ANALOG DEVICES

Technical Note

ONE TECHNOLOGY WAY • P.O.BOX 9106 • NORWOOD, MASSACHUSETTS 02062-9106 • 781/329-4700

Temperature Measurement using a Thermistor and the AD7711 Sigma Delta ADC

by Albert O'Grady

INTRODUCTION

Thermistors are electrical circuit elements formed with semiconducting materials that are characterized by a high negative temperature coefficient (NTC) or positive temperature coefficient (PTC). An NTC thermistor acts like a resistor with temperature coefficients of typically -3 to -5 %/°C. Thermistors offer the benefits of high stability, precision, size and compatibility at a competitive price in many applications. They also offer fast response times and are among the highest sensitivity temperature transducers available. Thermistors can be excited by using either voltage or current methods. Thermistors are used as thermal sensors or thermal probes in communications, instrumentation, automotive, medical, aerospace and consumer market segments.

In medical applications for example thermistors are used in skin sensors, renal dialysis, blood and urine analysers, incubators and respirators and also clinical and domestic thermometers. In communication applications they are used for temperature monitoring and compensation in mobile phones, base stations and laser drives. They are also used extensively in the protection of mobile phone battery packs against overcharging.

In data acquisition applications, high resolution analog to digital converters are required to digitize the signal produced from the measurement circuit incorporating the thermistor. The AD7711, a signal conditioning analog-to-digital converter from Analog Devices is an ideal choice in temperature measurement applications using thermistors and RTDs. The AD7711 as shown in Figure 1 is a complete analog front end for low frequency measurement applications. The device accepts low level signals directly from a transducer and outputs a serial digital word. It employs a sigma-delta conversion technique to realize up to 24 bits of no missing codes performance. The input signal is applied to a proprietary programmable gain front end based around an analog modulator. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1 to 128 is used in applications to amplify the signal from the front end transducer in order to use the full dynamic range of the ADC. With a 2.5V reference and a gain range of 1 to 128 the AD7711 can accept unipolar signals between 0 to 20mV and 0 to 2.5V and bipolar signal ranges from +/-20mV to +/-2.5V. The modulator output is processed by an on-chip digital filter. The first notch of this digital filter can be programmed via the on-chip control register allowing adjustment of the filter cutoff and settling time. The part features one differential analog input and one single ended analog input as well as a differential reference input. Normally, one of the input channels will be used as the main channel with the second channel used as an auxiliary input to periodically measure a second voltage. It can be operated from a single supply (by tying the VSS pin to AGND) provided that the input signals on the analog inputs are more positive than -30 mV. By taking the VSS pin negative, the part can convert signals down to -VREF on its inputs. The part provides two current sources that

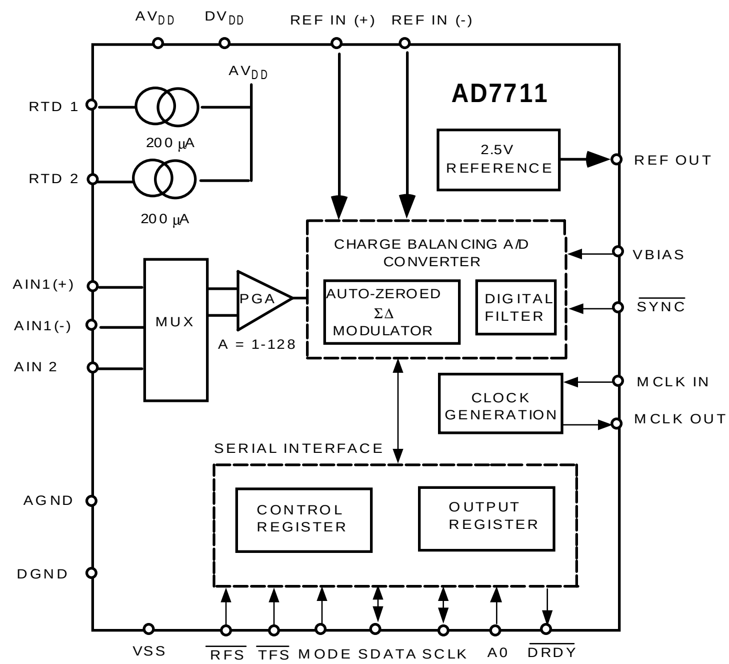

Figure 1. AD7711 Signal Conditioning Analog-To-Digital Converter.

can be used to provide excitation in three-wire and four-wire RTD configurations. A full data sheet on the AD7711 can be found on the Analog Devices web site at : http://www-corp.analog.com.

THERMISTOR APPLICATIONS USING CURRENT EXCITATION

Figure 2. shows a circuit using the AD7711 to digitize the output voltage generated across a thermistor using the AD7711s on-chip 200uA current source.

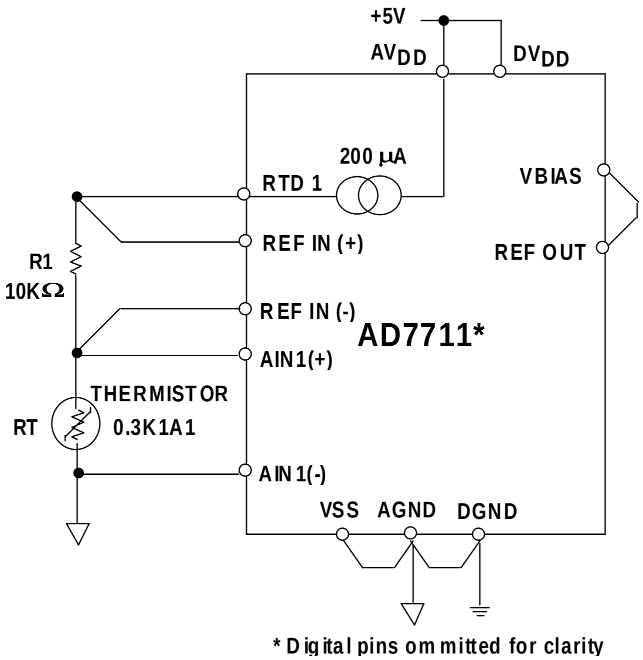

Figure 2. Temperature Measurement Application Using Current Excitation of the Thermistor

The thermistor chosen in this example is the 0.3K1A1 from Betatherm*. Appendix 1 shows a table of the R-T characteristics of this device. This device has a nominal resistance of 300 ohms at 25°C. In this example the same 200uA current source used to excite the thermistor is also used to generate the reference voltage for the AD7711. As a result variations in the excitation current do not affect performance. The most common wiring arrangement in these applications is a 4-wire force/sense configuration in order to reduce the effects of lead resistances on system performance. Lead resistance of the drive wires only shift the common mode voltage and do not degrade the performance of the circuit. Lead resistance of the sense wires is immaterial as no current flow in these wires due to the high input impedance af the AD7711 analog inputs. However, the the reference setting resistor must have a low temperature coefficient to avoid errors in the reference voltage over temperature. The operating temperature range of this circuit is from -35°C to + 100°C, the limitation on the lower end is due to voltage headroom in the circuit associated with the impedance of the thermistor increasing as the the temperature decreases and the output compliance of the current source. The output voltage from the thermistor seen by the analog inputs of the AD7711 varies from 7mV at 100°C to 0.75V at -35°C. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1 to 128 is used in this application to amplify the signal from the thermistor in order to maximize the signal-to-noise ratio (SNR) of the system. With a 2V reference and a gain range of 1 to 128 the AD7711 can accept unipolar signals between 0 to 15mV and 0 to 2V. For example if the operating range is from 25°C and to 100°C, the maximum output voltage generated across the thermistor is 60mV, this allows a gain of 32 to be used in covering this entire range.

THERMISTOR APPLICATIONS USING VOLTAGE EXCITATION

Figure 3 shows a circuit where the thermistor is excited using a voltage source which is obtained from the AD7711. The thermistor shown is the 10K3A1 thermistor from

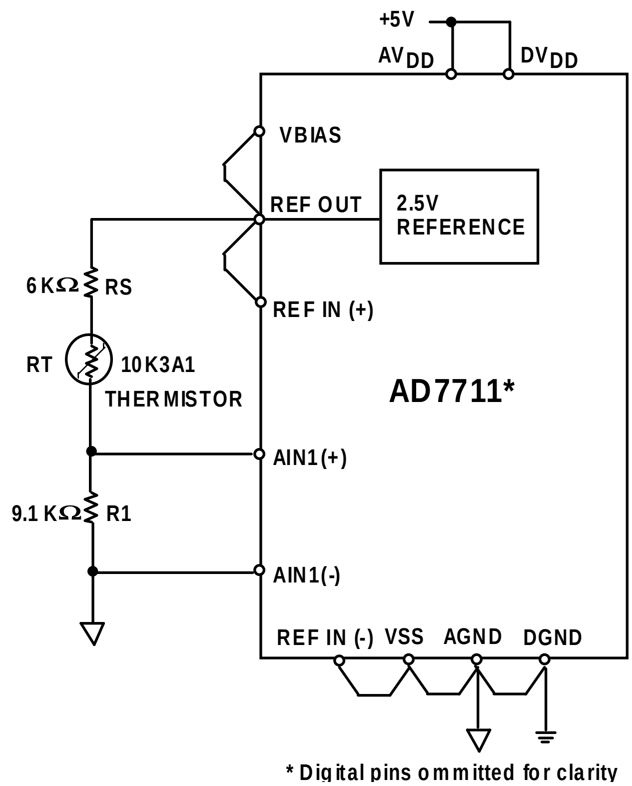

Figure 3. Temperature Measurement Application Using Voltage Excitation of the Thermistor and Linearizing the Output in the Analog Domain.

Betatherm which has a nominal impedance of 10kΩ at 25°C. Appendix 2 shows a table of the R-T characteristics of this device.

The circuit shown uses two resistors RS and R1 in series with the thermistor. Resistor RS is used to limit the thermistor power dissipation - see section on eliminating self heating effects. Resistor R1 is used to linearize the output of the thermistor. The output voltage across R1 varies from 33mV at -50°C to +2.329V at + 100°C. The AD7711 operating at a gain of 1 in unipolar operating

*Betatherm Corporation
910 Turnpike Road, Shrewsbury, MA 01545 .
Tel No. 508 842 0516.

* Betatherm Ireland Limited, Ballybrit Industrial Estate, Galway, Ireland. Tel No. 353-91-753238.

Web Site: http://www.betatherm.com

mode accomodates an input signal range of 0V to 2.5V. If the application requires the full dynamic range of the ADC to be used, then the system calibration feature on the ADC can be used to calibrate out the 33mV at the low end. Therefore, when the ADC sees 33mV on its input its output digital code would be all zeroes. Likewise at the top end a system fullscale can be used so that an input voltage of 2.329V outputs all ones from the AD7711. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1 to 128 can be used in this application to amplify the signal generated across R1 in order to maximize the signal-to-noise ratio (SNR) of the system.

LINEARIZING A THERMISTORS OUTPUT

Thermistors are non-linear devices and require linearization techniques to obtain accurate measurements. In general applications, linearization techniques can be implemented in one of two ways. Linearization can be performed in the digital domain using a look up table containing the manufacturer's device characteristics to linearize the thermistor output. Linearization can also be performed in the analog domain with the addition of series or parallel resistors which forces the voltage or the resistance of a simple fixed-resistor-thermistor to have zero error along a linear temperature scale at three equidistant points.

Figure 3 uses a resistor R1 in series with the thermistor to linearize the output of the thermistor . This approach forces the voltage across R1 to have zero error along a linear temperature scale at three points across the required temperature range. The maximum error is determined by the temperature range of the application. In this application the temperature range is taken to be -50°C to +100°C. The errors are zero at -50°C, 25°C and +100°C and the errors elsewhere are distributed in an S-shaped curve.

Using this method the nonlinear negative temperature characteristics of a thermistor are converted into a linear relationship with peak errors of +/-12%. If the temperature range is reduced the errors become appreciably smaller +/-0.01°C over a 10°C range, +/-0.05°C over a 30°C range and +/-2.0°C over a 60°C range.

The value for R1 is calculated as follows:

$$R1 = \{RT_{(MID)}*[RT_{(LOW)}+RT_{(HIGH)}] - [2*RT_{(LOW)}*RT_{(HIGH)}]\}/\{RT_{(LOW)}+RT_{(HIGH)}-2*RT_{(MID)}\}$$

Where:

$RT_{(MID)}$ is the thermister impedance at the middle of the range.

$RT_{(LOW)}$ is the thermister impedance at the low end of the range.

$RT_{(HIGH)}$ is the thermister impedance at the high end of the range.

ELIMINATE SELF HEATING EFFECTS

Self-heating effects of the thermistor can become significant and degrade the overall system performance. Self-heating effects are more pronounced in still air. If the thermistor is located in moving air, liquids or solids then the self-heating error is much lower. In order to keep the self-heating error within 0.1°C max, the current in the circuit should be limited so as to give a dissipation of 0.1mW max in the thermistor RT. In the circuit in Figure 2 which uses current excitation, the power dissipation in the thermistor is 12uW at 25°C. To keep the power dissipation to within 0.1mW the operating temperature range should be limited to operating above -27°C.

In Figure 3 the point of maximum power dissipation and thus self heating effects are worst when the value of RT is equal to R1. A series resistor Rs as shown in Figure 3 will limit the current in the circuit and thus keep the power dissipated in the thermistor to acceptable levels so that self heating effects in the thermistor can be ignored. A value of 6kΩ is sufficient to limit the current in the circuit and ensure that the max power dissipated in the thermistor is less than 0.1mW.

LAYOUT TECHNIQUES FOR OBTAINING OPTIMUM PERFORMANCE IN HIGH RESOLUTION APPLICATIONS

The printed circuit board which houses the AD7711 should be designed such that the analog and digital sections are separated and confined to certain areas of the board. This facilitates the use of ground planes which can be separated easily. A minimum etch technique is generally best for ground planes as it gives the best shielding. Digital and analog ground planes should only be joined in one place. If the AD7711 is the only device requiring an AGND to DGND connection, then the ground planes should be connected at the AGND and DGND pins of the AD7711. If the AD7711 is in a system where multiple devices require AGND to DGND connections, the connection should still be made at one point only, a star ground point which should be established as close as possible to the AD7711.

Avoid running digital lines under the device as these will couple noise onto the die. The analog ground plane should be allowed to run under the AD7711 to avoid noise coupling. The power supply lines to the AD7711 should use as large a trace as possible to provide low impedance paths and reduce the effects of glitches on the power supply line. Fast switching signals like clocks should be shielded with digital ground to avoid radiating noise to other sections of the board and clock signals should never be run near the analog inputs. Avoid crossover of digital and analog signals. Traces on opposite sides of the board should run at right angles to each other. This will reduce the effects of feedthrough through the board. A microstrip technique is by far the best but is not always possible with a double-sided board. In this technique, the component side of the board is dedicated to ground planes while signals are placed on the solder side.

Good decoupling is important when using high resolution ADCs. All analog supplies should be decoupled with 10µF tantalum in parallel with 0.1µF capacitors to AGND. To achieve the best from these decoupling components, they have to be placed as close as possible to the device, ideally right up against the device. All logic chips should be decoupled with 0.1µF disc ceramic capacitors to DGND. In systems where a common supply voltage is used to drive both the AV_{DD} and DV_{DD} of the AD7711, it is recommended that the system's AV_{DD} supply is used. This supply should have the recommended analog supply decoupling capacitors between the AV_{DD} pin of the AD7711 and AGND and the recommended digital supply decoupling capacitor between the DV_{DD} pin of the AD7711 and DGND.

APPENDIX 1.

R-T Specifications for Betatherm 0.3K1A1 Thermistor

Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)
-80	50763	-19	1735	42	170
-79	47473	-18	1659	43	164.7
-78	44417	-17	1586	44	159.6
-77	41576	-16	1516	45	154.7
-76	38935	-15	1451	46	149.9
-75	36477	-14	1388	47	145.3
-74	34190	-13	1328	48	140.9
-73	32060	-12	1272	49	136.6
-72	30076	-11	1218	50	132.5
-71	28227	-10	1167	51	128.5
-70	26503	-9	1118	52	124.7
-69	24895	-8	1071	53	121
-68	23394	-7	1027	54	117.5
-67	21993	-6	984.5	55	114
-66	20684	-5	944.2	56	110.7
-65	19461	-4	905.8	57	107.5
-64	18318	-3	869.1	58	104.4
-63	17249	-2	834.2	59	101.4
-62	16248	-1	800.8	60	98.5
-61	15312	0	769	61	95.7
-60	14436	1	738.6	62	93
-59	13614	2	709.5	63	90.4
-58	12845	3	681.8	64	87.8
-57	12123	4	655.3	65	85.4
-56	11447	5	630	66	83
-55	10812	6	605.8	67	80.7
-54	10216	7	582.7	68	78.5
-53	9656	8	560.5	69	76.4
-52	9131	9	539.4	70	74.3
-51	8637	10	519.1	71	72.3
-50	8173	11	499.7	72	70.4
-49	7737	12	481.2	73	68.5
-48	7326	13	463.4	74	66.7
-47	6940	14	446.4	75	64.9
-46	6576	15	430.1	76	63.2
-45	6234	16	414.5	77	61.6
-44	5911	17	399.6	78	60
-43	5607	18	385.2	79	58.4
-42	5320	19	371.5	80	56.9
-41	5050	20	358.3	81	55.4
-40	4795	21	345.7	82	54
-39	4554	22	333.5	83	52.7
-38	4327	23	321.9	84	51.3
-37	4113	24	310.7	85	50
-36	3910	25	300	86	48.8
-35	3719	26	289.7	87	47.6
-34	3538	27	279.8	88	46.4
-33	3367	28	270.3	89	45.3
-32	3205	29	261.2	90	44.1
-31	3052	30	252.4	91	43.1
-30	2907	31	244	92	42
-29	2769	32	235.9	93	41
-28	2639	33	228.1	94	40
-27	2516	34	220.6	95	39.1
-26	2400	35	213.4	96	38.1
-25	2289	36	206.5	97	37.2
-24	2184	37	199.8	98	36.4
-23	2085	38	193.4	99	35.5
-22	1990	39	187.2	100	34.7
-21	1901	40	181.3		
-20	1816	41	175.5		

APPENDIX 2.

R-T Specifications for Betatherm 10K3A1 Thermistor

Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)
-80	7296874.00	-3	38108.50	74	1530.28
-79	6677205.00	-2	36182.80	75	1480.12
-78	6114311.00	-1	34366.10	76	1431.87
-77	5602677.00	0	32650.80	77	1385.37
-76	5137343.00	1	31030.40	78	1340.68
-75	4713762.00	2	29500.10	79	1297.64
-74	4327977.00	3	28054.20	80	1256.17
-73	3966352.00	4	26687.60	81	1216.23
-72	3655631.00	5	25395.50	82	1177.75
-71	3362963.00	6	24172.70	83	1140.71
-70	3095611.00	7	23016.00	84	1104.99
-69	2851363.00	8	21921.70	85	1070.58
-68	2627981.00	9	20885.20	86	1037.40
-67	2423519.00	10	19903.50	87	1005.40
-66	2236398.00	11	18973.60	88	974.56
-65	2064919.00	12	18092.60	89	944.81
-64	1907728.00	13	17257.40	90	916.11
-63	1763539.00	14	16465.10	91	888.41
-62	1631173.00	15	15714.00	92	861.70
-61	1509639.00	16	15001.20	93	835.93
-60	1397935.00	17	14324.60	94	811.03
-59	1295239.00	18	13682.60	95	786.99
-58	1200732.00	19	13052.80	96	763.79
-57	1113744.00	20	12493.70	97	741.38
-56	1033619.00	21	11943.30	98	719.74
-55	959789.00	22	11420.00	99	698.82
-54	891689.00	23	10922.70	100	678.63
-53	828865.00	24	10449.90	101	659.10
-52	770880.00	25	10000.00	102	640.23
-51	717310.00	26	9572.00	103	622.00
-50	667828.00	27	9164.70	104	604.36
-49	622055.00	28	8777.00	105	587.31
-48	579718.00	29	8407.70	106	570.82
-47	540530.00	30	8056.00	107	554.86
-46	504230.00	31	7720.90	108	539.44
-45	470609.00	32	7401.70	109	524.51
-44	439445.00	33	7097.20	110	510.06
-43	410532.00	34	6807.00	111	496.08
-42	383712.00	35	6530.10	112	482.55
-41	358806.00	36	6266.10	113	469.45
-40	335671.00	37	6014.20	114	456.76
-39	314179.00	38	5773.70	115	444.48
-38	294193.00	39	5544.10	116	432.58
-37	275605.00	40	5324.90	117	421.06
-36	258307.00	41	5115.60	118	409.90
-35	242195.00	42	4915.50	119	399.08
-34	227196.00	43	4724.30	120	388.59
-33	213219.00	44	4541.60	121	378.44
-32	200184.00	45	4366.90	122	368.59
-31	188026.00	46	4199.90	123	359.05
-30	176683.00	47	4040.10	124	349.79
-29	166091.00	48	3887.20	125	340.82
-28	156199.00	49	3741.10	126	332.11
-27	146959.00	50	3601.00	127	323.67
-26	138322.00	51	3466.90	128	315.48
-25	130243.00	52	3338.60	129	307.53
-24	122687.00	53	3215.60	130	299.82
-23	115613.00	54	3097.90	131	292.34
-22	108991.00	55	2985.10	132	285.08
-21	102787.00	56	2876.90	133	278.03
-20	96974.00	57	2773.20	134	271.19
-19	91525.00	58	2673.90	135	264.54
-18	86415.00	59	2578.50	136	258.09
-17	81621.00	60	2487.10	137	251.82
-16	77121.00	61	2399.40	138	245.74
-15	72895.00	62	2315.20	139	239.82
-14	68927.00	63	2234.70	140	234.08
-13	65198.00	64	2156.70	141	228.50
-12	61693.00	65	2082.30	142	223.08
-11	58397.00	66	2010.80	143	217.80
-10	55298.00	67	1942.10	144	212.68
-9	52380.00	68	1876.00	145	207.70
-8	49633.00	69	1812.60	146	202.86
-7	47047.00	70	1751.60	147	198.15
-6	44610.00	71	1693.00	148	193.57
-5	42314.60	72	1636.63	149	189.12
-4	40149.50	73	1582.41	150	184.79