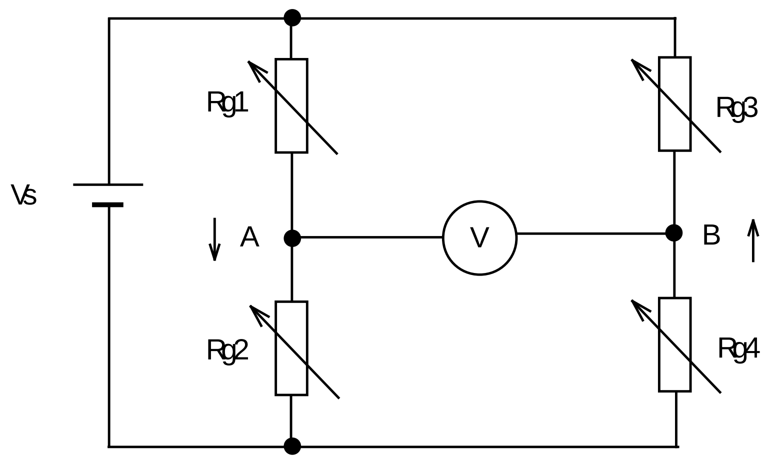
1) their effects reinforce one another to give double the output voltage of a single active gauge bridge

$$V_o = V_s \frac{G\varepsilon}{2}$$

2) Temperature compensation is achieved.

Four active gauges - Bending strain





Note the position of the gauges in the bridge are chosen so that :

1) their effects reinforce one another to give four times the output voltage of a single active gauge bridge

$$V_{out} = V_s G \varepsilon$$

2) Temperature compensation is achieved.

Amplification of the Bridge Output Voltage

Note the even the four active gauge bridge typically only produces a very small output voltage.

For example, for a four active gauge bridge, $V_{out} = V_s G\varepsilon$

If ε = 1μ (strain = 10^{-6}), V_s = 10 volts , G = 2.2 , then

$$V_{out} = 2.2 \times 10^{-5} = 22 \text{ microvolts}$$

Typically the elastic limit of metals might be reached by around 10000μ strain so even then the output is only 0.22 volts

Note that there is a limit to the size of the supply voltage that can be used because of the power dissipation in the strain gauges.

Typically the resistance of the gauge is 200Ω, so if V_s = 10 volts , the power dissipation in the gauge is $V^2/R = (10/2)^2/200 = 0.125$ watts.

Protection Circuit

There are many situations where the connection of a sensor to the next unit, e.g. a microprocessor, can lead to the possibility of damage as a result of perhaps a high current or high voltage.

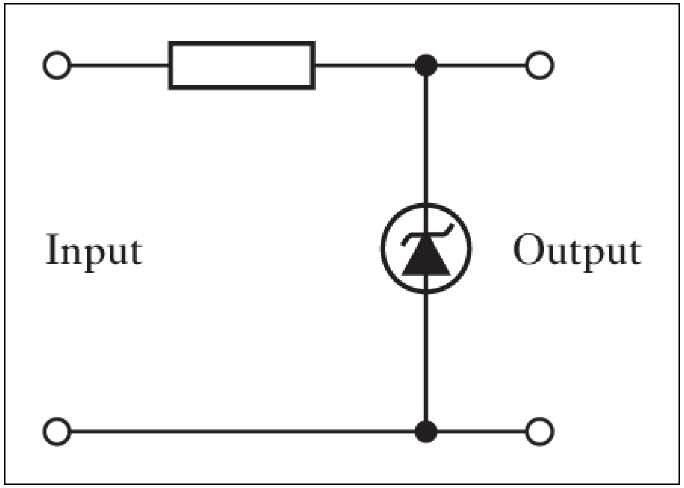


Fig. Zener diode protection circuit.

- Protection from high current by:
  - incorporating in the input line of a series resistor to limit the current to an acceptable level.
- Protection from high voltage by:
  - using a Zener diode circuit. Zener diodes behave like ordinary diodes up to some breakdown voltage when they become conducting. Its resistance drop to a very low value when voltage exceeds some threshold, say 5V.

Filtering

The term **filtering** is used to describe the process of removing a certain band of frequencies from a signal and permitting others to be transmitted.

- Passive filter: made up using only resistors, capacitors and inductors;
- Active filter: made up using amplifiers in addition to resistors, capacitors and inductors.

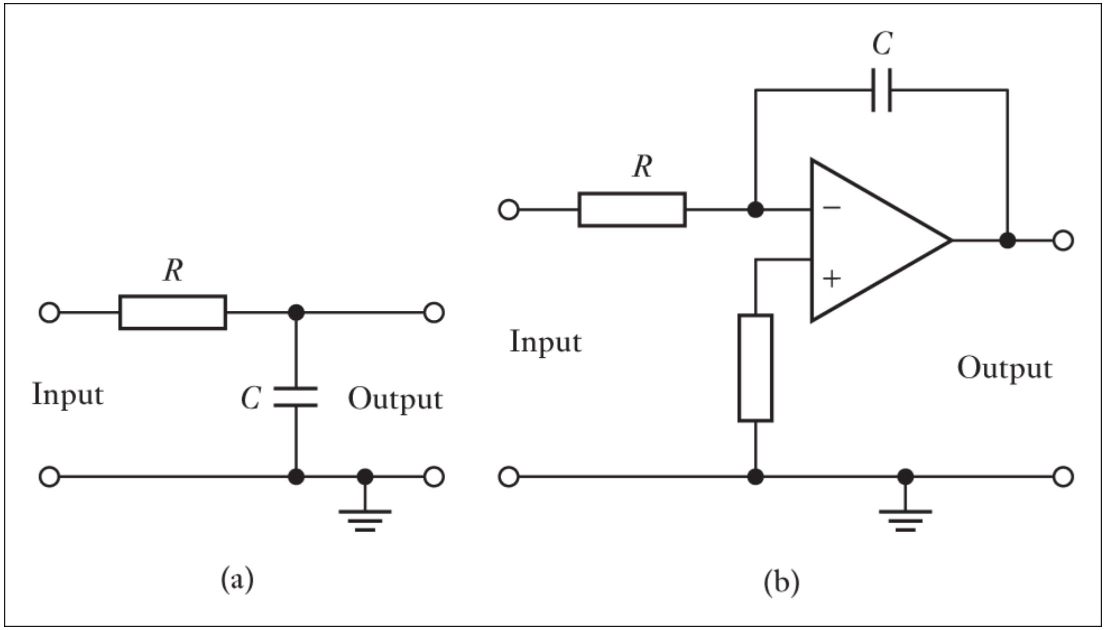


Fig. Low-pass filter: (a) passive, (b) active using an operational amplifier.

Characteristics of Ideal Filters

Cutoff frequency: the frequency at which the output voltage is 70.7% or attenuated by 3dB of that in the pass band.

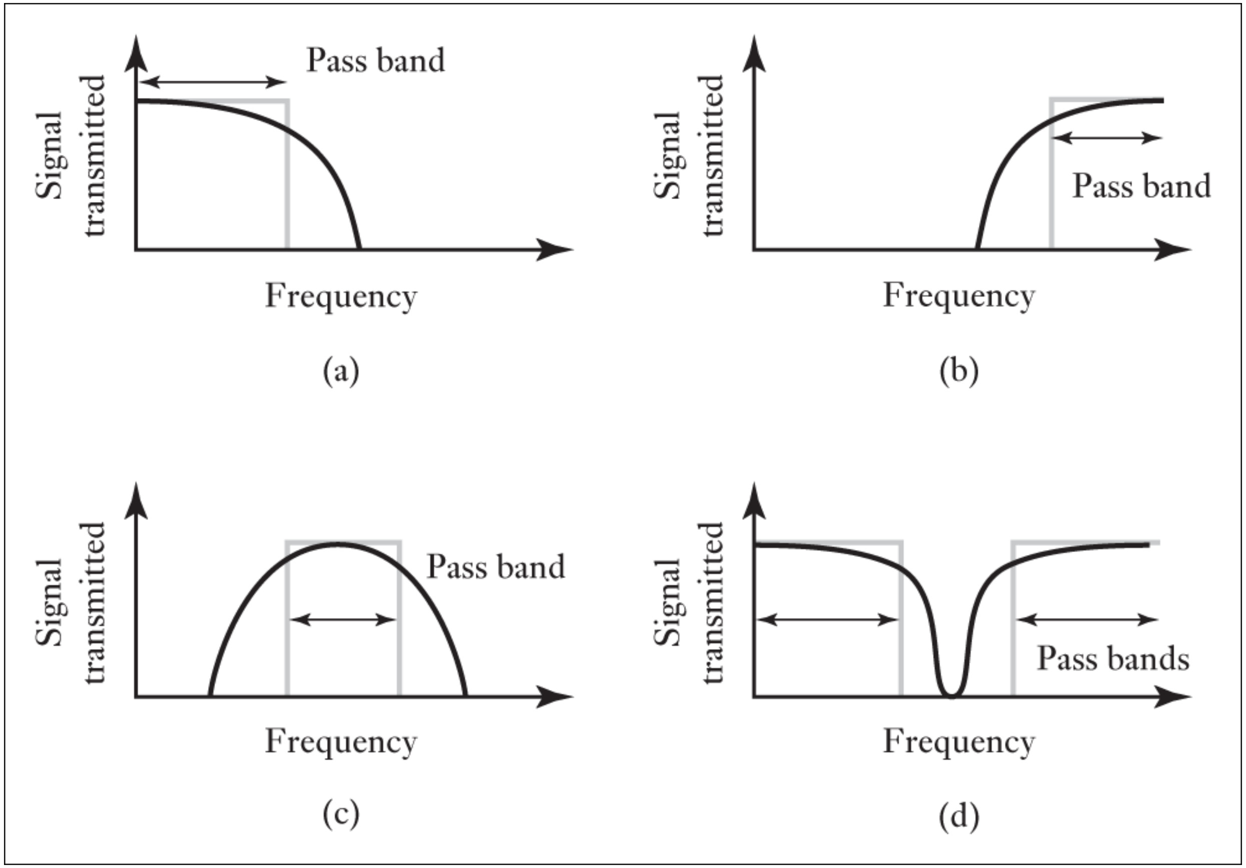


Fig. Filters (a) low-pass, (b) high-pass, (c) band-pass, (d) band-stop.

Quiz 5.1

1) Sketch a Wheatstone bridge circuit with two active strain gauges and two dummy gauges;

2) Explain how temperature compensation can be achieved by using mathematical derivations;

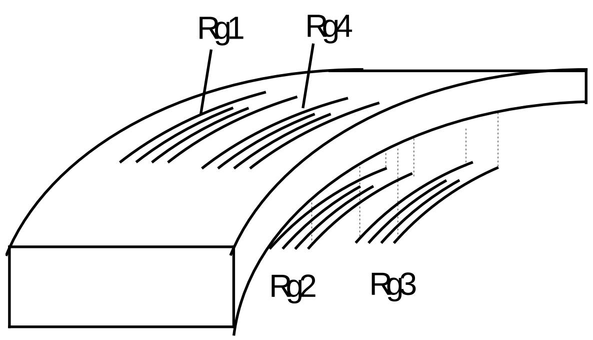
3) prove that

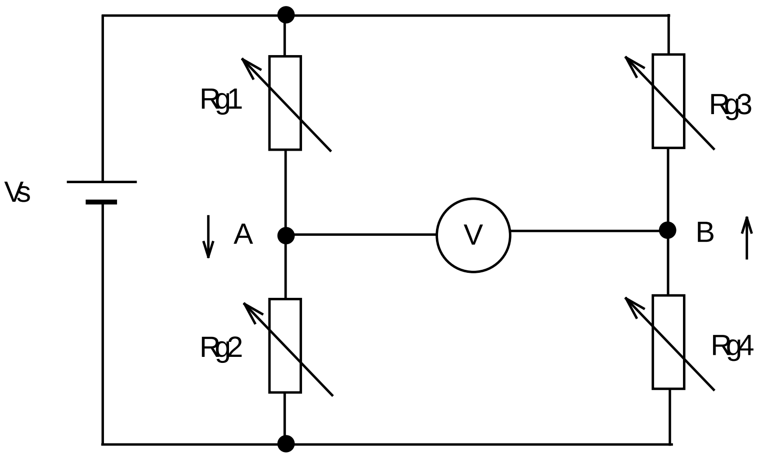
$$V_o = V_s \frac{G\varepsilon}{2}.$$

Quiz 5.2

The strain in a beam subject to tensile stress is to be measured using four strain gauges. The supply voltage to the bridge Vs is 6V, the gauge factor G=2.3, the gauges and the two fixed resistors have a resistance of 200Ω each, Young's modulus of the beam is 250 x 10^9 Newtons/m^2. (hint: Young's modulus=stress/strain)

Suppose the measured output voltage from the bridge is 80μV, determine the corresponding strain and stress.





Thank You !