Analogue to Digital Converter With Non-linear Transfer Function for Thermistor Applications

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Abstract: There exists a disproportionate difference between dynamic range, resolution, and accuracy when the output of sensors having non-linear characteristics like thermistors are digitized with the conventional linear ADCs. There are several methods to linearise the thermistor characteristics but at the expense of hardware, memory and time efficiency. This paper presents a new simple method of shaping the transfer function of a pulse width modulation ADC as per the thermistor characteristics. It is based on the principle of varying the amplitude of the reference voltage to reach the temperature equivalence of voltage being digitized.

Keywords: thermistor, PWM ADC, PSpice, NADC, transfer function

Introduction:

Temperature is an analog quantity, often required to be measured and monitored in industrial environment and also in day to day life. Digital systems are normally used to implement temperature measurement, control, and protection. At the heart of such digital portable instruments lies an analog-to-digital converter (ADC) which converts voltage equivalent of temperature, into a digital form, which can be read by the processor and manipulated as needed to support the application. The temperature is converted into electrical quantity by using sensors like thermocouple, resistive temperature detector, thermistor and silicon based sensors. Despite extensive research and development in this field, the transduction characteristics of all these sensors is far from ideal. Of all the temperature sensors mentioned earlier, thermistor is the only one that holds the esteemed position owing to its highest sensitivity, accuracy and low cost.[1] However thermistor characteristics has some peculiar features that makes its interfacing with the digital systems a challenge. The transfer function of thermistors is highly non-linear and hence compensation for the non-linearity with a look-up table, is required in a digital system. However this leads to loss of resolution. Several researchers have worked out analog signal conditioning modules to compensate the non-linearity. However this results into erroneous measurement as there will be adding up of errors from the thermistor-resistor combination, the amplifier offset voltage, the tolerance of gain-setting resistors, errors due to ADC, and the voltage reference error which may be more than the intended application can tolerate. Another striking feature of thermistor-ADC interfacing is need of variable resolution due to its variable dynamic range which can be described in terms of variation of temperature coefficient of resistance, material constant and resistance ratio with temperature. The problem could be solved by dividing the measuring range into several subranges and using variable gain amplifier controlled by microprocessor. However this results in a substantial increase in the measurement time, an unnecessary expansion of hardware and possible increase of measurement errors[2]. The problem may be solved by the use of a non-linear ADC (NADC) with its transfer characteristics being the inverse of the thermistor characteristics. This paper presents a novel modified pulse width modulation (PWM) ADC architecture suitable for thermistor interfacing.

Pulse Width Modulation ADC:

The block diagram of a conventional technique of the pulse width modulated ADC is shown in figure 1. The ADC operates by measuring the time in terms of pulse width for the output of the integrator to reach the output voltage of the thermistor bridge which is proportional to temperature to be measured. A constant voltage (reference voltage) acts as input to the integrator and the value is chosen after carefully studying the measurand voltage range. The measurement cycle consists of (i) rezeoring the counter and integrator (ii) beginning of the integration and counting (iii) Stopping the integration when the integrator output equates that of bridge output (iv) Delaying for few microseconds to allow the counter to read final value and simultaneously disabling it (v) Repeating the process.

In the method described above the integrator output reaches the input voltage with a fixed slope equal to the time constant RC. This leads to a nonlinear digital output code for a given temperature. The problem may be solved by the use of a non-linear ADC (NADC) with its transfer characteristics being the inverse of the thermistor characteristics. The present paper presents a novel modified pulse width modulation (PWM) ADC architecture suitable for thermistor interfacing. In this modified architecture an additional thermistor which is placed in the vicinity of the process forms the R of the integrator time constant and thus the slope of the output sawtooth waveform varies in a non-linear fashion and adapts itself with the characteristics of thermistor in the bridge.

The Modified Architecture:

Figure 2 shows the schematic of the modified architecture of PWM ADC to suit the thermistor requirements. The thermistor bridge with the instrumentation amplifier gives the voltage equivalent of temperature at the inverting terminal of the comaprator. The saw-tooth waveform is generated by a integrator based on Op amp and a transistor switch. The capacitor charges through Rt2 with a time constant Rt2C. The discharging is controlled by a 'rezero' pulse generated by the monostable multivibrator 1. At time t=0, the output of the thermistor bridge is higher than that of sawtooth amplitude. The capacitor C starts charging with a slope equal to Rt2C towards the supply voltage thus generating a positive going ramp. The output of the comparator is low and the NAND logic ensures triggering of monostable. The monostable output is high which enables the gating circuit and the counter starts counting up. When the positive going ramp reaches the bridge voltage, the comparator output becomes high, triggering the monostable multivibrator 1, which gives a 'rezero' pulse to integrator, which makes the transistor ON, and thus initiates discharging of capacitor. After a delay of few microseconds a pulse is also given to the counter to reset it. The delay is intentionally kept to latch the final counter reading. The cycle of operations is repeated continuously thereby giving a digital equivalence of the temperature at the output of counter.

Results and Discussions:

The circuit blocks shown in figure 2 were simulated successfully using PSpice-3. The instrumentation amplifier was simulated using two ideal op amps and a single active op amp. The real difficulty is simulating thermistor response in PSpice. Following equation describes thermistor resistance as a function of temperature.

$$R = R_o\, e^{\beta(1/T - 1/To)} \quad \text{………(I)}$$

A new EXP model [3] was used in which the thermistor is equivalent to voltage controlled voltage source with a polynomial expansion or by adapting the diode model within PSpice. After debugging the model, it was turned into a subcircuit with the following list of parameters as resistance at 300 Degree Kelvin, material constant β, heat capacity HC, thermal time constant and thermal boundary temperature in degree Kelvin. From the overall simulation, the variation of slope of sawtooth waveform with temperature was evident. Timing diagrams of a typical simulation are shown in figure 3. The circuit was then actually constructed and tested with op amps like μA741, instrumentation amplifier μA725, monostable multivibrator IC 74121, AND gate 7400, universal counters ICM7226B and a 74c14 Schmitt trigger inverter based clock circuit. The Hitachi thermistors were used with the bridge thermistor placed at the center of a tubular furnace and the second thermistor placed in the close vicinity. The monostable pulse width is designed to be 1 Second keeping in mind the temperature range right from room temperature to 150^{o}C.

Conclusion:

Presently used linear ADC technology poses various limitations while processing output of sensors like thermistors having highly non-linear characteristics. In this paper we have presented a novel modified PWM ADC architecture having a non-linear transfer function suitable for digitizing thermistor output. In a way of digitization the non-linearity of the thermistor is cancelled due to the adaptability of the sawtooth waveform. The circuit was successfully simulated using PSpice. The discrete version using various general purpose ICs was found to be working satisfactorily. The architecture suggested is suitable for integration in the form of a semi-custom IC.

References:

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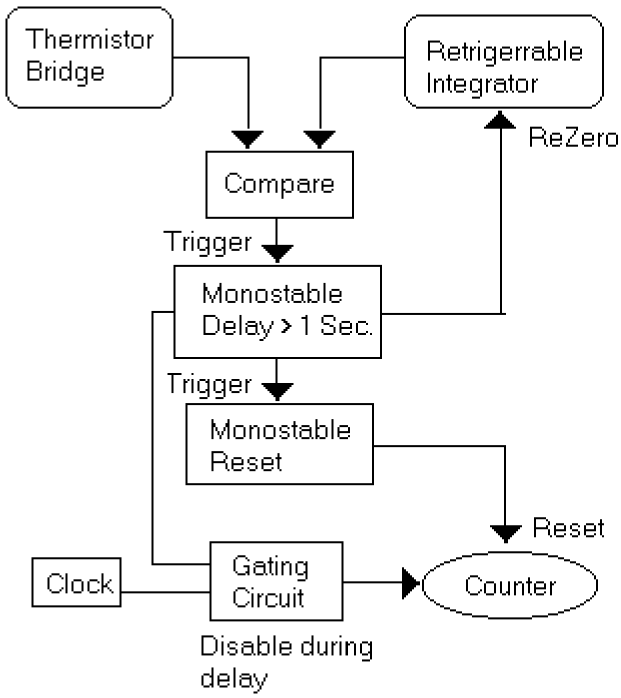

Figure 1: Block Diagram of PWM ADC

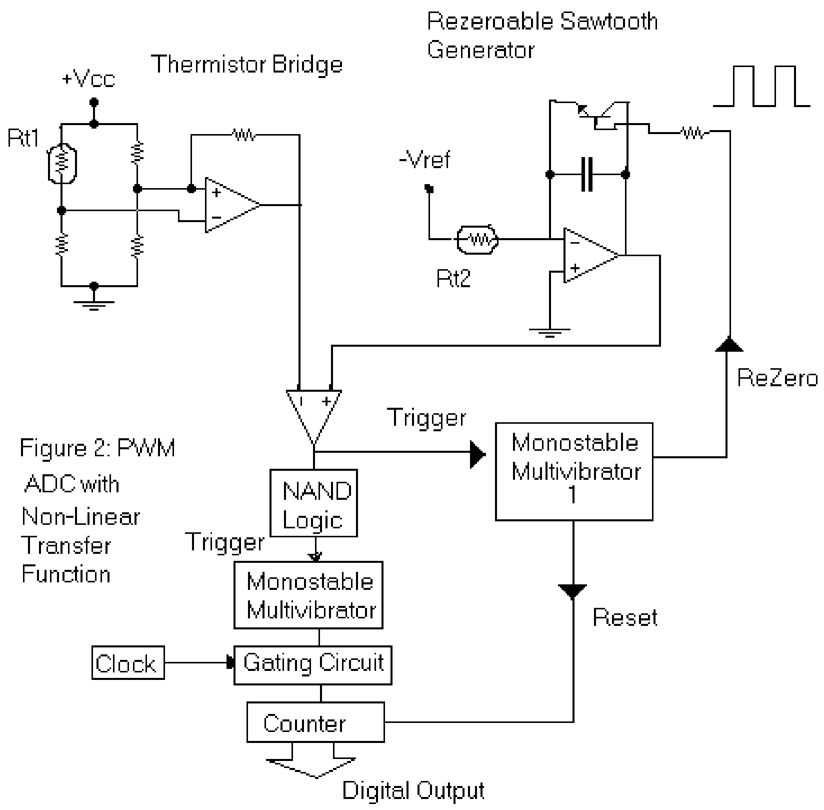

Figure 2: PWM ADC with Non-Linear Transfer Function

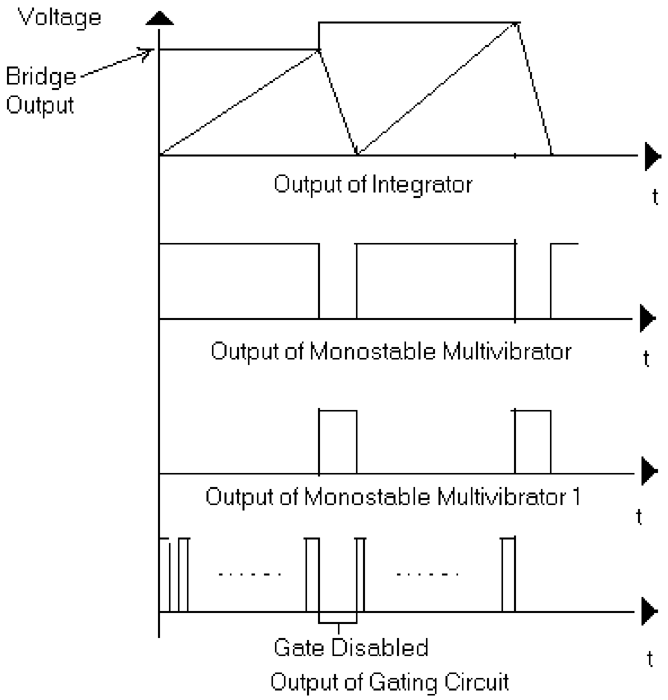

Figure 3: Timing Diagrams of Modified PWM ADC.