Microelectronics
Circuit Analysis and Design

Donald A. Neamen

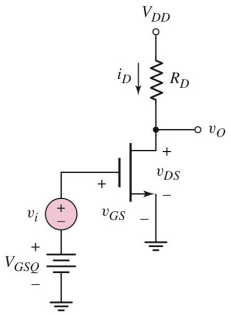
Chapter 4

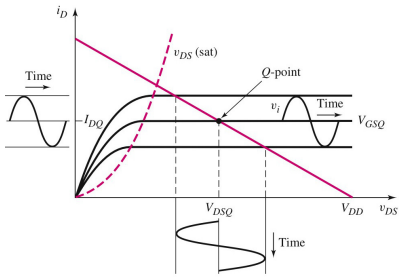
Basic FET Amplifiers

In this chapter, we will:

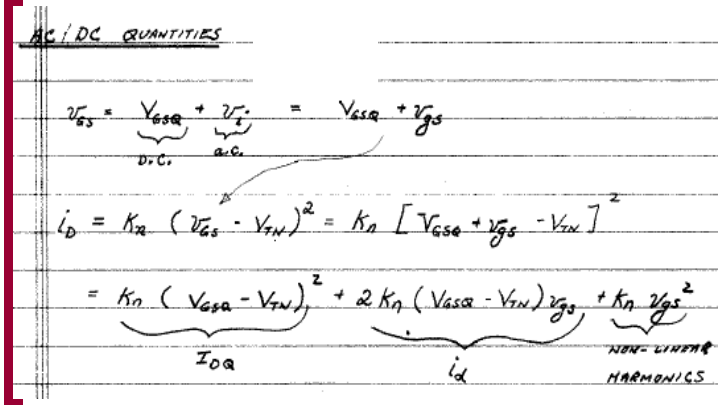
- Investigate a single-transistor circuit that can amplify a small, time-varying input signal
  - Develop small-signal models that are used in the analysis of linear amplifiers.
- Discuss and compare the three basic transistor amplifier configurations.
  - Analyze the common-source amplifier.
  - Analyze the source-follower amplifier.
  - Analyze the common-gate amplifier.
- Analyze multitransistor or multistage amplifiers.

NMOS Common-Source Circuit





NMOS Common-Source Circuit



NMOS Common-Source Circuit

Small signal requirement for Linear Amplifier

if: $k_n v_{gs}^2 << 2k_n (V_{GSQ} - V_{TN}) v_{gs}$

$$v_{gs} << 2(V_{GSQ} - V_{TN})$$

NMOS Common-Source Circuit

then: $i_D = I_{DQ} + i_d$

where: $I_{DQ} = k_n (V_{GSQ} - V_{TN})^2$

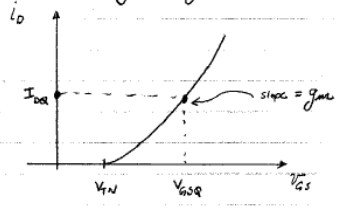
& $i_d = 2k_n (V_{GSQ} - V_{TN}) v_{gs}$

NMOS CS Circuit

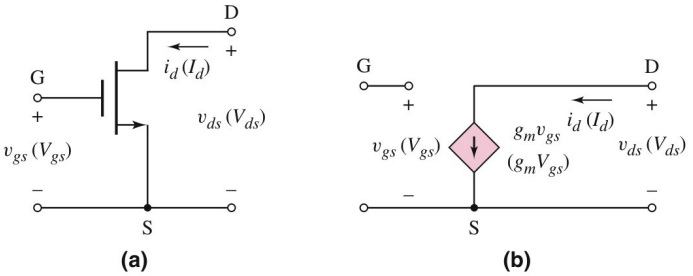
Define the transconductance g_m as

$$g_m = \frac{i_d}{v_{gs}} = 2k_n (V_{GSQ} - V_{TN}) = 2\sqrt{k_n I_{DQ}}$$

The transconductance is the slope of the curve of i_D vs. v_{GS} and for small v_{gs}, g_m is constant



Simple NMOS Small-Signal Equivalent Circuit



phasor components in parentheses

Simple NMOS Small-Signal Equivalent Circuit

Recall the slope in the MOSFET characteristic curve!
The effect is that of drain to source resistance r.

$$r_o = \left(\frac{\partial i_D}{\partial v_{DS}}\right)^{-1}$$

$$r_o = [\lambda K_n (V_{GSQ} - V_{TN})^2]^{-1} \cong [\lambda I_{DQ}]^{-1}$$

NMOS Transistor Small-Signal Parameters

- Values depends on Q-point

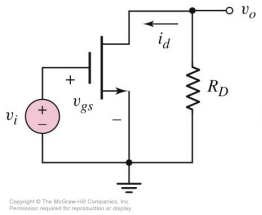
$$g_m = \frac{\partial i_D}{\partial v_{GS}} = \frac{i_d}{v_{gs}}$$

$$g_m = 2K_n (V_{GSQ} - V_{TN}) = 2\sqrt{K_n I_{DQ}}$$

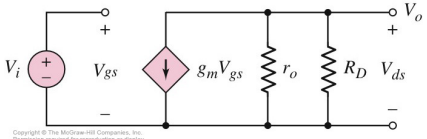
$$r_o = \left(\frac{\partial i_D}{\partial v_{DS}}\right)^{-1}$$

$$r_o = [\lambda K_n (V_{GSQ} - V_{TN})^2]^{-1} \cong [\lambda I_{DQ}]^{-1}$$

NMOS Common-Source Circuit



AC



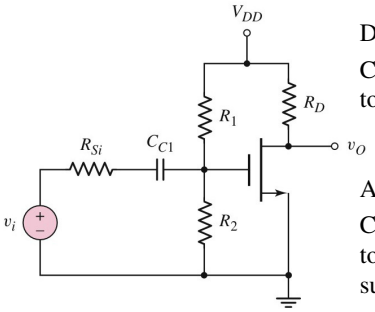
Small-signal

$$A_v = V_o / V_i = -g_m (r_o \| R_D)$$

Problem-Solving Technique: MOSFET AC Analysis

1. Analyze circuit with only the dc sources to find quiescent solution. Transistor must be biased in saturation region for linear amplifier.
2. Replace elements with small-signal model.
3. Analyze small-signal equivalent circuit, setting dc sources to zero, to produce the circuit to the time-varying input signals only.

Common-Source Configuration



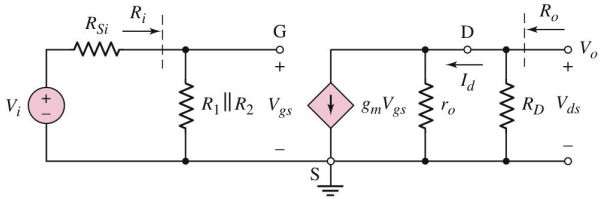
DC analysis:

Coupling capacitor is assumed to be open.

AC analysis:

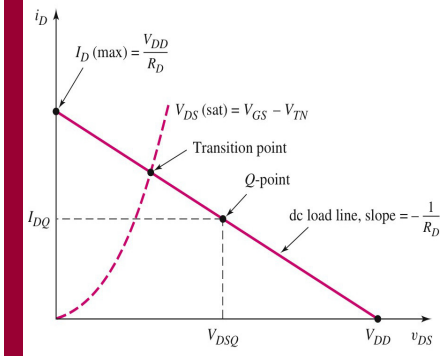
Coupling capacitor is assumed to be a short. DC voltage supply is set to zero volts.

Small-Signal Equivalent Circuit



$$A_v = V_o / V_i = -g_m (r_o \| R_D)\left(\frac{R_i}{R_i + R_{Si}}\right)$$

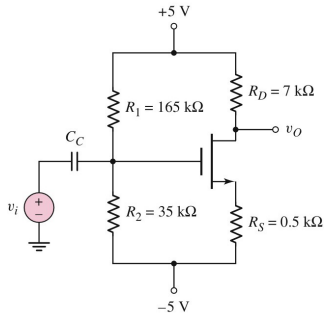
DC Load Line



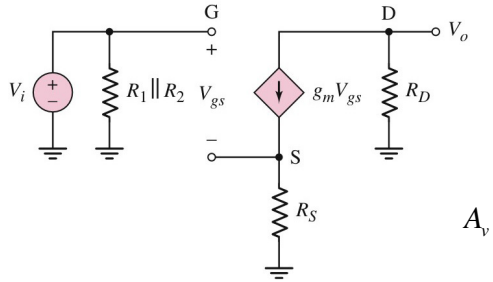
Q-point near the middle of the saturation region for maximum symmetrical output voltage swing,.

Small AC input signal for output response to be linear.

Common-Source Amplifier with Source Resistor

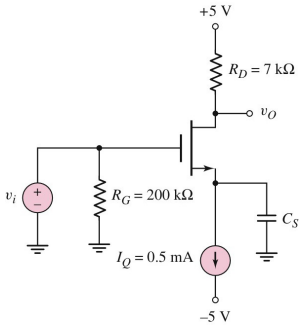


Small-Signal Equivalent Circuit for Common-Source with Source Resistor

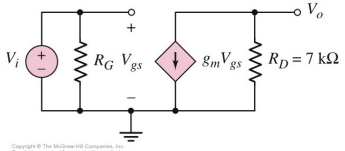


$$A_v = \frac{-g_m R_D}{1 + g_m R_S}$$

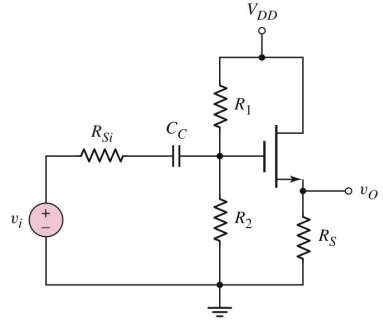
Common-Source Amplifier with Bypass Capacitor



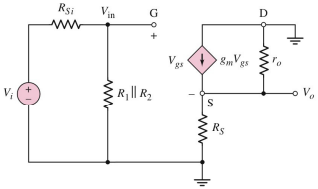
Small-signal equivalent circuit

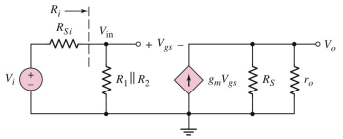


NMOS Source-Follower or Common Drain Amplifier



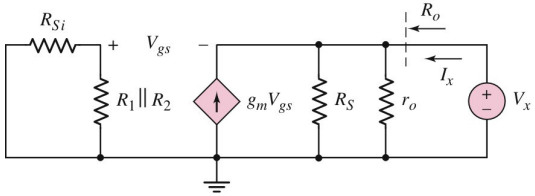
Small-Signal Equivalent Circuit for Source Follower





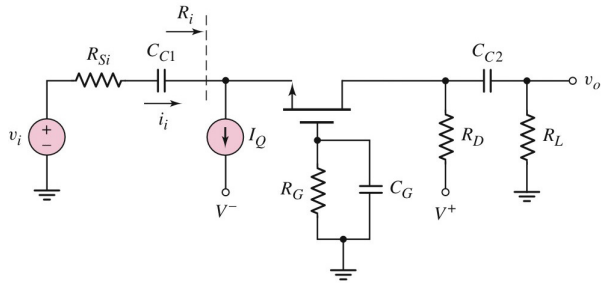
$$A_v = \frac{R_S \| r_o}{\frac{1}{g_m} + R_S \| r_o} \left(\frac{R_i}{R_i + R_{Si}} \right)$$

Determining Output Impedance NMOS Source Follower

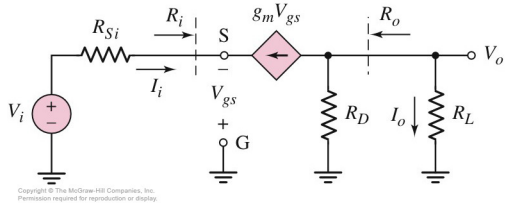


$$R_O = \frac{1}{g_m} \| R_S \| r_o$$

Common-Gate Circuit



Small-Signal Equivalent Circuit for Common Gate

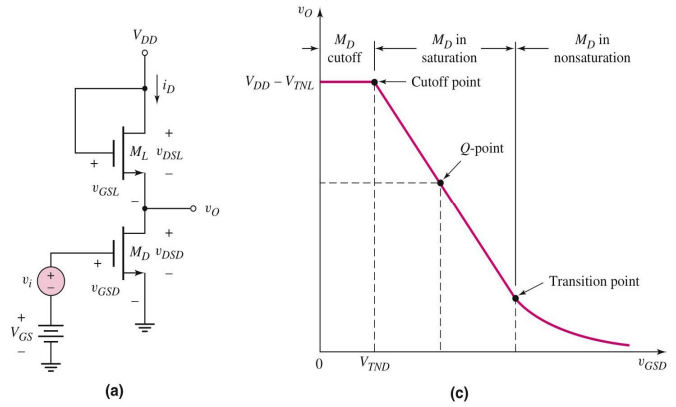


$$A_v = \frac{g_m (R_D \| R_L)}{1 + g_m R_{Si}} \qquad A_i = \frac{I_O}{I_i} = \left(\frac{R_D}{R_D + R_L}\right)\left(\frac{g_m R_{Si}}{1 + g_m R_{Si}}\right)$$

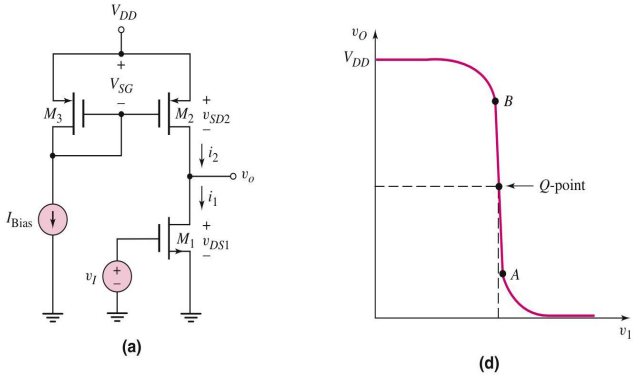
Comparison of 3 Basic Amplifiers

Configuration	Voltage Gain	Current Gain	Input Resistance	Output Resistance
Common Source	$A_v > 1$	—	R_{TH}	Moderate to high
Source Follower	$A_v \approx 1$	—	R_{TH}	Low
Common Gate	$A_v > 1$	$A_i \approx 1$	Low	Moderate to high

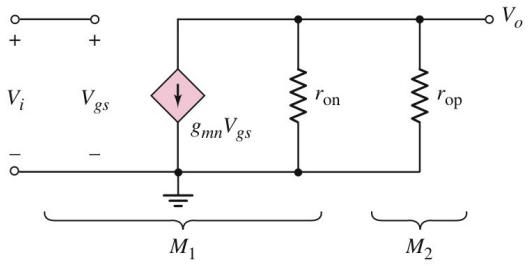
NMOS Amplifier with Enhancement Load Device



CMOS Common-Source Amplifier

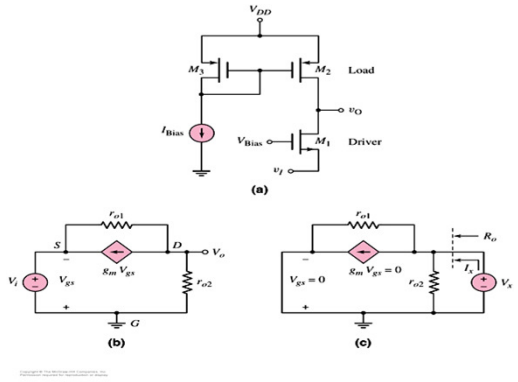


Small-Signal Equivalent Circuit for CMOS Common Source

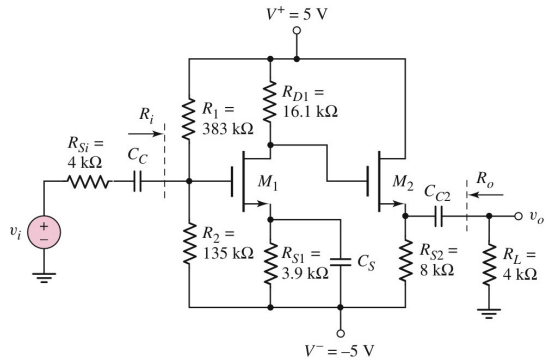


$$A_v = -g_{mn}(r_{on} \| r_{op})$$

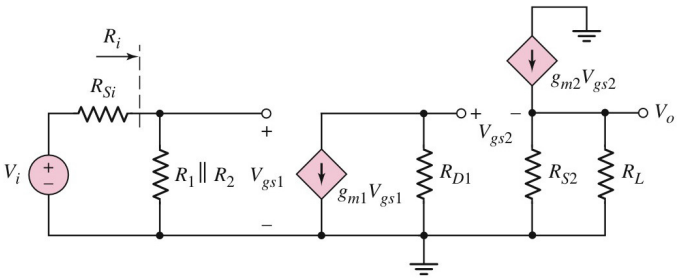
CMOS Common Gate



Cascade Circuit



Small-Signal Equivalent Circuit for Cascade Circuit



Cascode Circuit th Small-Signal Equivalent Circuit