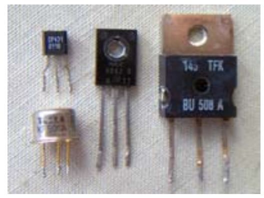
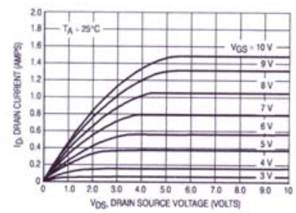
# TRANSISTOR CURVE TRACER

## BACKGROUND

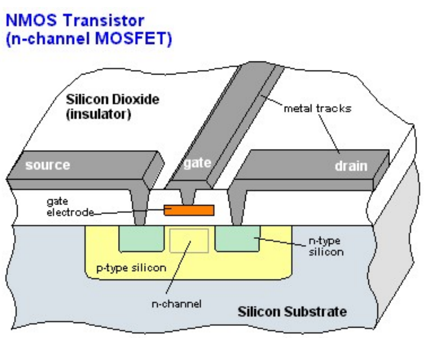
The MOSFET is by far the most widely used transistor in both digital and analog circuits and is the backbone of modern electronics. Hence it is important for you, as a student, to master its characteristics and use. Applications of the MOSFET include digital logic and switching circuits (central to all computers and their derivatives), operational amplifiers (important for a myriad of signal processing applications), and the random-access memory (RAM) used to store just about everything. Nearly all integrated circuits contain MOSFETs, often in large numbers.



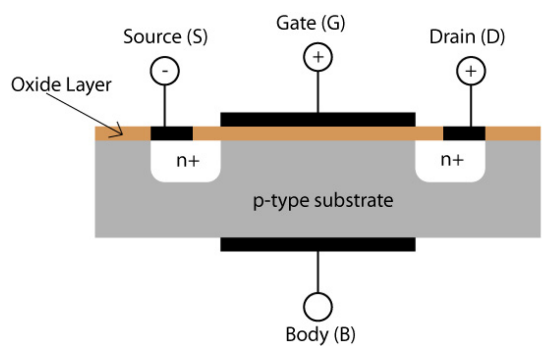




Unlike diodes and resistors, which are passive, two-terminal devices, the MOSFET is an active, three-terminal device. An active device is one that can deliver more power to a load than it takes from a signal source. The raw power is derived from a separate DC source connected to the MOSFET circuit. An active element such as a transistor can be thought of as a "valve" (much like a water faucet) which takes only a small amount of power to adjust (via your hand) but which allows the user to control a lot of water power originating at the high-pressure city water supply.

The physical structure of an *n*-channel MOSFET, or NMOS, is shown below in idealized form. MOSFETs also come in *p*-channel form (PMOS); these have similar properties except that the *n*- and *p*- channel materials are reversed, and the various voltages and currents are of opposite polarity to those of the NMOS.




NMOS structure on integrated circuit




Idealized representation of NMOS

In the *n*-channel device, *n*-type wells implanted into the *p*-type substrate comprise the drain and source terminals. (Metal contacts and pathways, usually aluminum, bring these terminal connections to the outside world or to other devices.) An insulating oxide layer separates the gate from the substrate. This layer is usually a thin film of silicon dioxide less than 50 nm (500 Å) thick. As we shall learn later in the course, the MOSFET is actually a four-terminal device because sometimes the substrate (body) is used as a fourth terminal that affects transistor operation.

Applying a voltage between the gate and the source creates an electric field in the oxide insulation layer – hence the name "field effect" transistor. This field, which extends from the gate to the substrate, pushes the holes that populate the *p*-type substrate away from the channel, and induces electrons up from the substrate into the channel, thereby allowing current to flow from drain to source. The higher the value of $v_{GS}$, the stronger the field and the large the number of induced electrons, hence the larger the current that can flow when the device is in its constant-current (horizontal) region of the $i_D$-$v_{DS}$ curve.

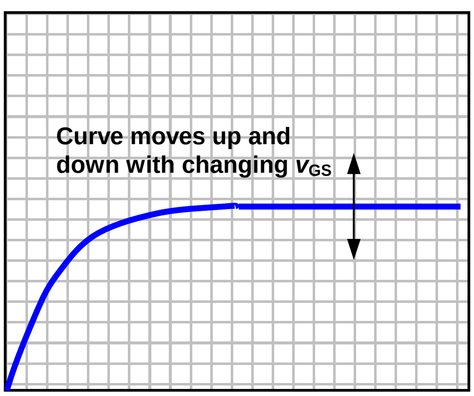
The substrate of an NMOS device must always be held at the most negative voltage in the circuit (or most positive for PMOS) so that the source-substrate and drain-substrate junctions never become forward biased. While not relevant to this assignment (you will use discrete MOSFETs only), this requirement is important to those designing integrated circuits in which many, many MOSFETs share the same substrate.

In this lab, we construct an instrument known as a "curve tracer". The curve tracer allows us to visualize the *i*-*v* characteristics of the MOSFET on the face of the oscilloscope so that we can better understand the MOSFET's properties and operation and measure its parameters such as $K$ and $V_{TR}$.

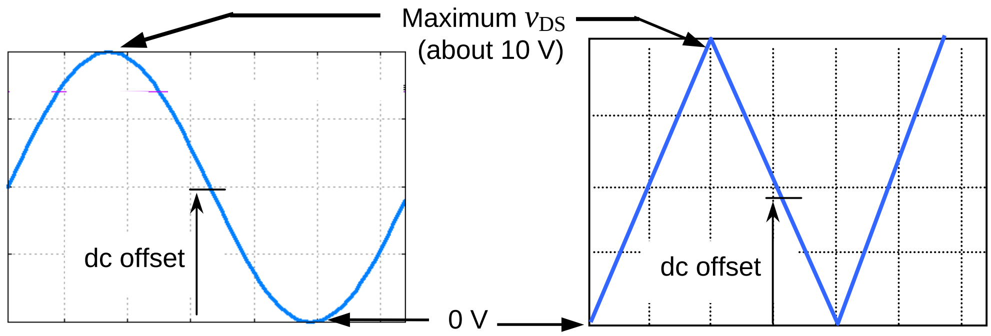
| | |
|---|---|
| *Laboratory Goal:* | To design a visual graphing system that can display the current-vs-voltage characteristics of a MOSFET device. |
| *Learning Objectives:* | Transistor *i*-*v* curves, signal-processing circuits, oscilloscope *x*-*y* mode. |
| *Suggested Tools:* | Variable voltage source, waveform or function generator, multimeter, oscilloscope, op-amps, digital counter. |

## ASSIGNMENT

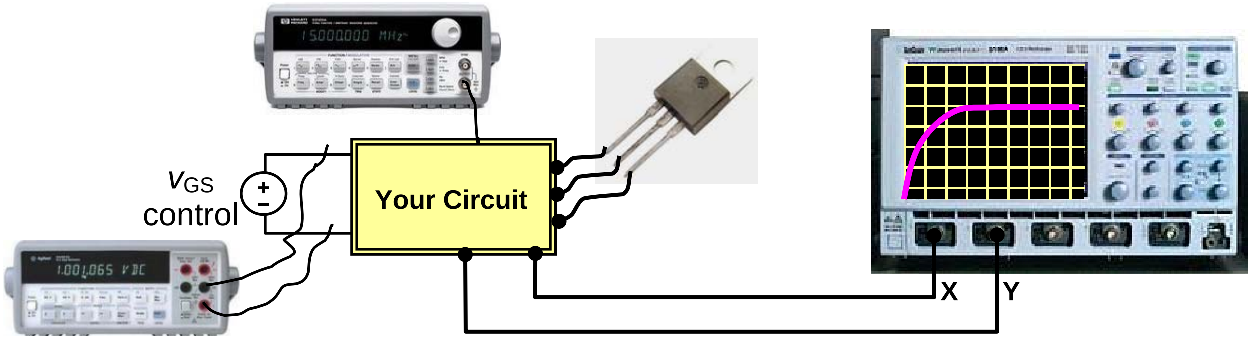
Level 1:
Using any one of the MOSFETs in your parts kit, build a system that can display the device's $i_D$-$v_{DS}$ characteristic on the oscilloscope screen. Your system should the show drain current $i_D$ on the *y*-axis of the "scope" versus drain-source voltage $v_{DS}$ on the *x*-axis. Display the $i_D$ vs $v_{DS}$ curve for a *single* value of $v_{GS}$ which you control manually by adjusting a variable voltage source. Your system should apply a constant $v_{GS}$ to the MOSFET, then "sweep" the value of $v_{DS}$ from 0 V to about 10 V or 12 V at a rapid rate so that the dot produced by the scope when it is in *x*-*y* mode looks like a solid line due to eye persistence. When you are finished, the screen of your scope should look something like this:




The voltage applied to $v_{DS}$ sweeps its value from the origin to its maximum value. It should be either a sinusoidal or saw-tooth waveform to which a DC offset has been added to that the voltage is never negative and always positive:




As noted above, you must include a method to *manually* adjust the gate-source voltage $v_{GS}$ using a separate source of variable voltage. A voltmeter should indicate the value of $v_{GS}$ being applied to the MOSFET. You can find the correct *D*, *S*, and *G* terminals for your device by looking up its datasheet on the web. A block diagram of the system you are to build is shown below:



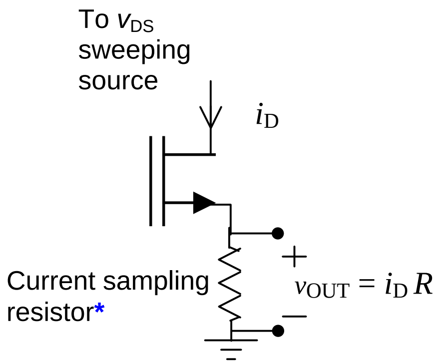

➔ **From your display, determine:**

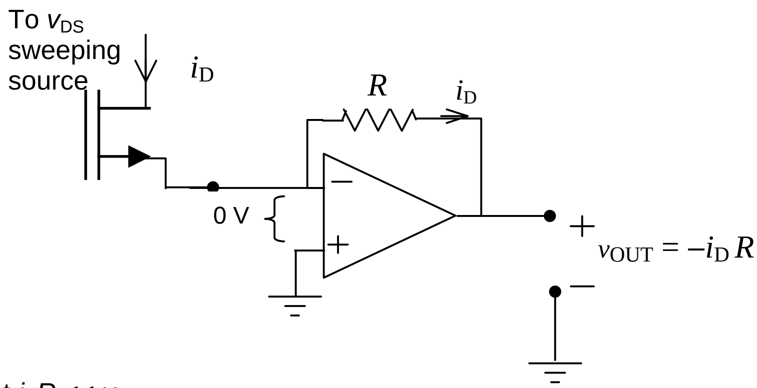
- The threshold voltage $V_{TR}$ for your MOSFET
- The value of the conductance parameter *K* for your MOSFET

**Oscilloscope X-Y Mode**

Every oscilloscope has an *x*-*y* mode in which one of its voltage channels is displayed on the horizontal axis, and the other voltage channel is displayed on the vertical axis. When a scope is operated in the *x*-*y* mode, the time base is disabled; the screen no longer provides time measurements. Rather, it displays the values of its two input voltages via a dot on the display screen. The displayed volts per division for each axis corresponds to the volts-per-division setting of the associated input channel. A scope measures only voltage, not current. Hence you will need some way to convert the MOSFET's drain current $i_D$ into a voltage that can be applied to the *y*-axis of the oscilloscope. Two possible methods are shown below. One consists of a current-sampling resistor placed between the source terminal and ground. This resistor can serve as a *i*-*v* converter, but its value must be very small so that its voltage drop produces only a small perturbation to the measured $v_{DS}$. Otherwise, the scope will interpret the voltage across $i_D R$ as part of $v_{DS}$. Another method is to use an op-amp current-to-voltage converter. You probably encountered such a circuit in Electric Circuit Theory. Both forms of current sampling are shown below.

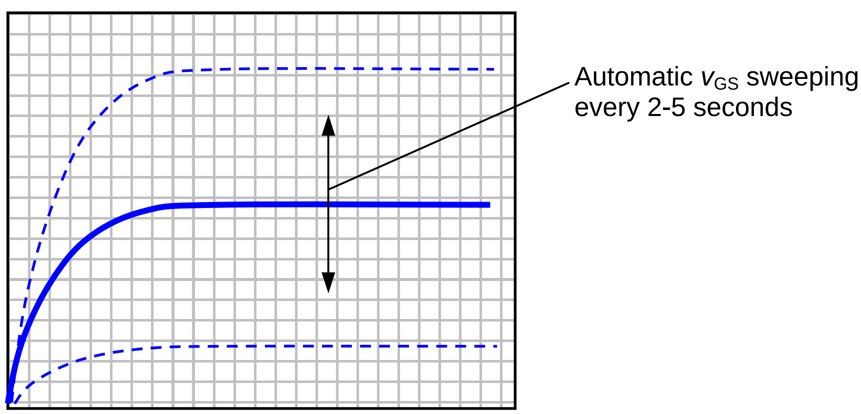
Possible Current-to-Voltage Converters




*must choose resistor value so that $i_D R << v_{DS}$

Level 2: (More difficult)
Now modify your display system so that the $i_D$-$v_{DS}$ curve is *continually* changed from a cutoff value ($v_{GS} < V_{TR}$) to a curve corresponding to some large value of $v_{GS}$ that you choose. (Don't overstress the gate-source terminals of the MOSFET! Look up $v_{GS\text{-}max}$ on the transistor's data sheet.) To accomplish this task, you will need a second signal generator to sweep $v_{GS}$. You may have to build your own, or use one of the low-voltage 60-Hz AC sources available in the lab. The following figure illustrates the goal of your circuit. The curve should move up and down about once every 2 to 5 seconds:




Level 3: (Hard)
Modify the system of Level 1 so that it displays a "family" of $i_D$-$v_{DS}$ curves at *discrete* jumps in $v_{GS}$ between $v_{GS}$ = 0 and $v_{GS}$ = 8 V. To accomplish this task, consider using any or all of the following:

- A digital circuit that counts from 0 to 8 in binary
- A digital-to-analog (D/A) converter to create $v_{GS}$
- A waveform generator that sweeps $v_{DS}$ from 0 V to 10-V *on demand.* You will need such a circuit if your $i_D$ vs $v_{DS}$ sweeps are to synchronized to the sequential jumps in $v_{GS}$.

Your finished display should look something like the figure to the right (voltage and current values may vary).