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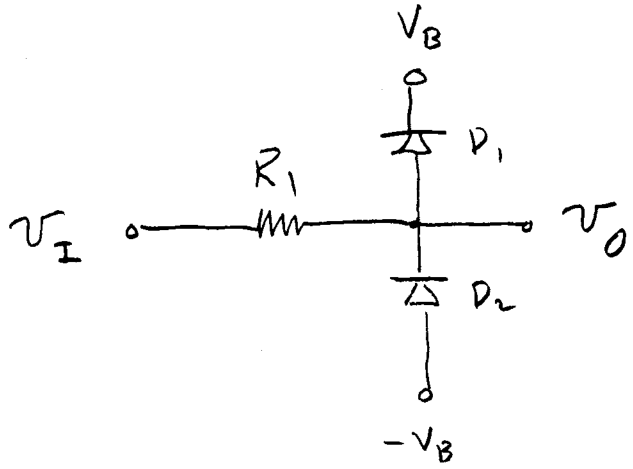
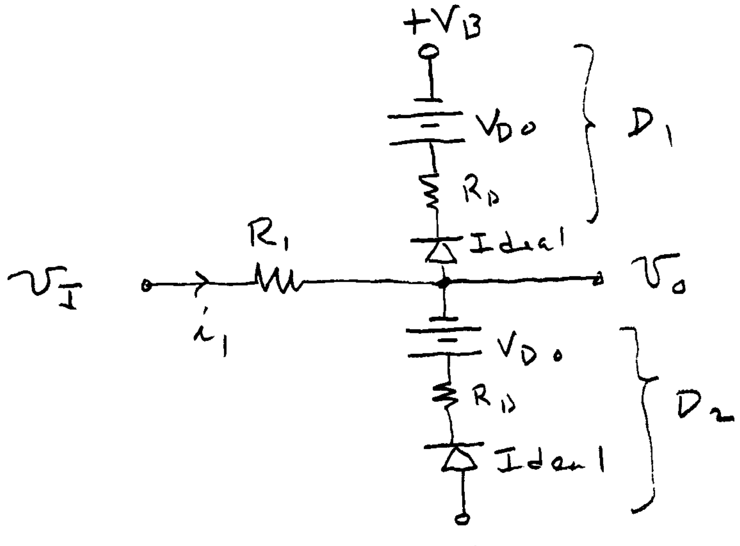
Diode Clipper Circuits

Peak Clipper

Used to clip off the peaks of a waveform



Replace the diodes with the large signal model



For $-(V_B + V_{D0}) < v_I < +(V_B + V_{D0})$, both diodes are reverse biased and $i_1 = 0$

$$\Rightarrow v_o = v_I$$

For $v_I > V_B + V_{D0}$, D_1 turns on.

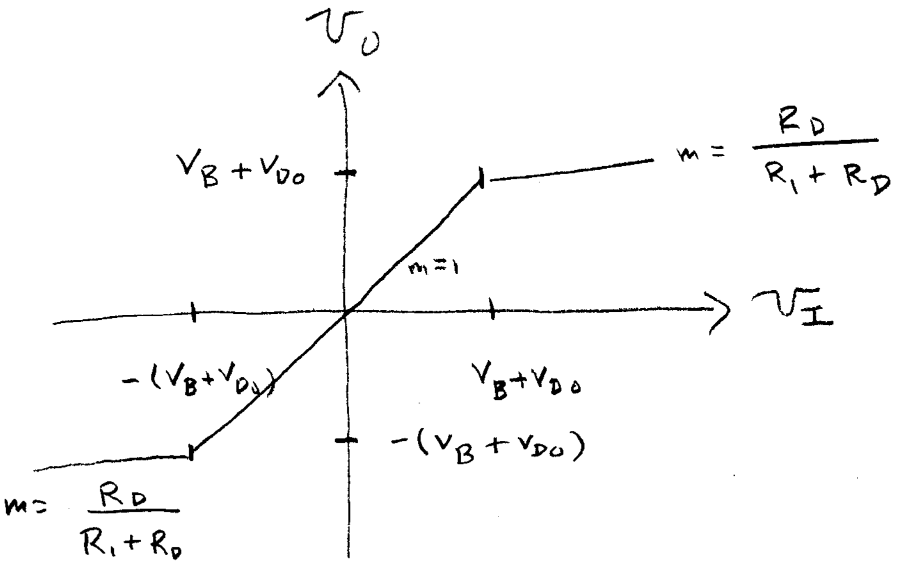
$$i_1 = \frac{v_I - (V_B + V_{D0})}{R_1 + R_D}$$

$$v_o = v_I - i_1 R_1$$

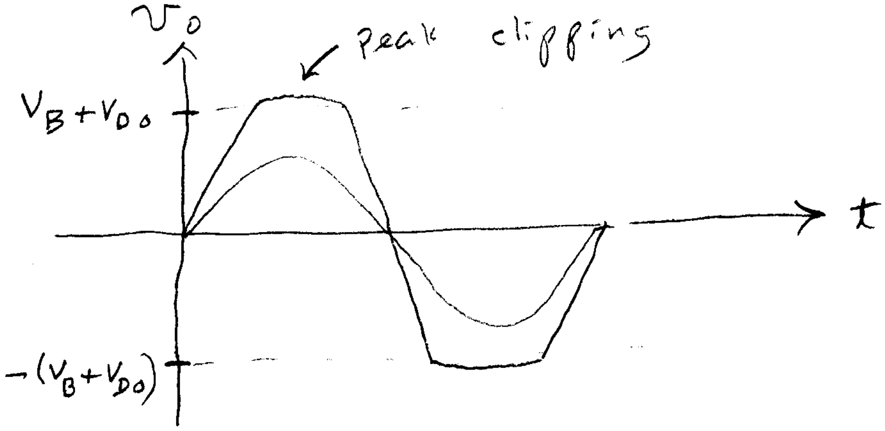
$$= (V_B + V_{D0}) \frac{R_1}{R_1 + R_D} + v_I \frac{R_D}{R_1 + R_D}$$

Similarly, for $v_I < -(V_B + V_{D0})$ D_2 turns on and

$$v_o = -(V_B + V_{D0}) \frac{R_1}{R_1 + R_D} + v_I \frac{R_D}{R_1 + R_D}$$

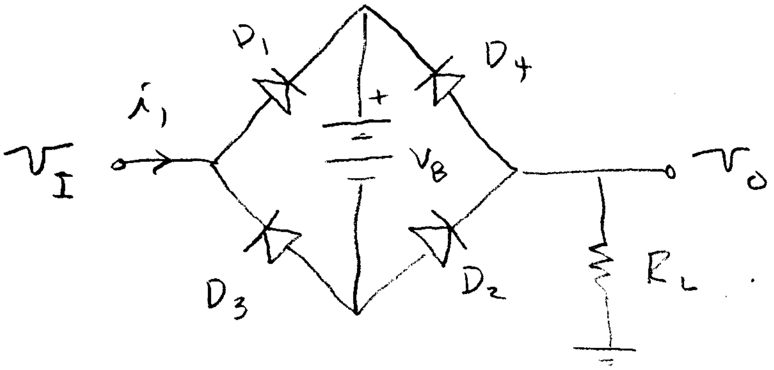


For a sine wave in



Fast switching diodes are required

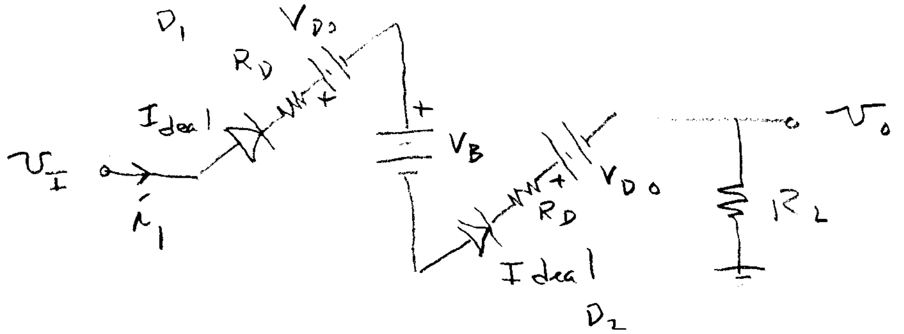
A Center Clipper



$v_I > V_{\gamma 1} + V_B + V_{\gamma 2} \Rightarrow i_1$ flows

up through D_1, down through V_B, up through D_2 and down through $R_L \Rightarrow v_o$ goes positive.

Eq. ckt. for $v_I > 0$



Assume both diodes are on.

$$\Rightarrow \quad i_1 = \frac{v_I - V_{D0} - V_B - V_{D0}}{2R_D + R_L}$$

$$= \frac{v_I - V_B - 2V_{D0}}{2R_D + R_L}$$

$$v_0 = i_1 R_L$$

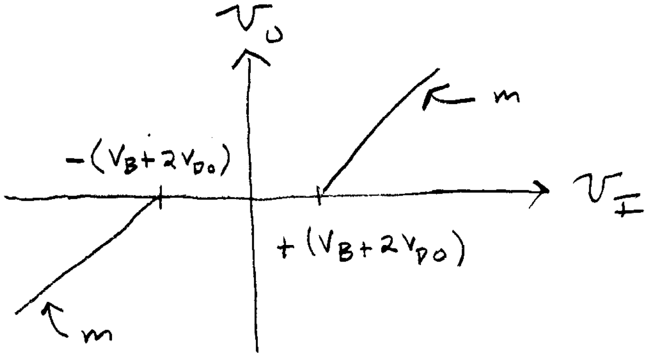
$$= \frac{R_L}{2R_D + R_L}\left(v_I - V_B - 2V_{D0}\right)$$

Because v_0 cannot go negative for $v_I > 0$, this holds only for $v_I > V_B + 2V_{D0}$

Similerly, for $v_I > 0$

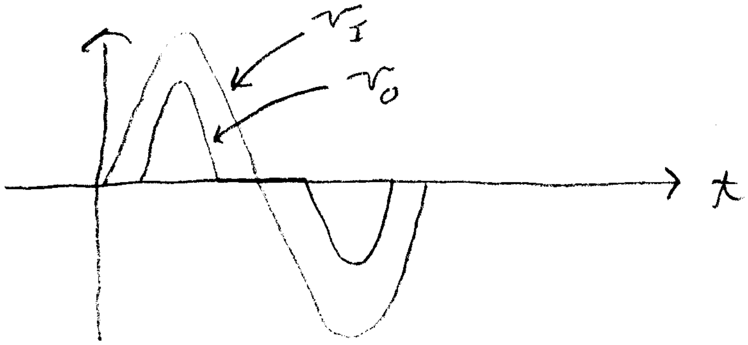
$$v_0 = \frac{R_L}{2R_D + R_L}\left(v_I + V_B + 2V_{D0}\right)$$

this holds only for $v_I < -(V_B + 2V_{D0})$



$$m = \frac{R_L}{R_L + 2R_D}$$

Let v_I be a sine wave



the center is clipped from v_O

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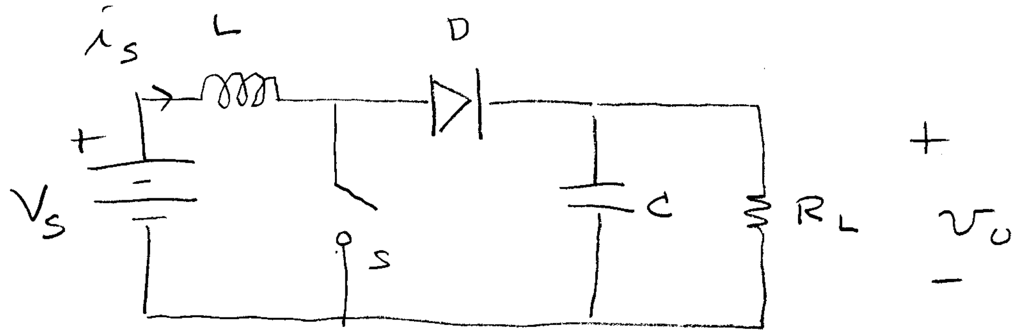
The Boost dc to dc converter



Consider the diode to be ideal.

Let the switch close for time Δt

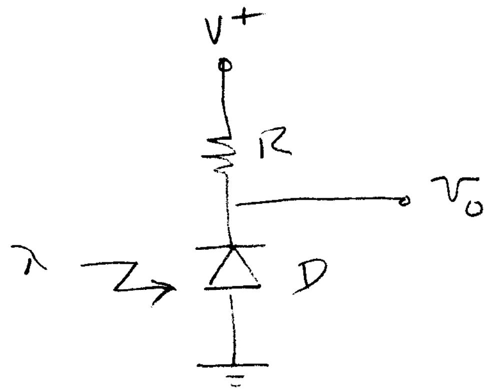
$$V_s = L \frac{d i_s}{dt}$$

$$\Rightarrow \quad i_s = \frac{1}{L}\int_0^{\Delta t} V_s \, dt = V_s \frac{\Delta t}{L}$$

Now let S open. i_s cannot stop in zero time. A voltage builds up across L which forward biases D. If C is absent, v_0 will increase to the value $i_s R_L = V_s \frac{\Delta t}{L} R_L$

This voltage can be much higher than V_s. Addition of C "smooths out" V_0 so that an approximate dc voltage can be obtained at V_0 if the switch is toggled on and off at an appropriate rate.

The Photo Diode - Used in Photodetector circuits, eg. remote controls



Diode is operated reverse biased.

The diode has its depletion region "exposed". A lens concentrates light λ into the depletion region

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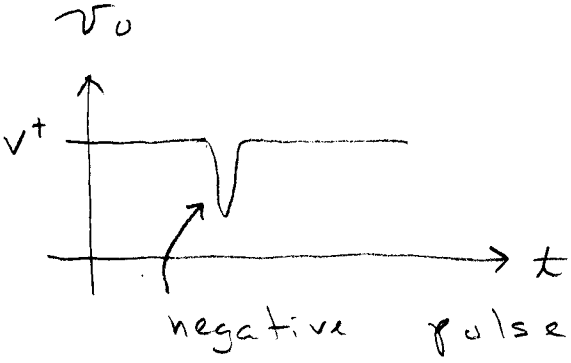
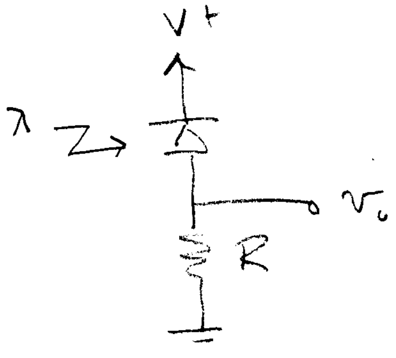
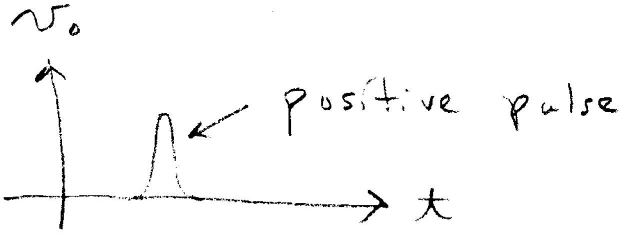
The light photons impart energy to the atoms in the depletion region creating hole-electron pairs. this causes a pulse of current to flow ⇒ a negative going pulse at v_o



An alternate circuit is





Light Emitting Diodes (LEDs)

In a forward biased diode, recombinations in the depletion region generate heat. If a diode is fabricated of suitable materials (GaAs or "ternary materials"), this heat can be made to have wavelengths in the optical band ⇒ light generation. A quantum mechanical analysis requires studying interactions of photons and lattice vibrations called phonons. The energy liberated by each recombination is qV_G, where V_G is the bandgap voltage.

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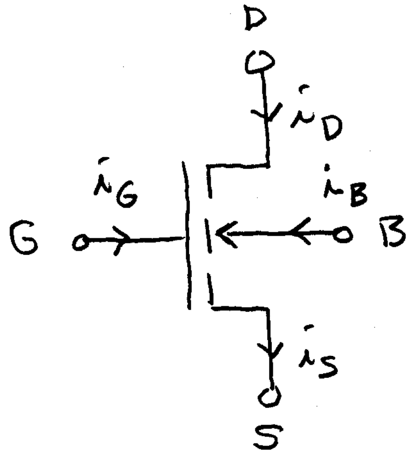
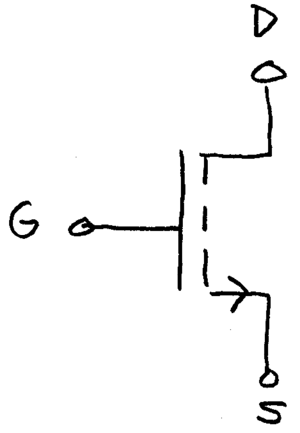
The Enhancement Mode Mosfet

We consider the n-channel device. Its symbol is as follows:



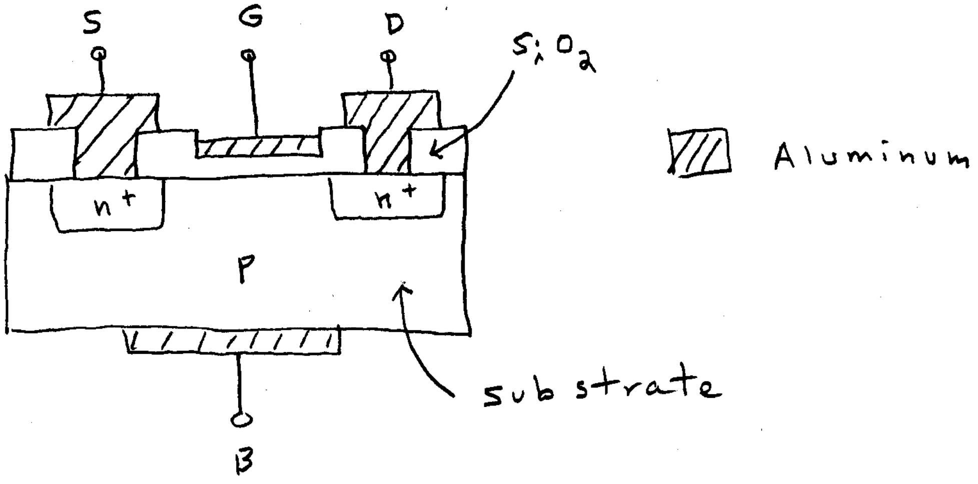
D - drain
G - gate
S - Source
B - body

The dashed line indicates that the device is an open circuit between D and S with no applied voltage. In discrete devices, the B is connected internally to the S. In this case, the symbol is



The direction of the arrow was into the device at the B. It is out of the device at the S.

Device Construction and Operation



The SiO_2 between the Al contacts is an insulator.

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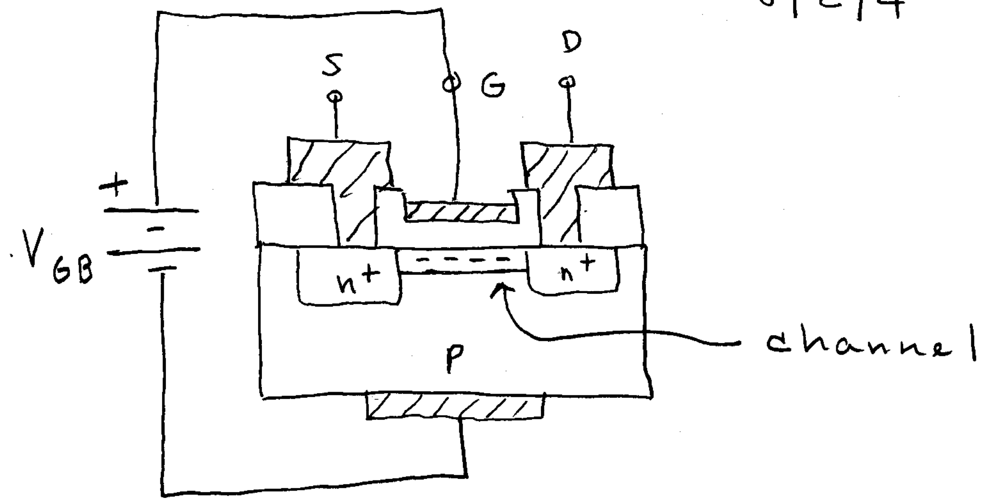
Now suppose a voltage is applied between the D and the S. There are 2 back-to-back diode junctions between the D and S, Thus no current can flow.

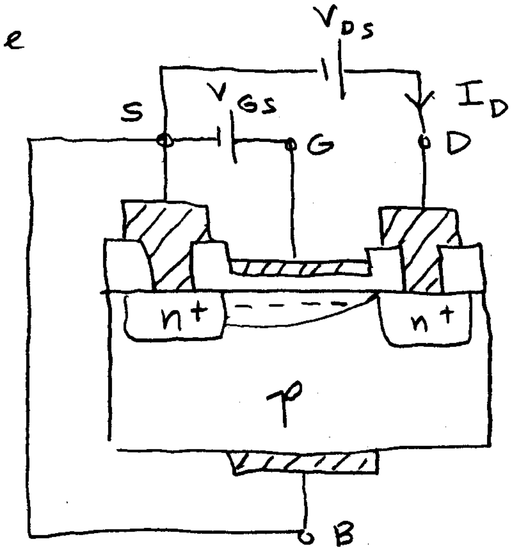
Now suppose the G voltage is made positive with respect to the B. The electric field repels mobile holes in the substrate, leaving a layer of bound electrons beneath the gate. Still no current can flow between the D and the S. If the G to B voltage is made more positive, the electric field will be strong enough to attract mobile electrons generated by thermal energy into a thin layer beneath the gate. The diagram now becomes



The region beneath the gate was a p region. Now it looks like an n region. It is called an inversion layer. It connects between the D and S. Mobile electrons can now travel from D to S is a voltage if applied between them.

The inversion layer is referred to as the channel. The value of V_{GB} at which it forms is called the threshold voltage V_{TH}.

Now consider the following case



Assume $V_{GS} > V_{TH}$. For $V_{DS} = 0$, the inversion layer has a uniform thickness. As V_{DS} is increased, D pulls electrons from the inversion layer, causing its thickness to decrease at the end near the D. The figure shows the case where the thickness just goes to zero at the D region. The device is said to have reached pinch-off at point. If V_{DS} is increased further, we obtain

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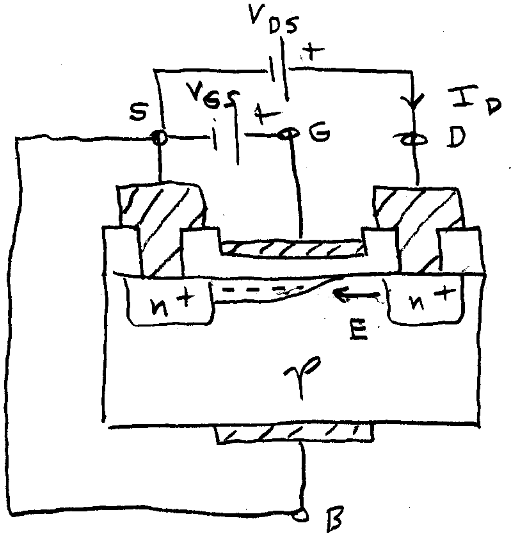
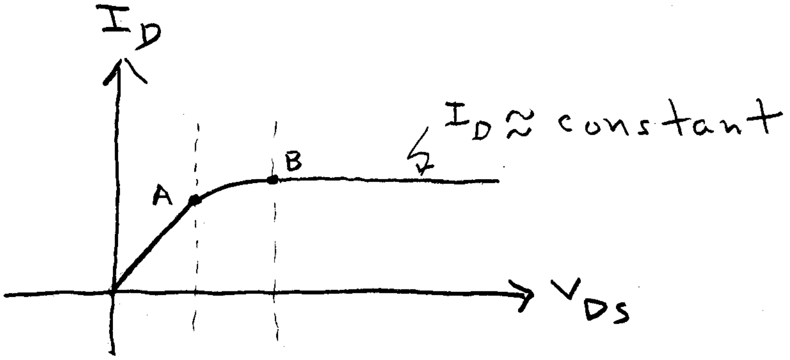


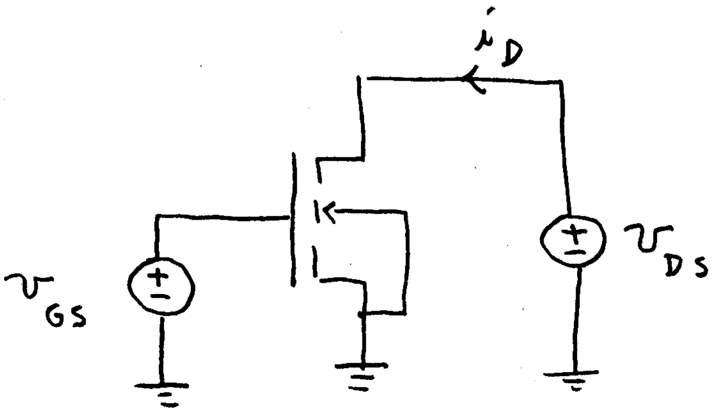
Think of E as the field between 2 plates of a capacitor.

It may seem like $I_D = 0$ after pinch-off occurs. However, the E field is strong enough to pull electrons from the inversion layer to the drain. The I_D vs. V_{DS} characteristic looks like



To the left of A, the device is not pinched off. The channel looks like a resistor. To the right of A, the device starts entering pinch off. To the right of B, it is fully pinched off.

Consider the circuit



Pinchoff occurs when

$$v_{DS} > v_{GS} - V_{TH}$$

where V_{TH} is the threshold voltage.

For $v_{DS} < v_{GS} - V_{TH}$, the device is said to be in the linear or triode range. In this range, the drain current is given by

$$i_D = 2K\left(v_{GS} - V_{TH} - \frac{v_{DS}}{2}\right) v_{DS}$$

where K is the transconductance parameter given by

$$K = \frac{K'}{2}\frac{W}{L}$$

where

W = channel width
L = channel length

The constant K' is given by

$$K' = \mu C_{ox}$$

where

μ = mobility of the free charge carriers in the channel
C_{ox} = gate to SiO_2 oxide capacitance per m^2

For $v_{DS} > v_{GS} - V_{TH}$, the device is in the pinch off region and i_D is given by

$$i_D = K(v_{GS} - V_{TH})^2$$

The pinch-off boundary is defined by

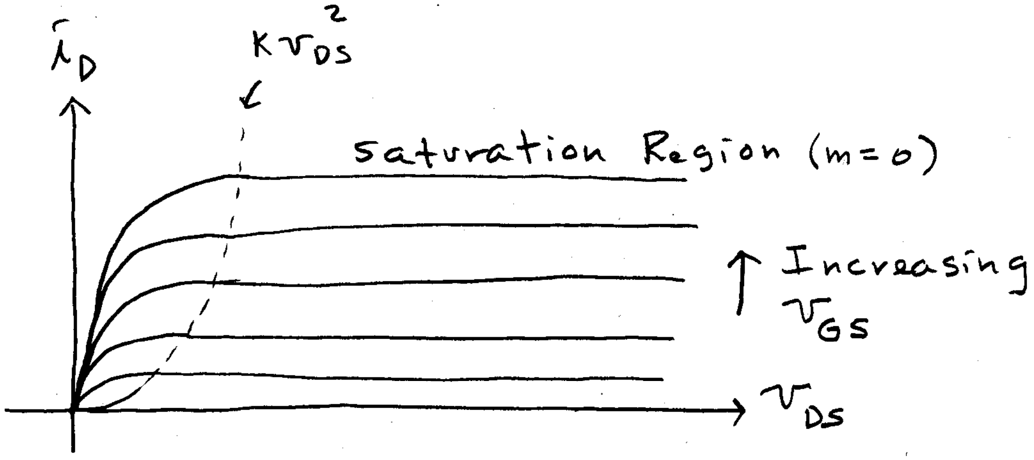
$$v_{DS} = v_{GS} - V_{TH}$$

$$\Rightarrow \quad v_{GS} = v_{DS} + V_{TH}$$

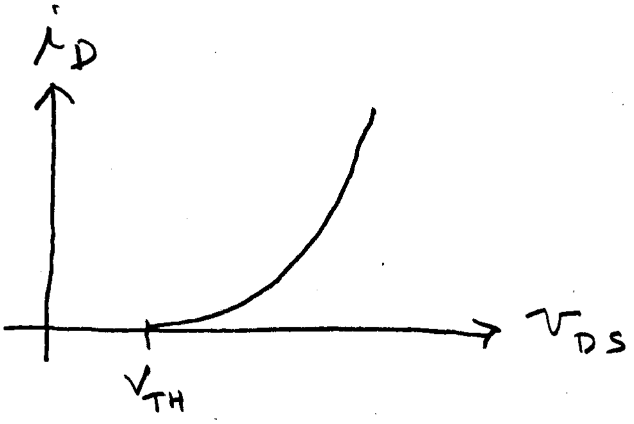
$$\Rightarrow \quad i_D = K(v_{DS} + V_{TH} - V_{TH})^2$$

$$= K\, v_{DS}^2$$

We can construct the plot of i_D versus v_{DS} as follows:



The plot of i_D versus v_{GS} is as follows



The Early Effect.

As v_{DS} is varied, the effective length of the channel varies. This is modeled by replacing the L in the equation for K by

$$\frac{L}{1+\lambda v_{DS}}$$

where λ is the channel length modulation parameter. Notice that L decreases as v_{DS} is increased. In the saturation region, the drain current is given by

$$i_D = \frac{K'}{2}\frac{W}{L}(1+\lambda v_{DS})(v_{GS}-V_{TH})^2$$

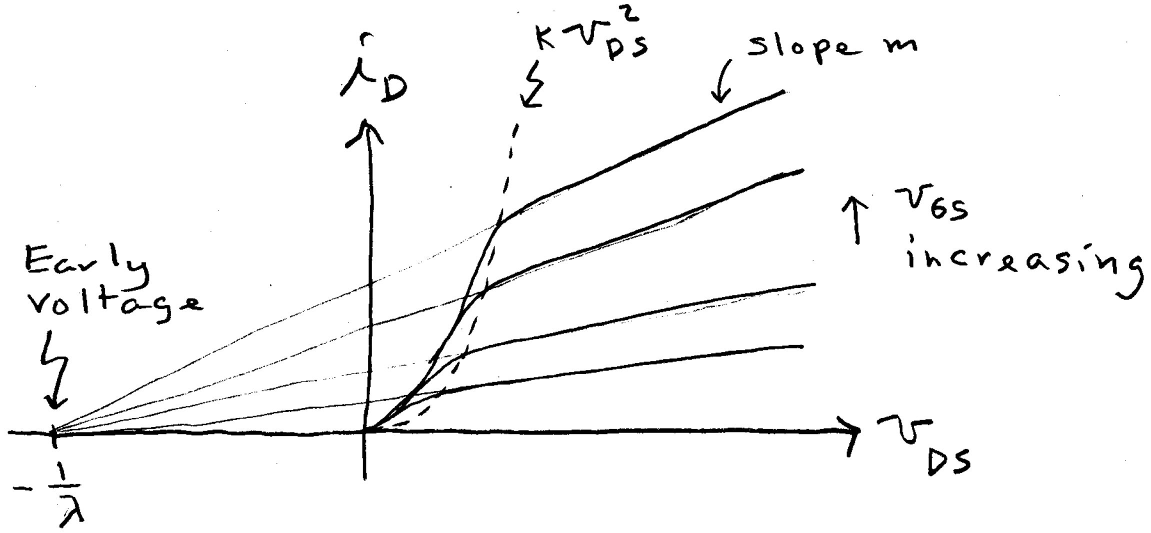
If we plot i_D versus v_{DS}, we obtain a straight line of slope

$$m = \frac{K'}{2}\frac{W}{L}\lambda(v_{GS}-V_{TH})^2$$

Note that the equation for i_D predicts that

$$i_D = 0 \quad \text{for} \quad v_{DS} = \frac{-1}{\lambda}$$

We can construct the new curves for i_D versus v_{DS} as follows:



Because $m = \frac{K'}{2}\frac{W}{L}\lambda(v_{GS} - V_{T0})^2$, it follows that the slope increases as v_{GS} increases.

The straight line projections cross at $v_{DS} = -1/\lambda$. This voltage is called the Early voltage.

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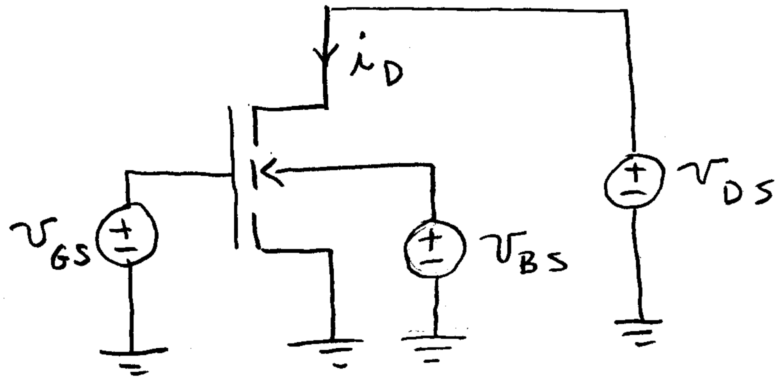
The Body Effect

So far we have assumed that $v_{BS} = 0$, i.e. the body is connected to the source. Consider the circuit



In this case, the threshold voltage is a function of v_{BS}. It is given by

$$v_{TH} = V_{TO} + \gamma\left[\sqrt{\phi - v_{BS}} - \sqrt{\phi}\right]$$

where V_{TO} = threshold voltage for $v_{BS} = 0$

γ = body threshold parameter

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ϕ = surface potential

In practice, $v_{BS} \leq 0$. Thus

$$v_{TH} \geq V_{TO}$$

Discrete devices usually have the body connected to the source so that

$$v_{TH} = V_{TH} = V_{TO}$$

In IC devices, the B is usually connected to the negative supply voltage for n-channel devices and to the positive supply voltage for p-channel devices.