Generalità sui sensori

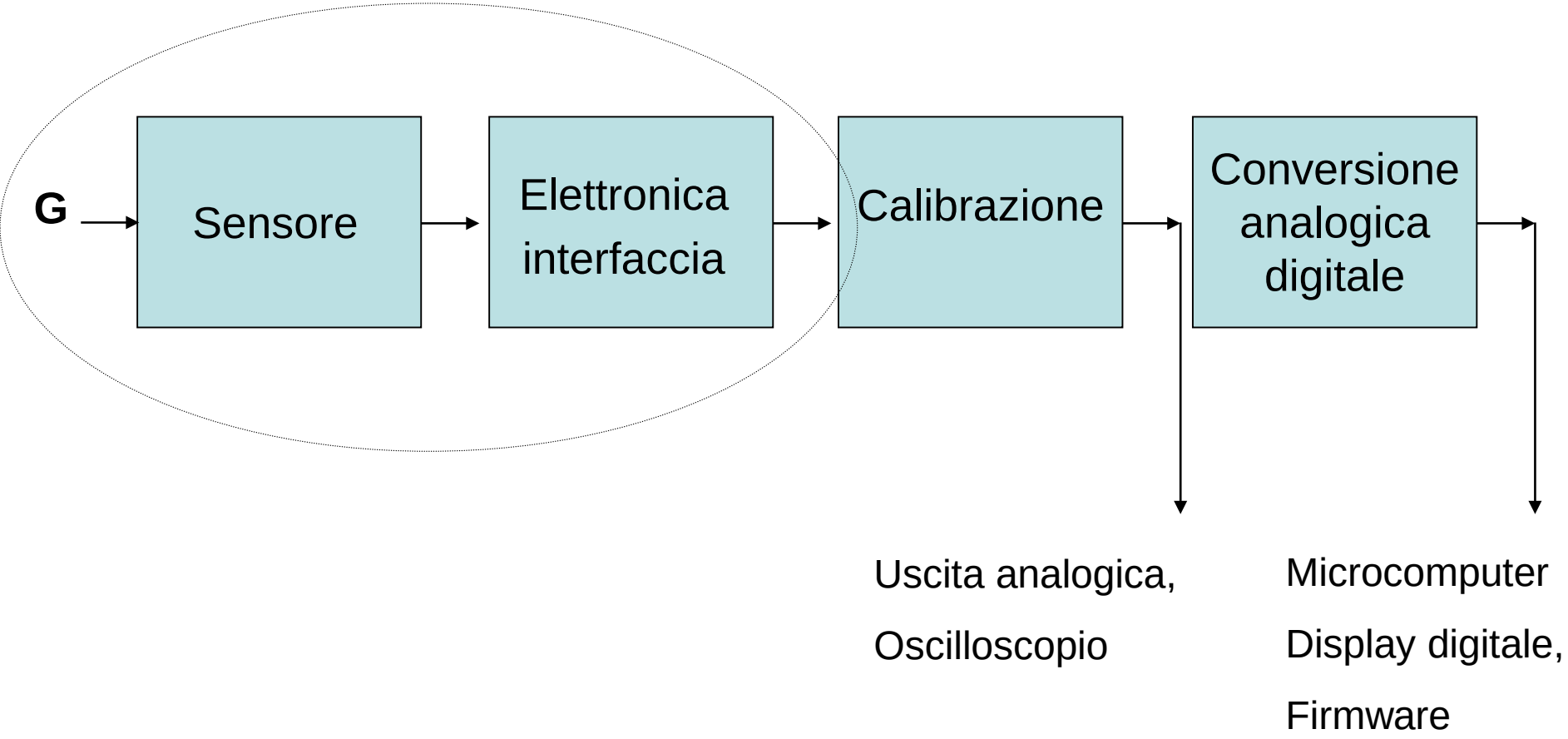
Elettronica dei Sistemi Analogici e Sensori

Corso di Laurea Magistrale Ingegneria Elettronica

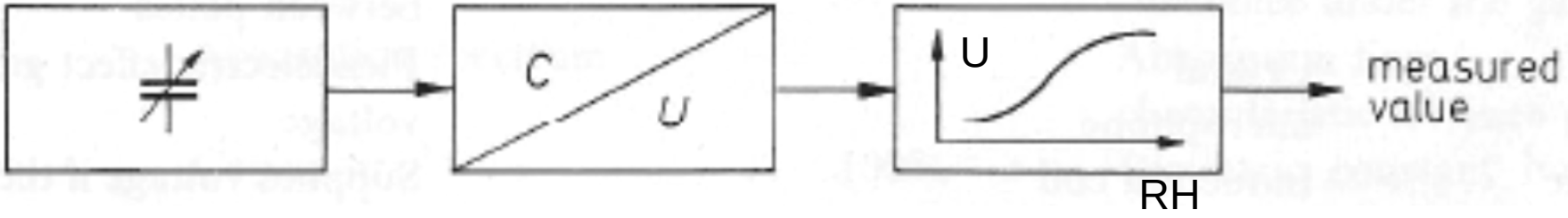
Università di Firenze

A.A. 2015-2016 , Prof. Ing. Lorenzo Capineri

Conversione di una grandezza *G* in un segnale calibrato



Linearità della risposta



Esempio: un sensore di umidità relativa (RH) converte il valore di capacità C(ε) in una tensione misurabile U

Funzione di Trasferimento

Sia **U** il segnale elettrico prodotto dal sensore e ***g*** lo stimolo ricevuto possiamo trovare una funzione **f()** tale per cui **U=f(*g*).** Sono esempi di funzioni di trasferimento (lineari o non lineari) le seguenti equazioni:

Lineare: $U = a + bg$ (dove ***a*** è l'uscita prodotta con ingresso nullo e ***b*** è la **sensibilità)**

Logaritmica: $U = a + b \ln g$

Esponenziale: $U = ae^{kg}$ (dove k è una costante numerica)

Potenza: $U = a_0 + a_1 g^k$

Tipi di sensori (parte 1)

Measurand	Sensor	Measurement range	Principle
Temperature	PTC metal	−200 . . . + 800° C	Pos. temperature coefficient of the resistance of metals, e.g. platinum
	PTC thermistor	− 50 . . . + 150° C	Pos. temperature coefficient of the resistance of semiconductors, e.g. silicon
	NTC thermistor	− 50 . . . + 150° C	Neg. temperature coefficient of the resistance of metal-oxide ceramic
	Transistor	− 50 . . . + 150° C	Neg. temperature coefficient of the base-emitter voltage of a transistor
	Thermocouple	−200 . . . + 2800° C	Thermo-electric voltage at contact of different metals
	Crystal oscillator	− 50 . . . + 300° C	Temperature coefficient of the resonant frequency of specially cut quartz crystals
Temperature via heat radiation	Pyrometer	−100 . . . + 3000° C	Spectral distribution of the luminance is temperature-dependent
	Pyroelement	− 50 . . . + 2200°C	Increase in temperature due to radiated heat generates polarization voltage

Tipi di sensori (parte 2)

Light intensity	Photodiode Phototransistor	$10^{-2}...10^{5}$ lx	Current increases with light intensity due to optically-released charge carriers
	Photoresistor	$10^{-2}...10^{5}$ lx	Electrical resistance reduces as illumination increases
	Photomultiplier	$10^{-6}...10^{3}$ lx	Light releases electrons from a photocathode which are multiplied by subsequent dynodes
Sound	Dynamic microphone		Induction of a voltage by movement of a coil within a magnetic field
	Condenser microphone		Voltage of a charged capacitor varies with distance between plates
	Crystal microphone		Piezoelectric effect generates voltage
Magnetic field	Induction coil		Supplies voltage if the magnetic field changes or the coil moves within the field
	Hall-effect device	$10^{-4}...1$ T	Produces a voltage across the semiconductor by deflection of electrons in the magnetic field
	Magnetoresistor	$0.1...1$ T	Resistance increases in semiconductor as a function of field strength

Tipi di sensori (parte 3)

Measurand	Sensor	Measurement range	Principle
Force	Strain gauge	10^{-2} . . . 10^{7} N	Force causes elastic elongation of a thin-film resistor, thereby increasing its resistance
Pressure	Strain gauge	10^{-3} . . . 10^{3} bar	Bridge circuit of strain gauge on diaphragm is detuned by pressure
Acceleration	Strain gauge	1 . . . 5000 g	Strain-gauge bridge is detuned by acceleration force on weighted diaphragm
Linear displacement	Potentiometric displacement transducer	µm . . . m	Potentiometer tap is shifted
	Inductive displacement transducer	µm . . . 10^{-1} m	Inductive bridge is unbalanced by displacement of a ferrite core
	Incremental displacement transducer, optical	µm . . . m	Reticle pattern is scanned. Number gives displacement
Angle	Incremental angular displacement transducer, optical	1 . . . 20000/rev.	Reticle pattern is scanned. Number gives angle of rotation
	Incremental angular displacement transducer, magnetic	1 . . . 1000/rev.	Magnetic scanning of a toothed-wheel sensor
	Incremental angular displacement transducer, capacitive	1 . . . 1000/rev.	Capacitive scanning of a toothed-wheel sensor

Tipi di sensori (parte 4)

Flow velocity	Windmill-type anemometer		Rotational speed increases with speed of flow
	Heated-wire anemometer		Cooling increases with rate of flow
	Ultrasound transceiver		Doppler shift increases with rate of flow
Gas concentration	Ceramic resistor		Resistance changes with adsorption of test substance
	MOSFET		Change in threshold voltage during adsorption of test substance under the gate
	Absorption spectrum		Absorption lines characteristic for each gas
Humidity	Capacitor	1...100%	Dielectric constant increases due to water absorption as relative humidity rises
	Resistor	5...95%	Resistance decreases due to water absorption as relative humidity rises

Measurand	Sensor	Measurement range	Principle
Temperature	PTC metal	−200 . . . + 800° C	Pos. temperature coefficient of the resistance of metals, e.g. platinum
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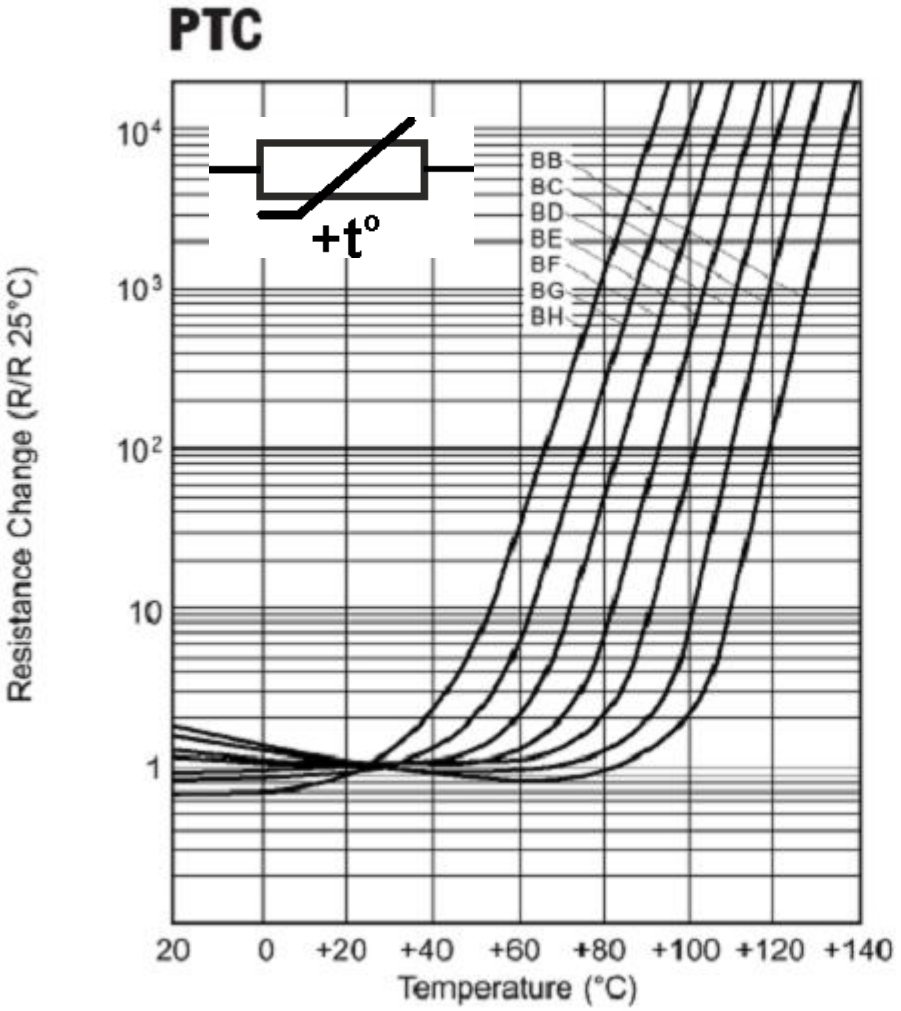
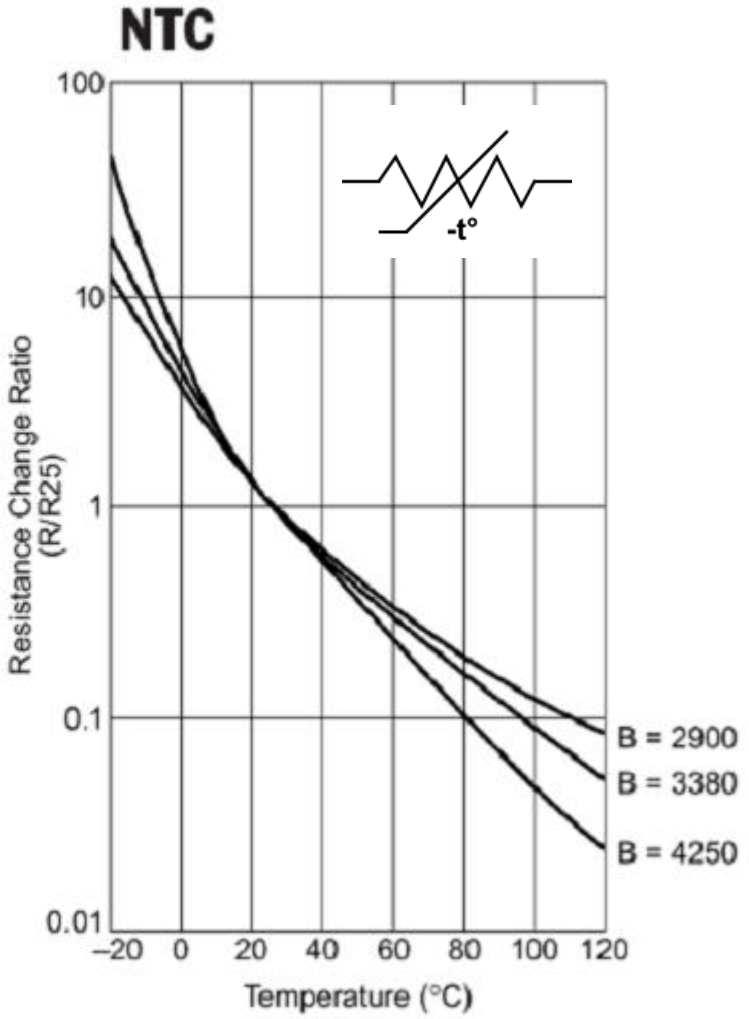
Campo di misura e variazione di resistenza

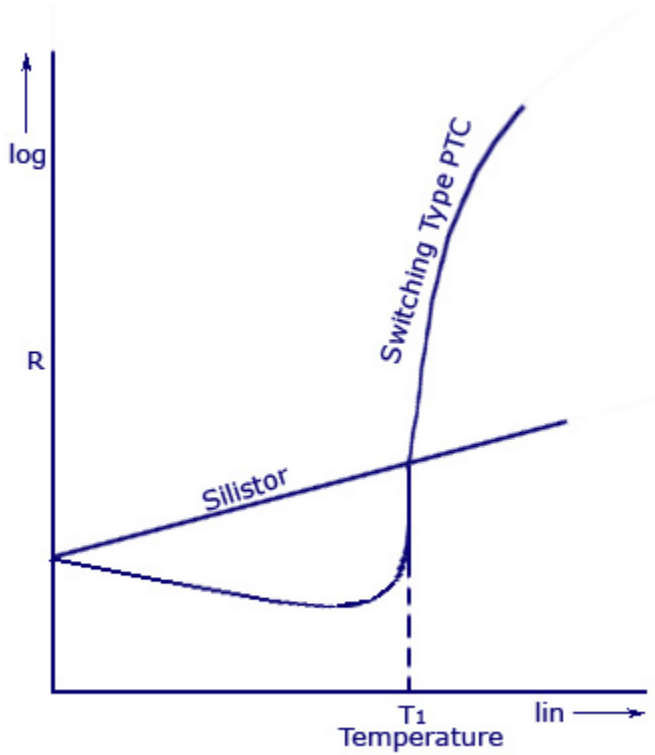
	Campo di misura ΔT	Variazione ottenibile ΔR
NTC metallo – ceramica	$-80°C \rightarrow +200°C$	$100\,\Omega \rightarrow 1\,M\Omega$
PTC metallici (tipo platino) LINEARI per MISURE DI TEMPERATURA	$-250°C \rightarrow +850°C$	$100\,\Omega \rightarrow 1\,k\Omega$
PTC in Silicio (s.c. policristallini) NON–LINEARI (FUSIBILI allo stato solido)	$-50°C \rightarrow +300°C$	$1\,k\Omega \rightarrow 2\,k\Omega$

Curve caratteristiche termistori

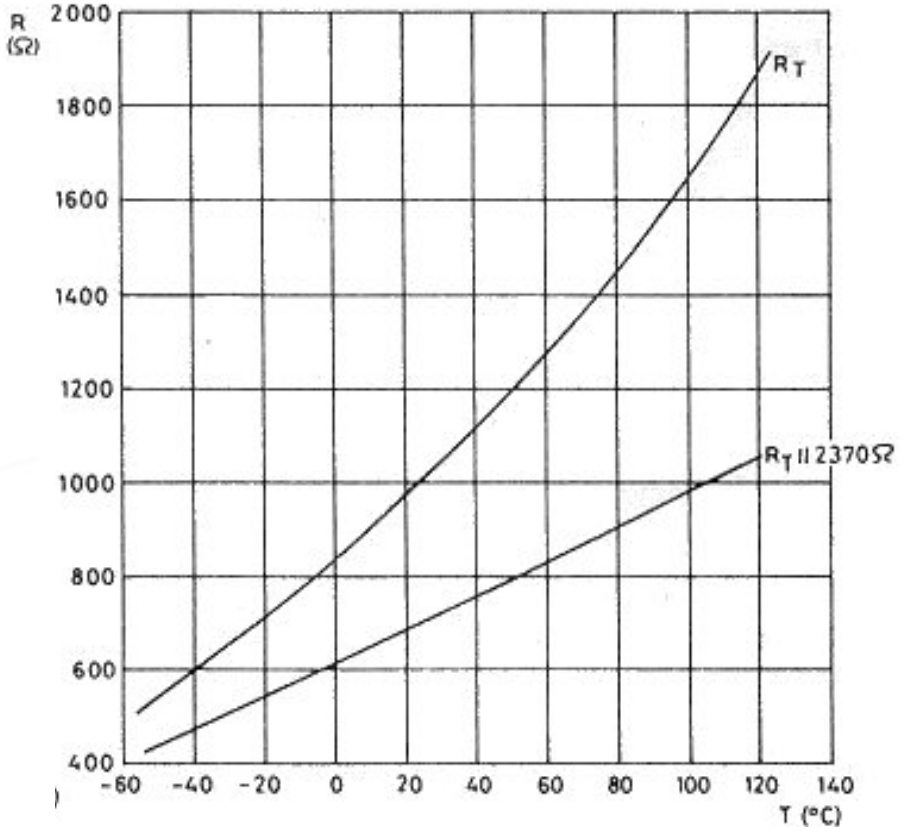




Termistori PTC e Silistor



R-T Characteristics of PTC Thermistors

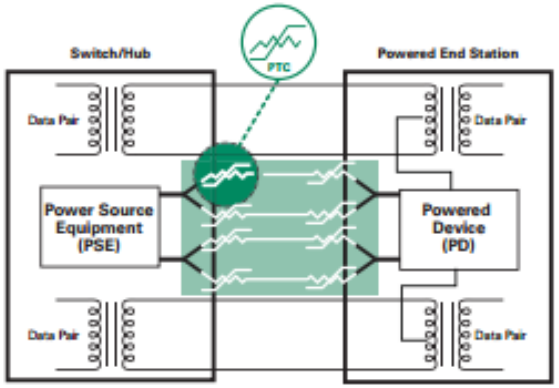


Silistor : RT, linearized RT// Rlin

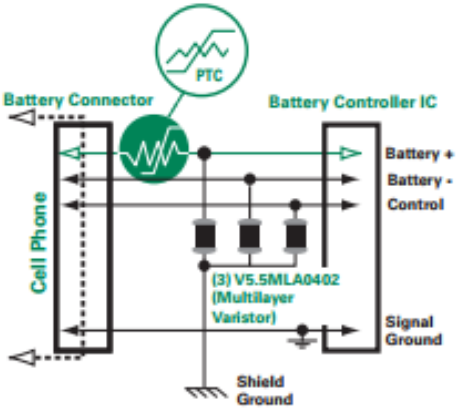
Silistor . This type of PTC thermistor uses a semiconductor as its base material and it is characterized by a linear characteristic. As a result this type of device is used in temperature sensors. The Silistor PTC thermistor is generally manufactured from doped silicon. It exhibits a resistance / temperature characteristic that is virtually linear, the exact characteristic depending upon the semiconductor used and the level of doping.

Applicazione PTC come fusibile stato solido in sistemi elettronici

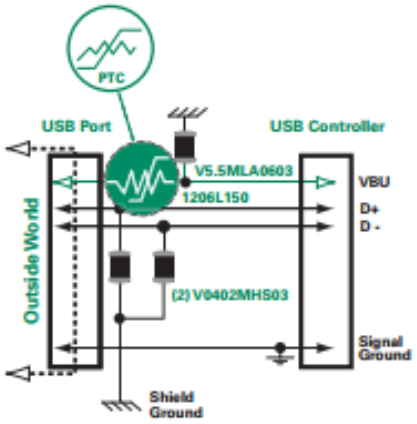
POWER OVER ETHERNET



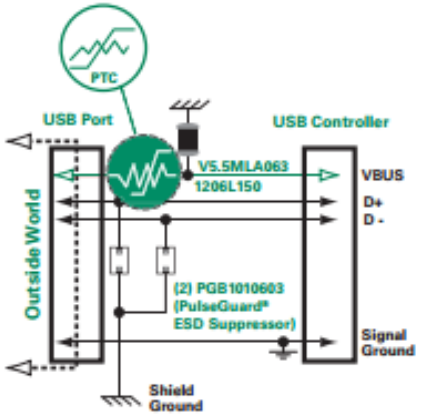
LI-ION BATTERY PACK



USB 1.1



USB 2.0



Linearizzazione della risposta di sensori di tipo resistivo e relativi circuiti di interfaccia

Coefficiente di Temperatura TC

- La resistenza R e' funzione non lineare della temperatura T : R=*f*(T)

- Si definisce coefficiente di Temperatura TC:

$$TC = \frac{1}{R} \cdot \frac{dR}{dT} \qquad \left[1/°C\right]$$

Dove R e' il valore ad una temperatura fissata

Risposta caratteristica

- Il valore di TC dipende dal materiale con cui sono realizzati i termistori e non dalle loro dimensioni.
- La dipendenza della resistività ρ si ottiene come segue:

$$TC = \frac{1}{R}\frac{dR}{dT} = \frac{1}{\rho}\cdot\frac{d\rho}{dT} \qquad [1/°C]$$

- Da cui l'espressione di R=*f*(T) approssimata al primo ordine:

$$R(T) = R(T_0)\cdot\left[1 + TC\cdot(T - T_0)\right] \qquad [Ohm]$$

- Dove TC [1/°C] e' dato rispetto a T_0

Tolleranza in temperatura

- La variazione di temperatura misurabile e' affetta dalla tolleranza del resistore dR_0/R_0, a cui e' legata tramite il TC:

$$\Delta T = \frac{1}{TC} \cdot \frac{dR_0}{R_0}$$

(Rispetto ad una temperatura fissata T_0)

Valori coeff. temp. (TC)

Sensori a filo o film metallico:

- Platino TC = 3.85×10^{-3} [1/°C]
- Nickel TC = 6.7×10^{-3} [1/°C]
- Ferro-Nickel TC = 5.2×10^{-3} [1/°C]

Silistori (Termistori PTC a semic.) :

- PTC semic. TC= 7.95×10^{-3} [1/°C]

Coeff. temp. (TC) per sensori NTC (metallo – ceramica)

Legge di Steinhart-Hart semplificata per R(T):

NTC

$$R(T) = R_{NOMIN} e^{\left(B\left(\frac{1}{T} - \frac{1}{T_{NOMIN}}\right)\right)}$$

$B = 1500K \div 7000K$

Coefficiente caratteristico del materiale

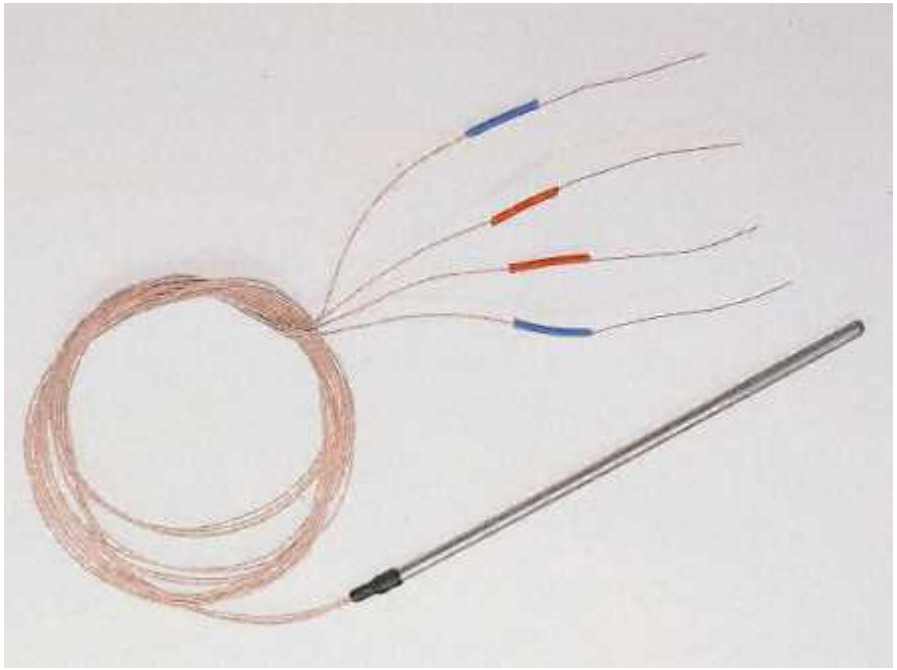
$$T_K = 273°C + T_{°C}$$

Coefficiente di temperatura

$$TC = \frac{1}{R}\frac{dR}{dT} = -\frac{B}{T^2} \qquad [\% / °C]$$

Es.: T=25°C e B=1250°C risulta TC= - 2 %/°C (elevata sens. alle basse T)

SENSORE COMMERCIALE Pt100



Termometro,resistenza di platino,PT100,acciaio inox,terminali PTFE

Temperatura di funzionamento -50°C to +200°C

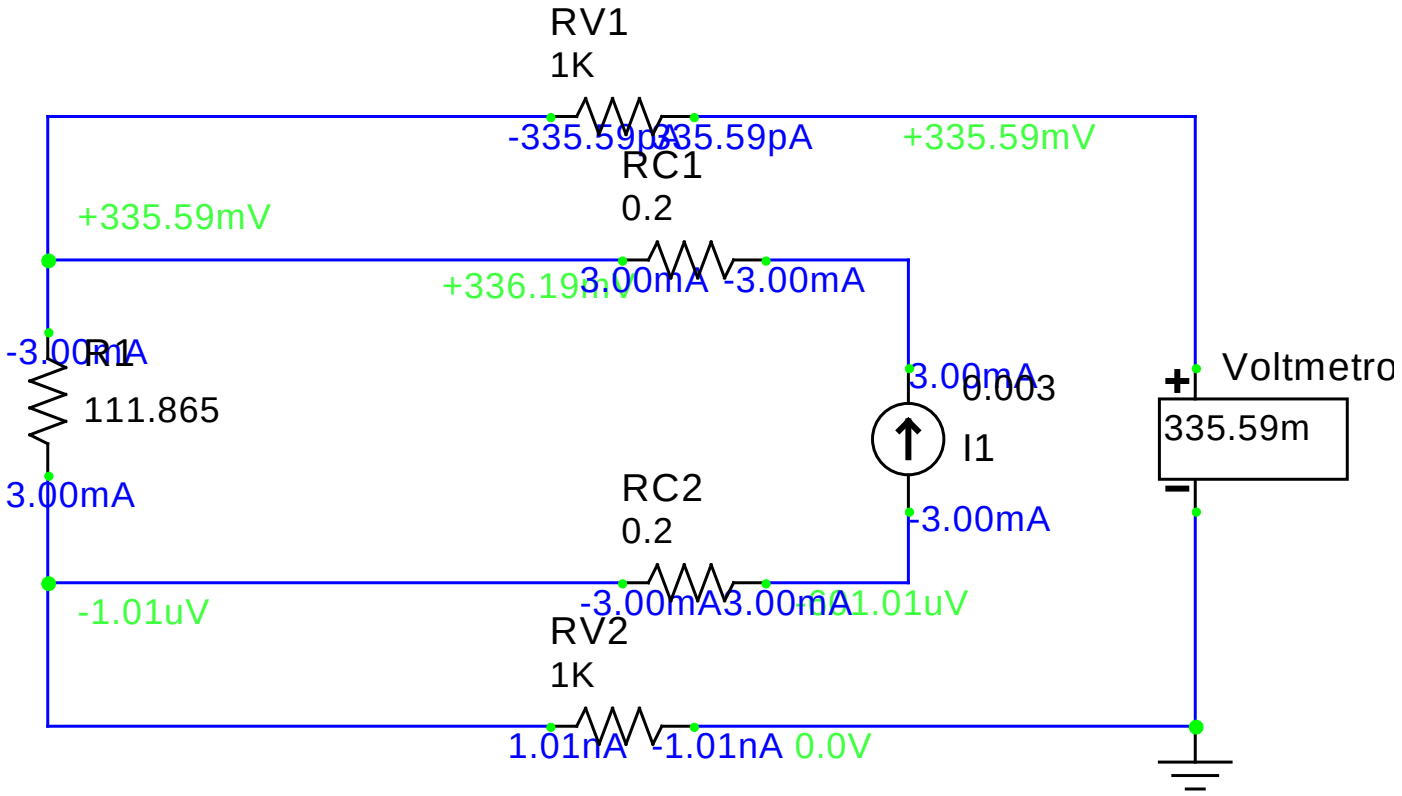
Materiale sonda Platinum (Probe); Stainless Steel (Sheath)

Tipo cavo-materiale PTFE Insulated

Diametro sonda 3mm

Lunghezza sonda 100mm

Circuito di misura con RTD



Misura a 4 fili : RC1 e RC2 resistenza dei fili di collegamento della sorgente di alimentazione di corrente continua I1=3mA, RV1 e RV2 resistenze dei collegamenti al voltmetro.

Potenza assorbita dal resistore $R1x(I1)^2$=1 mW

Linearizzazione della risposta PTC metallico di platino

Per elevate variazioni della temperatura (es. oltre 800°C) la risposta non e' più lineare e quindi e' necessaria una correzione tramite un circuito appositamente progettato per un tipo specifico di RTD.

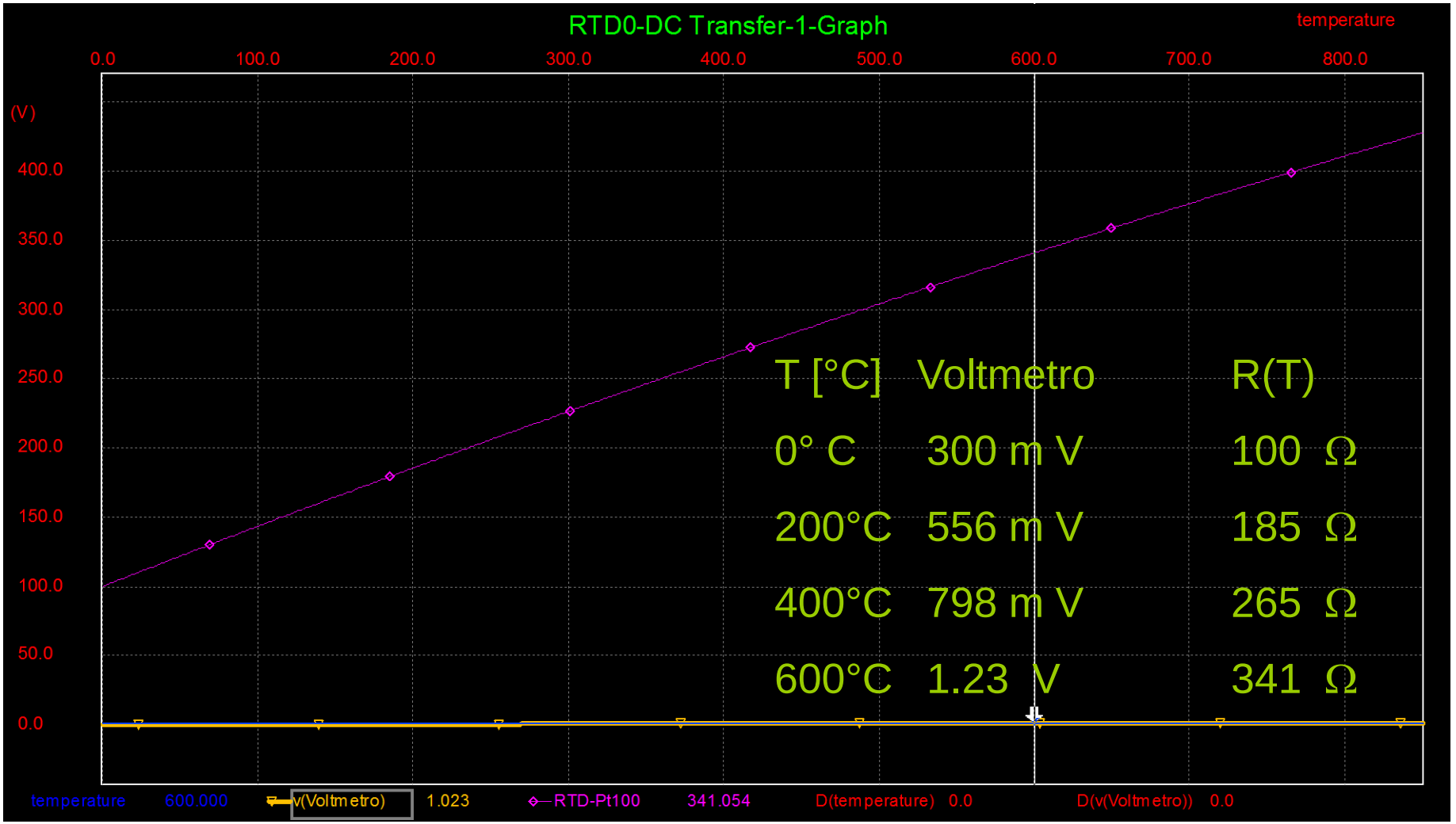
Ad esempio per un PTC a filo metallico di platino Pt100, la norma IEC571 fornisce la seguente relazione per il campo di temperatura 0-850°C:

$$R(T) = R(T_0) \cdot \left[1 + 3.90802 \cdot 10^{-3} \cdot T - 0.580195 \cdot 10^{-6} T^2\right] \quad \Omega$$

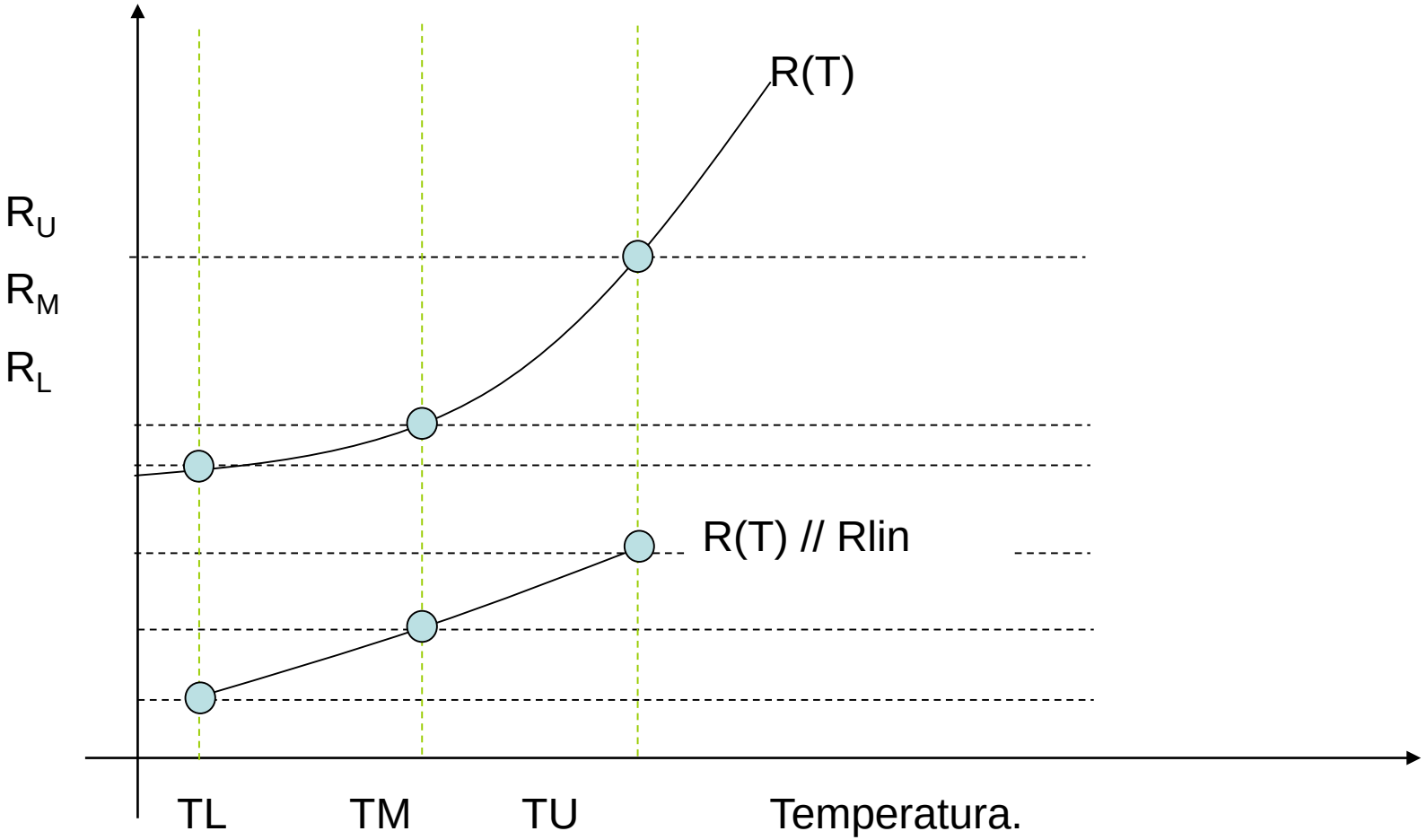
Con $R(T_0 = 27°C)$ =111.8 Ohm

Con $R(T_0 = 0°C)$ =100 Ohm (Pt100)

Simulazione tra 0-850°C



Effetto della linearizzazione con R_{lin} in parallelo a R(T)



Calcolo della resistenza di linearizzazione Rlin

- Si definiscono i valori di resistenza R_L, R_M, R_U rispettivamente per i valori di temperatura minimo, medio e massimo (T_L, T_M, T_U).
- Il valore di Rlin da porre in parallelo al RTD, tale da rendere uguale la variazione di resistenza nei due intervalli (T_M- T_L) e ($T_U - T_M$), e' definito da:

$$R_{lin} = \frac{R_M \cdot (R_U + R_L) - 2R_U \cdot R_L}{(R_U + R_L) - 2R_M}$$

Esempio numerico

Valutiamo mediante i valori simulati la Rlin per un intervallo di temperatura tra 200°C e 600°C, centrato su 400°C:

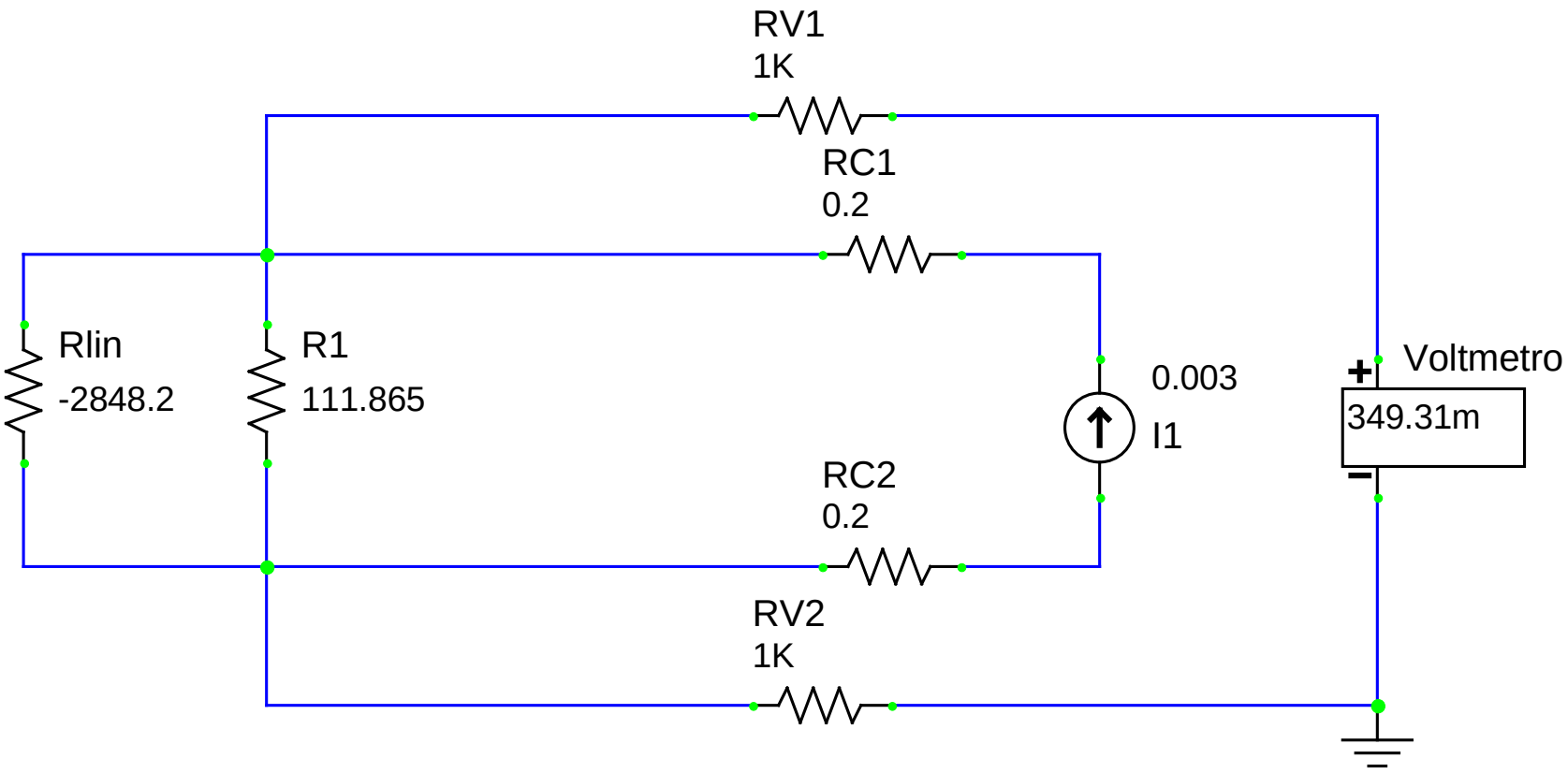
TL = 200°C RL=185.55 Ω

TM= 400°C RM=265.9 Ω

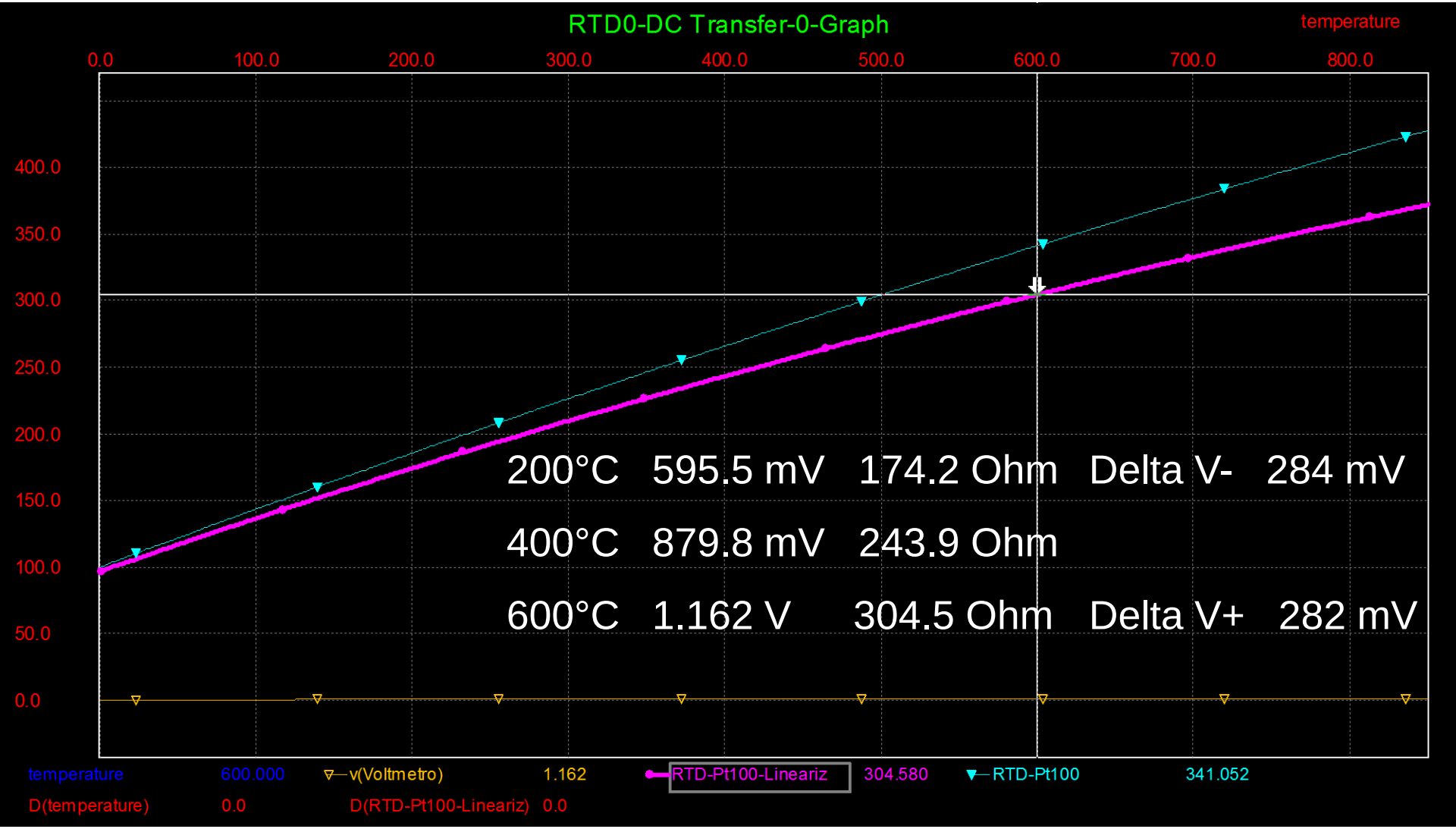
TU= 600°C RU=341.54 Ω

Rlin = - 2848.2 Ω

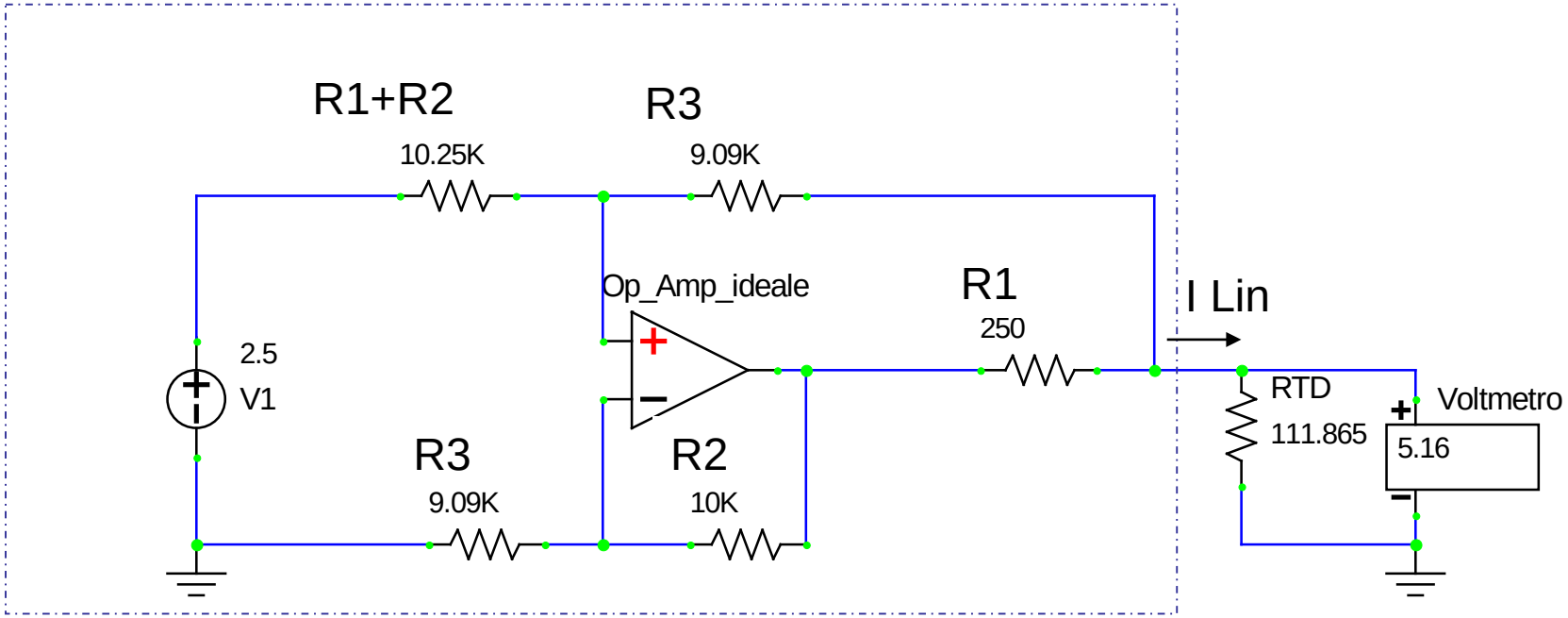
Circuito Linearizzato



Risultato con Rlin= -2848.2 Ohm



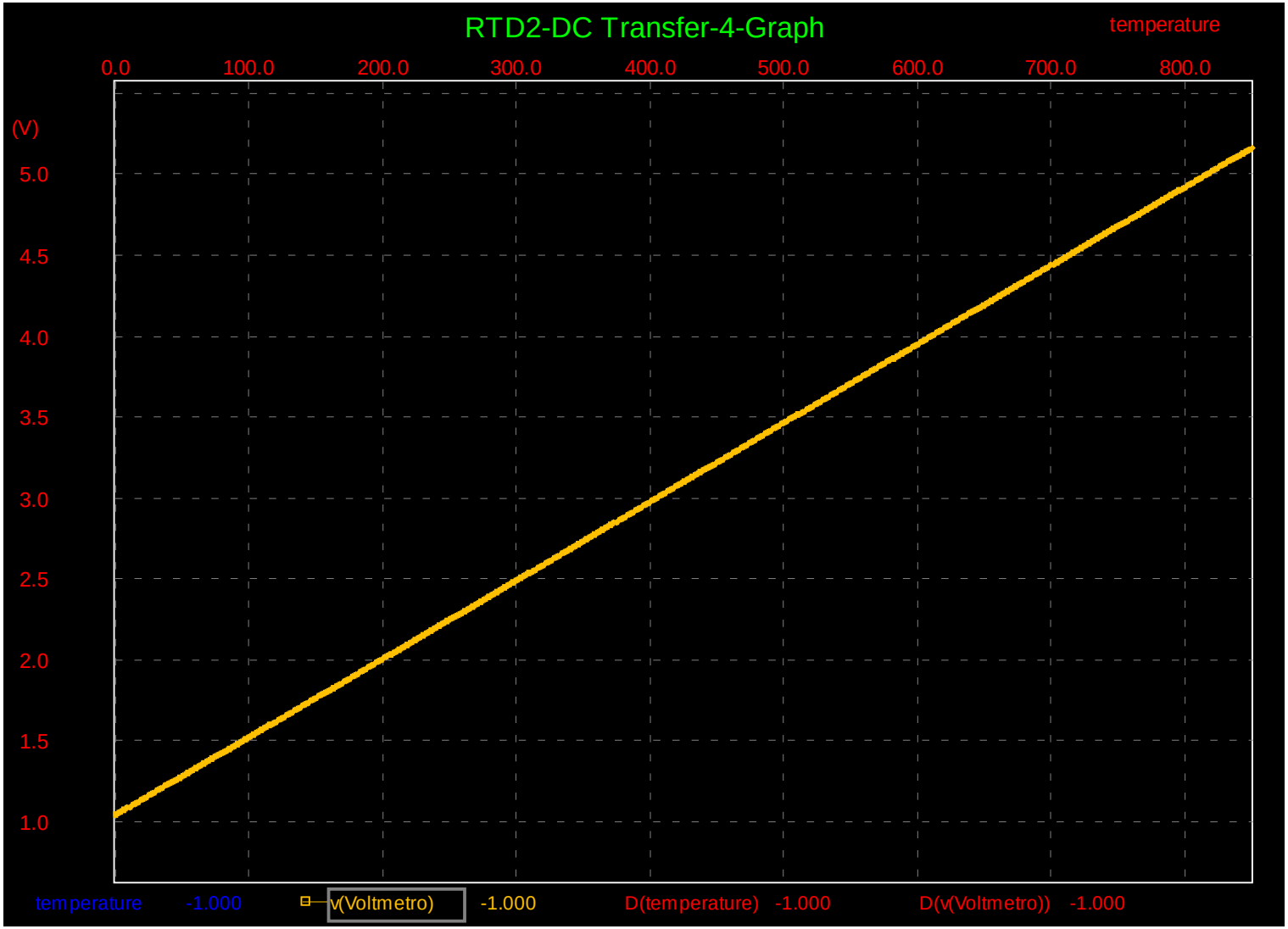
Generatore di corrente con resistenza d'uscita negativa



$$R_{lin} = -\frac{\Delta Voltmetro}{\Delta Iuscita} \cong \frac{R_1 R_3 \cdot (R_2 + R_3)}{R_3^2 - R_2^2}$$

$$Hp) \quad R_1 << R_3 \; ; R_1 << R_2$$

Simulazioni con generatore di corrente costante a resistenza di uscita negativa (Rlin)



Esercizio: progetto del circuito di interfaccia per sensore PTC

- Vref=2.5 V (bandgap reference)
- Dinamica ingresso ADC = 0-2 V
- Intervallo di temperatura linearizzato 0-100°C
- Circuito capace di autocalibrarsi

Richieste:

- Valori delle resistenze del circuito
- Caratteristiche Op. Amp.

Linearizzazione di PTC a semiconduttore tipo KTY83/110 (Philips) tra 0° e 100°C

$$R(T) = R(T_0 = 25°C) \cdot \left[1 + 7.95 \cdot 10^{-3} \cdot \Delta T + 1.95 \cdot 10^{-5} \Delta T^2\right] \quad \Omega$$

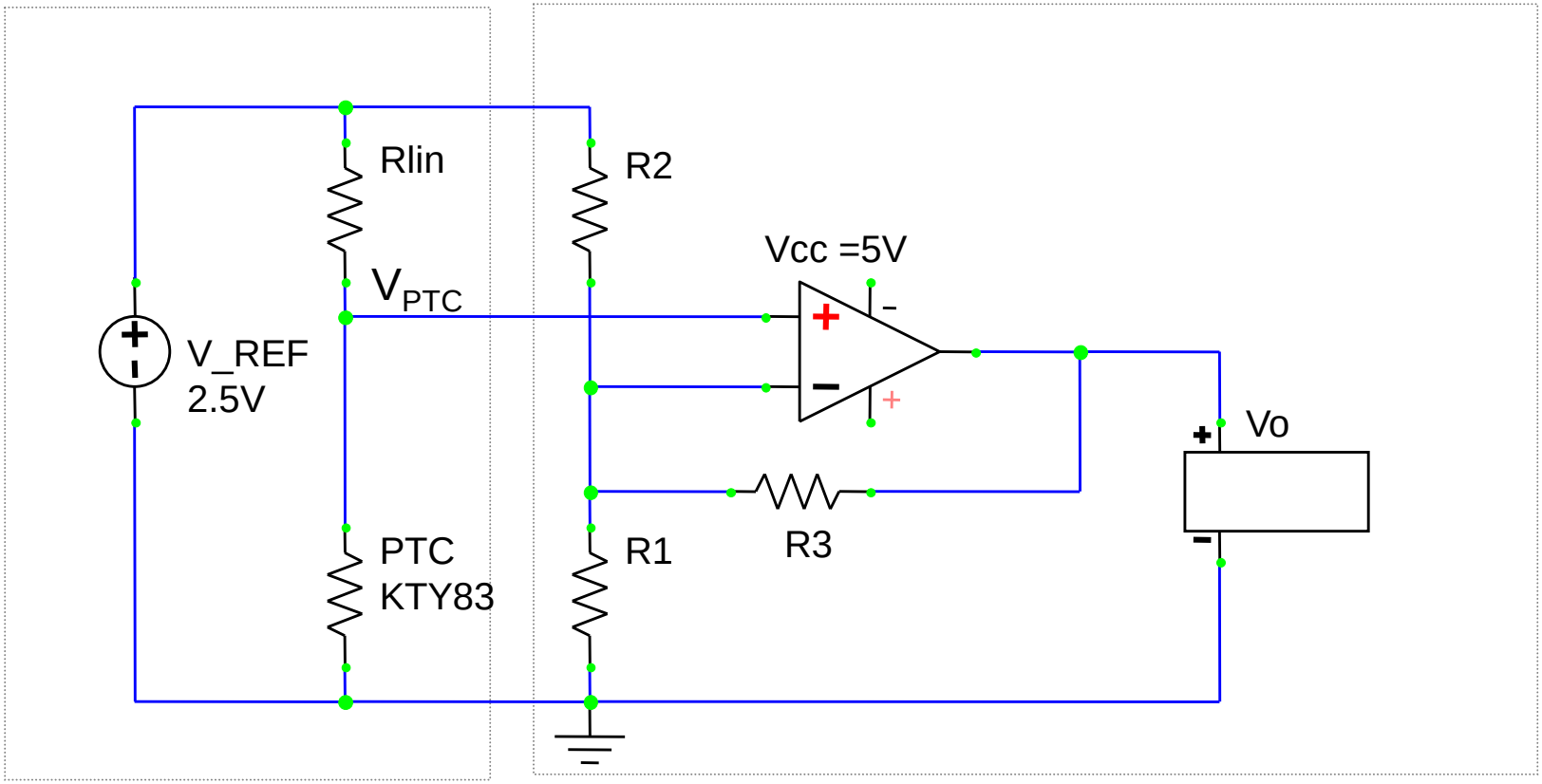
$$dove\ \Delta T = T - T_0$$

CHARACTERISTICS

T_{amb} = 25 °C in liquid unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
R_{25}	sensor resistance	I_{cont} = 1 mA				
	KTY83/110		990	–	1010	Ω
	KTY83/120		980	–	1020	Ω
	KTY83/121		980	–	1000	Ω
	KTY83/122		1000	–	1020	Ω
	KTY83/150		950	–	1050	Ω
	KTY83/151		950	–	1000	Ω
TC	temperature coefficient		–	0.76	–	%/K
R_{100}/R_{25}	resistance ratio	T_{amb} = 100 °C and 25 °C	1.65	1.67	1.69	
R_{-55}/R_{25}	resistance ratio	T_{amb} = –55 °C and 25 °C	0.49	0.50	0.51	
τ	thermal time constant; note 1	in still air	–	20	–	s
		in still liquid; note 2	–	1	–	s
		in flowing liquid; note 2	–	0.5	–	s
	rated temperature range		–55	–	+175	°C

Circuito di interfaccia per PTC a semiconduttore tipo KTY83/110 (Philips)



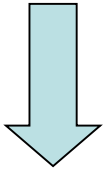
Specifiche progetto: Vo=20mV/°C nell'intervallo 0°-100°C

Calcolo Rlin

T_L = 0°C R_L=820 Ω V_{PTCL}=0,558V Vo_L=0V

T_M= 50°C R_M=1202 Ω V_{PTCM}=0,741V Vo_M=1V

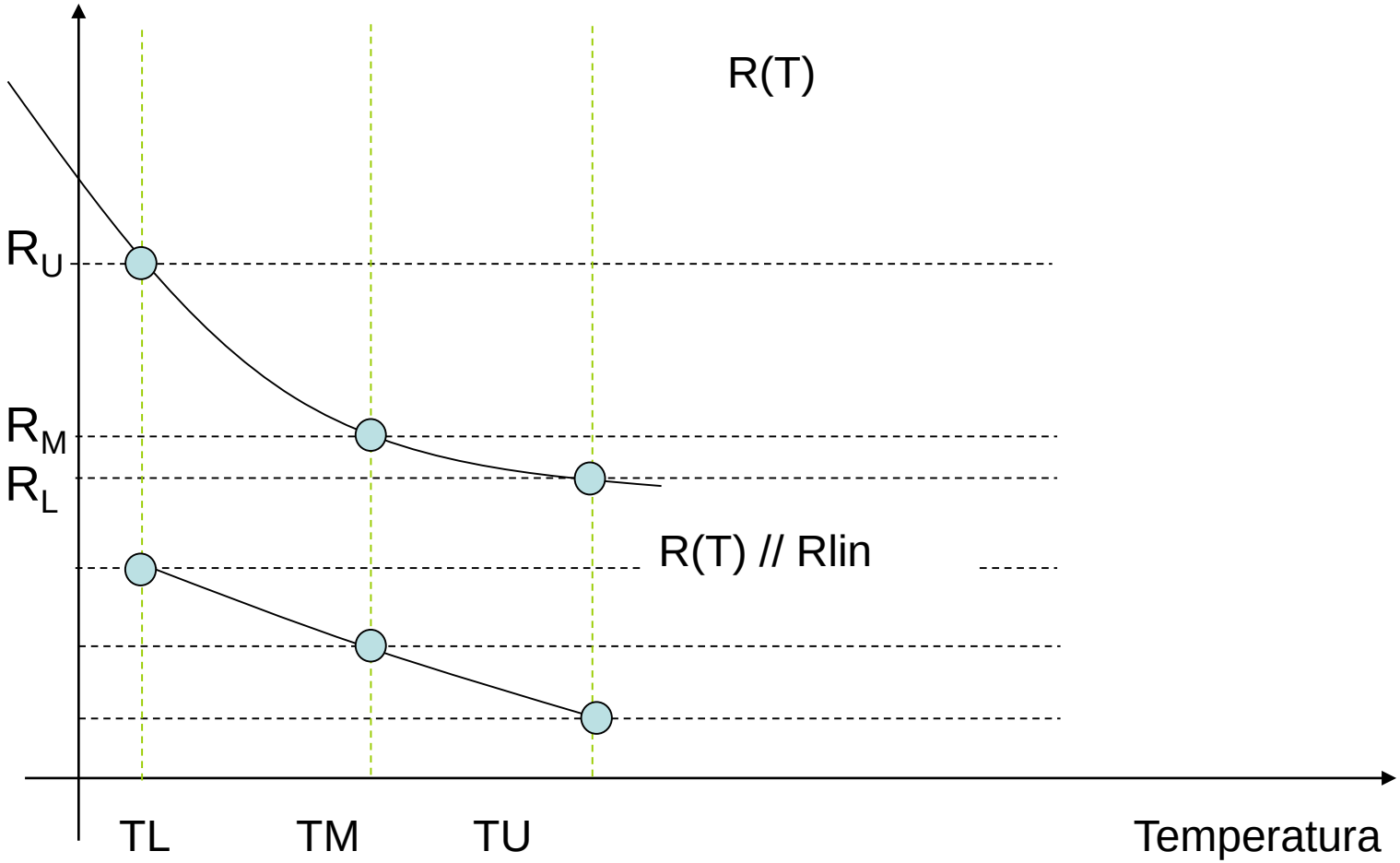
T_U= 100°C R_U=1706Ω V_{PTCU}=0,936V Vo_U=2V



Rlin = + 2851 Ω

Con tale valore di Rlin si calcolano i valori di tensione sul PTC (V_{PTC}) ed i relativi valori desiderati in uscita per una dinamica di ingresso di un convertitore A/D di 2V. Si assume inoltre R_2= Rlin

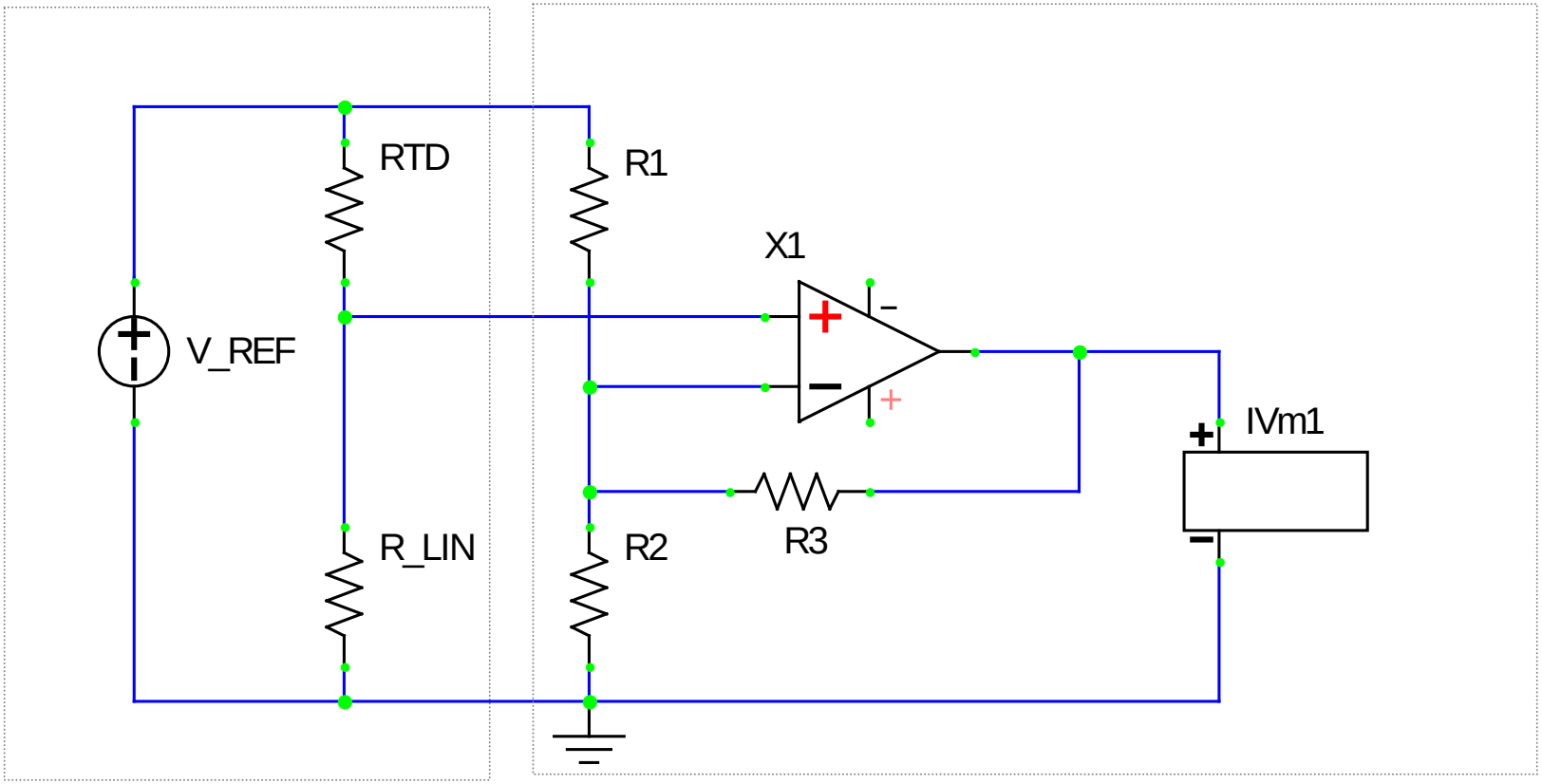
Linearizzazione di un NTC



Resistore linearizzazione Rlin in parallelo con valore $\approx R_M$

Metodo valido per un intervallo ristretto di temperature (TL, TU)

Linearizzazione di un NTC



Alimentazione stabilizzata e

R_LIN resistore serie di linearizzazione

del sensore RTD tipo NTC

Calibrazione zero e guadagno