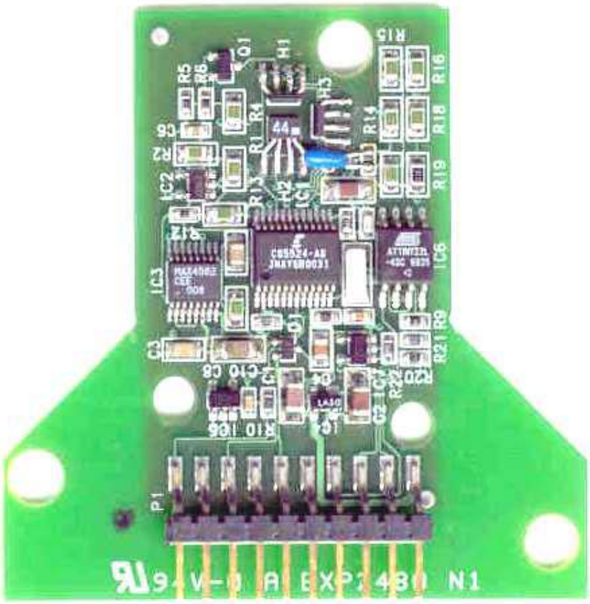

B-sensor

with addressable Serial Peripheral Interface

user manual v1.5

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1 Introduction

The **B-sensor with addressable SPI** is a compact module with integrated Hall-sensors on a PCB containing the 24-bit CRYSTAL CS5524 ADC to digitize the analog signals from the Hall-sensors, and an ATMEL ATtiny22L (inside there is an AT90LS2343…) 8-bit microcontroller. A picture of the module is shown in Figure 1 with its main components indicated.

The module is connected to the outside world via a so-called Serial Peripheral Interface or SPI (signals **SCLK**, **SDI** and **SDO**) and a single 'select' signal (**CS**). Via this serial interface a controlling system is able to communicate with either the microcontroller or the ADC.

An SPI serial link is a simple point-to-point link but the additional microcontroller provides the capability to address modules connected to the SPI link, turning the SPI *link* effectively into an SPI *bus*, at the expense of some extra protocol overhead for the controlling system.

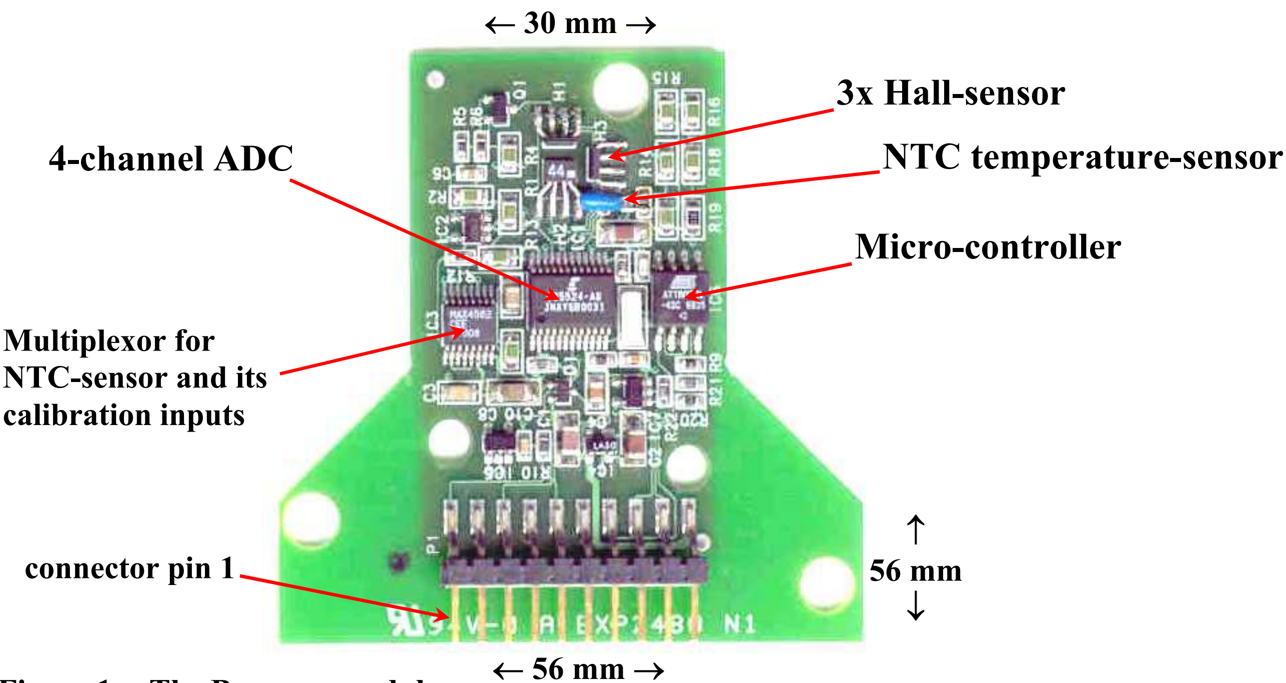


Figure 1. The B-sensor module.

2 How it works

2.1 Description

Figure 2 below shows schematically a setup between a controlling system and two B-sensor modules, with only the SPI and microcontroller/ADC interconnection shown.

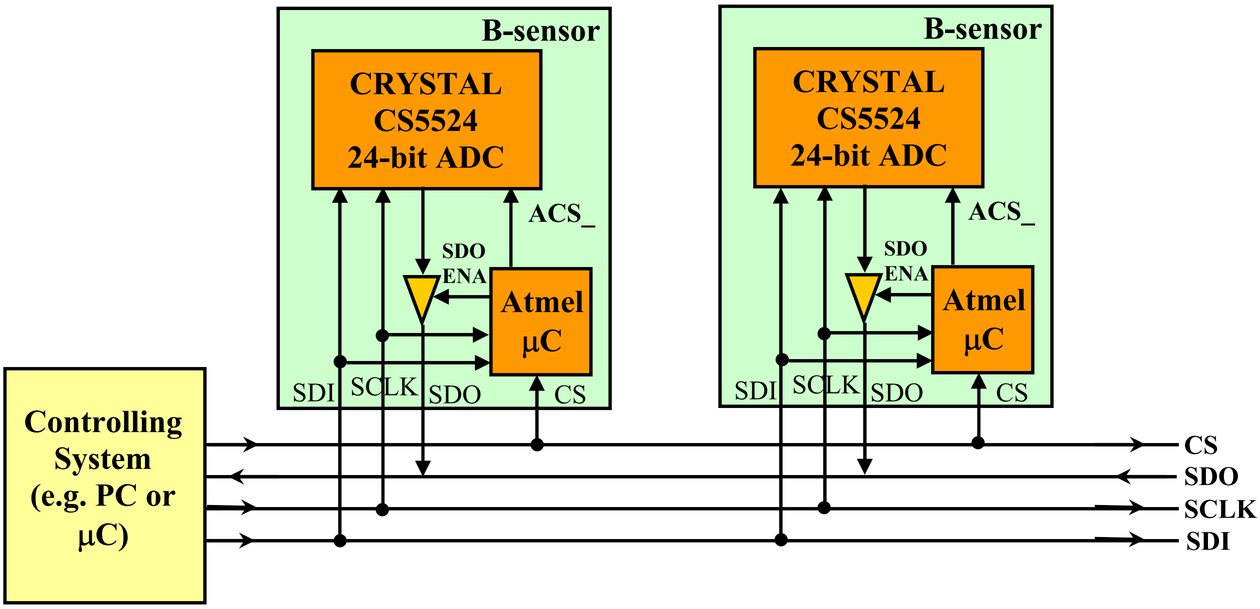


Figure 2. A system with two B-sensor modules connected to one SPI interface.

If the microcontroller is present, the **CS** signal serves to *select* between microcontroller and ADC, although an ADC is only accessible after a successful *selection protocol* with the microcontroller (the microcontroller is in control of the ADC chip-select signal **ACS_**). The syntax and workings of the selection protocol are explained in the next sections of this document.

(If the microcontroller is *not* installed some extra resistors have to be mounted, causing **CS** to be connected directly to **ACS_** so that the controlling system directly controls the ADC chip-select; also the SDO enable/disable circuit is circumvented. In this case only <u>one</u> B-sensor module can be connected to the SPI interface of the controlling system ! (unless multiple chip-select signals are provided)).

In the rest of this document we assume the microcontroller is present and programmed !

At power-up the B-sensor module goes into the following state: the ADC is not selected (**ACS_** is high) and **SDO** output (from the ADC) is not enabled (**SDO_ENA** is low) and the microcontroller is *idle*.
Now when **CS** transitions from low to high the microcontroller wakes up and is ready to receive commands via **SDI** (clocked via **SCLK**). So the microcontrollers from all SPI connected B-sensor modules are now *listening* to the data on the SPI *bus*.

When **CS** is taken low again the microcontroller makes **ACS_** and **SDO_ENA** active…or not, depending on the previously received command(s) and goes back to idle mode (to wake up again at the next **CS** transition from low to high). When **CS** is low the B-sensor is in a mode where the controlling system can talk to one (*single mode, read and write*) ADC or all (*broadcast mode, write-only*) ADCs, or none, when a non-existent ADC was selected...

When the command(s) to the microcontroller resulted in selection of this B-sensor's ADC (either in *single mode* or *broadcast mode*) the microcontroller makes **ACS_** active (enabling the ADC), before it goes back into idle mode; it makes **SDO_ENA** active (enabling SDO output from the ADC) *only* if this B-sensor was selected in *single mode*; **SDO_ENA** remains inactive when the ADC was not selected or when *broadcast mode* has been selected.

In *broadcast mode* it is possible to access all ADCs simultaneously for writing only, thus enabling e.g. a simultaneous start of conversion on all connected ADCs. To read out the results of the conversions from the ADCs they must be selected and read out individually, one-by-one. (Note that the ADC requires that the conversion data must be read out !).

The B-sensor is selected in *single mode* when its *Module-ID* has been selected or it is selected in *broadcast mode* when the *Broadcast-ID* has been selected.
The B-sensor's *Module-ID* is a one-byte number which is stored in the microcontroller's non-volatile memory (EEPROM). It must lie between 0 and 127 (7Fh). After production every B-sensor has *Module-ID* 255 (FFh) and should be set to the required value before use in a multi-B-sensor setup. When the module is tested the address is set equal to a serial number shown on a sticker on the module. The *Broadcast-ID* is 254 (FEh) and can not be changed.

It is *not* possible to find out via the SPI interface which *Module-ID* a B-sensor module has. If this information somehow gets lost one could find out by connecting the B-sensor to a microcontroller programmer which can read out the microcontroller's EEPROM: the B-sensor's *Module-ID* is located in byte 1 of the EEPROM. It could also be set using the programmer.
An alternative way to set a new Module-ID in a B-sensor with an unknown Module-ID is to connect the B-sensor –on its own– to a controlling system and to set the required B-sensor Module-ID for every possible Module-ID (one must know the *current* Module-ID to be able to change it to a new one…), effectively setting a new ID without knowing the old one.

Details of the protocol between the on-board microcontroller and host system are given in the next section.

Important:

1) If you have more than one B-sensor module connected to one cable make sure to disconnect SDO_ENA; it is an output of the B-sensor microcontroller and thus cannot be connected to the same output of other B-sensors! (in modules produced sofar, this pin has been disconnected so there is nothing to worry about…).
2) Due to a hardware bug in the ATMEL AT90LS2343 microcontroller the program in the microcontroller does not start up at the first power-up: it needs to be powered off and soon after (within seconds) powered on again, only then the program will start running !

2.2 Protocol

A message to the microcontroller always consists of a *sync*-byte, a command byte and one or two data bytes. A correctly received *sync*-byte hopefully ensures correct reception of the rest of the message

The table below summarizes the possible byte-sequences between controlling system and the B-sensor's microcontroller. Once an ADC has been selected communication is directly to the selected ADC; the B-sensor's microcontroller has become *transparent*. A description of the communication protocol of the ADC can be found in the CS5524 ADC datasheet.

Byte 0	Byte 1	Byte 2	Byte 3	ACS_/SDO_ENA (after **CS** goes low)
SYNC	**BS_SELECT**	*ModID*	–	**ACS_/SDO_ENA** active
SYNC	**BS_SELECT**	**BS_BRC_ID**	–	**ACS_** active, **SDO_ENA** inactive
SYNC	**BS_SET_ID**	*ModID*	*NewModID*	**ACS_/SDO_ENA** inactive

with:
SYNC = F5h
BS_SELECT = 11h
BS_SET_ID = 21h
BS_BRC_ID = FEh
and: $0 \le ModID \le 127$, $0 \le NewModID \le 127$

If several messages are sent in a row (leaving **CS** high) only the first one is read/accepted and the rest ignored !
So individual messages to the microcontroller <u>must</u> be separated by taking **CS** low and then high again.

A sequence of bits and bytes sent to the microcontroller can be interrupted at anytime, but in order to synchronize the microcontroller for a new message **CS** should be taken low and then high again.

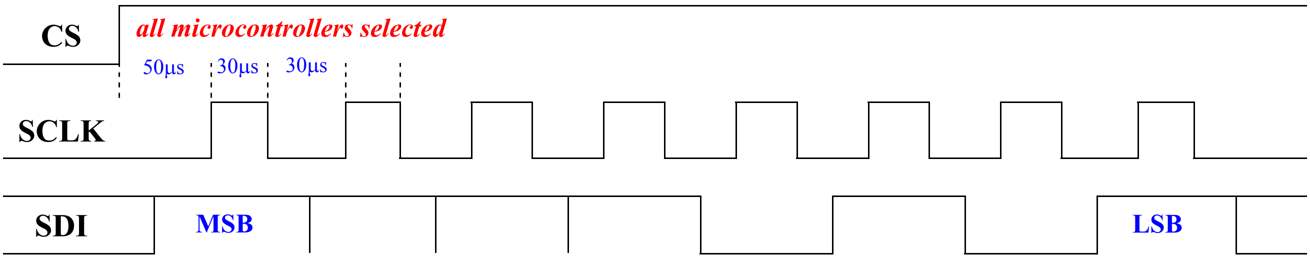
2.3 Signal Timing

The *relative* timings between CS, SDI and SCLK for communication with the microcontroller is the same as for the ADC (CS5524); see for a picture the figure labeled "SDI Write Timing" in the CS5521/22/23/24/28 datasheet.
However the absolute timings of the signals must be far greater when communicating with the microcontroller than when communicating with the ADC. This is because the protocol is implemented in software and the microcontroller runs on a clock of only 1 MHz.

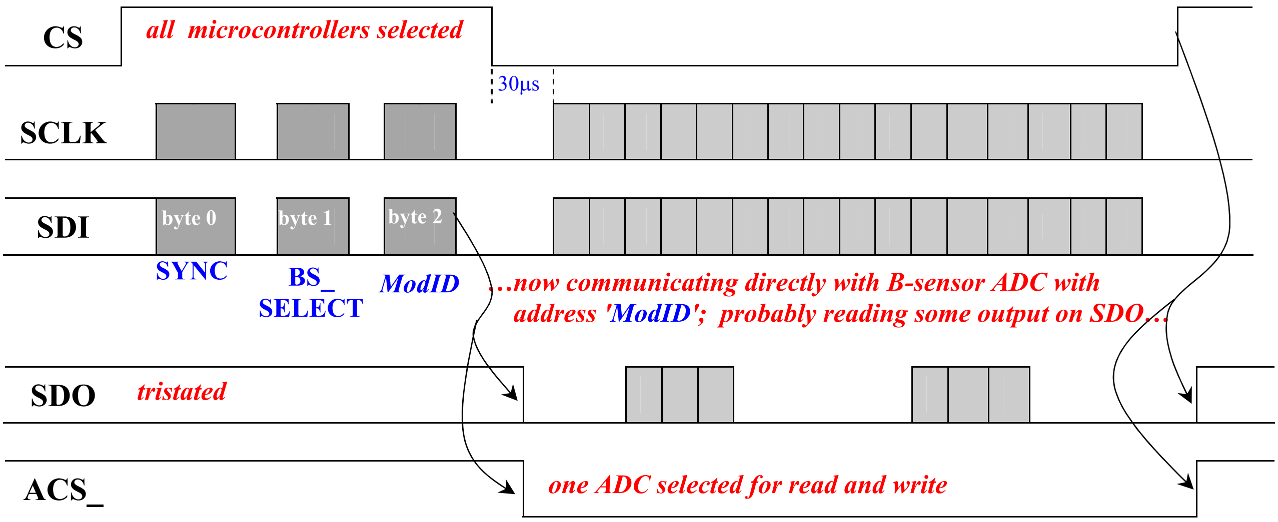
Safe limits to the timing of the SPI signals that the microcontroller can handle are the following (taking into account the microcontroller's internal clock of 1 MHz):

- after **CS** goes high (=*'select microcontroller'*) wait at least 50 µs before the first **SCLK** rising edge; **SDI** data is 'clocked in' with the rising edge of **SCLK**.
- the time between two edges in the **SCLK** signal should be at least 30 µs or -in other words- **SCLK**'s frequency should not exceed 16 kHz.
- after setting a new Module-ID (command ***BS_SET_ID***) wait a period of at least 4 ms before giving a new command (that same B-sensor can only be selected by subsequently sending a ***BS_SELECT*** command with the new Module-ID).
- after deselecting the microcontroller wait at least 30 µs before starting communicating to the ADC (which can be done at the full speed the ADC allows; see the CS5524 datasheet).

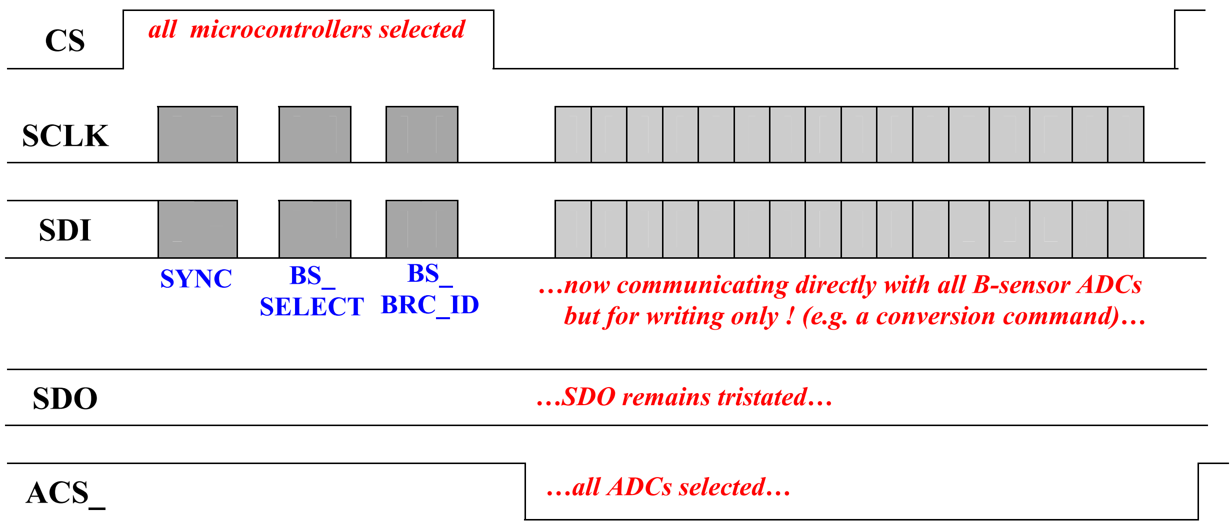
The figure below shows schematically the timing for writing a first byte (which should be the **SYNC** byte = F5h) on **SDI** to the B-sensor microcontrollers.



The figure below shows schematically an example of selecting a B-sensor (ADC) and subsequently communicating with the selected ADC.



The figure below shows schematically an example of selecting B-sensors (ADCs) broadcast mode and subsequently writing to all selected ADCs.



3 Some Technical Details

3.1 ADC Configuration

The ADC on the B-sensor module (24-bit CRYSTAL CS5524) has 4 inputs, called AIN1, AIN2, AIN3 and AIN4.
Hall-sensor H1 (in picture the top one) is read out on input AIN1, Hall-sensor H2 (in picture the bottom one) is read out on input AIN2 and Hall-sensor H3 (in picture to the right of the other 2) is read out on input AIN3.
Input AIN4 is used to read the NTC-sensor and its 2 calibration inputs, using a multiplexor and the ADC's 2 output latches A0 and A1, shown below in Table 1.
Input AIN4 also provides access to a full-scale calibration input for the Hall-sensor inputs.

AIN	A1A0	Input	Comment
1	–	Hall H1	
2	–	Hall H2	
3	–	Hall H3	
4	00	current monitor	ca. 87 mV, full-scale calibration input for Hall sensor inputs
	01	NTC	ca. 0.43 V ≤ value ≤ 2.43 V
	10	0º C calib input	ca. 0.43 V (see section 3.4)
	11	100º C calib input	ca. 2.43 V (see section 3.4)

Table 1. Input channels connected to the B-sensor ADC inputs.

AIN1, AIN2 and AIN3 are used in the 100 mV ADC input range, bipolar.
AIN4 is used in the 2.5V ADC input range, unipolar (Note that in order to read AIN4 with A1A0=00 (the 87 mV input), the input range and calibration must be adjusted).
The ADC's Charge Pump must be enabled (this is the power-up default).

3.2 ADC Calibration

- Hall-sensor calibration procedure:
  - perform a *Self* Offset calibration on each of the 3 Hall sensor inputs AIN1, AIN2 and AIN3, and also AIN4, voltage range 100 mV, A1A0 mux-setting irrelevant.
  - perform a *System* Gain calibration on AIN4 with mux-setting A1A0=00, thus selecting the current monitor input, voltage range 100 mV; the resulting gain value is read from the AIN4 Gain Register and copied to the Gain Registers of inputs AIN1, AIN2 and AIN3.

- T-sensor calibration procedure (resulting in a 16-bits ADC value of 0x0000 at 0ºC and 0xFFFF at 100 ºC):
  - perform a *System* Offset calibration on AIN4 using mux-setting A1A0=10 thus selecting the 0 ºC offset calibration input, voltage range 2.5V.
  - perform a *System* Gain calibration on AIN4 using mux-setting A1A0=11 thus selecting the 100 ºC full-scale calibration input, voltage range 2.5V (now the AIN4 Gain Register has the proper value for the NTC-sensor read-out).

3.3 Connector Pin-out

Table 2 shows the B-sensor module's connector pin-out configuration for normal operation (*Read-out*) and for In-System-Programming of the module's microcontroller.

Pin	Read-out	In-System-Programming
1	***SCLK***	***SCK***
2	GND	GND
3	***SDI***	–
4	GND	GND
5	***SDO***	–
6	GND	GND
7	***CS***	***MISO***
8	***SDO_ENA***	***MOSI***
9	–	***RESET***
10	V+	V+

Table 2. B-sensor module connector pin-out.

3.4 T-sensor

The T-sensor is an NTC, type number DC95F502W, with a nominal resistance of 5 kΩ. The table below shows a list of resistance values for this NTC at different temperatures, and the resulting B-sensor module ADC input voltage, with R14=23.2 kΩ, V_{cc}=5V and V_{ref}=2.5V. In the shaded part of the table (between 0 and 70º C) the precision is ±0.2º C.

Temperature	Normalized Resistance	Resistance	AIN4 (ADC)
[C]	Ohm	Ohm	Volt
-50	68.60	343000.00	-2.1832
-45	48.16	240800.00	-2.0606
-40	34.23	171150.00	-1.9031
-35	24.62	123100.00	-1.7071
-30	17.91	89550.00	-1.4712
-25	13.17	65850.00	-1.1974
-20	9.782	48910.00	-0.8913
-15	7.339	36695.00	-0.5633
-10	5.558	27790.00	-0.2250
-5	4.247	21235.00	0.1106
0	3.274	16370.00	0.4315
5	2.544	12720.00	0.7294
10	1.992	9960.00	0.9982
15	1.572	7860.00	1.2347
20	1.250	6250.00	1.4389
25	1.000	5000.00	1.6135
30	0.8056	4028.00	1.7603
35	0.6530	3265.00	1.8831
40	0.5326	2663.00	1.9852
45	0.4369	2184.50	2.0697
50	0.3604	1802.00	2.1396
55	0.2989	1494.50	2.1974
60	0.2491	1245.50	2.2452
65	0.2087	1043.50	2.2848
70	0.1756	878.00	2.3177
75	0.1485	742.50	2.3449
80	0.1261	630.50	2.3677
85	0.1075	537.50	2.3868
90	0.09209	460.45	2.4027
95	0.07916	395.80	2.4161
100	0.06831	341.55	2.4275
105	0.05916	295.80	2.4371
110	0.05141	257.05	2.4452
115	0.04483	224.15	2.4522
120	0.03922	196.10	2.4581
125	0.03442	172.10	2.4632

Table 3. NTC resistance/temperature table, and resulting ADC input voltage.