Low-Power, Fast-Response Active Gas-Gap Heat Switches For Low Temperature Applications

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Astro-H Adiabatic Demagnetization Refrigerator (ADR) and Detector Assembly

Diagram showing the components:
- 0.050 K Detector
- ADR Stage 1
- GGHS 1
- ADR Stage 2
- GGHS 2
- 1.2 K Helium Tank
- GGHS 3
- ADR Stage 3
- GGHS 4
- 4.5 K JT Cooler
Heat Switch Design

- Getter Assembly
- Hermetic Outer Shell
- Conducting Fins (2 sets)
- All Metal Seals
- Interior filled with 3He Gas
Compact Design with built in redundancy

On-state conductance determined by 3He gas pressure (up to a limit) and surface area of conducting fins
• ~ 0.3 ATM 3He fill at room temperature
• Fins cut from solid billet of copper using wire EDM
• 100 mW / K conductance ~ 1 K (switch only)

Off-state conductance determined by heat leak through outer shell
• Strong dependence on choice of material
• Linear dependence on length and cross sectional area
• Desired to be less than 1μW in Astro-H design
Heat Switch Design – Switches 1 and 2

**Engineering Model (2011)**
- Carbon Fiber Outer Shell epoxied to copper flanges
- T-300, two layers, 0.28 mm thick
- Uniform thickness flanges

**Flight Model (Final Design)**
- Ti 15-3-3-3 Outer Shell brazed to 17-4 PH steel flanges
- Reentrant tube geometry, 0.13 mm thick
- Crenellations in flanges
Titanium 15-3-3-3 has more conductivity at 1 K compared to T-300 carbon fiber

- For same shell geometry 3x the off-state conductance
- Use reentrant design to produce 3x thermal length in same spatial length
  - Orbital weld three shells together
- Braze reentrant shells into flanges
  - Choose material to match thermal expansion of shell at braze temperature
  - 17-4 PH
Heat Switch Design – Getter Assembly

- Activated charcoal is getter material
- Activation is via heater, no moving parts
- Same design for all four heat switches
- Each assembly has built-in redundancy
  - 4 Identical chips
    - 2 heaters
    - 2 thermometers
- Low activation power (~ 0.300 mW) and quick on / off time (~ 1 minute)
  - Low thermal conductance between getter and switch body
  - Low heat capacity of getter
Crenellated Design

- Allows the screws that integrate the switch into the assembly to not compress the indium seal
  - May add or remove switch from assembly without stressing the indium seal
  - Space for belleville washers

- Made from 17-4 PH steel
  - Chosen to match CTE of Ti-15-3-3-3 at high temperature to not gap the braze joint
  - CTE close to copper at low temperature
Low-Temperature Off-State Conductance

Ti-15-3-3-3 becomes superconducting ~ 3.9 K *
• Temperature dependence of conductance described by an exponential function *

\[ \dot{Q} = \frac{A}{L} \int_{T_{\text{low}}}^{T_{\text{high}}} \alpha T e^{-\beta T_c/T} dT \]

• Low thermal conductivity at low temperature
  • From 0.5 to 0.050 K: 0.003 mW / cm (helium in dewar)
    • For HS1 the shell conducts ~ 15 nW
  • From 1.2 to 0.050 K: 0.080 mW / cm (cryogen-free mode)
    • For HS1 the shell conducts ~ 400 nW

* Wikus et al., Cryogenics 51 2011
Validation of Off-State Conductance

- Measure total heat load on coldest salt pill
- Subtract from this the calculated contribution from the heat switch in the off-state
- Add the contribution from the Kevlar suspension *
- Add the contribution from the detector assembly **

* Ventura et al., Cryogenics 2000
** F. Scott Porter, Private Communications
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Validation of Off-State Conductance

- Measure total heat load on coldest salt pill
- Subtract from this the calculated contribution from the heat switch in the off-state
- Add the contribution from the Kevlar suspension *
- Add 2.2 times the contribution from the detector assembly

* Ventura et al., Cryogenics 2000
** F. Scott Porter, Private Communications
Contact resistance from straps to switch is in series with the conduction of the copper fins and 3He gas

- 0.8 K:
  - ~ 100 mW / K (switch only)
  - ~ 20 mW / K (integrated to system)

- 1.8 K: 35 – 50 mW / K (integrated to system)

- 4.7 K: ~ 180 mW / K (integrated to system)
Heat switches developed for the Astro-H ADR are compact and robust
- Getter integrated directly onto the switch body
- All metal design

Quick on / off times (~ 1 minute)
Low activation power (~ 300 µW)

On-state conduction 20 – 180 mW / K; 0.8 – 4.7 K

Low off-state conduction has many inputs
- Thin-walled shell provides low conductivity
- Reentrant design provides 3x thermal length for given spatial length
- Ti 15-3-3-3 has low κ plus becomes superconducting at 3.9 K
  - Aides by lowering conductivity further (temperature dependent)
- 15 nW from 0.5 → 0.050 K
- 400 nW from 1.2 → 0.050 K