JEDEC STANDARD

Thermal Impedance Measurements for Insulated Gate Bipolar Transistors

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Electronic Industries Alliance

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THERMAL IMPEDANCE MEASUREMENTS FOR INSULATED GATE BIPOLAR TRANSISTORS (DELTA GATE-EMITTER ON VOLTAGE METHOD)

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(From JEDEC Council Ballot JCB-91-07, formulated under the cognizance of JC-25 Committee on Transistors.)

1. PURPOSE

The purpose of this test method is to measure the thermal impedance of the IGBT under the specified conditions of applied voltage, current and pulse duration. The temperature sensitivity of the gate-emitter ON voltage, under conditions of applied collector-emitter voltage and low emitter current, is used as the junction temperature indicator. This method is particularly suitable to enhancement mode, power IGBTs having relatively long thermal response times. 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 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 applied during measurement of the gate-emitter ON voltage.

b. I_H - Heating current through the collector or emitter lead

c. V_H - Heating voltage between the collector and emitter

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. VTC - Voltage-temperature coefficient of $V_{GE(ON)}$ with respect to T_J; in mV/°C

g. K - Thermal calibration factor equal to reciprocal of VTC; 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

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. $V_{GE(ON)}$ - Gate-emitter ON voltage in millivolts
$V_{GE(ON)i}$ - Initial gate-emitter ON voltage in millivolts
$V_{GE(ON)f}$ - Final gate-emitter ON in millivolts

k. $V_{GE(M)}$ - Gate-emitter voltage during measurement periods
V_{GE} - Gate-emitter voltage during heating period

l. $V_{CE(M)}$ - Collector-emitter voltage during measurement periods
V_{CE} - Collector-emitter voltage during heating period

m. V_{CG} - Collector-gate voltage, adjusted to provide appropriate V_{CE}

n. t_{MD} - Measurement delay time is defined st the time from the removal of heating power P_H to the start of the $V_{GE(ON)}$ measurement

o. t_{SW} - Sample window time during which final V_{SD} measurement is made

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

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

where: ΔT_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 Measuring

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 K-Factor

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

A K-factor calibration setup, as shown in Figure 1, that measures $V_{GE(ON)}$ for a specified values of V_{CE} and I_M in an environment where temperature is both controlled and measured. A temperature controlled, circulating fluid bath is recommended. The current source must be capable of supplying I_M with an accuracy of $\pm$2%. The voltage source V_{CG} is adjusted to supply V_{CE} with an accuracy of $\pm$2%. The voltage measurement of $V_{GE(ON)}$ shall be made with a voltmeter capable of 1 mV resolution. the device-to-current source wire size shall be sufficient to handle the measurement current (AWG size 22 stranded is typically used for up to 100 mA).

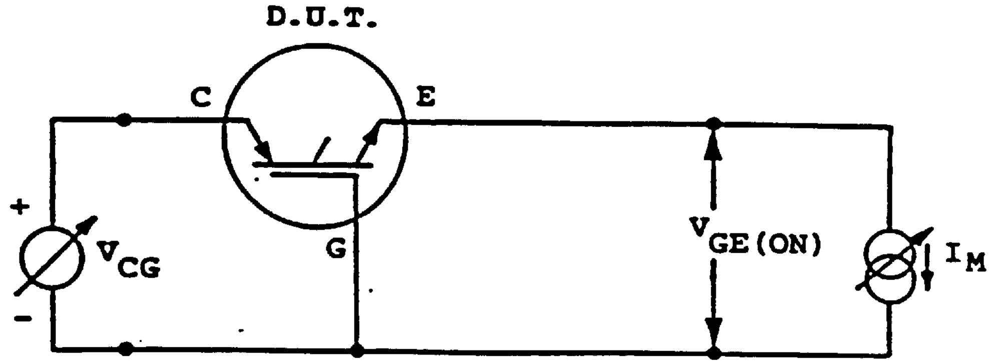

Figure 1
K-Factor Calibration Setup

3.4 Thermal Testing

There are two approaches to the actual thermal testing - either the common-gate or the common-source method. Both methods work equally well, although the common-source method may be more reliable and less potentially damaging to the device-under-test.

The figures and description below describe the thermal measurement for N-channel Enhancement Mode devices. Opposite polarity devices can be tested by appropriately reversing the various supplies. Depletion Mode devices can be tested by applying the gate-emitter voltage (V_{GE}) in the appropriate manner.

3.4.1 Common-Gate Thermal Test Circuit

A common-gate configuration test circuit used to control the device and to measure the temperature using the gate-emitter ON voltage as the temperature sensing parameter as shown in Figure 2. Polarities shown are for N-channel devices but the circuit may be used for P-channel types by reversing the polarities of the voltage and current sources.

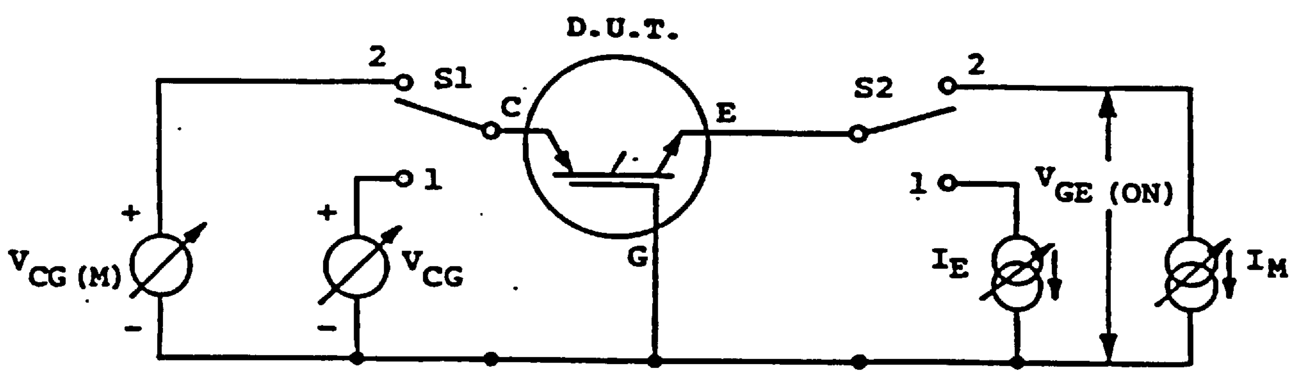

Figure 2
Common-Gate Thermal Impedance Measurement Circuit
Gate-Emitter On Voltage Method

The circuit consists of the DUT, two voltage sources, two current sources, and two electronic switches. During the heating phase of the measurement, switches S1 and S2 are in position 1. The values of V_{CG} and I_E are adjusted to achieve the desired values of I_D and V_{CE} for the P_H "heating" condition.

To measure the initial and post heating pulse junction temperatures of the DUT, switches S1 and S2 are each switched to position 2. This puts the gate at the measurement voltage level $V_{CG(M)}$ and connects the current source I_M to supply measurement current to the emitter. The values of $V_{CG(M)}$ and I_M must be the same as used in the K-factor Calibration if actual junction temperature rise data is required. Figures 4 and 5 show the waveforms associated with the three segments of the test.

3.4.2 Common Source Thermal Test Circuit

A common source configuration test circuit used to control the device and to measure the temperature using the gate-emitter on voltage as the temperature sensing parameter as shown in Figure 3. Polarities shown are for N-channel devices but the circuit may be used for P-channel types by reversing the polarities of the voltage and current sources.

The circuit consists of the DUT, four voltage sources and two electronic switches. During the heating phase of the measurement, switches S1 and S2 are in position 1. The values of V_{CE} and V_{GE} are adjusted to achieve the desired values of I_C and V_{CE} for the P_H "heating" condition.

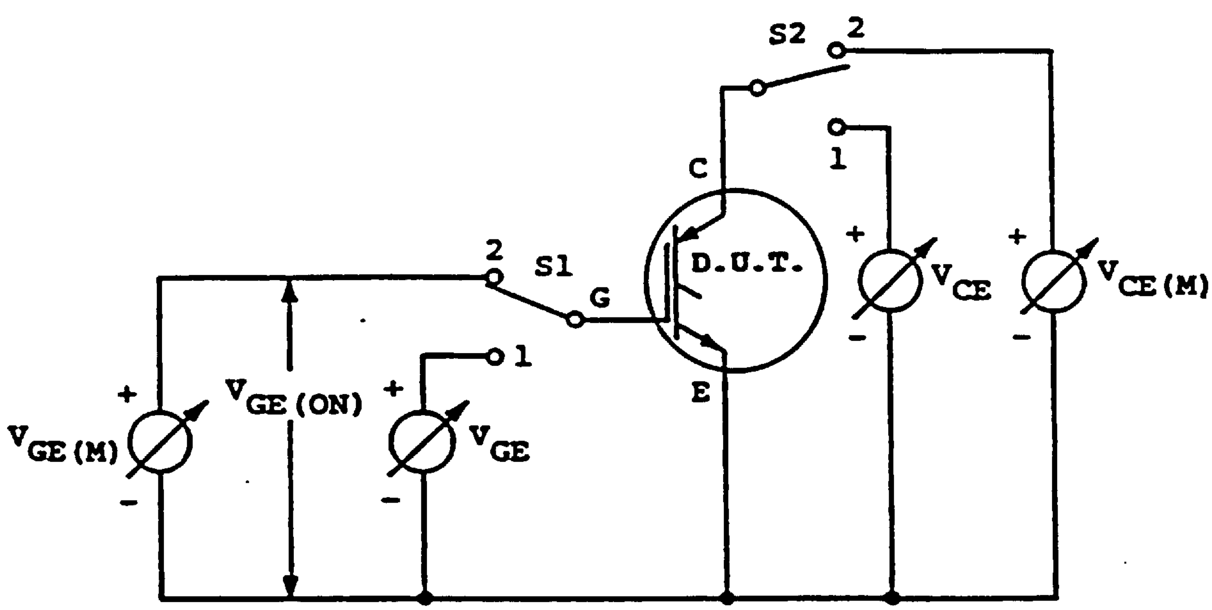

Figure 3
Common-Source Thermal Impedance Measurement circuit
Gate-Emitter On Voltage Method

To measure the initial and post heating pulse junction temperatures of the DUT, switches S1 and S2 are each switched to position 2. This puts the collector at the measurement voltage level $V_{CE(M)}$ and the gate at $V_{GE(M)}$, which must be adjusted to obtain I_M. The values of $V_{CE(M)}$ and I_M must be the same as used in the K-Factor calibration if actual junction temperature rise data is required. Figures 4 and 5 show the waveforms associated with the three segments of the test.

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.

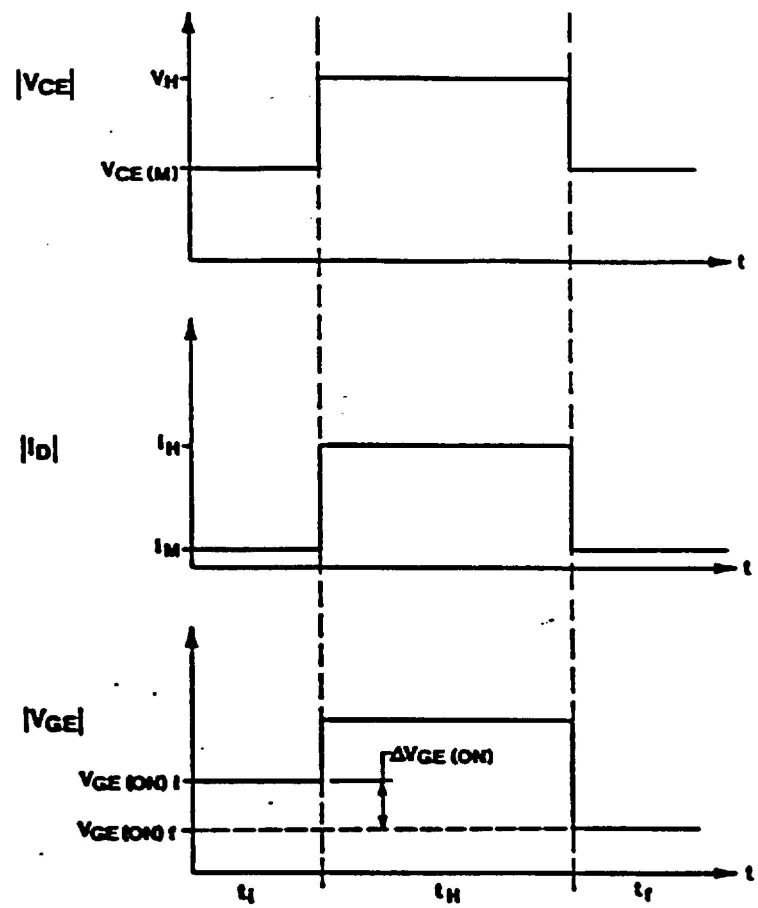

Figure 4
Device Waveforms During the Three Segments
of the Thermal Transient Test

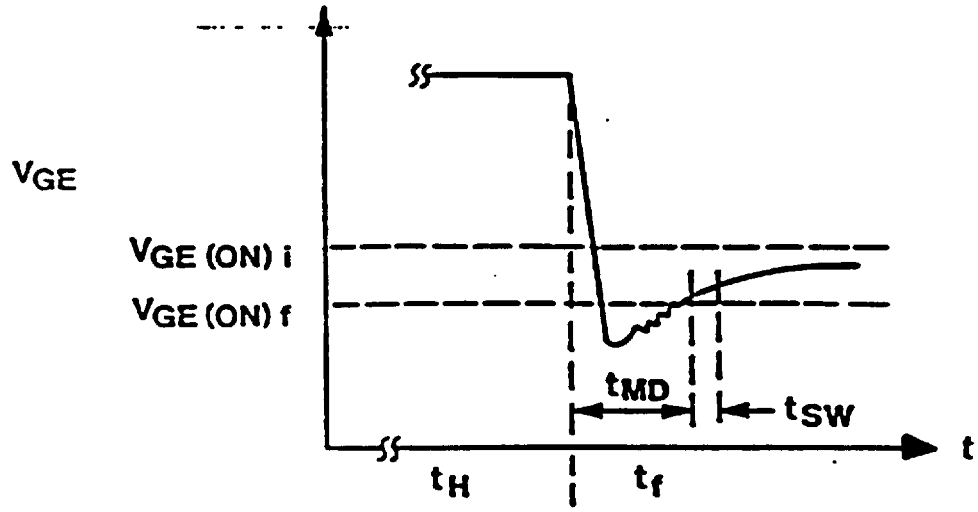

Figure 5
Final $V_{GE(On)}$ Measurement Waveform

NOTE: The circuits for both common-gate and common-source thermal measurements can be modified so that V_{CE} is applied during both measurement and heating periods if the value of V_{CE} is at least ten times the value of $V_{GE(ON)}$. Further, the common-gate circuit can be modified so that I_M is continually applied as long as the I_E current source can be adjusted for the desired value of heating current.

3.5 Sample-and-Hold Voltmeter

Suitable sample-and-hold voltmeter of oscilloscope to measure source-drain forward voltage at specified times. $V_{GE(ON)}$ shall be measured to within 5 mV, or within 5% of $V_{GE(ON)i}$ or $V_{GE(ON)f}$, whichever is less.

4. MEASUREMENT OF THE TEMPERATURE SENSITIVE PARAMETER

The required calibration of $V_{GE(ON)}$ vs T_J is accomplished by monitoring $V_{GE(ON)}$ for the required values of V_{CE} and I_M as the heat sink temperature (and thus the DUT temperature) is varied by external heating. The magnitudes of V_{CE} and I_M shall be chosen so that $V_{GE(ON)}$ is a linearly decreasing function over the expected range of T_J during the power pulse. For this condition, V_{CE} must be at least three times $V_{GE(ON)}$. I_M must be large enough to ensure that the device 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 100mA for large ones.) An example calibration curve is shown in Figure 6.

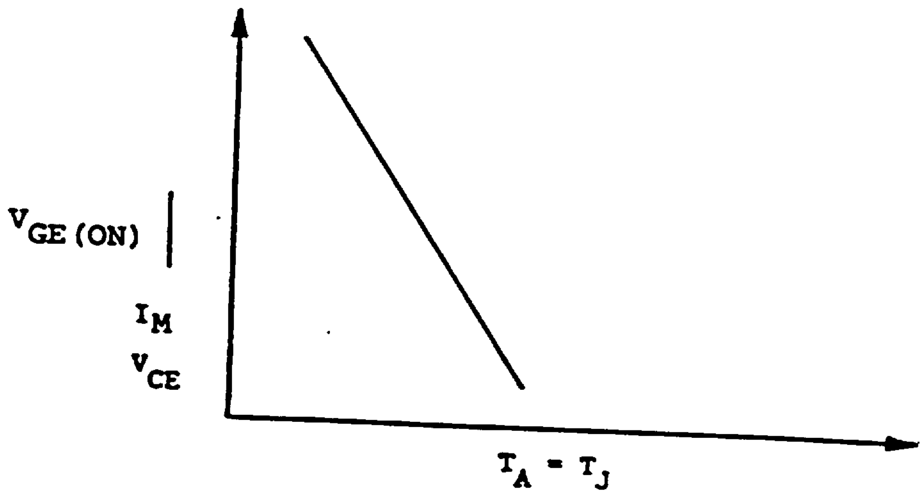

Figure 6
Example Curve of $V_{GE(ON)}$ vs T_J

4.1 Calibration Factor K

A calibration factor K (which is the reciprocal of VTC or the slope of the curve in Figure 6) can be defined as:

$$K = \frac{1}{VTC} = \left| \frac{T_{J1} - T_{J2}}{V_{GE(ON)1} - V_{GE(ON)2}} \right| \quad {}^{o}C/mV$$

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_K). If σ_K 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_K is greater than 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 $V_{GE(ON)}$ values for comparison purposes.

When screening to ensure proper die attachment within a given lot, this calibration step is not required, (e.g., devices of a single manufacturer with identical part number and case style). In such cases, the measure of thermal response may be delta $V_{GE(ON)}$ 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 up to 100 ms (typically 30 to 50 ms) for TO-3 packages.)

5. TEST PROCEDURE

5.1 Calibration

K Factor must be determined according to the procedure outline in 4., except as noted in 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 (TO-3) metal can or in close promimity 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 the t_H for this case are in the 10 ms to 100 ms range, depending on DUT package type and material.

5.3 Thermal Measurements

The following sequence of tests and measurements must be made.

5.3.1 Power Pulse

Prior to the power pulse:

a. Establish reference point temperature T_{Xi}.
b. Apply measurement voltage V_{CE}.
c. Apply measurement current I_M.
d. Measure gate-emitter on voltage $V_{GE(ON)i}$ (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 as required by adjustment of gate-emitter voltage.
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.

5.3.5 Post Power Pulse Measurements

a. Apply measurement current I_M.
b. Apply measurement voltage V_{CE}.
c. Measure gate-emitter on voltage $V_{GE(ON)f}$ (a measurement of the final junction temperature).
d. Time delay between the end of the power pulse and the completion of the $V_{GE(ON)f}$ measurement as defined by the waveform of Figure 3103-4 in terms of t_{MD} plus t_{SW}.

5.4 Value of Thermal Impedance

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

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

$$= \left| \frac{K\,(V_{GE(ON)f} - V_{GE(ON)i})}{(I_H)\,(V_H)} \right| \quad {}^{o}C/W$$

This value of thermal impedance will have to be corrected if T_{Xf} is greater than T_{Xi} by more than 5% ΔT_J, per Section 5.2. 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:

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

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

then:

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

Note that 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

Specify the following test conditions:

a. I_M current magnitude (See detail specification for current value.)	_____ mA
b. V_{CE} voltage magnitude (See detail specification for voltage value)	_____ V
c. Initial junction temperature (Normally 25 $\pm$ 5_0C.)	_____ °C
d. Final junction temperature (Normally 100 $\pm$ 10°C)	_____ °C

Record the following data:

a. Initial $V_{GE(ON)}$ voltage	_____ mV
b. Final $V_{GE(ON)}$ voltage	_____ mV

Calculate K-factor per following equation:

$$K = \left| \frac{T_{J1} - T_{J2}}{V_{GE(ON)1} - V_{GE(ON)2}} \right| \ {}^{\circ}\mathrm{C/mV}$$

For die attachment evaluation, this step may not be necessary (see Section 4.1).

6.2 Thermal Impedance Measurements

Specify the following test conditions:

a. I_M current magnitude (Must be same as used for K Factor Calibration)	_____ mA
b. V_{CE} measuring voltage magnitude (Must be same as used for K Factor Calibration)	_____ V
c. I_H heating current	_____ A
d. V_H Collector-emitter heating voltage	_____ V
e. t_H heating current	_____ s
f. t_{MD} measurement time delay	_____ μs
g. t_{SW} sample window time	_____ μs

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

Record the following data:

a. T_{Xi} initial reference temperature ____ °C
b. T_{Xf} final reference temperature ____ °C
c. $V_{GE(ON)}$ ____ mV
d. $V_{GE(ON)i}$ initial gate-source voltage ____ V
e. $V_{GE(ON)f}$ final gate-source voltage ____ V

T_x measurements are not required if the t_H values meet the requirements stated in Section 5.2.

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

6.3 $\Delta V_{GE(ON)}$ Measurements 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.

Specify the following test conditions:

a. I_M current magnitude ____ mA
b. V_{GE} measuring voltage ____ V
c. I_H heating current ____ A
d. V_H Collector-emitter heating voltage ____ V
e. t_H heating current ____ s
f. t_{MD} measurement time delay ____ μs
g. t_{SW} sample window time ____ μs

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

The following data is compared to the specified limits:

a. $\Delta V_{GE(ON)}$ ____ mV
b. $V_{GE(ON)i}$ initial gate-source voltage ____ V
c. $V_{GE(ON)f}$ final gate-source voltage ____ V

Compute $\Delta V_{GE(ON)}$ ____ mV

Optionally calculate ΔT_J for comparison and/or screening purposes if the K factor results produce a σ_k greater than 3% of the average value of K.

$\Delta T_J = K(\Delta V_{GE(ON)})°C$

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