EPC GaN Transistor Parametric Characterization Guide

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TABLE OF CONTENTS

General Information

The EPC GaN transistors generally behave like n-channel power MOSFETs. Common curve tracers, parametric analyzers, and automatic discrete device parametric testers that are used for an n-channel power MOSFET will be applicable for the characterization of GaN transistors. This applications note provides guidelines to characterize DC parameters using Tektronix 576 curve tracer, Keithley 238 parametric analyzer, TESEC 881-TT/A discrete device test system.
Some tests use high voltages. Proper safety procedures must be followed.

This apps note emphasizes those test areas that might be different from silicon power MOSFETs.

There are important notes, cautions or warnings in each section. It is highly recommended that those items be reviewed in advance of testing and be complied with to avoid accidental damage or degradation of the parts.

MOS-gate transistors are sensitive to static. GaN transistors have very low capacitances. Wrist straps, grounding mats, and other ESD precautions must be followed.

A summary of the key DC characteristics for EPC products is shown in the Tabl e 1, below:

Part Number	V_{DS} (Max)	V_{GS} (Max)	V_{GSTH} (Typ)	V_{GSTH} (Min)	V_{GSTH} (Max)	$R_{DS(ON)}$ (Typ) @ V_{GS}=5V_{DC}	$R_{DS(ON)}$ (Max) @ V_{GS}=5V_{DC}	V_{SD} (Typ)	I_D	Package
	V_{DC}	V_{DC}	V_{DC}	V_{DC}	V_{DC}	mΩ	mΩ	V_{DC}	A_{DC}	(mm)
EPC1014	40	+6/-5	1.4	0.7	2.5	12	16	1.80	10	LGA 1.7x1.1
EPC1015	40	+6/-5	1.4	0.7	2.5	3	4	1.80	33	LGA 4.1x1.6
EPC1009	60	+6/-5	1.4	0.7	2.5	24	30	1.80	6	LGA 1.7x1.1
EPC1005	60	+6/-5	1.4	0.7	2.5	6	7	1.80	25	LGA 4.1x1.6
EPC1007	100	+6/-5	1.4	0.7	2.5	24	30	1.80	6	LGA 1.7x1.1
EPC1001	100	+6/-5	1.4	0.7	2.5	6	7	1.80	25	LGA 4.1x1.6
EPC1013	150	+6/-5	1.4	0.7	2.5	70	100	1.80	3	LGA 1.7x0.9
EPC1011	150	+6/-5	1.4	0.7	2.5	18	25	1.80	12	LGA 3.6x1.6
EPC1012	200	+6/-5	1.4	0.7	2.5	70	100	1.80	3	LGA 1.7x0.9
EPC1010	200	+6/-5	1.4	0.7	2.5	18	25	1.80	12	LGA 3.6x1.6

WITH A TEKTRONIX 576, THE INITIAL SETTINGS ARE ASSUMED TO BE AS FOLLOWS:

- LEFT / RIGHT switch is in "off" position;
- VARIABLE COLLECTOR SUPPLY is at zero;
- DISPLAY is not inverted;
- DISPLAY OFFSET is at zero;
- STEP / OFFSET POLARITY is not inverted (OUT);
- VERT /HORIZ DISPLAY MAGNIFIER is at NORM (OFF);
- The ZERO button for OFFSET is IN.
- STEPS button on PULSED STEPS is IN
- The REP button on the STEP FAMILY selector is IN;
- The NORM button on the RATE is IN
- The EMITTER GROUNDED switch is set to BASE TERM SHORT

Some tests use high voltages. Proper safety procedures must be followed.

V_{TH} Measurement

V_{TH} is gate-source voltage ($V_{DS} = V_{GS}$) which produces a specified drain current on the data sheet. This test shorts the drain and gate.

V_{TH} measurement on curve tracer

Device terminal connection to the curve tracer: Drain to "C", Source to "E", Gate to Drain is shorted through an external 100 Ω resistor.

Curve tracer settings:

- Set HORIZONTAL VOLTS /DIV to 500 mV/div for EPC1001. Data sheet V_{TH} is 0.7 V to 2.5 V as shown in Table 1.
- Set VERTICAL CURRENT /DIV to 1 mA/div for EPC1001. It should be noted that each device type has a different Id specification for the V_{TH}. Set VERTICAL CURRENT /DIV accordingly so that the specified drain current for Vth measurement is approximately at the middle of the screen.
- Set Polarity to NPN;
- DISPLAY INVERT button is out
- Set Mode control to NORM;
- Set MAX PEAK VOLTS to 15 V;
- Set SERIES RESISTOR to 0.3 Ω (220 watts)
- STEPS button on PULSED STEPS is IN
- The EMITTER GROUNDED switch is set to BASE TERM SHORT
- Connect the device using the LRFT /RIGHT switch.

Increase the VARIABLE COLLECTOR VOLTAGE until the current reaches 5mA. Read the voltage which is V_{TH} for EPC1001. For other device types, take the reading at the data sheet specified current.

Caution for V_{TH} curve tracer testing: If there is no gate resistor (R_G) put into series with the gate during the V_{TH} measurement, you may see oscillation on the gate which will result in a typical S curve like that shown in figure 1 for V_{TH} curve without R_G that can occur at the gate and drain pins during a V_{TH} test. The oscillation voltage can become many times the input voltage. See Figure 2 oscilloscope trace. **THESE OSCILLATIONS CAN DAMAGE OR DESTROY THE DEVICE.** Care must be taken to avoid exposing devices to uncontrolled oscillation conditions!

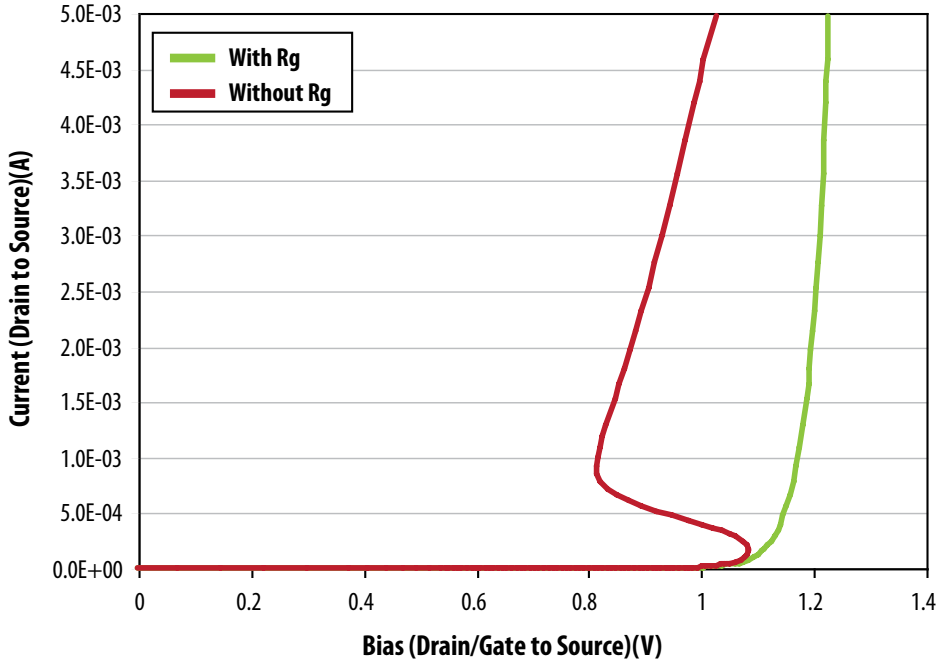

Figure 1: Comparison of V_{TH} curves obtained with and without gate resistor for EPC1001.

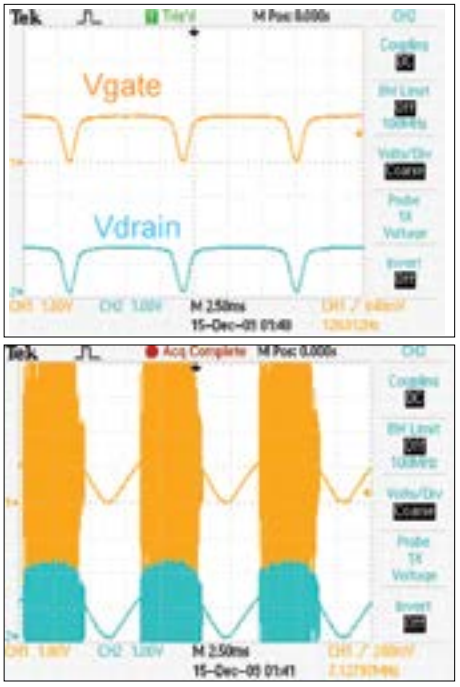

Figure 2: Oscilloscope trace of V_{TH} measurement a) with 180 Ω resistor in series with gate, b) without gate resistor. A high level of gate and drain oscillation is seen without the damping gate resistor.

The EPC GaN device technology has a very high transconductance. This makes the devices sensitive to feedback between the gate and drain during testing of V_{TH}. Figure 2 shows the high level of oscillation seen without the damping gate resistor. Choice of gate resistor is influenced by the test conditions of the curve tracer used, such as power level. The internal series resistor of the curve tracer acts to dampen the oscillations as well. An external gate resistor above 100 Ω is also encouraged, with little change in V_{TH} test results from resistors of 1 kΩ or more.

V_{TH} Measurement with a Keithley 238 Parametric Analyzer

Device terminal connection to SMU's: Connect Source to SMU1, short Drain to Gate and connect to SMU2.

SMU settings:

- SMU1 (Source): $V_S = 0$ V, I_S Max = 10 mA
- SMU2 (Gate & Drain): I_D Max = 10 mA, sweep V_D from 0 V to 2 V at 0.05 V per step

Record I_D and V_D: For EPC1001, V_{TH} is the V_D value at I_D = 5 mA. For other device types, take the reading at the data sheet specified current.

V_{TH} Measurement with TESEC 881-TT/A

- Select function: V_{TH}
- Set IG = 5 mA for EPC1001 (set ID according to data sheet drain current for V_{TH})
- Set test time = 380 µS with a packaged die in a socket, or 2.5 mS with probe needles on the bare die.

I_{GSS} Measurement with a Keithley 238 Parametric Analyzer

Device terminal connection to SMU's: Connect gate to SMU1, short Drain to Source and connect to SMU2.

SMU settings:

- SMU1 (Gate): I_G Max = 10 mA, sweep V_G from -5 V to +5 V at 1 V per step
- SMU2 (Drain and Source): V_D = 0 V, I_D Max = 10 mA
- Record I_G and V_G.

I_{GSS} measurement with TESEC 881-TT/A

- Select function: I_{SGS}
- Set V_G =5 V, check Rv flag for positive I_{GSS} gate measurement. Set I_G Max to 10 mA.
- Set test time = 380 µS with a packaged die in a socket, or 2.5 mS with probe needles on the bare die.

For negative I_{GSS} measurement, uncheck the Rv flag.

Note: It is NOT recommended to use the Autorange function during I_{GSS} testing as range changes during testing can lead to spiking.

I_{GSS} General ATE measurement guidelines

It should be verified that there is no spiking above voltage test settings in the measurements on the gate. It is recommended to use controlled voltage ramp settings to aid in avoiding overshoots.

The drain and the source are shorted together for this measurement.

It is suggested that ATE measurement be performed at +5 V and -5 V for comparison to specification. Suggest it is best if you use a 10 mA max current clamp on the gate to source leakage test at +/-5 V.

***Warning:* Do not exceed 6 V on the gate in the positive direction or 5 V in the negative direction as that is the maximum gate rating for the device.**

I_{GSS} Measurement

I_{GSS} is the gate-source leakage current with the drain shorted to the source.

I_{GSS} measurement on curve tracer

Device terminal connection to the curve tracer: Gate to "C", Source to "E", Drain is shorted to Source.

Note: It is very important to short the drain and the source together to get an accurate I_{GSS} measurement.

Curve tracer settings:

- Set HORIZONTAL VOLTS /DIV to 1 V/div. I_{GSS} will be measured at 5 V according to data sheet.
- Set VERTICAL CURRENT /DIV to 1 mA/div for EPC1001. It is set with respect to the I_{GSS} spec for the device being tested.
- Set POLARITY to NPN;
- DISPLAY INVERT button is out
- Set Mode control to NORM;
- Set MAX PEAK VOLTS to 15 V;
- Set MAX PEAK POWER to 220 W.
- STEPS button on PULSED STEPS is IN
- The EMITTER GROUNDED switch is set to BASE TERM SHORT
- Connect the device using the LEFT /RIGHT switch.

Increase the VARIABLE COLLECTOR VOLTAGE until the voltage reaches 5 V. Read the current which is I_{GSS} at V_{GS} = 5 V.

***Warning:* Do not exceed 6 V on the gate in the positive direction or 5 V in the negative direction as that is the maximum gate rating for the device.**

The above procedure is for measuring I_{GSS} with a positive gate voltage. To make a measurement with a negative voltage on the gate, reduce the VARIABLE COLLECTOR VOLTAGE TO zero and also :

- Set POLARITY to PNP position
- Press in DISPLAY INVERT button
- Set vertical scale to 50 µA for EPC1001
- Reapply the voltage to 5 V.

The trace will take time to settle because of the gate-source capacitance.

Note: Remember to take out the DISPLAY INVERT button after finishing the negative I_{GSS} test.

$R_{DS(ON)}$ Measurement

$R_{DS(ON)}$ is the drain to source resistance at 25 °C with V_{GS} = 5 V. Since $R_{DS(ON)}$ is sensitive to temperature, it is important to minimize heating of the junction during the test. A drain pulse test is therefore used to measure $R_{DS(ON)}$.

Accurate $R_{DS(ON)}$ measurement requires the use of Kelvin Sense on both drain and source. The locations of sense points have a strong influence on $R_{DS(ON)}$ readings.

$R_{DS(ON)}$ Measurement on Curve Tracer:

Device terminal connection to the curve tracer: Gate to "B", Drain to "C", Source to "E".

Curve Tracer settings:

- For EPC1001 example, set HORIZONTAL VOLTS /DIV to 50 mV/div. Scale is set according to the product of $R_{DS(ON)}$ and the drain current at which $R_{DS(ON)}$is specified on the data sheet.
- For EPC1001 example, set VERTICAL CURRENT /DIV to 2 A/div. It is set with respect to the drain current at which $R_{DS(ON)}$ is specified on the data sheet. Please note that the Max current for Tektronix 576 is 20 A. For measurements requiring greater than 20 A, the Tektronix 176 Pulsed High Current Fixture must be used.
- Set POLARITY to NPN;
- DISPLAY INVERT button is out
- Set Mode control to NORM;
- Set MAX PEAK VOLTS to 15 V;
- Set MAX PEAK POWER to 220 W.
- Set the STEP AMPLITUDE to 1 V;
- Set the NUMBER OF STEPS to 5;
- Set the OFFSET LIMIT to 0 V;
- The STEP MULTIPLIER button is OUT (the 0.1X not selected);
- Set the 80 microsec button on the PULSE STEPs to the IN position;
- Set the 0.5X button on the RATE selector to the IN position;
- Set the EMITTER GROUNDED switch to the "STEP GEN" position in the "BASE TERM" sector;
- Connect the device using the LEFT /RIGHT switch.

Increase the VARIABLE COLLECTOR VOLTAGE until the desired value of the drain current is obtained. Rdson is obtained by dividing VDS by ID. Please note that the Max current on Tektronix 576 is 20 A. The extreme left hand curve will be the 5 V gate reading.

Caution: The $R_{DS(ON)}$ measurement is sensitive to the sense contact locations. With EPC bumped die on a DUT card, the drain and source sense points should be immediately outside of the die.

***Warning:* It is not recommended to use needles on a bare die to measure $R_{DS(ON)}$ measurement. Too high current density at the probe needle /solder bump contacts could damage the device.**

It is also important to not exceed the 6V on the gate as that is the maximum gate rating for the device. It is also important to observe the maximum I_D rating of the device and not exceed it during the $R_{DS(ON)}$ test. Maximum I_D ratings for EPC GaN products are shown in Table 2 on the previous page in the suggested $R_{DS(ON)}$ curve trace setup table.

$R_{DS(ON)}$ Measurement with a Keithley 238 Parametric Analyzer

Device terminal connection to SMU's: Connect gate to SMU1, Source to SMU2, and Drain to SMU3.

SMU settings:

- SMU1 (Gate): V_G = 5 V, I_G Max = 10 mA;
- SMU2 (Source): V_S = 0 V, I_S Max = 1 A;
- SMU3 (Drain): I_D Max = 1 A, sweep V_D from 0 to 10 mV at 1 mV per step. The Max V_D is selected according to the $R_{DS(ON)}$ specification of the device. For example, EPC1001 $R_{DS(ON)}$ is 7 mΩ. At the Max current of 1 A on Keithley 238, Max V_{DS} is 7 mΩ * 1 A = 7 mV.

Record V_D and I_D: $R_{DS(ON)}$ is obtained by dividing V_{DS} by I_D.

$R_{DS(ON)}$ Measurement with TESEC 881-TT/A

- Select function: $R_{DS(ON)}$
- Set VG = 5 V
- Set ID according to data sheet specification. Drain current is limited to 20 A on TESEC 881-TT/A. If greater than 20 A is desired, a high current unit will be required.
- Clamp max $R_{DS(ON)}$ to 5X datasheet $R_{DS(ON)}$ max value.
- Set test time = 380 µS with a packaged die in a socket, or 5 mS with probe needles on the bare die.

Note: It is NOT recommended to use the Autorange function during $R_{DS(ON)}$ testing as range changes during testing can lead to spiking.

Part Number	Datasheet $R_{DS(ON)}$ Max (mΩ)	Datasheet I_D max (A)	V_G to use for curve tracing (V)	Horizontal V Range to use	Vertical I range to use	Do not exceed this I_{MAX} for curve tracing (A)	Typical horizontal readings at I_{MAX} (mV)	$R_{DS(ON)}$ at typical horizontal reading = V_{DS}/I_D (mΩ)
EPC1015	4	33	5	50 mV	2 A	20	60	3
EPC1001	7	25	5	50 mV	2 A	20	120	6
EPC1005	7	25	5	50 mV	2 A	20	120	6
EPC1014	16	10	5	50 mV	2 A	10	120	12
EPC1010	25	12	5	50 mV	2 A	12	220	18
EPC1011	25	12	5	50 mV	2 A	12	220	18
EPC1007	30	6	5	50 mV	1 A	6	145	24
EPC1009	30	6	5	50 mV	1 A	6	145	24
EPC1012	100	3	5	50 mV	0.5 A	3	210	70
EPC1013	100	3	5	50 mV	0.5 A	3	210	70

I_{DSS} / BV_{DSS} Measurement

BV_{DSS} is the rated voltage of the device at V_{GS} = 0 V. I_{DSS} is the drain current at a specified drain-source voltage which is equal or less than the rated voltage of the device, with V_{GS} = 0 V.

Important Note: The BV_{DSS} for a device is generally above the maximum drain-source voltage rating of the device. Therefore a BV_{DSS} test should not be done on the device because the maximum V_{DSS} rating will be exceeded. Degradation of device $R_{DS(ON)}$ characteristics may be seen if the max rating is exceeded. From a testing standpoint, the drain to source measurements performed should be like those for an n-channel FET in a traditional CMOS technology where I_{DSS} measurements at maximum ratings are performed instead of BV_{DSS} measurements.

I_{DSS} /BV_{DSS} Measurement on Curve Tracer

Device terminal connection to the curve tracer: Drain to "C", Source and Gate are shorted and to "E".

Curve tracer settings:

Note: It is very important to short the gate and the source to avoid floating the gate with respect to the source and accidentally turning on the device. The device could be damaged during the I_{DSS} testing if this occurs.

- Set HORIZONTAL VOLTS /DIV to 20 V/div for EPC1001. It is set with respect to the max V_{DSS} rating for the device.
- Set VERTICAL CURRENT /DIV to 50 µA/div for EPC1001 which is specified at 300 µA on data sheet. It is set according to the specified drain current at which the device V_{DSS} is rated.
- Set Polarity to NPN;
- DISPLAY INVERT button is out
- Set Mode control to NORM;
- STEPS button on PULSED STEPS is IN
- The EMITTER GROUNDED switch is set to BASE TERM SHORT
- Set MAX PEAK VOLTS to 350 V. It is set according to the device V_{DSS} rating.
- Set SERIES RESISTOR to Max peak power = 2.2 watts for EPC1001.
- Connect the device using the LEFT /RIGHT switch.

Increase the VARIABLE COLLECTOR VOLTAGE until the desired drain voltage is reached. Read the current which is I_{DSS} at this V_{DS}.

***Warning:* During I_{DSS} / BV_{DSS} measurement, do not exceed the device V_{DSS} rating. Degradation of device $R_{DS(ON)}$ characteristics may be seen if the max rating is exceeded. From a testing standpoint, the drain to source measurements performed should be like those for an n-channel FET in a traditional CMOS technology where I_{DSS} measurements at maximum ratings are performed instead of BV_{DSS} measurements.**

I_{DSS}/BV_{DSS} measurement with a Keithley 238 parametric analyzer

Device terminal connection to SMU's: Connect Drain to SMU1, short Gate to Source and connect to SMU2.

SMU settings:

- SMU1 (Drain): I_D Max = 1 mA, sweep V_D from 0 to 100 V for EPC1001. Max V_D is according to data sheet device V_{DSS} rating. Do not exceed device rating.
- SMU2 (Gate and Source): V_S = 0 V, I_S Max = 1 mA.
- Record V_D and I_D.

I_{DSS}/BV_{DSS} Measurement with TESEC 881-TT/A

- Select function: I_{DSS}
- Set V_{DS} = 100 V for EPC1001. It is set to the device BV_{DSS} rating.
- Set test time = 380 µS with a packaged die in a socket, or 2.5 mS with probe needles on the bare die.

Note : It is NOT recommended to use the Autorange function during I_{DSS} testing as range changes during testing can lead to spiking

***Warning:* Do not use Function BV_{DSS}. Do not measure device breakdown voltage at a fixed drain current as it will exceed device V_{DS} rating.**

Degradation of device $R_{DS(ON)}$ characteristics may be seen if the max rating is exceeded. From a testing standpoint, the drain to source measurements performed should be like those for an n-channel FET in a traditional CMOS technology where I_{DSS} measurements at maximum ratings are performed instead of BV_{DSS} measurements.

I_{DSS} ATE Measurement Guidelines

User needs to verify that there is no spiking above voltage test settings in the I_{DSS} measurements. It is recommended to use controlled voltage ramp settings to aid in avoiding overshoots.

Suggest 10 mA max current clamp or less on the drain to source leakage test.

The gate and the source are shorted together for this measurement.

Caution: It is very important to short the gate and the source to avoid floating the gate with respect to the source and accidentally turning on the device. The device could be damaged during the I_{DSS} testing if this occurs. It is not sufficient to set the gate to 0 V. It is very important to have a very low resistance short from the gate to the source.

***Warning:* Per previous notes, the BV_{DSS} for a device is generally above the maximum rating of the device and therefore a BV_{DSS} test should not be done on a device because the maximum V_{DS} rating will be exceeded. Degradation of device $R_{DS(ON)}$ characteristics may be seen if the max rating is exceeded. From a testing standpoint, the drain to source measurements performed should be like those for an n-channel FET in a traditional CMOS technology where I_{DSS} measurements at maximum ratings are performed instead of BV_{DSS} measurements.**

Test Socket Breakout Box Schematics and Definition Table

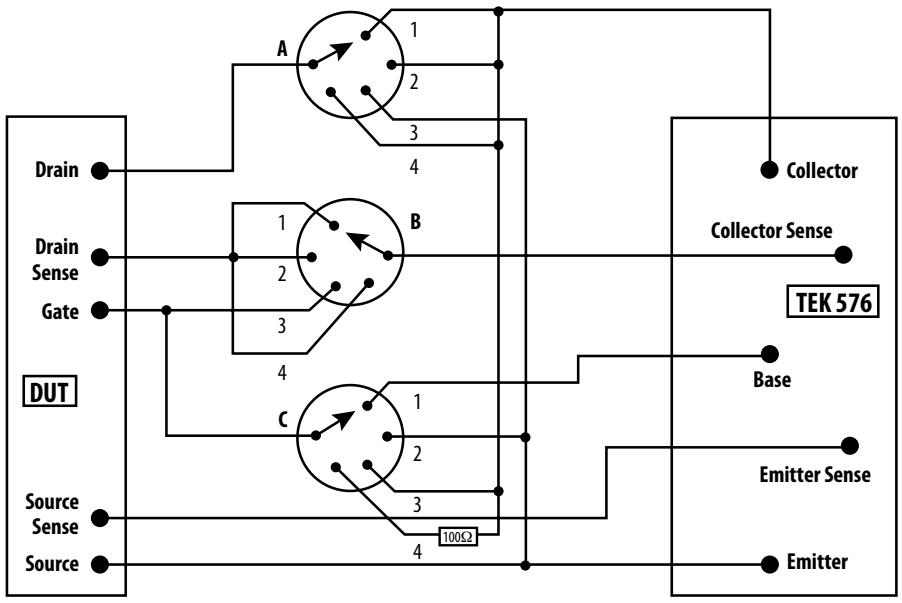

Figure 3: Test Socket Breakout Box

Table 3: Definition Table for Test Box

Box Knob Position	Knob Position Test Name	Collector connections	Base Connections	Emitter Connections
1	Through (for $R_{DS(ON)}$ testing)	Drain	Gate	Source
2	I_{DSS}	Drain		Source, Gate
3	I_{GSS}	Gate		Source, Drain
4	V_{TH}	Drain, Gate		Source

Useful References

1. "Using Enhancement Mode GaN-on-Silicon Power Transistor", Edgar Abdoulin, Steve Colino, Alana Nakata, www.epc-co.com
2. International Rectifier, Application Note AN-957, "Measuring HEXFET® MOSFET Characteristics", www.irf.com/technical-info/appnotes/an-957.pdf
3. "Fundamentals of Gallium Nitride Power Transistors", Steve Colino and Robert Beach, www.epc-co.com