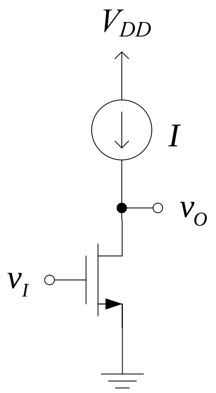
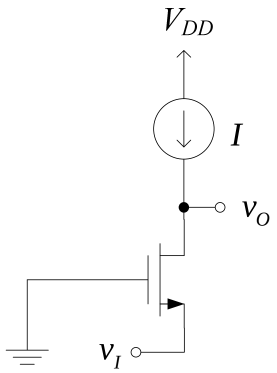
Lecture 33: CMOS Common Source Amplifier.

As was mentioned in Lecture 30, there are two different environments in which MOSFET amplifiers are found, (1) discrete circuits and (2) integrated circuits (ICs). We will now begin to look at the IC MOSFET amplifiers.

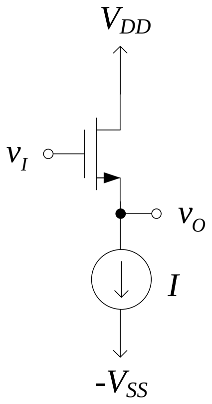
There are three basic configurations of IC MOSFET amplifiers:



Common source



Common gate



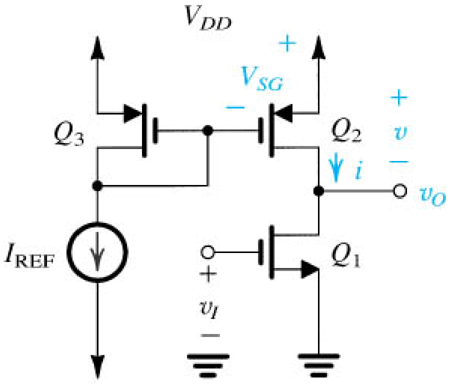
Common drain
(source follower)

As was also mentioned in Lecture 30, large-valued resistors and capacitors are not often used in these IC environments. Instead, active loads are incorporated using MOSFETs as loads. In the amplifier circuits shown above, the active loads are actually the nonideal current sources. [Also notice that there are no bypass capacitors as we saw with discrete MOSFET (and BJT) amplifiers.]

We will look at all three of these amplifiers more closely over the next few lectures. The intention is to pair the discrete version of the MOSFET amplifier with its IC version. Since we've covered the CS amplifier in discrete form already, we'll begin with the analysis of the CMOS CS amplifier.

CMOS Common Source Amplifier

An example of a complementary MOSFET amplifier is shown in text Figure 8.16(a):



(Fig. 8.16a)

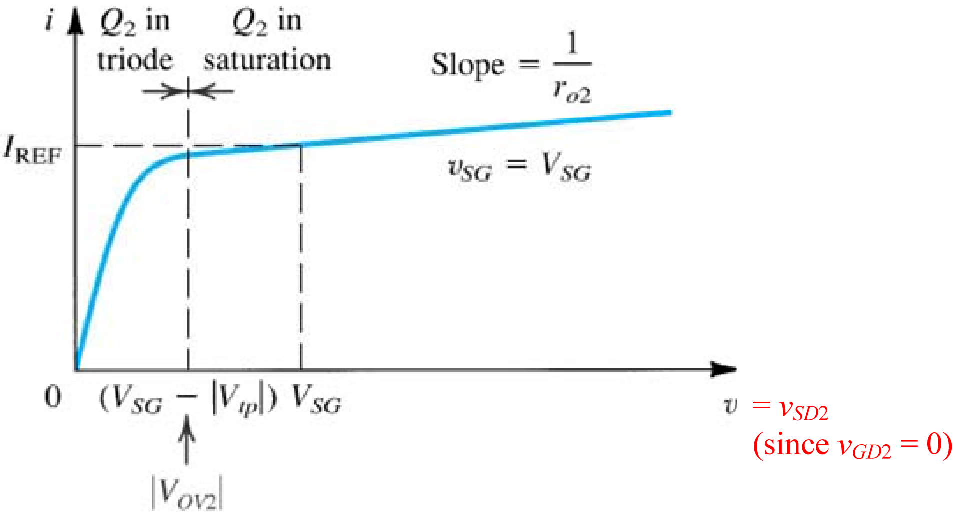
In this circuit, Q_2 and Q_3 form a PMOS current mirror. Because both PMOS and NMOS devices are used in this circuit, it is called a complementary MOS (CMOS) circuit.

In addition to forming part of the current mirror, **Q_2 also functions as the current source load** (aka active load) for Q_1.

For Q_2 to be a current source, Q_2 must operate in the saturation mode, of course. The output resistance r_{o2} of Q_2 is

$$r_{o2} = \frac{|V_{A2}|}{I_{\text{REF}}} \qquad (8.48),(1)$$

It is helpful to observe the characteristic curve for Q_2 to understand its active-load role:

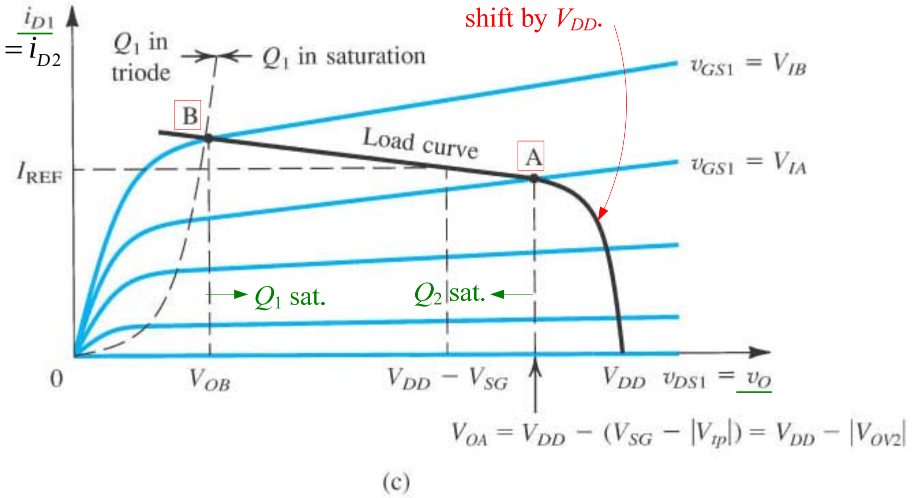


(b)

(Fig. 8.16b)

Referring to the CS amplifier circuit above in Fig. 8.16(a), when $i = I_{\text{REF}}$ then $V_{GD2} = 0$ (by **symmetry** with Q_1). This implies that $v = V_{SG}$, which is the Q point shown in Fig. 8.16(b).

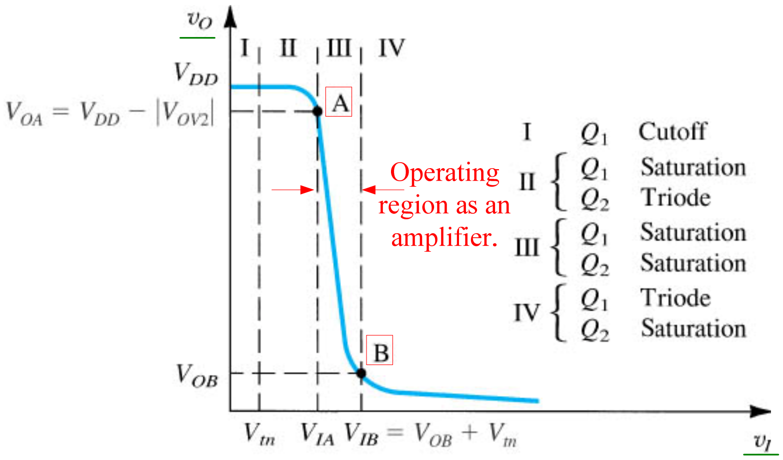
Furthermore, it is useful to observe the graphical construction of the transfer function v_O/v_I for this amplifier, as illustrated in Figs. 8.16(c) and (d) shown below. The drain currents of Q_1 and Q_2 are the same. The operating point of the amplifier is found from the intersection of the Q_1 characteristic curve with the load curve of Q_2 for a particular v_{GS1}:



By KVL $v_O = V_{DD} - v$
Therefore, for the load curve, "flip over" and shift by V_{DD}.

(Fig. 8.16c)

Collecting these intersections from this figure as v_{GS1} $(= v_I)$ changes, we can construct point-by-point the transfer characteristic curve for this amplifier:



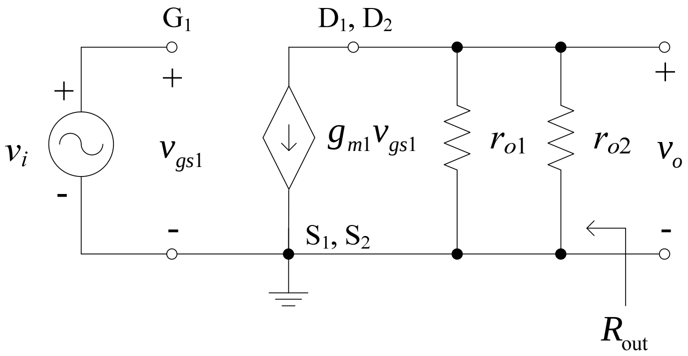
Operating region as an amplifier.

(Fig. 8.16d)

From this plot, we can see that Region III shows a linear relationship between v_O and v_I. This is the region where the circuit of Fig. 8.16(a) can be used as a linear amplifier.

Small-Signal Voltage Gain and Output Resistance

Now we'll determine the small-signal voltage gain and output resistance of this amplifier. The small-signal equivalent circuit for this CMOS CS amplifier is:



It is important to recognize that no small-signal model is needed for Q_2 because its affect on the signal v_o can be incorporated using the small-signal resistance r_{o2} as shown above.

So, at the output

$$v_o = -g_{m1} v_{gs1} (r_{o1} \| r_{o2}) \tag{2}$$

while at the input

$$v_{gs1} = v_i \tag{3}$$

Substituting (3) into (2) gives the open circuit small-signal voltage gain for the CMOS CS amplifier to be

$$A_{vo} \equiv \frac{v_o}{v_i} = -g_{m1}(r_{o1} \| r_{o2}) \tag{8.49),(4}$$

or substituting for g_{m1}, r_{o1}, and r_{o2}

$$A_{vo} = -\frac{\sqrt{2k_n'\left(\frac{W}{L}\right)_1}}{\frac{1}{|V_{A1}|}+\frac{1}{|V_{A2}|}}\frac{1}{\sqrt{I_{REF}}} \tag{5}$$

Since r_{o1} and r_{o2} are usually large, this A_{vo} gain is typically relatively large (approximately -20 to -100, or so).

Neat! We have incorporated the effects of relatively large resistance for this amplifier without having to actually construct a large resistor.

From the small-signal model we see from inspection that

$$R_{\text{out}} = r_{o1} \,||\, r_{o2}$$

Summary for CMOS CS amplifier:

1. Very large input resistance.
2. Very large output resistance.
3. Potentially large small-signal voltage gain.

Example N33.1 (similar to text Example 8.4). A CMOS CS amplifier shown in Fig. 8.16(a) is fabricated with $W/L = 100\ \mu\text{m}/1.6\ \mu\text{m}$ for all transistors. With $k_n' = 90\ \mu\text{A/V}^2$, $k_p' = 30\ \mu\text{A/V}^2$, $I_{\text{REF}} = 100\ \mu\text{A}$, $V_{An} = 8$ V/μm, and $V_{Ap} = 12$ V/μm, determine the following quantities:

(a) Find g_{m1}. The common expression for g_m we use is

$$g_m = k_n' \frac{W}{L}\left(V_{GS} - V_t\right) \tag{6}$$

For a MOSFET in the saturation mode

$$I_D = \frac{1}{2} k_n' \frac{W}{L}\left(V_{GS} - V_t\right)^2 \tag{7}$$

Substituting (7) into (6) gives the transconductance for Q_1 in terms of I_{D1} to be

$$g_{m1} = \sqrt{2k_n'\left(\frac{W}{L}\right)_1 I_{D1}} \tag{8}$$

[This form of g_m was actually used earlier in (5).] Because the amplifier is biased so that $I_{D1} = I_{\text{REF}}$, then

$$g_{m1} = \sqrt{2\cdot 90\times10^{-6}\cdot\frac{100}{1.6}\cdot 100\times10^{-6}} = 1.06 \text{ mA/V}^2$$

(b) Find r_{o1}.

$$r_{o1} = \frac{|V_A|_1}{I_{D1}} = \frac{V_{An}}{I_{\text{REF}}} = \frac{8\cdot 1.6}{100\times10^{-6}} = 128 \text{ k}\Omega$$

(c) Find r_{o2}.

$$r_{o2} = \frac{|V_A|_2}{I_{D2}} = \frac{V_{Ap}}{I_{\text{REF}}} = \frac{12\cdot 1.6}{100\times10^{-6}} = 192 \text{ k}\Omega$$

(d) Find A_{vo}.

$$A_{vo} = -g_m\left(r_{o1} \,\|\, r_{o2}\right) = -1.06\times10^{-3}\left(128 \text{ k}\Omega \,\|\, 192 \text{ k}\Omega\right)$$

$$A_{vo} = -81.4 \ \frac{\text{V}}{\text{V}}$$

This value represents the largest gain. The gain will be reduced when an actual load is attached to the amplifier.