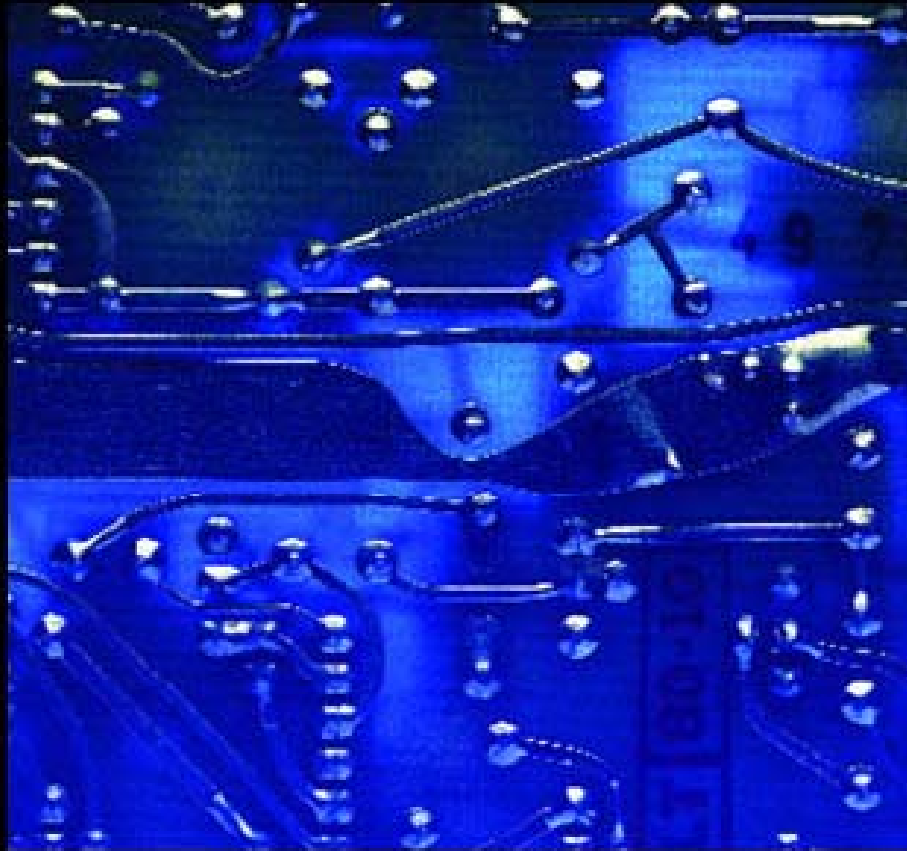# ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION

BOYLESTAD

PEARSON

Chapter 8:
FET Amplifiers

Introduction

FETs provide:

- Excellent voltage gain
- High input impedance
- Low-power consumption
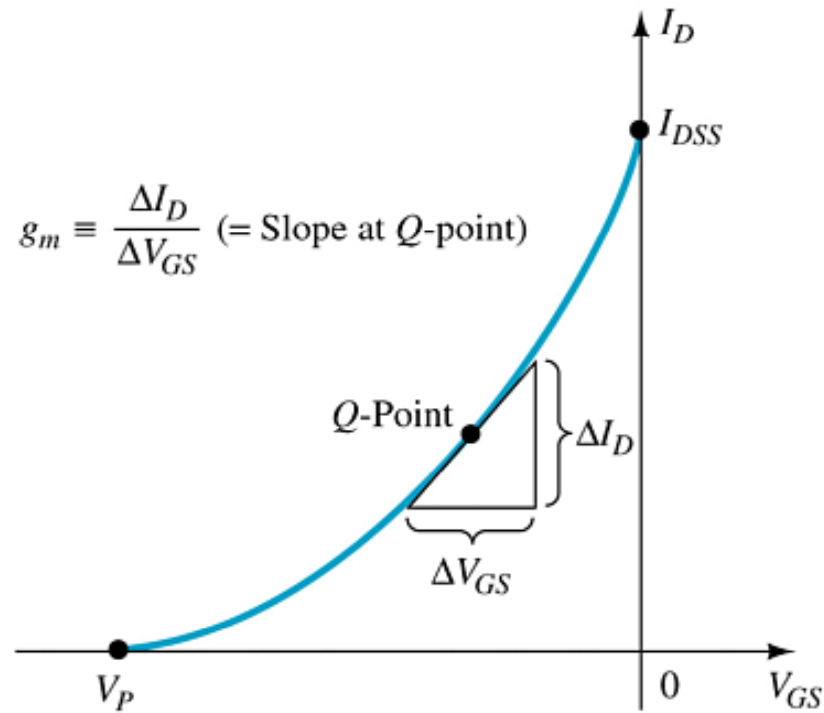- Good frequency range

FET Small-Signal Model

Transconductance

The relationship of a change in I_D to the corresponding change in V_{GS} is called **transconductance**

Transconductance is denoted g_m and given by:

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Graphical Determination of g_m

Mathematical Definitions of g_m

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]$$

Where $V_{GS} = 0V$ $\quad g_{m0} = \frac{2I_{DSS}}{|V_P|}$

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]$$

Where $\quad 1 - \frac{V_{GS}}{V_P} = \sqrt{\frac{I_D}{I_{DSS}}}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = g_{m0}\sqrt{\frac{I_D}{I_{DSS}}}$$

FET Impedance

Input impedance:

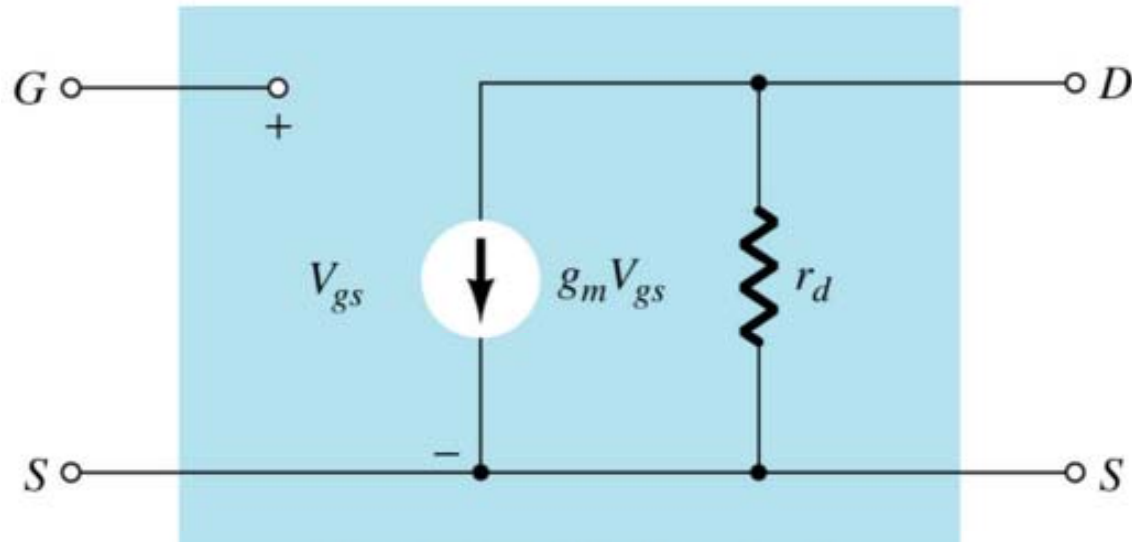$$Z_i = \infty\,\Omega$$

Output Impedance:

$$Z_o = r_d = \frac{1}{y_{os}}$$

where:

$$r_d = \left.\frac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}\,=\,\text{constant}}$$

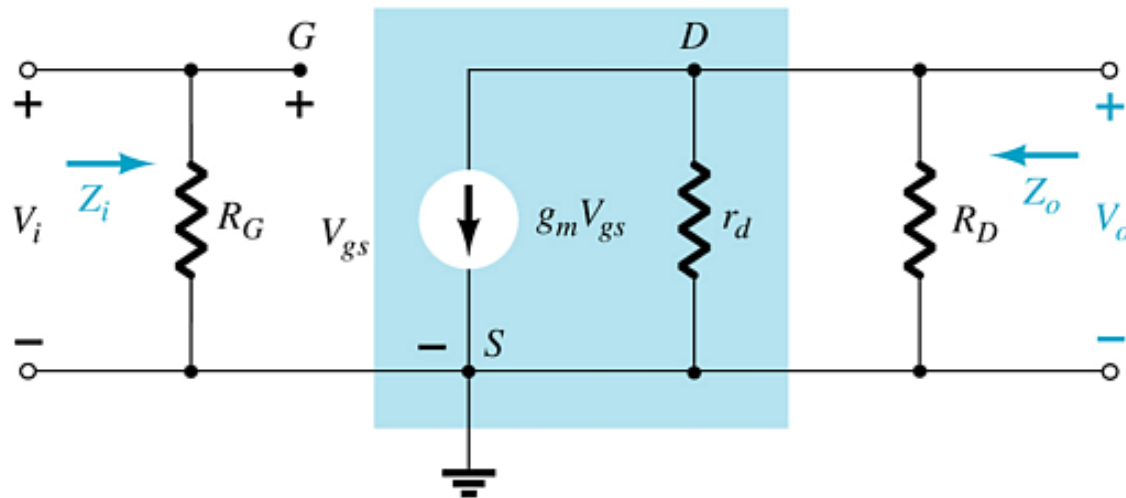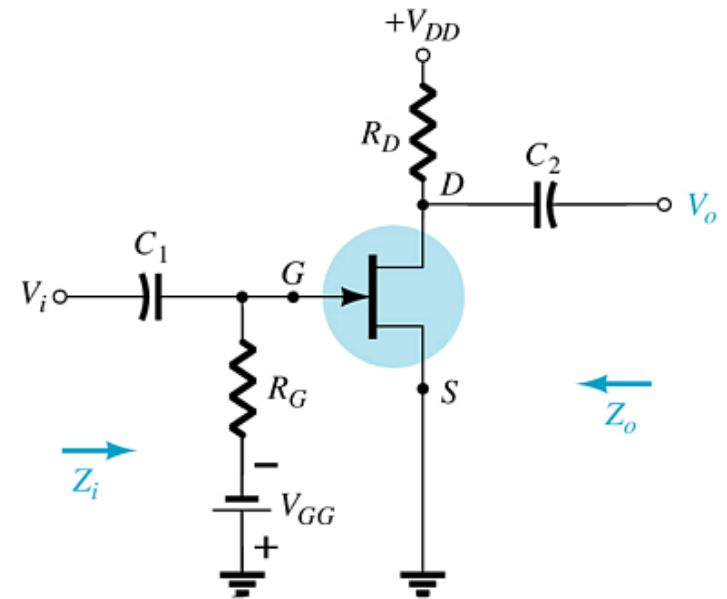y_{os} = admittance parameter listed on FET specification sheets.

FET AC Equivalent Circuit

Common-Source (CS) Fixed-Bias Circuit

The input is on the gate and the output is on the drain

There is a 180° phase shift between input and output

Calculations

Input impedance:
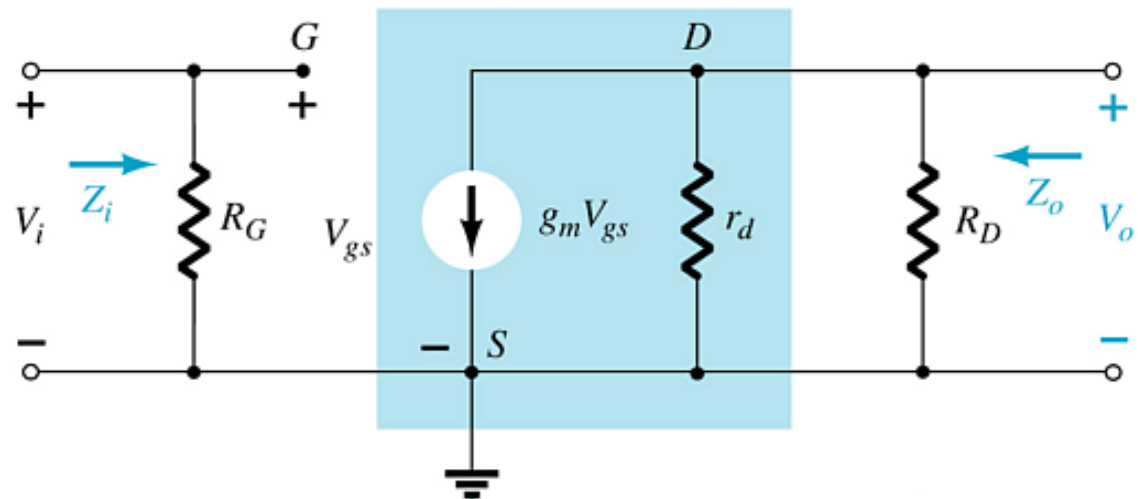
$$Z_i = R_G$$

Output impedance:

$$Z_o = R_D \parallel r_d$$

$$Z_o \cong R_D \Big|_{r_d \geq 10R_D}$$

Voltage gain:

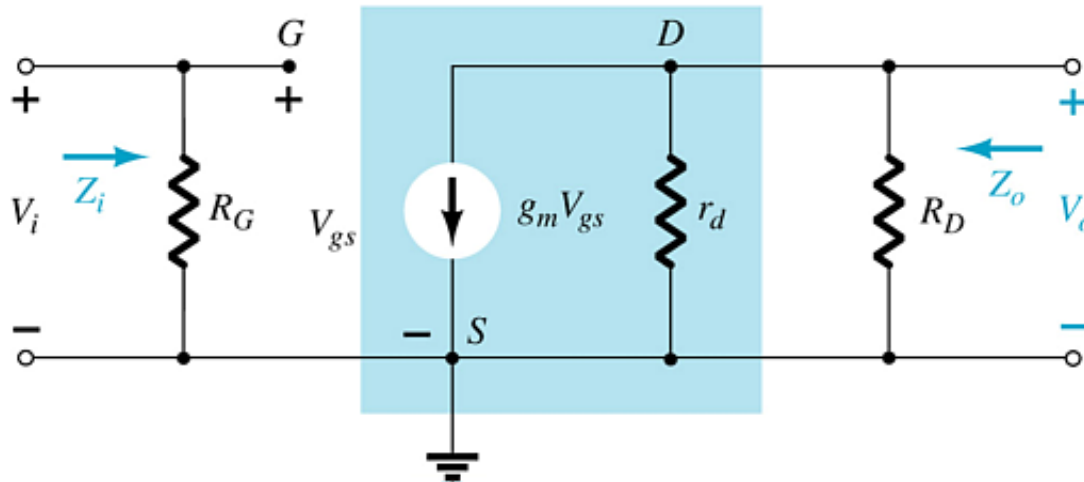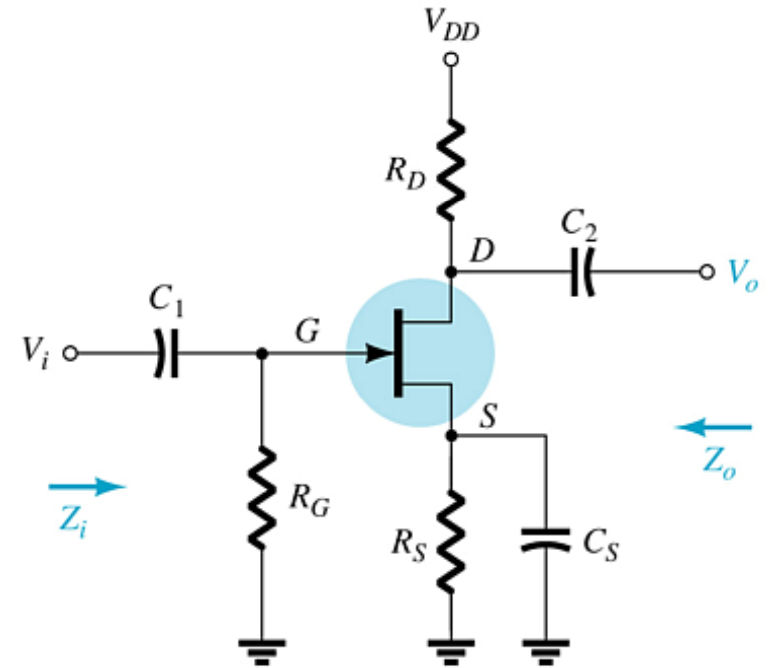$$A_v = \frac{V_o}{V_i} = -g_m(r_d \parallel R_D)$$

$$A_v = \frac{V_o}{V_i} = -g_m R_D \Big|_{r_d \geq 10R_D}$$

Common-Source (CS) Self-Bias Circuit

This is a common-source amplifier configuration, so the input is on the gate and the output is on the drain

There is a 180° phase shift between input and output

Calculations

Input impedance:

$$Z_i = R_G$$
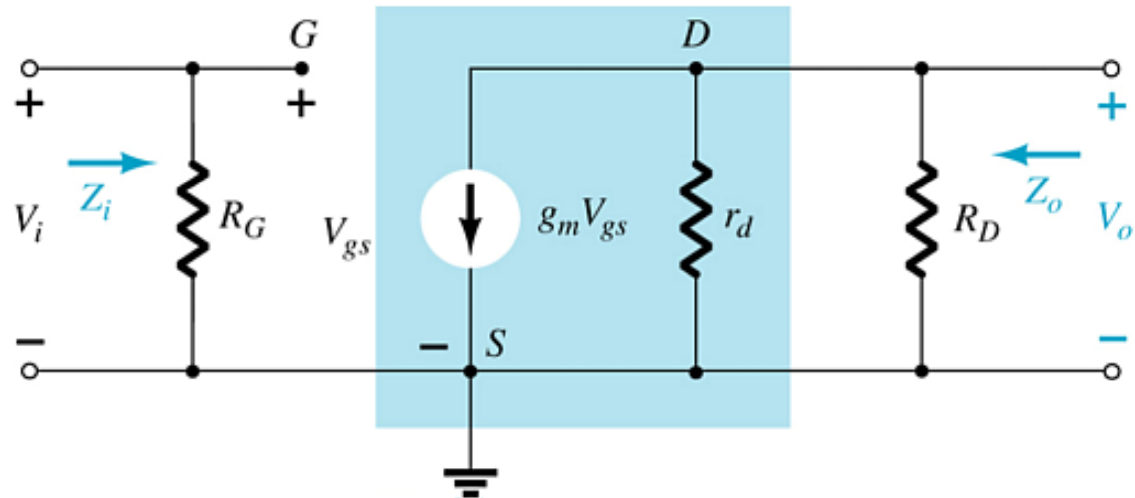
Output impedance:

$$Z_o = r_d \parallel R_D$$

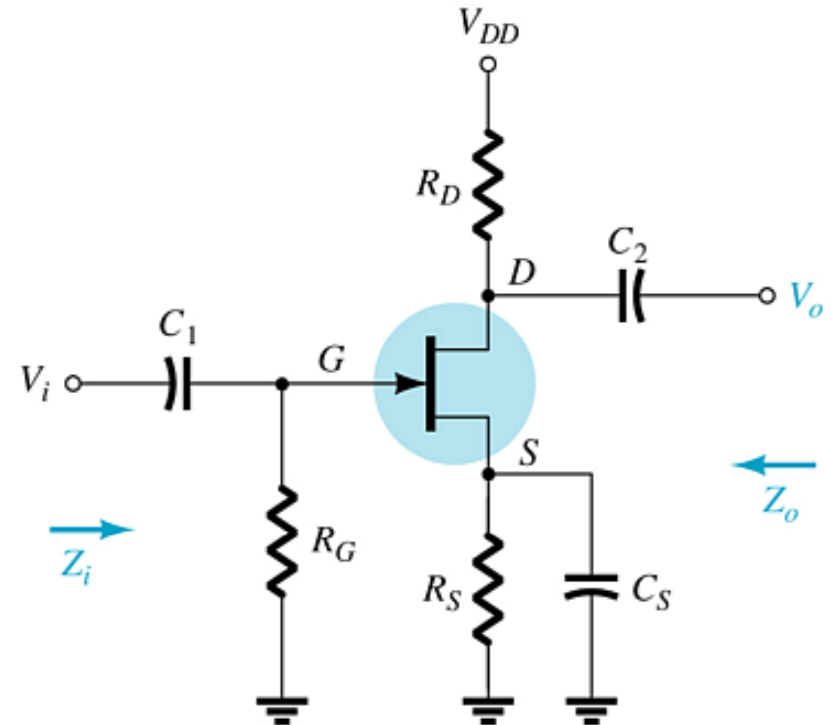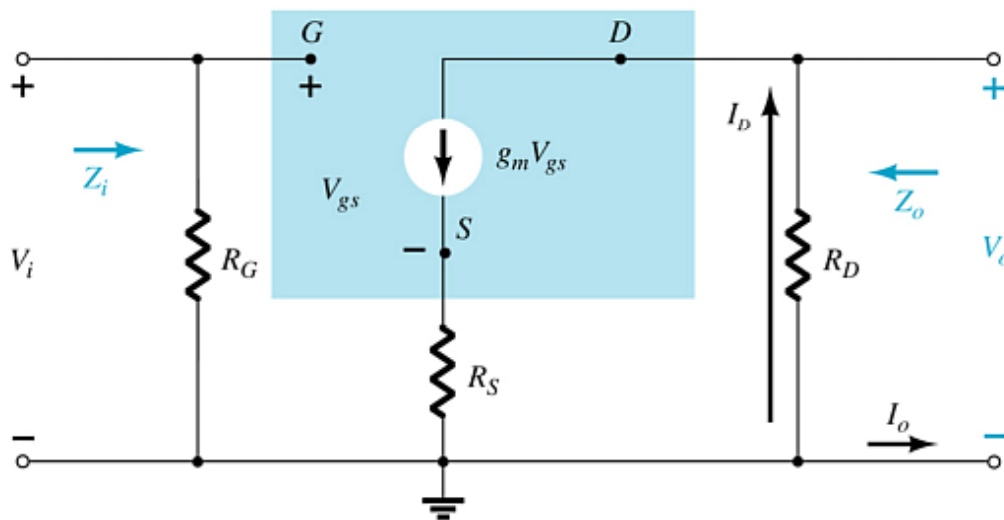$$Z_o \cong R_D \bigg|_{r_d \geq 10R_D}$$

Voltage gain:

$$A_v = -g_m(r_d \parallel R_D)$$

$$A_v = -g_m R_D \bigg|_{r_d \geq 10R_D}$$

Common-Source (CS) Self-Bias Circuit

**Removing C$_S$ affects
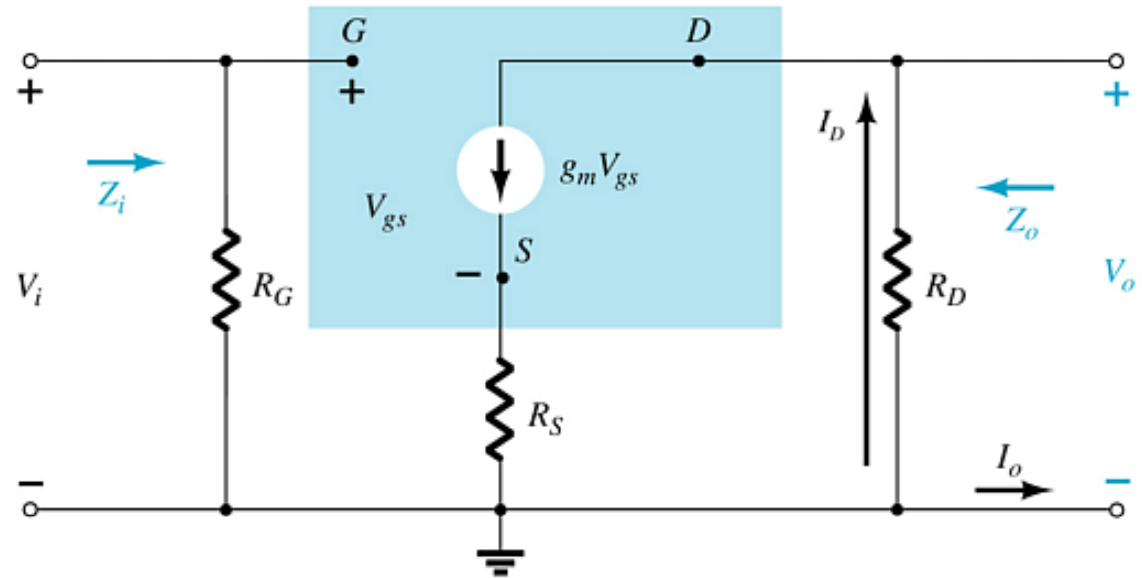the gain of the circuit.**

Calculations

Input impedance:

$$Z_i = R_G$$

Output impedance:
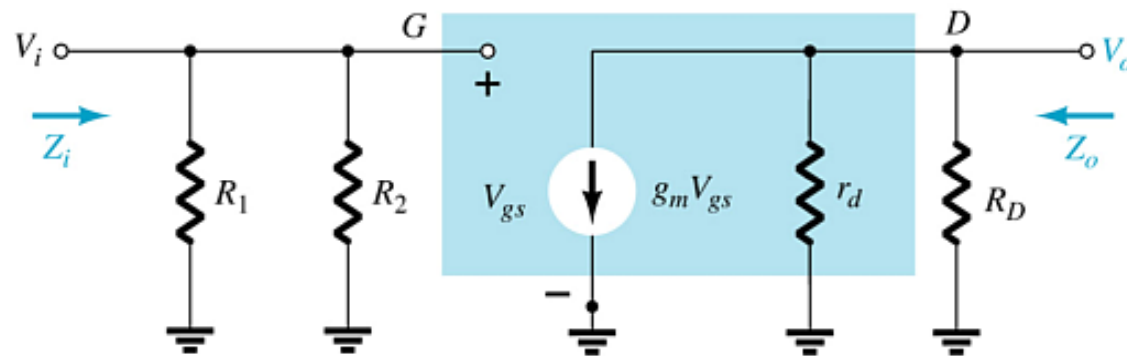
$$Z_o \cong R_D \bigg|_{r_d \geq 10R_D}$$

Voltage gain:
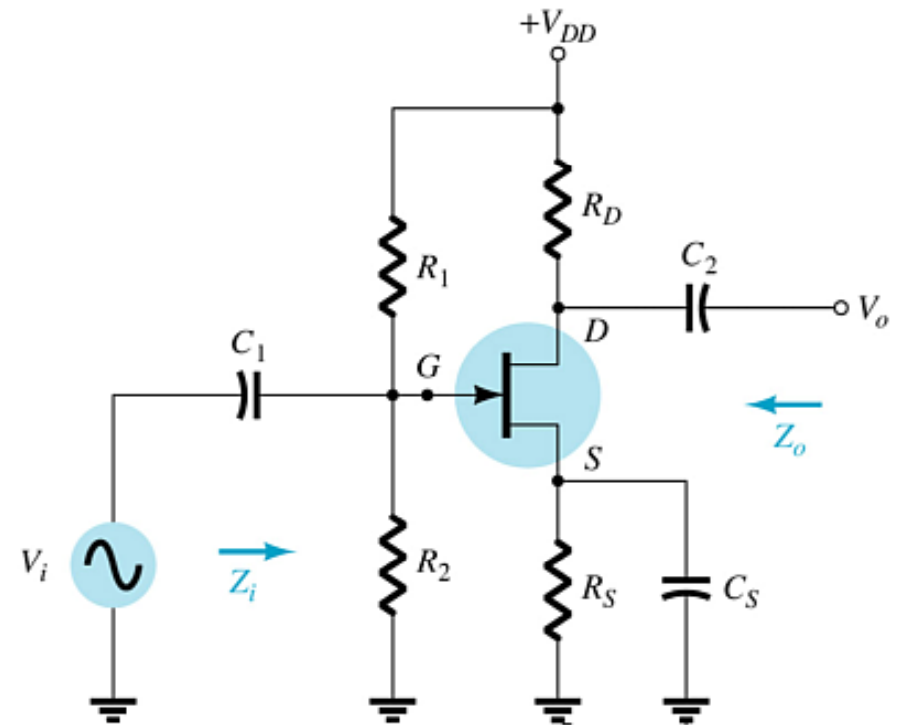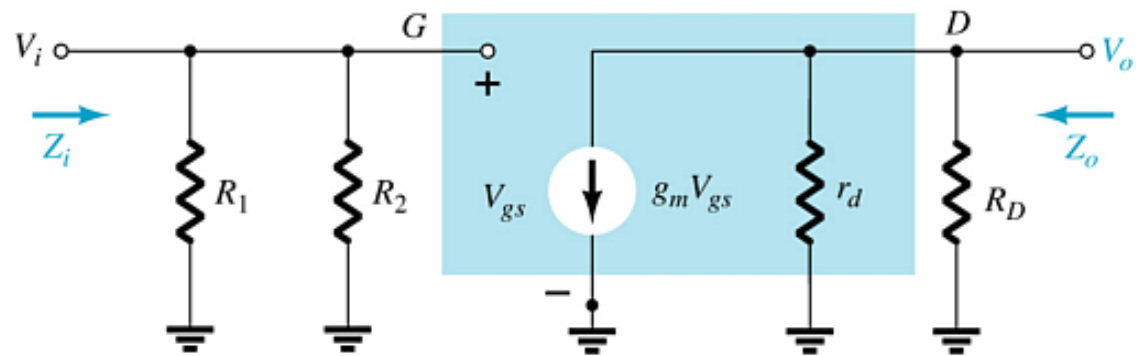
$$A_v = \frac{V_o}{V_i} = -\frac{g_m R_D}{1 + g_m R_S + \dfrac{R_D + R_S}{r_d}}$$

$$A_v = \frac{V_o}{V_i} = -\frac{g_m R_D}{1 + g_m R_S} \bigg|_{r_d \geq 10(R_D + R_S)}$$

Common-Source (CS) Voltage-Divider Bias

This is a common-source amplifier configuration, so the input is on the gate and the output is on the drain.

Impedances

Input impedance:

$$Z_i = R_1 \| R_2$$

Output impedance:

$$Z_o = r_d \| R_D$$

$$Z_o \cong R_D \Big|_{r_d \geq 10R_D}$$

Voltage gain:
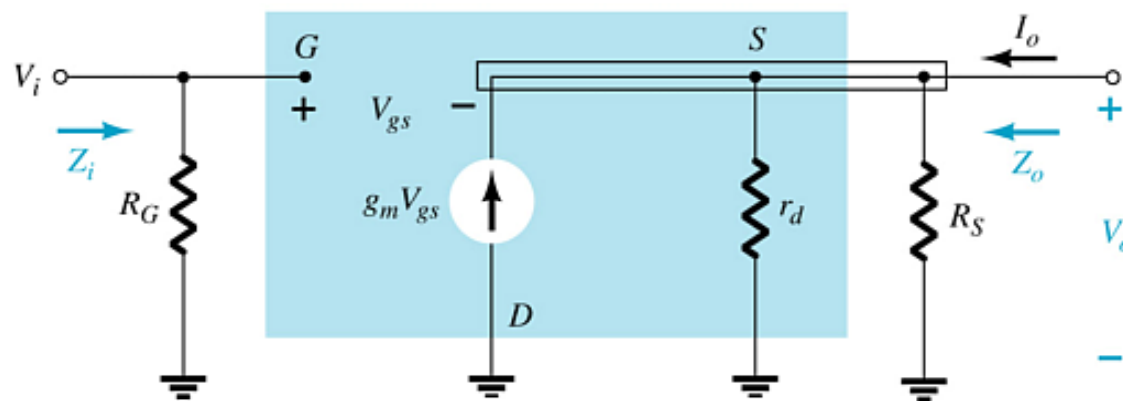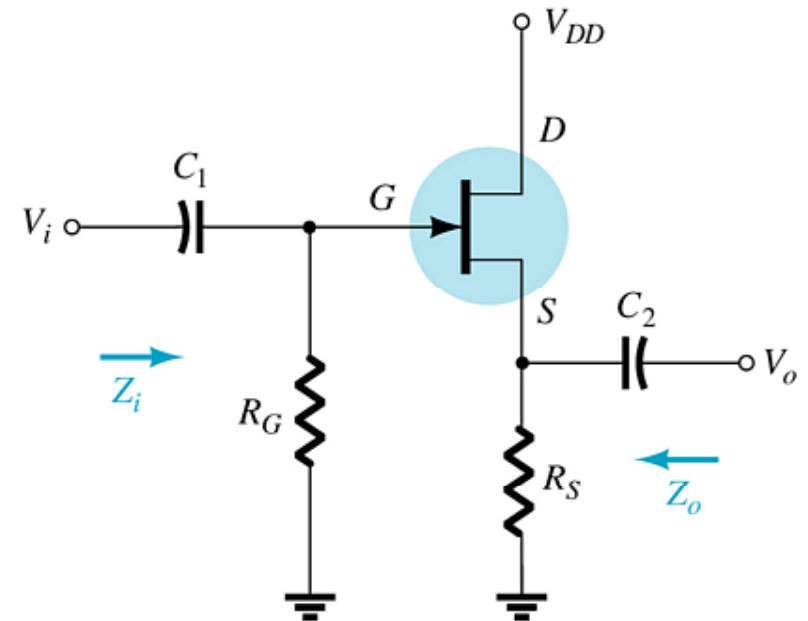
$$A_v = -g_m(r_d \| R_D)$$

$$A_v = -g_m R_D \Big|_{r_d \geq 10R_D}$$

Source Follower (Common-Drain) Circuit

In a common-drain amplifier configuration, the input is on the gate, but the output is from the source.

There is no phase shift between input and output.

Impedances

Input impedance:
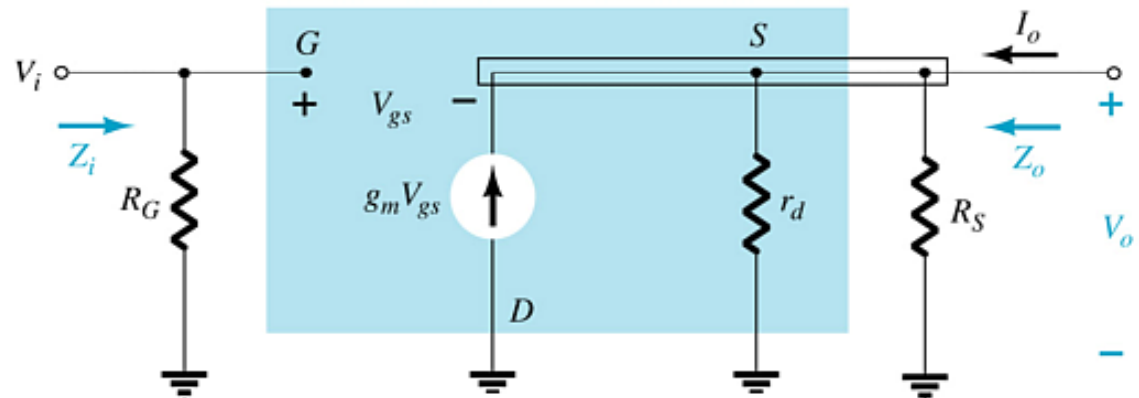
$$Z_i = R_G$$

Output impedance:

$$Z_o = r_d \parallel R_S \parallel \frac{1}{g_m}$$

$$Z_o \cong R_S \parallel \frac{1}{g_m} \bigg|_{r_d \geq 10 R_S}$$

Voltage gain:

$$A_v = \frac{V_o}{V_i} = \frac{g_m(r_d \parallel R_S)}{1 + g_m(r_d \parallel R_S)}$$
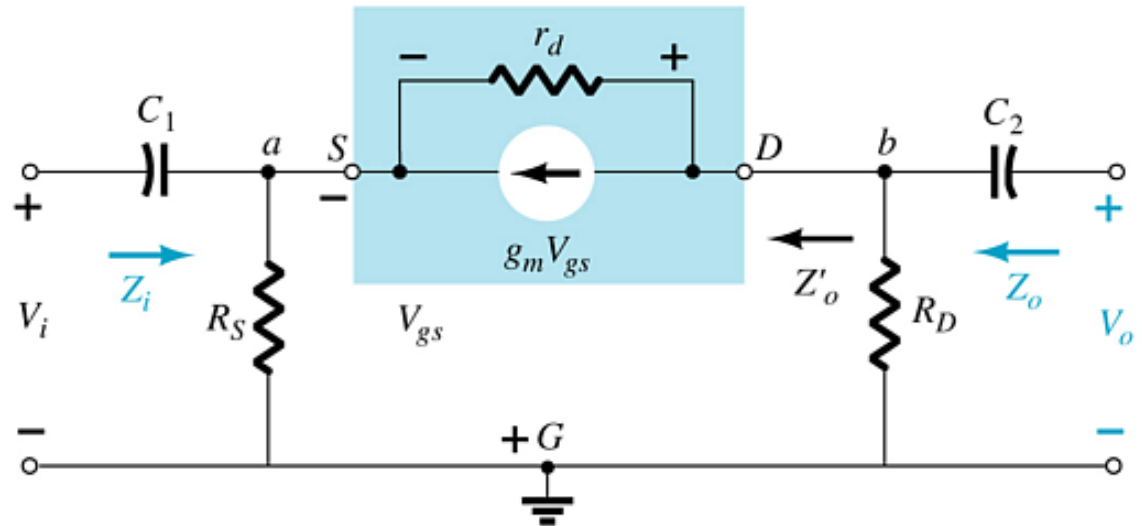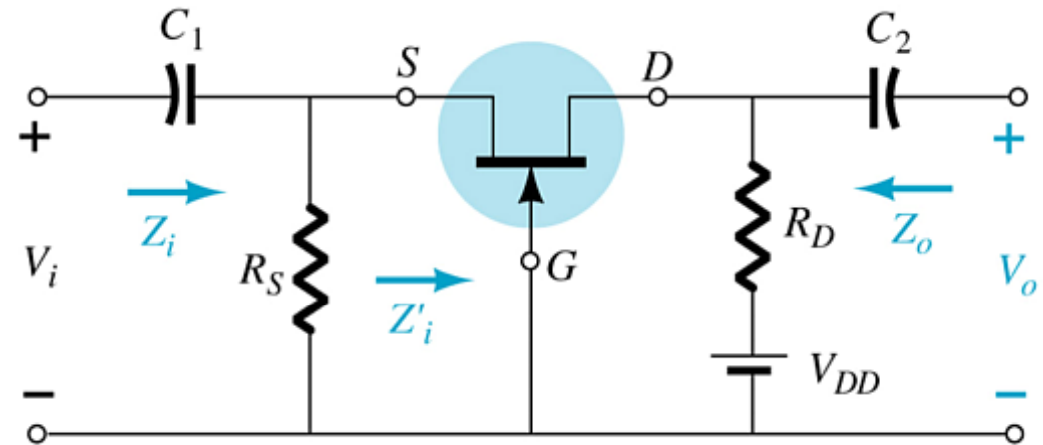
$$A_v = \frac{V_o}{V_i} = \frac{g_m R_S}{1 + g_m R_S} \bigg|_{r_d \geq 10}$$

Common-Gate (CG) Circuit

The input is on the source and the output is on the drain.

There is no phase shift between input and output.

Calculations

Input impedance:

$$Z_i = R_S \parallel \left[\frac{r_d + R_D}{1 + g_m r_d} \right]$$

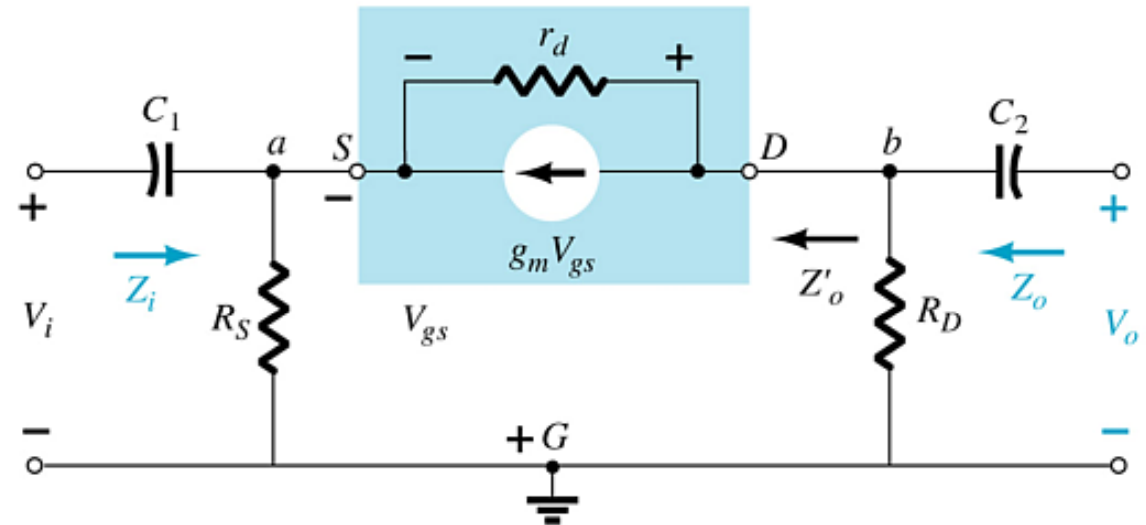$$Z_i \cong R_S \parallel \frac{1}{g_m} \bigg|_{r_d \geq 10 R_D}$$
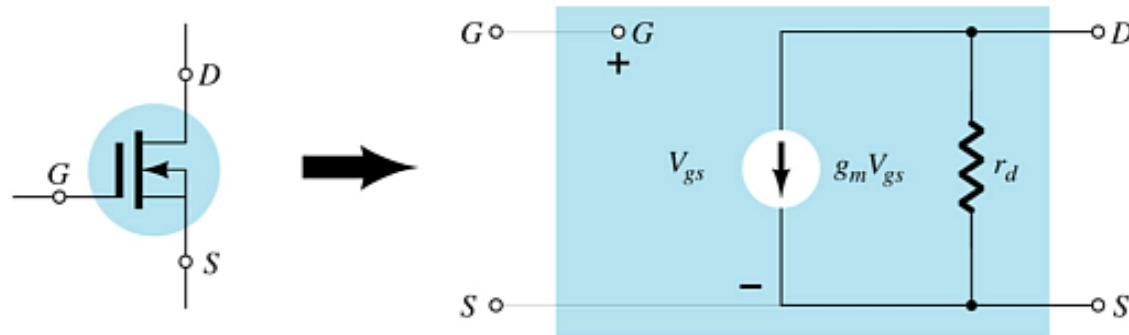

Output impedance:

$$Z_o = R_D \parallel r_d$$

$$Z_o \cong R_D \big|_{r_d \geq 10}$$

Voltage gain:

$$A_v = \frac{V_o}{V_i} = \frac{\left[g_m R_D + \dfrac{R_D}{r_d} \right]}{\left[1 + \dfrac{R_D}{r_d} \right]} \qquad A_v = g_m R_D \big|_{r_d \geq 10 R_D}$$
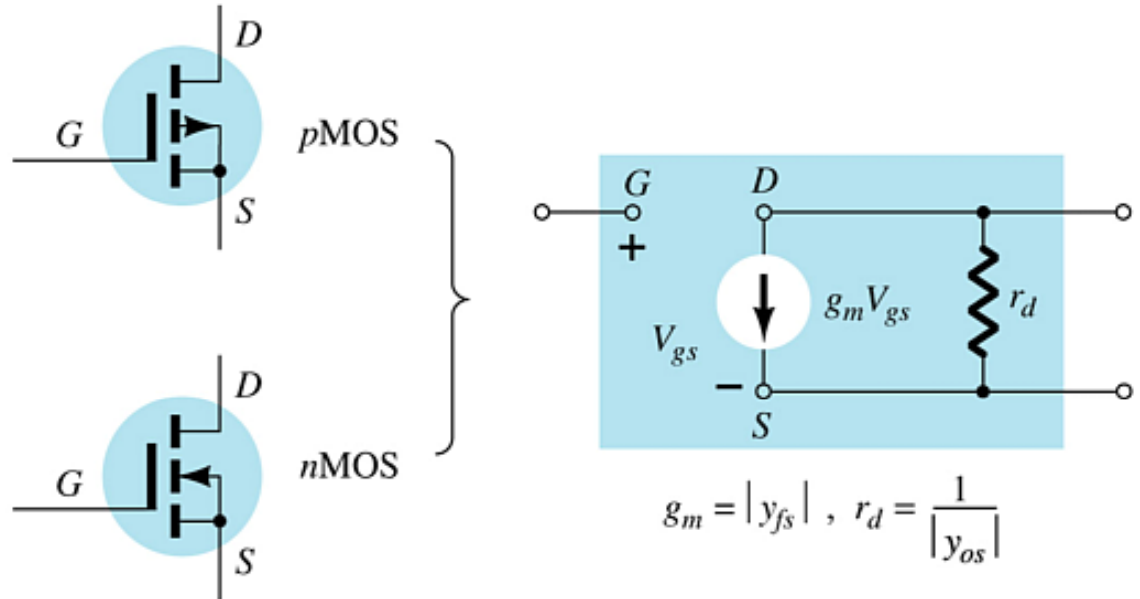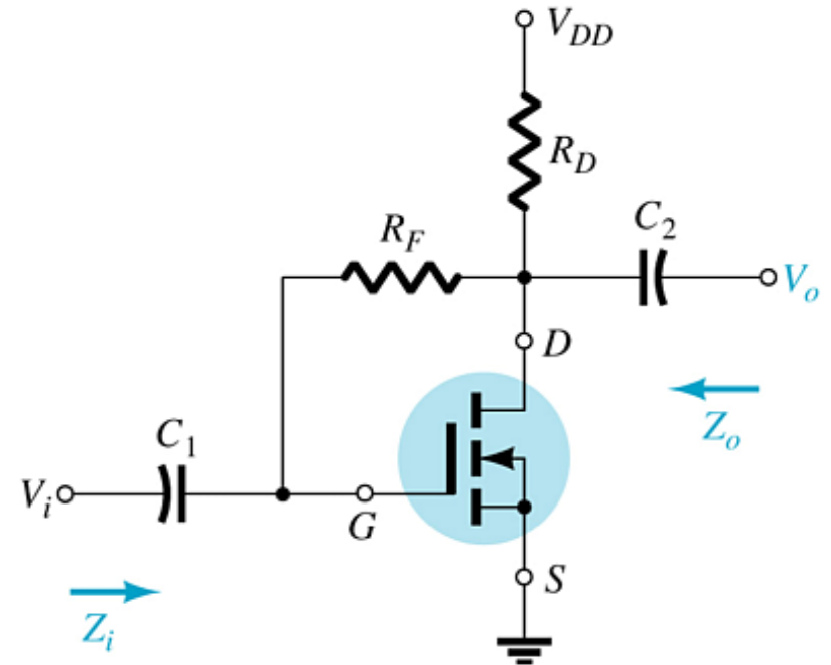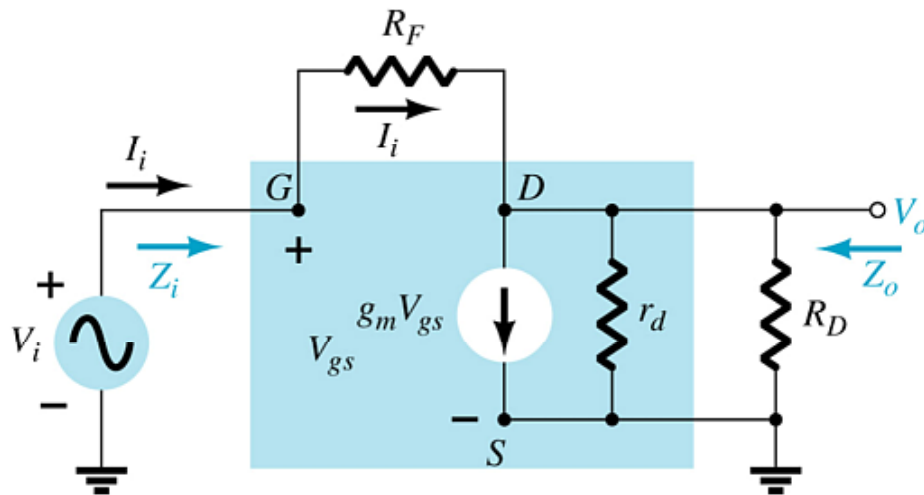
D-Type MOSFET AC Equivalent

E-Type MOSFET AC Equivalent

g_m and r_d can be found in the specification sheet for the FET.

$$g_m = |y_{fs}| \ , \ \ r_d = \frac{1}{|y_{os}|}$$

Common-Source Drain-Feedback

There is a 180° phase shift between input and output.

Calculations

Input impedance:

$$Z_i = \frac{R_F + r_d \| R_D}{1 + g_m(r_d \| R_D)}$$

$$Z_i \cong \frac{R_F}{1 + g_m R_D}\bigg|_{R_F \gg r_d \| R_D, r_d \geq 10 R_D}$$
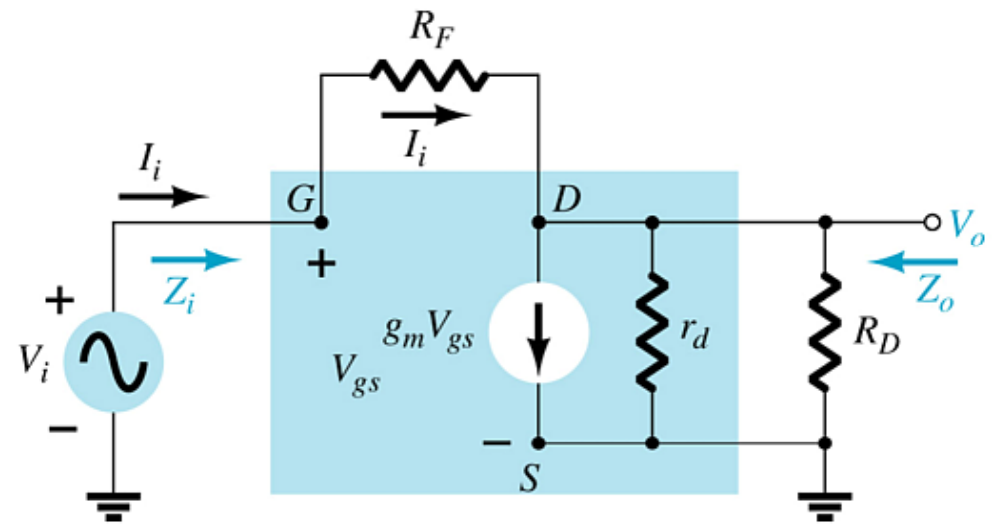
Output impedance:

$$Z_o = R_F \| r_d \| R_D$$

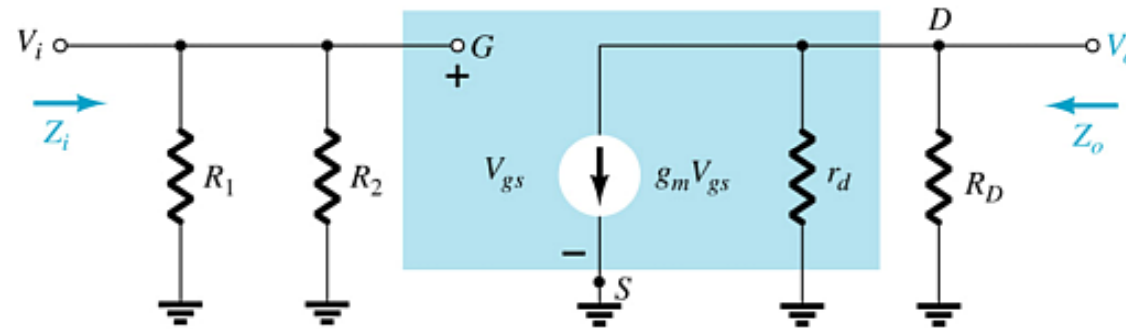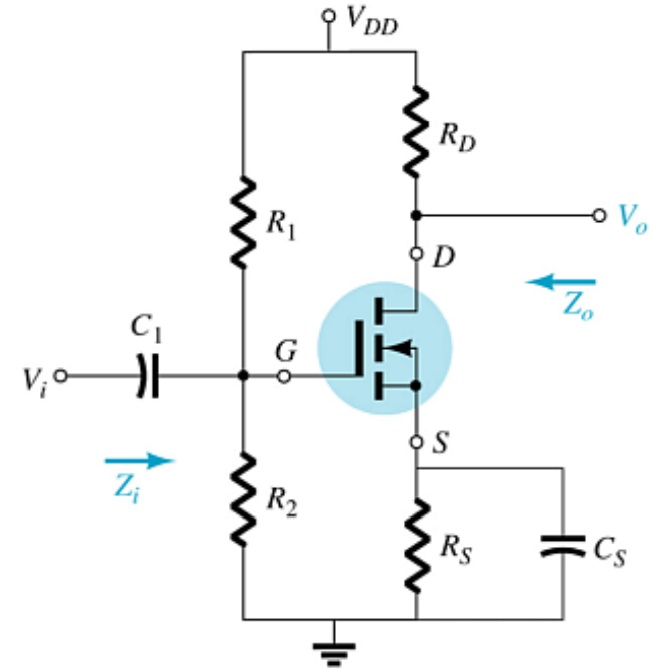$$Z_o \cong R_D\big|_{R_F \gg r_d \| R_D, r_d \geq 10 R_D}$$

Voltage gain:

$$A_v = -g_m(R_F \| r_d \| R_D)$$

$$A_v \cong -g_m R_D\big|_{R_F \gg r_d \| R_D, r_d \geq 10 R_D}$$

Common-Source Voltage-Divider Bias

Calculations

Input impedance:

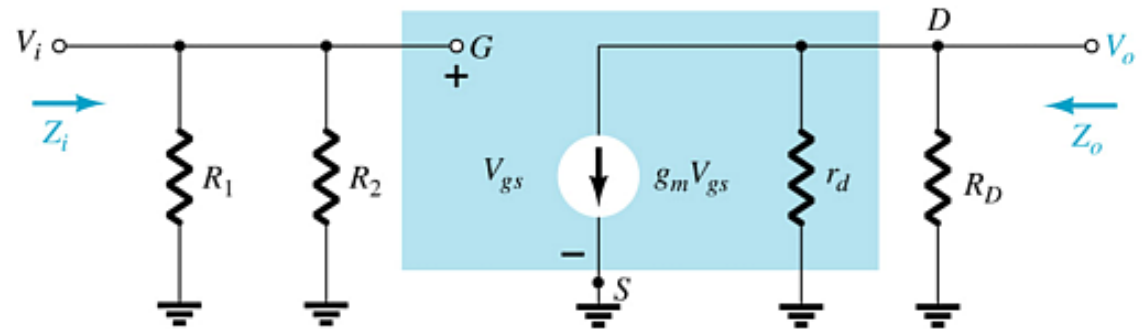$$Z_i = R_1 \parallel R_2$$

Output impedance:

$$Z_o = r_d \parallel R_D$$

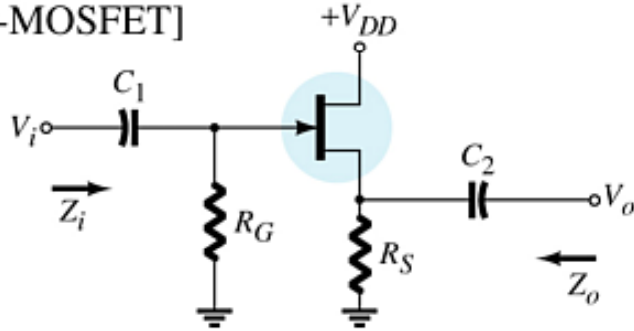$$Z_o \cong R_D \big|_{r_d \geq 10}$$

Voltage gain:

$$A_v = -g_m (r_d \parallel R_D)$$

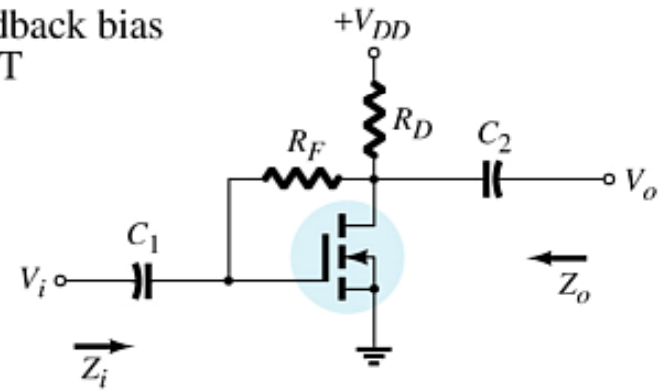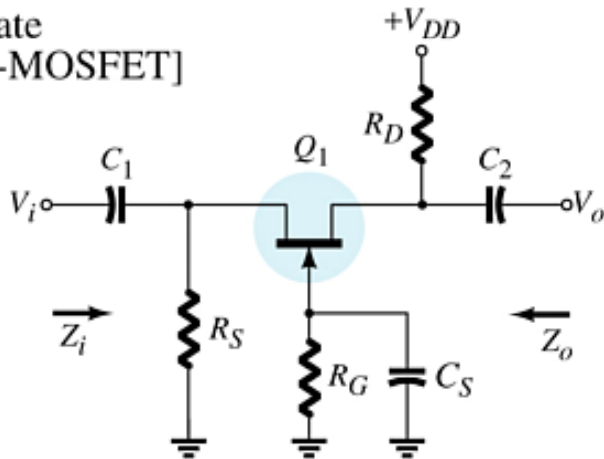$$A_v \cong -g_m R_D \big|_{r_d \geq 10 R_D}$$

Summary Table

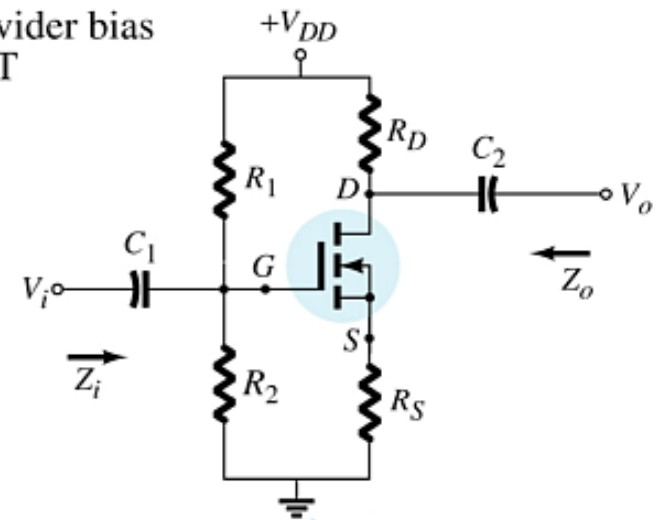Source-follower
[JFET or D-MOSFET]

Drain-Feedback bias
E-MOSFET
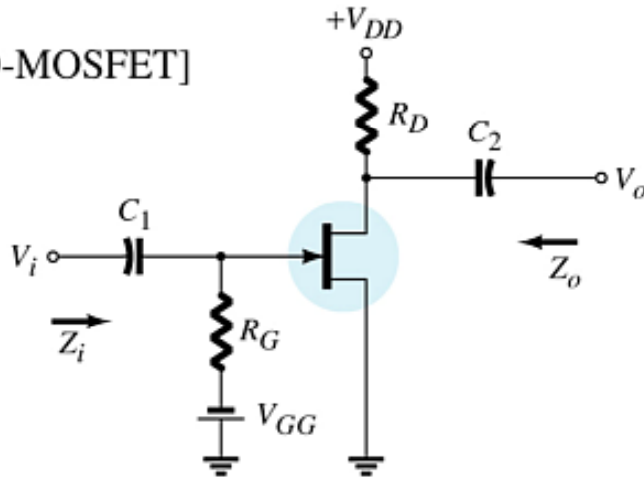

Common-gate
[JFET or D-MOSFET]
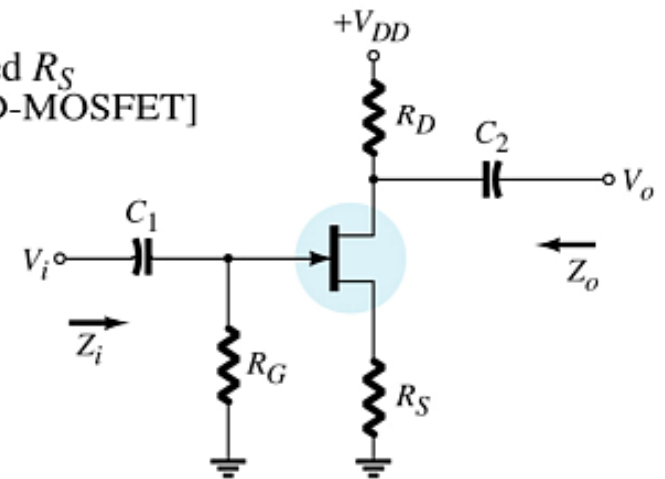

Voltage-divider bias
E-MOSFET

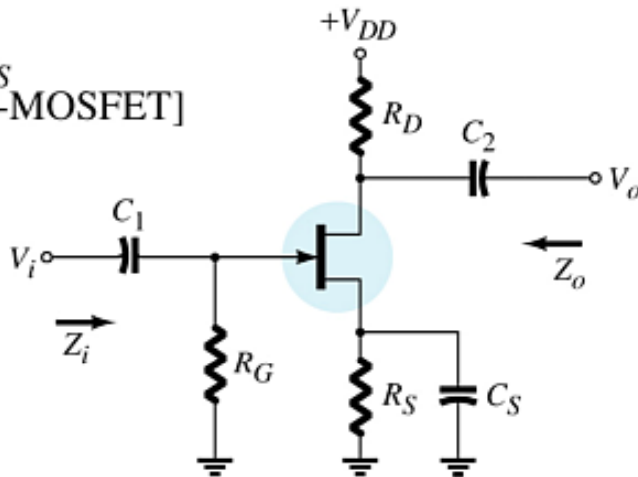**more…**
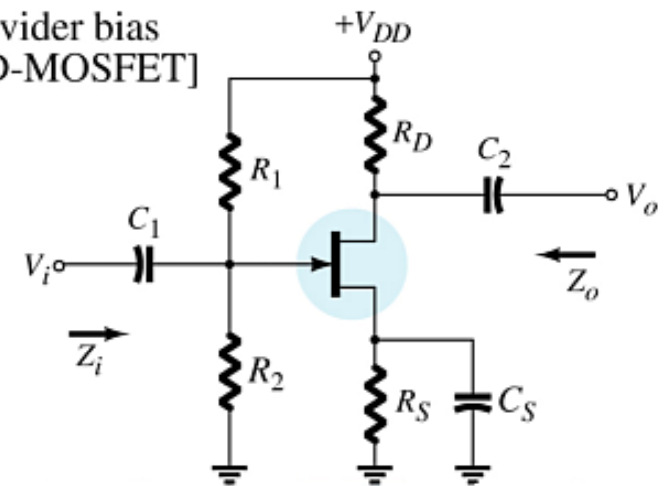
Summary Table

Fixed-bias [JFET or D-MOSFET]

Self-bias Unbypassed R_S [JFET or D-MOSFET]

Self-bias bypassed R_S [JFET or D-MOSFET]

Voltage-divider bias [JFET or D-MOSFET]

Troubleshooting

Check the DC bias voltages:

    If not correct check power supply, resistors, FET. Also check to ensure that the coupling capacitor between amplifier stages is OK.

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Check the AC voltages:

    If not correct check FET, capacitors and the loading effect of the next stage

Practical Applications

Three-Channel Audio Mixer
Silent Switching
Phase Shift Networks
Motion Detection System