

Microelectronics Circuit Analysis and Design

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Chapter 4

Basic FET Amplifiers

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Chapter 4-1

In this chapter, we will:

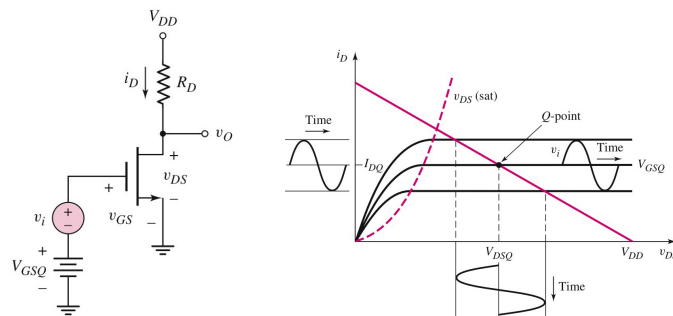
- Investigate a single-transistor circuit that can amplify a small, time-varying input signal
 - Develop small-signal models that are used in the analysis of linear amplifiers.
- Discuss and compare the three basic transistor amplifier configurations.
 - Analyze the common-source amplifier.
 - Analyze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

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NMOS Common-Source Circuit



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Chapter 4-3

NMOS Common-Source Circuit

AC/DC QUANTITIES

$$v_{gs} = \underbrace{V_{GSQ}}_{\text{D.C.}} + \underbrace{v_i}_{\text{a.c.}} = V_{GSQ} + v_{gs}$$

$$i_D = K_n (v_{gs} - V_{TN})^2 = K_n [V_{GSQ} + v_{gs} - V_{TN}]^2$$

$$= \underbrace{K_n (V_{GSQ} - V_{TN})^2}_{I_{DQ}} + \underbrace{2K_n (V_{GSQ} - V_{TN}) v_{gs}}_{i_d} + \underbrace{K_n v_{gs}^2}_{\text{NON-LINEAR HARMONICS}}$$

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NMOS Common-Source Circuit

Small signal requirements for Linear Amplifier

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

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

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NMOS Common-Source Circuit

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

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

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

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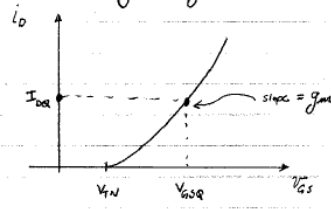
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NMOS CS Circuit

Define the transconductance g_m as

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

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

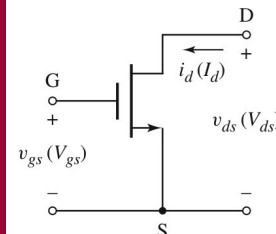


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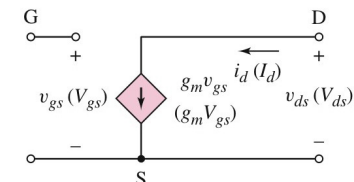
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Simple NMOS Small-Signal Equivalent Circuit



(a)



(b)

phasor components in parentheses

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Simple NMOS Small-Signal Equivalent Circuit

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

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

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

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NMOS Transistor Small-Signal Parameters

Values depends on Q-point

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

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

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

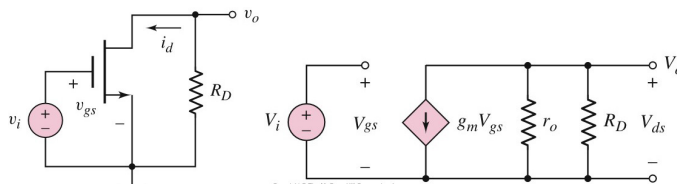
$$r_o = [\lambda K_n (V_{GSQ} - V_{TN})^2]^{-1} \cong [\lambda I_{DQ}]^{-1}$$

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NMOS Common-Source Circuit



AC

Small-signal

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

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Problem-Solving Technique: MOSFET AC Analysis

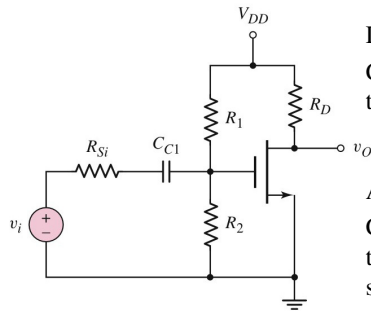
1. Analyze circuit with only the dc sources to find quiescent solution. Transistor must be biased in saturation region for linear amplifier.
2. Replace elements with small-signal model.
3. Analyze small-signal equivalent circuit, setting dc sources to zero, to produce the circuit to the time-varying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

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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.

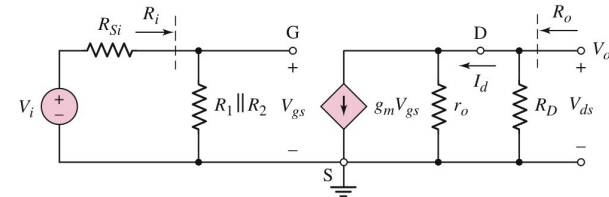
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Small-Signal Equivalent Circuit



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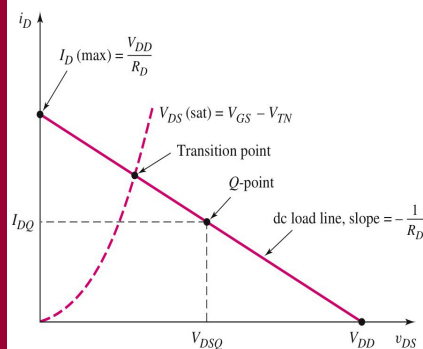
$$A_v = V_o/V_i = -g_m(r_o \parallel R_D)\left(\frac{R_i}{R_i + R_{Si}}\right)$$

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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.

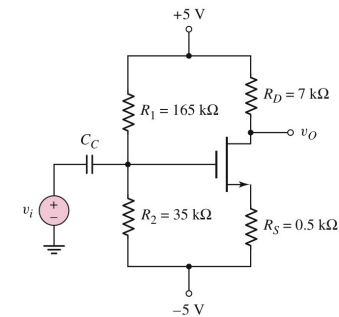
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Common-Source Amplifier with Source Resistor



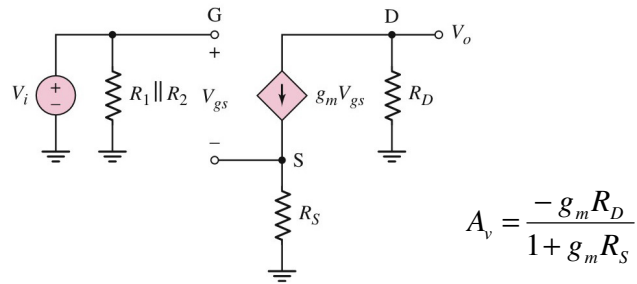
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Small-Signal Equivalent Circuit for Common-Source with Source Resistor



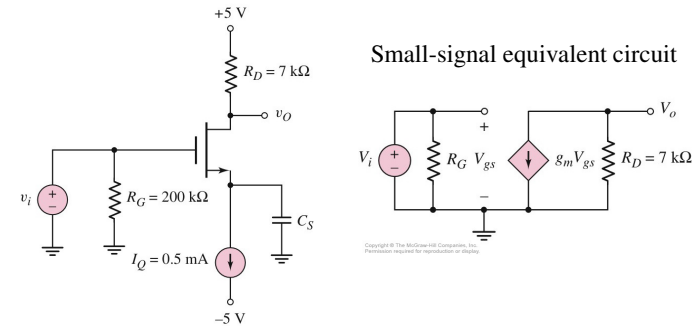
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Common-Source Amplifier with Bypass Capacitor



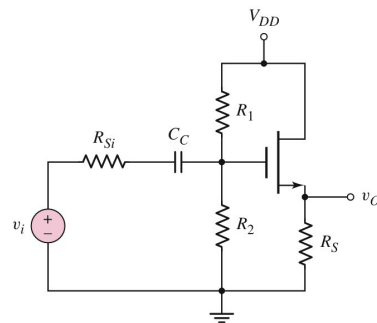
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NMOS Source-Follower or Common Drain Amplifier



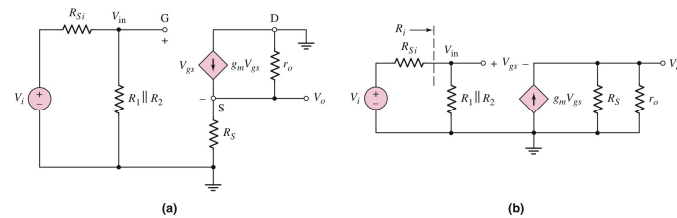
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Small-Signal Equivalent Circuit for Source Follower



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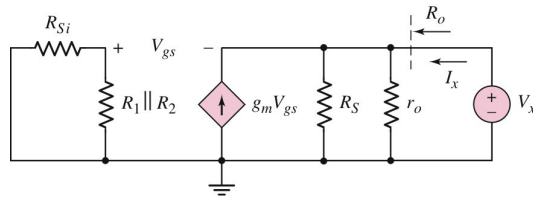
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$$A_v = \frac{R_S \parallel r_o}{\frac{1}{g_m} + R_S \parallel r_o} \left(\frac{R_i}{R_i + R_{Si}} \right)$$

Determining Output Impedance NMOS Source Follower



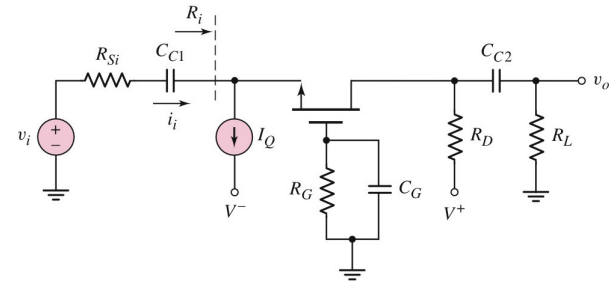
$$R_o = \frac{1}{g_m} \parallel R_S \parallel r_o$$

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Common-Gate Circuit

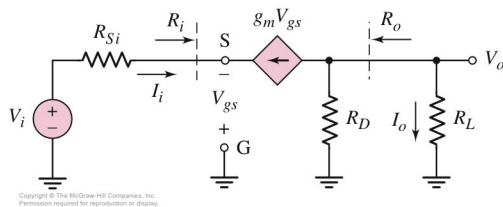


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Small-Signal Equivalent Circuit for Common Gate



$$A_v = \frac{g_m (R_D \parallel R_L)}{1 + g_m R_{Si}}$$

$$A_i = \frac{I_o}{I_i} = \left(\frac{R_D}{R_D + R_L} \right) \left(\frac{g_m R_{Si}}{1 + g_m R_{Si}} \right)$$

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Comparison of 3 Basic Amplifiers

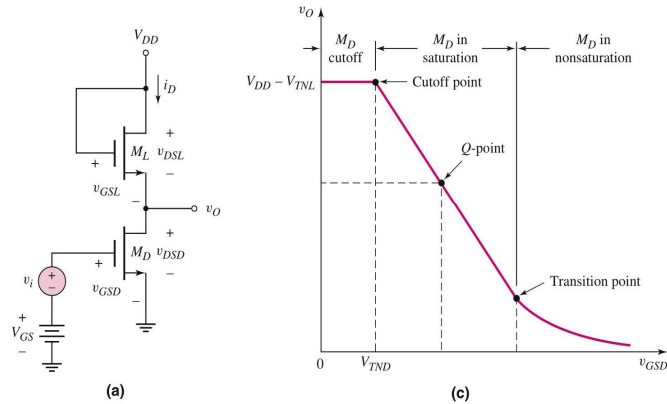
Configuration	Voltage Gain	Current Gain	Input Resistance	Output Resistance
Common Source	$A_v > 1$	—	R_{TH}	Moderate to high
Source Follower	$A_v \approx 1$	—	R_{TH}	Low
Common Gate	$A_v > 1$	$A_i \approx 1$	Low	Moderate to high

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NMOS Amplifier with Enhancement Load Device

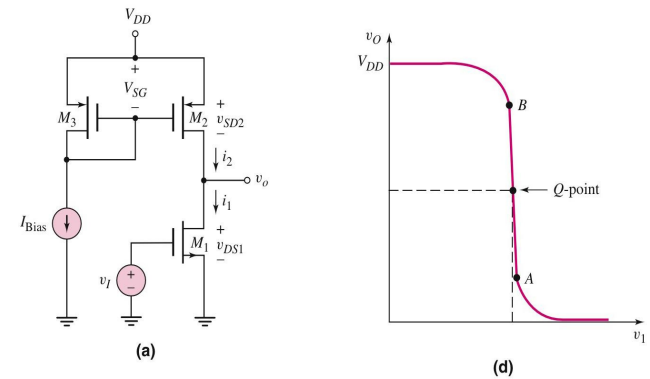


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CMOS Common-Source Amplifier

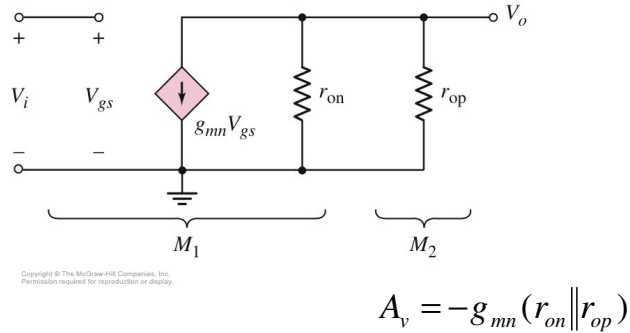


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Small-Signal Equivalent Circuit for CMOS Common Source

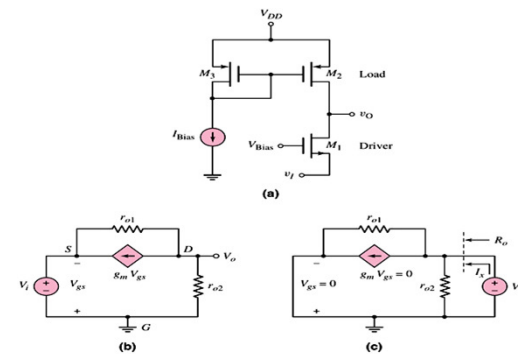


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CMOS Common Gate

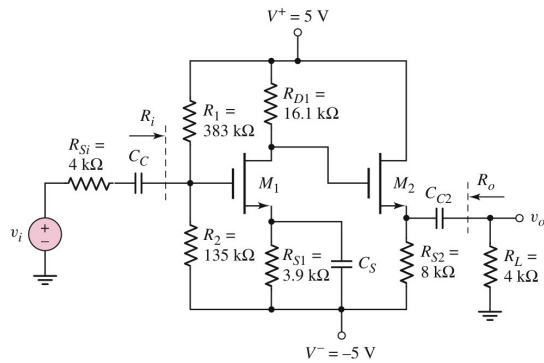


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Cascade Circuit

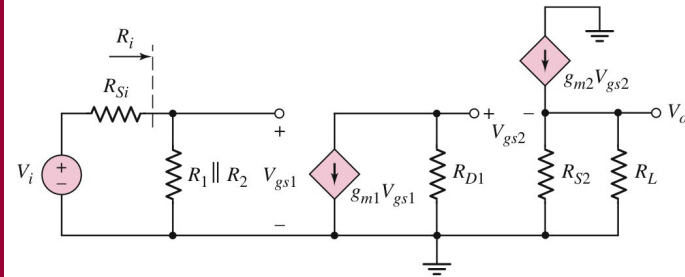


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Small-Signal Equivalent Circuit for Cascade Circuit

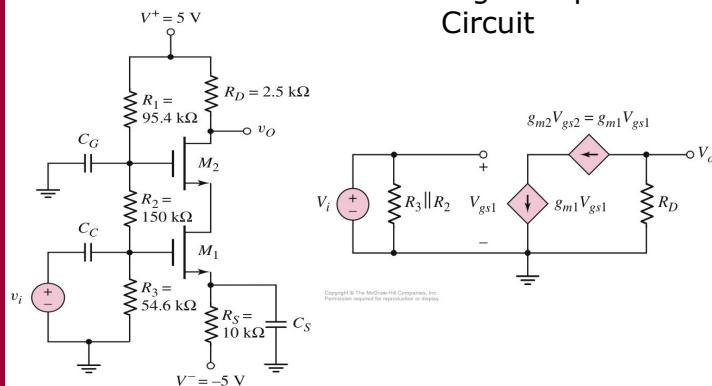


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Cascode Circuit th Small-Signal Equivalent Circuit



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