Thermometry

WE Requirements

Presented by:

Bruce Swinyard / RAL

Subsystem Definition

- The SPIRE Instrument Cold Focal Plane Unit (FPU) will operate at cryogenic temperatures between 15 and 1.7 K
- Any parts of the FPU that are “warm” could produce excess photon background in the detectors
- Thermometers will be placed at strategic locations within the FPU to monitor the temperature during operations and to be used for diagnostic and problem solving during ground test
- In addition, there is the possibility that the detector 300 mK stage will require a thermal control loop
- The warm electronics units will also contain thermometers to provide monitoring and diagnostic functions - for instance the performance of the BAU may be affected by temperature changes.

Table of Required FPU Thermometers (1)

Unit	Power	Location	Sensor	Res.	Range	Rate(Hz)	Criticality
FSFPU	I	200 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	200 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	350 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	350 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	500 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	500 µm array	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	FTS array 1	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	FTS array 1	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	FTS array 2	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	FTS array 2	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	SQUIDS 1*	Ge 4 wire	12	1K>10K	1	B
FSFPU	I	SQUIDS 3*	Ge 4 wire	12	1K>10K	1	B
FSFPU	S	PHOT 2-K box	Diode 4W	12	1 K>300 K	1	C
FSFPU	I	PHOT 2-K box	Ge 4 wire	12	1 K>10 K	1	C
FSFPU	S	FTS 2-K box	Diode 4W	12	1 K>300 K	1	C
FSFPU	I	FTS 2-K box	Ge 4 wire	12	1 K>10 K	1	C
FSFPU	S	4-K structure	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	4-K structure	Diode 4W	12	3 K>300 K	1	C
FSFPU	S	Instrument cover	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	Instrument cover	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	Phot Calibrator	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	Phot Calibrator	Diode 4W	12	3 K>300 K	1	C

Table of Required FPU Thermometers (2)

Unit	**Power**	**Location**	**Sensor**	**Res.**	**Range**	**Rate**	**Criticality**
FSFPU	I	FTS Mechanism	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	FTS Mechanism	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	FTS Calibrator	Diode 4W	12	3 K>300 K	1	B
FSFPU	I	FTS Calibrator	Diode 4W	12	3 K>300 K	1	B
FSFPU	I	Cooler Pump	Diode 4W	12	3 K>300 K	1	B
FSFPU	I	Cooler Pump	Diode 4W	12	3 K>300 K	1	B
FSFPU	I	Cooler Evaporator	Ge 4W	16	0.2 K>5 K	10	B
FSFPU	I	Cooler Evaporator	Ge 4W	16	0.2 K>5 K	10	B
FSFPU	I	Thermal Control Node	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	Thermal Control Node	Bolometer	16	0.2 K>1 K	10	B
FSFPU	I	Cooler Pump HS	Diode 4W	12	1 K>50 K	1	C
FSFPU	I	Cooler Pump HS	Diode 4W	12	1 K>50 K	1	C
FSFPU	I	Cooler Evap. HS	Diode 4W	12	1 K>50 K	1	C
FSFPU	I	Cooler Evap. HS	Diode 4W	12	1 K>50 K	1	C
FSFPU	I	Shutter Vane	Diode 4W	12	3 K > 30 K	1	B
FSFPU	I	Shutter Vane	Diode 4W	12	3 K > 30 K	1	B
FSFPU	I	BSM (TBC)	Diode 4W	12	3 K>300 K	1	C
FSFPU	I	BSM (TBC)	Diode 4W	12	3 K>300 K	1	C
FSFTB	S	JFET/Filter box	Diode 4W	12	3 K>300 K	1	B
FSFTB	I	JFET/Filter box	Diode 4W	12	3 K>300 K	1	B

Thermometers for the Warm Electronics Units

Unit	Power	Location	Sensor	Res.	Range	Rate	Criticality
FSBAU	S	BAU	Diode 4W	12	70K>300 K	1	B
FSBAU	I	BAU	Diode 4W	12	70K>300 K	1	B
FSDRC	S	DRCU	Diode 4W	12	-40^{0}C>80^{0}C	1	B
FSDRC	I	DRCU	Diode 4W	12	-40 ^{0}C >80 ^{0}C	1	B
FSDRC	I	DRCU	Diode 4W	12	-40 ^{0}C >80 ^{0}C	1	B
FSDPU	S	DPU	Diode 4W	12	-40 ^{0}C >80 ^{0}C	1	B
FSDPU	I	DPU	Diode 4W	12	-40 ^{0}C >80 ^{0}C	1	B

Summary of Types of Thermometers

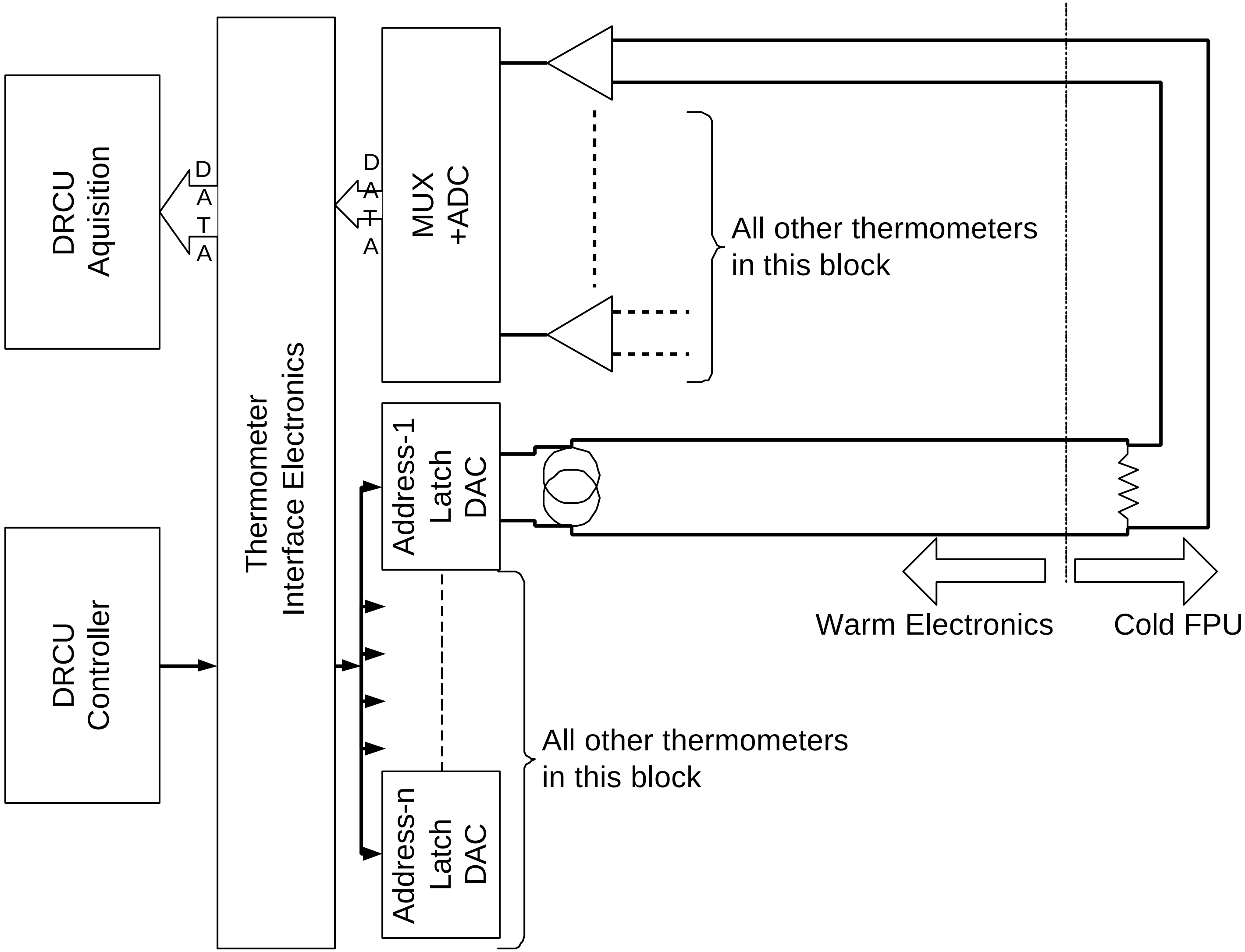
Instrument:

Type	**Number**	**Sample (Hz)**	**Bits**	**R (typ.W**
0.2-1 K Bolometer	12	10	16	N/A
0.2-5 K Ge 4 Wire	2	10	16	~1000
1-10 K Ge 4 Wire	4	1	12	~500
3-300 K Diode 4 Wire	13	1	12	N/A
1-50 K Diode 4 Wire	4	1	12	N/A
3-30 K Diode 4 Wire	2 (Shutter)	1	12	N/A
70-300 K Diode 4 Wire	1 (BAU)	1	12	N/A
-40-80^{o}c Diode 4 Wire	3 (DRCU/DPU)	1	12	N/A
Spacecraft				
1-300 K Diode 4 Wire	2	1	12	N/A
3-300 K Diode 4 Wire	3	1	12	N/A
70-300 K Diode 4 Wire	1 (BAU)	1	12	N/A
-40-80^{o}c Diode 4 Wire	2 (DRCU/DPU)	1	12	N/A

Resistance/Diode Thermometer Implementation

- The baseline assumption is that each sub-system will provide its own thermometers - perhaps procured centrally.
- The thermometer wiring for each sub-system will be part of that sub-system 's harness.
- The structure will require a harness specfically for the thermometers
- All thermometers will be four wire devices. The block diagram will be the same for each thermometer with different values of the currents; voltages and ADC resolution
- It should be possible to multiplex the thermometer read-outs

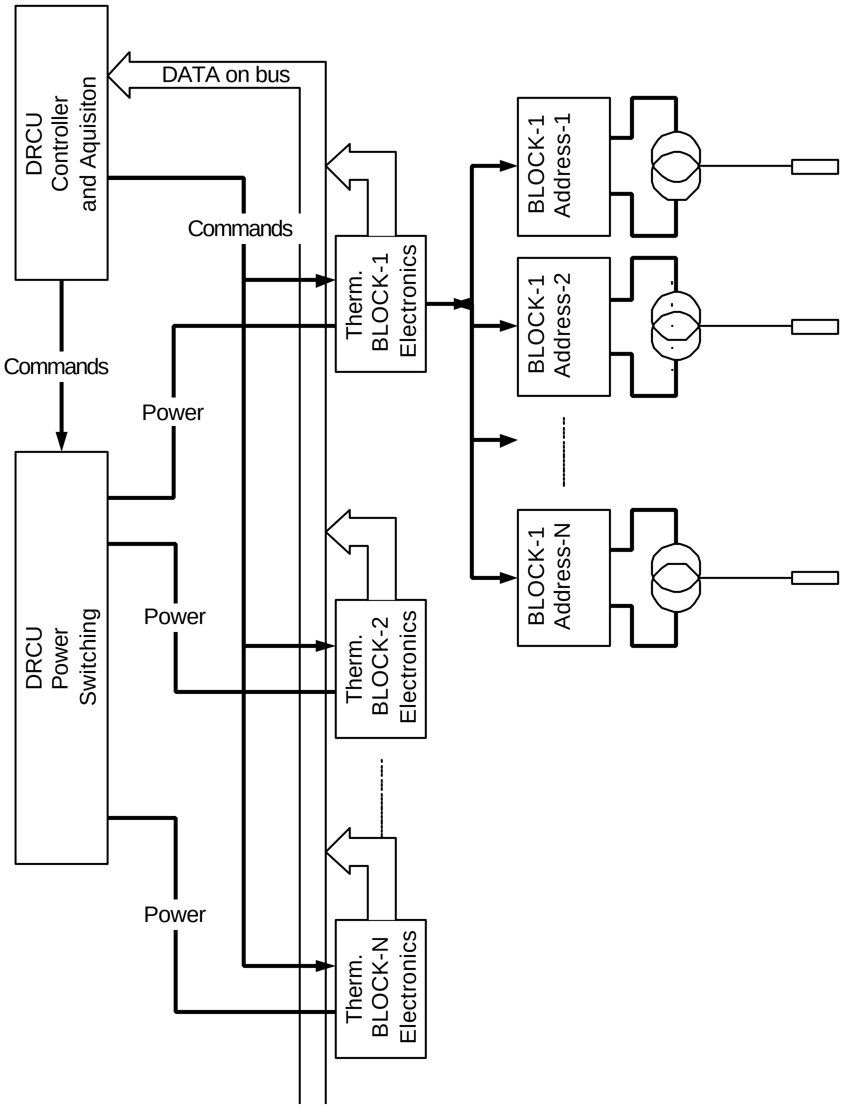
Circuitry for DC 4-Wire Thermometer



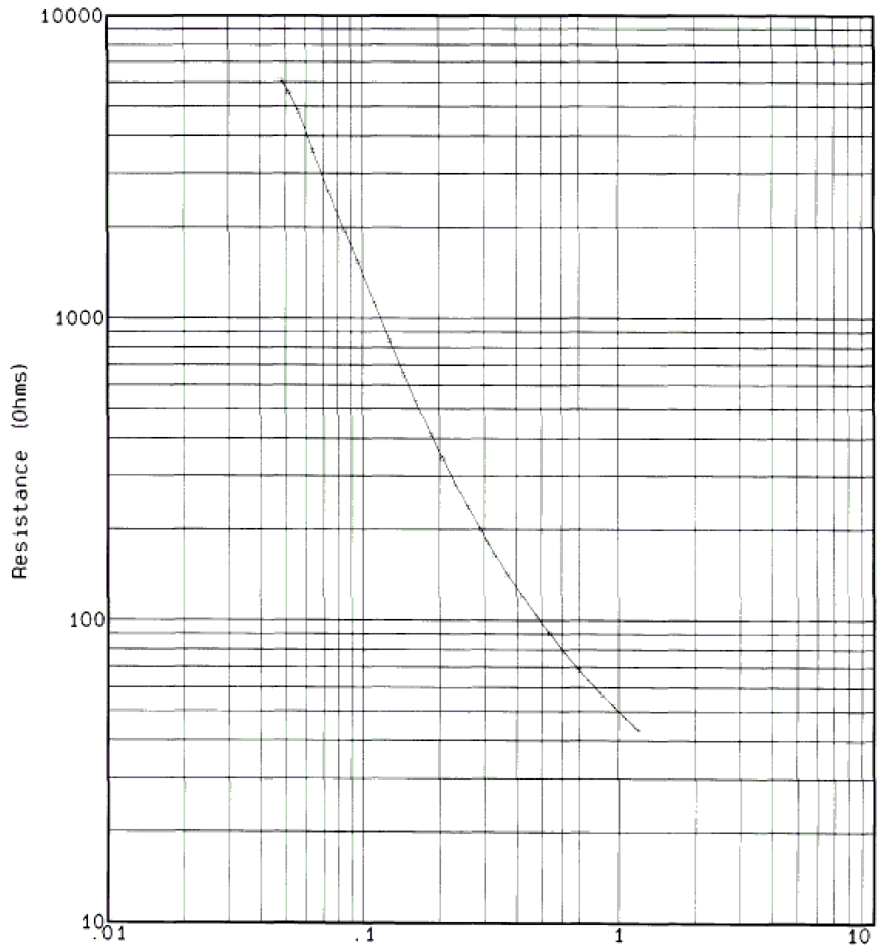
Thermometer I/Fs (1)

- The thermometers will be grouped into blocks according to type and redundancy
- Each block can be switched on or off with the central DRCU power distribution and switching circuitry
- One address/latch/DAC will be used for each thermometer within a block to allow faulty sensors to be switched off independently of all others
- The baseline is to have four wires to each thermometer resistance or diode this allieviates the resistance requirement on the harness
- Some of the thermometers (as indicated in the table) will be driven directly from the S/C. These will require a separate harness and will be incorporated as part of the cryostat thermometry

Thermometer I/Fs (2)

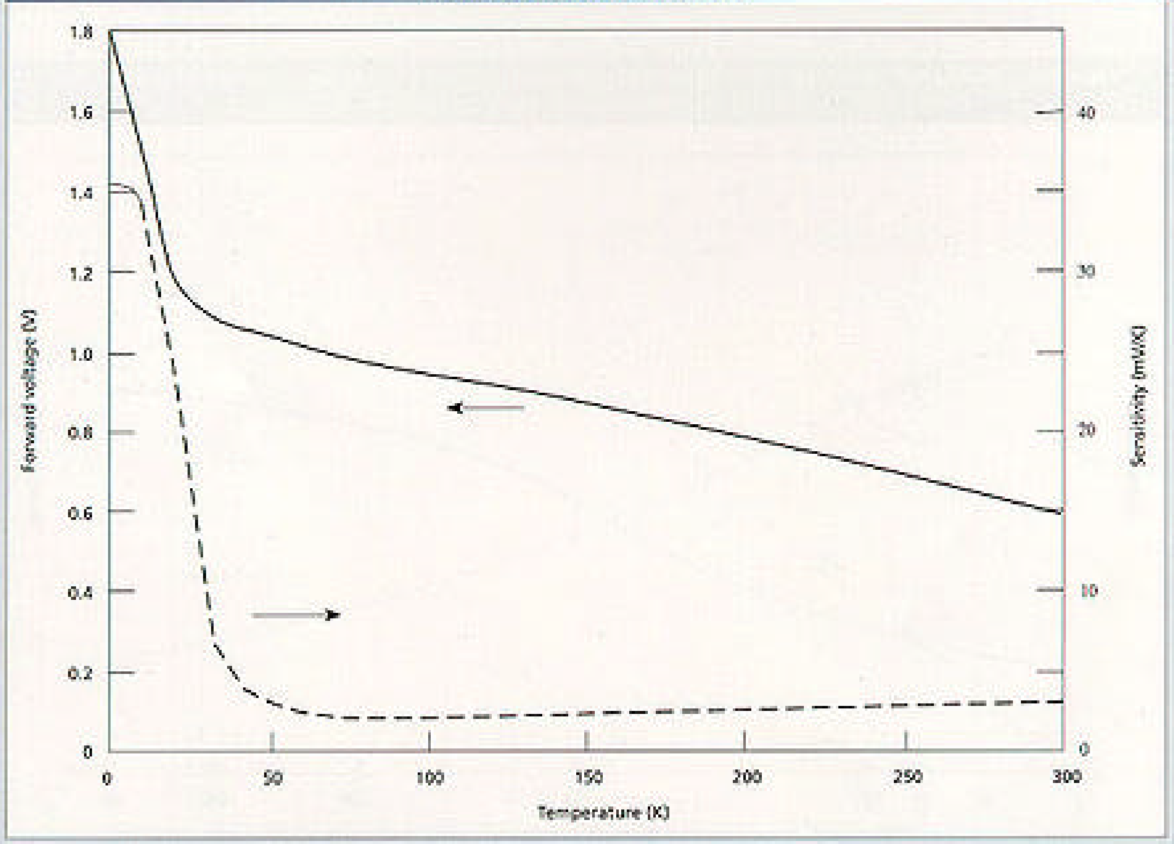


Thermometer Parameters
Lakeshore Ge Resistance Thermometer

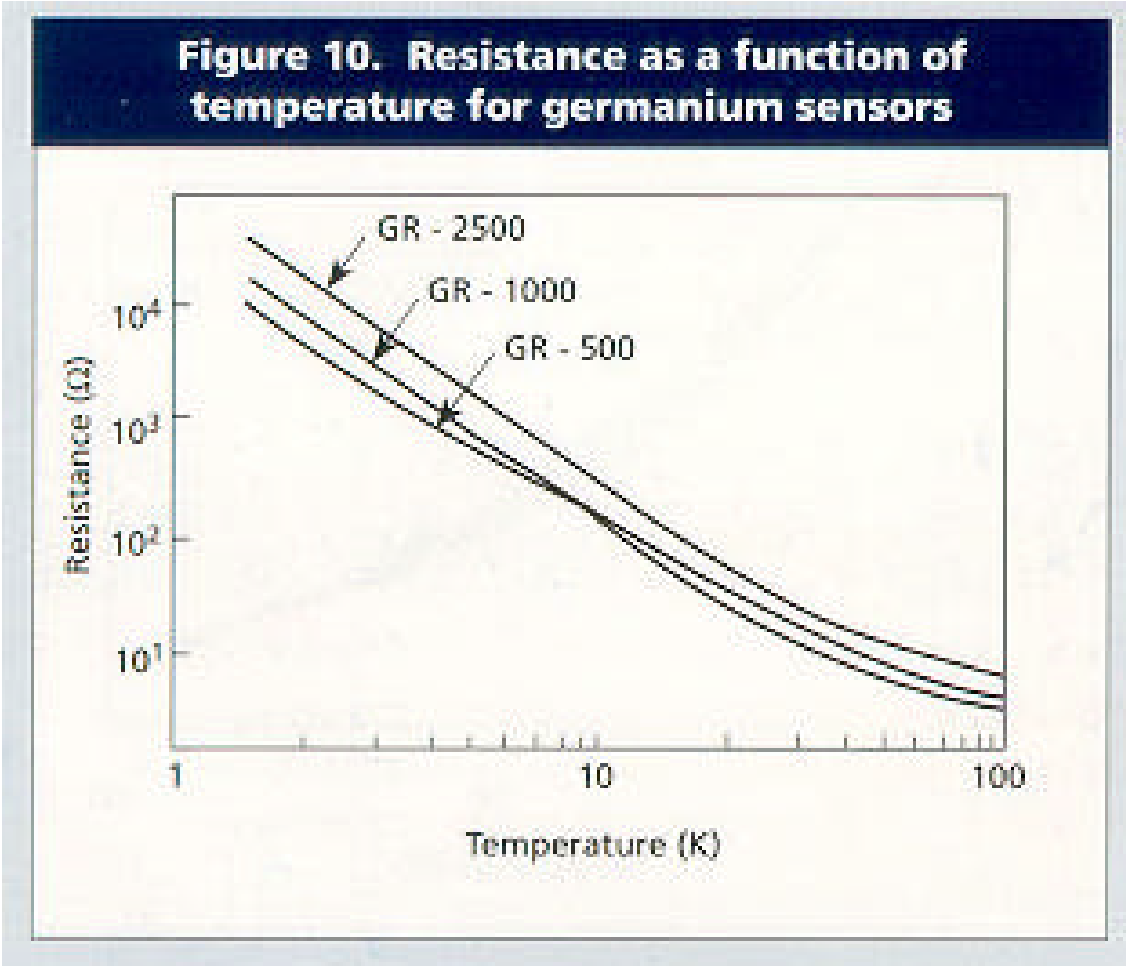


Thermometer Parameters
Oxford Instruments Silicon Diode

Figure 5. Silicon diode voltage (solid line) and sensitivity (dashed line) as a function of temperature (typical curves)



Thermometer Parameters
Oxford Instruments Ge Resistance



Thermometer Criticality Analysis

- The failure of any one thermometer will not lead to the loss of any critical temperature measurement.
- Multiple thermometers implemented at critical points
- Each thermometer has its own current source and amplifier
- Redundant thermometers will be on separate harnesses and multiplexer electronics

Thermometers Control

- Each block of thermometers can be switched from **OFF** to **ON** and **ON** to **OFF** by a command to the DRCU power distribution and switching unit
- Each thermometer within a block be addressed individually and commanded **ON** or **OFF**

Thermometers WE constraints

- The resistance/diode thermometers will require a constant current source that will give between 1 (TBC) and 10 (TBC) μA depending on the generic type.
- Individual thermometers will be calibrated against a constant current - i.e. there is no requirement for set on test restistors etc. to change the current according to the performance of each thermometer
- The current source must be stable to within 0.1 % (TBC)

Thermometer WE implementation

- The instrument thermometer electronics, including the DRCU and BAU, will be part of the DRCU electronics
- The DPU thermometers will be part of the DPU electronics
- The thermometer electronics design could be based, in the first instance, on the design used for the ISO instruments

300 mK Thermal Control Requirements

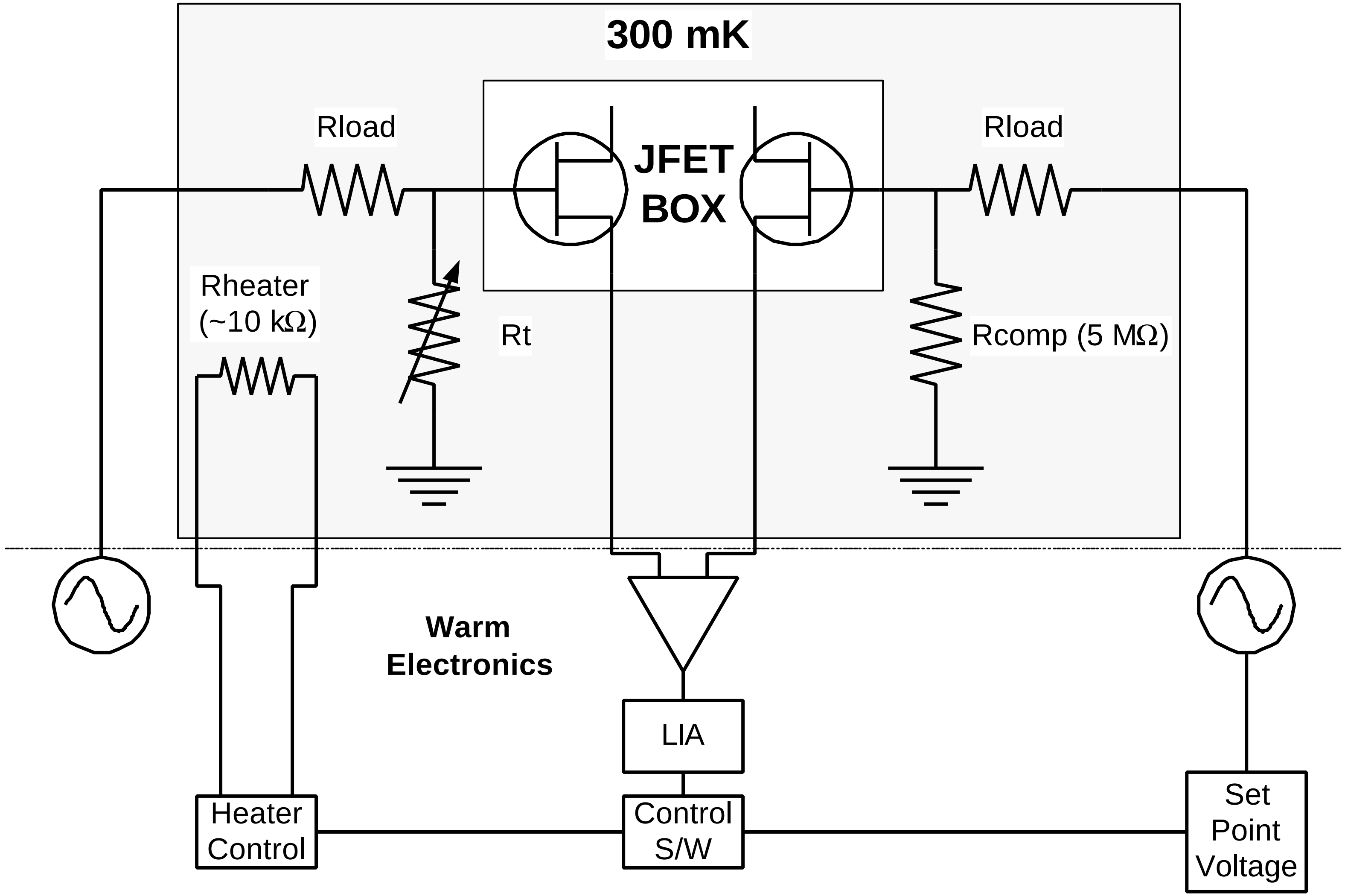
The Instrument Requirements Document sets the following requirements on the 300 mK stage temperature stability

IRD-COOL-R05	Temperature fluctuations at the evaporator cold tip	No more than 150 nK $Hz^{-1/2}$ in a frequency band from 0.1-100 Hz.
IRD-COOL-R06	System low frequency temperature stability with active temperature control	TBD nK at 0.015 Hz at a maximum power dissipation of TBD μW

Whether a thermal control circuit is needed will depend on the value of “TBD” in IRD-COOL-R06 and the performance of the cooler.

Although we believe a thermal control circuit will not be necessary, we are including one as a baseline.

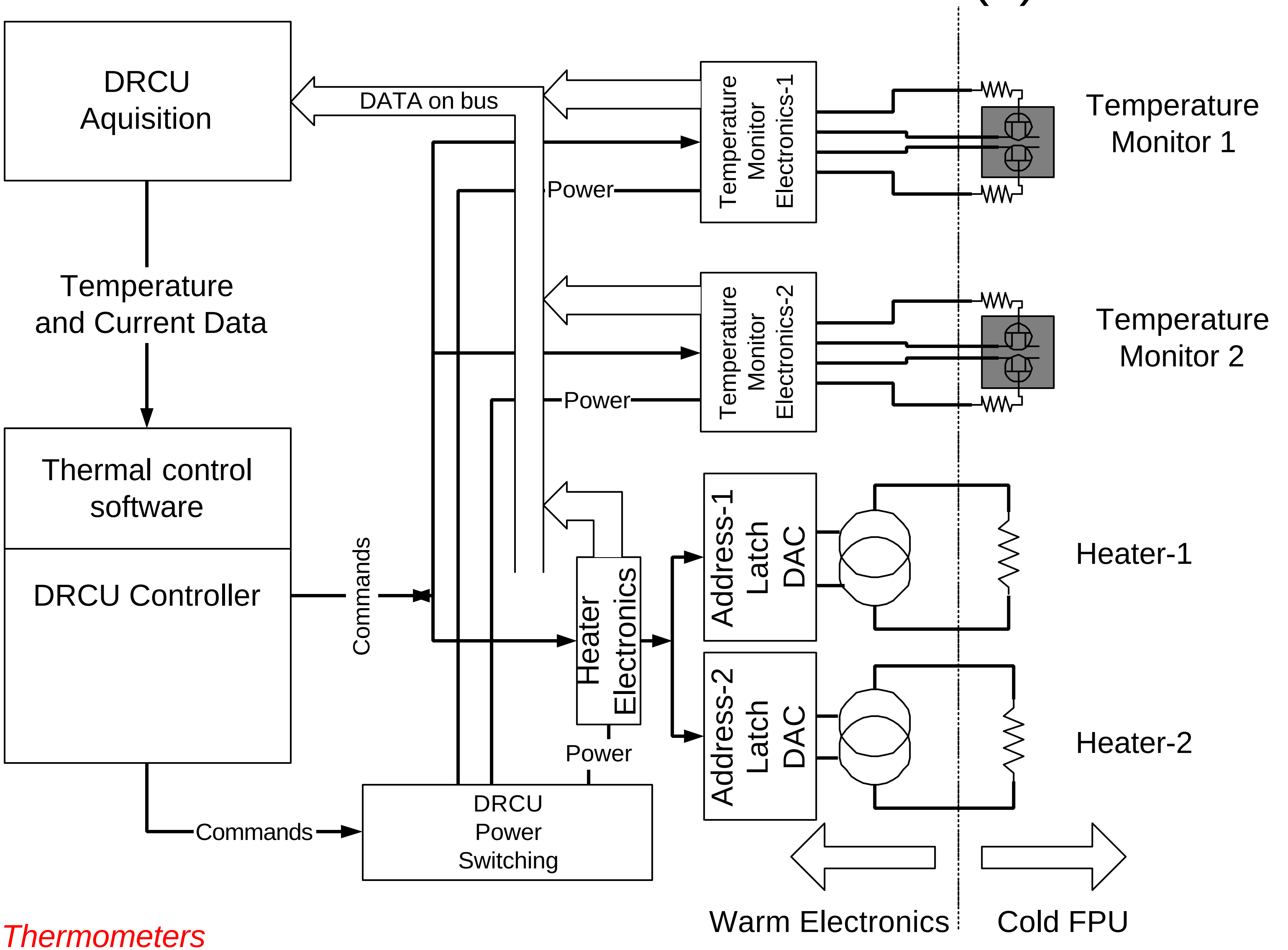
Thermal Control Circuit using NTD Ge Thermistors



Thermal Control Circuit I/Fs (1)

- It is proposed to have cold redundant circuits for the temperature monitors
- Each will be powered and commanded separately from the central DRCU master controller and power switching circuitry
- There will be two heaters with separate current sources driven from a common interface circuit
- One address/latch/DAC will be used for each heater
- The data acquisition system will pass the measured temperature and heater current to the DRCU controller at 5 Hz (TBC)
- The DRCU software will calculate the required current for the heater and update the value appropriately
- The update rate will be at 1 Hz (TBD)
- The set point temperature will be a variable

Thermal Control Circuit I/Fs (2)



Options without NTD Ge thermistors

- The example given here is using NTD Ge Thermistors.
- For the filled array options this may not be the most appropriate choice as they require cold JFET amplifiers that would not necessarily be present
- The filled arrays could use a “blind” bolometer channel which would be read out as part of the detectors
- The data would be need to be separated out in the acquisition system and passed to the DRCU master controller for the thermal control software

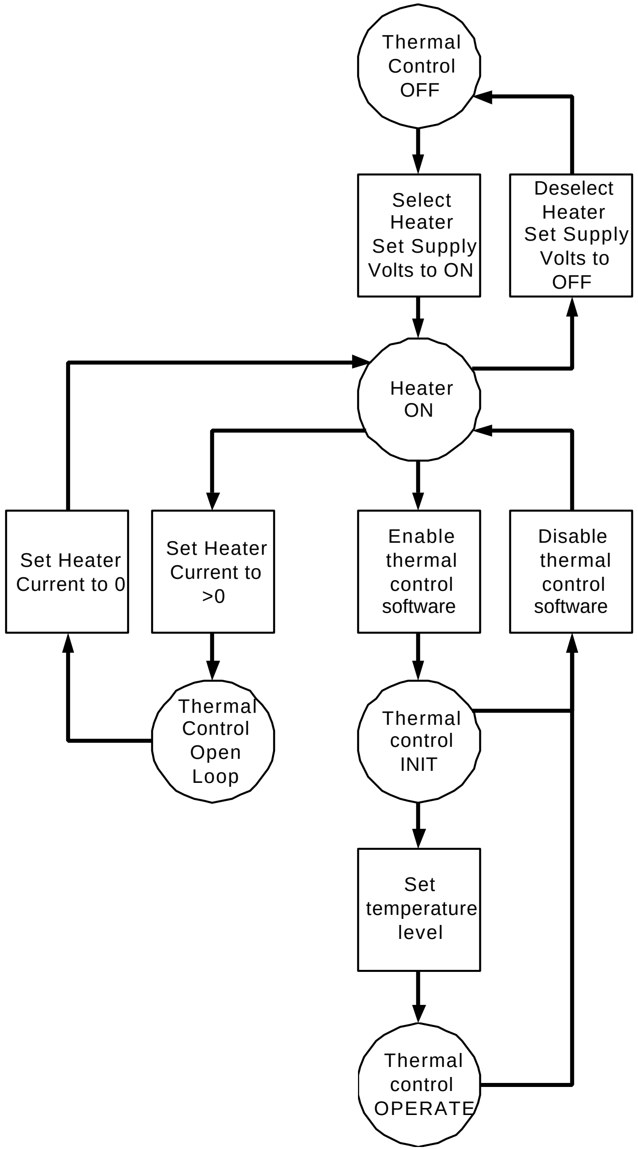
Thermal Control Circuit Criticality Analysis

- Failure of the thermal control circuit may lead to increased systematic noise but is not mission critical
- Full cold redundancy is foreseen on the temperature monitors (TBC)
- The heaters will share control circuits but will be fully redundant on the current amplifiers
- In the event of failure of both of the thermistors it may be possible to use the temperature sensors on the detector heads themselves for the thermal control

Thermal Control Circuit Control

Thermal control is initiated by selecting one of the heaters and powering up the current supply.

The heater can then be run in closed loop with the temperature readout and a temperature set point or in open loop by applying a fixed current to the heater.



Thermal Control Circuit WE constraints

- Heater current supply stability requirements to be established by modelling of detector/cooler thermal response
- DRCU on board software will implement the thermal control algorithm - this algorithm is TBD

Thermal Control Circuit WE implementation

- The thermal control circuitry will be implemented in the DRCU
- The heater control circuits can be the same as those used for the calibrator heaters and based on the ISO LWS designs.
- The NTD thermistor read-out circuits (if implemented) can be based on designs for the Caltech/JPL test bolometer set up.
- If filled arrays are implemented the temperature monitors will appear as another detector channel

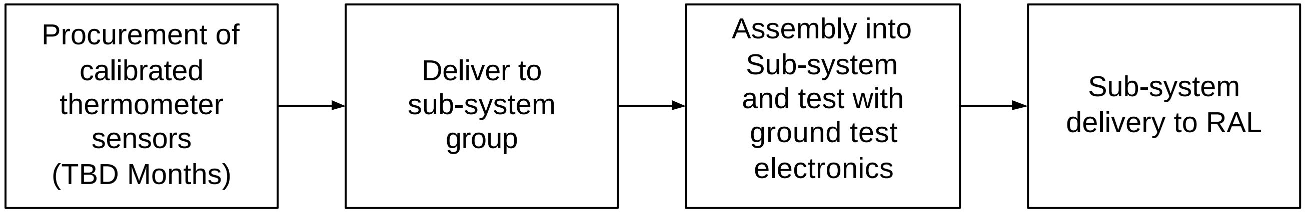
Model Definition

- EM/AVM
  - resistors to simulate a few temperature values
  - If thermal control is implemented then FPU simulator may need some intelligence to reflect thrmal control operation
- CQM
  - no redundant thermometers - commercial grade electronics and sensors (if different to flight).
  - Possible addition of extra sensors to be used for ground test only. These will be on a separate harness and use commercial electronics
  - Fully implemented thermal control circuit - including redundancy
- PFM/FS
  - all thermometers - flight grade sensors and electronics
  - Fully implemented thermal control circuit

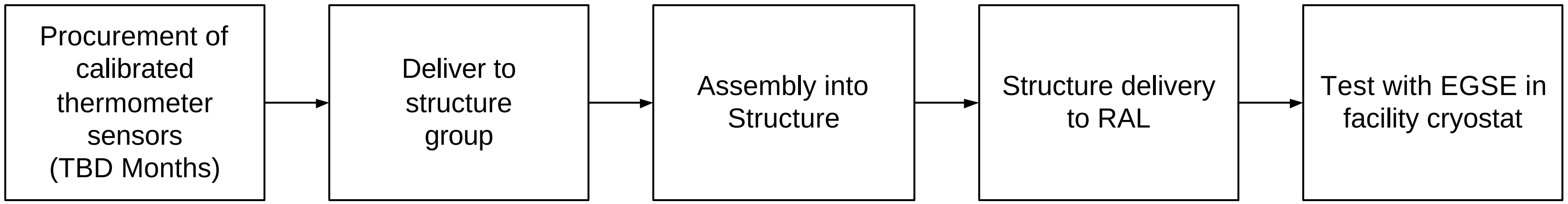
Cold Thermometer AIV Procedures

AIV is the same for CQM/PFM and FS

Thermometer AIV flow for all sub-systems except structure



Thermometer AIV flow for structure



Test Equipment

- All cold sub-systems will require ground test electronics to drive the thermometers - constant current source and voltage measurement.
- This could/should be implemented as part of the sub-system grond test electronics.
- The structure thermometer ground test electronics could be part of the facility cryostat electronics.
- Accurate resistors will be needed for the EM/AVM DRCU cold FPU simulator for electronics development and test. These will provide sample “temperatures” for each of the types of thermometer.
- The same equipment can be used for the other models of the DRCU.

Development Schedule

- Decision will be made by the Spring 2000 PDR on how the thermometers are to be procured and who will do it.
- Somewhere around 120 thermometers will be needed for whole of SPIRE programme. These are to be procured pre-calibrated if not too expensive.
- Possible suppliers are Oxford Instruments; Lakeshore…….
- Delivery times; costs and qualification status have yet to be investigated
- Decision will be made on the implementation of the thermal control circuit following cooler development model tests. This will be by the time of the DDR in Autumn 2000
- Thermometer electronics will be developed and built as part of the generic DRCU electronics