ESc201 : Introduction to Electronics

Amplifiers

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Objective

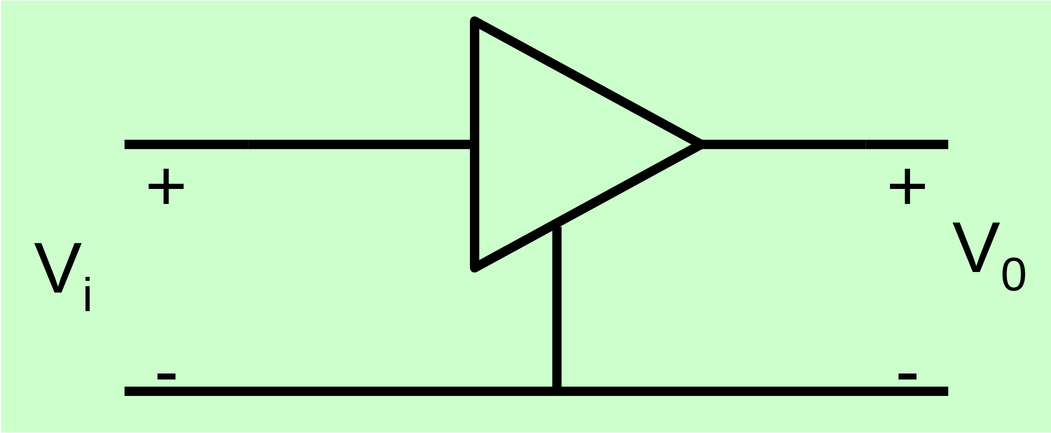
1. Learn ideal Transistor characteristics required for Voltage Amplification

2. Learn to build amplifiers using elements which have non-ideal characteristics.

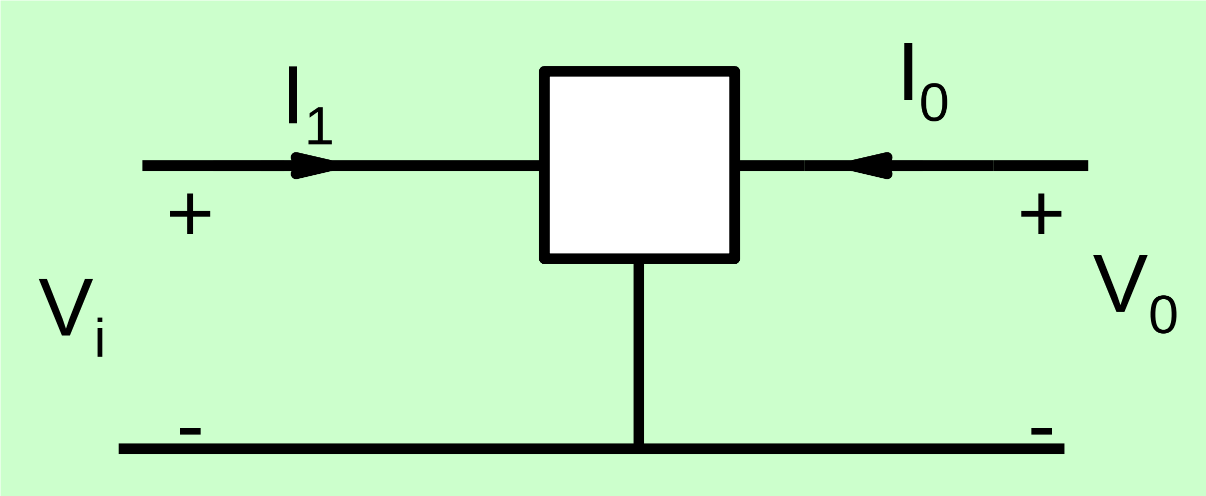
Voltage Amplification

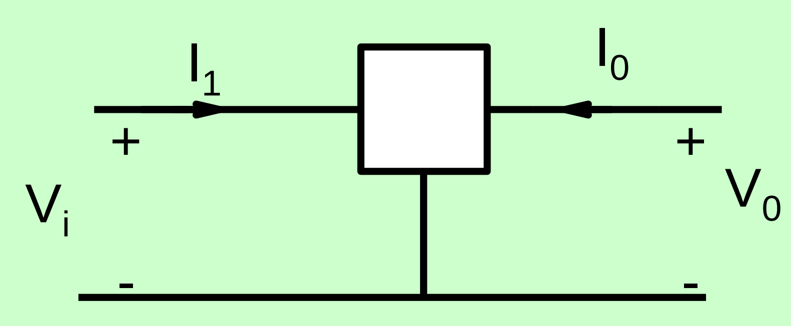
$$V_o = G \times V_i$$

$$G > 1$$



3-terminal unilateral linear device





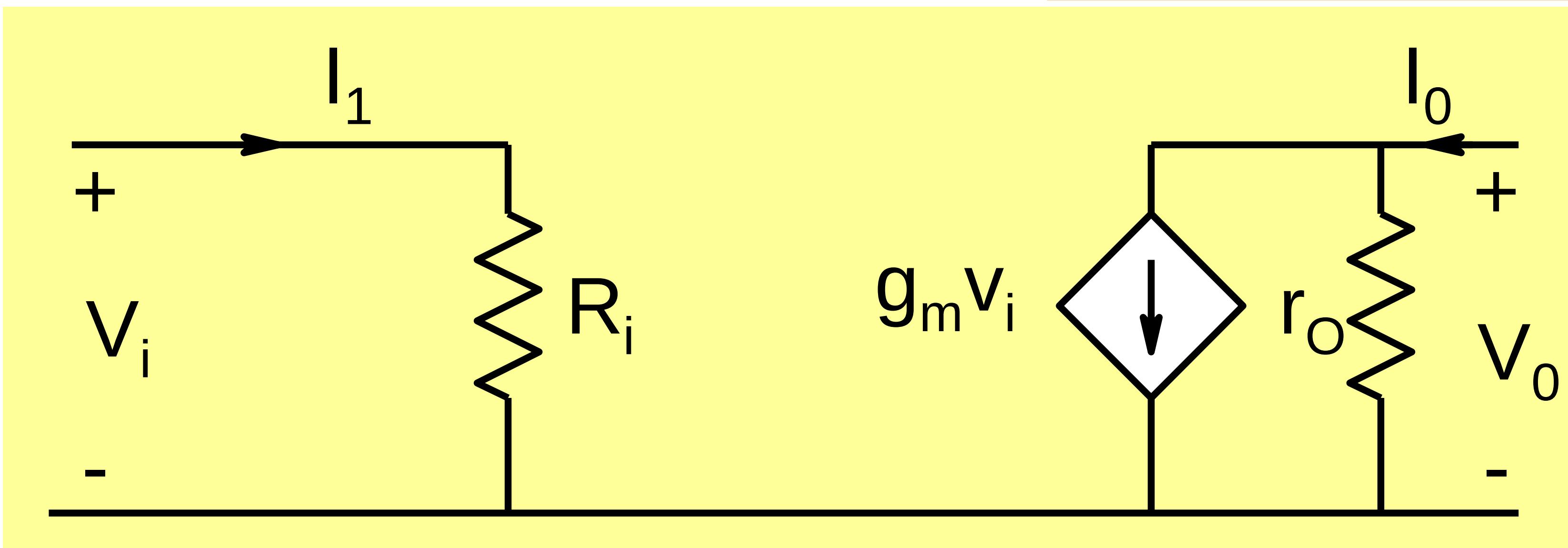
Input resistance $R_i = V_i / I_i$

(Ideally large)

Trans conductance

$$g_m = \left.\frac{I_o}{V_i}\right|_{V_0 = 0}$$

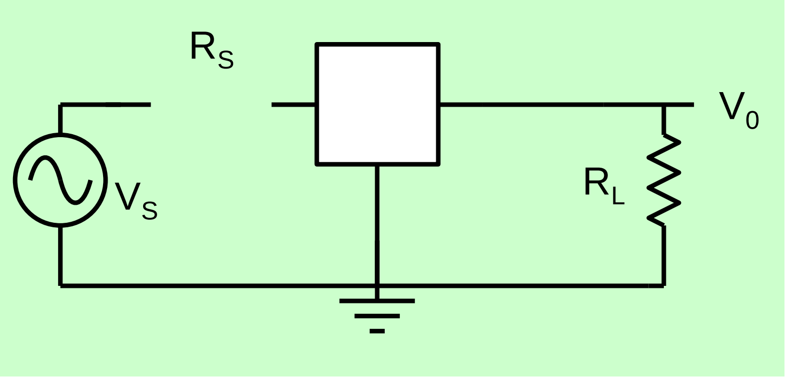
(Ideally large)

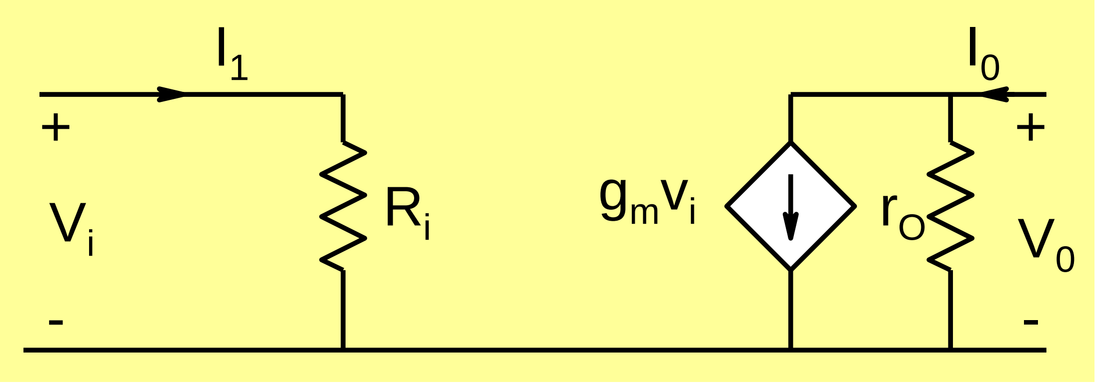


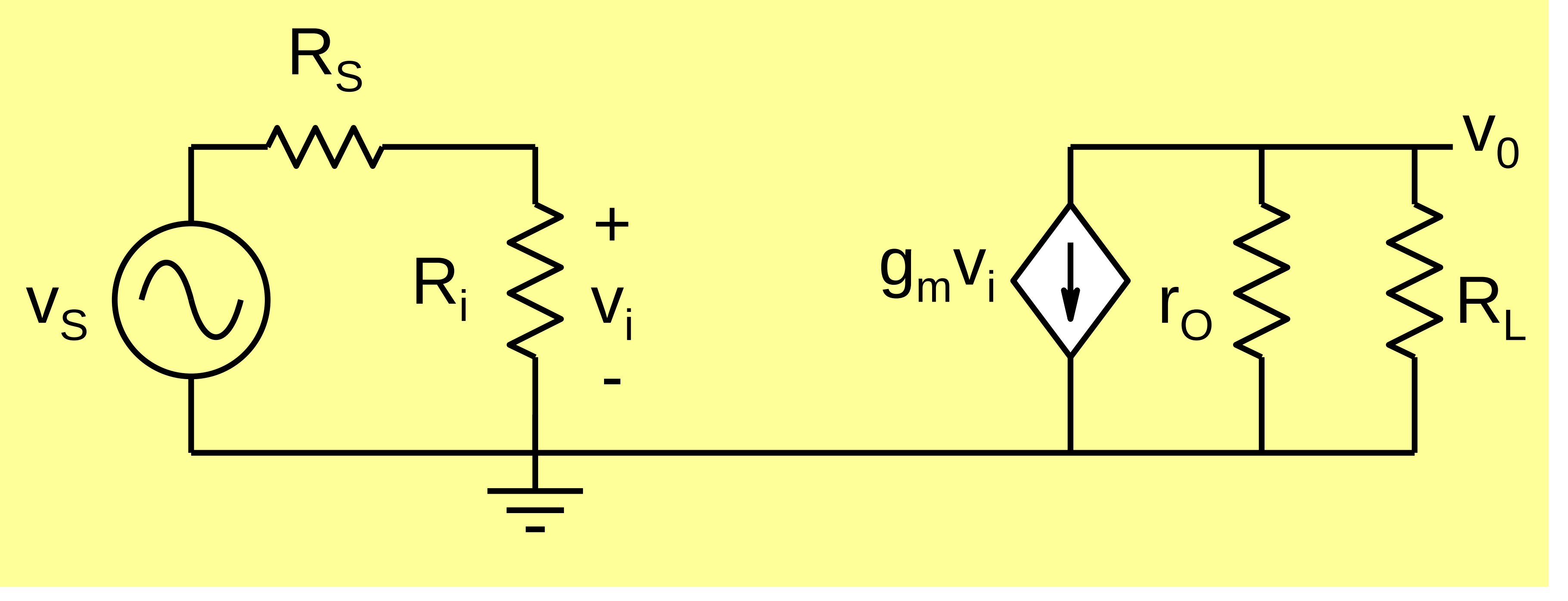
Output conductance: $g_o = 1/r_o = \left.\frac{I_o}{V_o}\right|_{V_i = 0}$

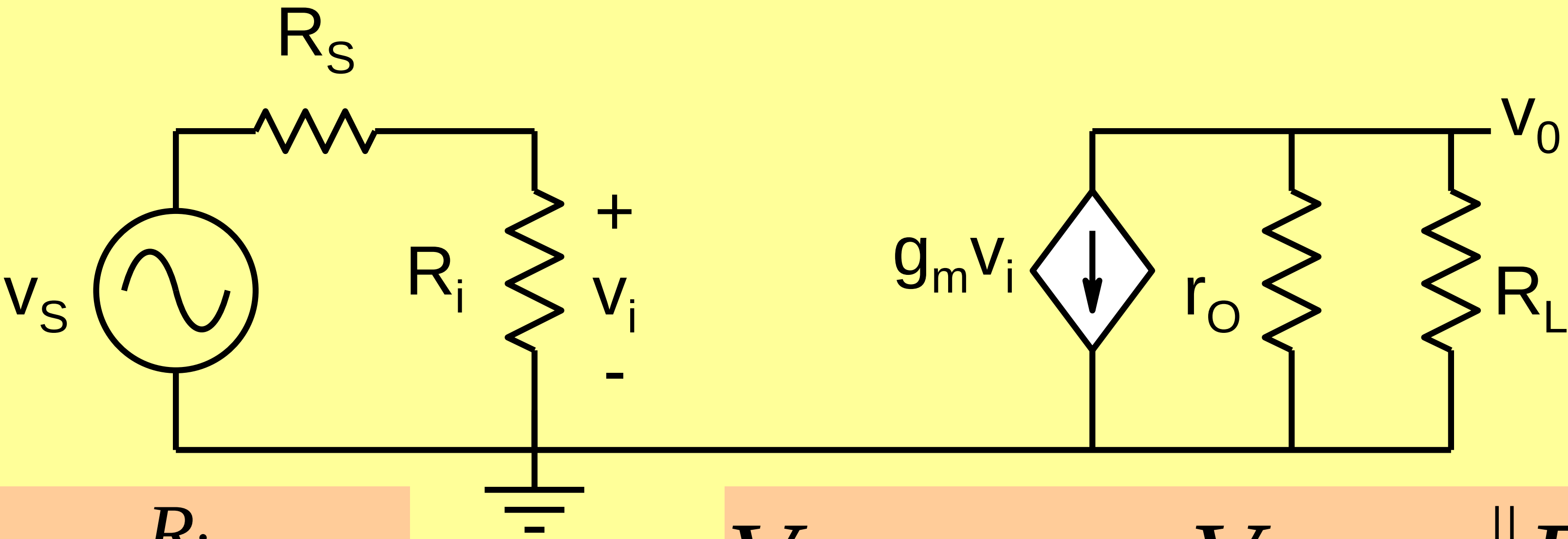
(Ideally small)

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

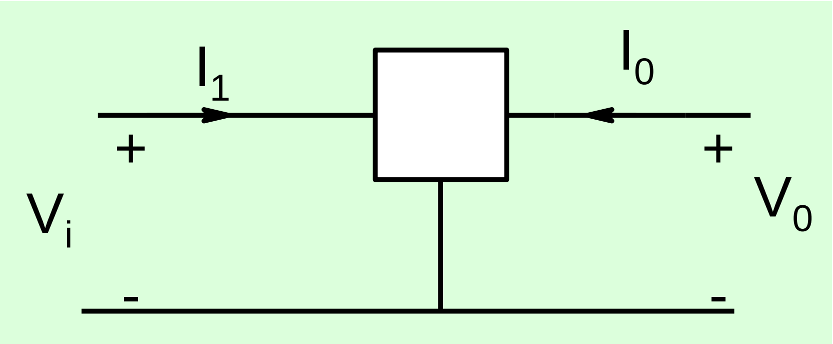
$$g_m r_o >> 1$$

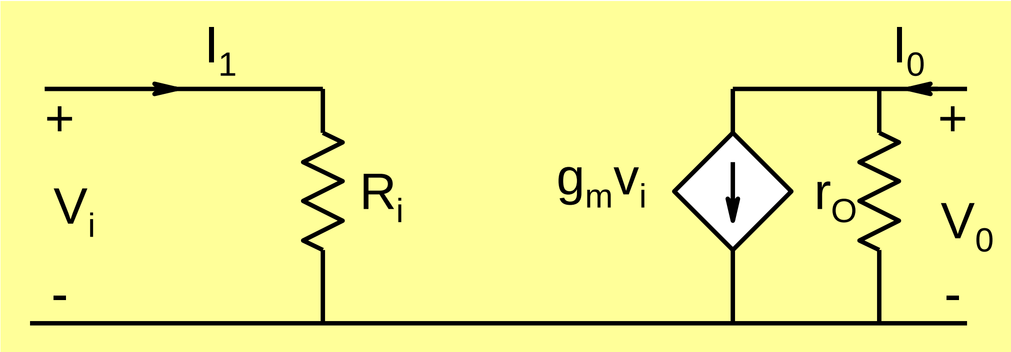
$$g_m >> g_o$$

Trans-conductance >> Output Conductance

$$g_m = \left.\frac{I_o}{V_i}\right|_{V_0=0}$$

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





Transistor

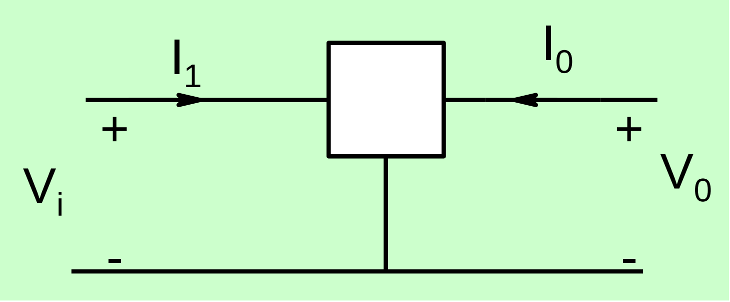
Transistor

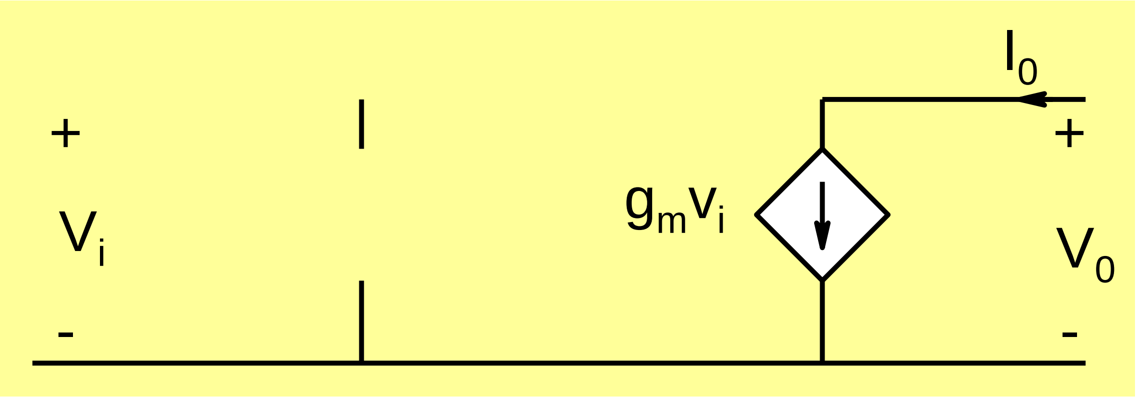
Trans-resistor

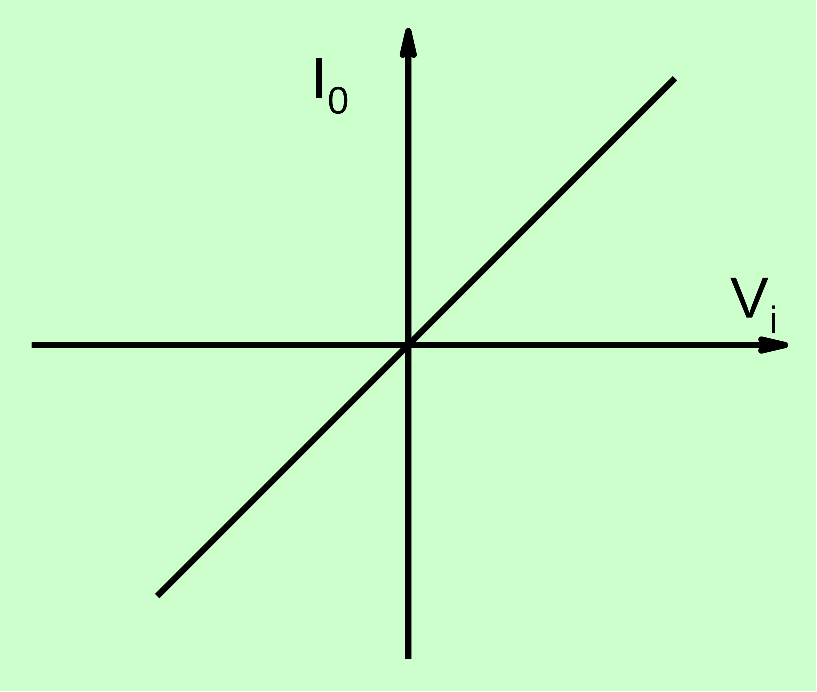
Current I_O is much more sensitive to V_{IN} than V_O

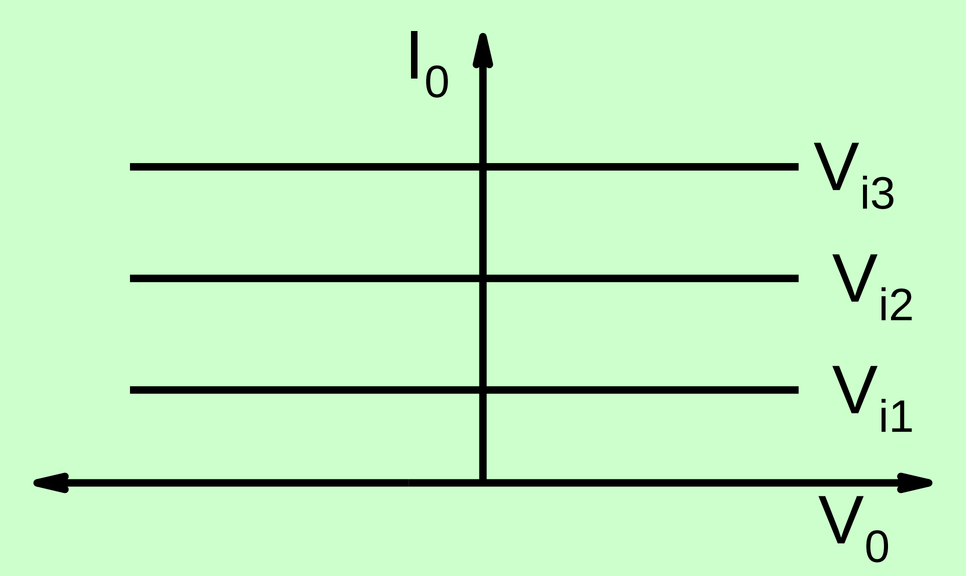
- Can be used for voltage amplification
- Can be used as a switch
- Implement logic
- …

An ideal 3-terminal device for Voltage Amplification





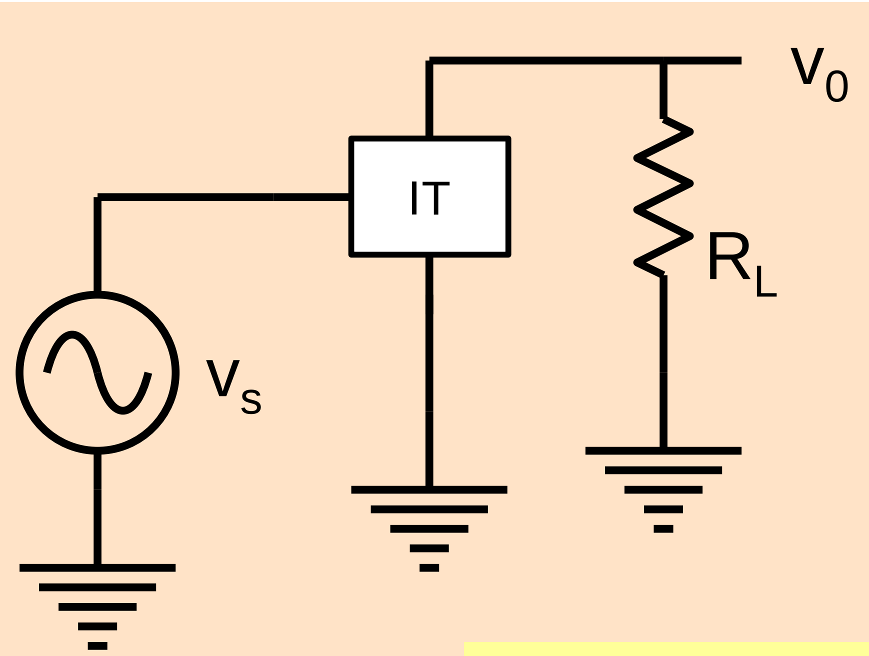


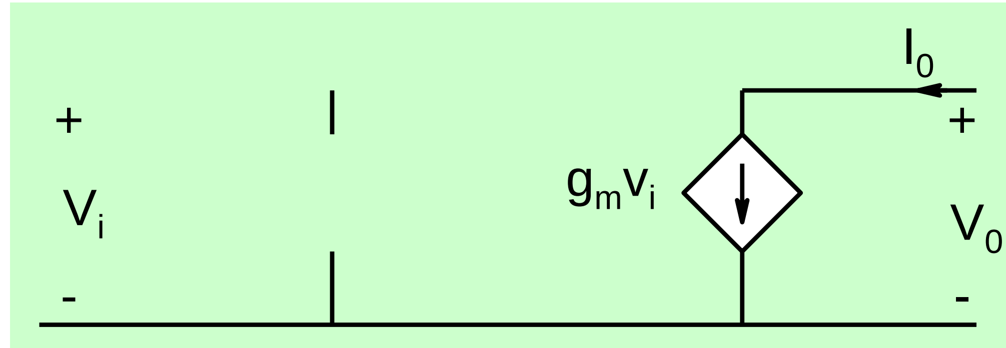


Ideal Transistor Characteristics

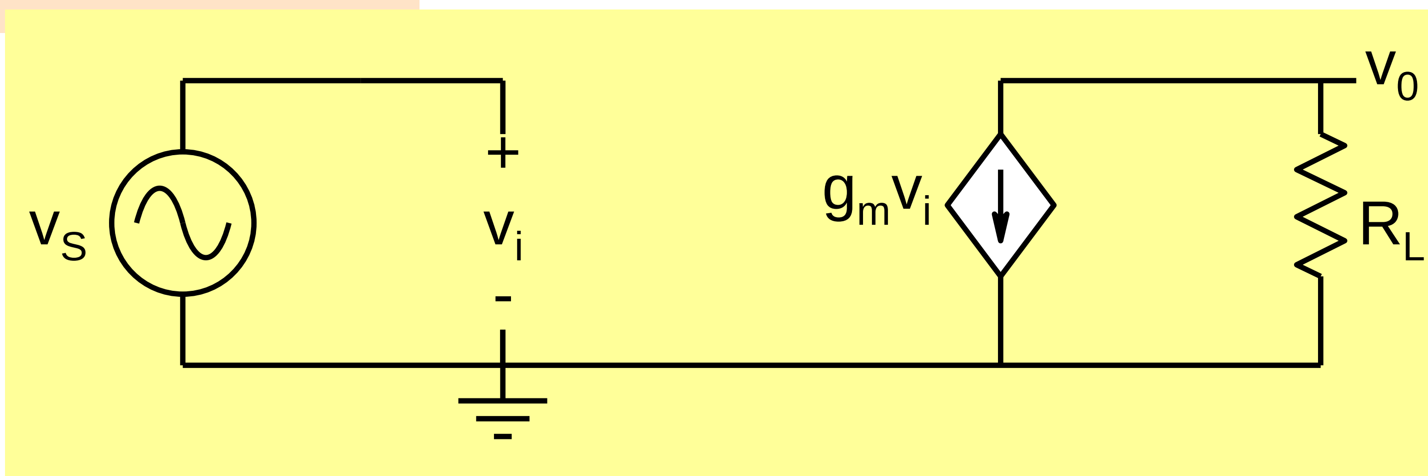
Ideal Transistor (IT)

Making a voltage amplifier with an ideal transistor is straightforward



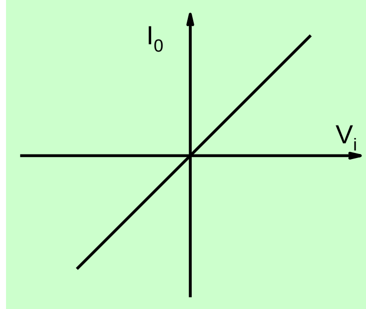


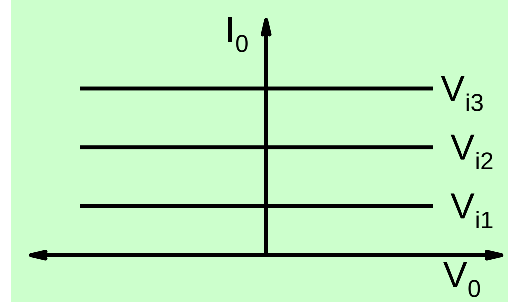
$$A_V = \frac{v_o}{v_s} = -g_m R_L$$



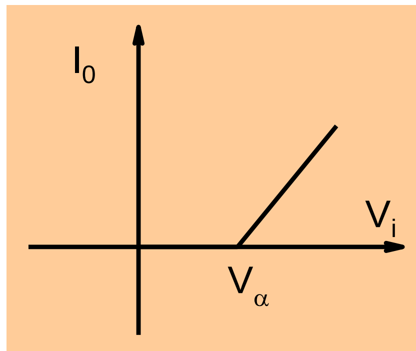
In practice there is no element which has the characteristics of ideal transistor !

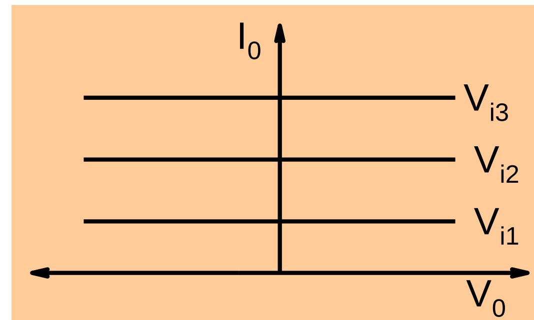
Ideal transistor



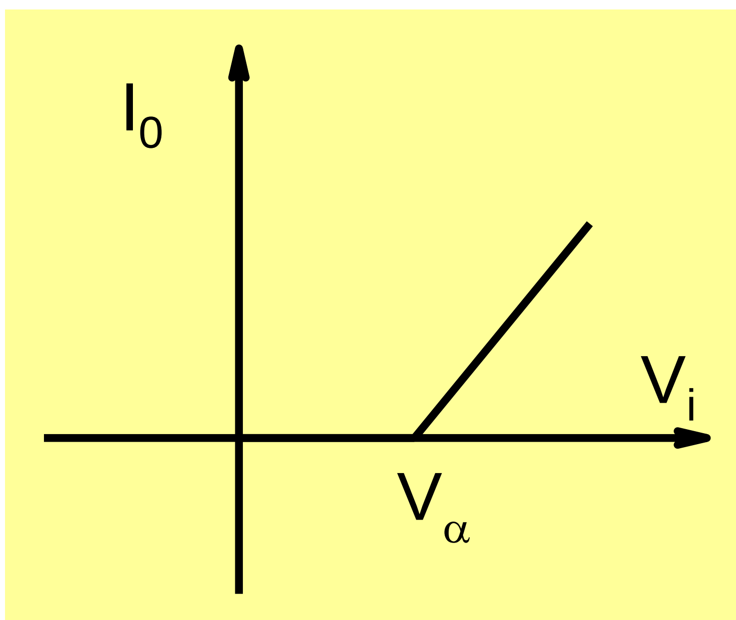


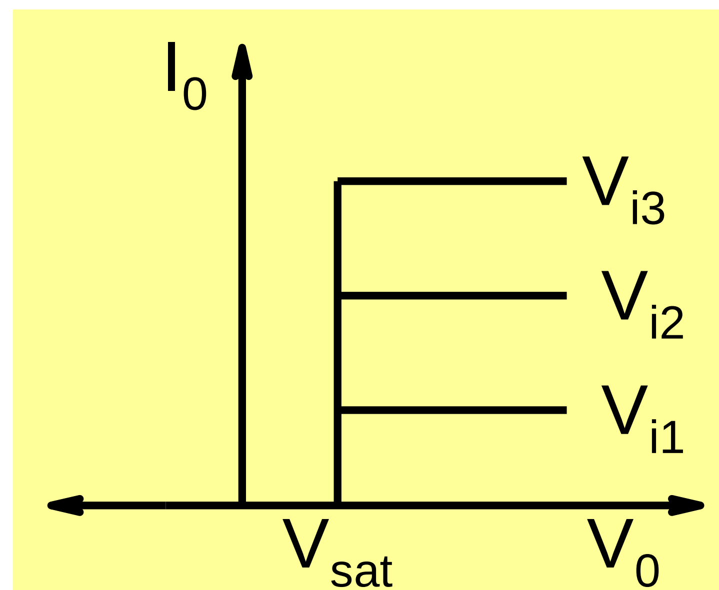
Device X





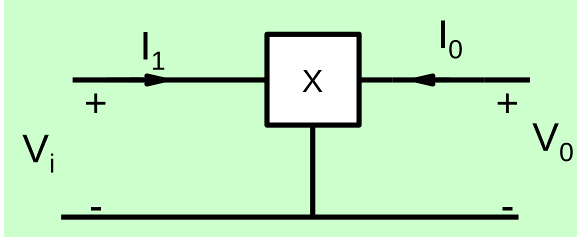
Device Y



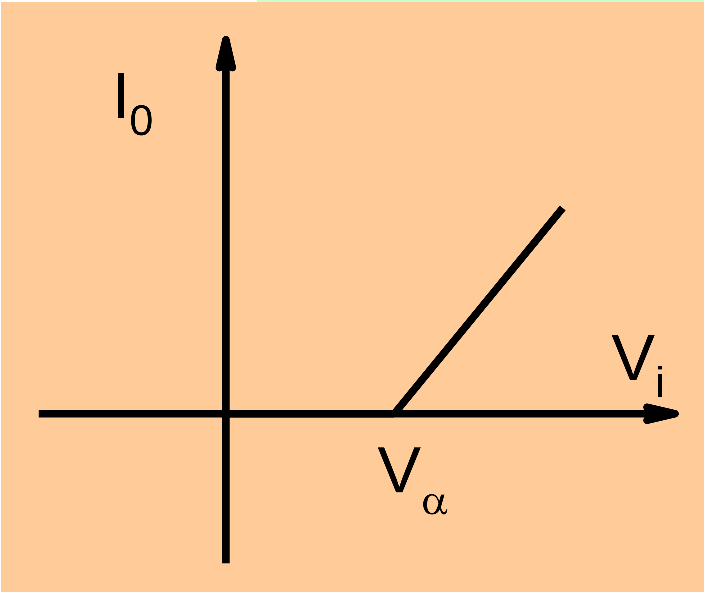


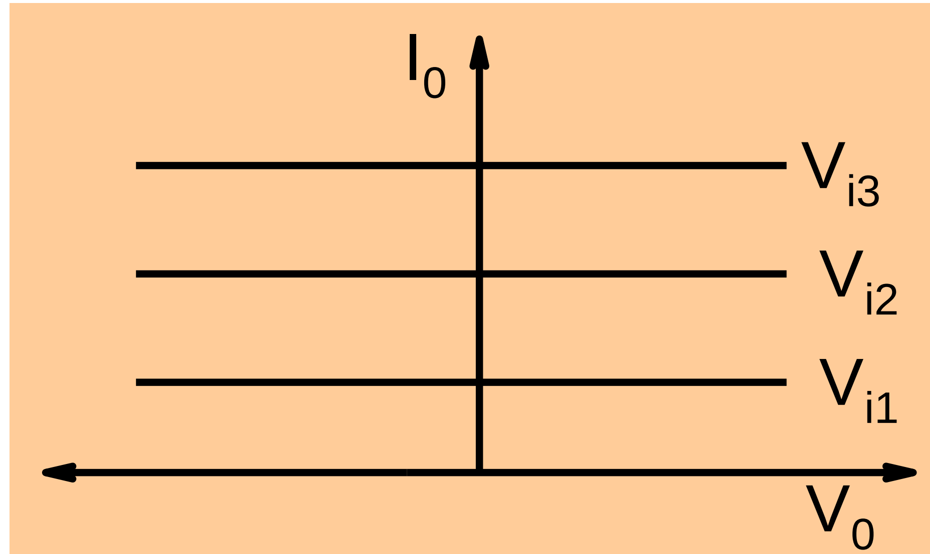
How do we use elements such as X, Y etc to make amplifiers?

Device X

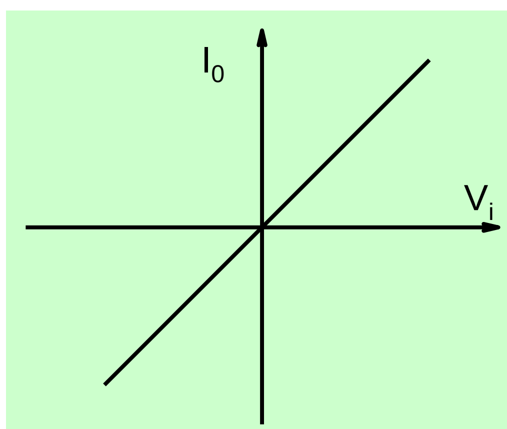


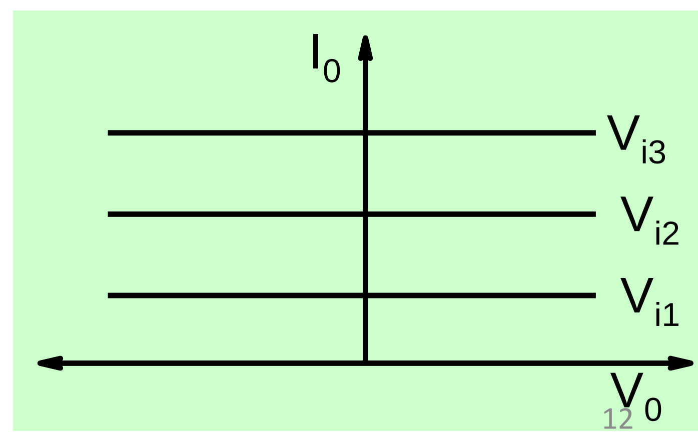
$$
\begin{aligned}
I_o &= 0 && \text{for } V_i \le V_\alpha \\
&= g_m \times (V_i - V_\alpha) && \text{for } V_i > V_\alpha
\end{aligned}
$$



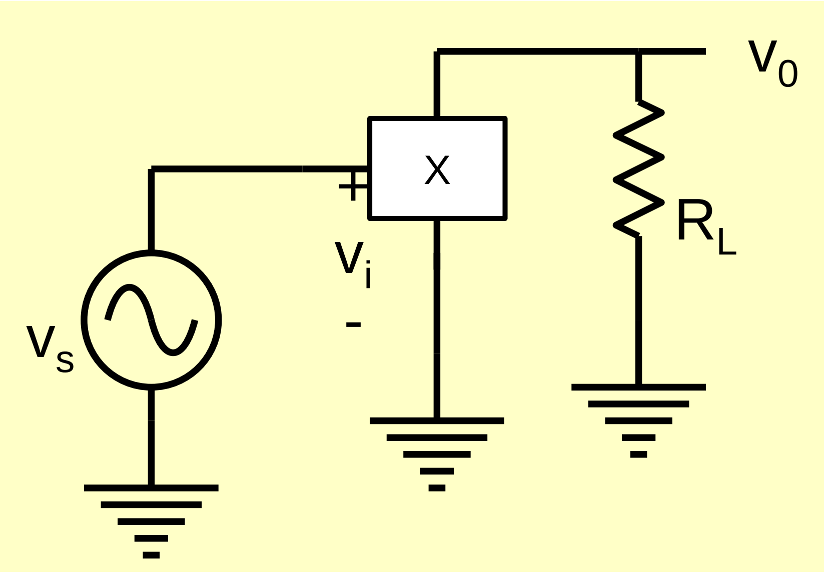


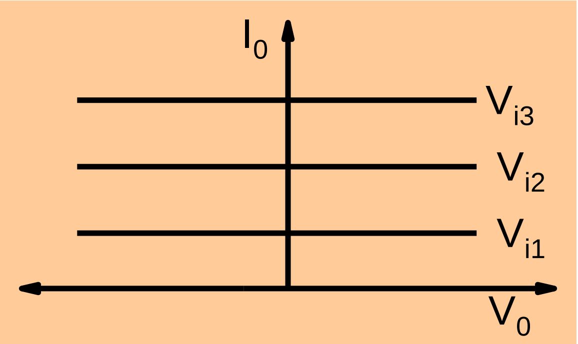
Ideal Characteristics

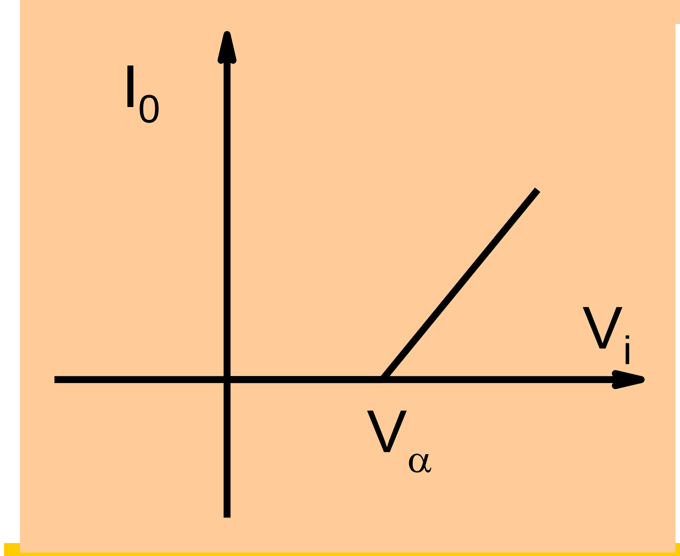


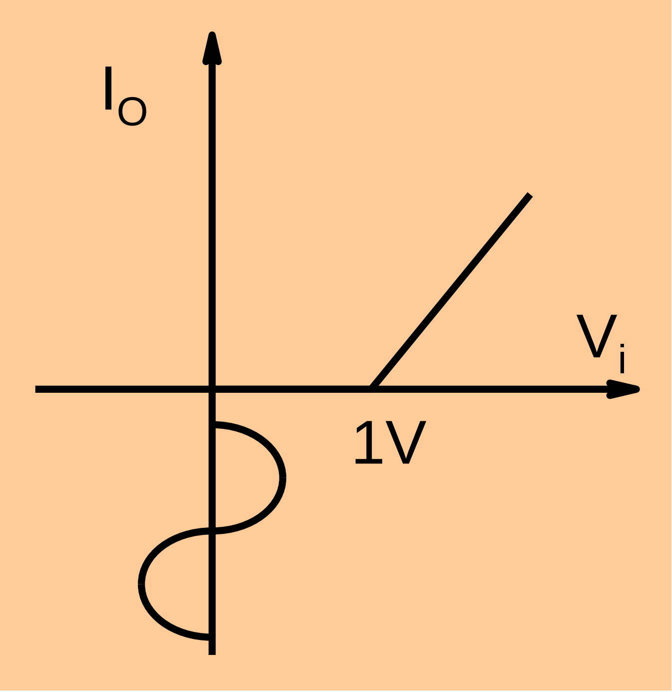


How do we use device X to make an amplifier?









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

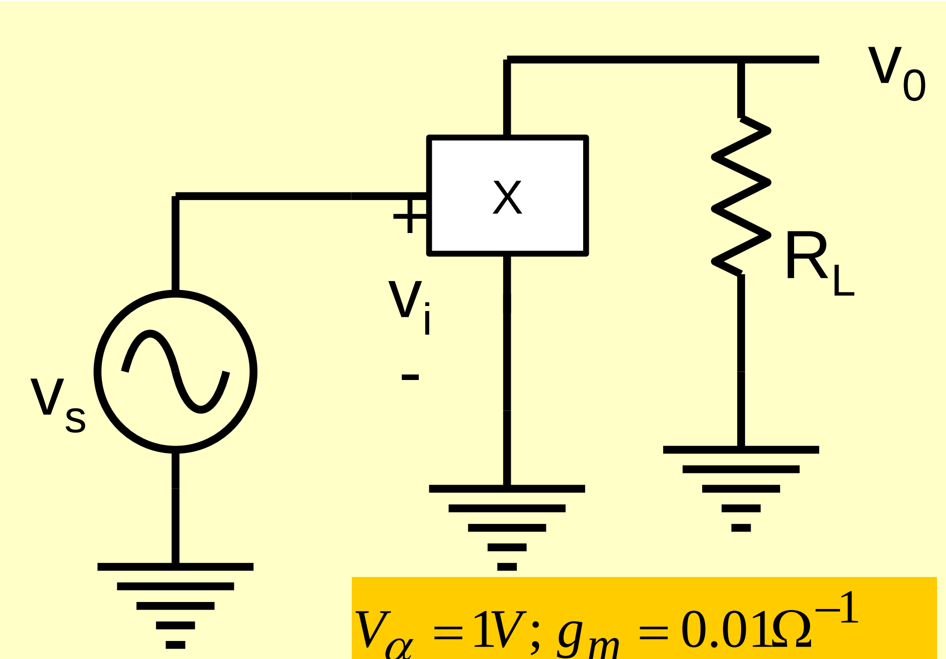
$$R_L = 1K\ ;\ v_s = 0.5V\ Sin\ \omega t$$

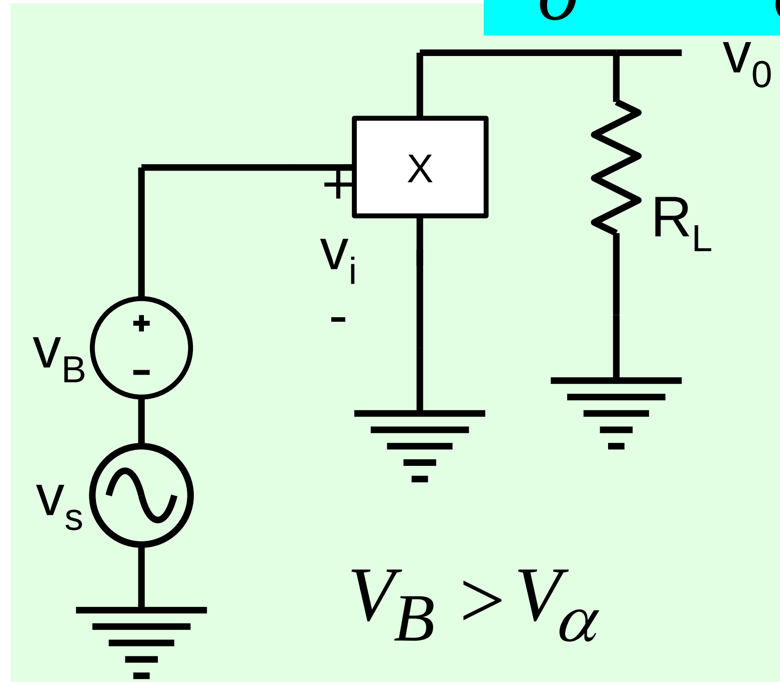
$$I_O = 0 \Rightarrow V_O = 0$$

No Amplification

How do we use device X to make an amplifier?

$$V_o = -I_o R_L$$





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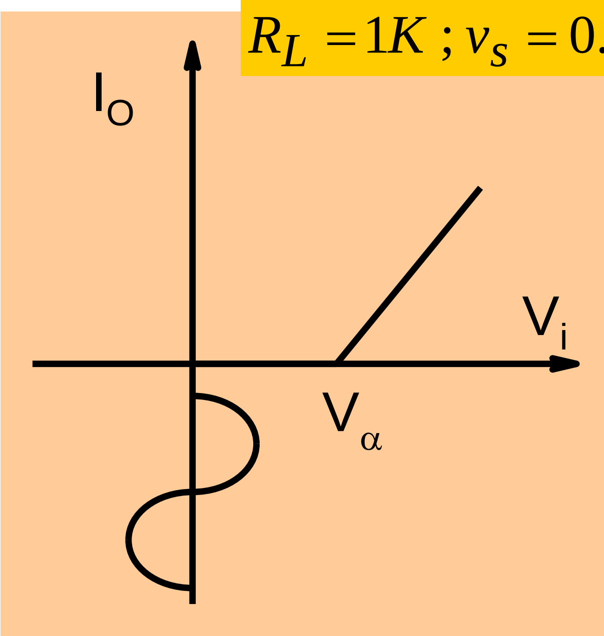
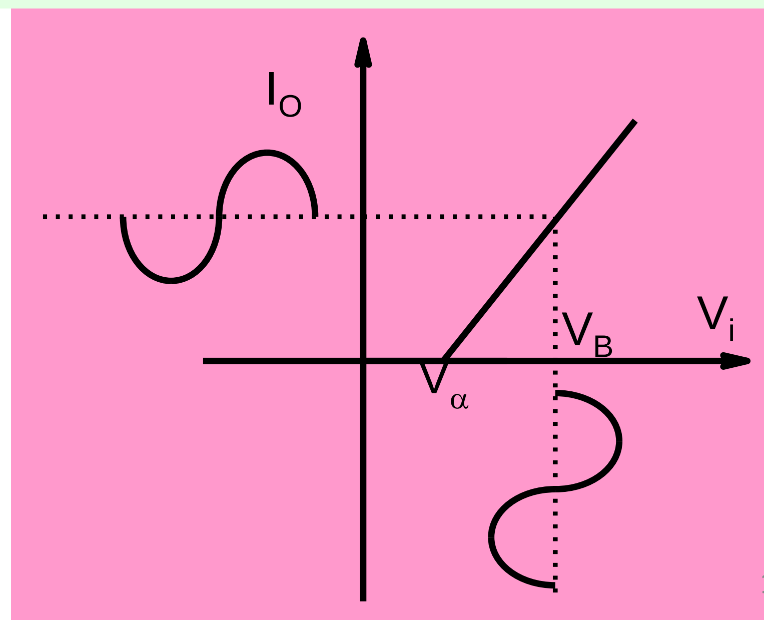
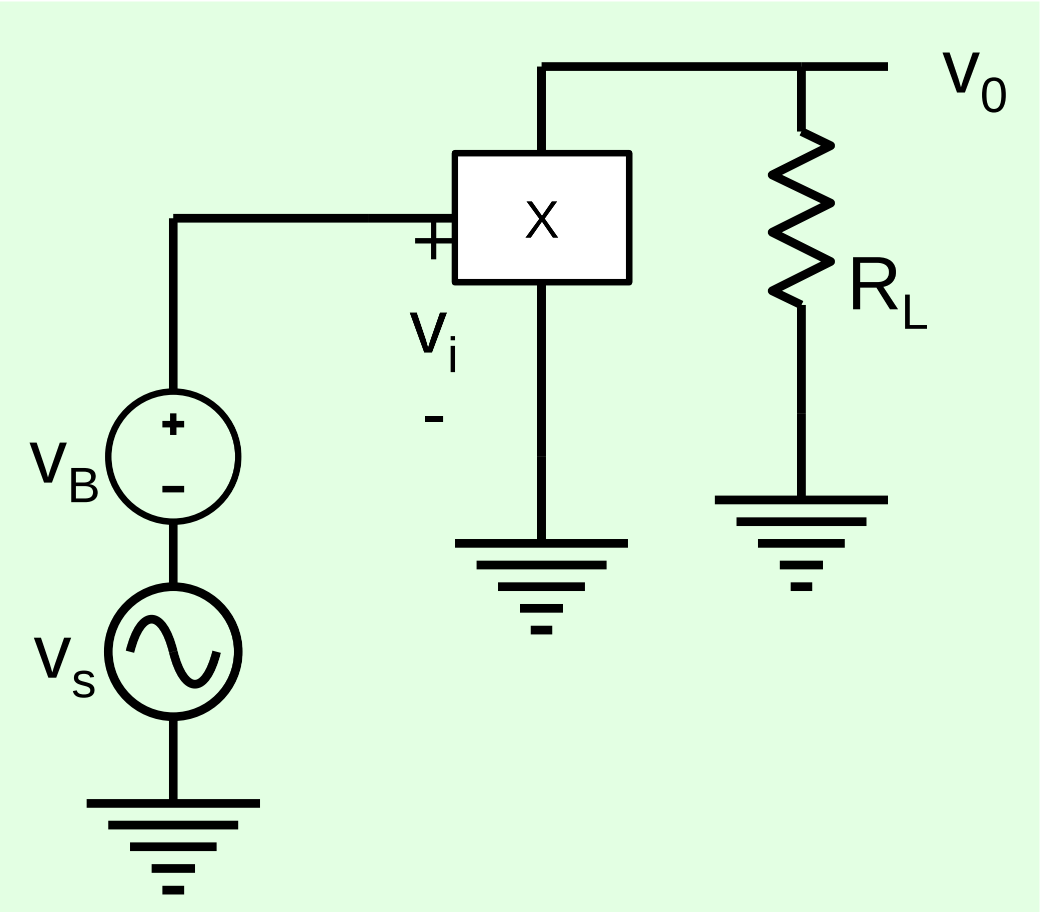
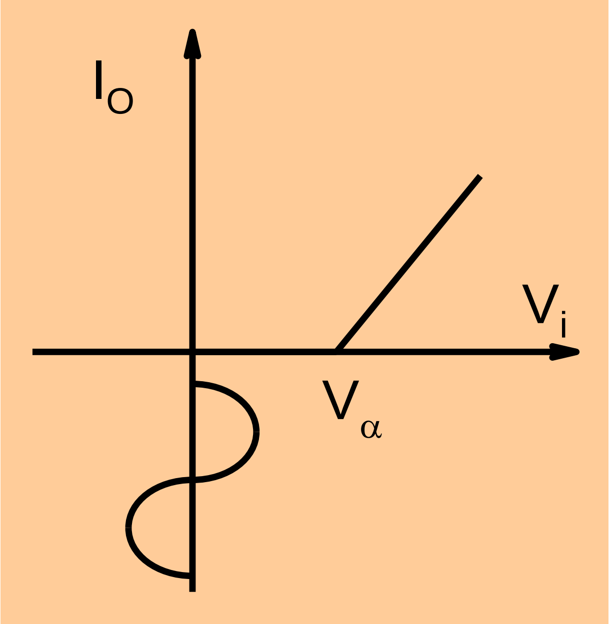
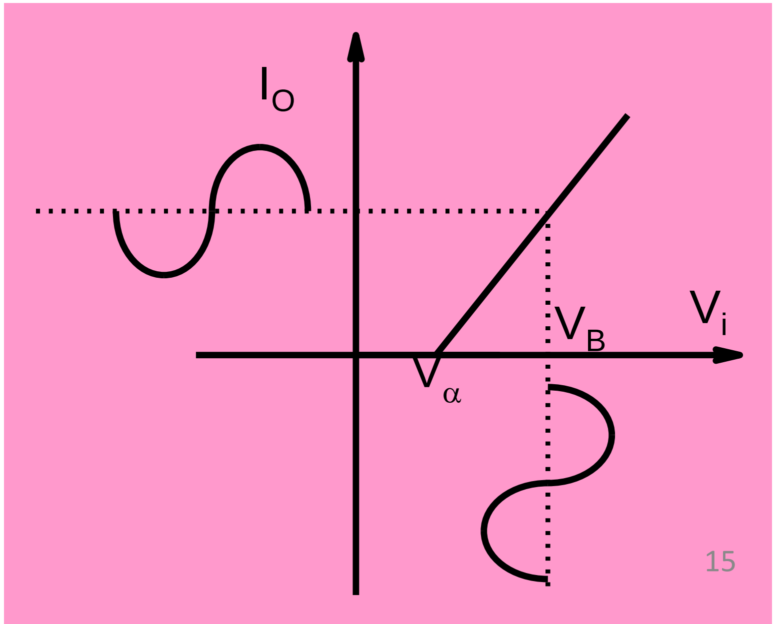




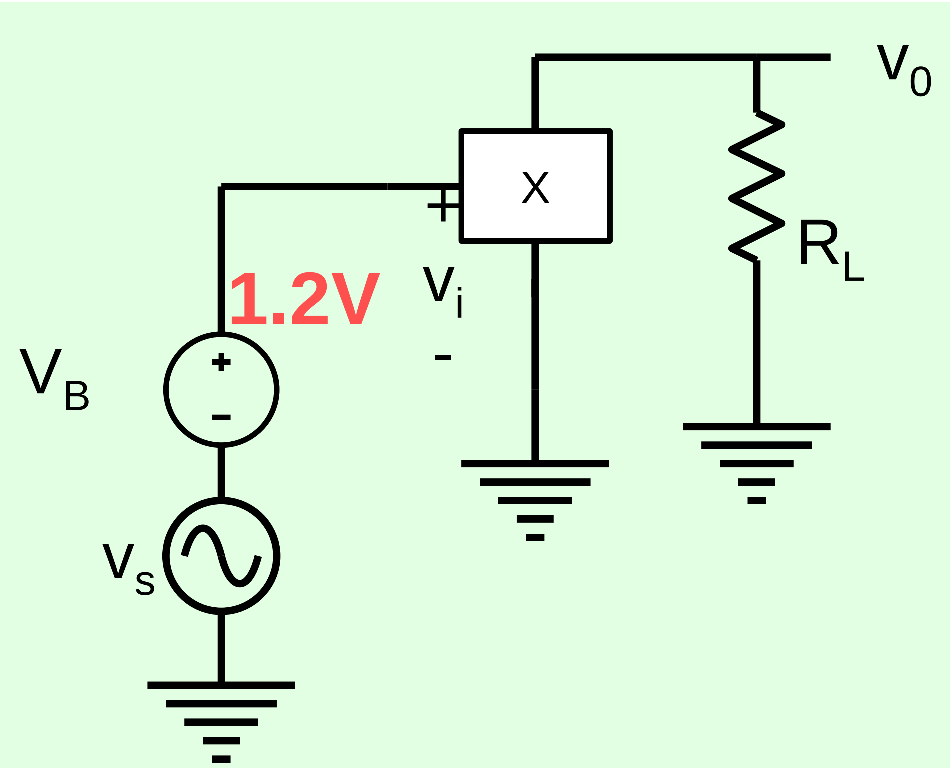
When only a part of device characteristics is suitable for amplification, then we need to push the device into that region by applying suitable bias voltages. This process is called **BIASING**



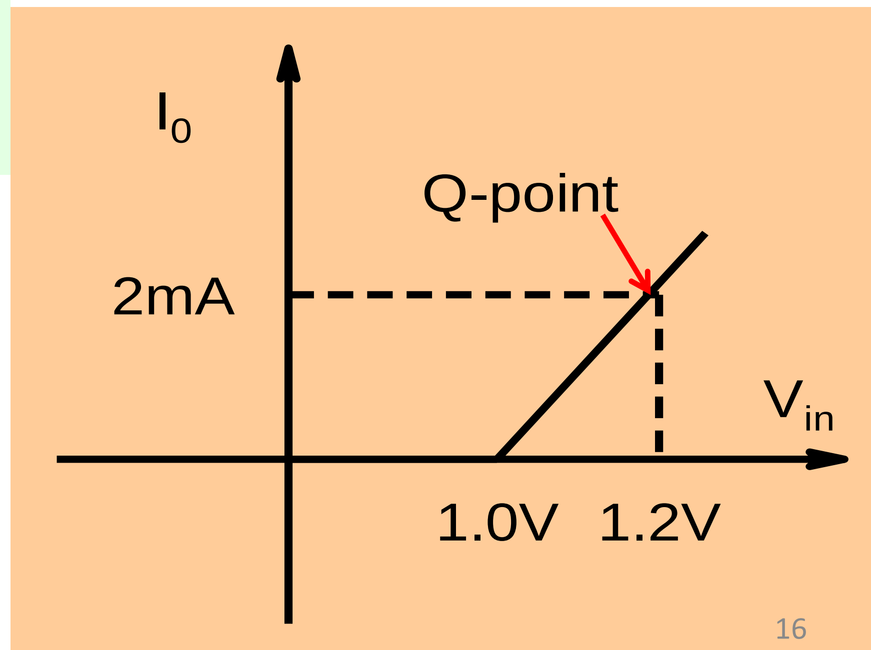




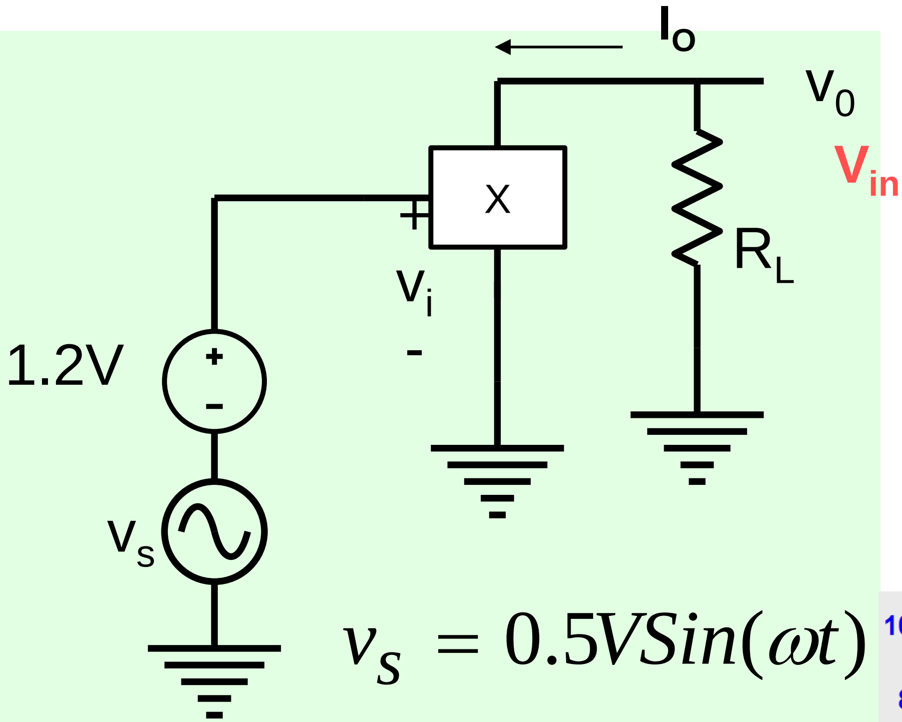
How should one choose the bias voltage V_B ?



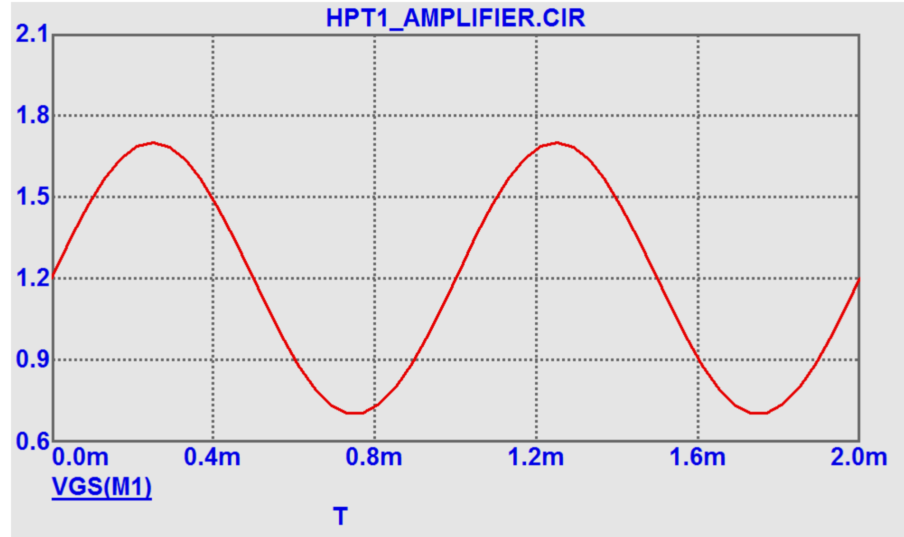
$$v_s = 0.5V\ Sin\ \omega t$$

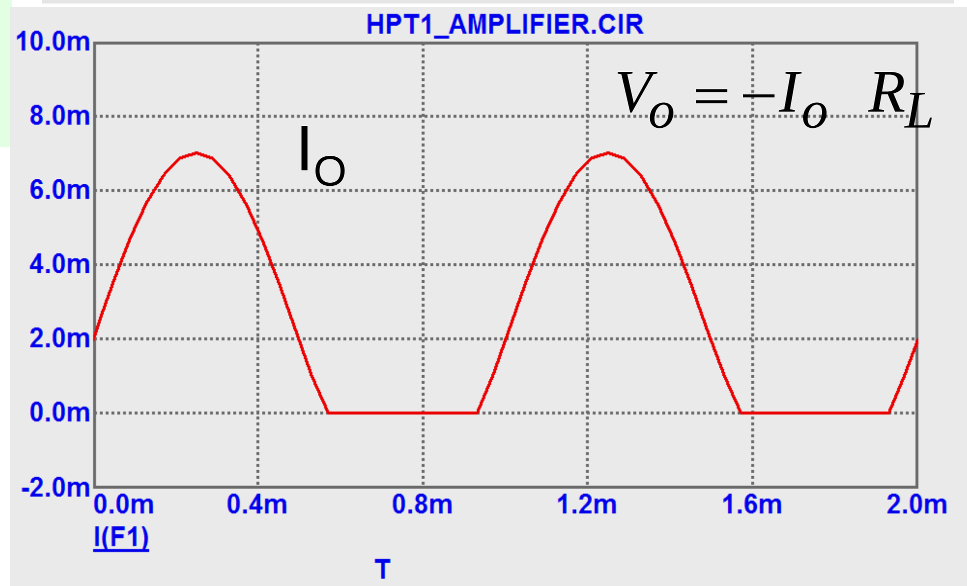


Quiescent point or Bias point

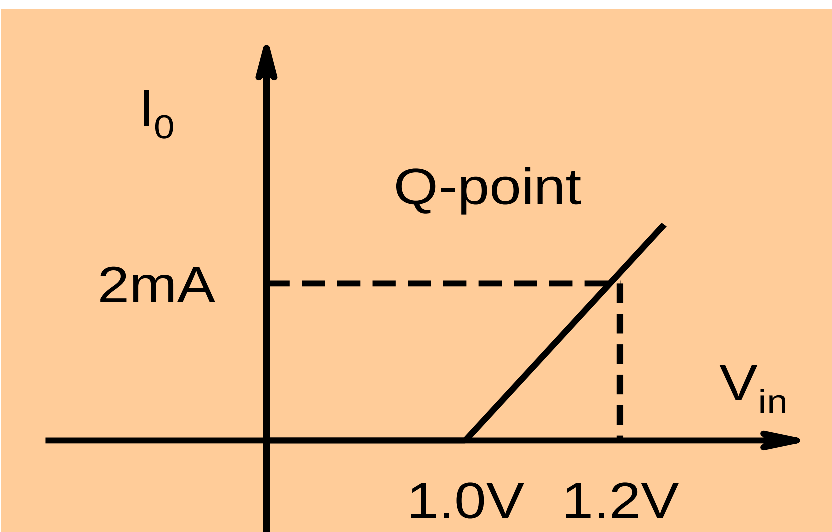


$$v_s = 0.5VSin(\omega t)$$





$$V_o = -I_o \ R_L$$



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

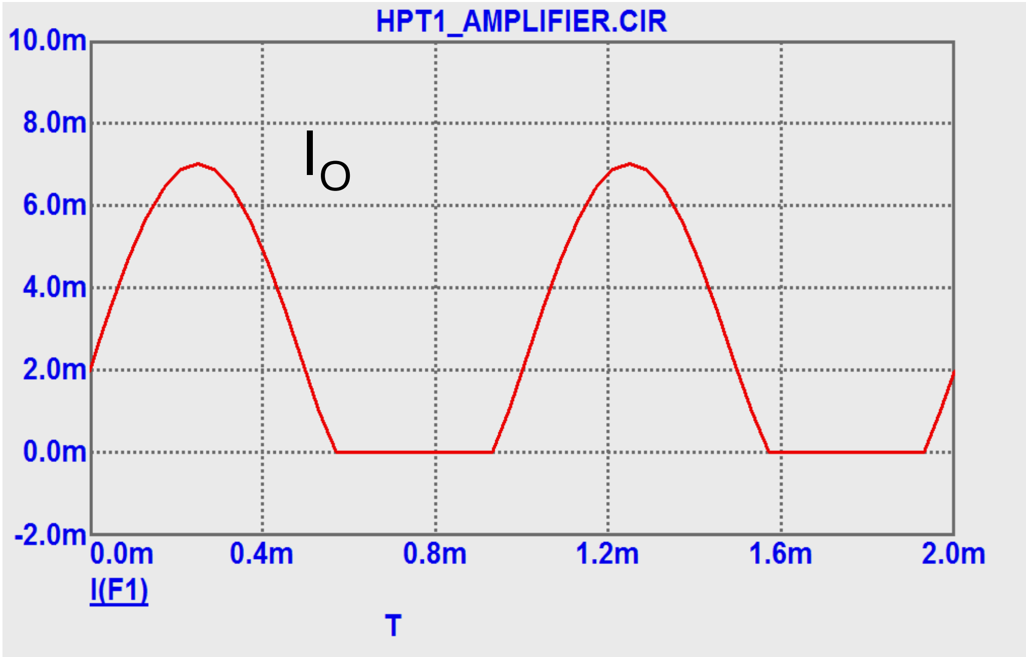
$$I_o = 0 \qquad \text{for } V_i \le V_\alpha$$

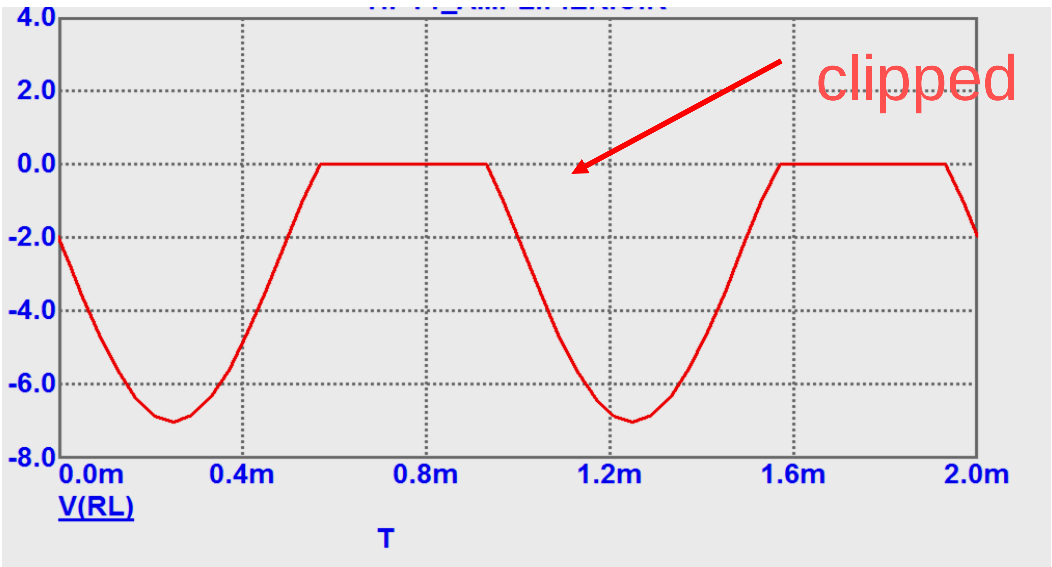
$$= g_m \times (V_i - V_\alpha) \text{ for } V_i > V_\alpha$$

Output voltage is distorted !

RL=1kΩ

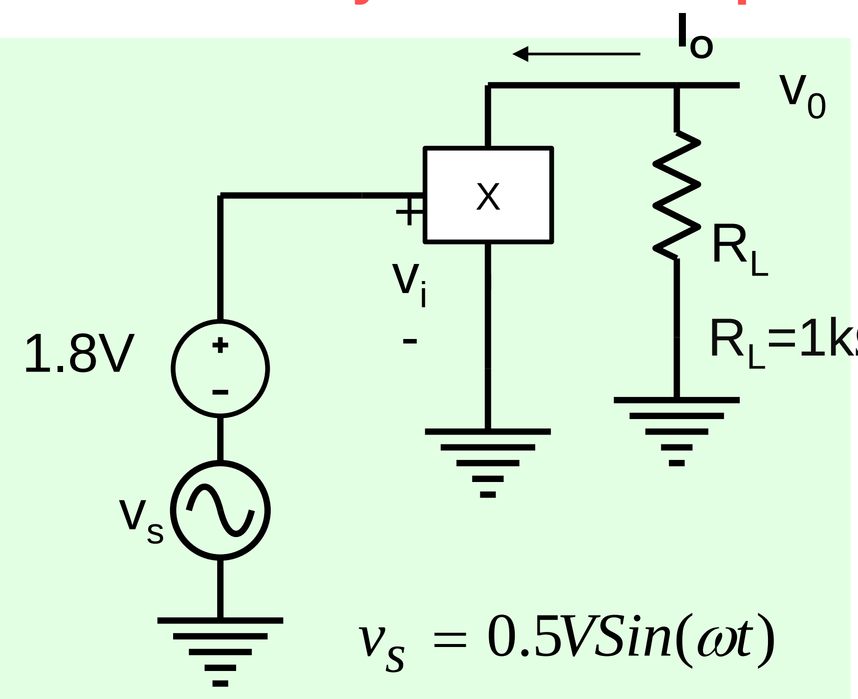
$$V_O = -I_O \ R_L$$

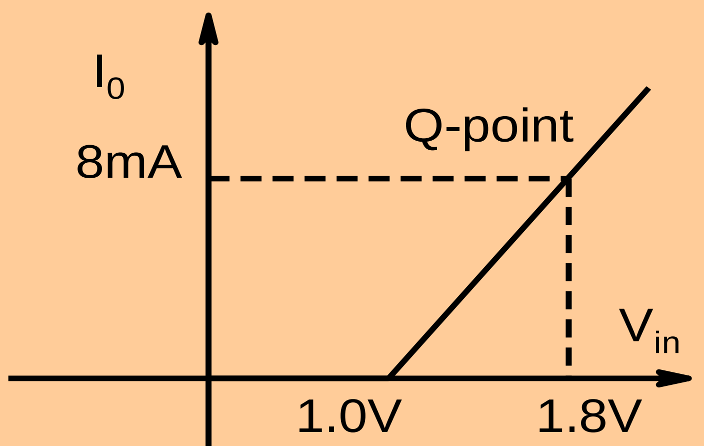




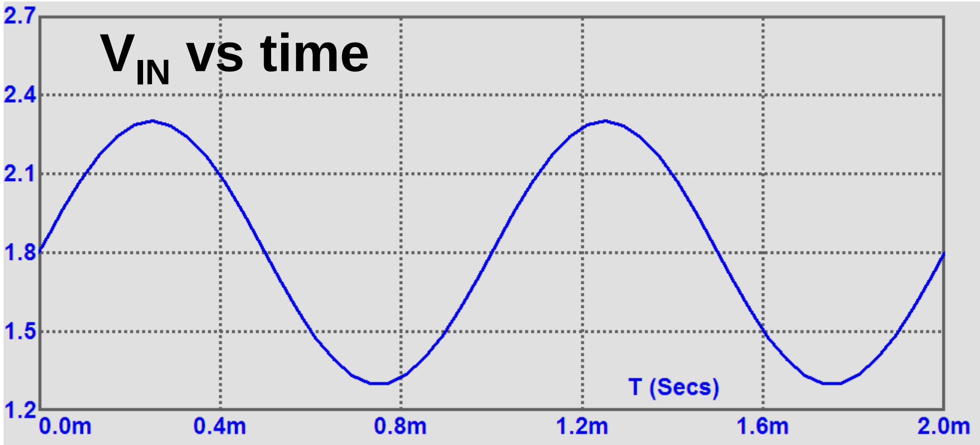
Need to choose a proper value of biasing Voltage

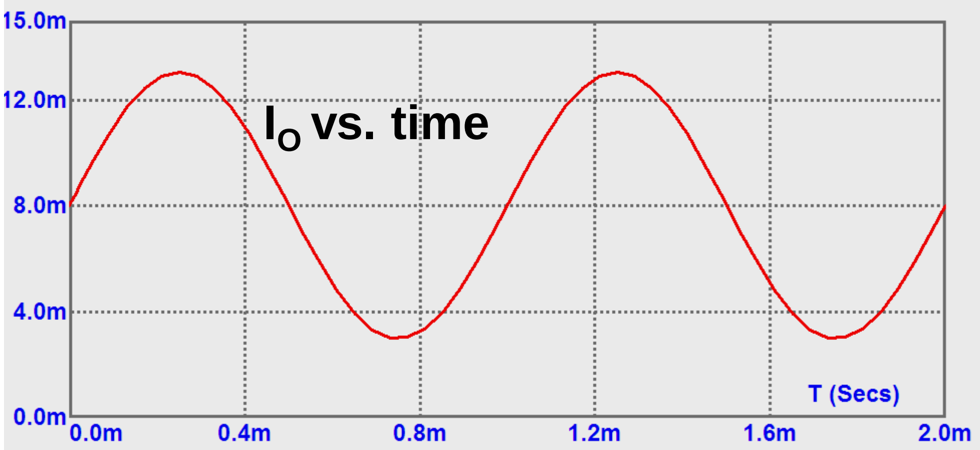
Unnecessary Power Dissipation

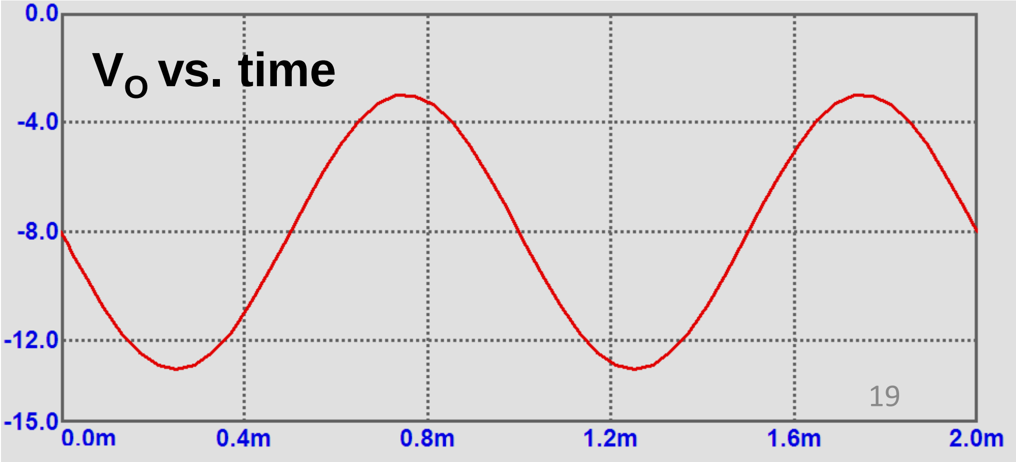




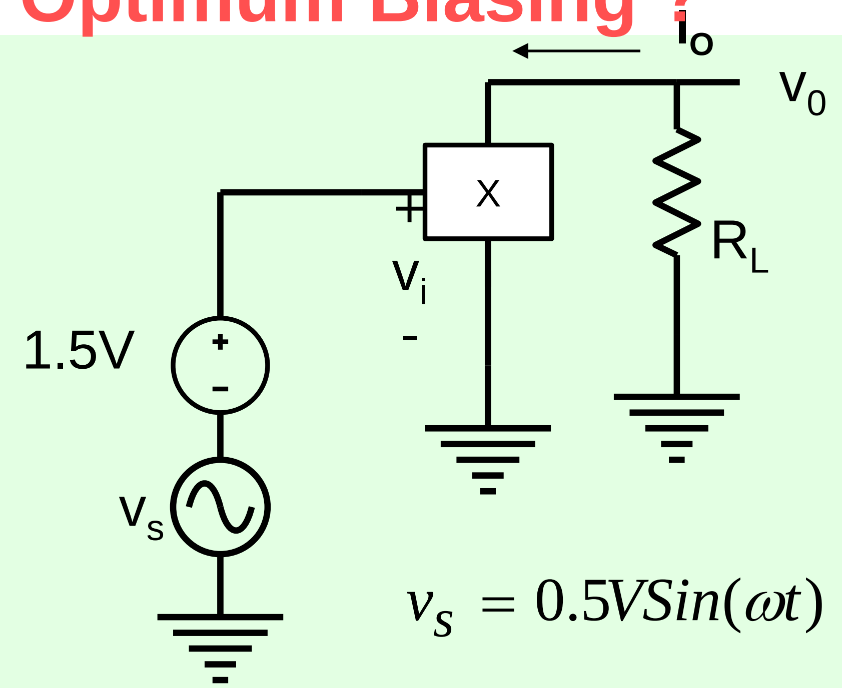
$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

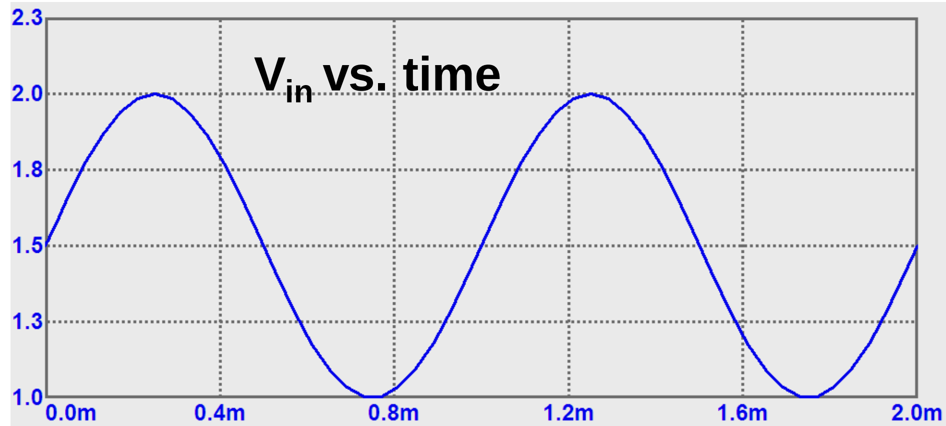


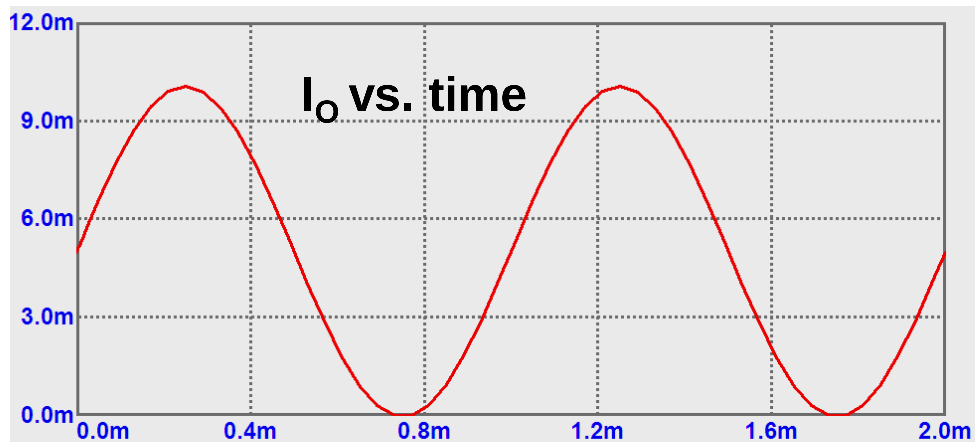


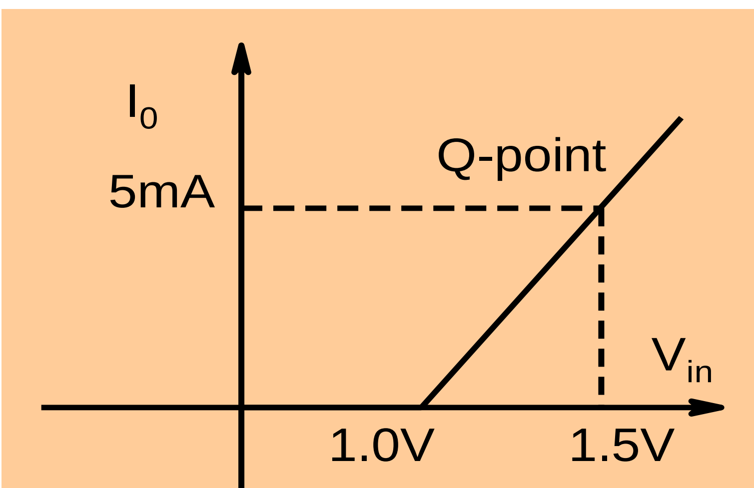


Optimum Biasing ?

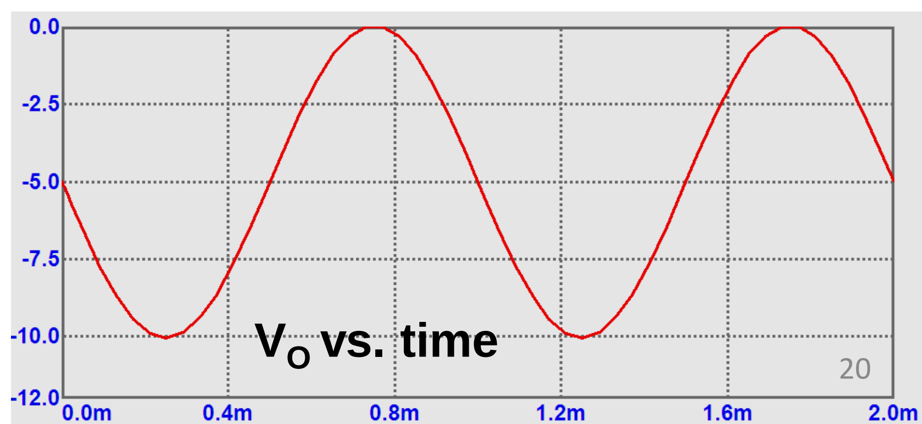




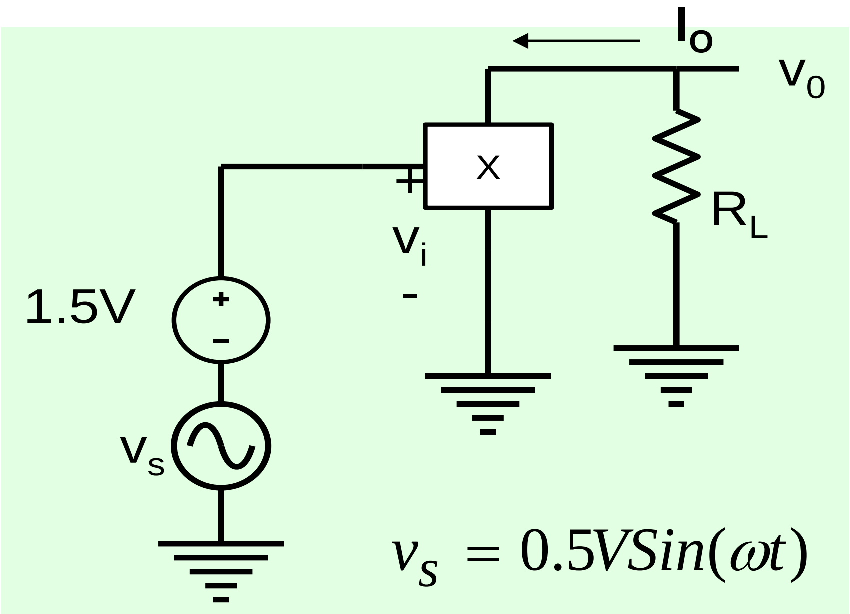


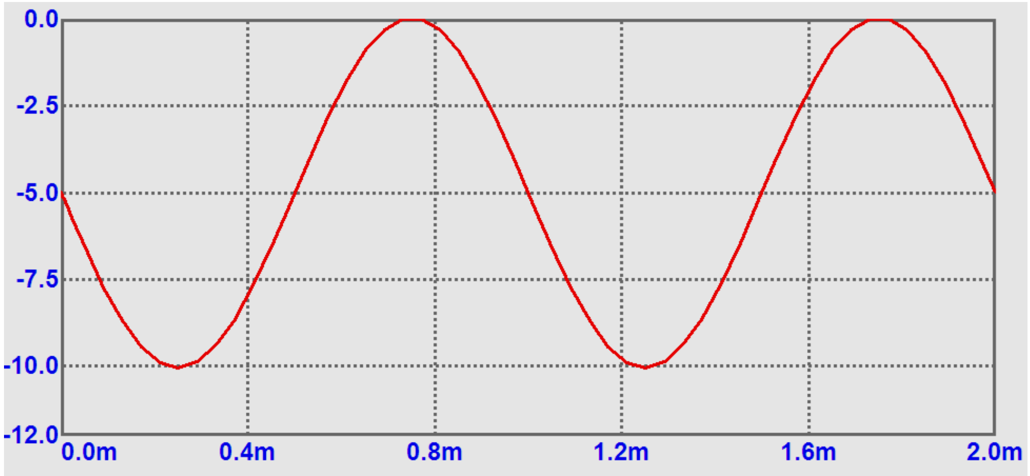


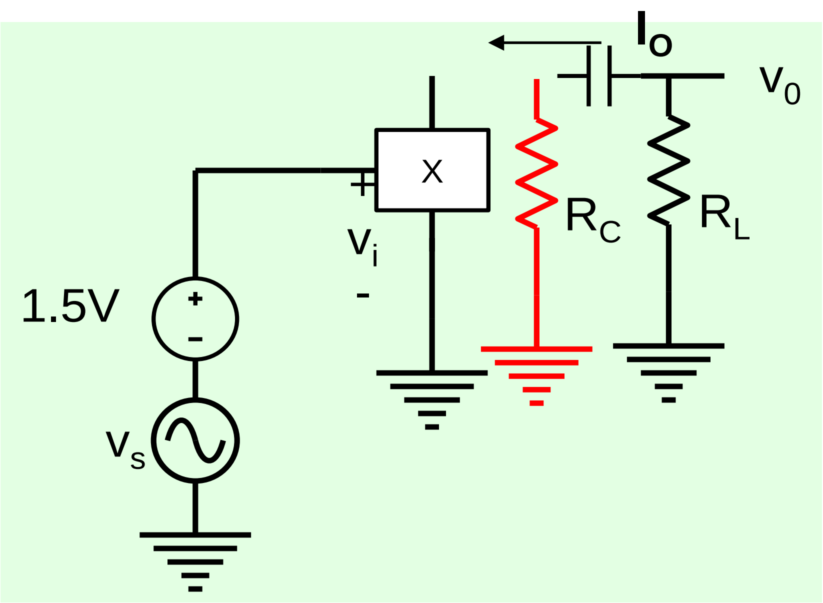
$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

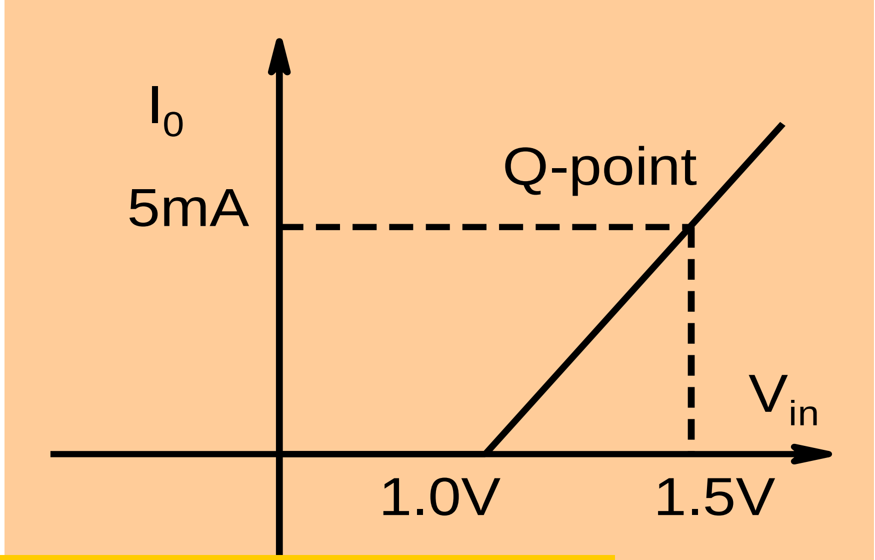


How do we get rid of unwanted dc voltage at the output ?

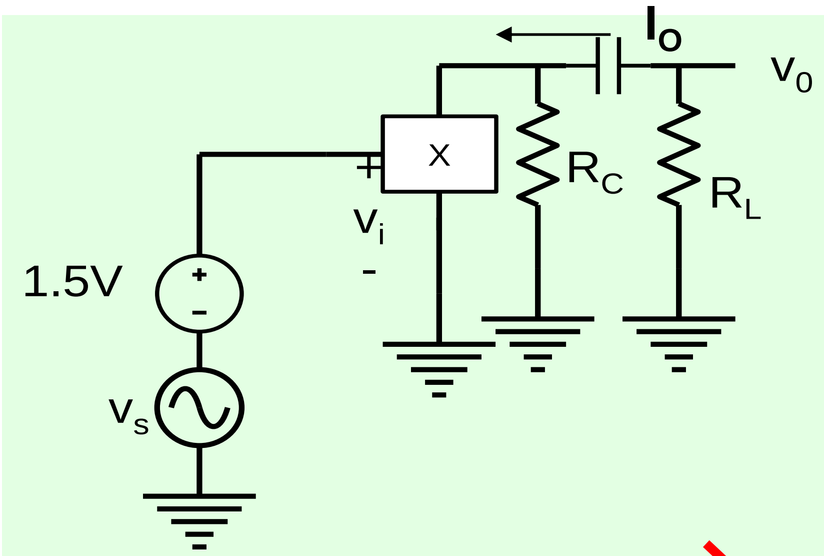


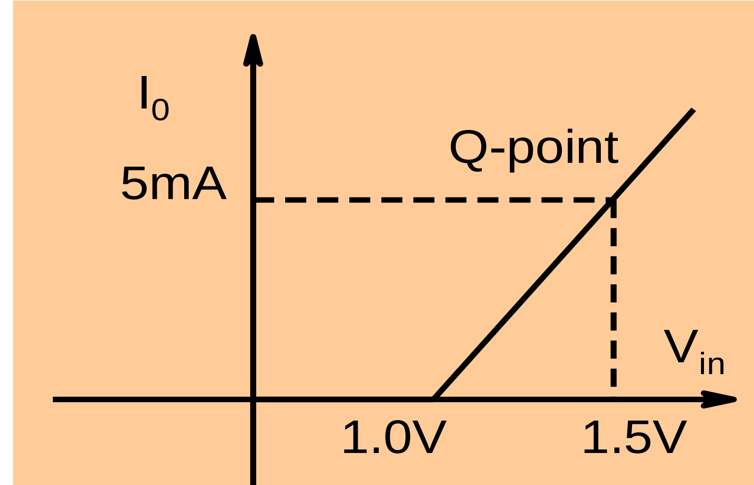






$$V_\alpha = 1V; \; g_m = 0.01\Omega^{-1}$$

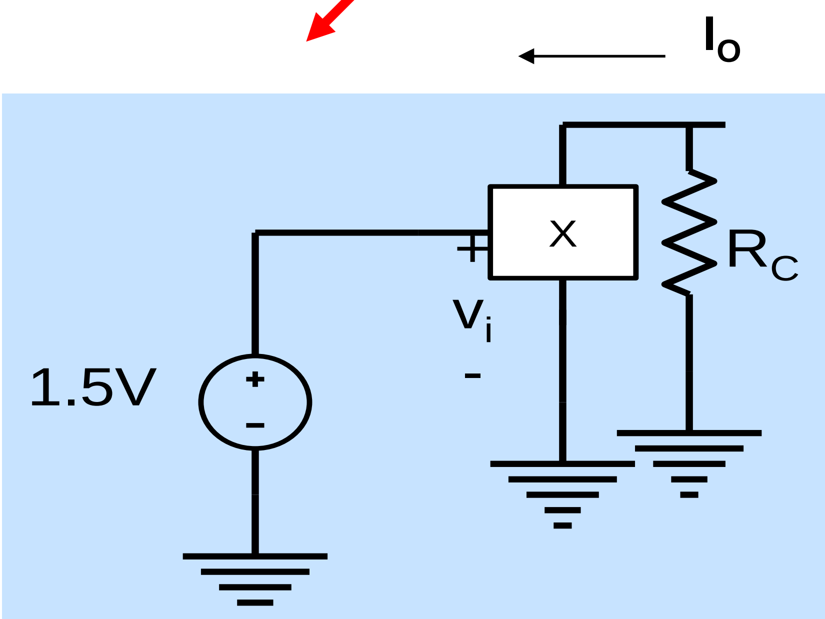


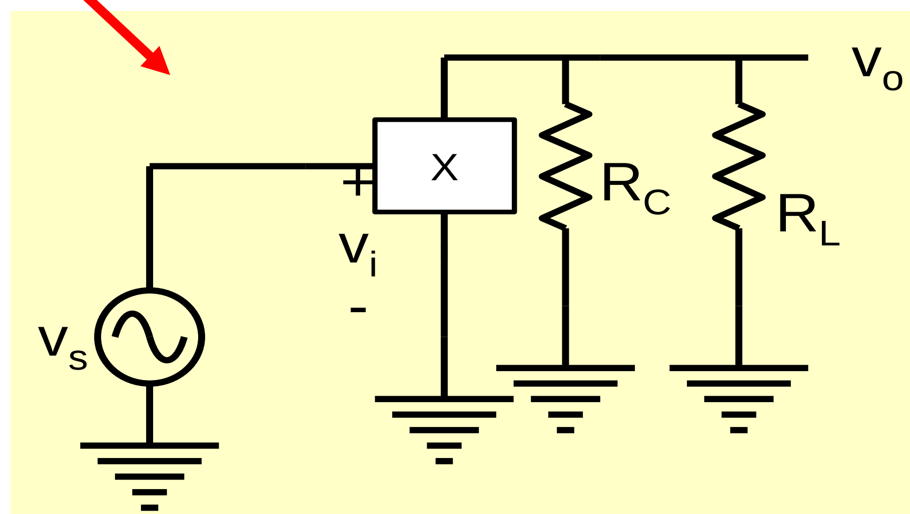


$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

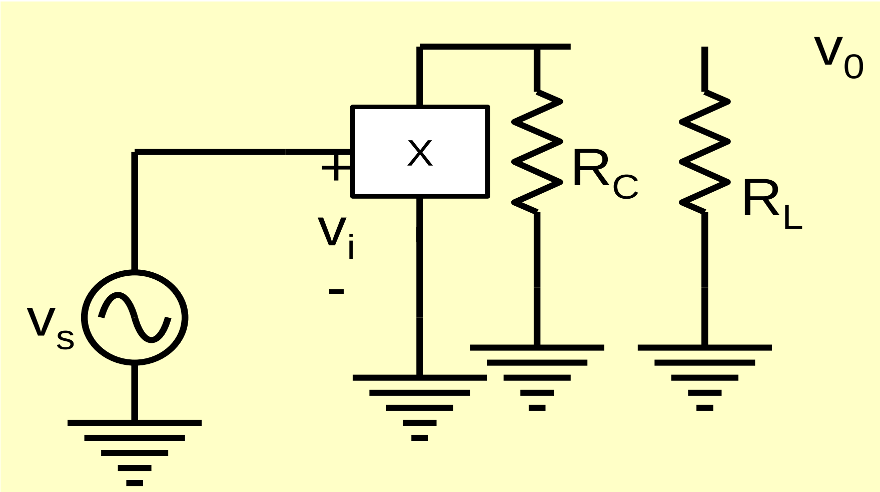
dc

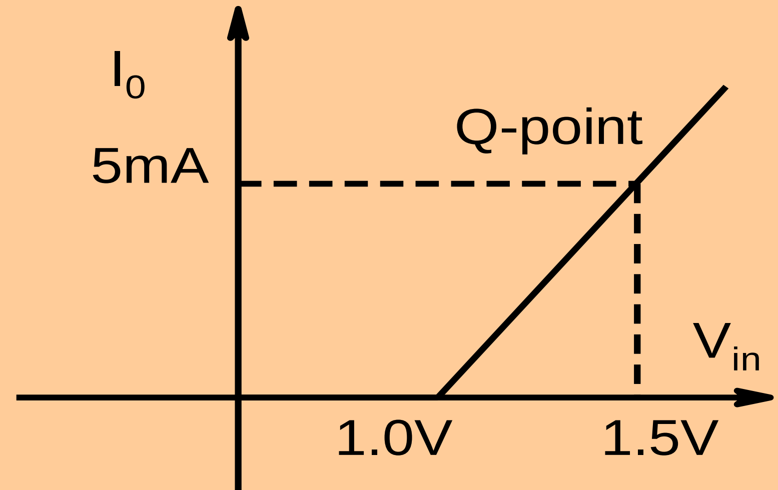
ac (signal)





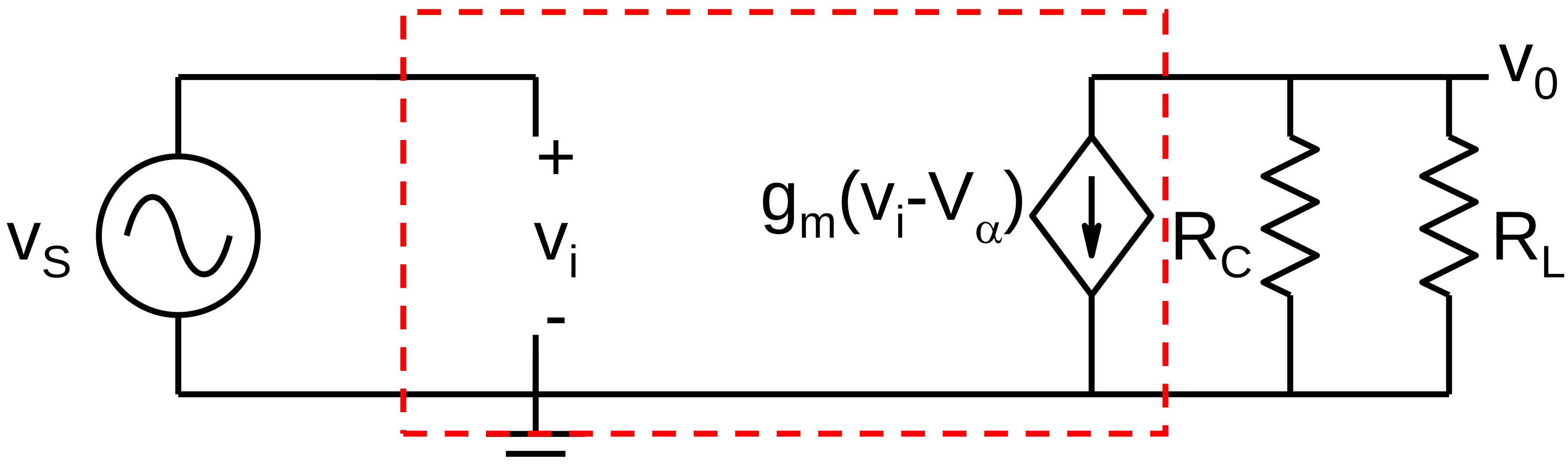
Capacitor is chosen large enough so that at the signal frequency $1/j\omega C_2 \sim 0$.



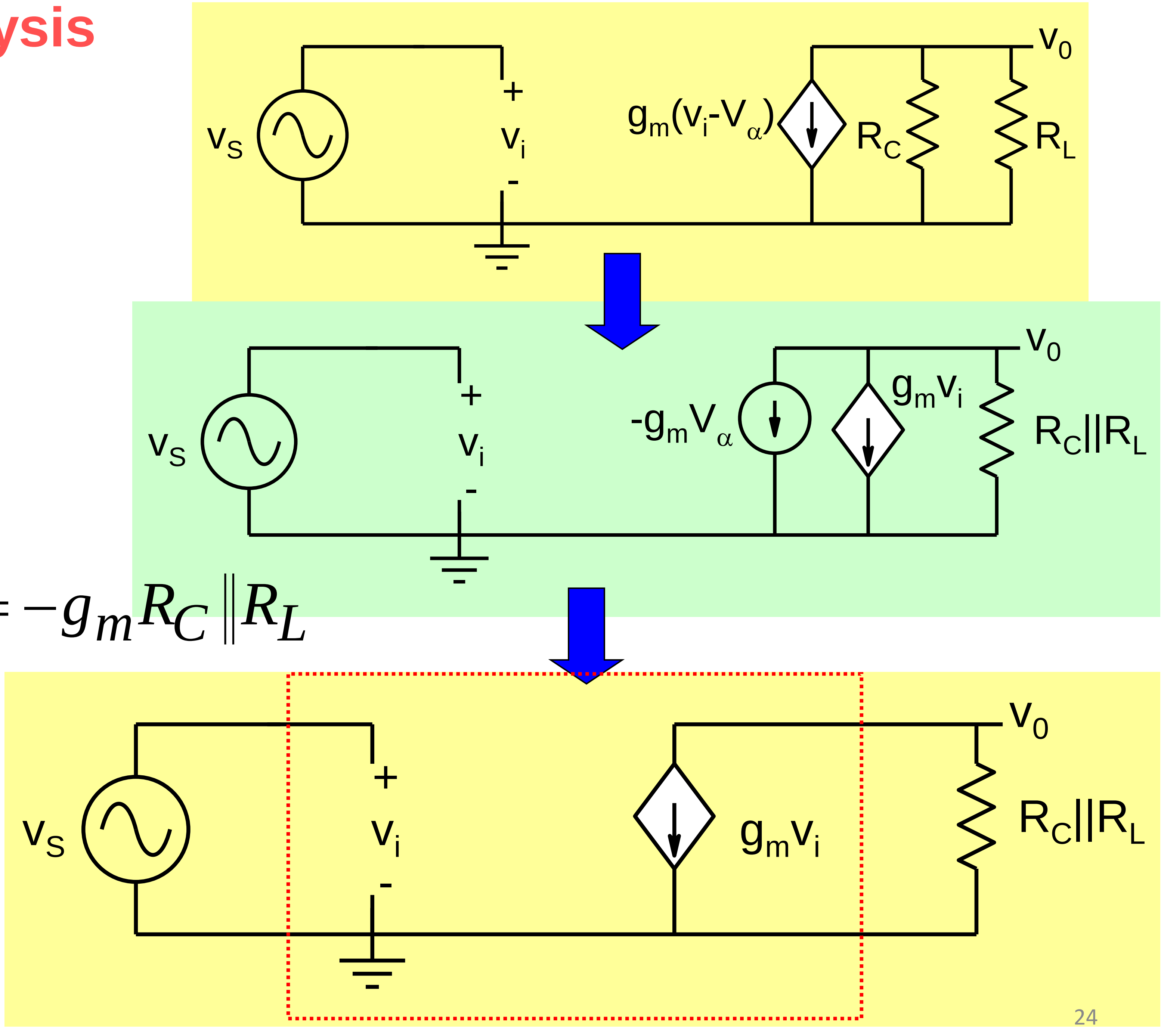


$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

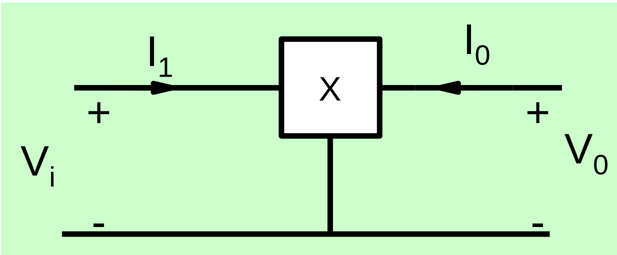
$$I_o = g_m \times (V_i - V_\alpha) \text{ for } V_i > V_\alpha$$

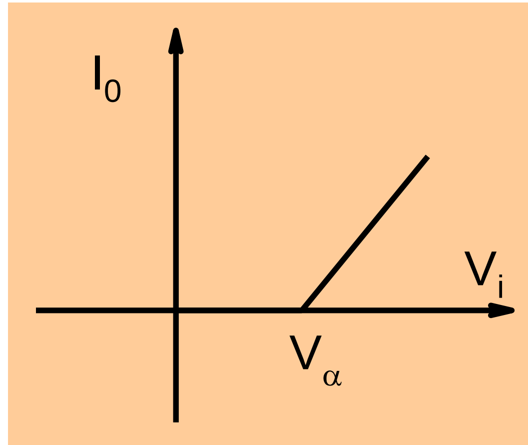


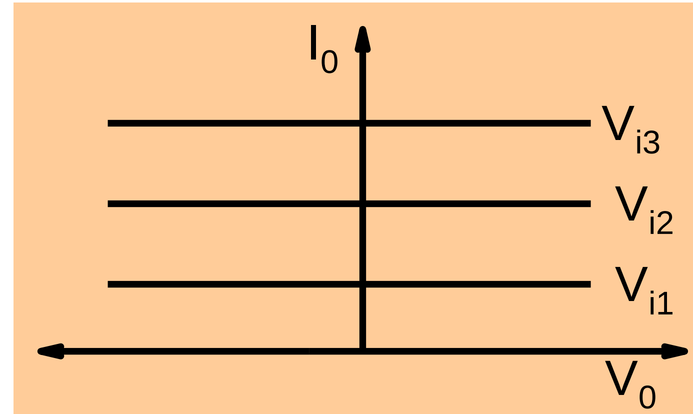
AC Analysis

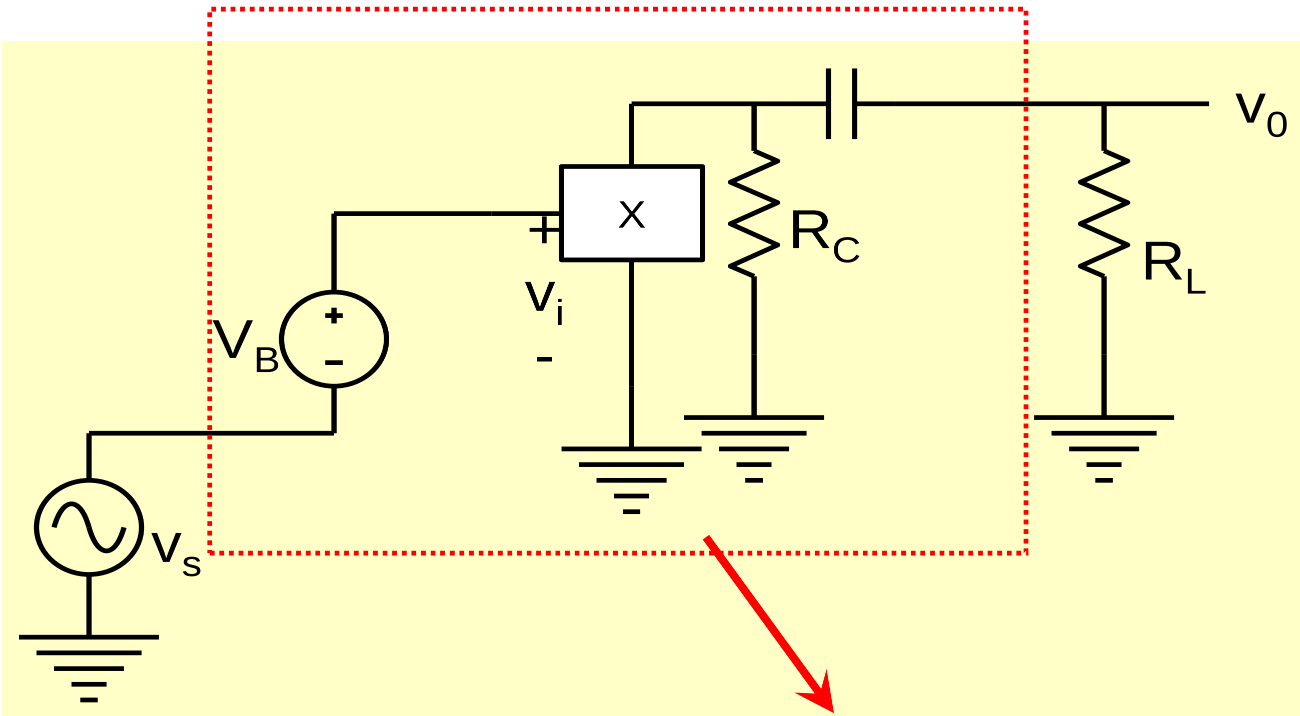


$$A_V = \frac{v_o}{v_s} = -g_m R_C \| R_L$$



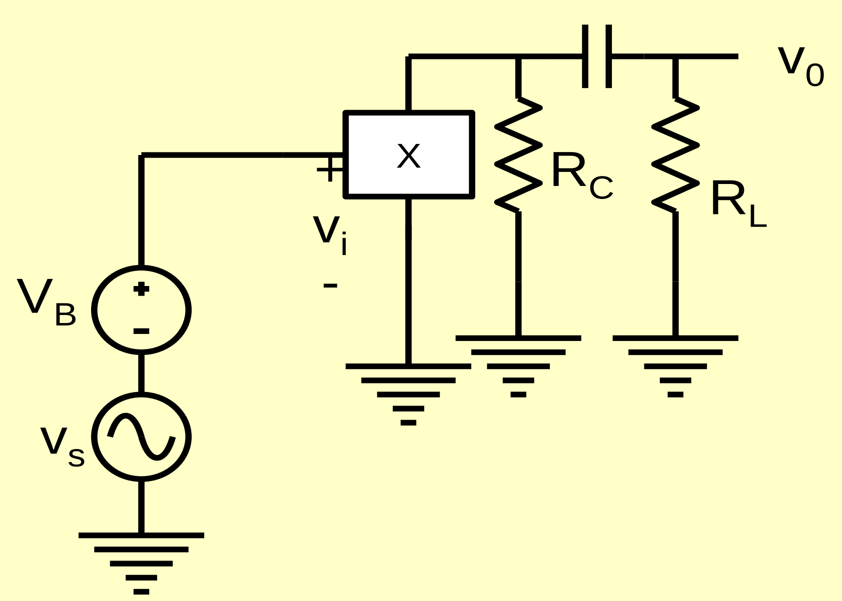


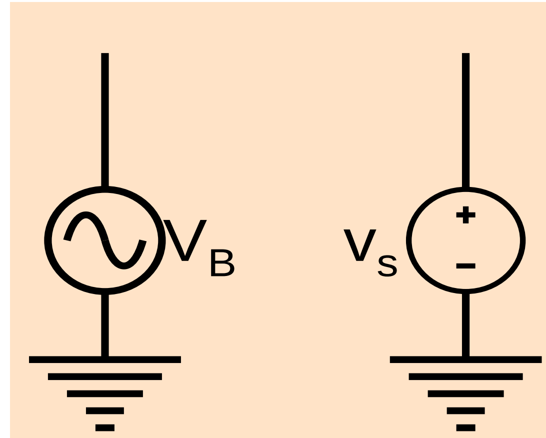


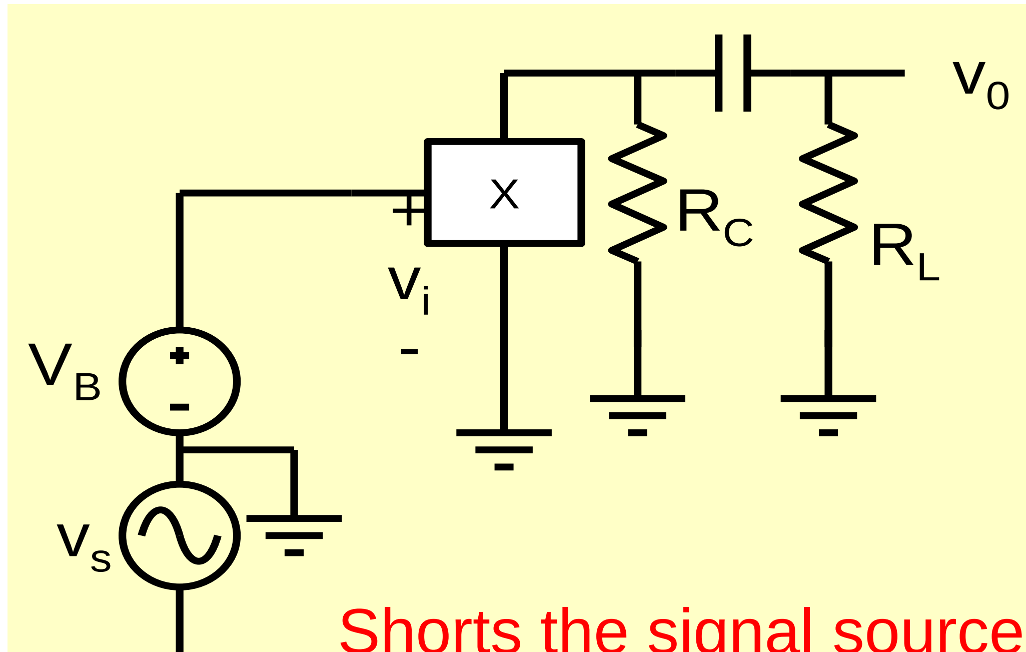


The addition of biasing network allows element X to appear as an ideal transistor to the signal source

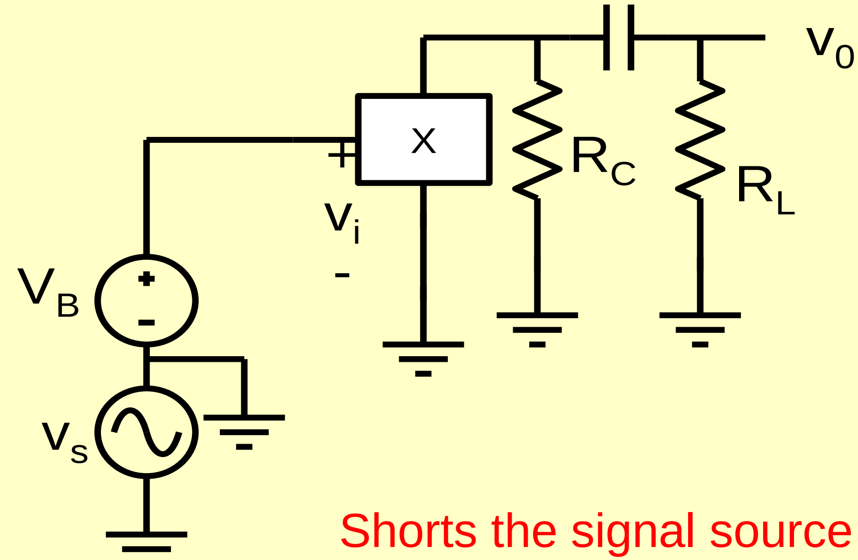
What happens if both dc voltage source and signal source have one terminal as ground?



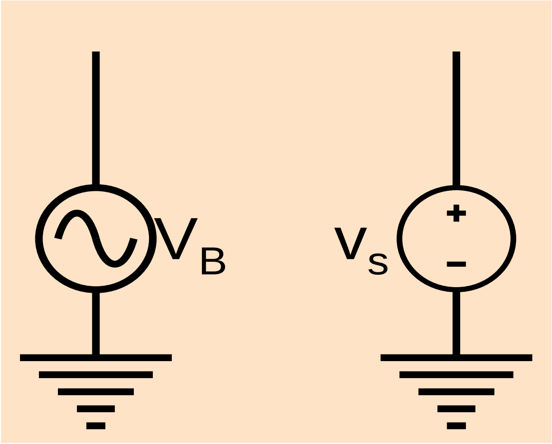




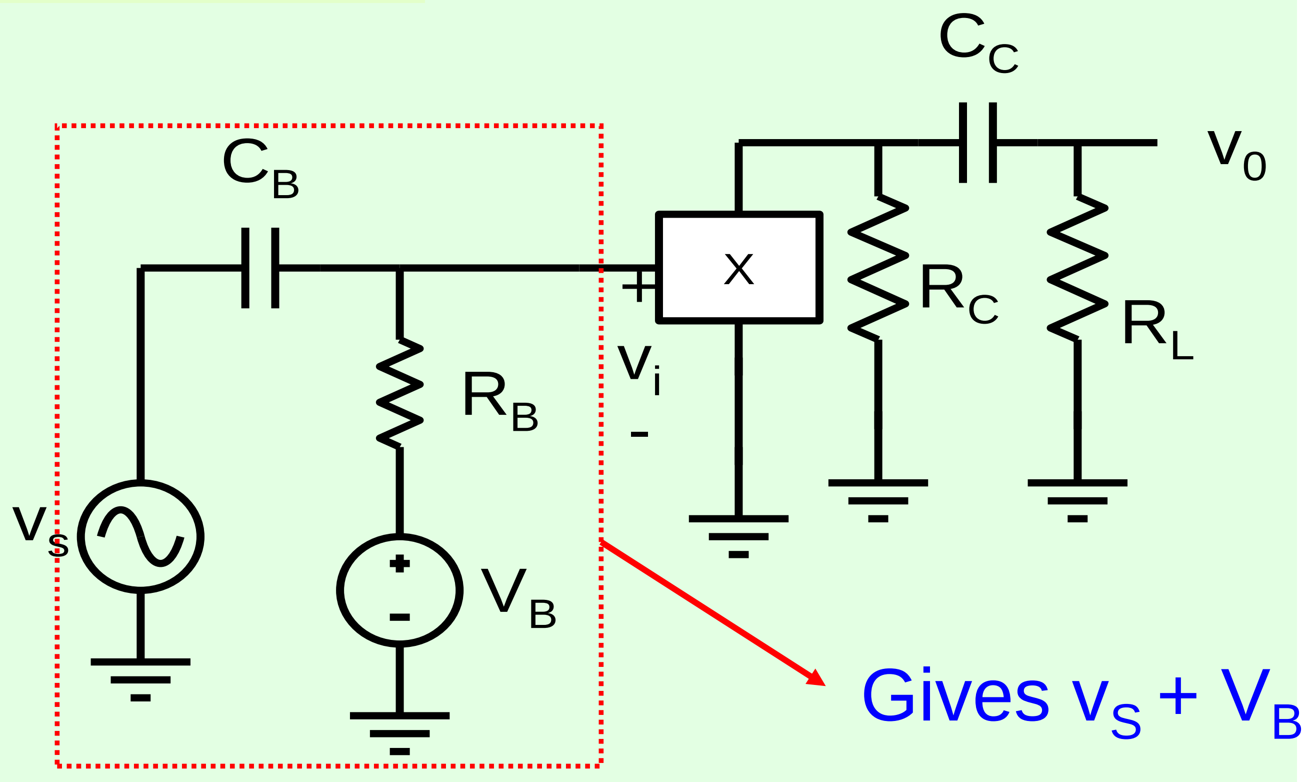
Shorts the signal source



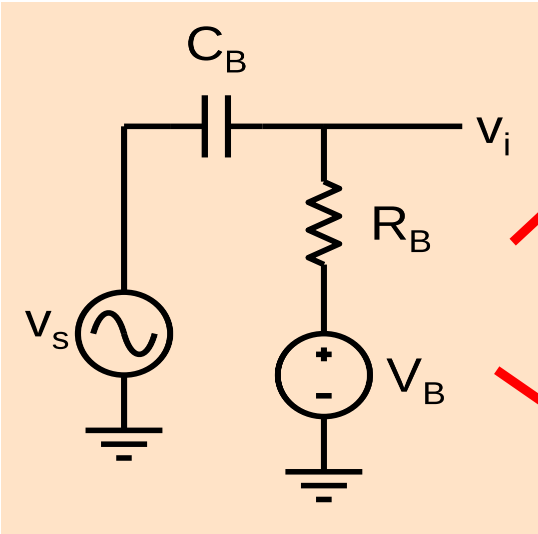
Shorts the signal source

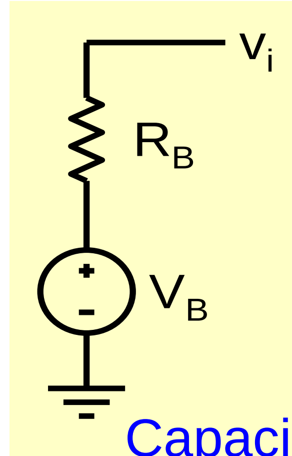


Solution



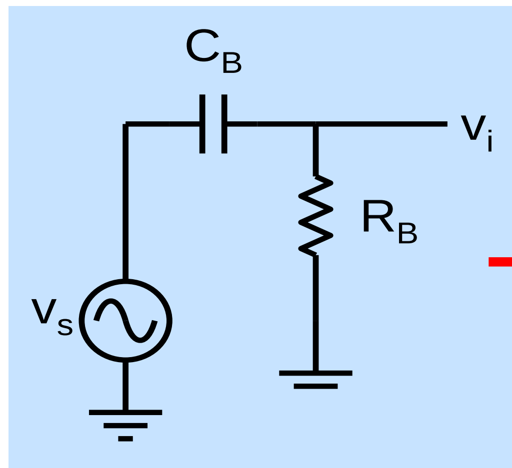
Gives $v_S + V_B$

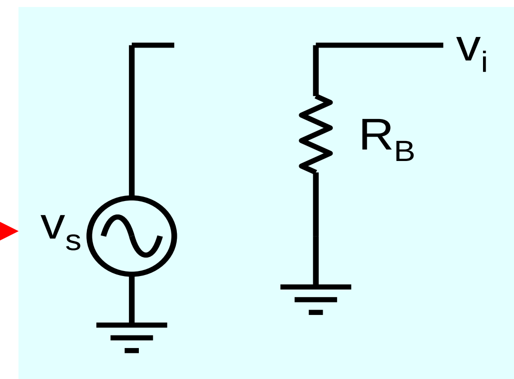




$$v_i = V_B$$

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