Designation: F 617 – 00

Standard Test Method for Measuring MOSFET Linear Threshold Voltage[1]

This standard is issued under the fixed designation F 617; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of MOSFET (see Note 1) linear threshold voltage under very low sweep rate or d-c conditions. It is a d-c conductance method applicable in the linear region of MOSFET operation where a drain voltage V_D of approximately 0.1 V is typical.

NOTE 1—MOS is an acronym for metal-oxide semiconductor; FET is an acronym for field-effect transistor.

1.2 This test method is applicable to both enhancement-mode and depletion-mode MOSFETs, and for both silicon-on-insulator (SOI) and bulk-silicon MOSFETs. The test method specifies positive voltage and current conventions specifically applicable to *n*-channel MOSFETs. The substitution of negative voltage and negative current make the test method directly applicable to *p*-channel MOSFETs.

1.3 The values stated in International System of Units (SI) are to be regarded as standard. No other units of measurement are included in this test method.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *drain-leakage current—of a MOSFET,* the d-c current from the drain terminal when the gate voltage with respect to the threshold voltage is such that the MOSFET is in the OFF state.

2.1.2 *threshold voltage—of a MOSFET,* for operation in the linear region, the gate-to-source voltage at which the drain current is reduced to the leakage current.

3. Summary of Test Method

3.1 The drain-source current of the MOSFET under test is measured at several values of gate voltage for a fixed drain-source voltage. A linear plot is made of the drain current as a function of gate voltage. The maximum tangent to the resulting curve is extrapolated to the gate-voltage axis or to the voltage independent line representing the drain-leakage current. This intercept is the threshold voltage for the drain-source voltage and temperature conditions of the test.

3.2 Before this test method can be implemented, test conditions appropriate for the MOSFET to be measured must be selected and agreed upon by the parties to the test. Conditions will vary from one MOSFET type to another, and are determined in part by the intended application. The following items are not specified by this test method, and shall be agreed upon between the parties to the test:

3.2.1 Reference temperature to which the measured threshold voltages shall be normalized.

3.2.2 Permissible range of ambient temperature within which the measurement is to be conducted. The reference temperature shall be within this range.

NOTE 2—The temperature sensitivity of the threshold voltage may be as large as – 5 mV/°C, or more. The reproducibility of the measurements will be degraded accordingly, unless the values of the threshold voltage are normalized to a common reference temperature. To reduce the effect that uncertainties in the temperature sensitivity of the test devices will have on the reproducibility, no more than an appropriately small range of test temperatures should be allowed.

3.2.3 Drain voltage V_D at which the measurement is to be made.

3.2.4 Maximum drain current, I_{DM}, maximum gate voltage, V_{GM}, and gate voltage steps, ΔV_G, over which the measurement is to be made. Values for I_{DM}, V_{GM}, and ΔV_G shall be selected to permit taking enough data points to define adequately the drain-current, gate-voltage characteristic curve in the region of the inflection point, namely, where the tangent to the curve has the largest slope (maximum tangent). The value selected for ΔV_G shall be one of the following: 0.02, 0.05, 0.10, 0.20, or 0.50 V. The recommended procedure for selecting values for I_{DM}, V_{GM}, and ΔV_G is provided in the Appendix.

4. Significance and Use

4.1 The threshold voltage is a basic MOSFET parameter that must be determined for the design and application of discrete MOSFETs and MOS (see Note 1) integrated circuits. Threshold voltage is utilized in circuit design to specify the

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turn-on voltage of MOSFETs, and thereby determine performance attributes such as speed, power, noise margin, etc., of digital and analog circuitry.

4.2 The threshold voltage change in MOSFET devices, which will be exposed to ionizing radiation is a key factor in the selection of devices to be utilized in such an environment. Radiation induced charges trapped in the gate insulator and in the insulator-semiconductor interface regions of the MOSFET cause changes in the threshold voltage of the device and, hence, the device performance. This must be considered during design and MOSFET selection.

5. Interferences

5.1 If the gate current is greater than 1 % of the drain current, the threshold voltage measurement results are not valid.

5.2 If the current through voltmeter V_2(see Fig. 1) is large enough to alter the threshold voltage, either a meter with a higher impedance must be used (see 6.2.2) or the drain-current reading must be reduced by the amount of the meter current.

5.3 The high (positive) input of the ammeter, *A*, (see Fig. 1) must always be connected to the drain side of the MOSFET, regardless of the polarity of the device. Note that with such a connection, the ammeter will give negative current readings for *n*-channel MOSFETs. The reason for connecting the high input to the drain side of the MOSFET is to reduce errors in the measurement of drain current due to meter-leakage currents. Electronic ammeters are designed for low internal-leakage operation only when the high input is connected to the low-leakage, high-resistance side of the current path.

5.4 Care must be taken to prevent electrical voltage overstress damage to the gate dielectric as a result of device handling during the threshold voltage measurement. Under certain conditions, electrostatic discharge from the human body can result in permanent damage to the gate insulator.

5.5 Valid threshold voltage measurement data will be obtained only if the magnitude of the drain voltage applied during the threshold voltage measurement is less than the drain-substrate junction-breakdown voltage.

5.6 The reproducibility of the test method is degraded by the uncertainty and variation of the MOSFET temperature during the test and by the temperature sensitivity of the threshold voltage (see Note 2).

5.6.1 It is expected that the power dissipation of the MOSFET during the measurement of the linear threshold voltage will be so low that a negligible increase in device temperature will occur. This is the reason that the temperature of the package ambient is to be measured rather than the temperature of the MOSFET.

5.6.2 Before the measurement is begun it is important that the device will have reached its equilibrium temperature after transfer and handling, for example, and that the temperature indicator is adjacent to the MOSFET.

5.6.3 The range of the package-ambient temperature (see 8.18) is a measure of the uncertainty and variation of the MOSFET temperature during the test.

5.7 This test method is valid only if the MOSFET stability is sufficient to prevent changes in threshold voltage due to bias-temperature stress applied during the threshold voltage measurement.

5.8 MOSFET threshold voltage measurements should be made under dark conditions when the MOSFET package admits enough light to increase the apparent leakage current.

5.9 Care must be taken that the manufacturer's specification limits on the MOSFET are not exceeded, even for very brief periods, or the characteristics of the MOSFET may be changed.

6. Apparatus

6.1 *Transistor Test Fixture*, to connect the MOSFET under test to the test circuit. Electrical contacts shall be clean and of good quality.

6.2 *Voltmeters*:

6.2.1 V_1, with an input impedance of approximately 10 MΩ or greater, and a capability of measuring a voltage as large as V_{GM} (see 3.2.4) to within ±0.5 mV.

6.2.2 V_2, with an input impedance of approximately 10 MΩ or greater (see 5.2) and a capability of measuring a voltage as large as V_D(see 3.2.3) to within ±1 %.

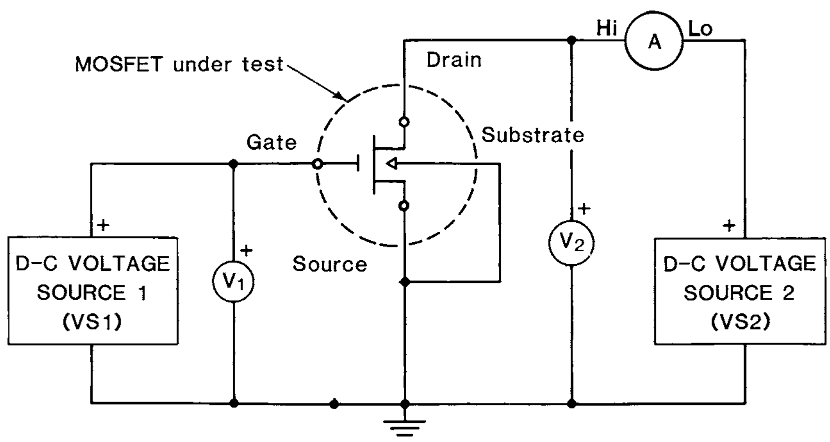


FIG. 1 Test Circuit for *n* -Channel Enhancement-Mode MOSFETs (see 1.2 and 5.3)

6.3 *Ammeter, A*, capable of measuring I_{DM}(see 3.2.4) with a minimum accuracy of ±0.5 %.

6.4 *Voltage Sources*, VS_1 and VS_2, meeting the following specifications after warmup:

6.4.1 Drift less than ±0.15 % of the set voltage over an 8-h period.

6.4.2 Periodic and random deviation (noise and ripple) less than 0.5% of the output voltage.

6.4.3 Voltage adjustable to at least the minimum accuracy requirements defined for meters V_1 and V_2, respectively, and

6.4.4 Capable of supplying voltages and currents required to make the measurements of the method.

6.5 *Temperature-Measuring Device*, capable of measuring the temperature of the package ambient with a precision of ±0.2°C.

7. Sampling

7.1 This test method determines the properties of a single specimen. If sampling procedures are used to select devices for test, the procedures shall be agreed upon by the parties to the test.

8. Procedure

8.1 Assemble the test circuit shown in Fig. 1.

8.2 If a substrate electrode is provided on the MOSFET, connect the substrate to the source electrode.

8.3 Turn on the apparatus and allow it to warm up at least for the period specified by the apparatus manufacturer before proceeding further.

8.4 Set voltage sources VS_1 and VS_2 to 0 V and insert the MOSFET to be tested into the test fixture. Wait until the MOSFET has reached its equilibrium temperature in the fixture before proceeding further.

NOTE 3—The time for the device to reach an equilibrium temperature after having been handled or transferred from a different temperature environment can be a minute or more, depending on the magnitude of the temperature change and the design of the package.

8.5 Measure and record the temperature of the package ambient and ensure that the temperature is within the range agreed upon between the parties to the test (see 3.2.2).

8.6 Adjust the voltage source VS_2 until voltmeter V_2 indicates the specified voltage value V_D (see 3.2.3 and 1.1).

8.7 Adjust voltage source VS_1 to change the gate voltage (indicated by voltmeter V_1) in the direction of increasing drain current, I_D, until a current is attained that is approximately 1 % of the specified value of I_{DM}(see 3.2.4).

8.8 Verify that voltmeter V_2 continues to read the specified value V_D and, if necessary, readjust voltage source VS_2 to obtain the specified value V_D.

8.9 Record the drain current, I_D, indicated by ammeter, *A* (see 6.3). Record the gate voltage, V_G, and call this voltage V_{GL}.

8.10 Adjust voltage source VS_1, to change the gate voltage an amount equal to $0.5\ |V_{GM} - V_{GL}|$ in the direction of decreasing drain current.

8.11 Verify that voltmeter V_2 continues to read the specified value V_D and, if necessary, readjust voltage source VS_2 to obtain the specified value V_D.

8.12 Record the current indicated by ammeter *A* and call it I_L. This is the drain leakage current to be used in this test method.

8.13 Adjust voltage source VS_1 until the gate voltage is at the nearest ΔV_G step below V_{GL}(see 3.2.4 and X1.4).

8.14 Adjust voltage source VS_1 to change the gate voltage by ΔV_G in the direction of increasing drain current.

8.15 Verify that voltmeter V_2 continues to read the specified value V_D and, if necessary, readjust voltage source VS_2 to obtain the specified value V_D.

8.16 Record the drain current, I_D, indicated by ammeter *A* and the gate voltage, V_G, indicated by voltmeter V_1.

8.17 Repeat 8.14, 8.15, and 8.16 until either I_{DM} or V_{GM}(see 3.2.4) is reached or until it is established that enough data points have been taken to determine the tangent with the largest slope.

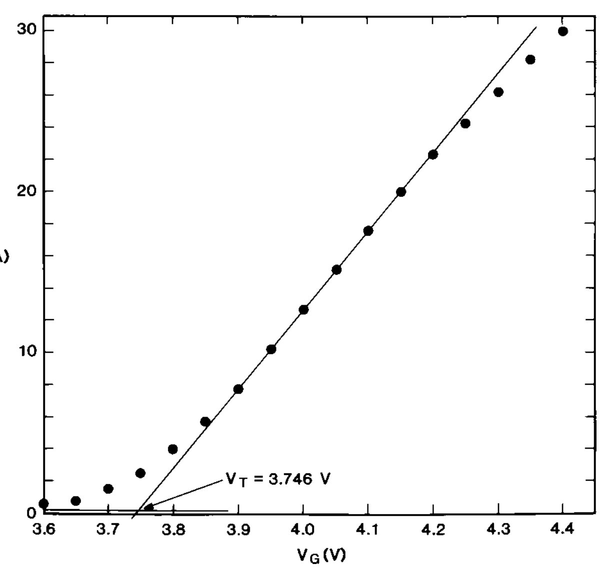
8.18 Measure and record the temperature of the package ambient. Record the average and the difference of the temperature measured here and in step 8.5; call these values the mean and the range of the package ambient temperatures, respectively.

9. Calculations and Interpretation

9.1 *Option I—Determination of Threshold Voltage by Graph Analysis*:

9.1.1 Data shall be graphed so that the gate voltage, V_G, is plotted on the abscissa and the drain current, I_D, is plotted on the ordinate (Fig. 2).

9.1.1.1 Select the voltage scale, V_S(voltage/cm), in accordance with the value of ΔV_G specified (see X1.4), as shown below:



NOTE 1—The size of the data points in this graph is grossly exaggerated for the purpose of clarity.

FIG. 2 Illustrative Data for an *n* -Channel Enhancement Device with a Reading of 3.746 V for the Threshold Voltage