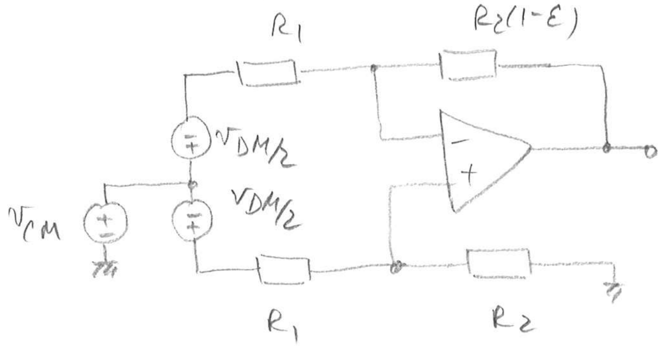
– Last time: **Difference Amplifiers** (2.4)



$$v_O = A_{dm} \cdot v_{DM} + A_{cm} \cdot v_{CM}$$

$$A_{cm} = \frac{R_2}{R_1+R_2}\varepsilon$$

$$A_{dm} = \frac{R_2}{R_1}\left(1 - \frac{R_1+2R_1}{R_1+R_2}\frac{\varepsilon}{2}\right)$$

Definition: $\varepsilon \triangleq$ imbalance factor.

Definition: $CMRR \triangleq \frac{A_{dm}}{A_{cm}}$

$$CMRR_{dB} = 20 \cdot \log\left|\frac{A_{dm}}{A_{cm}}\right|$$

- input resistance

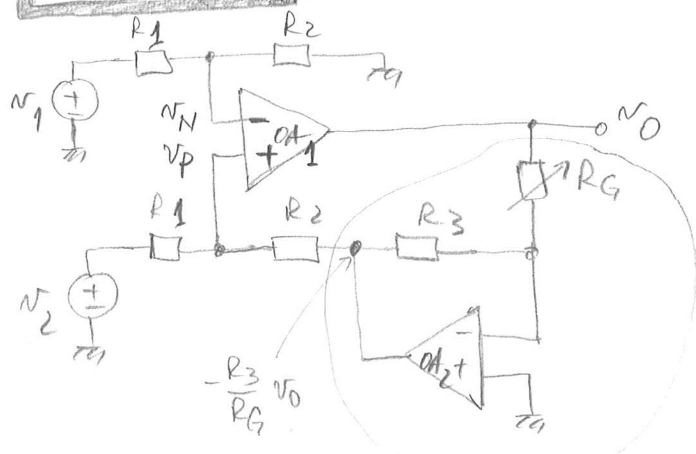
$R_{id} = 2R_1$

- Output resistance

$R_{ic} = \frac{R_1+R_2}{2}$

Note: ideally $A_{cm} \to 0$, for a true difference amplifier.

– **Variable gain** – we want the gain to vary linearly with the adjustment of the potentiometer



inverting configuration => OA_1 sees a negative feedback!

$$\Rightarrow v_O = \frac{R_2 R_G}{R_1 R_3} \cdot (v_2 - v_1)$$

Negative feedback => use virtual short concept => $v_N = v_P$

$$v_N = \frac{R_2}{R_1+R_2}v_1$$

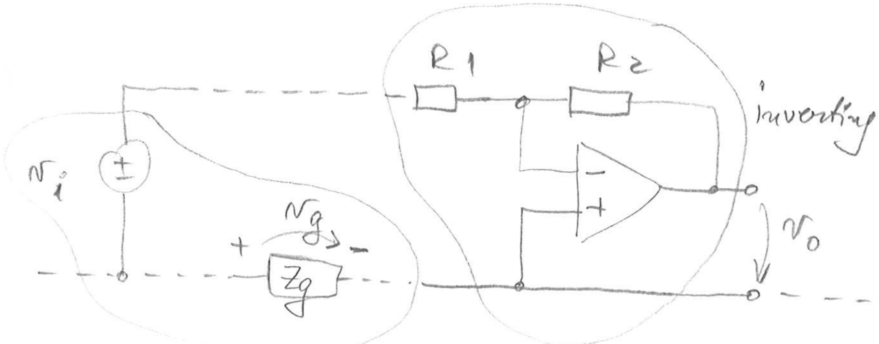
$$v_P = \frac{R_2}{R_1+R_2}v_2 + \frac{R_1}{R_1+R_2}\left(-\frac{R_3}{R_G}v_O\right)$$

↑ use superposition.

$$\Rightarrow R_2 v_1 = R_2 v_2 + R_1\left(-\frac{R_3}{R_G}\right)v_O \Rightarrow$$

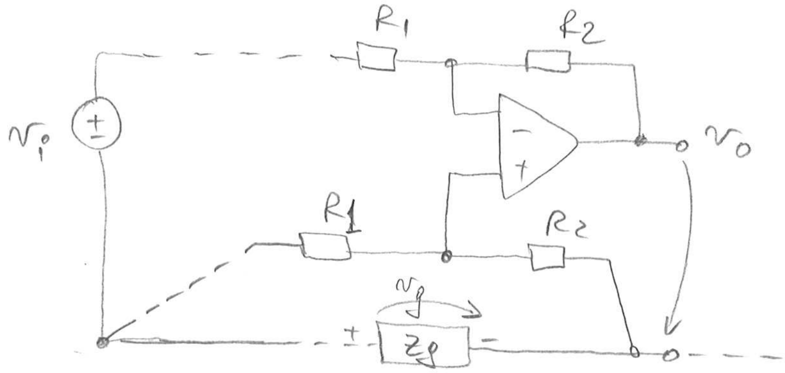
$$\Rightarrow v_O = \frac{R_2}{R_1} \cdot \frac{R_G}{R_3}(v_2 - v_1)$$

– Ground-loop interference elimination



Seen as $v_i + v_g$ by the inverting amplif! => $v_0 = -\frac{R_2}{R_1}(v_i + v_g)$ ← NOT wanted.

How to get rid of it?



Solution: Use a difference amplifier configuration in which v_g will appear as common mode signal that will be rejected!

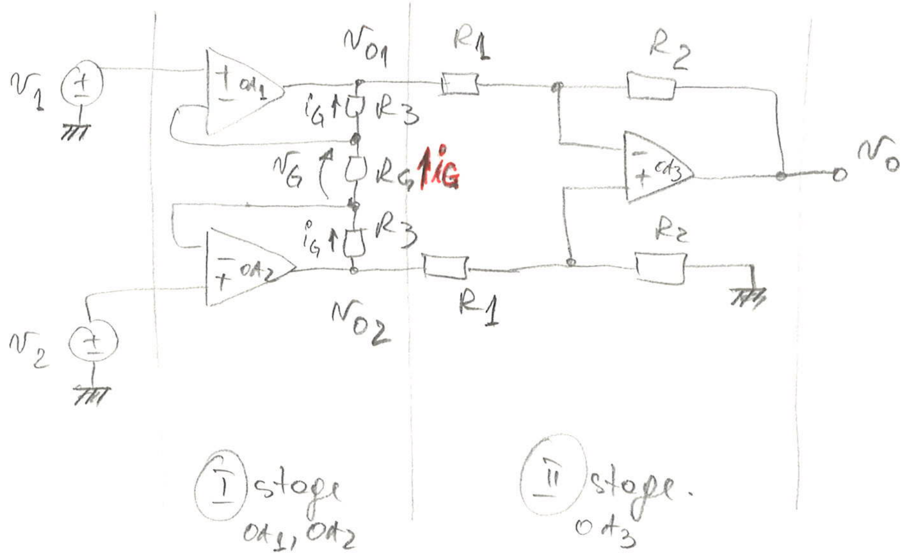
$$v_0 = +\frac{R_2}{R_1}\Big[\underbrace{v_g}_{=v_2} - (\underbrace{v_i + v_g}_{=v_1})\Big] = \boxed{-\frac{R_2}{R_1} v_i = v_0}$$

2.5. Instrumentation amplifiers

IA ≡ difference amplifier with:

- extremely high R_{ic}, R_{id}
- very low output impedance.
- accurate and stable gain.
- extremely high CMRR.

- Triple OpAmp IA's



$$v_G = v_2 - v_1$$

$$i_G = \frac{v_G}{R_G} = \frac{v_2 - v_1}{R_G} \Rightarrow \frac{v_{O2} - v_{O1}}{R_3 + R_3 + R_G} = i_G \Rightarrow v_{O2} - v_{O1} = \frac{R_G + 2R_3}{R_G}(v_2 - v_1)$$

$$\Rightarrow (v_{O2} - v_{O1}) = \left(1 + \frac{2R_3}{R_G}\right) \cdot (v_2 - v_1)$$

OA_3 ≡ difference amplifier $\Rightarrow$ $v_O = \frac{R_2}{R_1}(v_{O2} - v_1)$

$\Rightarrow$

$$\Rightarrow A = A_I \cdot A_{II} = \underbrace{\left(1 + \frac{2R_3}{R_G}\right)}_{= A_I} \cdot \underbrace{\left(\frac{R_2}{R_1}\right)}_{= A_{II}}$$

≡ Overall gain is the product of individ. stages gains!

- Dual OpAmp IA's
- Monolithic IA's
- Flying capacitor technique

exercise!

(2.6). instrumentation Applications

exercise!

- active guard drive
- digitally programmable gain
- Output offsetting
- Current output IA's, Current input IA's

(2.7) Transducer bridge amplifiers

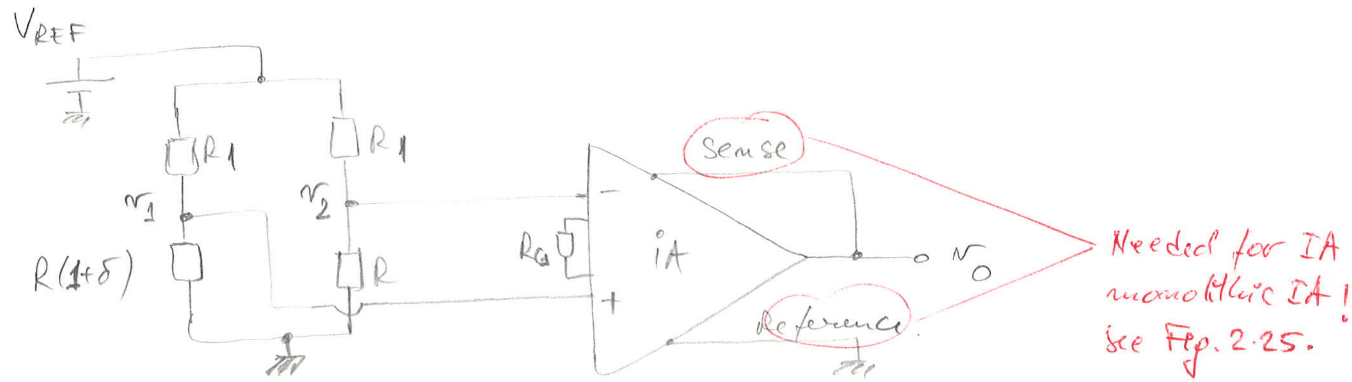
Resistive transducer ≡ device whose resistance varies with the **environment**: (Temperature, Light, strain, pressure)

- Transducer resistance deviation:

$$R + \Delta R = R(1+\delta) \quad , \quad \delta = \frac{\Delta R}{R} \triangleq \text{fractional deviation}$$

(R ↑ resistance as reference condition (e.g. °C); ΔR ↑ deviation)

- **The transducer bridge**: measure resistance deviation (variation) by converting $\Delta R \rightarrow$ voltage variation ΔV



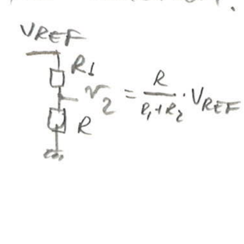
Transducer voltage $v_1 = \frac{R(1+\delta)}{R(1+\delta)+R_1} \cdot V_{REF}$

$$(\Leftrightarrow) \quad v_1 = \frac{R}{R_1+R} V_{REF} + \frac{\delta}{2 + R_1/R + R/R_1 + (1+R/R_1)\delta} \cdot V_{REF}.$$

↑ put in insightful form.

want to eliminate it. ← → interested in amplifying this

Use an IA! perfect candidate. together w/ a second divider



$$\Rightarrow \quad v_0 = A \cdot V_{REF} \cdot \frac{\delta}{1 + \frac{R_1}{R} + \left(1 + \frac{R}{R_1}\right)(1+\delta)}$$

$\delta << 1 \Rightarrow$

$$v_0 \cong A \cdot V_{REF} \cdot \frac{1}{2 + \frac{R_1}{R} + \frac{R}{R_1}} \cdot \delta = f(\delta)$$

linear dependence!

Typically: $R_1 = R \Rightarrow v_0 = \frac{A \cdot V_{REF}}{4} \cdot \frac{\delta}{1 + \frac{\delta}{2}}$

$$v_0 \cong \frac{A\, V_{REF}}{4} \cdot \delta$$

- Bridge calibration
- Strain-Gauge Bridges
- Single OpAmp amplifier
- Bridge Linearization

exercise!