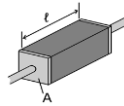
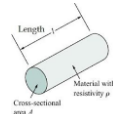


## 2. Odporové snímače

1

### Elektrický odpor

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



#### Závislosť od

1. geometrické rozmery
2. teploty

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

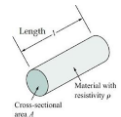
kovy: PTC  
polovodiče a oxidy: NTC  
ale aj  $l = l_0(1 + \gamma \Delta t)$

3. piezorezistívny jav
4. vlhkosť

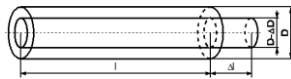
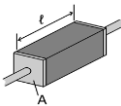
2

### Elektrický odpor

#### 2.1 Závislosť na rozmeroch a deformácii



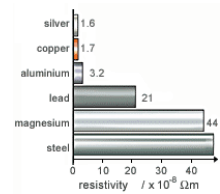
$$R = \rho \frac{l}{A}$$



3

### 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

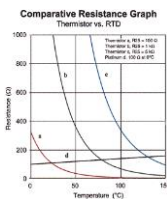
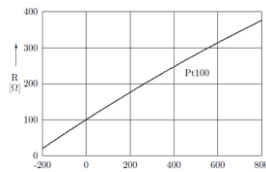


4

### Elektrický odpor

#### 2.2 Závislosť od teploty

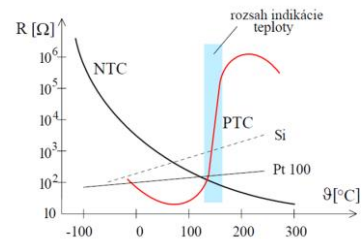
$$R(\theta) = R_0(1 + A\theta + \beta\theta^2) \quad A = 3,9083 \cdot 10^{-4} \quad B = -5,775 \cdot 10^{-7}$$



5

### Elektrický odpor

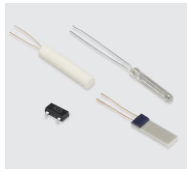
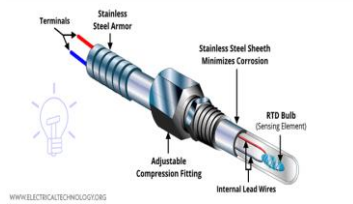
#### Závislosť od teploty



6

2. Resistive sensors  
2.2 Odporové snímače teploty

**RTD - Resistance Temperature Detector**  
Construction, Types, Working & Applications



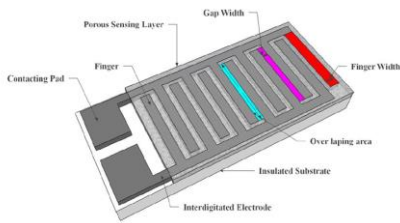
2. Resistive sensors  
Odporové snímače teploty



7

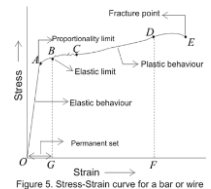
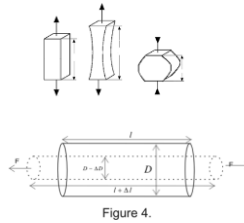
8

Elektrický odpor  
Závislost' od vlhkosti



9

Elektrický odpor  
Závislost' od deformácie



10

Elektrický odpor

Gage factors and the piezoresistive effect

What is the relation between deformation and resistance?

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

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

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

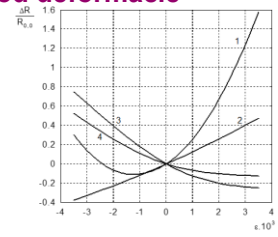
**Metals**  
Changes in geometry dominate  
 $\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A}$

**Semiconductors**  
Changes in resistivity dominate  
 $\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho}$

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

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Elektrický odpor  
2.4 Závislost' od deformácie

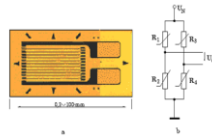


Závislosť relatívnej zmeny odporu od relatívnej deformácie pre kremík

- (1) P-tyt  $\rho \approx 10^{-3} \Omega \cdot m$
- (2) P-tyt  $\rho \approx 2 \cdot 10^{-4} \Omega \cdot m$
- (3) N-tyt  $\rho \approx 10^{-3} \Omega \cdot m$
- (4) N-tyt  $\rho \approx 3 \cdot 10^{-4} \Omega \cdot m$

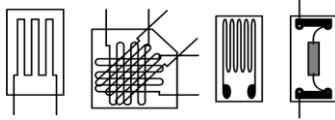
12

## Tenzometer Strain Gauge



Def.:  
pomerné predĺženie (strain)  $\epsilon$

$$\epsilon = \frac{\Delta L}{L}$$



13

## Tenzometre

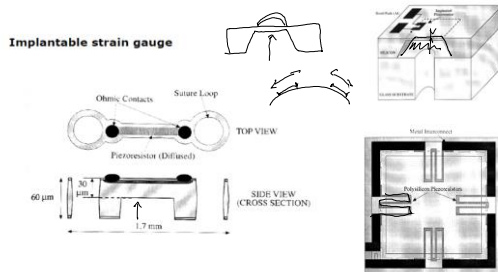
Tab. 1 Prehľad vlastností nalepených tenzometrov

Tenzometre	Fólové	Polovodičový	
Typ	KFC-2-D1-23 (R <sub>0a</sub> )	KFC-5-350-C1-23 (R <sub>0</sub> , R <sub>0a</sub> , R <sub>0b</sub> )	KSP-2-E3 (R <sub>0a</sub> )
Odpor R [Ω]	120, 350, 1 k	Kódová	120, 225
Sčítateľ deformácie citlivosť K	2.11	Kε	2.1±1%
Teplotný sčítateľ deformácie citlivosť α <sub>0a</sub> [1/°C]	≈ 0	≈ 0	0.14%
Teplotný sčítateľ elektrického odporu α <sub>0a</sub> [μm/m/°C, Ω, °C]	1.8	1.8	13.8
Sčítateľ teplotnej rozťažnosti materiálu tenzometra α <sub>0</sub> [μm/m/°C]	≈ 0	≈ 0	7-22
Výrobca	Kyowa Tokyo	Kyowa Tokyo	Kyowa Tokyo
Max. relatívne predĺženie ε [μm/m]	±3000	±3000	±2000
Dĺžka aktívnej mriežky [mm]	2	5	2
Poznámka	tepelná kompenzácia pre namáhaný materiál (23 μm/m/°C)	tepelná kompenzácia pre namáhaný materiál (23 μm/m/°C)	

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## MEMS Tenzometre

Membrane type gauges: typical pressure sensor



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## Využitie tenzometrov Sila

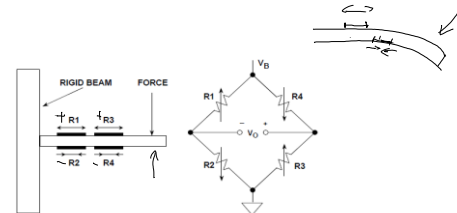


Figure 3.83: A beam force sensor using a strain gauge bridge

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## Využitie tenzometrov Vázenie



17

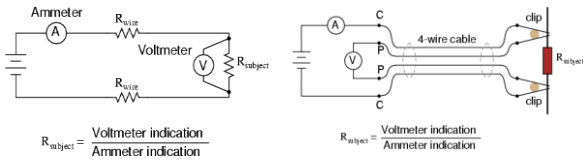
## Meranie odporu

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



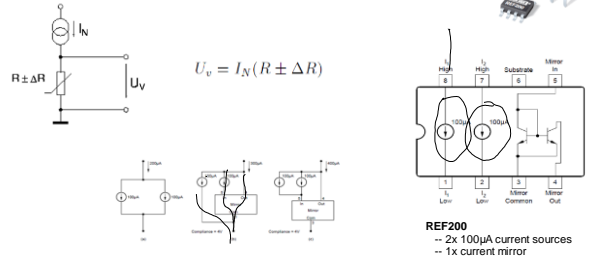
18

Meranie odporu  
Meranie napätia a prúdu



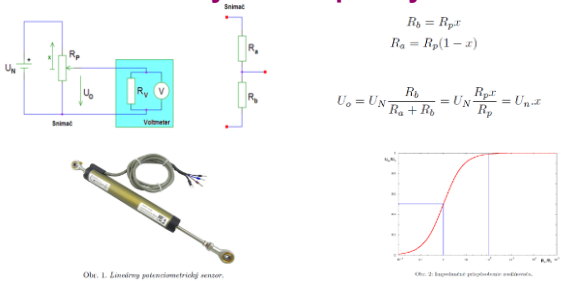
19

Meranie odporu  
Meranie napätia / zdroj prúdu

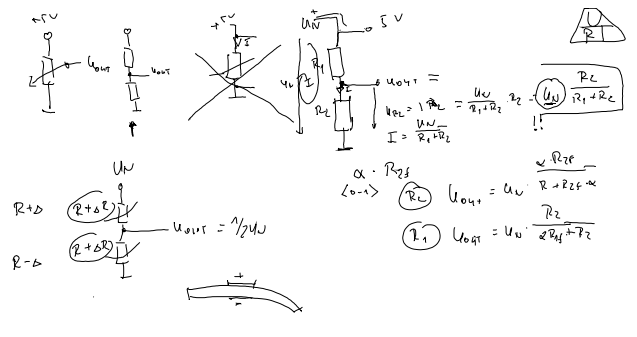


20

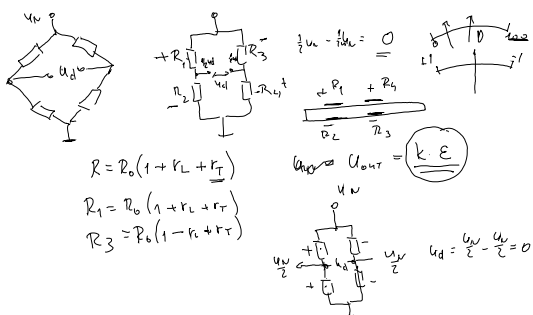
Meranie odporu  
Potenciometrický snímač polohy



21

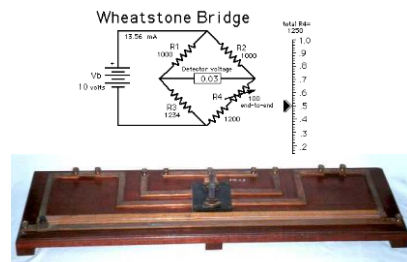


22



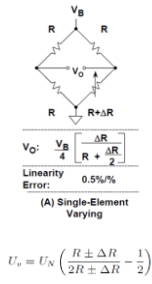
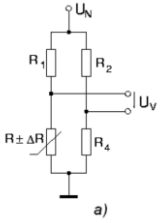
23

Mostíkové zapojenia  
Wheatstonov mostík  
The Differential Resistance Measurer



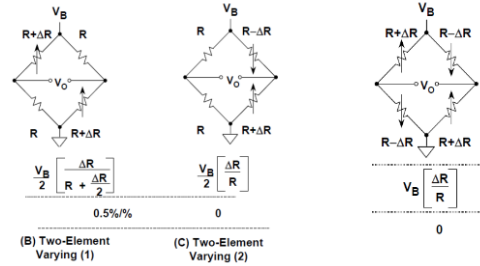
24

Meranie odporu  
Mostíkové zapojenia



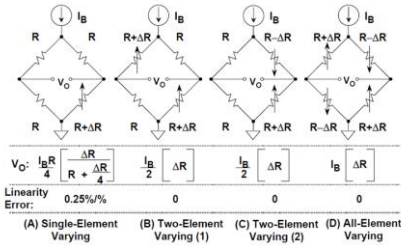
25

Meranie odporu  
Mostíkové zapojenia



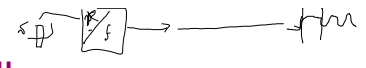
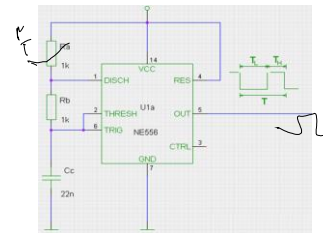
26

Meranie odporu  
Mostíkové zapojenia



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Meranie odporu  
Prevod na frekvenciu



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

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

$$T_L = 0,7R_b C_c$$

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Zafažovacia konštanta

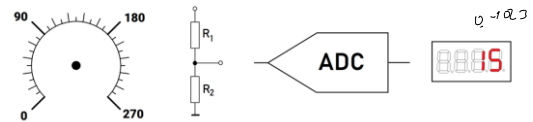
Zafažovacia konštanta  $D$  [ $W.K^{-1}$ ] predstavuje príkon  $P$ , potrebný k ohriatiu senzora o teplotu  $\Delta \vartheta = 1K$  nad teplotu okolitého prostredia.

Max. hodnota meracieho prúdu  $I_{dov}$

$$I_{dov} = \sqrt{\frac{\Delta \vartheta_{max} 17}{R_s}} [W.K^{-1}]$$

29

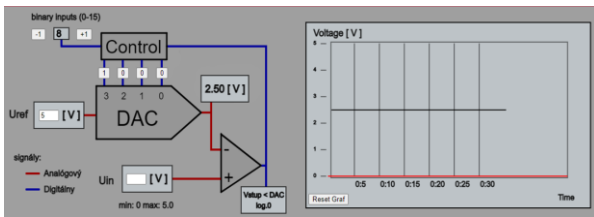
Príklad 1: meranie



Uhol	N
[°]	[-]
0	0
90	5
180	10
270	15

30

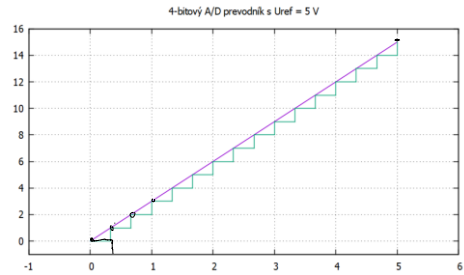
### Príklad 1: 4-bitový A/D prevodník



[https://senzor.robotika.sk/mmp/anim/ADC\\_4bit/sac.html](https://senzor.robotika.sk/mmp/anim/ADC_4bit/sac.html)

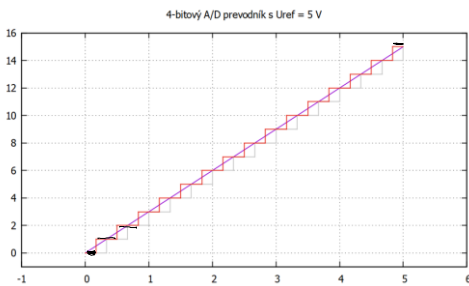
31

### Príklad 1: 4-bitový A/D prevodník



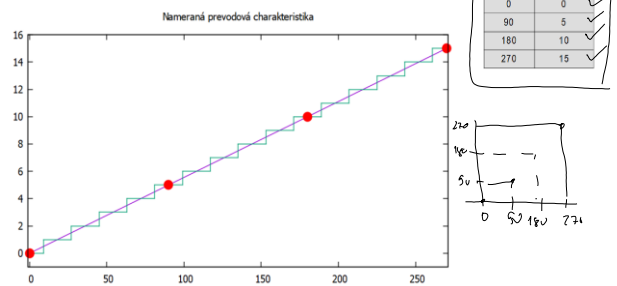
32

### Príklad 1: 4-bitový A/D prevodník



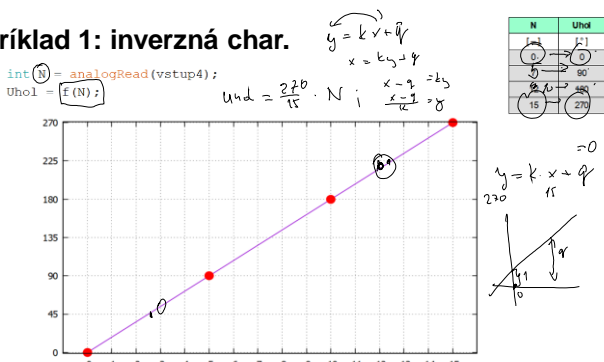
33

### Príklad 1: charakteristika



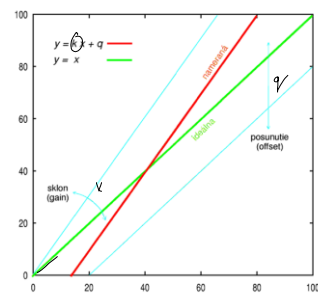
34

### Príklad 1: inverzná char.



35

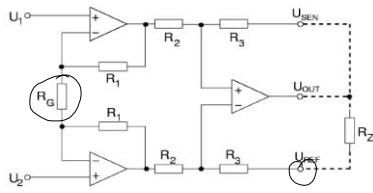
### Nastavovanie K a q



36

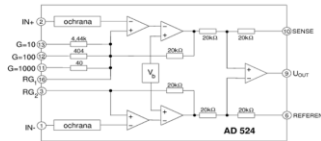
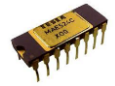
### Klasický prístrojový zosilňovač

$$U_o = \Delta_K(u_1 - u_2) = K u_1 - K u_2$$



### Integrovaný obvod AD 524

Analog Devices, TESLA (MAC524), a pod.



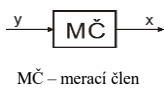
Nelinearita	0,003%	Zosilnenie	1, 10, 100, 1000, A
CMRR	120 dB	Offset	50 μV
Drift	0,5 μV/°C	Sum	0,3 μV p-p
I vst	50 nA	R vst	10 <sup>6</sup> Ω

Ochrana vstupov (max. 3 mA pre ±36 V). Puzdro DIL 16

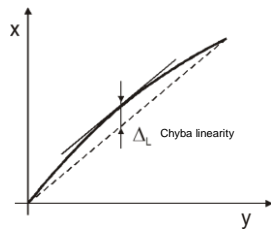
37

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### Nelineárna prevodová charakteristika



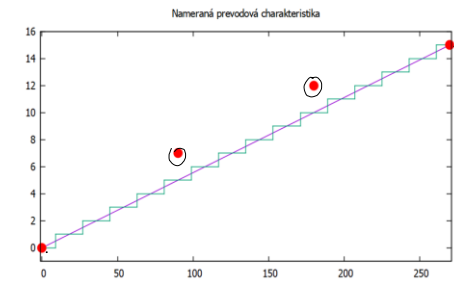
MČ – merací člen



39

### Príklad 2: charakteristika namerané údaje

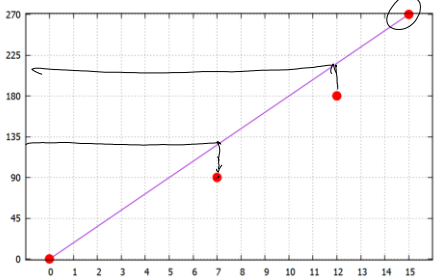
Uhoh	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15



40

### Príklad 2: inverzná char.

Uhoh	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15

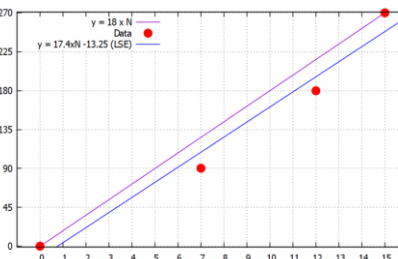


```
> N = [0 15]
> Uhoh = [0 270]
> p = polyfit(N,Uhoh,1)
p = 17.4419  -13.2558
> polyval(p,[0 7 12 15])
ans = 126.210  210.000  270.000
t = 3  7  12  15
```

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### Príklad 2: inverzná char. metóda najmenších štvorcov least squares estimation

Uhoh	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15



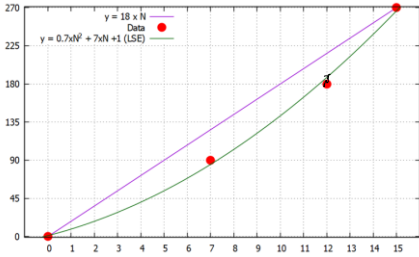
```
> N = [0 7 12 15]
> Uhoh = [0 90 180 270]
> p = polyfit(N,Uhoh,1)
p = 17.4419  -13.2558
> polyval(p,N) - Uhoh
ans = 13.2558  18.8372  16.0465  -21.6279
```

Uhoh = 17,4419 \* v - 13,2558

42

### Príklad 2: inverzná char. metóda najmenších štvorcov least squares estimation

Uhol	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15



```

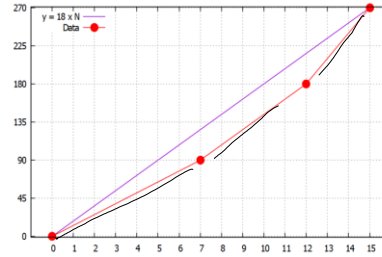
> N = [0 7 12 15]
> Uhol = [0 90 180 270]
> p = polyfit(N,Uhol,2)
p
[0.7091 7.0364 1.0089]
> polyval(p,N) - Uhol
1.09 -4.98 7.63 -3.81
    
```

$u_{lin} = 0,7x^2 + 7x + 1$

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### Príklad 2: inverzná char. po častiach lineárna náhrada PWL - piecewise linear approx.

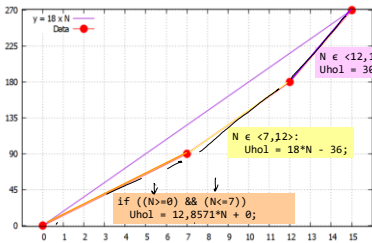
Uhol	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15



44

### Príklad 2: inverzná char. po častiach lineárna náhrada PWL - piecewise linear approx.

Uhol	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15



```

if ((N>=0) && (N<=7))
    Uhol = 12,8571*N + 0;
    
```

```

N ∈ <12,15>:
Uhol = 30*N - 180;
    
```

```

N ∈ <7,12>:
Uhol = 18*N - 36;
    
```

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### Príklad 2: inverzná char. tabuľka

Uhol	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15

```

> N = [0 7]
> Uhol = [0 90]
> p = polyfit(N,Uhol,1)
p
12.8571
0
> polyval(p,[0 1 2 3 4 5 6 7])
12.8571 12.8571 25.7143 38.5714
51.4286 64.2857 77.1429 90.0000

> N = [7 12]
> Uhol = [90 180]
> p = polyfit(N,Uhol,1)
> polyval(p,[7 8 9 10 11 12])
108 126 144 162 180

> N = [12 15]
> Uhol = [180 270]
> p = polyfit(N,Uhol,1)
> polyval(p,[12 13 14 15])
210 240 270
    
```

N	Uhol
0	0
1	13
2	26
3	38
4	51
5	64
6	77
7	90
8	108
9	126
10	144
11	162
12	180
13	210
14	240
15	270

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### Príklad 2: inverzná char. tabuľka

Uhol	Lin	N
[*]	[*]	[*]
0	0	0
90	5	7
180	10	12
270	15	15

N	Uhol
0	0
1	13
2	26
3	38
4	51
5	64
6	77
7	90
8	108
9	126
10	144
11	162
12	180
13	210
14	240
15	270

```

#include <avr/pgmspace.h>
//
const PROGMEM int tabuľka[] = {0, 13, 26, 38, 51, 64, 77, 90, 108, 126, 144, 162, 180, 210, 240, 270};
...
int N = atoi(argv[4]);
Uhol = tabuľka[N];
    
```

Spotreba pamäti: sizeof(int) = 2; ==> 2x16 B = 32 B

Pre 10-bitový prevodník: 2 x 1024 = 2kB

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