ispPAC®10 Low Cost Temperature Measurement

Introduction

This application note describes how to use the ispPAC10 and a single transistor to implement a low-cost temperature measurement system. The temperature measuring device is a 2N2222A transistor. In-System Programmability (ISP™) enables programming, verification and reconfiguration directly on the printed circuit board using the IEEE standard 1149.1 compliant serial port.

The ispPAC10 contains four integrated programmable analog modules known as PACblocks and a programmable interconnect system (Figure 1). Each PACblock emulates a collection of op amps, resistors and capacitors. The ispPAC10 is easily configured using PAC-Designer®, a Windows®-based design environment. The temperature measuring system requires only a single PACblock but can include in-system programmable offset cancellation and gain adjustment to “zoom in” for higher resolution measurements.

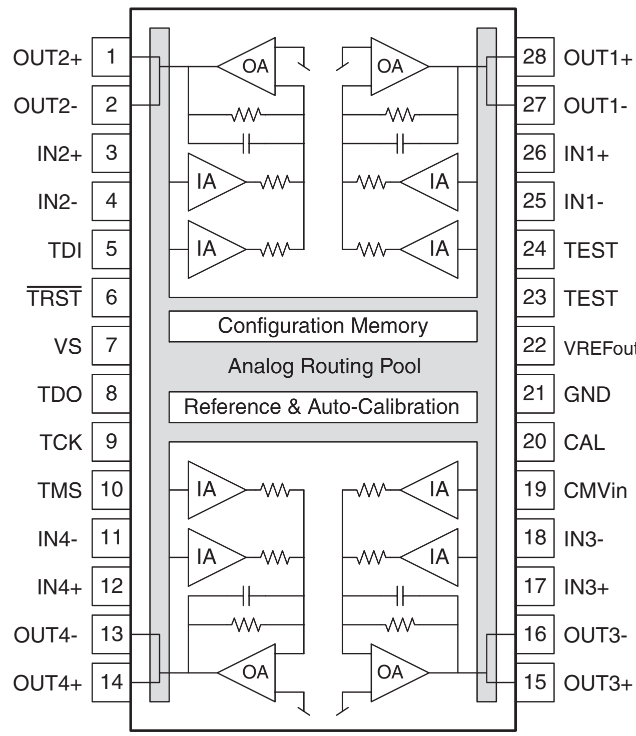
Silicon PN junctions exhibit a change in potential inversely proportional to temperature, which is approximately -2.2 mV/°C over a wide temperature range. This phenomenon can be used to make a low-cost, fast-response temperature sensor. While commercial devices are available that specify the nominal junction V_{BE} and the junction’s temperature coefficient, not all temperature measurement systems require such precision. In these cases, a common diode or bipolar transistor can serve as the temperature-sensing element. Figure 2 shows a circuit for such a case.

This circuit uses a PACblock output as a stable 2.5V reference to bias the transistor. By default, the PAC-Designer software configures unused PACblocks to output 2.5V. This voltage is generated internally using a bandgap reference and is available externally at the $VREF_{OUT}$ output. However, $VREF_{OUT}$ is strictly a reference and is not capable of sourcing any current. Therefore, it is not usable as a source without some kind of buffering. A PACblock whose output is a voltage source capable of supplying 10mA is ideal as a buffer for $VREF_{OUT}$. If another reference is available, this may be used in place of a PACblock to bias the 2N2222A.

Circuit Details

The resistor R_1 establishes the nominal collector current (I_C) for the transistor. A transistor’s current gain (beta) varies with the collector current, so the value of I_C is chosen to be large enough to ensure that the transistor achieves a good beta value. This can be determined by referring to the transistor’s data sheet or by measurement. In Figure 2, R_1 equals 19.1 kΩ which establishes a collector current of about 100 µA, assuming a nominal V_{BE} of 590 mV.

Figure 1. ispPAC Block Diagram



A PACblock input is true differential, which means it will amplify the difference between its two inputs. It is desired to have this difference be equal to 0V at some (reference) temperature. With a voltage dependent on the transistor’s V_{BE} connected to the positive input, a constant reference value for comparison must be connected to the minus input. Resistors R_2 and R_3 form a voltage divider whose purpose is to generate a voltage nominally equal to the transistor’s V_{BE}. That is, the voltage drop across R_2 should equal the V_{BE} of the transistor at the reference temperature. In the circuit shown, R_2 and R_3 were chosen to provide 590mV across R_2, to match the nominal V_{BE} of the 2N2222A at room temperature.

Figure 2. Temperature Measurement Circuit

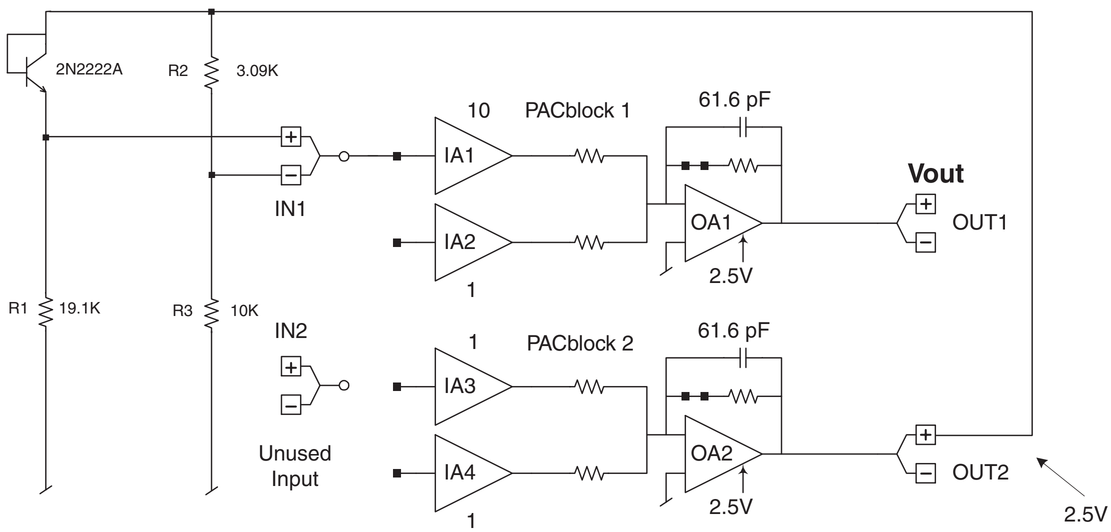
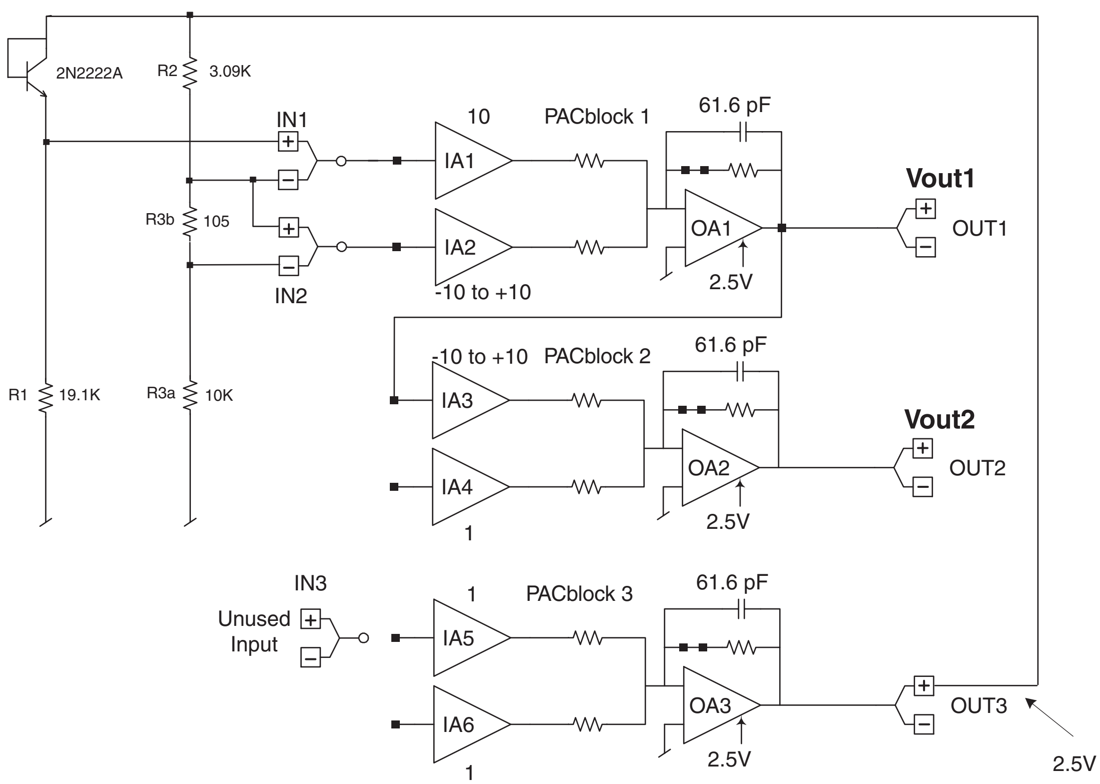


Figure 3. Temperature Measurement Circuit with Offset Cancellation



Using PAC-Designer, a single PACblock is configured to a gain of 10 and the PACblock filter pole is set to its lowest frequency value to minimize noise at the output. In this circuit, the change in output voltage is proportional to the change in transistor temperature with a slope of 24.7 mV/°C. The dynamic range of the circuit is over 250°C. Additional gain can be provided by internally cascading the circuit output (Output 1) into another PACblock input.

Adding Offset Compensation

When the output voltage does not equal the desired value at a specified temperature, an offset exists. It can sometimes be introduced by the amplifying element, but in this case it is largely due to the voltage drop across R_2 not equaling the V_{BE} of the transistor. Figure 3 shows a circuit that adds software-configurable offset. This circuit, as shown, functions primarily to allow the output voltage to be set to any desired value at room temperature, compensating for transistor static V_{BE} variations.

In this circuit, resistor R_{3b} is added in series with R_2 and R_{3a} and connected to Input 2 of the ispPAC10. For the values shown in Figure 3, the voltage across R_{3b} (V_{R3b}) is about 20mV. Because the PACblock allows summation, V_{R3b} can be amplified and/or inverted before adding it to the 2N2222A temperature sensing input. This can be done using in-system programmability, which makes possible an automated test and adjust system. Since the PACblock has a gain range of ±10, system offset up to ±200 mV can be added in 20 mV steps. This range is equivalent to about ±8.5 degrees. If more or less offset is desired, the value of R_{3b} can be changed; increasing R_{3b} increases the range of available offset but decreases the resolution. Again, if more gain is desired, the circuit output (Output 1) can be internally cascaded into the input of another PACblock, whose output is shown as Output 2 in Figure 3.

This circuit can also be used to set the output voltage to a desired value at any given temperature. Resistor R_2 is the coarse adjustment and R_{3b} the fine adjustment to do this. In Figure 3, the change in output voltage increases (becomes more positive) for an increase in R_2. For example, increasing R_2 by 10% lowers the Input 1 reference voltage by approximately 7.5%. This results in the output voltage increasing by about 440mV, corresponding to a temperature change of approximately -18°C. "Zooming in" around the desired temperature is still accomplished by changing the gain and/or polarity (using in-system programmability) of the ispPAC10 input connected across R_{3b}.

Results

The circuit in Figure 3 was built and the output versus temperature was measured using a random population of 2N2222As, with the composite result shown in Figure 4. The result is very linear over the temperature range used. Figure 5 is a series of histograms of the circuit's output at various temperatures for the population. This data shows that at all temperatures, the total variation is only about ±1.2 degrees.

Figure 4. Temperature Measurement Results

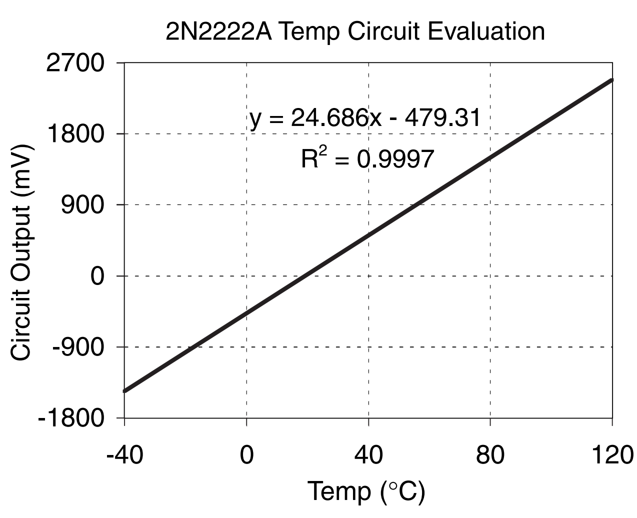
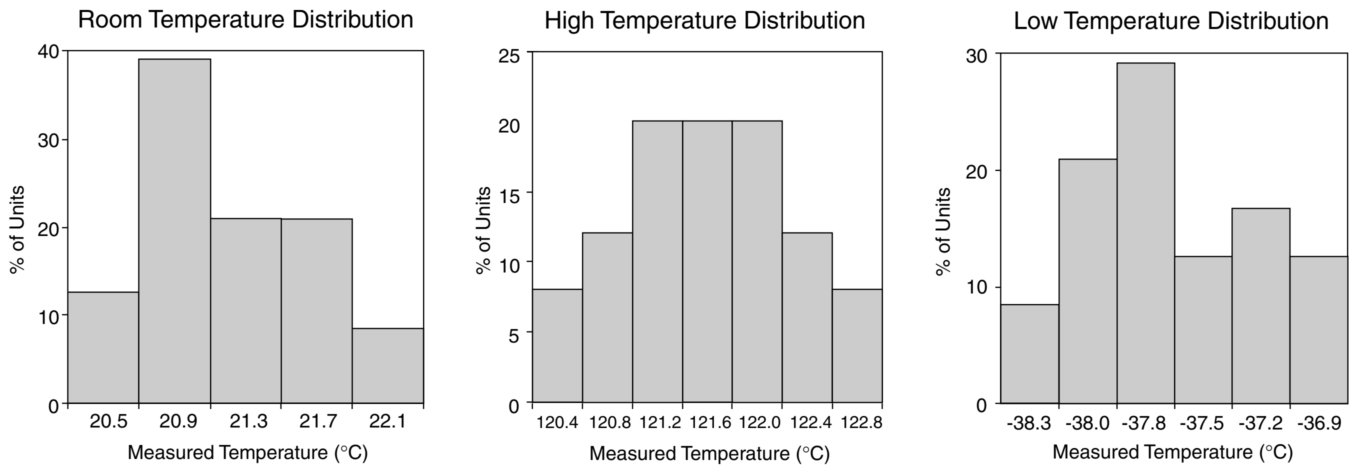


Figure 5. Variation Across Transistor Population



Impact of ispPAC10 Specifications

The ispPAC10 gain specification of ±3.0% affects the slope of the temperature measurement curve. With the offset adjusted to provide a known output at some temperature, the IC's gain error causes a corresponding error in the temperature value of up to 3.0%. For example, at a temperature 100° away from where the offset was normalized, the error could be ±3.0°C. Since it is systematic, this error could be eliminated with a multipoint calibration. However, even without this extra effort, the combination of the transistor characteristic and ispPAC10 gain error results in a measurement error of less than 3.3° over a 100° span.

The ispPAC10 offset does not affect the measurement accuracy. Using the auto-cal feature, the typical offset specification of the ispPAC10 is 200µV. Because of the device architecture, this same level is present at the output regardless of gain. This corresponds to less than 0.01°C of error, which is insignificant in this measurement.

Summary

The ispPAC10 is a versatile component for analog signal processing. In this case, a simple, low-cost temperature measurement system is realized using a readily-available 2N2222A transistor. The ispPAC10 provides gain and filtering and makes it possible to perform automatic offset adjustment. The resulting circuit is highly linear over a wide temperature range. The repeatability is dependent on the junction characteristics of the device used and was found to be within a few degrees over a 160° span for the 2N2222A transistor used.

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