

# MEMS Inteligentné senzory a aktuátory

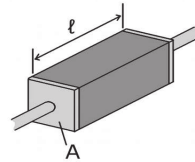
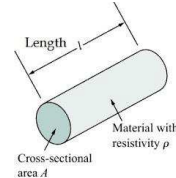
Ing. Richard Balogh

## Odporové snímače

28. 2. 2022

### Elektrický odpor

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



### Závislosť od

1. geometrické rozmery
2. teploty

$$R = R_0(1 + \alpha \Delta t)$$

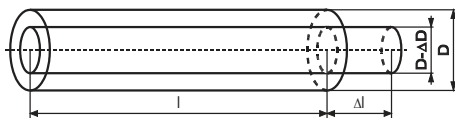
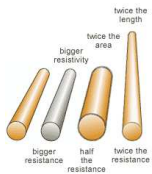
kovy: PTC

polovodiče a oxidy: NTC

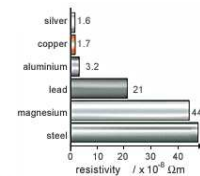
$$l = l_0(1 + \gamma \Delta t)$$

3. piezorezistívny jav
4. vlhkosť

### Elektrický odpor

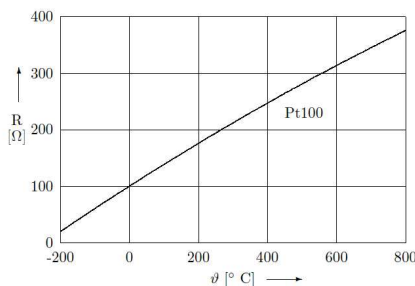


### Elektrický odpor - tabuľky

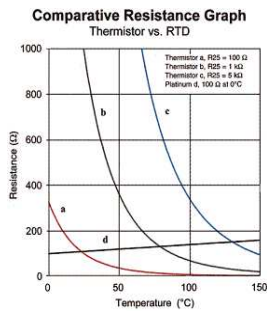


- ◆ Strain Gages 120Ω, 350Ω, 3500Ω
- ◆ Weigh-Scale Load Cells 350Ω - 3500Ω
- ◆ Pressure Sensors 350Ω - 3500Ω
- ◆ Relative Humidity 100kΩ - 10MΩ
- ◆ Resistance Temperature Devices (RTDs) 100Ω, 1000Ω
- ◆ Thermistors 100Ω - 10MΩ

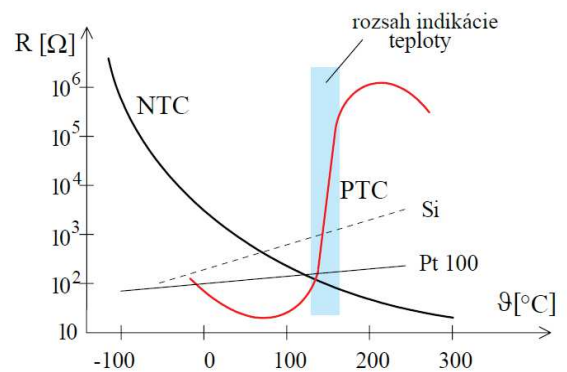
### Elektrický odpor Závislosť od teploty



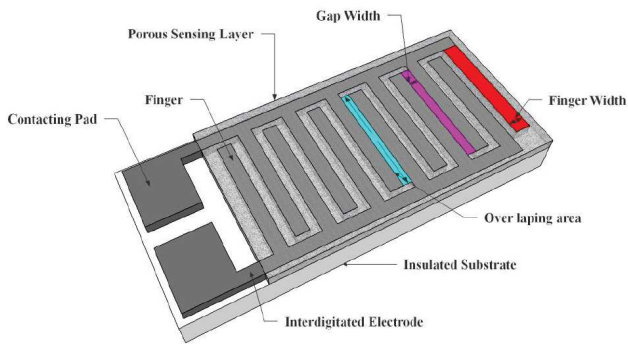
Obr. 33: Prevodová charakteristika Pt100.



### Elektrický odpor Závislosť od teploty



## Elektrický odpor Závislosť od vlhkosti



## Elektrický odpor Závislosť od deformácie

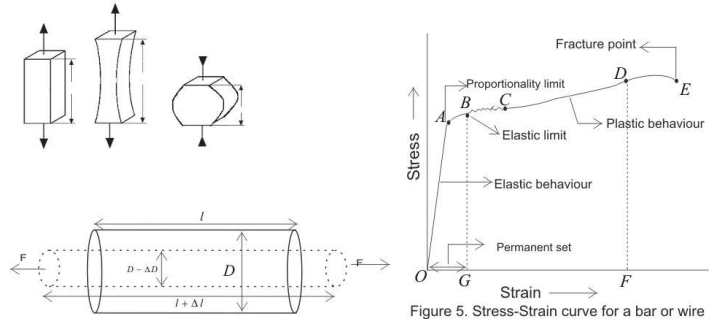
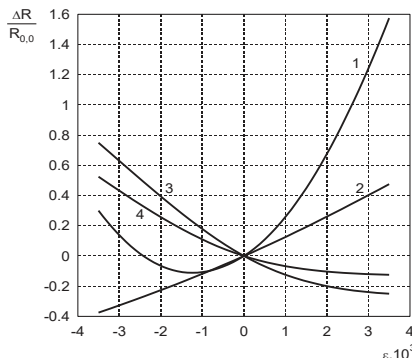


Figure 4.

Figure 5. Stress-Strain curve for a bar or wire

## Elektrický odpor Závislosť od deformácie



Závislosť relatívnej zmeny odporu od relatívnej deformácie pre kremík:

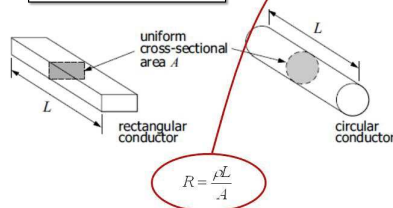
- (1) P-typ s  $\rho > 10^{-3} \Omega m$  (3) N-typ s  $\rho > 10^{-3} \Omega m$   
 (2) P-typ s  $\rho = 2 \cdot 10^{-4} \Omega m$  (4) N-typ s  $\rho = 3,1 \cdot 10^{-4} \Omega m$

## Elektrický odpor

### Gage factors and the piezoresistive effect

What is the relation between deformation and resistance?

$$\text{Gage factor: } F = \frac{\Delta R/R}{\epsilon_L}$$



$$\Delta R = \frac{\partial R}{\partial \rho} \Delta \rho + \frac{\partial R}{\partial L} \Delta L + \frac{\partial R}{\partial A} \Delta A + \text{higher order terms}$$

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta A}{A}$$

**Metals** Changes in geometry dominate  
**Semiconductors** Changes in resistivity dominate

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} \quad \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho}^*$$

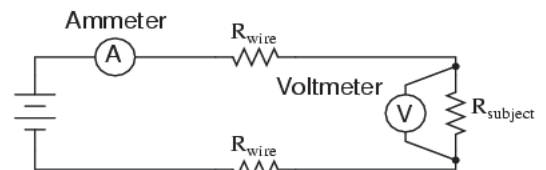
\* Strain causes differences in atomic spacing, which in turn causes changes in band gaps and thus  $\rho$ .

## Meranie odporu

- meranie U a I
- meranie U (konšt. I)
- prevod na frekvenciu
- mostíkové zapojenia

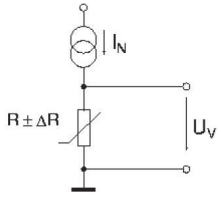


## Meranie odporu Meranie napätia a prúdu

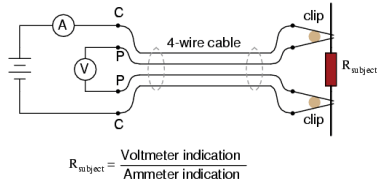


$$R_{\text{subject}} = \frac{\text{Voltmeter indication}}{\text{Ammeter indication}}$$

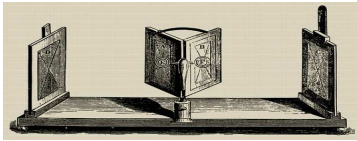
# Meranie odporu Meranie napätia



$$U_v = I_N(R \pm \Delta R)$$



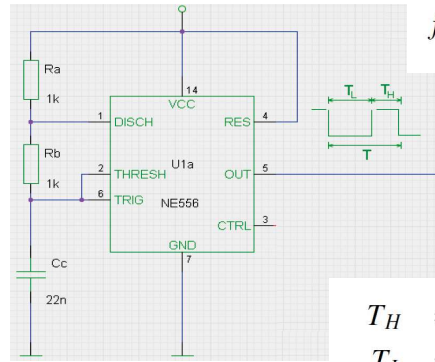
# Mostíkové zapojenia Wheatstonov mostík



Charles Wheatstone (1802-75)



# Meranie odporu Prevod na frekvenciu

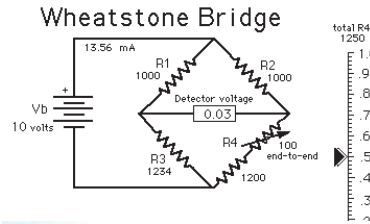


$$f = \frac{1,429}{C_c(R_a + 2R_b)}$$

$$T_H = 0,7(R_a + R_b)C_c$$

$$T_L = 0,7R_b C_c$$

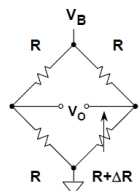
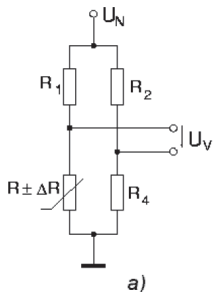
# Mostíkové zapojenia Wheatstonov mostík The Differential Resistance Measurer



Samuel Hunter Christie



# Meranie odporu Mostíkové zapojenia



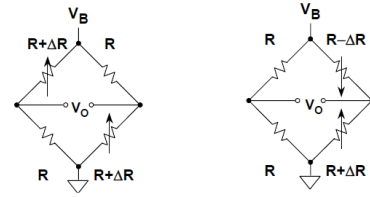
$$V_O = \frac{V_B}{4} \left[ \frac{\Delta R}{R + \frac{\Delta R}{2}} \right]$$

Linearity Error: 0.5%/%

(A) Single-Element Varying

$$U_v = U_N \left( \frac{R \pm \Delta R}{2R \pm \Delta R} - \frac{1}{2} \right)$$

# Meranie odporu Mostíkové zapojenia



$$\frac{V_B}{2} \left[ \frac{\Delta R}{R + \frac{\Delta R}{2}} \right]$$

0.5%/%

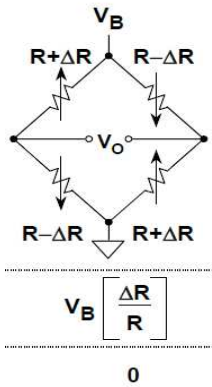
(B) Two-Element Varying (1)

$$\frac{V_B}{2} \left[ \frac{\Delta R}{R} \right]$$

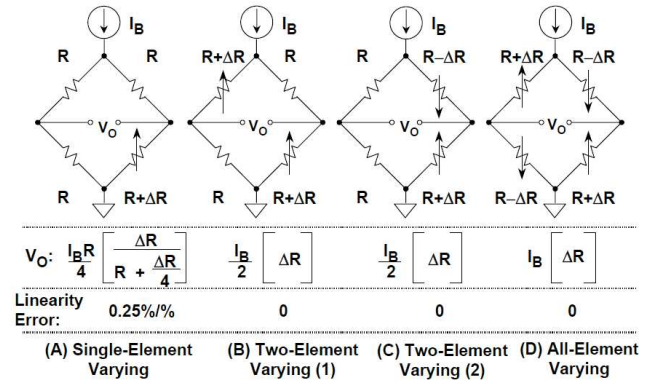
0

(C) Two-Element Varying (2)

## Meranie odporu Mostíkové zapojenia



## Meranie odporu Mostíkové zapojenia



## Meranie odporu Mostíkové zapojenia - vyhodnotenie

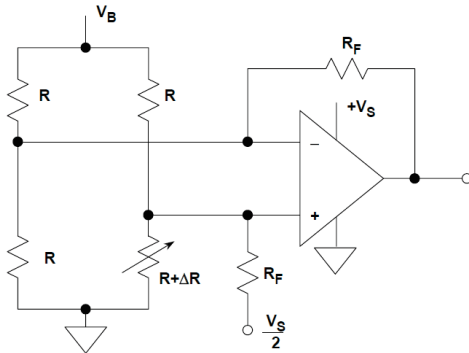


Figure 4-9: Using a single op amp as a bridge amplifier

## Meranie odporu Mostíkové zapojenia - vyhodnotenie

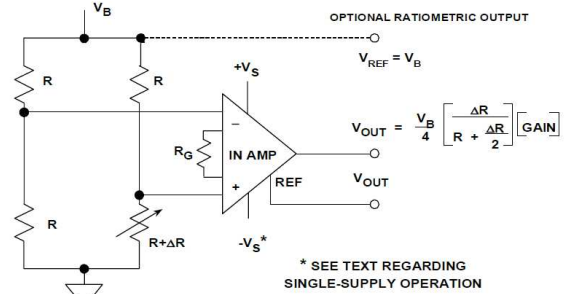
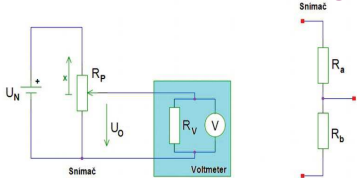


Figure 4-10: A generally preferred method of bridge amplification employs an instrumentation amplifier for stable gain and high CMR

## Meranie odporu Potenciometrický snímač polohy



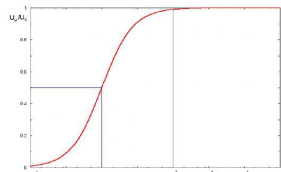
$$R_b = R_p x$$

$$R_a = R_p(1 - x)$$

$$U_o = U_N \frac{R_b}{R_a + R_b} = U_N \frac{R_p x}{R_p} = U_N x$$

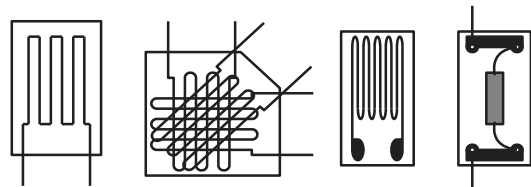
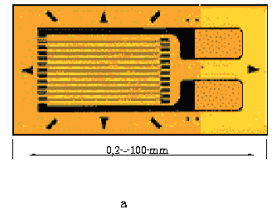


Obr. 1. Lineárny potenciometrický senzor.



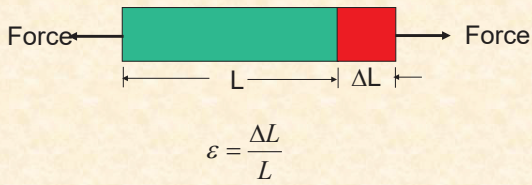
Obr. 2. Impedančné prispôsobenie zozlňovača.

## Tenzometre



# Tenzometer Strain Gauge

Definition of strain,  $\varepsilon$



# Tenzometre

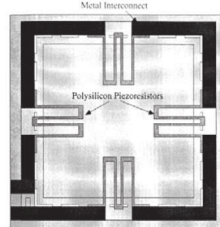
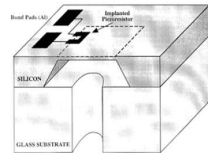
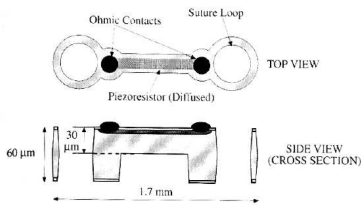
Tab.1 Prehľad vlastností nalepených tenzometrov

Tenzometre	Fóľové	Polovodičový	
Typ	KFC-2-D1-23 (R <sub>CE</sub> )	KFC-5-350-C1-23 (R <sub>CA</sub> , R <sub>CB</sub> , R <sub>CE</sub> )	KSP-2-E3 (R <sub>CB</sub> )
Odpor R [Ω]	119.9±0.4	350±0.6	110±2%
Súčiniteľ deformačnej citlivosti K	2.11	2.1±1%	124±3%
Teplotný súčiniteľ deformačnej citlivosti α <sub>0,01</sub> [1/°C]	≈ 0	≈ 0	0.14%
Teplotný súčiniteľ elektrického odporu α <sub>0,01</sub> [μm/m/°C, tj. 10 <sup>-6</sup> /°C]	1.8	1.8	13.8
Súčiniteľ teplotnej rozťažnosti materiálu tenzometra α [μm/m/°C]	≈ 0	≈ 0	7÷22
Výrobca	Kyowa Tokyo	Kyowa Tokyo	Kyowa Tokyo
Max. relatívne predženie ε [μm/m]	±3000	±3000	±2000
Dĺžka aktívnej mriežky [mm]	2	5	2
Poznámka	tepelná kompenzácia pre namáhaný materiál-hliník(23μm/m/°C)	tepelná kompenzácia pre namáhaný materiál-hliník(23μm/m/°C)	

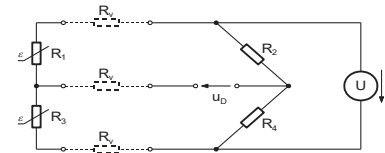
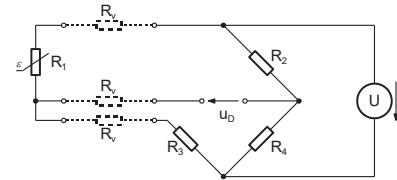
Membrane type gauges: typical pressure sensor

# MEMS Tenzometre

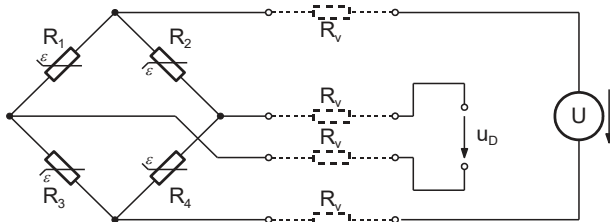
Implantable strain gauge



# Tenzometre



# Tenzometre



# Využitie tenzometrov Váženie



# Využitie tenzometrov

## Sila

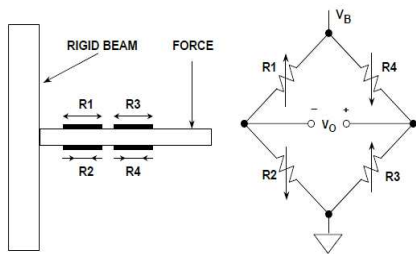


Figure 3.83: A beam force sensor using a strain gage bridge