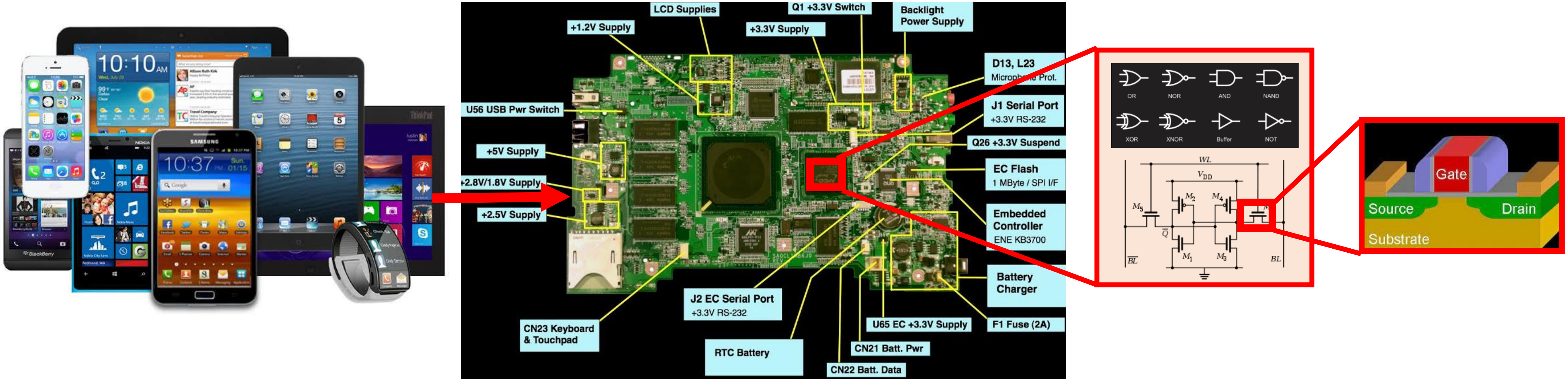

ESC201: Introduction to Electronics

Module 5: Amplifiers

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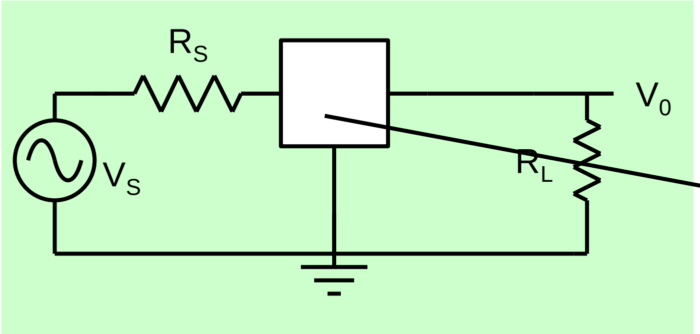
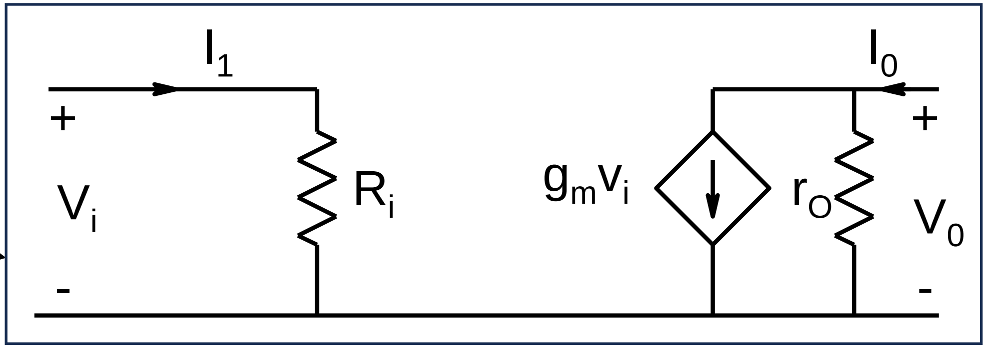
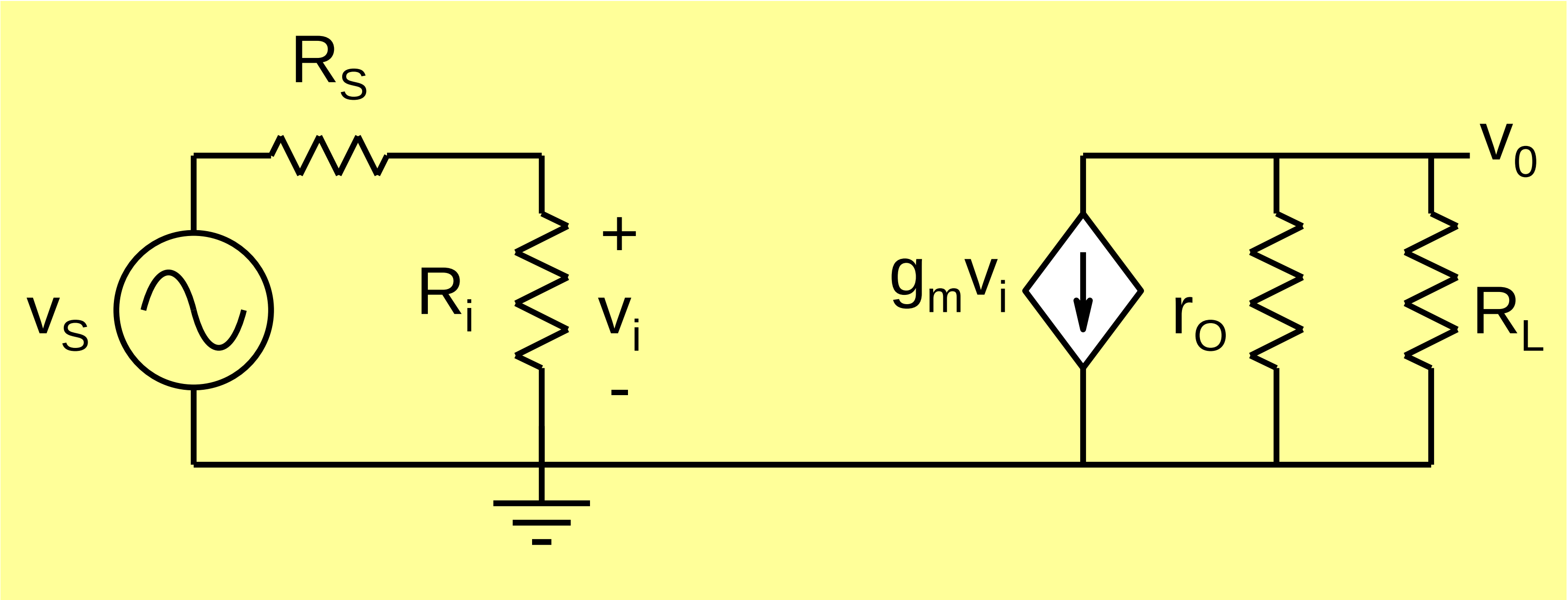
Assistant Professor,
Department of Electrical Engineering,
IIT Kanpur

Amplifier circuits





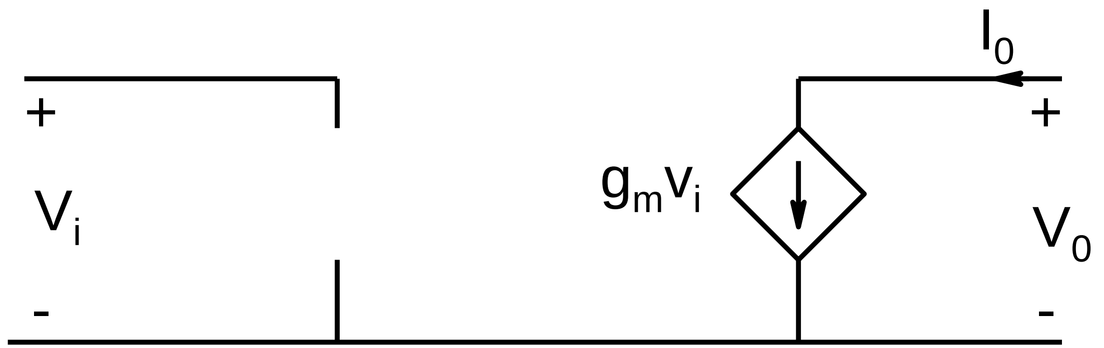


Ideal transistor

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

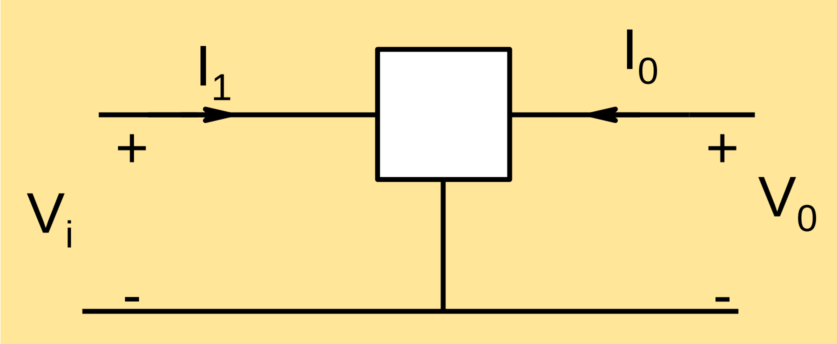
- Ideally, r_o and R_i are infinite

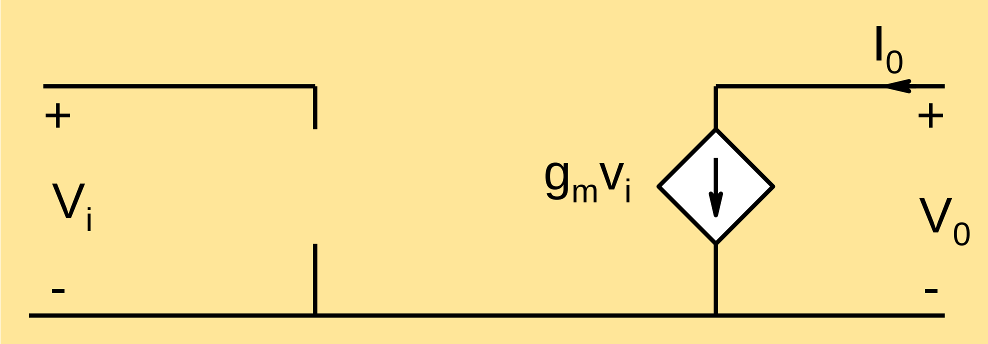
$$A_V = -g_m R_L$$



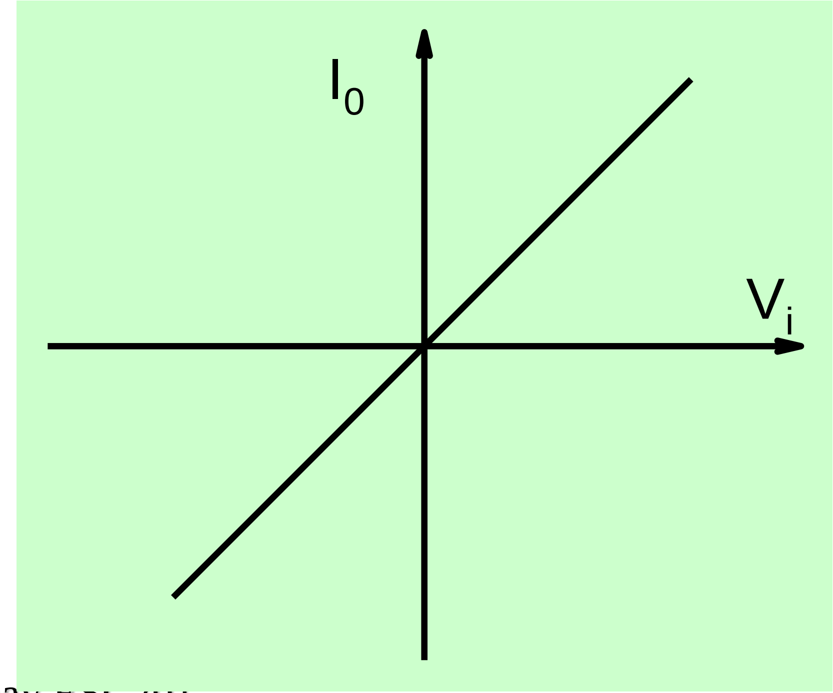
Key device needed: voltage controlled current source

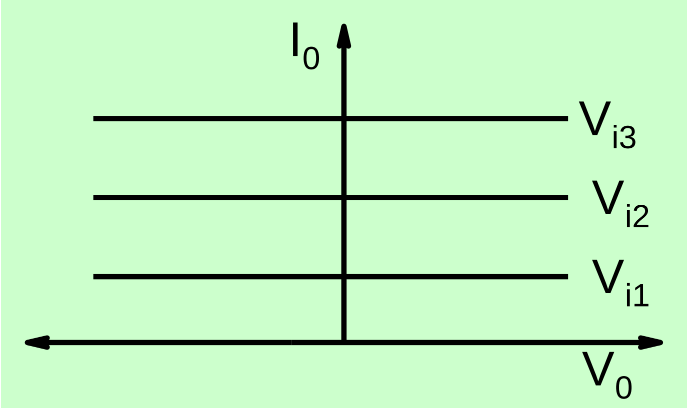
Ideal transistor characteristics





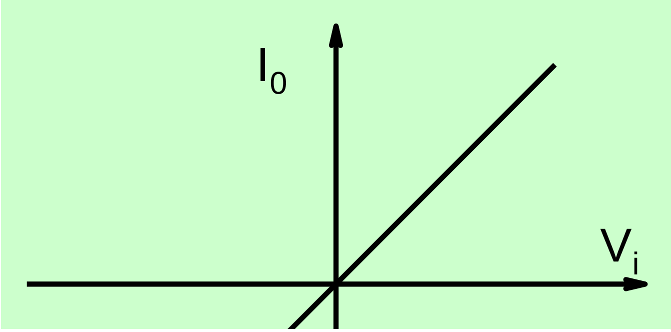
$$A_V = \frac{v_o}{v_s} = -g_m R_L$$

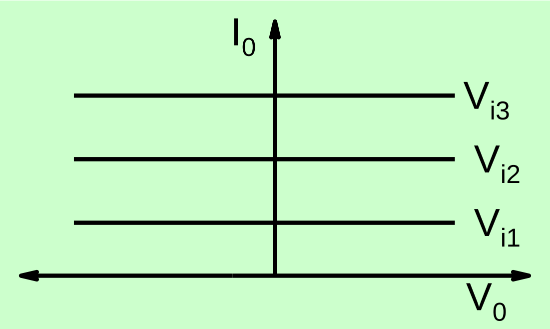


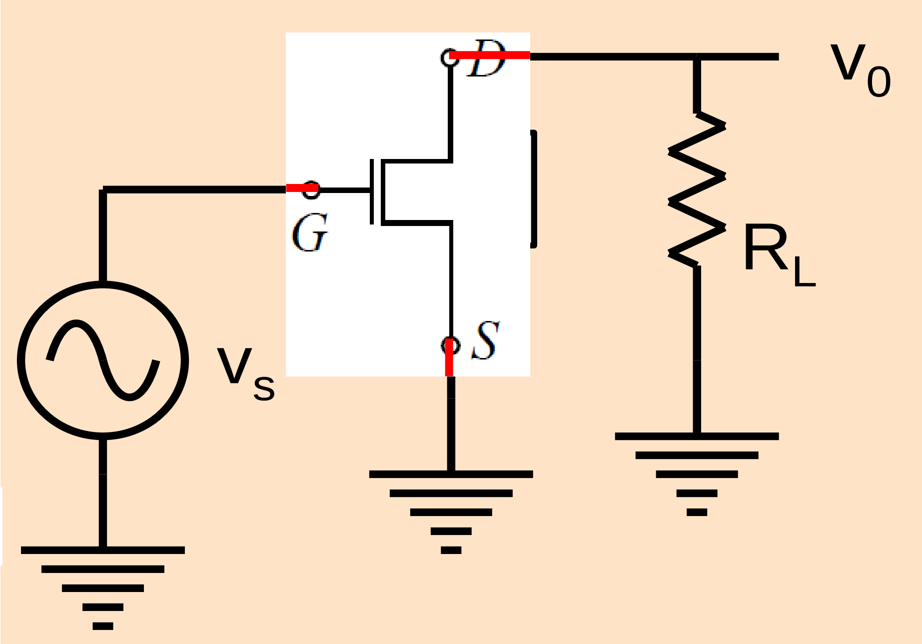


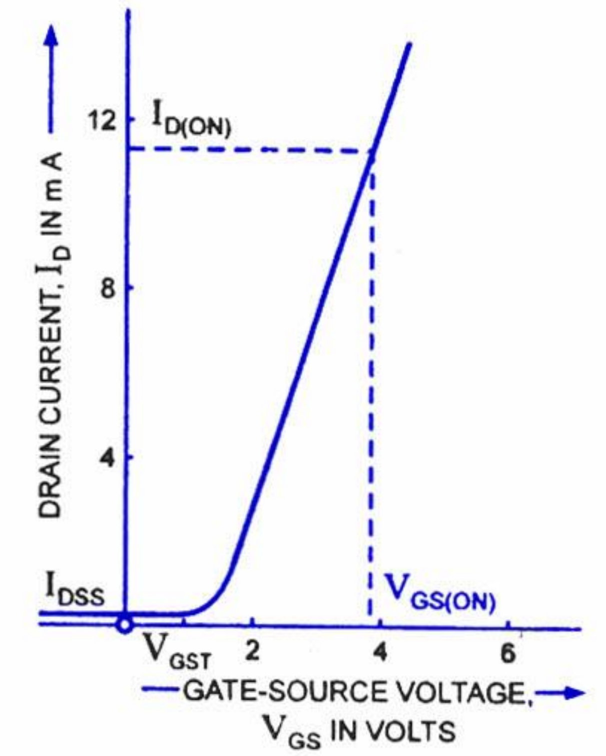
In practice there is no element which has the characteristics of ideal transistor !

Real transistors



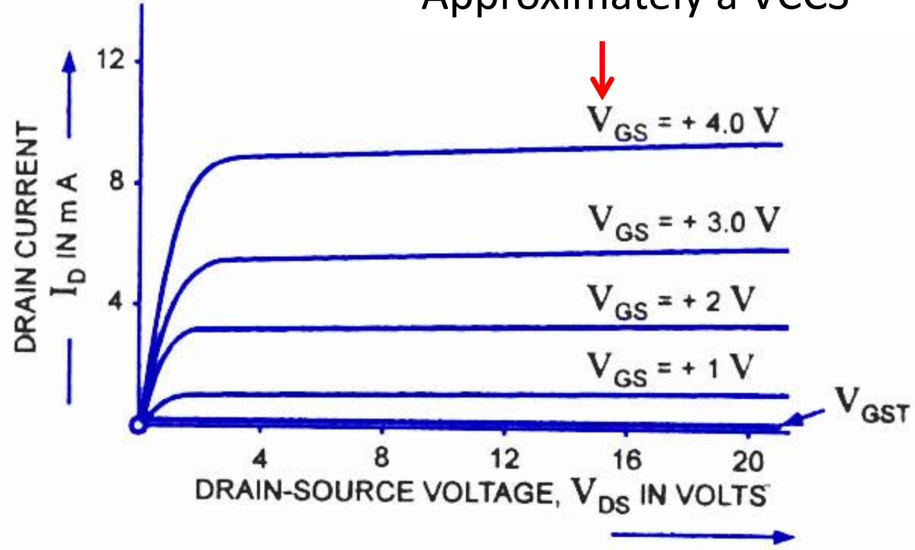






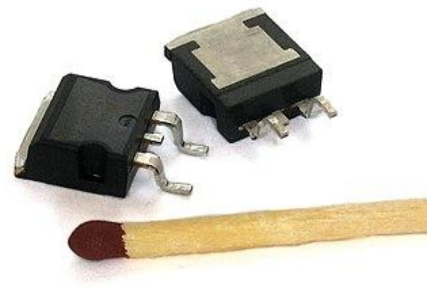
Transfer Characteristic

Approximately a VCCS



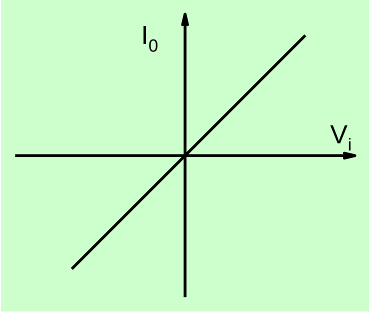
Drain Characteristics

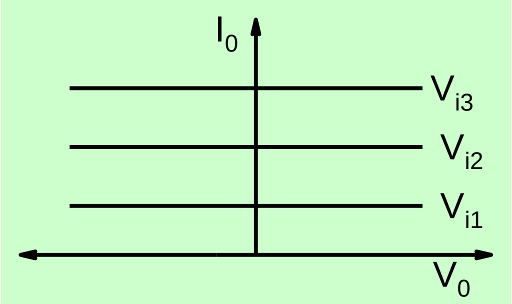
metal-oxide-semiconductor field-effect transistor MOSFET



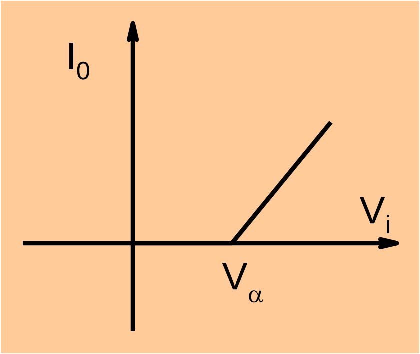
Real Devices to Amplifiers

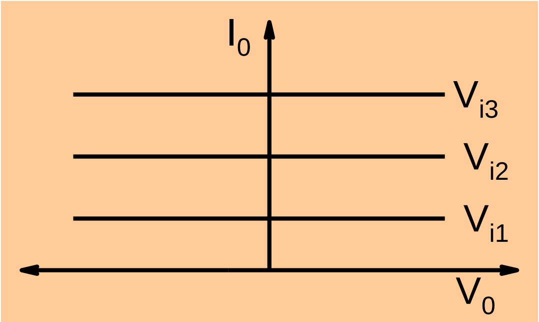
Ideal transistor



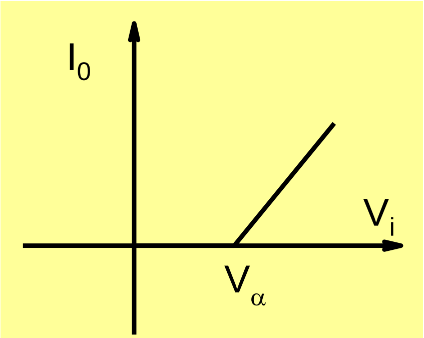


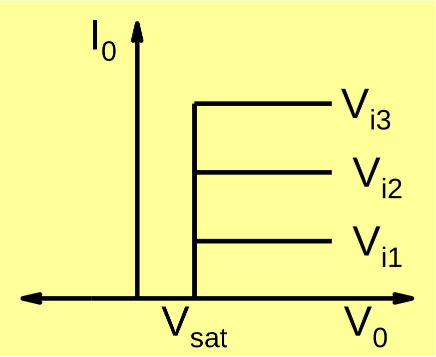
How do we use devices such as X, Y etc to make amplifiers?



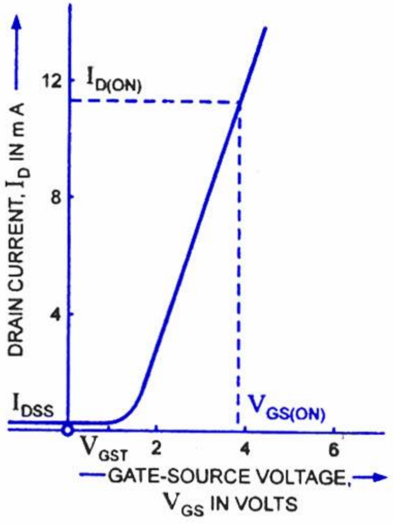


Device X

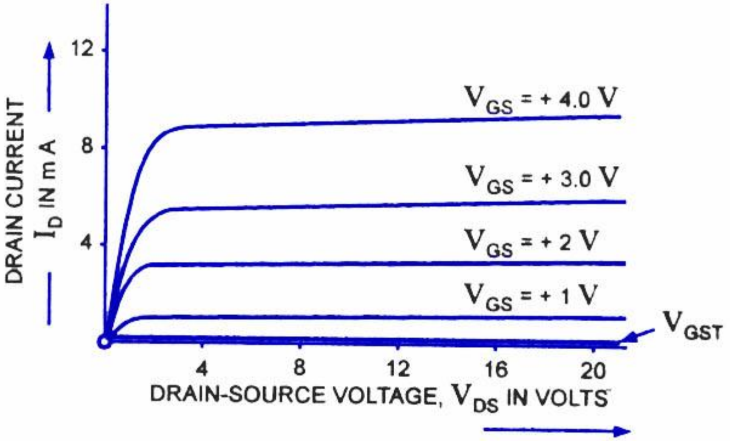




Device Y



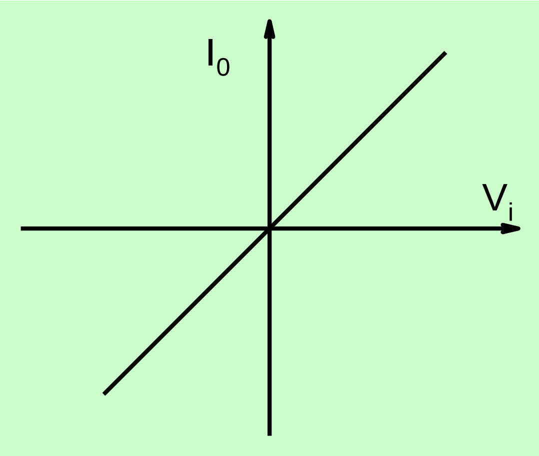
Transfer Characteristic

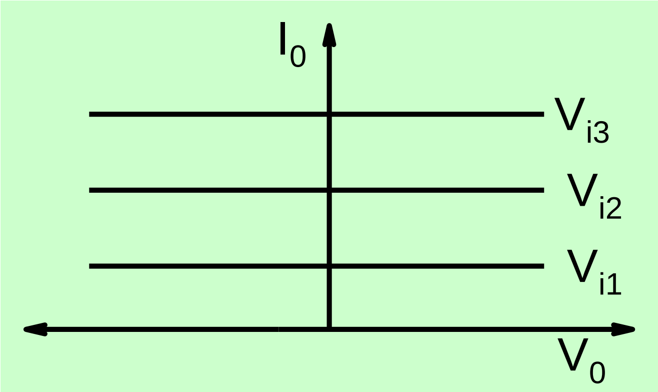


Drain Characteristics

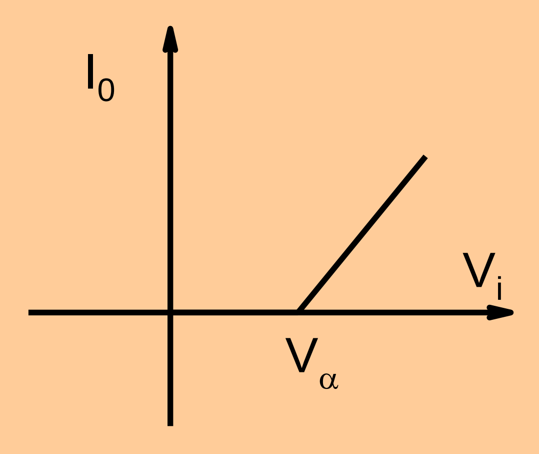
Simplified model X

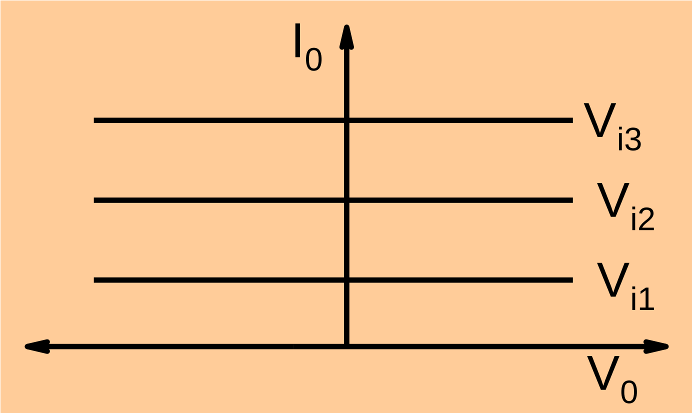
Ideal transistor





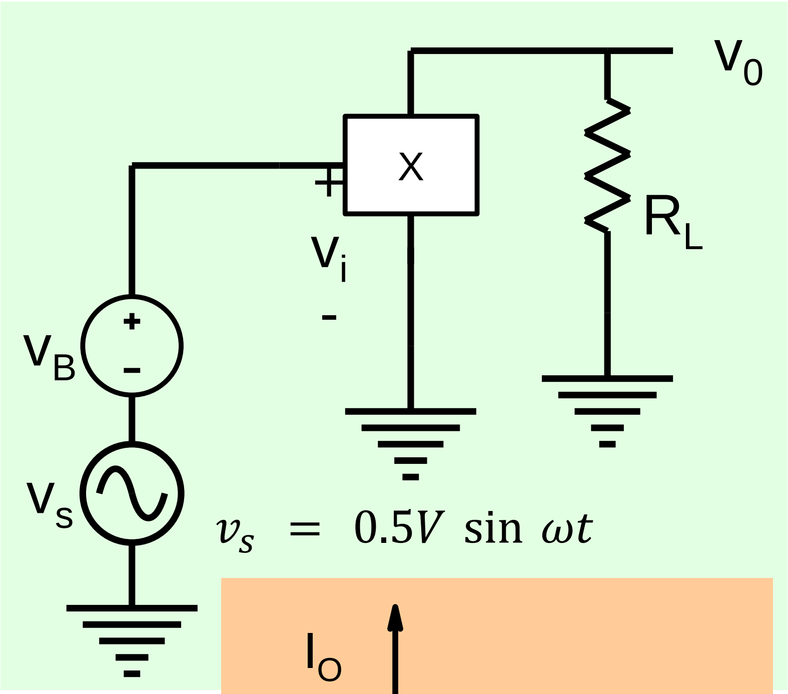
Device X (non-linear)





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

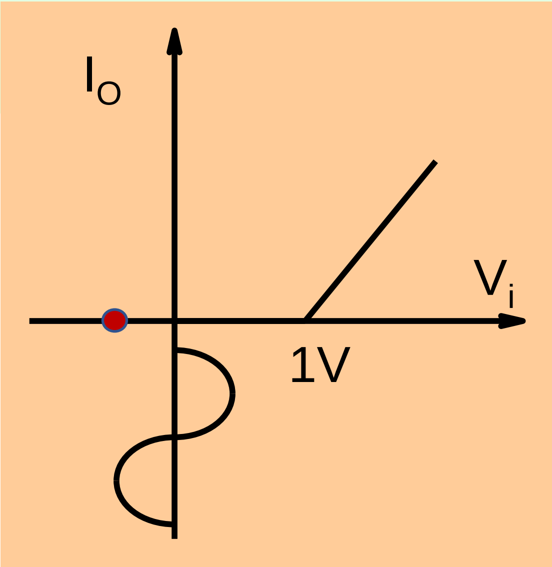
Amplifier with biasing



$v_s = 0.5V \sin \omega t$

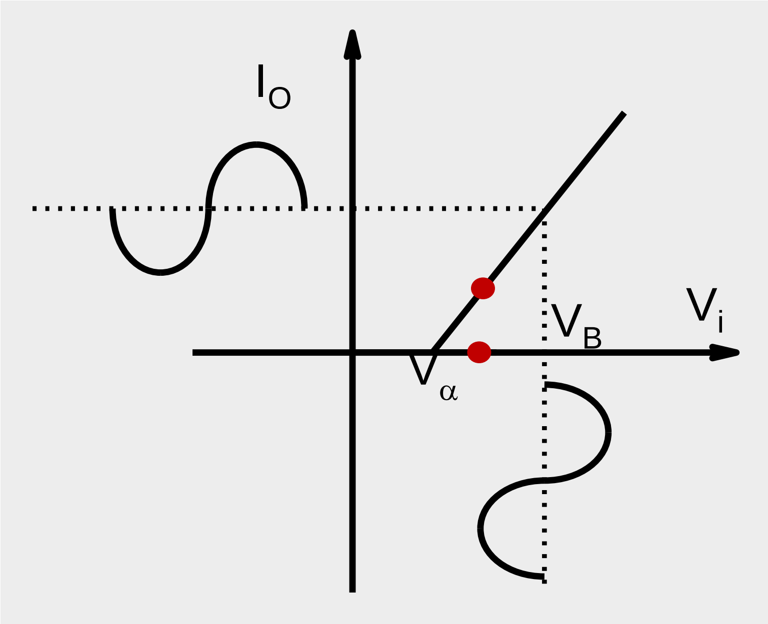
Bias Voltage

$V_B > V_\alpha$



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

$R_L = 1K\ ;$



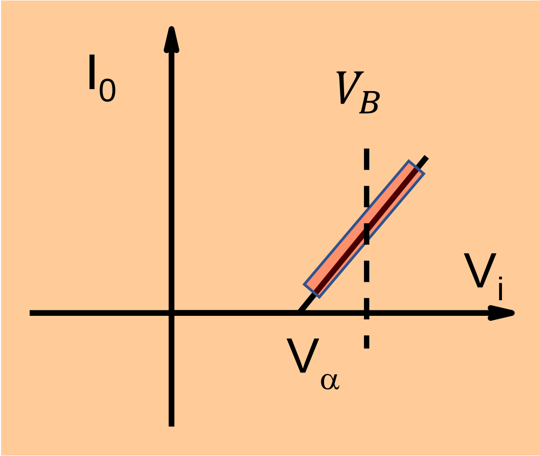
$V_o = -I_o R_L$

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.

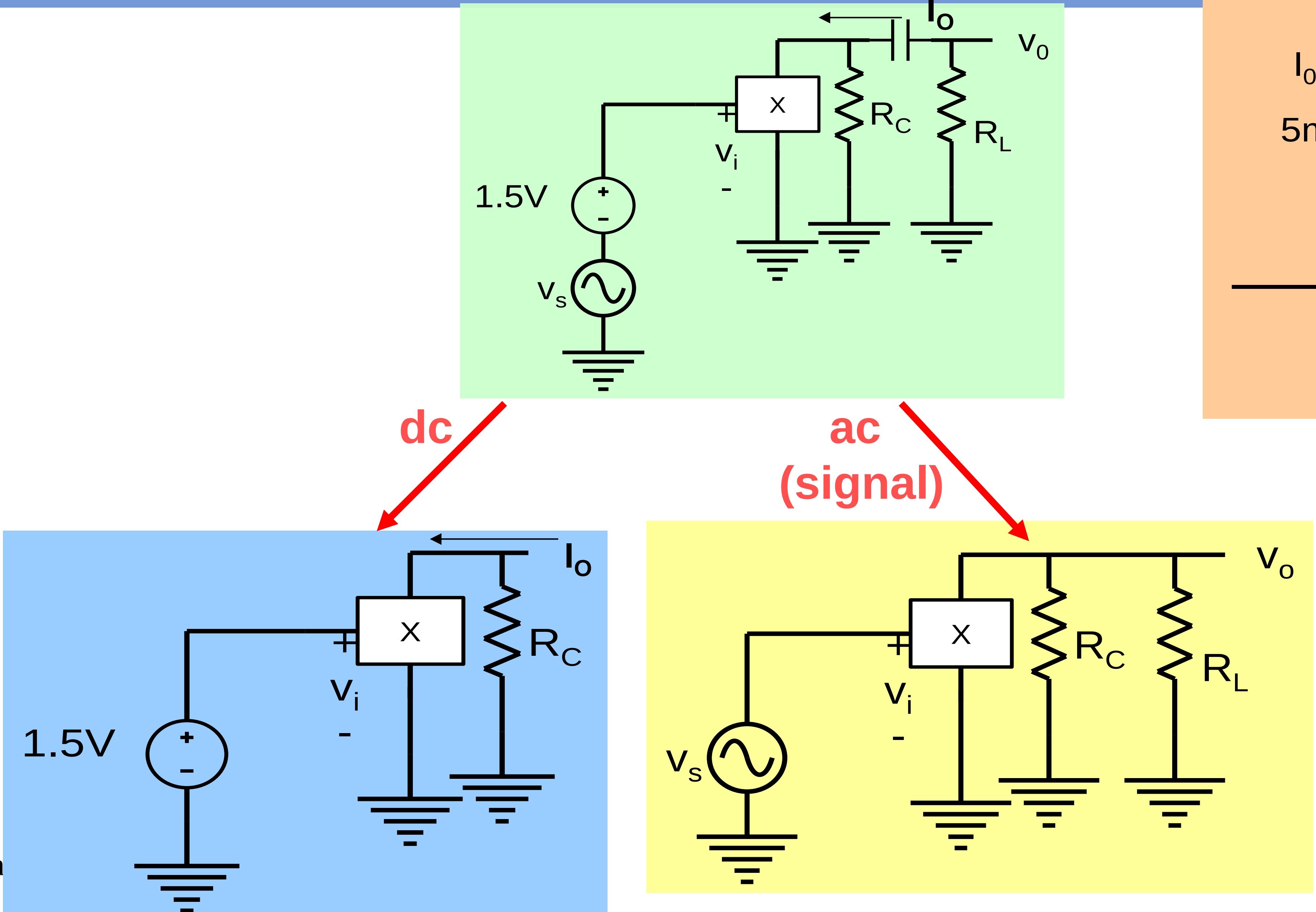
How to choose the bias voltage V_B?

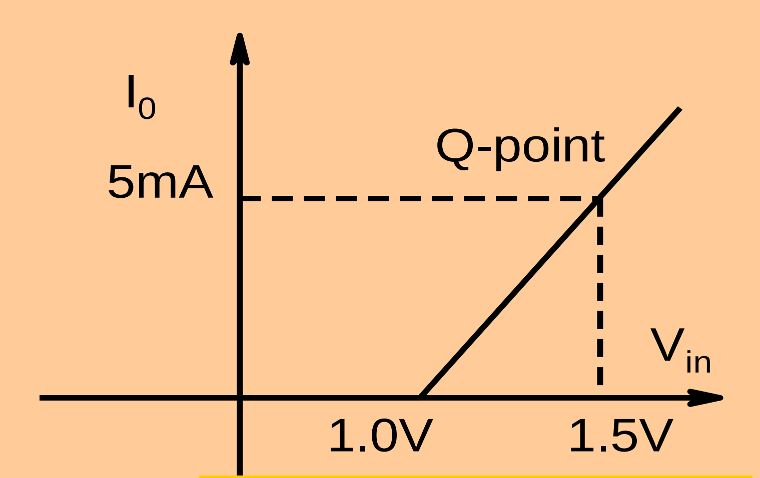
- Choose V_B as the center point of desired operating range
- Otherwise: clipping!



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

DC vs AC Components





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

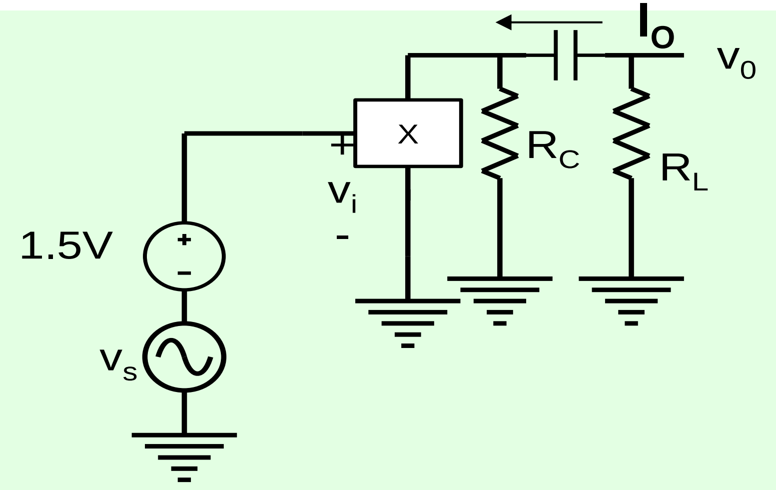
Capacitor is chosen large enough so that at the signal frequency ,

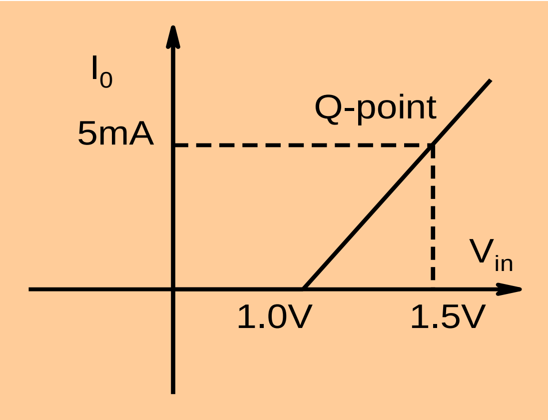
$$\frac{1}{j\omega C} \sim 0.$$

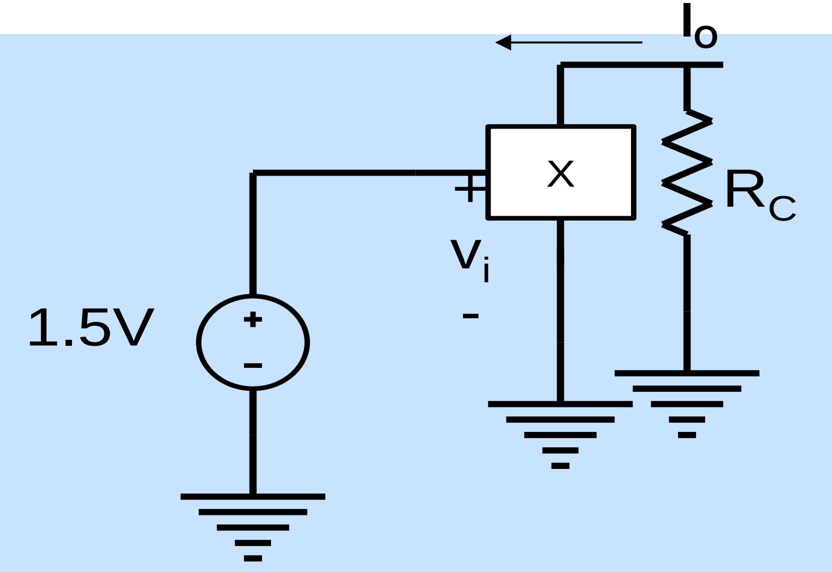
Large signal model: non linear

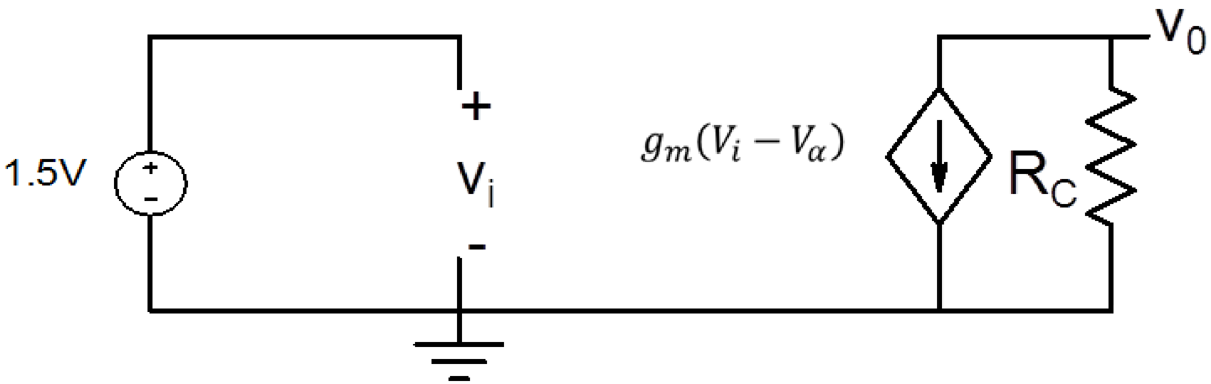
$V_\alpha = 1V$;
$g_m = 0.01\Omega^{-1}$

Large signal model
(aka dc model)









$V_i = 1.5\text{V}$ $\qquad$ $I_o = g_m(V_i - V_\alpha) = 5\text{mA}$

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

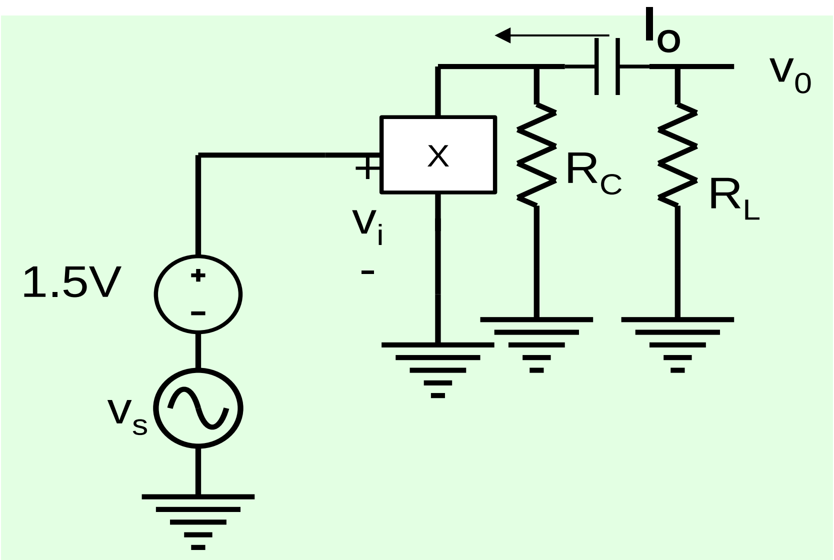
$$v_D = V_D + v_d$$

signal Bias Additional small signal

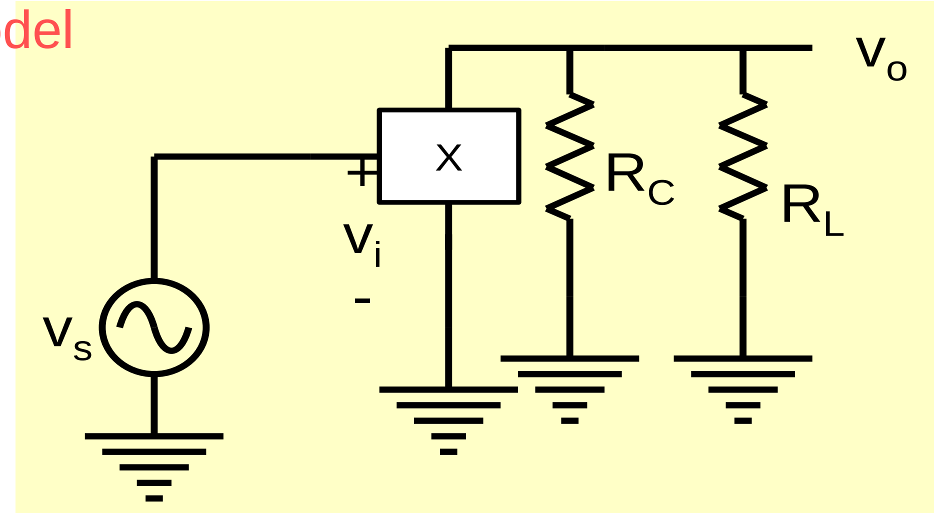
Linear

$$i_d = k\, v_d$$

Small signal model: linear



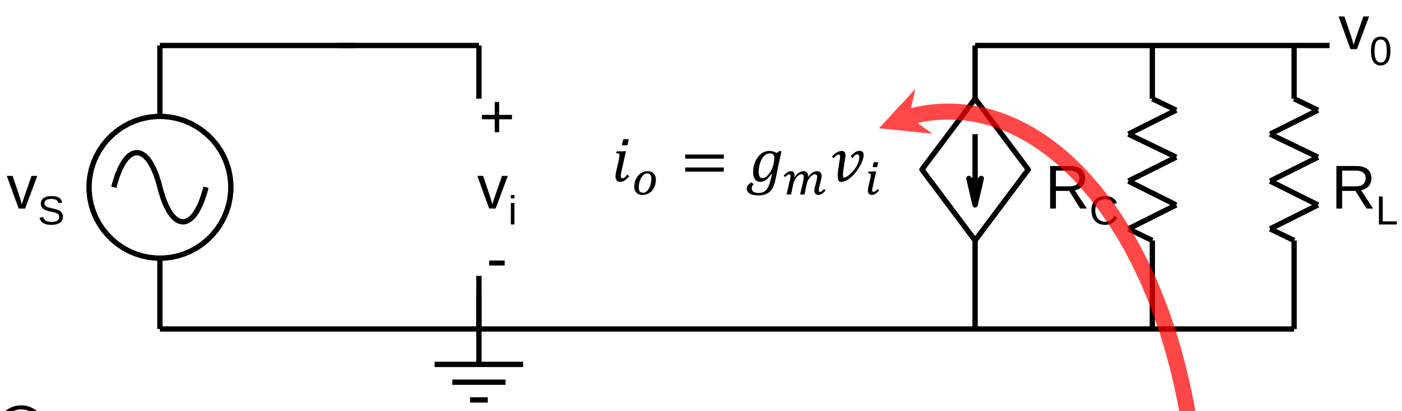
Small signal model
aka ac model



Small signal model

input

$$\overline{v_i} = V_i + v_i$$



Output

$V_i \rightarrow$ $\qquad I_o = g_m(V_i - V_\alpha)$

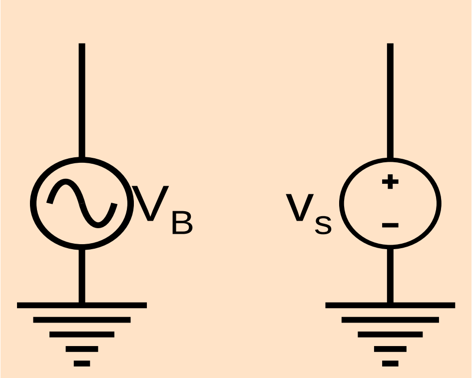
$V_i + v_i \rightarrow$ $\qquad I_o + i_o = g_m(V_i + v_i - V_\alpha)$

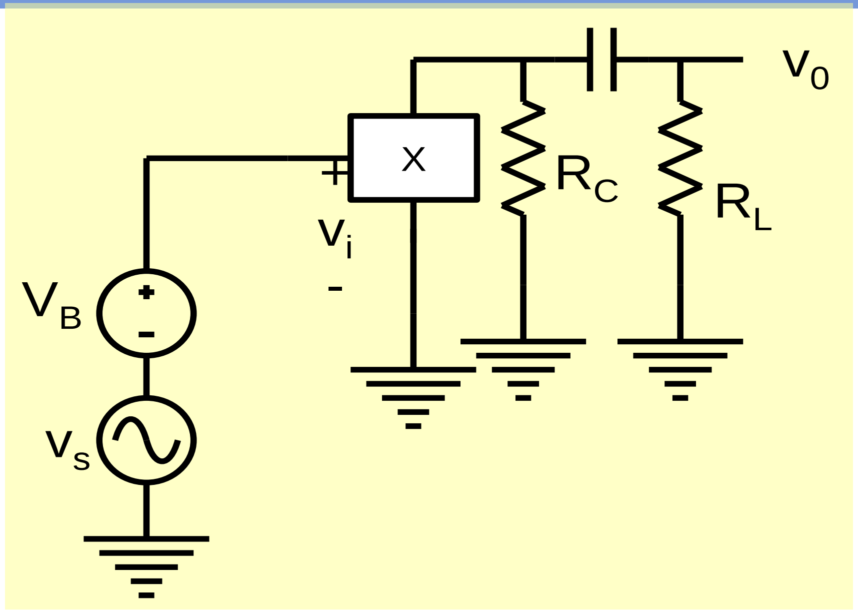
additional $v_i \rightarrow$ $\qquad i_o = g_m(v_i)$

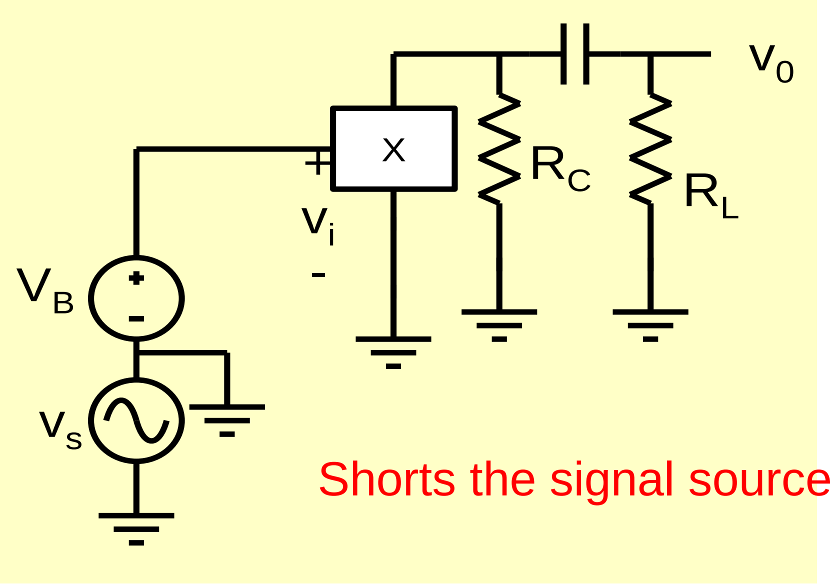
$$v_o = -g_m v_i (R_C || R_L)$$

Alternative biasing technique

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

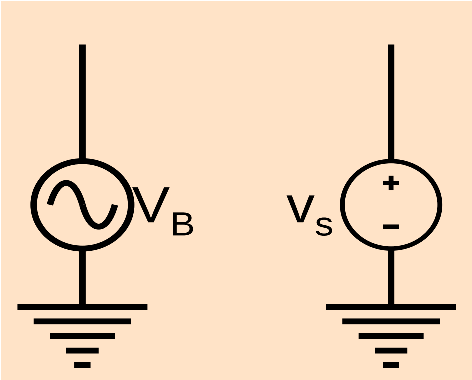


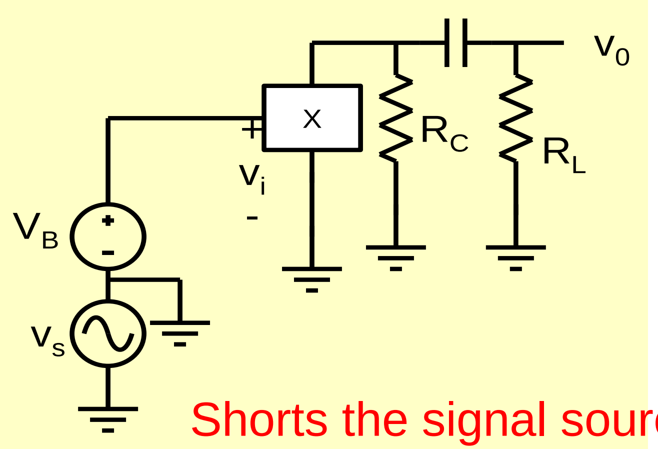




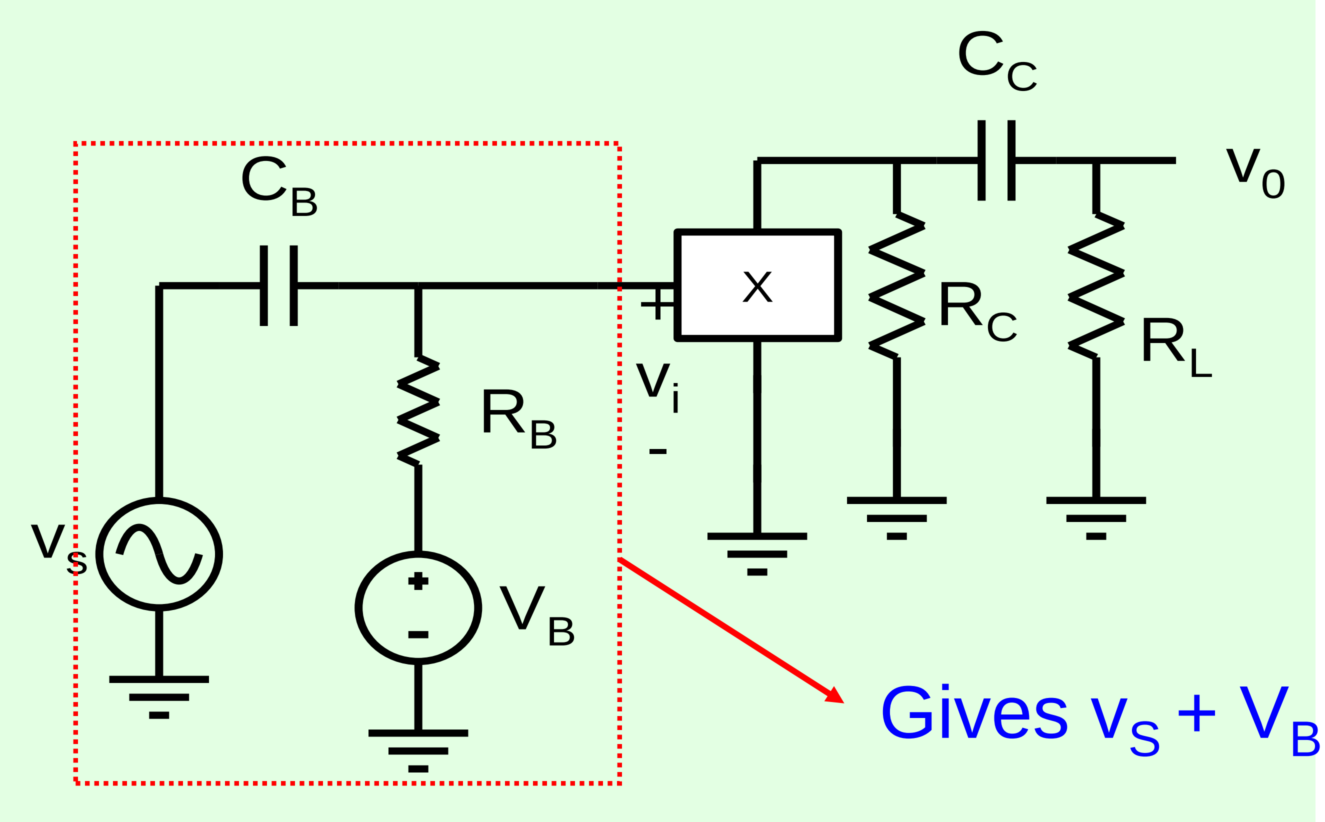
Alternative biasing technique

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



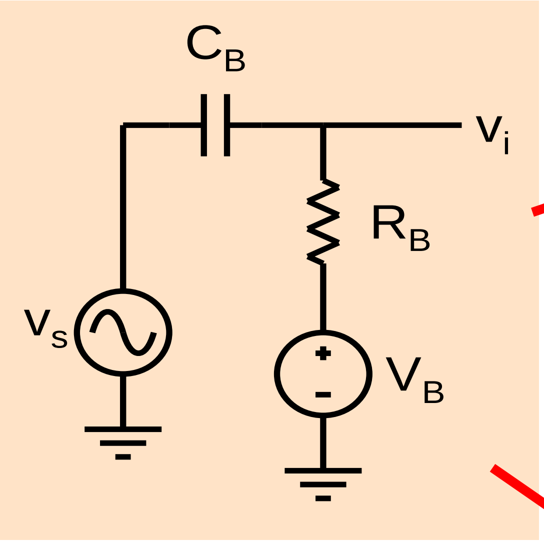


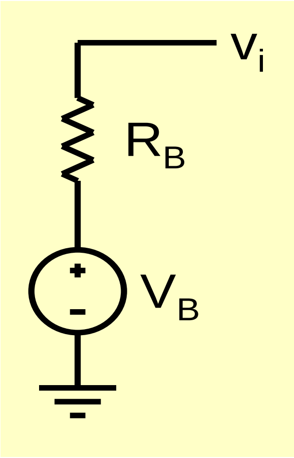
Shorts the signal source



Gives $v_S + V_B$

Alternative biasing technique

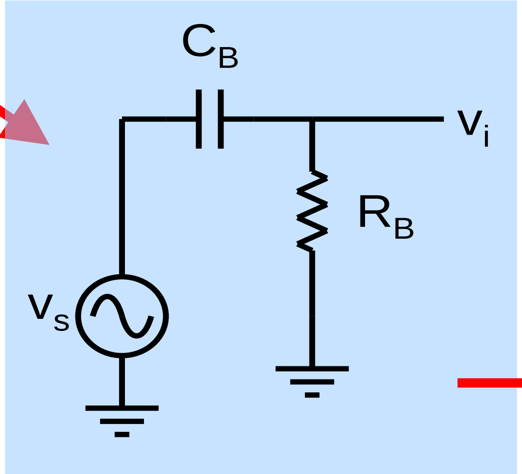


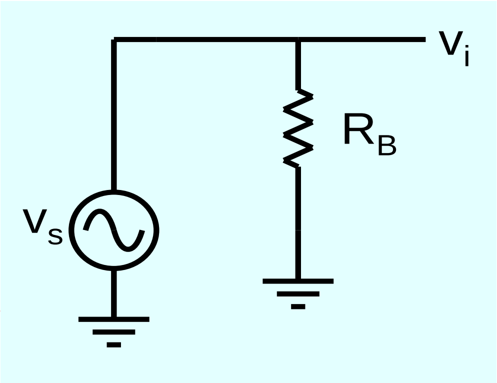


$$v_i = V_B$$

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

$$\bar{v}_i = v_s + V_B$$



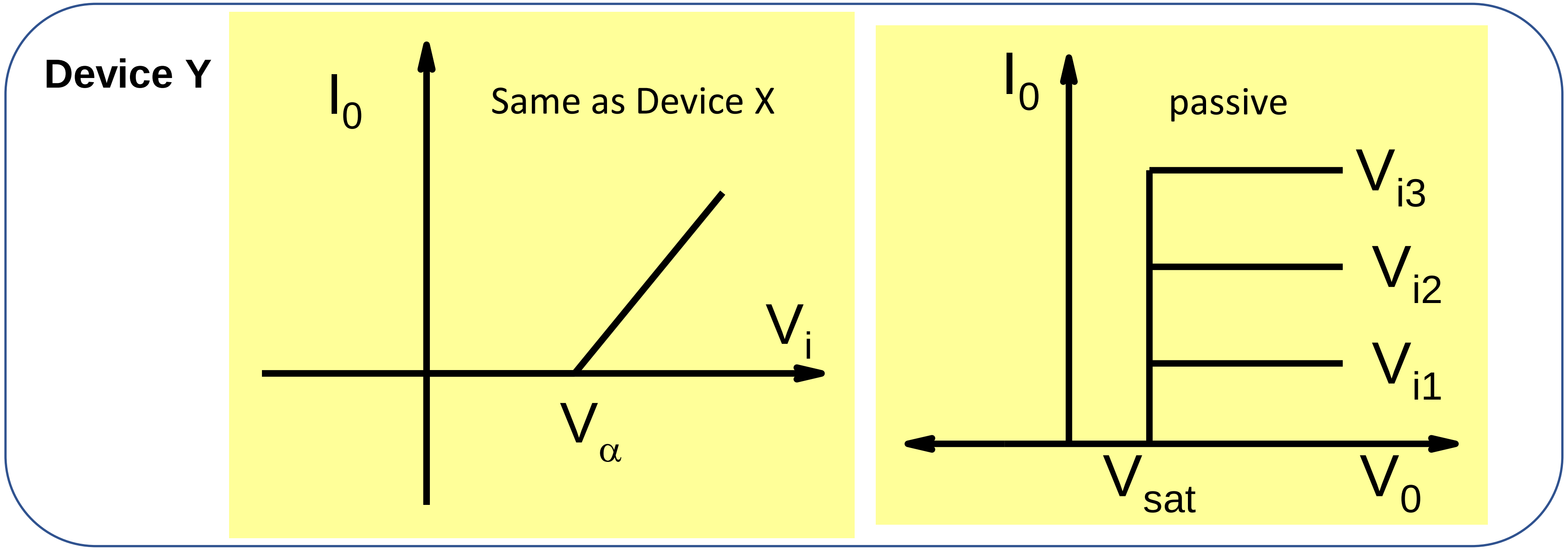


Note the role of R_B

$$v_i = v_s$$

Simplified model Y

How do we use element Y to make amplifiers?

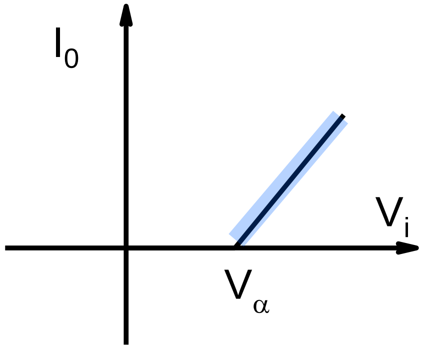


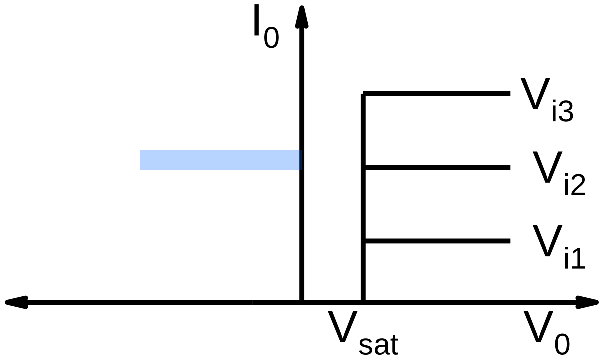
for $V_O < V_{sat}$: $I_o = 0$

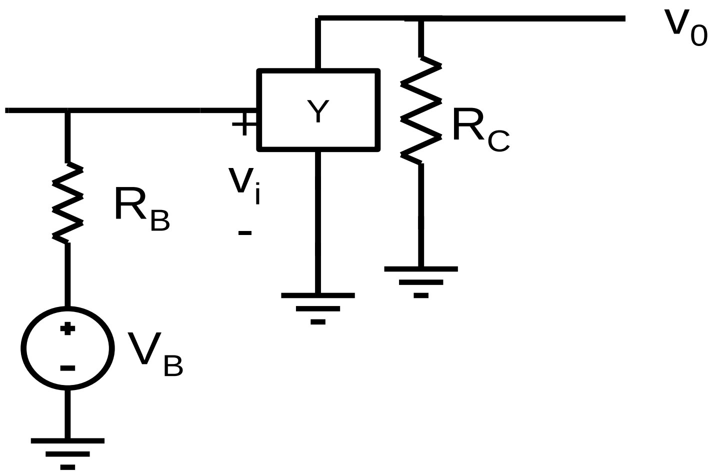
for $V_O \geq V_{sat}$:

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

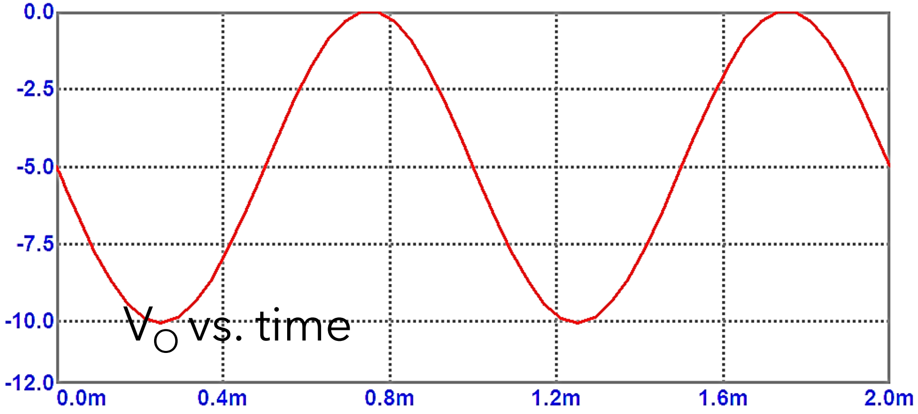
Can we use the circuit for model X?



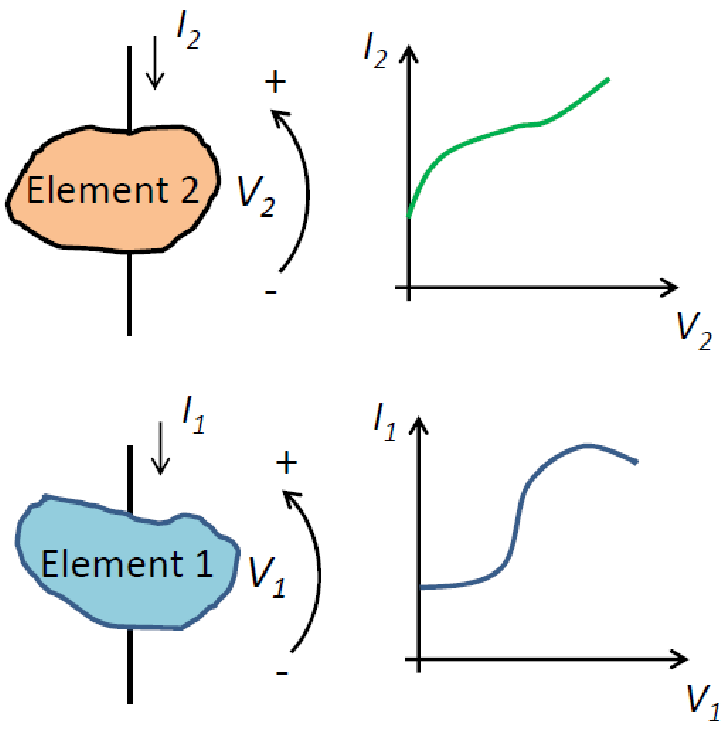


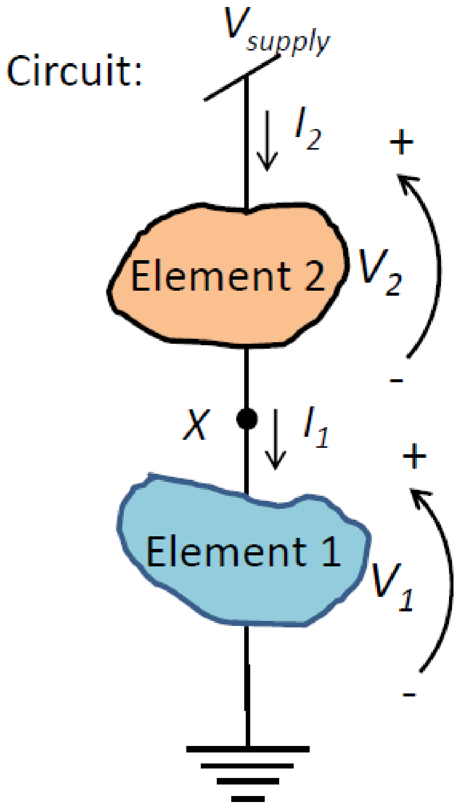


V_O is -ve which will not produce any current in device Y



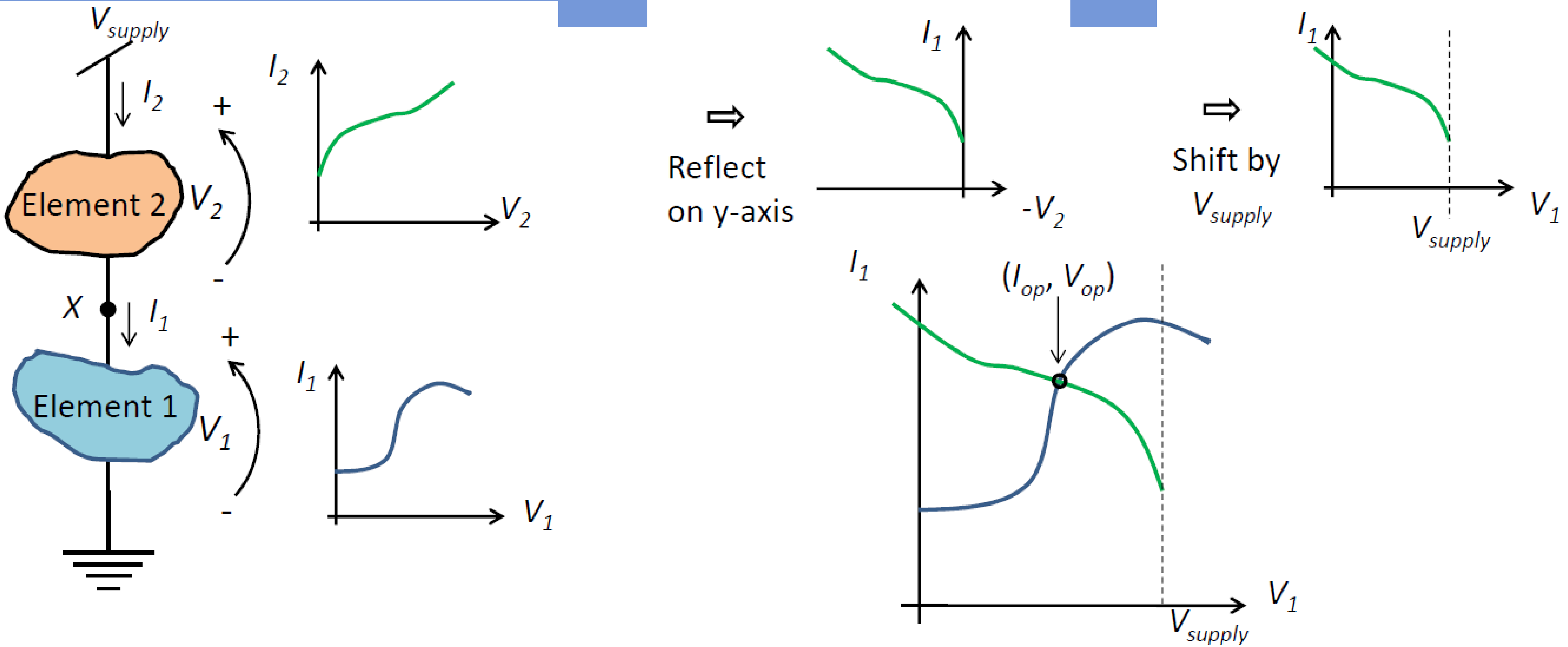
Analyzing Two Element System





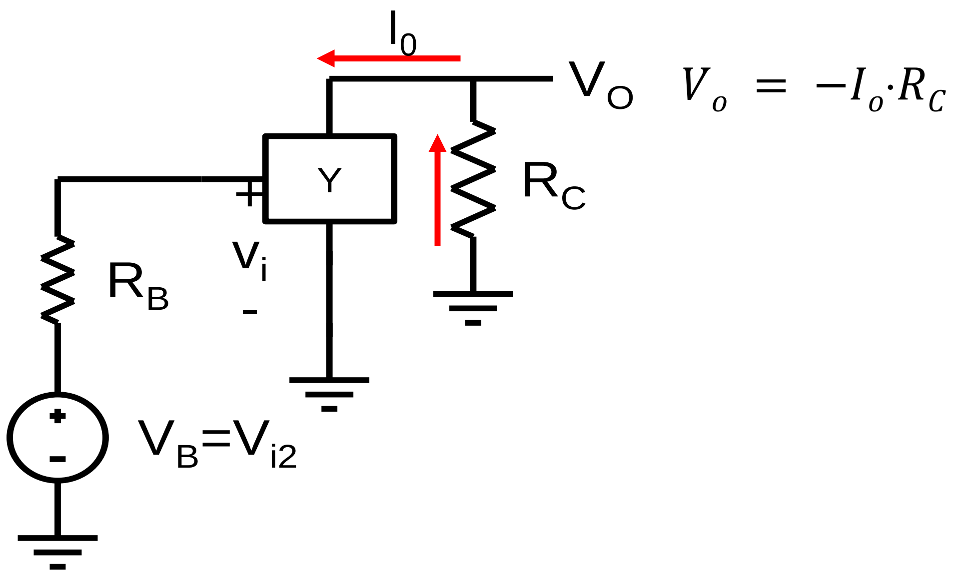
- Usually element close to the ground treated as primary element (if input given to both).
- Other element: load to primary element.
- Goal is to find the operating point of the circuit: Load line analysis.
- Represent electrical characteristics of both elements on a single plot.
- Intersection gives Operating Point.

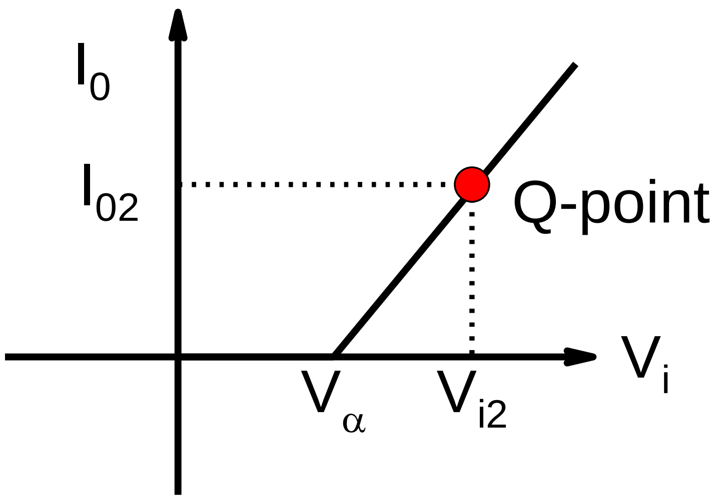
REVISITING LOAD LINE ANALYSIS



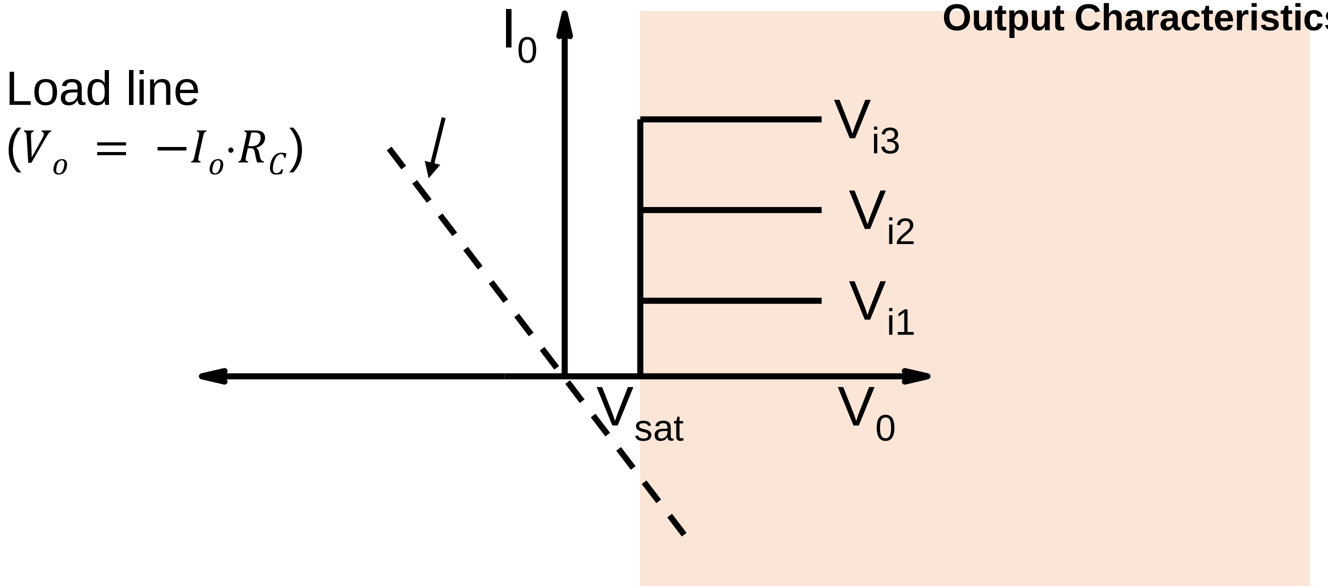
- $I_2 = I_1$ (no change in the direction); $V_2 = V_{supply} – V_1$ i.e. $V_1 = V_{supply} – V_2$
- Current in both Elements 1 & 2 is I_{op}.
- Voltage in node X is V_{op}.
- Voltage drop is V_{op} and (V_{supply} - V_{op}) in Elements 1 & 2, respectively.

Understanding Load Line





Transfer Characteristics

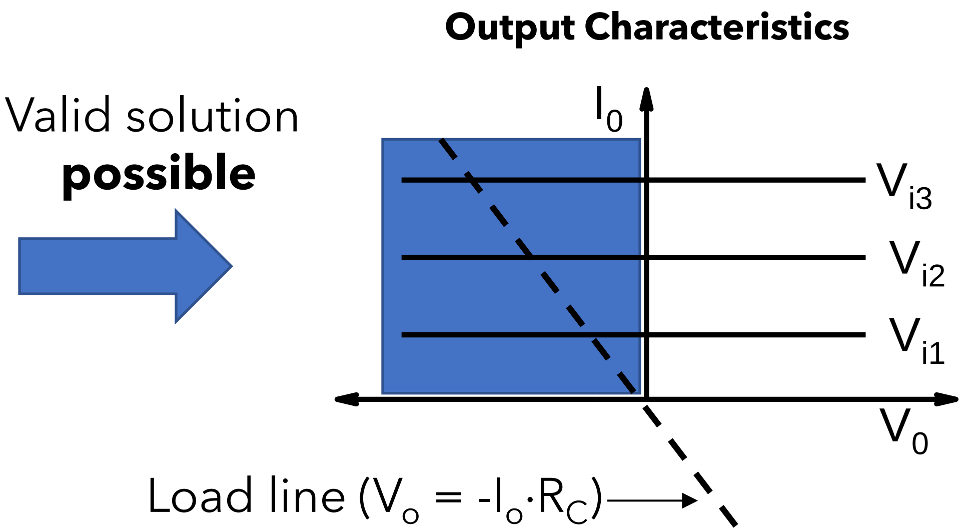


Output Characteristics

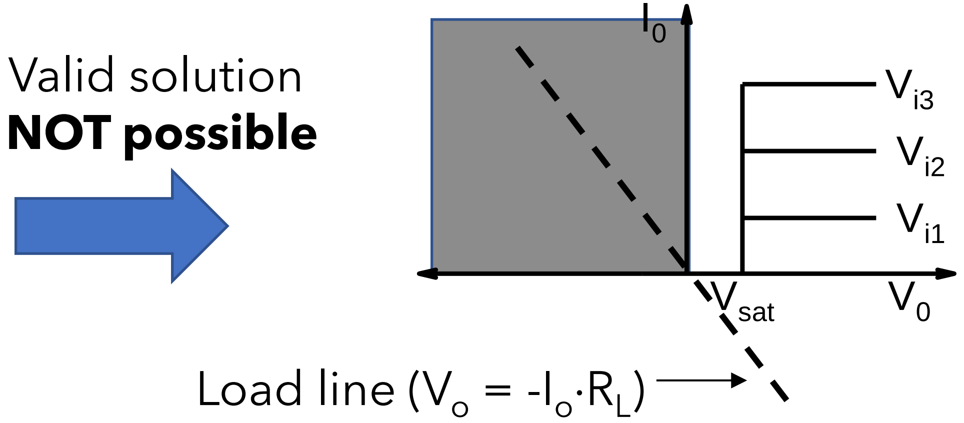
No solution possible
that satisfies both load line
and device Y

Why is circuit working for Device X and not for Device Y?

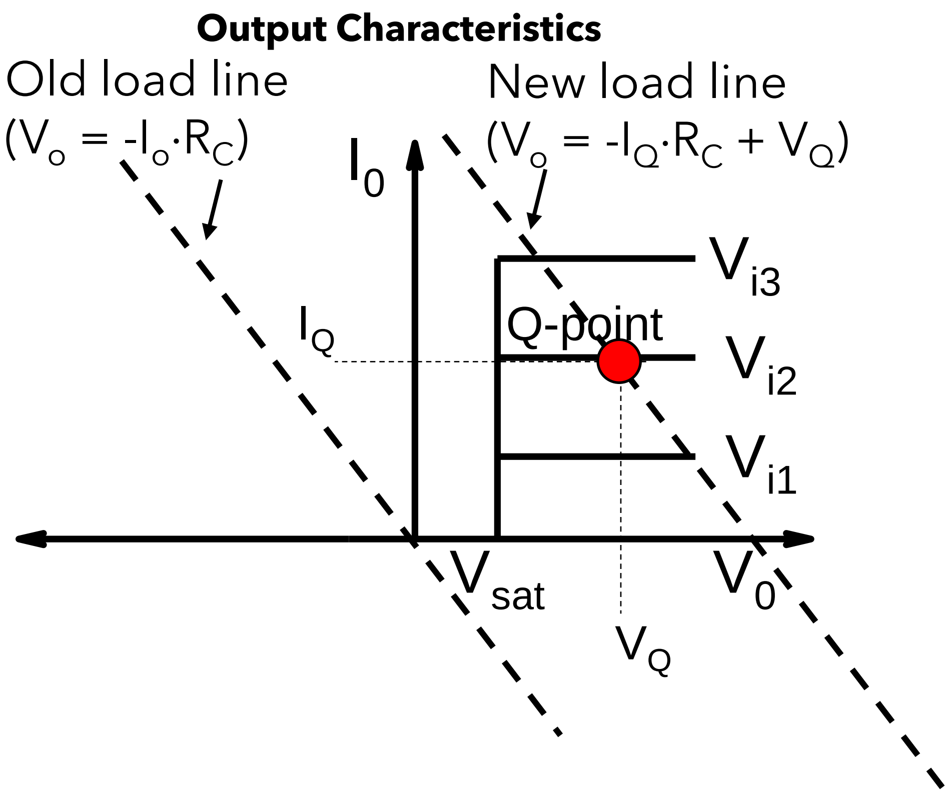
Device X

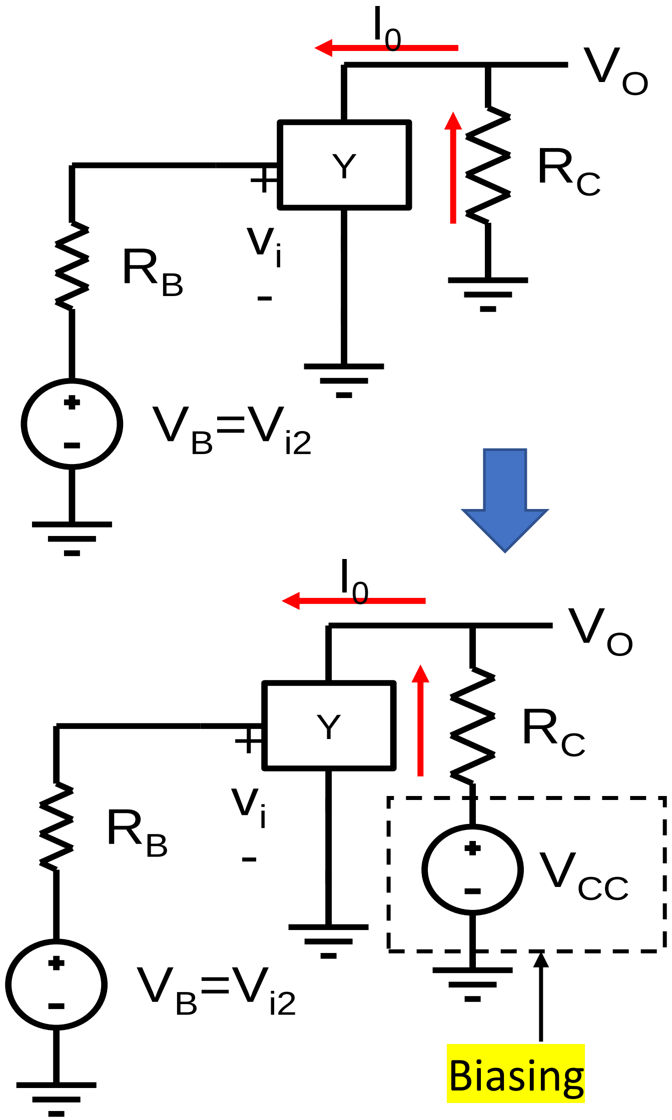


Device Y



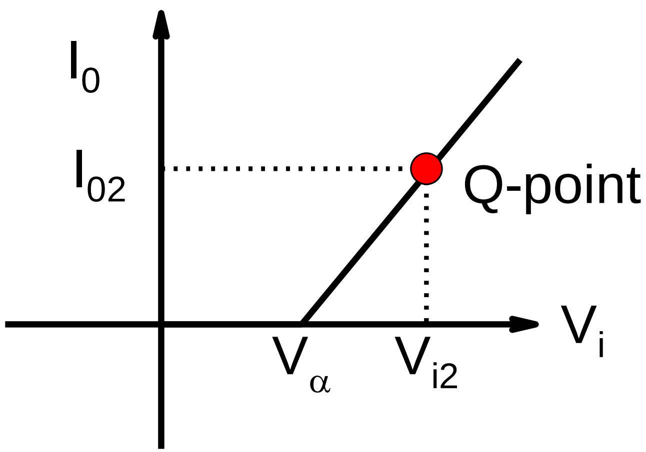
Solution to get meaningful Q point

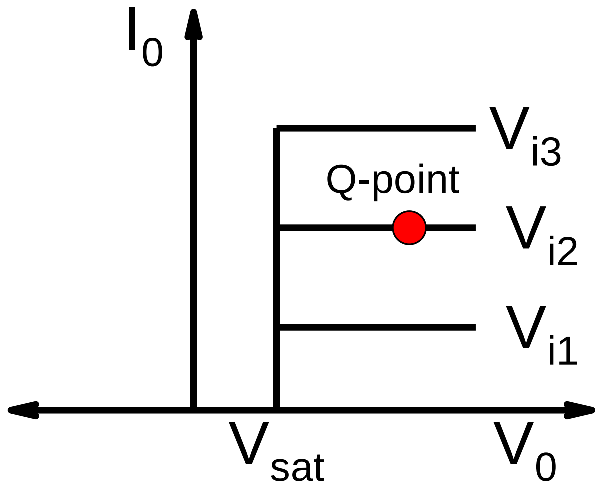


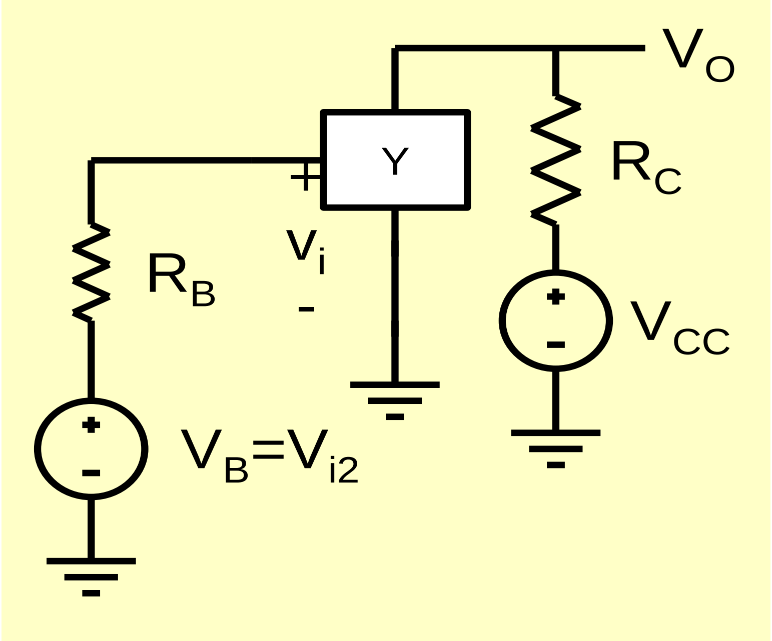


Purpose of biasing network is to operate the device in a region which resembles ideal transistor

Need bias at output

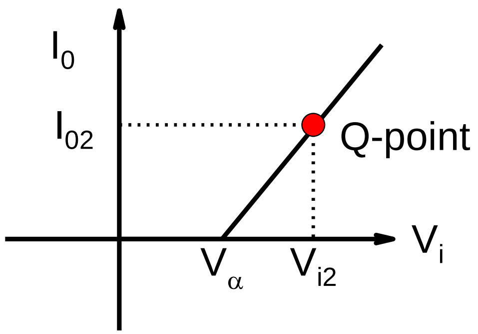




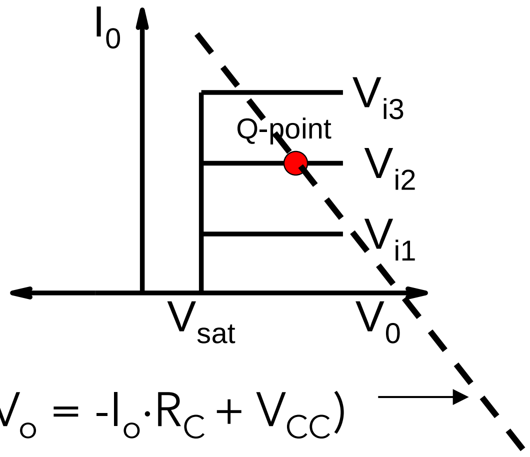


Revised Amplifier Schematic for Device Y

Transfer Characteristics

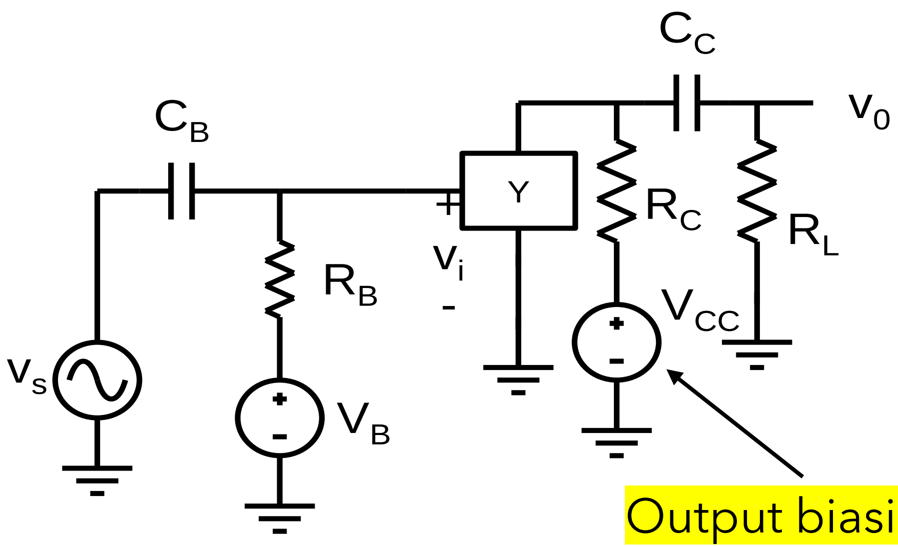


Output Characteristics



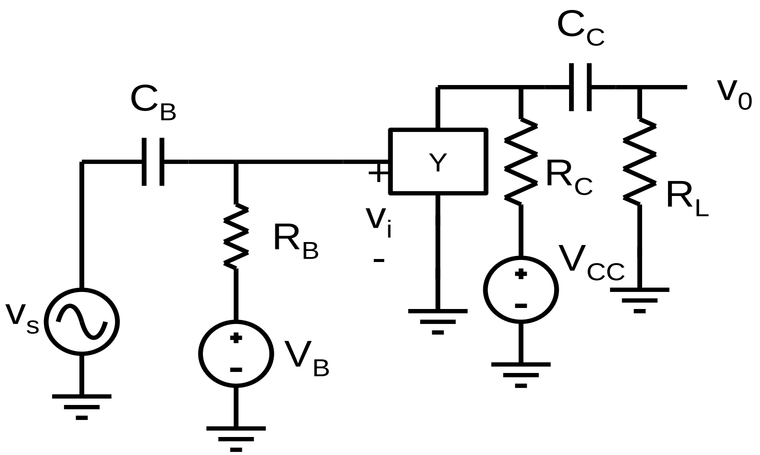
Usually V_{CC} is fixed
I_0 and R_C are varied

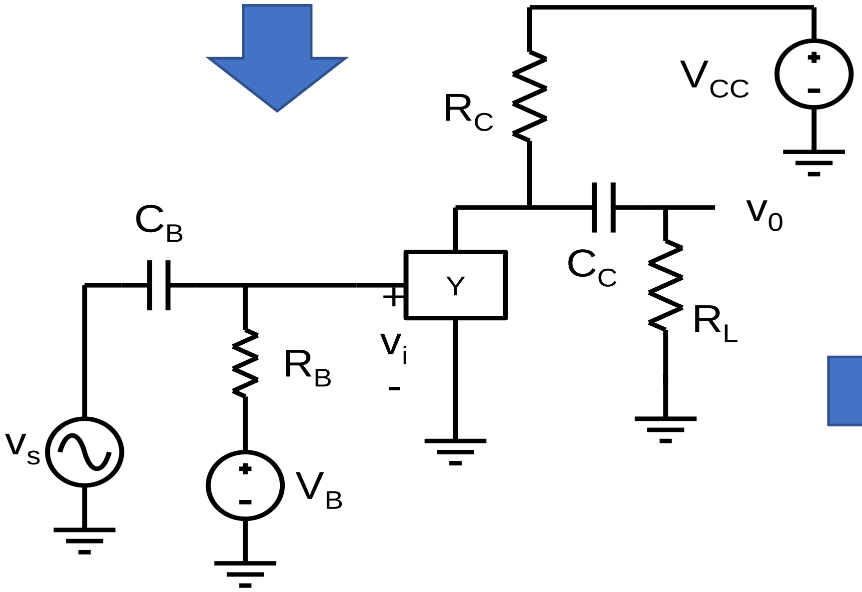
Load line ($V_o = -I_o \cdot R_C + V_{CC}$)



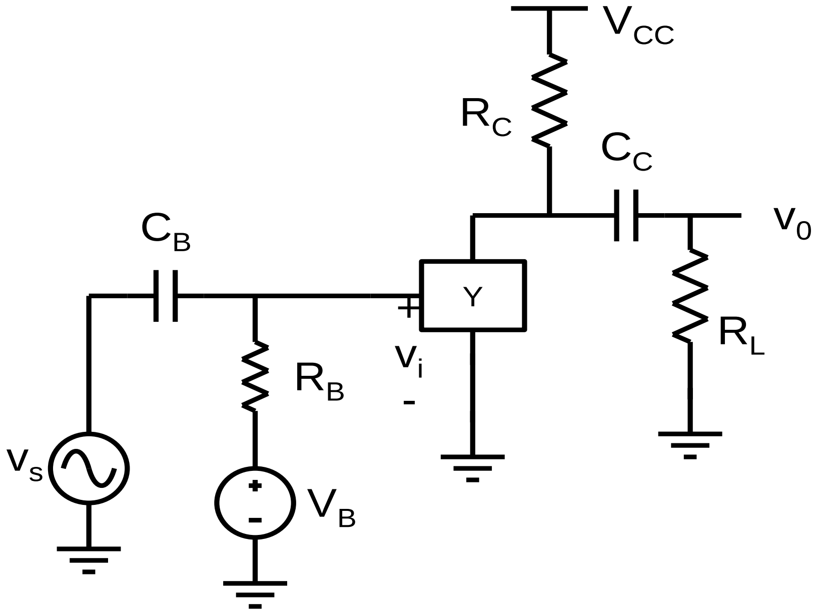
Output biasing is included

Another representation of biasing

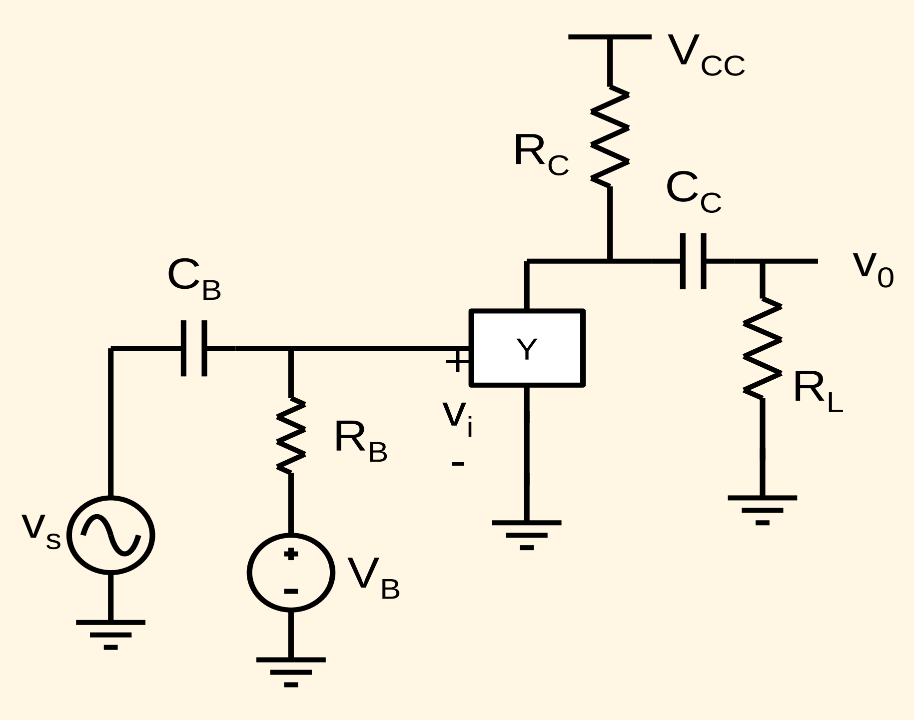


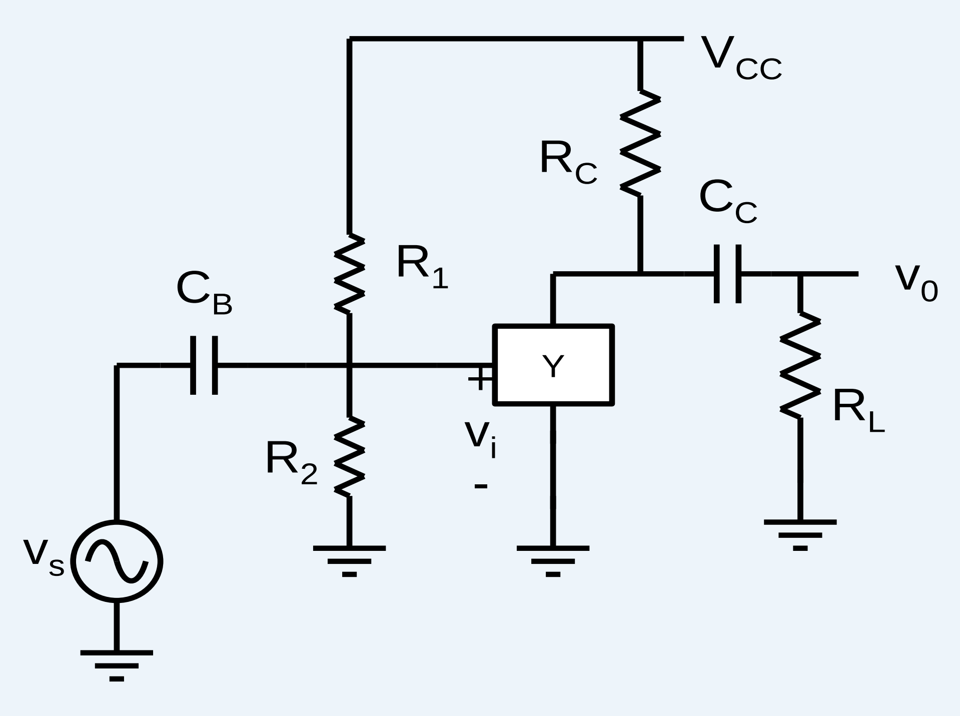


A more common representation



Do we really need two DC power supplies?



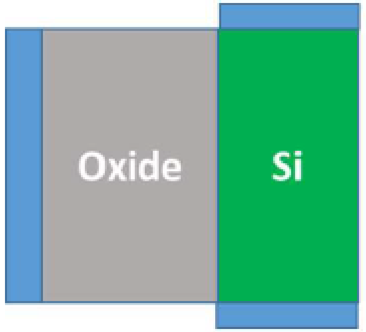


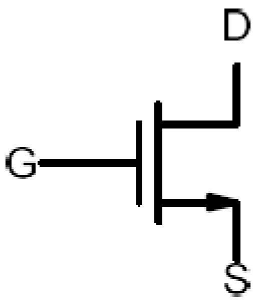
$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2}$$

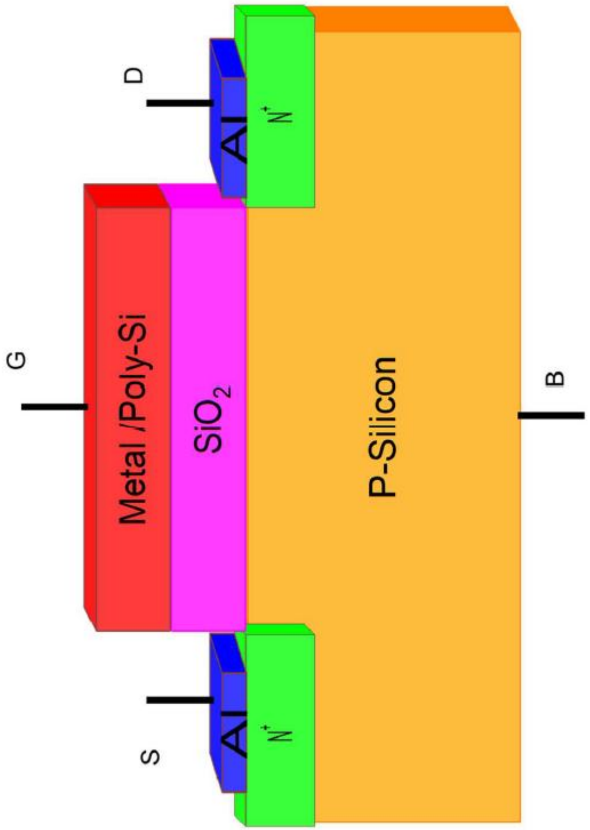
Remember: input of Y is open circuit

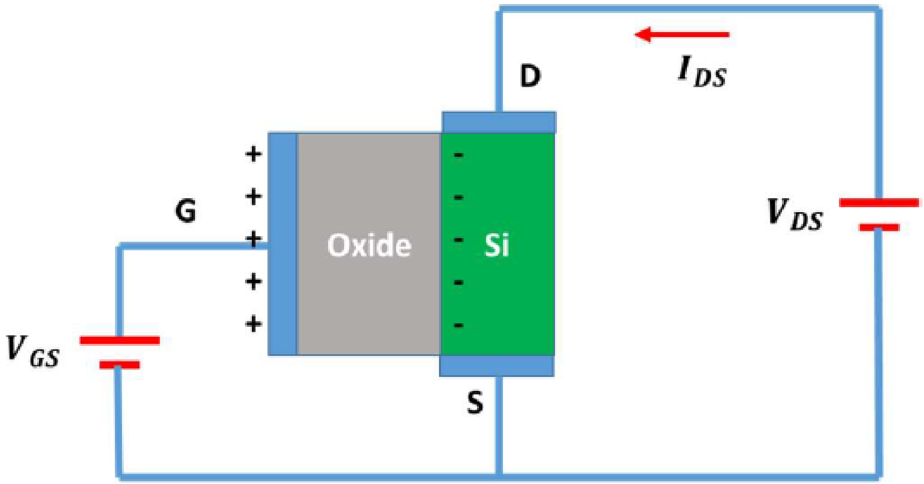
MOSFETs: Workhorse of Semiconductor Industry

MOSFET : Metal Oxide Semiconductor Field effect Transistor

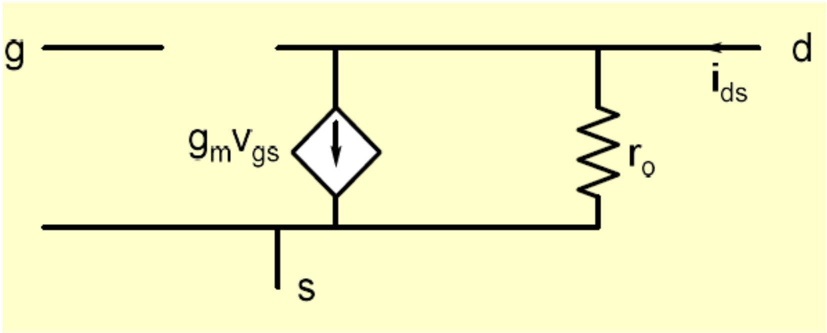






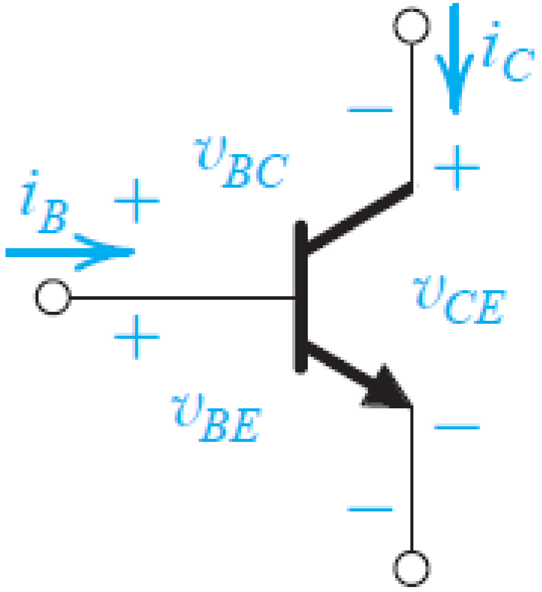


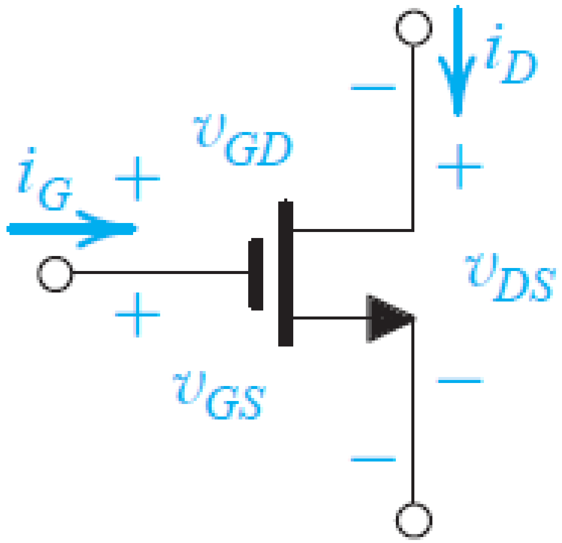
Drain current is controlled by gate voltage



Voltage controlled current source

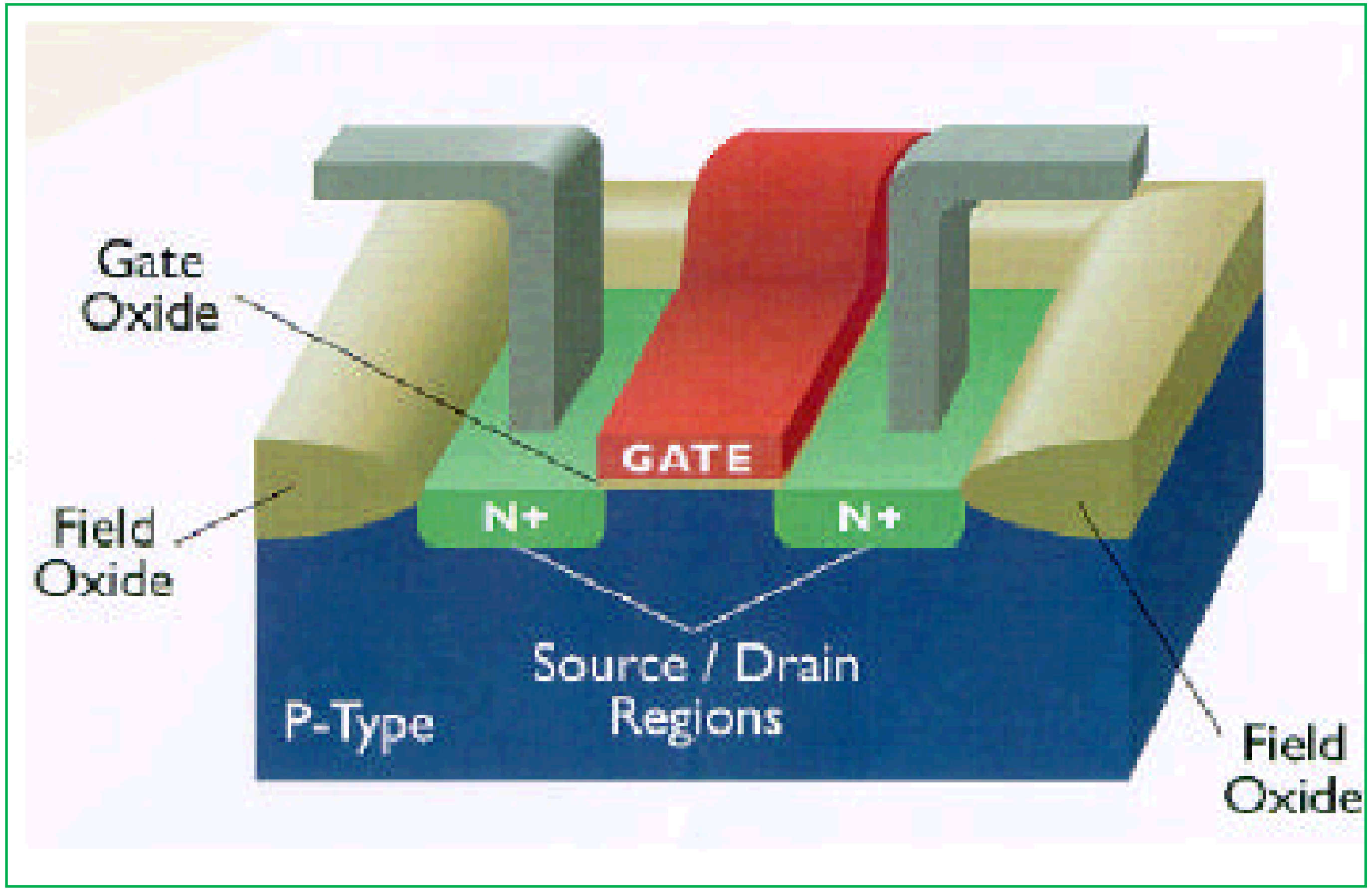
BJT vs. MOSFET



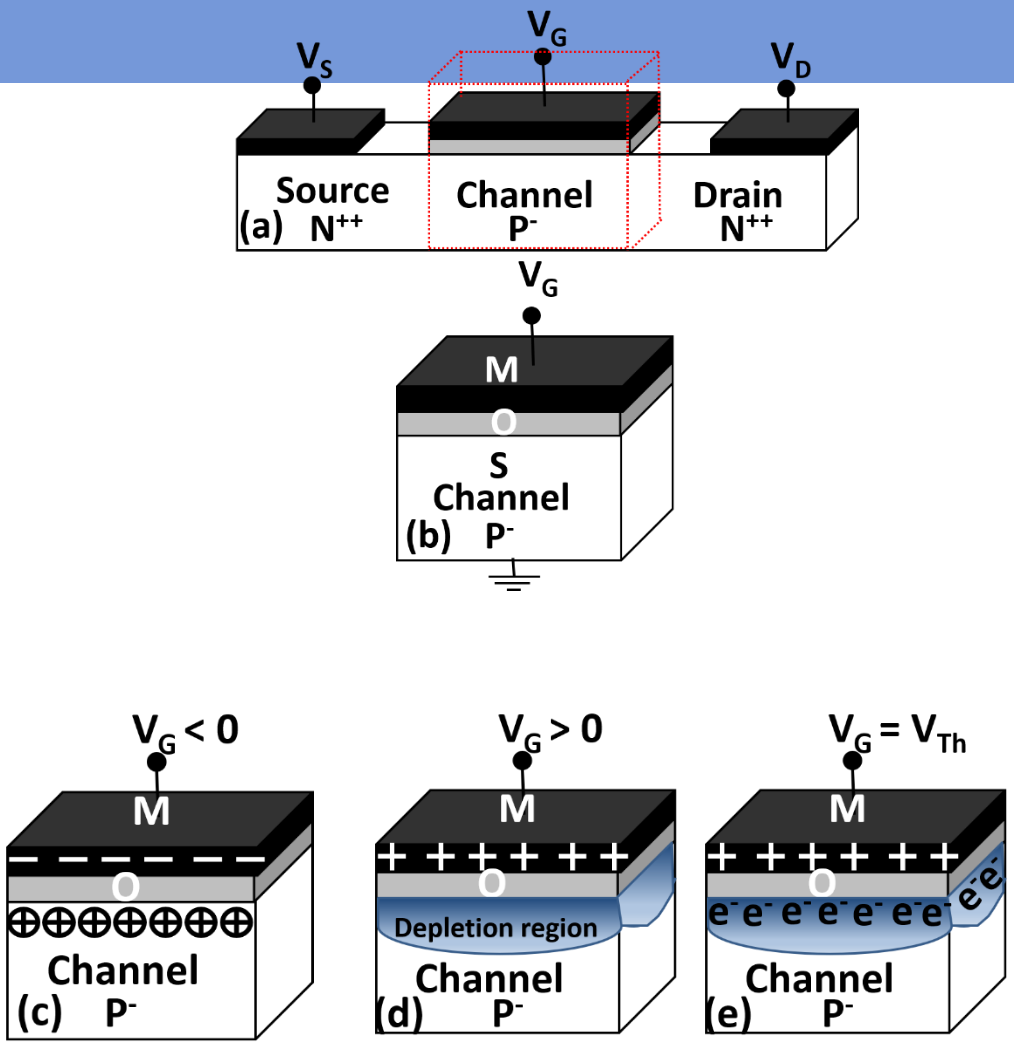


BJT	MOSFET
High gain	Low gain
Small caps	Large caps
Static power	Dynamic power

The MOSFET



Gate Oxide
GATE
N+
N+
Field Oxide
Source / Drain Regions
P-Type
Field Oxide



V_S
V_G
V_D
Source
(a) N^{++}
Channel
P^-
Drain
N^{++}
V_G
M
O
S
Channel
(b) P^-
$V_G < 0$
M
O
Channel
(c) P^-
$V_G > 0$
M
O
Depletion region
Channel
(d) P^-
$V_G = V_{Th}$
M
O
Channel
(e) P^-