OCAMS Flight Software Engineering Dictionary

OSIRIS-REx DOCUMENT

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CM FORWARD

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Acronyms

BOD = Body Metal
FOH = Focus Housing
FOM = Focus Motor
FSW = Flight Software
FWH = Filter Wheel Housing
FWM = Filter Wheel Motor
LEN = Lens Assembly
PRI = Primary Mirror
RAD = Radiator Metal
S/C = Space craft
SEC = Secondary Mirror

1 Introduction

1.1 Document Purpose

This document is intended to be used as an engineering dictionary to define all of the housekeeeping channels and their conversion algorithms for the OCAMS instrument.

1.2 Applicable Documents

2 OCAMS Engineering

This section lists the housekeeping chanels for the OCAMS hardware.

2.1 OCAMS Engineering Channels

1	MapCam_FWM_Therm
2	MapCam_LEN_Therm
3	SamCam_FWM_Therm
4	SamCam_LEN_Therm
5	PolyCam_FOM_Therm
6	PolyCam_SEC_Therm
7	PolyCam_TBD_Therm
8	MapCam_ROE_Therm
9	SamCam_FWH_Therm
10	SamCam_ROE_Therm
11	MapCam_FWH_Therm
12	PolyCam_ROE_Therm
13	PolyCam_FOH_Therm
14	PolyCam_PRI_Therm
15	GND_A1
16	Htr_BRD_Temp
17	DPU_BRD_Temp
18	LVPS_BRD_Temp
19	Motor_BRD_Temp
20	Idet_n24
21	MapCam_Temp
22	SamCam_Temp
23	Idet_p24
24	Heater_Current
25	Motor_Current
26	Index_Lamp_Current
27	Cal_Lamp_Current
28	Primary_Voltage
29	PolyCam_Temp
30	m24V_MonB
31	m12V_Mon
32	p24V_Mon
33	p4_5V_Therm_Mon1

34	p4_5V_Therm_Mon2
35	p12V_Mon
36	p5V_Mon
37	p5V_Ref_Mon
38	GND_A2
39	Idet_p5

ROE = Read Out Electronics
LEN = Lens Assembly
FOH = Focus Housing
FWH = Filter Wheel Housing
MIR = Mirror
FOM = Focus Motor
FWM = Filter Wheel Motor

These channels can be read out by the FSW at 1 to 360 second intervals and then packetized into a Housekeeping Packet to be sent to the S/C and then downlinked.

2.2 OCAMS Housekeeping Conversions

The circuits in the OCAMS CCM transform the sensor readings to voltages at a 12-bit ADC, V_{adc}, ranging in values between GND (0V) and V_{ref}(+5V). This gives a digital housekeeping reading, H_x, between 0 and 4095 using the follow equation:

$$H_x = Round\left[4095 * \left(\frac{V_{adc}}{V_{ref}}\right)\right]$$

Equation 1

Since rounding only gives a half width bin to both the lowest and highest H_x values
$H_x = 0 \in [0,0.5)$, $H_x = 1 \in [0.5,1.5)$, …,
$H_x = 4095 \in [4094.5,4095]$
there are the equivalent of 4095 full width bins:

$$V_{adc} \approx V_{ref} * \frac{H}{4095} \approx 0 + \frac{\mathrm{V_{ref}}}{4095} * H$$

Equation 2

2.2.1 Thermistor Conversion

The raw thermistors values have a voltage divider (Rpull) and a separate thermistor voltage reference. Which are as follows:

R_{pull} = 5K
V_{therm} = +4.54545V

In the circuit, the raw thermistor resistance is converted in a voltage read by the A/D with the following equation:

$$V_{adc} = V_{therm}\left(\frac{R_{therm}}{R_{pull} + R_{therm}}\right)$$

Equation 3

Solving for R_{therm} gives:

$$R_{therm} = \frac{R_{pull} * V_{adc}}{V_{therm} - V_{adc}} = \frac{R_{pull} * H_{therm}}{4095 * \left(\frac{V_{therm}}{V_{ref}}\right) - H_{therm}}$$

Equation 4

The first step is to convert ADC measurement to an estimate of the Thermistors resistance. Thus the ideal conversion to resistance is:

$$R_{therm} = \frac{5000 * H_{therm}}{3722.7 - H_{therm}}$$

Equation 5

Next apply the following formula to estimate temperature:

$$T_{therm} = \frac{1}{A_0 + A_1 * ln(\mathrm{R}_{therm}) + A_3 * ln(\mathrm{R}_{therm})^3} - 273.15$$

Equation 6

Where:
ln() is the natural log function and, for the 44901 GSFC Space Qualified Thermistor,
A_0 = 0. 001467062557626247
A_1 = 0. 0002384344349699632
A_3 = 1.007709917088872 e-7

For Example when H_{therm} = 2048, the temperature is ~ +3.4 C.
See the Calibration section for measured coefficients.

2.2.2 Motor Current

The motor current is a single value that is the sum of all motor currents. (Current in a coil is summed as a positive value, regardless of current direction). Estimates of power dissipation in the motors is approximately the motor current value times the motor drive voltage, which is +24V, nominal.

The motor current scaling applied on the MTR board generates a backplane signal as follows:

$$V_{mik} = I_{mik} * \left(\frac{R2}{2}\right) * \left(\frac{R7}{1k}\right)$$

Equation 7

Where
R2 = 4.02Ω , R7 = 4.99KΩ, thus the gain = 10.0299 V/A

Thus

$$V_{mik} = I_{mik} * 10.0299\ \frac{V}{A}$$

Equation 8

Thus, if the sum of motor's currents is 300mA, the backplane voltage sent to the DPU will be +3.009 Volts. The conversion from measured A/D value (H_{mik}) to motor current in (I_{mik}) Amps is as follows

$$I_{mik}\ (Amps) = \left[\left(\frac{V_{ref}}{10.0299}\right) * \left(\frac{H_{mik}}{4095}\right)\right]$$

Equation 9

where V_{ref} = +5 Volts
See the Calibration section for measured coefficients.

2.2.3 Index Lamp Current

The scaling applied to the backplane position lamp current signals (VPI) is as follows:

$$V_{PI} = I_{pi} * \left(\frac{R219}{2}\right) * 1 * \left[1 + \left(\frac{R259}{R260}\right)\right]$$

Equation 10

Where, R219= 3Ω , R259 = 15KΩ, R260 = 1KΩ thus the gain = 24 V/A

For example, if there is one active position lamp circuit drawing a total of 120mA, the backplane voltage sent to the DPU will be +2.88 Volts (DC).

The conversion from measured A/D value (H_{pi}) to Position lamp current (I_{pi}) in Amps is as follows:

$$I_{pi} = \left[\left(\frac{V_{ref}}{24}\right) * \left(\frac{H_{pi}}{4095}\right)\right]$$

Equation 11

Where V_{ref} = +5 Volts
See the Calibration section for measured coefficients.

2.2.4 Calibration Lamp Current

The scaling applied to the calibration lamp current signals (VCI) is as follows:

$$V_{CI} = I_{lamp} * \left(\frac{R134}{2}\right) * \left(\frac{R139}{1k}\right)$$

Equation 12

Where, R134= 60.4Ω, R139 = 6.34KΩ, thus the gain = 191.468 V/A

For example, if there is one active calibration lamp circuit drawing 16mA, the backplane voltage sent to the DPU will be +3.06 Volts (DC).

The conversion from measured A/D value (H_{lamp}) to Position lamp current in Amps is as follows:

$$I_{lamp} = \left[\left(\frac{V_{ref}}{191.468}\right) * \left(\frac{H_{lamp}}{4095}\right)\right]$$

Equation 13

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.5 S/C Voltage Monitor

The scaling applied to the Spacecraft +28 Voltage (VSC) is as follows:

$$V_{ref} = V_{SC} * \left(\frac{R621}{R621 + R513 + R546}\right) * \left(\frac{R623}{R506}\right)$$

Equation 14

Where, R621 = 49.9KΩ, R513,546 = 10KΩ, R506 = 1MΩ, R623 = 200KΩ, thus the gain = 0.14278

For example, if 28 Volts is provided by the S/C, the backplane voltage sent to the DPU will be +4.00 Volts (DC).

The conversion from measured A/D value (H_{sc}) to S/C voltage (also heater voltage) in Volts is as follows:

$$V_{sc} = \left[\left(\frac{V_{ref}}{0.14278}\right) * \left(\frac{H_{sc}}{4095}\right)\right]$$

Equation 15

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.6 Heater Current

The heater current is a single value that is the sum of all heater currents. Estimates of power dissipation in the heaters is approximately the heater current value times the primary voltage, which is +27V, nominal.

The heater current scaling applied on the MTR board generates a backplane signal is as follows:

$$V_{hik} = I_{hik} * \left(\frac{R542}{4}\right) * \left(\frac{R625 + R503}{R502}\right) * \left(\frac{R505}{R509}\right) * \left(\frac{R508}{R511}\right)$$

Equation 16

Where R542= 1.1Ω, R502&R503 = 200kΩ, R625=5 kΩ, R505 = 12.4kΩ, R509 = 6.19kΩ, R508=5KΩ, R511=1KΩ
Thus the gain = 2.8233 V/A
The conversion from measured A/D value (H_{hik}) to Heater Current in Amps is as follows:

$$I_{hik} = \left[\left(\frac{V_{ref}}{2.8233}\right) * \left(\frac{H_{hik}}{4095}\right)\right]$$

Equation 17

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.6.1 Heater Current (EQM)

For the EQM, the only difference is in R509 which has a value of 6.20kΩ rather than 6.19kΩ, thus the gain = 2.81875 V/A

$$I_{totheat} = \left[\left(\frac{V_{ref}}{2.81875}\right) * \left(\frac{H_{heatcurr}}{4095}\right)\right]$$

Equation 18

Where V_{ref}= +5 Volts

2.2.6.2 Heater Current (EM)

For the EM units, the heater current is sensed on the low side using a diff amp. If we assume the differential ampflier is balanced (i.e. R122=R125, R1=R3 and R2=R4

$$V_{HI} = I_{totheat} * \left(\frac{R4}{4}\right) * \left(\frac{R2}{R122 + R1}\right) * \left(\frac{R5}{R9}\right) * \left(\frac{R8}{R11}\right)$$

Equation 19

Where R4= 1.1Ω, R1&R2 = 200kΩ, R122=5 kΩ, R5 = 12kΩ, R9 = 6.2kΩ, R8=5KΩ, R11=1KΩ
Thus the gain = 2.60 V/A
The conversion from measured A/D value ($H_{currvolt}$) to Heater Current in Amps is as follows:

$$I_{totheat} = \left[\left(\frac{V_{ref}}{2.60}\right) * \left(\frac{H_{heatcurr}}{4095}\right)\right]$$

Equation 20

Where V_{ref}= +5 Volts

2.2.7 CCD Temperature

The CCD temperature is measured using different sensors between the primary and redundant sides of the CCM. The CCM measurement circuitry is identical on both sides and was designed to support both sensor types. However, because of the different sensor characteristics, the conversion equations must be slightly different.

Computing the CCD temperature from the raw housekeeping value is a two step process. First, we use the following equations to convert the housekeeping value to an estimate of the sensor resistance.

$$V_i = (V_{adc} - V_2) * \left(\frac{R_{173}}{R_{173} + R_{167}}\right) + V_2 = V_{adc} * \left(\frac{R_{173}}{R_{173} + R_{167}}\right) + V_2 * \left(\frac{R_{167}}{R_{173} + R_{167}}\right)$$

Equation 21

And

$$R_{ccd} = \frac{R_{164} * \frac{V_i}{V_{therm}}}{1 - \frac{V_i}{V_{therm}}}$$

Equation 22

Where V_2 = 0.201557V, V_{therm} = 4.54545V, R_{164} = 5000Ω, R_{167} = 49900Ω, and R_{173} = 3920Ω.

After substitutions, the theoretical equation is:

$$R_{ccd} = \frac{R_{164} * (A * H_{ccd} + B)}{1 - (A * H_{ccd} + B)}$$

Equation 23

With

$$A = \left(\frac{1}{4095}\right) * \left(\frac{V_{ref}}{V_{therm}}\right) * \left(\frac{R_{173}}{R_{173} + R_{167}}\right) = 1.956e - 005$$

Equation 24

Where V_{ref}= +5 Volts. And

$$B = \left(\frac{V_2}{V_{therm}}\right) * \left(\frac{R_{167}}{R_{173} + R_{167}}\right) = 0.041113$$

Equation 25

Then the temperature is estimated from the calculated resistance with the following equation, where R_{0C} is the resistance of the sensor at 0C and Slope is the ohms per degree slope of the sensor.

$$T_{ccd} = \frac{R_{ccd} - R_{0C}}{Slope}$$

Equation 26

However, parts and circuits are not ideal, and it turns out that the measured conversions from ADC measurement to approximate sensor resistance are different for every CCD termperature channel on each CCM. See the Calibration section for measured coefficients.

2.2.7.1 Primary

This section covers the Primary side, which uses an integrated sensor within the CCD with the following characteristics:

Primary CCD Sensor: 325-345 Ohms at 0 C with approximately +1.3 Ohm/C slope

Coefficients for the FM CCDs are in the following table. They are derived from data collected in each CCD's Environmental and Characterization Test Report.

Flight CCD	R_{0C}	Slope
MapCam	326.6978205589	1.3313629162
SamCam	331.0751118373	1.3393694249
PolyCam	335.3621028386	1.3549217533

Coefficients for the EQM CCDs are in the following table. They are derived from data collected in each CCD's Environmental and Characterization Test Report.

EQM CCD	R_{0C}	Slope
MapCam	325.7520672004	1.3125082032
SamCam	334.6421545977	1.3202191564

PolyCam	322.3677866315	1.2688423083

2.2.7.2 Redundant

This section covers the redundant measure, which uses an separate sensor attached to the CCD with the following characteristics:

Goodrich 0118MF500: ~500 Ohms at 0C with 1.9-2.0 Ohm/K slope

The conversion from raw housekeeping value to measure resistance is identical to the primary side. See section 2.2.7 for that conversion.

Coefficients for the redundant side of the FM CCDs are in the following table. They are derived from data collected in each CCD's as run Thermal Vacuum Test Procedure from the EIDP.

Flight CCD	R_{0C}	Slope
MapCam	503.9276903762	1.9863664275
SamCam	498.9512431914	1.9956981407
PolyCam	503.150781437	2.0338843914

2.2.8 Positive Voltage Rail Conversions

All positive rail voltage measurements use a simple Resistive divider and produce the following conversion formulas. The different resistive values are tabulated below.

$$V_{ADC} = \left(\frac{R_B}{R_A + R_B}\right) * V_{rail} = V_{ref} * \left(\frac{H_{rail}}{4095}\right)$$

Equation 27

Where V_{rail} is the rail voltage and V_{ref}= +5 Volts

	R_A (ohms)	R_B (ohms)	Digital value (nom)
+5V_Mon	2,800	2,800	2048
+12V_Mon	10,000	2,800	2150
+4.5V1_Therm	2800	2,000	1536
+4.5V2_Therm	2800	2,000	1536
+24V_Mon	10,000	1,000	1787
+5V_Ref_Mon	5,000	5,000	2048

See the Calibration section for alternate coefficients.

2.2.9 Negative Voltage Rail Conversions

All negative rail voltage measurement uses a simple Resistive voltage divider followed by an inverter. This uses 3 resistors and produces the following conversion formula. The different resistive values are tabulated below.

$$V_{ADC} = \left(\frac{R_B \parallel R_C}{R_A + (R_B \parallel R_C)}\right) * \left(\frac{R_D}{R_C}\right) * (-V_{rail}) = V_{ref} * \left(\frac{H_{rail}}{4095}\right)$$

Equation 28

Where V_{rail} is the rail voltage and V_{ref}= +5 Volts

	R_A (ohms)	R_B (ohms)	R_C(ohms)	R_D(ohms)	Digital value (nom)
-12V_Mon	10,000	2,800	10,000	10,000	1764
-24V_Mon	10,000	1,000	10,000	10,000	1638

See the Calibration section for alternate coefficients.

2.2.10 Sum of Camera Current on +5V rail

This measurement samples the total current applied to the 3 camera +5V inputs.

$$VC5 = I_{cam5V} * \left(\frac{R136 * R137}{R136 + R137}\right) * \left(\frac{R141}{R139}\right) * \left(1 + \frac{R144}{R143}\right)$$

Equation 29

Where R136, R137= 0.1Ω, R141 = 13.7kΩ, R139=500Ω, R144 = 10kΩ, R143 = 8.06kΩ
Thus the gain = 3.07 V/A

The conversion from measured A/D value (H_{cam5V}) to Camera current in amps is as follows:

$$I_{cam5V} = \left[\frac{V_{ref}}{3.07} * \left(\frac{H_{cam5v}}{4095}\right)\right]$$

Equation 30

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.11 Sum of Camera Current on +24V rail

This measurement samples the total current applied to the 3 camera +24V inputs.

$$VCP24 = \mathrm{I}_{\mathrm{cam+24V}} * (R146) * \left(\frac{R151}{R149}\right) * \left(1 + \frac{R154}{R153}\right)$$

Equation 31

Where R146=0.2Ω, R151=5kΩ, R149=500Ω, R153 = 1kΩ, R154 = 8.06kΩ
Thus the gain = 18.12 V/A

The conversion from measured A/D value ($H_{cam+24V}$) to Camera current in amps is as follows:

$$\mathrm{I}_{\mathrm{cam+24V}} = \left[\frac{V_{ref}}{18.12} * \left(\frac{\mathrm{H}_{\mathrm{cam+24v}}}{4095}\right)\right]$$

Equation 32

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.12 Sum of Camera Current on -24V rail

This measurement samples the total current applied to the 3 camera -24V inputs.

$$VCN24 = \mathrm{I}_{\mathrm{cam-24V}} * (R156) * \left(\frac{R161}{R160}\right) * \left(\frac{R167}{R166 + R168}\right)$$

Equation 33

Where R156=0.2Ω, R161=5kΩ, R160=500Ω, R166=100Ω, R167=12.4kΩ, R168 = 2.15kΩ
Thus the gain = 11.022 V/A

The conversion from measured A/D value ($H_{cam-24V}$) to Camera current in amps is as follows:

$$\mathrm{I}_{\mathrm{cam-24V}} = 1 * \left[\frac{V_{ref}}{11.022} * \left(\frac{\mathrm{H}_{\mathrm{cam-24v}}}{4095}\right)\right]$$

Equation 34

Where V_{ref}= +5 Volts
See the Calibration section for measured coefficients.

2.2.13 TestPoints and ground

These have inputs tied to ground and should produce an output close to zero.

$$V_{gndtp} = V_{ref} * \left(\frac{H_{gndtp}}{4095}\right)$$

Equation 35

Where V_{ref}= +5 Volts
See the Calibration section for alternate coefficients

3 OCAMS Engineering Limits

Name	Check interval, persistance	Limit Action		Operational Yellow Limits		Operational Red Limits		Non-Op Red Limits	
		Low	High	Low	High	Low	High	Low	High
MapCam_FWM_Therm	1s, 5	Htr	Motor abort	-47C	+75C	-52C	+80C	-52C	+80C
MapCam_LEN_Therm	1s, 5	Htr	Htr off	-47C	+55C	-52C	+60C	-52C	+60C
SamCam_FWM_Therm	1s, 5	Htr	Motor abort	-47C	+75C	-52C	+80C	-52C	+80C
SamCam_LEN_Therm	1s, 5	Htr	Htr off	-47C	+55C	-52C	+60C	-52C	+60C
PolyCam_FOM_Therm	1s, 5	Htr	Motor abort	-47C	+75C	-52C	+80C	-52C	+80C
PolyCam_SEC_Therm	None	None	None	N/A	N/A	N/A	N/A	N/A	N/A
PolyCam_ TBD _Therm	None	None	None	N/A	N/A	N/A	N/A	N/A	N/A
MapCam_ROE_Therm	1s, 5	CCD Htr	CCD Htr & camera off	-35C	+50C	-42C	+55C	-52C	+65C
SamCam_FWH_Therm	1s, 5	Htr	Htr off	-42C	+50C	-52C	+60C	-52C	+60C
SamCam_ROE_Therm	1s, 5	CCD Htr	CCD Htr & camera off	-35C	+50C	-42C	+55C	-52C	+65C
MapCam_FWH_Therm	1s, 5	Htr	Htr off	-42C	+50C	-52C	+60C	-52C	+60C
PolyCam_ROE_Therm	1s, 5	CCD Htr	CCD Htr & camera off	-35C	+50C	-42C	+55C	-52C	+65C
PolyCam_FOH_Therm	1s, 5	Htr	Htr off	-42C	+50C	-52C	+60C	-52C	+60C
PolyCam_PRI_Therm	1s, 5	Htr	Htr off	-47C	+55C	-52C	+60C	-52C	+60C
GND_A1	None	None	None	0V	0.005V	0V	0.01V	N/A	N/A
Htr_BRD_Temp	1s, 5	None	Red Safe	-30C	+70C	-35C	+75C	N/A	N/A
DPU_BRD_Temp	1s, 5	None	Red Safe	-30C	+70C	-35C	+75C	N/A	N/A
LVPS_BRD_Temp	1s, 5	None	Red Safe	-30C	+70C	-35C	+75C	N/A	N/A
Motor_BRD_Temp	1s, 5	None	Red Safe	-30C	+70C	-35C	+75C	N/A	N/A
Idet_n24	50ms, 3	None	Red camera safe	N/A	214 ma	N/A	257 ma	N/A	N/A
MapCam_Temp	1s, 5	Htr	CCD Htr & camera off	-30C	+35C	-32C	+40C	-42C	+45C
SamCam_Temp	1s, 5	Htr	CCD Htr & camera off	-30C	+35C	-32C	+40C	-42C	+45C
Idet_p24	50ms, 3	None	Red camera safe	N/A	128 ma	N/A	154 ma	N/A	N/A
Heater_Current	50ms, 3	None	All htr off	N/A	505 ma	N/A	555 ma	N/A	N/A
Motor_Current	50ms, 3	None	Motor abort & fail	N/A	500 ma	N/A	500 ma	N/A	N/A
Index_Lamp_Current	50ms, 3	None	Motor abort & fail	N/A	135 ma	N/A	175 ma	N/A	N/A
Cal_Lamp_Current	50ms, 3	None	Lamp off	N/A	8 ma	N/A	10 ma	N/A	N/A
Primary_Voltage	None	None	None	24V	33V	22V	34V	N/A	N/A
PolyCam_Temp	1s, 5	Htr	CCD Htr & camera off	-30C	+35C	-32C	+40C	-42C	+45C
m24V_MonB	None	None	None	-25.2V	-23.5V	-26.4V	-23V	N/A	N/A

Name	Check interval, persistance	Limit Action		Operational Yellow Limits		Operational Red Limits		Non-Op Red Limits	
		Low	High	Low	High	Low	High	Low	High
m12V_Mon	None	None	None	-12.6V	-11.4V	-13.2V	-10.8V	N/A	N/A
p24V_Mon	None	None	None	23.5V	25.2V	23V	26.4V	N/A	N/A
p4_5V_Therm_Mon1	None	None	None	4.45V	4.65V	4.275V	4.725V	N/A	N/A
p4_5V_Therm_Mon2	None	None	None	4.45V	4.65V	4.275V	4.725V	N/A	N/A
p12V_Mon	None	None	None	11.4V	12.6V	10.8V	13.2V	N/A	N/A
p5V_Mon	None	None	None	4.9V	5.1V	4.75V	5.25V	N/A	N/A
p5V_Ref_Mon	None	None	None	4.95V	5.05V	4.75V	5.25V	N/A	N/A
GND_A2	None	None	None	0V	0.001V	0V	0.002V	N/A	N/A
Idet_p5	50ms, 3	None	Red camera safe	N/A	960 ma	N/A	1150ma	N/A	N/A

4 Calibration

Parts and circuits are not ideal, so an effort was undertaken to calibrate the housekeeping values returned for the thermistors and CCD temperature channels, the current monitors, and the S/C voltage monitor. Testing characterized the CCM housekeeping performance over temperature, and provide engineering conversion data that takes the CCM temperature and the S/C bus voltage into account. In the tables below, FM1 refers to the OCAMS Primary CCM and FM2 refers to the OCAMS Redundant CCM.

For the thermistors, the following equations to convert from ADC (H) value to thermistor resistance are used:

$$V_{adc} = A + B * H$$

From Equation 2

CCM	A	B
FM1	-4.332800E-04	1.221460E-03
FM2	-3.721960E-04	1.220920E-03

$$R_{therm} = \frac{R_{pull} * V_{adc}}{V_{therm} - V_{adc}}$$

From Equation 4

CCM, Thermistor	R_{pull}	V_{therm}
FM1, DPU	5000	4.54545
FM1, LVPS	5000	4.56000
FM1, others	5000	4.55020
FM2, DPU	5000	4.54545
FM2, LVPS	5000	4.54836
FM2, others	5000	4.54836

The CCD temperature channels were found to have a linear dependence on the DPU card temperature over the operational range of the CCM, so the following equations to convert from ADC (H) value to CCD temperature are used:

$$V_i = A + B * T_{DPU} + (C + D * T_{DPU}) * H_{CCD}$$

From Equation 21

$$R_{ccd} = \frac{R * V_i}{V_{therm} - V_i}$$

From Equation 22

$$T_{ccd} = \frac{R_{ccd} - R_{0C}}{Slope}$$

From Equation 26

Where A, B, C, and D are taken from the following table, T_{DPU} is the current DPU board temperature in Celcius, R=5000 and V_{therm}=4.5454545, and R_{0C} and Slope are taken from the Flight CCD tables in 2.2.7.1 and 2.2.7.2

CCM, CCD	A	B	C	D
FM1, MapCam	0.186890	-2.701220E-06	8.897210E-05	7.018930E-10
FM1, SamCam	0.186935	-1.541830E-06	8.896410E-05	1.035520E-09
FM1, PolyCam	0.186985	-1.978430E-06	8.898940E-05	3.151190E-10

FM2, MapCam	0.186868	-2.540420E-06	8.891030E-05	9.618650E-10
FM2, SamCam	0.186964	-5.214520E-07	8.889760E-05	1.947350E-09
FM2, PolyCam	0.186921	-1.605010E-06	8.892870E-05	6.995460E-10

For the current monitors, the Motor, Index Lamp, and Calibration Lamp conversions remain simple linear equations:

$$I\ (mA) = A + B * H$$

From Equations 9, 11, 13

CCM, Current	A	B
FM1, Motor	-0.37298	1.242960E-01
FM1, Index	-0.73974	5.105010E-02
FM1, CalLamp	-0.290019	6.449520E-03
FM2, Motor	-0.38027007	1.242099E-01
FM2, Index	-0.67460939	5.104598E-02
FM2, CalLamp	-0.289352	6.427780E-03

The DA current monitors on the +5V, +24V, and -24V rails were found to have their conversion coefficients from ADC reading (H) vary as a linear function of the LVPS board temperature as shown in the following equation.

$$I\ (mA) = A + B * T_{LVPS} + (C + D * T_{LVPS}) *$$

From Equations 30, 32, 34

Where A, B, C, and D are taken from the following table and T_{LVPS} is the current LVPS board temperature in Celcius.

CCM, Current	A	B	C	D
FM1, +5V rail	-0.203635	0	4.058697E-01	-2.988403E-05
FM1, +24V rail	-3.85935	-8.044750E-03	6.651824E-02	-2.033818E-06
FM1, -24V rail	-3.85935	-8.044750E-03	1.050580E-01	-2.520850E-05
FM2, +5V rail	-1.0012927	5.382530E-03	4.051890E-01	-2.796033E-05
FM2, +24V rail	-4.8329921	-4.090474E-03	6.640949E-02	-2.515610E-06
FM2, -24V rail	-7.6928807	-8.995052E-04	1.050898E-01	-2.710333E-05

The heater current was found to vary with Motor-Heater board temperature and the S/C voltage.

$$I_{HTR}(mA) = A + B * T_{MHTR} + (C + D * T_{MHTR}) * H_{HTR} + (E + F * T_{MHTR}) * H_{SC}$$

From Equation 17

Where A - F are taken from the following table, T_{MHTR} is the average of the current Motor and Heater board temperatures in Celcius, and H_{SC} is the ADC reading for the S/C voltage.

CCM	A	B	C	D	E	F
FM1	-8.37141	-3.98570E-02	4.29411E-01	-7.67726E-05	-2.98350E-03	-3.94774E-05
FM2	-8.57409	-5.51642E-02	4.29856E-01	-8.21478E-05	2.03688E-03	5.58536E-07

And finally, the S/C voltage monitor was found to still be a simple linear conversion:

$$V_{SC} = A + B * H_{SC}$$

From Equation 15

CCM	A	B
FM1	0.0242466	8.604870E-03
FM2	2.232130E-03	8.612550E-03

The remainder of the ADC conversions are to Volts, and since they could not be directly measured, are simple linear equations using the circuit components specified values :

$$V = A + B * H$$

From Equations 27, 28, 35

V	A	B
TestPt	0	1.221001E-03
Ground	0	1.221001E-03
+5V	0	2.442002E-03
+12V	0	5.581720E-03
+4.5V #1	0	2.930403E-03
+4.5V #2	0	2.930403E-03
+24V	0	1.343101E-02
+5V_Ref	0	2.442002E-03
-12V	0	-6.802728E-03
-24V	0	-1.465201E-02