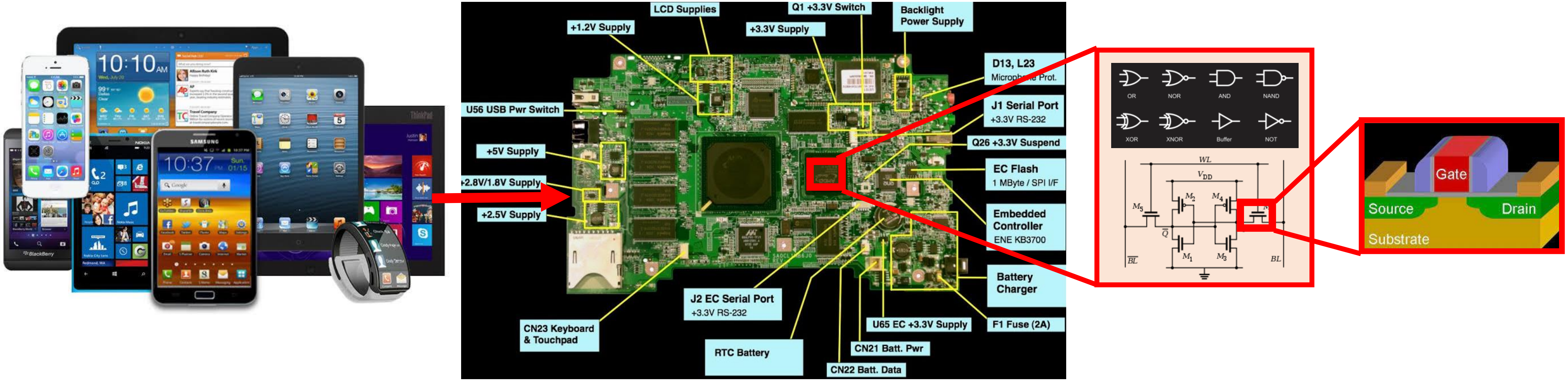

ESC201: Introduction to Electronics

Module 5: Amplifiers

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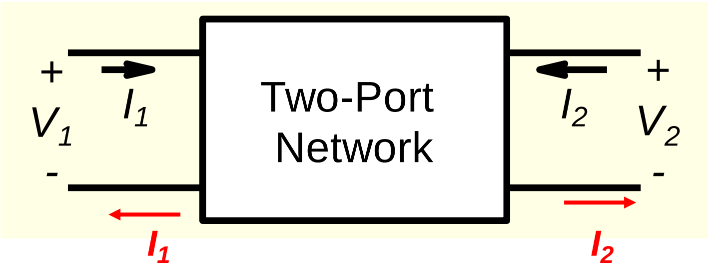
IIT Kanpur

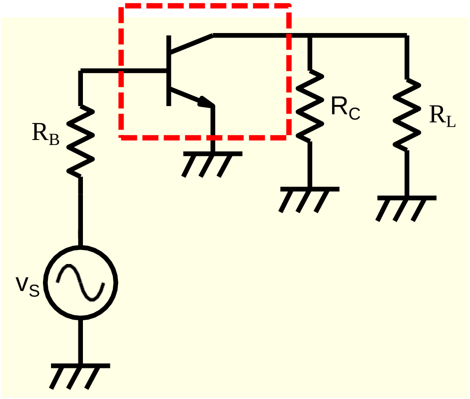
Two-Port Networks



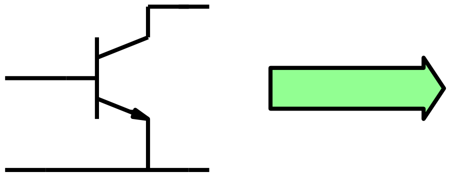
- Port: A pair of terminals through which a signal can enter/leave the network
  - Constraints on analysis:
    1. Linear elements only (R,L,C, dependent sources,..)
    2. No independent sources or stored energy inside the network

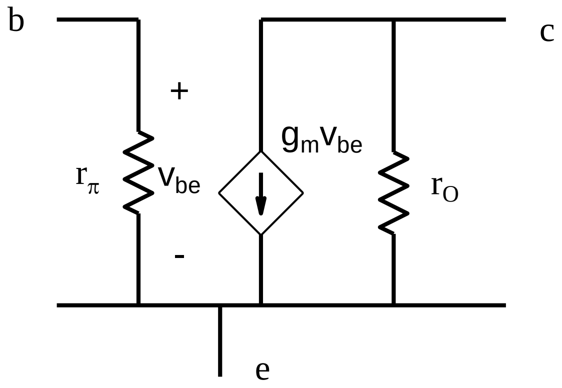
No matter how complicated is the circuit inside the two-port network, it can be represented by only four elements !

Representation of Complex Elements Within Circuits

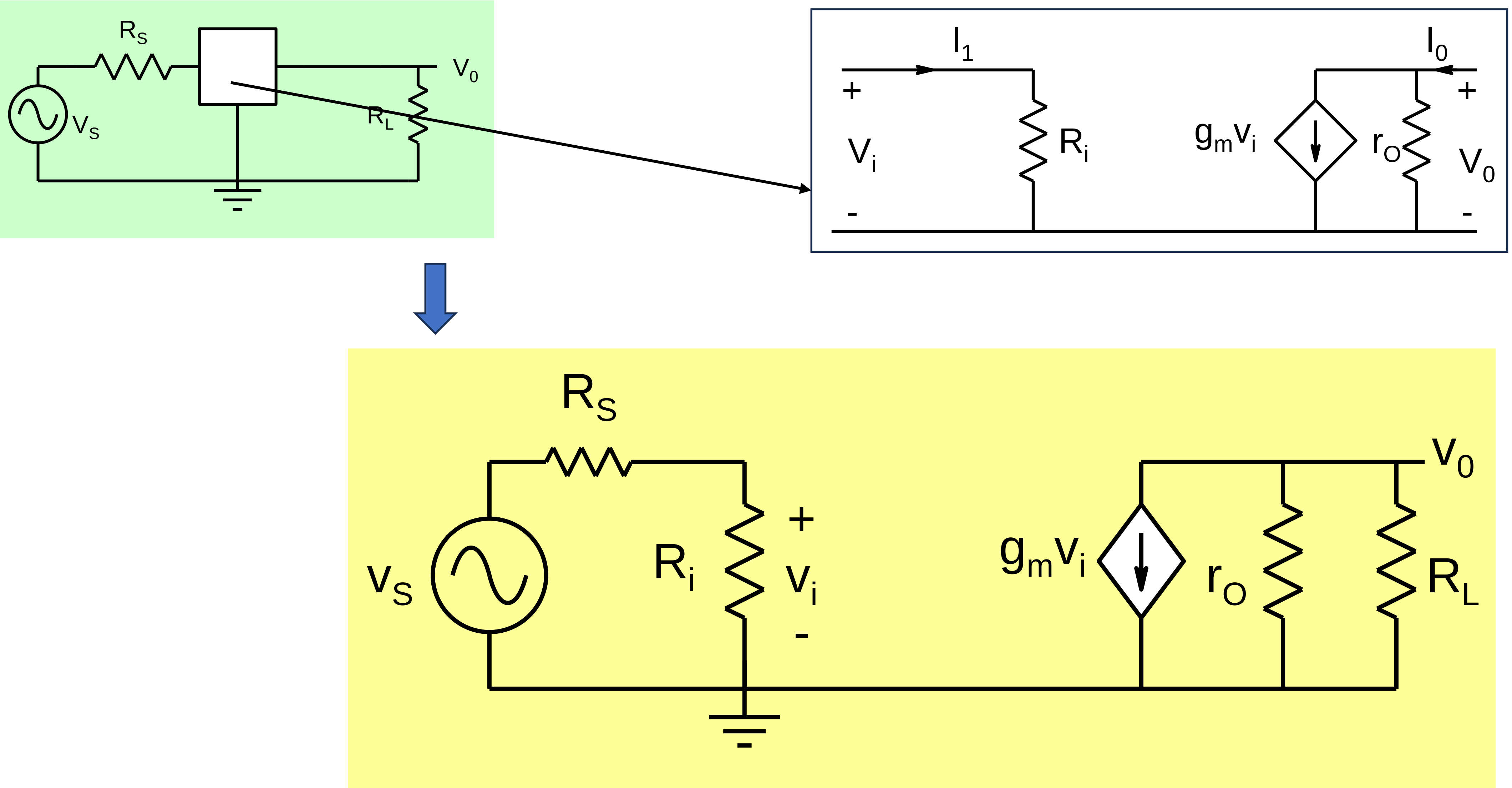


Two port network allows transistor representation in terms of familiar elements.

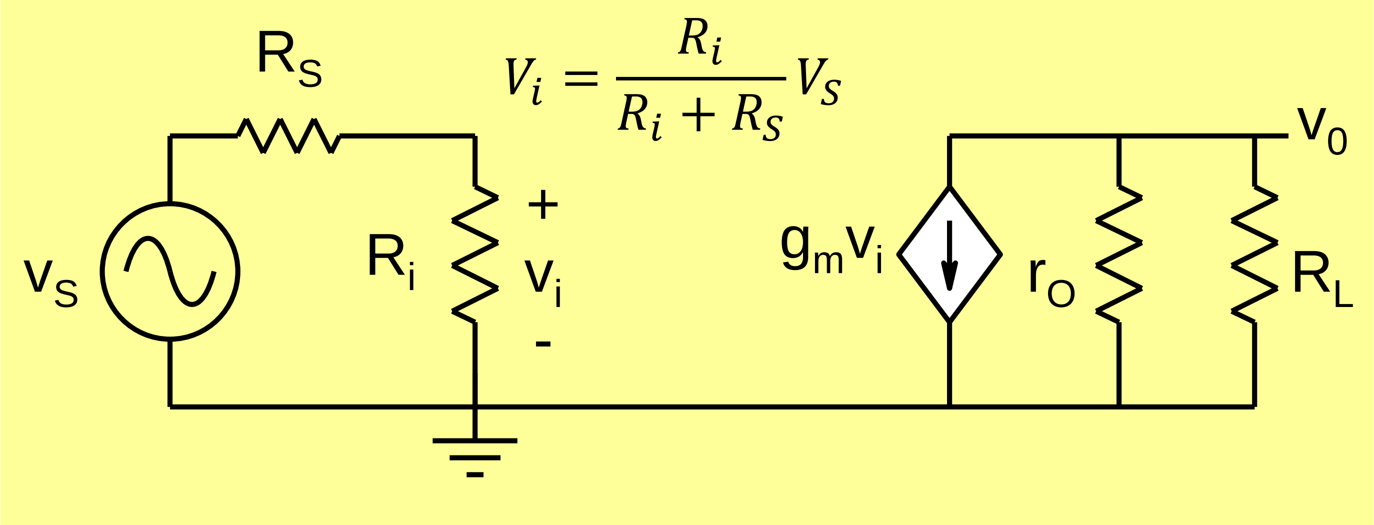




Amplifier circuits



Voltage gain



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

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

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

Necessary Condition for Voltage Amplification

$$|A_V| \leq g_m \times r_o$$

$$g_m \times r_o > 1$$

R_i Large

g_m Large

r_o Large

High voltage gain

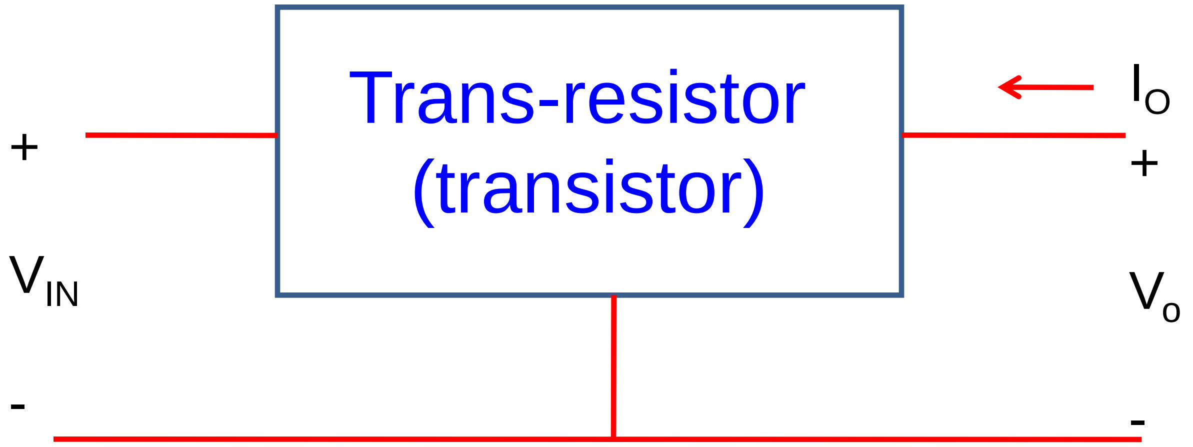
$$g_m\, r_o >> 1$$

$$g_m >> \frac{1}{r_o} = g_o$$

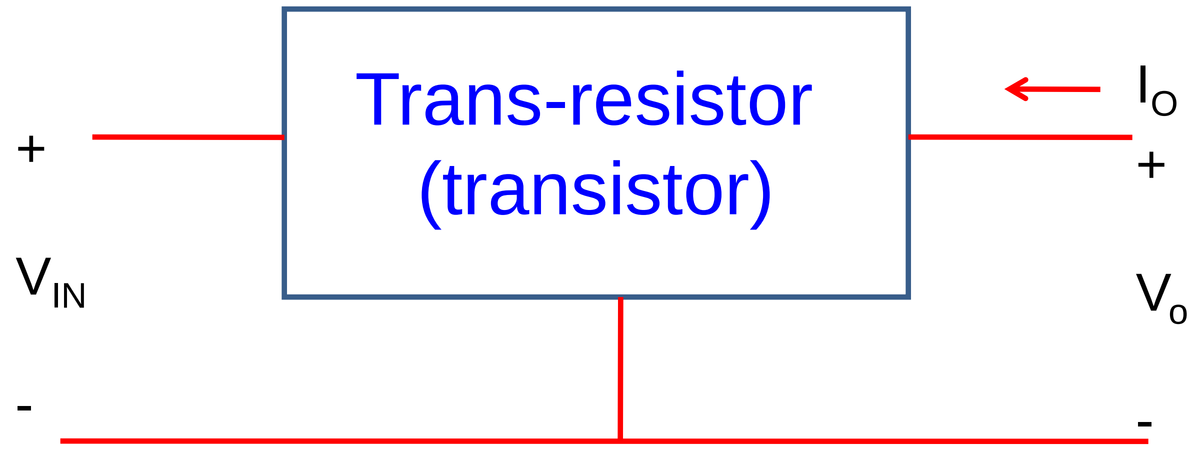
Trans-conductance >> Output Conductance

Trans-resistance << Output resistance

i.e. current I_O is much more sensitive to V_{IN} than V_O



High voltage gain



i.e. current I_O is much more sensitive to V_{IN} than V_O

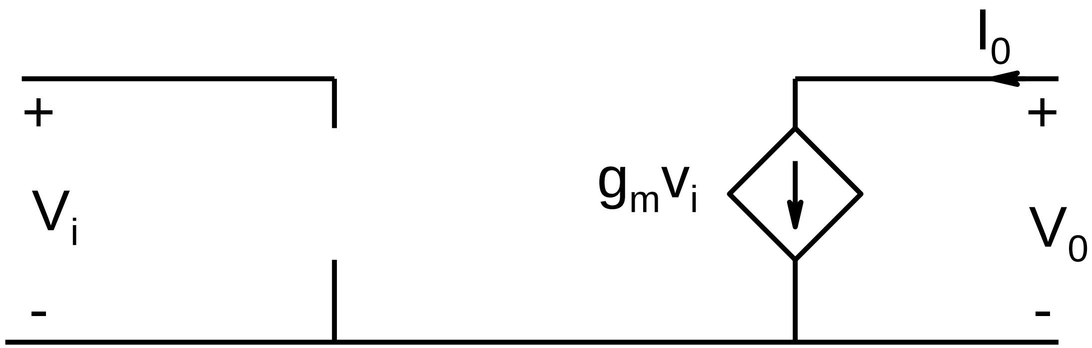
- Can be used for voltage amplification
- Can be used as a switch
- Implement logic
- …

Ideal transistor

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

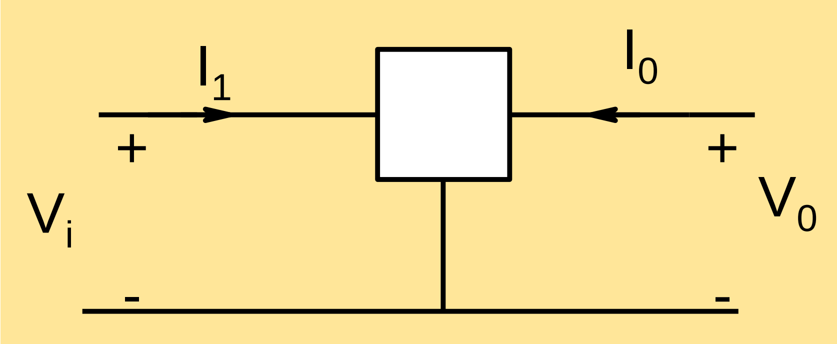
- Ideally, r_o and R_i are infinite

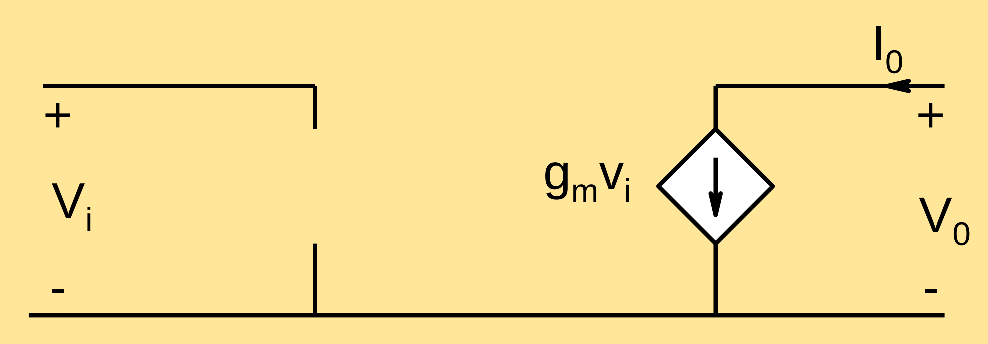
$$A_V = -g_m R_L$$



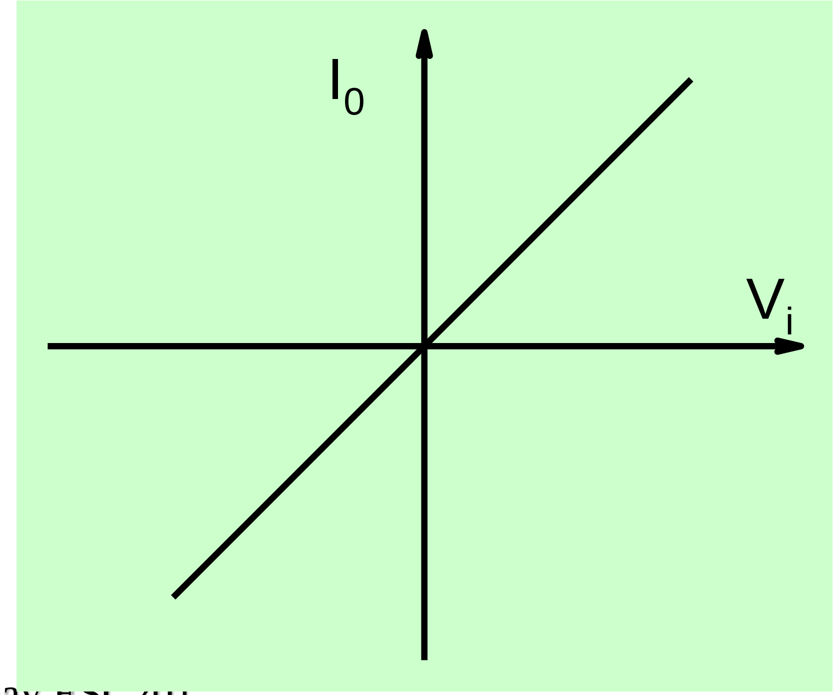
Key device needed: voltage controlled current source

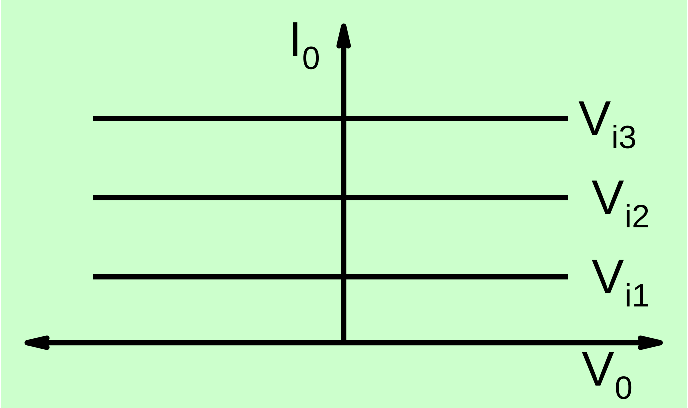
Ideal transistor characteristics





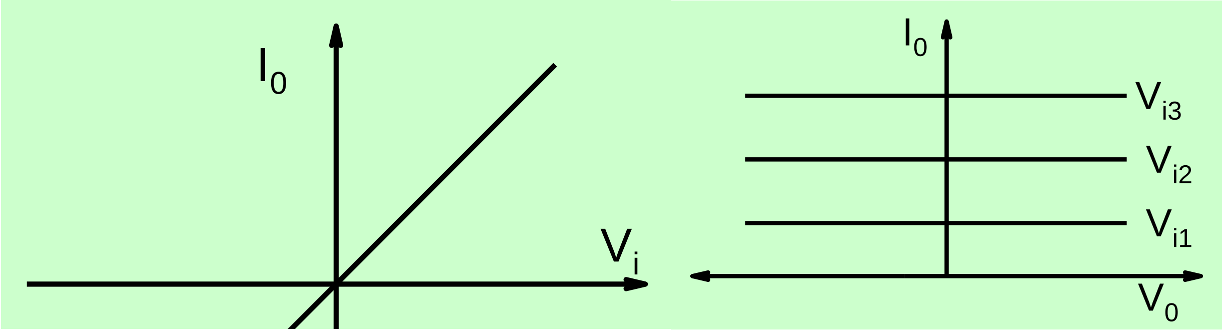
$$A_V = \frac{v_o}{v_s} = -g_m R_L$$

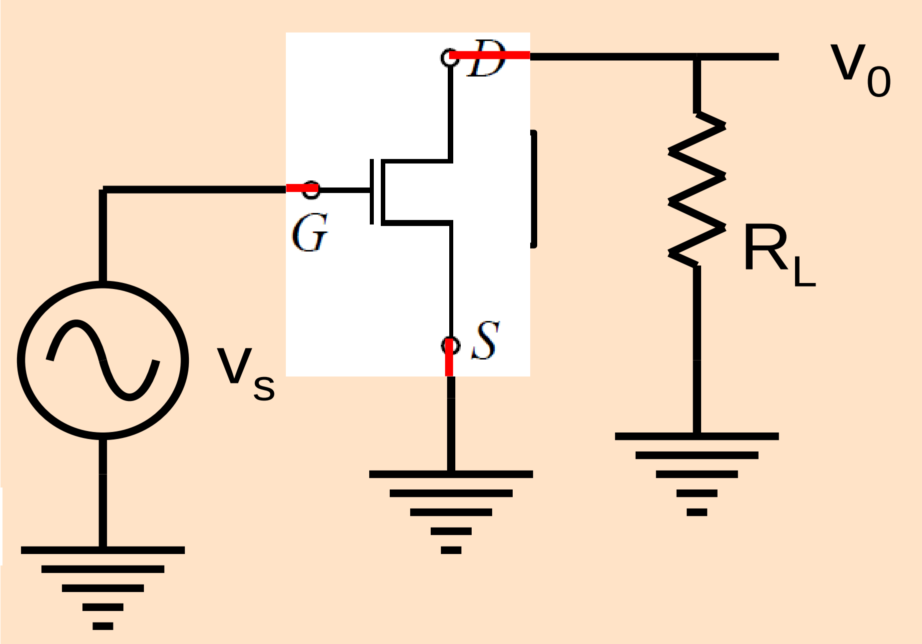


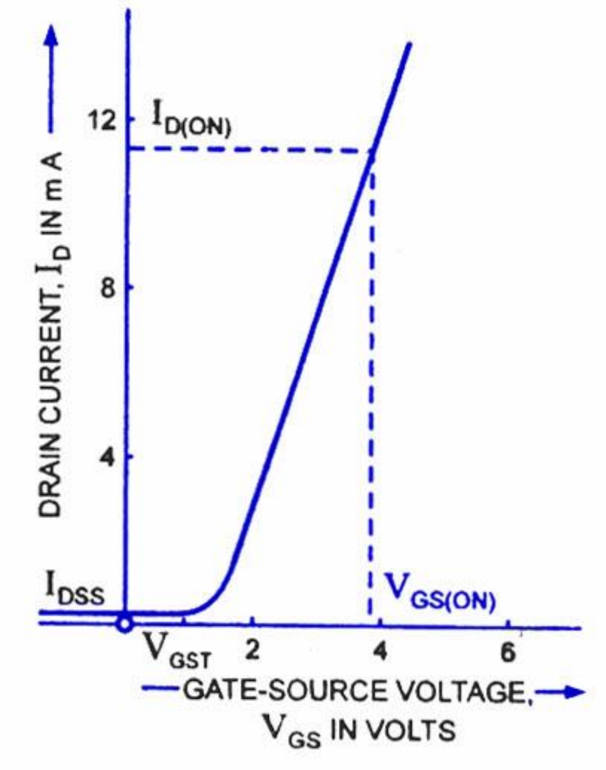


In practice there is no element which has the characteristics of ideal transistor !

Real transistors

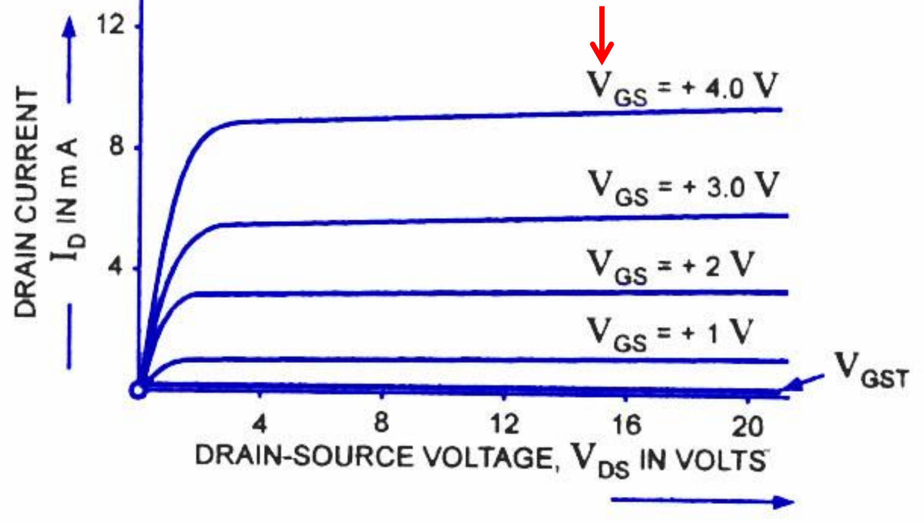






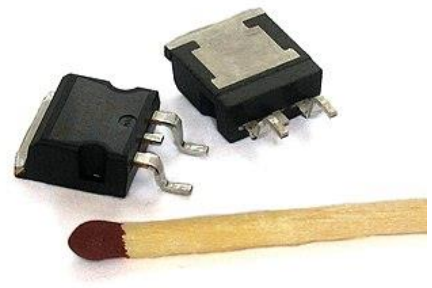
Transfer Characteristic

Approximately a VCCS



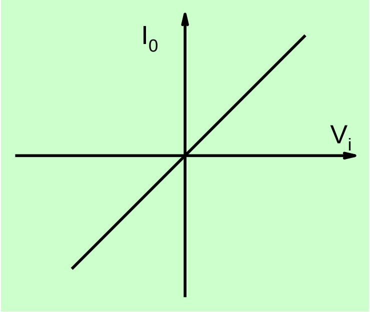
Drain Characteristics

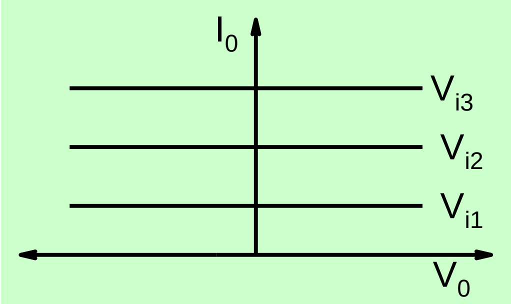
metal-oxide-semiconductor field-effect transistor
MOSFET



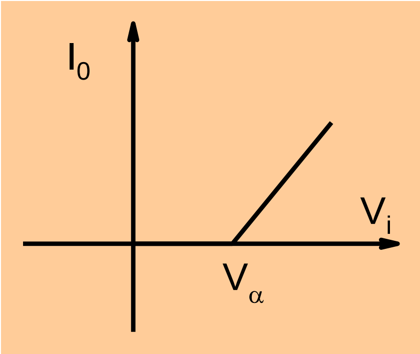
Real Devices to Amplifiers

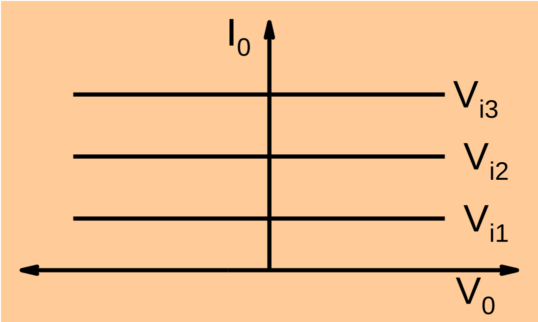
Ideal transistor



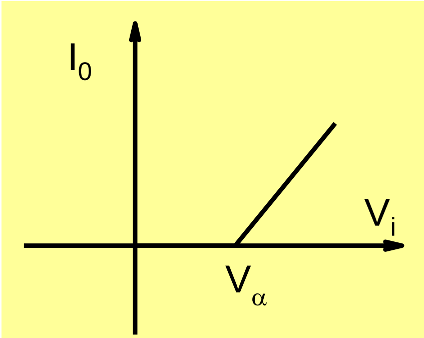


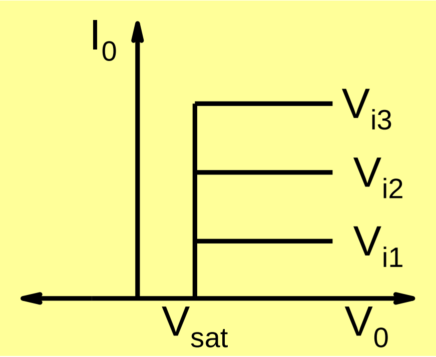
How do we use devices such as X, Y etc to make amplifiers?



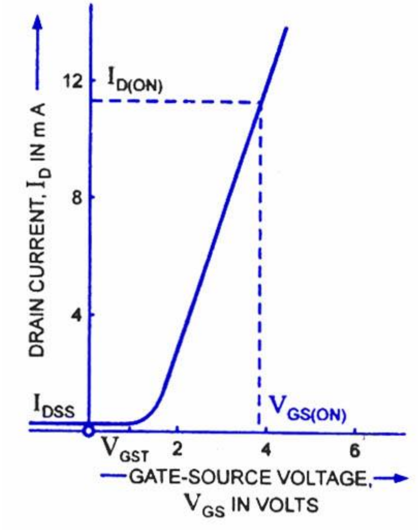


Device X

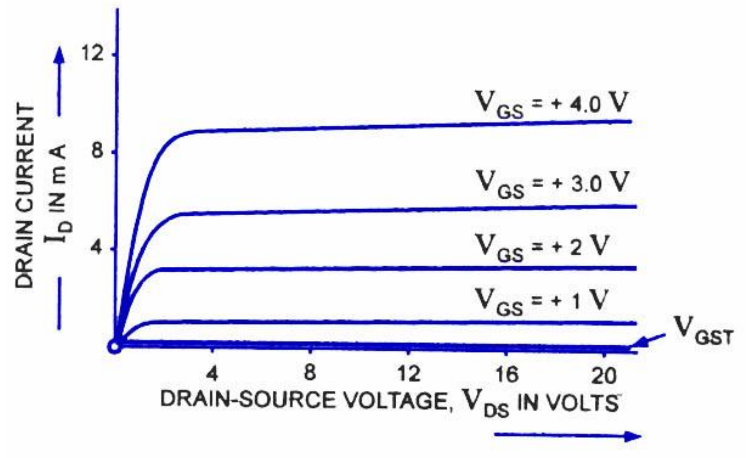




Device Y



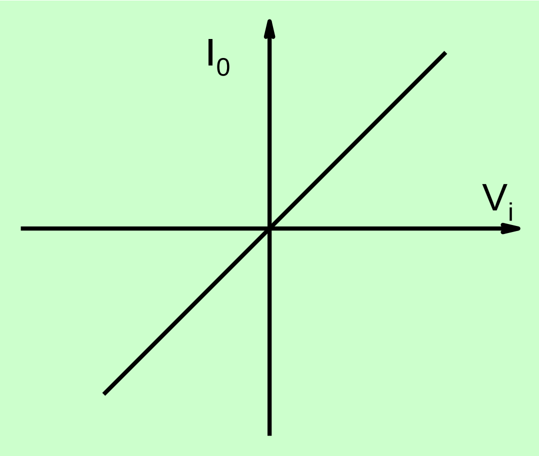
Transfer Characteristic

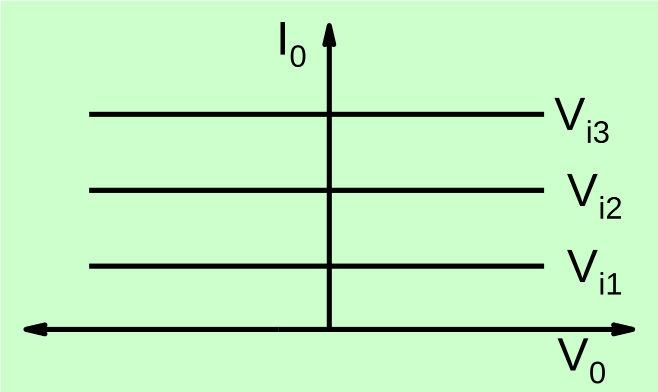


Drain Characteristics

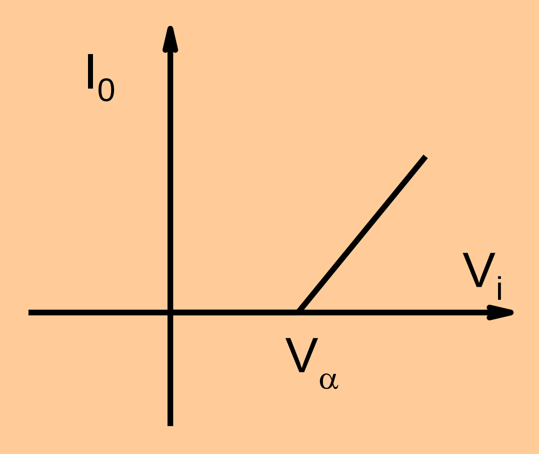
Simplified model X

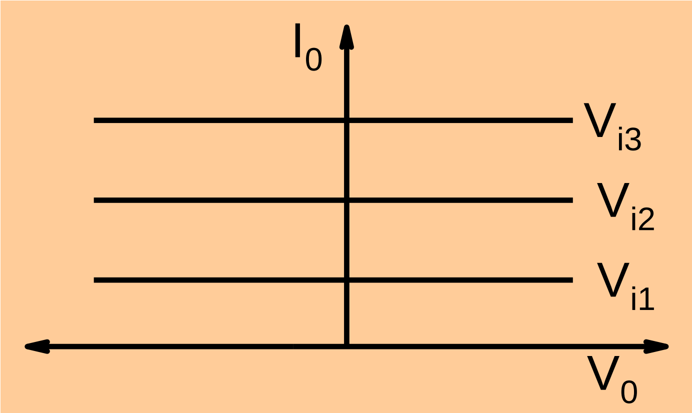
Ideal transistor





Device X (non-linear)

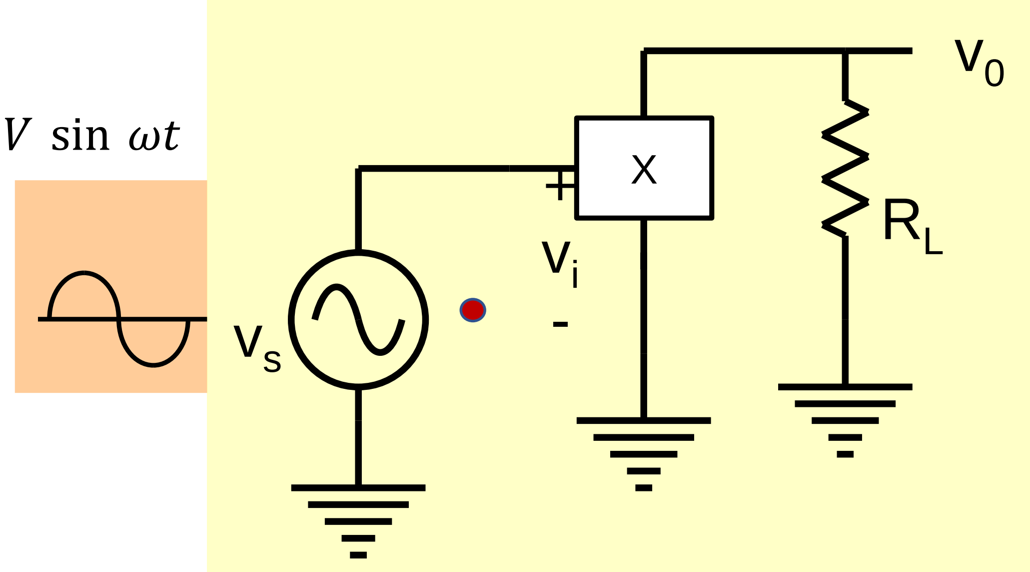




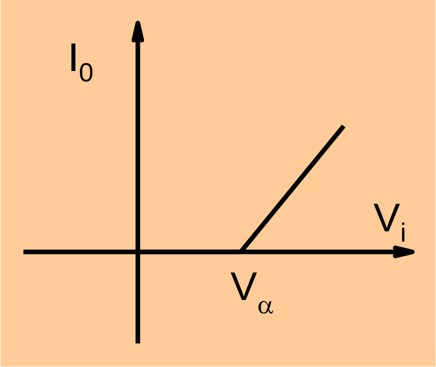
$$I_o = \begin{cases} 0 & \text{for } V_i \leq V_\alpha \\ g_m(V_i - V_\alpha) & \text{for } V_i > V_\alpha \end{cases}$$

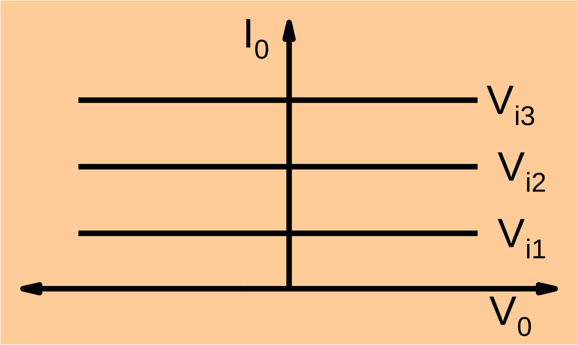
Amplifier circuit?

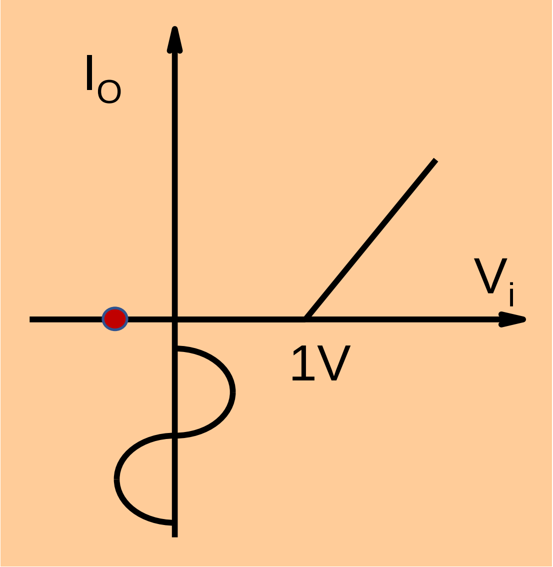
$v_s = 0.5V \sin \omega t$



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



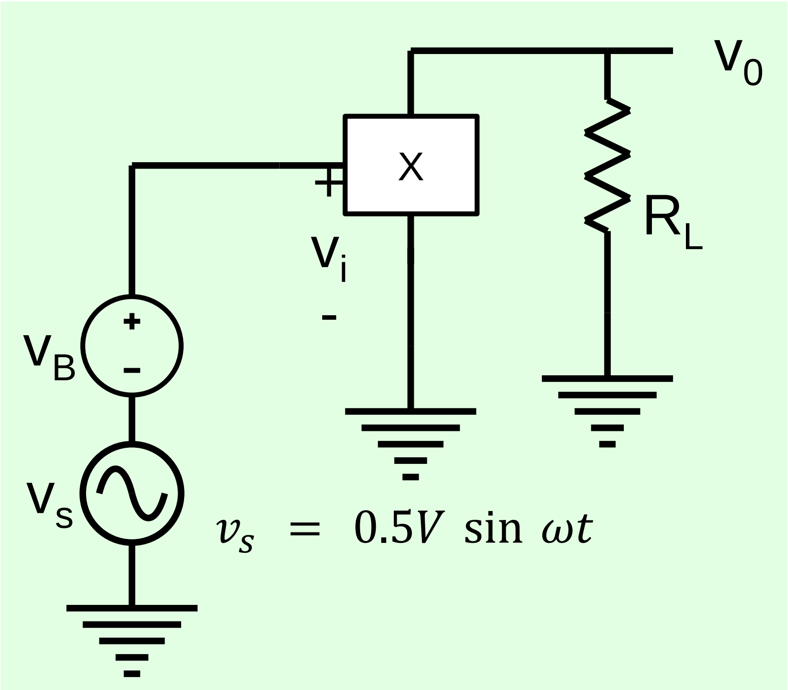




$$I_O = 0 \Rightarrow V_O = 0$$

No Amplification

Amplifier with biasing



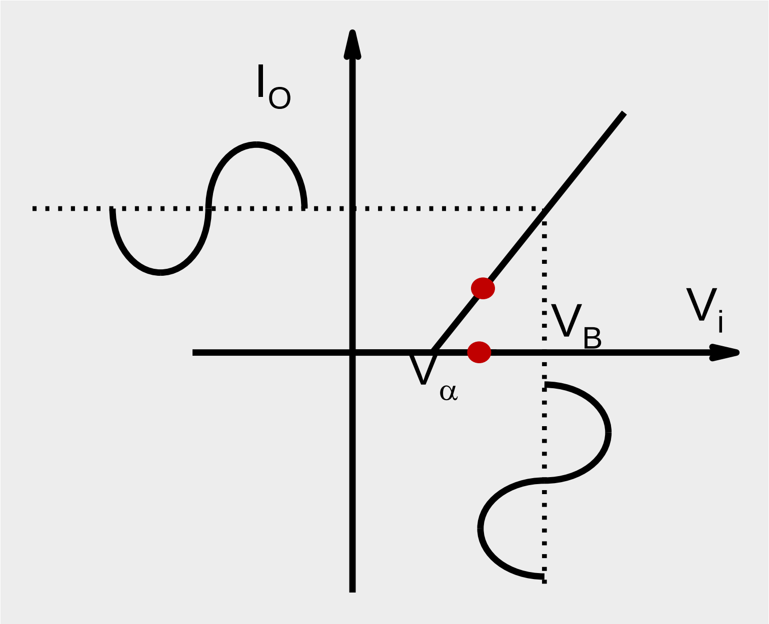
$v_s = 0.5V \sin \omega t$

Bias Voltage

$V_B > V_\alpha$

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

$R_L = 1K$;



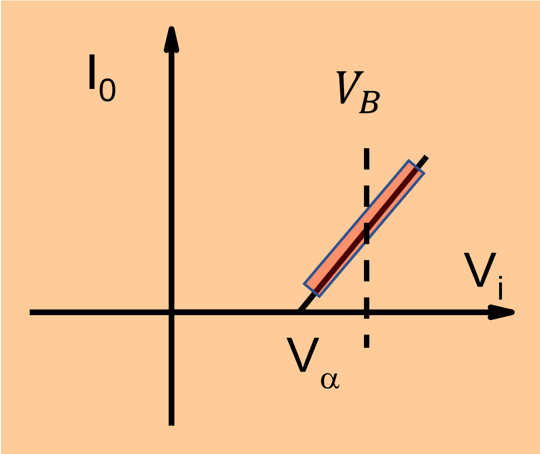
$V_o = -I_o R_L$

Biasing

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.

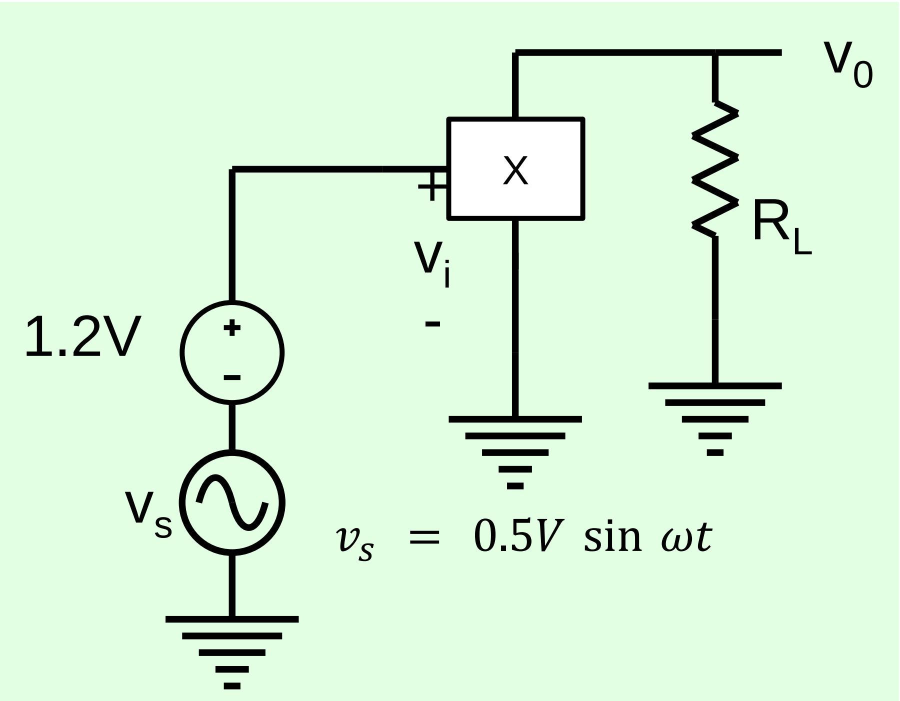
How to choose the bias voltage V_B?

- Choose V_B as the center point of desired operating range
- Otherwise: clipping!

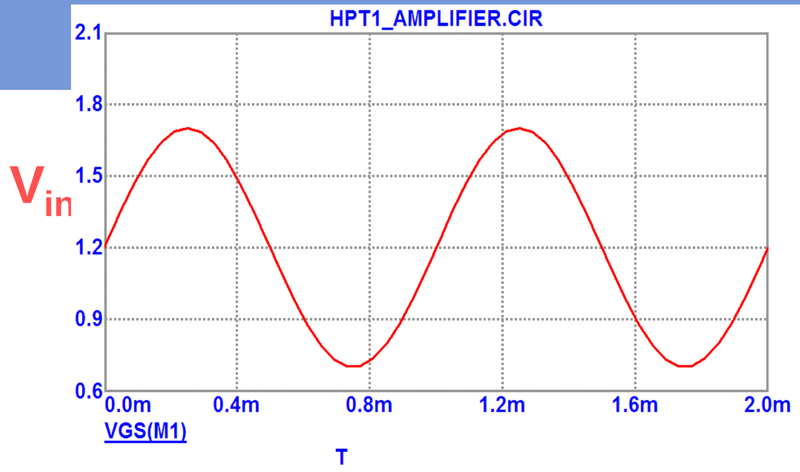


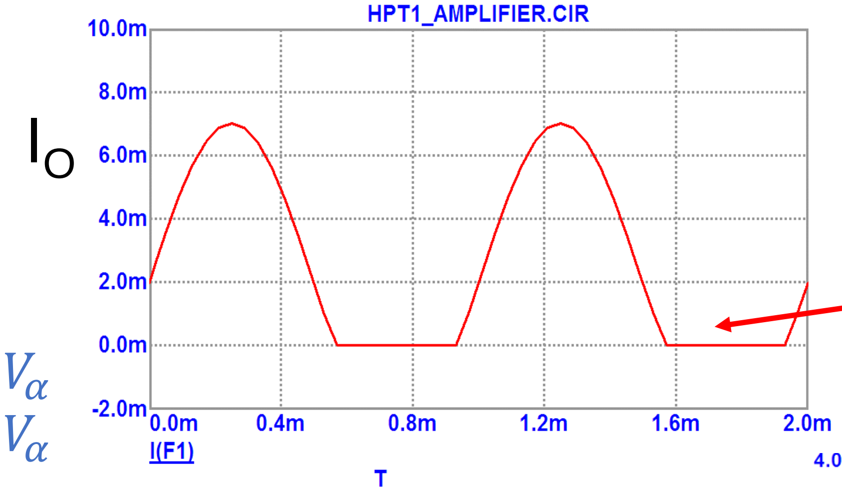
V_B : Bias point or Quiescent point (Q-point)

Need to choose a proper value of biasing voltage



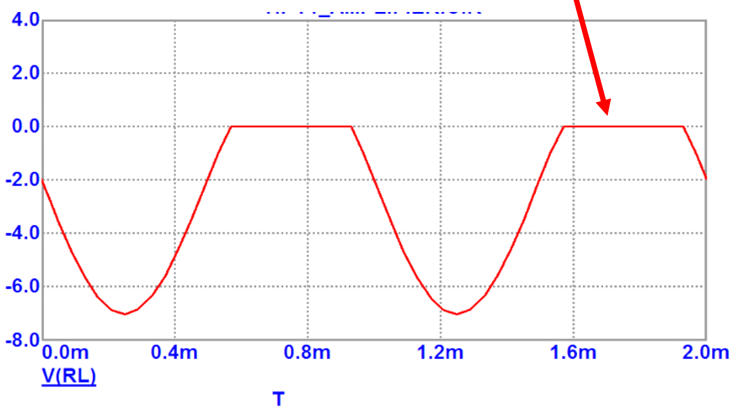
$$v_s = 0.5V \sin \omega t$$

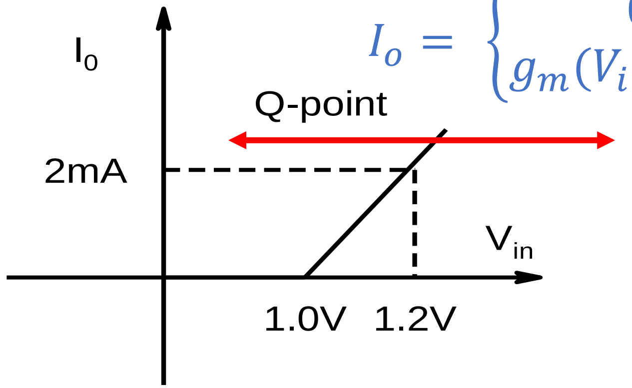




clipped

$$V_o = -I_o \;\; R_L$$



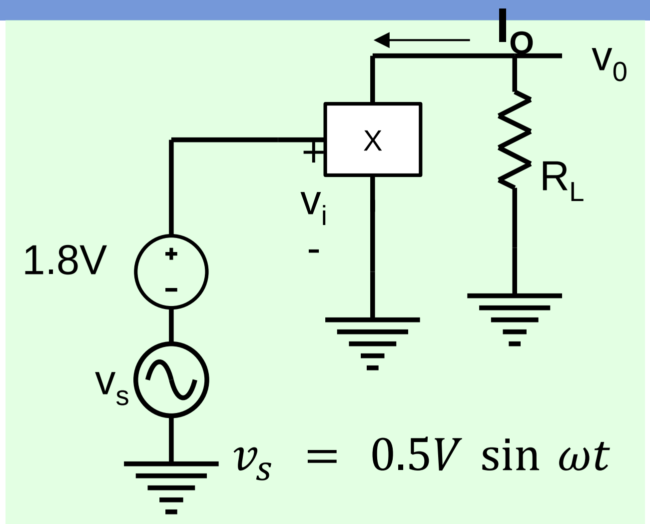


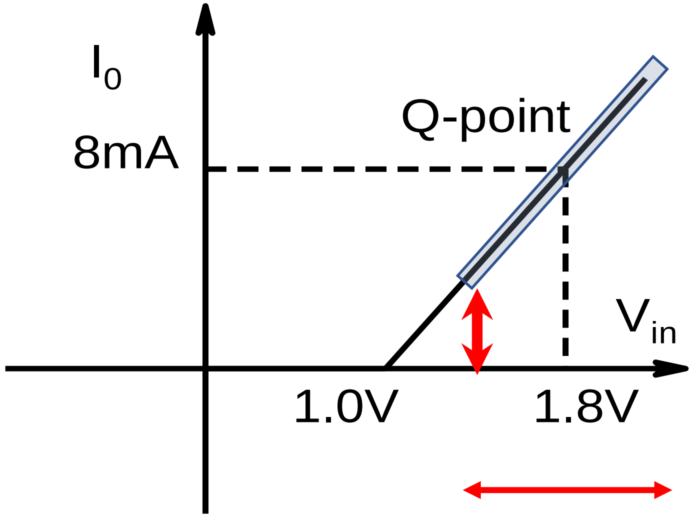
$$I_o = \begin{cases} 0 & \text{for } V_i \le V_\alpha \\ g_m(V_i - V_\alpha) & \text{for } V_i > V_\alpha \end{cases}$$

$V_\alpha = 1V;$

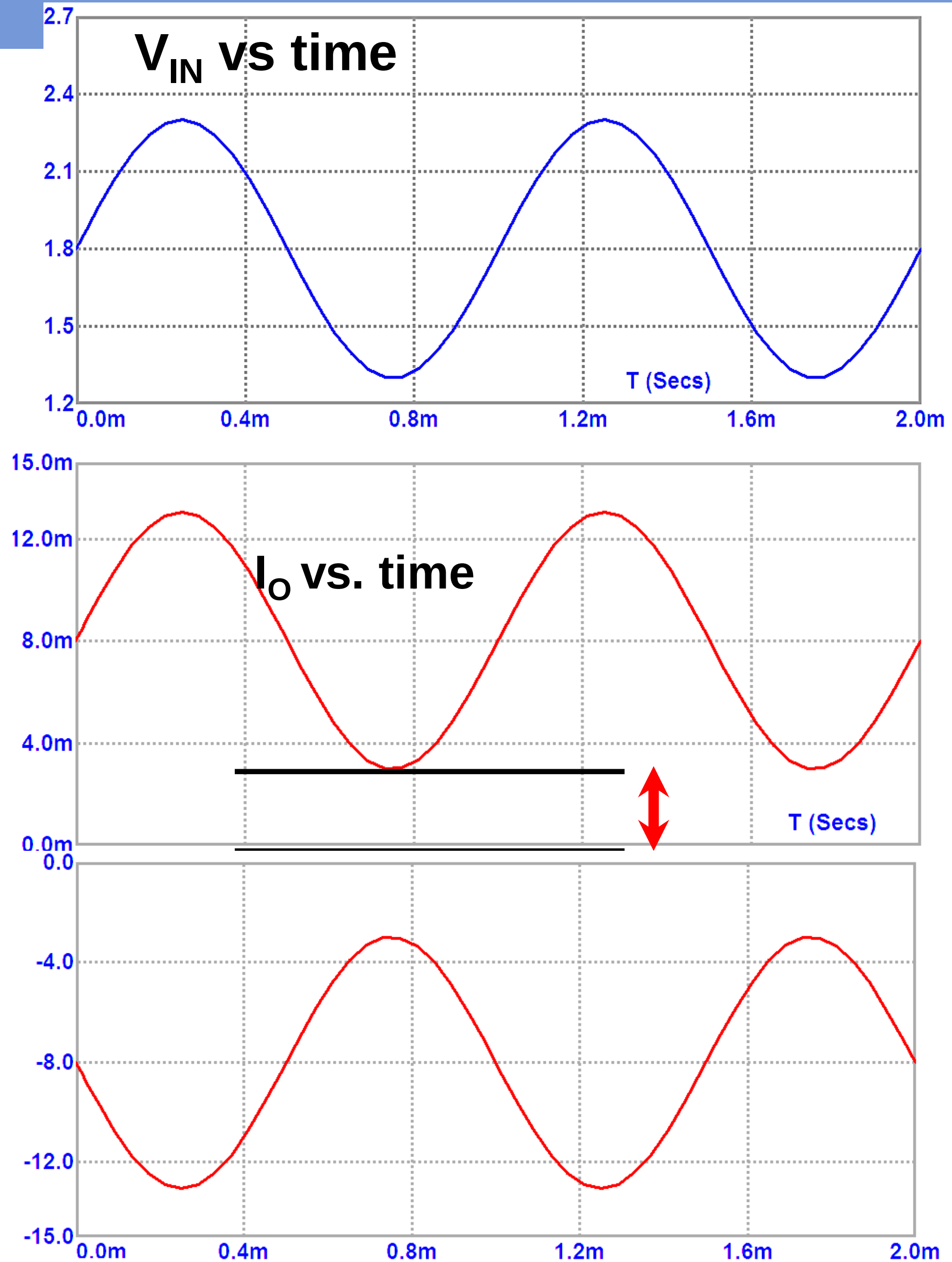
$g_m = 0.01\Omega^{-1}$

No clipping

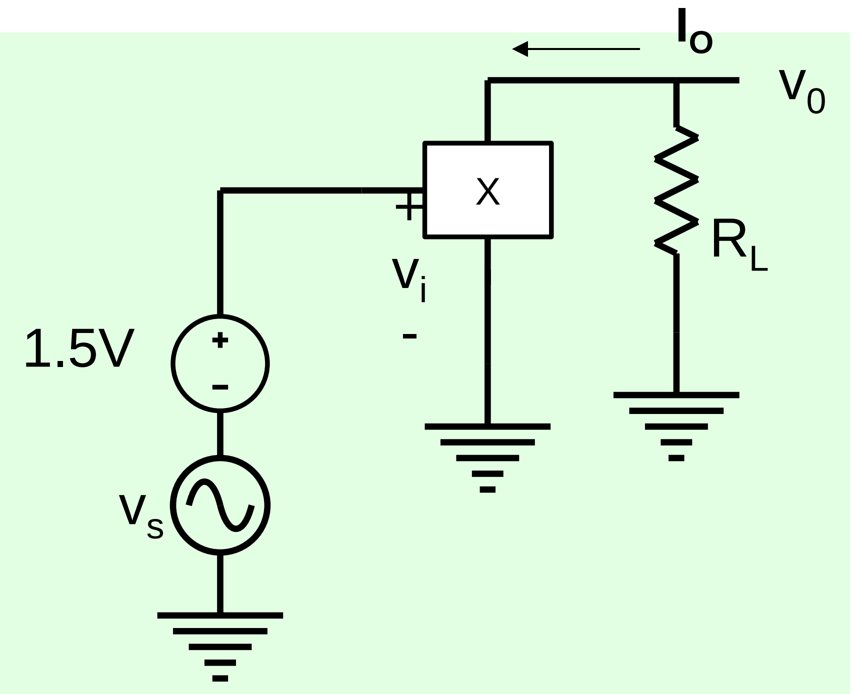


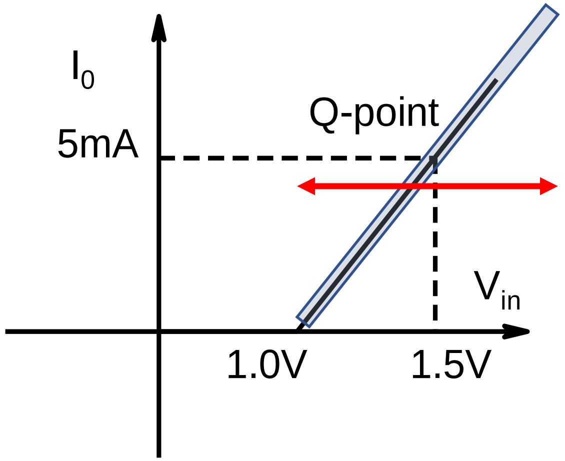


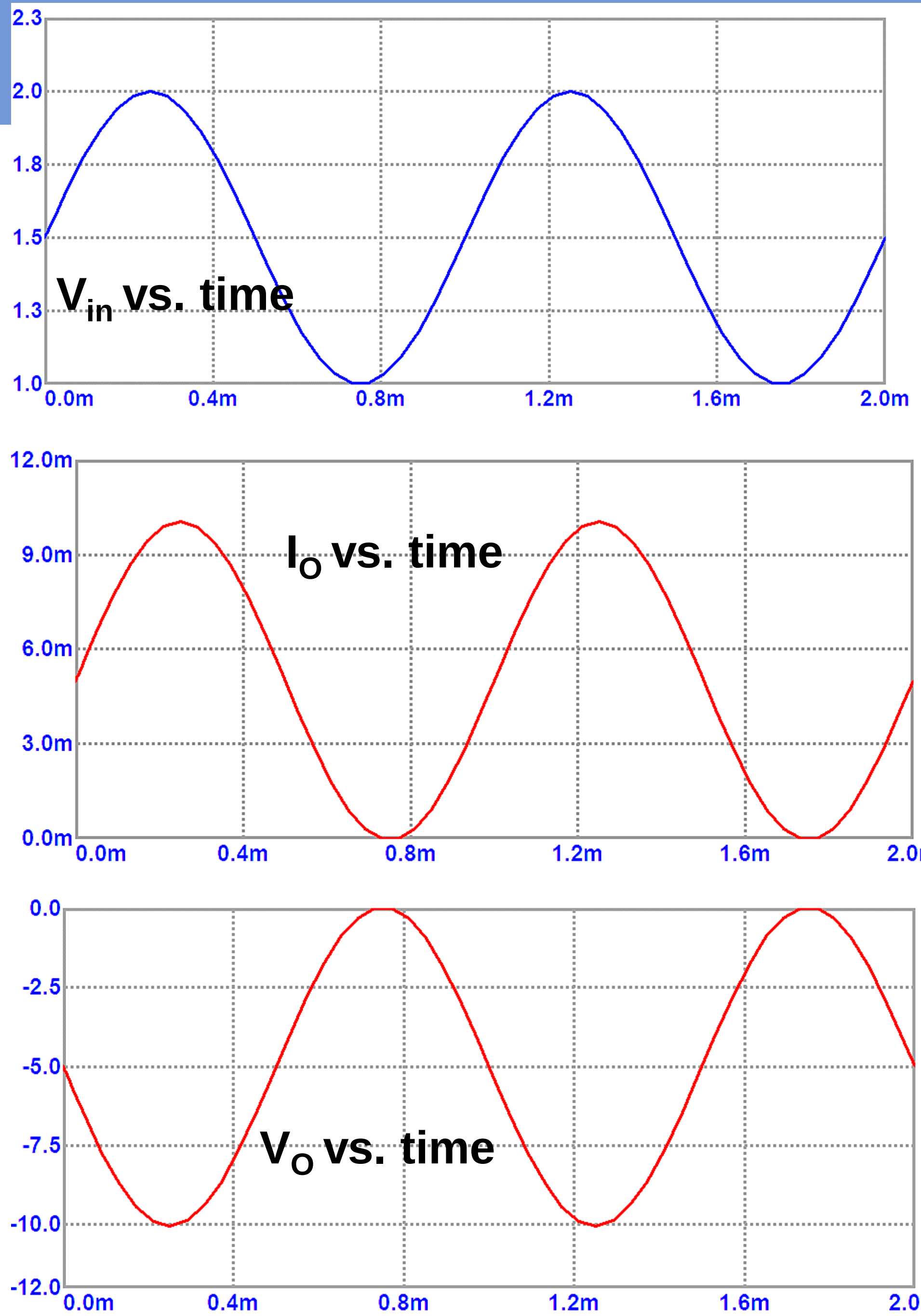
Unnecessary Power Dissipation



Optimum biasing

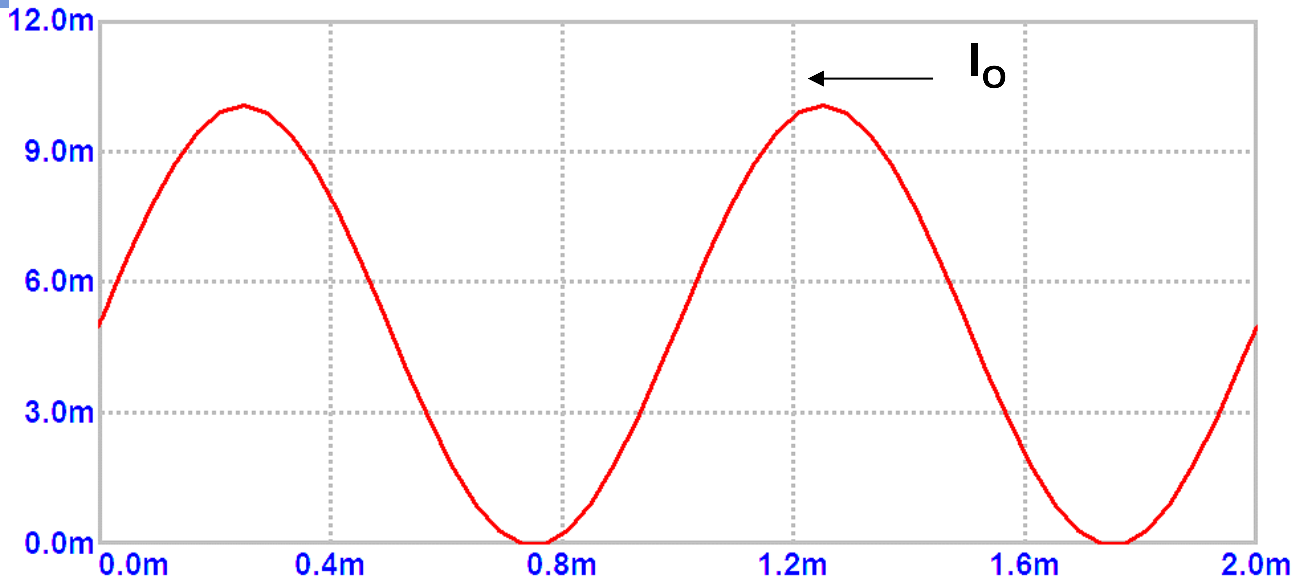






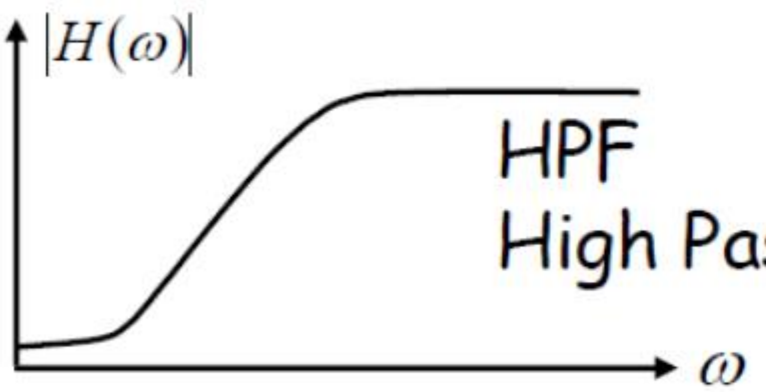
Dr. Shubham Saha

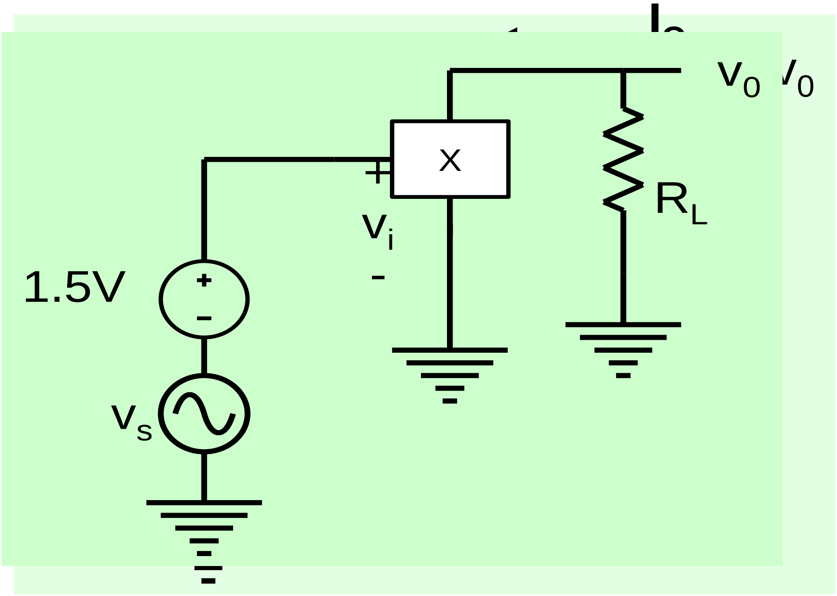
Removing the dc component



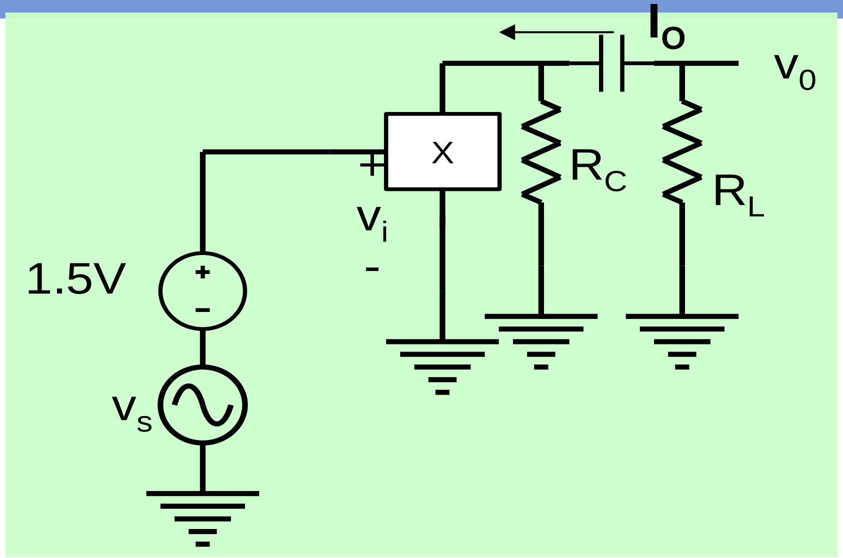
Capacitor is chosen large enough so that at the signal frequency ,

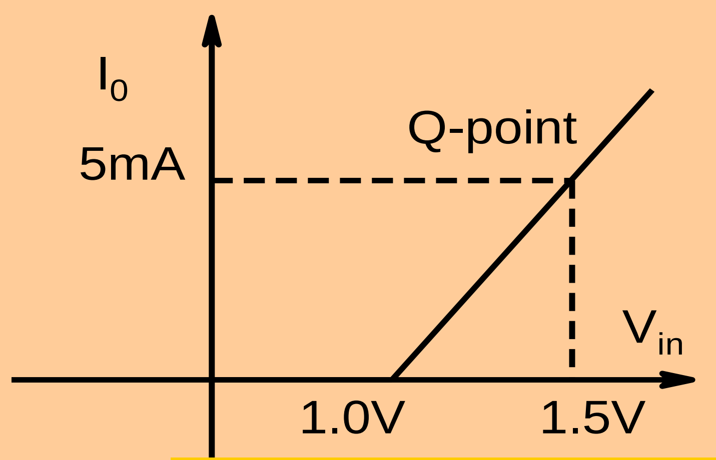
$$\frac{1}{j\omega C} \sim 0.$$





DC vs AC Components

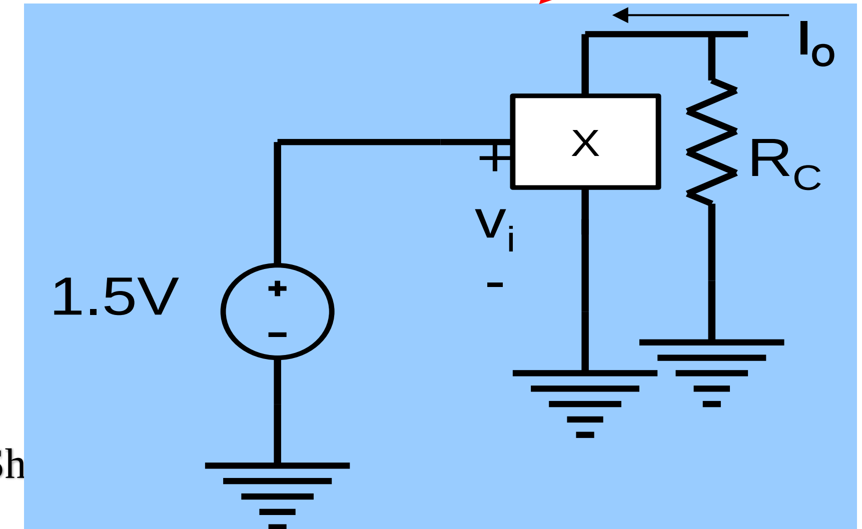


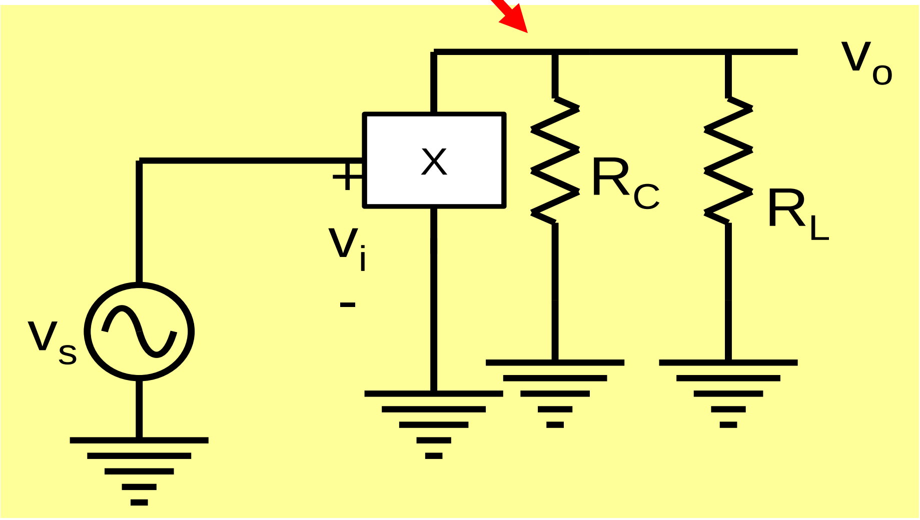


$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

dc

ac (signal)





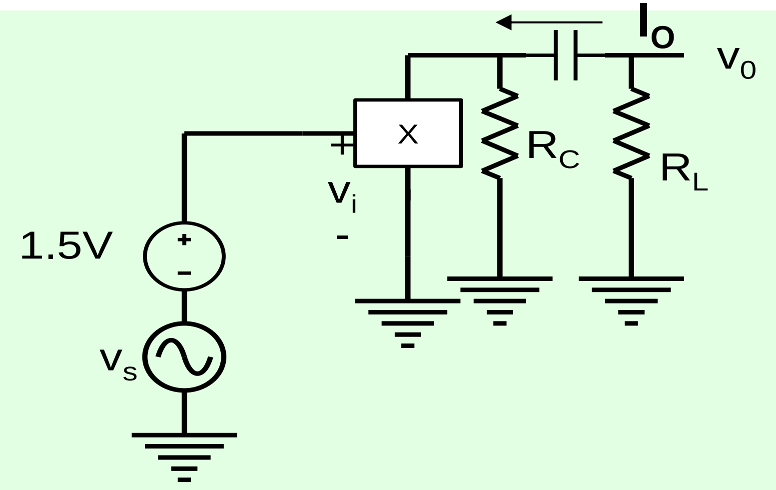
Capacitor is chosen large enough so that at the signal frequency ,

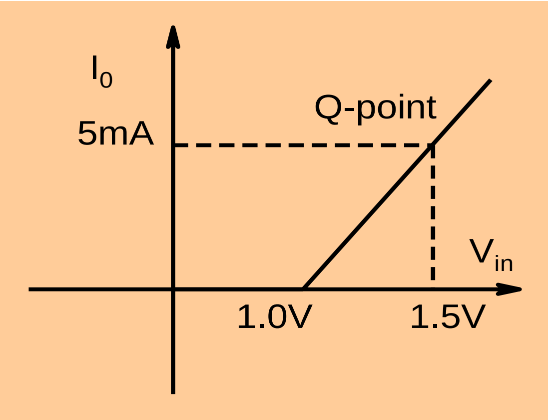
$$\frac{1}{j\omega C} \sim 0.$$

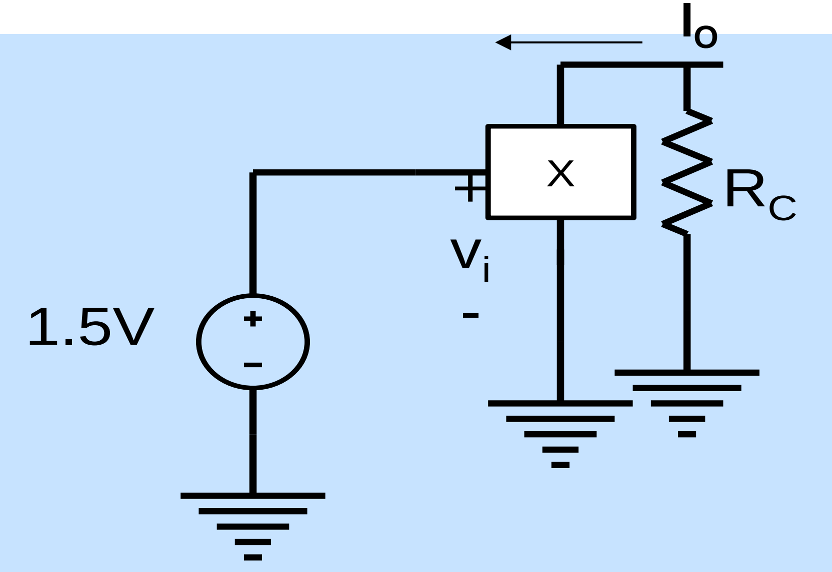
Large signal model: non linear

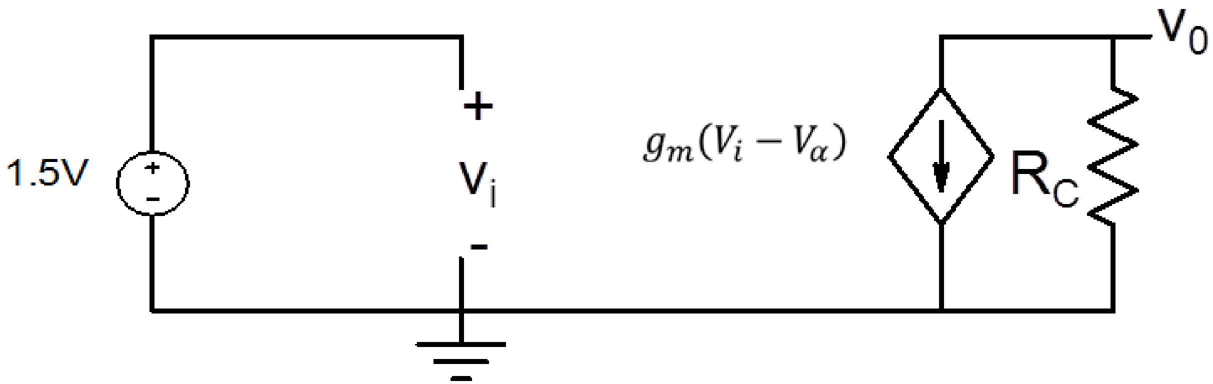
$V_\alpha = 1V;$
$g_m = 0.01\Omega^{-1}$

Large signal model (aka dc model)









$V_i = 1.5\text{V}$

$I_o = g_m(V_i - V_\alpha) = 5\text{mA}$

Non-linear characteristics since superposition does not hold

Small signal method

- Operate at some bias point V_D, I_D
- Superimpose small signal v_d on top of V_D
- Response i_d to small signal v_d is approximately linear.

- Also known as
  - Incremental model
  - Linearized model
  - AC model

$$i_D = I_D + i_d$$

signal Bias Additional small signal

$$v_D = V_D + v_d$$

signal Bias Additional small signal

Linear

$$i_d = k\, v_d$$