The MOSFET as an amplifier

MOSFETs as an Amplifier

- **When the MOSFET is used to design an amplifier, it is operated in the saturation region. In saturation the drain current is constant determined by v_{GS} and is independent of v_{DS}. That is, the MOSFET operates as a constant-current source where the value of the current is determined by v_{GS}.**

MOSFETs as an Amplifier

- **The basis for this important application is that when operated in saturation, the MOSFET functions as voltage-controlled current source: The gate-to-source voltage v_{GS} controls the drain current i_D. Although the control relationship is nonlinear (square law), we will devise a method for obtaining almost-linear amplification from this fundamentally nonlinear device.**

$$\boxed{i_D = \frac{1}{2} K_n (v_{GS} - V_t)^2}$$

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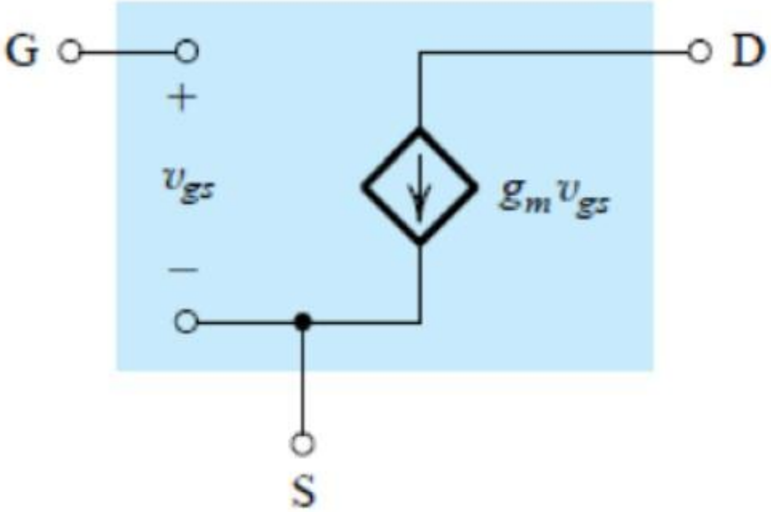
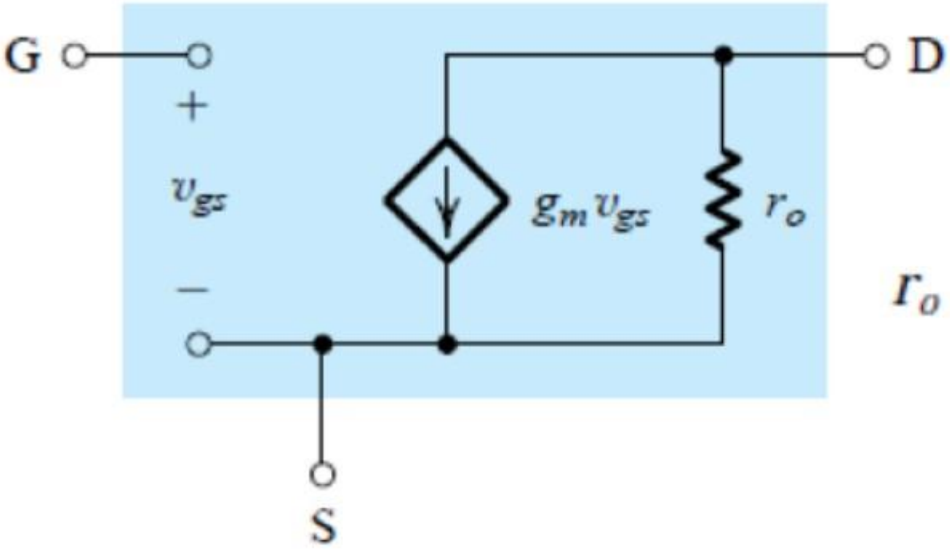
Small-Signal Equivalent-Circuit Models for MOSFET

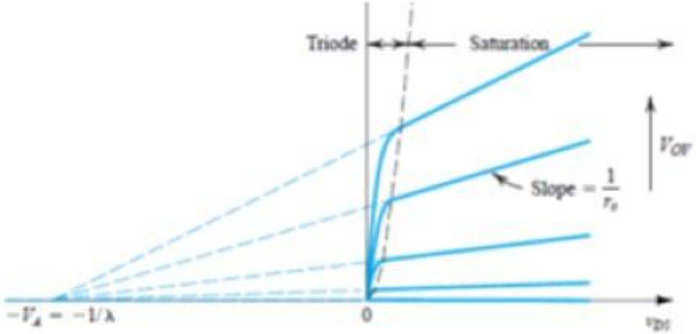
Hybrid-π model





$$r_o = \frac{|V_A|}{I_D}$$

(a) neglecting the dependence of i_D on v_{DS} in saturation



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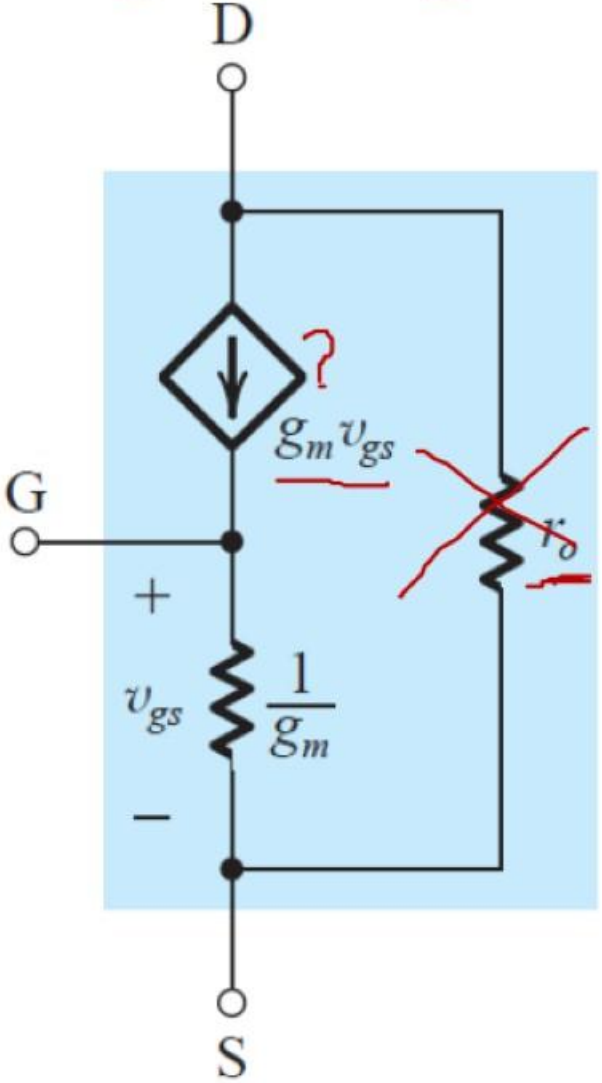
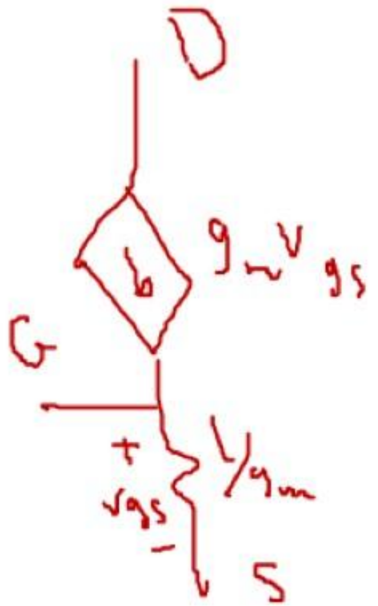
Small-Signal Equivalent-Circuit Models for FET



T model



$r_o = \infty$

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Small-Signal Equivalent-Circuit Models for MOSFET

Transconductance, gm :

- gm is equal to the slope of the $i_D - v_{GS}$ characteristic at the bias point,

$$g_m \equiv \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}}$$

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Small-Signal Equivalent-Circuit Models for MOSFET

Transconductance, gm :

$$g_m = \left(\frac{\partial i_D}{\partial v_{GS}} \right)_{\text{Q point}}$$

$$i_D = \frac{1}{2} K_n (v_{GS} - V_T)^2$$

$$g_m = K_n (V_{GS} - V_T) = \frac{2 I_D}{(V_{GS} - V_T)} = \sqrt{2 K_n I_D}$$

$$K_n = \mu_n C_{ox} \left(\frac{W}{L} \right)$$

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Small-Signal Equivalent-Circuit Models for MOSFET

Note

- **PMOSFET transistors** Same formulas as for NMOSFET **except** using $|(\boldsymbol{V_{GS}} - \boldsymbol{V_T})|$, and **replacing** μ_n with μ_p.

$$g_m = K_p|(V_{GS} - V_T)| = \frac{2I_D}{|(V_{GS}-V_T)|} = \sqrt{2K_pI_D}$$

$$K_p = \mu_p C_{ox}\left(\frac{W}{L}\right)$$

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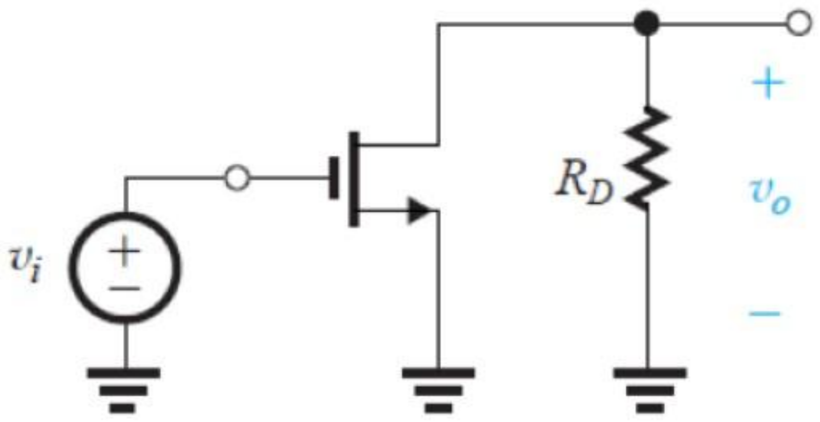
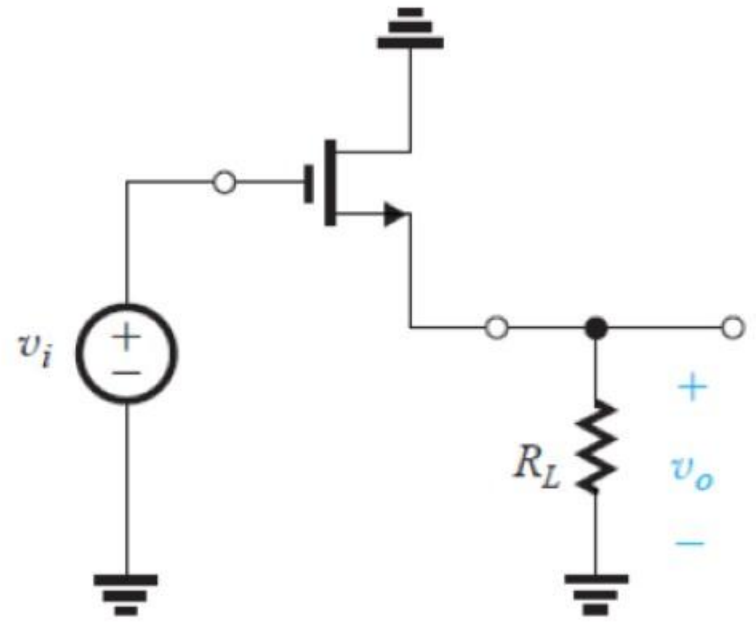
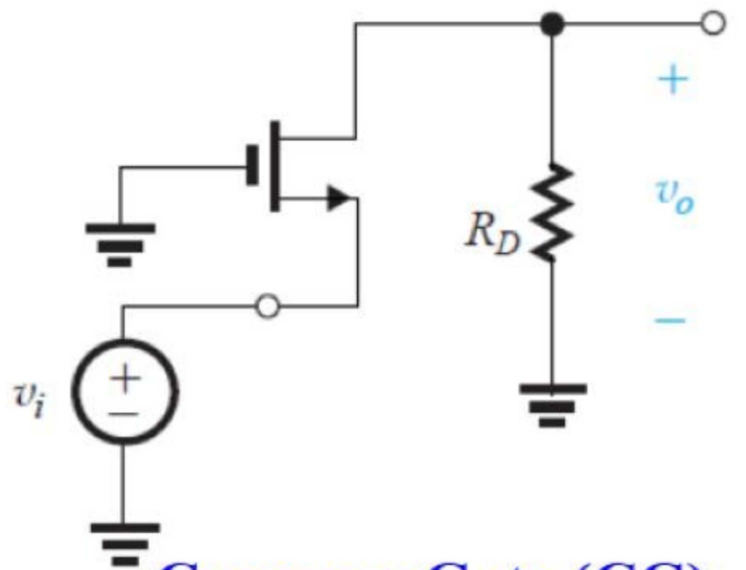
The Three Basic Configurations of MOSFET



Common Source (CS)



Common Drain (CD)



Common Gate (CG)

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The Common-Source (CS) Amplifier

Common Source (CS)

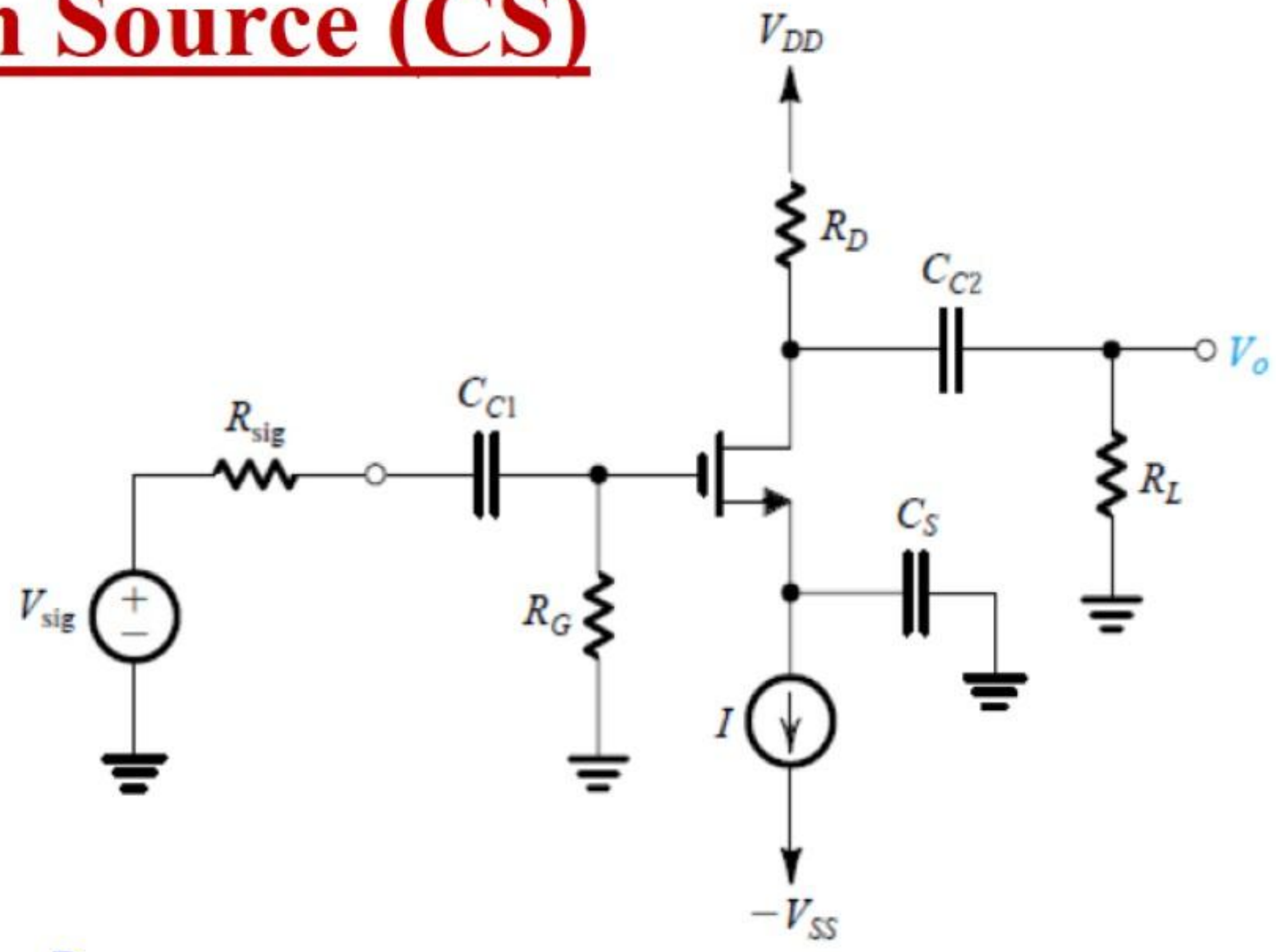
$$R_{in} = R_G$$

$$R_o = (r_o \| R_D)$$

$$A_{vo} = -g_m(R_D \| r_o)$$

$$A_v = \frac{v_o}{v_i} = -g_m(R_D \| r_o \| R_L)$$

$$G_v = \frac{v_o}{v_{sig}} = -g_m(R_D \| r_o \| R_L)\frac{R_G}{[R_{sig} + R_G]}$$



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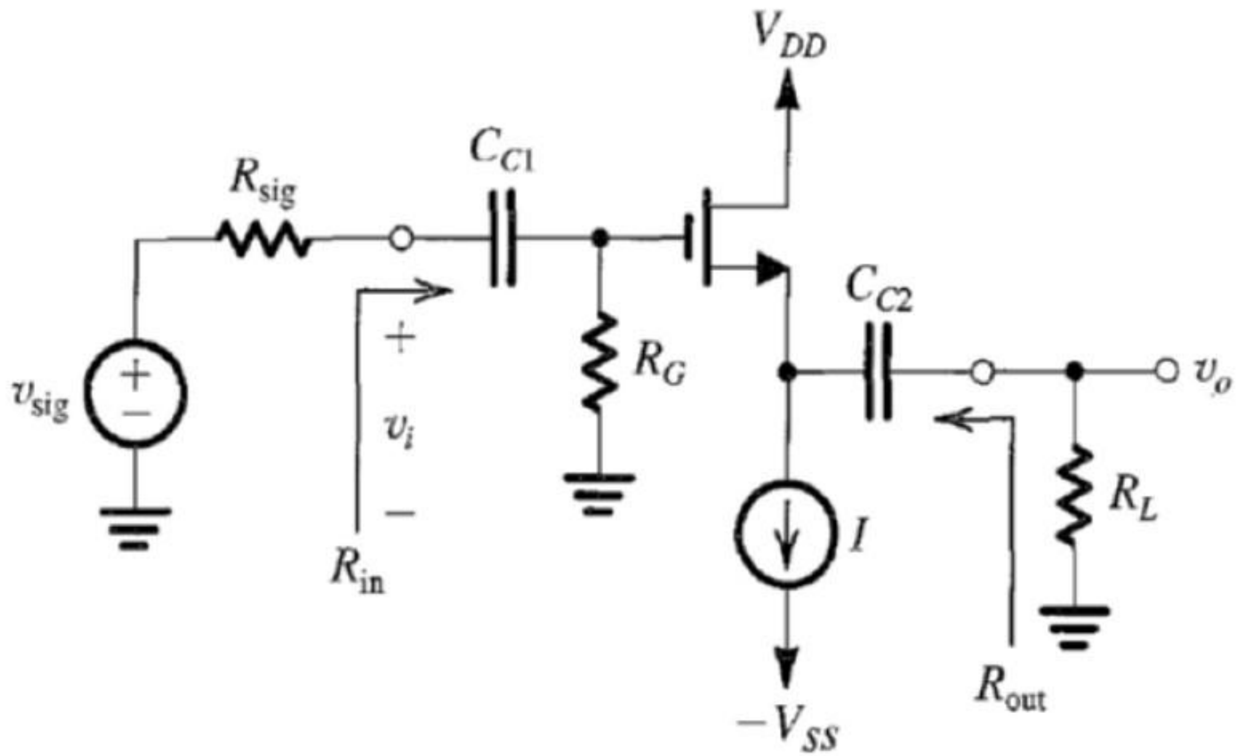
The Common-Drain (CD) Amplifier

The Common-Drain (CD) Amplifier

In a CD amplifier, the input signal is applied to the gate and the output signal is taken from the source.

The voltage gain is always < 1, but the power gain is not.



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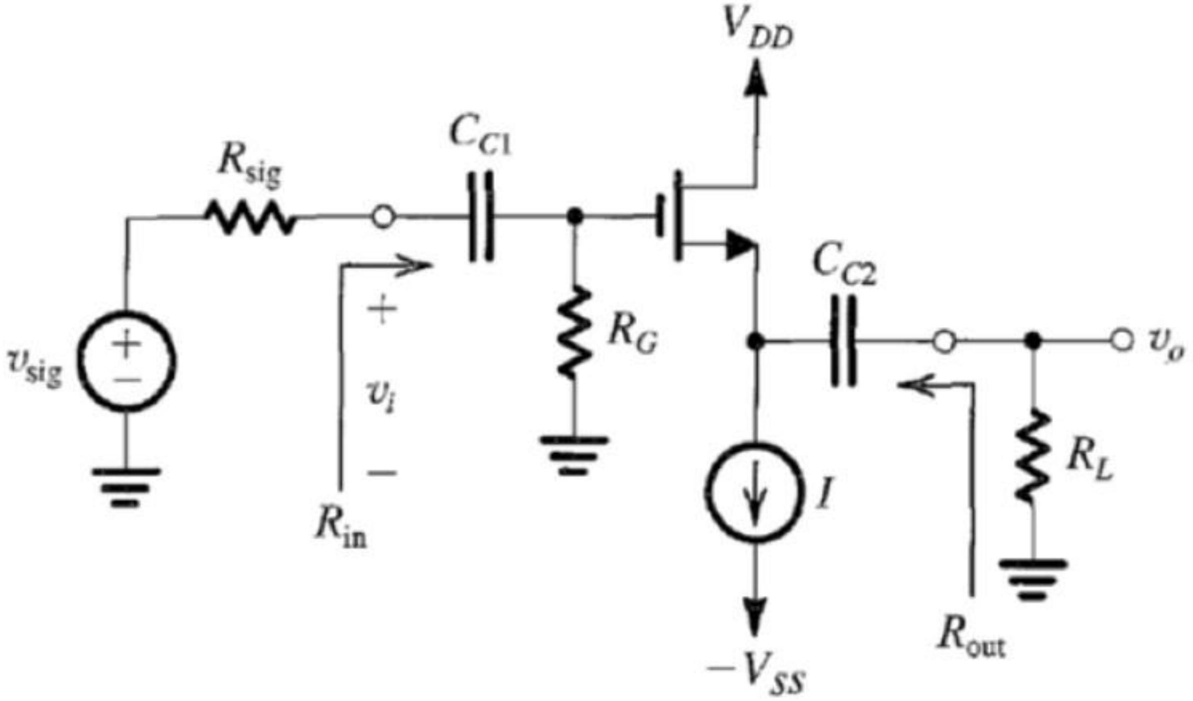
The Common-Drain (CD) or Source Follower Amplifier

Example

Determine the voltage gain of the Source Follower with biasing Using a Constant-Current Source



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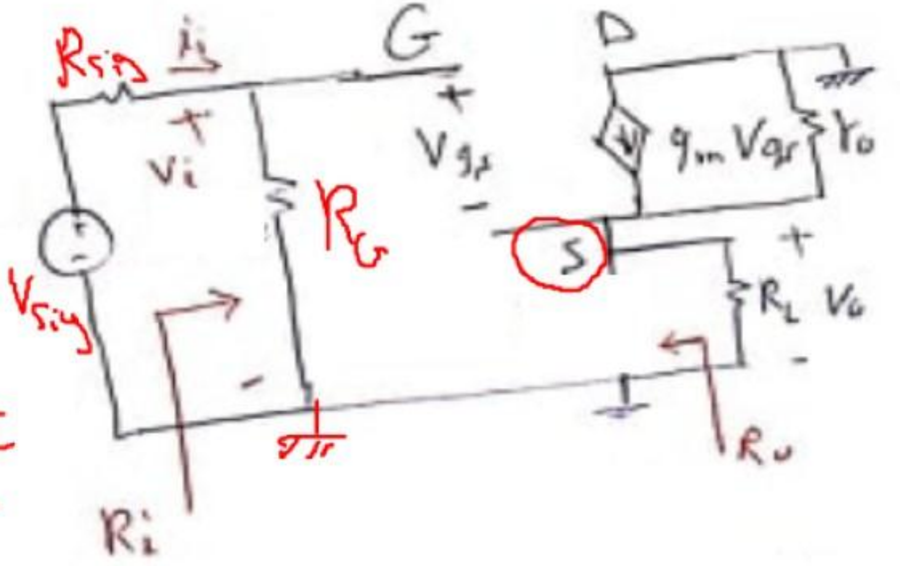
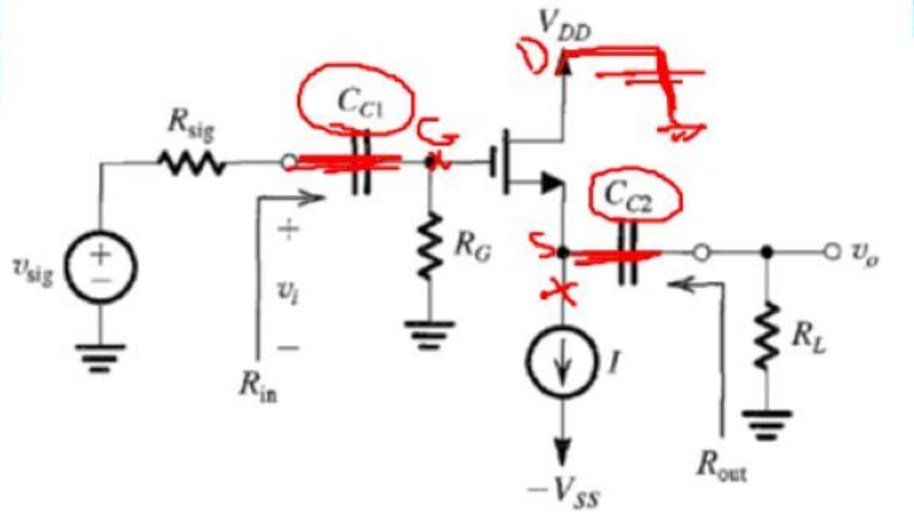
A. C analysis

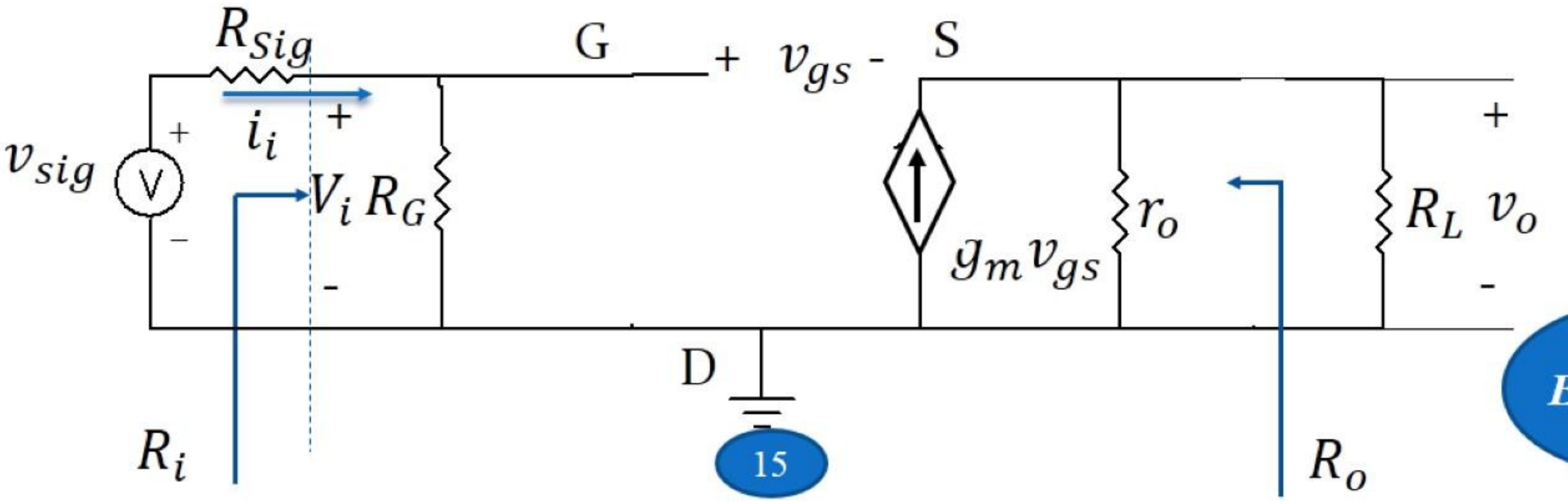
short cct

VDD short cct

I open cct







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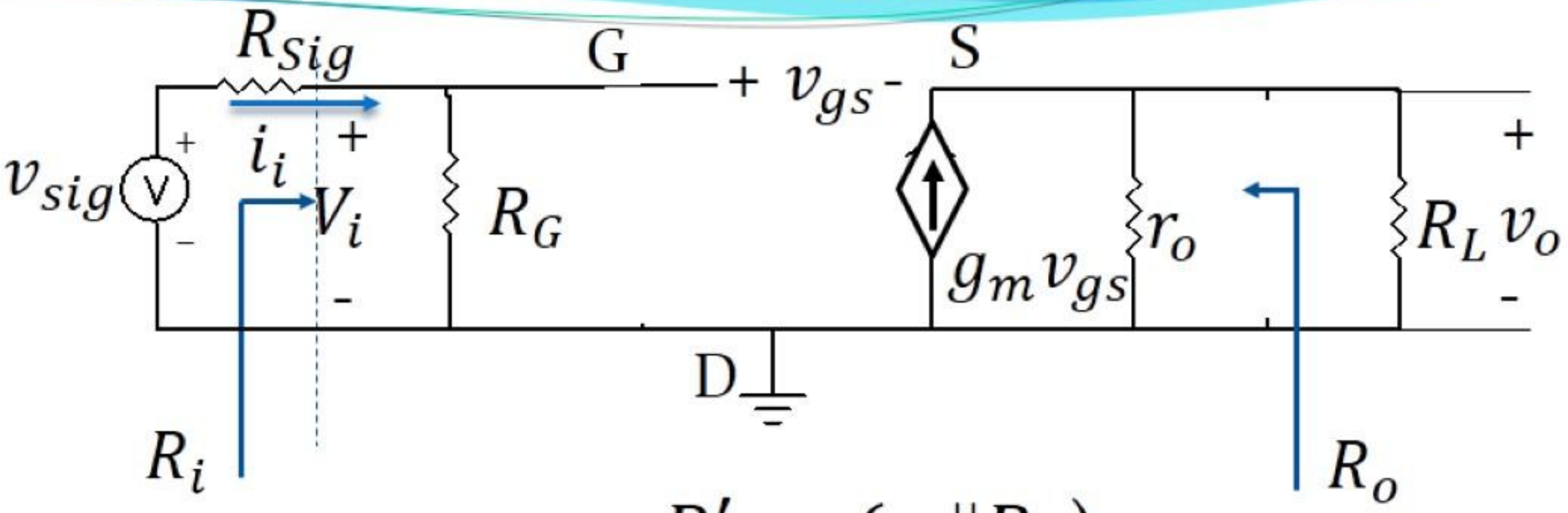

$$R'_L = (r_o \| R_L)$$

$$R_{in} = \frac{v_i}{i_i}$$

$$R_{in} = R_G$$

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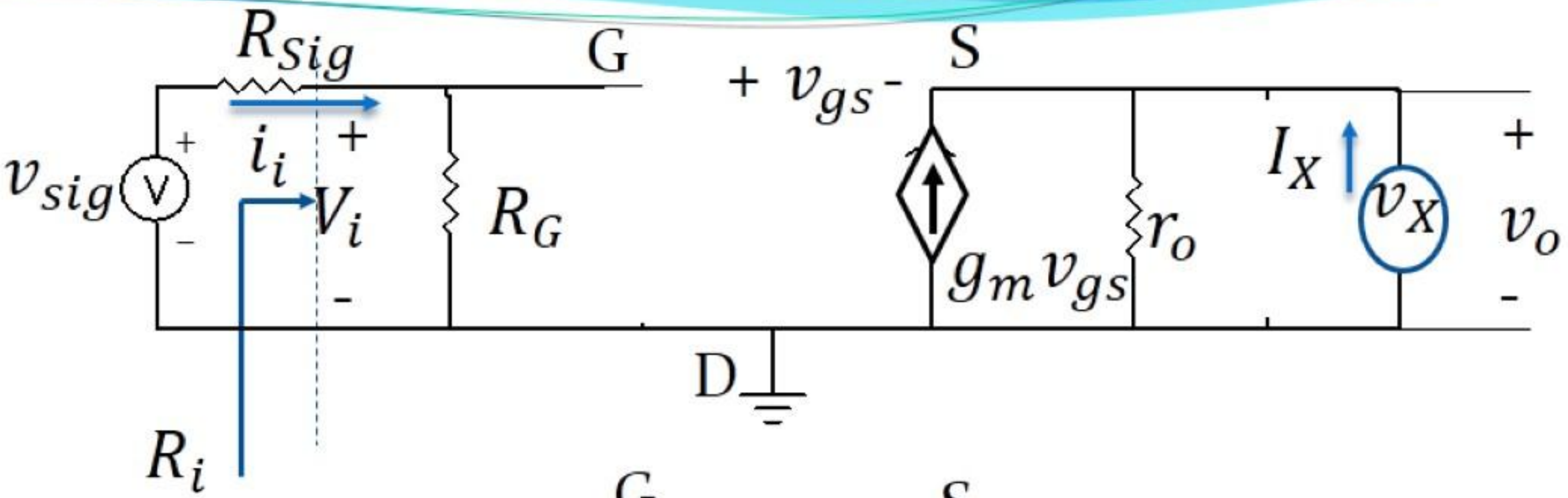
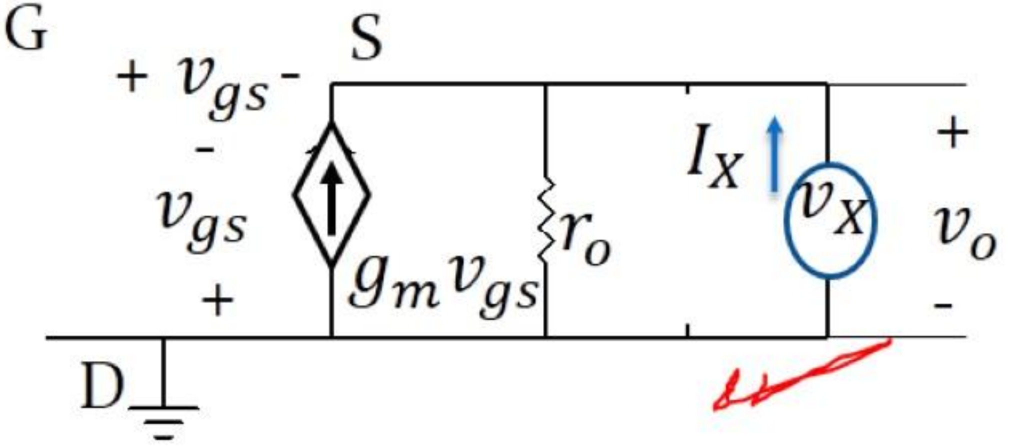
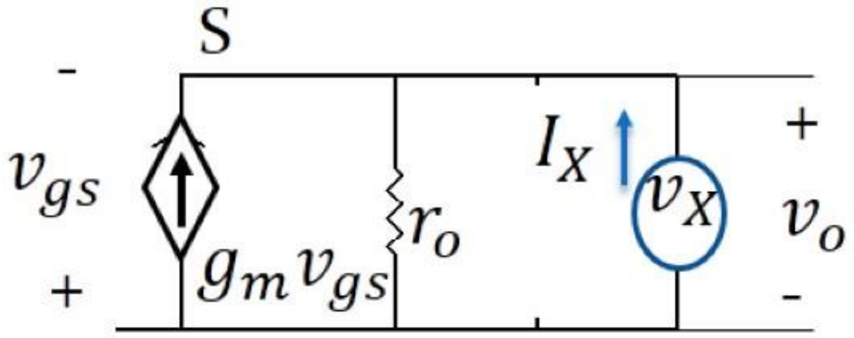
$$R_o = \frac{V_x}{I_x}\bigg|_{v_i=0}$$







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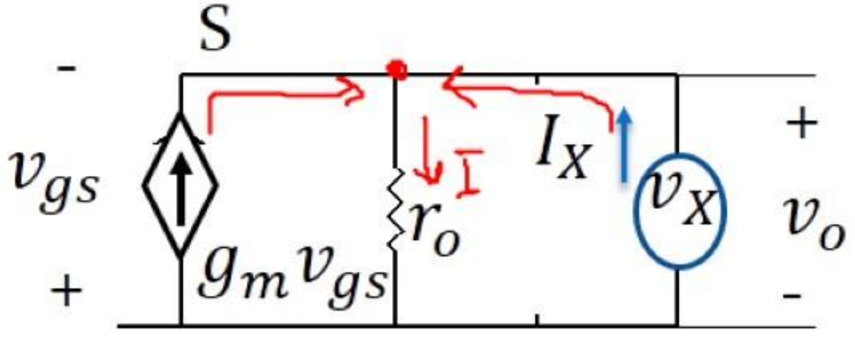
$V_X = -V_{gs}$



at node

$I_X + g_m V_{gs} = I$

$I_X - g_m V_X = \frac{V_X}{r_o}$

$I_X = \left(g_m + \frac{1}{r_o}\right) V_X$

$R_o = \frac{V_X}{I_X} = \frac{1}{\frac{1}{\frac{1}{g_m}} + \frac{1}{r_o}}$

$\boxed{R_o = 1/g_m \parallel r_o}$

$R_t = R_1 \parallel R_2$

$\frac{1}{R_t} = 1/R_1 + 1/R_2$

$R_t = \frac{1}{1/R_1 + 1/R_2}$

$R_o \simeq 1/g_m <<$

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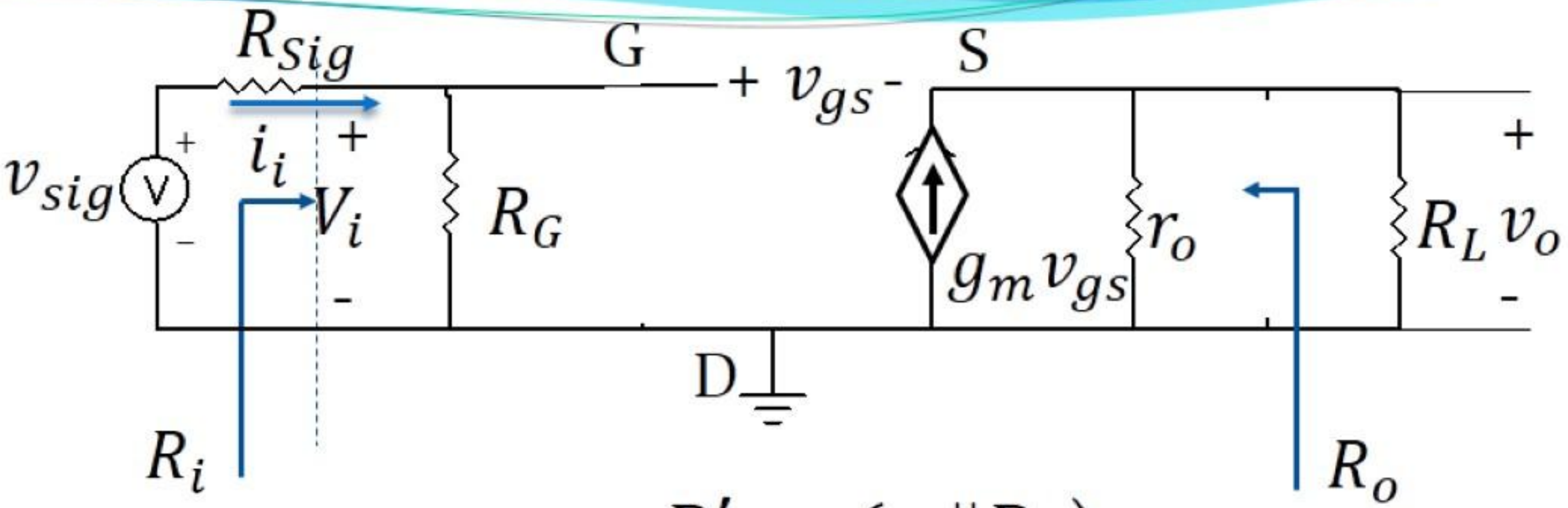

$$R_L' = (r_o \| R_L)$$

$$v_0 = g_m v_{gs} R_L^{'}$$

$$v_{in} = v_{gs} + v_o = v_{gs}\left(1 + g_m R_L^{'}\right)$$

$$A_v = \frac{v_0}{v_i} = \frac{g_m R_L^{'}}{1 + g_m R_L^{'}} \le 1$$

Since the output voltage is almost equal to the input – hence the name source follower

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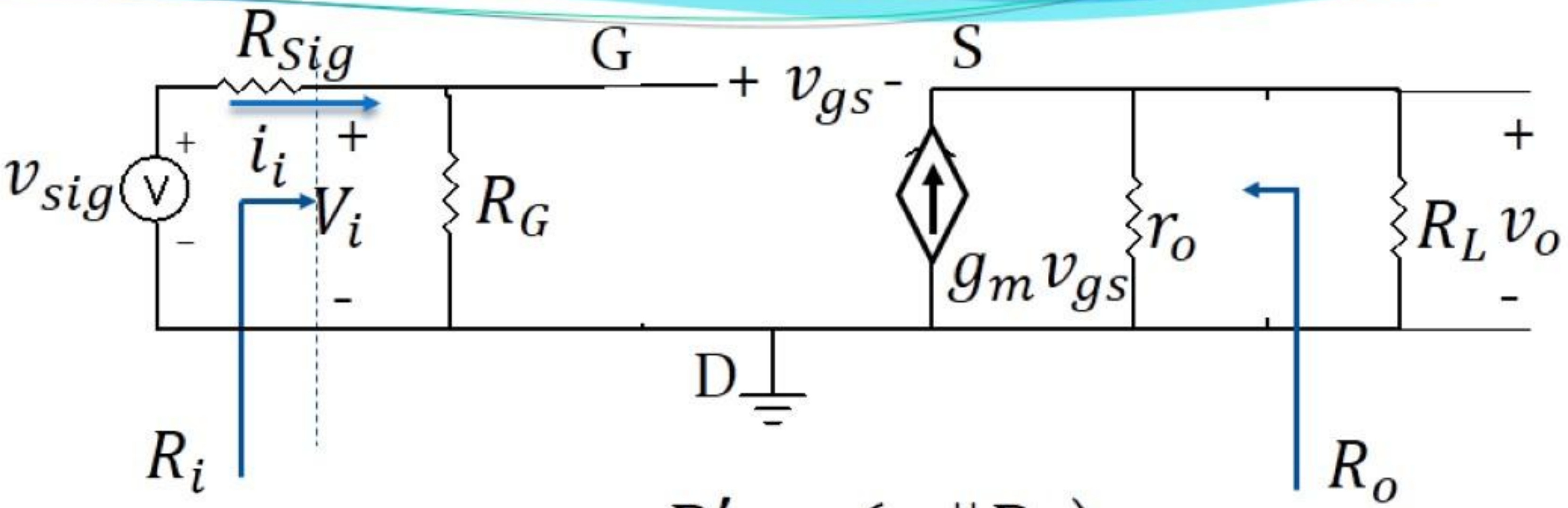

$$R'_L = (r_o \| R_L)$$

$$G_v = \frac{v_o}{v_{sig}} = A_v \frac{R_i}{[R_{sig} + R_i]}$$

$$G_V = \frac{g_m R'_L \quad R_G}{(1 + g_m R'_L)(R_{sig} + R_G)}$$

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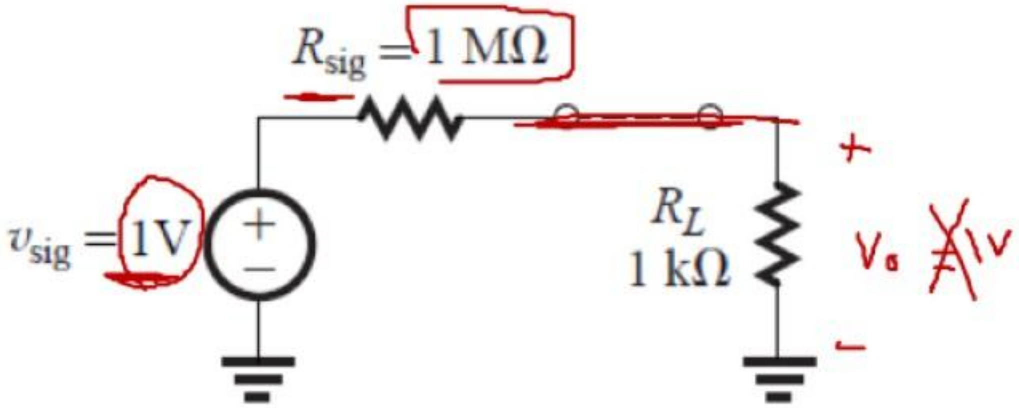
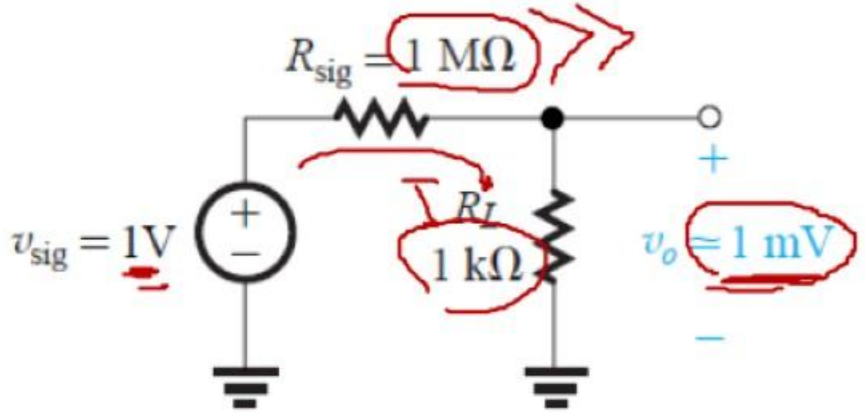
The Common-Drain Amplifier or Source Follower

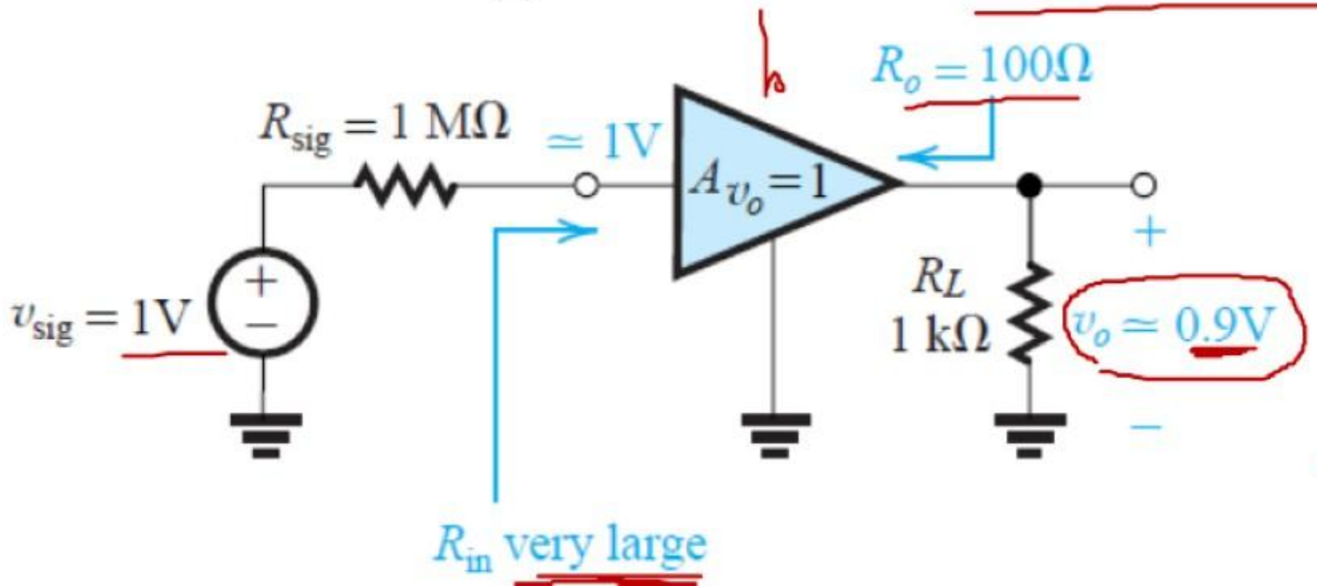




$$I = \frac{1V}{1M\Omega + R_L} = \frac{1V}{1000+1}$$

$$V_o = R_L I \simeq 1\ mV$$

Illustrating the need for a unity-gain buffer amplifier.



$$\frac{V_o}{V_{sig}} = G_v = A_{v_o}\left(\frac{R_L}{R_L+R_o}\right)\left(\frac{R_i}{R_i+R_{sig}}\right)$$

$$\frac{V_o}{V_{sig}} = 1 \times \left(\frac{1000}{1000+100}\right)\left(\frac{100M}{100M+1M\Omega}\right)$$

$$V_o = G_v V_{sig} \simeq 0.9V$$

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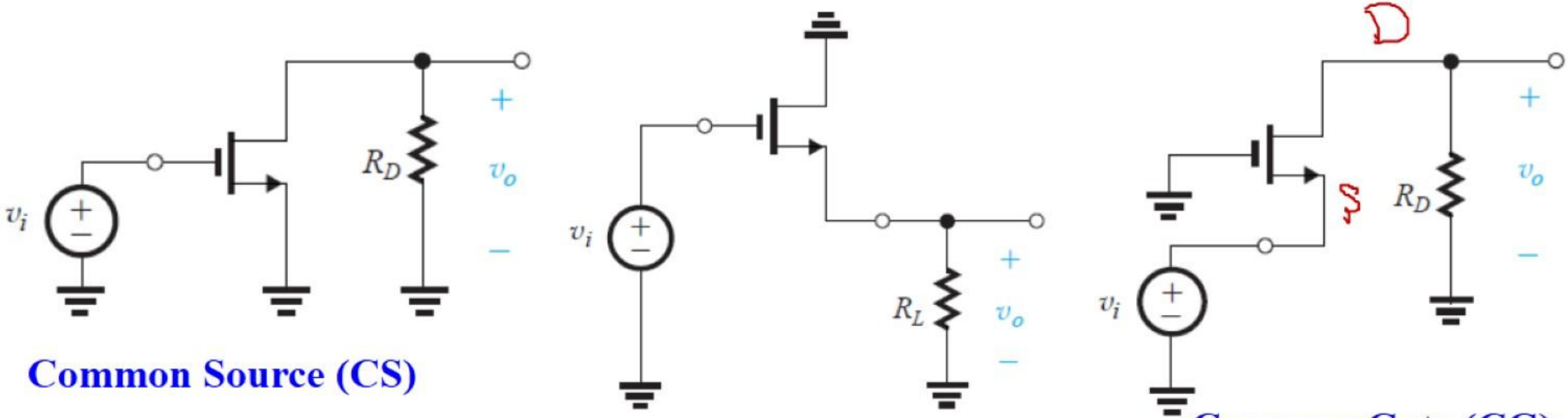
The Common-Drain (CD) Amplifier or Source Follower

- In conclusion, the source follower features a very high input resistance (ideally, infinite), a relatively low output resistance, and an open-circuit voltage gain that is near unity (ideally, unity). Thus the source follower is ideally suited for implementing the unity-gain voltage buffer. The source follower is also used as the output (i.e., last) stage in a multistage amplifier, where its function is to equip the overall amplifier with a low output resistance, thus enabling it to supply relatively large load currents without loss of gain (i.e., with little reduction of output signal level).

The Three Basic Configurations of MOSFET



Common Source (CS)

Common Drain (CD)

Common Gate (CG)

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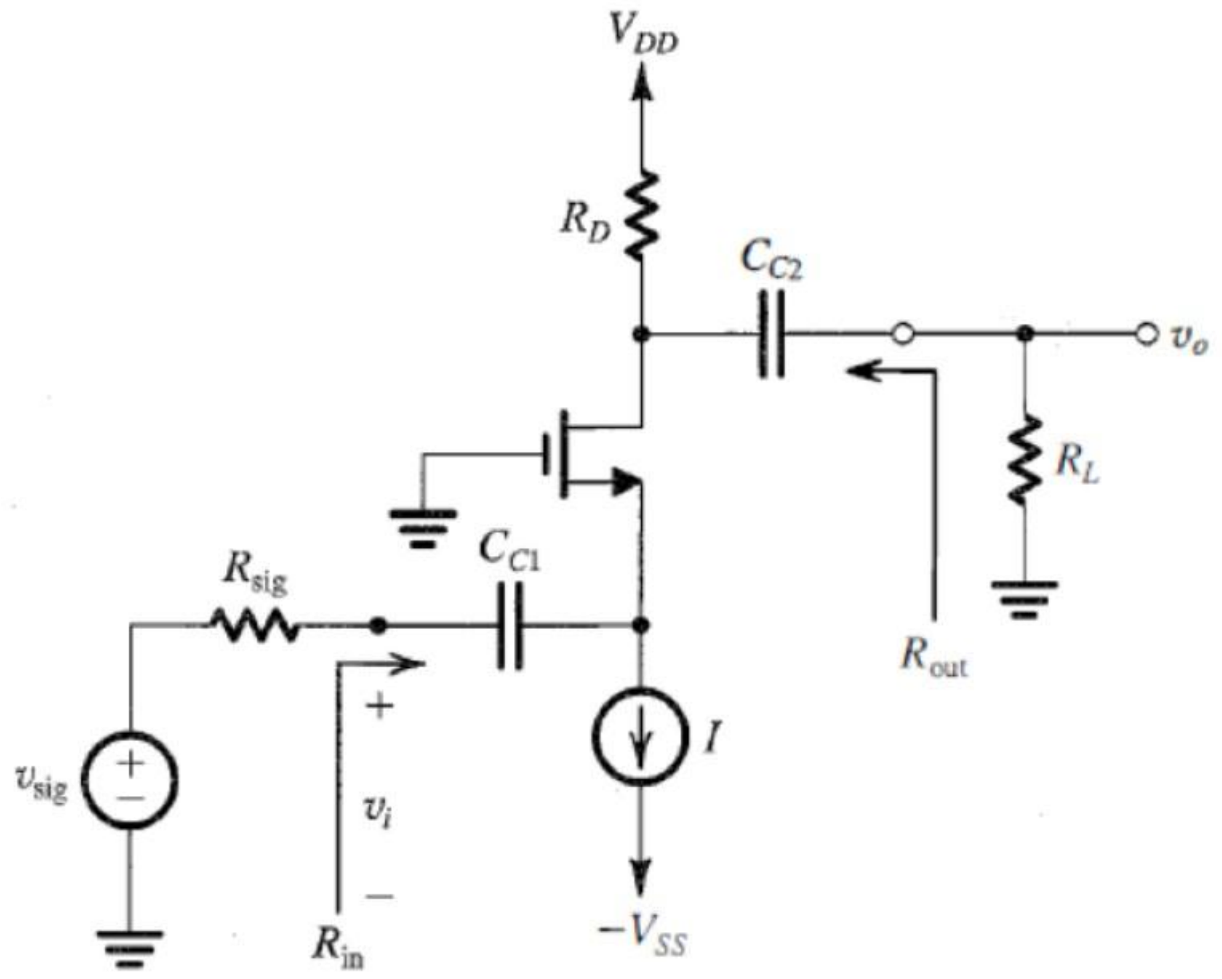
The Common-Gate (CG) Amplifier

- **What are the voltage gain v_o/v_i , overall voltage gain v_o/v_{sig}, input resistance and output resistance for the Common-Gate (CG) amplifier shown in Fig?**



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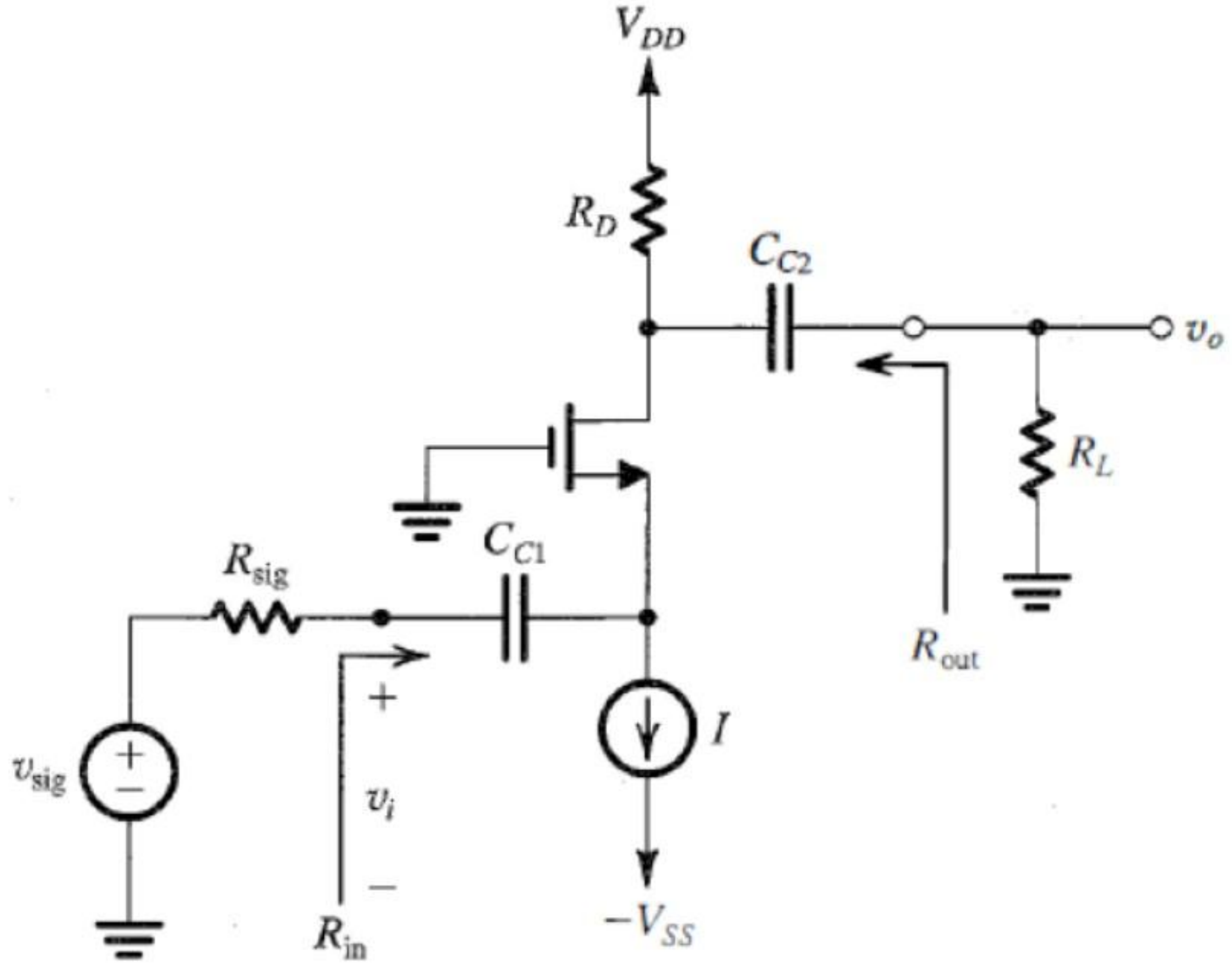
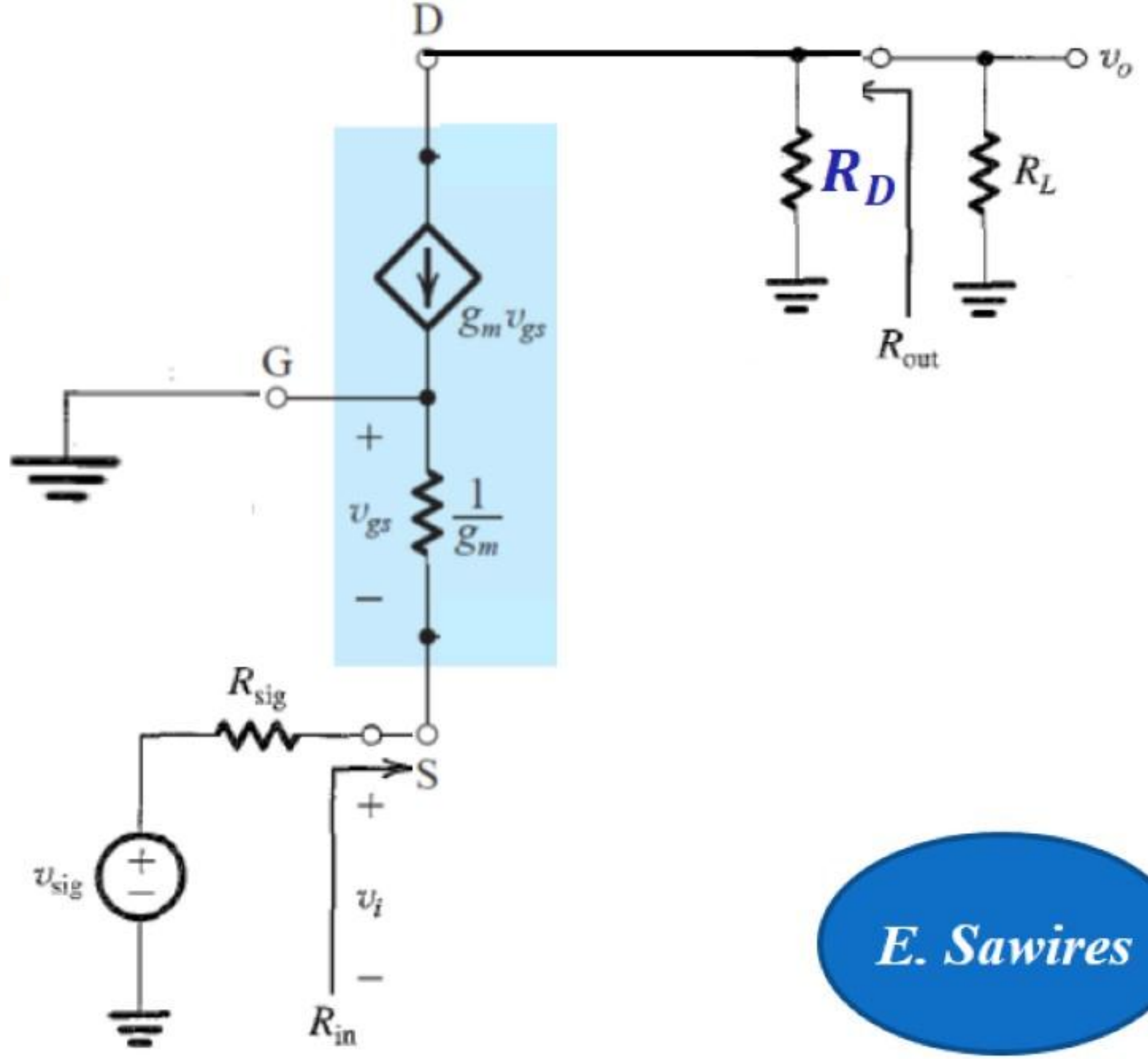
The Common-Gate (CG) amplifier





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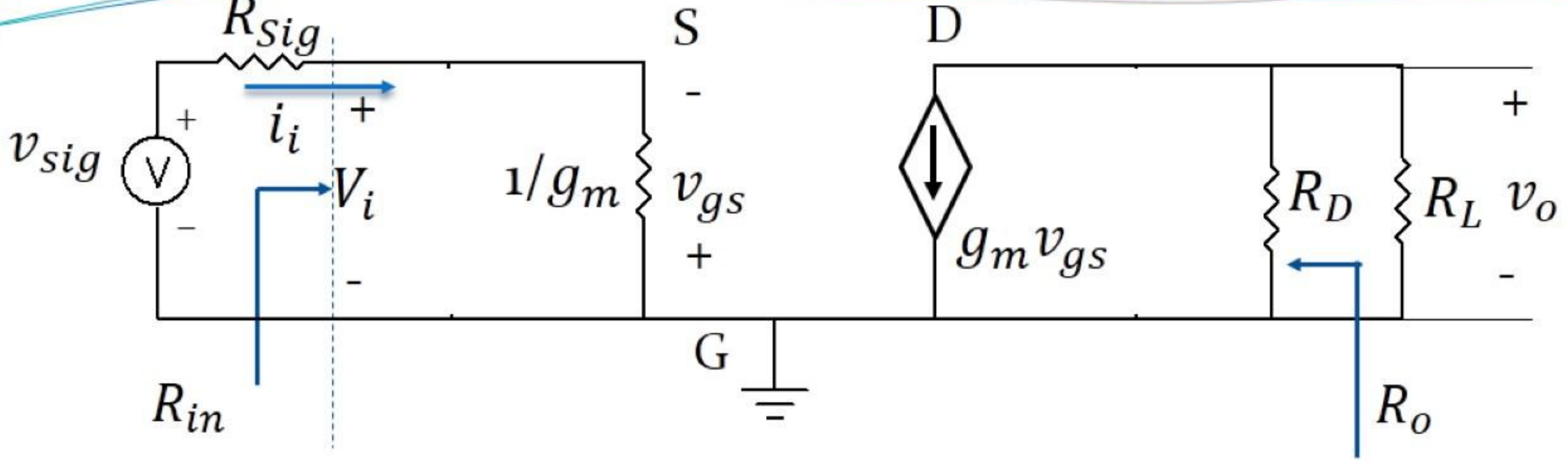

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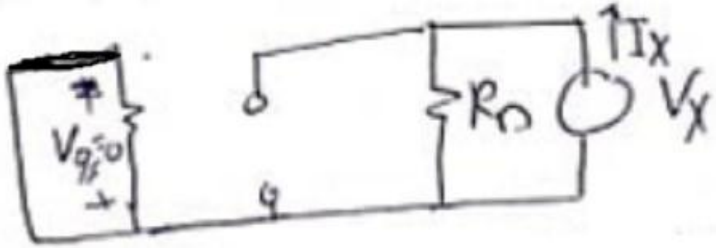
$$\boxed{R_i = V_i / I_i = 1/g_m}$$

$$R_o = V_x / I_x$$

so



$$\boxed{R_o = R_D}$$

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

$$V_{gs} = -V_i$$

$$\boxed{A_v} = V_o / V_i = \boxed{+ g_m (R_D \| R_L)}$$

$$\boxed{G_V = + g_m (R_D \| R_L) \frac{1}{1 + g_m R_{sig}}}$$

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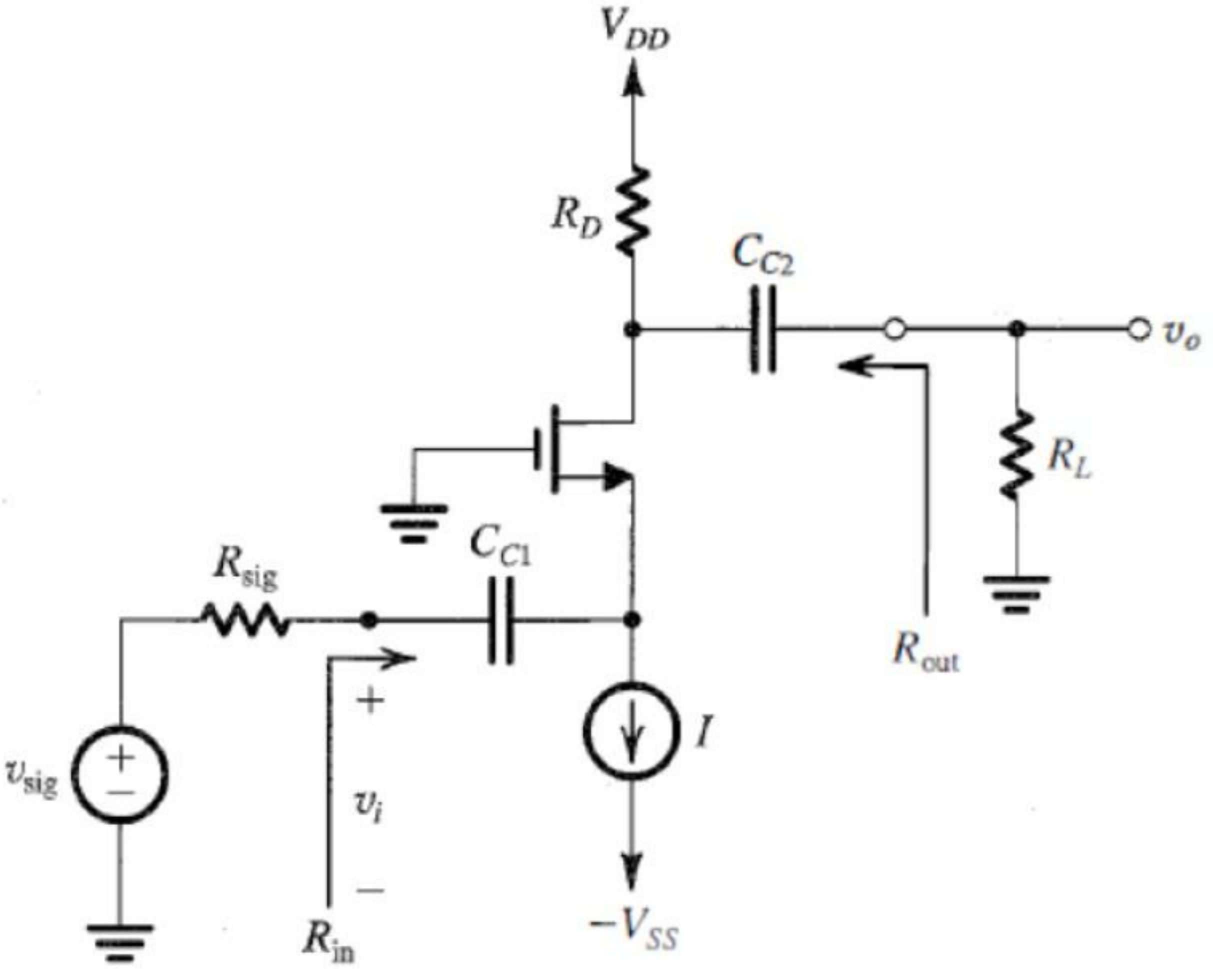

Neglecting r_o:

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

$$A_v = g_m(R_D \parallel R_L)$$

$$R_{out} = R_D$$

$$G_v = \frac{1}{1 + g_m R_{sig}} g_m(R_D \parallel R_L)$$

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The Common-Gate (CG) Amplifier

- **Because of its low input resistance, the CG amplifier alone has very limited application. One such application is to amplify high-frequency signals that come from sources with relatively low resistances. These include cables, where it is usually necessary for the input resistance of the amplifier to match the characteristic resistance of the cable.**

- **The CG amplifier has excellent high-frequency response. Thus it can be combined with the CS amplifier in a very beneficial way that takes advantage of the best features of each of the two configurations.**

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Summary and Comparisons of MOSFET Configurations

- The CS configuration is the best suited for realizing the bulk of the gain required in an amplifier. Depending on the magnitude of the gain required, either a single stage or a cascade of two or three stages can be used.

- The low input resistance of the CG amplifier makes it useful only in specific applications. It has a much better high-frequency response than the CS amplifier. This superiority makes it useful as a high-frequency amplifier, especially when combined with the CS circuit.

- The source follower finds application as a voltage buffer for connecting a high resistance source to a low-resistance load and as the output stage in a multistage amplifier where its purpose is to equip the amplifier with a low output resistance.

Thank You

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Have a Wonderful Semester