MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Ciclo de Palestras Sobre Controle Térmico de Satélites

Sensores de Temperatura, Aquecedores Elétricos, Termostatos e Controladores de Estado Sólido

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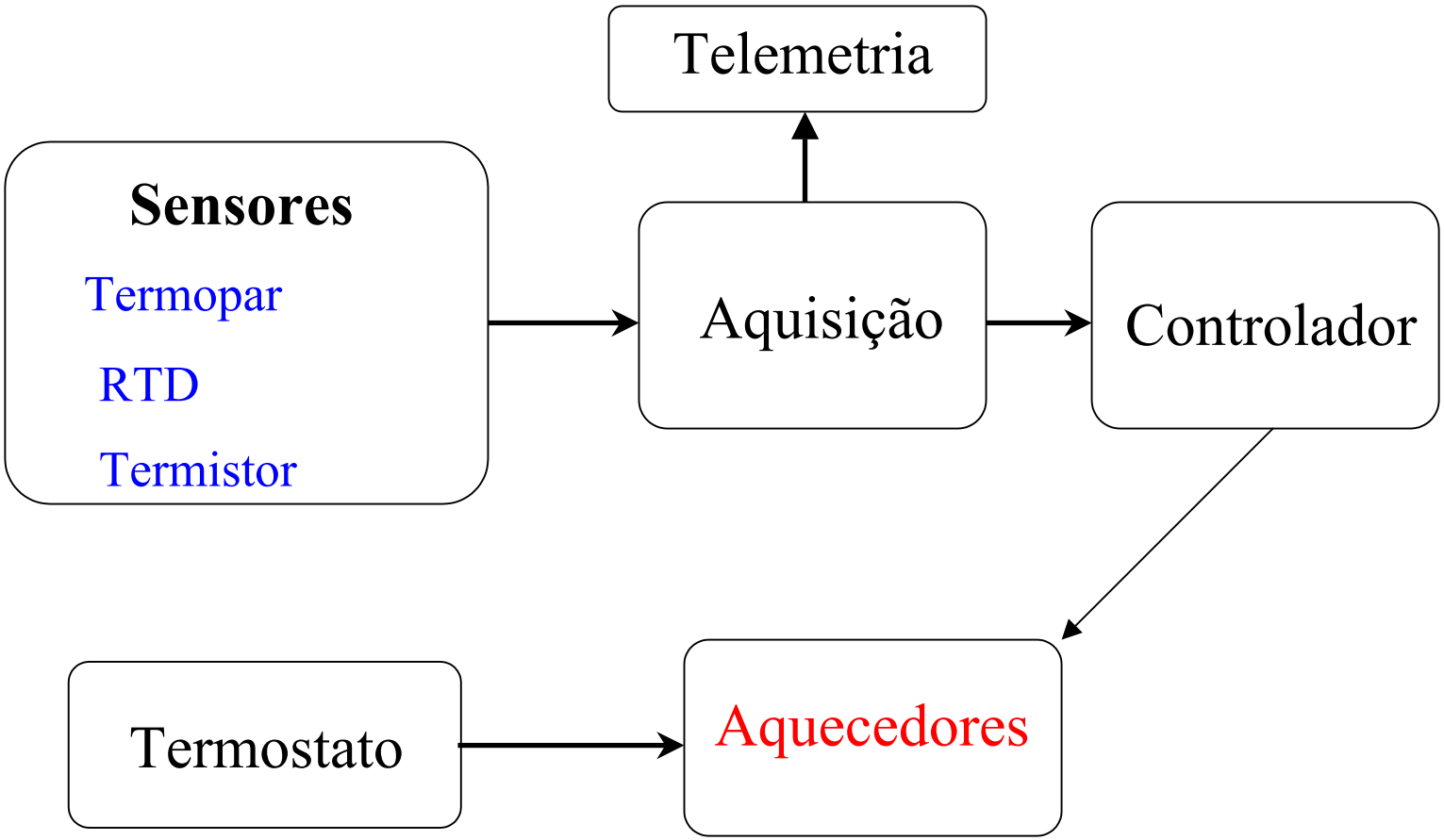
Divisão de Mecânica Espacial e Controle - DMC

- A distribuição de temperaturas em um satélite precisa ser monitorada.
- Elementos do satélite podem requerer aquecimento e/ou controle estrito de temperatura.



Termopares

Basicamente, consiste de dois fios de materiais distintos conectados em uma extremidade, que submetida à uma temperatura produz uma diferença de potencial na extremidade aberta.

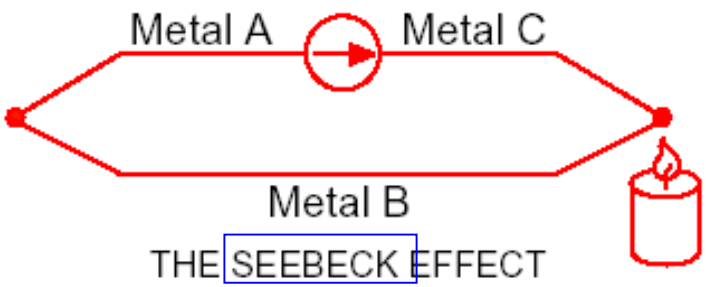


Figure 2

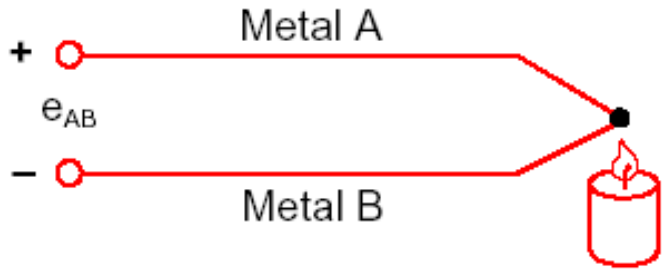
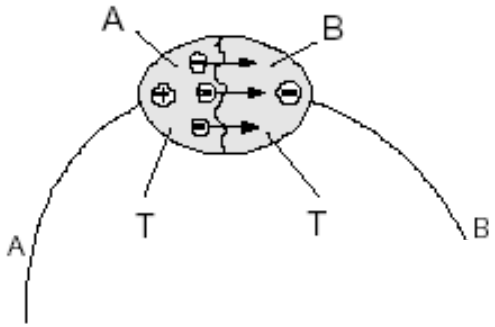
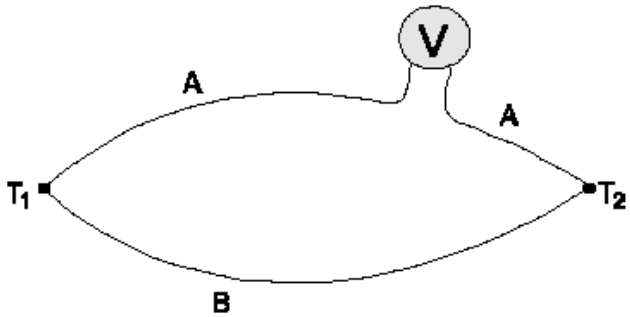


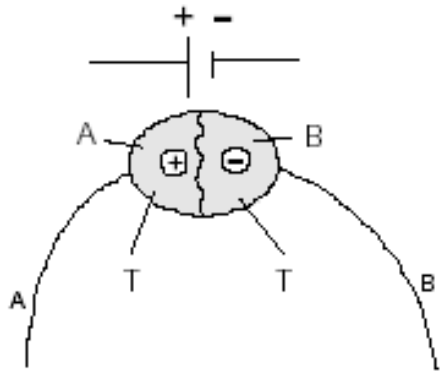
Figure 3

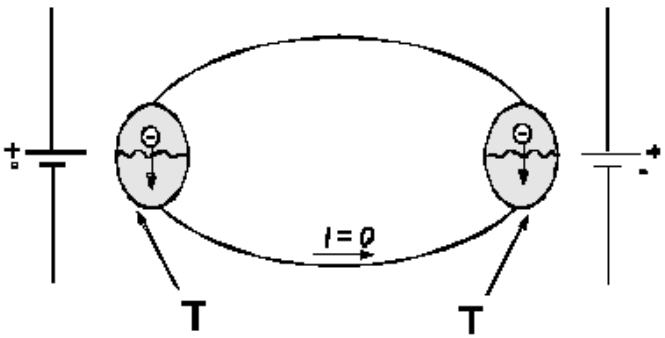
Thomas Seebeck, 1821.

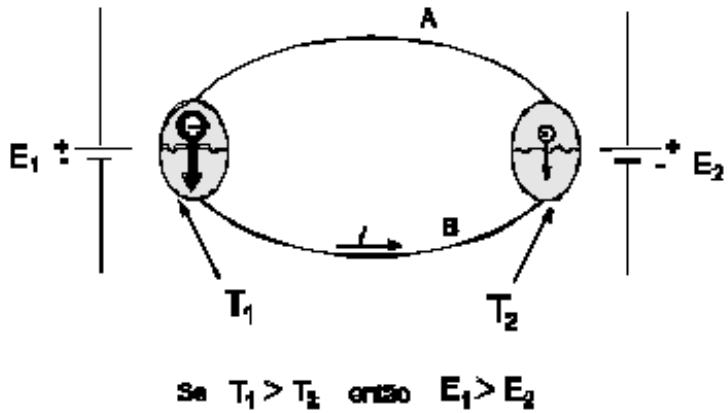
- Termopares: princípio físico.





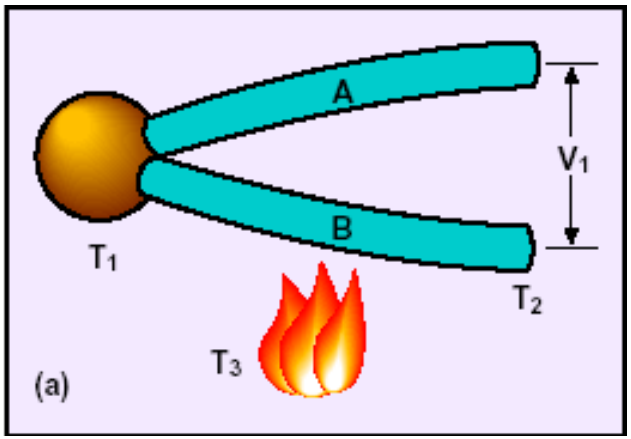


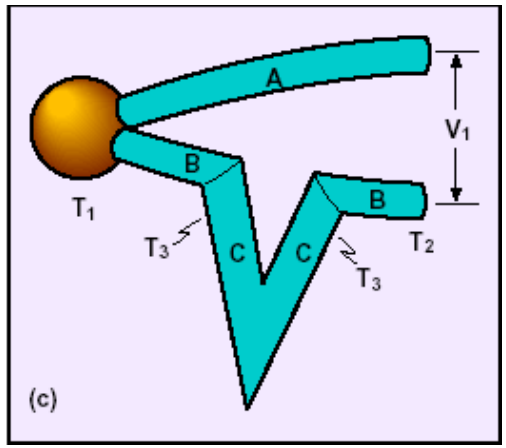


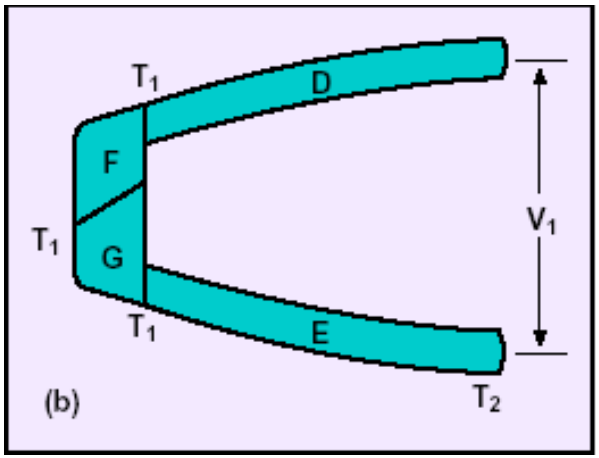


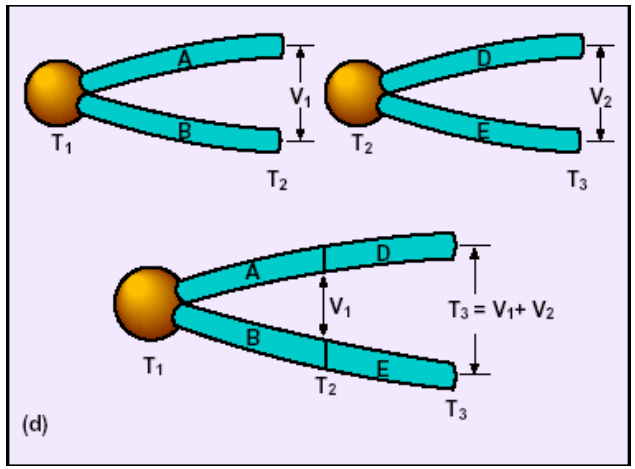
Se $T_1 > T_2$ então $E_1 > E_2$

- Leis básicas dos termopares



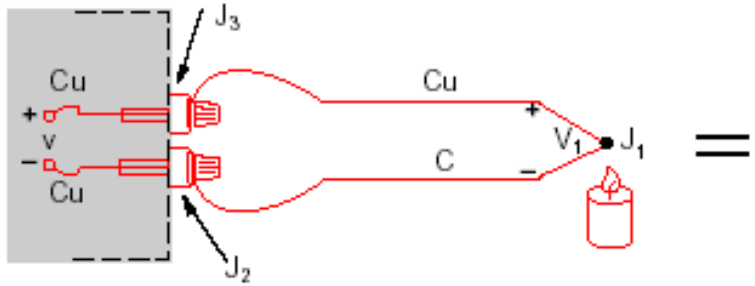




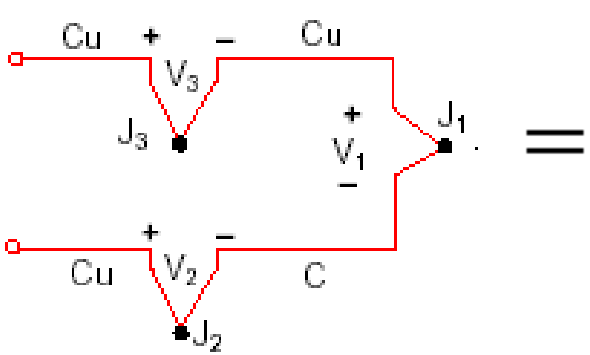


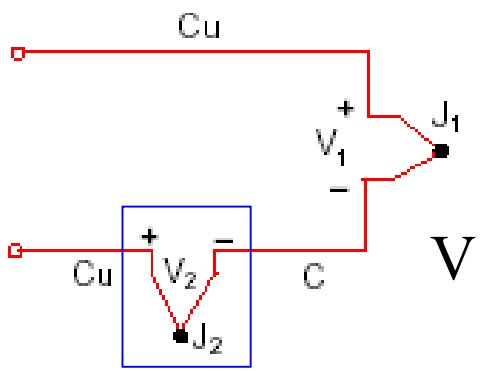
- A tensão na extremidade aberta é função das temperaturas nas extremidades fechada e aberta.

- Como medir a temperatura?



EQUIVALENT CIRCUITS



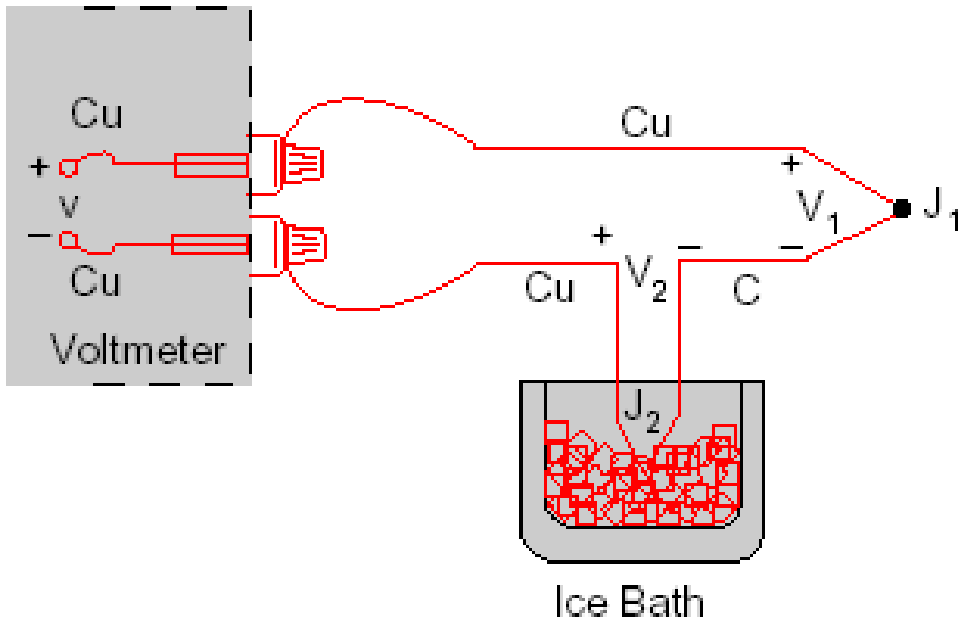


Junção de referência

$$V = (V_1 - V_2) \approx \alpha\,(T_{J1} - T_{J2})$$

α depende da temperatura

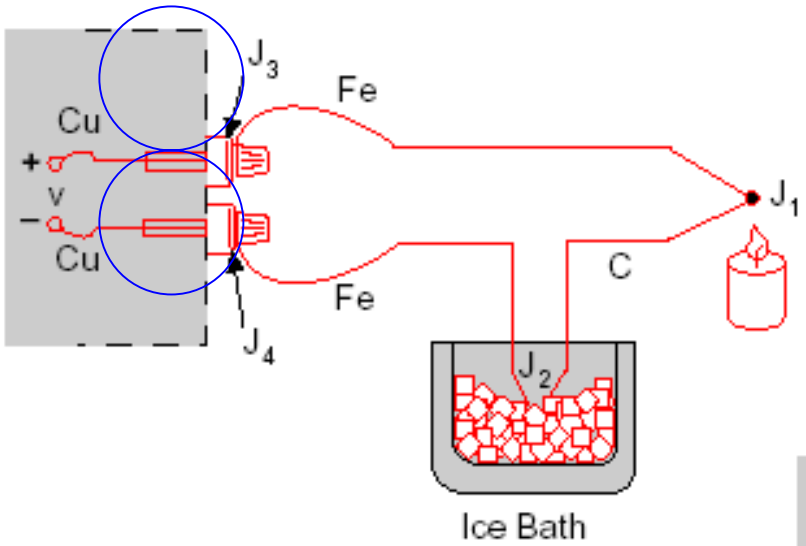
- Temperatura de referência mais precisa: Banho de gelo.



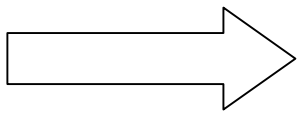
EXTERNAL REFERENCE JUNCTION

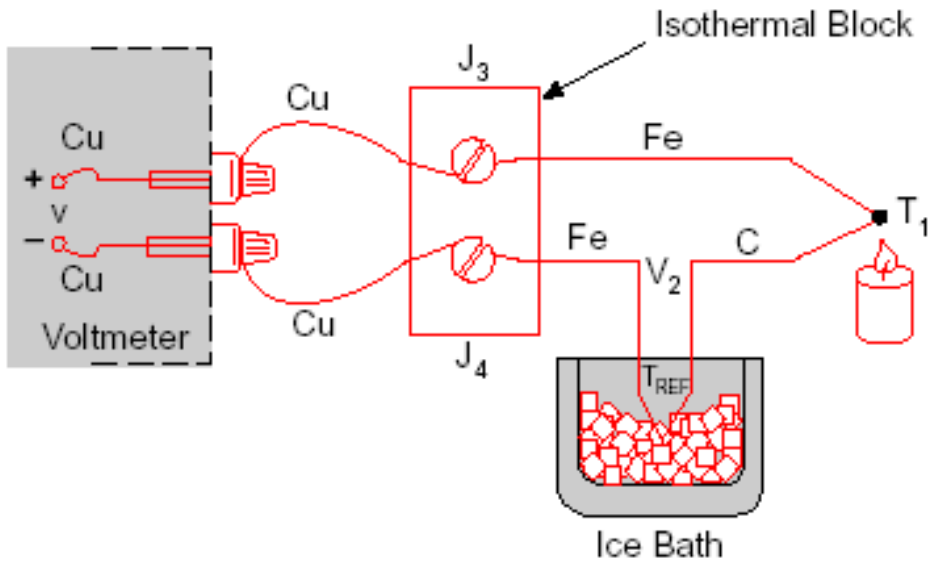
- Termopares são calibrados para esta temperatura de referência.

Outros tipos de materiais dissimilares: juntas adicionais.



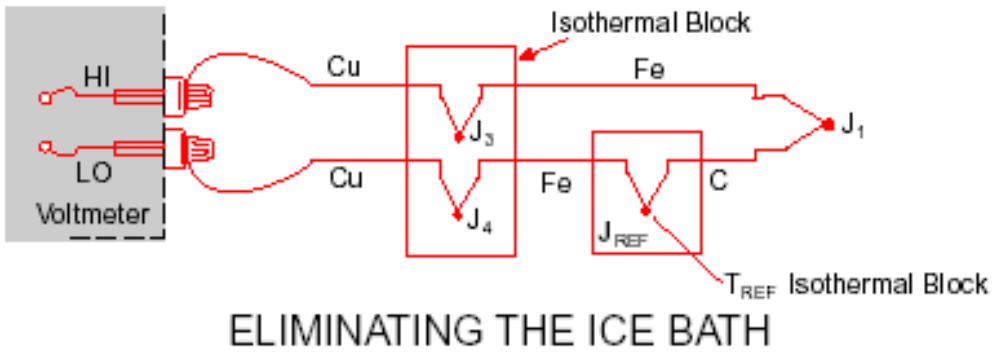
Por J3 e J4 na mesma temperatura.



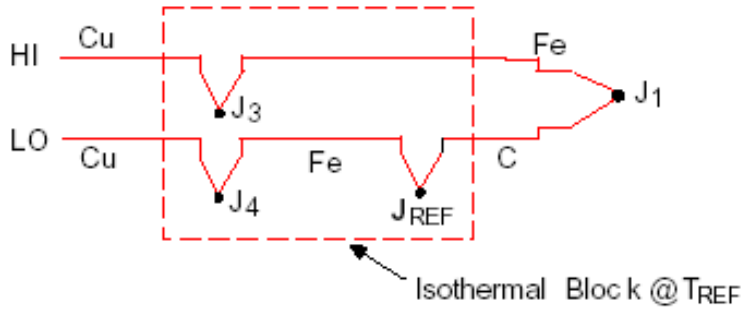


REMOVING JUNCTIONS FROM DVM TERMINALS

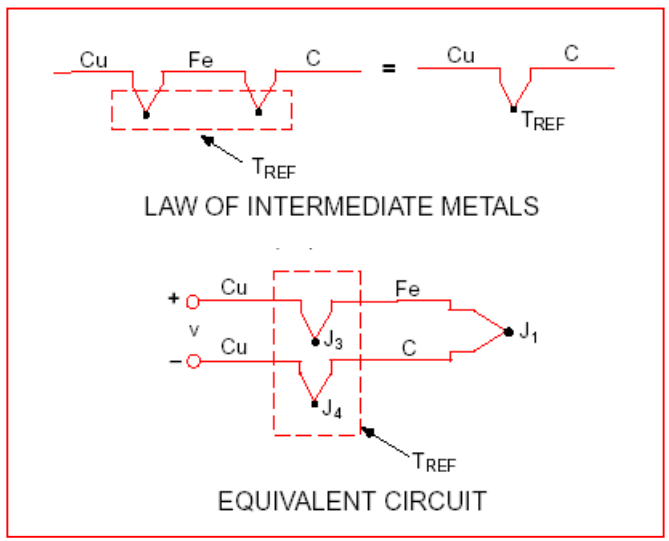
- Em um satélite não vou ter um banho de gelo para usar como referência:



ELIMINATING THE ICE BATH

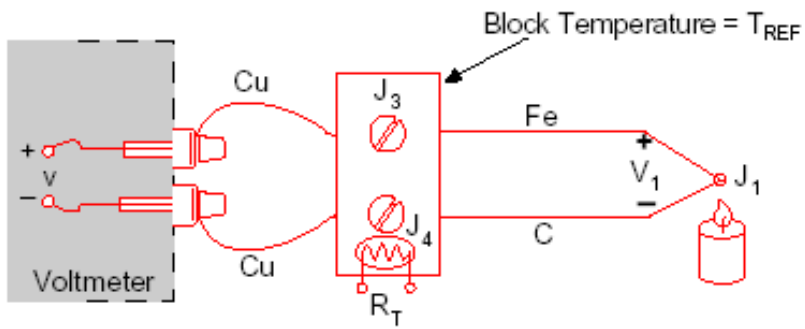


JOINING THE ISOTHERMAL BLOCKS



LAW OF INTERMEDIATE METALS

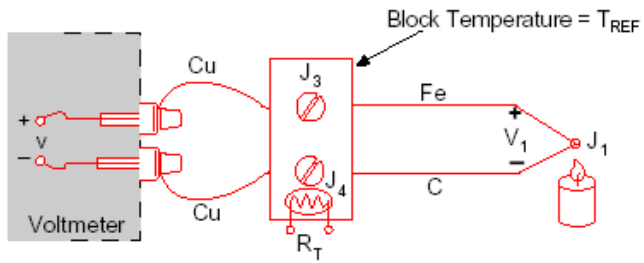
EQUIVALENT CIRCUIT



EXTERNAL REFERENCE JUNCTION-NO ICE BATH

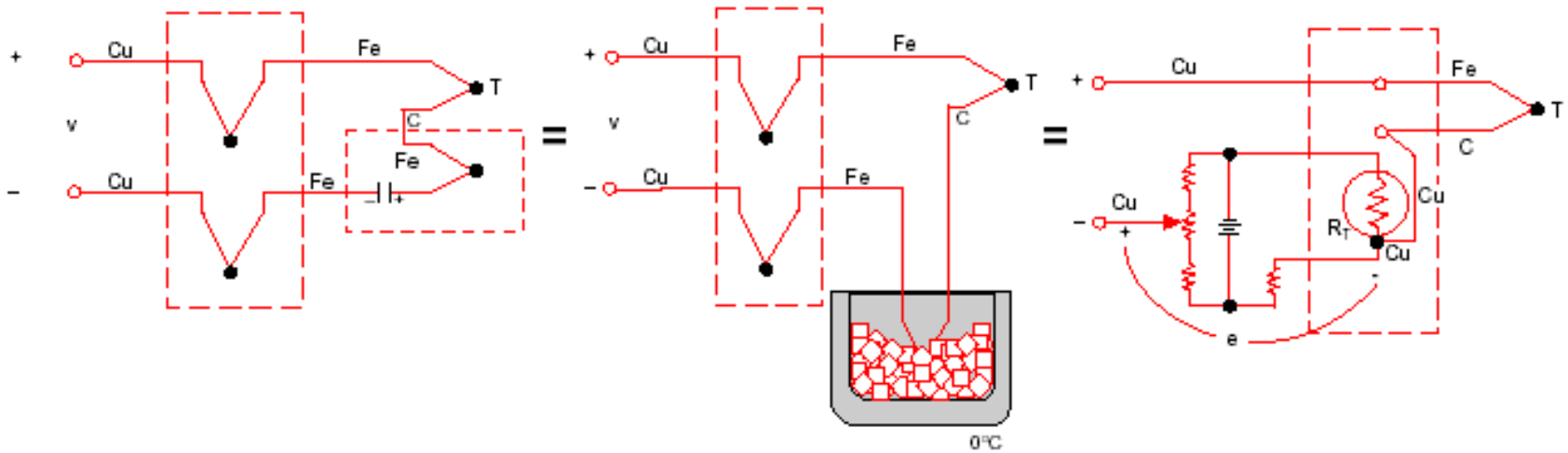
Compensação por *software*:

1) Mede T e infere V_{ref} ,
2) Mede V e calcula $V_1 = (V\text{-}V_{ref})$,
3) Converte V_1 em T_{J1}.

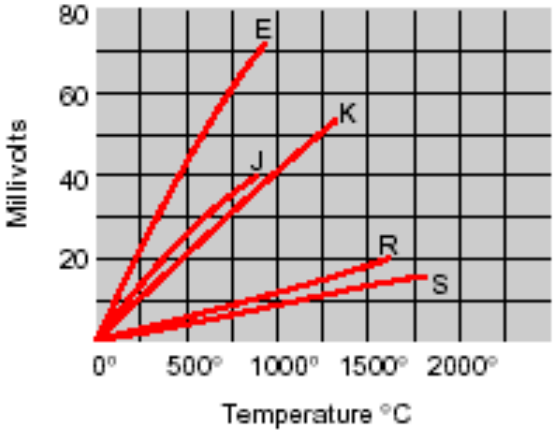


EXTERNAL REFERENCE JUNCTION-NO ICE BATH

Compensação por *hardware* ou "ponto de gelo eletrônico":

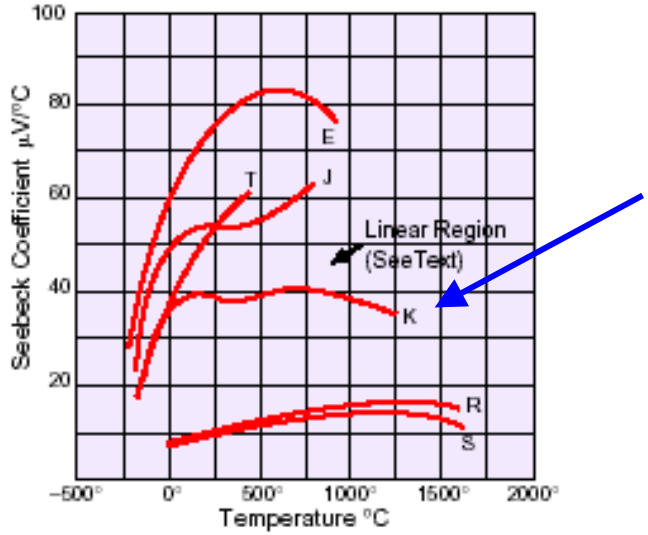


- Variação de α com T



Type	Metals +	Metals −
E	Chromel vs. Constantan	
J	Iron vs. Constantan	
K	Chromel vs. Alumel	
R	Platinum vs. Platinum 13% Rhodium	
S	Platinum vs. Platinum 10% Rhodium	
T	Copper vs. Constantan	

THERMOCOUPLE TEMPERATURE
VS.
VOLTAGE GRAPH



SEEBECK COEFFICIENT vs. TEMPERATURE

- Uso de polinômios para interpolar curvas: n = 9 para ± 1 °C.

• Escolha do tipo de termopar.

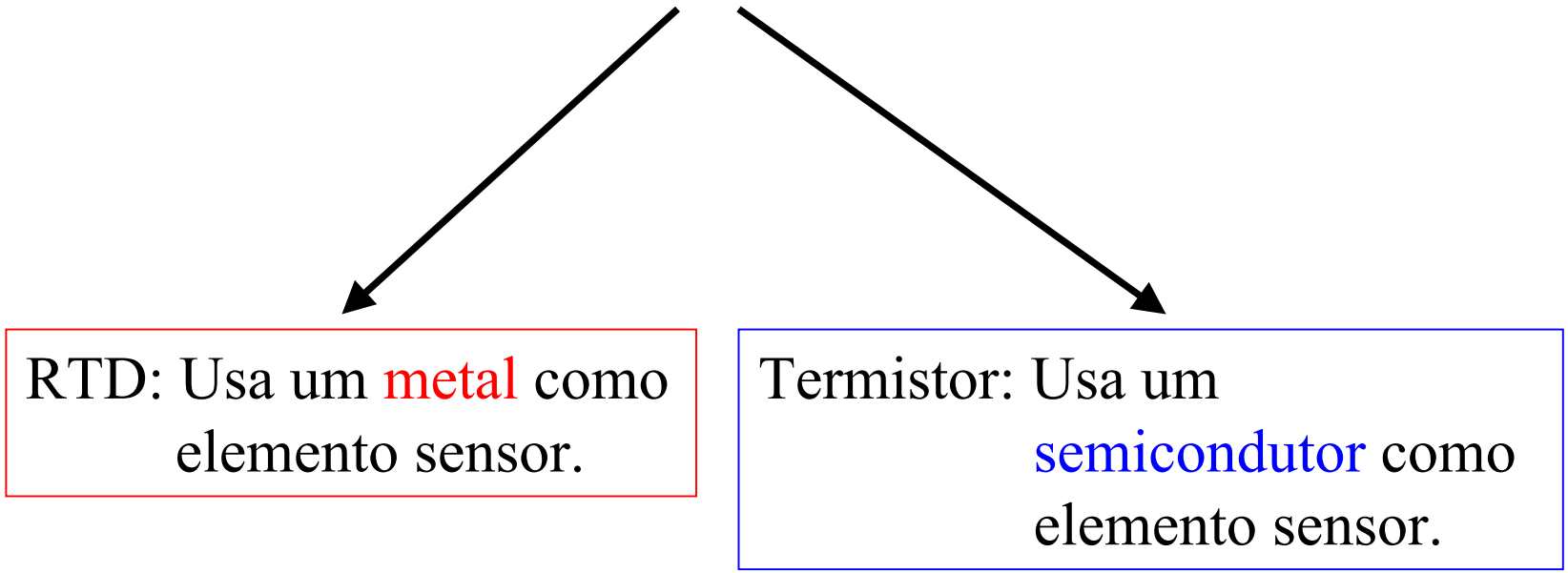
Tipo	Elemento positivo	Elemento negativo	Poder Termoel a 25 °C (μV/°C)	Faixa de temp. usual	Vantagens	Restrições
T	Cobre	Constantan	40.5	-184 a 370 °C	- Resiste a atmosfera corrosiva - Aplicável em atmosfera redutora ou oxidante abaixo de 310°C - Sua estabilidade o torna útil a em temperaturas abaixo de 0 °C	- Oxidação do cobre acima de 310 °C
K	Cromel	Alumel	40.5	0 a 1260°C	- Indicado para atmosfera oxidante - Para faixa de temperatura mais elevada fornece rigidez mecânica melhor que os tipos S ou R e vida mais longa do que o tipo J	- Vulnerável em atmosferas redutoras, sulfurosas e gases como SO_2 e H_2S,
J	Ferro	Constantan	52.0	0 a 760 °C	- Baixo custo - Indicado para serviços contínuos até 760 °C em atmosfera neutra ou redutora	- Limite máximo de utilização em atmosfera oxidante de 760 °C devido a rápida oxidação do ferro.
E	Cromel	Constantan	61.0	0 a 870 °C	- Alta potência termoelétrica - Os elementos são altamente resistentes a corrosão,	- Baixa estabilidade em atmosfera redutora
S	Platina 10 % Ródio	Platina	5.8	0 a 1480°C	- Indicado para atmosferas oxidastes - Apresenta boa precisão a altas temperaturas	- Vulnerável a contaminação em atmosferas que não sejam oxidastes - Para altas temperaturas, utilizar isolamento de alumina
R	Platina 13 % Ródio	Platina	6.0	0 a 1480°C	idem anterior	idem anterior
B	Platina 30 % Ródio	Platina 6 % Ródio	10 a 800 °C	870 a 1705 °C	- Melhor estabilidade que os tipos S ou R - Melhor resistência mecânica - Mais adequado para altas temperaturas do que os tipos S ou R - Não necessita de compensação de junta de referência se esta não exceder a 50°C	- Vulnerável a contaminação em atmosferas que não sejam oxidantes - Utilizar isoladores e tubos de proteção de alta alumina

- Considerações práticas:

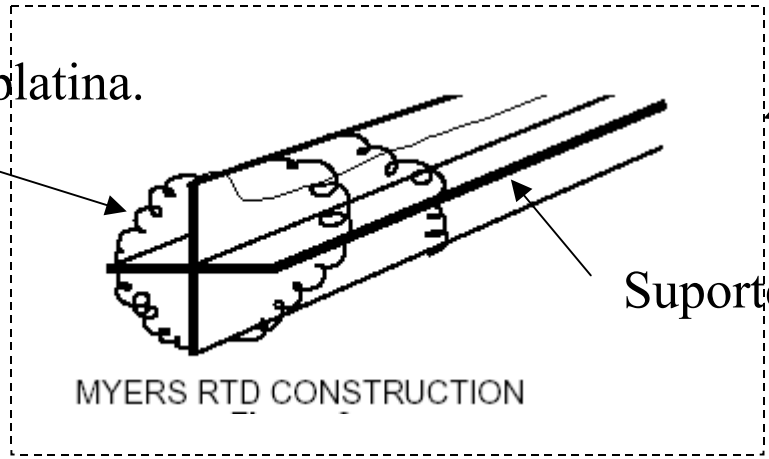
- Instalação do termopar.
- Ruído.
- Baixa qualidade da solda da junção.
- Descalibração.
- Manuseio dos fios.
- Curto circuito.

Termoresistências ou Termômetros de Resistência

• Operam sobre o princípio da variação da resistência elétrica do material com a temperatura.



RTD "clássico" usando platina (C.H. Meyers, 1932).



RTDs atuais

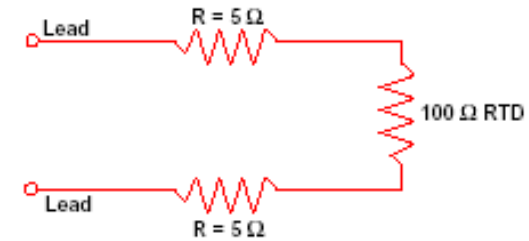
- Similar ao clássico, mas bifilar, usando diferentes tipos de suporte e selado com vidro derretido.
- Em formato de filme.

- Materiais usados como sensor para RTD.

METAL		RESISTIVITY OHM/CMF (cmf = circular mil foot)	
Gold	Au	13.00	→ Raramente usados
Silver	Ag	8.8	
Copper	Cu	9.26	→ Barato
Platinum	Pt	59.00	
Tungsten	w	30.00	→ Altas temperaturas
Nickel	Ni	36.00	→ Barato, não-linear.

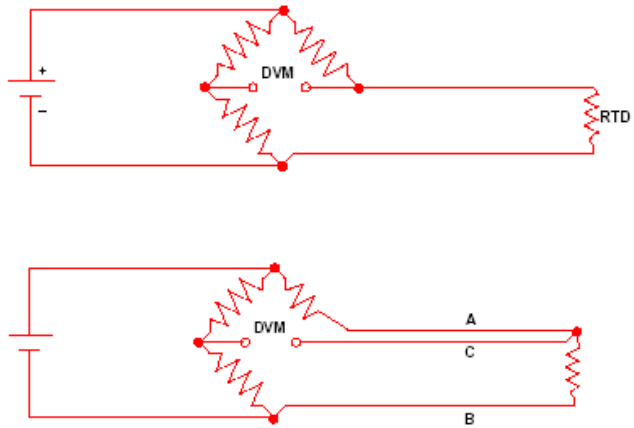
- Tipo mais usado: PT100 (elemento sensor de platina com R = 100 Ω a 0 °C).

- Medida da resistência do RTD.



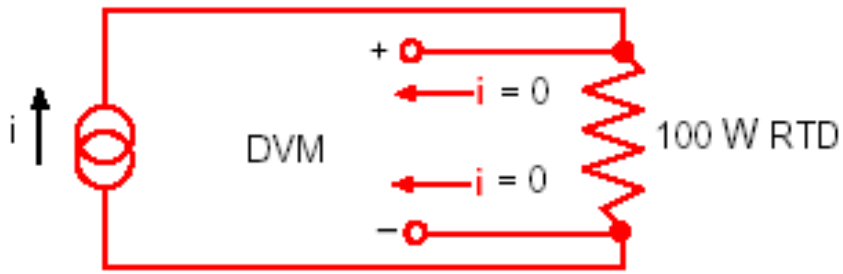
EFFECT OF LEAD RESISTANCE

WHEATSTONE BRIDGE



- Ponte adiciona não-linearidades.

- Outro tipo de circuito de medida



4-WIRE OHMS MEASUREMENT

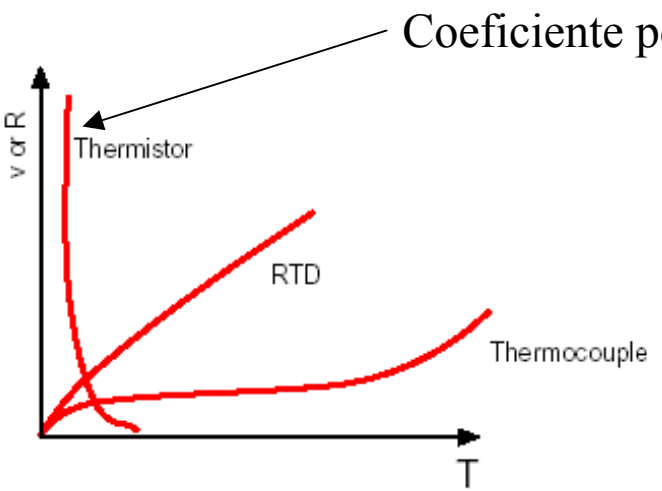
• Considerações práticas:

- Instalação do RTD.
- Ruído.
- Descalibração.
- Manuseio dos fios.
- Curto circuito.
- Mais frágio que o termopar.
- Maior que o termopar.
- Auto-aquecimento.

Termistor

- O elemento sensor é um material semi-condutor (por exemplo, uma mistura de óxido de mangânes, níquel e cobalto).

- Resposta altamente não-linear: alta sensibilidade.

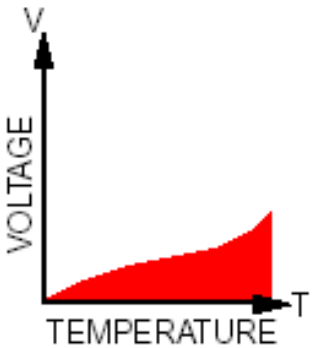
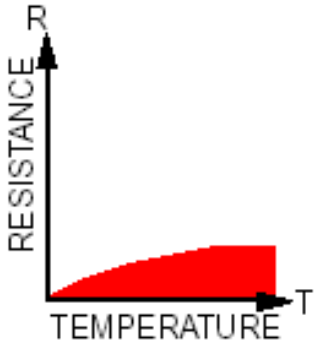
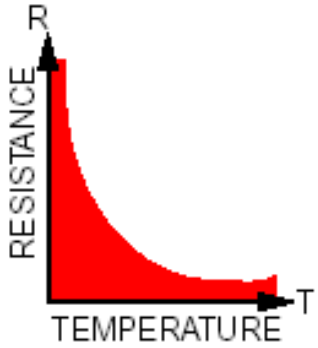


- Alta resistividade facilita leitura da resistência. Valor típico: 5 kΩ a 25 ^{o}C.

• Considerações práticas:

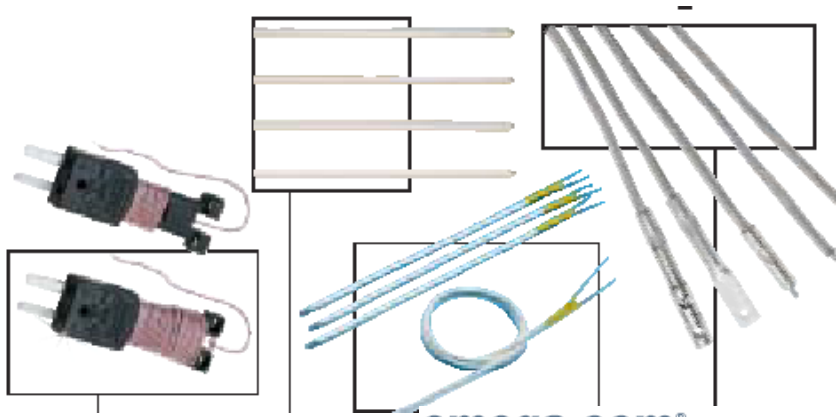
- Instalação do termistor.
- Mais frágio que o termopar e o RTD.
- Mais susceptível à descalibração.
- Faixa estreita de utilização: normalmente entre -40 e +150 ^{o}C.
- Norma para uso espacial: NASA S-311-P-18.

Termopar x RTD x Termistor

	Thermocouple	RTD	Thermistor
			
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small Δ R ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating

Alguns exemplos de sensores comerciais

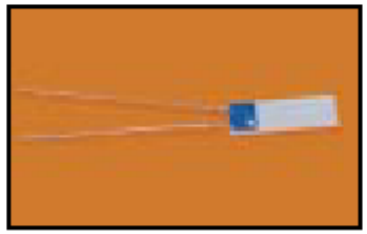
Termopares



RTDs

Typical RTD Probes

Thick Film Omega Film Element



Thin Film Omega TFD Element

Glass sealed Biflar Winding

omega.com®
Your One-Stop Source for Process Measurement and Control!

Termistors

Mil Spec GSFCS - 311 - P-18 Discrete Thermistor Product Code: PC153

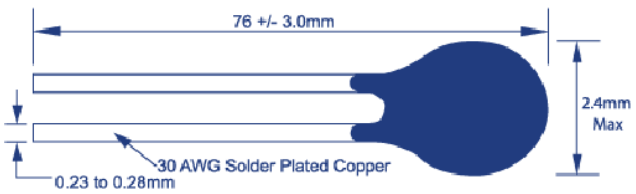
Introduction

NTC Thermistor soldered to 30 AWG Solder PLated Copper. Unit is coated with an epoxy resin.

Betatherm is approved on the ESA QPL since June 2001. Betatherm has manufactured 'Flight Components'for the European Space Commercial Programme since 1994.

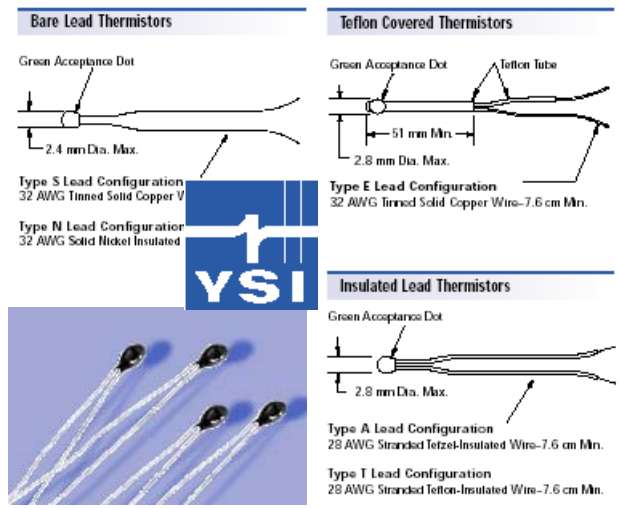
BetaTHERM Sensors
TEMPERATURE SOLUTIONS

Shape and Dimension

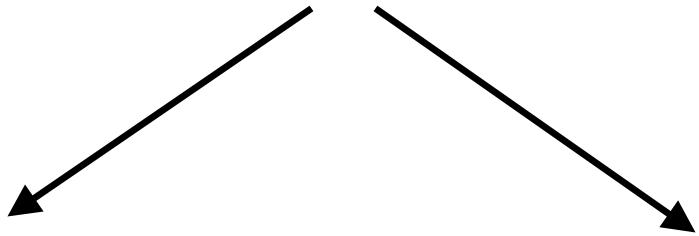


Features

- Resistance values @25ºC: 2.2K , 3K , 5K , 10K & 30K.
- Tolerance values: ±0.1ºC & ±0.2ºC from 0ºC to 70ºC.
- Manufactured to Mil.Spec. 'GSFCS-311-p-18'.
- Wire Conductor: Copper, Nickel or Stranded.
- Wire type: Insulated or Non-Insulated.
- Wire Size: 28 AWG to 32 AWG.

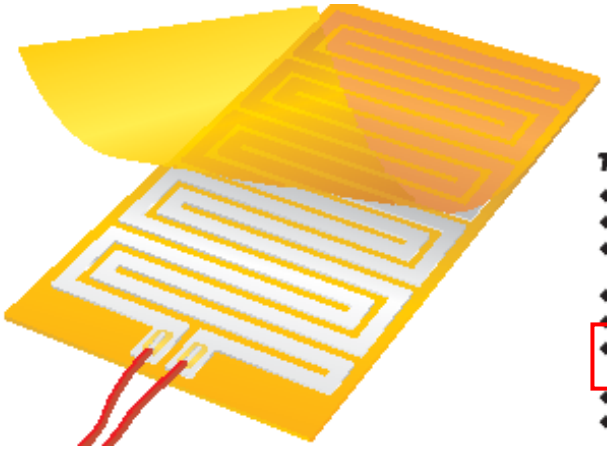


Aquecedores elétricos (heaters)



Planos: utilizados para aquecer equipamentos
ou partes do satélite.

Cartucho: utilizados para aquecer componentes que exijam altas temperaturas, como em micro-propulsores à hidrazina.



MINCO

Thermofoil™ etched foil heaters

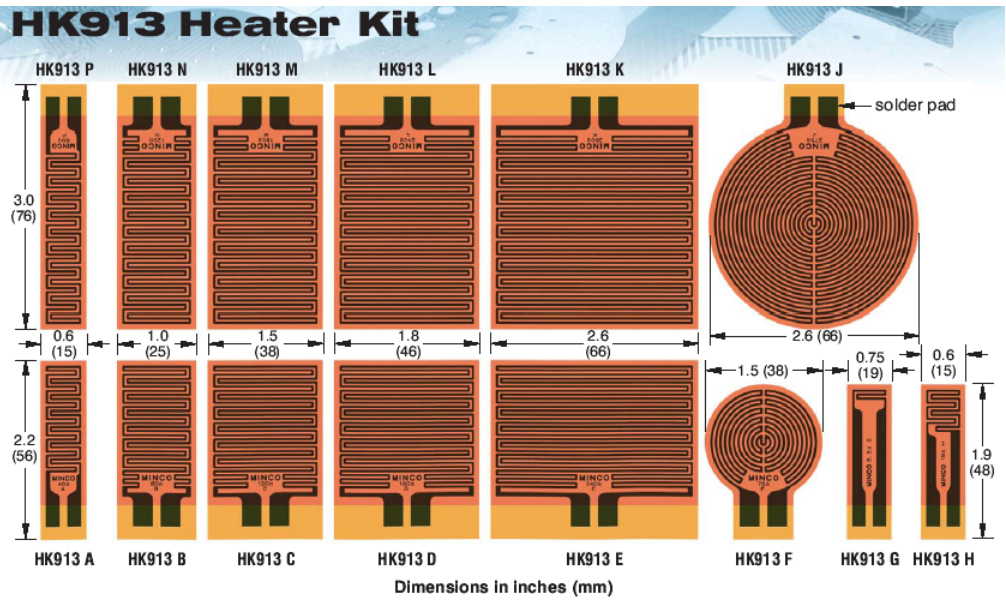
- Foil element
- Uniform heat patterns
- Permits complex shapes and profiled heat patterns
- Thin, small bend radius
- Small sizes
- Many insulation options (Kapton™, silicone rubber, mica, polyester, PTFE)
- High watt density
- Welded leadwires

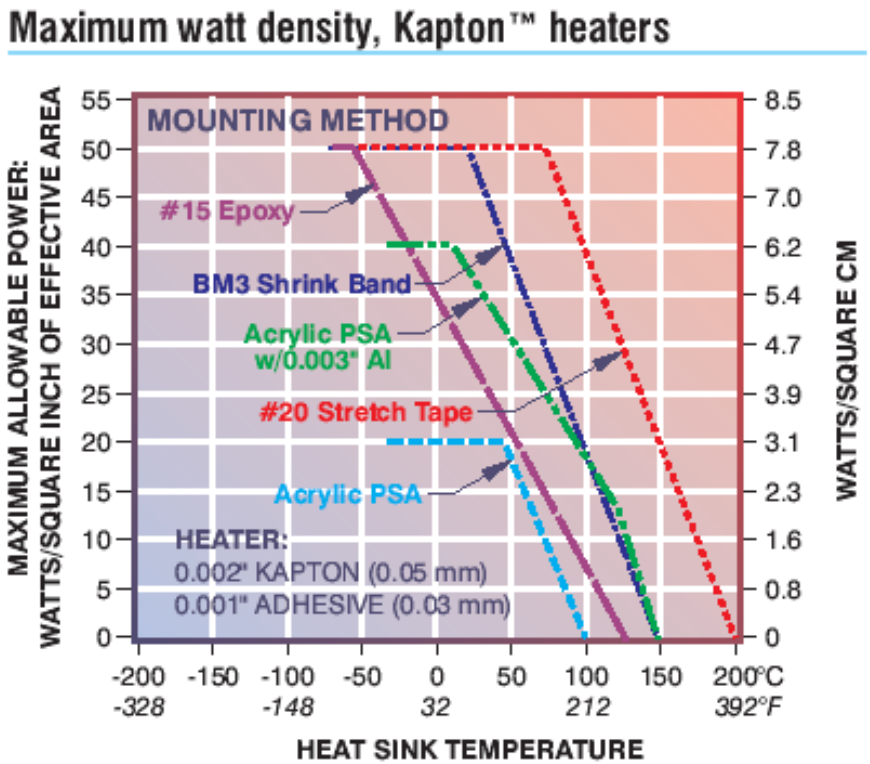
Aquecedores Planos

HEATER TYPE	SURFACE/SHAPE	DESIGN FEATURES	TYPICAL APPLICATIONS	AVAILABLE ELEMENTS
FLAT	planar cylindrical conical	• to evenly distribute heat to flat surfaces	in-flight meal trays sterilizing medical equipment	single & multi-layer etched circuit single & multi-layer wire wound
MOLDED-TO-SHAPE	curved cylindrical areas complex 3D shapes	• molded to custom configurations/specifications	aerospace electronics aircraft galley equipment copy machines thermal printers	single & multi-layer etched circuit single & multi-layer wire wound
SPIRAL WRAP	for uniform heat distribution where complete coverage of material is not necessary	• to prevent pipes from freezing in high altitudes and cold climates	aircraft waste disposal systems industrial piping	single & multi-layer etched circuit single & multi-layer wire wound
TRANSPARENT	for areas that require clear display and wireless design	• transparent in viewing area (no wires) • VLT properties range between 80% and 95% (application dependent)	gasoline pumps LCD instrument panels refrigerators surveillance cameras windows of fork lift trucks	single-layer polymer circuit only
BLANKET	various	• to provide efficient component heating in a custom configuration	copy machines potable water tank heaters thermal printers	single & multi-layer polymer circuit single & multi-layer wire wound
HI-TEMP	various	• to provide thermal stability at high temperatures (up to 550°F)	HI-Rel low outgassing	single & multi-layer etched circuit

Elmwood Sensors

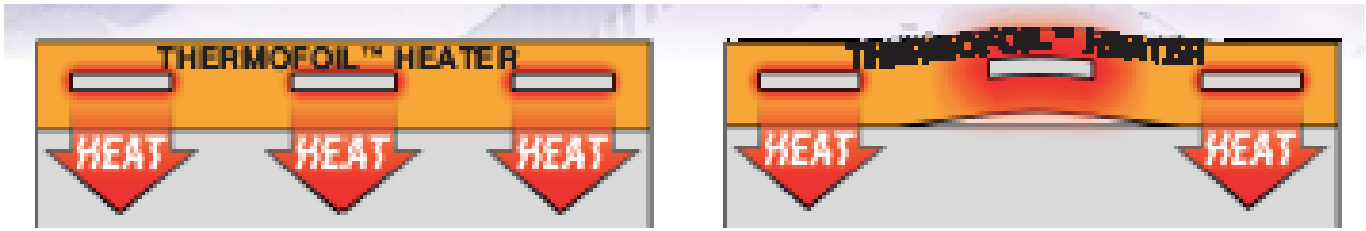
- Para uso espacial são usados aquecedores de Kapton





Example: At 50°C, the maximum power for a heater mounted with acrylic PSA is 18 W/in².

• Meios de fixação



Pressure-sensitive adhesive (PSA) and #17 film

With factory-applied PSA, you simply remove the backing paper and press the heater in place.

Description	Temperature rating	Comments	Installation instruction*
Acrylic PSA 0.002" (0.05 mm) acrylic film	See heater ordering information	♦ NASA approved for outgassing ♦ Flat surfaces only, unless aluminum backed	EI 138
#12 PSA 0.002" (0.05 mm) silicone film		♦ Flat or slightly curved surfaces	EI 266

Epoxy and cement

Description	Temperature rating	Comments	Installation instruction*
#6 RTV cement Room temperature vulcanizing silicone for rubber heaters	-45 to 235°C -49 to 455°F	♦ Distance from center of heater to edge must be less than 5" (127 mm) ♦ 3 oz. tube covers 800-	EI 117

Easy installation methods for cylindrical surfaces

Shrink bands are pre-stretched strips of film with adhesive coated ends. Wrap around the heater and heat to shrink. Stretch tape installs quickly with no heat required.

Description	Temperature rating	Comments	Installation instruction*
BM3 shrink band Polyester strip	-73 to 149°C -100 to 300°F	♦ To order, specify band width and cylinder diameter	EI 103
BK4 shrink band Kapton strip	-73 to 177°C -100 to 350°F		
#20 stretch tape Self-fusing silicone tape	-51 to 200°C -60 to 392°F	♦ Comes in 6 or 36 foot rolls, 1" wide. Figure 25% overlap when calculating length required.	EI 124

*Installation instructions and AA #22 available at www.minco.com/support

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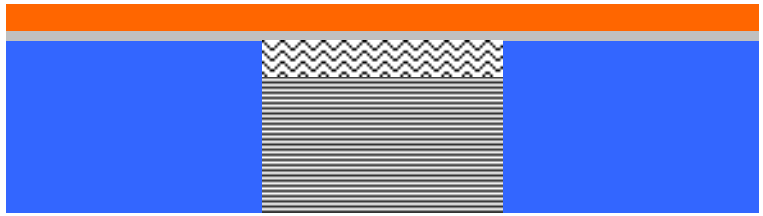
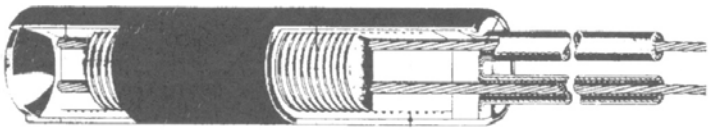


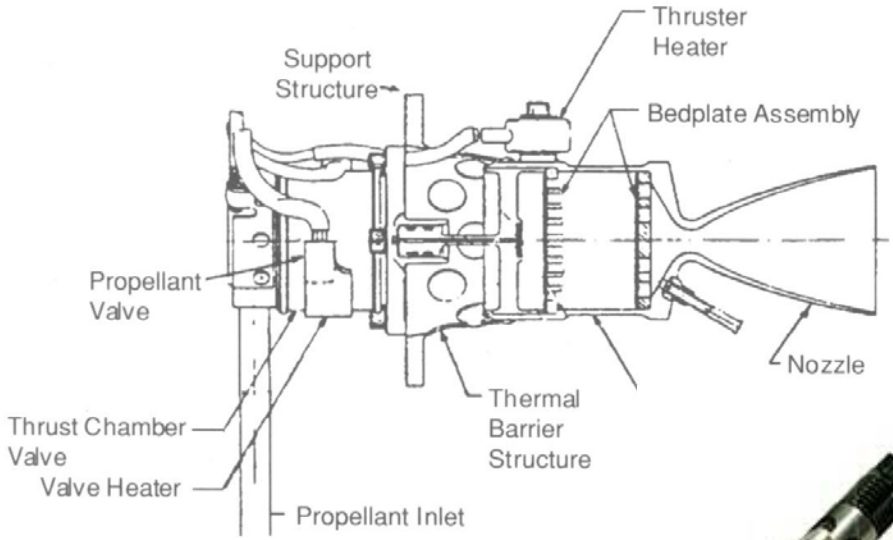
- Uso de aquecedores planos: Considerações práticas.

- When ever possible, use aluminum tape on top of heaters to help overall heater temperatures.
  - Without tape, the emissivity of Kapton is high compared to the aluminum. An independent analysis showed that 50% of the heat into the system will be radiated by the heater to the environment. Aluminum emissivity much smaller.
  - Aluminum allows for heat to spread from hot spots to cooler ones.
- For MIL-STD qualification criteria, heaters with bubbles over through holes should not operate with a flux above 3 W/in^2 for any environment.
- For commercial satellite acceptance, a bubble diameter of 0.5” should be used as an criteria for bubbles formed during installation.
  - With 4 W/in^2 and an environment temperature of 20^oC, the maximum heater temperature reached 190^oC.
- In all cases, special attention should be given to heaters during installation to eliminate any bubbles or irregularities in heater bonding.

Fonte: Cabral, 2003.

Aquecedores do Tipo Cartucho





Cartridge Heater

Cartridge heaters use an innovative free-standing coil heating element to survive extreme temperature cycling and vibration exposure. Light weight: The heater shown weighs .024 pound (10.9 g). Operating temperature: 0 to 1700 deg. F.
Used on numerous satellites as a catalyst bed heater.

Thruster Heater

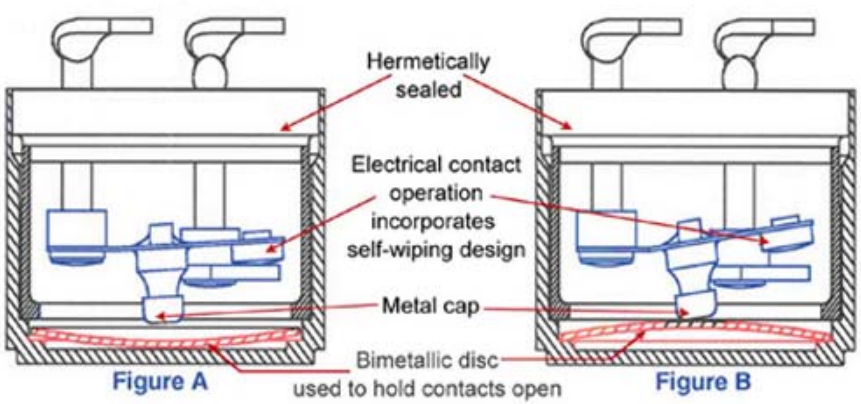
TAYCO ENGINEERING, INC.

Augmentation Heater

Mounted to heat exchanger cavity, this device generates temperatures to 4,200 deg. F. Orbital life duty cycle is 12 years. Over 86 separate pieces of hardware are used to manufacture the complete heater. Materials include tungsten, thoriated tungsten, TZM, inconel 600 and ceramics. Augmentation heater is an integral part of advanced satellite propulsion system. Two heaters are mounted to a thruster heat exchanger cavity where exhaust is super heated to provide extra thrust. This additional thrust substantially extends the life of the satellite.

Controladores

Termostatos



Controladores de estado sólido

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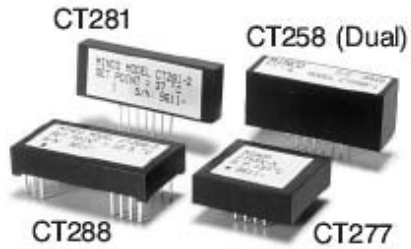
Miniature Heaterstat controllers

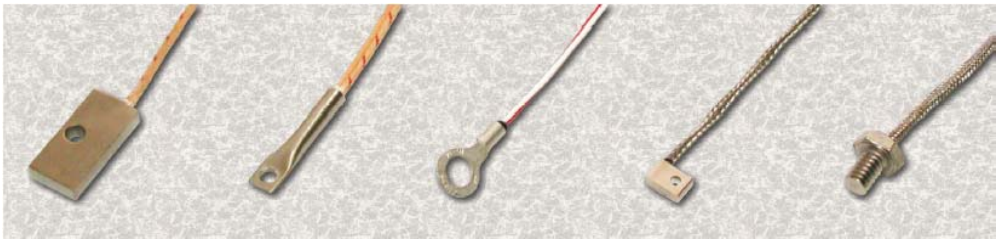
Minco can furnish SIP or DIP packages using remote digital setpoint adjustment.



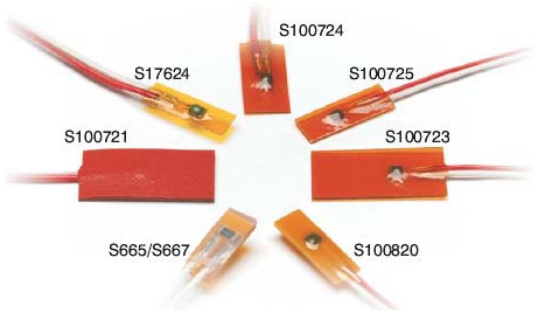
Controle por software

Alguns novos produtos

"Bolt sensors" (RTD)



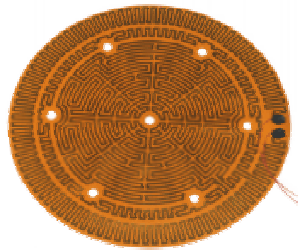
Sensores planos enrrigecidos (RTD)



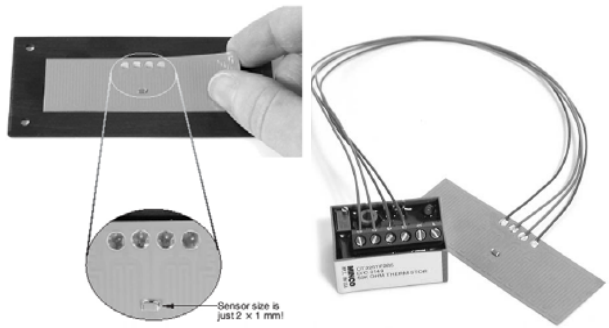
RTD 10kΩ

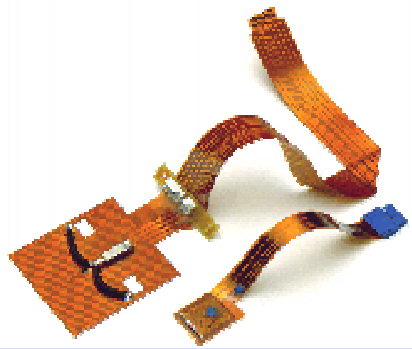
TC plano

All-Polyimide heater heater/adesivo - 260 ºC.



Sensor/Aquecedor/ Controlador integrados





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REFERÊNCIAS

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[3] Güths, S. e Paulo, V. Instrumentação em Ciências Térmicas. Apostila, UFSC, Departamento de Engenharia Mecânica, 1998.

[4] Internet:

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