Introduction

With the addition of a few external components, the Lattice ispPAC®30 can be used as the heart of a high-resolution temperature measurement system which outputs temperature readings in the form of a high-level calibrated output voltage. The high-level output provided by the ispPAC30 can be easily read into the ADC port of a microcontroller, or be used directly as the feedback signal in a temperature controller.

While temperature sensor signal-conditioning circuits have long been built using discrete operational amplifiers and other components, the ispPAC30 offers several advantages over traditional implementations. The first advantage is integration; the ispPAC30 can integrate circuits which would require several IC’s and passive components in a traditional implementation. The ispPAC30 thermistor signal conditioner described here provides a conditioned and calibrated high-level output signal, using only a single ispPAC30 and three external resistors. An equivalent opamp-implementation would have a significantly higher component count.

In-system-programmability also offers significant advantages over traditional designs. The ability to individually program device parameters such as gains and offsets can be used to eliminate manual potentiometers, both decreasing the cost and increasing the reliability. In-system-programmability also allows for automated calibration at end-of-line test, reducing manufacturing costs and defects associated with manual unit calibration.

Finally, in addition to being configurable at end-of-line test, the ispPAC30 can be dynamically reconfigured by a supervising microcontroller through its SPI interface. In addition to allowing the ispPAC30 to adapt to a variety of conditions, dynamic reconfiguration allows an intelligent system to time-share the ispPAC30’s hardware among several temperature measurement channels, making it even more cost-competitive when compared to traditional, hardwired signal-conditioning circuitry.

Thermistor Interfacing

The key component in any temperature measurement system is the temperature transducer. Of the many types of temperature transducers available, thermistors are often a good choice for measuring over modest temperature ranges (e.g. 0-70°C). A thermistor is a resistor which is specially designed to have a highly temperature dependent resistance. While all resistors exhibit some degree of temperature dependence (often in the range of 10-100 ppm/°C), the resistance of a typical thermistor can change by as much as 4%/°C (40,000 ppm/°C).

One disadvantage of using a thermistor is that the resistance is an extremely non-linear function of temperature, and is often approximated as an exponential function. Figure 1 shows the resistance vs. temperature characteristic for a ‘typical’ negative temperature coefficient thermistor (Beta₀-50° = 3890), normalized to a value of ‘1.00’ at 25°C.

Figure 1. Resistance vs. Temperature Response of Thermistor
While look-up table techniques can be used to accurately derive temperature from a measured resistance, there are also simple and inexpensive analog circuit techniques that can provide a significant degree of linearization over limited measurement ranges. One example of such a linearization circuit is the balanced bridge shown in Figure 2.

**Figure 2. Differential Bridge Bias Circuit**

![Differential Bridge Bias Circuit](image)

In this circuit, the relationship between output voltage ($V_{OUT}$) and the resistance of $R_{TH}$ is given by:

$$V_{OUT} = V_{BIAS} \left( \frac{R_{TH}}{R_{TH} + R_{REF}} - 0.5 \right)$$

(1)

A graph illustrating this relationship for $R_{REF} = 10k\Omega$, and $R_{TH}$ varying over the range of 1kΩ to 100kΩ is shown in Figure 3.

**Figure 3. Bridge Output voltage vs. Thermistor Resistance**

![Normalized Bridge Output Voltage vs. Resistance](image)

Over a limited range, the relationship between thermistor resistance and bridge output voltage is very nearly logarithmic. The thermistor's resistance varies as a nearly exponential function of temperature. Combining these two non-linear functions results in a bridge output voltage that is close to a linear function of temperature over a small temperature range surrounding the zero-voltage output temperature (25°C). A graph of this combined function is shown in Figure 4.
Signal Conditioning with the ispPAC30

The Lattice ispPAC30 programmable analog circuit can be used to both bias the bridge, and to provide adjustable span (gain) and offset correction. Figure 5 shows a complete ispPAC30-based thermistor interface circuit.

A stable bridge bias source is necessary because the span of the bridge output is linearly dependent on the bridge bias voltage. Errors in bridge bias translate directly into measurement errors for non-zero bridge voltage outputs. A stable bridge bias voltage is developed in this circuit by the combination of VREF1, IA2, and OA1. By suitable choices for VREF1’s output voltage and IA2’s gain, bias voltages in the range of 0 to 5 V can be readily set. Additionally, the high output current drive capabilities of OA1 (up to 30 mA) ensure the ability to drive even bridges with resistances down to a few hundred ohms.

An appropriate choice of bridge bias voltage is influenced by several factors. A larger bridge voltage will result in a higher output sensitivity (V/°C), reducing the measurement errors introduced by amplifier input offset voltage. A larger bridge voltage, however, will also increase errors caused by self-heating effects in the thermistor. Finally,
because the common-mode input voltage range of the ispPAC30 ranges from 0-2.8V, the bias voltage should be chosen so that the bridge’s output voltage is safely within this range.

IA3 and MDAC1 control the amplification of the bridge output voltage, and therefore the span of the output voltage seen at OUT2. IA3’s gain can be adjusted from -10 to +10 in steps of 1, while MDAC1 can be adjusted to provide gains from -1 to +0.994 in steps of approximately 0.008. Paralleling IA3 and MDAC1 provides a total gain adjustable from -11 to +10.99, with better than 0.1% resolution.

Offset adjustment is provided by the combination of VREF2 and MDAC2. By selecting suitable settings for these two functions, offset voltages ranging over +/-2.5V can be added to OUT2.

As an example of how the ispPAC30 can be used, consider a bridge based on a 10K thermistor, providing the response of Figure 4. At a bias of 2.5V, the sensitivity will be ~30mV/°C, with 0V differential output at 25°C. By providing a gain of -3.6 through IA2 and MDAC1, this can be raised to ~100mV/°C. Finally, by adding a 2.5V offset with VREF2 and MDAC2, an output voltage of 2.5V at 25°C can be achieved. The ispPAC30’s output as a function of temperature is shown in Figure 6, and can be seen to be substantially linear from 0°C to 40°C. Other output spans and offsets can be easily accommodated by varying the setting stored in the MDACs and IAs.

**Figure 6. ispPAC30 Output Voltage (OUT2) vs. Temperature**

The ispPAC30 can be used as the basis for a flexible, single-chip thermistor interface circuit, providing a high-level linearized voltage output. Bridge bias, and amplifier gain and offset parameters can all be permanently stored in the ispPAC30’s non-volatile EE memory, or can be dynamically loaded on-the-fly through the device’s SPI or JTAG interfaces.

**Technical Support Assistance**

Hotline: 1-800-LATTICE (Domestic)
1-408-826-6002 (International)
e-mail: ispPACs@latticesemi.com