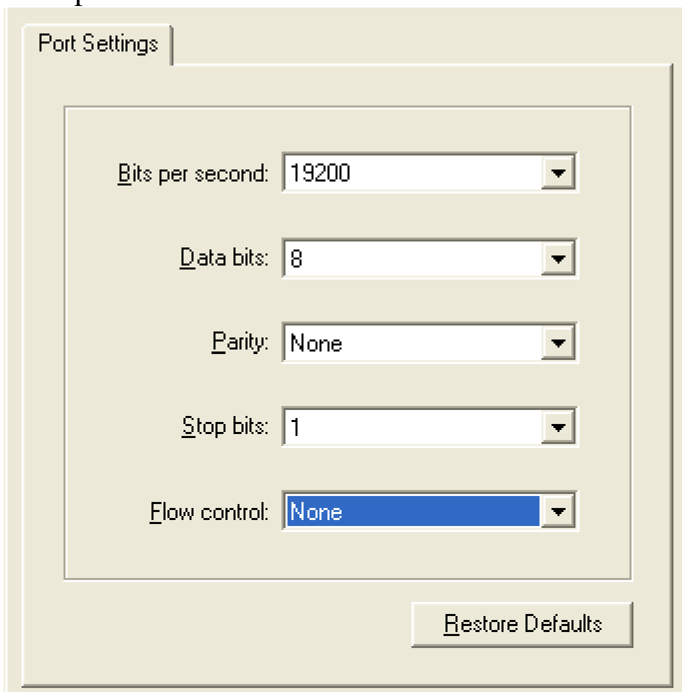
1 Serial Port (RS232) Protocol

The host or PC communicates to the system over an asynchronous RS232 interface. The asynchronous interface parameters are:

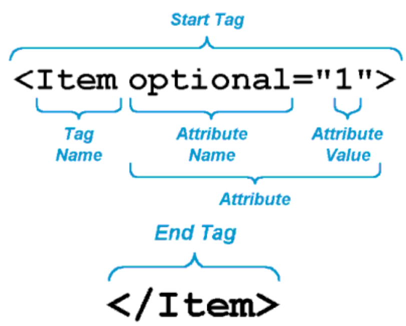


The asynchronous serial interface uses a query response XML protocol.

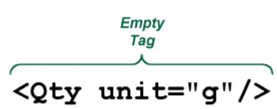
1.1 Extensible Markup Language (XML) Commands

The command types are query commands, those sent from the host or PC to the system, and response commands, those sent back from the system to the host or PC. There is a response for each query.

The commands are formatted using XML format. In the figure, there is a start tag, which begins an enclosed area of text, known as an Item, according to the tag name. As in HTML, tags may include a list of attributes (consisting of an attribute name and an attribute value.) The Item defined by the tag ends with the end tag. The text or command data is placed between the start and end tags. Each data value is separated by a white space or comma.



The commands that do not have corresponding data, use an empty XML tag. The empty tag may have attributes. The empty tag is shorthand for the start and end tags without inclosing text.



A typical query command would look like:

<TN OP=”GT” LC=”MS”/>

and its response:

<TN OP=”GT” LC=”MS”> 2FFF 5678 1 </TN>

The command tag names and valid attributes are defined in the Command section.

Attributes that are common between all commands are listed in the table.

mnemonic	**Name**	**description**	**value**	**mnemonic**
OP	operation	the operation to perform on the location	Get Set Clear Reset	GT ST CL RS
LC	location	the location		
IN	index	the index of the item at location		
DT	data type	the type of data sent.	hex integer pack char	HX WD
CS	checksum	checksum over the entire ASCII XML command	16 bit integer	hex data

The Get and Clear operations data field is empty on query messages. The Set and Clear operations data field is empty on response messages. These commands use the empty tags. Otherwise, the data field is filled with the data specified for each tag between the start and end tags.

The data type specifies the type of data in the data field. It is either:

- an ASCII representation of a hex integer or
- two packed ASCII characters into a word. The upper byte is the first character and the lower byte is the second character. The character string ABCD would be sent as two words ('A'<<8)|'B' and ('C'<<8)|'D'.

2 Command

The Command Module contains the methods that process messages received over the communications port. The commands are processed in three steps:

- the command is receive and copied over to the local XML tag.
- the command is processed by a module.
- the command response is posted.

When the posted response is read, the module is ready to accept a new command.

The command state machine the following states:

- null - the state machine is waiting.
- process commands - the state machine is processing a received command.
- post.response - the response to the command is ready.

The command task processes the XML tags described in the following sections.

2.1 System

The System (SY) tag gives access to the system constants using the Ok (OK), Get (GT), Set (ST), Reset (RS), and Clear (CL) operations.

Operation	Location		data order	data type
Ok				
Get	Status	ST	Program Reboot EEPROM Valid Flash Valid	Int Boolean Boolean
Get Set	Status	SU	Best Effort	Boolean
Get	Stack	SK	Stack available size	Int
Get	Communication	SC	Transmitter Error Receiver Error Transmitter Overflow Error Receiver Overflow Error Encoder Error Decoder Error	Int
Get	Program	PR	Version major number Version minor number Version build number Build date month Build date day Build date year Checksum	unsigned int
Get Set	EEPROM	EP	Same as in Program Set does not have checksum	unsigned int
Get Set	Serial Number	SY CL DW BP MD	System serial number Cooler serial number Dewar serial number Bypass serial number Model number	word[8]
Reset	EEPROM Flash	EP FL		
Clear	Program	PR		
Clear	Communication	SC	DSP SCI Error DSP SCI Error DSP SCI Error DSP SCI Error App Comm Error App Comm Error	Boolean Boolean Boolean Boolean Boolean Boolean

The Ok sends the Ok back. It is used to query if the DSP is operational. The Status (ST) data Program Reboot is a count of the number of times the DSP has been rebooted since the counter was cleared (CL). The Status (SU) selects if the DSP is operating in best effort mode (1) or normal no effort mode (0).

The EEPROM valid checks the checksum of the EEPROM and returns true (1) if it is ok. The Flash valid checks the checksum of the Flash and returns true (1) if it is ok. The EEPROM Reset resets the EEPROM constants to the factory defaults and generates the EEPROM checksum. The Flash Reset generates the Flash checksum. The EEPROM and Flash Reset command is only active while the system is in shutdown state.

The Clear (CL) operation resets the program reboot counter to one or the individual communication errors to zero.

The system status is queried by:

<SY OP=”GT” LC=”ST”/>

The response for a single program reboot and valid EEPROM and Flash is:

<SY OP=”GT” LC=”ST”> 1 1 1 </SY>

The program counter is cleared by:

<SY OP=”CL” LC=”PR”/>

The response for a single program reboot and valid EEPROM and Flash is:

<SY OP=”CL” LC=”PR”/>

2.2 Time

The Time (TM) tag gives access to the operating times using the Get (GT) and Clear (CL) operations.

Operation	**Location**		**data order**	**data type**
Get	Current Operating Time	CR	Days Hours Minutes Seconds	unsigned int
Clear	Current Operating Time	CR		
Get Set	Accumulated Operating Time	AC	System days System hours Cooler days Cooler hours	unsigned int
Clear	Accumulated Operating Time	AC	System Cooler	boolean

The Clear (CL) operation resets the current operating time or the accumulated operating times to zero. There are no data values for the current operating time. The accumulated operating time requires two integer data values where a 1 in the first location will clear the system and a one in the second location will clear the cooler. Else, the locations will not be cleared.

The accumulated run time is cleared by:

< TM OP=”CL” LC=”AC”> 1 1</TM >

The response is the same.

The current operation time is queried by:

< TM OP=”GT” LC=”CR”/>

The response for 16 hours, 5 minutes and 26 seconds is:

< TM OP=”GT” LC=”CR”> 10 5 1A </ TM>

2.3 Relays

The Relay (RL) tag gives access to the relays using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get Set	Status	ST	Fault On/Off Bypass On/Off Forced Bypass On/Off LNA Power On/Off	boolean
Get	Measurement	MS	Internal LNA Current External A LNA Current External B LNA Current	int
Get Set	Bounds	BN	Internal LNA minimum current Internal LNA maximum current External A LNA minimum current External A LNA maximum current External B LNA minimum current External B LNA maximum current	int

The Status data sets/resets with True(1)/False(0), else it does nothing. The Forced Bypass is toggled when there is a True (1) or False (0) value entered.

The Relay status is queried by:

< RL OP="GT" LC=" ST"/>

The response for the fault and bypass relays on and the forced bypass relay and LNA power off is:

< RL OP="GT" LC="ST"> 1 1 0 0 </ RL >

2.4 LEDs

The LED (LD) tag gives access to the LEDs using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get Set	Status	ST	Ready On/Off Fault On/Off	boolean
Get Set	Status	ST	Alarm On/Off	boolean

The LED commands are similar to the relay command.

2.5 Motor Drive

The Motor Drive (MD) tag gives access to the Motor Drive constants using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get Set	Status	ST	Frequency Table On/Off	boolean
Get Set	Setpoint	SP	Period Offset DSP Clock Frequency PWM duty	int
Get	Measurement	MS	Period count Duty cycle	int
Get Set	Bounds	BN	Motor minimum period Motor maximum period	int
Get Set	Coefficient	CF	Power Square Power Gain Power Offset Temperature Square Temperature Gain Temperature Offset	int

The DSP Clock frequency is accessible by Get only.

The frequency table in status turns on (1) or off (0) the frequency adjustment from the lookup table over motor power and ambient temperature as described in the section. The frequency minimization in status turns on (1) or off (0) the motor frequency minimization control loop. The coefficients are described in section.

The setpoints set the PWM period as described in the section. The offset is a signed 16 bit value that introduces a dc offset to the motor drive voltage. The DSP Clock frequency is in MHz and is scaled down by 2^{16}. It is used to calculate the PWM frequency from the PWM period.

The Motor Drive status is queried by:

< MD OP=”GT” LC=” ST”/>

The response for the frequency adjust off is:

< MD OP=”GT” LC=”ST”> 0 </ MD >

The frequency adjust is turned on with:

< MD OP=”ST” LC=”ST”> 1 </ MD >

2.6 Power

The Power (PW) tag gives access to the Power constants and measurements using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get	Status	ST	Loop is Regulating Power Loop is Active Power Duty at Limit Power Drive Foldback type	Boolean int
Get	Status	SU	Cooldown on Tamb/Trej Power Loop is enabled Power Drive is enabled Power Model is enabled Power Fault type	Boolean int
Get Set	Setpoint	SP	Motor Power Motor Duty cycle	int
Get	Measurement	MS	Motor Power (real) Motor Voltage (real) Motor Current (real) Input Voltage PWM Gain Motor Current (real peak) Motor Current (imaginary peak) Motor Voltage (real peak) Motor Power Setpoint Voltage Feedforward Ratio	int
Get Set	Calibration	CL	Motor voltage gain Motor voltage offset Motor current gain Motor current offset Motor phase gain Motor phase offset	int
Get Set	Coefficient	CF	Input new coefficient Input new shift Input old coefficient Input old shift	int
Get Set	Bounds	BN	Motor minimum power Motor maximum power Minimum input voltage Maximum input voltage Motor minimum impedance Motor maximum impedance Power loop negative error limit	int

			Power loop positive error limit	
Get Set	Bounds	BM	Motor current maximum limit PWM Duty maximum limit	int
Get Set	Limit	LM	Trej Temperature Gain Trej Temperature Offset Minimum Rejection Temperature Maximum Rejection Temperature Input Voltage Gain Input Voltage Offset Minimum Input Voltage Maximum Input Voltage	int
Get Set	Limit	LN	Phase Gain Phase Offset	int
Get Set	Limit	LO	Tamb Temperature Gain Tamb Temperature Offset	int
Get Set	Cooldown Table	CT	Second Order Trej Gain First Order Trej Gain Second Order Tcsw Gain First Order Tcsw Gain Power Constant	int

The status gets if the power loop is regulating (1) or not (0) and if the power duty has exceeded the maximum limit (1). The power drive foldback types are:

- Cooldown Table 0
- Trej Foldback 1
- Tamb Foldback 2
- Vin Foldback 3
- Phase Foldback 5

The status (SU) sets the cooldown using Tamb (0) or Trej (1). The remaining selections should be set to –1 so as not to change their status.

The setpoint gets or set the current motor power. The motor power can only be set while the temperature loop is disabled and the state is not in shutdown state. The motor power conversion is in Power (Pm) section. The motor duty is not setable using this tag.

The measurements get the measured ADC values. The conversions for the values are in the following sections:

- Power in Power (Pm) section.
- Voltage in Input Voltage (Vin) section. The conversion for motor Vrms is the same as for the input voltage.
- Current in Motor Current (Imot) section.

The PWM Gain is the drive level to the PWM section where 2^{15} is maximum PWM drive and 0 is minimum. The Voltage Feedforward ratio is the Power control loop feedforward ratio where 2^{14} is unity. The real and imaginary peak currents are referenced to the PWM voltage waveform and are the equivalent sinewave peak value at the fundamental frequency.

The calibration calibrates the motor voltage and current measurements and is described in the section. The limit is an upper bounds on the motor drive power with respect to motor rejection temperature and is described in the section.

The power bounds define the upper and lower limits of power to the motor. The lower limit is the idle current used at state initial. The motor drive power will limit at the maximum power in initial state. It will be limited by the less of the maximum power bounds; the motor temperature rejection, input voltage, or motor phase foldback limit; and the cooldown table limit in all other states. The input voltage range is used to detect an input voltage fault during state regulation. The power loop error limits are scaled by the power shifted down by 16 bits.

2.7 Temperature

The Temperature (TP) tag gives access to the Temperature constants and measurements using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get	Status	ST	Temperature Loop is regulating Narrow range temperature is out of bounds Wide range temperature is out of bounds Rejection temperature is out of bounds Ambient temperature is out of bounds	boolean
Get Set	StatUs	SU	Temperature Loop is enabled. Temperature loop mode of operation TemperatureLoopIsRegulatingTight Tcsn is within range Tcsw is within range Trej is within range Tamb is within range Tcsw Backup sensor is enabled Tcsn is too cold Tcsw is too warm	Boolean Int Boolean Boolean Boolean Boolean Boolean Boolean Boolean Boolean
Get Set	Setpoint	SP	Cold stage narrow range temperature	Int
Get	Measurement	MS	Cold stage narrow range temperature Cold stage wide range temperature in use Motor rejection temperature Ambient temperature Cold stage narrow temperature setpoint Cold stage wide range temperature primary Cold stage wide range temperature backup	int
Get	Loop	LP	Loop remainder Loop error Loop accumulator lower Loop accumulator lower middle Loop accumulator upper middle Loop accumulator upper	int
Get Set	Coefficient	CF	Input upper coefficient Input upper shift Input lower coefficient Input lower shift	int
Get Set	Bounds	BN	Narrow range minimum temperature Narrow range maximum temperature Wide range minimum temperature	int

			Wide range maximum temperature Motor rejection minimum temperature Motor rejection maximum temperature Ambient minimum temperature Ambient maximum temperature Temperature loop error limit	
Get Set	Bounds	BM	Wide range temperature too Warm	int
Get Set	State	SM	Mode State	int

The temperature status reports if the temperature loop is regulation (1) or the temperatures are out of bounds (1).
The temperature status (SU) reports if the temperature loop is enabled (1). The temperature loop mode can be set to regulating on:

- Tcsn 0
- Tcsw 1
- Open 2

The setpoint is the temperature the cold stage is regulated to. The conversion factor is described in Narrow Range Cold Stage Temperature (Tcsn) section.

The measurements get the measured ADC values. The conversions for the values are in the following sections:

- Cold stage narrow range temperature in Narrow Range Cold Stage Temperature (Tcsn) section.
- Cold stage wide range temperature in Wide Range Cold Stage Temperature (Tcsw) section.
- Motor rejection temperature in Motor Heat Rejection Temperature (Trej) section.
- Ambient temperature in Ambient Temperature (Tamb) section.

The PWM Gain is the drive level to the PWM section where 2^{15} is maximum PWM drive and 0 is minimum.

The bounds are used in the temperature state machine logic to trip a fault as described in section. The temperature loop limits are scaled by the negative of the cold stage narrow range temperature gain.

The states and modes are described in section. These commands report back minor version 2 states only for backward compatability, whereas Sequence reports the new additional fault states. The additional fault state report back as bypass state.

2.8 Sequence

The Sequence (SQ) tag gives access to the sequencer state machine constants and measurements using the Get (GT) and Set (ST) operations.

Operation	Location		data order	data type
Get Set	StaTus	ST	Fault detection is enabled.	boolean
Get Set	State	SM	Mode State	int

The state status reports if the fault detection is enabled (1) or disabled (1).

The states and modes are described in the section.

2.9 Fault

The Fault (FL) tag gives access to the fault records using the Get (GT) and Clear (CL) operations.

Operation	Location		data order	data type
Get	Status	ST	Motor power regulation	boolean
Clear			Wide range	boolean
			Motor rejection	boolean
			Temperature regulation	boolean
			LNA current	boolean
			Input voltage	boolean
			Duty cycle	boolean
			Active fault	unsign int
			Ambient Temperature	boolean
Get	Motor power regulation (first)	PM	Fault Type	unsign int
	Motor power regulation (recent)	PN	Operating State	unsign int
	Wide range temperature (first)	TW	Fault Count	unsign int
	Wide range temperature (recent)	TX	Runtime days	unsign int
	Motor rejection (first)	TR	Runtime hours	unsign int
	Motor rejection (recent)	TS	Runtime seconds	unsign int
	Temperature regulation (first)	TN	System days	unsign int
	Temperature regulation (recent)	TO	System hours	unsign int
	LNA current (first)	IL	Ambient temperature	int
	LNA current (recent)	IM	Motor rejection temperat	int
	Input voltage (first)	VI	Wide range temperature	int
	Input voltage (recent)	VJ	Narrow range temperature	int
	Duty Cycle (first)	DT	Input voltage	int
	Duty Cycle (recent)	DS	Motor voltage	int
	Wide range temperature (first)	TA	Motor current	int
	Wide range temperature (recent)	TB	LNA current	int

The Clear command does not clear the Active Fault, only the Boolean variables.
The valid data is as defined in the fault record section.

There is two fault records stored for each type: the first occurrence and the most recent occurrence. The status returns true if there is a fault record for that fault record type. The active fault in status is the number of the active fault. The active fault codes are:

code	Fault type
0x00	Trej OutOfRange
0x01	Tamb OutOfRange
0x02	Internal LNA Current OutOfRange
0x12	External A LNA Current OutOfRange
0x22	External B LNA Current OutOfRange
0x03	Vin OutOfRange
0x04	Tcsw OutOfRange
0x14	Tcsw too warm
0x05	Duty OutOfRange
0x06	Tcsn NotRegulating
0x07	Pmx NotRegulating
0x17	Impedance out of range
0x27	Motor current not regulating

There can be a first and most recent fault record. Clear clears both the first and most recent faults.

3 Formulas

The formulas to convert between standard units and ADC units for the variables and constants used by the commands is described below. The formulas convert from standard units to voltages read by the ADC. The conversion from voltages to ADC counts is:

$$ADCounts = \frac{2^{15}}{5} \cdot Voltage$$

3.1 Motor AC Frequency

The PWM period (Tpwm) determines the motor frequency (Fmot). Tpwm is inversely proportional to Fmot. It is dependent on the CPU frequency (Fcpu).

$$Tpwm = \frac{Fcpu}{(2 * Rpwm * Fmot)}$$

Rpwm is the resolution of the PWM sinewaveform and is currently 256. The period that is loaded to the DSP is Tpwm-1.

The spreadsheet calculates Tpwm for a given motor frequency.

Motor Frequency

CPU Frequency (MHz)	Motor Frequency (Hz)	PWM Period (-)
40	60	1302

3.2 Motor Heat Rejection Temperature (Trej)

The Motor Heat Reject temperature circuitry uses a YSI type 44017 thermistor as part of a voltage divider network.

The Steinhart and Hart equation is an empirical expression used for converting the thermistor resistance into temperature. It's inverse is.

$$= \frac{a - \frac{1}{T}}{c}$$

$$= \sqrt{\left(\frac{b}{3c}\right)^{3} + \frac{{}^{2}}{4}}$$

$$R = \exp\left(\left(- \frac{}{2}\right)^{1/3} - \left(+ \frac{}{2}\right)^{1/3}\right)$$

where for the YSI type 44017 Thermistor:

$$a = 0.0012474 \quad b = 0.000235 \quad c = 9.466E-08$$

The temperature is in degrees Kelvin.

The voltage that will be presented to the ADC, using the voltage divider rule, is:

$$R_x = \frac{R * 20K}{R + 20K}$$

$$V_T = \frac{5V * R_x}{R_x + 4.99K}$$

The Trej spreadsheet calculates the ADC voltage for a given Trej.

Motor Rejection Temperature Conversion

a	b	c	Kadc (Vadc/V)
0	0	0	6553.6

Trej (oC)	Trej (oK)	alpha (-)	beta (-)	R (ohm)	Rx (ohm)	Vt (V)	Vadc (-)
-40	233.15	-32132.73	28719.53	200804	18188	3.924	25713
-35	238.15	-31181.43	28456.17	144939	17575	3.894	25522
-30	243.15	-30269.25	28208.87	105768	16820	3.856	25271
-25	248.15	-29393.84	27976.47	77992	15918	3.807	24947
-20	253.15	-28553	27757.91	58086	14877	3.744	24538
-15	258.15	-27744.74	27552.24	43674	13718	3.666	24028
-10	263.15	-26967.19	27358.55	33137	12472	3.571	23404
-5	268.15	-26218.64	27176.04	25362	11182	3.457	22657
0	273.15	-25497.49	27003.96	19573	9892	3.323	21781
5	278.15	-24802.27	26841.6	15226	8645	3.170	20776
10	283.15	-24131.6	26688.32	11935	7474	2.998	19650
15	288.15	-23484.2	26543.55	9424	6405	2.811	18419
20	293.15	-22858.89	26406.73	7493	5451	2.610	17107
25	298.15	-22254.56	26277.36	5998	4614	2.402	15743
30	303.15	-21670.16	26154.96	4832	3892	2.191	14358
35	308.15	-21104.72	26039.11	3917	3275	1.981	12985
40	313.15	-20557.34	25929.41	3194	2754	1.778	11654
45	318.15	-20027.17	25825.47	2619	2316	1.585	10388

3.3 Ambient Temperature (Tamb)

The ambient temperature is measured with an LM335AZ Precision Temperature Sensor. The sensor transfer function is:

$$Vadc = \frac{10\,mV}{K}$$

The sensor is specified to operate between –15C (258.15K) to +65C (338.15K).

Ambient Temperature Conversion

gain (V/oK)	Kadc (Vadc/V)
0.01	6553.6

Tamb (oC)	(oK)	V (Vdc)	Vadc (bits)
-25	248.15	2.482	16263
25	298.15	2.982	19540
85	358.15	3.582	23472

3.4 LNA Current (Ilna)

The circuitry that measures the LNA supply current uses a differential op-amp configuration to measure the voltage drop across a 10Ω precision resistor. The transfer function is:

$$Vadc = 10 \cdot I_{LNA}$$

LNA Current Conversion

gain (ohm)	Kadc (Vadc/V)
10	6553.6

I (mA)	V (Vdc)	Vadc (bits)
125	1.250	8192
60	0.600	3932
40	0.400	2621

3.5 Motor Current (Imot)

The Imot calculation is in Irms. The transfer function from the motor current measurement circuitry is:

$$Vadc = \frac{0.1\mathrm{V}}{A} * Irms$$

Motor Current Conversion

gain (ohm)		Kadc (Vadc/V)
0.1		6553.6

I (A)	V (Vdc)	Vadc (bits)
1.5	0.150	983
3	0.300	1966
5	0.500	3277

3.6 Input Voltage (Vin)

The input voltage to the system is measured by a differential amplifier whose transfer function is:

$$Vadc = \frac{75\,mV}{V} \cdot Vin$$

Input Voltage Conversion

gain (ohm)		Kadc (Vadc/V)
0.08	491.52	6553.6

Vin (Vdc)	V (Vdc)	Vadc (bits)
43.2	3.240	21234
48	3.600	23593
52.8	3.960	25952

3.7 Power (Pm)

The power into the motor is the motor current times the voltage. The voltage is derived from the input voltage times the PWM duty cycle. The power units in the DSP is the square root of the measured power.

Motor Drive Power

power gain (V^2/W)	Kadc (Vadc/V)
0.01	6553.6

power (W)	power (V^2)	power (adc^2)	sqrt(power) (adc)
0	0	0	0
10	0.08	3221225	1795
30	0.23	9663676	3109
50	0.38	16106127	4013
70	0.53	22548578	4749
90	0.68	28991029	5384

3.8 Wide Range Cold Stage Temperature (Tcsw)

The analog, wide-range temperature sensor circuitry was designed to cover an input range of temperatures from 360K to 65K, over 0.2V to 4.8V output range. The temperature to voltage is approximated by a first order fit where:

$$V_{\mathrm{adc}} = (-15.59 \cdot 10^{-3} V/K) * T_{CSW_K} + 5.814\mathrm{V}$$

Wide Range Cold Stage Temperature C

slope	offset	Kadc
(V/oK)	(V)	(Vadc/V)
-0.02	5.81	6553.6

Tcsw		V	Vadc
(oC)	(oK)	(Vdc)	(bits)
-203.15	70	4.723	30951
-193.15	80	4.567	29929
84.85	358	0.233	1526

3.9 Narrow Range Cold Stage Temperature (Tcsn)

The analog, wide-range temperature sensor circuitry was designed to cover an input range of temperatures from 83K to 73K, over 0.2V to 4.8V output range. The temperature to voltage is approximated by a first order fit where:

$$V_{\mathrm{adc}} = (-0.46\, V/K) * T_{CSW_K} + 38.38\, V$$

Narrow Range Cold Stage Temperature

slope	offset	Kadc	slope
(V/oK)	(V)	(Vadc/V)	(Vadc/oK)
-0.46	38.38	6553.6	-3015

Tcsw		V	Vadc
(oC)	(oK)	(Vdc)	(bits)
	0.1		-302
-191	82	0.660	4325
-194	79	2.040	13369
-195	78	2.500	16384
-196	77	2.960	19399
-199	74	4.340	28443