

# 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:

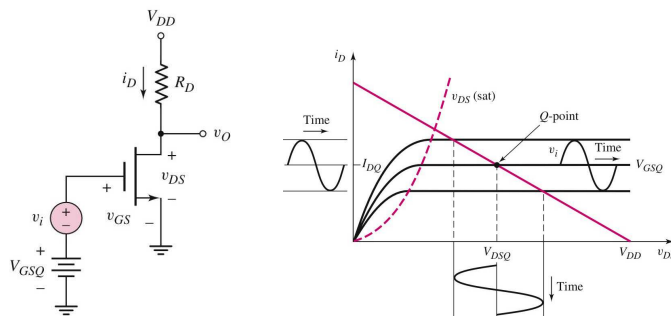
- Investigate a single-transistor circuit that can amplify a small, time-varying input signal
  - Develop small-signal models that are used in the analysis of linear amplifiers.
- Discuss and compare the three basic transistor amplifier configurations.
  - Analyze the common-source amplifier.
  - Analyze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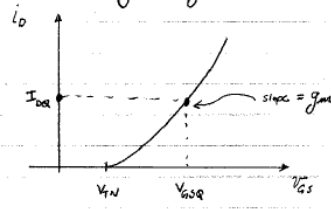
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# NMOS CS Circuit

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

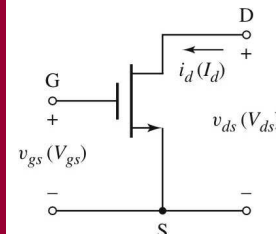


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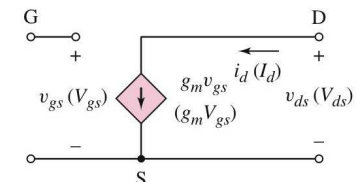
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# Simple NMOS Small-Signal Equivalent Circuit



(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

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

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

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

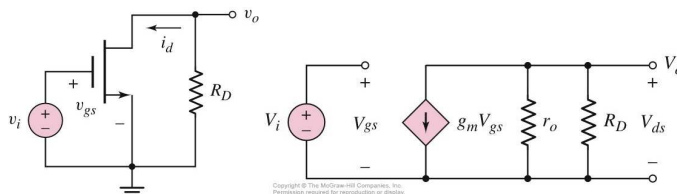
$$r_o = [\lambda K_n (V_{GSQ} - V_{TN})^2]^{-1} \cong [\lambda I_{DQ}]^{-1}$$

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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

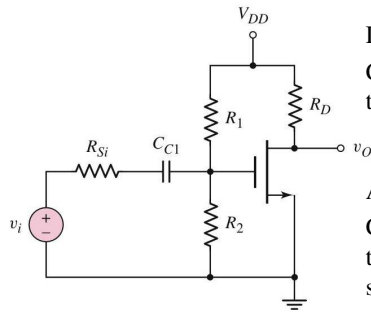
1. Analyze circuit with only the dc sources to find quiescent solution. Transistor must be biased in saturation region for linear amplifier.
2. Replace elements with small-signal model.
3. Analyze small-signal equivalent circuit, setting dc sources to zero, to produce the circuit to the time-varying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

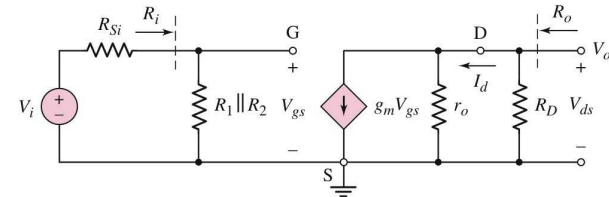
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## Small-Signal Equivalent Circuit



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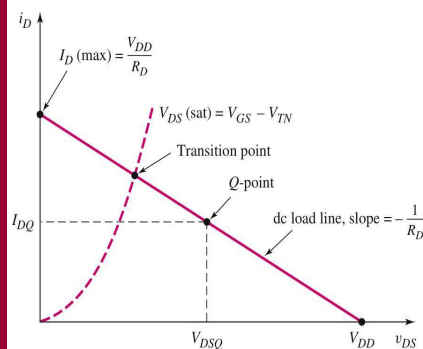
$$A_v = V_o/V_i = -g_m(r_o \parallel R_D)\left(\frac{R_i}{R_i + R_{Si}}\right)$$

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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.

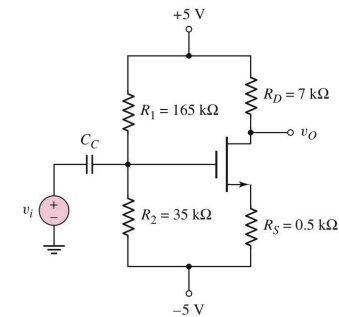
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## Common-Source Amplifier with Source Resistor



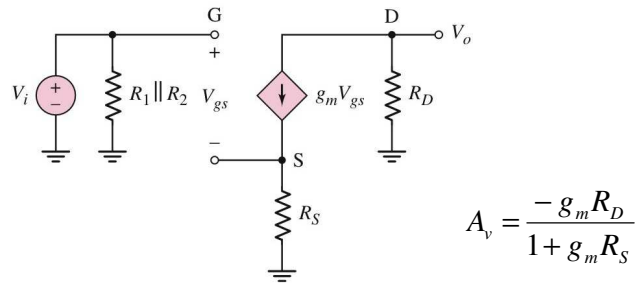
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### Small-Signal Equivalent Circuit for Common-Source with Source Resistor



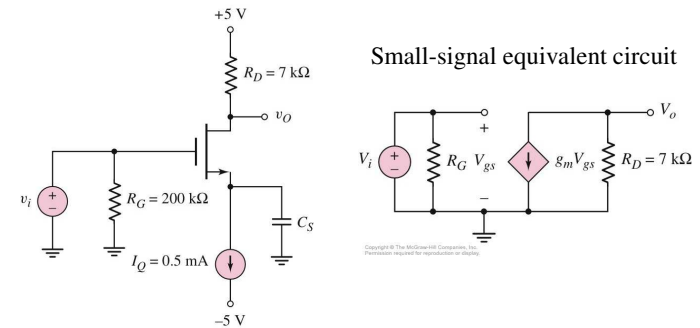
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### Common-Source Amplifier with Bypass Capacitor



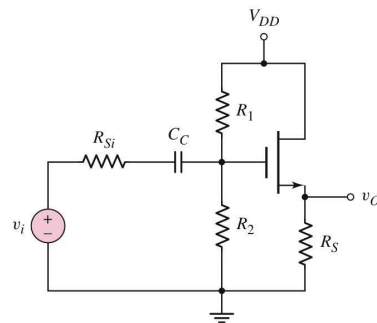
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### NMOS Source-Follower or Common Drain Amplifier



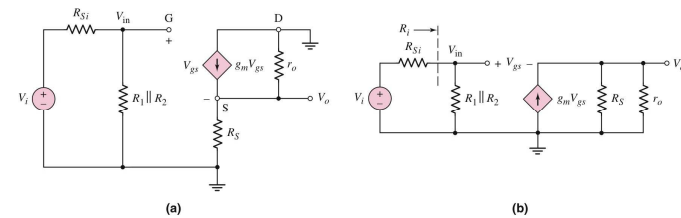
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### Small-Signal Equivalent Circuit for Source Follower



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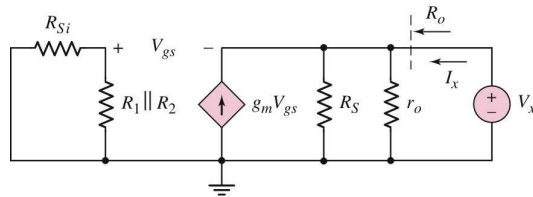
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$$A_v = \frac{R_S \parallel r_o}{\frac{1}{g_m} + R_S \parallel r_o} \left( \frac{R_i}{R_i + R_{Si}} \right)$$

### Determining Output Impedance NMOS Source Follower



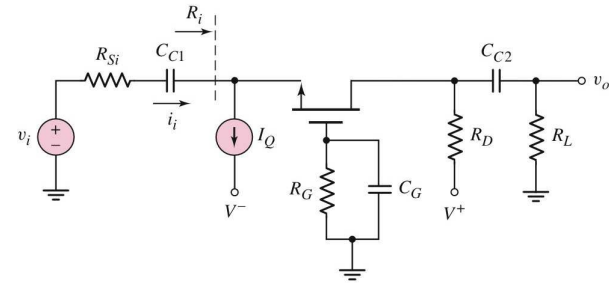
$$R_o = \frac{1}{g_m} \parallel R_S \parallel r_o$$

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### Common-Gate Circuit

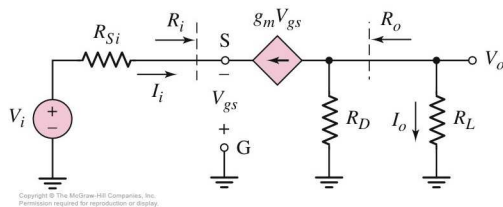


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### Small-Signal Equivalent Circuit for Common Gate



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

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

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### Comparison of 3 Basic Amplifiers

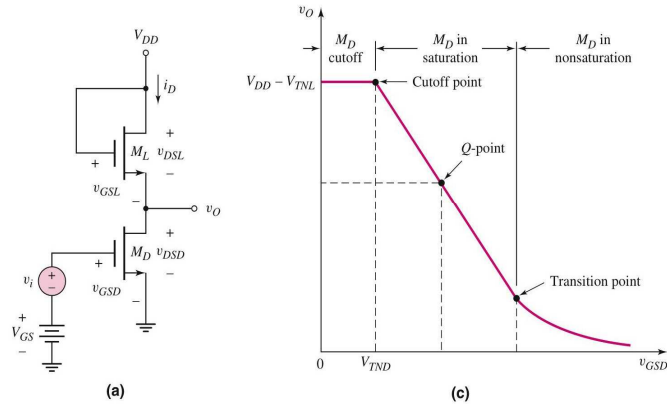
Configuration	Voltage Gain	Current Gain	Input Resistance	Output Resistance
Common Source	$A_v > 1$	—	$R_{TH}$	Moderate to high
Source Follower	$A_v \approx 1$	—	$R_{TH}$	Low
Common Gate	$A_v > 1$	$A_i \approx 1$	Low	Moderate to high

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## NMOS Amplifier with Enhancement Load Device

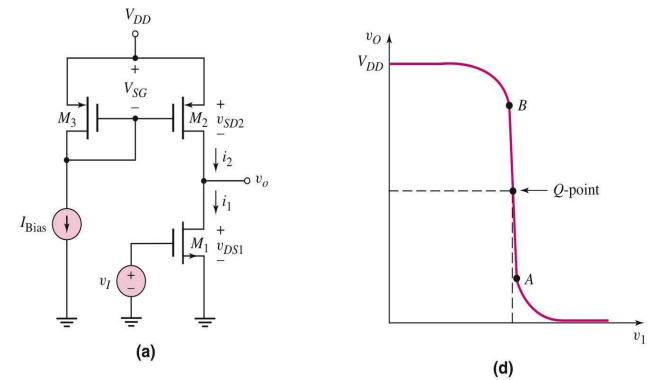


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## CMOS Common-Source Amplifier

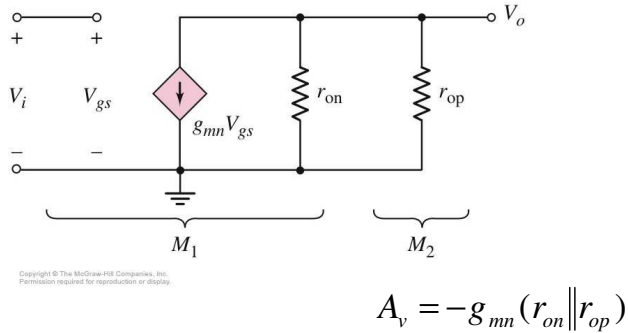


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## Small-Signal Equivalent Circuit for CMOS Common Source

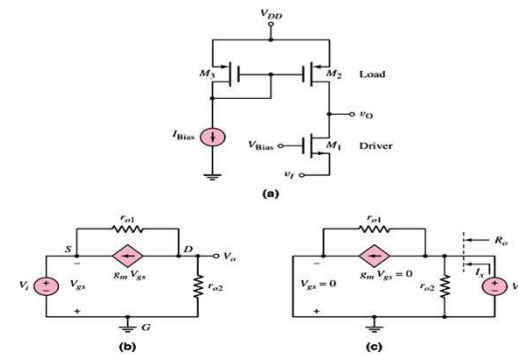


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## CMOS Common Gate

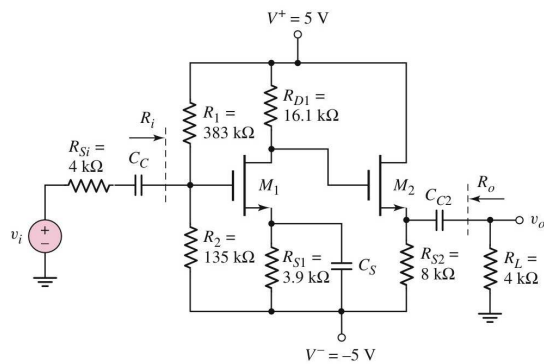


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### Cascade Circuit

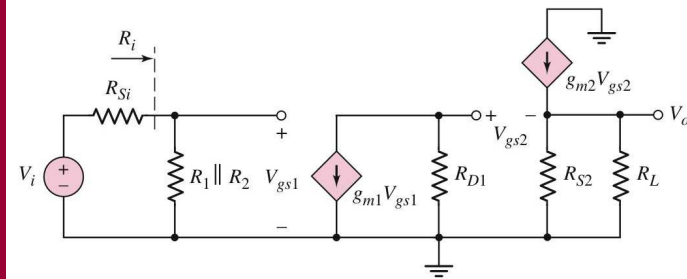


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### Small-Signal Equivalent Circuit for Cascade Circuit

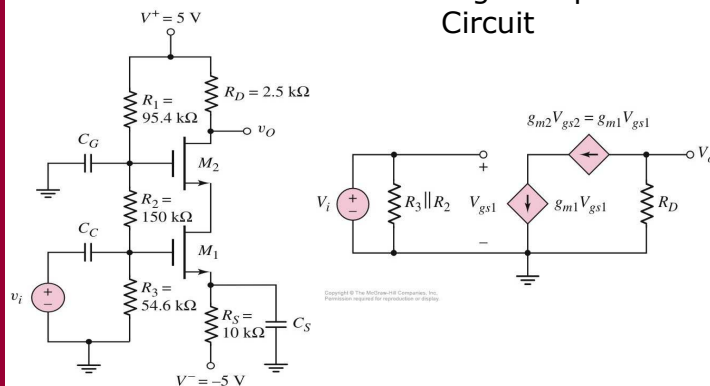


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### Cascode Circuit th Small-Signal Equivalent Circuit



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