LECTURE 27

Today we will

- Put a twist on our normally linear operational amplifier circuits to make them perform nonlinear computations
- Make a linear circuit model for the nonlinear NMOS transistor (Preview of EE 105)

Next time we will

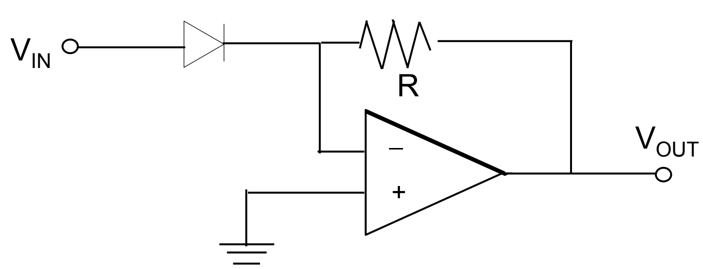
- Show how we can design a pipelined computer datapath at the transistor level
- Use a relay to design an analog circuit that counts

Trying to expose you to various complicated circuits/topics to use the tools you've developed and prepare you for final exam…

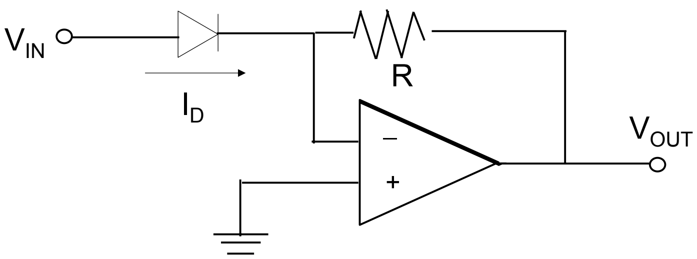
NONLINEAR OPERATIONAL AMPLIFIERS

When I put a nonlinear device in an operational amplifier circuit, I can compute a nonlinear function.

Consider the following circuit using the realistic diode model:



NONLINEAR OPERATIONAL AMPLIFIERS



Computes an exponential function of V_{IN} !

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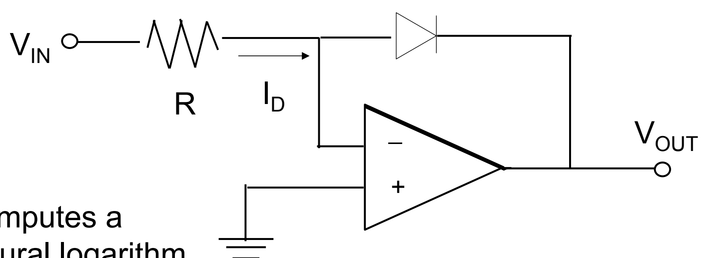
NONLINEAR OPERATIONAL AMPLIFIERS

What if I switch the positions of the resistor and the diode (and make sure $V_{IN} \geq 0$ V)?



Computes a natural logarithm function of V_{IN} !

Changing the position of the elements **inverted** the function performed!

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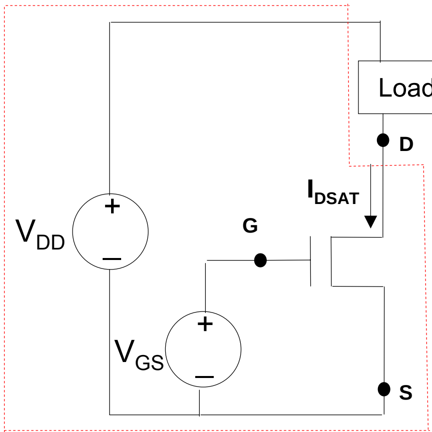
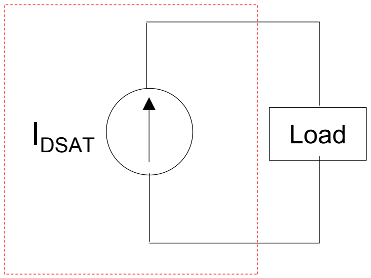
TRANSISTOR AS CURRENT SOURCE

This circuit acts like a constant current source, as long as the transistor remains in saturation mode.



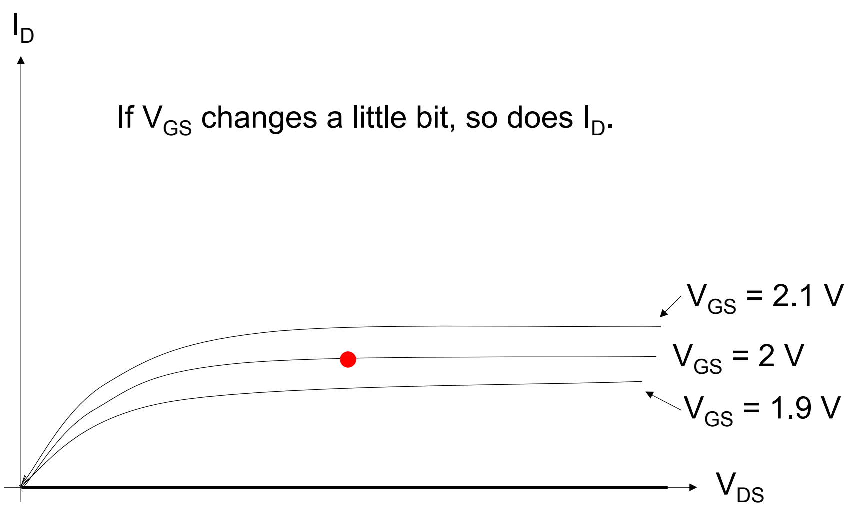
But this hides the fact that I_{DSAT} depends on V_{GS}; it is really a **voltage-dependent current source!**

If V_{GS} is not constant, the model fails. What if V_{GS} changes? What if there is noise in the circuit?



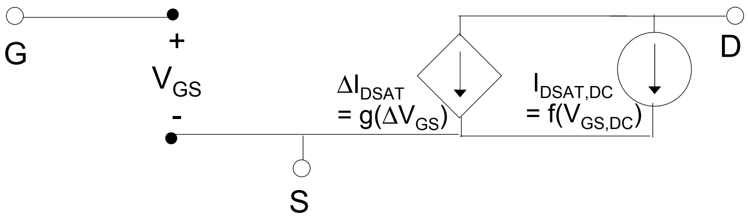
THE EFFECT OF A SMALL SIGNAL

If V_{GS} changes a little bit, so does I_D.



THE SMALL-SIGNAL MODEL

Let's include the effect of noise in V_{GS}. Suppose we have tried to set V_{GS} to some value $V_{GS,DC}$ with a fixed voltage source, but some noise ΔV_{GS} gets added in. $V_{GS} = V_{GS,DC} + \Delta V_{GS}$



We get the predicted $I_{DSAT,DC}$ plus a change due to noise, ΔI_{DSAT}.

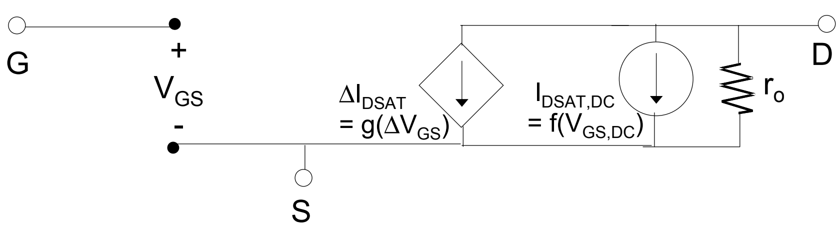
No current flows into or out of the gate because of the opening.

THE SMALL-SIGNAL MODEL

To be even more accurate, we could add in the effect of λ.

When λ is nonzero, I_D increases linearly with V_{DS} in saturation.

We can model this with a resistor from drain to source:



The resistor will make more current flow from drain to source as V_{DS} increases.

THE SMALL-SIGNAL MODEL

How do we find the values for the model?

$I_{DSAT,DC} = ½\ W/L\ \mu_N\ C_{OX}\ (V_{GS,DC} – V_{TH})^2$

This is a constant depending on $V_{GS,DC}$.

$$\Delta I_{DSAT} \approx \frac{\partial\ I_{DSAT}}{\partial\ V_{GS}}(V_{GS,DC})\Delta V_{GS}$$

This is a first-order Taylor series approximation which works out to

$\Delta I_{DSAT} = W/L\ \mu_N\ C_{OX}\ (V_{GS,DC} – V_{TH})\Delta V_{GS}$

We often refer to $W/L\ \mu_N\ C_{OX}\ (V_{GS,DC} – V_{TH})$ as g_m, so

$\Delta I_{DSAT} = g_m\ \Delta V_{GS}$.

THE SMALL-SIGNAL MODEL

Including the effect of λ via r_o, the added current contributed by the resistor is

$I_{r0} = ½\ W/L\ \mu_N\ C_{OX}\ (V_{GS} – V_{TH})^2\lambda V_{DS}$

To make things much easier, since the λ effect is small anyway, we neglect the effect of ΔV_{GS} in the resistance, so the current is

$I_{r0} \approx ½\ W/L\ \mu_N\ C_{OX}\ (V_{GS,DC} – V_{TH})^2\lambda V_{DS}$
$= I_{DSAT,DC}\ \lambda\ V_{DS}$

This leads to

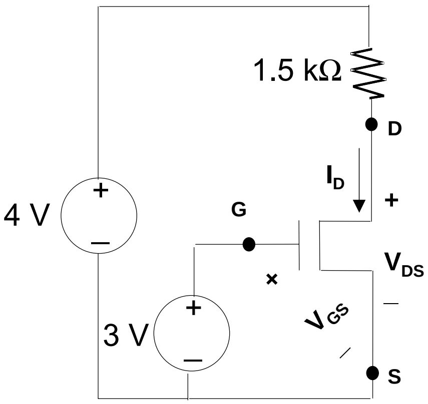
$r_0 = V_{DS} / I_{r0} = (\lambda\ I_{DSAT,DC})^{-1}$

EXAMPLE

Revisit the example of Lecture 20, but now the 3 V source can have noise up to ± 0.1 V.

Find the range of variation for I_D.

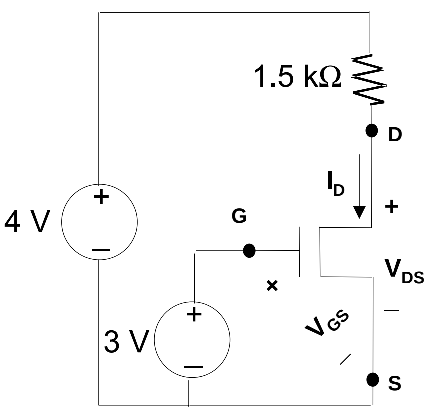
$V_{TH(N)} = 1$ V,
$W/L\ \mu_n C_{OX} = 500\ \mu$ A/V^2,
$\lambda = 0$ V^{-1}.



We figured out that saturation is the correct mode in Lecture 20.

The “noiseless” value of I_D is

EXAMPLE



The variation in I_D due to noise:

So I_D could vary between:

Will saturation mode be maintained?