The objective of this lab is to become familiar with methods to measure the dc current-voltage (IV) behavior of diodes and metal-oxide-semiconductor field-effect transistors (MOSFETs).

In this exercise we will configure the Analog Discovery module to emulate a semiconductor curve tracer. We will save these instrument configurations as Analog Discovery Workspace files for use in future labs.
What is A Curve Tracer?

A curve tracer is an instrument that measures and plots the dc current-voltage characteristics of a semiconductor device. For four terminal devices like MOSFETs, the output (ID vs VDS) and transfer (ID vs VGS) characteristics are very useful in describing device behavior. The plot below shows the output (ID vs VDS) behavior for a NMOSFET device found in the ALD1103 IC array. This data was measured using the Analog Discovery module configured as a curve tracer.

IDS is determined by measuring the voltage across a 100 ohm resistor in series with the drain.

VGS stepped in 0.5 V increments for 10 steps from 0 – 4V.

VD is swept from 0 to 5 V for each gate step voltage.
Test Circuits for Characterizing Semiconductor Devices

The current-voltage (IV) behavior of diodes and metal-semiconductor field-effect transistors (MOSFETs) is characterized by stimulating selected device terminals and measuring the response. The IV response is measured using test setups like those below. The value of resistor R1 is scaled in size to develop about 4V across the resistor at maximum current for the device under test. $R1 = 10 \, \Omega$ works well for the ALD1103 series NMOSFETs.

(a) Diode IV Curve           (b) MOSFET Output IV Curve           (c) MOSFET Transfer IV Curve
Some Observations about Configuring the Analog Discovery Module as a Curve Tracer

Diode characteristics like that in setup (a) are measured simply by sweeping VD and measuring ID.

Configuring the Discovery module for MOSFET device measurement requires the simultaneous stimulation of two separate device terminals as previously shown in setups (b) and (c).

The differential scope channels of the Discovery module allow for convenient measurement of differential voltages across elements like resistor R1. These differential voltages convert directly to current by the resistor scale factor.

The terms sweep and step imply that device terminals are being changed over time. As long as the stepping and sweeping is conducted at low frequencies the measured characteristics will represent device dc behavior.

The measurement techniques will take advantage of the X-Y scope configuration in the Waveform software for plotting either ID vs VDS or ID vs VGS for our test setups. The X-Y scope mode defaults to Channel 2 Y-axis and Channel 1 X-axis.
Configuring the Discovery Module to Measure NMOSFET Output Characteristics (ID vs VDS)

The figure at the right is the test setup for measuring NMOS output characteristics. The drain voltage $V_D$ is swept over the desired range by configuring AWG2 as a saw tooth waveform generator. The gate voltage $V_{GS}$ is configured as a staircase generator with the number of steps and the incremental step size required.

AWG2 is set to run 10 X times as fast as AWG1 so that the drain current is swept for each gate step value. As long as the time periods for the AWG waveforms are on the order of milliseconds MOSFET dc behavior is measured.

Scope channel probes are positioned to measure $ID$ (Ch2) and $VDS$ (Ch1). Resistor $R1$ value is chosen to limit the voltage drop across $R1$ to a maximum of 4V and to optimize the current plot for the specific NMOSFET device.
AWG Channel 1 Configured as a Gate Voltage Step Generator to Measure NMOSFET Output Characteristics (ID vs VDS)

The Analog Discovery AWG 1 configured as a repetitive 10 step generator operating a 100 Hz. With 10 voltage steps of 0 to +4V the device exhibits increasing drain current with increasing gate to source voltage. Note the AWG 1 settings for the VGS step generator below.
AWG Channel 2 Configured as a Drain Voltage Sweep Generator to Measure NMOSFET Output Characteristics (ID vs VDS)

The Analog Discovery AWG 2 is configured as a repetitive ramp generator operating at 1 KHz. This frequency is 10 times greater than the frequency of the gate voltage step generator to complete a complete sweep for each gate step voltage. The voltage ramp is between 0 and 5 V so that VDS forces the device drain current through all regions of operation (cutoff, triode, saturation). Note the AWG2 settings for the ramp generator below.
The ALD 1103 MOSFET IC (shown at the right) contains 2 NMOS and 2 PMOS devices. You will use 1 NMOS device in this test procedure.

These devices can be damaged if care is not taken when connecting the pins! Also exercise caution when handling MOSFETs. Your body can generate thousands of volts of electrostatic discharge.

Complete the test circuit setup (b) on your solderless bread board including connections to the Discovery module. Connect the ALD1103 DN1, SN1, and V- (body) pins on the prototype board to the appropriate locations in the test setup (b).

***As a special precaution connect the GN1 Gate pin last and remove GN1 first when wiring devices on the bread board***
ALD1103 NMOSFET Output Characteristics (ID vs VDS)

Download the Waveform workspace file NMOS Output Curve Tracer2 (ALD1103) into your Discovery module. Now that you have carefully wired and verified the test circuit (b) on your solderless breadboard, you can activate the Discovery module and measure the output current-voltage (IV) behavior for the ALD1103 NMOSFET. Your results should resemble that of the figure below.

VGS stepped in +0.5 V increments for 10 steps from 0 to +4V
Making the Output Trace Look Like a Curve Tracer
Converting the Y Axis to Units of Current

• To convert from volts to current we introduce a custom math channel through the Waveform software by right clicking on the area of C1 and C2 to the right of the scope trace and selecting **Add Math Channel -> Custom** as shown at the right.

• Enter the function **C2/10** to represent the current as the voltage divided across R1 divided by the resistor (in this case 10 ohms).

• Set the Y axis units in the right pull down menu to **A** for amperes.

• Right click in the XY#1 trace area and select **Channel 1 for X** and **Math 1 for Y**.

• Adjust the math channel **offset** and **range** values for an optimal display of current.
ALD1103 NMOSFET Output Characteristics (ID vs VDS)  
Y Axis Scaled in Units of mA

Your results after inserting the custom math channel to set the Y axis to display current should resemble that of the figure below.

VGS stepped in +0.5 V increments for 10 steps from 0 to +4V
Configuring the Discovery Module to Measure NMOSFET Transfer Characteristics (ID vs VGS)

The figure at the right is the test setup for measuring NMOS transfer characteristics. The drain voltage VD is fixed at +5V using the Discovery V+ supply (don’t forget to power on).

The gate voltage VGS is swept over the desired range by configuring the AWG2 as a saw tooth waveform generator. AWG1 for VBS voltage is configured as a staircase generator with the number of steps and the incremental step size required.

AWG2 is set to run 10 X times as fast as AWG1 so that the drain current is swept for each body terminal step value. As long as the time periods for the AWG waveforms are on the order of milliseconds MOSFET dc behavior is measured.

The scope channel probes are positioned to measure ID (Ch2) and VGS (Ch1). R1 is chosen to optimize the current plot for the NMOS device.
AWG Channel 1 Configured as a Body Voltage Step Generator to Measure NMOSFET Transfer Characteristics

The Analog Discovery AWG 1 configured as a repetitive 10 step generator operating a 100 Hz. With 10 voltage steps of 0 to -4V the device exhibits increasing threshold voltage with increasing negative body to source voltage. Note the AWG 1 settings for the VBS step generator below.
The Analog Discovery AWG 2 is configured as a repetitive ramp generator operating at 1 KHz. This frequency is 10 times greater than the frequency of the body voltage step generator to complete a complete gate voltage sweep for each body step voltage. The gate voltage ramp is between 0 and 4 V so that VDS is always greater than VGS-VT to keep the device in saturation. Note the AWG2 settings for the ramp generator below.
Measuring ALD1103 NMOSFET Transfer Curves with the Discovery Module

Download the Waveform workspace file **NMOS Transfer Curve Tracer (ALD1103) V2** into your Discovery module. Now that you have carefully wired and verified the test circuit (c) on your solderless breadboard, you can activate the Discovery module and measure the output current-voltage (IV) behavior for the ALD1103 NMOSFET. Your results should resemble that of the figure below.

![Graph showing the transfer curves of ALD1103 NMOSFET with different VBS values. The x-axis represents VGS (V), and the y-axis represents IDS (10 mA/V). The graph shows curves for VBS = 0 V, VBS = -1 V, VBS = -2 V, VBS = -3 V, and VBS = -4 V.](image)
ALD1103 NMOSFET Transfer Characteristics (ID vs VGS)

Y Axis Scaled in Units of mA

Your results after inserting the custom math channel to set the Y axis to display current should resemble that of the figure below.
Measuring ALD1103 NMOSFET Transfer Curves with the Discovery Module
Measuring PMOS IV Curves with the Discovery Module

PMOSFET Devices can be characterized much the same way using the Analog Discovery module as a curve tracer. The test circuit configurations remain the same. However, the PMOS device is complementary to the NMOS device and requires reversing polarities on the terminal stimuli (AWGs and power supply). This conversion is easily accomplished by starting with the NMOS Curve Tracer files.

For measuring **PMOS output characteristics** download the **NMOS Output Curve Tracer** workspace file into the Analog Discovery module. Convert the gate voltage step generator (AWG1) from positive polarity gate voltages to negative polarity gate voltages by changing the **amplitude** from +2 V to –2 V and the **offset** from +2 V to –2 V. Likewise convert drain voltage sweep generator, AGW2, by changing the **amplitude** from +2.5 to –2.5 V and the **offset** from +2.5 V to –2.5 V.

For measuring **PMOS transfer characteristics** download the **NMOS Transfer Curve Tracer** workspace file into the Analog Discovery module. Convert the body voltage step generator (AWG1) from negative polarity body voltages to polarity polarity gate voltages by changing the **amplitude** from –2 V to +2 V and the **offset** from –2 V to +2 V. Likewise convert the gate voltage sweep generator, AGW2, by changing the **amplitude** from +2.5 to –2.5 V and the **offset** from +2.5 V to –2.5 V. Set **VD** to –5 V.

Once you have configured and verified the Discovery module for each test condition, save each workspace file as **PMOS Output Curve Tracer** and **PMOS Transfer Curve Tracer**. You will then have a library of standard MOSFET curve tracer configurations.
ALD1103 PMOSFET Output Curves
Measured with the Discovery Module

IDS (100 mA/V)

VDS (V)
ALD1103 PMOSFET Transfer Curves
Measured with the Discovery Module

IDS (100 mA/V)

VBS = 4 V
VBS = 3 V
VBS = 2 V
VBS = 1 V
VBS = 0 V