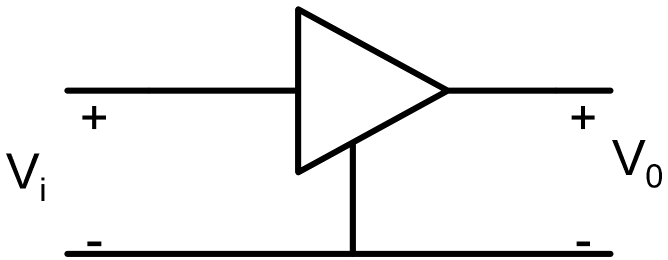
ESC201T : Introduction to Electronics

Lecture 25: Amplifiers-1

B. Mazhari
Dept. of EE, IIT Kanpur

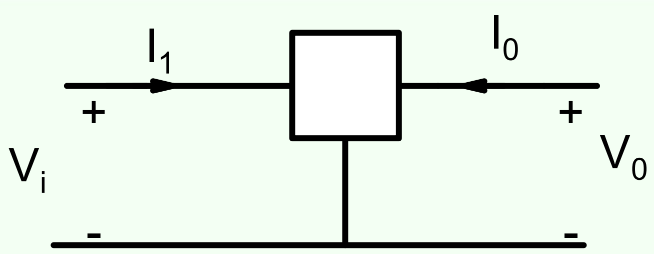
“Amplification is the heartbeat of Electronics”

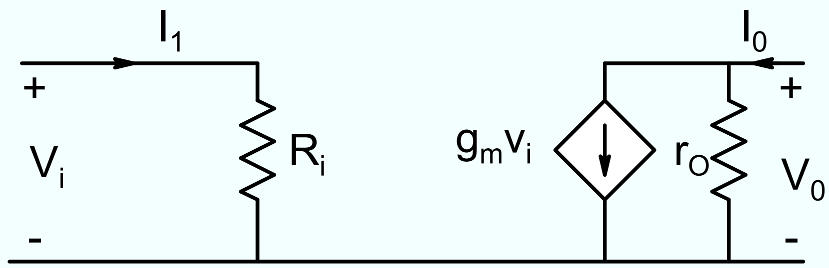
Voltage Amplification



$$V_o = G \times V_i$$
$$G > 1 \text{ and constant}$$

Consider a 3-terminal unilateral linear device

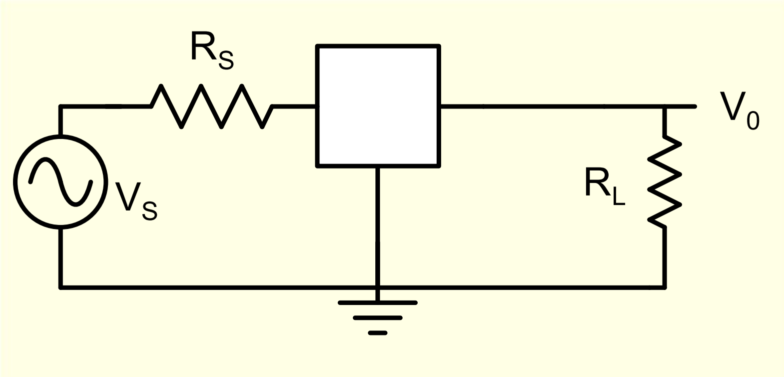


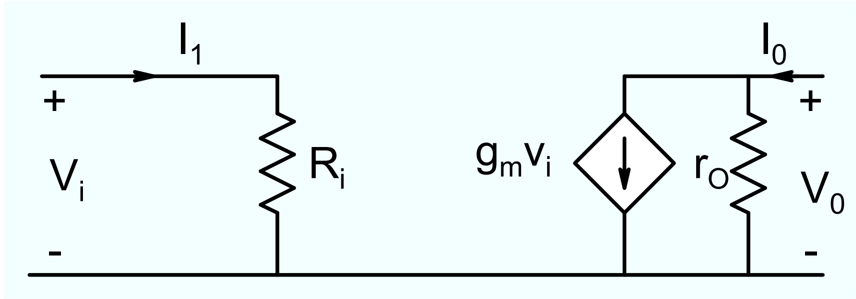


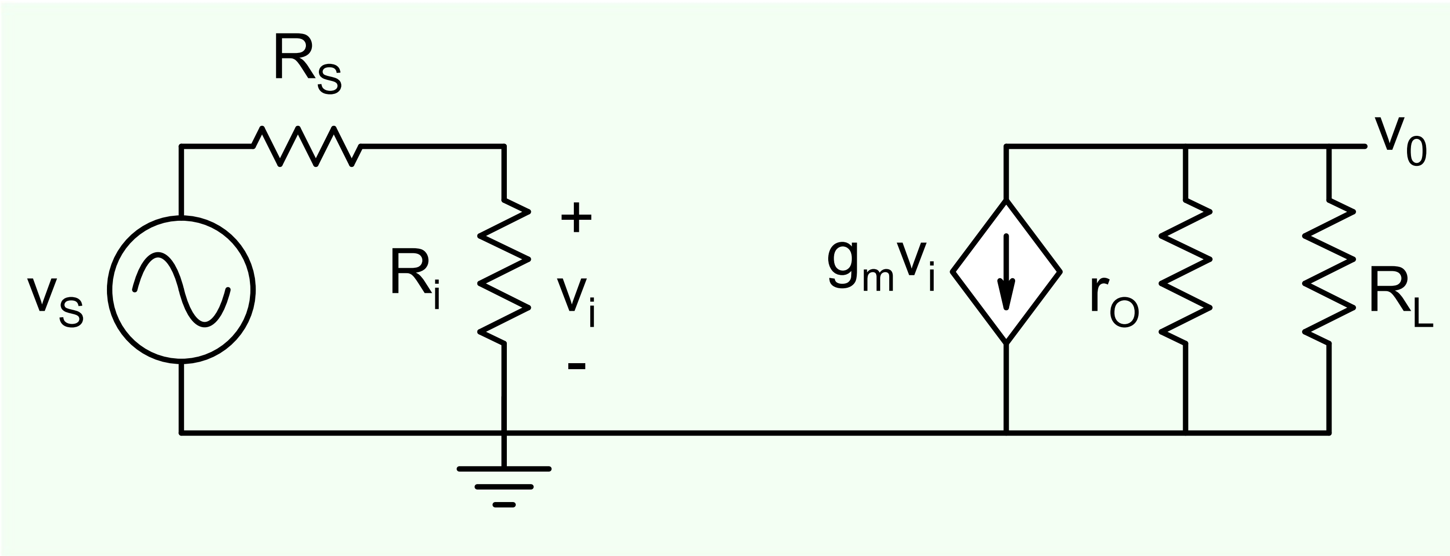
R_i=input resistance=V_i/I_i ; Transconductance:$g_m = \left.\frac{I_o}{V_i}\right|_{V_O=0}$

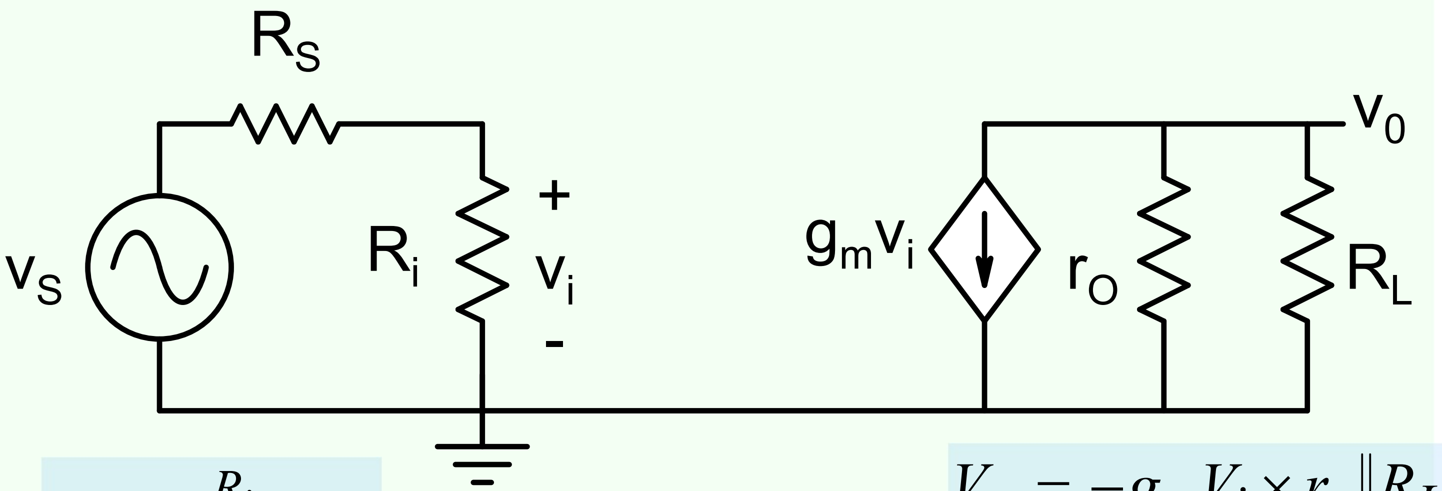
Output conductance:$g_o = 1/r_o = \left.\frac{Io}{V_o}\right|_{V_i=0}$

Voltage Amplifier









$$V_i = \frac{R_i}{R_i + R_S} V_S$$

$$V_o = -g_m V_i \times r_o \| R_L$$

$$A_V = \frac{V_o}{V_s} = -g_m r_o \times \frac{R_L}{r_o + R_L} \times \frac{R_i}{R_i + R_S}$$

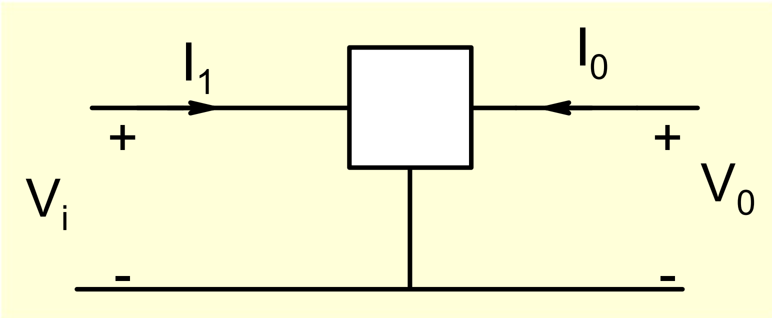
$$|A_V| \le g_m \times r_o$$

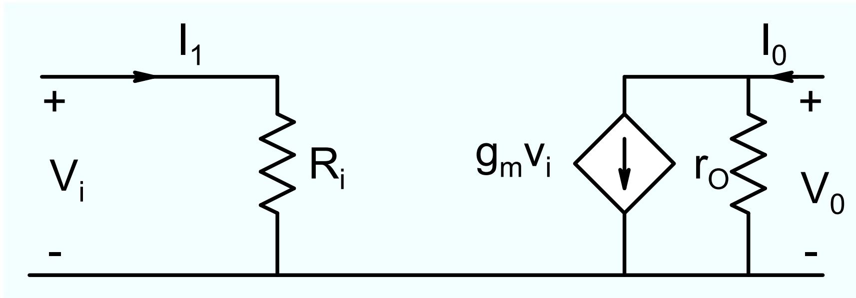
Necessary Condition for Voltage Amplification : $g_m \times r_o > 1$

Voltage Amplification

$$g_m r_o >> 1 \qquad g_m >> g_o$$

Transconductance >> Output Conductance



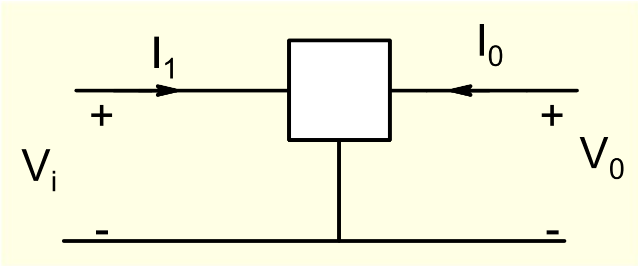


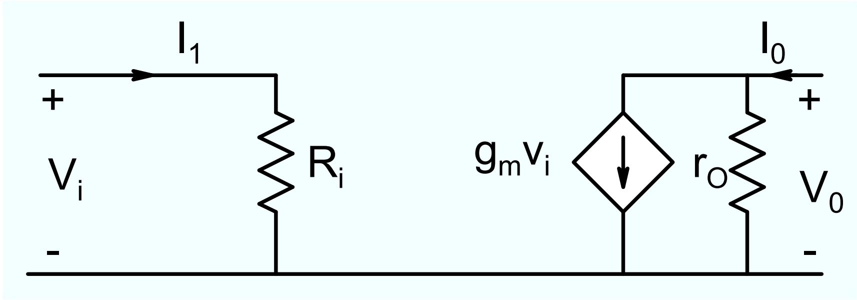
Transistor

Transistor

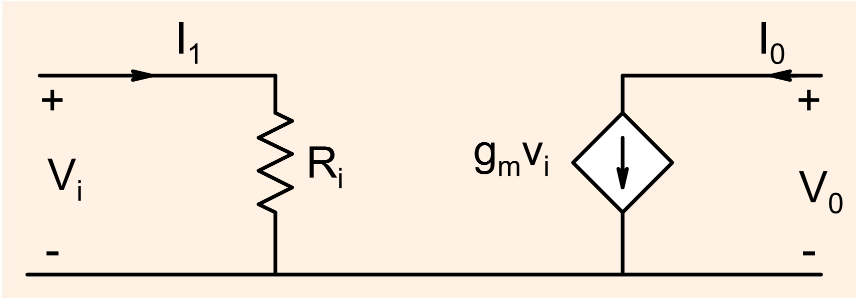
Trans-resistor

Current I_O is much more sensitive to V_{IN} than V_O





$$g_m\, r_o >> 1$$



In the ideal case r_o is infinite

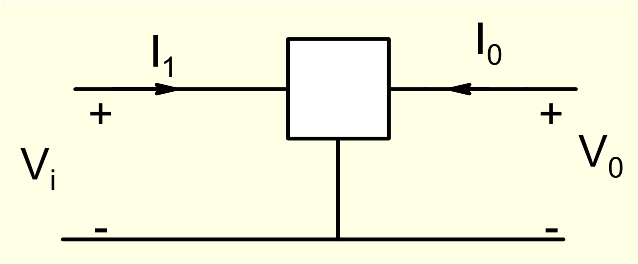
$$A_V = \frac{V_o}{V_s} = -g_m r_o \times \frac{R_L}{r_o + R_L} \times \frac{R_i}{R_i + R_S} = -g_m R_L \times \frac{R_i}{R_i + R_S}$$

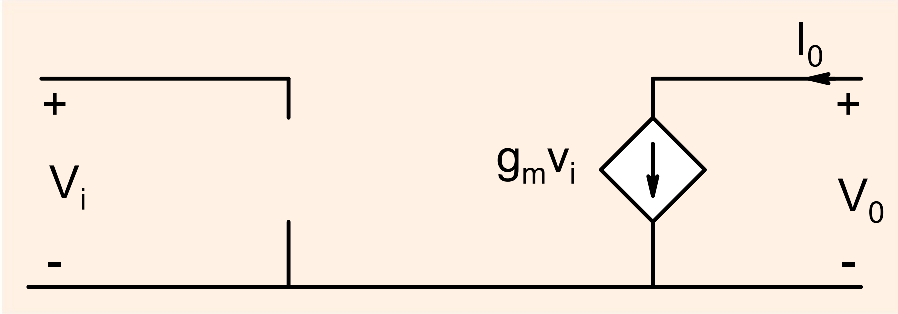
We would ideally like input resistance R_i to be infinite as well !

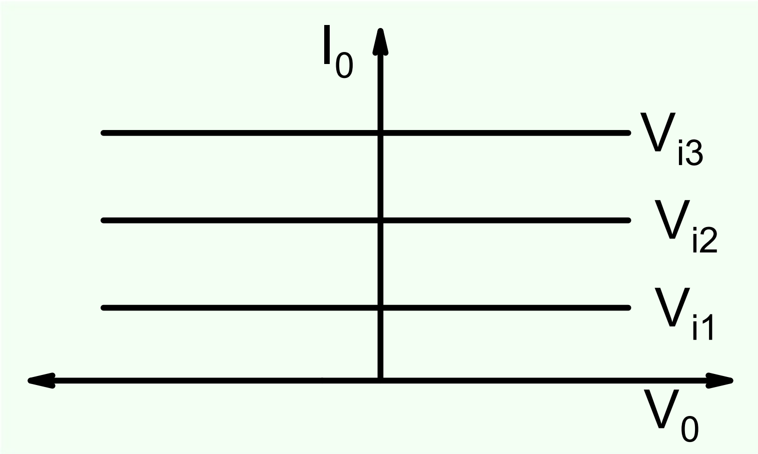
$$A_V = -g_m R_L$$

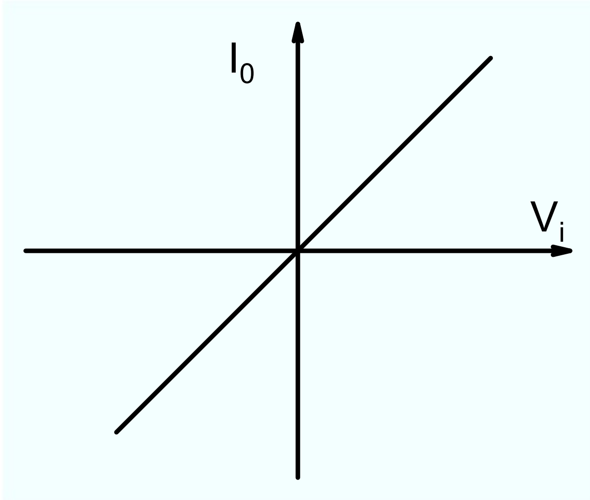
Note that we have power gain as well which is essential for calling a device as an Amplifier

An ideal 3-terminal device for Voltage Amplification





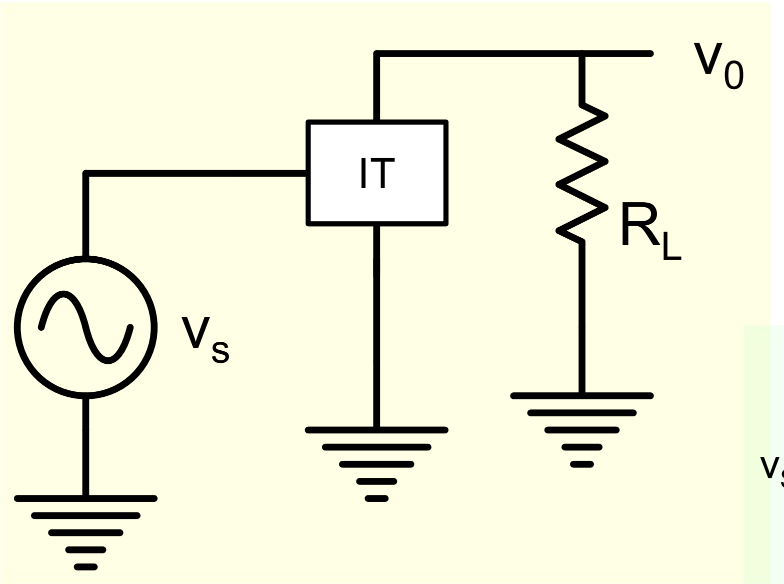


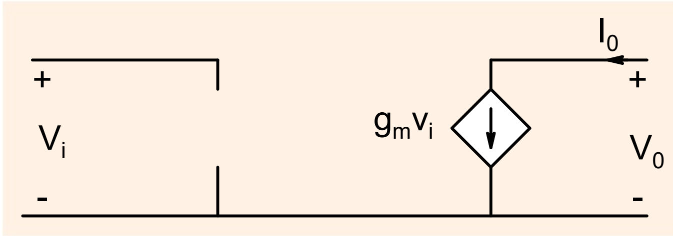


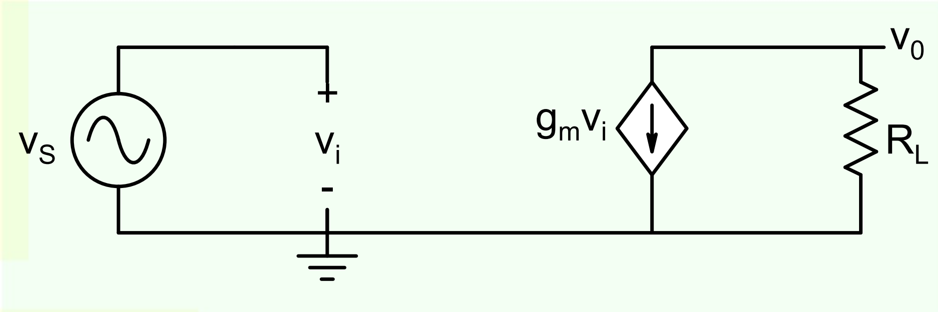
Ideal Transistor Characteristics

Ideal Transistor (IT)

Making a voltage amplifier with an ideal transistor is straightforward



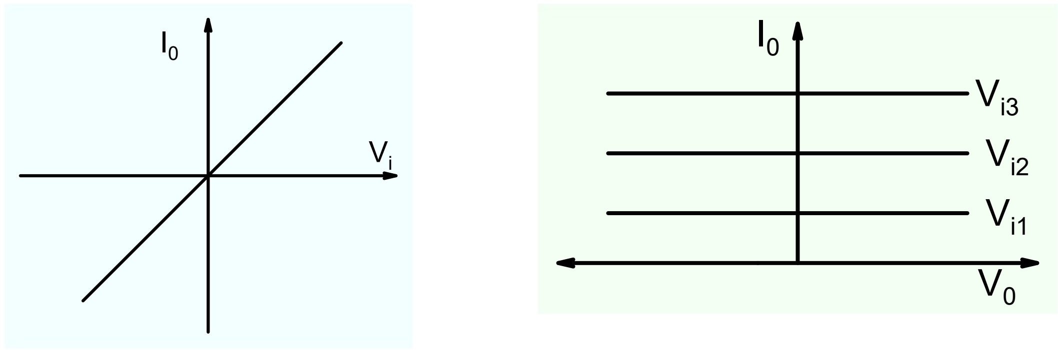




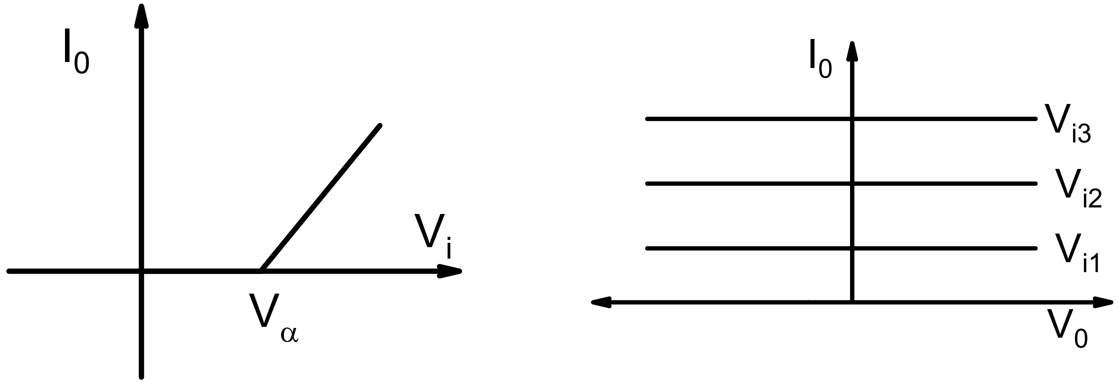
$$A_V = \frac{v_o}{v_s} = -g_m R_L$$

In practice there is no element which has the characteristics of ideal transistor !

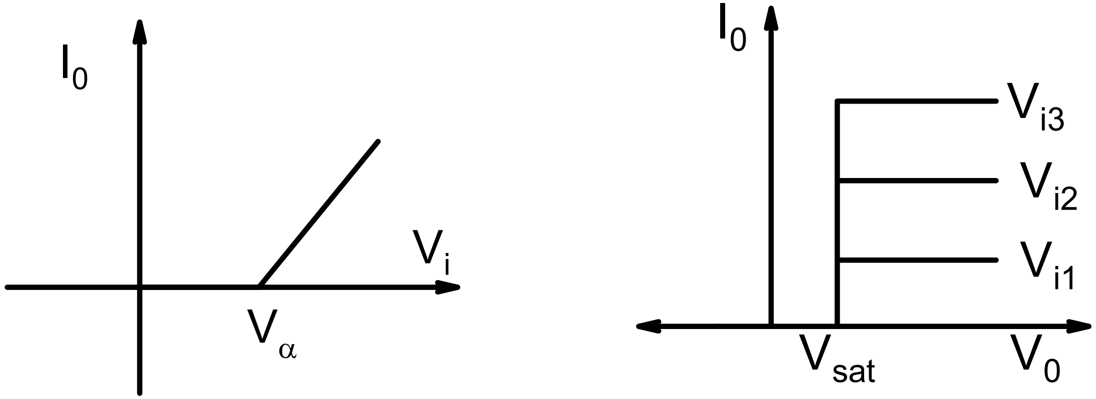
Ideal transistor



Device X

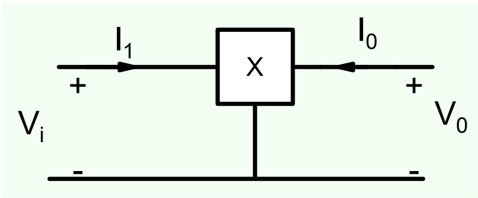


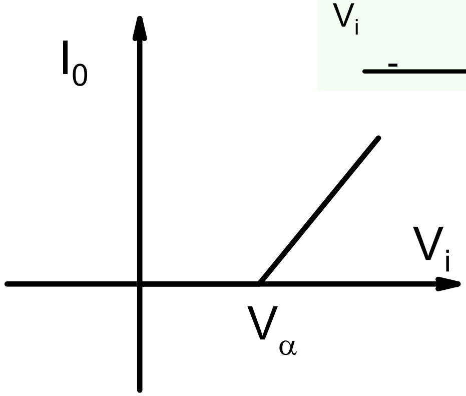
Device Y

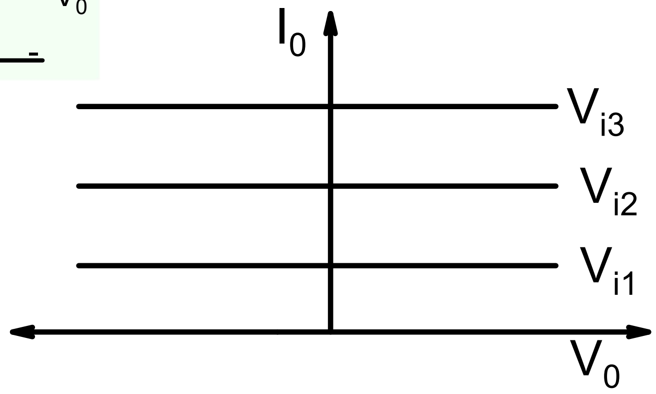


How do we use elements such as X, Y etc to make amplifiers?

Device X

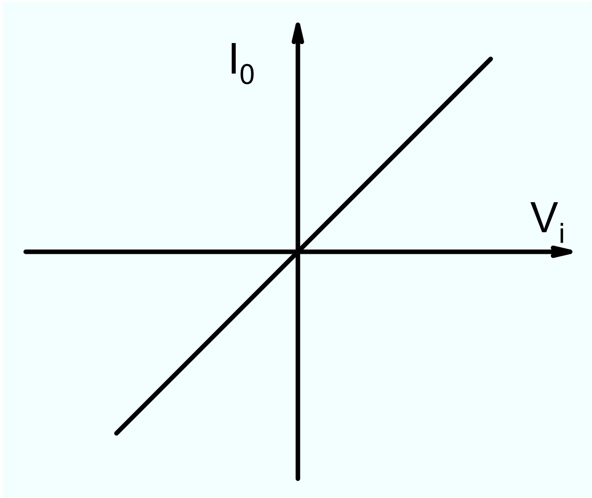


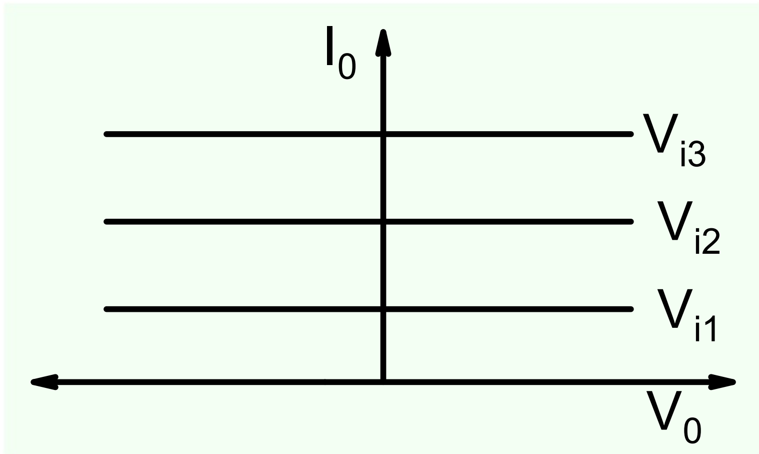




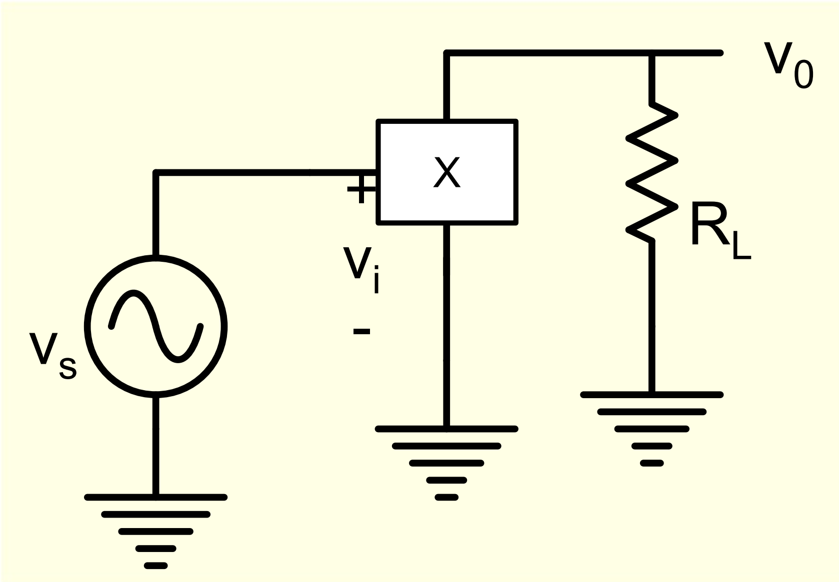
$$\begin{aligned} I_o &= 0 && \text{for } V_i \leq V_\alpha \\ &= g_m \times (V_i - V_\alpha) && \text{for } V_i > V_\alpha \end{aligned}$$

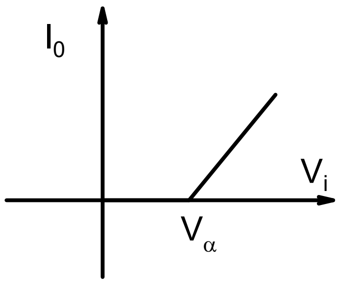
Ideal Characteristics

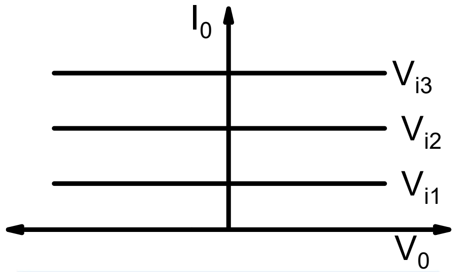




How do we use device X to make an amplifier?

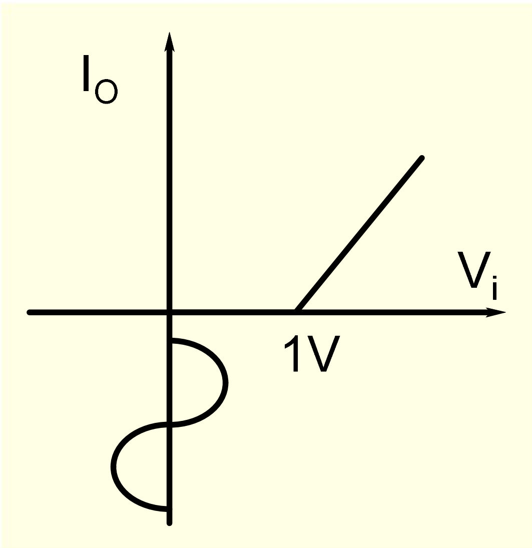






$V_\alpha = 1V; \; g_m = 0.01\Omega^{-1}$

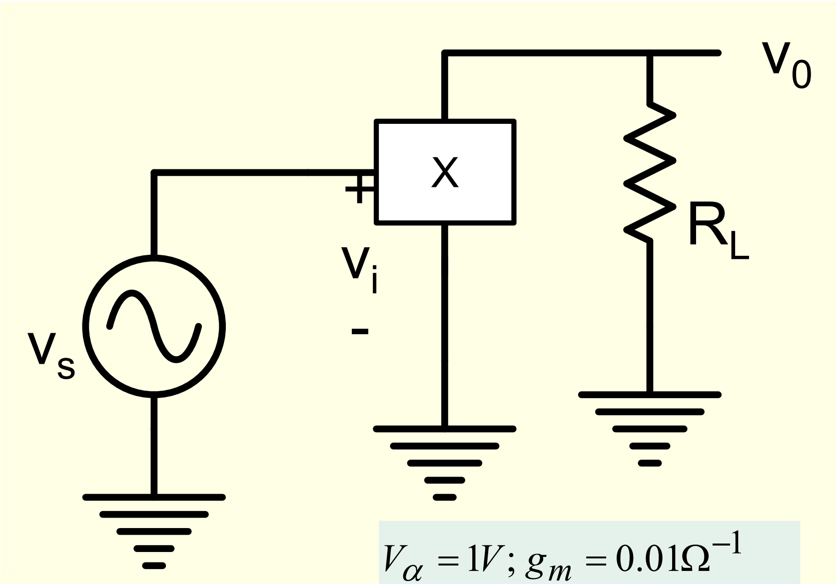
$R_L = 1K \; ; \; v_s = 0.5V \; Sin\, \omega t$



$$I_O = 0 \Rightarrow V_O = 0$$

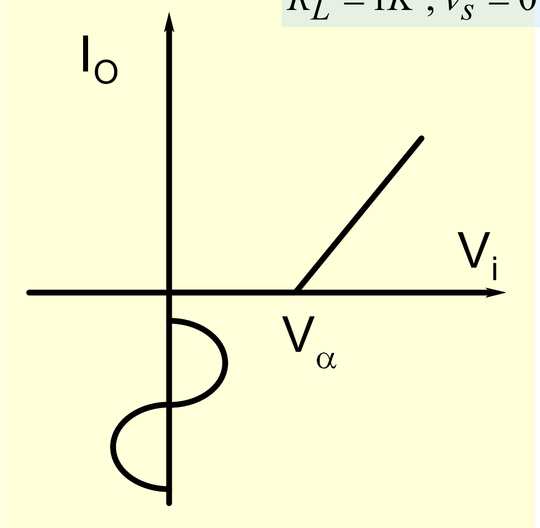
No Amplification

How do we use device X to make an Amplifier?

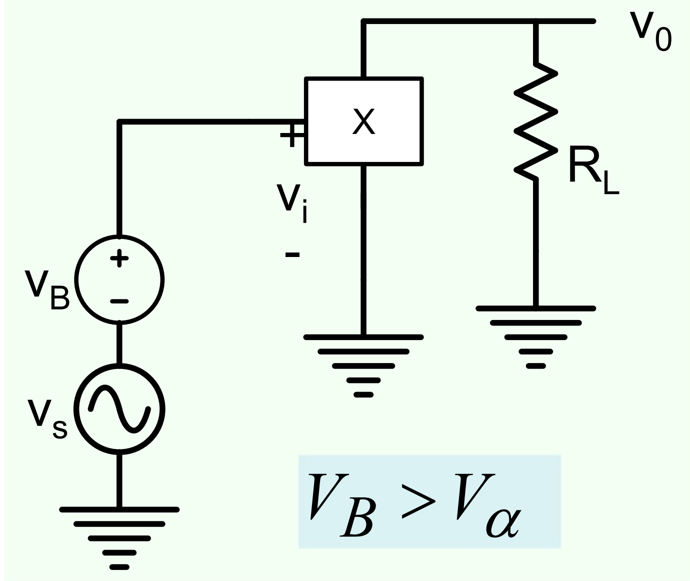


$V_\alpha = 1V ; g_m = 0.01\Omega^{-1}$

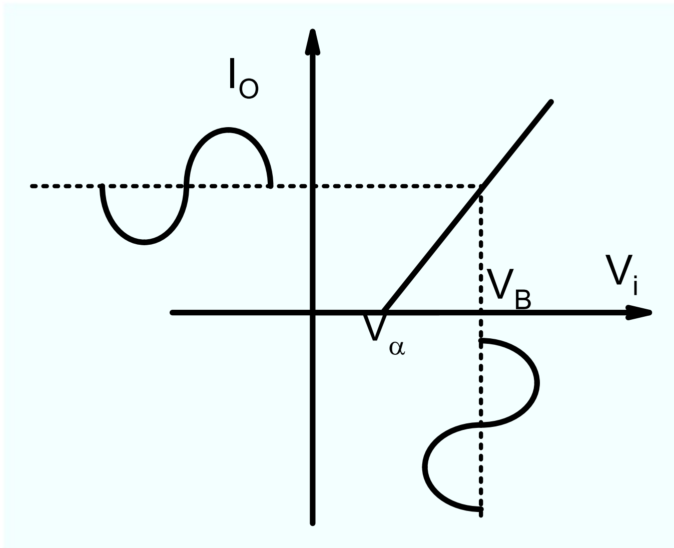
$R_L = 1K ; v_s = 0.5V \ Sin\ \omega t$



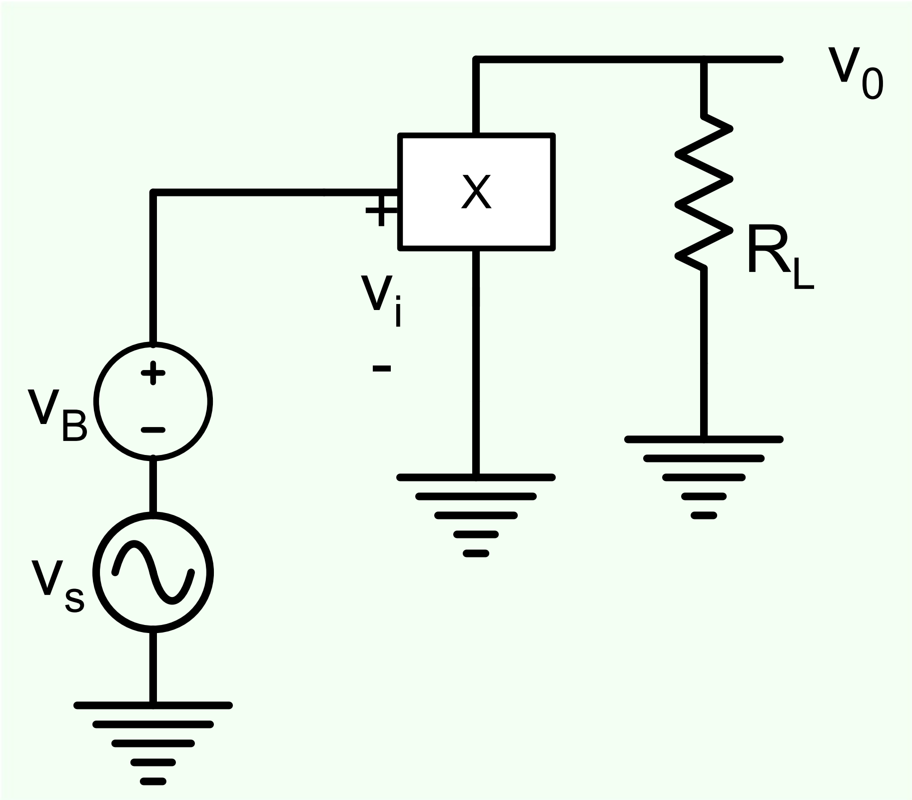
$V_O = -I_O \ R_L$

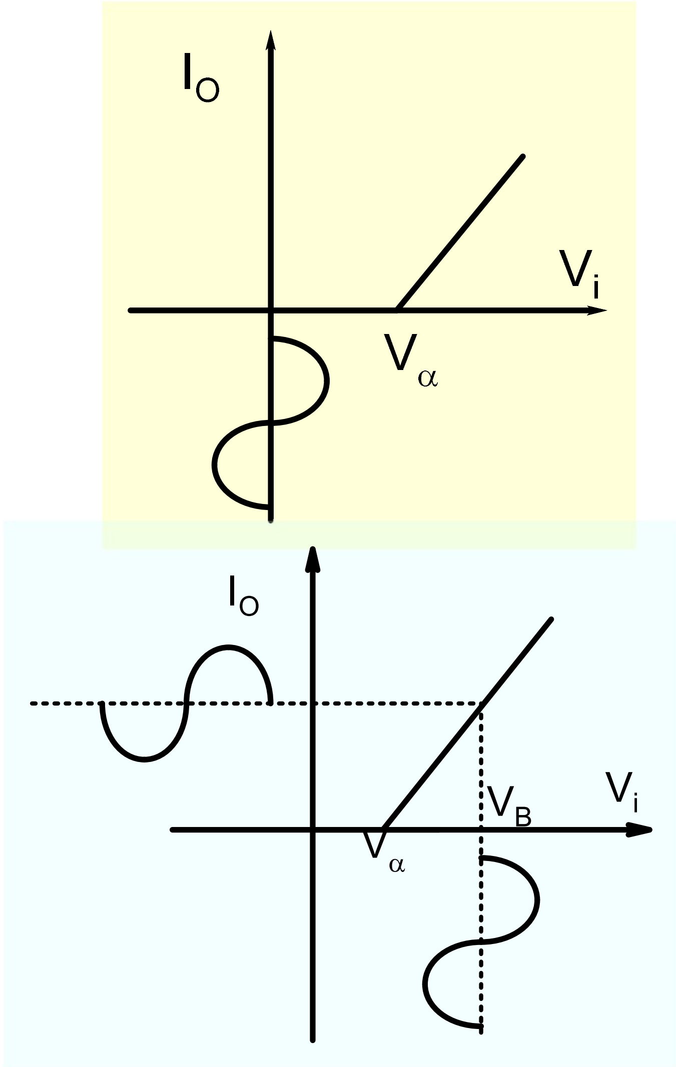


$V_B > V_\alpha$

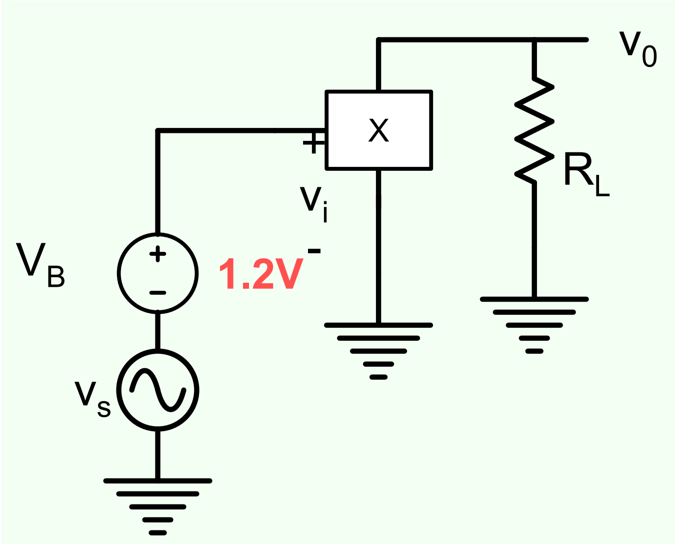


When only a part of device characteristics is suitable for amplification, then we need to push the device into that region by applying suitable bias voltages. This process is called BIASING

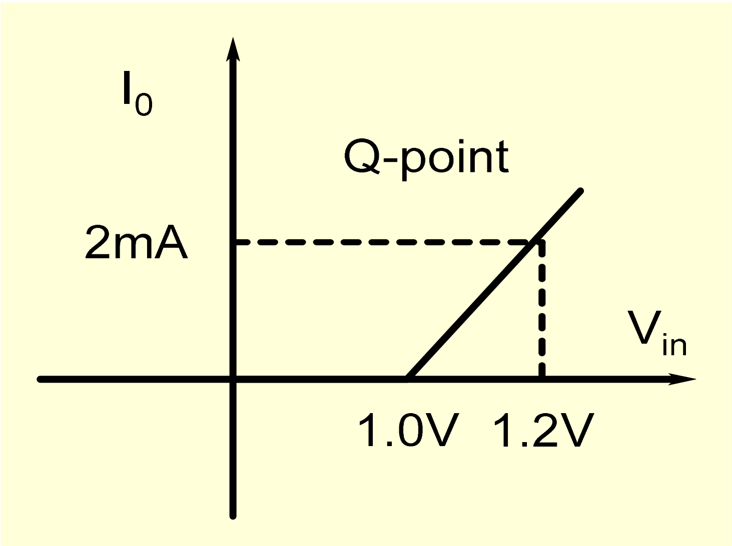




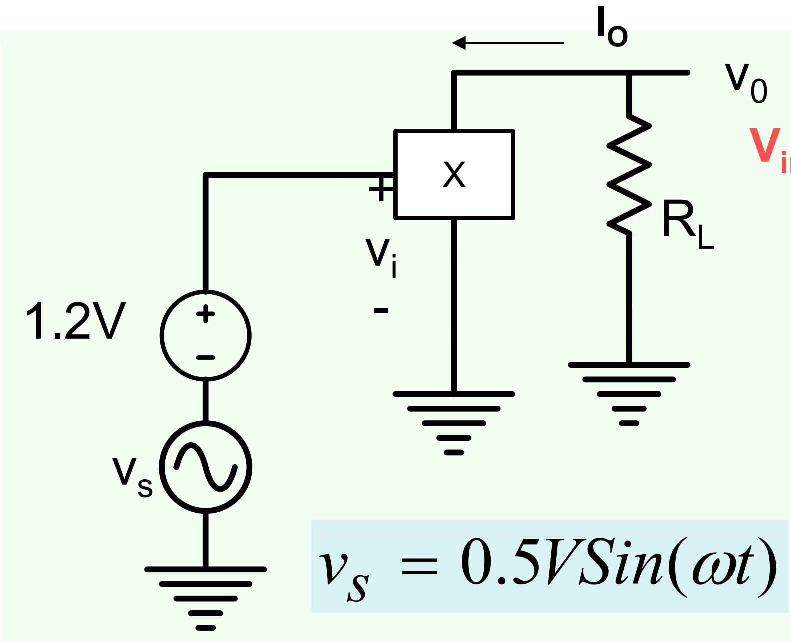
How should one choose the bias voltage V_B ?



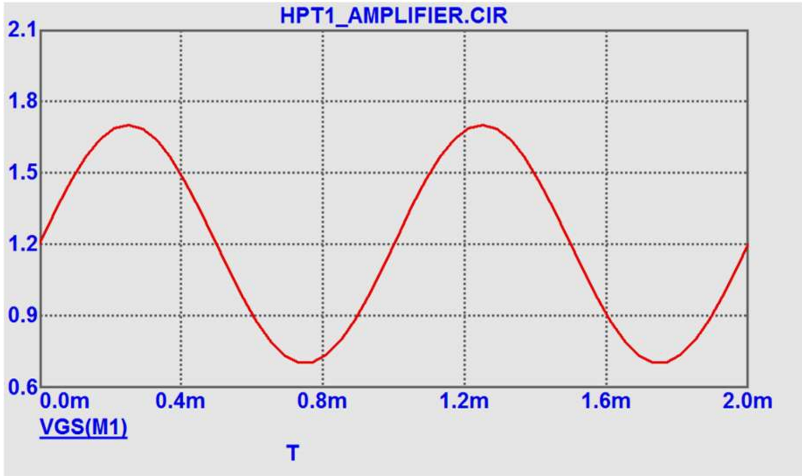
$$v_s = 0.5V\ Sin\ \omega t$$

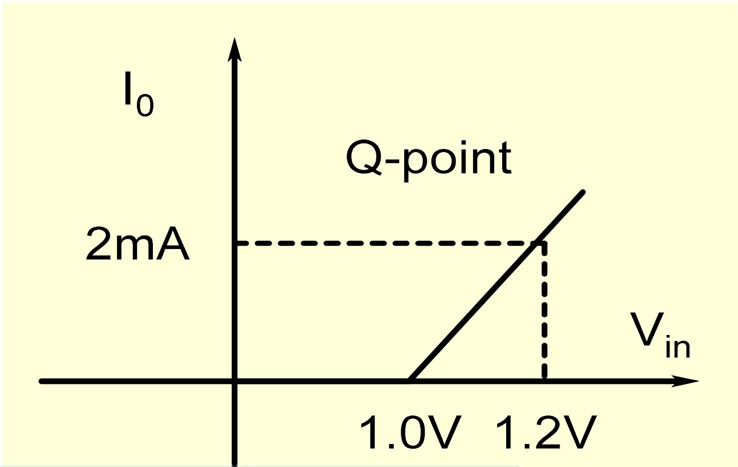


Quiescent point or Bias point

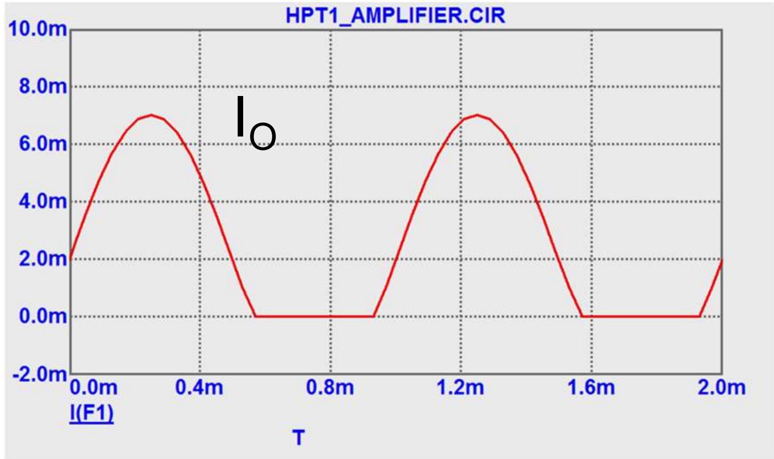


$$v_s = 0.5V Sin(\omega t)$$



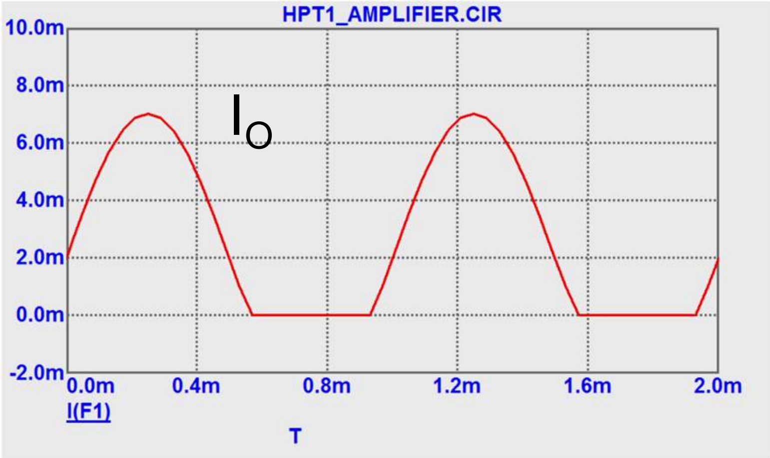


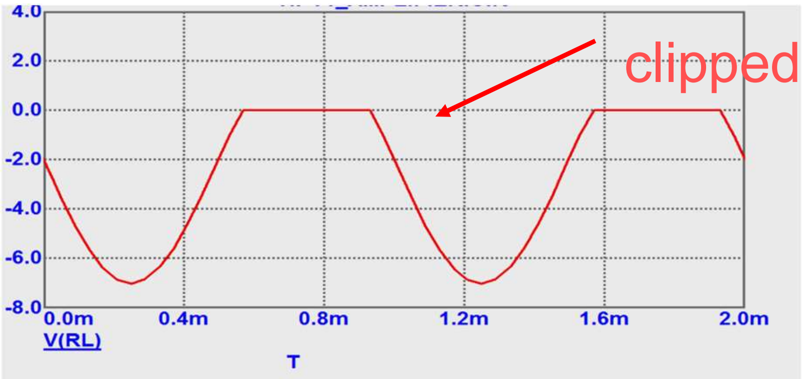
$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

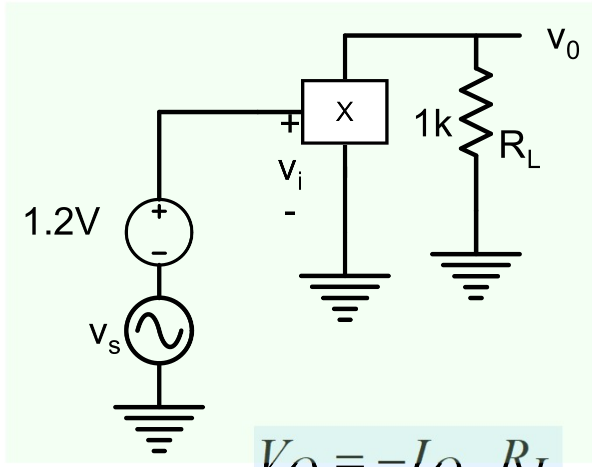


$$V_O = -I_O\ R_L$$

Output voltage is distorted !



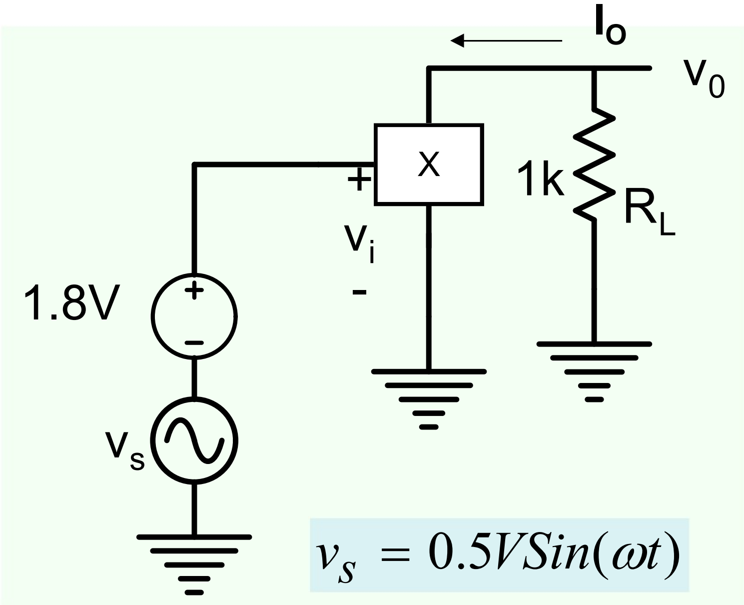




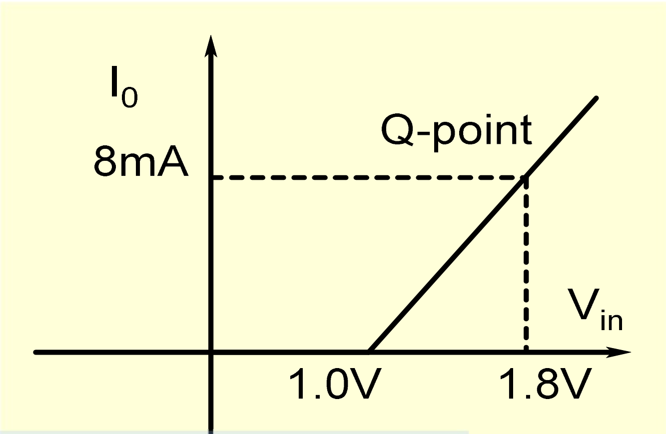
$$V_O = -I_O \ R_L$$

Need to choose a proper value of biasing Voltage

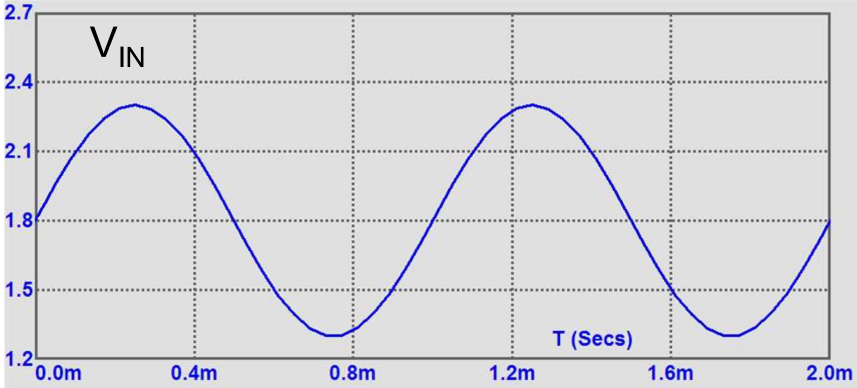
Unnecessary Power Dissipation

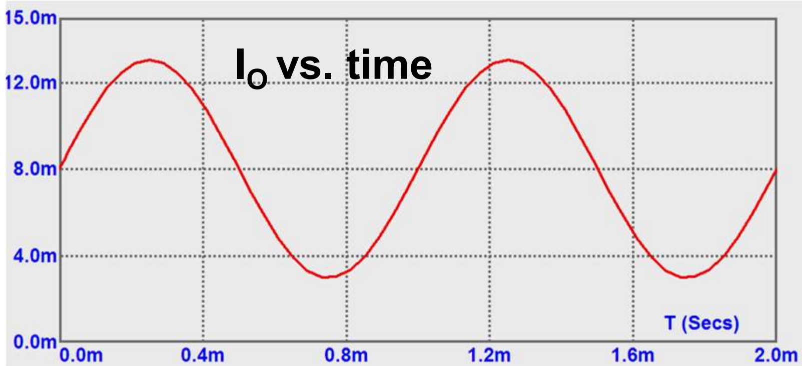


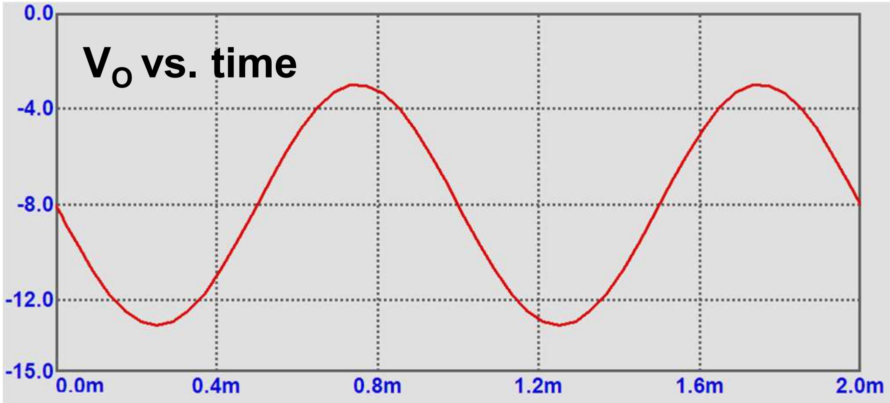
$$v_s = 0.5V Sin(\omega t)$$



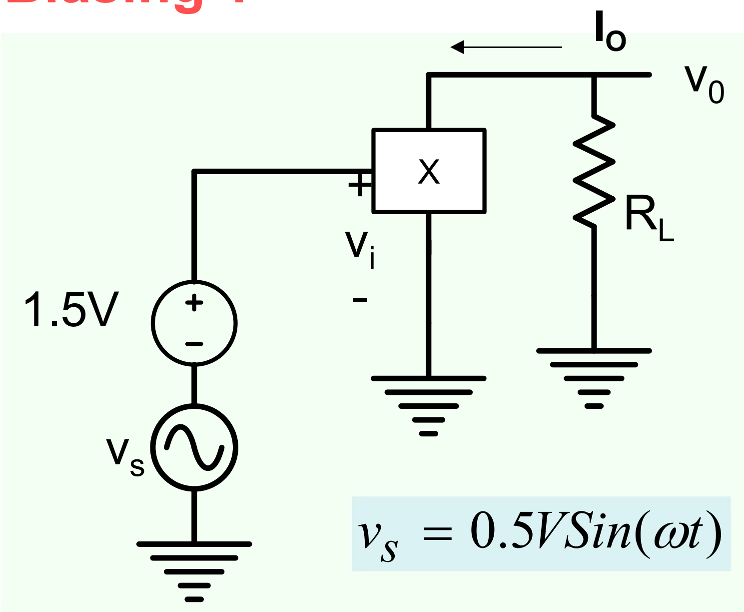
$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$



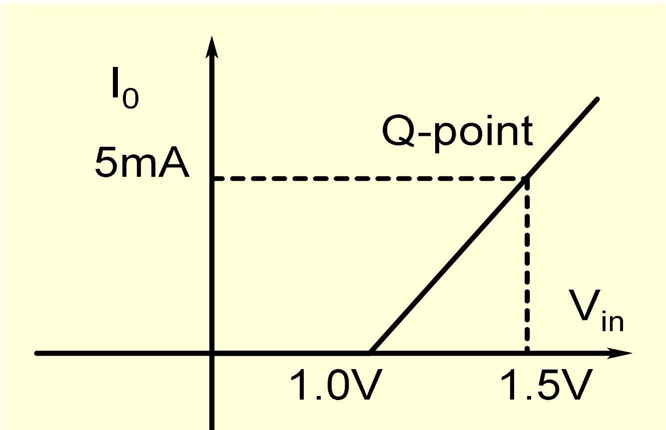




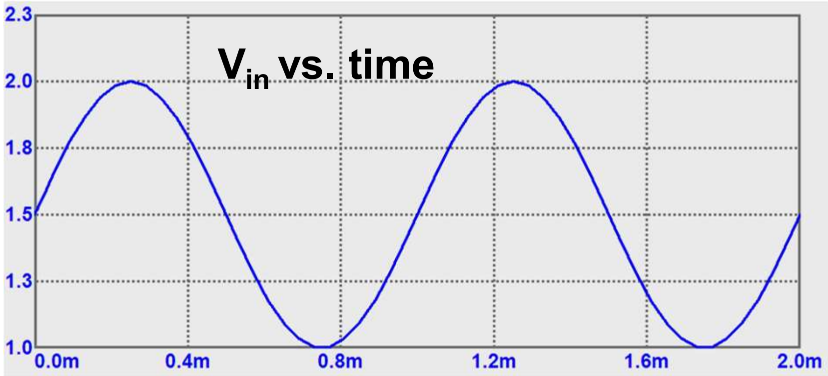
Optimum Biasing ?

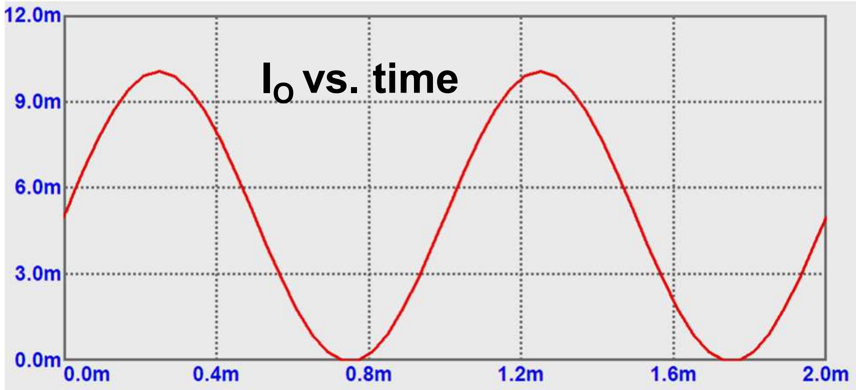


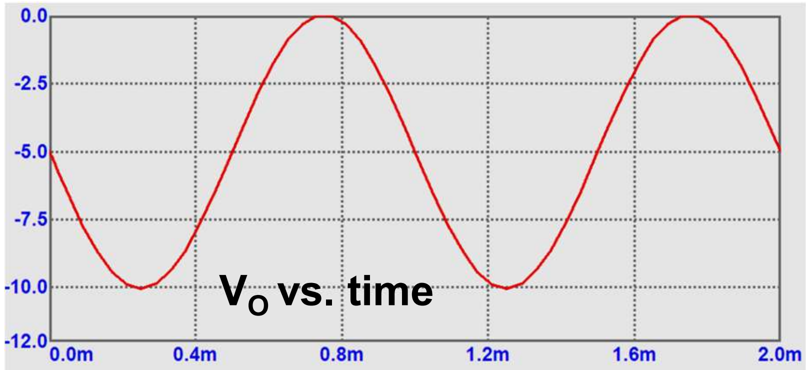
$$v_s = 0.5VSin(\omega t)$$



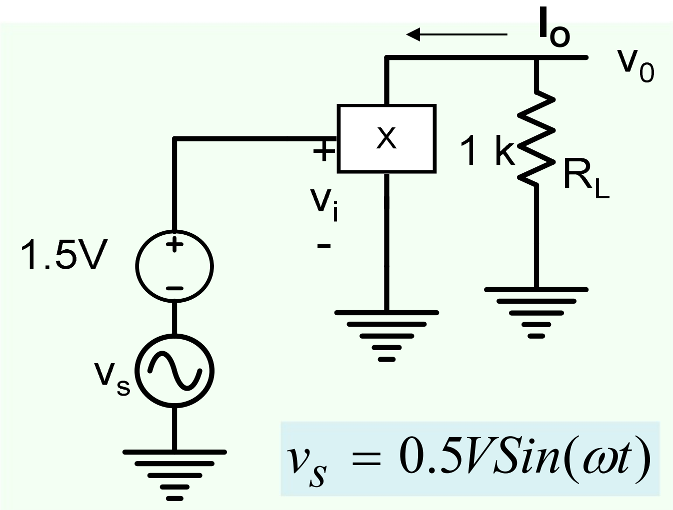
$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

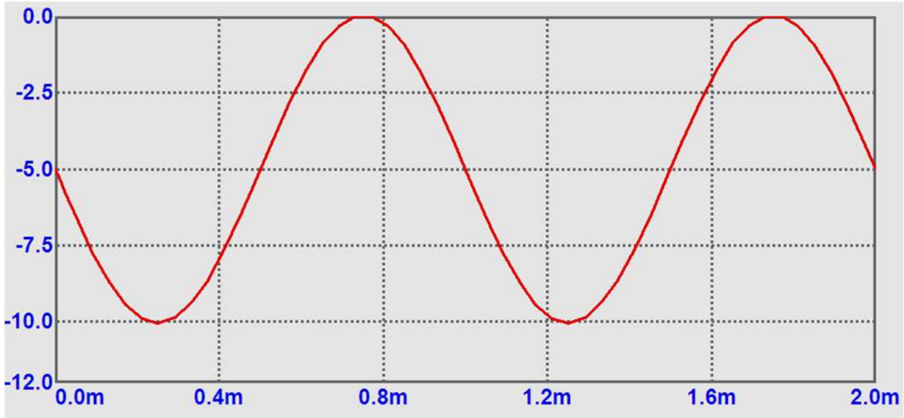


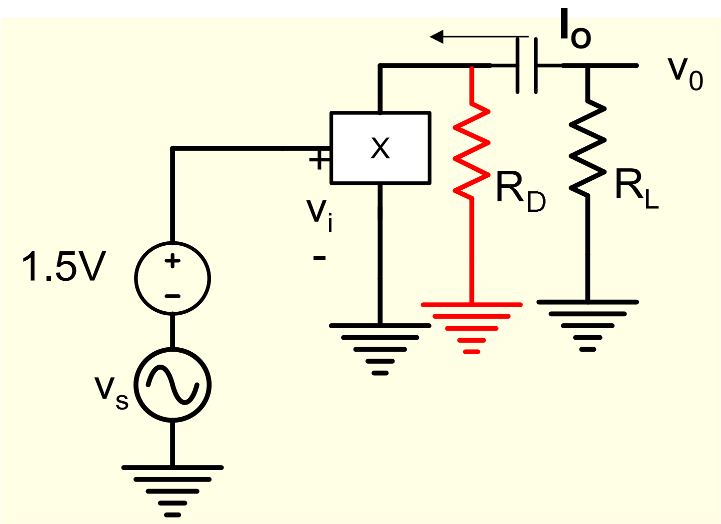


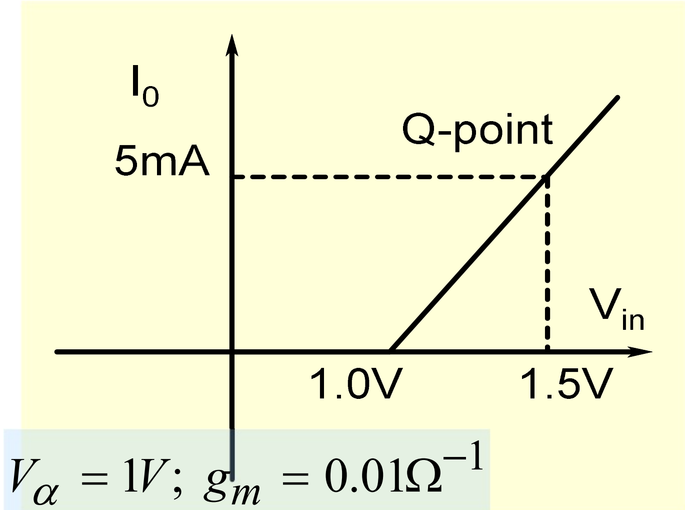


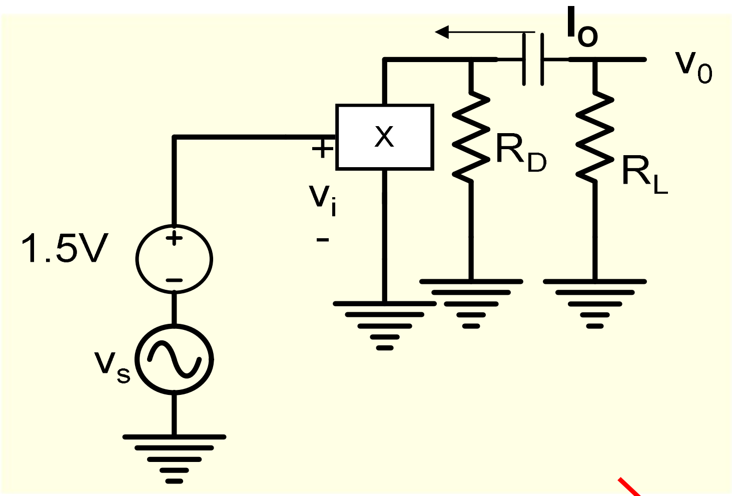
How do we get rid of unwanted dc voltage at the output ?

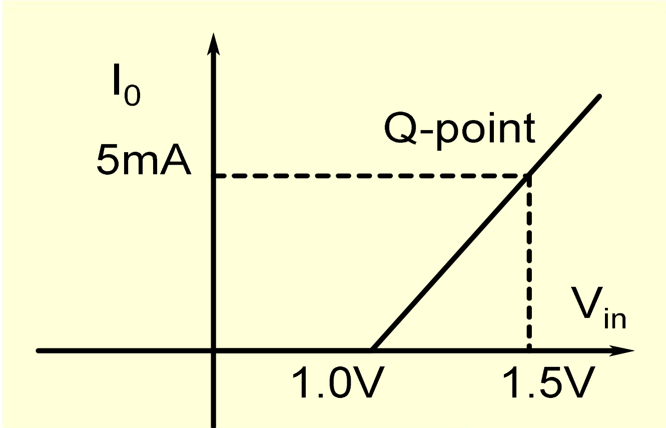








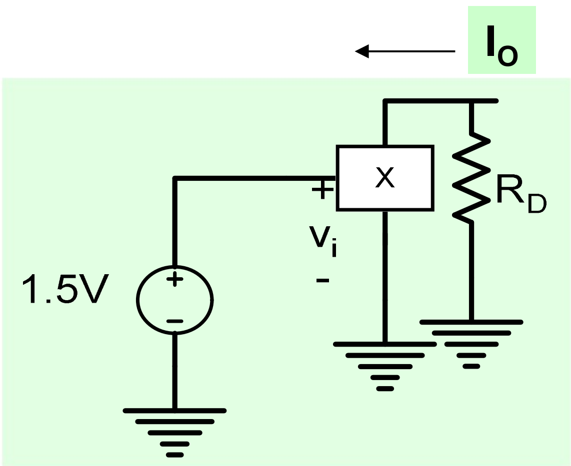


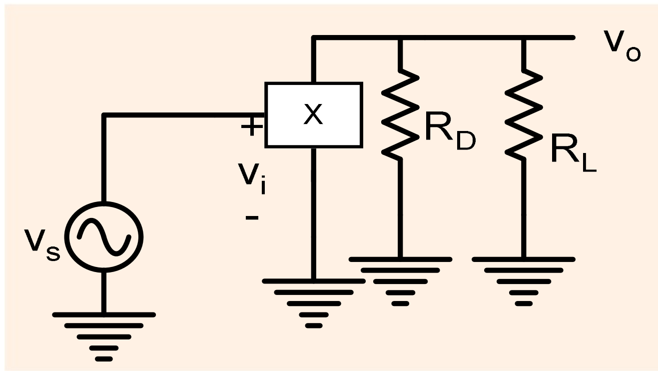


$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

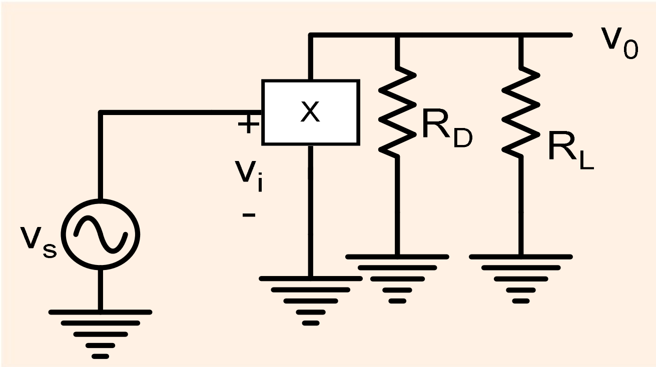
dc

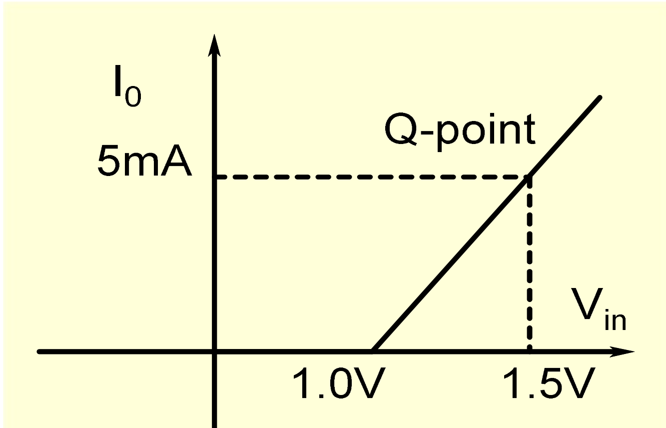
ac (signal)





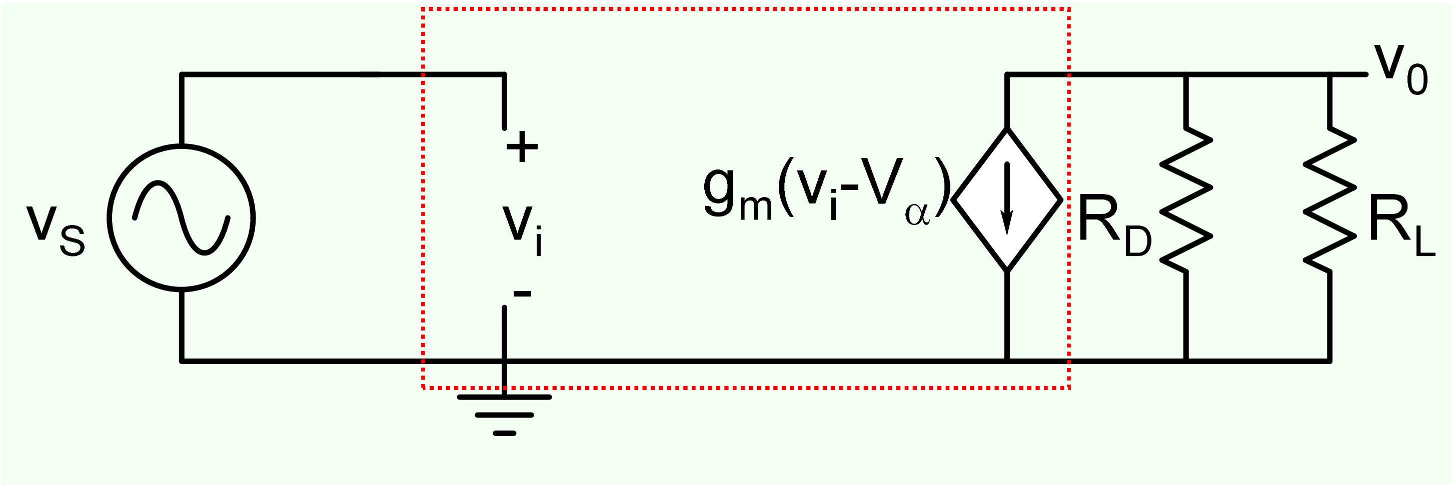
Capacitor is chosen large enough so that at the signal frequency $1/j\omega C \sim 0$.



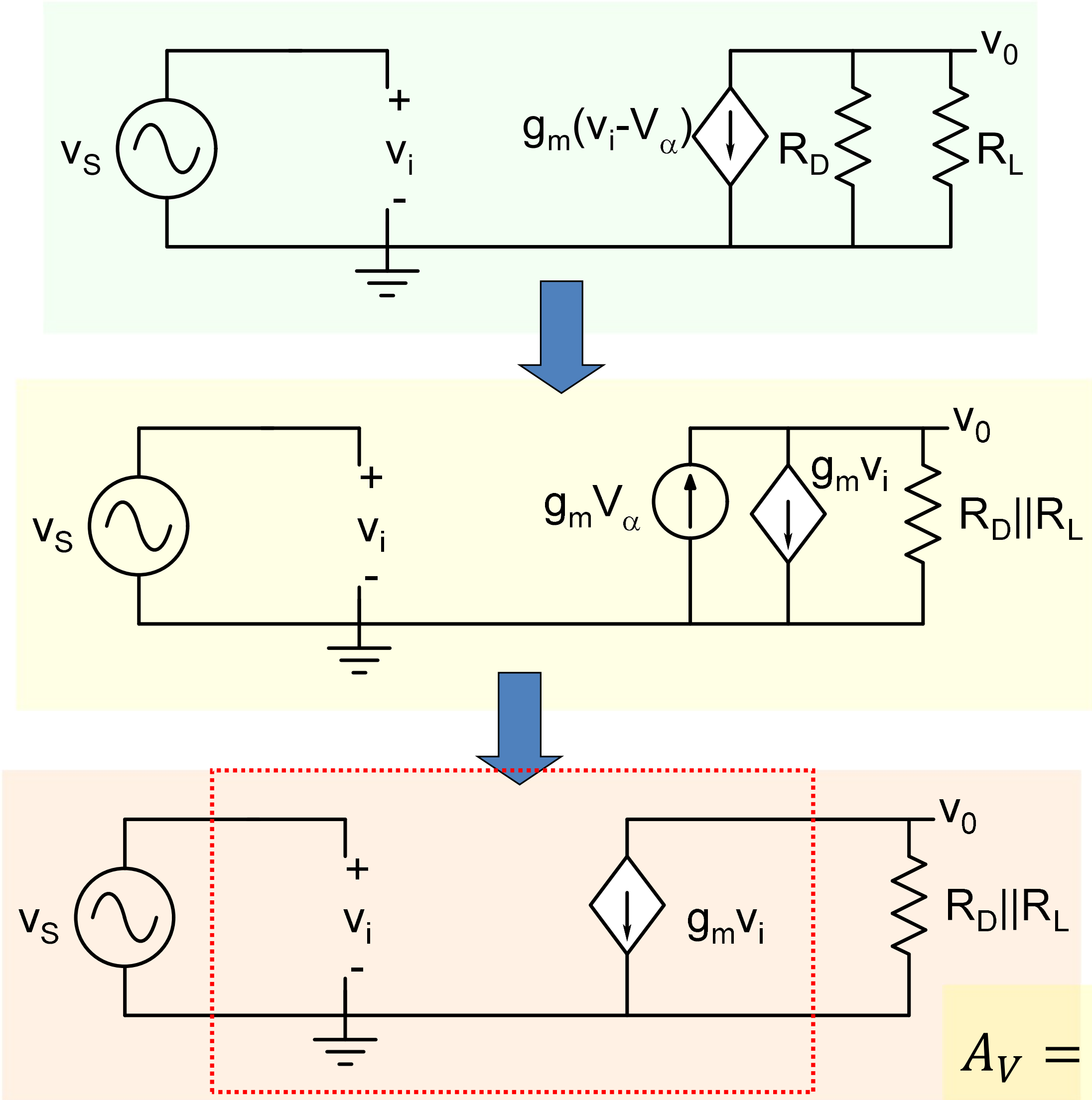


$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

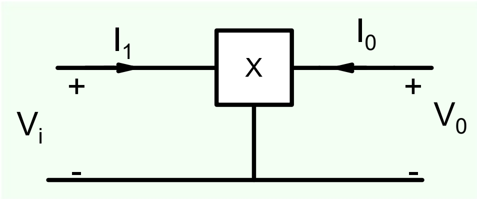
$I_o = g_m \times (V_i - V_\alpha)$ for $V_i > V_\alpha$

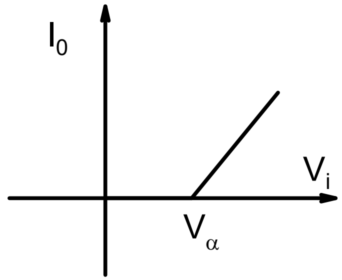


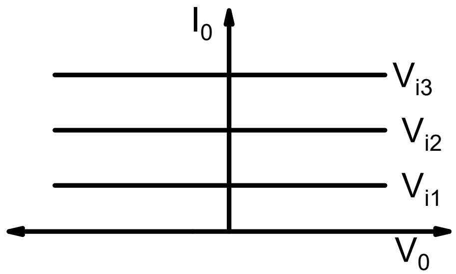
Ac Analysis

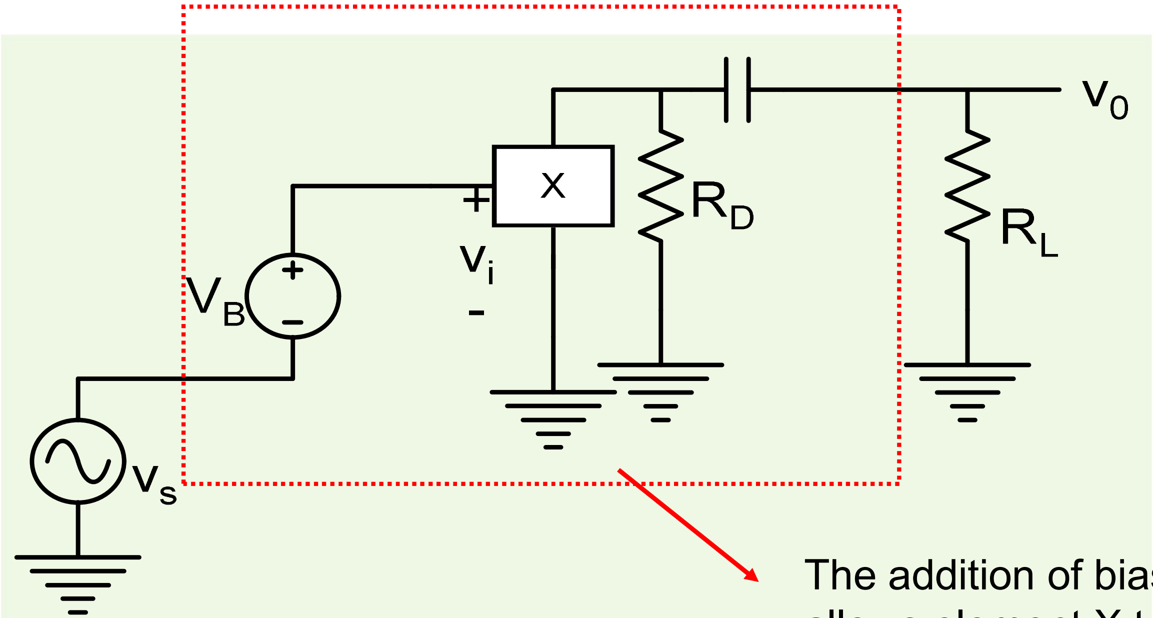


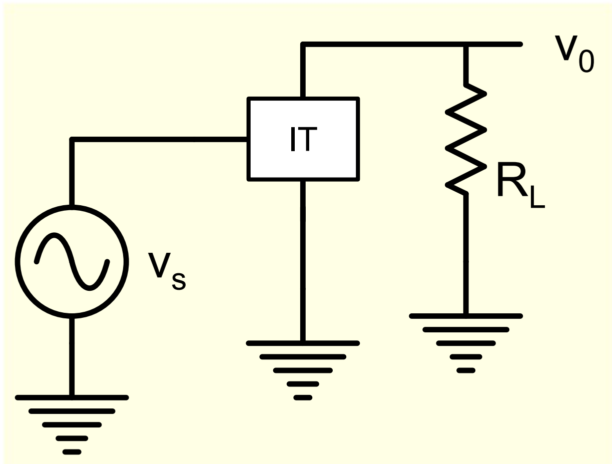
$$A_V = \frac{v_o}{v_s} = -g_m R_D \| R_L$$





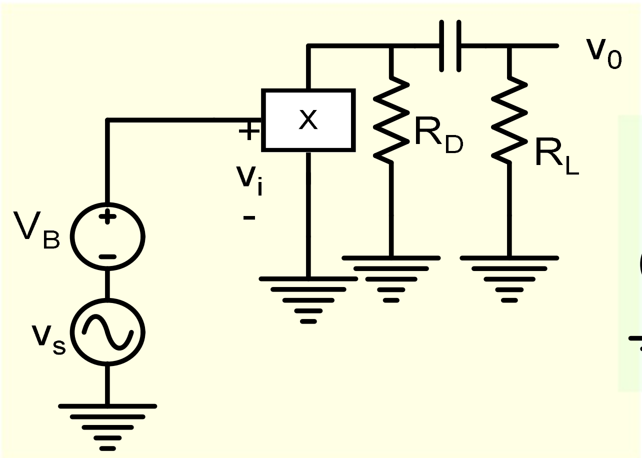


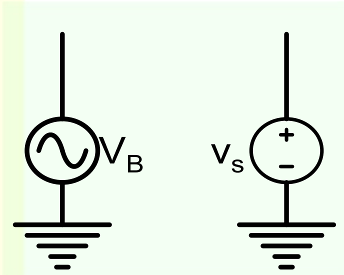


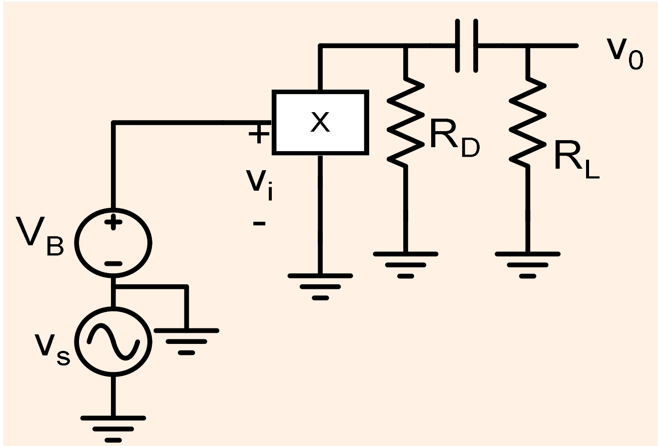


The addition of biasing network allows element X to appear as an ideal transistor to the signal source

What happens if both dc voltage source and signal source have one terminal as ground?

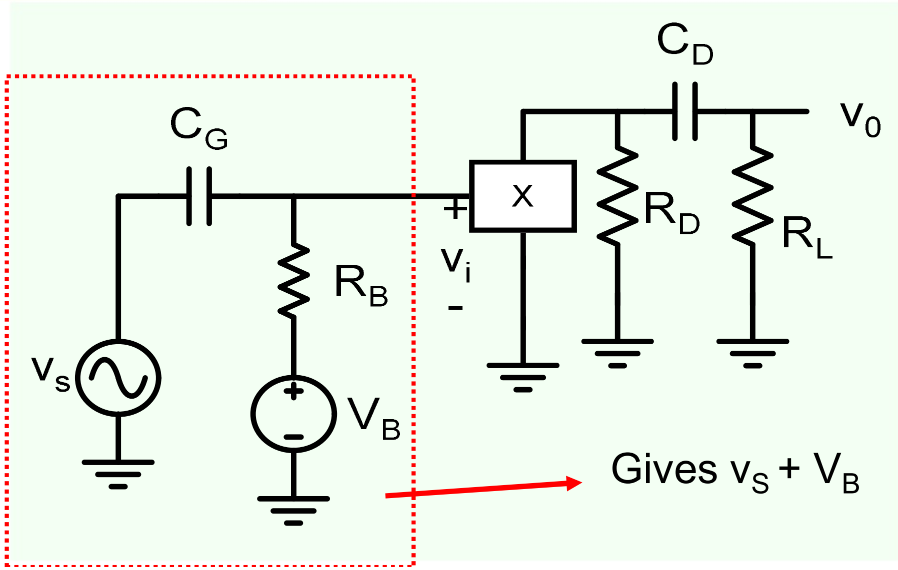


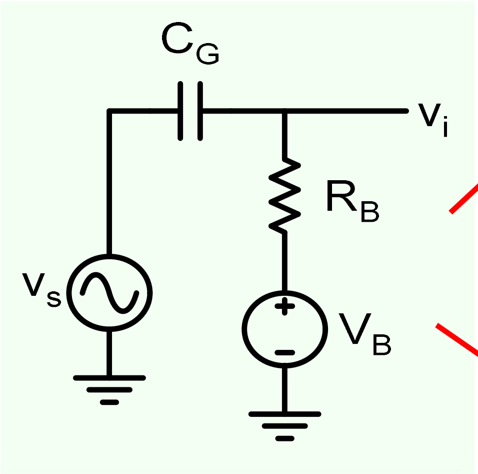


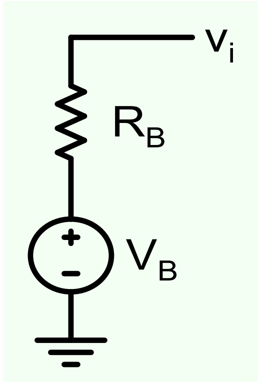


Shorts the signal source

Solution

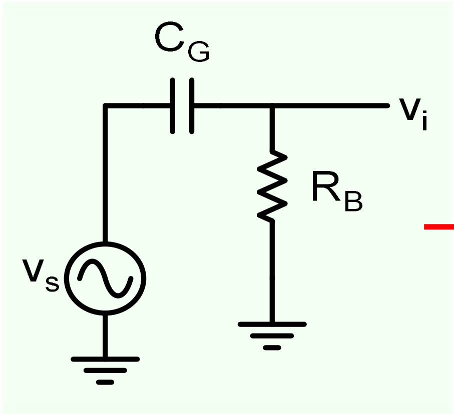


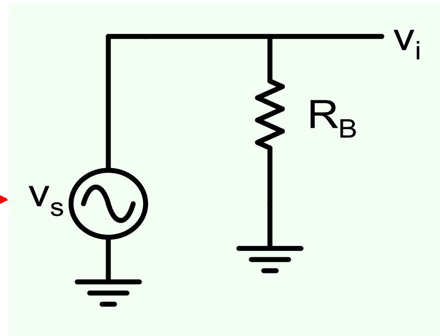




$$v_i = V_B$$

Capacitor is chosen large enough so that at the signal frequency 1/jωC ~0.





$$v_i = v_s$$

$$v_i(total) = v_s + V_B$$

Note the role of R_B

Amplifier Schematic