METHOD 3104

THERMAL RESISTANCE MEASUREMENTS OF GaAs MOSFET's (CONSTANT CURRENT FORWARD-BIASED GATE VOLTAGE METHOD)

1. Purpose. The purpose of this test method is to measure the thermal resistance of the MESFET under the specified conditions of applied voltage, current, and pulse width. The temperature sensitivity of the forward voltage drop of the gate-source diode is used as the junction temperature indicator. This method is particularly suitable for completely packaged devices.

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

a.	I_M:	Measuring current in the gate-source diode.
b.	I_H:	Heating current through the drain.
c.	V_H:	Heating voltage between the drain and source.
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.	K:	Thermal calibration factor (°C/mV).
g.	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.
h.	T_X:	Reference temperature in degrees Celsius.
	T_{Xi}:	Initial reference temperature in degrees Celsius.
	T_{Xf}:	Final reference temperature in degrees Celsius.
i.	V_{GSf}:	Forward-biased gate-source junction diode voltage drop in volts.
	$V_{GSf(i)}$:	Initial gate-source voltage.
	$V_{GSf(f)}$:	Final gate-source voltage.
j.	t_{MD}:	The time from the start of heating power (P_H) removal to the completion of the final V_{GSf} measurement.
k.	Θ_{JX}	Junction-to-reference point thermal resistance in degrees Celsius/watt. Θ_{JX} for specified heating power conditions is:

$$\theta_{JX} = \frac{(T_{Jf} - T_{Ji})}{P_H}$$

l.	CU:	Comparison unit for screening devices against specification limits. Defined as the change in forward biased gate-source voltage divided by heating current in mV/A.

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

3.1 Case reference point temperature. The case reference point temperature shall be measured using a thermocouple. The recommended reference point should be located immediately outside 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 to form a bead rather than soldered or twisted. The accuracy of the thermocouple and associated measuring system shall be ±0.5°C.

3.2 Controlled temperature environment. A controlled temperature environment capable of maintaining the case temperature during the device calibration procedure to within ±1°C over the temperature range of room temperature (approximately +23°C) to +100°C.

3.3 K factor calibration setup. A K factor calibration setup, as shown on figure 3104-1, that measures V_{GSf} for a specified value of I_M in an environment that is both temperature controlled and measured. The current source must be capable of supplying I_M with an accuracy of ±1 percent and have a compliance of at least 1 volt and not more than 2 volts. The voltage measurement of V_{GSf} should be made to 1 mV resolution. The device-to-current source wire size shall be sufficient to handle the measurement current (AWG size 26 stranded is typically used for up to 10 mA).

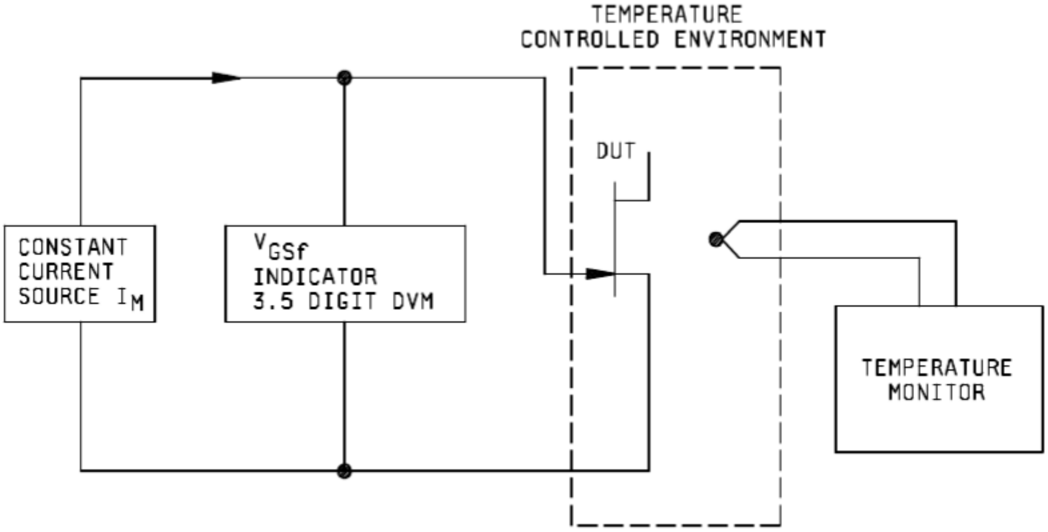
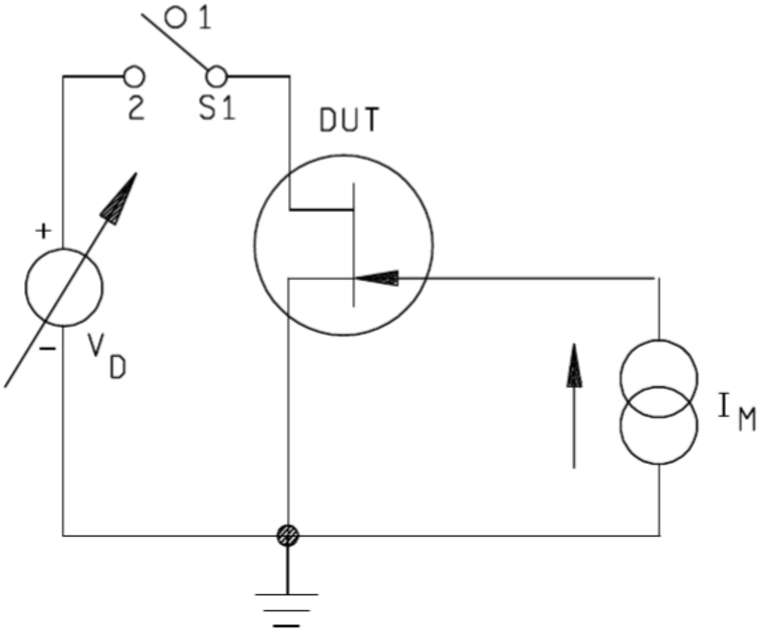


FIGURE 3104-1. K factor calibration setup.

3.4 Controlled temperature heat sink. Controlled temperature heat sink capable of maintaining the specified reference point temperature to within ±5 of the preset (measured) value.

3.5 Test circuit. The circuit used to control the device and to measure the temperature using the forward voltage of the gate-source diode as the temperature sensing parameter is shown on figure 3104-2. 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.



NOTE: The circuit consists of the DUT, one voltage source, one current source, and one electronic switch. During the heating phase of the measurement, switch S1 is in position 2. The value of V_D is adjusted to achieve the desired values of I_D and V_{DS} for the P_H "heating" condition.

FIGURE 3104-2. Thermal resistance measurement circuit (constant current forward-biased gate voltage method).

To measure the initial and post heating pulse junction temperature of the DUT, switch S1 is switched to position 1. This disconnects the V_D source during the measurement time and allows for the measurement of $V_{GSf(i)}$ and $V_{GSf(f)}$ before and after the heating time, respectively. Figure 3104-3 shows the waveforms associated with the three segments of the test.

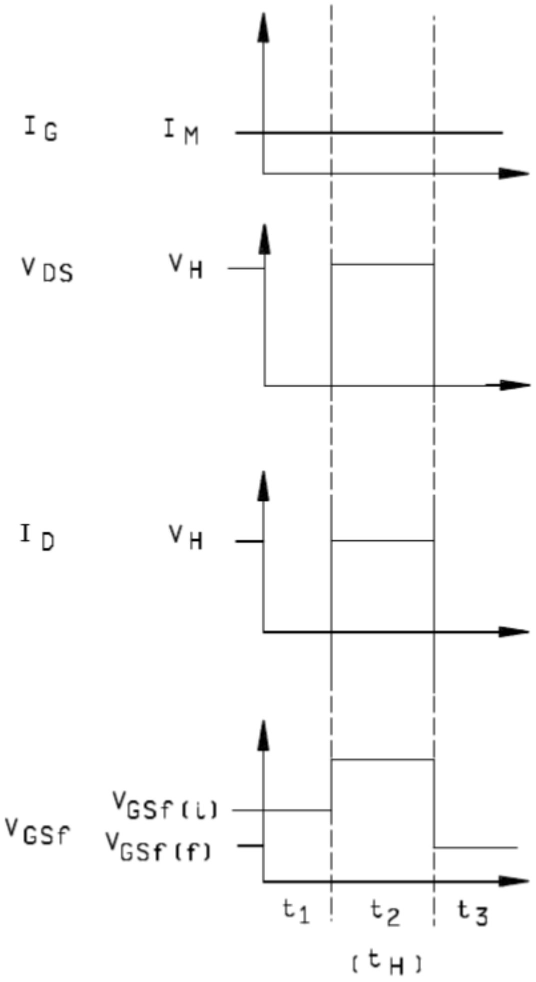


FIGURE 3104-3. Device waveforms during the three segments of the thermal resistance test.

The time required to make the second V_{GSf} reading is critical to the accuracy of the measurement and must be properly specified in order to ensure measurement repeatability. The definition of measurement delay time (t_{MD}) are described by the waveform on figure 3104-4.

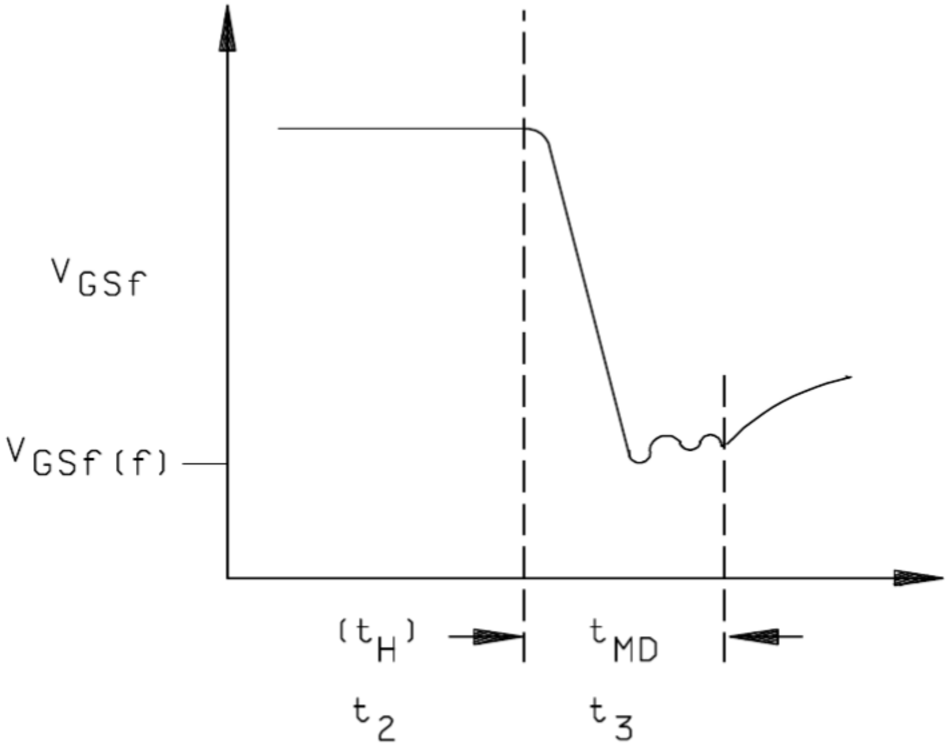


FIGURE 3104-4. Second V_{GSf} measurement waveform.

3.6 Source-drain forward voltage. Suitable sample-and-hold voltmeter or oscilloscope to measure source-drain forward voltage at specified times. V_{GSf} should be measured with 1 mV resolutions.

4. Measurement of the TSP V_{GSf}. The required calibration of V_{GSf} versus T_J is accomplished by monitoring V_{GSf} for the required value of I_M without any connection to the drain as the heat sink temperature (and thus the DUT temperature) is varied by external heating. The magnitude of I_M should be chosen so that V_{GSf} is a linearly decreasing function over the expected T_J range during the power pulse. I_M must be large enough to ensure that the gate-source junction is turned on but not large enough to cause significant self-heating or device destruction. An example calibration curve is shown on figure 3104-5.

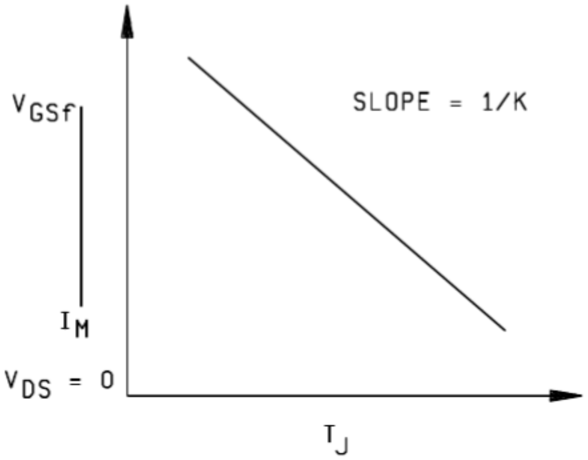


FIGURE 3104-5. Calibration curve.

A calibration factor K (which is the reciprocal of the slope of the curve on figure 3104-5) can be defined as:

$$K = \left| \frac{T_J 1 - T_J 2}{V_{GSf} 1 - V_{GSf} 2} \right| \ {}^\circ C / mV$$

It has been found experimentally that the K factor should vary less than several percent for all devices within a given device type class. 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 three percent 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 than the average value of K, then all the devices in the lot should be calibrated and the individual values of K should be used in thermal resistance calculations.

5. Test procedure.

5.1 Calibration. K factor must be determined according to the procedure outlined in 4.

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. Reference temperature point location must be specified and its temperature should be monitored using the thermocouple mentioned in 3.1 during the preliminary testing. If it is ascertained that T_{Xf} increases by more than +5°C 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 resistance must be corrected to take into account the thermal resistance associated with the temperature rise of the reference point.

5.3 Thermal measurements. The following sequence of tests and measurements must be made:

a. Prior to the power pulse:

(1) Establish reference point temperature: T_{Xi}.

(2) Apply measurement current: I_M.

(3) Measure gate-source voltage drop: $V_{GSf(i)}$ (A measurement of the initial junction temperature).

b. Heating pulse parameters:

(1) Maintain measurement current: I_M.

(2) Apply drain-source heating voltage: V_H.

(3) Measure drain heating current: I_H.

(4) Allow heating condition to exist for the required heating pulse width: t_H.

(5) Measure reference point temperature: T_{Xf}, at the end of heating pulse width.

c. Post power pulse measurements:

(1) Maintain measurement current: I_M.

(2) Measure gate-source voltage drop: V_{GSf}(f) (A measurement of the final junction temperature).

(3) Determine time delay between the end of the power pulse and the completion of the $V_{GSf(f)}$ measurement as defined by the waveform of figure 3104-4.

5.4 Thermal resistance. The value of thermal resistance, θ_{JX}, is calculated from the following formula:

$$\theta_{JX} = \frac{\text{Ø}\ T_J}{P_H} = \frac{K\,|V_{GSF(f)} - V_{GSf(i)}|}{(I_H)\,(V_H)}$$

This value of thermal resistance will have to be corrected if T_{Xf} is greater than TX_i. The correction consists of subtracting out the component of thermal resistance due to the heat flow path from the reference point (typically the device case) to the heat sink and the environment. This thermal resistance component has a value calculated as follows:

$$\theta_{X\text{-}HS} = \frac{\text{Ø}\ T_X}{P_H} = \frac{(T_{Xf} - T_{Xi})}{(I_H)\,(V_H)}$$

Then:

$$\underset{\text{Corrected}}{\theta_{JX}} = \underset{\text{Calculated}}{\theta_{JX}} - \theta_{X\text{-}HS}$$

An additional correction may be required because of the fast cooling of a typical MESFET heat source area. This requires that the thermal resistance measurements be made for two different values of t_{MD}. Care must be taken to ensure that the shorter of the chosen t_{MD} values does not lie within the non-thermal (i.e, electrical) switching transient region. Similarly, if the longer t_{MD} value is too large, the resultant value of θ_{JX} will be too small for an accurate measurement due to device cooling. The correction for the calculated thermal resistance is given below for test conditions in which I_M, V_H, and t_H remain the same for both tests.

$$\theta_{JX} = \theta_{JX} = \underset{\substack{|\\|\\\text{calculated value}}}{\theta_{JX}\,|} = \left|\frac{\theta_{JX}2 - \theta_{JX}1}{t_{MD1}^{1/2} - t_{MD2}^{1/2}}\right|$$

6. Test conditions and measurements to be specified and recorded.

6.1 K factor calibration.

a. Specify the following test conditions:

(1) I_M current magnitude ___mA
(See detail specification for current value.)

(2) Initial junction temperature ___°C
(Normally +25°C ±5°C.)

(3) Final junction temperature ___°C
(Normally +100°C ±10°C.)

b. Record the following data:

(1) Initial $V_{GSf(i)}$ voltage ___mV

(2) Final $V_{GSf(f)}$ voltage ___mV

c. Calculate K factor in accordance with the following equation:

$$K = \left|\frac{T_{J1} - T_{J2}}{V_{GSf1} - V_{GSf2}}\right| \,^{\circ}C/mV$$

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

6.2 Thermal impedance measurements.

6.2.1 Test conditions. Specify the following test conditions:

a. I_M measuring current ___mA
(Must be same as used for K factor calibration)

b. V_H drain-source heating voltage ___V

c. t_H heating time ___s

d. t_{MD} measurement time delay ___µs

e. t_{SW} sample window time ___µs

(The value of V_H is usually chosen to produce an I_H value that results in a P_H approximately two-thirds of the device rated power dissipation.)

6.2.2 Record data. Record the following data:

a. T_{Xi} initial reference temperature ___°C

b. T_{Xf} final reference temperature ___°C

c. I_H current during heating time ___A

6.2.2.1 ΔV_{GSf} data:

ΔV_{GSf} ___mV

6.2.2.2 V_{GSf} data:

a. $V_{GSf(i)}$ initial gate-source voltage ___V

b. $V_{GSf(f)}$ final gate-source voltage ___V

6.2.2.3 θ_{JX} data:

θ_{JX} ___°C/W

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

6.2.3 Thermal impedance calculations. Using the data collected in 6.2.2 and the procedure and equations shown in 5.4, calculate the thermal resistance.

6.3 ΔV_{GSF} measurements for screening. These measurements are made for t_H values that meet the intent of 4.1 and the requirements stated in 5.2.

6.3.1 Test conditions. Specify the following test conditions:

a. I_M measuring current ___mA

b. V_H drain-source heating voltage ___V

c. t_H heating time ___s

d. t_{MD} measurement time delay ___μs

e. t_{SW} sample window time ___μs

(The value of V_H is usually chosen to produce an I_H value that results in a P_H equal to or greater than the values used for thermal impedance measurements.)

6.3.2 Specified limits. Data from one or more of the following is compared to the specified limits:

6.3.2.1 ΔV_{GSf} data:

ΔV_{GSf} ___mV

6.3.2.2 V_{GSf} data:

a. $V_{GSf(i)}$ initial gate-source voltage ___V

b. $V_{GSf(f)}$ final gate-source voltage ___V

Compute ΔV_{SD} ___mV

6.3.2.3 ΔT_J data. Optionally calculate ΔT_J if the K factor results (see 4. and 6.1) produce a σ greater than three percent of the average value of K and if the I_H variation between devices to be compared is relatively small.

$$\varnothing\ T_J = K(\varnothing\ V_{GSf}\ )\ \Upsilon C$$

NOTE: The test apparatus may be capable of directly providing a computed value of ΔT_J.

6.3.2.4 CU data. Optionally calculate CU for comparison purposes if the K factor results (see 4. and 6.1) produce a σ less than three percent of the average value of K and if the I_H variation between devices to be compared is relatively large.

CU = comparison unit

CU = $\Delta V_{GSf}/I_H$ mV/A

NOTE: The test apparatus may be capable of directly providing a computed value of CU.