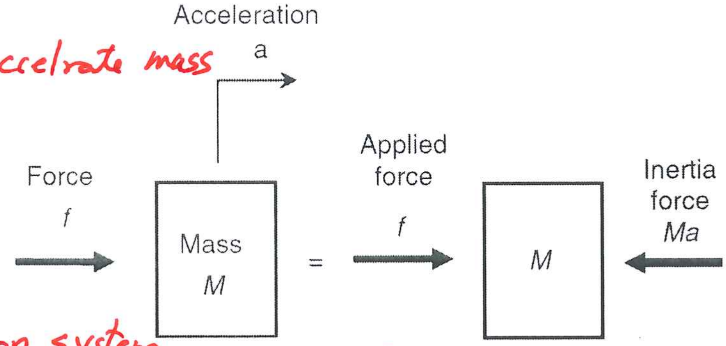
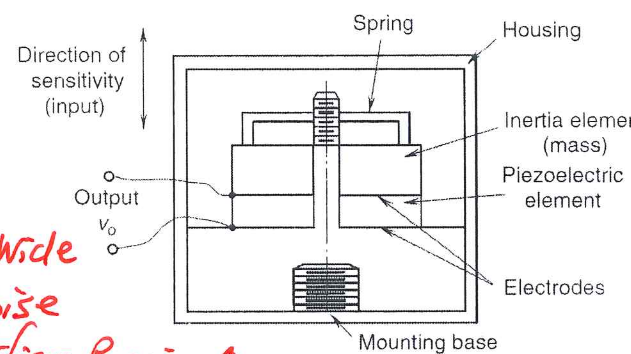
Accelerometers:

- $F = Ma$; Force necessary to accelrate mass
- Inertia force
- If a force Ma is applied to accelrating mass in the direction opposing accelration, system can be analyzed using static equillibrium. (d'Alembert's principle)
- Force that causes accelration itself is a measure of accelration.
- Force → displacement → displacement sensor → voltage



Piezoelectric Accelerometer:

A piezoelectric velocity transducer is simply a piezoelectric accelerometer with a built-in integrating amplifier in the form of a miniature integrated circuit.



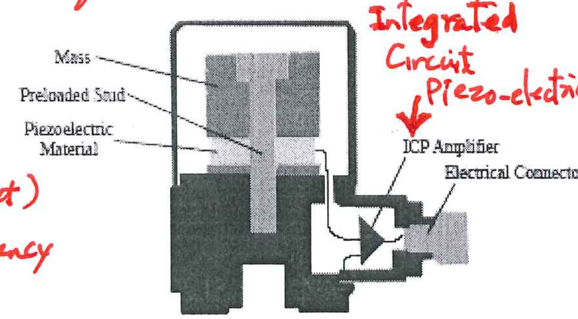
Adv: Light Weight, frequency response is Wide

Dis: Low output Voltage, Lots of Noise
High Output Impedance, Amplifier Required

Operating Range (1 kHz → 5 kHz)

Large Mass → distorts Motion Variable (Mechanical loading Effect)
→ Lower Resonant frequency
∴ Lower useful range.

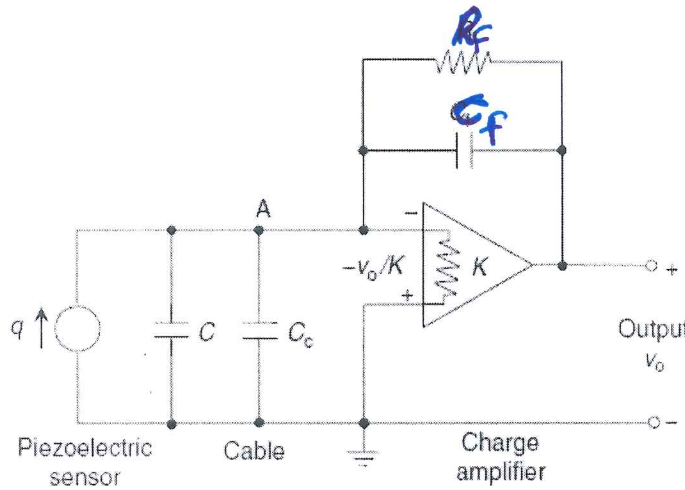
Integrated Circuit
Piezo-electric.



Charge Amplifier:

Piezoelectric signals cannot be read using low-impedance devices. The two primary reasons for this are:

1. High output impedance in the sensor results in small output signal levels and large loading errors.
2. The charge can quickly leak out through the load.



A charge amplifier is commonly used as the signal-conditioning device for piezoelectric sensors, in order to overcome these problems to a great extent.

- Because of impedance transformation, the impedance at the ***output of the charge amplifier becomes much smaller than the output impedance of the piezoelectric sensor***. This virtually eliminates loading error and provides a low-impedance output for purposes such as signal communication, acquisition, recording, processing, and control.
- Also, by using a charge amplifier circuit with a ***relatively large time constant, the speed of charge leakage can be decreased***.

For example, consider a piezoelectric sensor and charge amplifier combination, as represented by the circuit above. Let us examine how the rate of charge leakage is reduced by using this arrangement.

Current Balance @ point A

$$\dot{q} + C\cancel{\frac{\dot{v}_o}{K}}^{\,0} + C_c\cancel{\frac{\dot{v}_o}{K}}^{\,0} + C_f\left(\dot{v}_o + \cancel{\dot{v}_o/K}^{\,0}\right) + \frac{v_o + \cancel{v_o/K}^{\,0}}{R_f} = 0$$

K is Large ∴ Equation Reduces to $R_f C_f \frac{dv_o}{dt} + v_o = -R_f \frac{dq}{dt}$

In Laplace form $\boxed{\frac{v_o(s)}{q(s)} = \frac{-R_f s}{1 + R_f C_f s}}$; $s = j\omega$

If $w=0$, $s=0$, $\frac{v_o}{q(s)}=0$ this can't be used for DC signals

If $s=jW$, is Very high, $\frac{v_o(s)}{q(s)} = -\frac{\cancel{R_f}\cancel{s}}{\cancel{R_f}C_f\cancel{s}} = -\frac{1}{C_f}$

Strain Gages:

- Many types of force and torque sensors are based on strain-gage measurements.
- Although strain gages measure strain, the measurements can be directly related to stress and force. Therefore, it is appropriate to discuss strain gages under force and torque sensors.
- Note, however, that strain gages may be used in a somewhat indirect manner (using auxiliary front-end elements) to measure other types of variables, including displacement, acceleration, pressure, and temperature.

Equations for Strain-Gage Measurements:

- Change of electrical resistance in material when mechanically deformed is property used in resistance-type strain gages.

Recall Resistance $R = \rho \frac{l}{A}$

l ← length of conductor; A ← x-section Area; ρ ← material resistivity

Taking Log on both sides

$$\log R = \log \rho + \log (l/A)$$

differentiating

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{d(l/A)}{l/A}$$

Fractional change in resistivity

deformation

∴ change in Resistance : change of resistivity + change in shape of Material

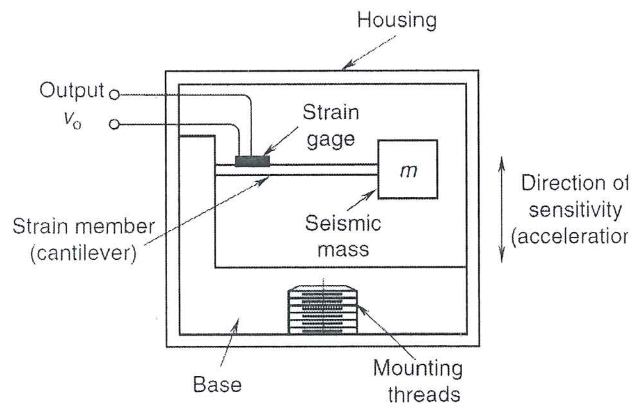
$$\therefore \quad \frac{\delta R}{R} = S_s \epsilon$$

S_s ← gage factor or (sensitivity of strain-gage element
2→6 Metallic
to→200 semi-conductor)

ϵ ← STRAIN

Examples:

- Acceleration may be measured by first converting it into an inertia force of a suitable mass (seismic mass) element, then subjecting a cantilever (strain member) to that inertia force and, finally, measuring the strain at a high-sensitivity location of the cantilever element.



- Temperature may be measured by measuring the thermal expansion or deformation in a bimetallic element.
- Thermistors are temperature sensors made of semiconductor material whose resistance changes with temperature. Resistance temperature detectors (RTDs) operate by the same principle, except that they are made of metals, not of semiconductor material.
- Note that these temperature sensors, and the piezoelectric sensors, should not be confused with strain gages.
- Resistance strain gages are based on resistance change as a result of strain, or the piezo-resistive property of materials.

A direct way to obtain strain-gage measurement is:

- To apply a constant dc voltage across a series-connected pair of strain-gage element (of resistance R) and a suitable (complementary) resistor R_c, and
- To measure the output voltage V_0 across the strain gage under open-circuit conditions (using a voltmeter with high input impedance).
- It is known as a potentiometer circuit or ballast circuit.

Temprature Coeff.

We can define $R = R_0 + \alpha \Delta T$

$$V_0(\text{old}) = \left(\frac{R}{R+R_c}\right) V_{ref}.$$

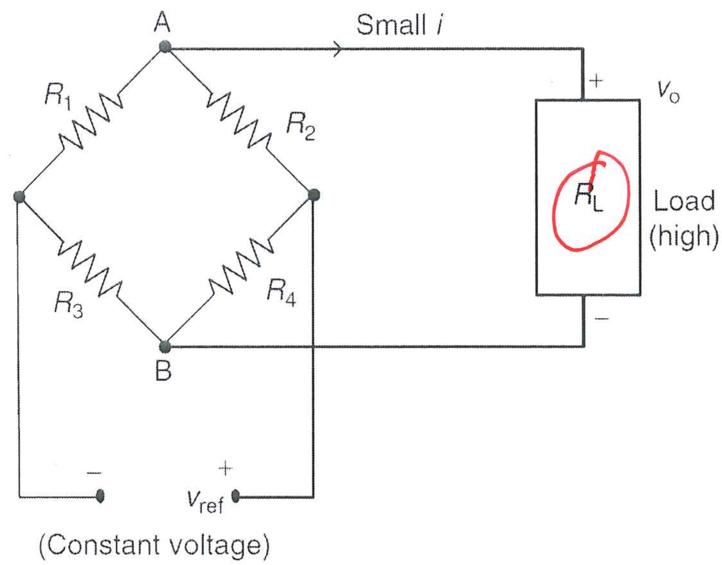
$$V_0(\text{New}) = \left(\frac{R+\Delta R}{R+\Delta R+R_c+\Delta R}\right) V_{ref} = \left(\frac{R+\Delta R}{R+R_c+2\Delta R}\right) V_{ref}$$

Could work But Ambient temprature → strain gage R & Electrical Loading Error.

More favourable choice is wheatstone Bridge.

Bridge Sensitivity:

- Strain-gage measurements are calibrated with respect to a balanced bridge.
- When the strain gages in the bridge deform, the balance is upset.
- If one of the arms of the bridge has a variable resistor, it can be changed to restore balance.
- The amount of this change measures the amount by which the resistance of the strain gages changed, thereby measuring the applied strain.
- This is known as the *null-balance method* of strain measurement.



Recall wheatstone bridge Equations: $V_o = \left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4}\right)V_{ref} = \frac{R_1R_4 - R_2R_3}{(R_1+R_2)(R_3+R_4)}V_{ref}$

When $V_o = 0$; Bridge is balanced & $\frac{R_1}{R_2} = \frac{R_3}{R_4}$; EVEN FOR SMALL R_L

* However, this Method is SLOW; Balancing bridge for each reading.

* More common method: Dynamic Readings from a strain-gage bridge.
: Output Voltage resulting from Imbalance Caused by deformation of active-strain gages in the bridge.

$$\frac{\delta V_o}{V_{ref}} = \frac{R_2\delta R_1 - R_1\delta R_2}{(R_1+R_2)^2} - \frac{R_4\delta R_3 - R_3\delta R_4}{(R_3+R_4)^2}$$

- If all four resistors are equal (value + material), ΔR due to Ambient Conditions Cancel out. ⇒ V_o : No change
- If R_1 and R_2 ; R_3 and R_4 have same Temp. Coeff: Compensation is achieved
- If R_1 changes by δR: $\frac{\delta V_o}{V_{ref}} = \frac{\delta R}{4R}$; R : strain-gage Resistance
- If $R_1 \to R+\delta R$, $R_2 \to R-\delta R$ $\quad \frac{\delta V_o}{V_{ref}} = \frac{\delta R}{2R}$
- If $\left.\begin{matrix} R_1, R_4 \to +\delta R \\ R_2, R_3 \to -\delta R \end{matrix}\right\} \longrightarrow \frac{\delta V_o}{V_{ref}} = \frac{\delta R}{R}$

The Bridge Constant and the Calibration Constant:

If more than one strain-gage is active, the bridge output may be expressed as:

$$\frac{\delta V_o}{V_{ref}} = K \frac{\delta R}{4R} \qquad — (1)$$

$$K = \frac{\text{bridge output in general case}}{\text{bridge output if only one strain gage is active}}$$

Bridge Constant: Larger the bridge Constant
Better the Sensitivity of Bridge.

Calibration Constant of a strain-gage bridge relates the strain that is measured to the output of the bridge

$$\frac{\delta V_o}{V_{ref}} = C \epsilon \qquad — (2)$$

Recall $\frac{\delta R}{R} = S_s \epsilon \qquad — (3)$

S_s: gage factor, ϵ: strain

(1) + (3) ⇒ $\frac{\delta V_o}{V_{ref}} = \frac{K}{4} S_s \epsilon . \qquad — (4)$

Now Compare (2) + (4) ⇒ $\boxed{C = \frac{K}{4} S_s}$

∴ Calibration Constant $C = \frac{K}{4} S_s .$