Introduction

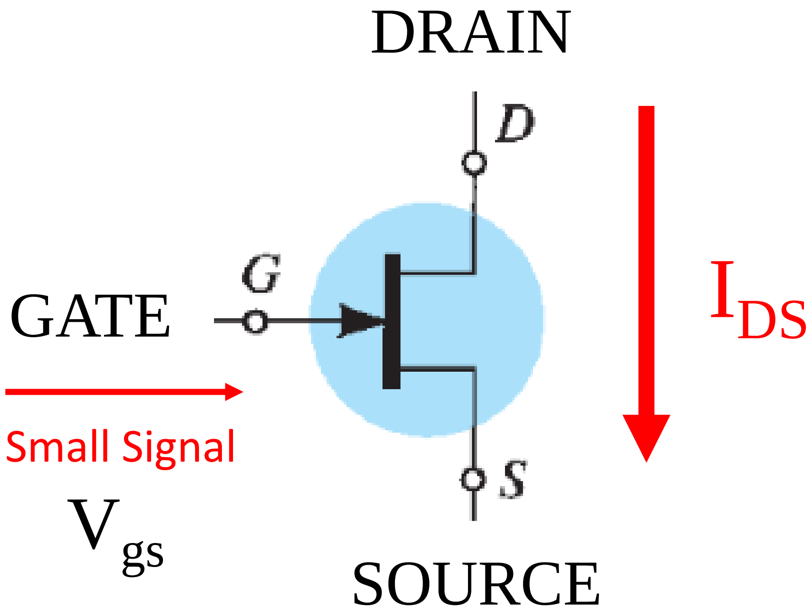
FET (Field-effect transistor)

- High input impedance
- Low power consumption
- Control an output drain current by a small input voltage (gate voltage)
- Widely use in high-frequency application

BJT = Current control device
FET = Voltage control device

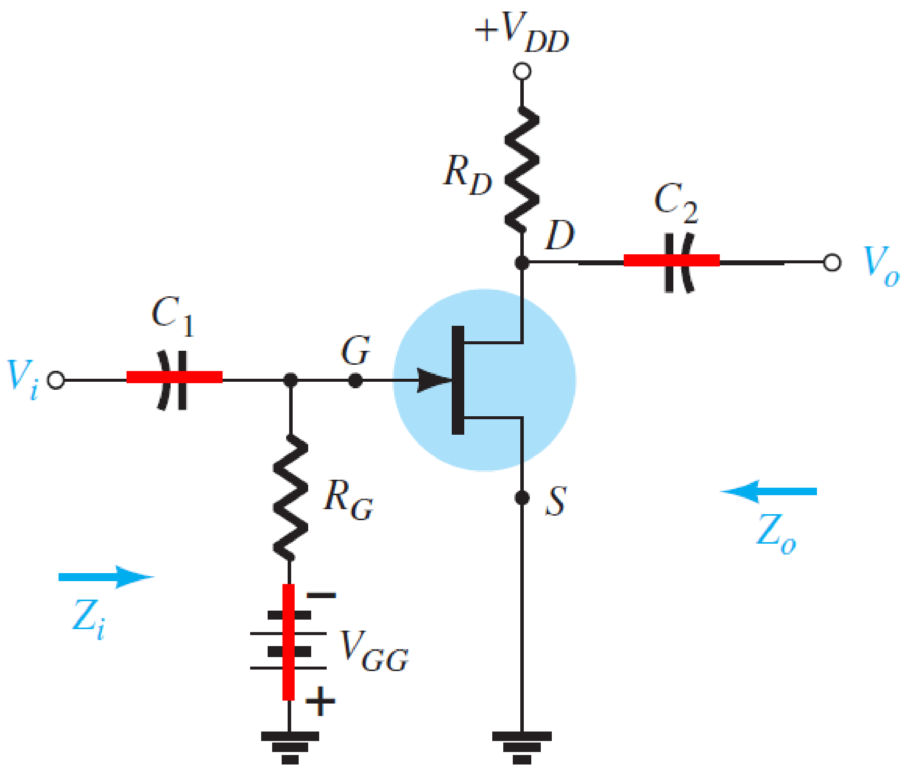
BJT has β (beta)
FET has g_m transconductance factor

JFET

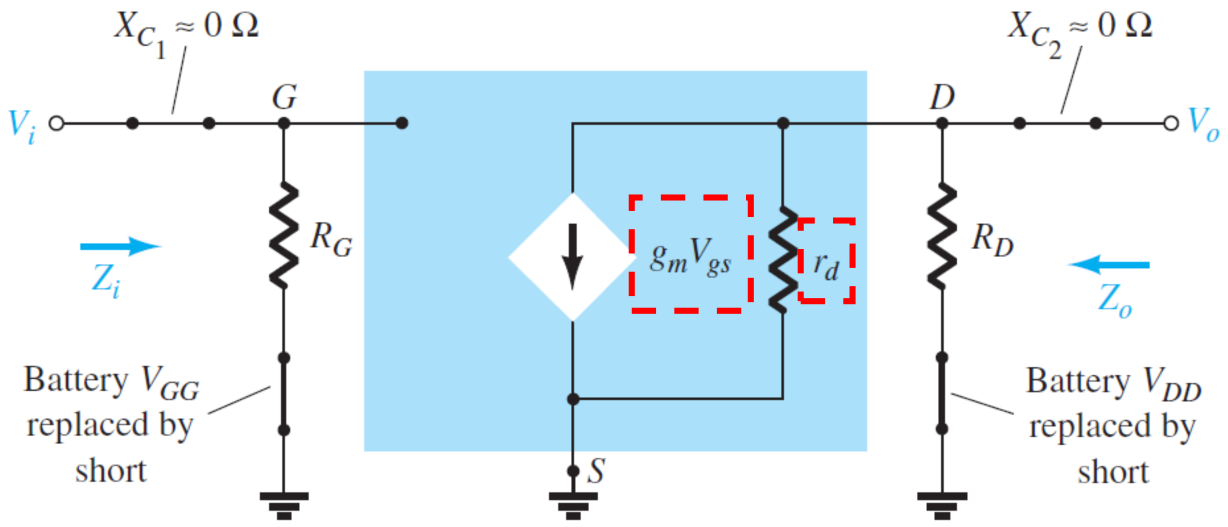


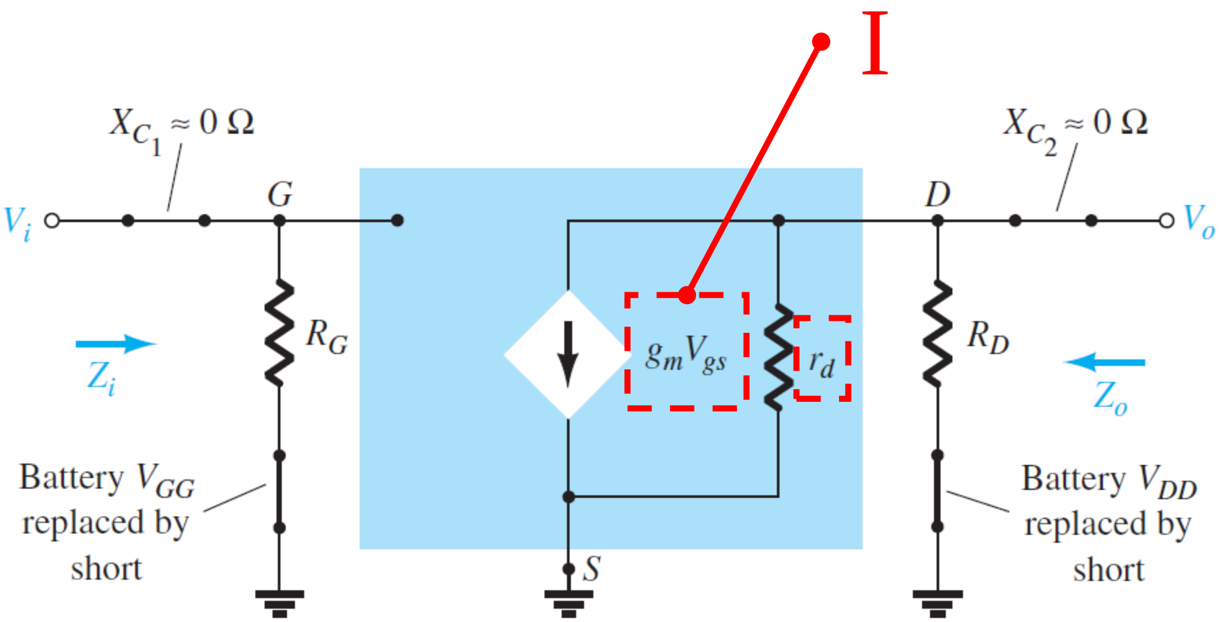
- Input AC voltage to Gate-Source
- The main current I_{DS} is controlled
- No current flow from gate
- Very high input impedance
- Current Gain = ∞

Fixed-Bias Configuration

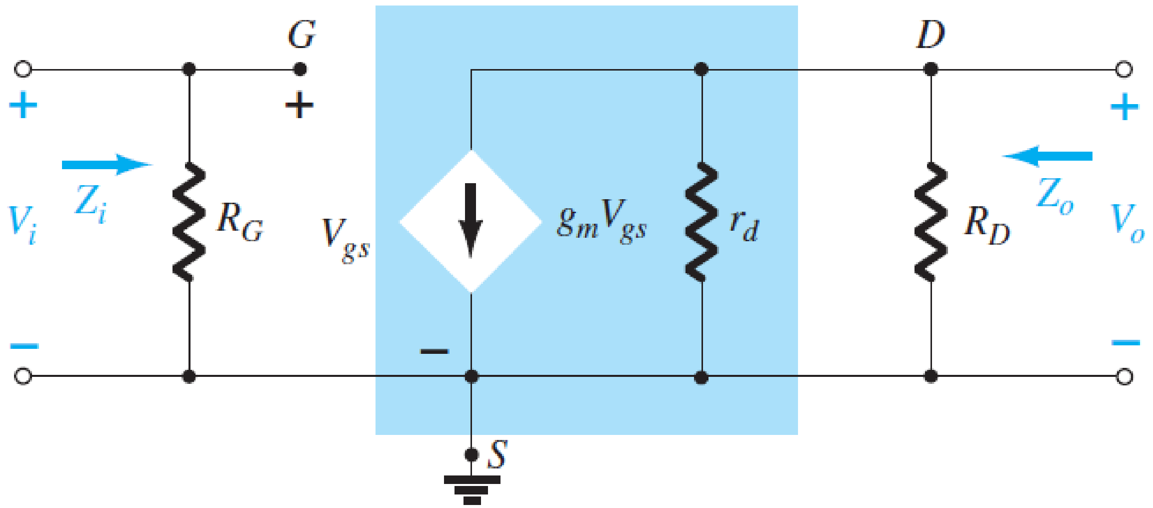


- In case of ac analysis, the ac equivalent model is used.
- Small signal analysis is necessary.
- Short source, Short C and redraw





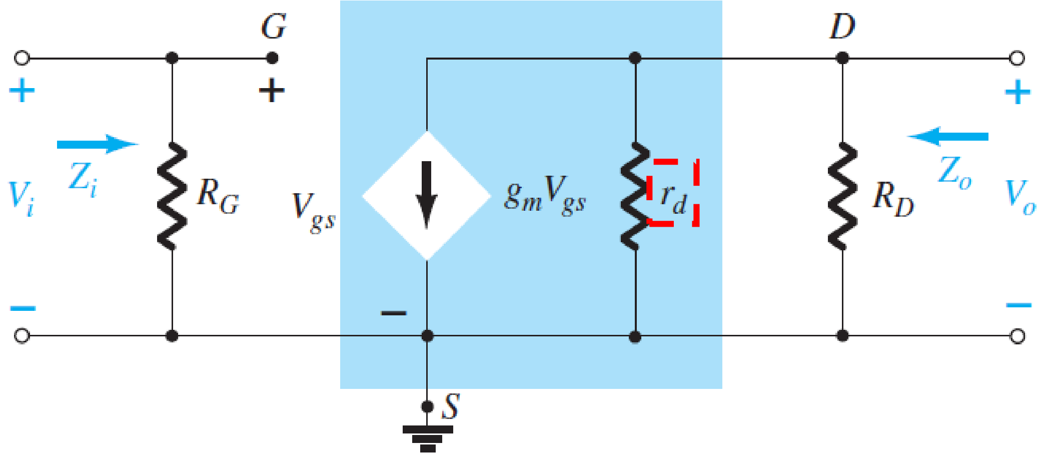
Connect ground,
obtain ac equivalent circuit



$$G = \frac{1}{R}$$

Conductance

Find Parameters



$$\boxed{Z_i = R_G}$$

$$\boxed{Z_o = R_D \| r_d}$$

See next slide

$$\boxed{Z_o \cong R_D}$$

$r_d \geq 10R_D$

Good switch

r_d High or Low ??

Find gain A_v

V_i

$$V_o = -g_m V_{gs} (r_d \| R_D)$$

$$= -g_m V_i (r_d \| R_D)$$

Minus sign means inverse phase i/p and o/p

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

$$\boxed{A_v = \frac{V_o}{V_i} = -g_m R_D}$$

$r_d \geq 10R_D$

Z_o

- Short input source $V_i = 0$ V

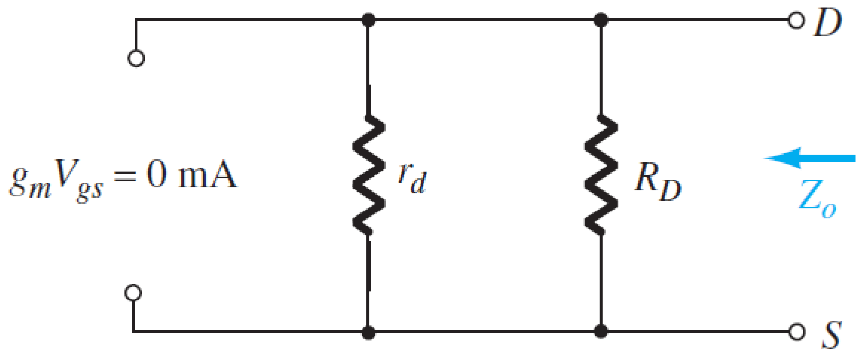
$$V_{gs} = 0 \text{ V}$$

$$g_m V_{gs} = 0 \text{ mA}$$

means

Current Source = $g_m V_{gs}$ open circuit, no current flow

Finally we obtain the equivalent circuit



Small Signal Analysis

Shockley's equation (From Ch.6)

Show ac input G to S can control current level on D to S

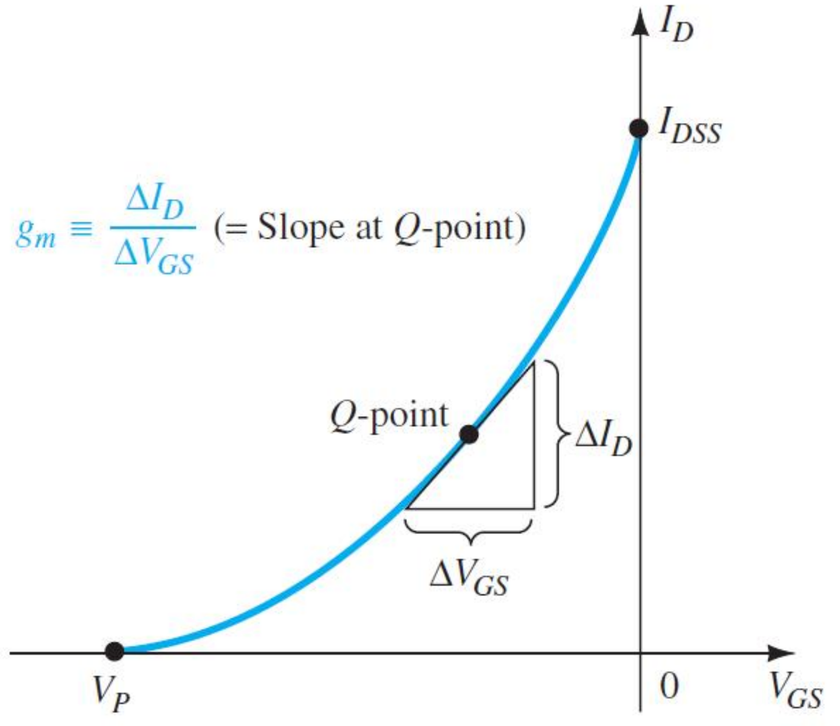
control variable

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

constants

transconductance factor g_m

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



Transfer Characteristic Curve

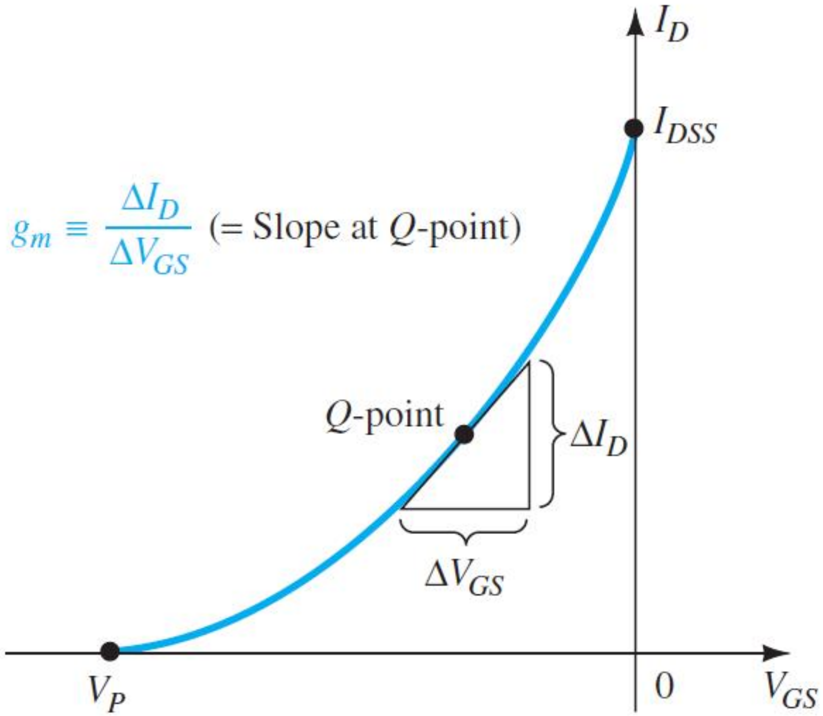
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Drain current changing

Current to Voltage ratio

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

Mathematical Definition of g_m



Transfer Characteristic Curve

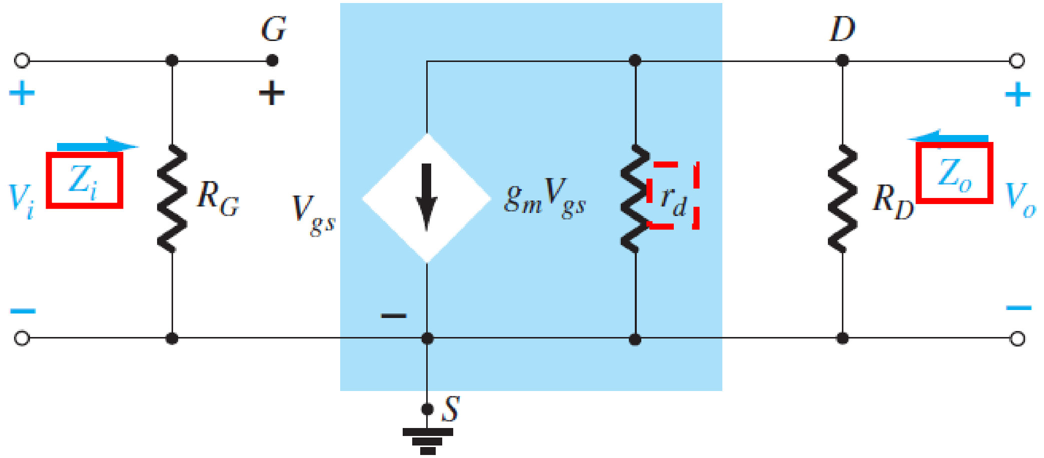
$$g_m = \left.\frac{dI_D}{dV_{GS}}\right|_{Q\text{-pt.}} = \frac{d}{dV_{GS}}\left[I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2\right]$$

$$= I_{DSS}\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$= 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\left[\frac{d}{dV_{GS}}(1) - \frac{1}{V_P}\frac{dV_{GS}}{dV_{GS}}\right] = 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\left[0 - \frac{1}{V_P}\right]$$

$$\boxed{g_m = \overbrace{\frac{2I_{DSS}}{|V_P|}}^{g_{m0}}\left[1 - \frac{V_{GS}}{V_P}\right]} \Rightarrow \boxed{g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]}$$

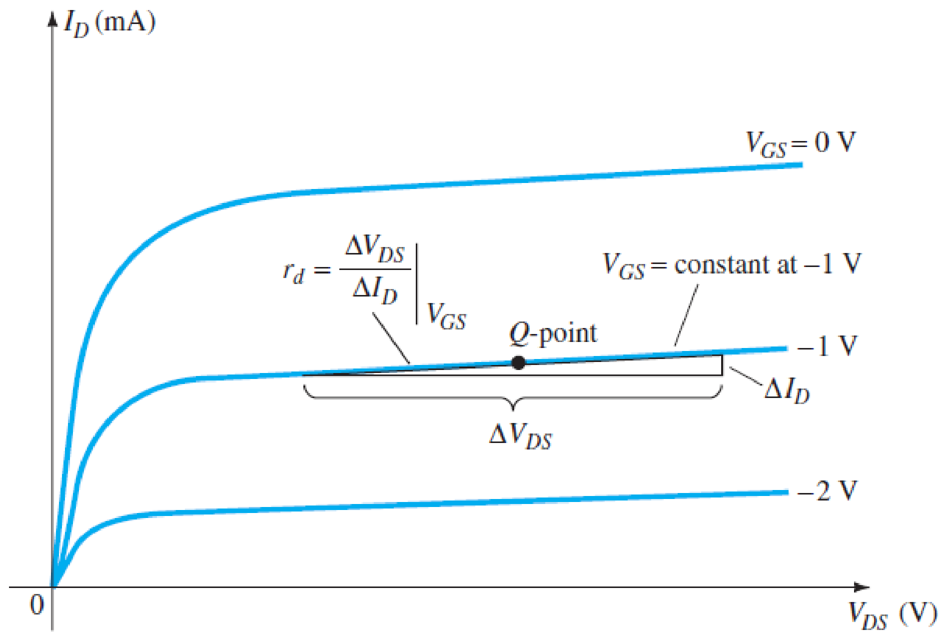
Z_i, Z_o, r_d



$$Z_i\,(\text{JFET}) = \infty\,\Omega$$

$$Z_o\,(\text{JFET}) = r_d = \frac{1}{g_{os}} = \frac{1}{y_{os}}$$

admittance



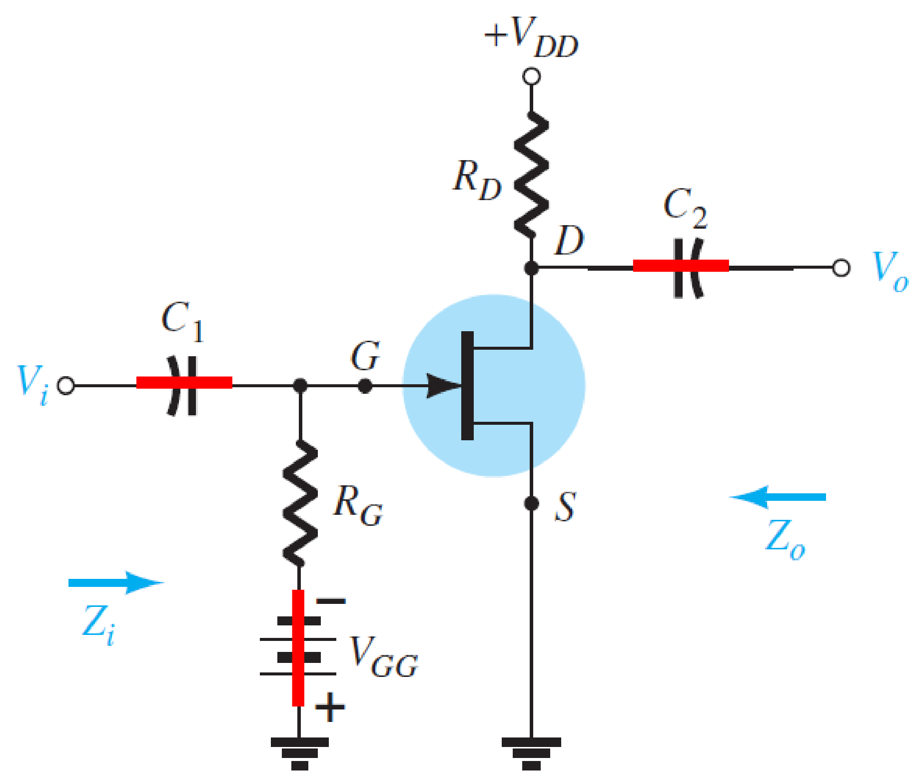
Definition of r_d using JFET drain characteristics

$$r_d = \frac{\text{นอน}}{\text{ดิ่ง}}$$

Large r_d → Slope??

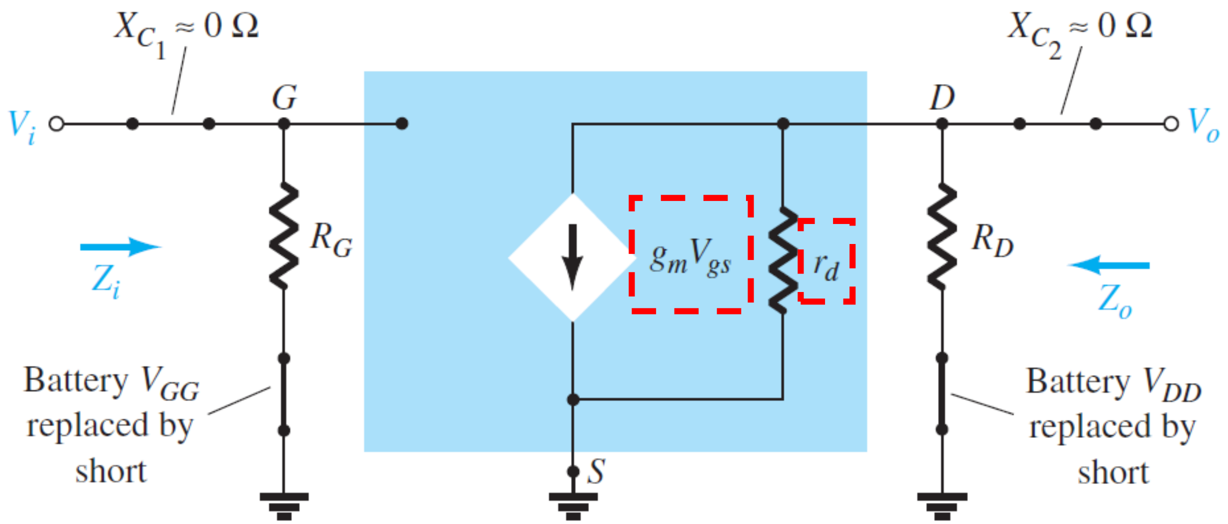
Small r_d → Slope??

Fixed-Bias Configuration



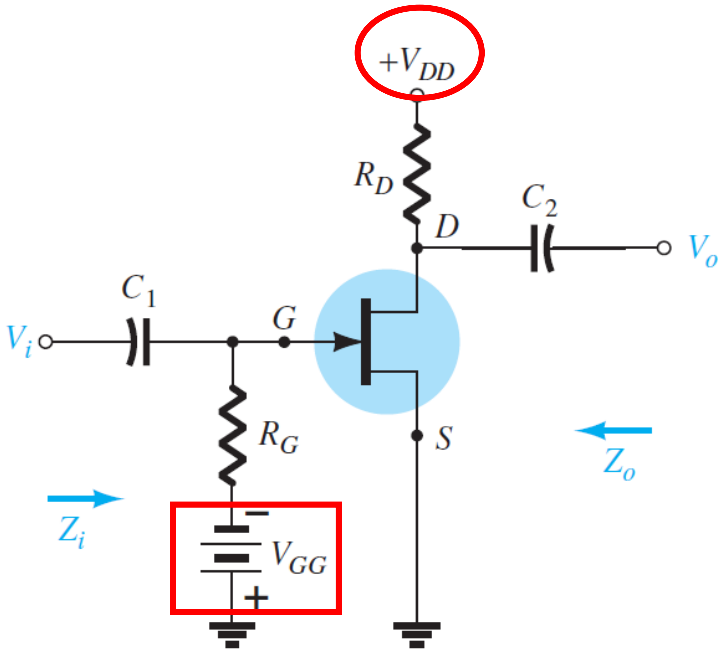
$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]$$

$$Z_o\,(\text{JFET}) = r_d = \frac{1}{g_{os}} = \frac{1}{y_{os}}$$

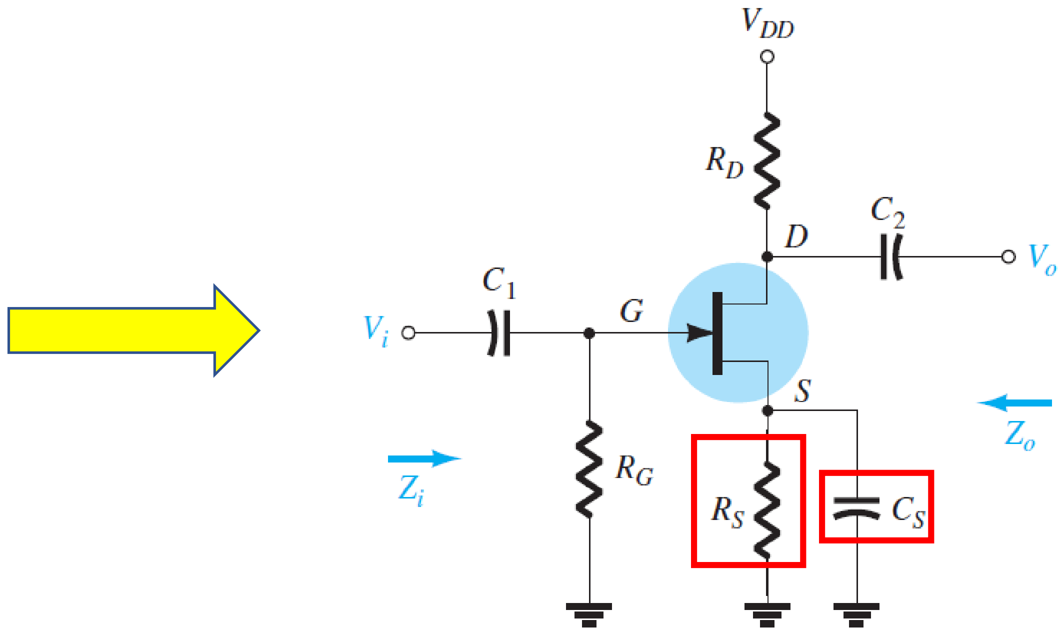


See Example 8.7

Self-Bias Configuration (bypass R_s)



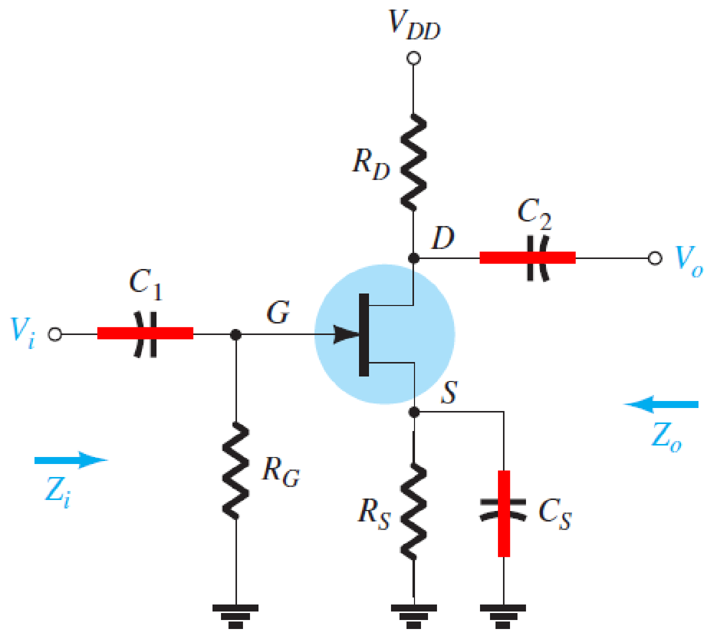
Fixed-Bias Configuration

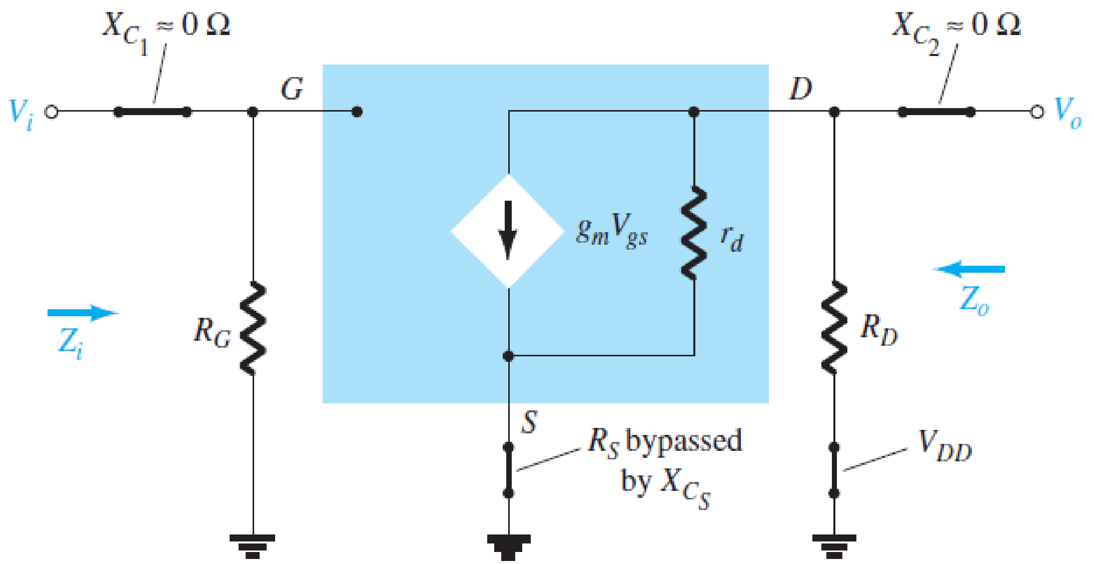


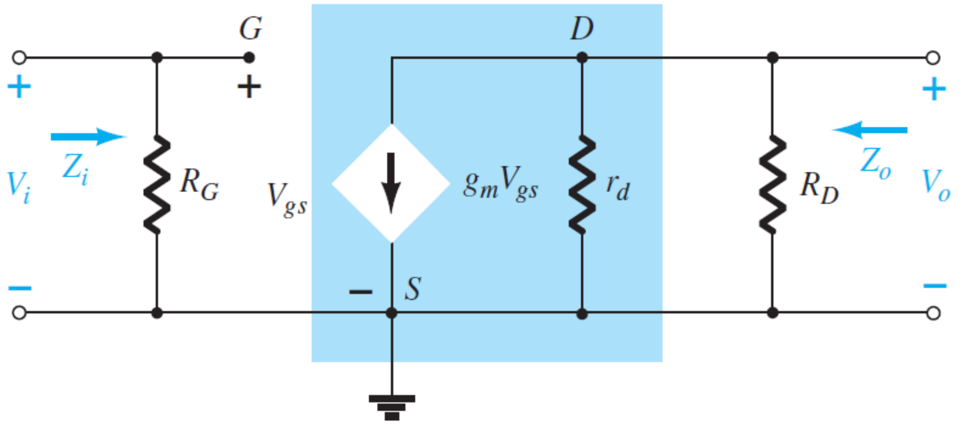
Self-Bias Configuration

Demerit: 2 voltage sources

AC Equivalent Circuit







$$Z_i = R_G$$

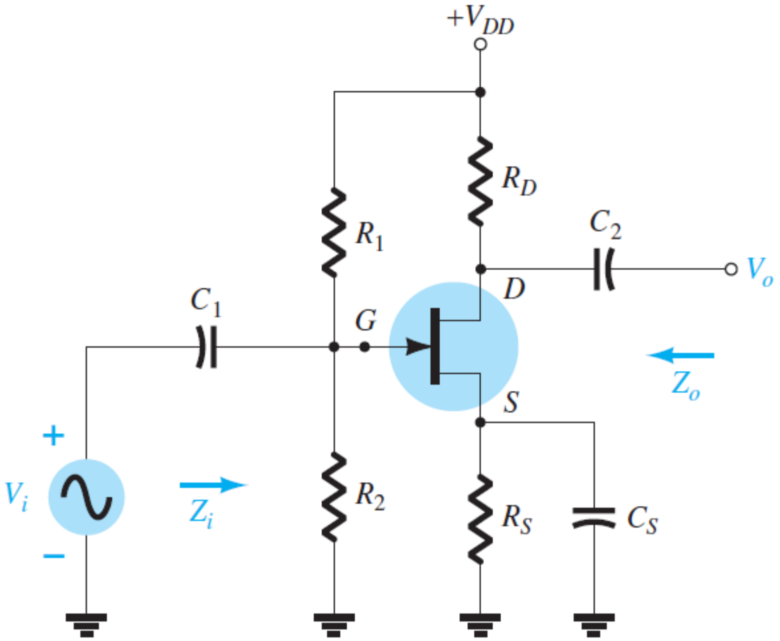
$$Z_o = r_d \| R_D$$

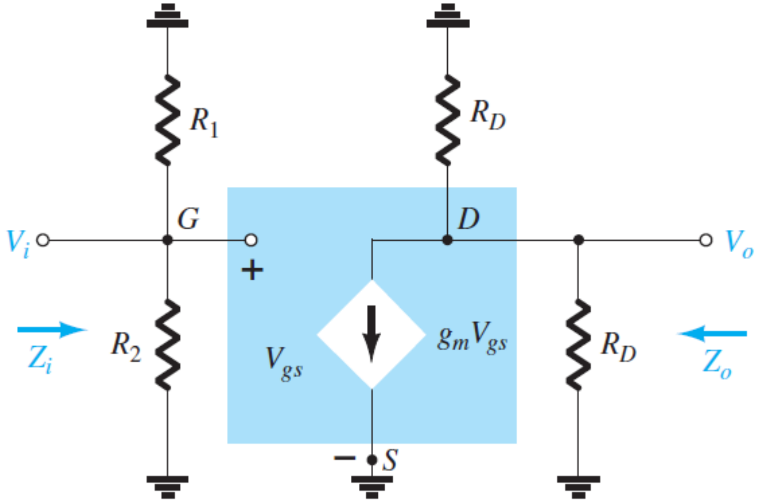
$$Z_o \cong R_D$$

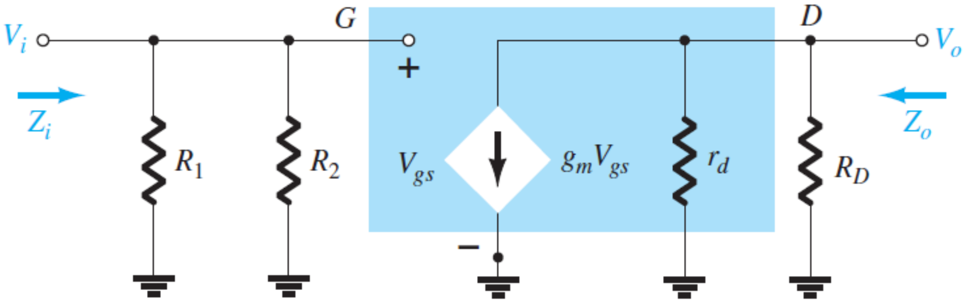
$$A_v = -g_m(r_d \| R_D)$$

$$A_v = -g_m R_D$$

VOLTAGE-DIVIDER CONFIGURATION







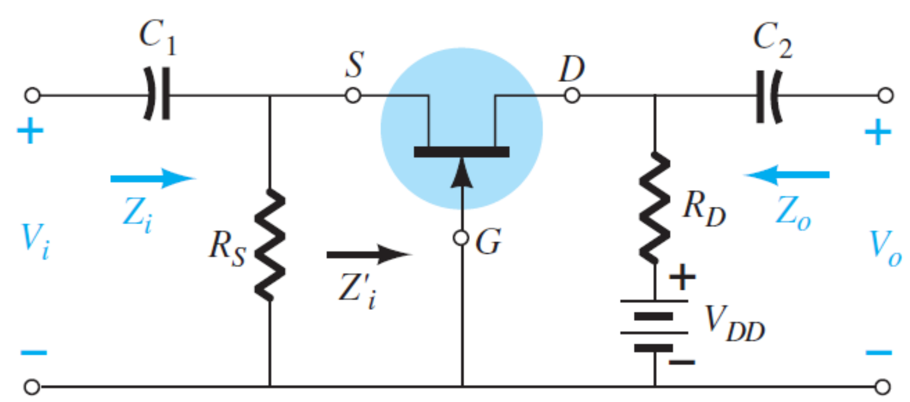
$$\boxed{Z_i = R_1 \| R_2}$$

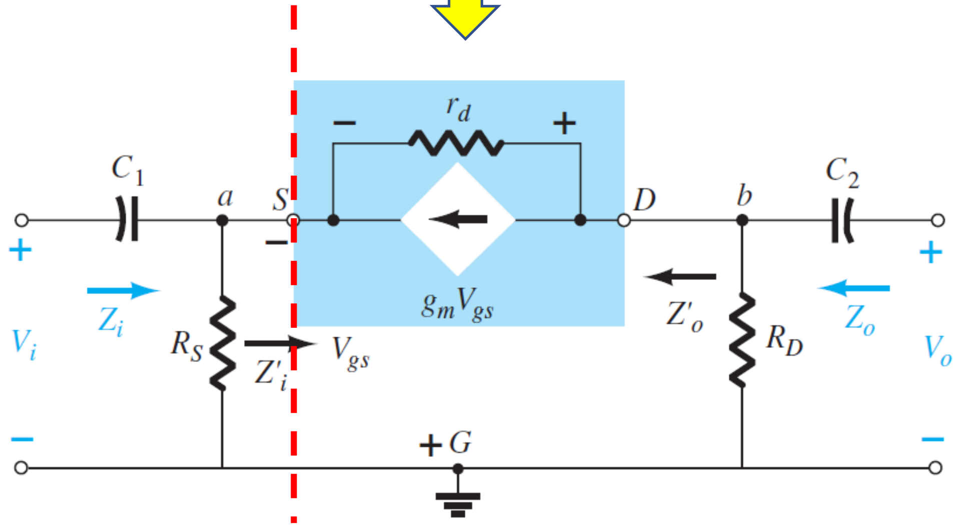
$$\boxed{Z_o \cong R_D} \quad r_d \geq 10R_D$$

$$\boxed{Z_o = r_d \| R_D}$$

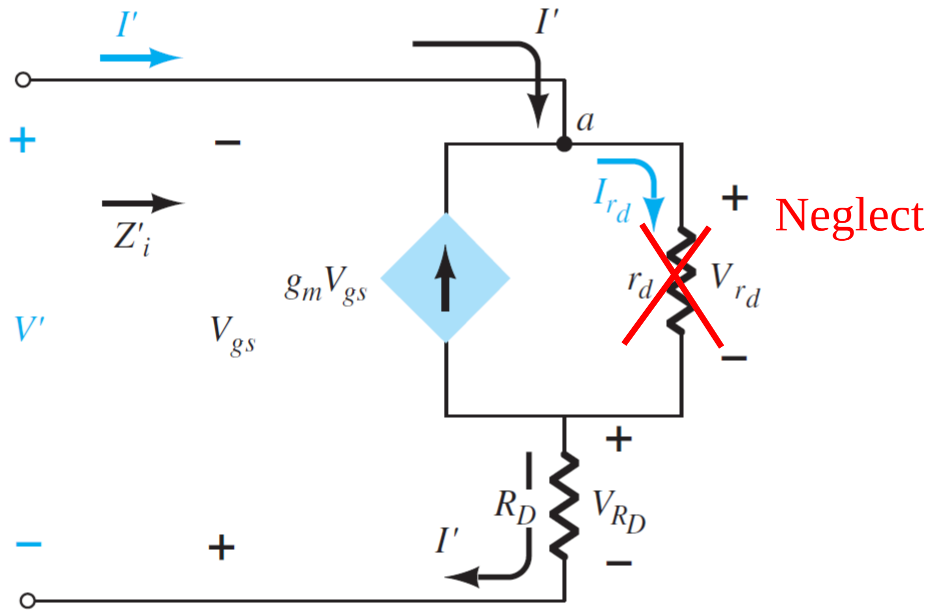
$$\boxed{A_v = \frac{V_o}{V_i} = -g_m(r_d \| R_D)}$$

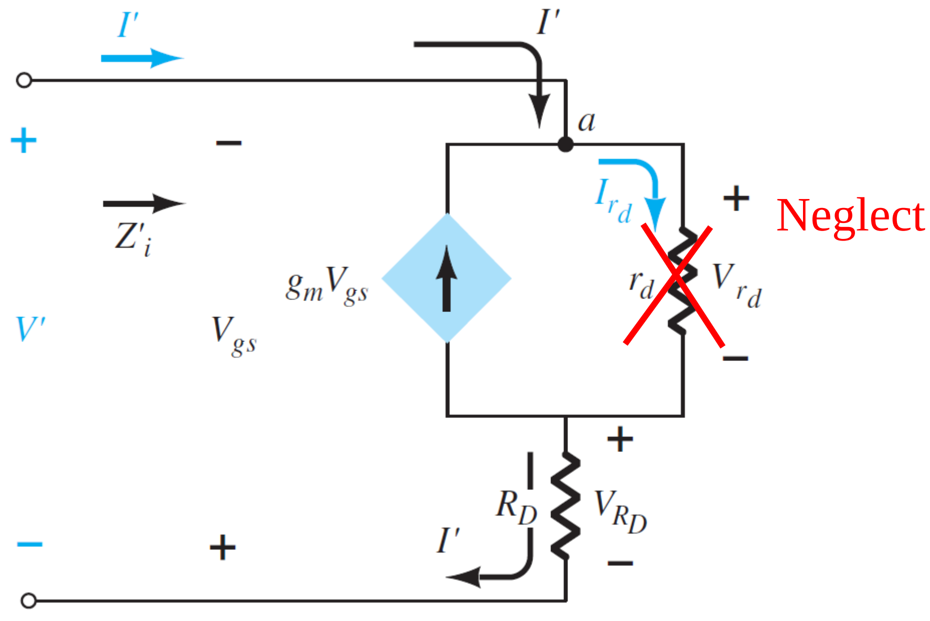
COMMON-GATE CONFIGURATION (COMMON-GROUND)





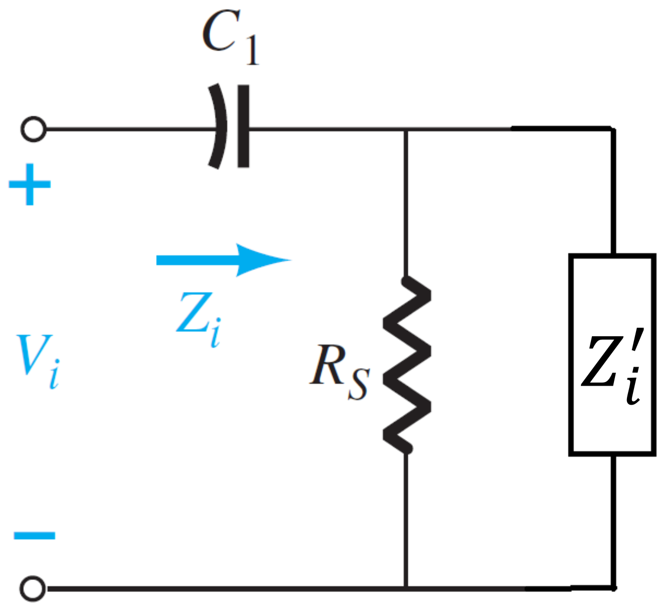
- The controlled source $g_m V_{gs}$ be connected from drain to source
- No isolation between input and output





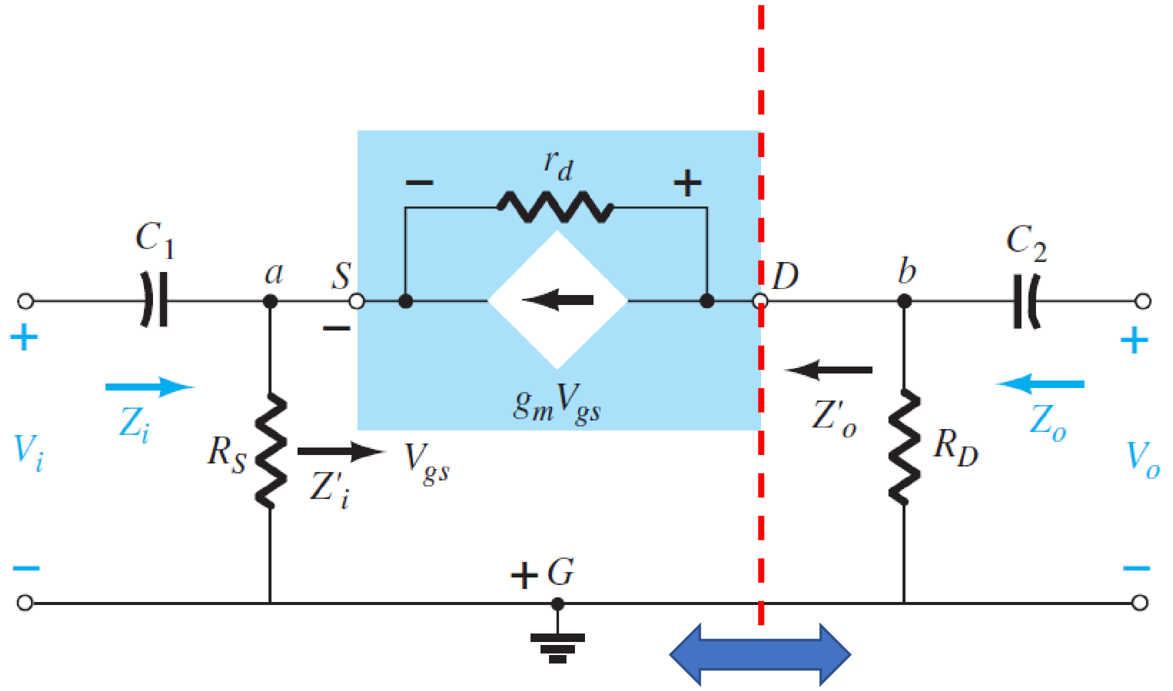
$$Z'_i = \frac{V'}{I'} = \frac{V_{RD}}{g_m V_{gs}} \quad ; V_{RD} = V_{gs}$$

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



$$\boxed{Z_i \cong R_S \| 1/g_m}$$

Find Z_o , A_v



Give $V_i = 0$ ⟹ $V_{gs} = 0$

No current flow

$$\boxed{Z_o = R_D}$$

A_v : Consider Node b

$$I_D + g_m V_{gs} = 0$$

$$I_D = -g_m V_{gs}$$

$$= g_m V_i$$

$-V_i$

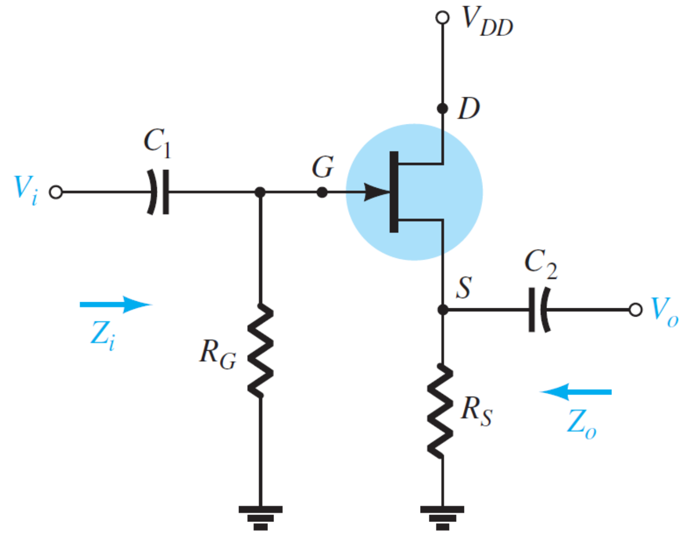
$$V_o = I_D R_D$$

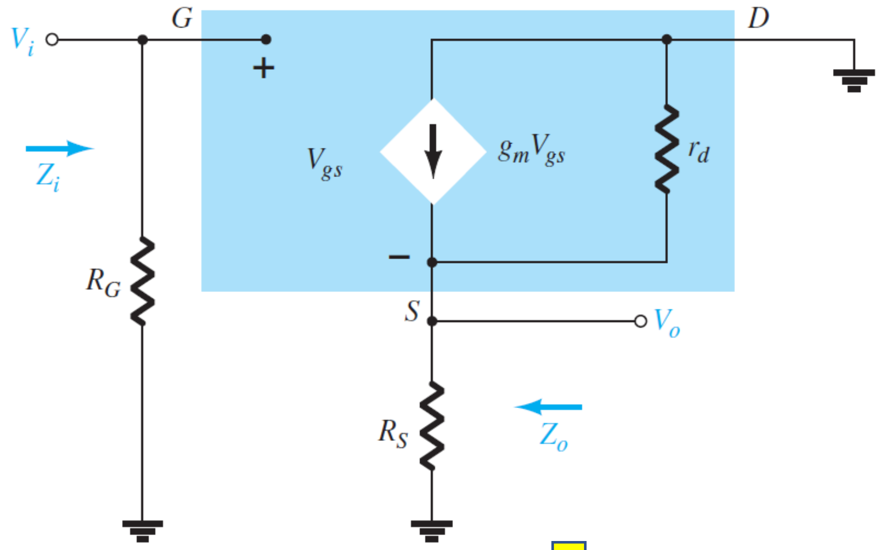
$$= g_m V_i R_D$$

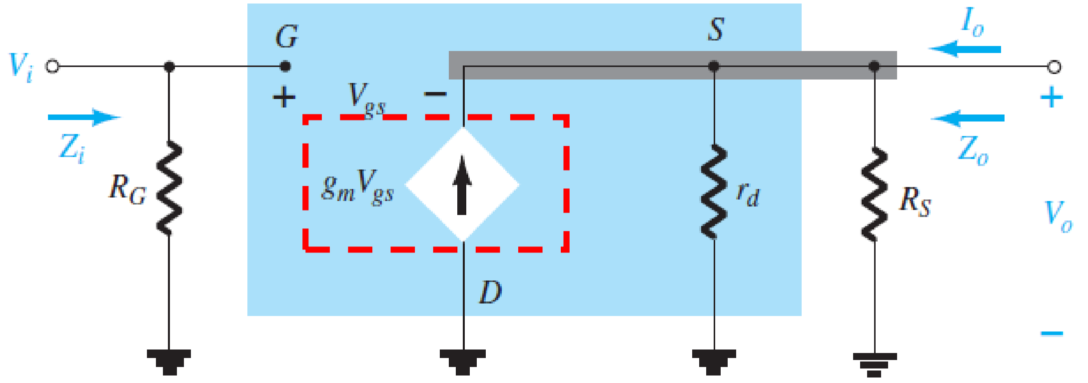
A_v $$\boxed{\frac{V_o}{V_i} = g_m R_D}$$

✚ means in-phase

SOURCE-FOLLOWER (COMMON-DRAIN) CONFIGURATION

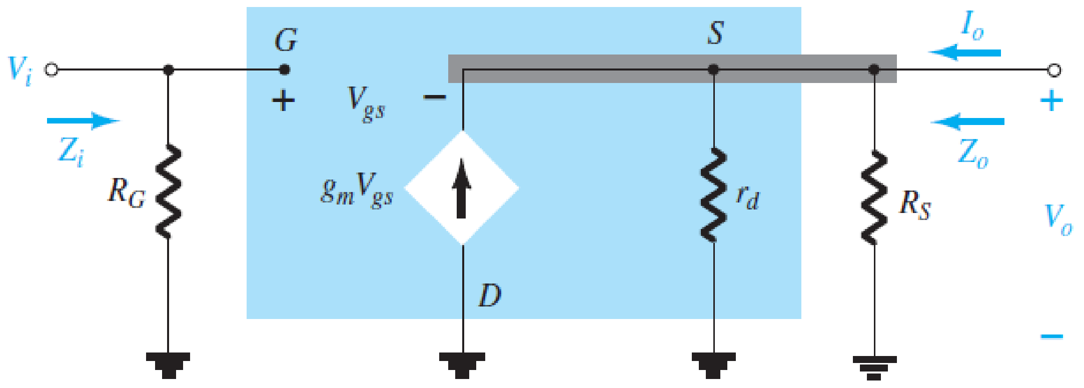


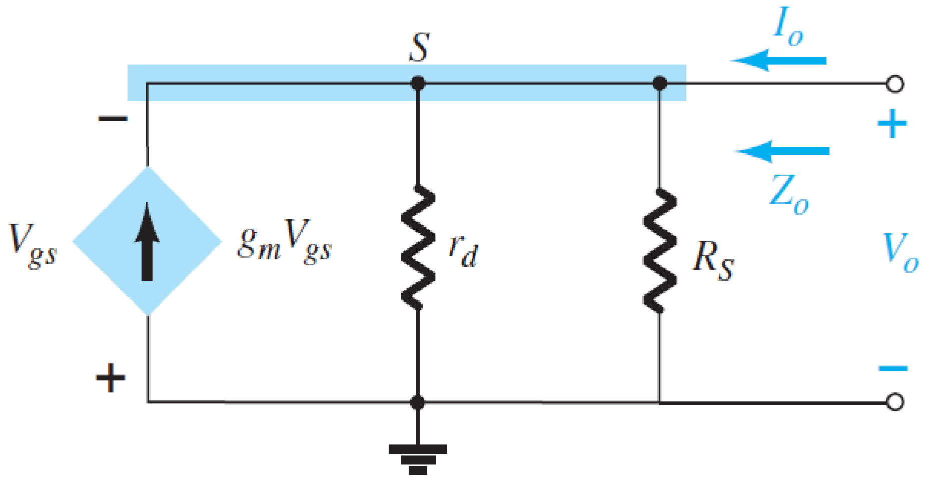




- BJT emitter-follow configuration
- V_o out from source (normally from drain)
- Short VDD to ground → Drain to ground

Find Z_i, Z_o, A_v



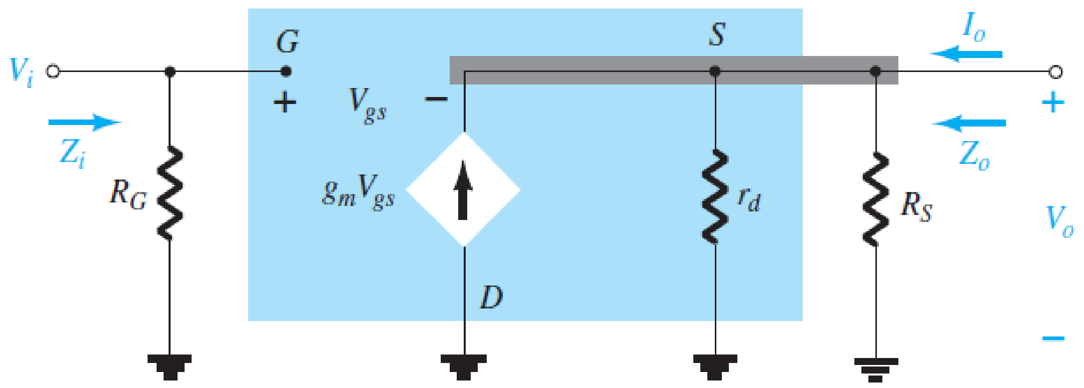


$$\boxed{Z_i = R_G}$$

$$Z_o = \frac{V_o}{I_o} = \frac{V_o}{V_o\left[\frac{1}{r_d} + \frac{1}{R_S} + g_m\right]} = \frac{1}{\frac{1}{r_d} + \frac{1}{R_S} + g_m} = \frac{1}{\frac{1}{r_d} + \frac{1}{R_S} + \frac{1}{1/g_m}}$$

$$V_o = -V_{gs}$$

$$\boxed{Z_o = r_d \| R_S \| 1/g_m}$$



$$V_o = g_m\boxed{V_{gs}}(r_d \| R_S)$$

Consider outer loop

$$V_i = V_{gs} + V_o$$

$$V_{gs} = \boxed{V_i - V_o}$$

$$V_o = g_m(V_i - V_o)(r_d \| R_S)$$

$$= g_mV_i(r_d \| R_S) - g_mV_o(r_d \| R_S)$$

$$V_o[1 + g_m(r_d \| R_S)] = g_mV_i(r_d \| R_S)$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)}}$$

Gain always < 1