

Logger model MS9

8-Channel neural logger

Featuring 8 differential-input neural channels
and 4 high-resolution thermometry channels

Supplemental instructions and
Information for this Logger Model

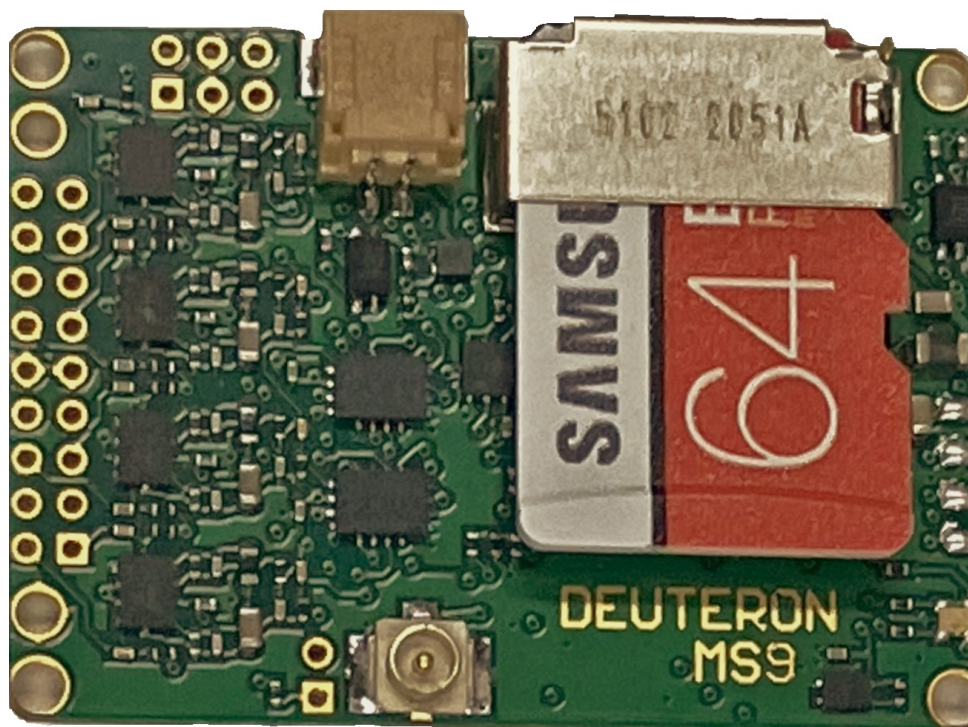


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1 Introduction

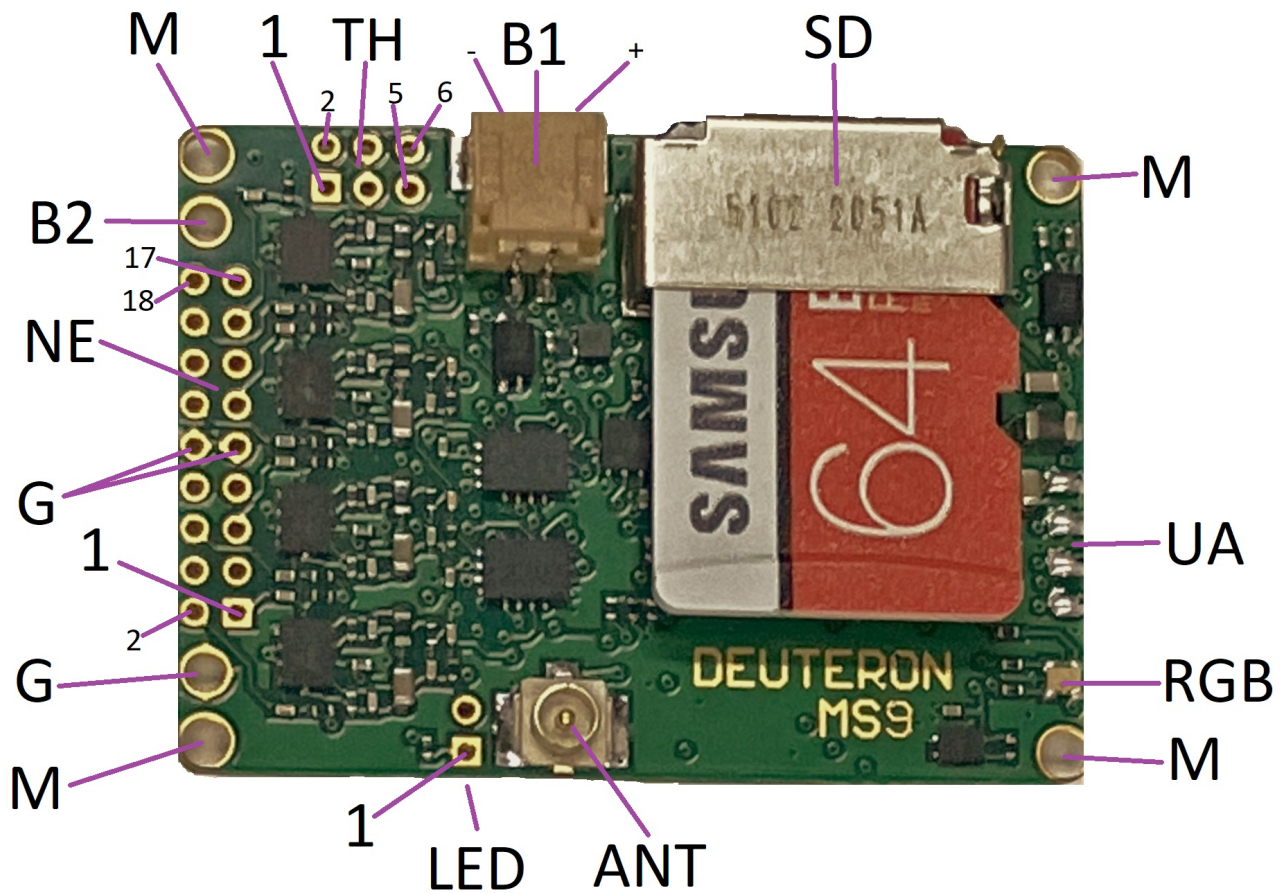
This document is intended to cover all aspects of the MS9 logger that are different to Deuteron Technology's loggers for general use. The MS9 differs from general-use loggers, such as the MS4 or MS5 16 channel loggers, in the following main ways:

- ❑ It has just 8 neural channels. Deuteron's other loggers have 16,32,64 or 128 neural channels
- ❑ Its neural channels have differential inputs
- ❑ It uses a low-noise wide-range preamplifier that is not based on the Intan preamplifier chips
- ❑ It provides the ability to record data from four thermometry channels.
- ❑ It provides a connection for an external tracking LED

For information about features that are common to many other Deuteron neural loggers, see the relevant documentation available on Deuteron's website.

2 Connections

2.1 Connection Diagram



2.2 Key to connection diagram

Annotation	Function	Details
ANT	Antenna for radio link	U.FL connector
B1	Battery connector	JST connector
B2	Alternative battery positive connector mounting location	1.2mm diameter hole
G	Ground	Includes 1.2mm hole for use with B2
LED	Connector for external LED	
M	Mounting hole, not electrically connected	1.4mm hole. Max screw head or spacer diameter is 2mm
NE	Neural input connector, 9 x 2 on 1.27mm pitch	For Mill-max connectors
RGB	Tri-color LED	
SD	Socket for MicroSD memory card	
TH	Connector for thermistors	For Mill-Max connectors
UA	Connection for serial communication option (UART) On the underside of the board at this location are connections for initial programming and debugging.	Pads for soldering. Future optional feature. Do not make connections to these pads
<Numbers>, +,-	Pin numbers of connectors	

2.3 Making connections to the board

Antenna: A whip antenna should be connected here with a U.FL snap-on plug. The ideal length for the antenna is 82mm, but in small arenas, a shorter antenna can be used

Battery. A lithium-polymer battery with a nominal voltage of 3.7 should be connected with a suitable connector. The connector on the board is JST part SM02B-SRSS-TB(LF)(SN). A pre-wired matching connector is part number A02SR02SR30K305B. Note the battery polarity. Some batteries are supplied with a compatible 1mm-pitch connector but unfortunately there is no standard for the polarity, so this must be checked. If a battery is connected with reverse polarity, the logger will not operate but it will also not be damaged. An alternative battery connection can be made by way of the pad marked B2.

Neural inputs. Normally, the logger will be supplied with a right-angle female connector. Note that the central two pins are ground. Differential pairs are pins that are opposite each other, for example pins 1 and 2 form a differential pair.

Thermistor inputs

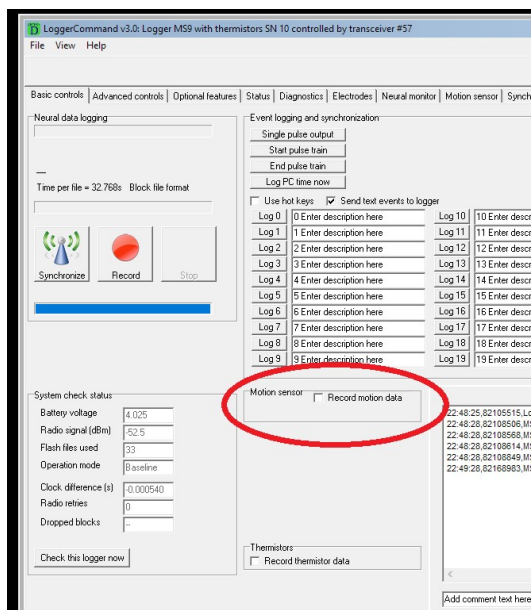
The four thermistor inputs are on pins 1,2,5 and 6 of the thermistor connector. The other end of each thermistor should be tied to ground. Pins 3 and 4 of that connector are ground.

External LED

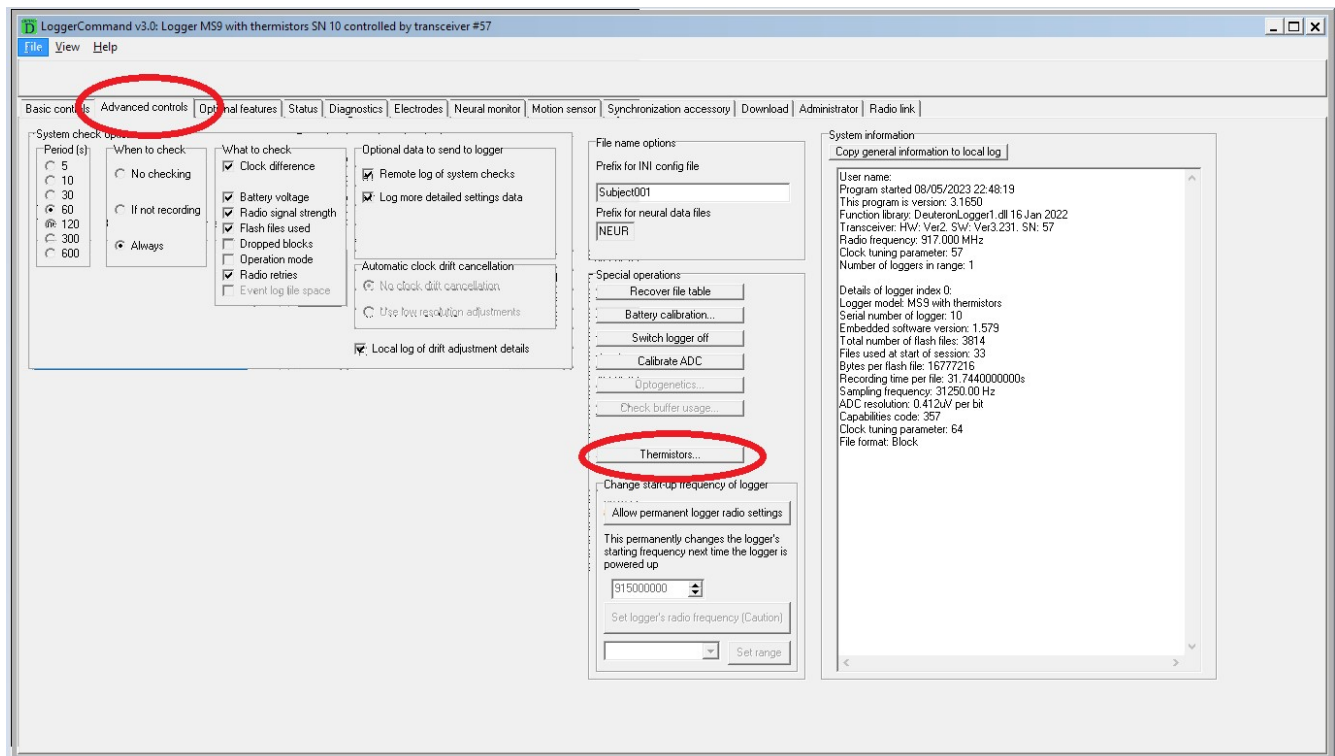
An external LED can be connected to the location shown. The positive (anode) of the external LED should be connected to pin 2, and this is at a constant 3 Volts above ground. Take care not to short this pin to ground, the logger will stop working under that condition. Pin 1 of that connector needs to be connected to the negative (cathode) of the external LED. This pin is connected via a 1k Ω resistor to a digital line that goes to zero volts when the LED is to be turned on. Thus the current in the external LED will be about 1mA for a red LED. The voltage requirement of many blue or white LEDs is too high for use with this drive. The external LED shares its control signal with the red LED within the tri-color LED. To control the external LED, use the controls provided by the LoggerCommand program for the red LED.

3 Special software for support of the thermistors

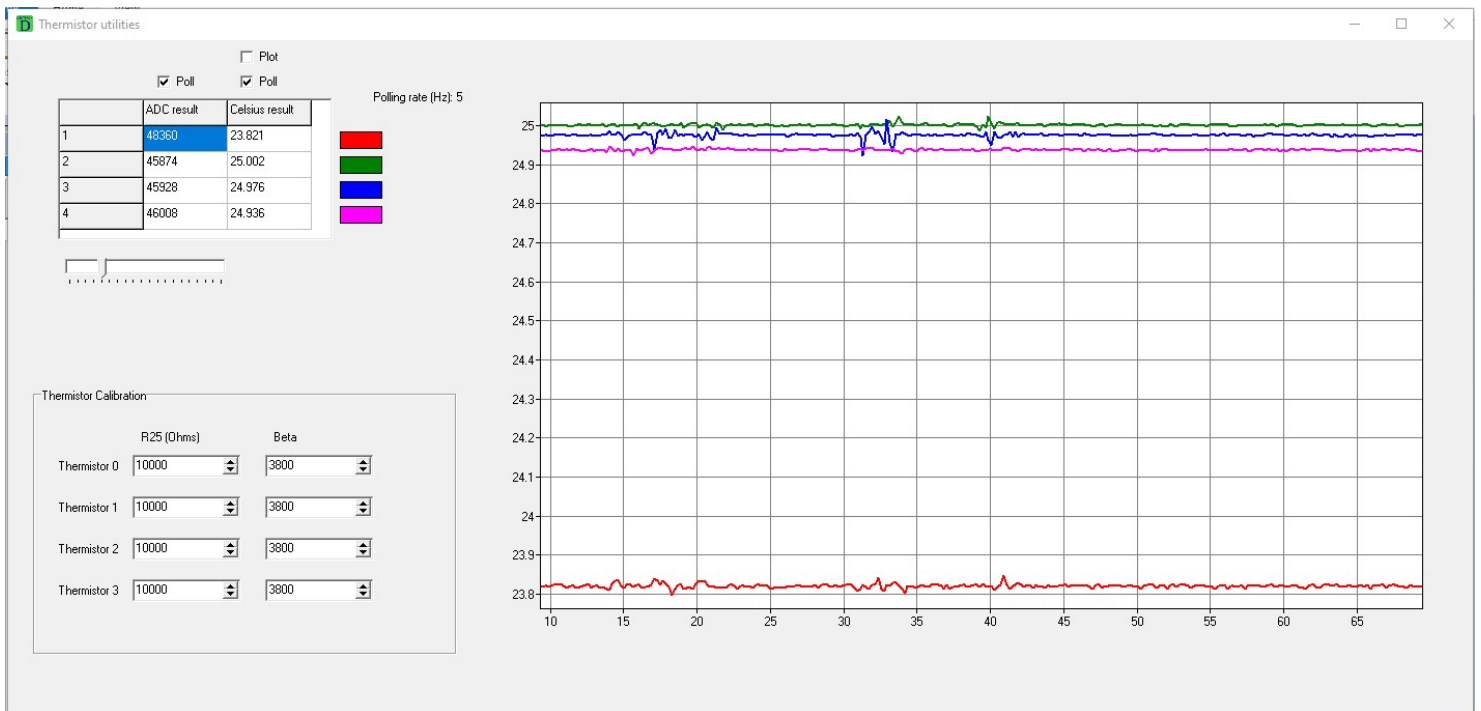
To record thermistor data alongside neural data, ensure that the checkbox that enables this (see picture) is checked. It is not checked by default, but it can be enabled by checking this checkbox manually or by loading a configuration file that includes this option.



To access all the functions that allow you to set up, check and calibrate the thermistors, press the "Thermistors..." special option button located on the "Advanced controls" tab (second tab from left) of the LoggerCommand program.



When the “Thermistors...” button is pressed, a new window of thermistor utilities will open, which will look like this:



To set up the thermistors, use the fields in the “Thermistor Calibration area” to enter the beta of each thermistor, and its nominal resistance for 25 Celsius. You can then plot the measured temperature of each sensor by checking the “poll” and “plot” checkboxes.

Note that changing the entries in the thermistor calibration area results in the values being stored permanently in the flash memory of the logger. The new value is saved to memory as soon as one clicks the computer’s mouse on any area other than the number being changed, or as soon as <Enter> is pressed on the computer keyboard.

3.1.1 Using Thermistors without calibration

In many cases, if one enters the R25 and beta values provided by the thermistor manufacturer, temperature measurements can be made with satisfactory accuracy. The total overall error can be calculated from the stated tolerance of the thermistor’s parameter, as well as the uncalibrated error of the logger. The maximum uncalibrated resistance error of the logger is 1%, but is typically 0.2%.

3.1.2 Single point calibration

A single point calibration will typically provide excellent accuracy at temperatures close to the calibration temperature.

To perform a single-point calibration of the thermistors, immerse the thermistor in a fluid of accurately known temperature, and adjust the R25 value in order to get a Celsius result of the known temperature.

3.1.3 Two-point calibration

For a simple way to perform a two-point calibration, immerse the thermistor in a fluid set to exactly 25 Celsius. Adjust the R25 value until the reading is 25 Celsius. Now immerse the thermistors in a fluid at a different known temperature, and adjust the beta until the measured temperature matches the known temperature. It is also possible to perform two-point calibration using any two known temperatures, by calculating R25 and beta from the two measurements. There is almost never a need to perform calibrations at more than two points, since only two calibration parameters can be set.

4 Using the Neural Inputs

The majority of Deuteron's wireless neural loggers use Intan preamplifier ICs. These provide a fixed input range of 10mV p-p, and have a typical input noise of 2.4 μ V rms for a 6kHz bandwidth. The MS9 logger uses preamplifiers made from discrete operational amplifiers. Since the properties of the discrete amplifier are different from those of the Intan amplifiers, these are detailed in this section.

In this document, the preamplifier inputs are called neural inputs. While these are most often used for signals from electrodes inserted into the brain, they can be used for any other source of low-voltage signals, such as EMG, EEG, EKG, or LFP studies.

4.1 Input Connector

The pin-out of the input connector is as follows.

Pin number	Function
1	Channel 0, positive
2	Channel 0, negative
3	Channel 1, positive
4	Channel 1, negative
5	Channel 2, positive
6	Channel 2, negative
7	Channel 3, positive
8	Channel 3, negative
9	Ground
10	Ground
11	Channel 4, positive
12	Channel 4, negative
13	Channel 5, positive
14	Channel 5, negative
15	Channel 6, positive
16	Channel 6, negative
17	Channel 7, positive
18	Channel 7, negative

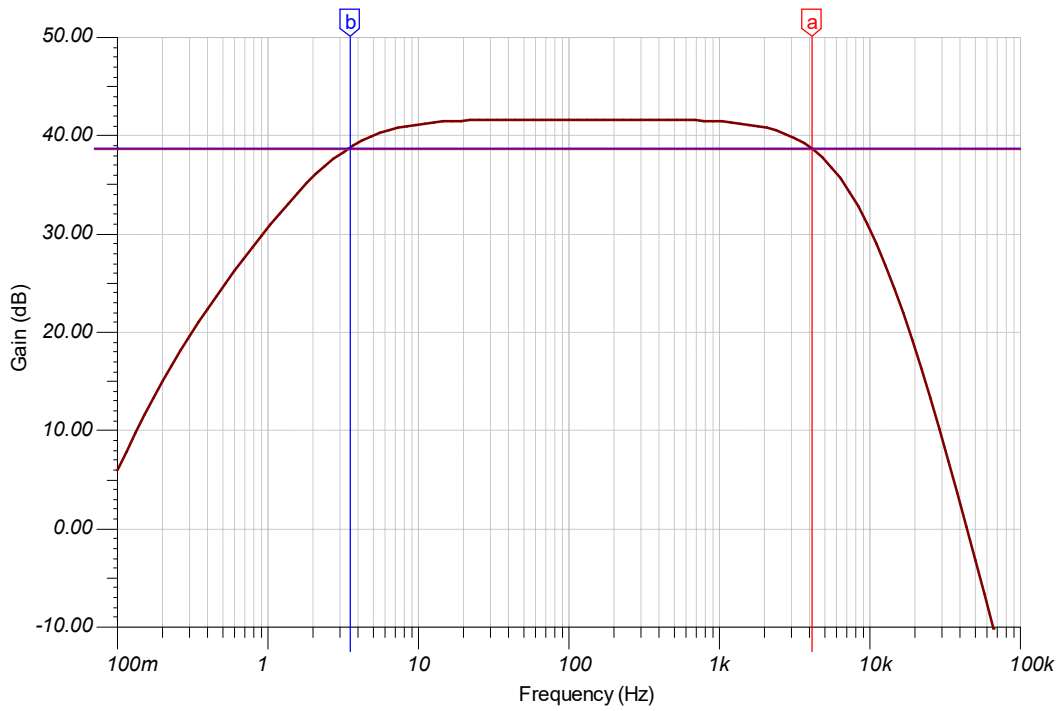
4.2 Analog Characteristics

The full-scale range and the bandwidth of the preamplifier can be specified by the customer. The first units supplied were have a nominal full-scale range of 19.47mV pk-pk and thus have a resolution of 0.297 μ V per bit.

The signal pass-band measured between points where the gain drops by 3dB, is 4.5Hz to 4100Hz. The low frequency limit has a high-pass filter whose response is between first order and second order. The upper frequency limit is defined by a third order low-pass filter.

The sampling frequency is 31250Hz, that is one sample per channel per 32 μ s. The signal is thus over-sampled at about 4 times the Nyquist frequency, making interpolation easy, and ensuring alias-free sampling.

The nominal Bode plot of the amplifier is shown below.



The total broadband input-referred noise is $1.02\mu\text{V rms}$. The total input-referred noise, when bandwidth-limited to 4kHz, is $0.66\mu\text{V rms}$. This represents a sensitivity that is better than the Intan preamplifier by a factor of 2.35, and a dynamic range that is greater than that of the Intan preamplifier by a factor of 4.6. The input-referred noise density at 1kHz is $10.63\text{nV}/\text{rtHz}$.

5 How temperature measurements are made by thermistor on the MS9 (and similar) neural loggers

In addition to neural recording and motion sensor recording, the MS9 logger records the temperature of four external thermistors. This section describes the theory and practical aspects of how thermistors are used by the MS9 to measure temperature.

The system was designed to be used with thermistors that have a negative temperature coefficient of resistance (NTC). The design was optimized for thermistors with a mid-range resistance equal or close to 10kΩ.

The relationship between the resistance of an NTC thermistor and its temperature is most usually characterized by two parameters: the “beta parameter (β) and the resistance at a specified mid-range temperature, usually 25 Celsius, in which case that parameter is called R_{25} .

5.1.1 Thermistor theory

A very good approximation to the temperature-resistance curve of most NTC thermistors is given by the following formula:

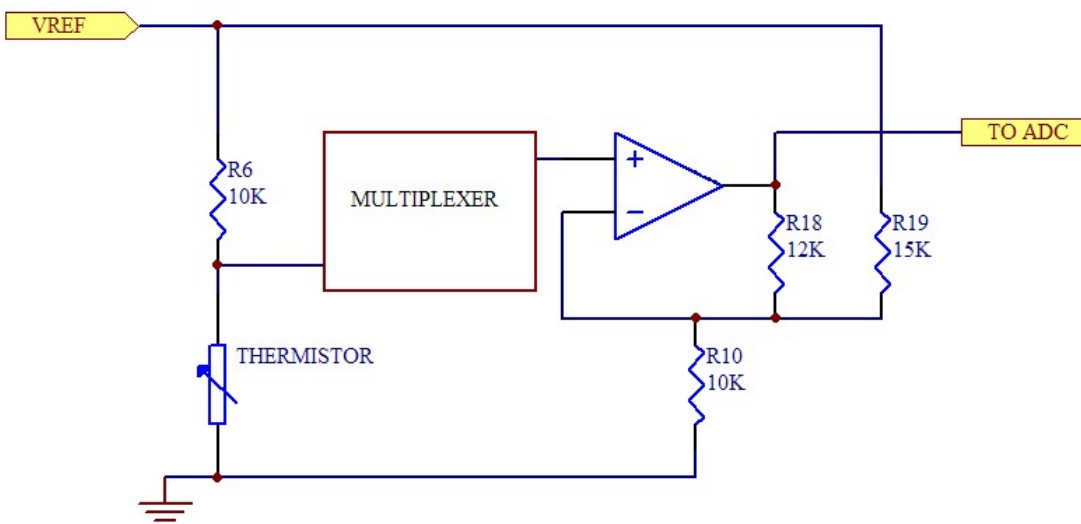
$$R = R_{25} \exp(\beta (1/T - 1/T_{25})), \quad [\text{eqn 1}]$$

Where T is the absolute (Kelvin) temperature of the thermistor, and T₂₅ is 25 Celsius in Kelvin (=25 + 273.15 = 298.15).

The system assumes that this formula is followed by the thermistor accurately enough for all envisioned applications.

5.1.2 Thermistor interface circuit theory

The thermistor is operated connected in the circuit summarized below.



R6 and the thermistor form a simple voltage divider, so that the voltage fed to the multiplexer is given by

$$V_{\text{mux}} = V_{\text{ref}} (R_t / (R_t + R_6)) \quad [\text{eqn 2}]$$

Where R_t is the resistance of the thermistor.

For a reference to the theory of a voltage divider like this, see here: ([Wikipedia link](#))

The purpose of the multiplexer is to select which of four thermistor-resistor pairs is selected to have its output voltage fed into the amplifier. Only one of the four thermistors and its associated resistor (R6) is shown in the diagram above.

The purpose of the amplifier and its three associated resistors is to allow the expected variations in the resistance of the thermistor to use the full input range (zero to Vref) of the ADC. For an ideal amplifier and if the resistors R10, R18 and R19 have precisely their nominal values, the transfer function of the amplifier stage is

$$V_{adc} = 3 V_{mux} - (4/5) V_{ref}. \quad [\text{eqn 3}]$$

For an explanation of why the transfer function of this amplifier circuit is given by eqn 3, see note 1 at the end of this section.

That is, the amplifier stage increases the voltage variations at its input by a factor of 3 and subtracts 0.8 times the reference voltage. The results of this is that the full range of the ADC will correspond to thermistor resistances in the range 3.636 kΩ to 15kΩ. For NTC thermistors with $\beta = 3800$, this provides a measurement range from 15.8 to 50.7 Celsius. If a greater temperature range is needed, a thermistor with a lower β can be used.

The ADC turns the voltage applied to it to a digital number, ideally according to this formula

$$N = 2^{16} \cdot V_{adc}/V_{ref} \quad [\text{eqn 4}]$$

Where n is the 16-bit unsigned digital word generated by the ADC.

This gives a single-measurement resolution of about 0.00052 Celsius.

Since both eqn 1 and eqn 2 are non-linear functions, it is clear that N is a non-linear function of the thermistor temperature. When combining eqn 1 through eqn 4 to get the relationship between the ADC code and the temperature, Vref in the numerator of eqn 2 will cancel with Vref in the denominator of eqn 4, so the overall function will be independent of Vref.

The non-linearity of eqn 1 has curvature opposite to that of eqn 2 such that when combined over a relatively small temperature range, the overall function that relates the ADC word to the temperature is quite linear; see the graph below.

The value of Vref is 1.200V. As stated, this is not needed for calculation of temperature but it may be useful when checking the voltage on the thermistor with a voltmeter.

5.1.3 After some algebra...

Combining equations 2,3 and 4 and rearranging to make R the subject, results in this formula

$$R = 10k\Omega \left((5N + 2^{18}) / (11 \cdot 2^{16} - 5N) \right) \text{ or}$$

$$R = 10k\Omega \left((5N + 262144) / (720896 - 5N) \right) \quad [\text{eqn 5}]$$

Inverting eqn 1 gives the absolute temperature of the thermistor as:

$$T = \beta / \ln (R/R_{inf}) \quad [\text{eqn 6}]$$

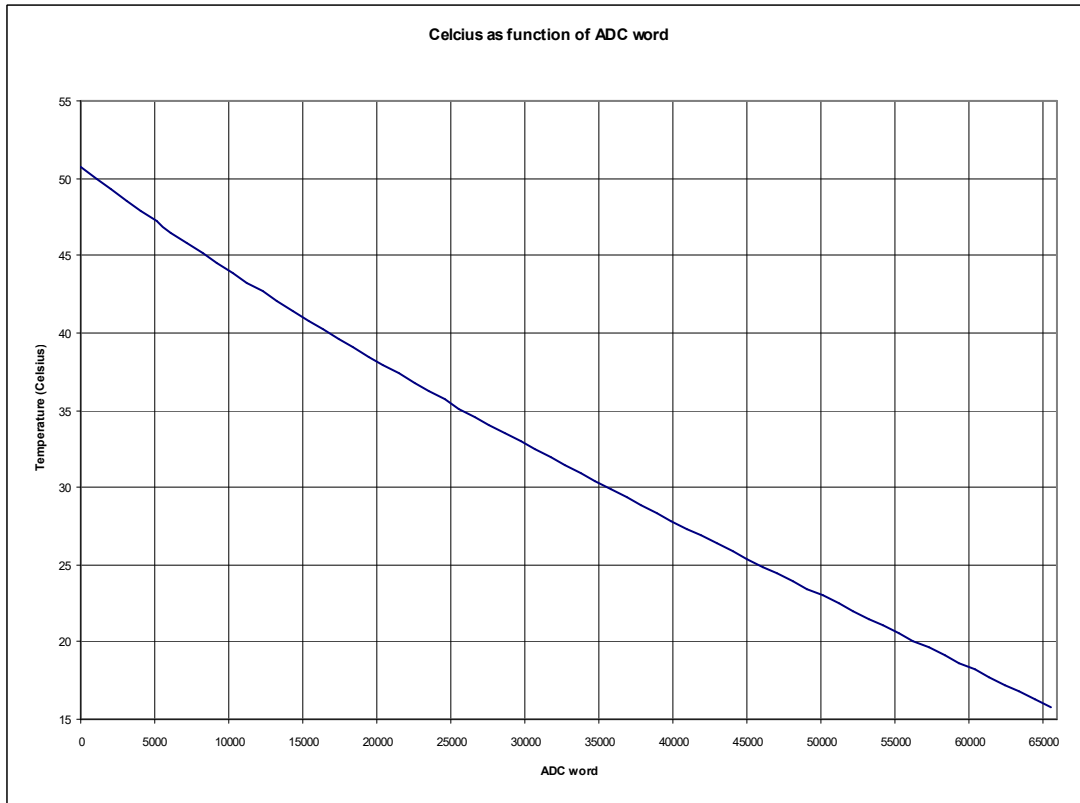
$$\text{Where } R_{inf} = R_{25} \exp (-\beta/T_{25}). \quad [\text{eqn 7}]$$

See the same here: (<https://en.wikipedia.org/wiki/Thermistor>)

$$\text{The Celsius temperature is given by } T_c = T - 273.15. \quad [\text{eqn 8}]$$

The embedded software uses equations 5,6,7,and 8 to calculate the Celsius temperature from the ADC's integer.

A graph is shown below of the relationship between the ADC digital word and the Celsius temperature of the thermistor, for a thermistor with $\beta = 3800$ and $R_{25} = 10k\Omega$.



5.2 Practical Application of the Thermistor Circuit

5.2.1 Thermistor Selection

As stated above, the circuit's full temperature measurement range corresponds to a resistance measurement range of $3.636 k\Omega$ to $15k\Omega$. If thermistors cannot be obtained that provide resistances in this range for the required temperature measurement range, one or more of the four resistors in the circuit shown above will need to be altered, and some of the equations given in the above theory section will need to be amended accordingly. In general NTC thermistors with R_{25} of about $10k\Omega$ will be a good match for this resistance range. If Thermistors with $R_{25} = 10k\Omega$ are used, the full-scale temperature range varies with the beta parameter as shown in this table.

Thermistor Beta	Minimum temperature (rounded to nearest °C)	Maximum temperature (rounded to nearest °C)
2000	8	77
2250	10	72
2500	12	66
2750	13	62
3000	14	58
3250	15	55
3500	16	53
3750	16	52
4000	17	49
4250	17	47
4500	17	46
4750	17	45
5000	18	44

The system provides more resolution than is normally needed, typically 0.00052 Celsius for a beta of 3800. Therefore, using a thermistor that provides a temperature range that is somewhat larger than optimal will provide performance that is adequate for most applications, and generally there is no need to search for thermistors with beta that is perfectly matched to the expected temperature measurement range.

If there is a need to lower (or raise) the overall range of measurable temperature, this can be done by specifying a lower (or higher) R25. For example, with R25 of 7500Ω and beta of 3000, the temperature range would be 6 to 48 Celsius.

5.3 Calibration Methods.

For many applications, particularly those that observe temperature variations rather than exactly measured temperatures, no calibration is needed beyond entering the thermistor's R25 and beta into the system.

If exact temperature measurements are needed, usually a single-point calibration is all that is needed, provided that the beta of the thermistor has a sufficiently tight tolerance relative to the measurement range needed. As a rule of thumb, which is actually remarkably accurate, a 1% error of beta results in a 1% error of temperature slope. Thus if a thermistor with rated beta tolerance of 1% maximum and 0.25% typical, and a single point calibration has been done at temperature T, then, at a temperature of T+10°C, the typical error will be 0.25% of 10°C, which is 0.025°C.

An easy way to perform a single point calibration is to adjust the stated R25 value until the indicated temperature matches the known temperature.

Note 1: Outline to the derivation of the transfer function of the thermistor amplifier circuit.

An operational amplifier (op-amp) performs the function

$$V_o = A_0 (V_+ - V_-) \quad [\text{Eqn 10}]$$

where A_0 is the open-loop gain. In an ideal op-amp, A_0 approaches infinity. Practical amplifiers like that used have A_0 of the order of one million. Since the output of the amplifier V_o is finite, and assuming that the amplifier circuit is stable and maintains its operation within its limited range, eqn 10 implies that

$$V_+ = V_- \quad [\text{Eqn 11}]$$

The current that runs into the input nodes of an ideal amplifier is zero, and in a practical amplifier like that used, this current is typically below 10^{-12} A.

Kirkhoff's law states that the sum of currents into a node is zero. Applying Korkhoff's law to the V_o node, and Ohm's law ($I=V/R$) to the three resistors, we can write down:

$$(V_{ref} - V_o) / R19 + (V_o - V_{in}) / R18 + (- V_o) / R10 = 0 \quad [\text{eqn 12}]$$

Solving eqn 12 for V_o, and substituting V₊ for V₋ (due to eqn 11), then substituting R10, R18 and R19 with their respective values of 10kΩ, 12kΩ and 15kΩ, and simplifying will result in the result of eqn 3.