



# Ciclo de Palestras Sobre Controle Térmico de Satélites

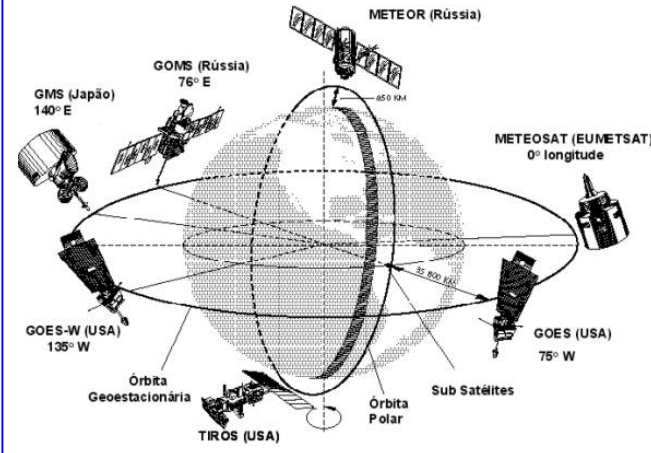
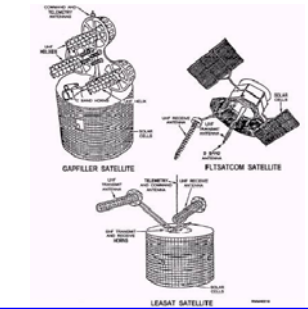
## Uma Introdução ao Controle Térmico de Satélites

**Dr. Fabiano Luis de Sousa**

Divisão de Mecânica Espacial e Controle - DMC



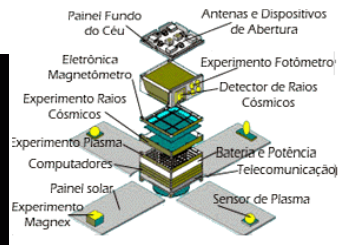
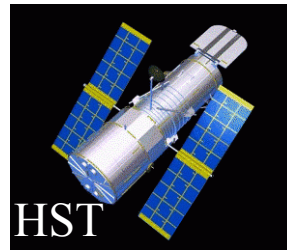
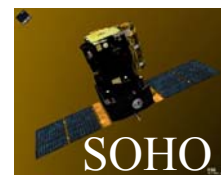
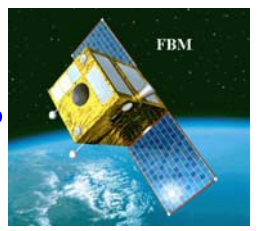
## Comunicações



## Meteorológicos

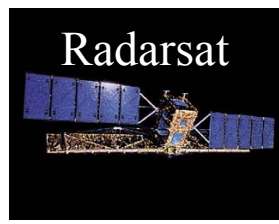
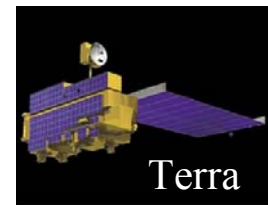
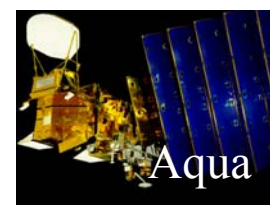
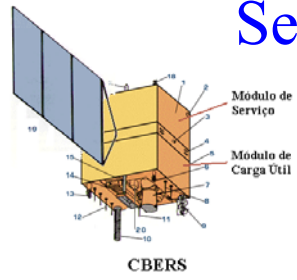
# TIPOS DE SATÉLITES

## Científicos/ Tecnológicos

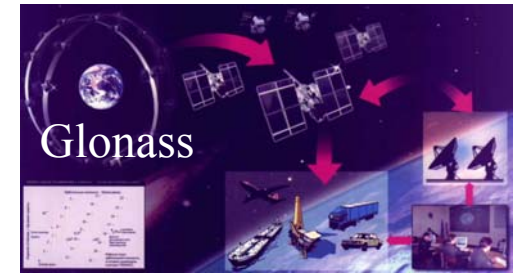
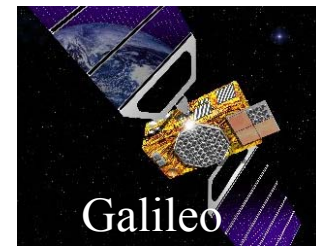


**SACI-1**

## Sensoramento Remoto



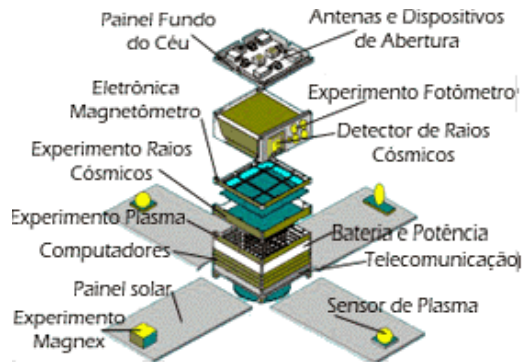
## Navegação



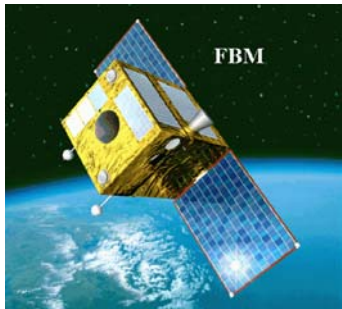
# SATÉLITE

Módulo de Serviço

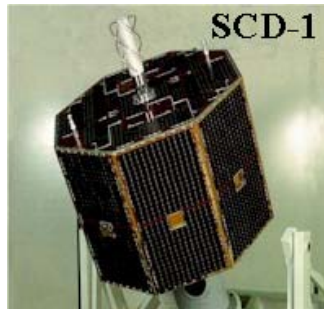
Carga Útil



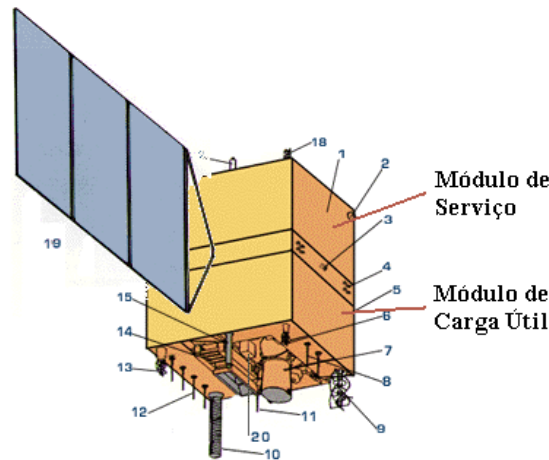
SACI-1



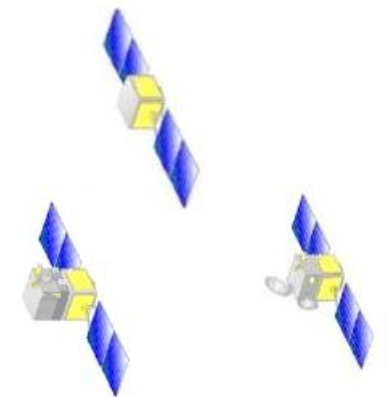
FBM



SCD-1

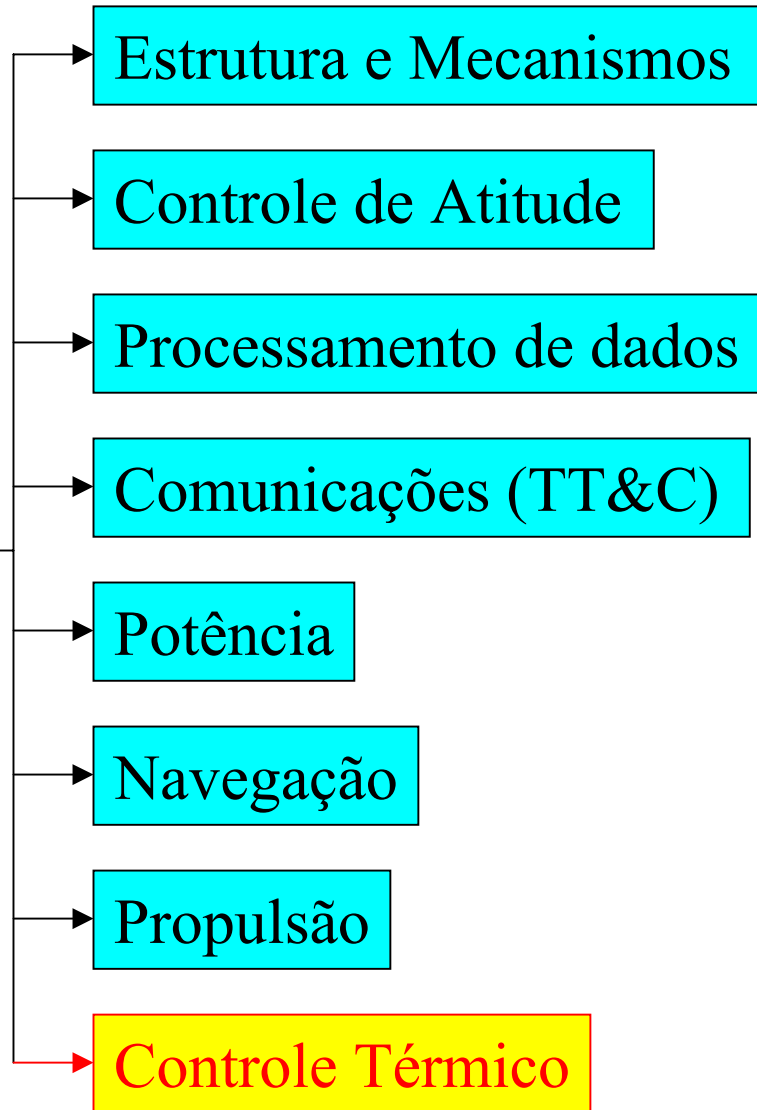


CBERS



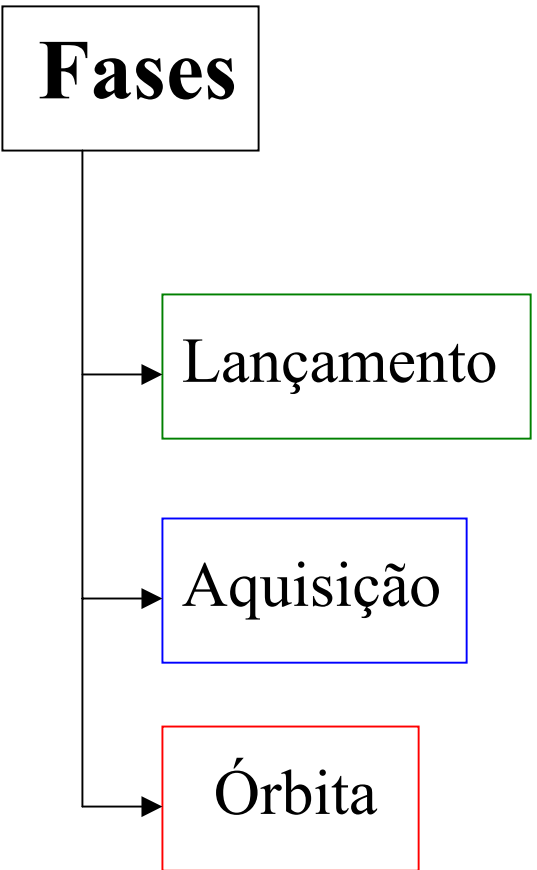
Plataforma Multi-missão

## Subsistemas de um Satélite



# OBJETIVOS DO CONTROLE TÉRMICO:

- Garantir que a *temperatura* dos componentes mecânicos, elétricos e eletrônicos do satélite permaneçam dentro das faixas requeridas para os mesmos.
- Garantir que os *gradientes/transientes de temperatura* nos componentes mecânicos, elétricos e eletrônicos do satélite permaneçam dentro das faixas requeridas para os mesmos.

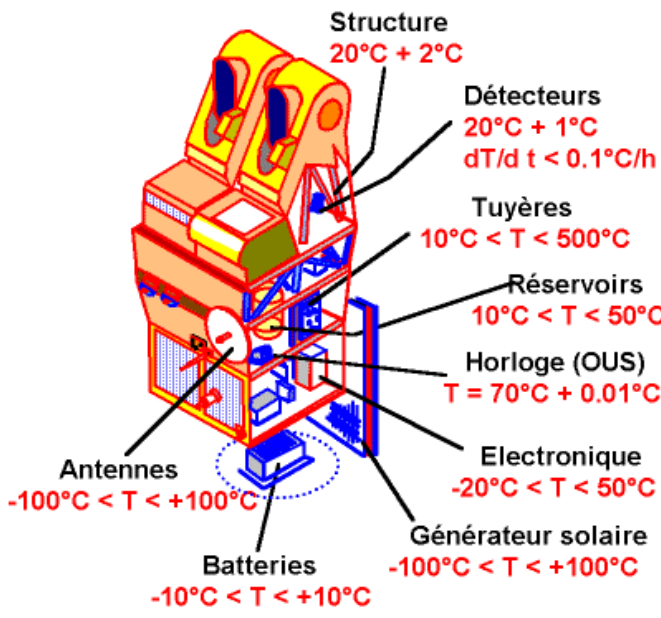


Animação: dsp\_titan\_launch.mpg

Condições Não-Operacionais      Condições Operacionais

## Intervalos Típicos Para Temperatura Operacional em Componentes de Satélites (Celsius)

Subsystem	Componente	SMAD	STCSE	SCD1/2	CBERS	MMP
<b>Estrutura e Mecanismos</b>	Estrutura com requisitos de alinhamento	+18 a +22				
	Estrutura sem requisitos de alinhamento	-45 a +65	-100 a +100			-100 a +100
	Pirotécnicos	-100 a +120				
	Dobradiças	-45 a +65				
<b>Controle de Atitude</b>	Conjunto de abertura dos PS	-35 a +60				-80 a +80
	Sensores de Sol e Terra	-30 a +50	-5 a +50	-25 a +60		-80 a +80
	Unidades Eletrônicas	-10 a +55	0 a +40		-10 a +45	
	Gyro	0 a +50	-5 a +45		0 a +45	
<b>Computador de Bordo</b>	Magnetômetro	-80 a +80		-15 a +55		-30 a +65
	Rodas de Reação	-5 a +45			+5 a +60	-35 a +60
		-10 a +50				
<b>TT&amp;C</b>	Eletrônica	-10 a +50		-5 a +35	-10 a +45	-20 a +50
	Antena parabólica	-160 a +65	-80 a +60			
	Antena GPS	-95 a +70				-50 a +60
	Antena TT&C	-65 a +95	-100 a +150			-70 a +80
<b>Propulsão</b>	Tanques, filtros, válvulas e linhas	+7 a +55	+10 a +50		+5 a +60	+10 a +50
	Propulsores	+7 a +65				+5 a +70
<b>Potência</b>	Baterias (NiH2)	-5 a +20				
	Baterias (NiCd)	0 a +25	0 a +20	-0 a +20	-5 a +15	-10 a +20
	Painéis Solares	-105 a +110	-100 a +85	-70 a +90	-75 a +70	-80 a +80
	PCU	-20 a +55	0 a +40	-5 a +45		-10 a +45
<b>Controle Térmico</b>	MLI	-160 a +250				
	Radiadores	-95 a +60				
	Heaters, Termostatos e HPs	-35 a +60				



**SPOT 4**

# Cargas Térmicas Sobre um Satélite em Órbita

Internas

Externas

Dissipação dos equipamentos e cargas úteis

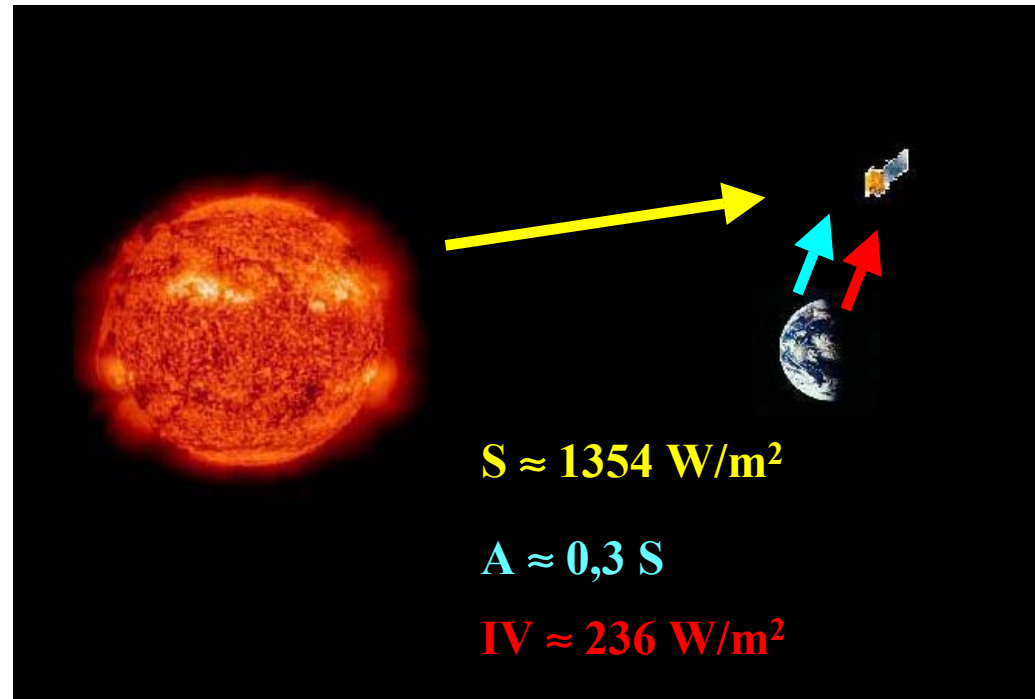
Solar

Albedo

Radiação da Terra

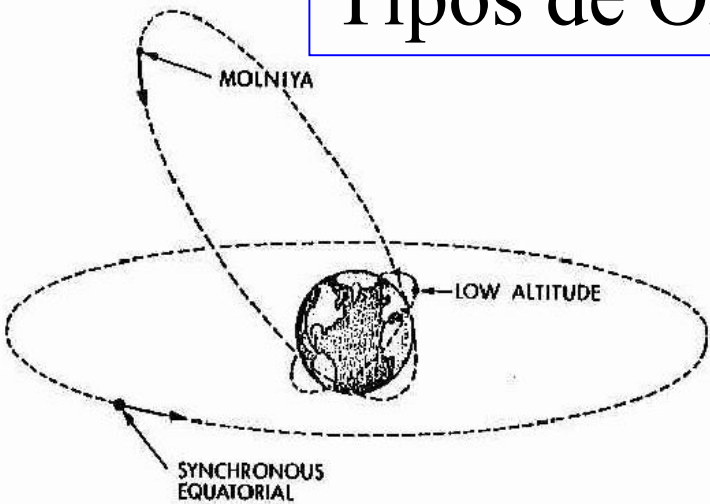
Atrito de moléculas livres (< 180 km)

Partículas Carregadas (sistemas criogênicos)





# Tipos de Órbita



**North polar view**  
 Satellite rotation rate equals Earth spin rate

**Instantaneous View by Satellite**

Satellite ground traces

1:30 noon 10:50 9:00

- Altitude approx. 90-500 ml.
- Satellite orbit period approx. 90 min.
- Satellite traces a different path over Earth each orbit

**View of Earth from LEO**

Satellites in this type of orbit:

- Weather satellites
- Earth resources satellites
- Space shuttle
- Space telescope
- Space station
- Gamma-ray observatory

**North polar view**  
 Satellite rotation rate equals Earth spin rate

**View always seen by satellite**

**Altitude: 22,300 miles (35680 km)**  
 Satellite is stationary over a point on the Earth

Satellites in this orbit:

- Commercial and military communications satellites (Intelsat, Palapa, Gorizont, Flitsatcom)
- Defense Support Program (DSP)
- Tracking and Data Relay Satellite System (TDRSS)

- Molniya means "lightning" or "first edition" in Russian
- This orbit was developed by the USSR for communications with their northern regions

Apogee  $\approx$  25,000 miles

Perigee  $\approx$  300 miles

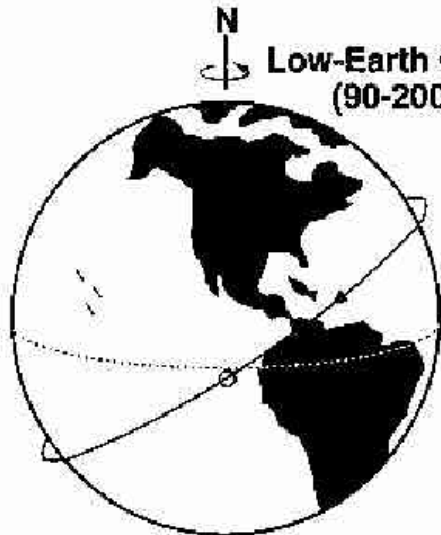
Time between each dot is one hour

Instantaneous view by satellite at apogee

- 12-hour orbit period
- Most of the time is spent at high altitudes

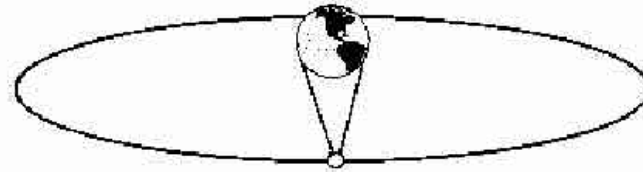
# Comparação Entre os Tipos de Órbita

(Drawn to scale)



**Low-Earth Orbit (LEO)**  
 (90-200 miles)

- Orbits take about 90 minutes
- Low altitude is good for fine sensor resolution
- Satellites move rapidly in and out of view of places on the Earth
- Space shuttle, space station orbits
- Atmospheric drag degrades orbits below ~90 miles

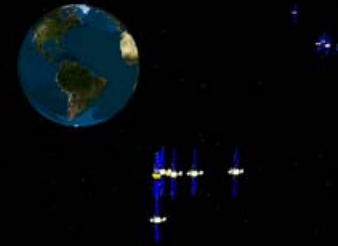


**Geosynchronous Equatorial Orbit (GEO)**  
 (23,000 miles)

- Orbits take 24 hours, same as Earth's rotation, so satellite is stationary relative to the Earth
- Orbit beyond Shuttle capabilities, requires upper stage rocket to transfer from LEO
- High altitude is good for covering large areas
- High altitude requires more powerful sensors, and communications to the ground

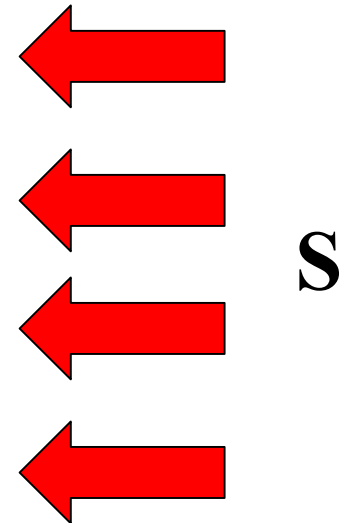
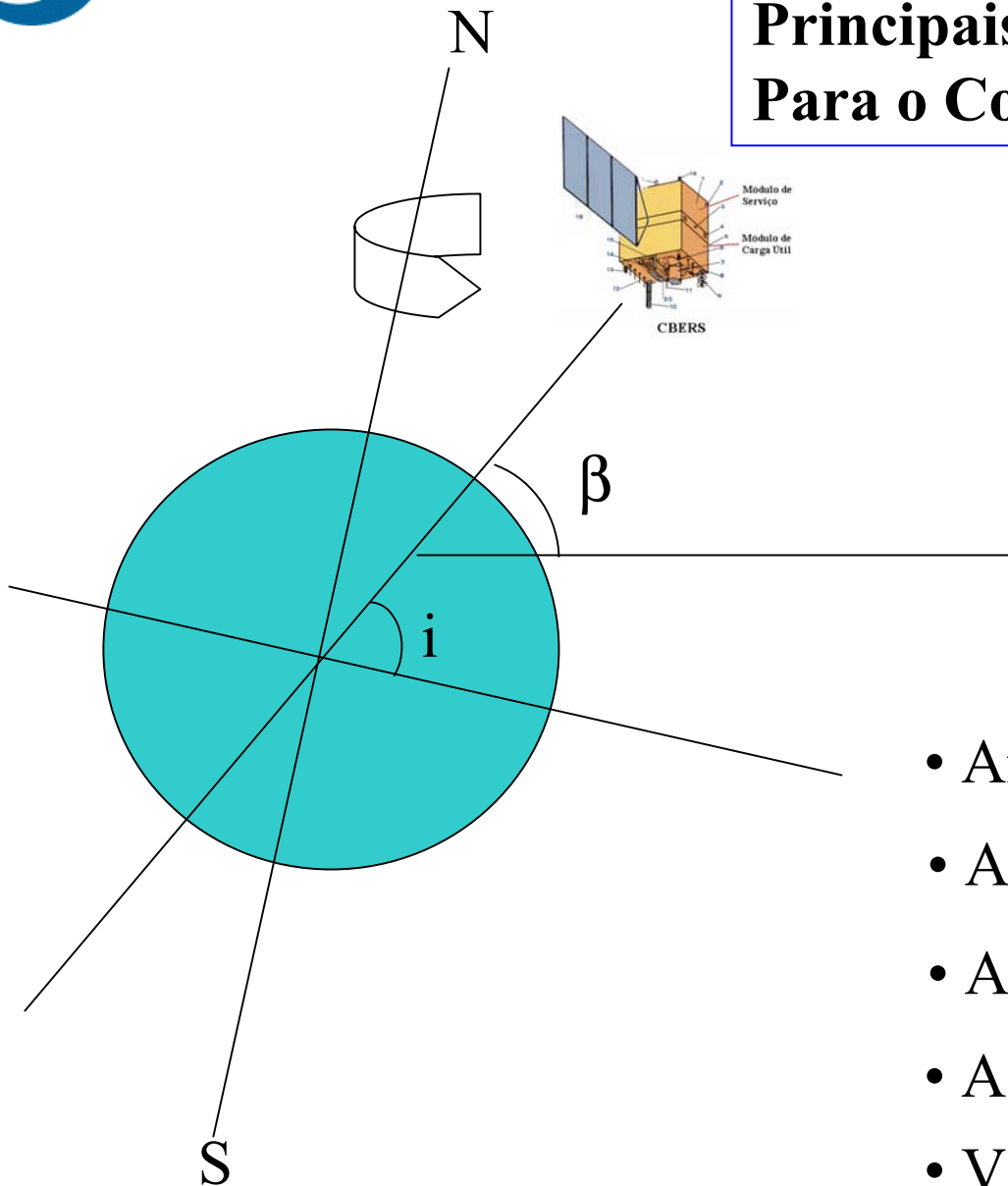
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Animação: [geosynch\\_omsats.mpg](#)



Animação: [mol\\_eng.mpg](#)

# Principais Parâmetros Órbitais Para o Controle Térmico

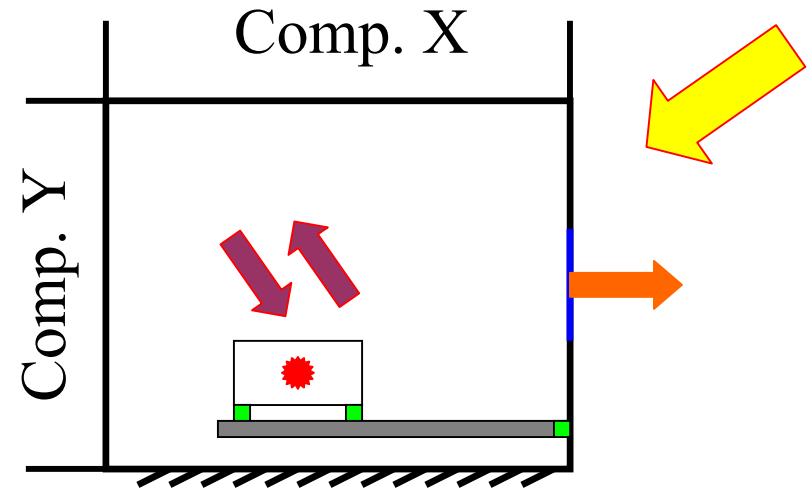
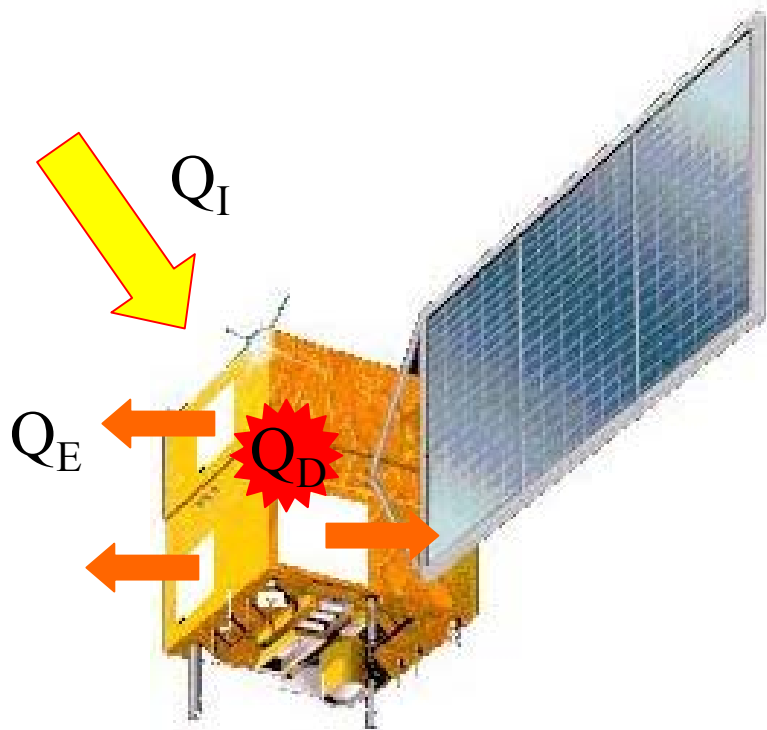


- Angulo de inclinação da órbita
- Angulo  $\beta$
- Atitude do satélite
- Altitude do satélite
- Variação da Constante Solar

# Trocas Térmicas no Satélite

## Balço Térmico Global no Satélite

$$A \sigma T_S^4 = \alpha Q_I + Q_D$$



- Dissipação do equipamento.
- Trocas radiativas no interior do compartimento.
- Acoplamento térmico nas interfaces (RTC).
- Acoplamentos condutivos na estrutura.
- Dimensionamento dos radiadores.

# Modelo Térmico

## Modelo Geométrico

- Define superfícies e nós.
- Cálculo dos acoplamentos radiativos.
- Cálculo das cargas térmicas externas.

- Acoplamentos condutivos
- Acoplamentos nas interfaces
- Capacitância dos nós
- Dissipação nos nós.

## Modelo Matemático

- Cálculo da distribuição de temperatura em regime permanente e transiente.

# Alguns Programas Para Projeto/Análise Térmica

**PCTER**  
 Dif. Fin.

Service Module Compartment 03

Payload Module Compartment 05

**Sinda/Fluint**  
**ThermalDesktop**  
 Dif. Fin./Elem. Fin.

**SINDA/G-Thermica**  
 Dif. Fin.

**Network Analysis, Inc.**  
 astrium

**Sater 100**  
 Vol. Fin/  
 Ele. Fin.

**equatorial sistemas**

# Algumas Considerações Importantes Para o Projeto Térmico

- Intervalos de Temperaturas Operacional e Não-Operacional.
- Existe uma grande variação nas cargas térmicas externas ou na dissipação do equipamento ao longo da órbita ?
- O equipamento apresenta alta densidade de dissipação de calor?
- O equipamento exige estrito controle de temperatura?
- É necessário manter pequenos gradientes de temperatura?
- É necessário (ou desejável) isolamento térmico?
- O equipamento necessita trabalhar em temperatura criogênica?

# Elementos do Sub-Sistema de Controle Térmico

- **Revestimentos térmicos: Tintas, fitas e superfícies óticas refletoras (OSR).**
- **Mantas Multicamada Super-Isolantes (MLI).**
- **Elementos nas interfaces.**
- **Radiadores.**
- **Capacitor térmico.**

- **Venezianas Térmicas.**
- **Tubos de Calor (HP), CPL e LHP.**

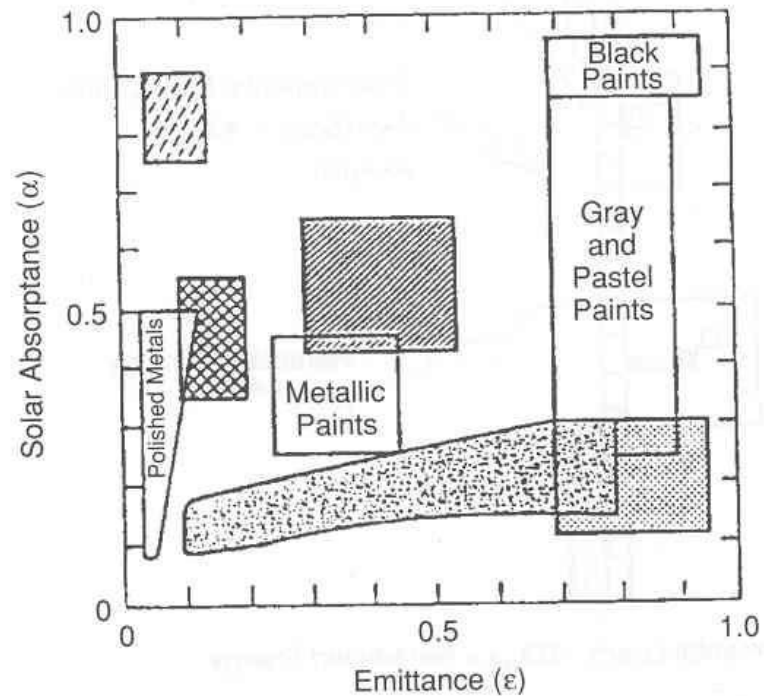
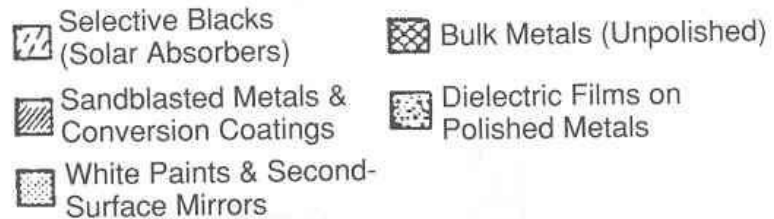
- **Aquecedores elétricos.**
- **Resfriadores termoelétricos.**
- **Cryocoolers.**
- **Circuitos com bombeamento mecânico.**

- **Sensores de temperatura, Termostatos e Controladores de estado sólido.**



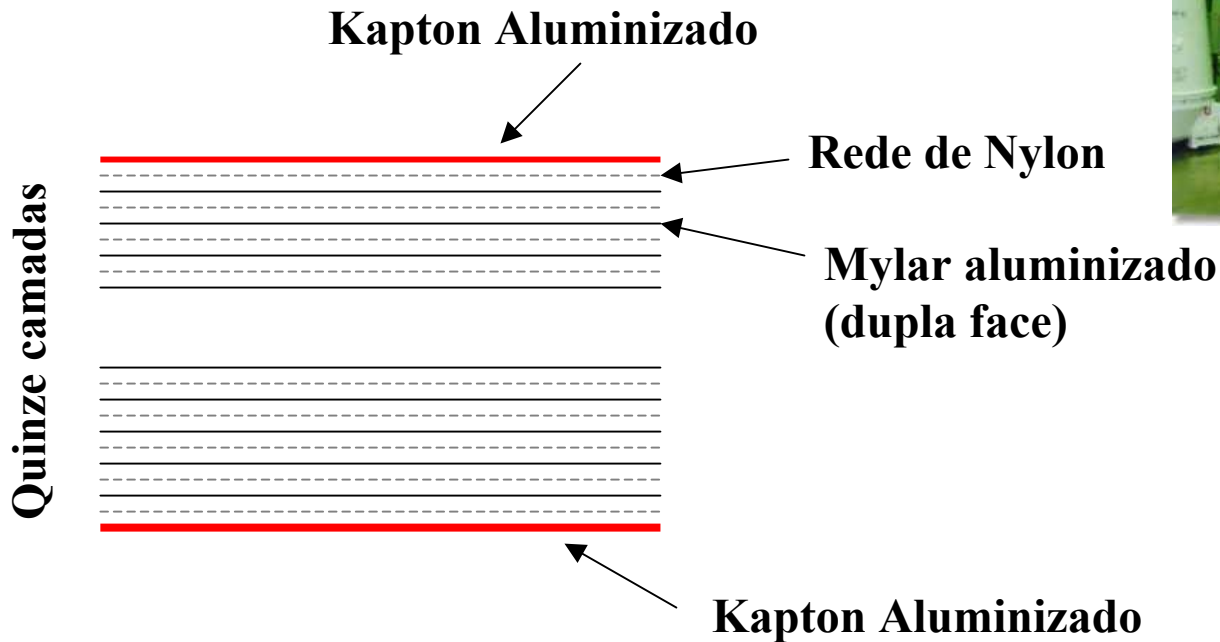
# Revestimentos Térmicos

- Tintas
- Anodização
- Fitas adesivas
- OSRs (SSM)



# Mantas Multicamadas Super-Isolantes (MLIs)

Uma Manta Típica



$$\epsilon_{\text{eff}} \approx 0,02 \text{ (mantas pequenas)}$$

$$\epsilon_{\text{eff}} \approx 0,005 ; k_{\text{eff}} \approx 10^{-4} \text{ W/m K (mantas grandes)}$$

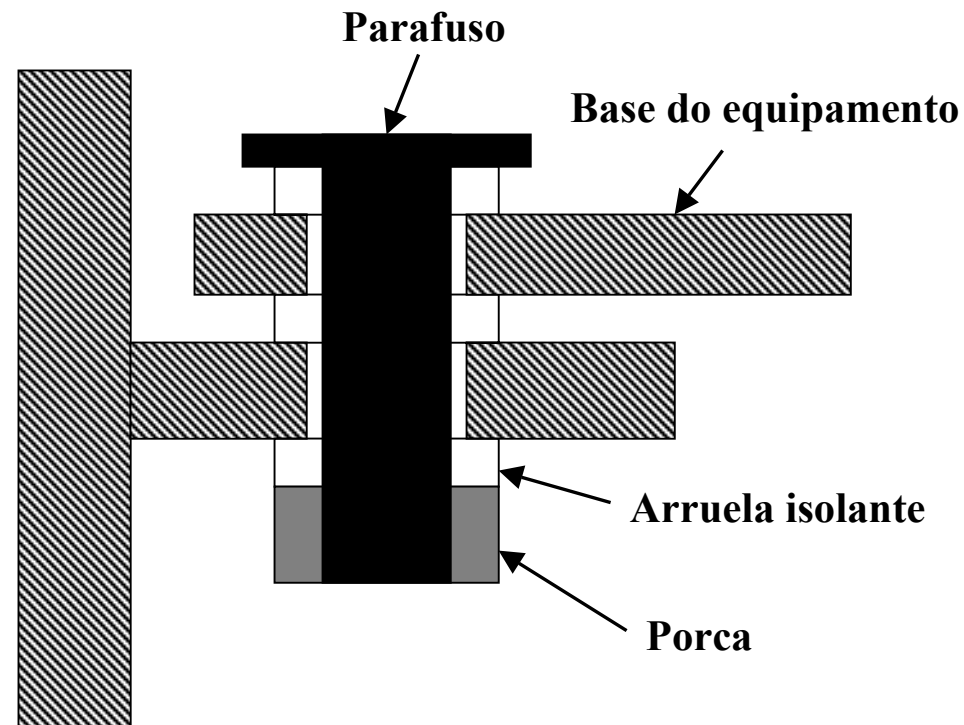
# Montagens nas Interfaces

## Interface Condutiva

Thermal doublers

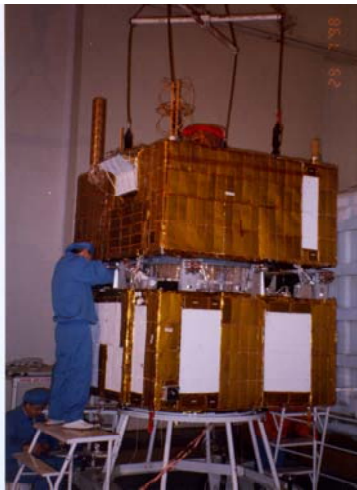
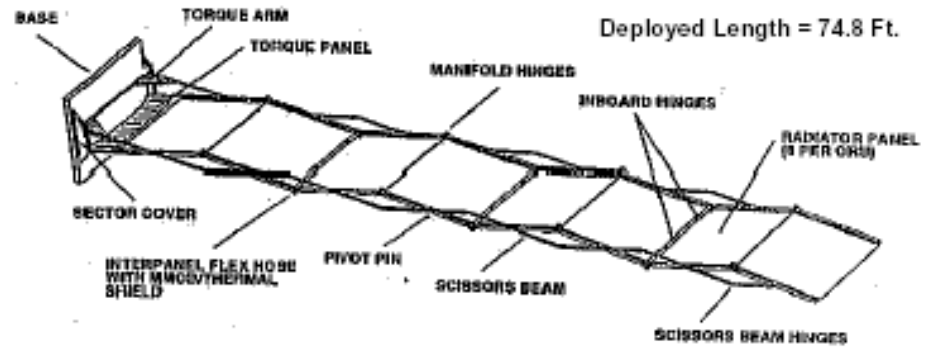
Interface Fillers

## Interface Isolante



# Radiadores

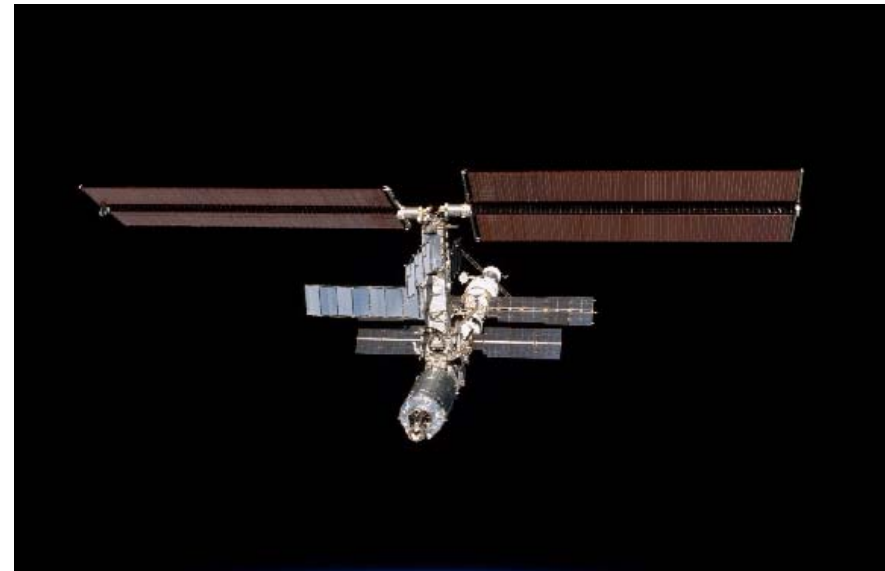
- Incorporados à estrutura
- Montados na estrutura
- Retrátéis



CBERS



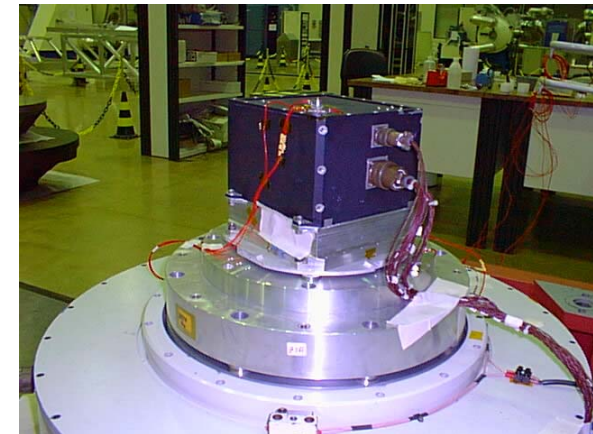
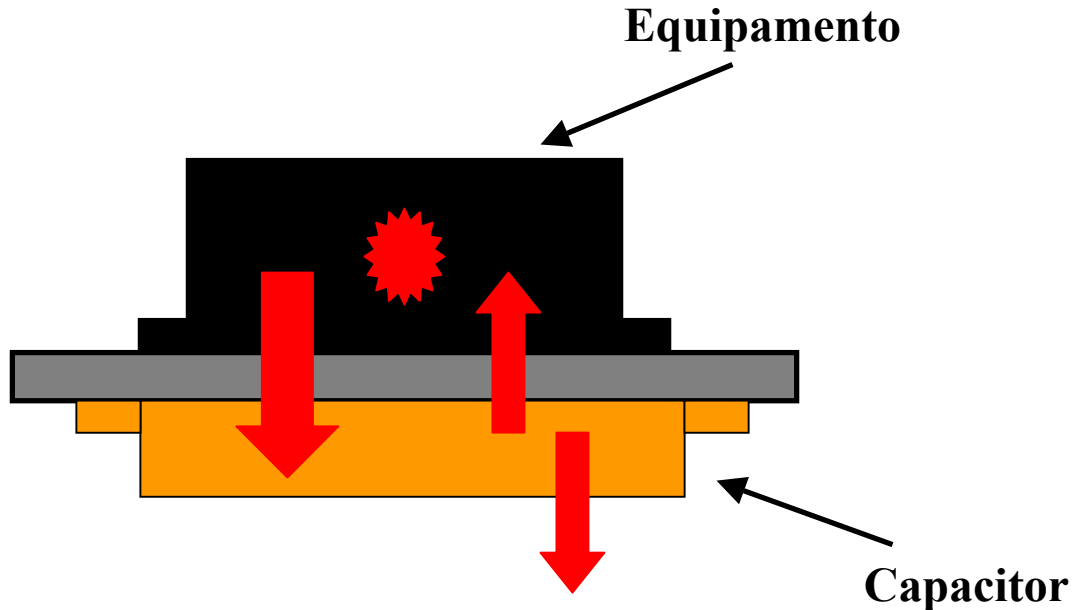
SACI



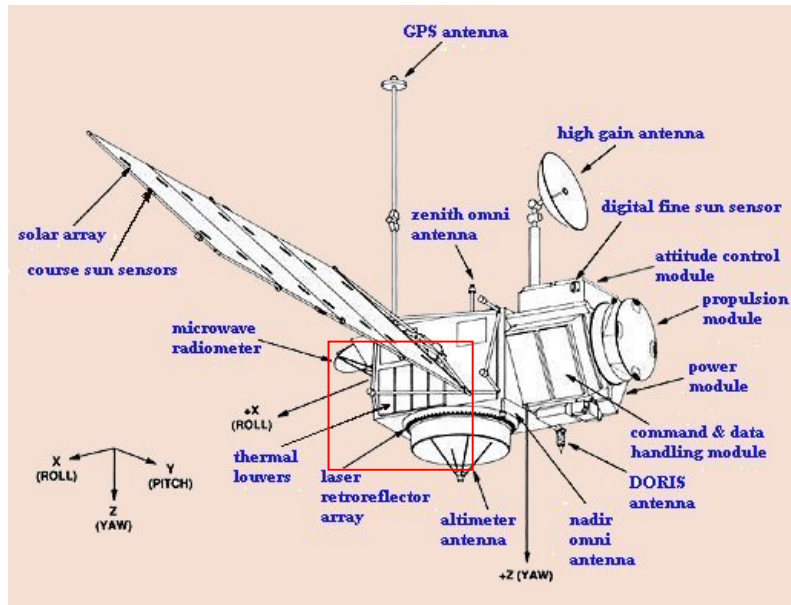
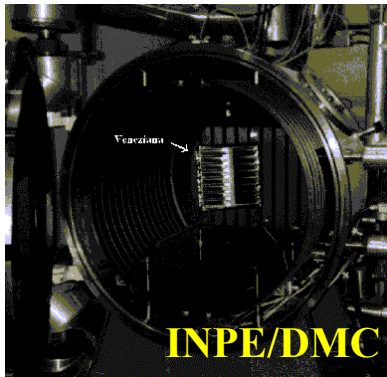
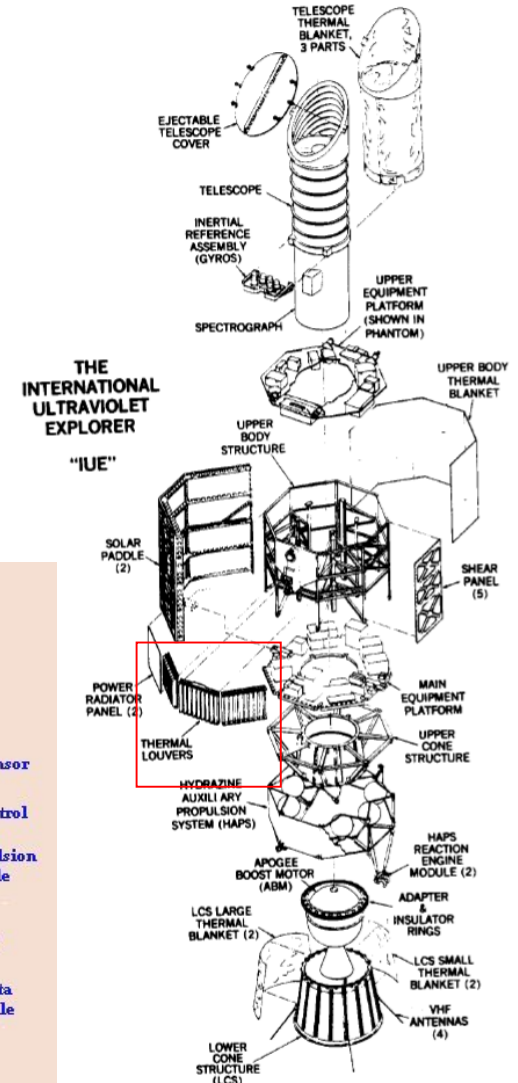
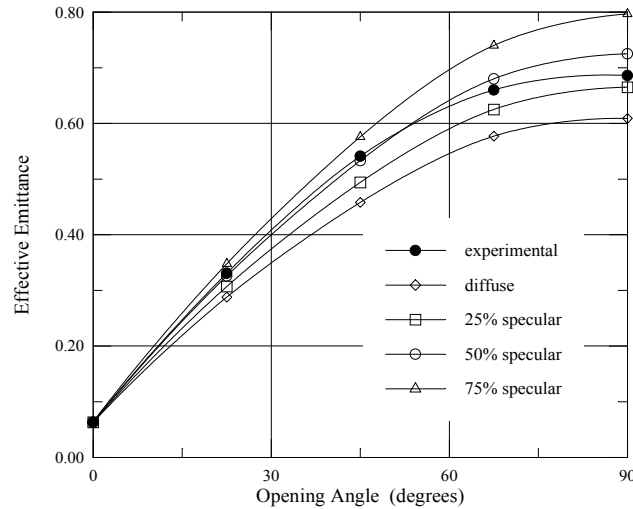
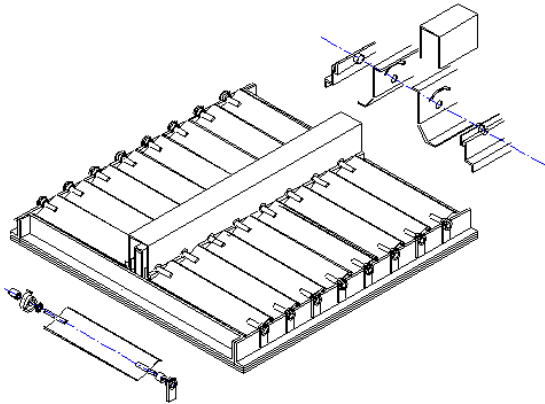
ISS

# Capacitor Térmico

- Usado quando é necessário absorver uma alta dissipação de calor em breves períodos de tempo.
- Usa calor latente para estabilização da temperatura.

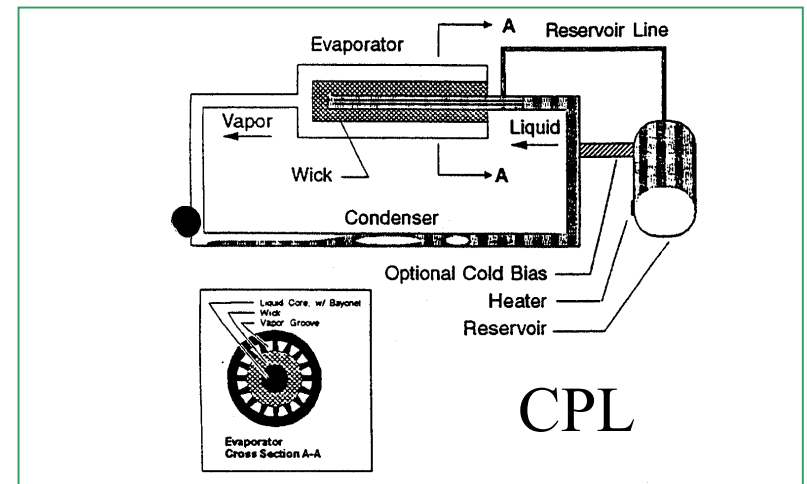
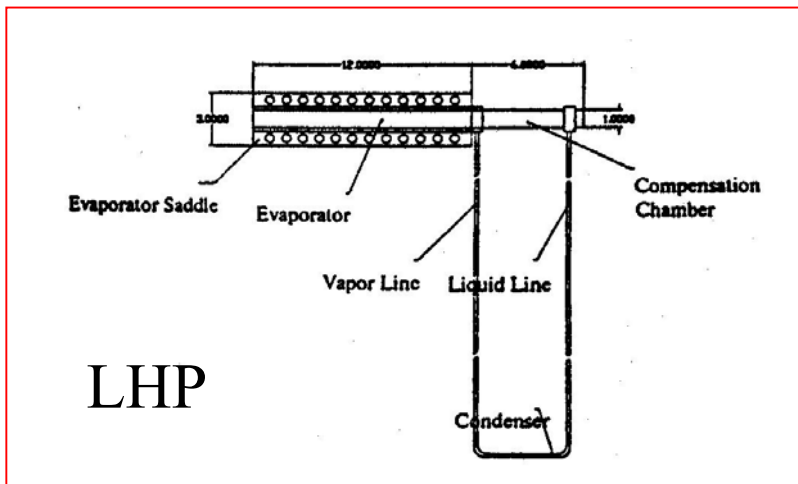
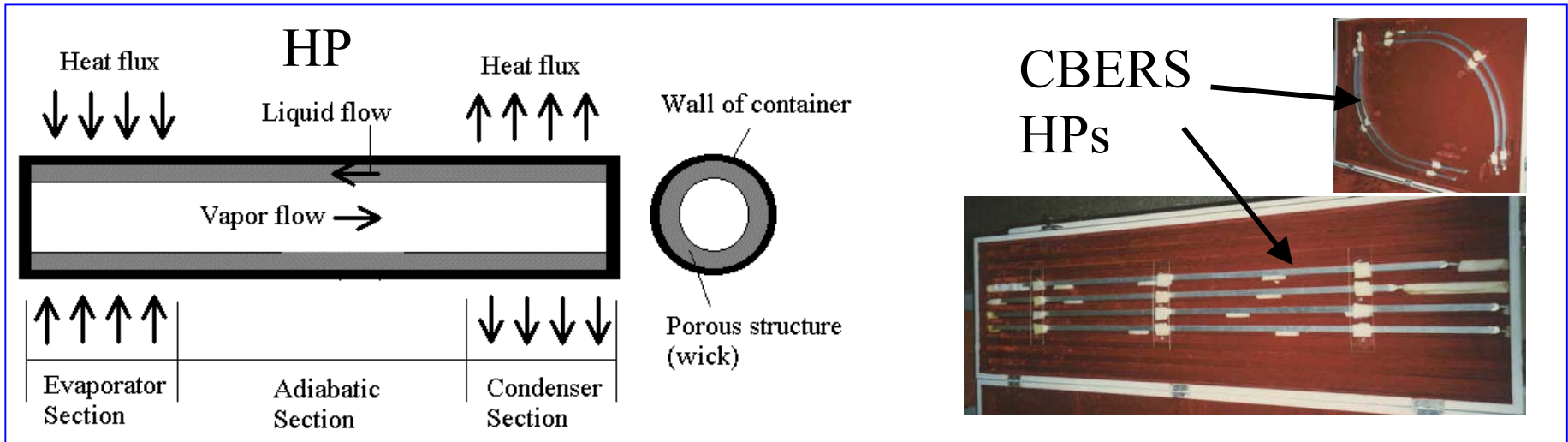


# Venezianas Térmicas



# Tubos de calor (HPs), CPLs e LHPs

➔ Dispositivos para transporte de grandes quantidades de calor com baixo gradiente de temperatura.



# Aquecedores elétricos (heaters)

**HK913 Heater Kit** **MINCO**

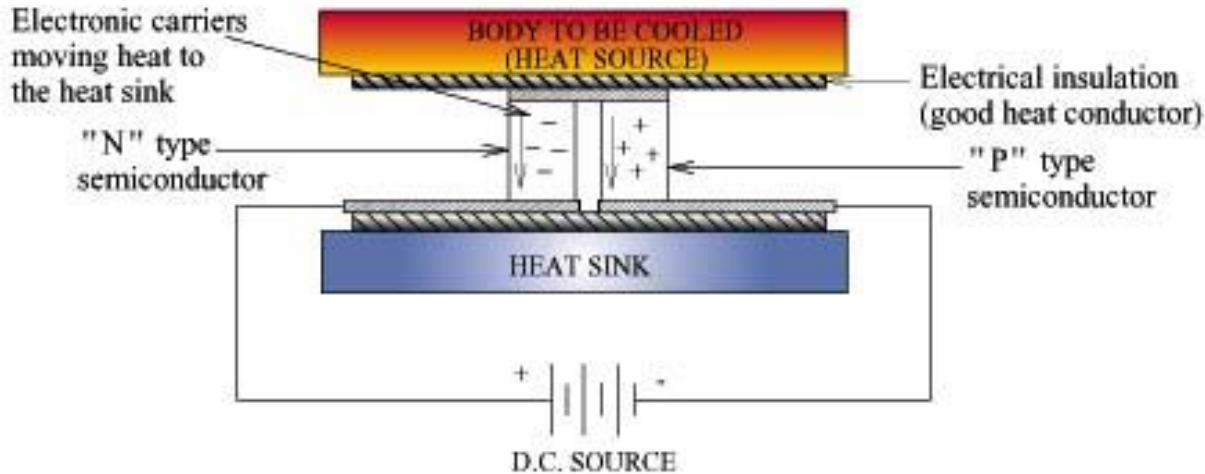
Dimensions in inches (mm)

## Do tipo plano

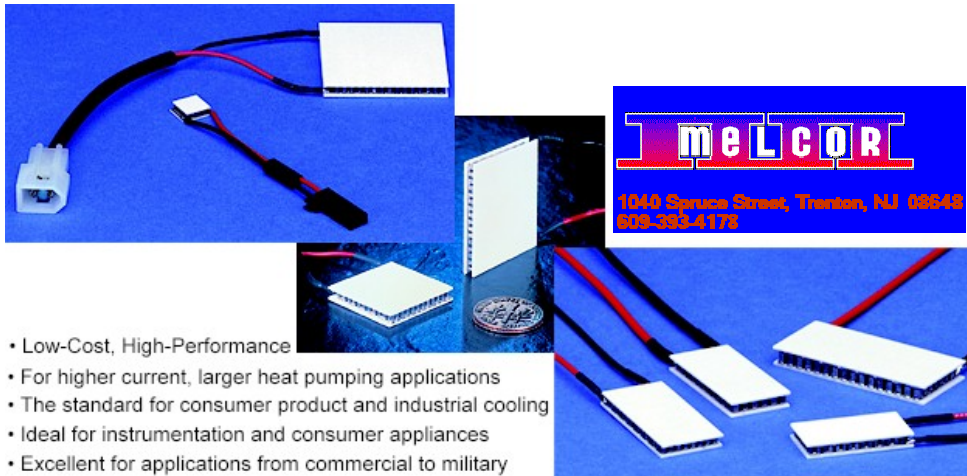
## Do tipo cartucho



# Resfriadores termoeétricos



- Efeito Peltier
- $\text{Bi}_2\text{Te}_3$



- Low-Cost, High-Performance
- For higher current, larger heat pumping applications
- The standard for consumer product and industrial cooling
- Ideal for instrumentation and consumer appliances
- Excellent for applications from commercial to military

## Aplicações espaciais:

- Refrigeração de equipamentos Eletrônicos.
- Câmeras imageadoras.

# Sistemas Criogênicos

- Radiadores criogênicos.

p/ LEO  $T_{\min} \geq 100 \text{ K}$

p/ GEO  $75 \text{ K} \leq T_{\min} \leq 90 \text{ K}$

- Evaporação de líquidos ou sólidos à temperatura criogênica.

He Supercrítico,  $\text{H}_2$  ou Ne sólido.

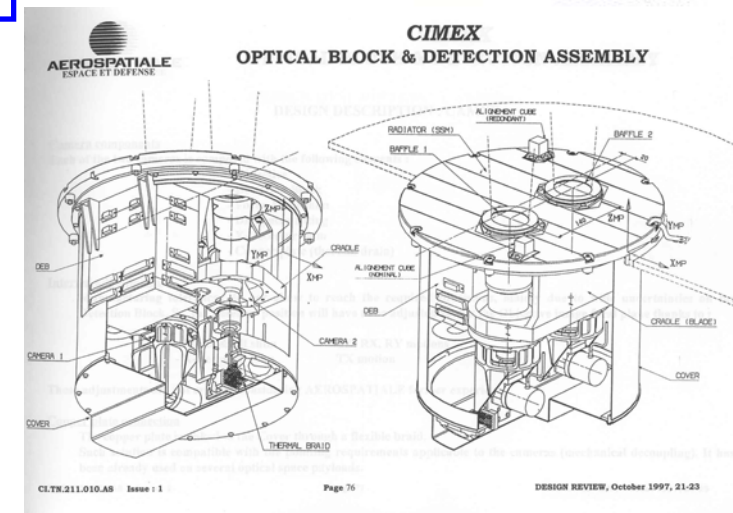
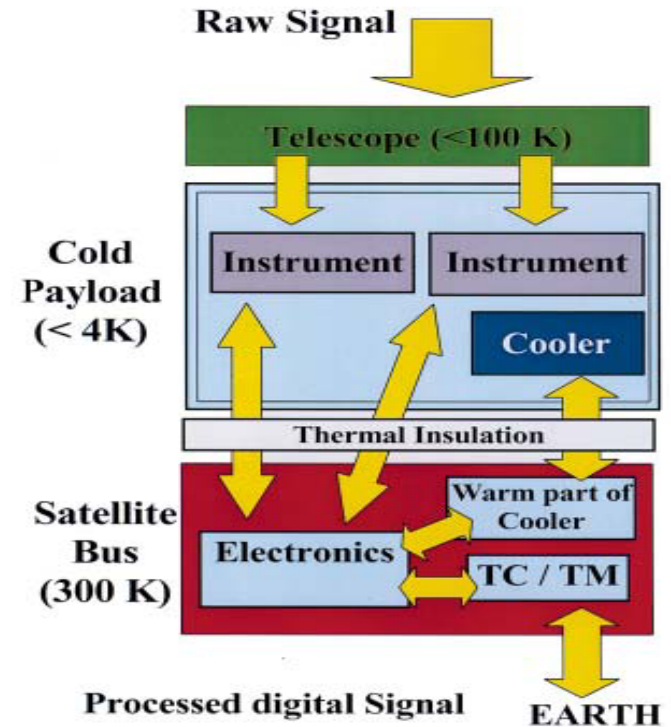
$T_{\min} \geq 4 \text{ K}$

- Resfriadores mecânicos

$T_{\min} \geq 4 \text{ K}$

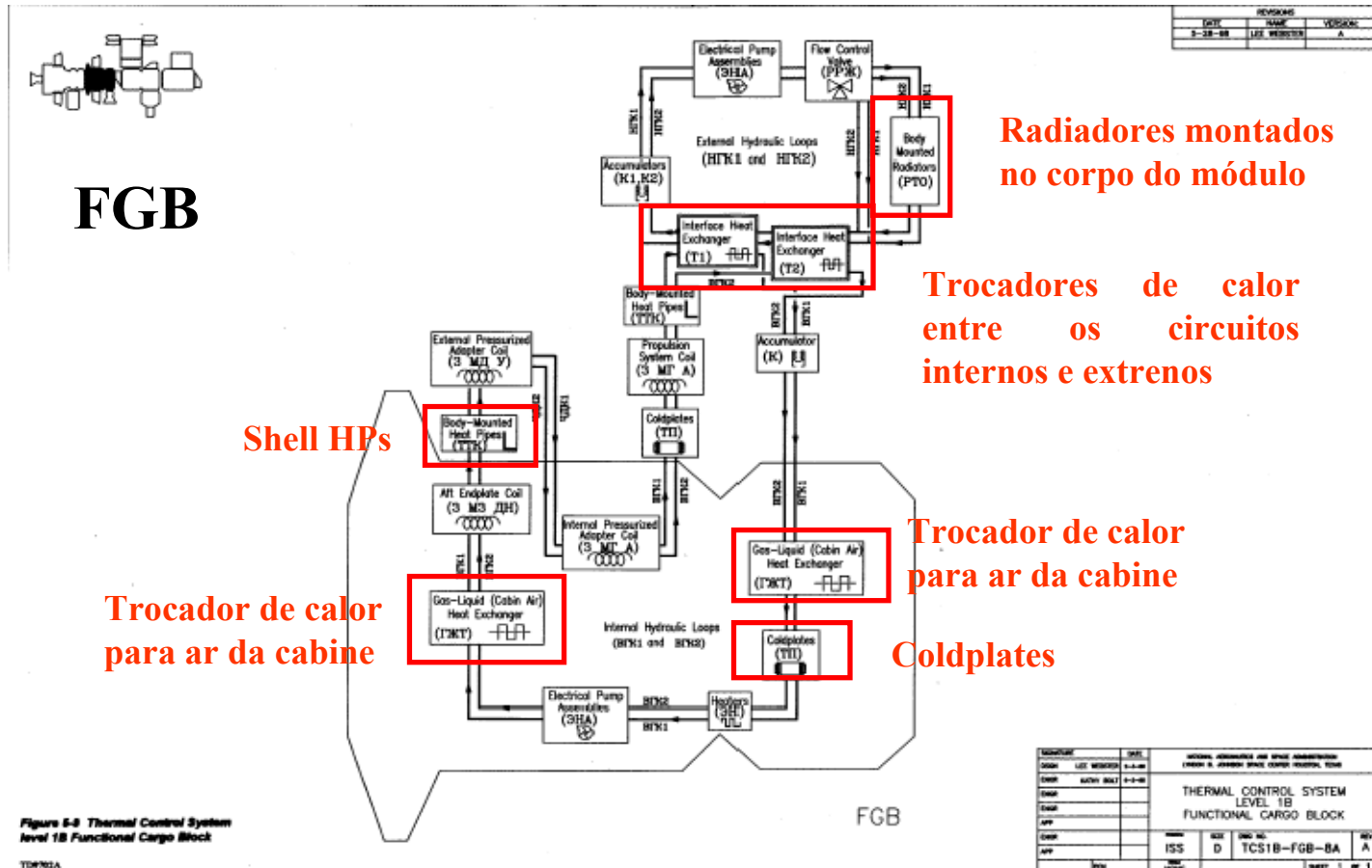
He sorption; Dillution  $^3\text{He} - ^4\text{He}$ ;  
Desmagnetização adiabática.

$10 \text{ mK} \leq T_{\min} \leq 1 \text{ K}$



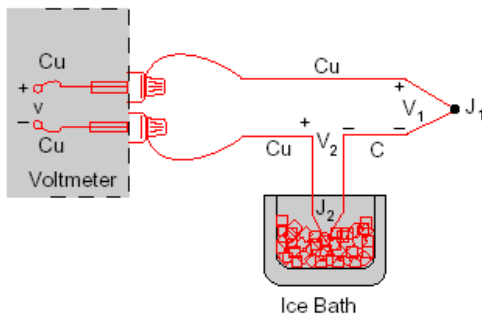
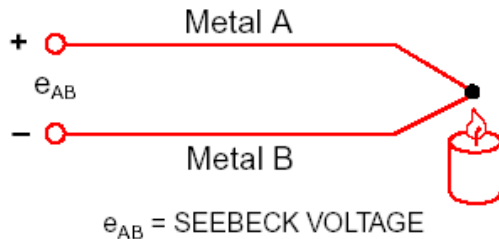
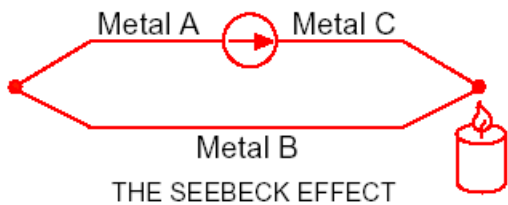
# Circuitos com bombeamento mecânico

→ Bombas mecânicas são usadas para circular um fluido de trabalho em um circuito fechado, transportando calor de fontes quentes para trocadores de calor.



# Sensores de temperatura

## Efeito Seebeck (Termopares)



EXTERNAL REFERENCE JUNCTION

**omega.com**<sup>®</sup>

Your One-Stop Source for Process Measurement and Control!

## Medida de resistência

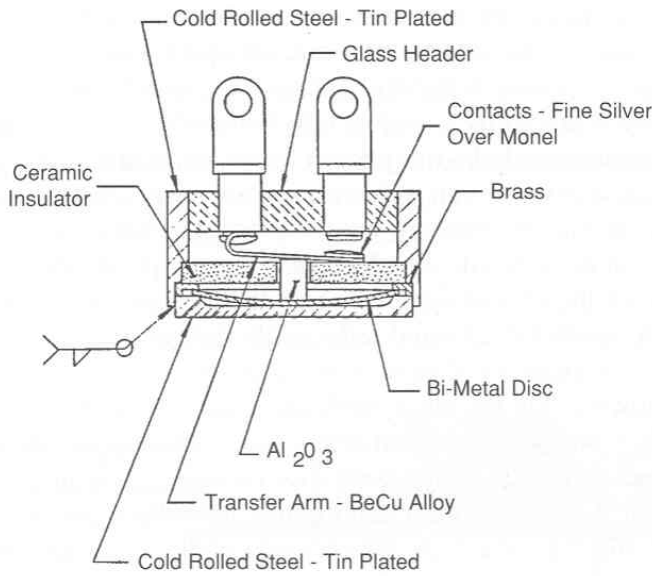
### RTD




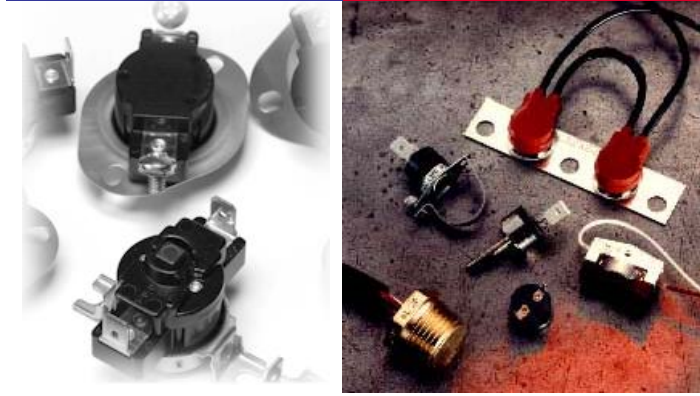
### Termistor

	<b>Thermocouple</b>  	<b>RTD</b>  	<b>Thermistor</b>  
<b>Advantages</b>	<input type="checkbox"/> Self-powered <input type="checkbox"/> Simple <input type="checkbox"/> Rugged <input type="checkbox"/> Inexpensive <input type="checkbox"/> Wide variety <input type="checkbox"/> Wide temperature range	<input type="checkbox"/> Most stable <input type="checkbox"/> Most accurate <input type="checkbox"/> More linear than thermocouple	<input type="checkbox"/> High output <input type="checkbox"/> Fast <input type="checkbox"/> Two-wire ohms measurement
<b>Disadvantages</b>	<input type="checkbox"/> Non-linear <input type="checkbox"/> Low voltage <input type="checkbox"/> Reference required <input type="checkbox"/> Least stable <input type="checkbox"/> Least sensitive	<input type="checkbox"/> Expensive <input type="checkbox"/> Current source required <input type="checkbox"/> Small $\Delta R$ <input type="checkbox"/> Low absolute resistance <input type="checkbox"/> Self-heating	<input type="checkbox"/> Non-linear <input type="checkbox"/> Limited temperature range <input type="checkbox"/> Fragile <input type="checkbox"/> Current source required <input type="checkbox"/> Self-heating

# Termostatos e Controladores de Estado Sólido

## Termostatos



- Controladores de estado sólido
- Controle por software

# Testes Térmicos

- ⇒ Verificar o correto funcionamento de equipamentos e do sistema em temperaturas extremas (realizados em níveis de qualificação e aceitação).
- ⇒ Validar o modelo térmico.

## Tipos de Teste Térmico

→ Ciclagem Térmica

→ Burn-in

→ Termo-vácuo

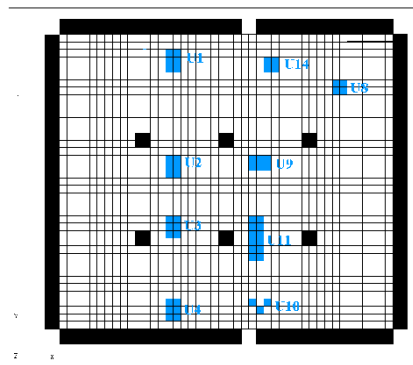
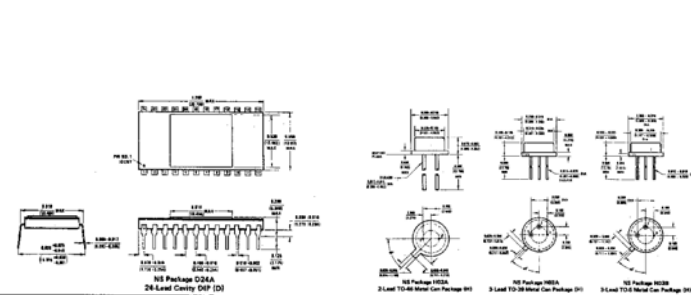
→ Balanço térmico

LIT/INPE

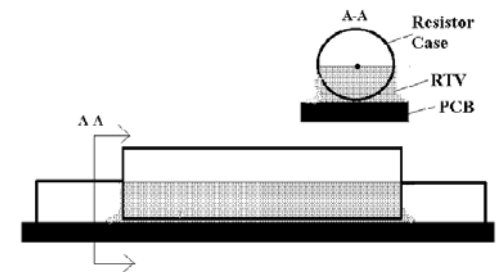
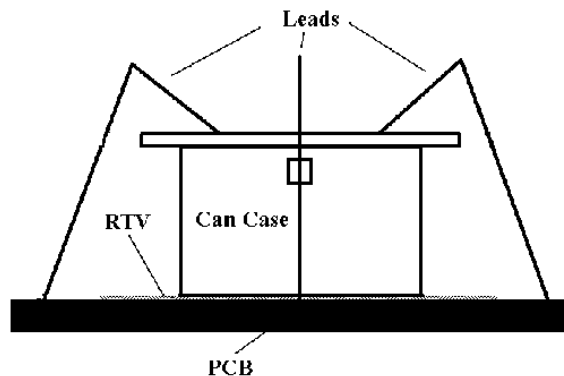
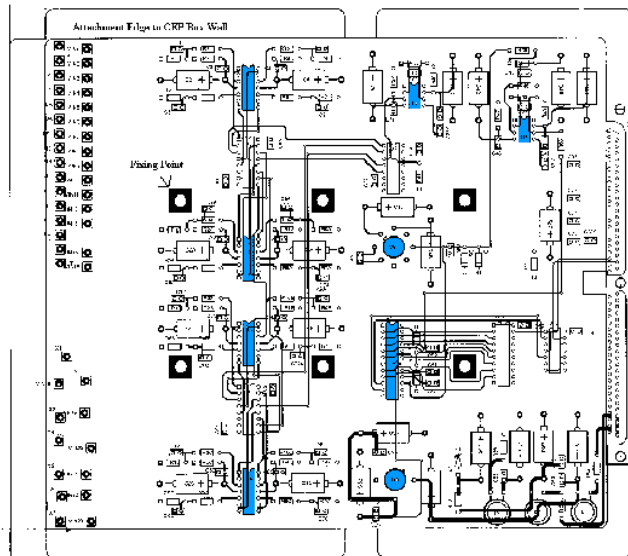
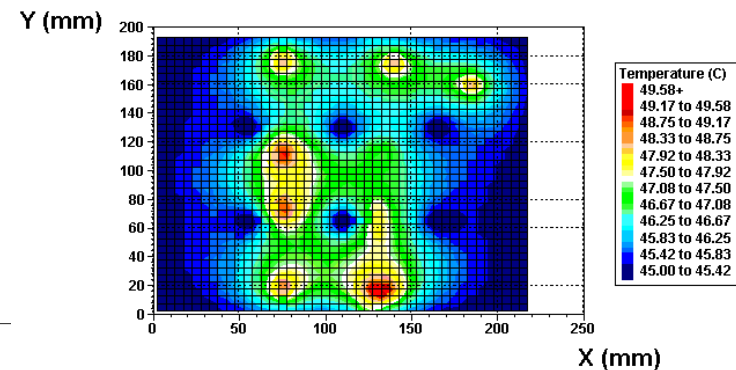


# Projeto Térmico de Equipamentos Eletrônicos

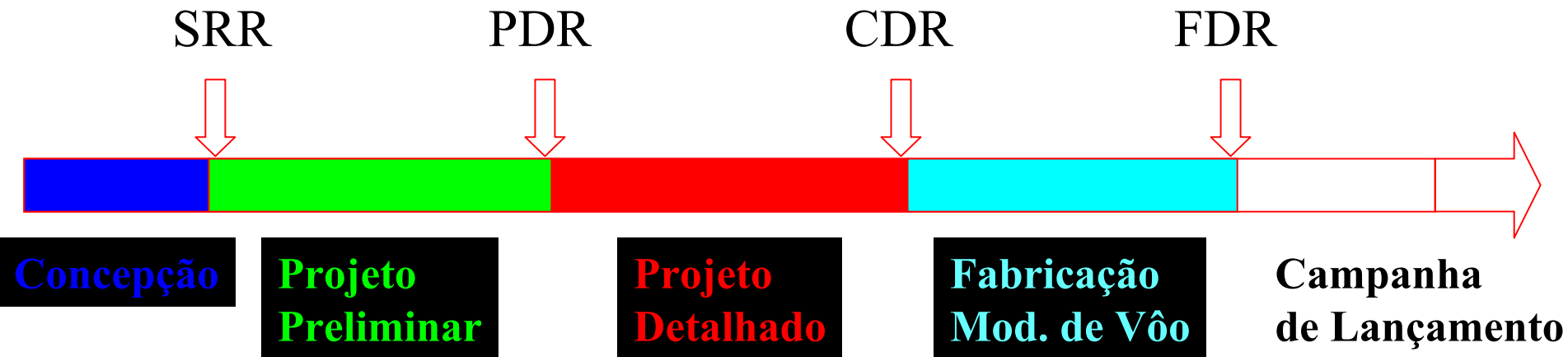
→ Garantir que a temperatura na junção dos componentes mantenha-se dentro da faixa operacional.



TEMPERATURE DISTRIBUTION ON VIDEO BOARD



# FASES DE PROJETO DE UM SATÉLITE





# Atividades do Projetista do Controle Térmico

- Participação na definição da arquitetura mecânica do satélite.
- Estabelecimento dos requisitos térmicos.
- Definição de uma concepção preliminar para o CT.

- Fazer modelo térmico simplificado do satélite.
- Identificar casos críticos.
- Realizar testes de desenvolvimento (se necessário) e planejar os testes de qualificação.

- Fazer modelo térmico detalhado do satélite.
- Realizar testes de qualificação (TBT e TVT).
- Correlacionar modelo com dados do TBT.
- Planejar os testes de aceitação.

- Realizar testes de aceitação (TVT).
- Pode ser feito também um TBT. Neste caso correlacionar modelo com dados do TBT.

- Acompanhar testes funcionais durante campanha de lançamento.
- Acompanhar comportamento térmico do satélite durante fase de lançamento, aquisição e primeiras órbitas na atitude operacional.

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