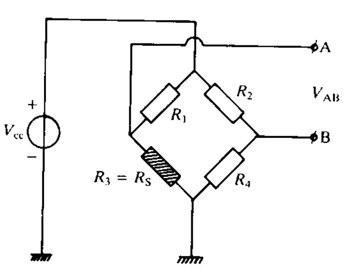
Measurement Systems

Tadeusz Stepinski, Signaler och system

- Elements of measurement systems
  - Bridge circuits
  - Analogue function circuits
    - differential amplifier
    - summing amplifiers
    - logarithmic amplifier
  - Analog filters

Bridge Configurations



- One sensor element
  - Bridge as a compensator
  - Bridge as a basic circuit for measuring passive variables
  - Absolute measurement of resistance deviation

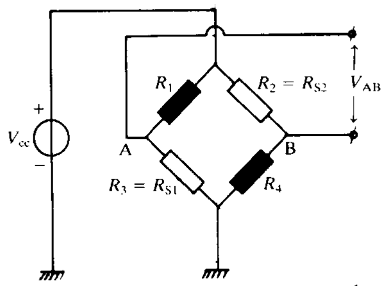
$$R_1 = R_2 = R_4 = R \qquad R_3 = R(1+\delta)$$

$$V_{AB} = V_{CC}\left[\frac{R(1+\delta)}{R+R(1+\delta)} - \frac{R}{2R}\right]$$

$$V_{AB} = V_{CC}\frac{\delta}{4+2\delta} \approx V_{CC}\frac{\delta}{4}$$

Nonlinear effect

Bridge Configurations



- Two sensor elements
  - Differential measurement of resistance deviation
  - High amplification
  - Used for temperature compensation

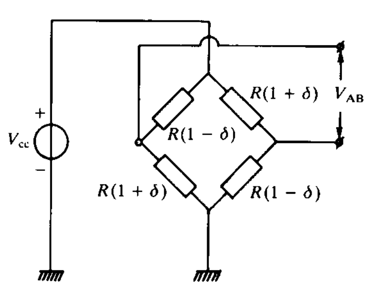
$R_1 = R_4 = R \qquad R_2 = R_3 = R(1+\delta)$

$$V_{AB} = V_{CC}\left[\frac{R(1+\delta)}{R(2+\delta)} - \frac{R}{R(2+\delta)}\right]$$

$$V_{AB} = V_{CC}\frac{\delta}{2+\delta} \approx V_{CC}\frac{\delta}{2}.$$

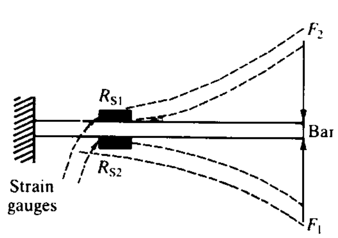
Nonlinear effect

Bridge Configurations



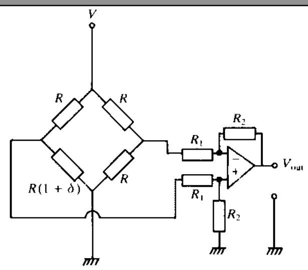
- Four sensor elements
  - Differential measurement of resistance deviation
  - Very high gain

$$V_{AB} = V_{CC}\,\delta$$

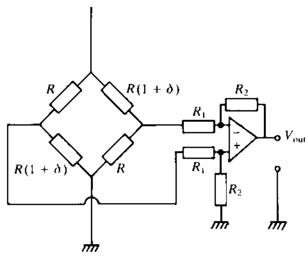


- Example:
  - strain gauge

Bridge Amplifier Configurations

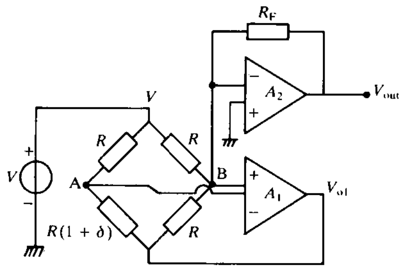


- Bridge with differential amplifier
  - one sensor element



  - two sensor elements

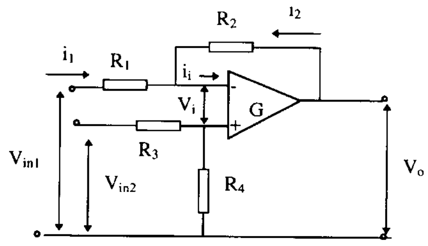
Bridge Amplifier Configurations



- Linearized configuration of a bridge with one sensor in feedback

$$V_{out} = (R_F / R)\, V\, \delta$$

Amplifier Configurations



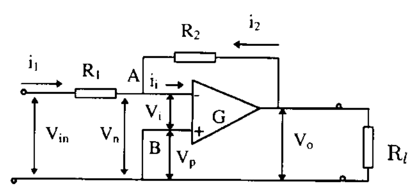
- Differential operational amplifier

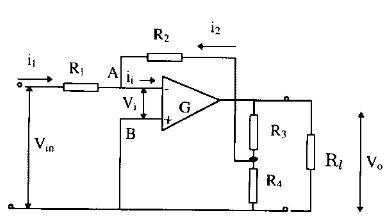
$$V_o = \left(1 + \frac{R_2}{R_1}\right)\frac{R_4}{R_3 + R_4} V_{in2} - \frac{R_2}{R_1} V_{in1}$$

if $R_1 = R_3$ and $R_2 = R_4$

$$V_o = \frac{R_2}{R_1}(V_{in2} - V_{in1})$$

Amplifier Configurations





- Operational amplifiers with feedback loop
  - ordinary amplifier

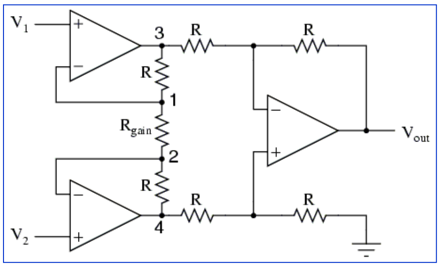
$V_{out} = (-R_2 / R_1)\, V_{in}$

  - fractional feedback
  - high gain for low resistor values

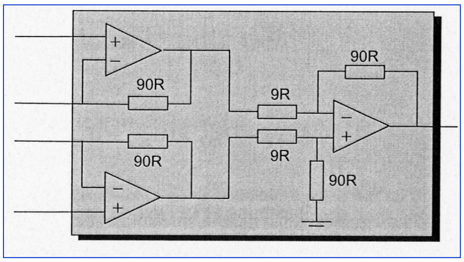
$V_{out} = -\,[(R_3 + R_4) / R_4]\,(R_2 / R_1)\, V_{in}$

Instrumentation Amplifier

- An amplifier with two symmetrical inputs
  - ⇨High impedance at both inputs
  - ⇨High rejection ratio of common mode signals



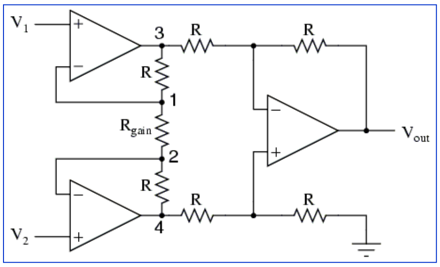
Principal schema



Example of an integrated amplifier

Instrumentation Amplifier - CMRR

- Common Mode Rejection Ratio (CMRR)



$V_{out} = K_{NM}V_{NM} + K_{CM}V_{CM}$

$V_{NM} = V_2 - V_1$

$V_{CM} = (V_2 + V_1)/2$

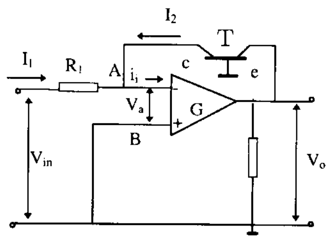
K_{NM} - *normal mode gain*

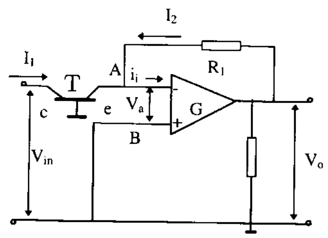
K_{CM} - *common mode gain*

$$CMRR = 20\log\frac{K_{NM}}{K_{CM}}$$

Example: thermoelement

Amplifier Configurations





- Logarithmic amplifier

  for the transistor

  $$I_C = I_{SS} \exp(qV_{BE}/kT)$$

  where: I_{SS} saturation current
  for node A

  $$\frac{V_{in}}{R_1} + I_C = 0 \quad \text{and} \quad \frac{V_{in}}{R_i} + I_{SS} \exp\left(\frac{qV_o}{kT}\right) = 0$$

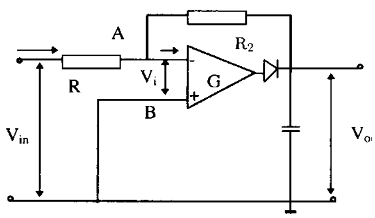
  since $V_{BE} = V_0$

  $$V_o = -\frac{kT}{q} \ln\left(\frac{V_{in}}{R_1 I_{SS}}\right)$$

- Exponential expansion

  $$V_o = R_1 I_{SS} \exp(qV_{in}/kT)$$

Amplifier Configurations



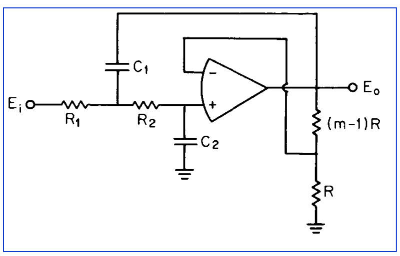
- Peak detector

Filter Configurations

- Second order low pass filter with variable gain

$$\frac{E_o(s)}{E_i(s)} = \frac{K\omega_o^2}{s^2 + s\omega_o/Q + \omega_o^2}$$

$$\frac{E_o(s)}{E_i(s)} = \frac{m/(R_1R_2C_1C_2)}{s^2 + s\,[1/R_1C_1 + 1/R_2C_1 - (m-1)/R_2C_2] + 1/R_1R_2C_1C_2}$$



$$K\omega_o^2 = \frac{m}{R_1R_2C_1C_2}$$

$$\frac{\omega_o}{Q} = \frac{1}{R_1C_1} + \frac{1}{R_2C_1} - \frac{m-1}{R_2C_2}$$

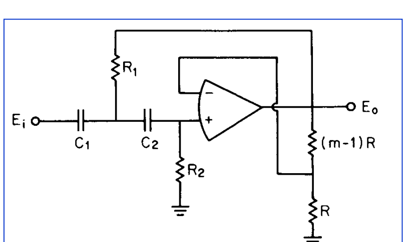
$$\omega_o^2 = \frac{1}{R_1R_2C_1C_2}$$

Filter Configurations

- Second order high pass filter with variable gain

$$\frac{E_o(s)}{E_i(s)} = \frac{Ks^2}{s^2 + s\omega_o/Q + \omega_o^2}$$

$$\frac{E_o(s)}{E_i(s)} = \frac{s^2 m}{s^2 + s\,[1/R_2C_2 + 1/R_2C_1 - (m-1)/R_1C_1] + 1/R_1R_2C_1C_2}$$



$$K = m$$

$$\omega_o^2 = \frac{1}{R_1R_2C_1C_2}$$

$$\frac{\omega_o}{Q} = \frac{1}{R_2C_2} + \frac{1}{R_2C_1} - \frac{m-1}{R_1C_1}$$

Filter Configurations

❑ Second order universal active filter

$$\frac{E_L(s)}{E_i(s)} = \frac{K_L\omega_o^2}{s^2 + s\omega_o/Q + \omega_o^2} \quad \text{low-pass}$$

$$\frac{E_H(s)}{E_i(s)} = \frac{K_H s^2}{s^2 + s\omega_o/Q + \omega_o^2} \quad \text{high-pass}$$

and

$$\frac{E_B(s)}{E_i(s)} = \frac{K_B s\omega_o/Q}{s^2 + s\omega_o/Q + \omega_o^2} \quad \text{bandpass}$$

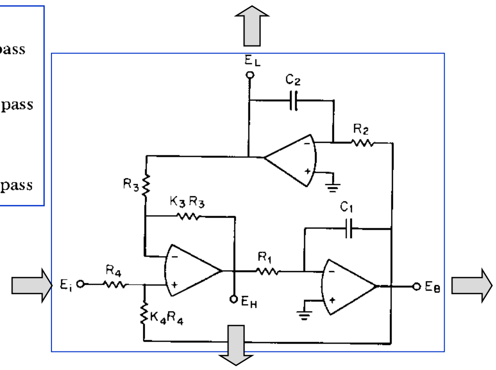
where $\omega_o = \sqrt{\frac{K_3}{R_1R_2C_1C_2}}$

$$Q = \frac{1+K_4}{1+K_3}\sqrt{\frac{K_3R_1C_1}{R_2C_2}}$$

$$K_L = \frac{K_4(1+K_3)}{K_3(1+K_4)}$$

$$K_H = \frac{K_4(1+K_3)}{1+K_4}$$

$$K_B = -K_4$$

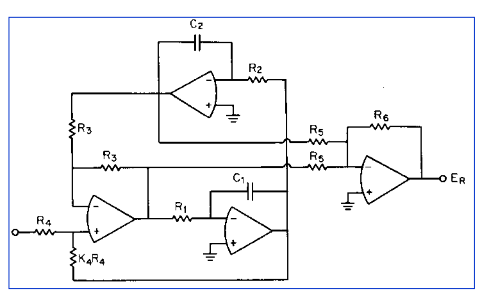


❑ Two integrators and one summing amplifier - state variable technique

Filter Configurations

❑ Band rejection filter using the state variable technique

$$\frac{E_R(s)}{E_i(s)} = \frac{K_R(s^2 + \omega_o^2)}{s^2 + s\omega_o/Q + \omega_o^2}$$



❑ Additional summing amplifier - sum of LP and HP