Sensors of temperature (contact)

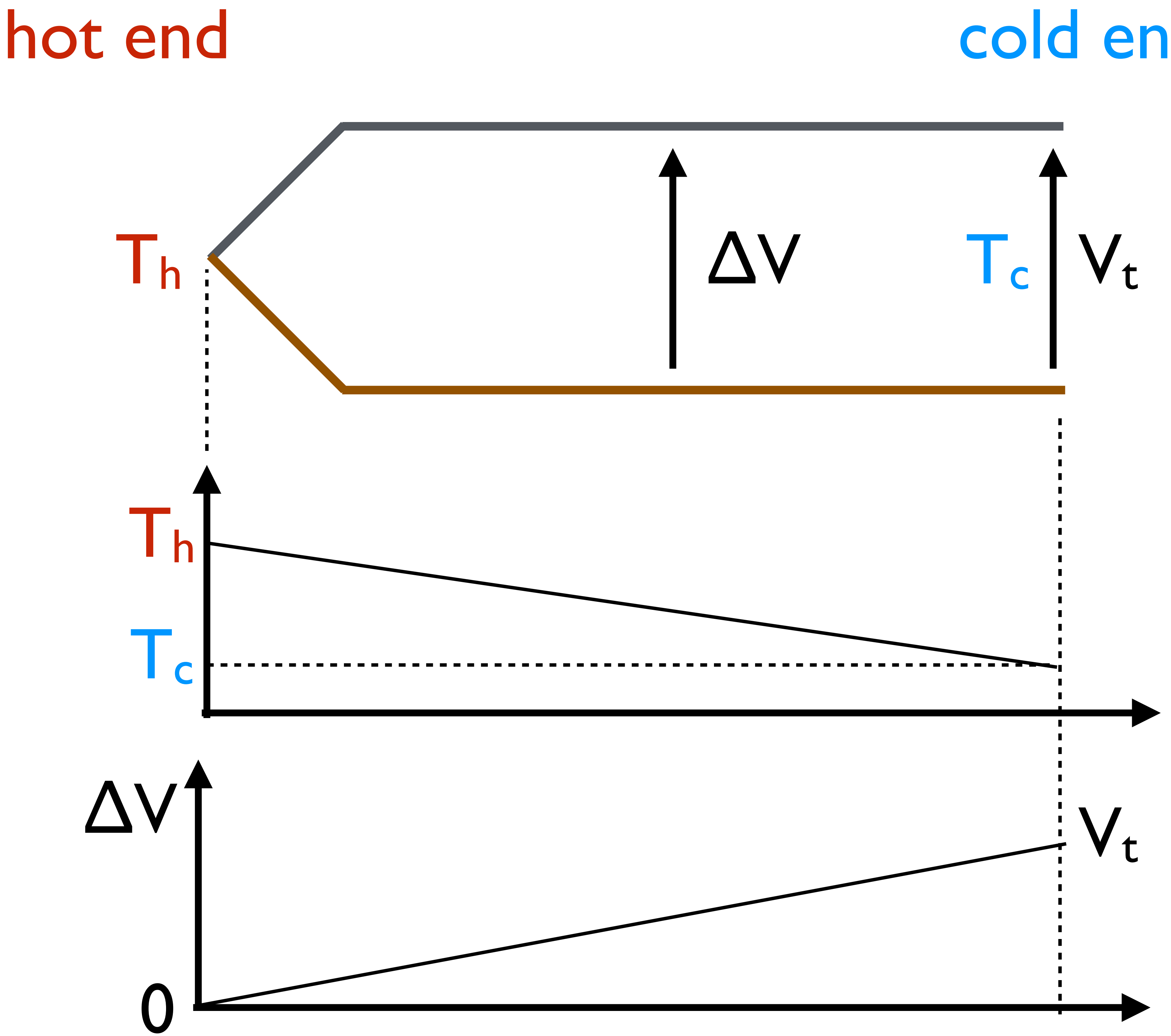
AE3B38SME - Sensors and Measurement

Thermocouples

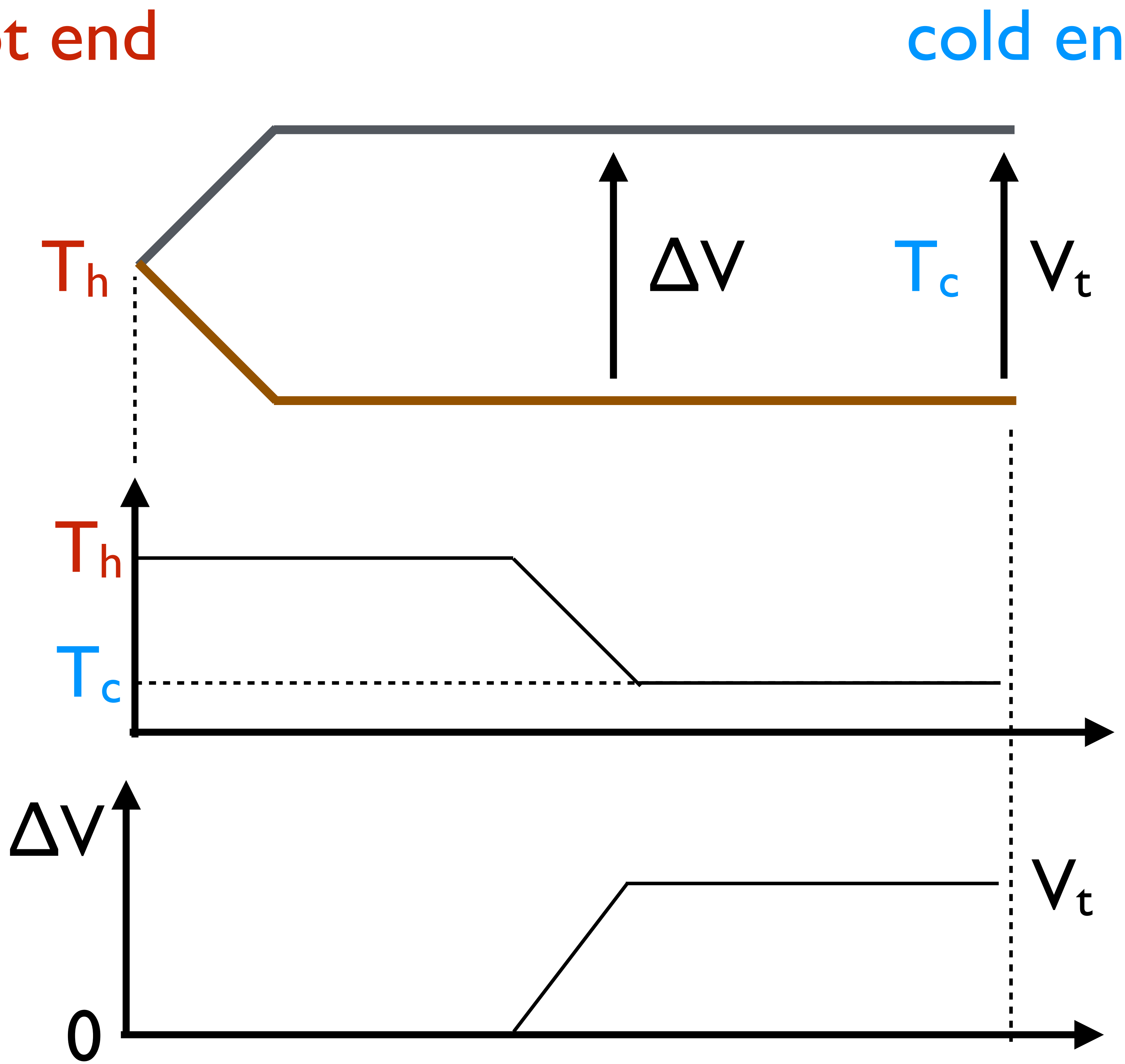
$$V_t = k\,(T_h - T_c)$$

- it is composed of different materials
- it measure the difference of temperature

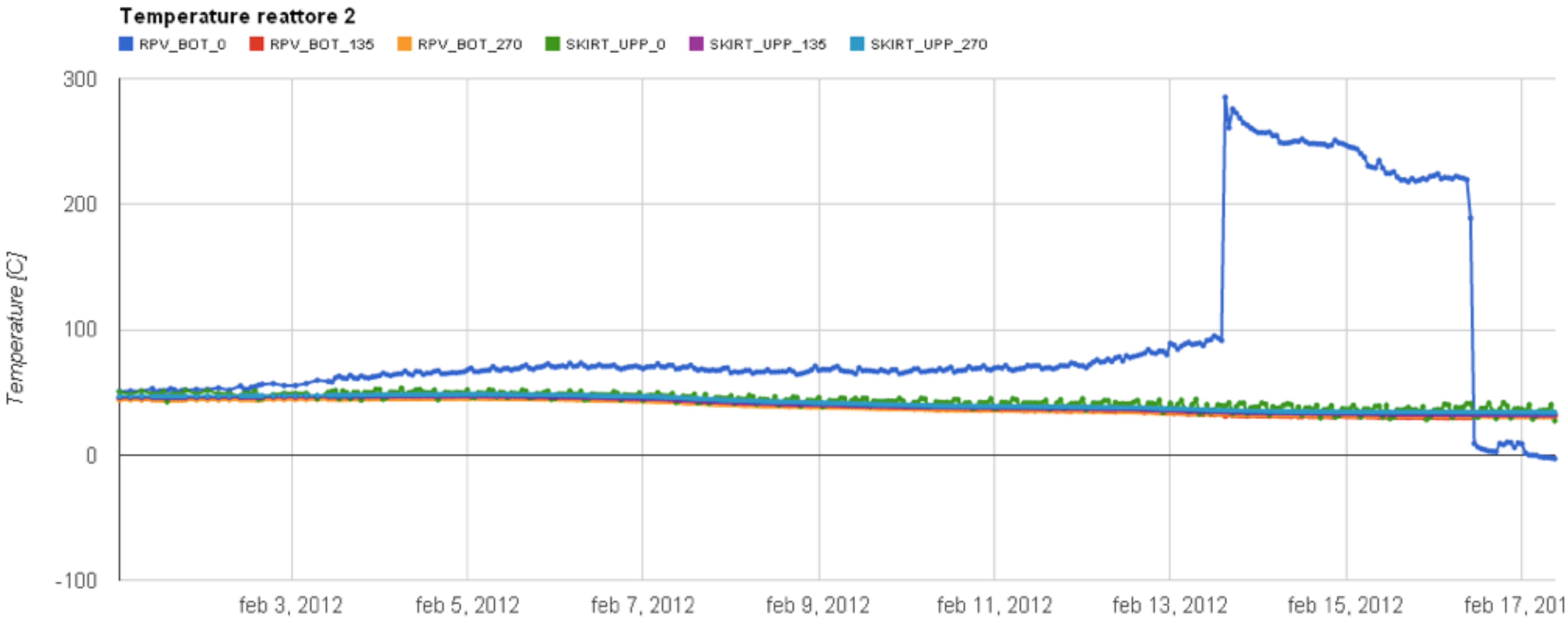
The voltage is generated by gradient of temperature



The voltage is generated by gradient of temperature



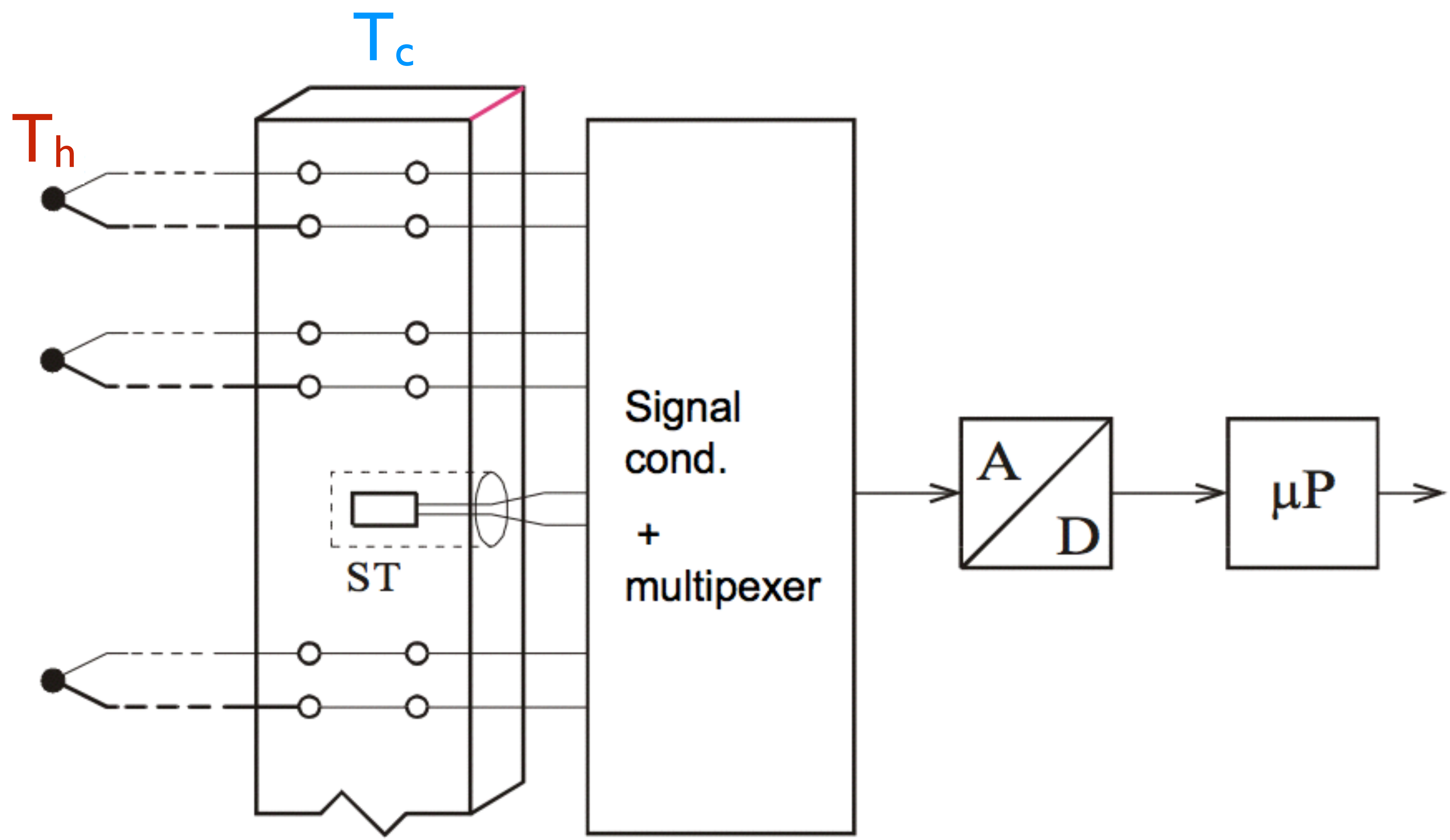
Thermocouples are very robust, but they might fail too



Unicolab

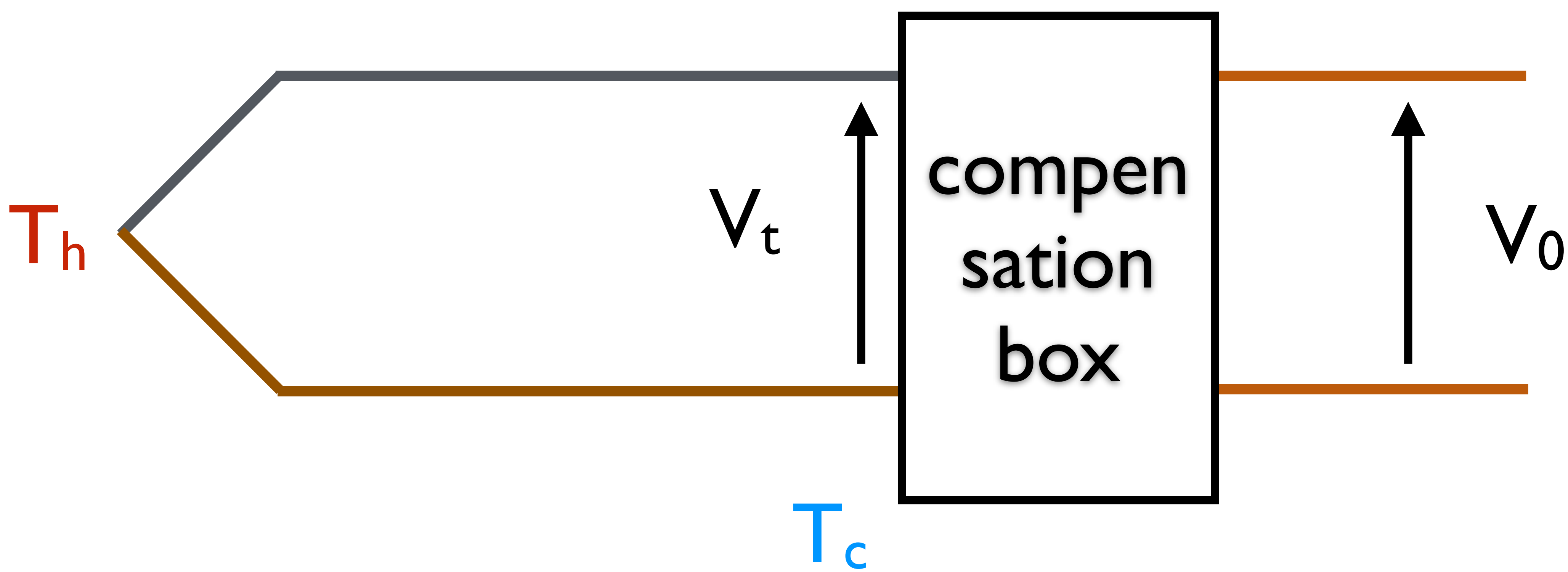
Compensation of cold end temperature

- by measuring the temperature at cold end and numerically adjust the reading



Compensation of cold end temperature

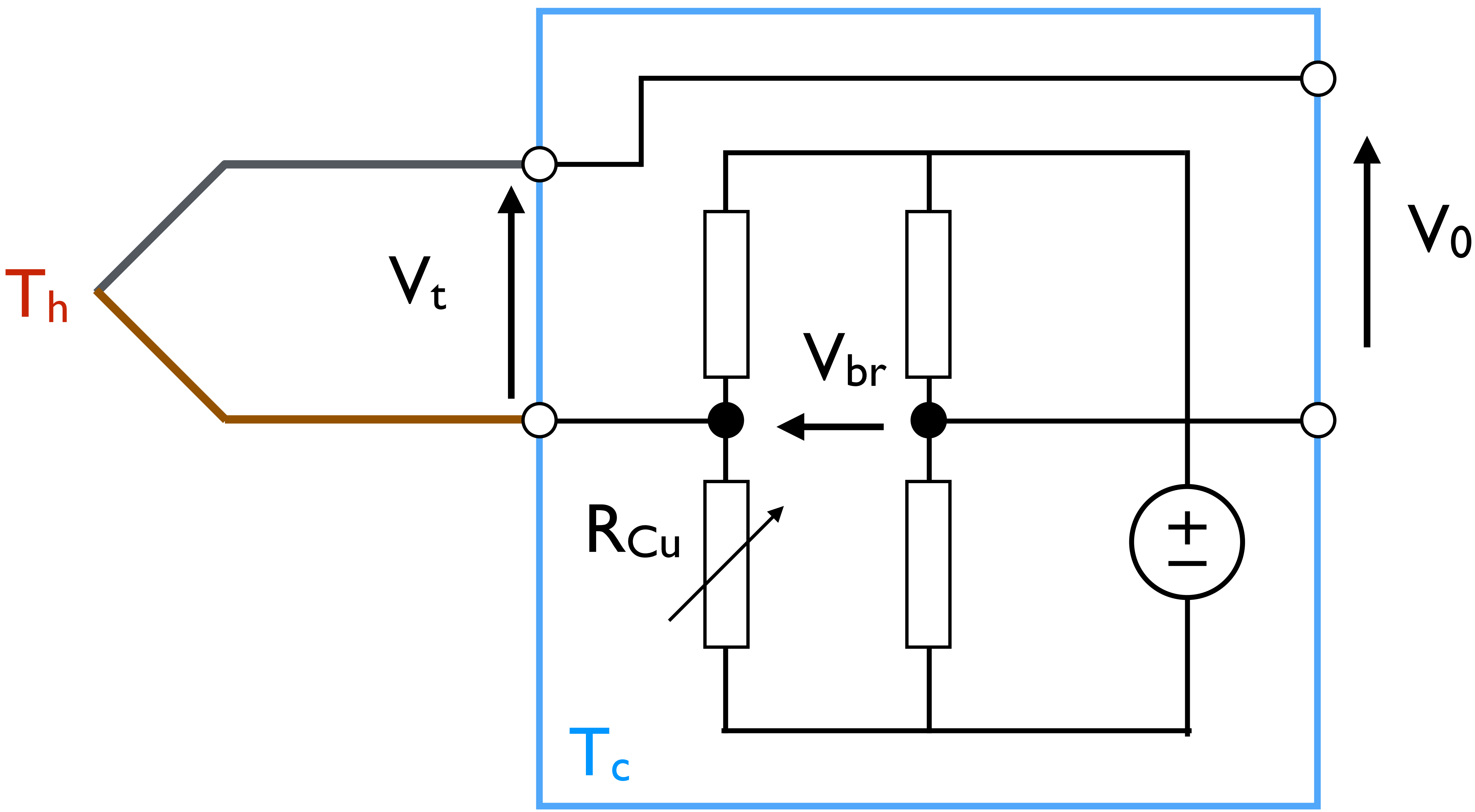
- using compensation box



$V_t = k\,(T_h - T_c)$

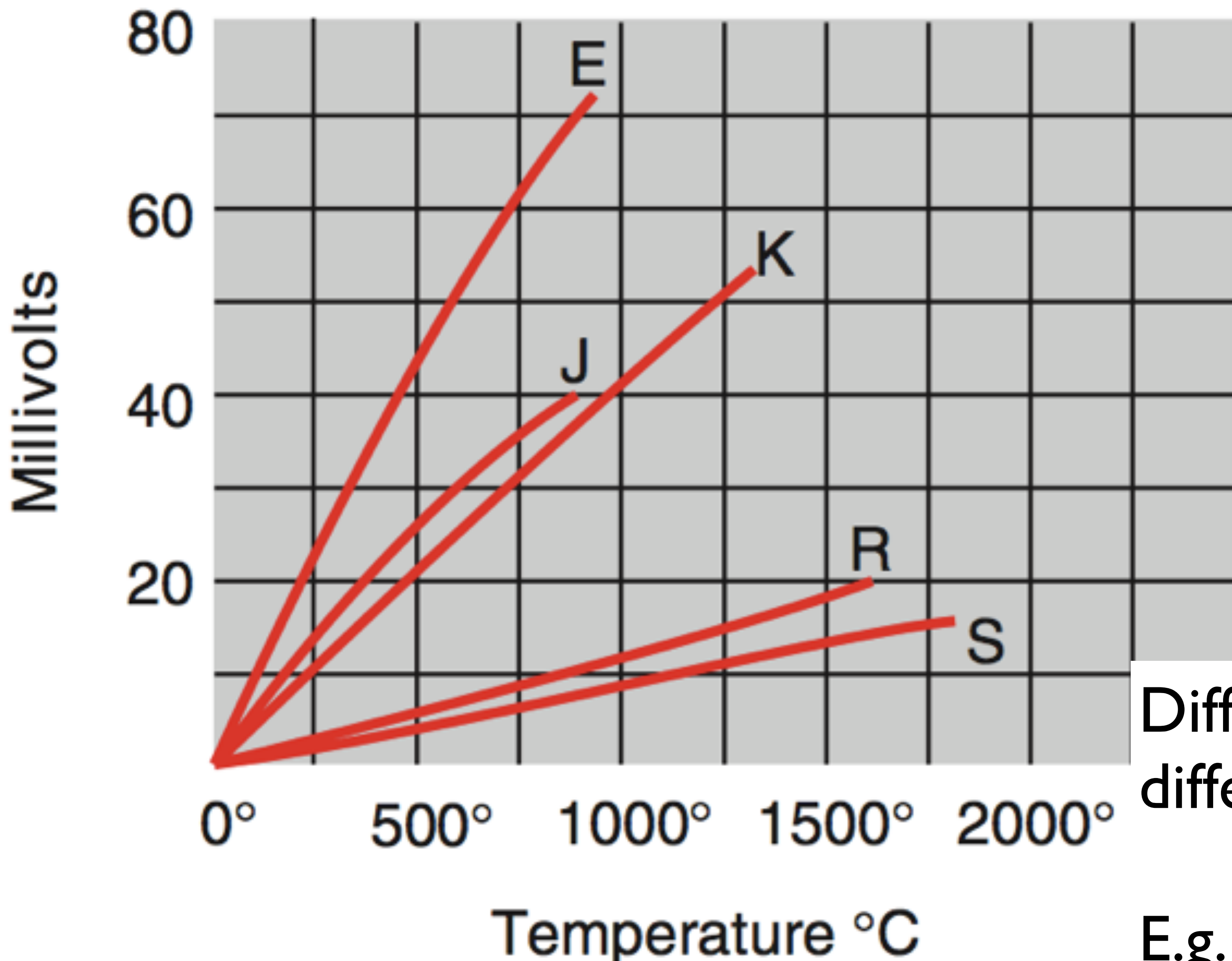
$V_0 = k\,T_h$

Compensation box



$$V_0 = V_t + V_{br} = k\,(T_h - T_c) + k'\,T_c$$

Types of thermocouples



Omega

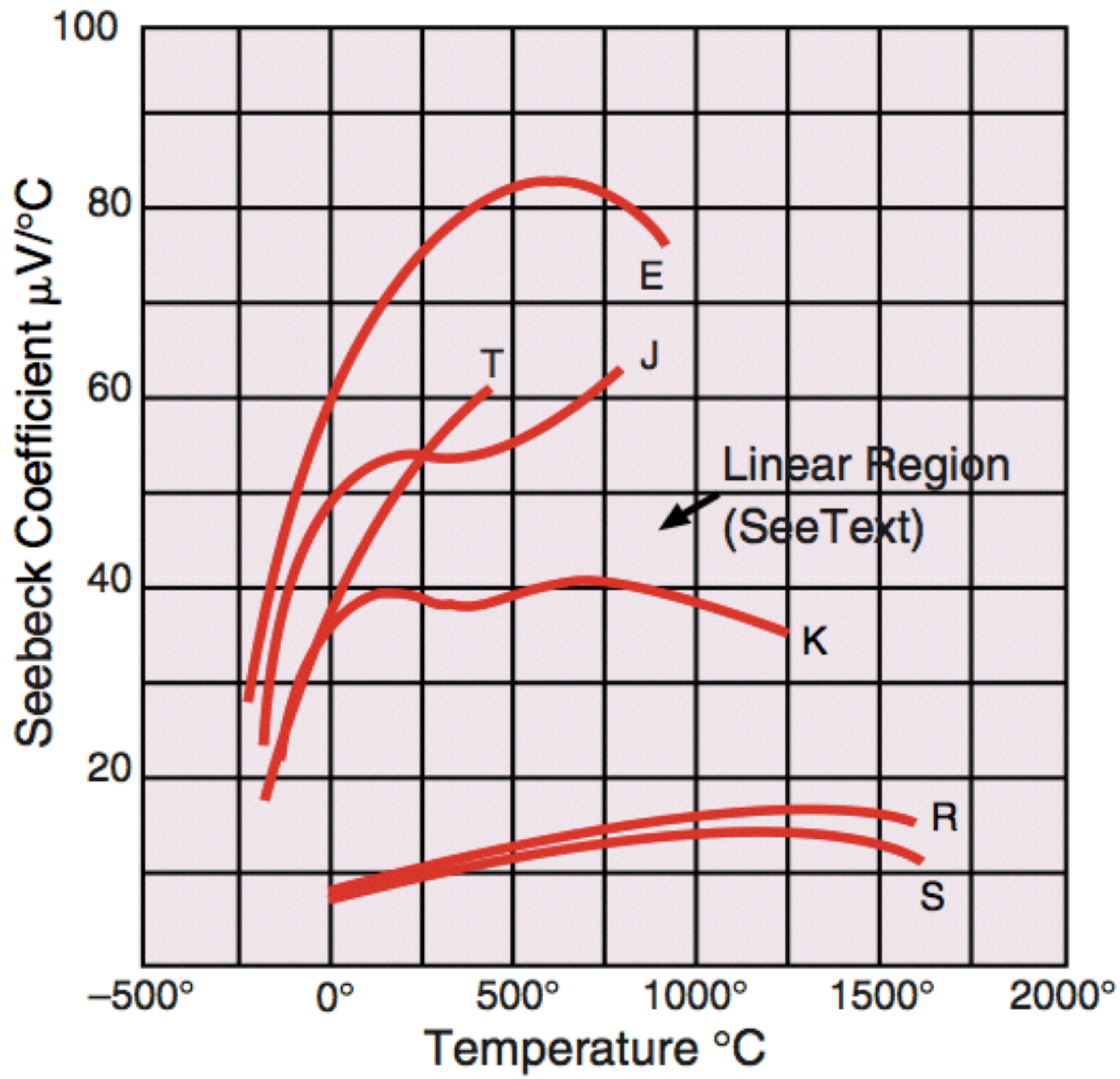
Different couples of metals give different response

E.g. K type : Chromel-Alumel

Chromel:90% nickel + 10% chromium

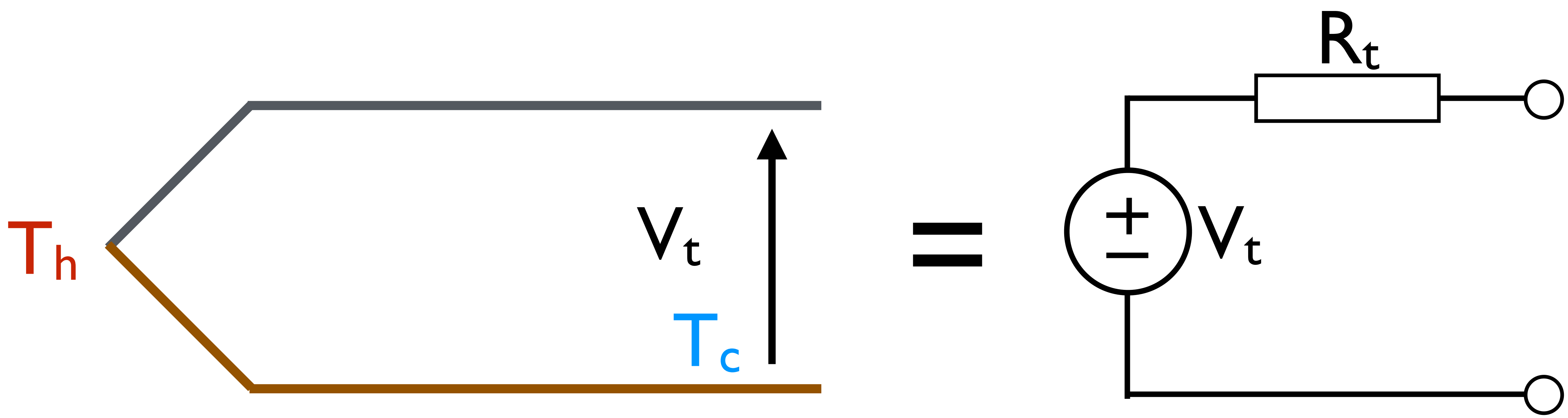
Alumel: 95% nickel, 2% manganese, 2% aluminium

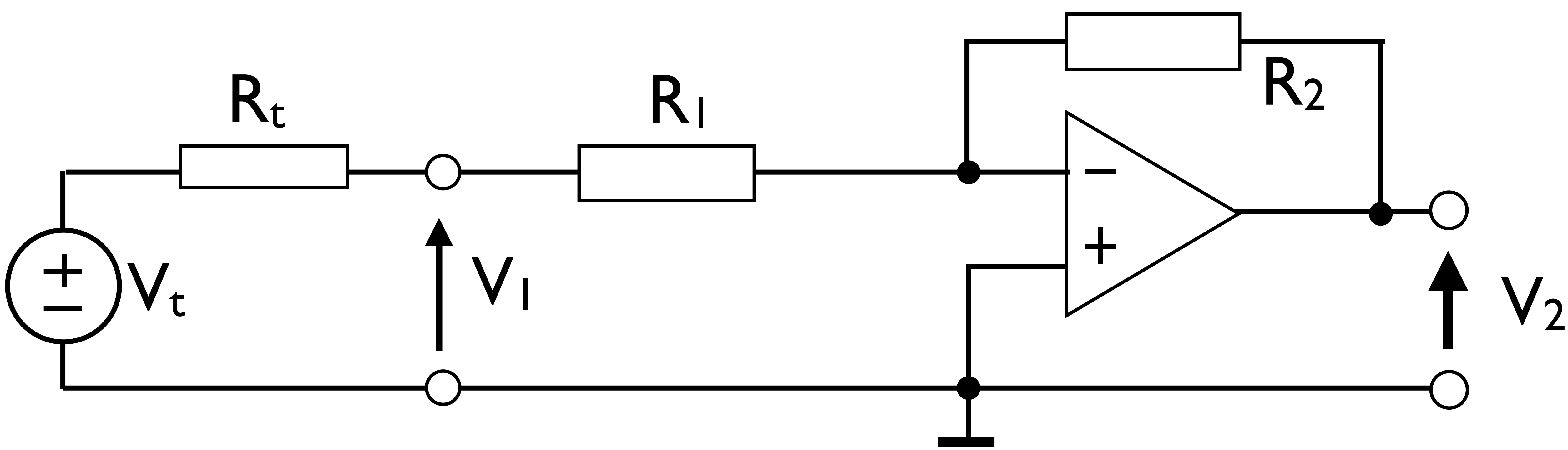
Sensitivity is not always constant



Omega

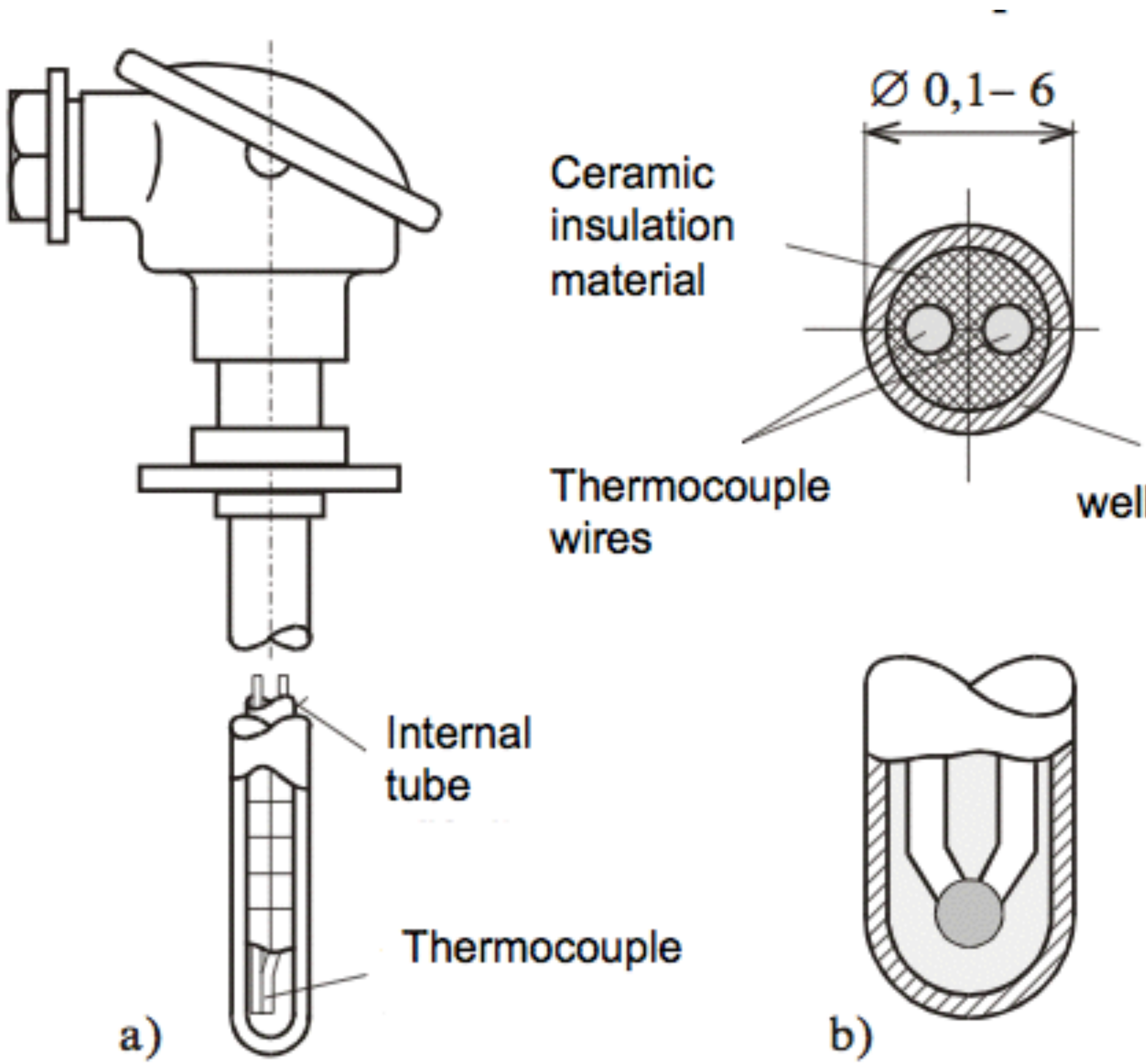
The sensitivity is always about tens of μV/K.
Amplification is often required.

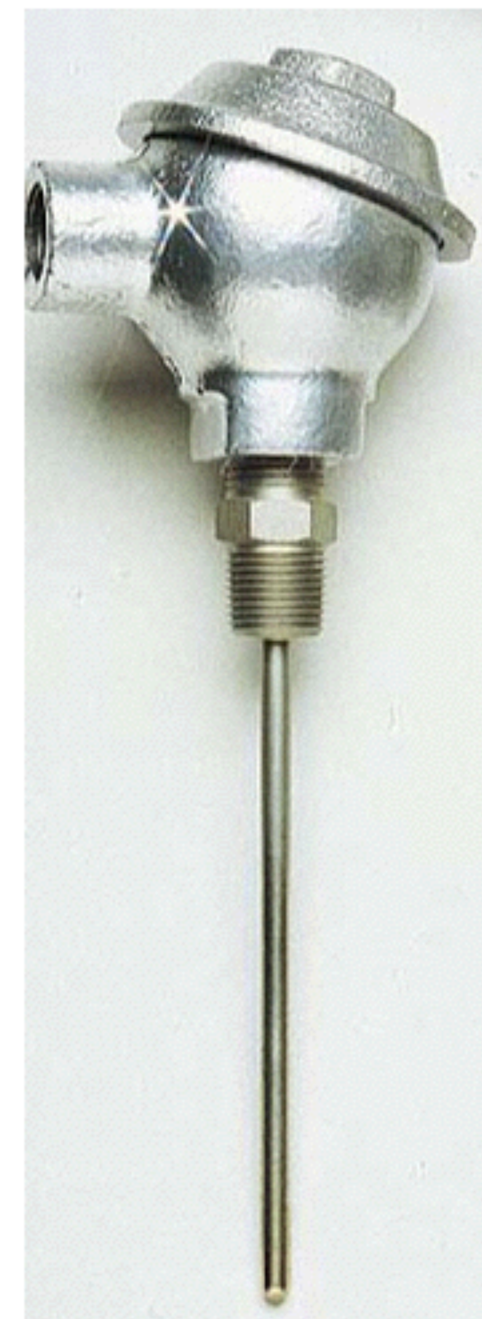




!!! $V_1 \neq V_t$

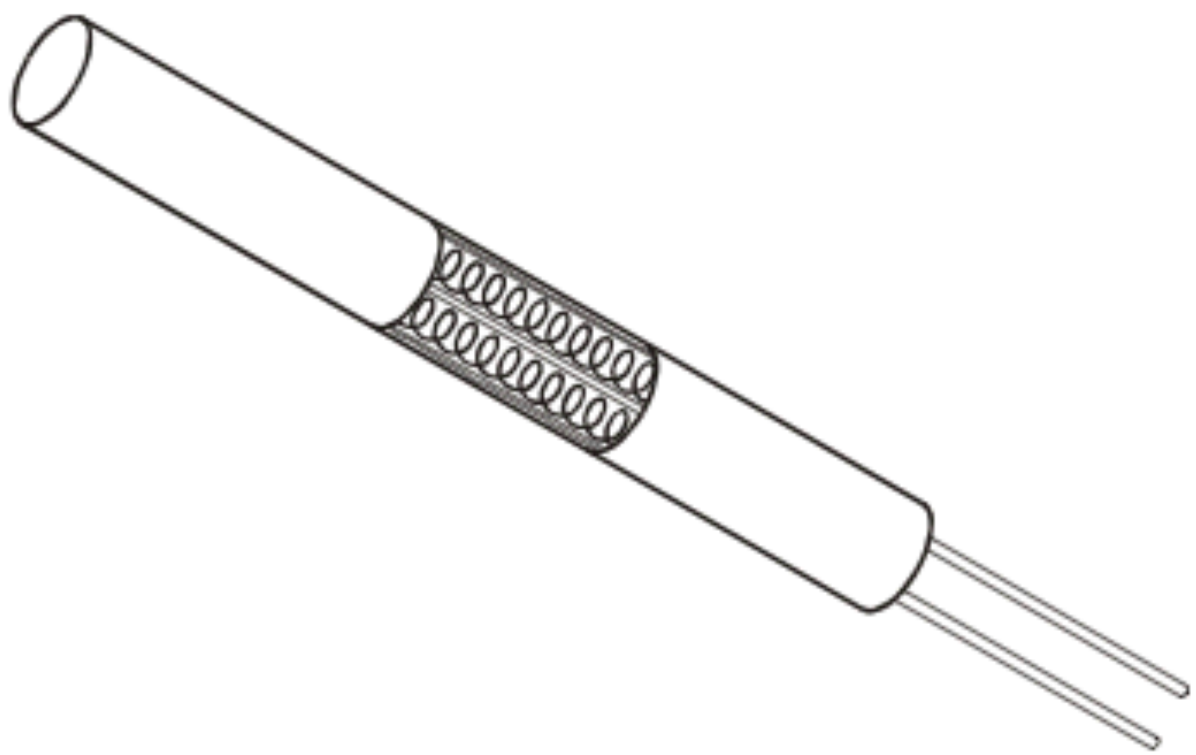
Industrial thermocouple





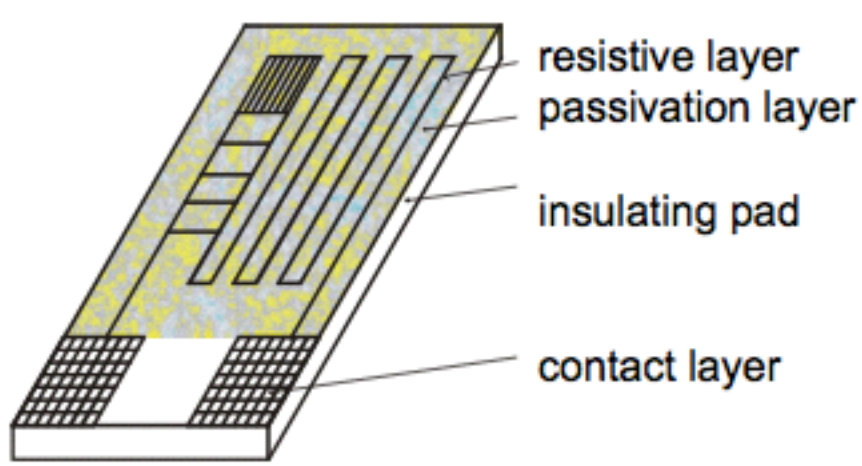
Metal Resistive Thermometers

wire wound thermometer



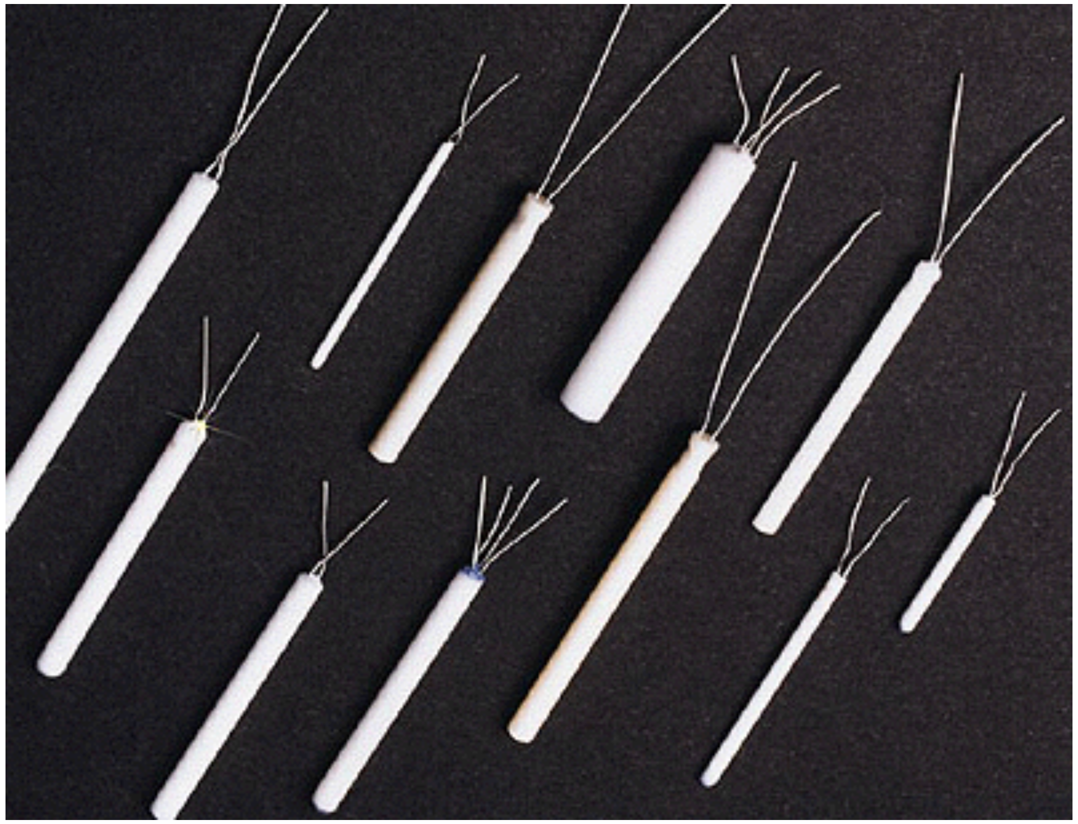
$$R = R_0 \cdot (1 + \alpha \cdot \Delta T)$$

thin layer resistive thermometer



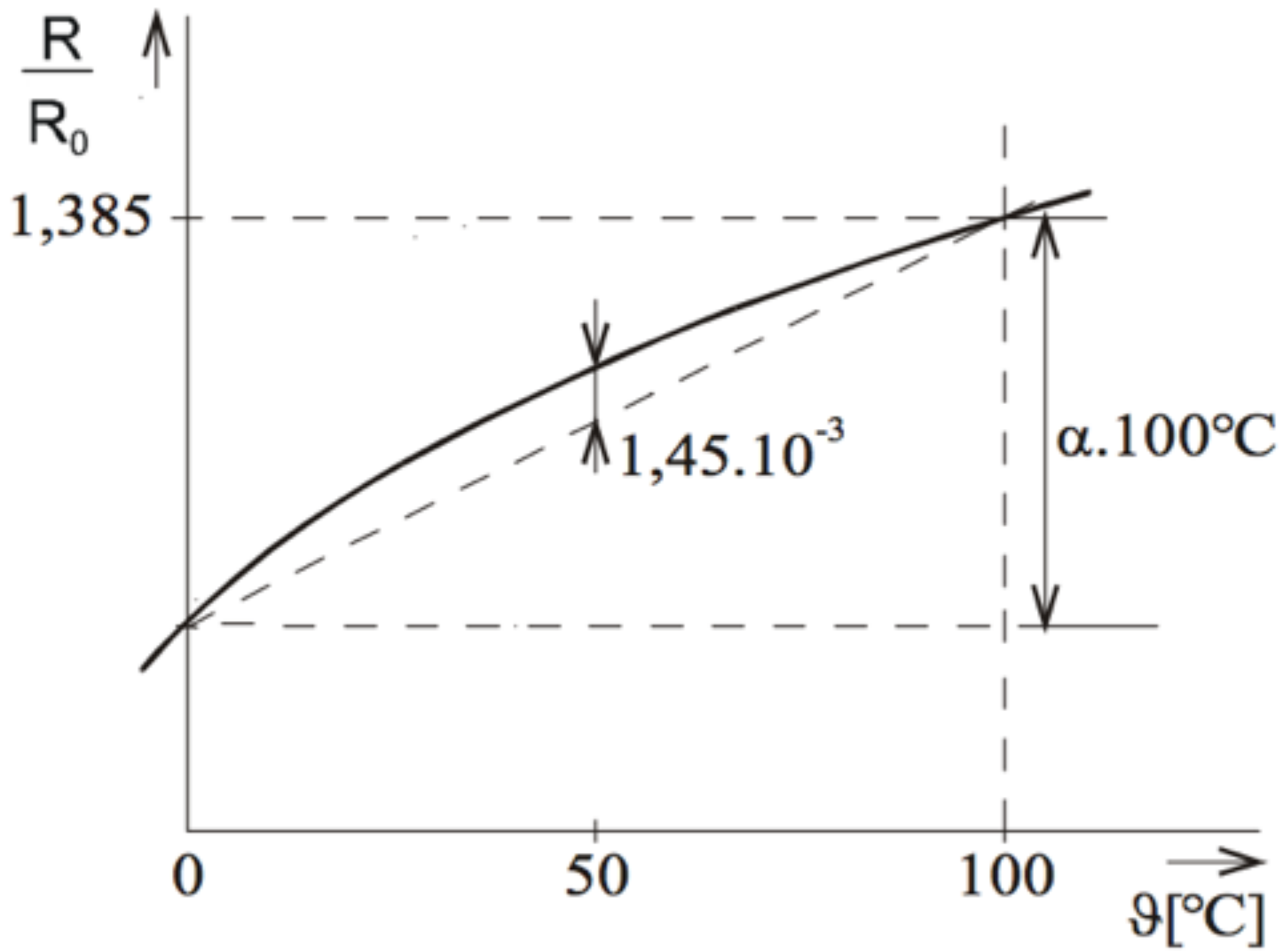
<u>Common materials</u>

	α [%/K]	range [°C]
Platinum	0.39	- 200 / 850
Nickel	0.69	- 80 / 320
Copper	0.43	- 200 / 260



Platinum resistive thermometers

Normalized resistance



$R_{100} / R_0 = 1.385$

Standards define the ratio between the resistance at 100 °C and the resistance at 0°C

(1.3910 in GB, USA, Japan, Russia)

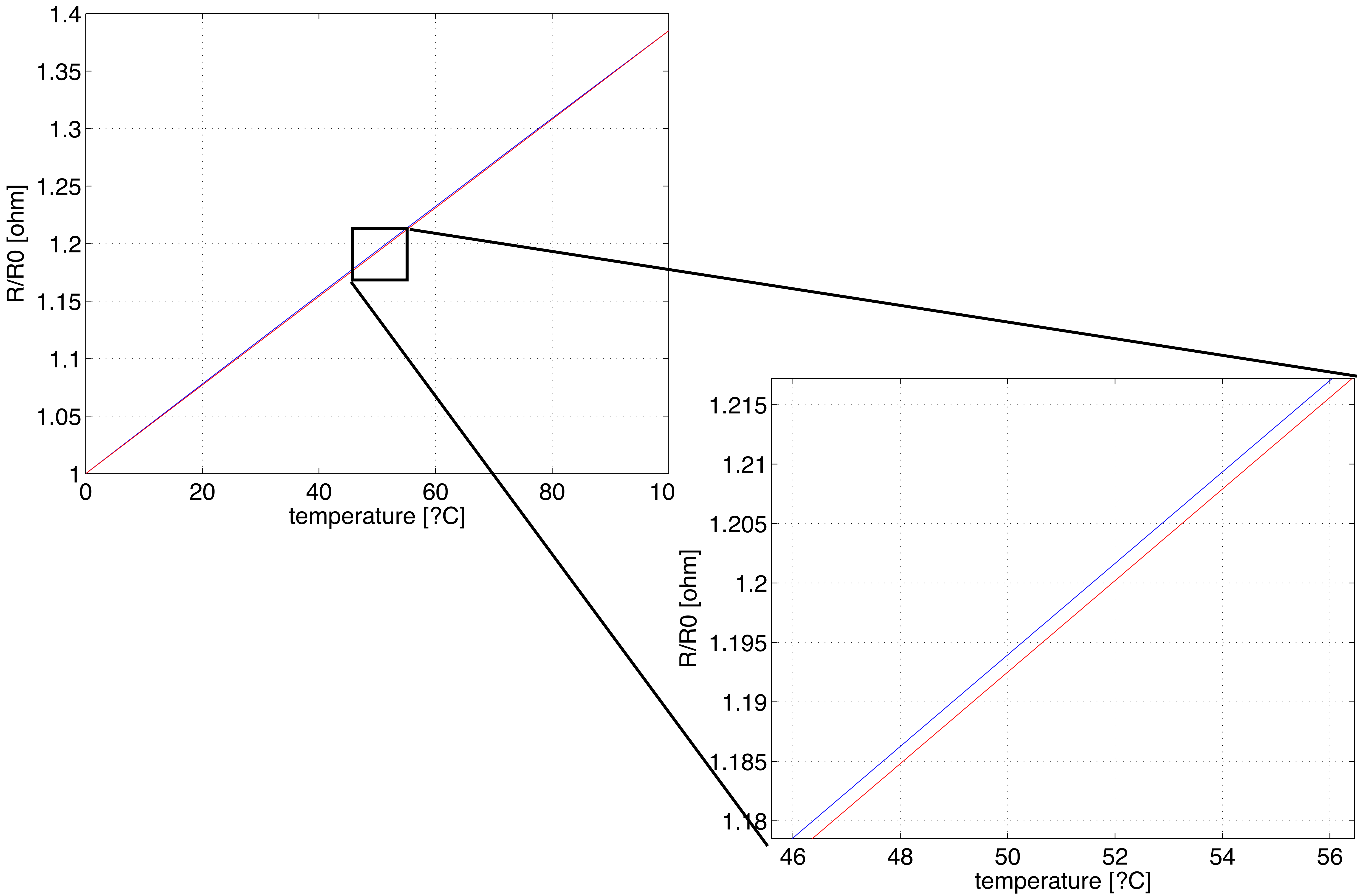
The resistance is not linear

$R_t = R_0 \,[\, 1 + A \cdot t + B \cdot t^2 + C \cdot t^3 \,(t - 100)]$

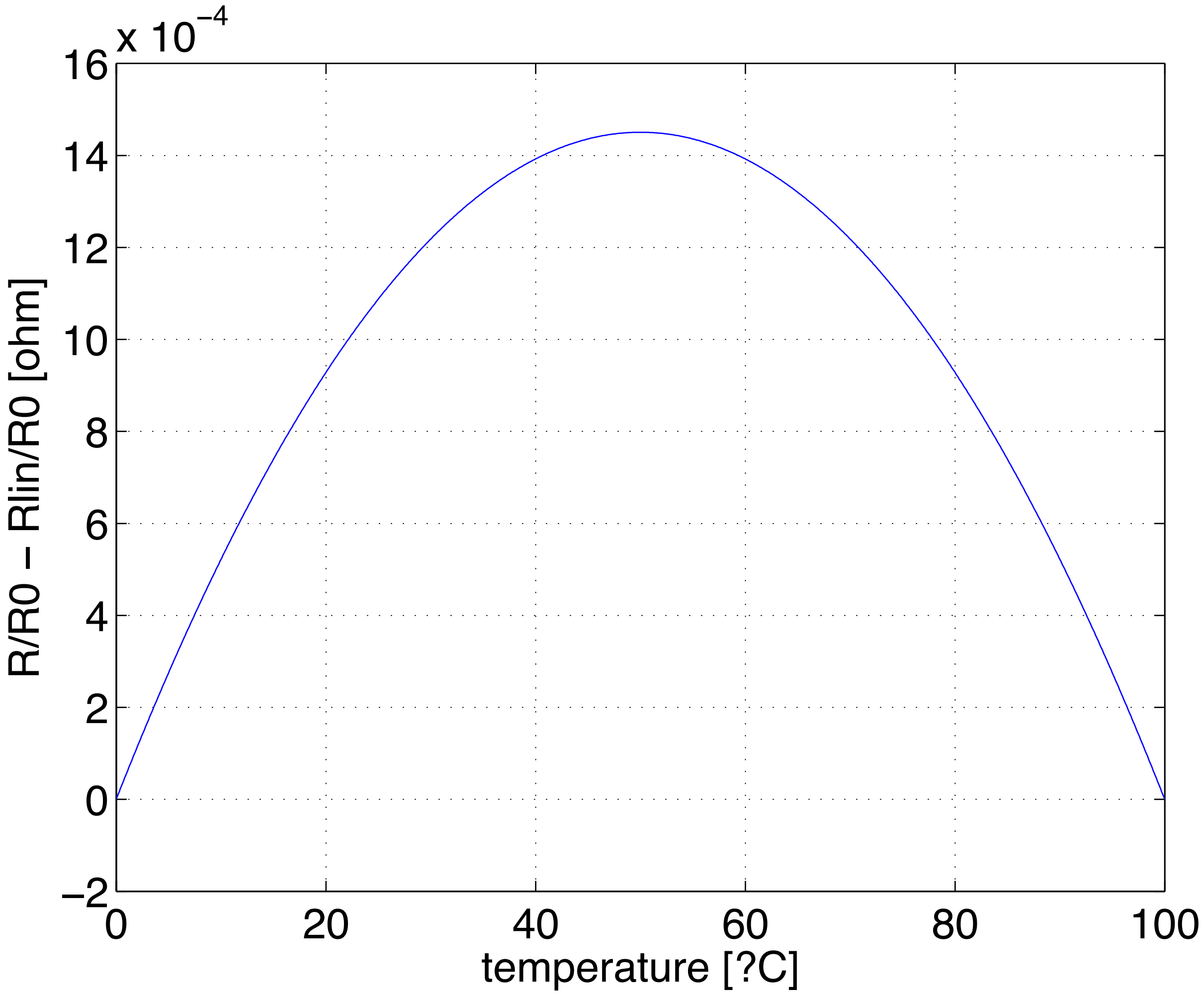
$A = 3.90802.10\text{-}3\ K^{-1}$
$B = -5{,}802.\ 10\text{-}7\ K^{-2}$

$t < 0°C$ $C = -4{,}27350.10\text{-}12\ K^{-4}$
$t > 0°C$ $C = 0$

Actual non-linearity



Actual non-linearity

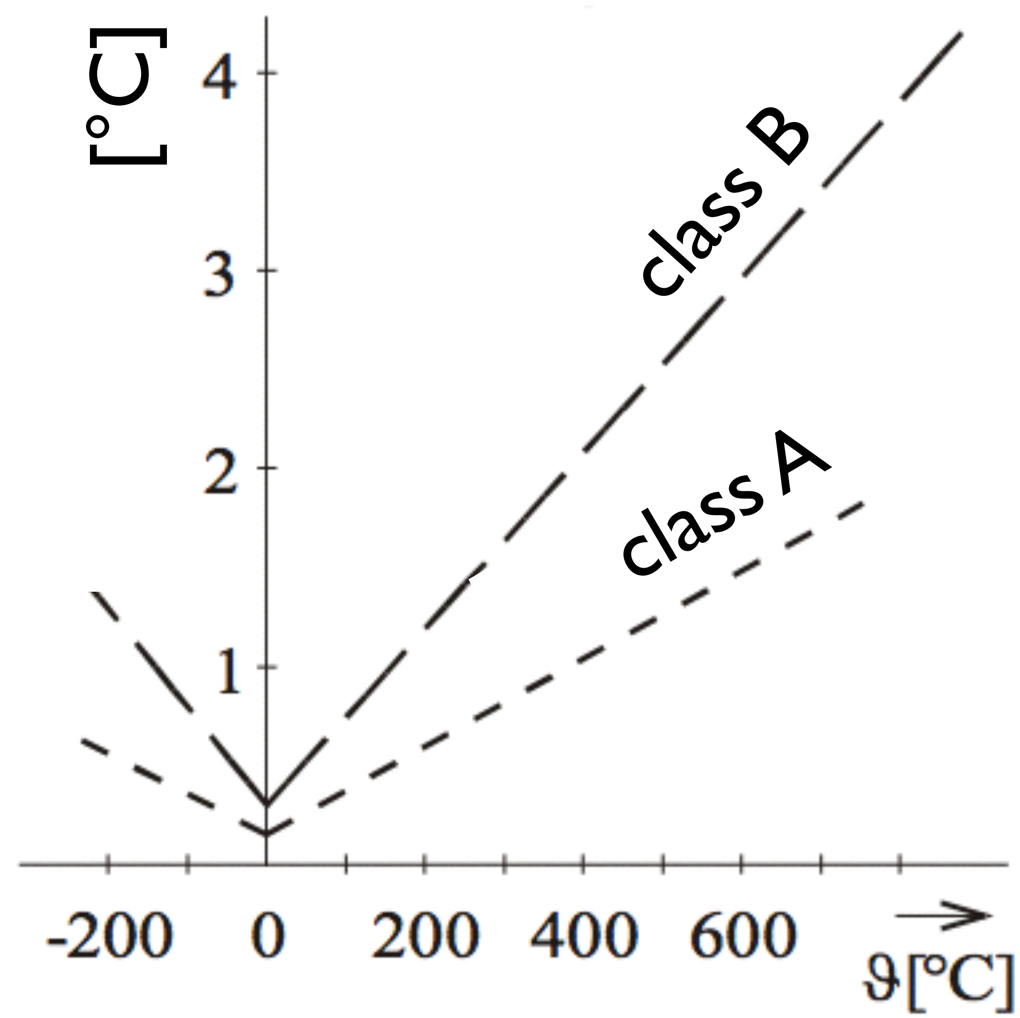


Standard value of Pt resistance:

Pt100 → 0°C R= 100 Ω

200, 500, 1000, 2000 Ω

tollerance



Nickel resistance thermometer:

- high sensitivity, quick response, small dimensions
- limited temperature range

$$R_t = R_0 \left[1 + A \cdot t + B \cdot t^2 + C \cdot t^2 (t - 100) \right]$$

$A = 5.49 \; 10^{-3} \; K^{-1}$
$B = 6.80 \; 10^{-6} \; K^{-2}$
$C = 9.24 \; 10^{-9} \; K^{-3}$ for $t>0$ (else $C=0$)

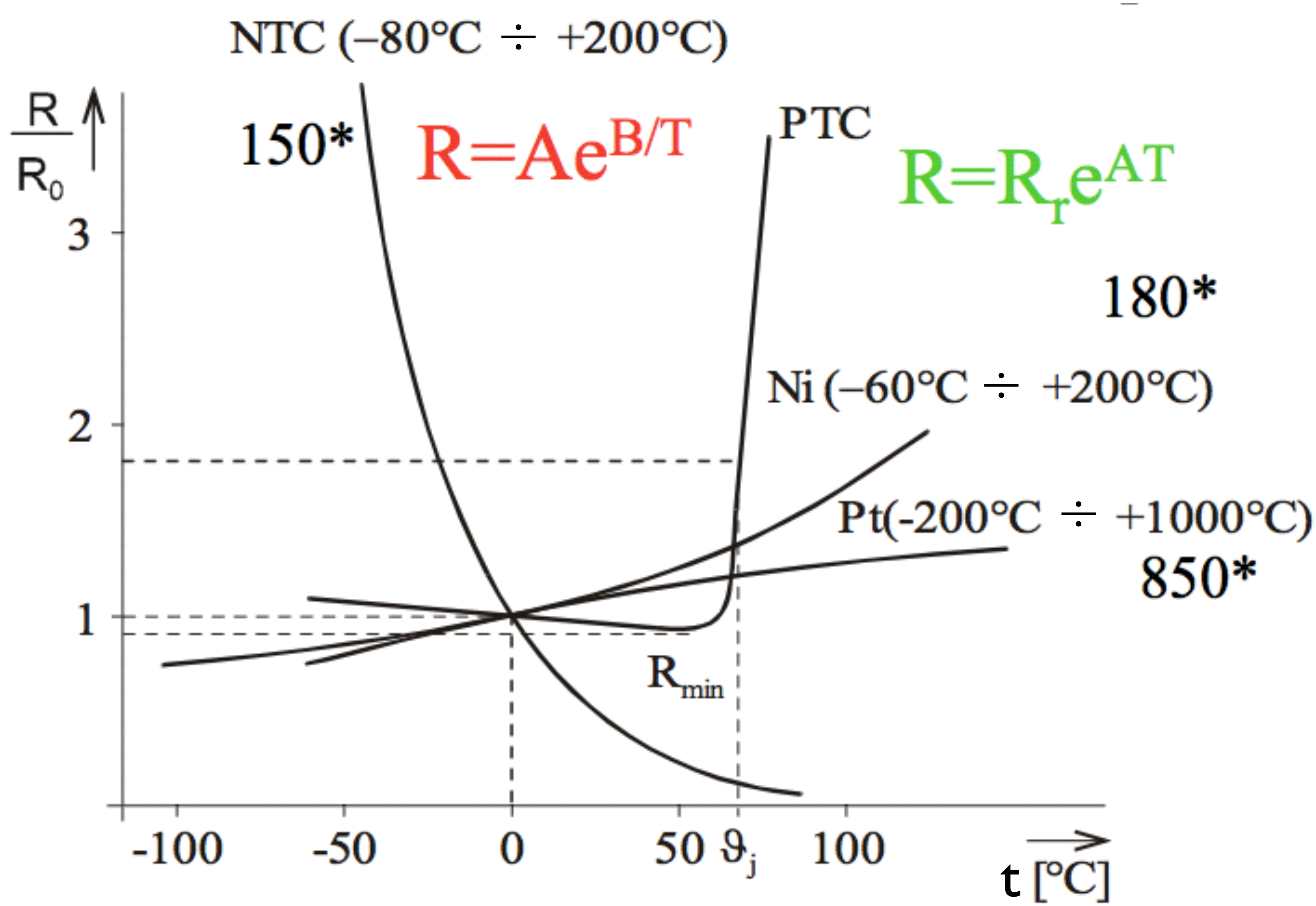
Copper resistance thermometer:

- limited range (from -200°C to + 200°C)
- small resistance
- direct measurement of windings temperature

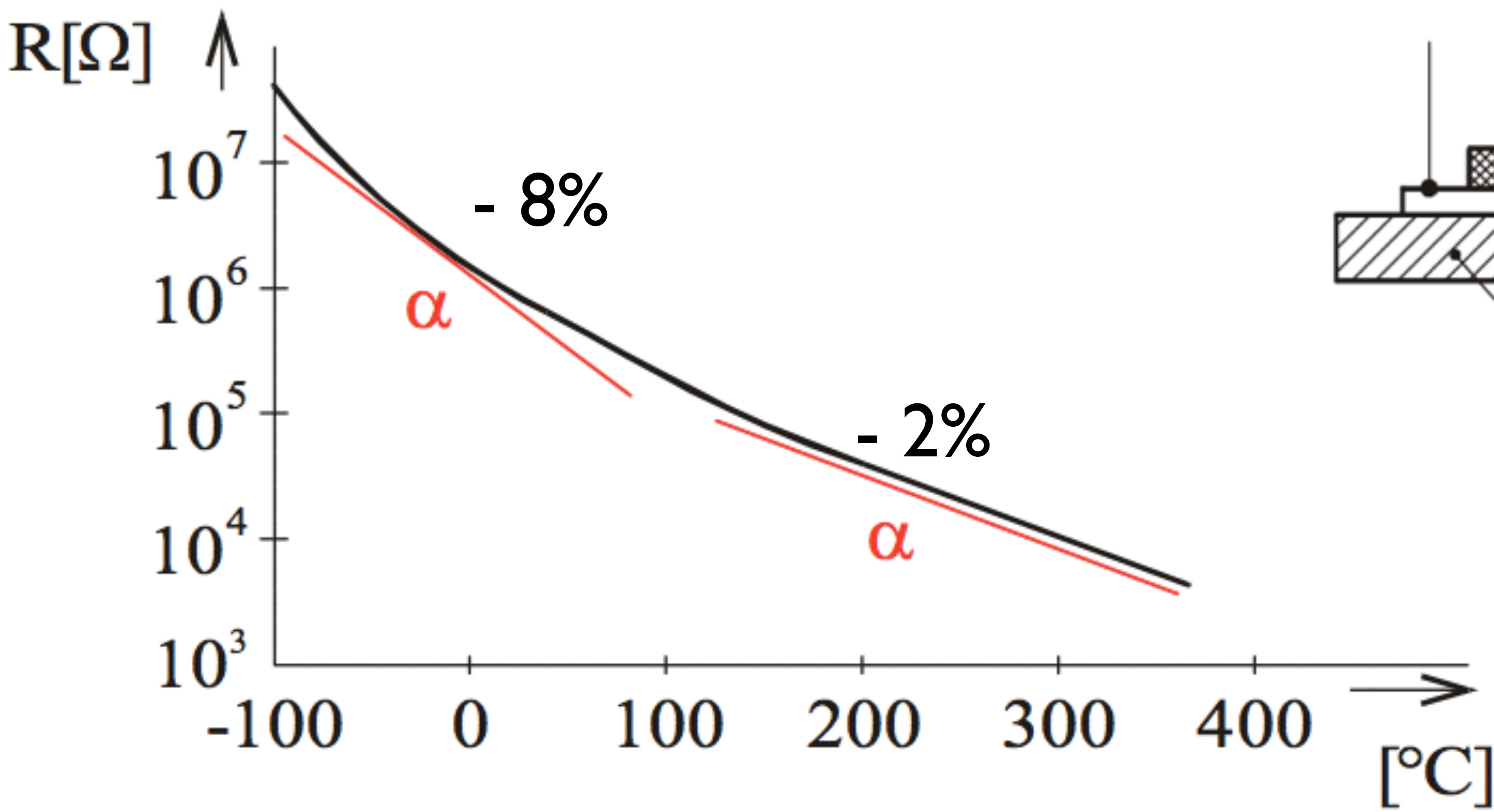
$$R_t = R_0 \left[1 + \alpha \cdot t \right] \qquad \alpha = 4.26 \; 10^{-3} \; K^{-1}$$

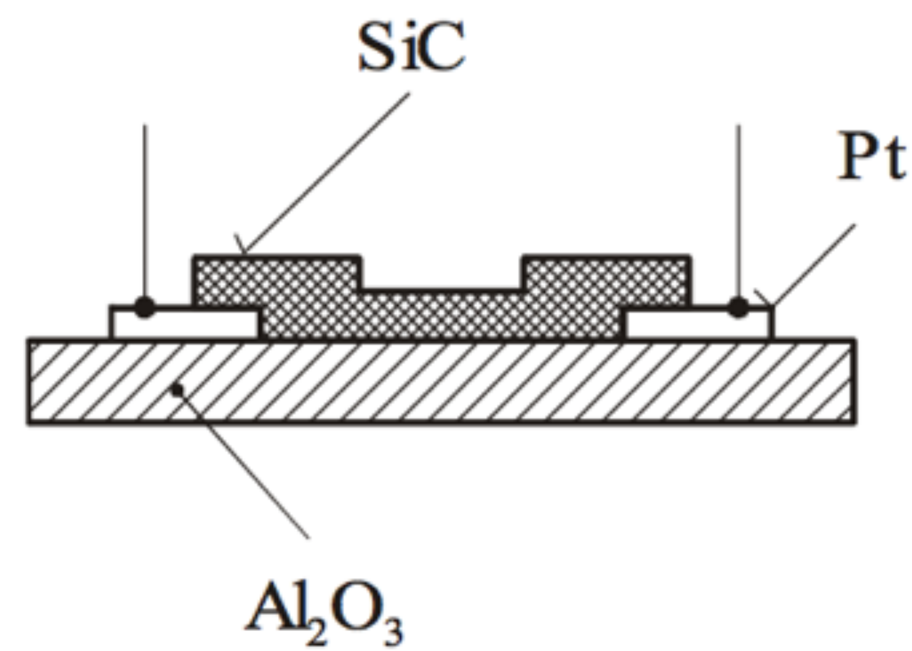
Semiconductor resistive sensors of temperature

Thermistor
PTC - Positive Temperature Coefficient
NTC - Negative Temperature Coefficient



NTC - Negative Temperature Coefficient





-produced e.g. by sintering technology from the powder of metal oxides
-usable range - from 4.2K to 1000 °C

$$\boxed{R = A \cdot e^{\frac{B}{T}}}$$

$$R_1 = A \cdot e^{\frac{B}{T_1}}$$

$$R_2 = A \cdot e^{\frac{B}{T_2}}$$

$$\rightarrow \quad \frac{R_1}{R_2} = e^{\left(\frac{B}{T_1} - \frac{B}{T_2}\right)} \quad \rightarrow \quad B$$

PTC, posistors

$\alpha>0$

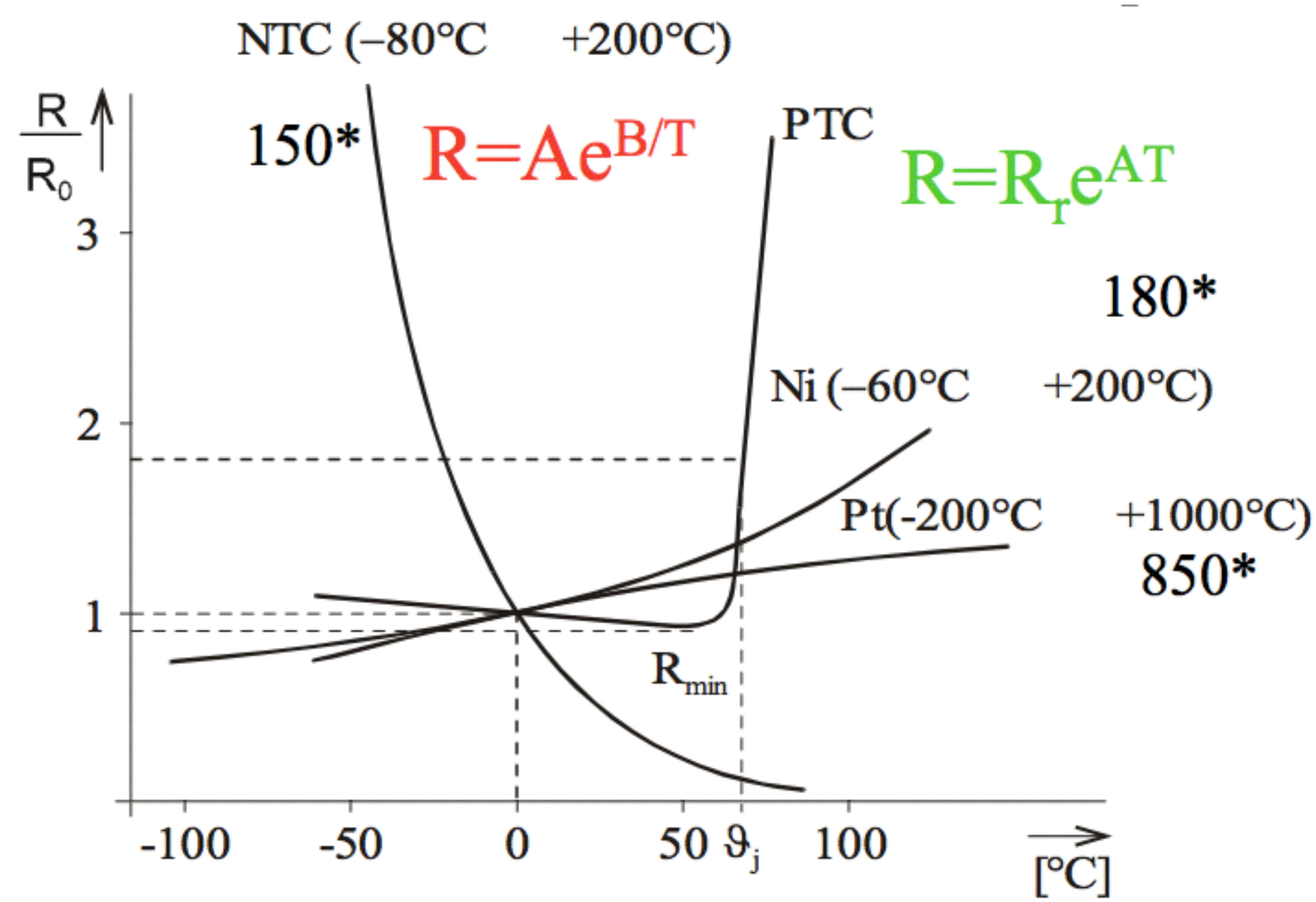
- made from polycrystalline ferroelectric ceramics e.g. ($BaTiO_3$)

- application: two state sensors

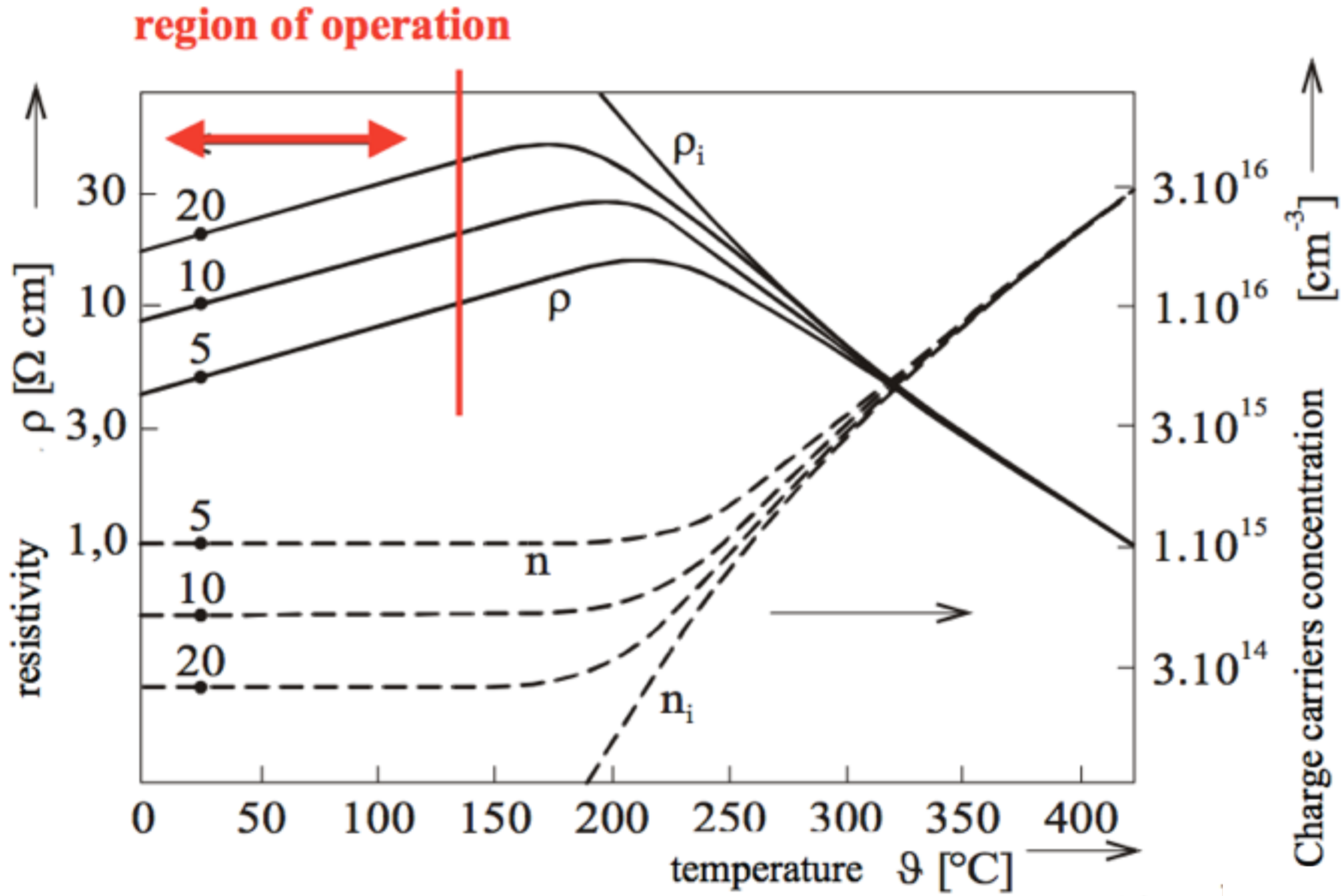
(thermal switches – indication of excessing max. temp.)

resistance slowly decrease with increasing temperature

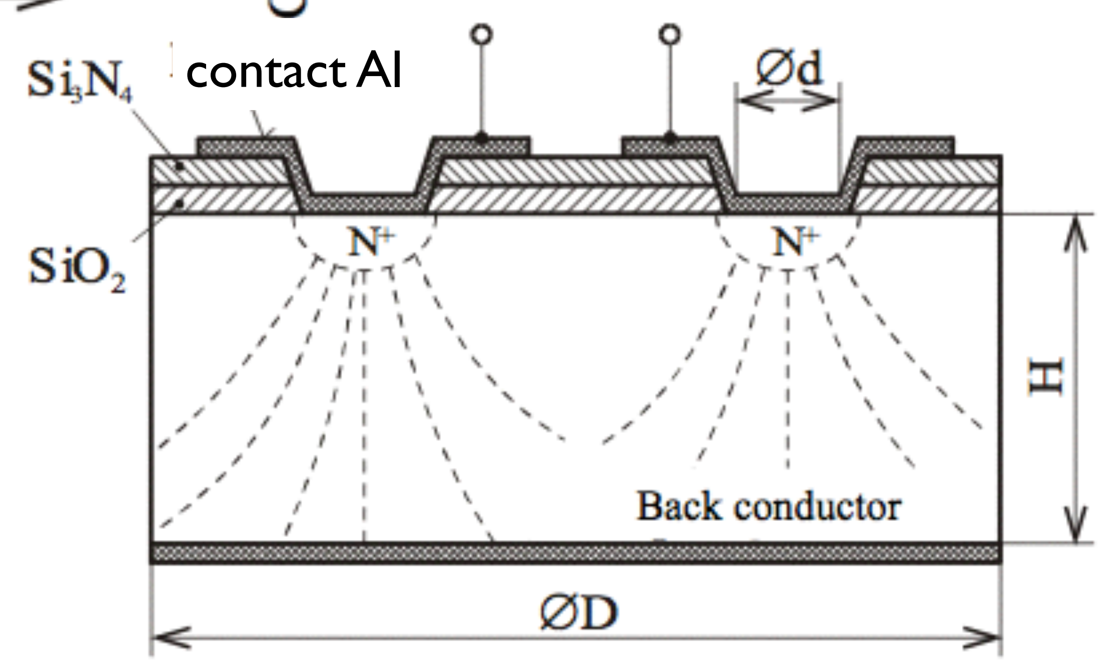
after Curie point rapid increase of resistance - relation for increase of resistance



Semiconductor monocrystalline sensors of temperature



α= 1%/K



Resistance of the sensor

$$R = \frac{\rho}{\beta d}$$

β– geometrical factor
d – diameter of contact
ρ – resistivity

Problem: in order to measure a resistance we need to inject a current which generates heat!

SELF HEATING

difference of temperature given by self heating:

$$\Delta T = \frac{RI^2}{D}$$

power loss

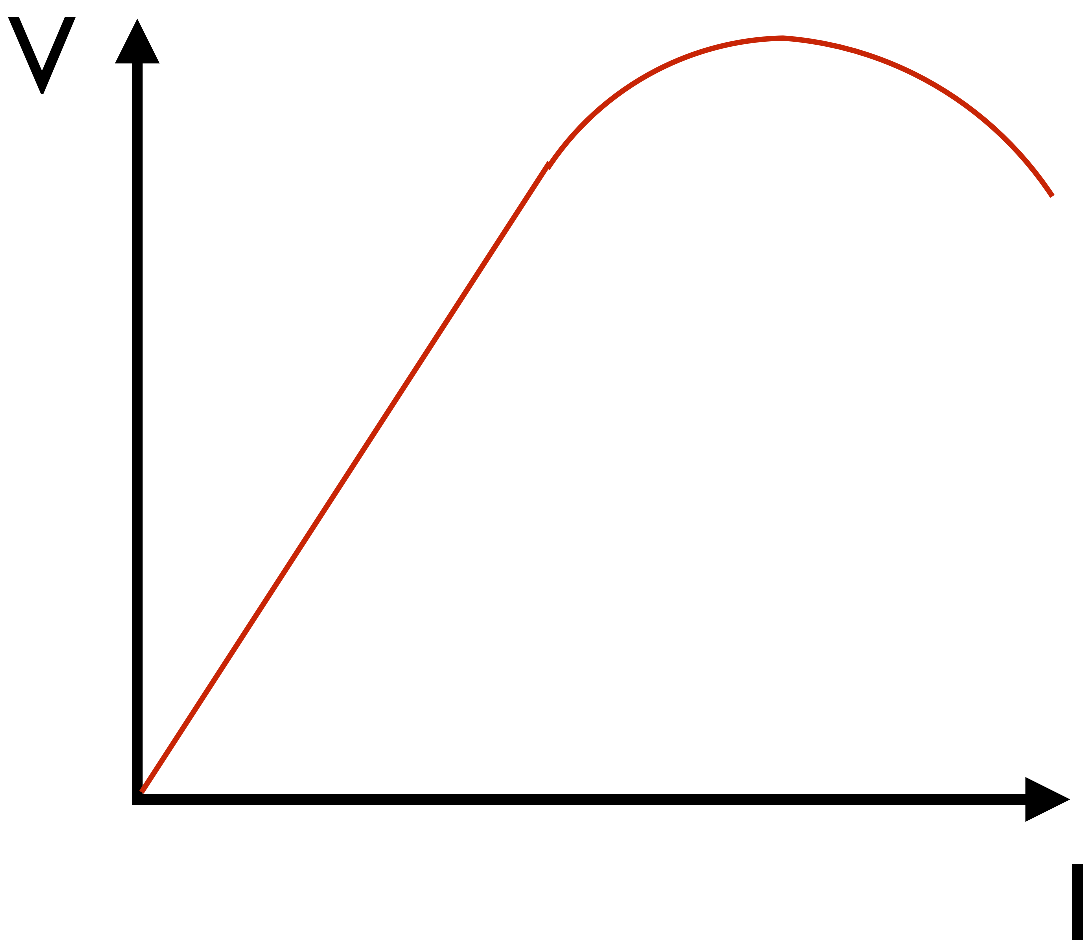
thermal resistance

Pt100 : max 1 mA to have max $\Delta T = 0.1°C$

Effect of self heating on

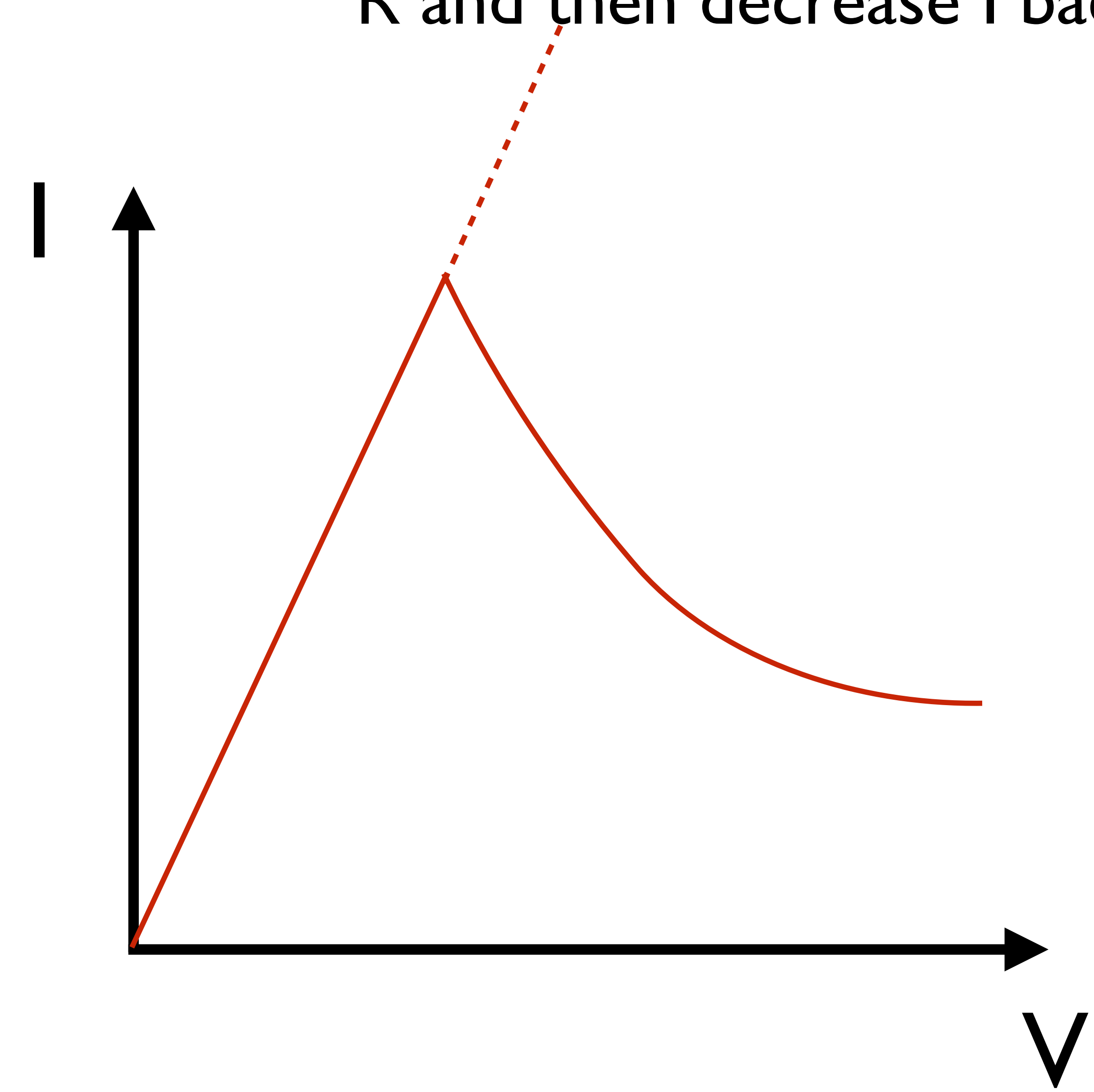
negastor (NTC thermistor)

at high I the temp increases so the R drops and therefore V=RI drops.

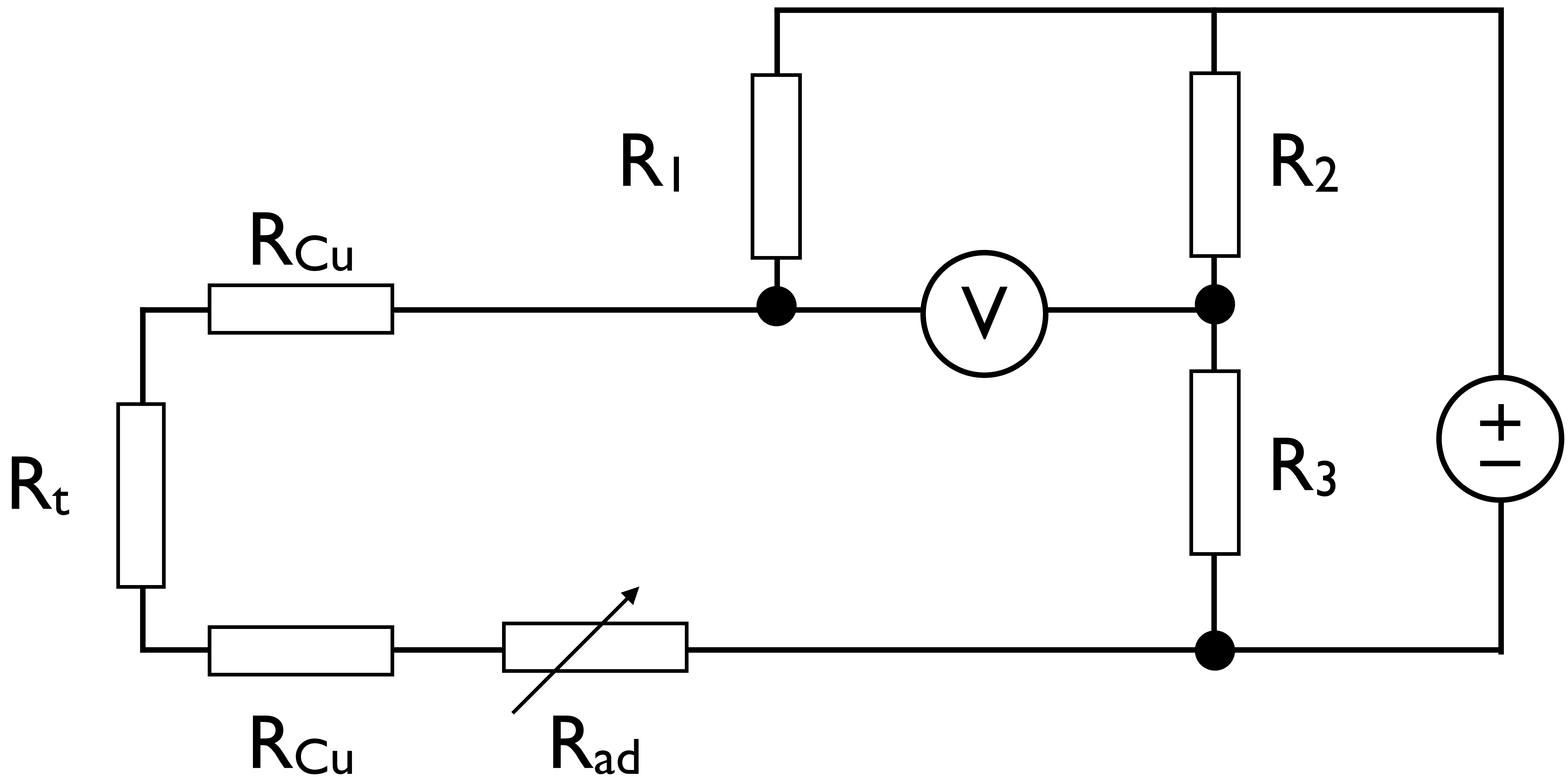


posistor (PTC thermistor)

we can't increase I because increment of I would increase R and then decrease I back.

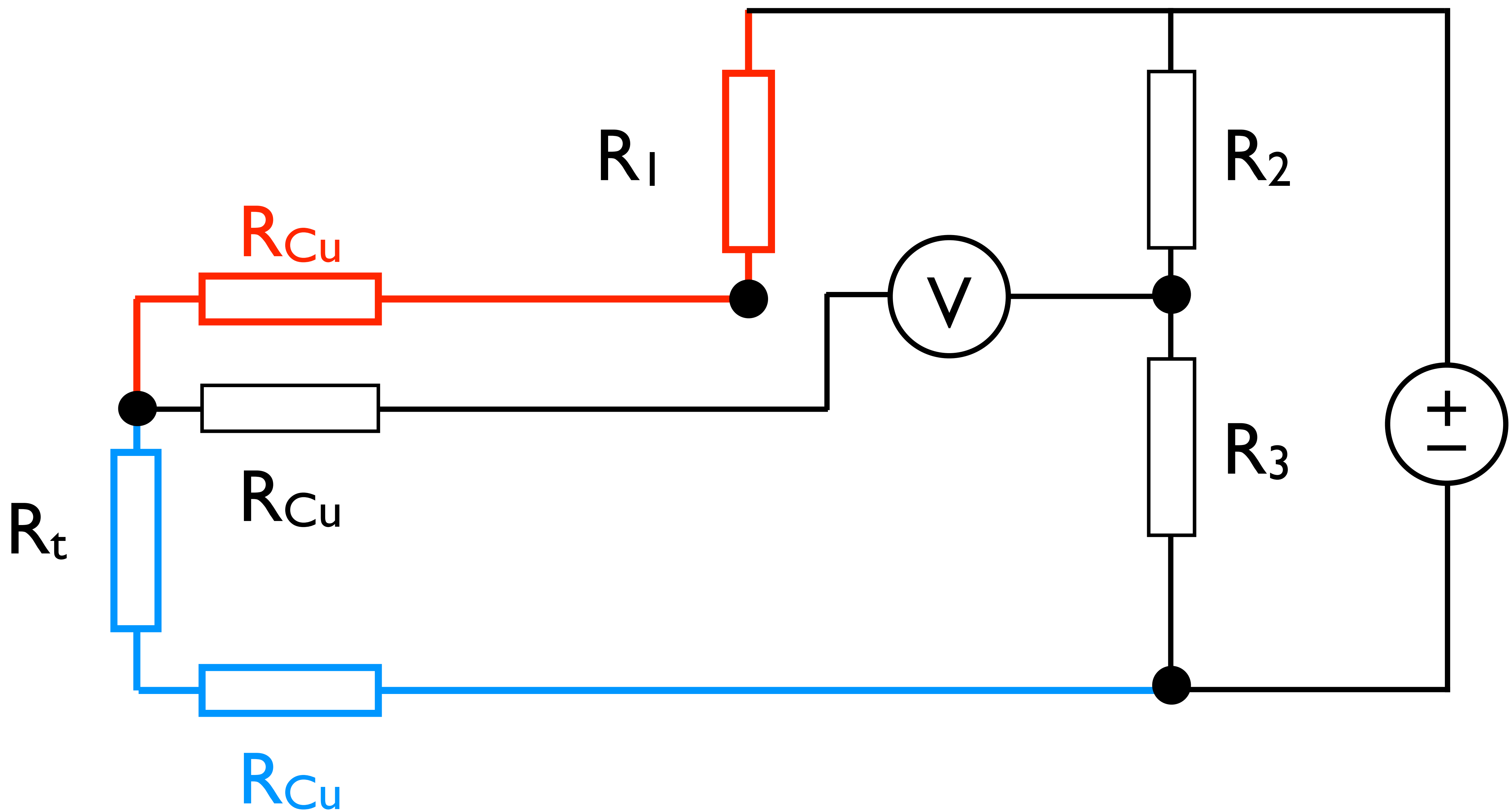


Two wire connection in a bridge



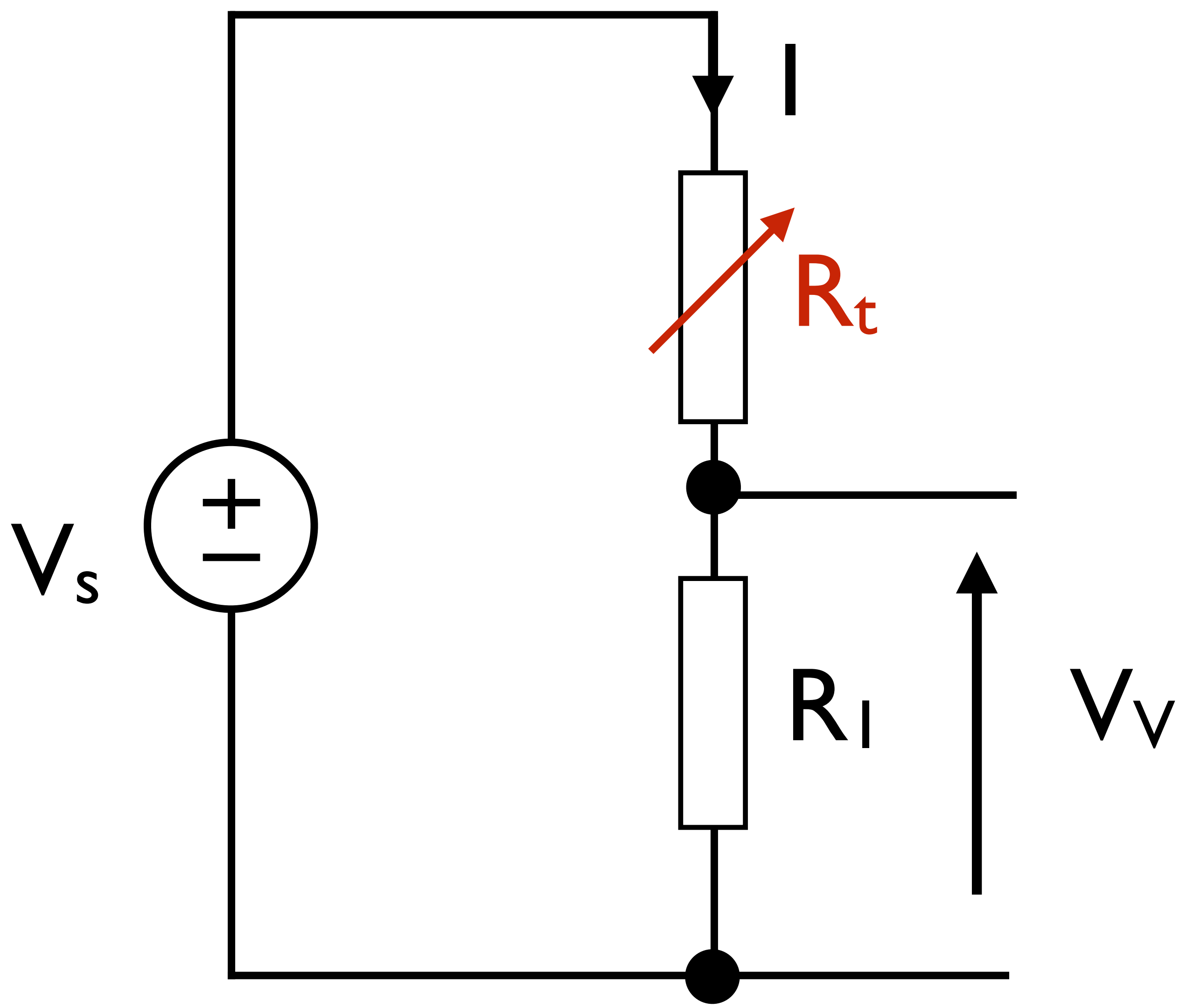
R_{ad} can be adjusted to balance the bridge and null the contribution of R_{cu}.
Problem: the resistance of the cables might change too with temperature

Three wire connection in a bridge



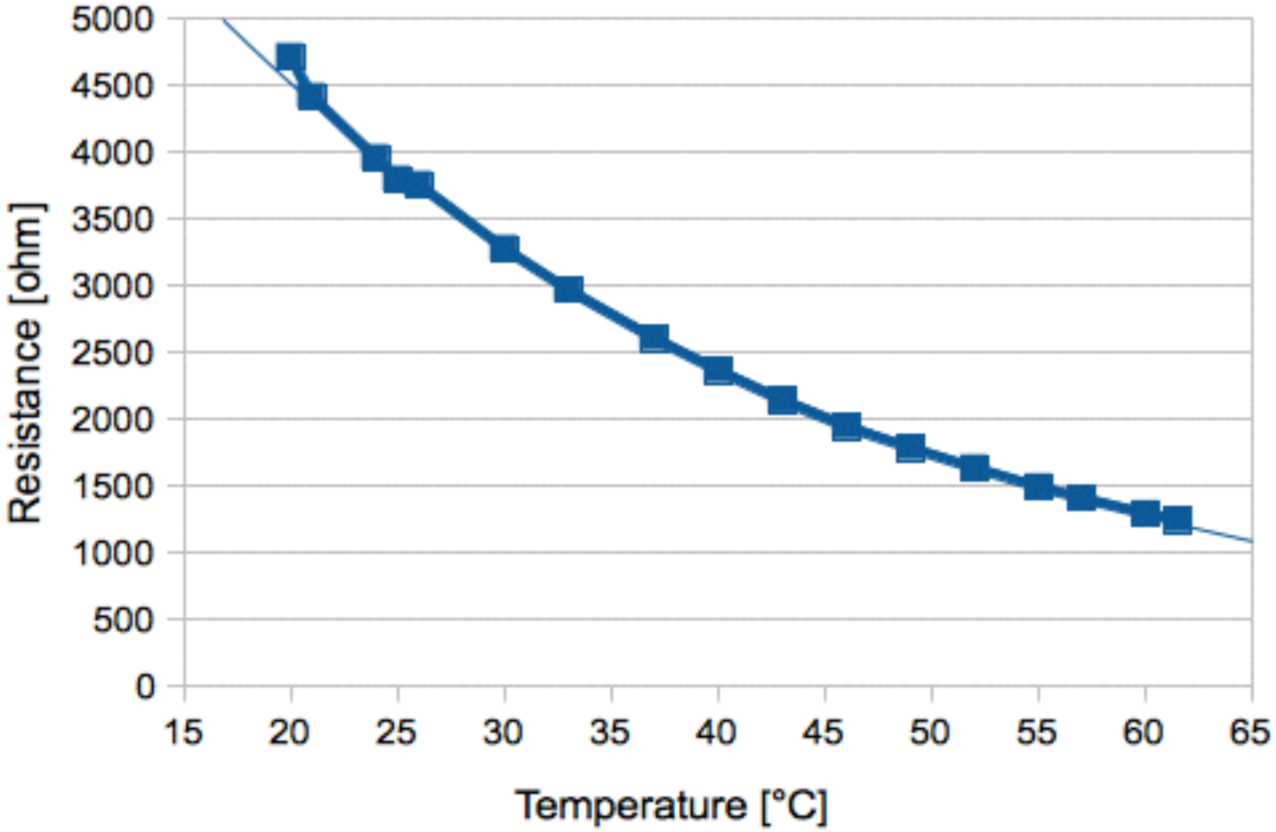
Two resistances of the cables fall in opposite sides of the bridge's leg, the compensate each other. The 3rd cable resistance has no effect (Iv=0)

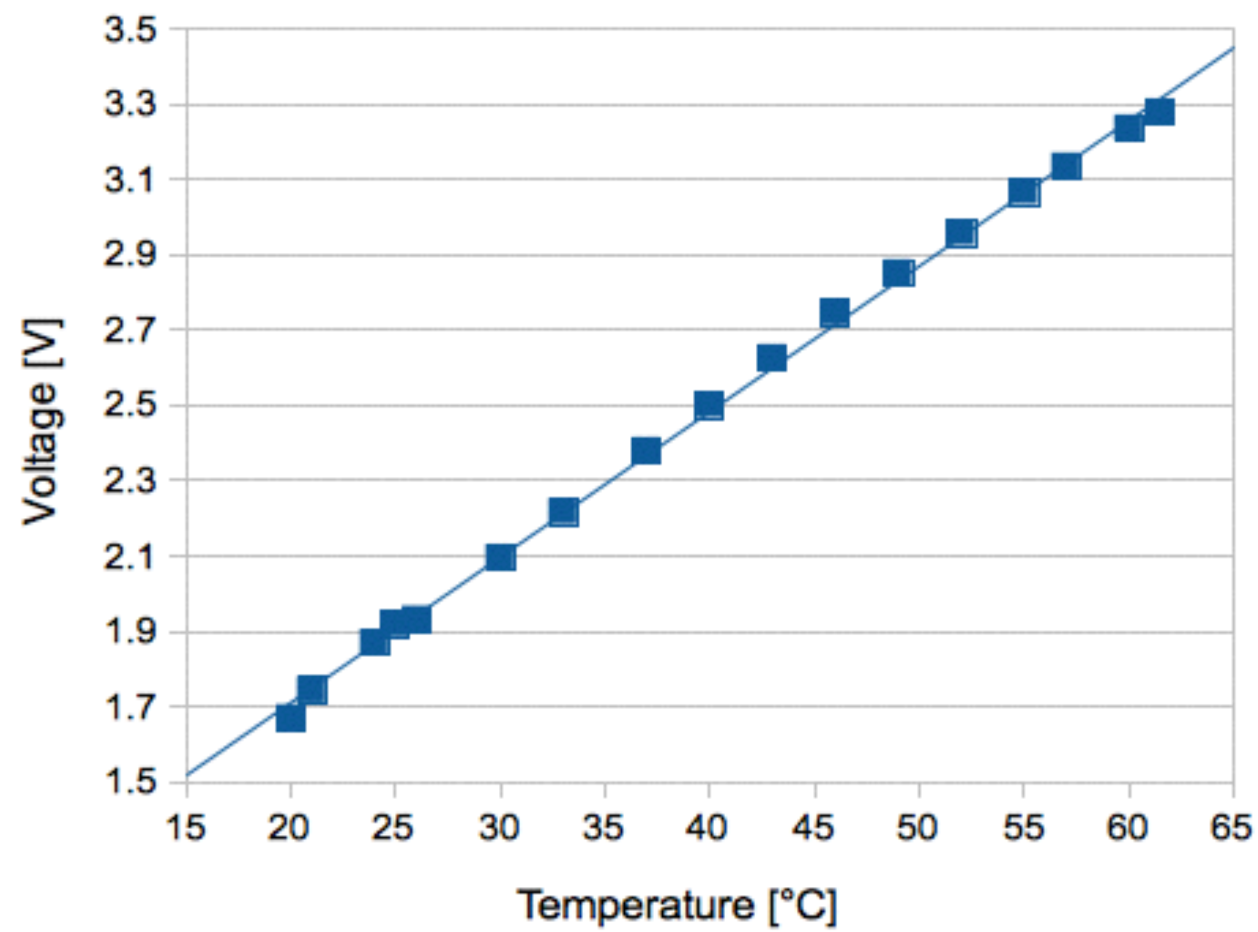
Linearization of thermistor with a series resistor



$$V_{lin} = V_S \frac{R_l}{R_l + R_t}$$

Linearization of thermistor with a series resistor

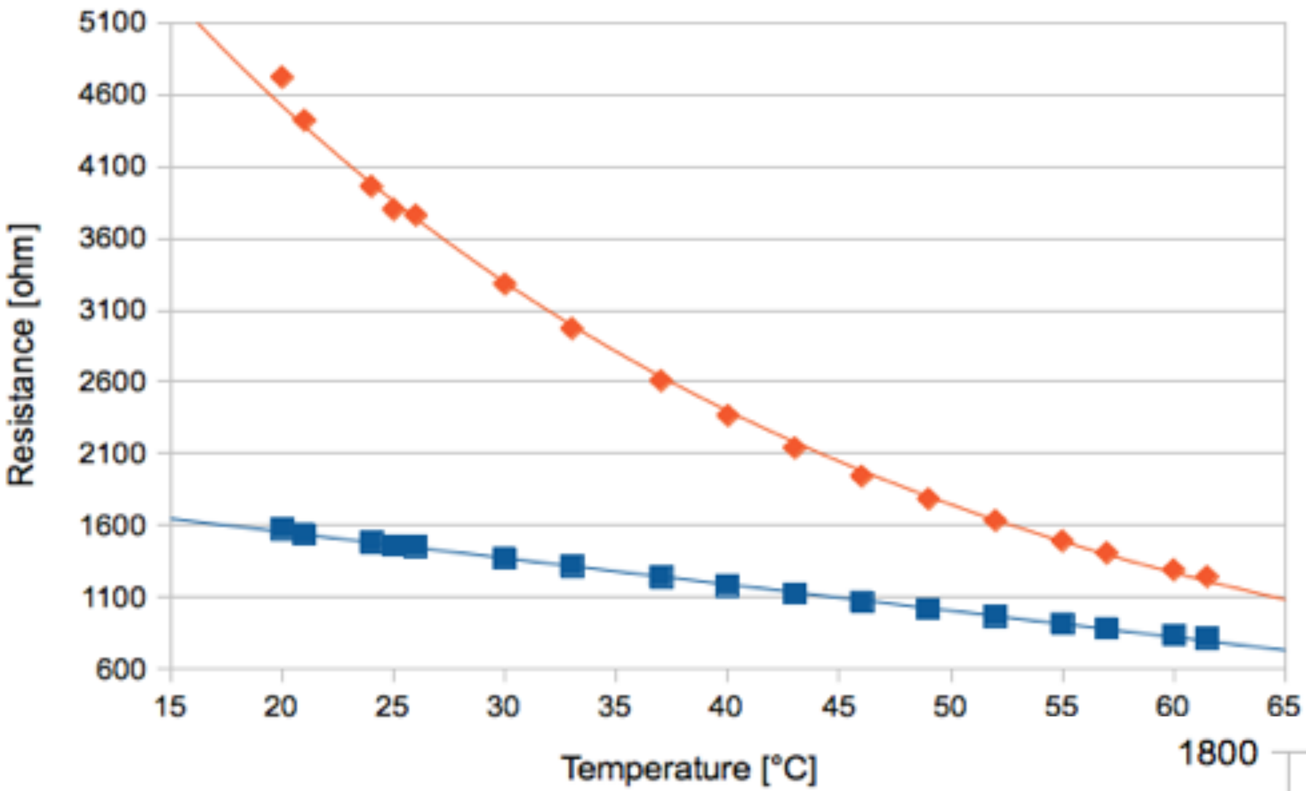


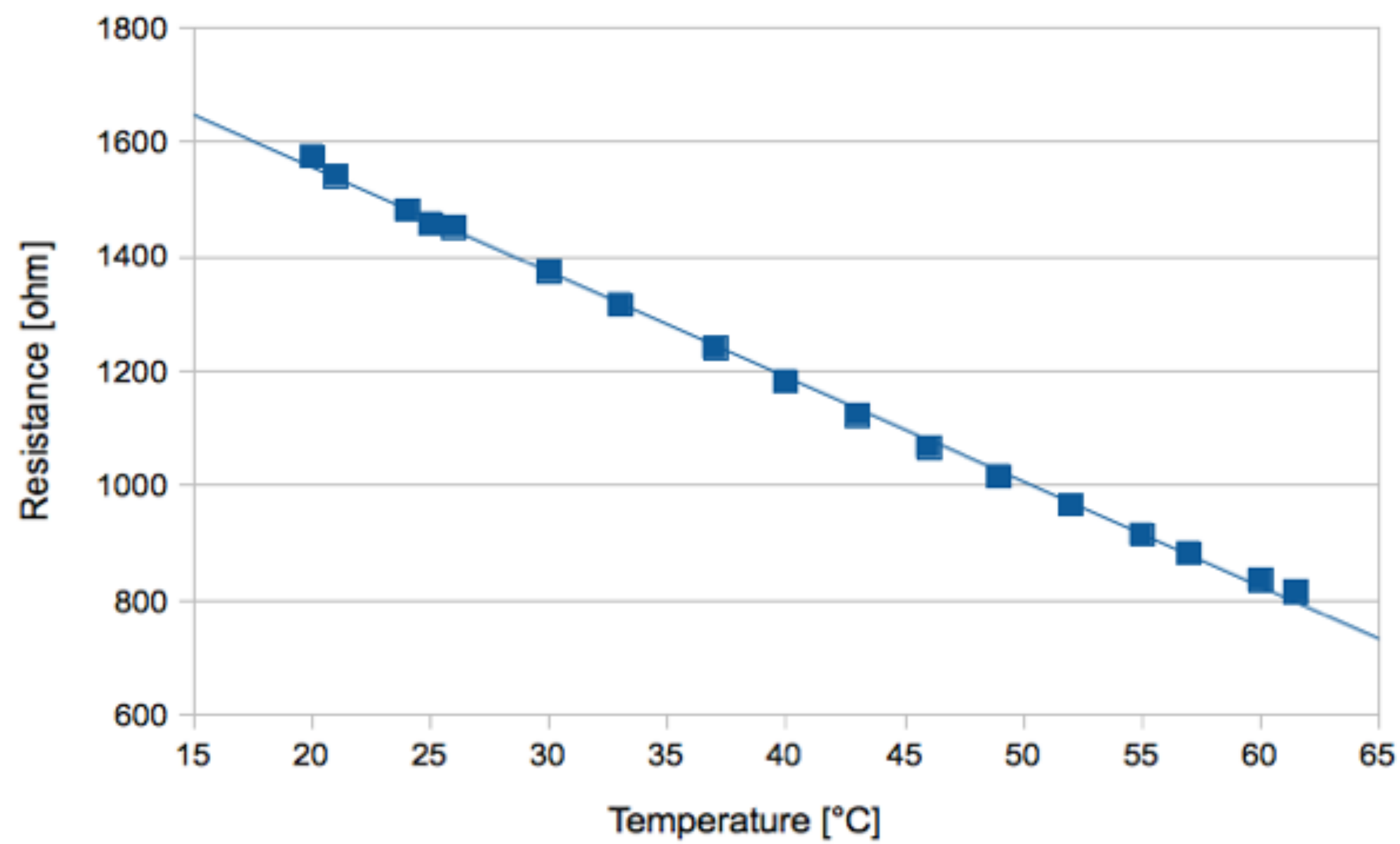


Vs= 5 V

R_l= 2,365 Ω

Linearization of thermistor with parallel resistor

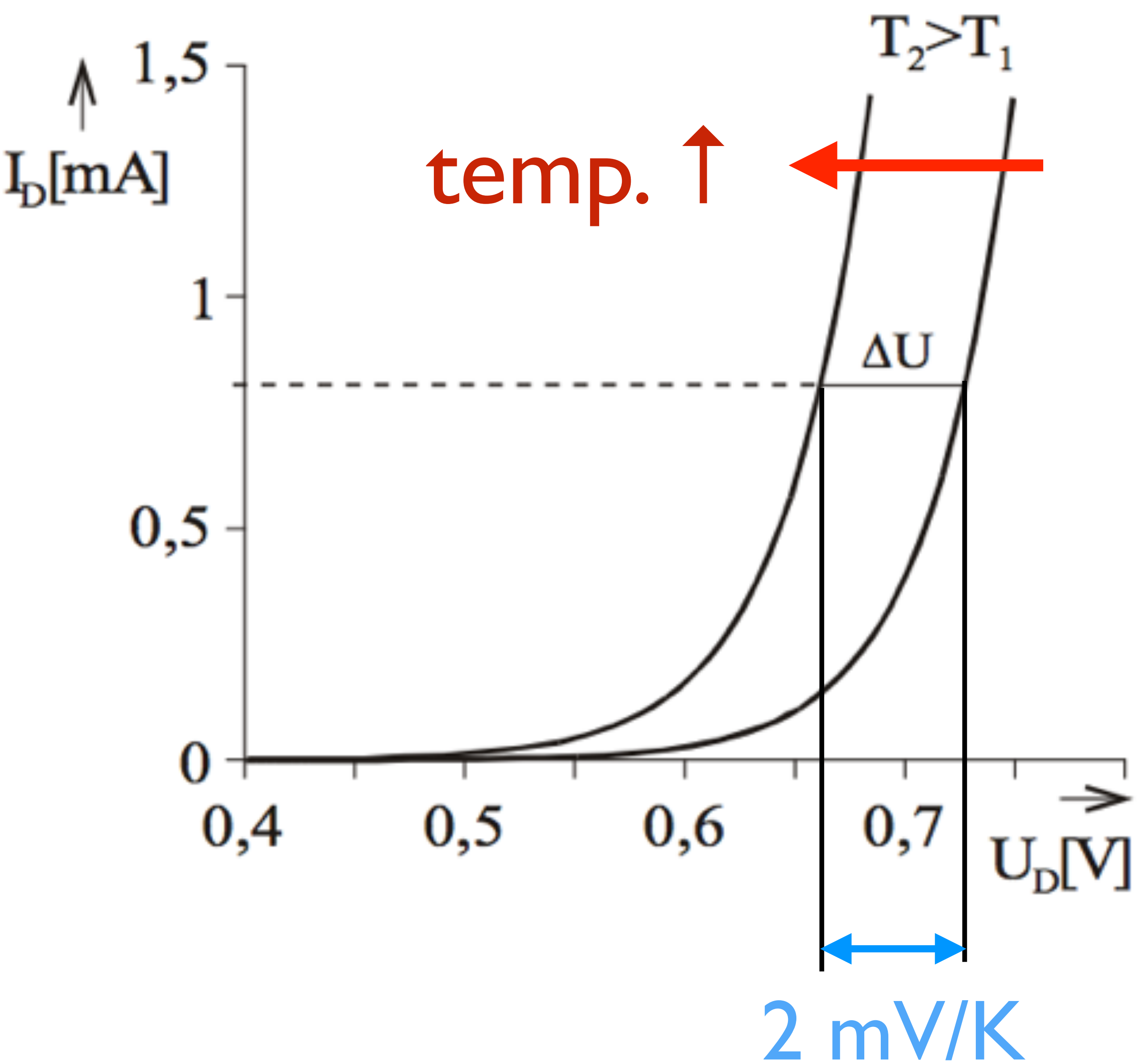




R_p= 2,365 Ω

PN junction based sensors of temperature

The V-I curve of PN junction depends on temperature



Shockley equation

$$I_D = I_S\left(e^{\frac{V_D}{mV_T}} - 1\right)$$

$$V_D = m \cdot V_T \cdot \ln\left(\frac{I_D}{I_S} + 1\right)$$

I_S – reverse saturation current

I_D - forward current in PN junction

m – coefficient of recombination

V_D – forward voltage on PN junction

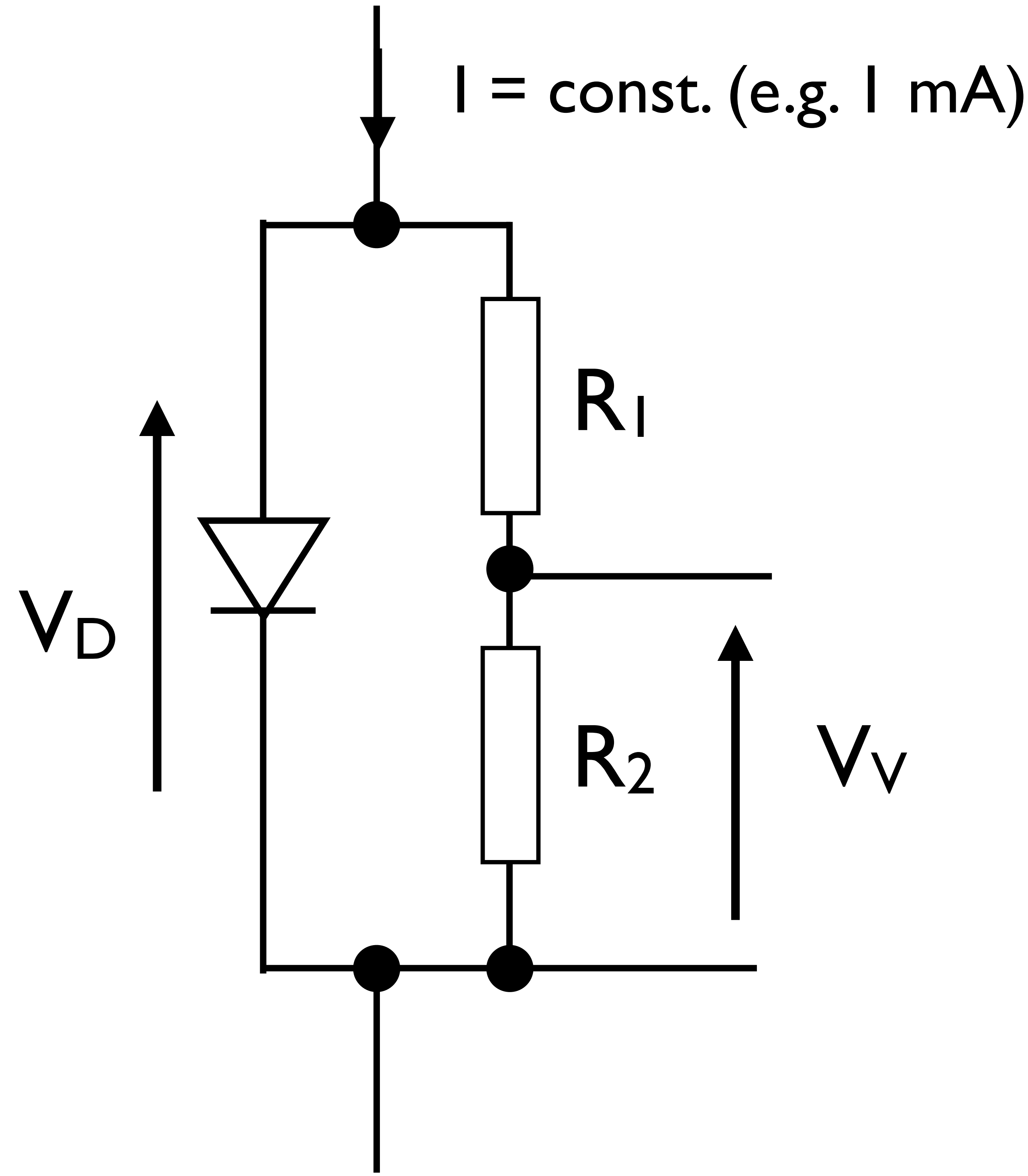
V_T – thermal voltage

e – elementary charge

k – Boltzmann constant

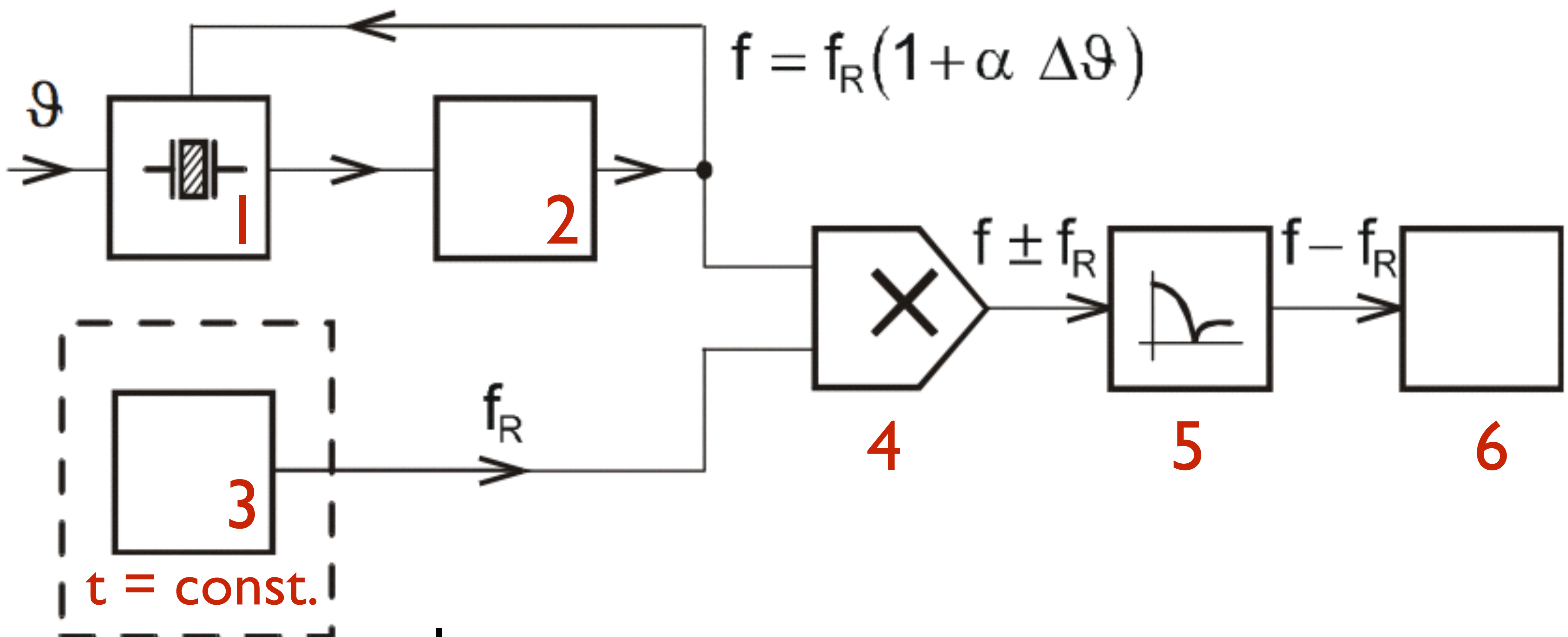
$$V_T = \frac{kT}{e}$$

This principle can be used to create a compensation circuit for thermocouples cold end



V_D changes with about 2 mV/K.
A voltage divider is used to achieved the desired sensitivity.

Quartz thermometer



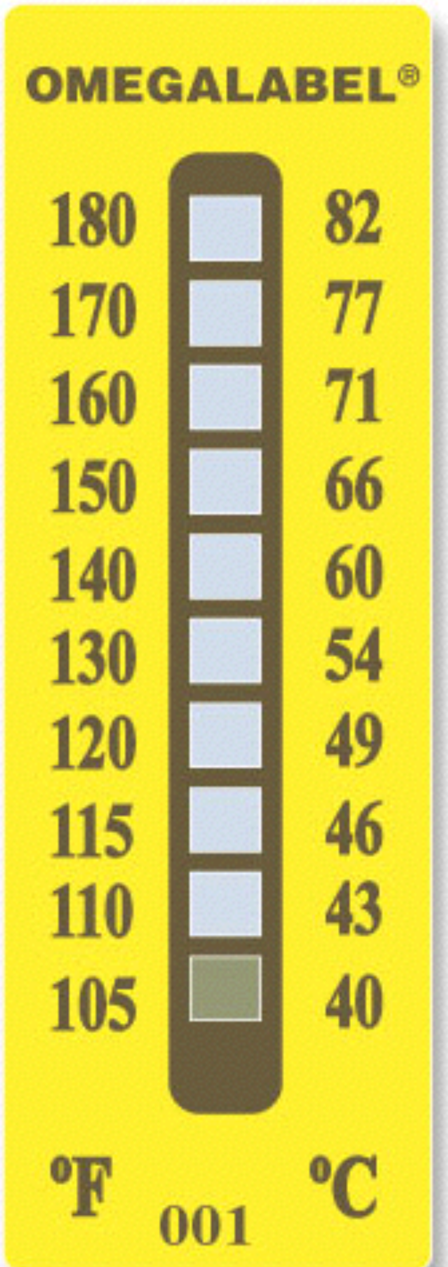
1 – quartz
2 – quartz controlled oscillator
3 – ref. quartz controlled oscillator (thermostated)
4 – mixer (analogue multiplier)
5 – low frequency filter (4+5=synchronous detector)
6 – counter with display

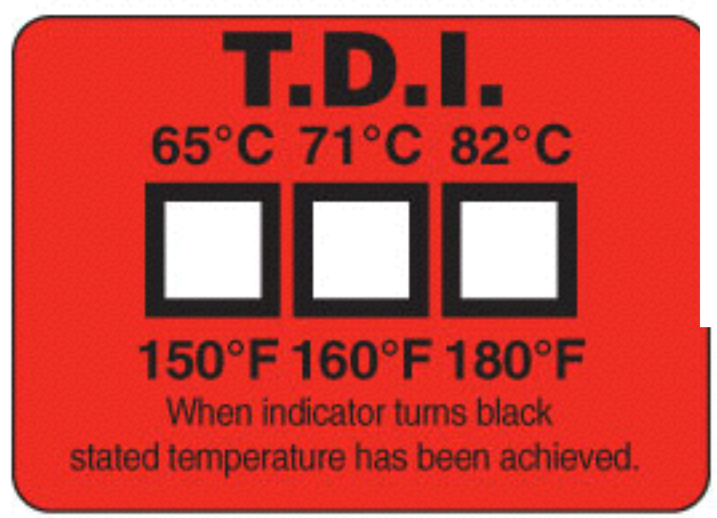
very precise!

Reversible temperatur labels

Omega

Non-reversible temperatur labels





Omega