Application Report

Remote Temperature Sensor Transistor Selection Guide

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ABSTRACT

Remote temperature sensors use bipolar junction transistors (BJTs) to measure temperature. This application report investigates the performance of twenty BJTs of varying sizes and packages that can be used for remote temperature sensing. The transistors were tested using the TMP468EVM in an oil bath, and the data was used with the Remote Temperature Sensor Calibration Tool to calculate η-factor correction and offset register settings to minimize temperature errors with each BJT. The results were used to make recommendations on selecting a transistor to use with Texas Instruments' remote temperature sensors. This application report describes the background and procedure for testing the devices, presents the optimization results, and discusses considerations in choosing one of these transistors.

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1 Introduction

Remote temperature sensors measure the temperature of an external transistor by measuring the base-emitter voltage (V_{BE}) of the BJT, which depends on temperature. One method of determining a transistor base-emitter voltage is the two current method, using the difference of two voltage measurements to calculate temperature, as shown in Figure 1-1. However, thermal diode signals can be sensitive to noise, series resistance, and variation in transistors' η-factors and betas can introduce additional errors if not accommodated.

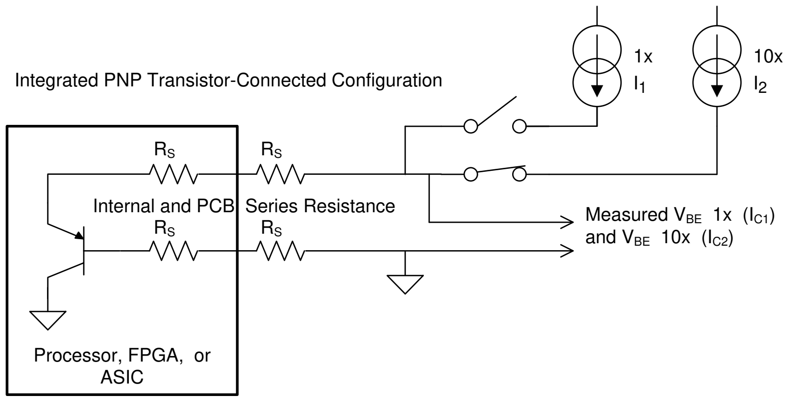

Figure 1-1. ΔV_{BE} Measurement with Two Currents

1.1 Series Resistance

Any resistance in PCB traces will cause a voltage drop between the actual V_{BE} at the transistor and the measured V_{BE} at the temperature sensor, which results in a temperature offset. Using three different current level measurements shown in Figure 1-2, a certain amount of series resistance can be canceled out when solving for temperature.

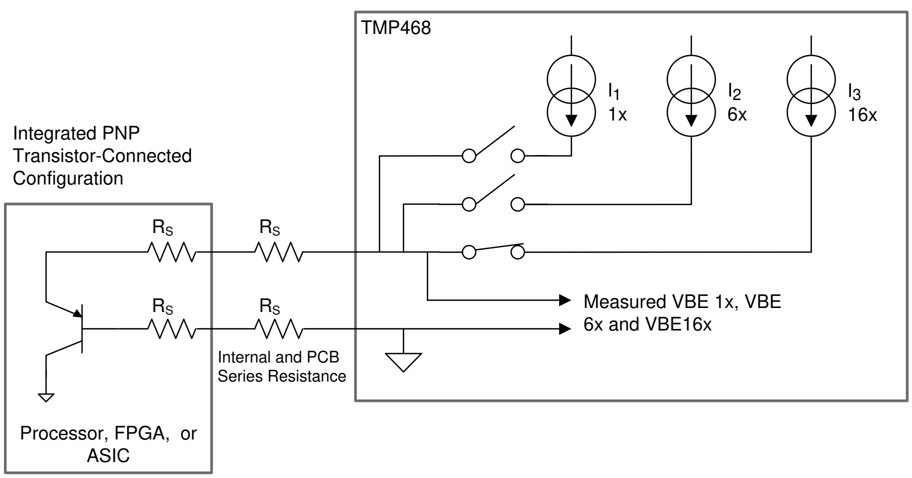

Figure 1-2. ΔV_{BE} Measurement with Three Currents

1.2 Variation of η-Factor

Remote temperature sensors are typically calibrated for transistors with an η-factor of 1.008, but transistors may have η-factors that differ from this. If the value is known, an η-factor correction register can be used to correct the error resulting from a deviation of the calibrated η-factor. A combination of offset and η-factor correction settings can correct for both η-factor errors and other system errors that are present. The Remote Temperature Sensor Calibration Tool can calculate the optimal offset and η-factor correction settings for a given data set, and these register settings can be used with devices such as the TMP468, which includes an independent register for each remote input.

1.3 Variation of Beta

The ratio between the emitter and collector current can be expressed as the reciprocal of beta plus 1 and directly affects temperature readings. Thus, transistors with larger betas experience negligible error due to beta variation, while transistors with beta less than 1 can have large temperature measurement errors as beta approaches 1. Remote temperature sensors with beta compensation, such as the TMP431, can correct for these errors, and devices without beta compensation but with offset and η-factor correction registers can also compensate for beta variation.

2 Transistor List

Table 2-1 lists the transistors tested and their relevant specifications. In addition, a transistor selected for remote temperature sensing should also satisfy the following criteria.

1. Base-emitter voltage is greater than 0.25 V when collector current is 6 µA, at the highest-sensed temperature.
2. Base-emitter voltage is less than 0.95 V when collector current is 120 µA, at the lowest-sensed temperature.
3. Base resistance is less than 100 Ω.
4. Variations in h_{FE} are small (50 to 150).
5. There is small lot to lot variation.
6. η-factor is consistent across temperatures.

Table 2-1. Transistor List and Specifications

Transistor Part Number	Package	Size	Grade	Operating and Storage Temperature Range (°C)	Type of BJT (NPN/PNP)
MMBT3904FZ-7B	DFN0606-3	0.36 mm^2, 0.6 x 0.6	Industrial	-55 to +150	NPN
MMBT3906FZ-7B	DFN0606-3	0.36 mm^2, 0.6 x 0.6	Industrial	-55 to +150	PNP
BC847BFZ-7B	DFN0606-3	0.36 mm^2, 0.6 x 0.6	Industrial	-55 to +150	NPN
MMBT3904FA-7B	DFN0806-3	0.48 mm^2, 0.8 x 0.6	Industrial	-55 to +150	NPN
MMBT3906FA-7B	DFN0806-3	0.48 mm^2, 0.8 x 0.6	Industrial	-55 to +150	PNP
MMBT3906LT1G	SOT-23	3.77 mm^2, 2.9 x 1.3	Automotive	−65 to +150	PNP
MMBT3904LP-7B	DFN1006-3	0.6 mm^2, 0.6 x 1.0	Industrial	-55 to +150	NPN
MMBT3904LT1	SOT-23	3.77 mm^2, 2.9 x 1.3	Automotive	−65 to +150	NPN
2SCR523MT2L	SOT-723	1.44 mm^2, 1.2 x 1.2	Industrial	-55 to +150	NPN
DP0150BLP4-7	DFN1006-3	0.6 mm^2, 0.6 x 1.0	Industrial	-55 to +150	NPN
BC847BFA-7B	DFN0806-3	0.48 mm^2, 0.8 x 0.6	Industrial	-55 to +150	NPN
BC857BFA-7B	DFN0806-3	0.48 mm^2, 0.8 x 0.6	Industrial	-55 to +150	PNP
PMBT3904MB,315	DFN1006B-3	0.6 mm^2, 0.6 x 1.0	Industrial	−65 to +150	NPN
PMST3904,115	SOT-323	2.5 mm^2, 2.0 x 1.25	Industrial	−65 to +150	NPN
MMBT2907	SOT-23	3.77 mm^2, 2.9 x 1.3	Industrial	-55 to +150	PNP
JANTX2N2907A	TO-18	5.6 mm base diameter	Space	-65 to +200	PNP
JANTXV2N2946A	TO-46	5.6 mm base diameter	Space	-65 to +200	PNP
JANTXV2N2222AUB	3-SMD, no lead	7.6 mm^2, 3.1 x 2.5	Space	-65 to +200	NPN
JANTX2N930	TO-18	5.6 mm base diameter	Space	-55 to +200	NPN
JANTX2N350	TO-39	9 mm base diameter	Space	-65 to +200	NPN

3 BJT Test Board

Figure 3-1 shows the three possible configurations for remote temperature sensing with BJTs using the TMP468EVM. The transistors included in these tests were used in the NPN or PNP diode-connected configurations, and Figure 3-2 shows the test board designed to connect eight of each BJT in Table 2-1 to the TMP468EVM, which can measure temperatures of up to eight remote transistors at once.

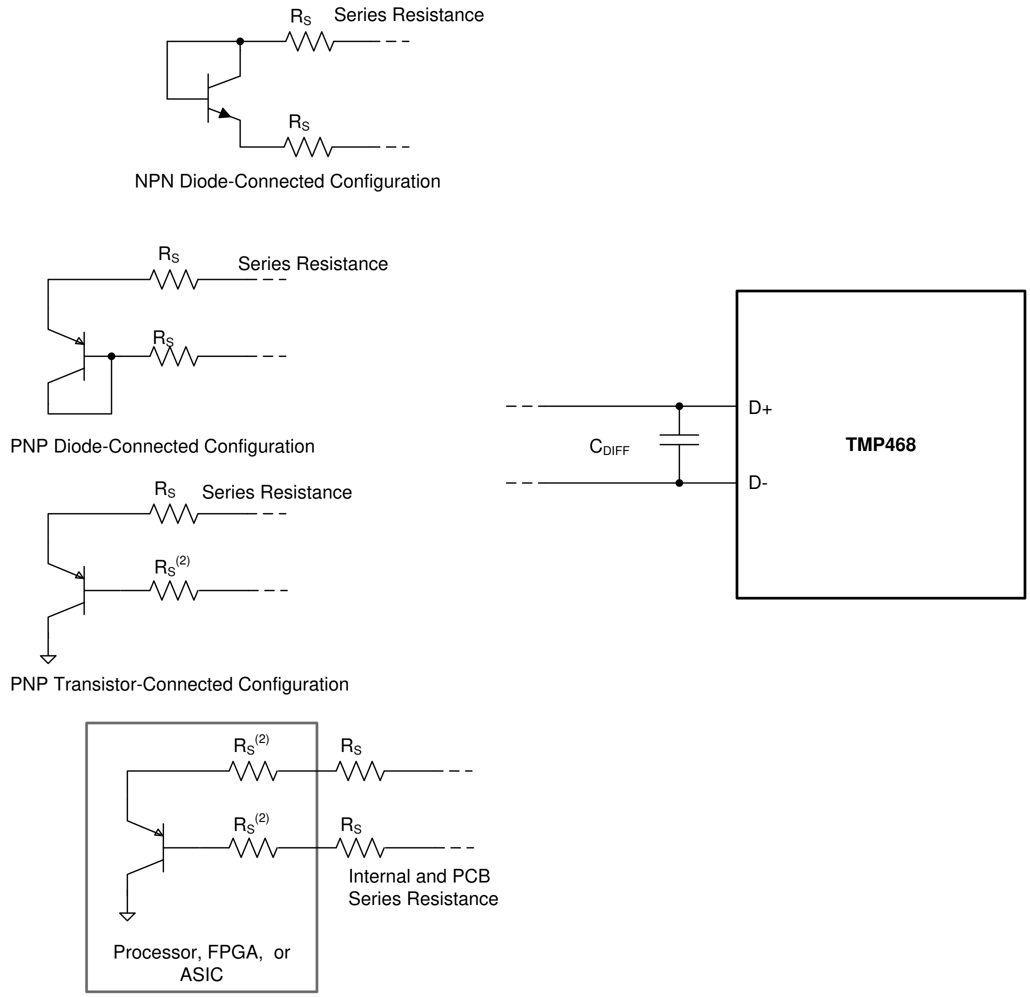

Figure 3-1. Remote Junction Configurations

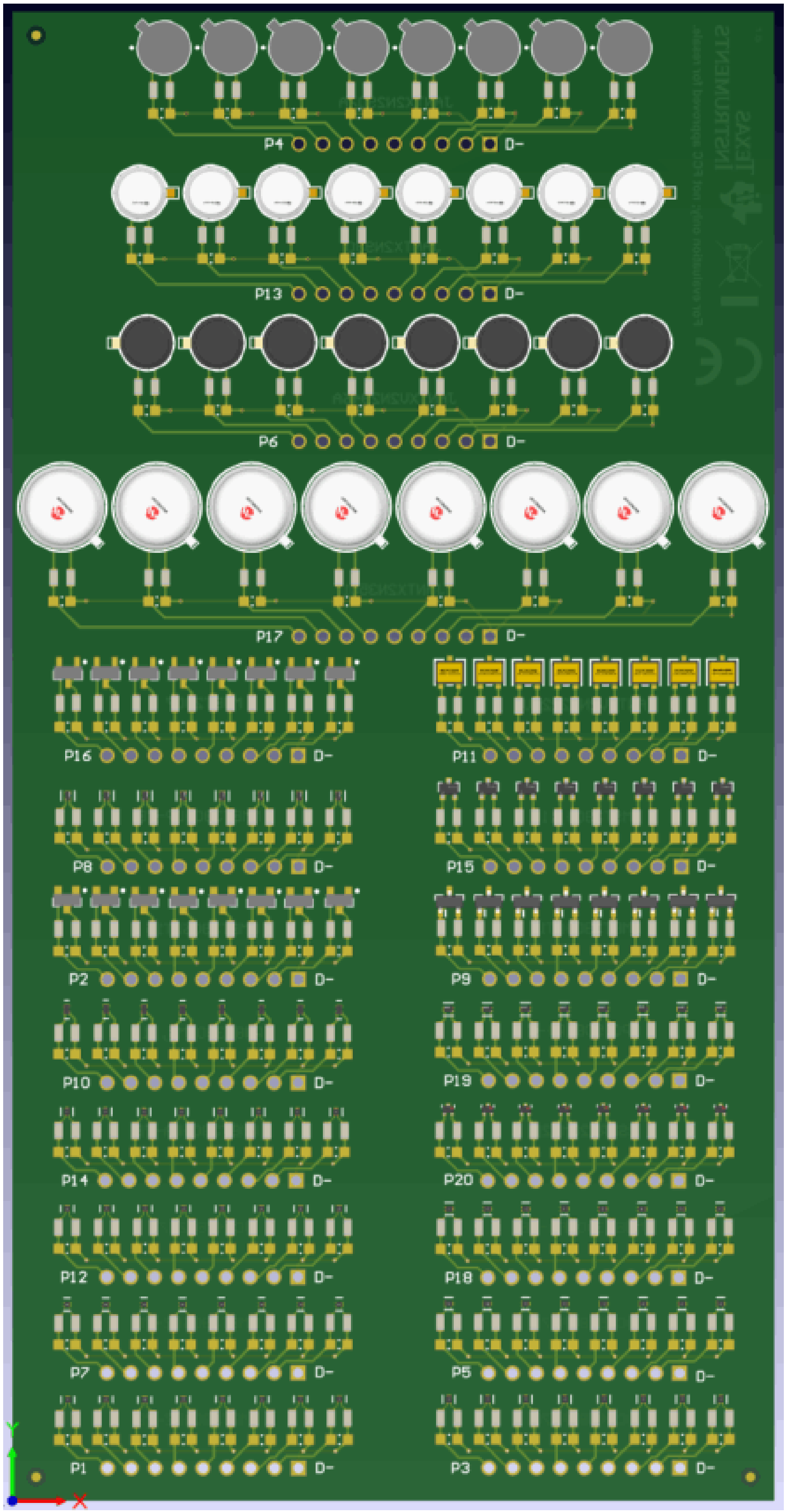

Figure 3-2. BJT Test Board

4 Test Procedure

Test Hardware

- TMP468EVM
- BJT test board
- Temperature oil bath
- Reference temperature probe

To test the BJTs, one set of transistors was connected to the TMP468EVM at a time. The BJT portion was placed in the oil bath, and temperature was swept from -40°C to 150°C in steps of 10°C. Once stabilized, temperature readings from the temperature probe and the TMP468 for the eight BJTs were recorded at each temperature step, using default settings on the EVM for η-factor correction and offset. The Remote Temperature Sensor Calibration Tool was run on the data to calculate η-factor and the η-factor correction register setting, as well as the optimal settings using both the η-factor correction and offset registers. This procedure was repeated to test all twenty sets of BJTs.

5 Data and Recommendations

The data collected was optimized for each transistor using the Remote Temperature Sensor Calibration Tool. Table 5-1 presents the results, including the η-factor register settings, offset register settings and recommended temperature range. These settings and the recommendations below are applicable only to Texas Instruments' remote temperature sensors. The recommended temperature range was limited for BJTs that showed large variance when exceeding this range. This data was collected only on limited sample size and does not account for lot to lot variations over time. Some transistors were removed from the table as part to part variation was too large to recommend.

The following recommendations were made by considering two criteria. First, the errors after optimizing the η-factor correction and offset register settings should be within ±1°C across the recommended temperature range. Second, among the eight channels that were tested for each device, the temperature measurements should be consistent, indicating little variation from device to device.

Table 5-1. Transistor Setting Recommendations

Transistor Part Number	η-Factor value	Offset value (°C)	η-Factor and Offset Settings (TMP468 hex values)		Recommended Temperature Range (°C)
			η-Factor	Offset	
MMBT3906FZ-7B	1.009934741	0.6875	0xFC00	0x0058	-20 to 125
BC847BFZ-7B	1.00945036	1.4375	0xFD00	0x00B8	-40 to 125
MMBT3904FA-7B	1.011876	2.4375	0xF800	0x0138	-40 to 110
MMBT3906FA-7B	1.014315	2.1875	0x0F3	0x0118	-40 to 125
MMBT3906LT1G	1.014315	1.3125	0x0F3	0x00A8	-40 to 125
MMBT3904LP-7B	1.008	0.00	0x0000	0x0000	-40 to 150
MMBT3904LT1	1.0070354	0.75	0x0200	0x0060	-40 to 125
2SCR523MT2L	1.006553802	0.25	0x0300	0x0020	-40 to 150
DP0150BLP4-7	1.016765217	1.875	0xEE00	0x00F0	-40 to 125
BC847BFA-7B	1.00945036	2.0	0xFD00	0x0100	-40 to 150
JANTX2N2907A	1.00945036	1.25	0xFD00	0x00A0	-40 to 110
JANTXV2N2222AUB	1.0070354	0.00	0x0200	0x0000	-40 to 125
JANTX2N930	1.00945036	1.0625	0xFD00	10x0088	-40 to 150

6 Summary

While many of the BJTs were able to achieve temperature errors within ±1.0 °C with optimized settings, the temperature range had to be limited for BJTs that had large variations at the high and low end of tested temperature range. Some BJTs could not be recommended because of large part to part variations throughout the tested temperature range. The MMBT3906LT1G, 2SCR523MT2L, BC847BFA_7B, and JANTX2N930 were able to stay with a ±1.0 °C temperature error across the entire temperature range. Too much device to device variation was observed to recommend on the MMBT3904FZ-7B, BC857BFA_7B, PMBT3904MB_315, PMST3904_115, MMBT2907, JANTX2N2946AA, and JANTX2N3501.

Related Devices

- TMP400
- TMP401
- TMP411
- TMP421
- TMP422
- TMP423
- TMP431
- TMP435
- TMP441
- TMP442
- TMP451
- TMP461
- TMP464
- TMP468

Related Documentation

1. Optimizing Remote Temperature Sensor Design, application report.
2. Remote Temperature Sensor Calibration Tool