Virtual Research Presentation Conference

Miniaturized Reverse-Operation Differential Thermal Expansion (DTE) Thermal Switch (Mini-ROD-TSW)

Principal Investigator: David C. Bugby (353G)
Co-Is: Jose G. Rivera (353F) and Robert M. Kovac (357E)
Program: Spontaneous

Assigned Presentation # RPC-222

Tutorial Introduction

OBJECTIVE: To miniaturize the JPL Reverse-Operation DTE Thermal Switch (ROD-TSW) using multiple nested stages.

APPLICATION: Miniaturized lunar instruments such as sub 1U VLBI (very long baseline interferometry) device networks.

APPROACH: Use multiple differential thermal expansion stages that maintain "stroke" but miniaturize size:

- ❑ Multiple stages with alternating use of modestly high CTE Aluminum (CTE 23E-6/K) with low CTE Invar 36 (CTE 1E-6/K)
- ❑ Use thin-walled cylindrical shells to minimize weight and attach the miniaturized parts using "micro-threading"
- ❑ Maintain ROD-TSW mating surface preparation/features, which includes near mirror finish and < 0.0001 inch surface parallelism
- ❑ Partner with small company involved in the development of miniaturized lunar devices (Space Initiatives, Inc.)
- ❑ Design, CAD model, perform thermal analysis, perform structural analysis, fabricate/assembly prototype

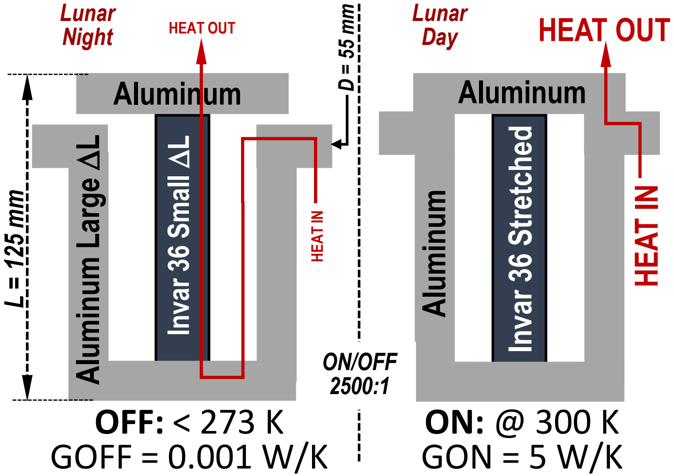
Lunar Thermal Problem

- Daytime highs of > 130 °C
- Nighttime lows of < -200 °C
- Days/nights 15 Earth days each

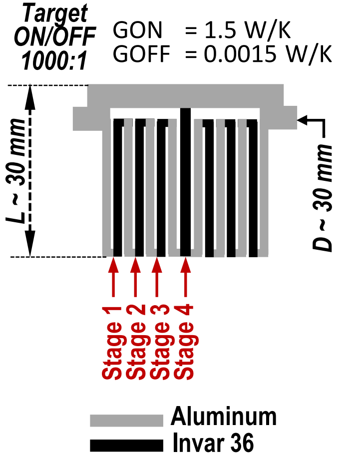
How/Why do we Miniaturize?

- ROD-TSW is too large for 1U
- DTE requires length L
- Idea is to embed the required L
- Even for large U, smaller better

ROD-TSW Operating Principles



Mini-ROD-TSW Idea



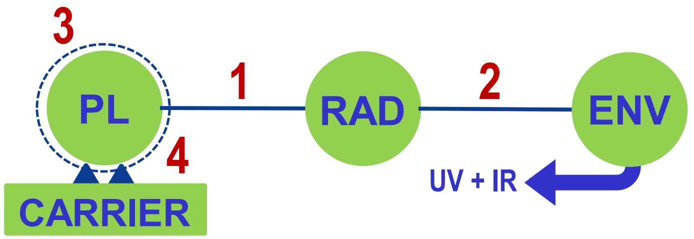
Miniaturized Reverse-Operation DTE Thermal Switch (Mini-ROD-TSW)

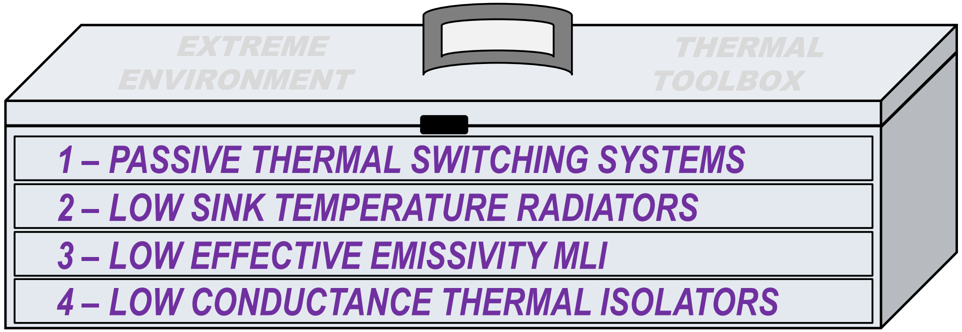
Problem Description

Science Payload Thermal Control in Extreme Environments

We want to use one of these ...	Carrying one or more of these …	To operate and stay within temperature limits, in Extreme Environments such as these …	Using a thermal control architecture that is …
Rover ***Lander*** ***Orbiter*** ***Flyer*** ***Airship***	***Science Payload (PL)*** ***253-313 K***	***Moon (100-380 K, Vac)*** ***Mars (148-293 K, Non-Vac)*** ***Europa (53-113 K, Vac)*** ***Titan (90-94 K, Non-Vac)*** ***Io (105-123 K, Vac)*** ***Venus 70-30 km (173-473 K, Non-Vac)***	***Low Power*** ***Lightweight*** ***Passive*** ***Compact*** ***Reliable*** ***Affordable*** ***Radioisotope-Free***

Extreme Environment operability/survivability requires 4 improved thermal toolbox elements …





Methodology

① Develop initial ***size*** as CAD model starting point

② Select ON force, determine rod ***pre-stretch***

Stroke = N x L x DTE x DT = ***rod pre-stretch + gap when OFF***

= (4)(30 mm)(23E-6 - 1E-6)(294 - 263) = 0.08 mm

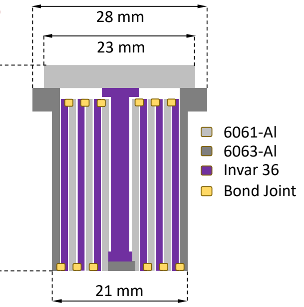
③ Create ***CAD*** models, resize for manufacturability

④ Check size relative to ***0.5 U lunar device***

⑤ Perform ***thermal analysis,*** deflection analysis

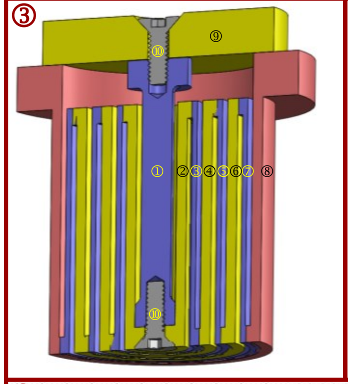
⑥ Fabricate ***prototype***, use micro-threaded joints

①

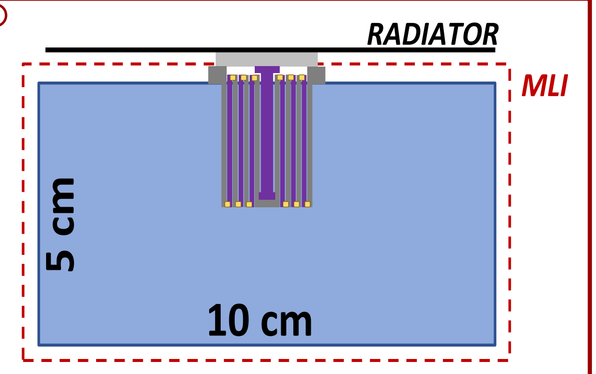


② ON FORCE	445	N	100	lbs			
Part	Material	OD (mm)	ID (mm)	t or L (mm)	E (Pa)	δ (m)	δ (mils)
Outer (8-Tube)	6063-Al	21.0	19.0	26	6.83E+10	2.70E-06	0.11
Outer (7-Tube)	Invar 36	18.0	17.0	22	1.41E+11	2.53E-06	0.10
Mid-Outer (6-Tube)	6061-Al	16.0	14.0	22	6.83E+10	3.04E-06	0.12
Mid-Outer (5-Tube)	Invar 36	13.0	12.0	22	1.41E+11	3.54E-06	0.14
Mid-Inner (4-Tube)	6061-Al	11.0	9.0	22	6.83E+10	4.56E-06	0.18
Mid-Inner (3-Tube)	Invar 36	8.0	7.0	22	1.41E+11	5.89E-06	0.23
Inner (2-Tube)	6061-Al	6.0	4.0	22	6.83E+10	9.13E-06	0.36
Inner (1-Rod)	Invar 36	3.0	0.0	24	1.41E+11	1.07E-05	0.42
Rod Pre-Stretch	0.0017	inches				4.21E-05	1.66

③



④



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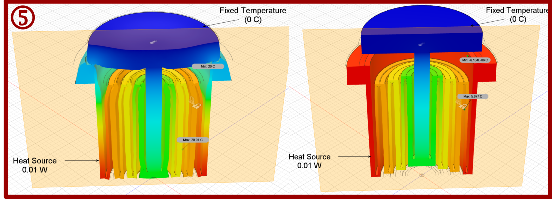
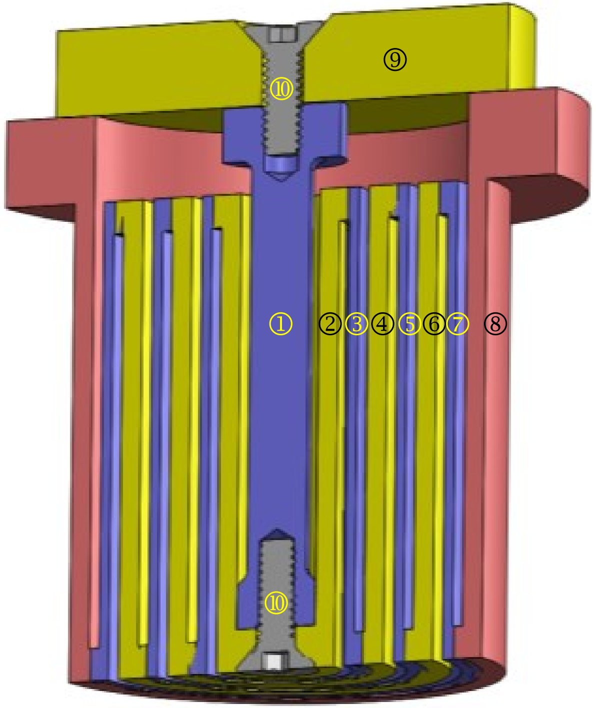
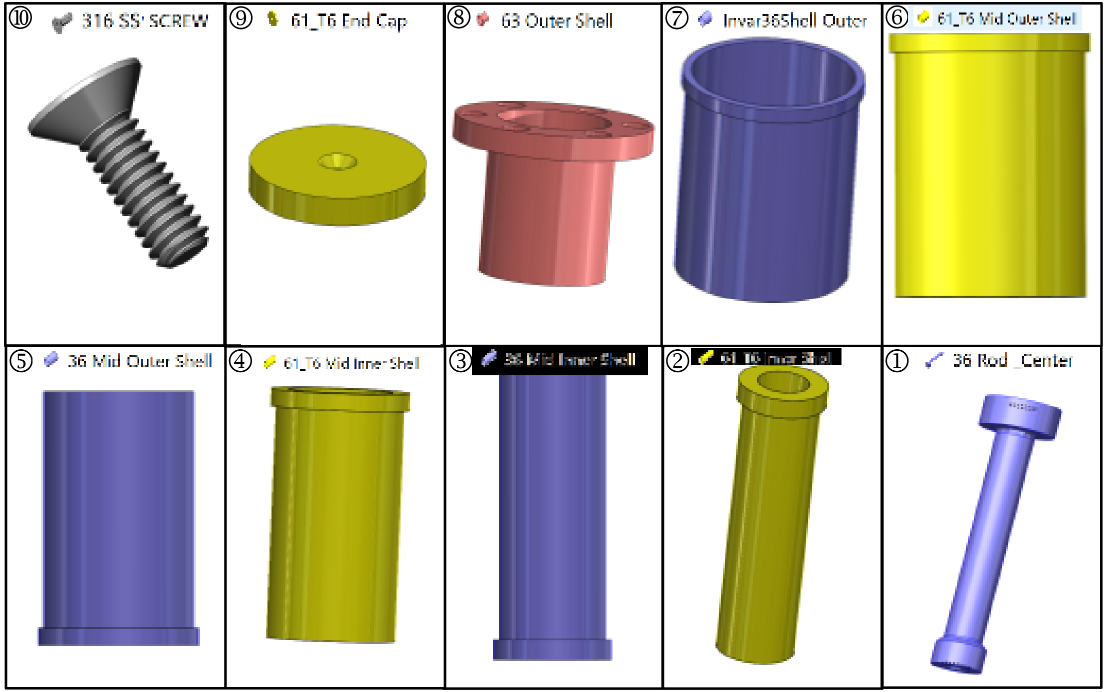


⑥

Miniaturized Reverse-Operation DTE Thermal Switch (Mini-ROD-TSW)

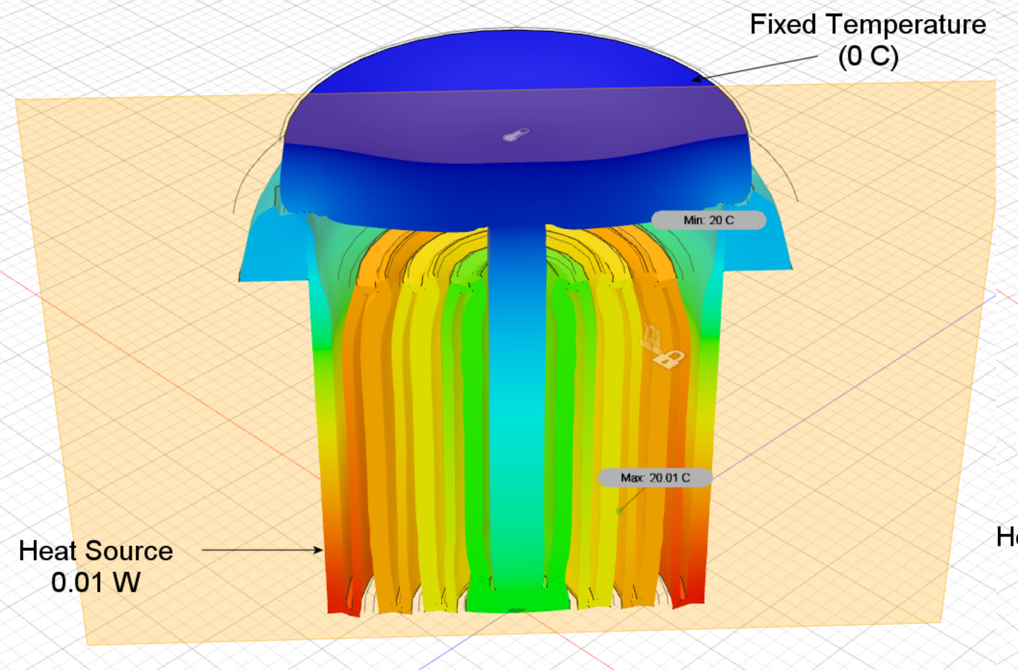
Results: CAD Model



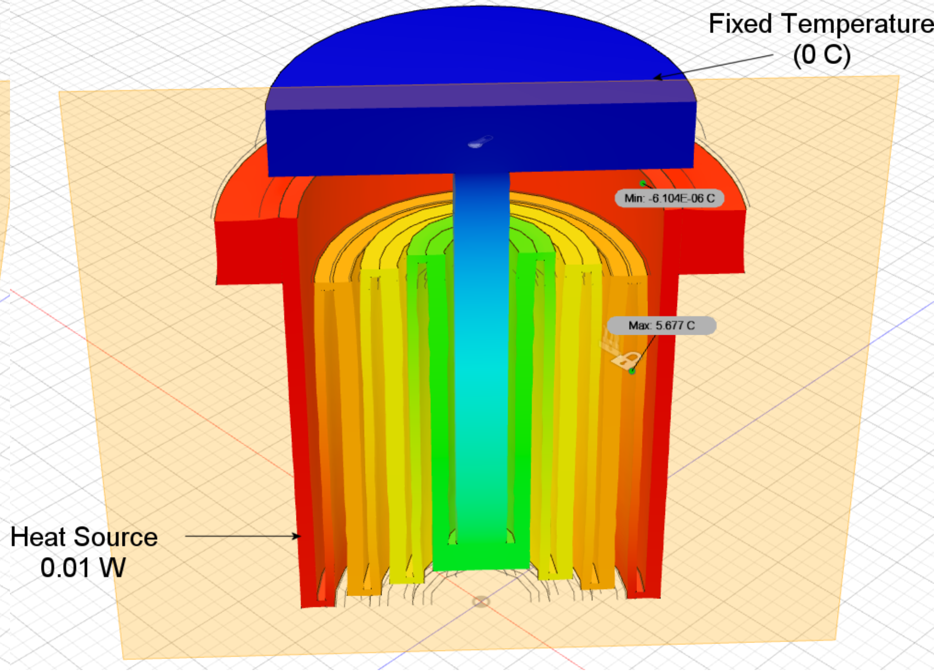


Results: Thermal Analysis (ON/OFF States at 0.01W)

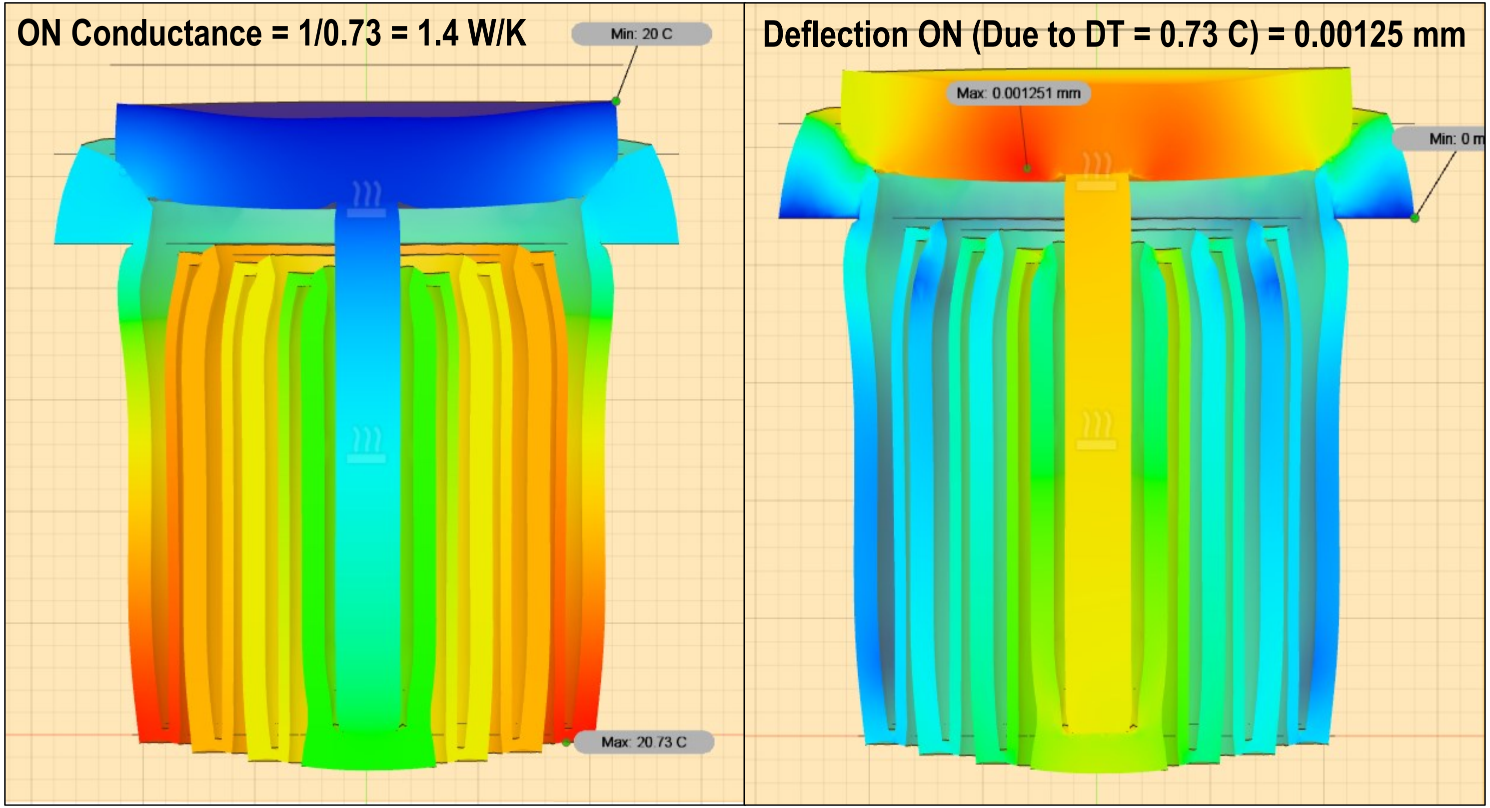
ON Conductance = 0.01 W/ 0.01 C = 1 W/K



OFF Conductance = 0.01 W/ 5.68 C = 0.0018 W/K

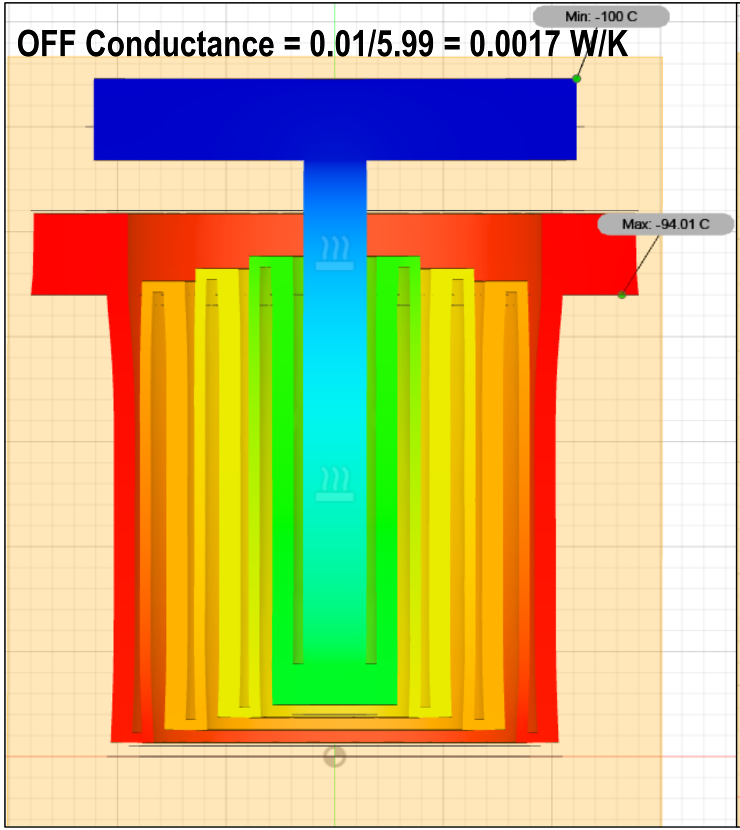


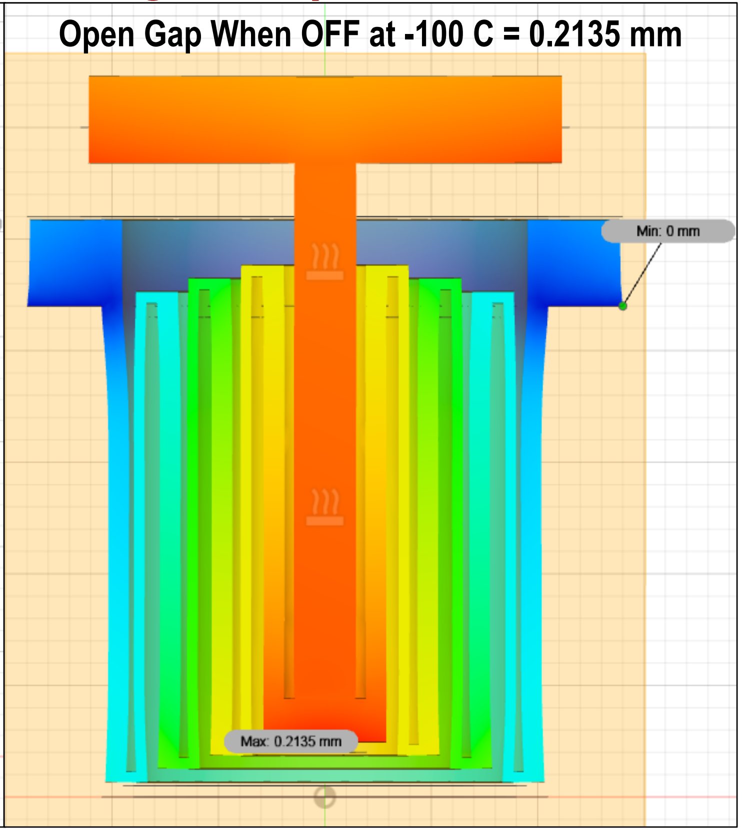
Results: Thermal/Deflection Analysis (ON State, 1W)



Miniaturized Reverse-Operation DTE Thermal Switch (Mini-ROD-TSW)

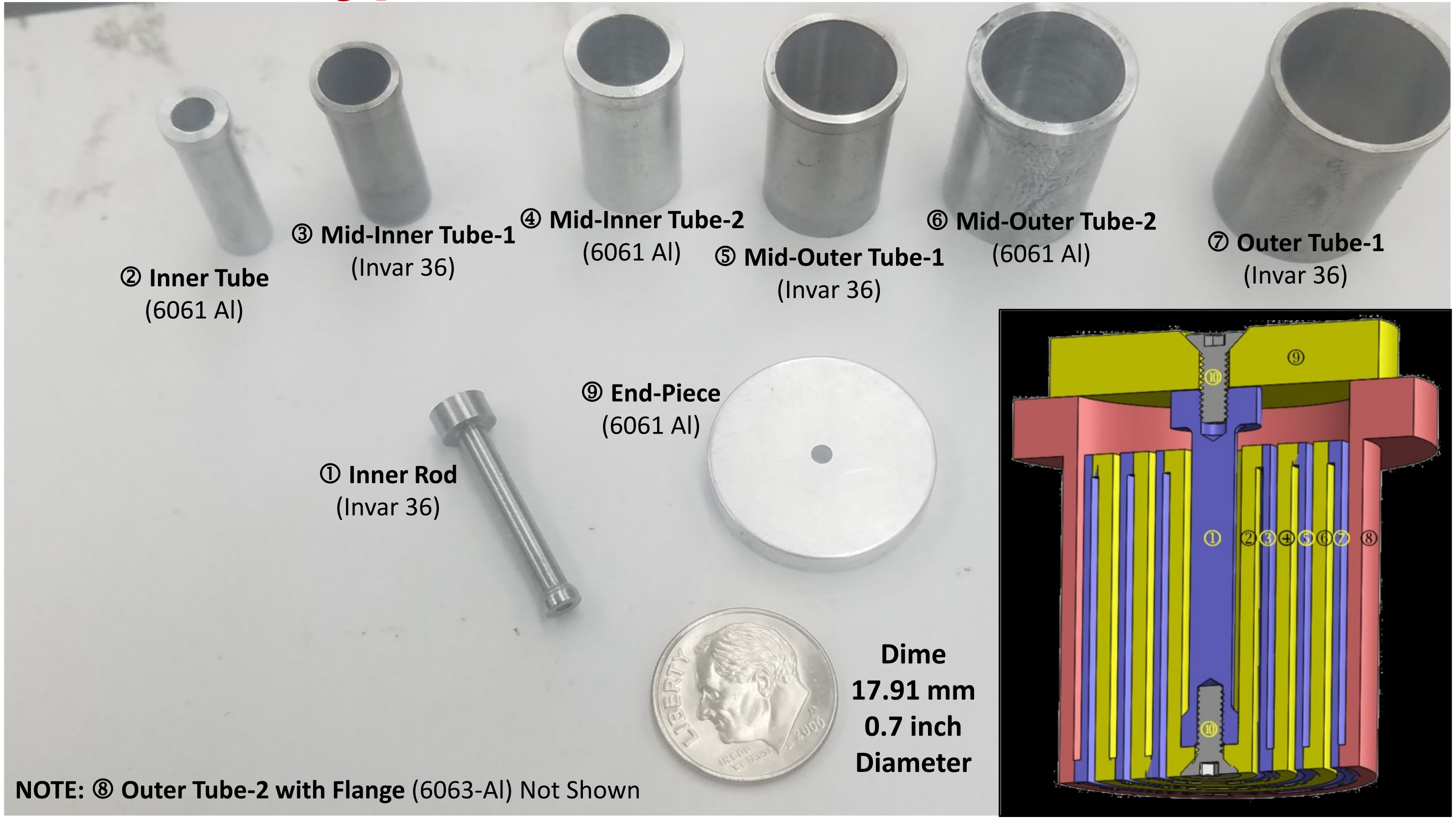
Results: Thermal/Deflection Analysis (OFF State at 0.1W)





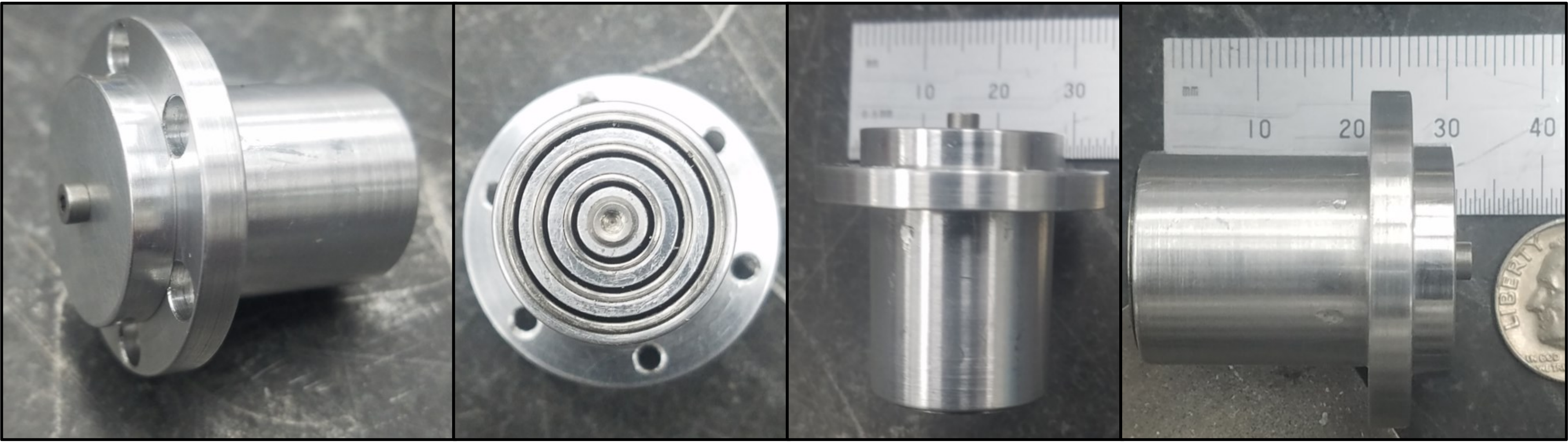
Miniaturized Reverse-Operation DTE Thermal Switch (Mini-ROD-TSW)

Results: Prototype Unit Piece Parts



Miniaturized Reverse-Operation DTE Thermal Switch (Mini-ROD-TSW)

Results: Prototype Unit Fully Assembled



Publications and References

Mini-ROD-TSW Related Presentations/Papers

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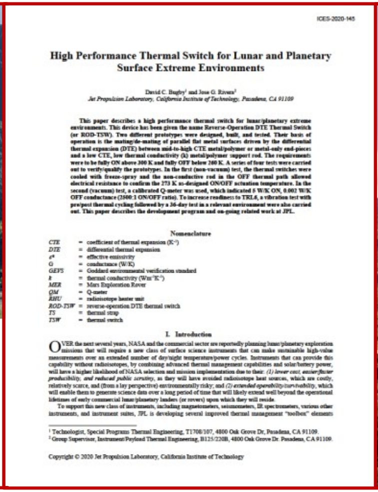

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High Performance Thermal Switch for Lunar and Planetary Surface Extreme Environments

David C. Bugby[1] and Jose G. Rivera[2]
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

This paper describes a high performance thermal switch for lunar/planetary extreme environments. This device has been given the name Reverse-Operation DTE Thermal Switch (or ROD-TSW). Two different prototypes were designed, built, and tested. Their basis of operation is the mating/de-mating of parallel flat metal surfaces driven by the differential thermal expansion (DTE) between mid-to-high CTE metal/polymer or metal-only end-pieces and a low CTE, low thermal conductivity (k) metal/polymer support rod. The requirements were to be fully ON above 300 K and fully OFF below 260 K. A series of four tests were carried out to verify/qualify the prototypes. In the first (non-vacuum) test, the thermal switches were cooled with freeze-spray and the non-conductive rod in the OFF thermal path allowed electrical resistance to confirm the 273 K as-designed ON/OFF actuation temperature. In the second (vacuum) test, a calibrated Q-meter was used, which indicated 5 W/K ON, 0.002 W/K OFF conductance (2500:1 ON/OFF ratio). To increase readiness to TRL6, a vibration test with pre/post thermal cycling followed by a 36-day test in a relevant environment were also carried out. This paper describes the development program and on-going related work at JPL.

Nomenclature

CTE	=	coefficient of thermal expansion (K^{-1})
DTE	=	differential thermal expansion
ε^{*}	=	effective emissivity
G	=	conductance (W/K)
GEVS	=	Goddard environmental verification standard
k	=	thermal conductivity ($Wm^{-1}K^{-1}$)
MER	=	Mars Exploration Rover
QM	=	Q-meter
RHU	=	radioisotope heater unit
ROD-TSW	=	reverse-operation DTE thermal switch
TS	=	thermal strap
TSW	=	thermal switch

I. Introduction

OVER the next several years, NASA and the commercial sector are reportedly planning lunar/planetary exploration missions that will require a new class of surface science instruments that can make sustainable high-value measurements over an extended number of day/night temperature/power cycles. Instruments that can provide this capability without radioisotopes, by combining advanced thermal management capabilities and solar/battery power, will have a higher likelihood of NASA selection and mission implementation due to their: *(1) lower cost, easier/faster producibility, and reduced public scrutiny*, as they will have avoided radioisotope heat sources, which are costly, relatively scarce, and (from a lay perspective) environmentally risky; and *(2) extended operability/survivability*, which will enable them to generate science data over a long period of time that will likely extend well beyond the operational lifetimes of early commercial lunar/planetary landers (or rovers) upon which they will reside.

To support this new class of instruments, including magnetometers, seismometers, IR spectrometers, various other instruments, and instrument suites, JPL is developing several improved thermal management "toolbox" elements

[1] Technologist, Special Programs Thermal Engineering, T1708/107, 4800 Oak Grove Dr, Pasadena, CA 91109.
[2] Group Supervisor, Instrument/Payload Thermal Engineering, B125/220B, 4800 Oak Grove Dr. Pasadena, CA 91109.