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Thermal Impedance Measurements for Bipolar Transistors (Delta Base-Emitter Voltage Method)

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THERMAL IMPEDANCE MEASUREMENTS FOR BIPOLAR TRANSISTORS (DELTA BASE-EMITTER VOLTAGE METHOD)

(From JEDEC Council Ballot JCB-90-04 formulated under the cognizance of JC-25 Committee on Transistors and Intelligent Power Devices.)

1. PURPOSE

The purpose of this test method is to measure the thermal impedance of the bipolar transistor under the specified conditions of applied voltage, current and pulse duration. The temperature sensitivity of the base-emitter voltage is used as the junction temperature indicator. This test method is used to measure the thermal response of the junction to a heating pulse. Specifically, the test may be used to measure dc thermal resistance, and to ensure proper die mountdown to its case. This is accomplished through the appropriate choice of pulse duration and heating power magnitude. The appropriate test conditions and limits are detailed in Section 6.

2. DEFINITIONS

The following symbols and terms shall apply for the purpose of this test method:

(a) I_M — Emitter current during measurement of the base-emitter voltage with applied collector-emitter voltage.

(b) I_H — Heating current through the collector.

(c) V_H — Heating voltage between the collector and emitter, V_{CE} during heating time.

(d) P_H — Magnitude of the heating power pulse applied to DUT in watts; the product of I_H and V_H.

(e) t_H — Heating time during which P_H is applied.

(f) α_{VBE} — Voltage-temperature coefficient of V_{BE} with respect to T_J: in mV/°C.

(g) K — Thermal calibration factor equal to reciprocal of α_{VBE}, the temperature coefficient of base-emitter voltage: in °C/mV.

(h) T_J — Junction temperature in degrees Celsius.

T_{Ji} — Junction temperature in degrees Celsius before start of the power pulse.

T_{Jf} — Junction temperature in degrees Celsius at the end of the power pulse.

2. DEFINITIONS (continued)

(i) T_X — Reference temperature in degrees Celsius.

T_{Xi} — Initial reference temperature in degrees Celsius.

T_{Xf} — Final reference temperature in degrees Celsius.

(j) V_{BE} — Base-emitter voltage drop in millivolts.

V_{BEi} — Initial base-emitter voltage drop in millivolts.

V_{BEf} — Final base-emitter voltage drop in millivolts.

(k) t_{MD} — Measurement delay time is defined as the time from the removal of heating power P_H to the start of the V_{BE} measurement.

(l) t_{sw} — Sample window time during which final V_{BE} measurement is made.

(m) $Z_{\theta JX}$ — Transient junction-to-reference point thermal impedance in degrees Celsius/Watt. $Z_{\theta JX}$ for specified power pulse duration is:

$$Z_{\theta JX} = (T_{Jf} - T_{Ji} - \hat{}T_X)/P_H$$

where: $\hat{}T_X$ = change in reference point temperature during the heating pulse. (See Sections 5.2 and 5.4. For short heating pulses, e.g., die attach evaluation, this term is normally negligible.)

3. APPARATUS

The apparatus required for this test shall include the following as applicable to the specified test procedure.

3.1 Thermocouple

A thermocouple for measuring the case temperature at a specified reference point. The recommended reference point shall be located on the case under the heat source. Thermocouple material shall be copper-constantan (type T) or equivalent. The wire size shall be no larger than AWG size 30. The junction of the thermocouple shall be welded, rather than soldered or twisted, to form a bead. The accuracy of the thermocouple and its associated measuring system shall be $\pm$ 0.5°C. Proper mounting of the thermocouple to ensure intimate contact to the reference point is critical for system accuracy.

3.2 Temperature

A controlled temperature environment capable of maintaining the case temperature during the device calibration procedure to within $\pm$ 1°C over the temperature range of 23°C to 100°C, the recommended temperature for measuring K-factor.

3.3 K-Factor Calibration Setup

The K-factor calibration setup, as shown in Figure 1, measures V_{BE} for a specified value of I_M and V_{CE} (usually the same as V_H) in an environment in which temperature is both controlled and measured. A temperature controlled, circulating fluid bath is recommend. The current source must be capable of supplying I_M with an accuracy of $\pm$ 2%.

The value of I_M is usually chosen to be very small compared to I_H so that the device junction and case temperatures are essentially the same. The voltage source must be capable of supplying V_{CE} with an accuracy of $\pm$ 2%. The voltage measurement of V_{BE} shall be made with a voltmeter capable of 1 mV resolution. The device-to-current/voltage source wire size shall be sufficient to handle the measurement current (AWG size 22 stranded is typically used for up to 100 mA).

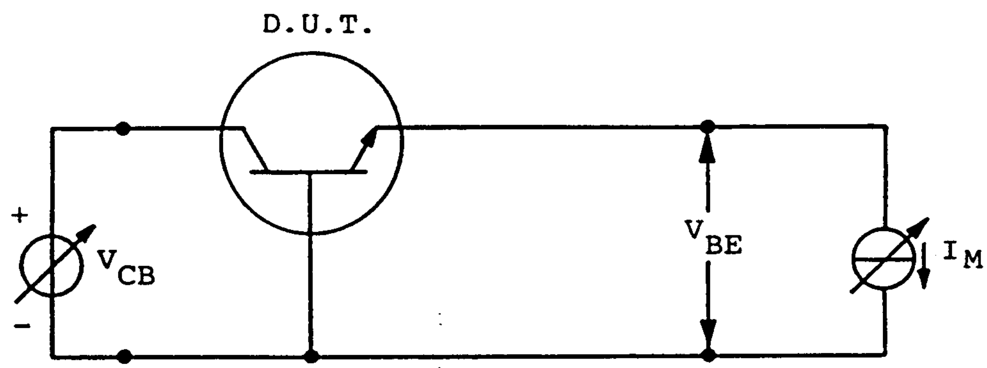

Figure 1
K-Factor Calibration Setup

3.4 Test Circuit

A test circuit used to control the device and to measure the temperature using the base-emitter voltage as the temperature sensing parameter is shown in Figure 2. Polarities shown are for NPN devices, but the circuit may be used for PNP types by reversing the polarities of the voltage and current sources.

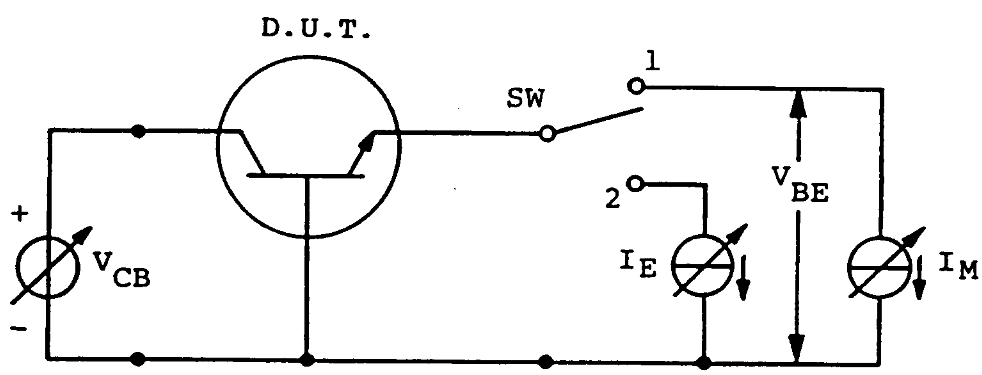

Figure 2
Thermal Impedance Measurement Circuit
Base-Emitter Method

3.4 Test Circuit (continued)

The circuit consists of the DUT, a voltage source, two current sources, and an electronic switch. During the heating phase of the measurement, switch SW is in position 1. The values of I_E and V_{CB} are adjusted to achieve the desired values of I_C and V_{CE} for the P_H "heating" condition.

To measure the initial and post heating pulse junction temperatures of the DUT, switch SW is switched to position 1. This applies the low-valued emitter current I_M to the device. I_M is chosen not to cause significant self-heating relative to the heating current I_H. If testing for absolute magnitude values of thermal resistance or junction temperature change, the value of I_M must be the same value used in the K-Factor calibration. Figures 3 and 4 show the waveforms associated with the three segments of the test.

Since I_E is adjusted to provide the desired I_C for heating, the circuit of Figure 2 can be modified so that I_M remains on at all times and I_E is switched in and out by SW.

I_M is usually chosen to be 2% or less of the I_C value. Typically, an I_M value of 10 mA is sufficient for most bipolar transistors for I_C up to 10 A. Darlington transistors having internal base resistors summing to 200 ohms or less typically require values of I_M equal to 25 mA or more.

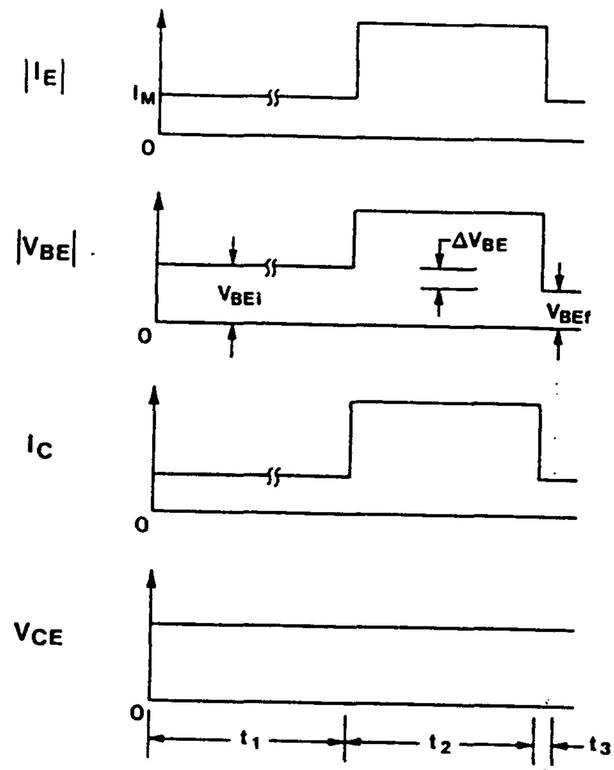

Figure 3
Device Waveforms During the Three Segments of the Thermal Test

3.4 Test Circuit (continued)

The value of t_{MD} is critical to the accuracy of the measurement and must be properly specified in order to ensure measurement repeatability. Note that some test equipment manufacturers include the sample and hold window time t_{SW} within their t_{MD} specification.

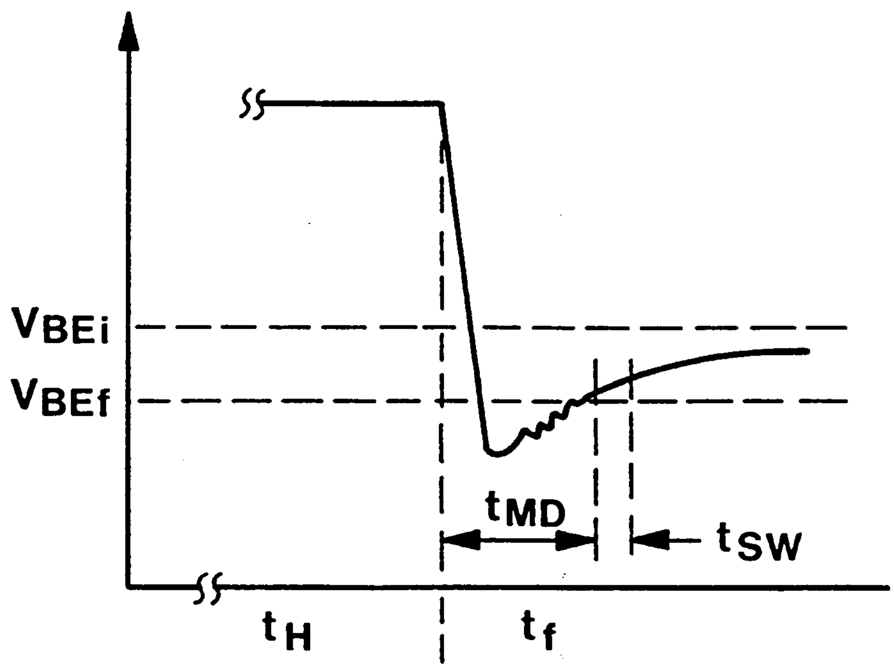

Figure 4
Final V_{BE} Measurement Waveform

3.5 Measurement of Base-Emitter Forward Voltage

Suitable sample-and-hold voltmeter or oscilloscope to measure base-emitter forward voltage at specified times. V_{BE} shall be measured to within 5 mV, or within 5% of (V_{BEi} - V_{BEf}), whichever is less.

4. MEASUREMENT OF THE TEMPERATURE SENSITIVE PARAMETER

The required calibration of V_{BE} vs T_J is accomplished by monitoring V_{BE} for the required values of I_M and V_{CE} as the heat sink temperature (and thus the DUT temperature) is varied by external heating. The magnitudes of I_M and V_{CE} shall be chosen so that V_{BE} is a linearly decreasing function over the expected range of T_J during the power pulse. I_M must be large enough to ensure that the base-emitter junction is turned on but not so large as to cause any significant self-heating. (This will normally be 1 mA for small power devices and up to 100 mA for large ones. Darlington transistors with low-valued internal base resistors will typically require greater than 20 mA.) An example calibration curve is shown in Figure 5.

4.1 Calibration

When screening to ensure proper die attachment within a given log or in a group of the same type number devices of one manufacturer, this calibration step is not required. In such cases, the measure of thermal response may be delta V_{BE} for a short heating pulse, and the computation of ΔT_j or $Z_{\Theta JX}$ is not necessary. (For this purpose, t_H shall be 10 ms for TO-39 size packages and 100 ms for TO-3 packages.)

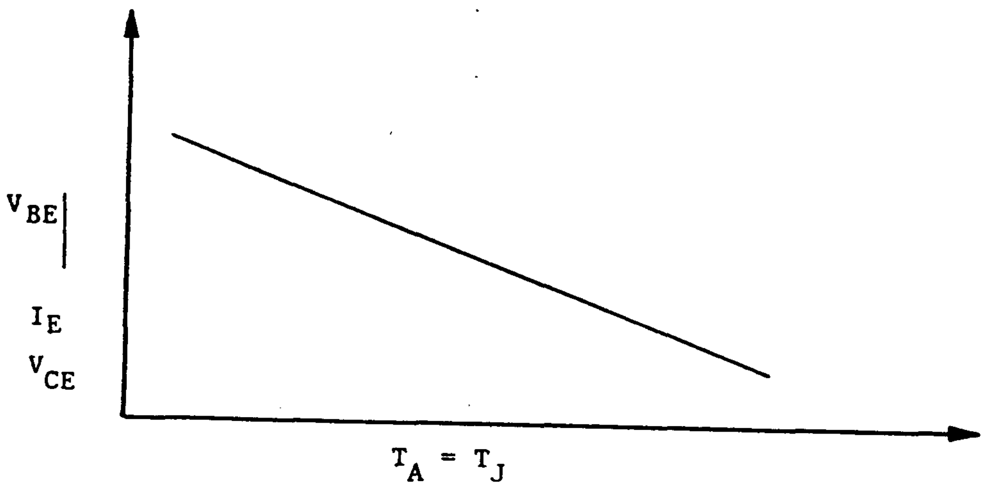

Figure 5
Example Curve of V_{BE} vs. T_J

A calibration factor K (which is the reciprocal of α_{BE} or the slope of the curve in Figure 5) can be defined as:

$$K = \frac{1}{\alpha_{BE}} = \left| \frac{T_{J1} - T_{J2}}{V_{BE1} - V_{BE2}} \right| \ ^\circ C/mV$$

It has been found experimentally that the K-factor variation for all devices within a given device type class is small. The usual procedure is to perform a K-factor calibration on a 10 to 12 piece sample from a device lot and determine the average K and standard deviation (σ). If σ is less than or equal to 3% of the average value of K, then the average value of K can be used for all devices within the lot. If σ is greater that 3% of the average value of K, then all the devices in the lot shall be calibrated and the individual values of K shall be used in thermal impedance calculations or in correcting ΔV_{BE} values for comparison purposes.

5. TEST PROCEDURE

5.1 Calibration

K-factor must be determined according to the procedure outlined in Section 4. except as noted in Section 4.1.

5.2 Reference Point Temperature

The reference point is usually chosen to be on the bottom of the transistor case directly below the semiconductor chip in a TO-204 metal can or in close proximity to the chip in other styles of packages. Reference temperature point location must be specified and its temperature shall be monitored using the thermocouple mentioned in 3.1 during the preliminary testing. If it is ascertained that T_X increases by more than 5% of measured junction temperature rise during the power pulse, then either the heating power pulse magnitude must be decreased, the DUT must be mounted in a temperature controlled heat sink, or the calculated value of thermal impedance must be corrected to take into account the thermal impedance of the reference point to the cooling medium or heat sink.

Temperature measurements for monitoring, controlling and/or correcting for reference point temperature changes are not required if the t_H value is low enough to ensure that the heat generated within the DUT has not had time to propagate through the package. Typical values of t_H for this case are in the 10 ms to 500 ms range, depending on DUT package type and material.

5.3 Thermal Measurements

The following sequence of tests and measurements must be made. Usual practice is that measure voltage V_{CE} is made equal in value to V_H and $I_H = I_C$ the collector current.

5.3.1 Prior to the Power Pulse

(a) Establish reference point temperature T_{Xi}.

(b) Apply measurement current I_M.

(c) Apply measurement voltage V_{CE}.

(d) Measure base-emitter voltage V_{BEi} (a measurement of the initial junction temperature).

5.3.2 Heating Pulse Parameters

(a) Apply collector-emitter heating voltage V_H.

(b) Apply collector heating current I_H.

(c) Allow heating condition to exist for the required heating pulse duration t_H.

(d) Measure reference point temperature T_{Xf} at the end of heating pulse duration.

NOTE: T_X measurements are not required if the t_H value meets the requirements stated in Section 5.2.

5.3.3 Post Power Pulse Measurements

(a) Apply measurement current I_M.

(b) Apply measurement voltage V_{CE}.

(c) Measure base-emitter voltage V_{BEf} (a measurement of the final junction temerpature).

(d) Time delay bewtween the end of the power pulse and the completion of the V_{BEf} measurement as defined by the waveform of Figure 3131.2-4 in terms of t_{MD} plus t_{SW}.

5.4 Value of Thermal Impedance

The value of thermal impedance, $Z_{\theta JX}$, is calculated using the following formula:

$$Z_{\theta JX} = \hat{=}T_J/P_H$$

$$= \left|\frac{K\,(V_{BEf} - V_{BEi})}{(I_H)\;(_{VH})}\right| \;°C/W$$

This value of thermal impedance will have to be corrected if T_{Xf} is greater than T_{Xi} by 5°C. The correction consists of subtracting the component of thermal impedance due to the thermal impedance from the reference point (typically the device case) to the cooling medium or heat sink. T_X measurements are not required if the t_H value meets the requirements stated in Section 5.2.

This thermal impedance component has a value calculated as follows:

$$Z_{\theta X\text{-}HS} = \hat{=}T_X/p_H$$
$$= (T_{Xf} - T_{Xi})/[(I_H)(V_H]$$

where: HS = Cooling medium or heat sink (if used)

Then:

$$\underbrace{Z_{\theta JX}}_{\text{Corrected}} = \underbrace{Z_{\theta JX}}_{\text{Calculated}} - Z_{\theta X\text{-}HS} =$$

NOTE: This last step is not necessary for die attach evaluation (See Section 4.1).

6. TEST CONDITIONS AND MEASUREMENTS TO BE SPECIFIED AND RECORDED

6.1 K-Factor Calibration

6.1.1 Specify the Following Test Conditions:

(a) I_M current magnitude ____mA
(See detail specification for current value.)

(b) V_{CE} Voltage magnitude ____V
(Normally the same as V_H)

(c) Initial junction temperature ____°C
(Normally 25 $\pm$ 5°C)

(d) Final junction temperature ____°C
(Normally 100 $\pm$ 10°C)

6.1.2 Record the Following Data

(a) Initial V_{BE} voltage (V_{BE1}) ____mV

(b) Final V_{BE} voltage (V_{BE2}) ____mV

6.1.3 Calculate K-Factor Per Following Equation

$$K = \left| \frac{T_{J1} - T_{J2}}{V_{BE1} - V_{BE2}} \right| \text{°C/mV}$$

6.1.4 For Die Attachment Evaluation

This step may not be necessary (see Section 4.1).

6.2 Thermal Impedance Measurements

6.2.1 Specify the Following Test Conditions:

(a) I_M measuring current ____mA
(Must be same as used for K-Factor calibration)

(b) V_{CE} collector-emitter voltage ____V
(Must be same as used for K Factor calibration
normally equal to V_H)

(c) I_H Collector heating current ____A

6.2.1 Specify the Following Test Conditions (continued)

(d) V_H Collector-emitter heating voltage ____V

(e) t_H heating time ____s

(f) t_{MD} measurement time delay ____μs

(g) t_{SW} sample window time ____μs

NOTE: I_H and V_H are usually chosen so that P_H is approximately two-thirds of device rated power dissipation or greater.

6.2.2 Record the Following Data

(a) T_{Xi} initial reference temperature ____°C

(b) T_{Xf} final reference temperature ____°C

6.2.2.1 ΔVBE Data

(a) ΔV_{BE} ____mV

6.2.2.2 V_{BE} Data

(a) $V_{BE(i)}$ initial base-emitter voltage ____V

(b) $V_{BE(f)}$ final base-emitter voltage ____V

T_X measurements are not required if the t_H value meets the requirements stated in Section 5.2.

6.2.3 Calculate thermal impedance using the procedure and equations stated in Section 5.4.

6.3 ΔV_{BE} Measurement for Screening

These measurements are made for t_H values that meet the intent of Section 4.1 and the requirements stated in Section 5.2.

6.3.1 Specify the Following Test Conditions

(a) I_M measuring current ____mA

(b) V_{CE} measuring voltage ____V

(c) I_H Collector heating current ____A

(d) V_H collector-emitter heating voltage ____V

6.3.1 Specify the Following Test Conditions (continued)

(e) t_H heating time ____s

(f) t_{MD} measurement time delay ____μs

(g) t_{SW} sample window time ____μs

NOTE: The values of I_H and V_H are usually chosen equal to or greater than the values used for thermal impedance measurements.

6.3.2 Specified Limits

The following data is compared to the specified limits.

6.3.2.1 ΔV_{BE} Data

(a) ΔV_{BE} ____mV

6.3.2.2 V_{BE} Data

(a) $V_{BE(i)}$ initial base-emitter voltage ____V

(b) $V_{BE(f)}$ final base-emitter voltage ____V

Compute ΔV_{BE} ____mV

6.3.2.3

Optionally calculate ΔT_j for comparison and/or screeing purposes if the K-factor results (see Sections 4. and 6.1) produce a σ greater than 3% of the average value of K.

$$\Delta T_j = K(\Delta V_{BE}) \, ^\circ C$$

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