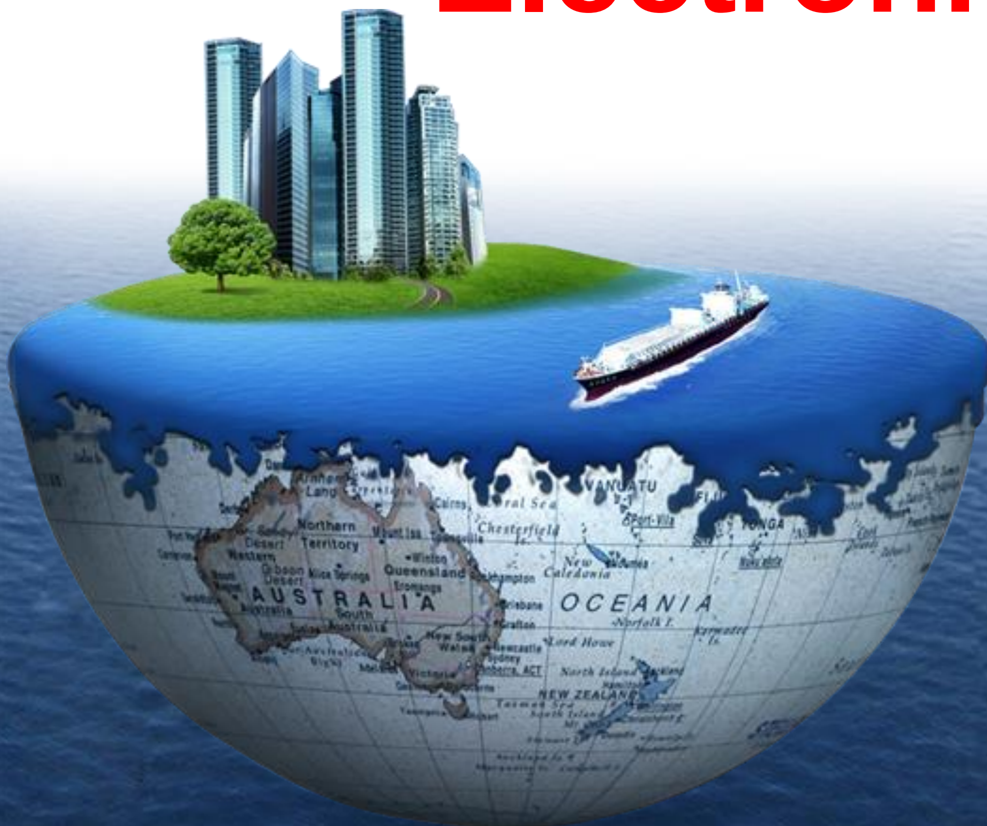
Electronic Engineering
COM 121



Assist. Prof.
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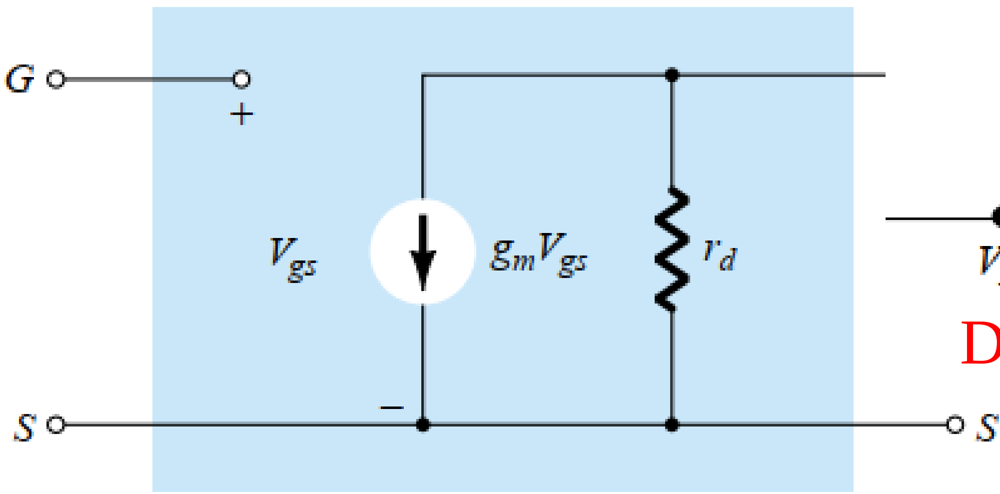
Introduction

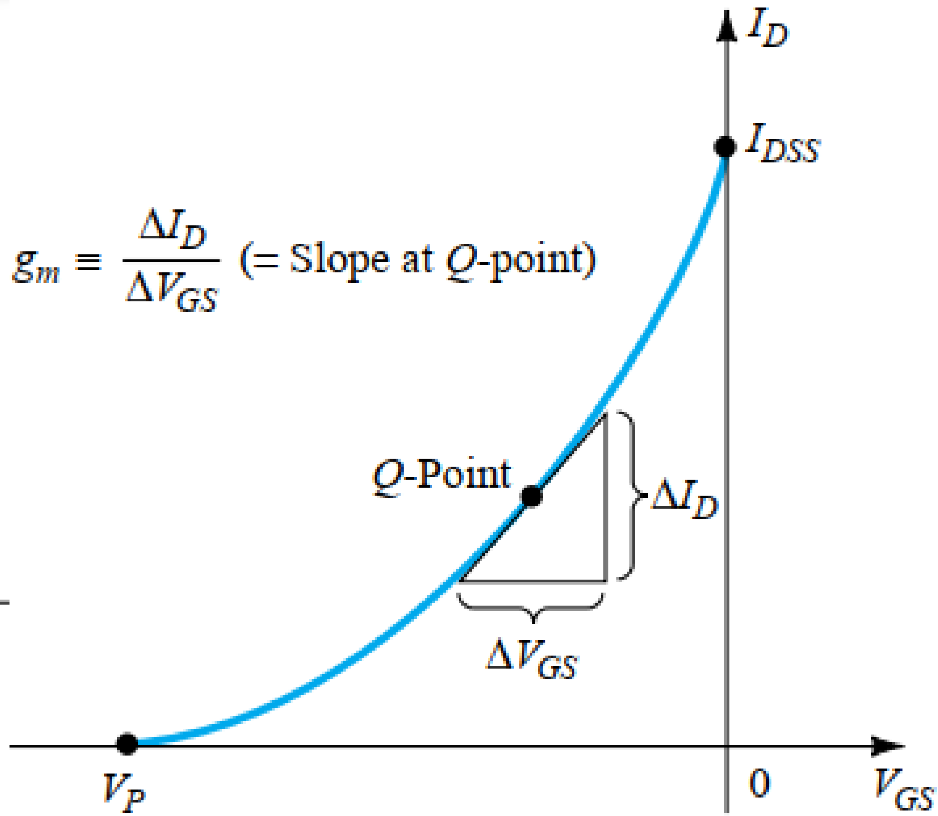
- The BJT transistor is a bipolar device, the prefix (bi) revealing that the conduction level is a function of two charge carriers, electrons and holes.
- The FET is a unipolar device depending solely on either electron (n-channel) or hole (p-channel) conduction.
- There are two types of FETs transistors. JFET and MOSFET.
- .MOSFET type can be broken down into depletion MOSFET and Enhancement MOSFET.
- The gate-to-source voltage controls the drain-to-source (channel) current of an FET. $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$.

Introduction

$$g_m = m = \frac{\Delta y}{\Delta x} = \frac{\Delta I_D}{\Delta V_{GS}}$$

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



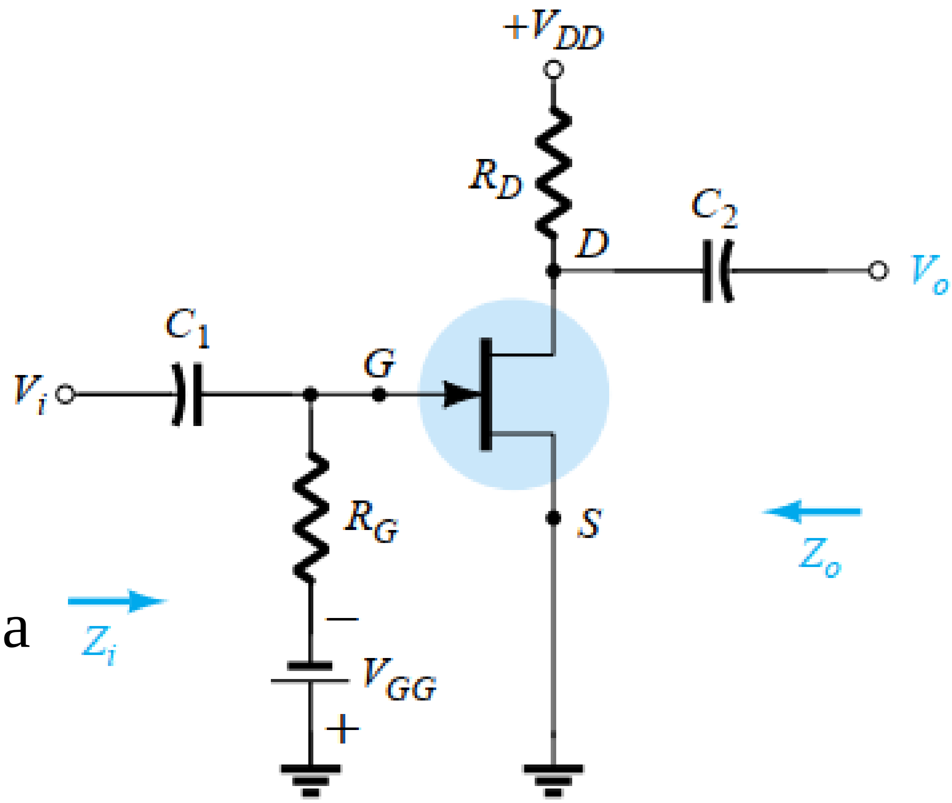


Definition of gm using transfer characteristic.

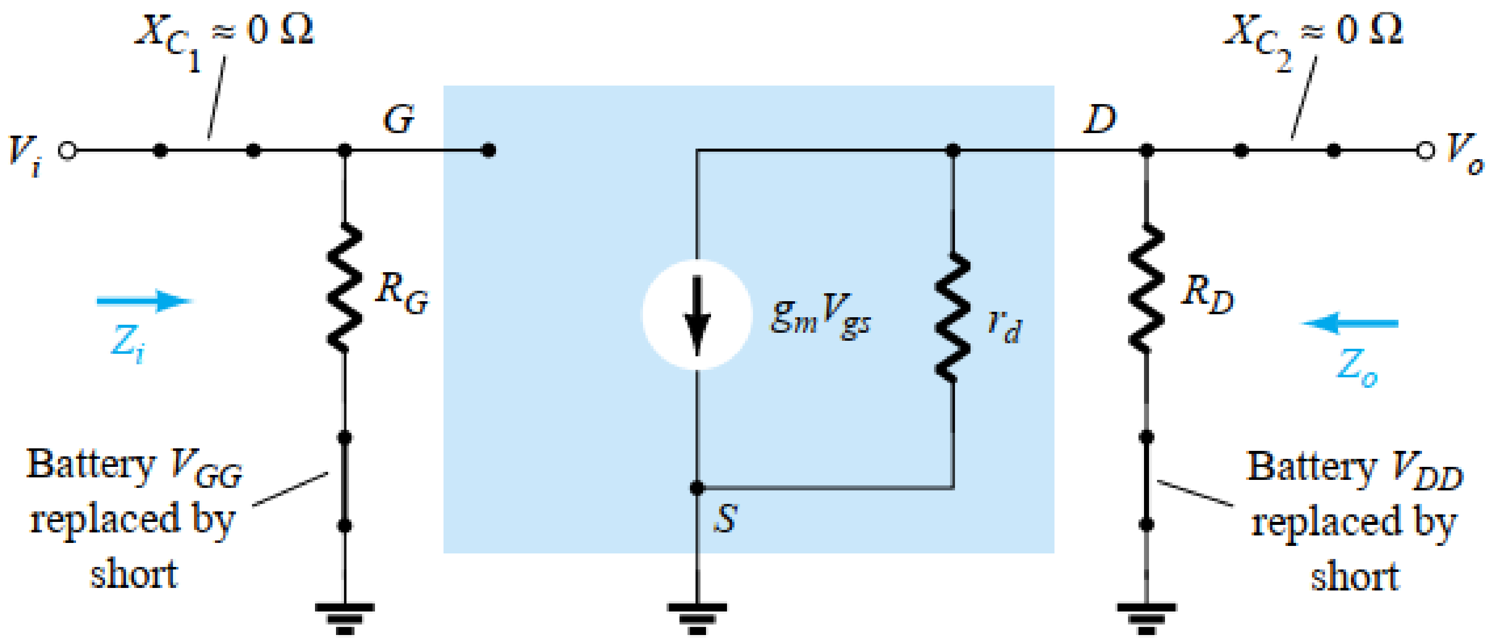
FET ac equivalent circuit

JFET Fixed-bias Configuration

- In AC analysis both capacitors have the short-circuit equivalent
- $X_c = \dfrac{1}{2\pi f C}$
- The dc batteries V_{GG} and V_{DD} are set to zero volts by a short-circuit equivalent.



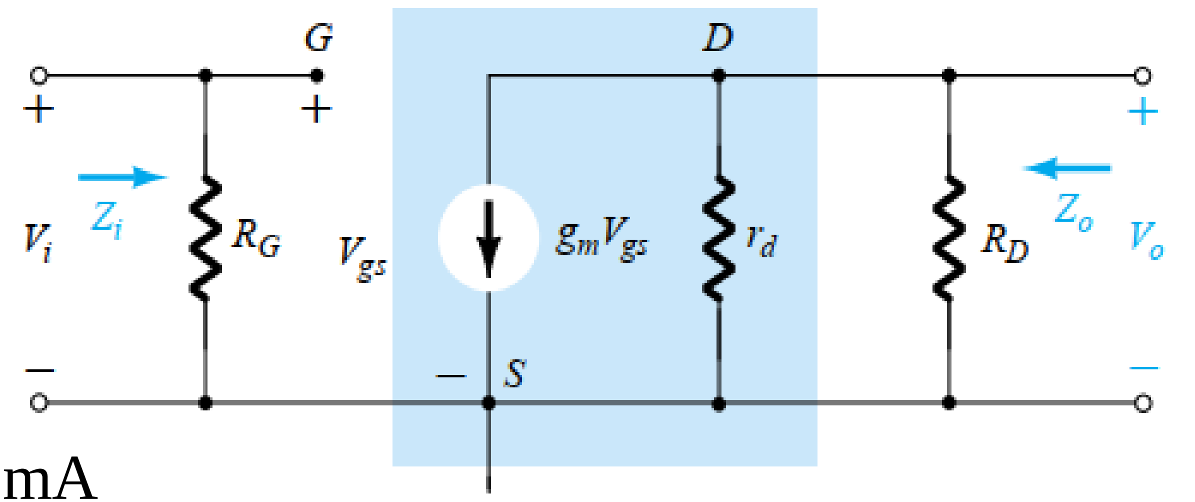
JFET Fixed-bias Configuration



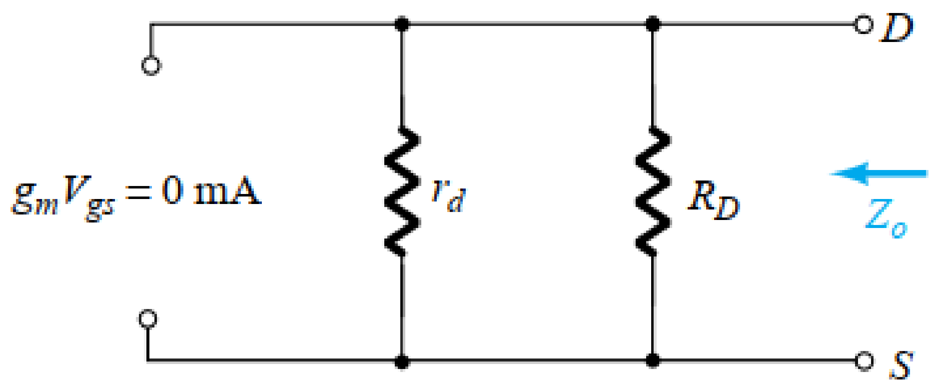
JFET AC équivalent fixed-bias configuration circuit

JFET Fixed-bias Configuration

$$\boxed{Z_i = R_G}$$



- To get Z_o set $V_i = 0\ v$
- $so\ V_{gs}$ as $0v$ also.
- The result is $g_mV_{gs} = 0$ mA



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

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

$r_d \geq 10R_D$

JFET Fixed-bias Configuration

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

$$V_{gs} = V_i$$

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

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

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

Phase Relationship: The negative sign in the resulting equation for A_v clearly reveals a phase shift of 180° between input and output voltages.

Example

For fixed-bias configuration in the figure had an operating point defined by $V_{GSQ} = 2v$ and $I_{DQ} = 5.625\ mA$, with $I_{DSS} = 10\ mA$ and $V_P = 8\ V$. The value of y_{os} is provided as $40\ S$.

(a) Determine g_m.

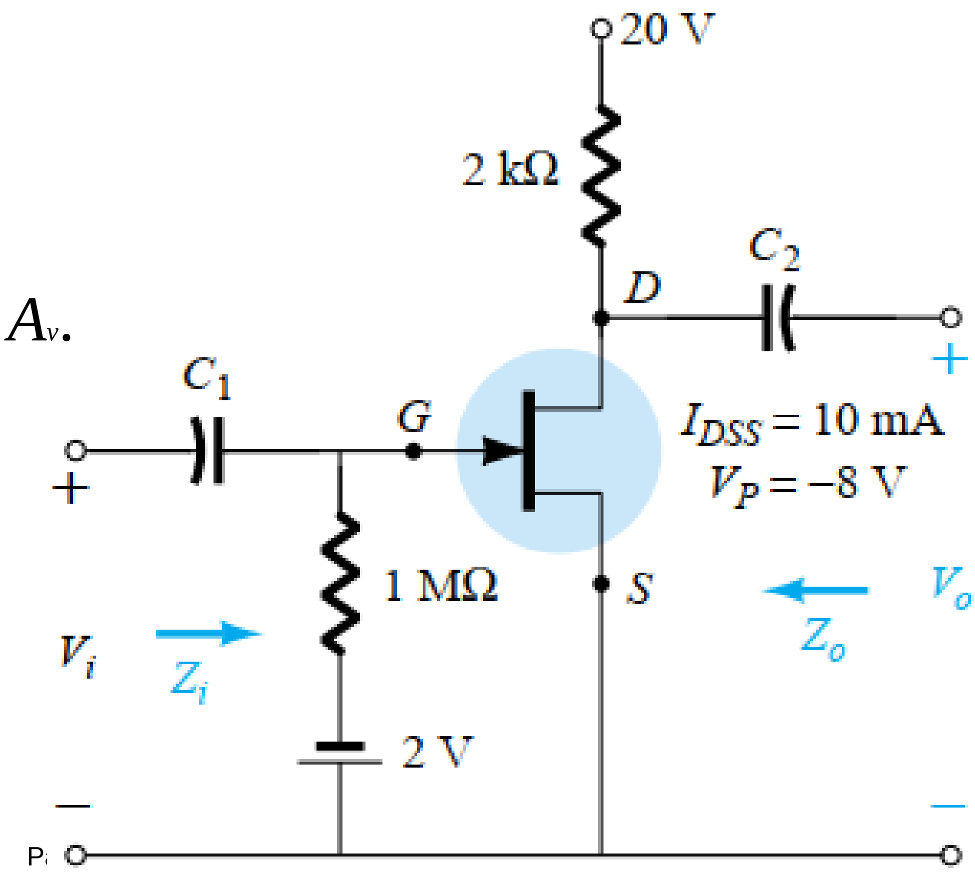
(b) Find r_d.

(c) Determine Z_i.

(d) Calculate Z_o.

(e) Determine the voltage gain A_v.

(f) Determine A_v ignoring the effects of r_d



Example

(a) $g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10 \text{ mA})}{8 \text{ V}} = 2.5 \text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2.5 \text{ mS}\left(1 - \frac{(-2 \text{ V})}{(-8 \text{ V})}\right) = \mathbf{1.88 \text{ mS}}$$

(b) $r_d = \frac{1}{y_{os}} = \frac{1}{40 \ \mu\text{S}} = \mathbf{25 \text{ k}\Omega}$

(c) $Z_i = R_G = \mathbf{1 \text{ M}\Omega}$

(d) $Z_o = R_D \| r_d = 2 \text{ k}\Omega \| 25 \text{ k}\Omega = \mathbf{1.85 \text{ k}\Omega}$

(e) $A_v = -g_m(R_D \| r_d) = -(1.88 \text{ mS})(1.85 \text{ k}\Omega)$

$= \mathbf{-3.48}$

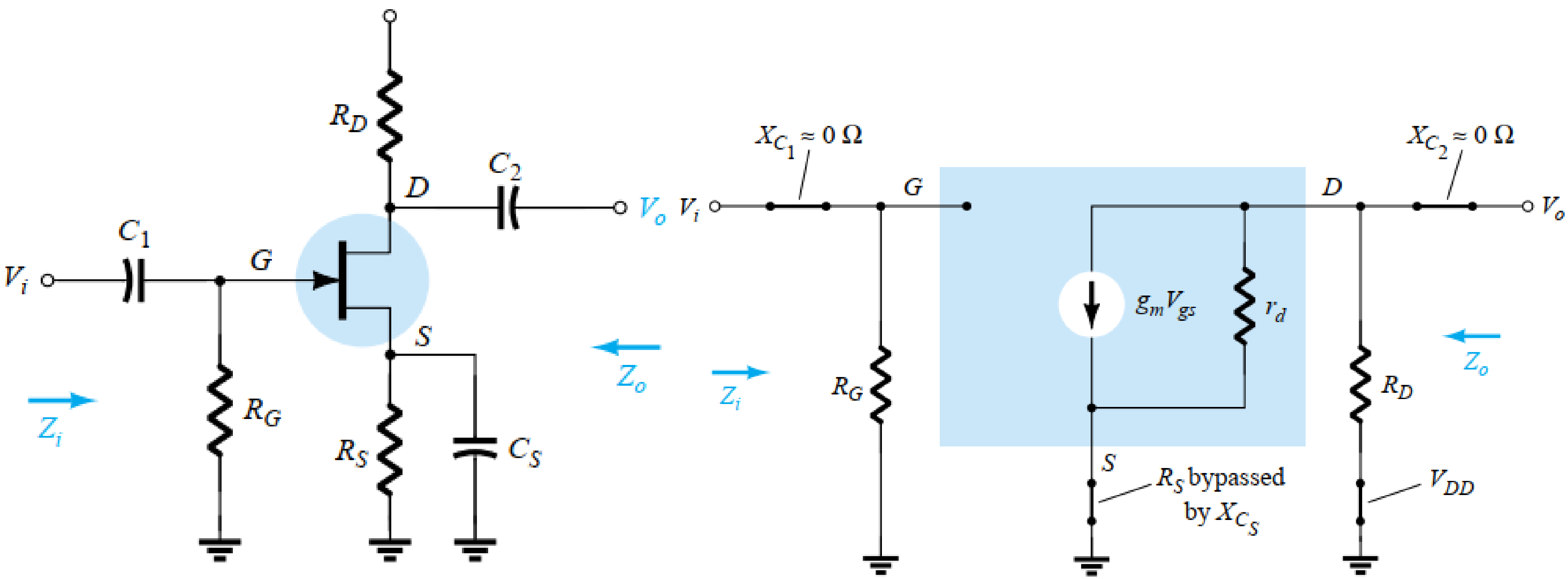
(f) $A_v = -g_m R_D = -(1.88 \text{ mS})(2 \text{ k}\Omega) = \mathbf{-3.76}$

As demonstrated in part (f), a ratio of 25 kΩ : 2 kΩ = 12.5 : 1 between r_d and R_D resulted in a difference of 8% in solution.

JFET Self-bias Configuration

Bypassed R_S

- In AC analysis both capacitors have the short-circuit equivalent



JFET Self-bias Configuration

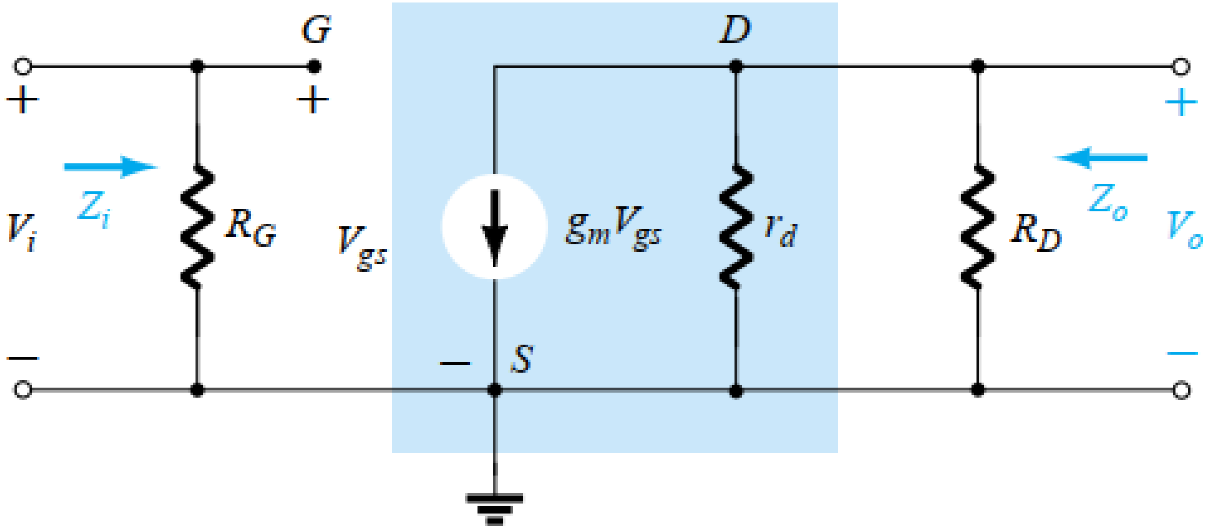
$$Z_i = R_G$$

$$Z_o = r_d \| R_D$$

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

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

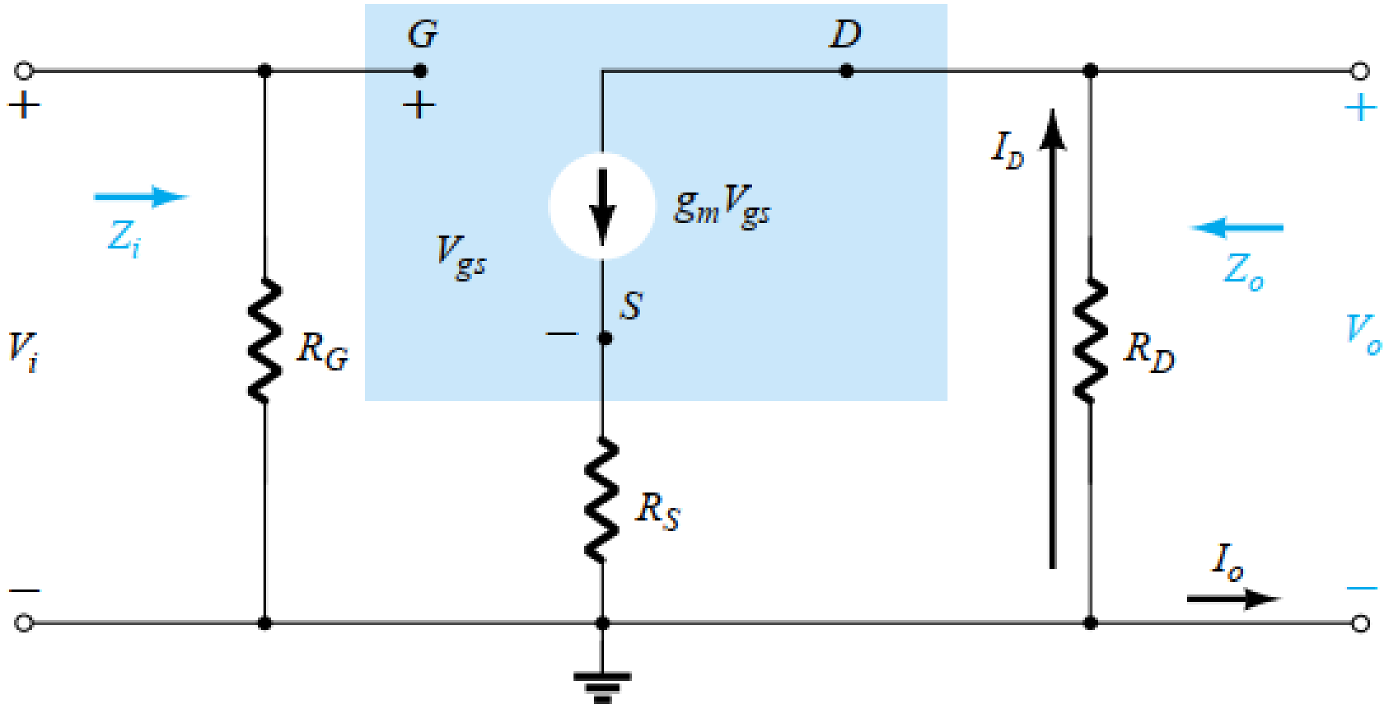
$$A_v = -g_m R_D \Big|_{r_d \geq 10 R_D}$$



JFET Self-bias Configuration

Un bypassed R_s

$$\boxed{Z_i = R_G}$$



JFET Self-bias Configuration

$$Z_o = \left.\frac{V_o}{I_o}\right|_{V_i = 0}$$

$$I_o + I_D = g_m V_{gS}$$

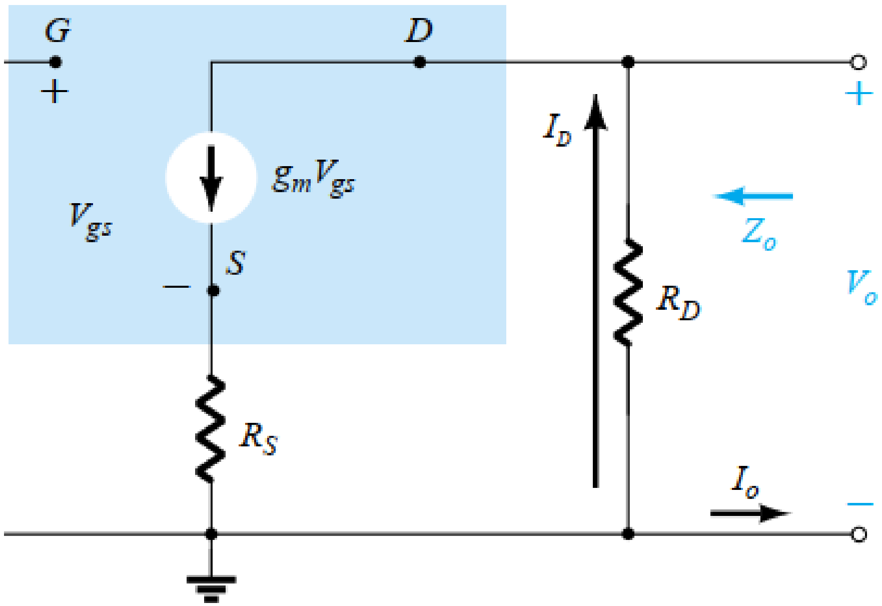
$$V_{gs} = -(I_o + I_D)R_S$$

$$I_o + I_D = -g_m (I_o + I_D)R_S = -g_m I_o R_S - g_m I_D R_S$$

$$I_o[1 + g_m R_S] = -I_D[1 + g_m R_S]$$

$$I_o = -I_D \qquad V_o = -I_D R_D$$

$$V_o = -(-I_o)R_D = I_o R_D$$



$$\boxed{Z_o = \frac{V_o}{I_o} = R_D} \quad r_d = \infty\Omega$$

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

JFET Self-bias Configuration

The self-bias configuration in the figure has an operating point defined by $V_{GSQ} = 2.6\,V$ and $I_{DQ} = 2.6\,mA$, with $I_{DSS} = 8\,mA$ and $V_P = 6\,V$. The value of y_{os} is given as 20 S.

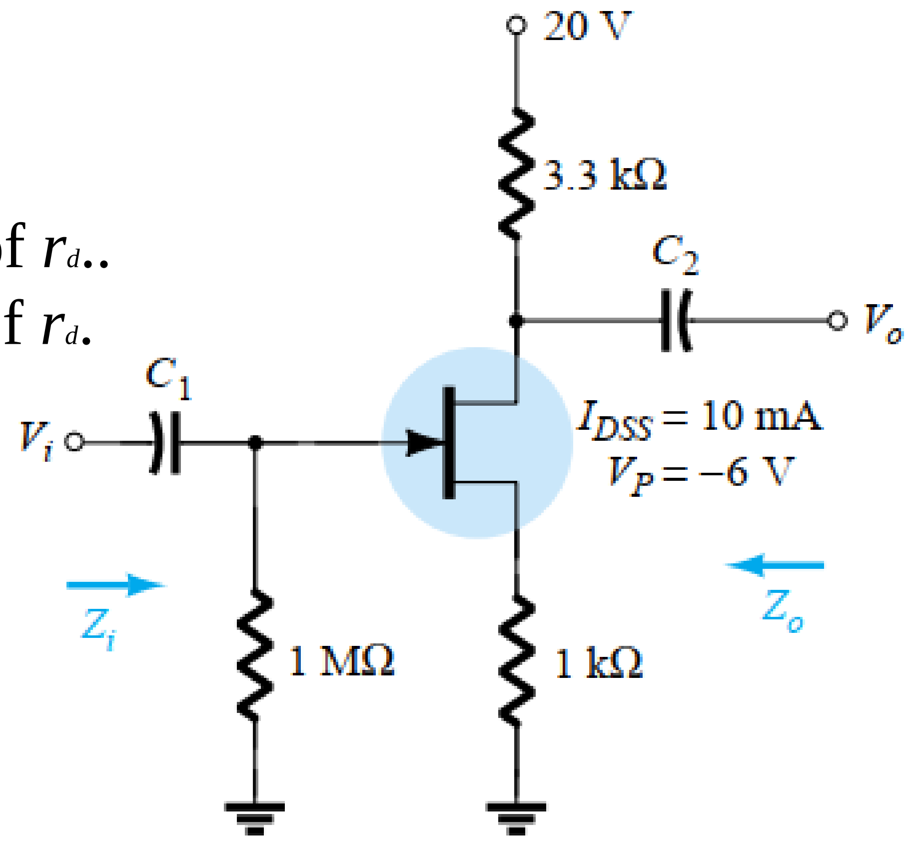
(a) Determine g_m.

(b) Find r_d.

(c) Find Z_i.

(d) Calculate Z_o without the effects of r_d..

(e) Calculate A_v without the effects of r_d.



JFET Self-bias Configuration

$$\text{(a)}\quad g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(8\text{ mA})}{6\text{ V}} = 2.67\text{ mS}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 2.67\text{ mS}\left(1 - \frac{(-2.6\text{ V})}{(-6\text{ V})}\right) = \mathbf{1.51\text{ mS}}$$

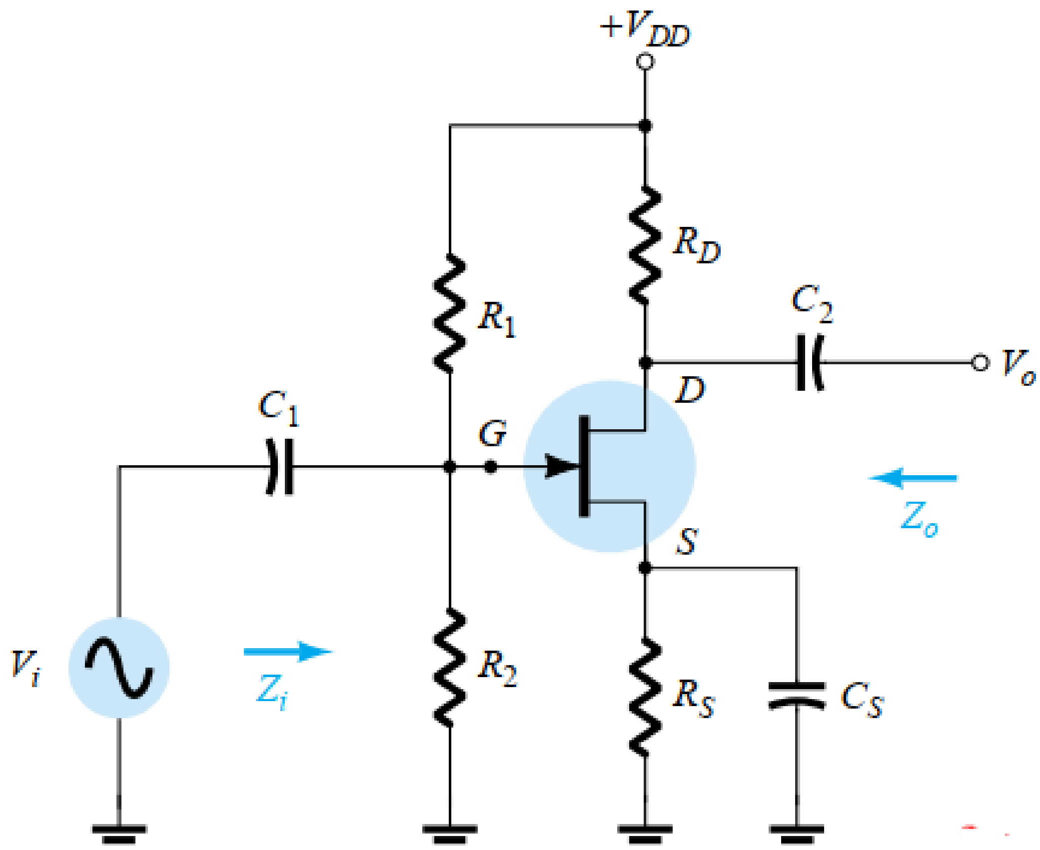
$$\text{(b)}\quad r_d = \frac{1}{y_{os}} = \frac{1}{20\ \mu\text{S}} = \mathbf{50\text{ k}\Omega}$$

$$\text{(c)}\quad Z_i = R_G = \mathbf{1\text{ M}\Omega}$$

$$Z_o = R_D = \mathbf{3.3\text{ k}\Omega}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_S} = \frac{-(1.51\text{ mS})(3.3\text{ k}\Omega)}{1 + (1.51\text{ mS})(1\text{ k}\Omega)} = \mathbf{-1.98}$$

JFET Voltage-divider Configuration



JFET Voltage-divider Configuration

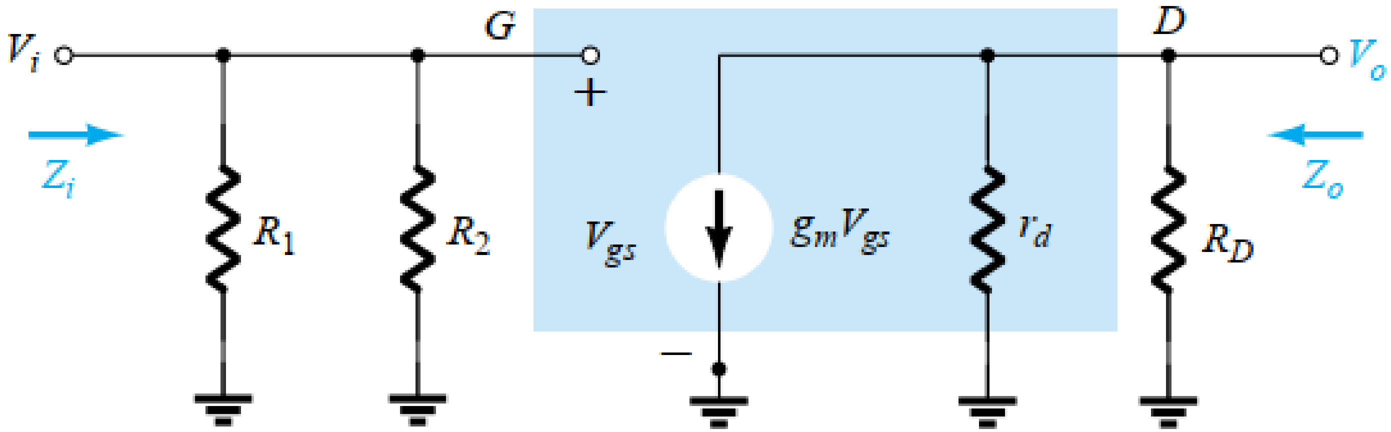
$$Z_i = R_1 \| R_2$$

$$Z_o = r_d \| R_D$$

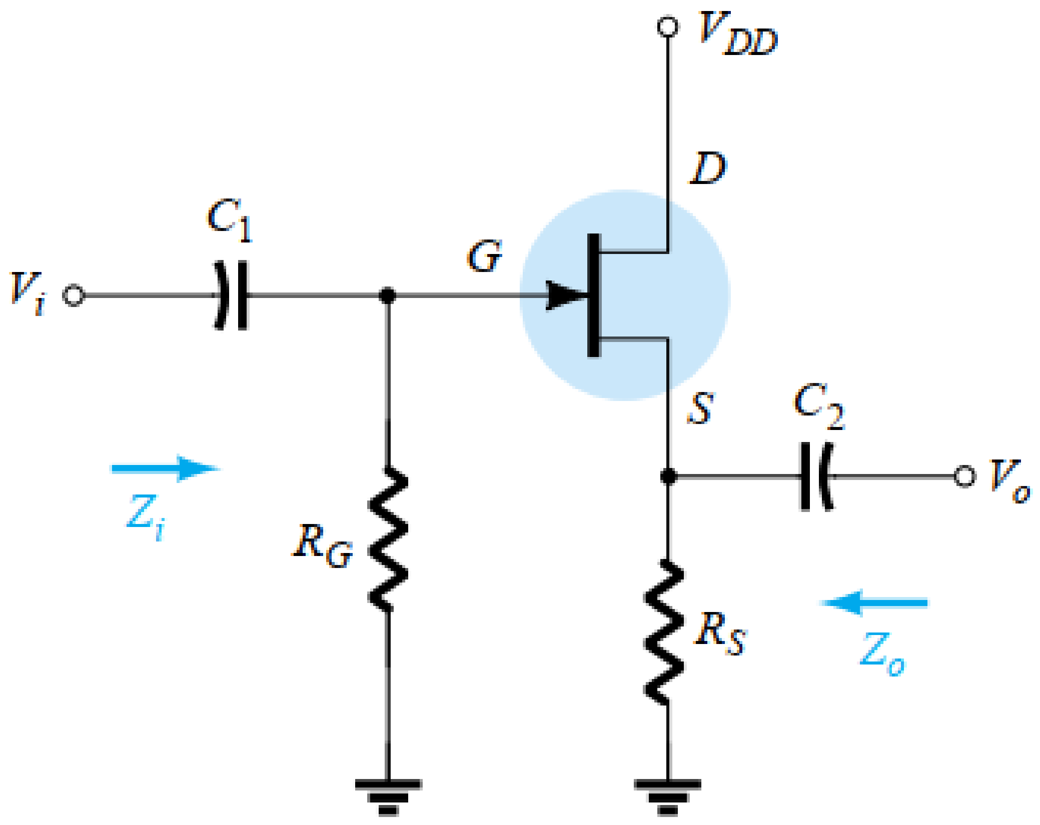
$$Z_o \cong R_D \quad {}_{r_d \geq 10R_D}$$

$$V_{gs} = V_i \qquad V_o = -g_m V_{gs}(r_d \| R_D) \Rightarrow A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs}(r_d \| R_D)}{V_{gs}}$$

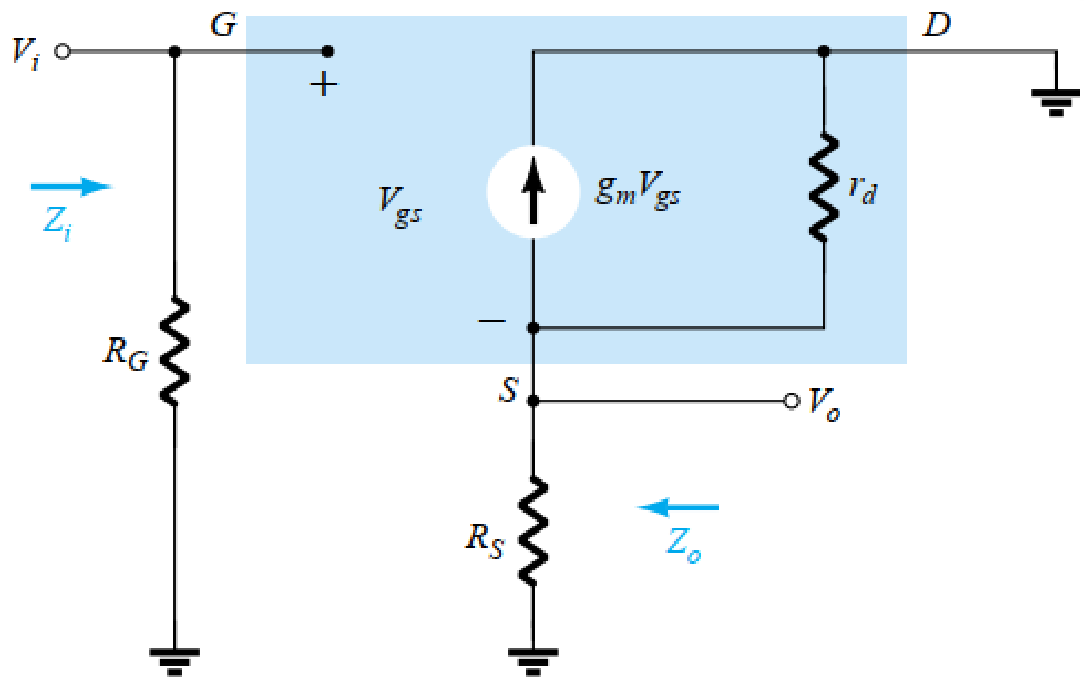
$$A_v = \frac{V_o}{V_i} \cong -g_m R_D \quad {}_{r_d \geq 10R_D}$$

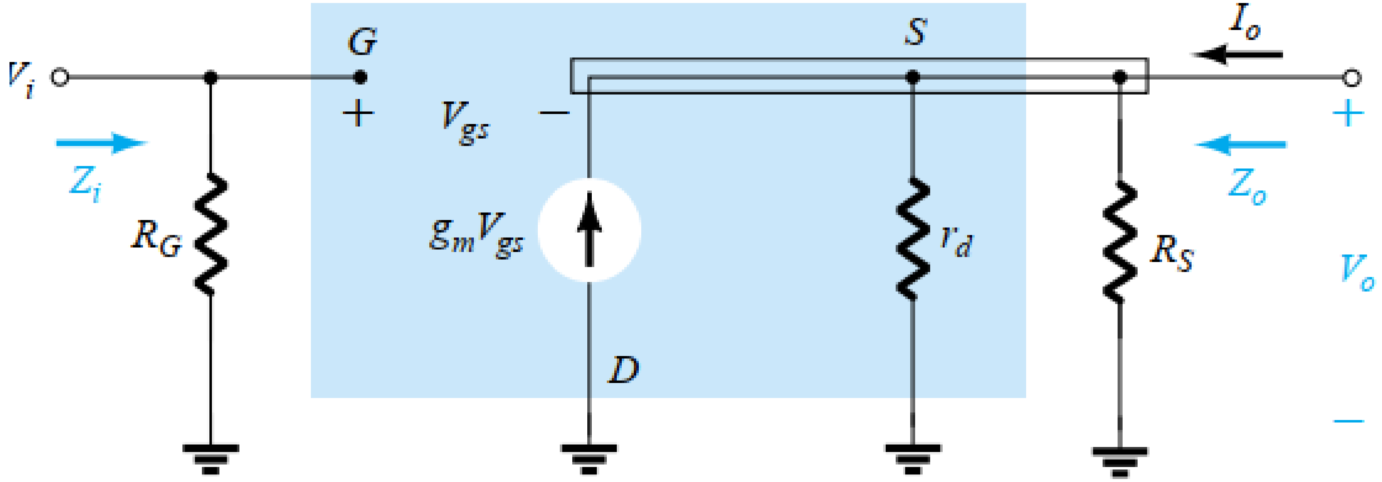


JFET Source-follower Configuration



JFET Source-follower Configuration





JFET Source-follower Configuration

$$\boxed{Z_i = R_G}$$

Applying Kirchhoff's current law at node *s*

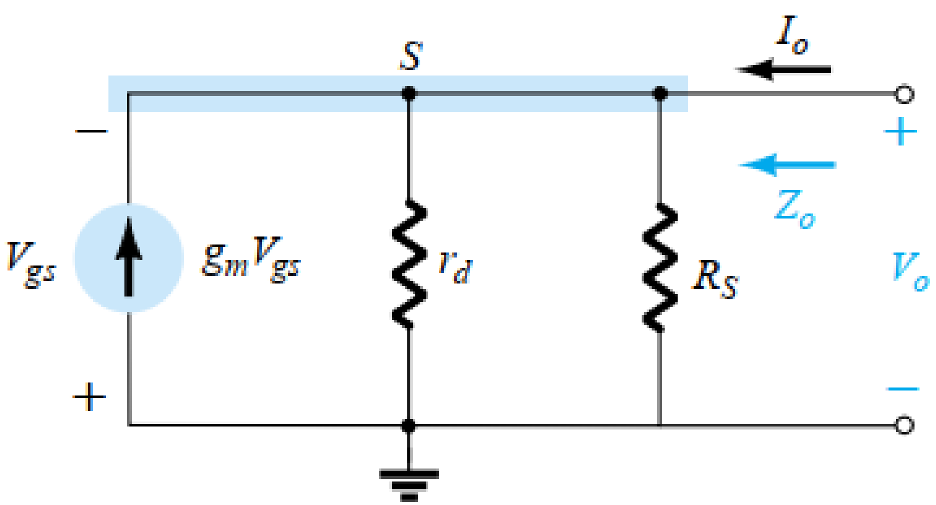
$$I_o + g_m V_{gs} = I_{r_d} + I_{R_S}$$

$$= \frac{V_o}{r_d} + \frac{V_o}{R_S}$$

$$I_o = V_o\left[\frac{1}{r_d} + \frac{1}{R_S}\right] - g_m V_{gs}$$

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

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



JFET Source-follower Configuration

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

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

$$\boxed{Z_o \cong R_S \| 1/g_m} \quad r_d \geq 10R_S$$

$$V_o = g_m V_{gs}(r_d \| R_S) \qquad V_i = V_{gs} + V_o$$

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

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

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{g_m(r_d \| R_S)}{1 + g_m(r_d \| R_S)}} \Rightarrow \boxed{A_v = \frac{V_o}{V_i} \cong \frac{g_m R_S}{1 + g_m R_S}} \quad r_d \geq 10R_S$$

Example

A dc analysis of the source-follower network of Figure will result in $V_{GSQ} = 2.86\,V\ and\ I_{DQ} = 4.56\,mA.$

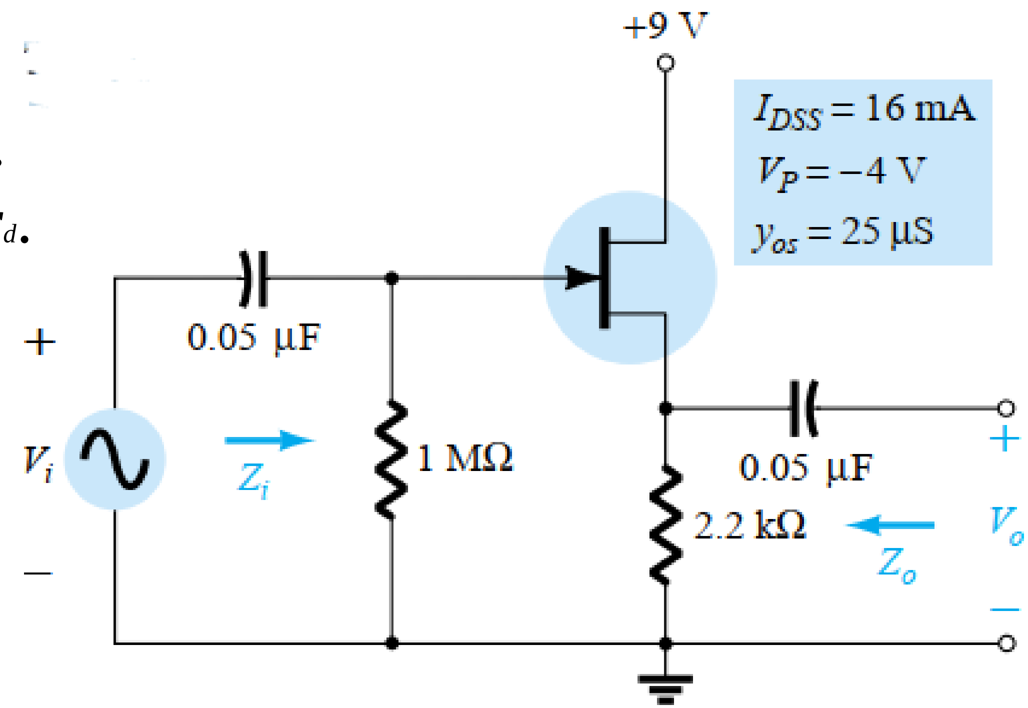
(a) Determining g_m.

(b) Find r_d.

(c) Determine Z_i.

(d) Calculate Z_o without r_d.

(e) Determine A_v without r_d.



Example

(a) $g_{m0} = \dfrac{2I_{DSS}}{|V_P|} = \dfrac{2(16\text{ mA})}{4\text{ V}} = 8\text{ mS}$

$$g_m = g_{m0}\left(1 - \frac{V_{GS_Q}}{V_P}\right) = 8\text{ mS}\left(1 - \frac{(-2.86\text{ V})}{(-4\text{ V})}\right) = \mathbf{2.28\ mS}$$

(b) $r_d = \dfrac{1}{y_{os}} = \dfrac{1}{25\ \mu\text{S}} = \mathbf{40\ k\Omega}$

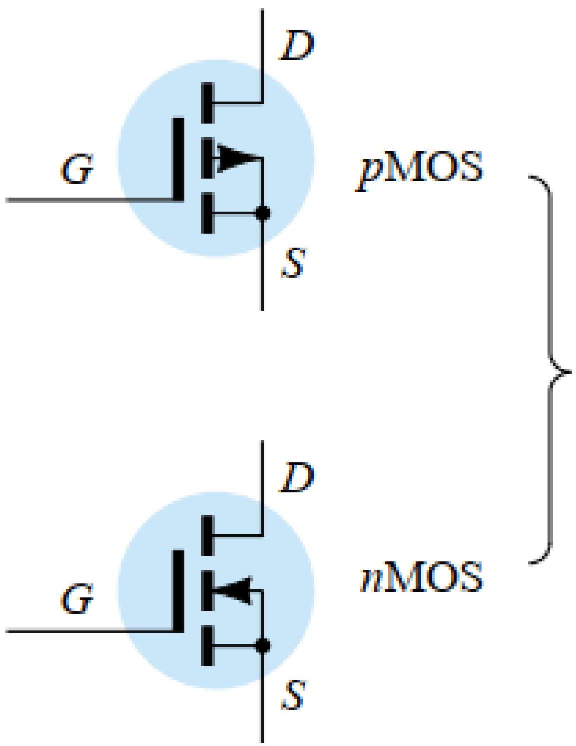
(c) $Z_i = R_G = \mathbf{1\ M\Omega}$

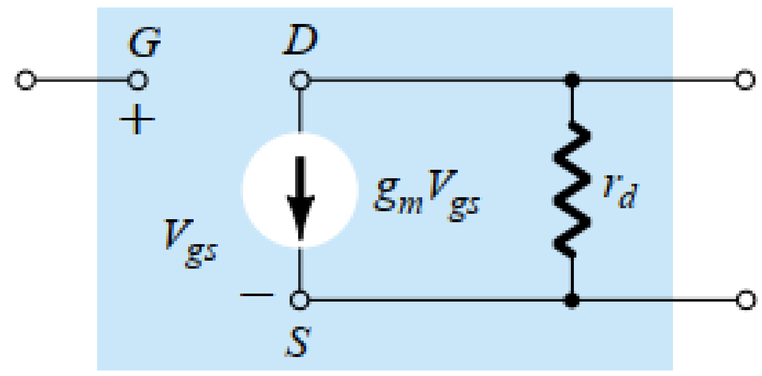
$$Z_o = R_S \| 1/g_m = 2.2\text{ k}\Omega \| 438.6\ \Omega = \mathbf{365.69\ \Omega}$$

$$A_v = \frac{g_m R_S}{1 + g_m R_S} = \frac{(2.28\text{ mS})(2.2\text{ k}\Omega)}{1 + (2.28\text{ mS})(2.2\text{ k}\Omega)}$$

$$= \frac{5.02}{1 + 5.02} = \mathbf{0.83}$$

Enhancement-Type MOSFETS

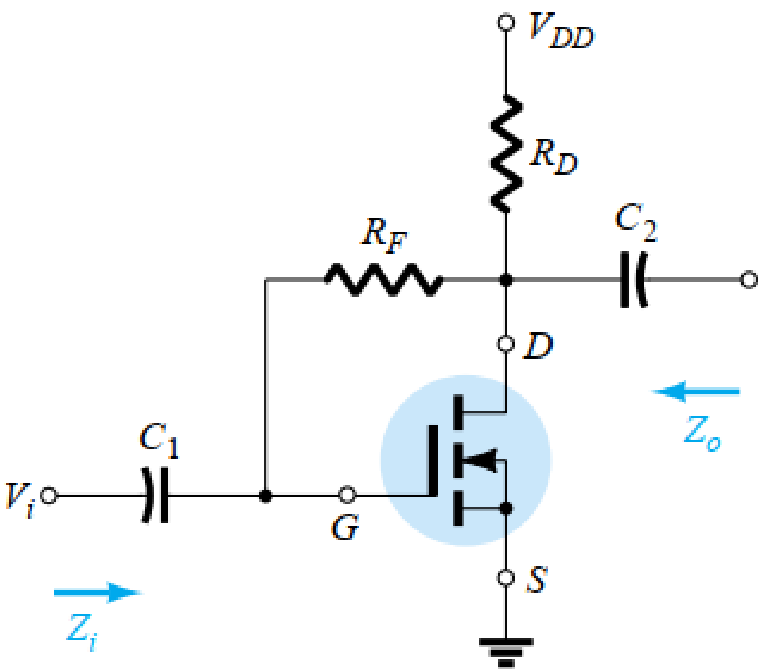


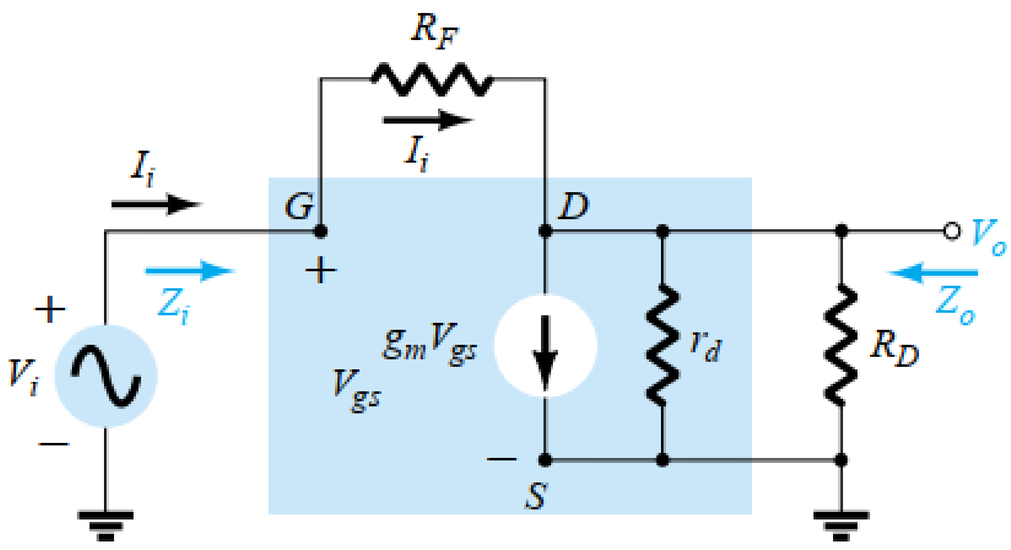


$$g_m = |y_{fs}| \ , \ r_d = \frac{1}{|y_{os}|}$$

E-MOSFET Drain-feedback Configuration

Recall from dc calculations that R_G could be replaced by a short-circuit equivalent since I_G=0 A and therefore V_{RG}=0 V.





Enhancement-Type MOSFETS

$$I_i = g_m V_{gs} + \frac{V_o}{r_d \| R_D}$$

$$V_{gs} = V_i$$

$$I_i = g_m V_i + \frac{V_o}{r_d \| R_D}$$

$$I_i - g_m V_i = \frac{V_o}{r_d \| R_D}$$

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

$$I_i = \frac{V_i - V_o}{R_F} = \frac{V_i - (r_d \| R_D)(I_i - g_m V_i)}{R_F}$$

Electronics

Enhancement-Type MOSFETS

$$I_i R_F = V_i - (r_d \| R_D) I_i + (r_d \| R_D) g_m V_i$$

$$V_i[1 + g_m(r_d \| R_D)] = I_i[R_F + r_d \| R_D]$$

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

Typically, $R_F \gg r_d \| R_D$, so that

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

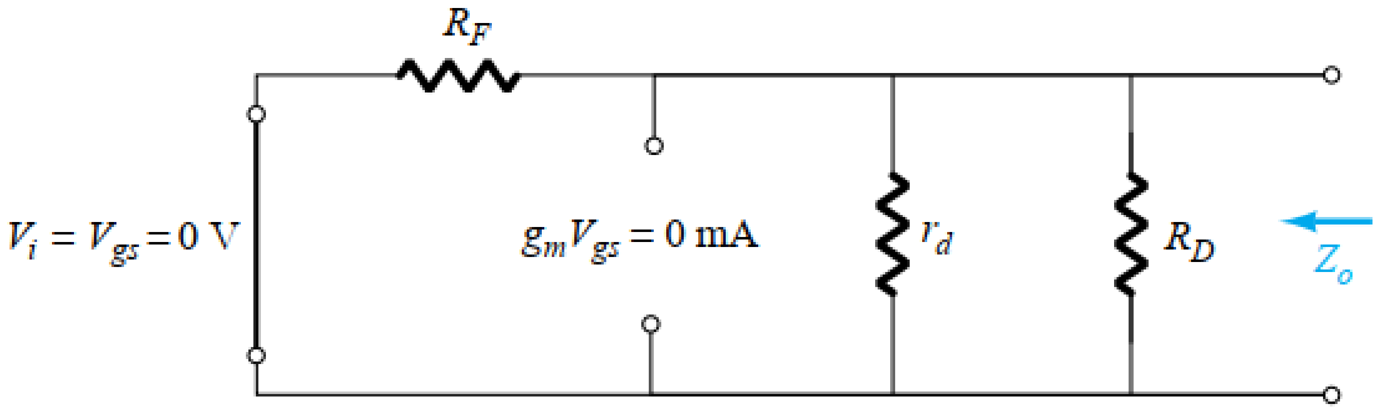
For $r_d \geq 10R_D$,

$$\boxed{Z_i \cong \frac{R_F}{1 + g_m R_D}}$$

$R_F \gg r_d \| R_D,\ r_d \geq 10R_D$

Enhancement-Type MOSFETS

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



Normally, R_F is so much larger than $r_d \| R_D$ that

$$Z_o \cong r_d \| R_D$$

and with $r_d \geq 10R_D$,

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

***A**$_v$*: Applying Kirchhoff's current law at node *D*

$$I_i = g_m V_{gs} + \frac{V_o}{r_d \| R_D}$$

$$V_{gs} = V_i \text{ and } I_i = \frac{V_i - V_o}{R_F}$$

$$\frac{V_i - V_o}{R_F} = g_m V_i + \frac{V_o}{r_d \| R_D}$$

$$\frac{V_i}{R_F} - \frac{V_o}{R_F} = g_m V_i + \frac{V_o}{r_d \| R_D}$$

$$V_o\left[\frac{1}{r_d \| R_D} + \frac{1}{R_F}\right] = V_i\left[\frac{1}{R_F} - g_m\right]$$

Enhancement-Type MOSFETS

$$A_v = \frac{V_o}{V_i} = \frac{\left[\dfrac{1}{R_F} - g_m\right]}{\left[\dfrac{1}{r_d \| R_D} + \dfrac{1}{R_F}\right]}$$

$$\frac{1}{r_d \| R_D} + \frac{1}{R_F} = \frac{1}{R_F \| r_d \| R_D}$$

$$g_m \gg \frac{1}{R_F}$$

so that

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

Since R_F is usually $>> r_d \| R_D$ and if $r_d \geq 10R_D$,

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

Example

E-MOSFET of Figure $k = 0.24 \times 10^{-3} A/V^2$, $V_{GQ} = 6.4\,V$, $and\ I_{DQ} = 2.75\,mA$.

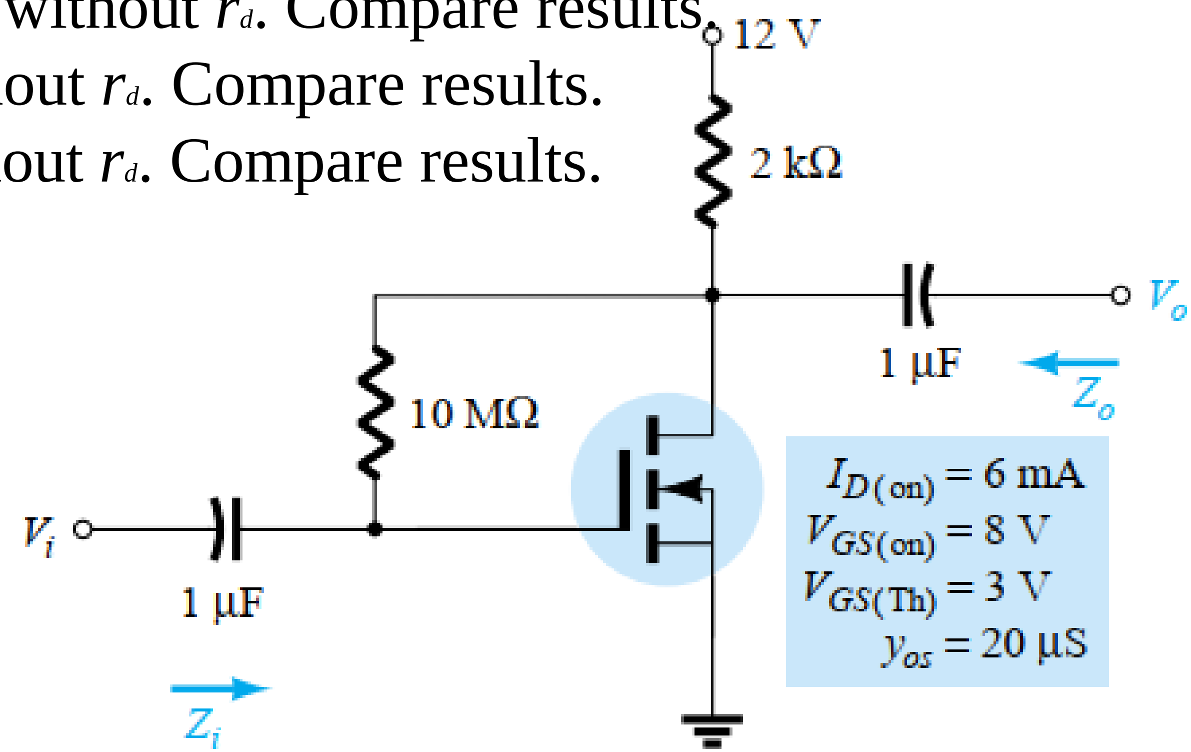
(a) Determine g_m.

(b) Find r_d.

(c) Calculate Z_i with and without r_d. Compare results.

(d) Find Z_o with and without r_d. Compare results.

(e) Find A_v with and without r_d. Compare results.



Example

(d) With r_d:

$$Z_o = R_F \| r_d \| R_D = 10\text{ M}\Omega \| 50\text{ k}\Omega \| 2\text{ k}\Omega = 49.75\text{ k}\Omega \| 2\text{ k}\Omega$$
$$= \mathbf{1.92\ k\Omega}$$

Without r_d:

$$Z_o \cong R_D = \mathbf{2\ k\Omega}$$

(e) With r_d:

$$\begin{aligned} A_v &= -g_m(R_F \| r_d \| R_D) \\ &= -(1.63\text{ mS})(10\text{ M}\Omega \| 50\text{ k}\Omega \| 2\text{ k}\Omega) \\ &= -(1.63\text{ mS})(1.92\text{ k}\Omega) \\ &= \mathbf{-3.21} \end{aligned}$$

Without r_d:

$$A_v = -g_m R_D = -(1.63\text{ mS})(2\text{ k}\Omega)$$
$$= \mathbf{-3.26}$$

THANK YOU

AUSTRALIA
OCEANIA
NEW ZEALAND
VANUATU
TONGA
Northern Territory
Queensland