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Excerpt of Sedra/Smith Chapter 6: Analog Transistor Model and basic Circuits

Content

The three single transistor amplifier configurations (book 6.1-6.3)

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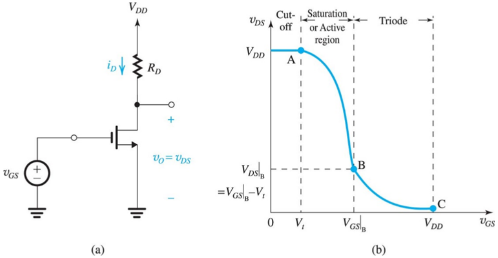
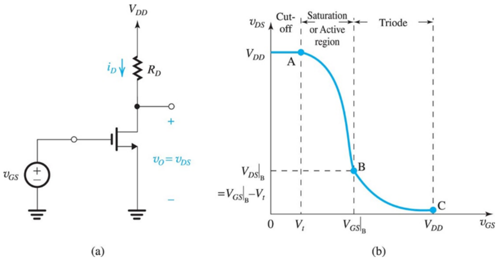
Amplifier Principle



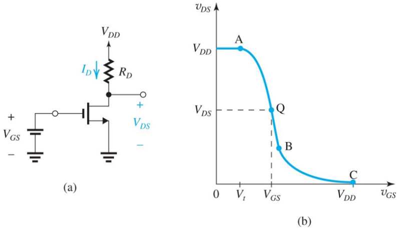
In this *common source amplifier* configuration the transistor acts like a voltage controlled current source in the amplifier's *linear range* and the voltage accross the *load resistance* is the amplified output voltage.

Amplifier Principle



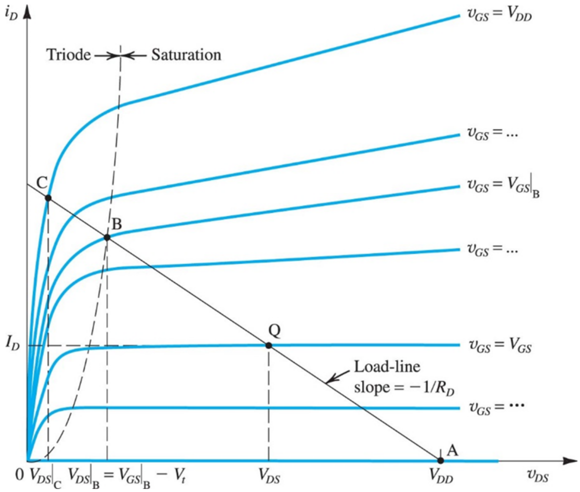
Question: how does the output look like given a sine wave input.
Answer: it depends on DC offset and amplitude of the input. Next question: how so?

Biasing to a Point of Operation

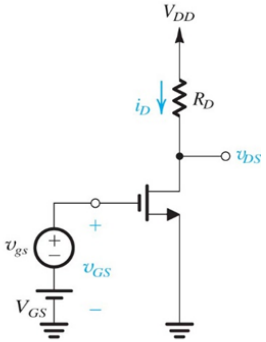


To use the amplifier in its linear range with minimal or no distortion of the output one needs to bias it correctly, i.e. the input needs to have a particular DC offset V_{GS}. Note the upper case letter V and remember the convention used in theSedra/Smith book.

Graphical Interpretation



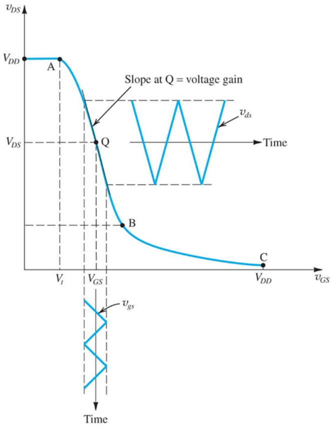
Point of Operation and Small Signal



(a)

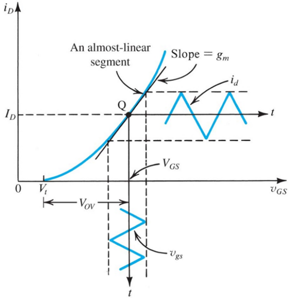
Thus at the correct biasing condition/point of operation (i.e. the righ V_{GS}(upper case!!!)) one can perform a linear circuit analysis for small signals (i.e. v_{gs} (all lower case!!!)) around that point of operation without distortion. Luckily a small signal at the input of an amplifier means almost the entire range between the power rails at the output!

Small Signal Analysis Principle



(b)

Small Signal Analysis $i_D(v_{GS})$



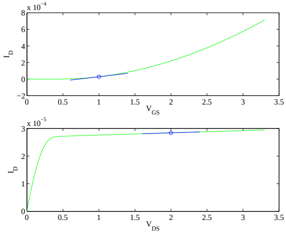
Equivalent to a 1st order Taylor expansion, the small signals only model a linear approximation around a point of operation. Thus:

$$i_D(v_{GS}) \approx \underbrace{i_D(V_{GS})}_{I_D} + \underbrace{(v_{GS} - V_{GS})}_{v_{gs}} * \underbrace{\frac{di_D}{dv_{GS}}}_{\frac{di_d}{dv_{gs}} = g_m}$$

For strong inversion, active region:

$$g_m = \frac{di_D}{dv_{GS}} = k_n V_{OV}$$

Small Signal Analysis $i_D(v_{DS})$



Again a 1^{st} order Taylor expansion, i.e. a linear approximation around a point of operation:

$$i_D(v_{DS}) \approx \underbrace{i_D(V_{DS})}_{I_D} + \underbrace{(v_{DS} - V_{DS})}_{v_{ds}} * \underbrace{\frac{di_D}{dv_{DS}}}_{\frac{di_d}{dv_{gs}} = \frac{1}{r_o}}$$

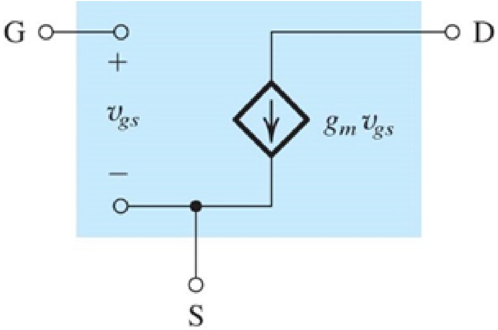
For strong inversion, active region:

$$r_o = \frac{dv_{DS}}{di_D} = \frac{1}{\lambda I'_D} = \frac{V_A}{I'_D} \quad (5.26/27)$$

Note that V_A is proportional to transistor length L and thus sometimes expressed as $V_A = V'_A L$.

MOSFET Small Signal Circuit Model

(low frequency and without r_o)

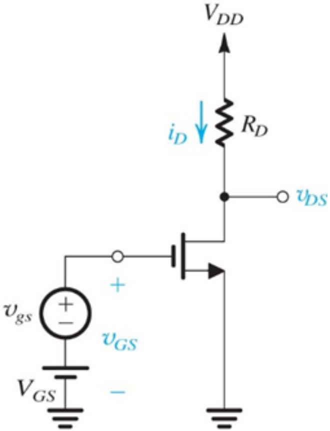


(a)

Applying the Small Signal Equivalent Circuits

1. Set all constant voltage sources (including DC biases) to Gnd
2. Set all constant current sources (including DC biases) to zero/open circuit
3. Substitute transistors with small signal equivalent circuit

Example: Common Source Amplifier



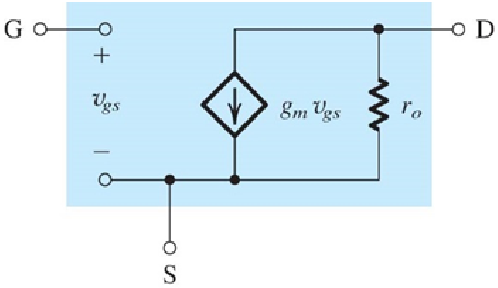
(a)

$$A = g_m R_D$$

$$R_O = R_D$$

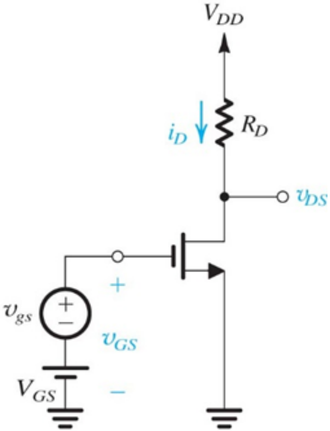
MOSFET Small Signal Circuit Model refined

(still low frequency and now with r_o)



(b)

Example: Common Source Amplifier Correction



(a)

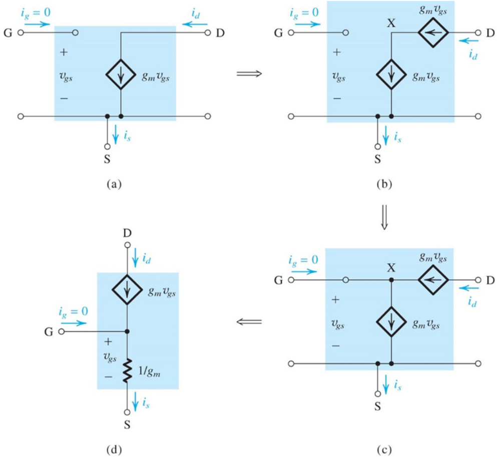
$$A = g_m(R_D||r_o)$$

$$R_O = R_D||r_o$$

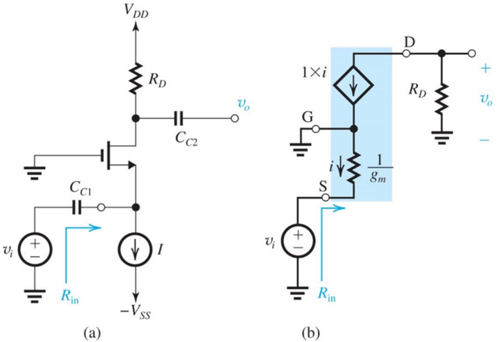
r_o can be neglected if $r_o >> R_D$, which is the case if R_D is a discrete resistor, but later in chapter 7 it WILL matter.

MOSFET Small Signal Circuit Model: T-Model

(for now without r_o)



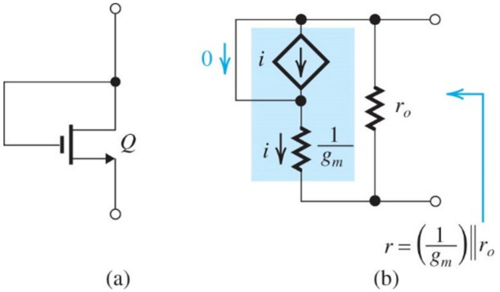
Common Gate Amplifier



$$A = g_m(R_D||r_o) \quad , \quad r_i = \frac{1}{g_m}$$

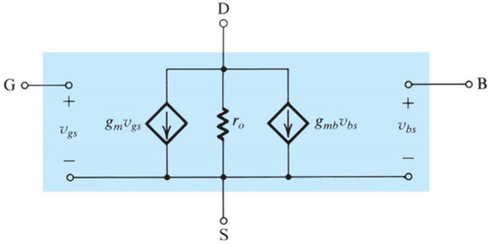
Input Resistance of Diode Coupled CMOS

(... and thus of a current mirror)



MOSFET Small Signal Circuit Model

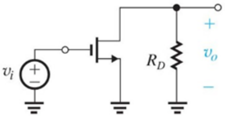
(still low frequency and now with 'back gate')



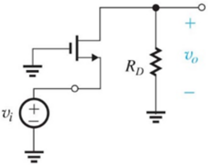
(b)

$$g_{mb} \approx 0.1 - 0.3 g_m$$

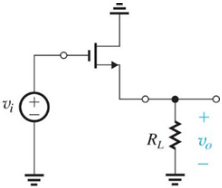
The Three Basic Configurations



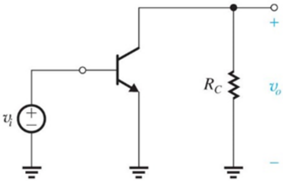
(a) Common Source (CS)



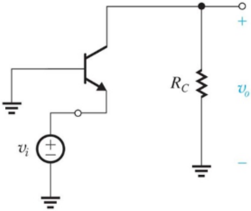
(b) Common Gate (CG)



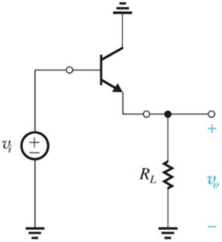
(c) Common Drain (CD)
or Source Follower



(d) Common-Emitter (CE)

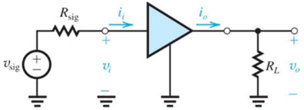


(e) Common-Base (CB)

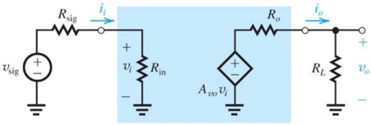


(f) Common-Collector (CC)
or Emitter Follower

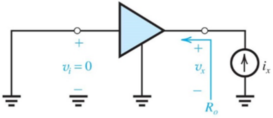
Amplifier Characteristics



(a)

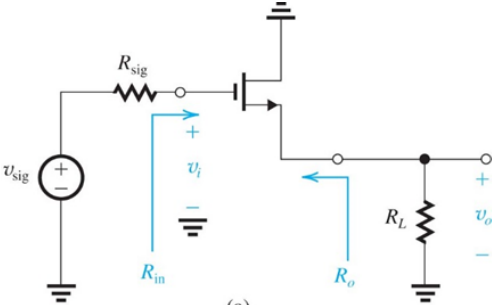


(b)



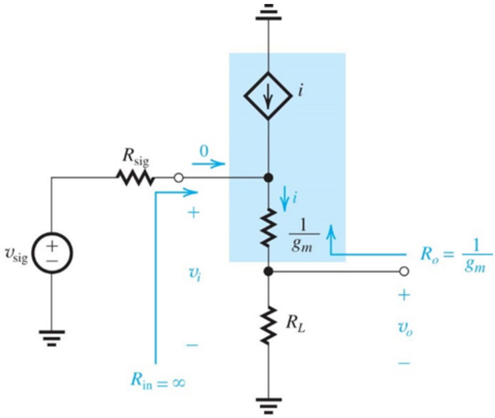
(c)

Common Drain Amplifier/Source Follower



(a)

Common Drain Amplifier/Source Follower



(b)

$$A = \frac{R_L}{R_L + \frac{1}{g_m}}$$

$$R_O = \frac{1}{g_m}$$