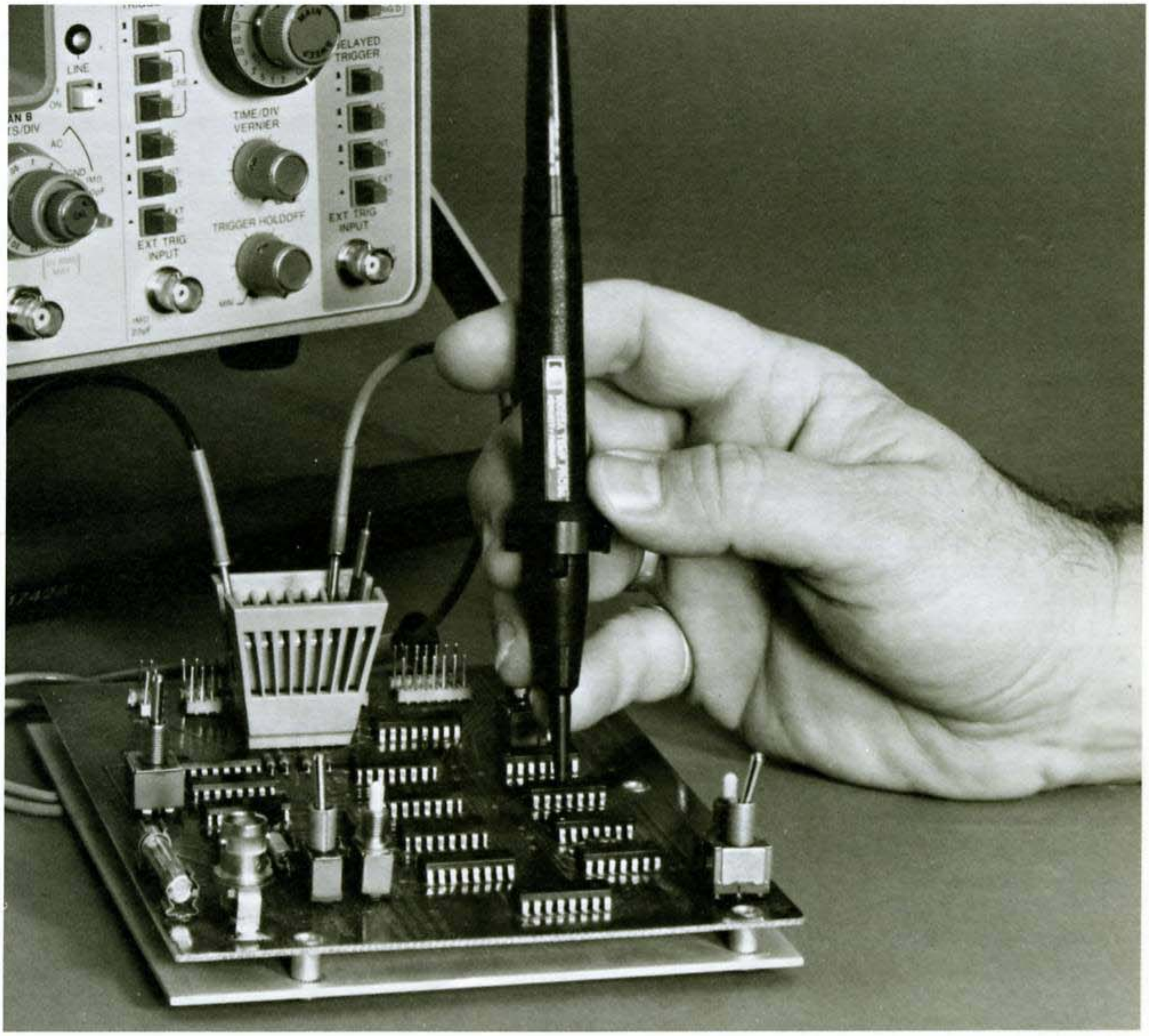
APPLICATION NOTE 263

THERMAL MEASUREMENTS OF ELECTRONIC COMPONENTS USING THE HEWLETT-PACKARD TEMPERATURE PROBE.



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INTRODUCTION

Operating temperatures of electronic components are the nemesis of all electronic designers. Difficult to calculate, subject to numerous real-life variables — thermally overstressed components are probably the single most important contributor to reliability problems in electronic devices.

The Hewlett-Packard Model 10023A Temperature Probe is an excellent tool for empirically determining the temperature of practically any electronic component. Direct temperature readouts in degrees Celsius are obtained with any high input impedance (≥10 MΩ) digital voltmeter. The pencil-like probe has a small sensor in the tip for making measurements on small components located in densely packed circuits. The measurement temperature range is —55°C to 150°C.

With the 10023A temperature probe you can spot-check PC board component temperatures or evaluate heat-sink performance for power-semiconductor devices by measuring case-to-heat-sink thermal drop. You can also conveniently make measurements to determine whether components are operating near their maximum rating. By using the calibration procedures described in this application note, you can obtain a good estimate of the junction temperature of a transistor by measuring the transistor case temperature.

To make a surface measurement, touch the probe tip to the component of interest, press the readout micro-switch, and wait for the voltmeter readout to stabilize. Optimum thermal transfer occurs when the surface of the component to be measured is coated with a thin coat of silicone thermal joint compound. Vary the probe angle slightly from perpendicular to obtain the best contact between the component and the probe sensor — the highest stabilized reading is the most accurate. The probe tip is electrically isolated so that temperature measurements can be made on electronic component surfaces which are up to 600 volts from ground.

SOURCES OF THERMAL MEASUREMENT ERRORS

When measuring the temperature of any solid surface, a temperature probe inherently creates some errors. The temperature of a component that is warmer than ambient temperature reads lower than the actual temperature. This difference between indicated and actual temperature is due to the combined effects of two physical phenomena:

1. Heat flows from the surface being measured through the sensor to the probe body, which is generally near ambient temperature. This heat flow creates a temperature gradient between the measured surface and the sensing device in the probe tip. The effect of this steady-state error increases as the differential between ambient and surface temperature increases. Although the probe design geometry reduces errors from this effect, anyone requiring more accurate absolute temperature measurements may wish to correct the readings. For this purpose a thermal gradient correction curve for the 10023A temperature probe is provided in figure 1.

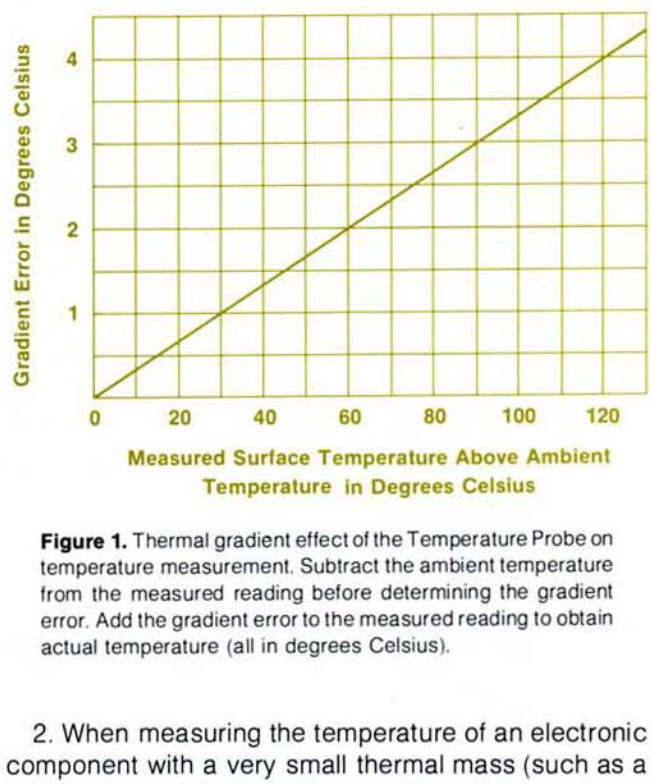

Figure 1. Thermal gradient effect of the Temperature Probe on temperature measurement. Subtract the ambient temperature from the measured reading before determining the gradient error. Add the gradient error to the measured reading to obtain actual temperature (all in degrees Celsius).

2. When measuring the temperature of an electronic component with a very small thermal mass (such as a transistor case) the heat flow can be sufficient to lower the temperature of the surface being measured. This phenomena is analogous to the voltage change in a high impedance electrical circuit due to voltmeter loading. The Temperature Probe has very high thermal isolation to minimize the effect of this heat sinking error source. Figure 2 illustrates the combined errors due to both thermal gradients and heat sinking for TO-5 and TO-18 transistor cases.

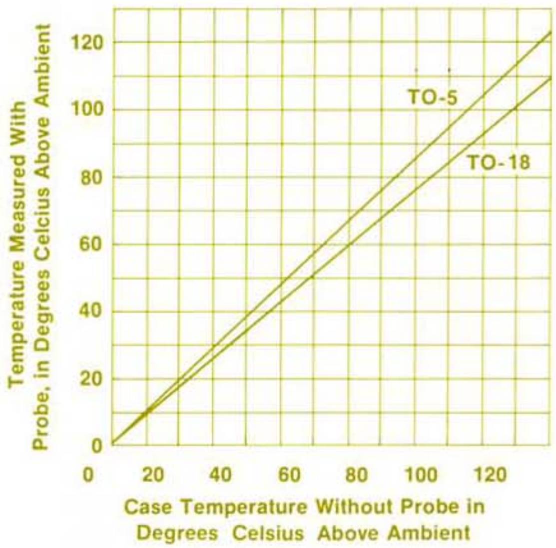

Figure 2. Typical decrease in device case temperature in degrees Celsius due to the combined temperature probe thermal gradient and heat-sinking effects on different transistor packages. Note that ambient temperature must be subtracted from the measured reading before using the correction curve.

JUNCTION TEMPERATURE MEASUREMENTS

In addition to electronic component surface temperature measurements, a circuit designer frequently needs to know the power input and junction temperature of a transistor. With a little effort, the power input can be determined by looking at the voltages and currents at the input ports, but the junction temperature cannot be easily determined. Junction temperature is a function of power input, ambient temperature, and thermal resistance between a) junction and case, and b) case and local ambient.

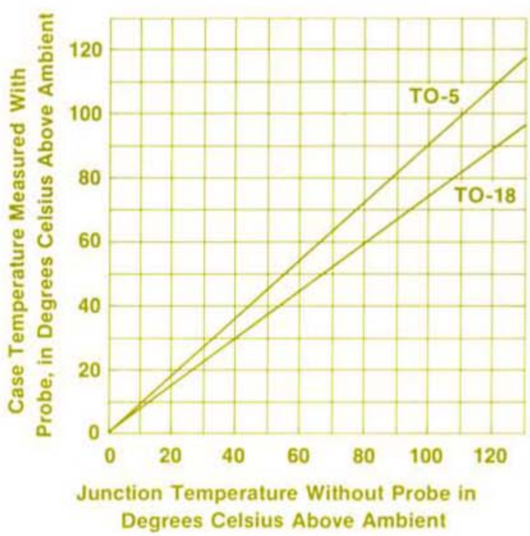

Figure 3. Measured Case Temperature vs Junction Temperature.

With the calibration procedure described in this application note, you can determine both the junction temperature and the corresponding average power input by simply making transistor case temperature readings with the Temperature Probe. The graphs of figures 3 and 4 illustrate the relationship between the probe indicated case temperature above ambient, the transistor junction temperature without temperature probe influences (figure 3) and the actual transistor power input (figure 4).

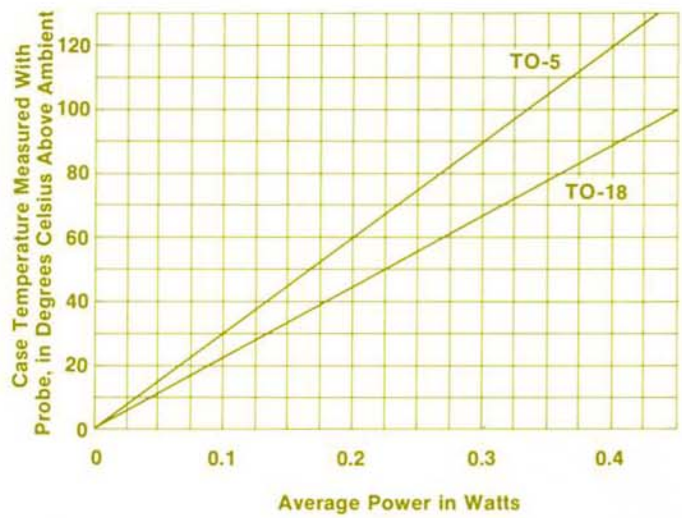

Figure 4. Measured Case Temperature vs Power.

MEASUREMENT THEORY

With a small constant sensing current, the base-to-emitter or collector-to-base junction of a silicon transistor exhibits a linear relationship between the junction forward-voltage drop and junction temperature. By first calibrating this relationship for a particular transistor, the transistor can then be used to construct conversion charts of juntion temperature and input power versus measured temperature above ambient.

Experimental analysis has demonstrated that a pair of conversion charts developed for one transistor type also applies to another transistor type with the same packaging geometry. Transistor mounting differences such as the use of external heat sinks, significant differences in PC board material, transistor lead lengths, use of transistor mounting sockets, etc., will affect the conversion chart corrections. Therefore, the transistor mounting used in the conversion chart development process should be as similar to that of the in-circuit transistors as possible.

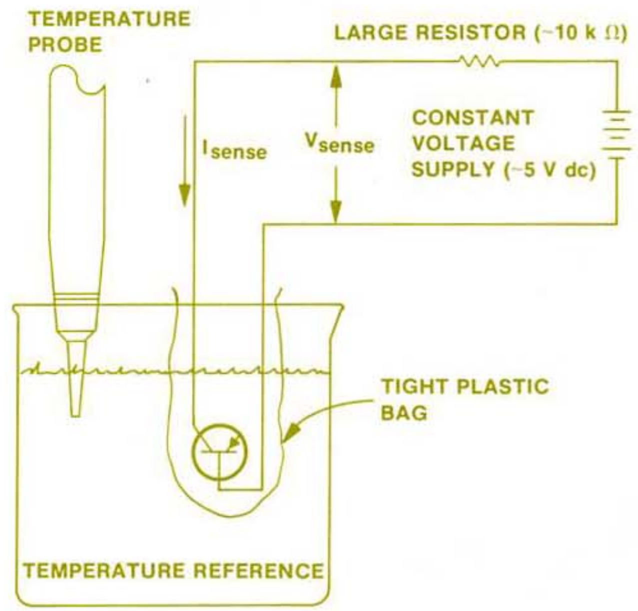

Figure 5. Sample method for obtaining the transistor forward-voltage drop to temperature relationship.

CONVERSION CHART DEVELOPMENT PROCEDURE

Part I. — Determine the transistor forward-voltage drop to temperature relationship.

To do this, a temperature reference, a constant-current source, and a millivoltmeter is required. A two-point temperature reference can be obtained from a beaker of ice water and a beaker of boiling water. The constant-current source can be a large resistor (~10 kΩ) and a constant voltage supply (~5 V dc). Please refer to the calibration circuit illustrated in figure 5. The sensing current must be small enough to not heat the junction — approximately one percent of the transistor operating current. If the sensing current is too small to achieve a stable voltage reading, use a low duty cycle pulse and a higher amplitude sensing current.

Place the transistor in a small, tight plastic bag and immerse in the ice water temperature reference. While using a stirring motion to maximize heat transfer, allow 2 to 3 minutes for the transistor temperature to stabilize. Measure and record both V_{sense} and the ice bath temperature. Using the same I_{sense} value as before, immerse the transistor in the boiling water temperature reference. Again, stir for approximately 2 to 3 minutes to allow the transistor temperature to stabilize. Measure and record both V_{sense} and the boiling water temperature. Although the relationship between V_{sense} and temperature is linear, you may wish to develop confidence in the technique by obtaining more data points at additional reference temperatures and plotting the data. Now you can determine the junction temperature by measuring V_{sense} (as long as the same value of I_{sense} is applied).

Part II. — Develop the conversion charts of measured case temperature versus junction temperature and input power.

First mount the transistor (used in Part I) in the same packaging environment experienced in the actual circuit (e.g., heat sink, circuit board, lead length, etc.). Build circuit shown in figure 6 making sure that I_{sense} is same value used in Part I and that P_{heat} (calculated as $V_{heat} \times I_{heat}$) is large enough to provide heating up to working temperatures. The circuit allows switching between a heating input (P_{heat}) and a sensing input (V_{sense}, I_{sense}). To construct conversion charts, follow steps 1 through 6.

1. In the heat input position, allow the junction operating temperature to stabilize by maintaining constant power input for approximately 5 minutes. Record the power input (P_{heat}).
2. Switch to the sensing input position momentarily and obtain a reading of V_{sense}.
3. Switch back to the power input position and check the power input, it should not have changed from step 1. Place the temperature probe on the junction case and record the temperature (T_c). Also record ambient temperatures.
4. Increase power input (P_{heat}) and repeat steps 1 through 3 to obtain at least one more set of values.
5. Convert V_{sense} readings to junction temperature (T_j) by using the relationship established in Part I.
6. Construct a conversion chart similar to figure 4 of power input (P_{heat}) vs temperature probe reading (T_c) minus ambient temperature; and construct a second conversion chart similar to figure 3 of junction temperature (T_j) minus ambient vs temperature probe reading (T_c) minus ambient.

Following these steps gives you a more precise measurement than using the standard conversion charts (figures 3 and 4) since the charts are constructed with data from a device configured to match its operational environment. The procedure also allows you to construct accurate conversion charts for unique or specially designed semiconductor packages.

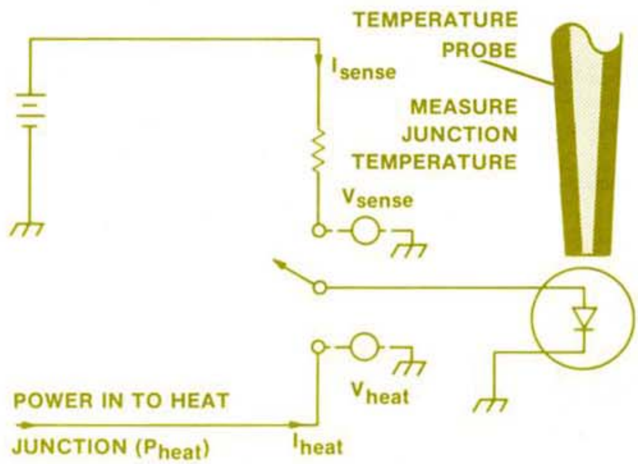

Figure 6. Switching circuit for obtaining required measurements to construct conversion graphs for specific devices in their actual operation environment.

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