ESc201 : Introduction to Electronics

Amplifiers

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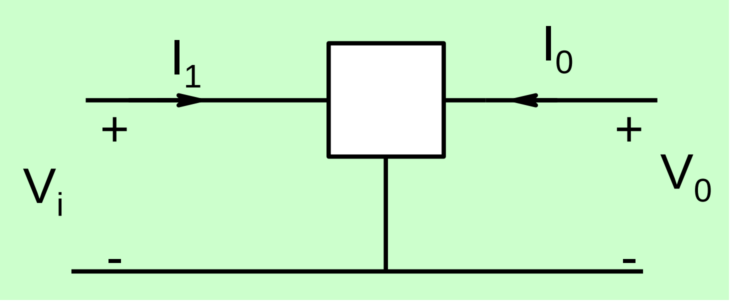
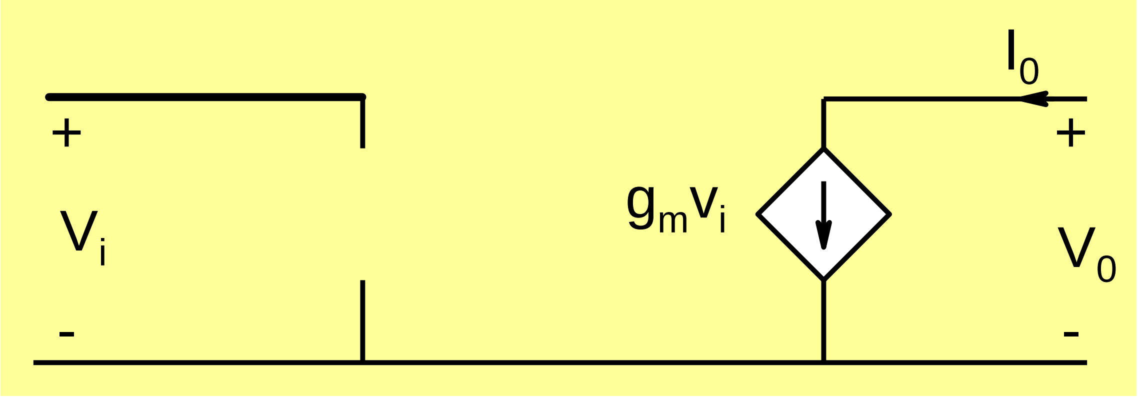
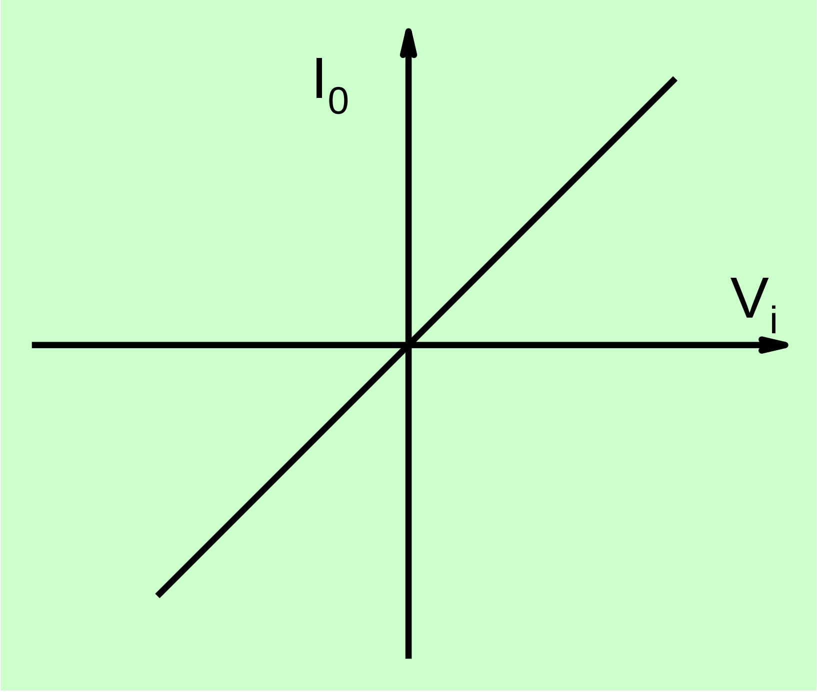
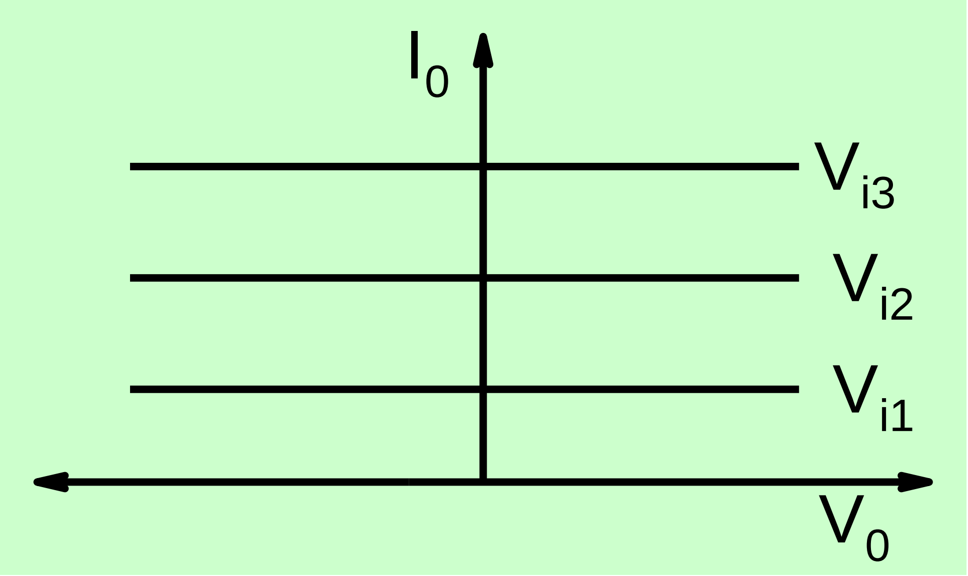
RECAP Ideal Transistor Characteristics









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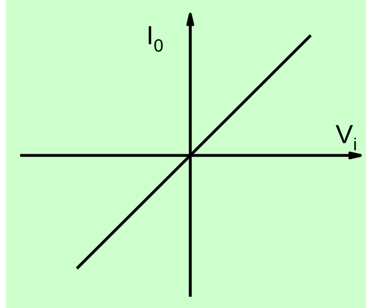
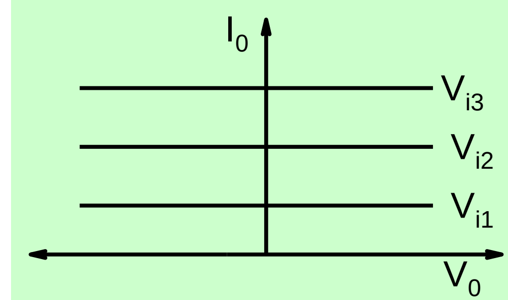
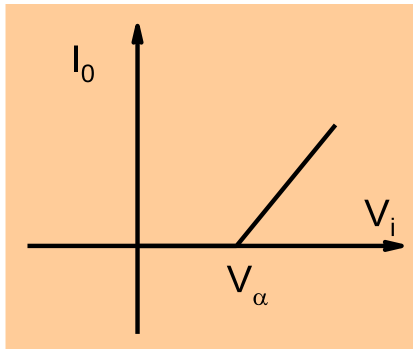
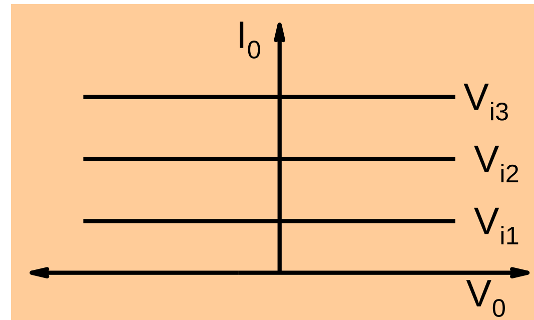
Ideal transistor



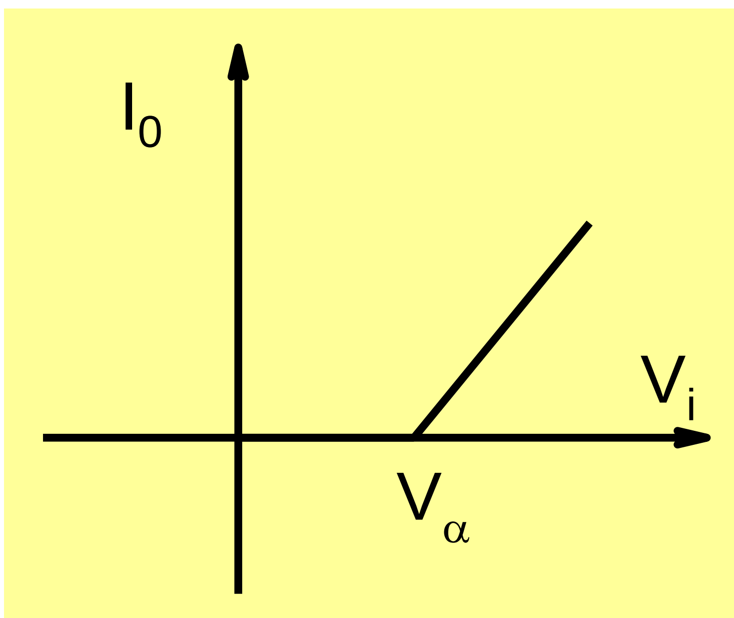


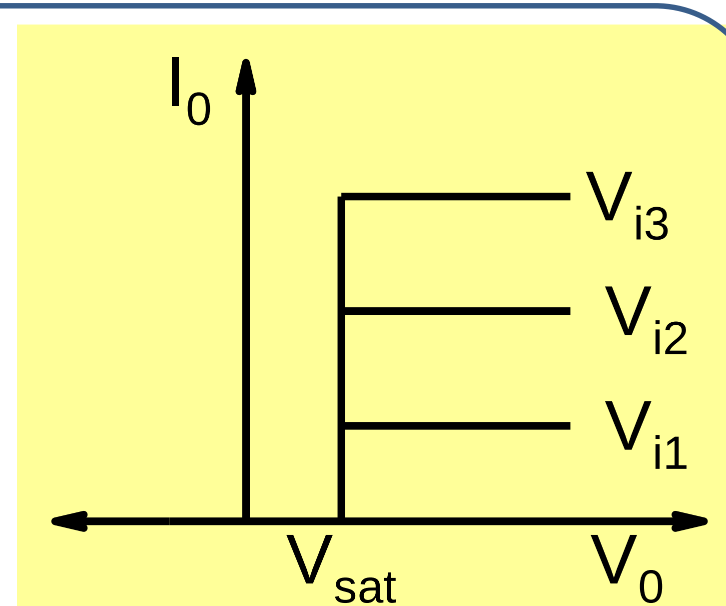
Device X





Device Y





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

Amplifier Schematic for Device Y

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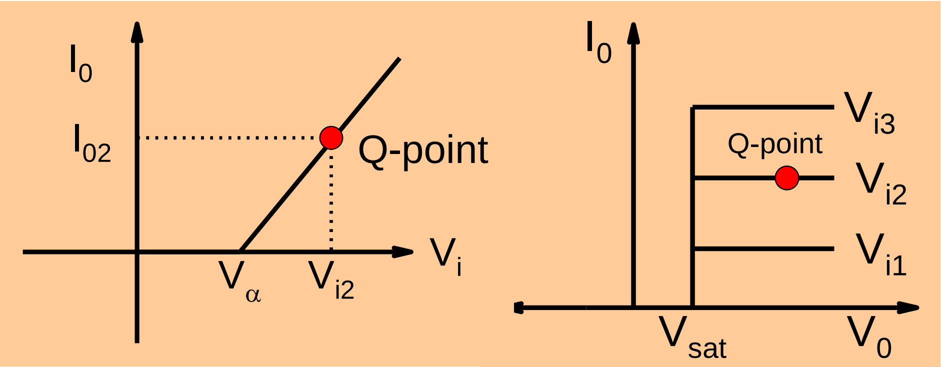
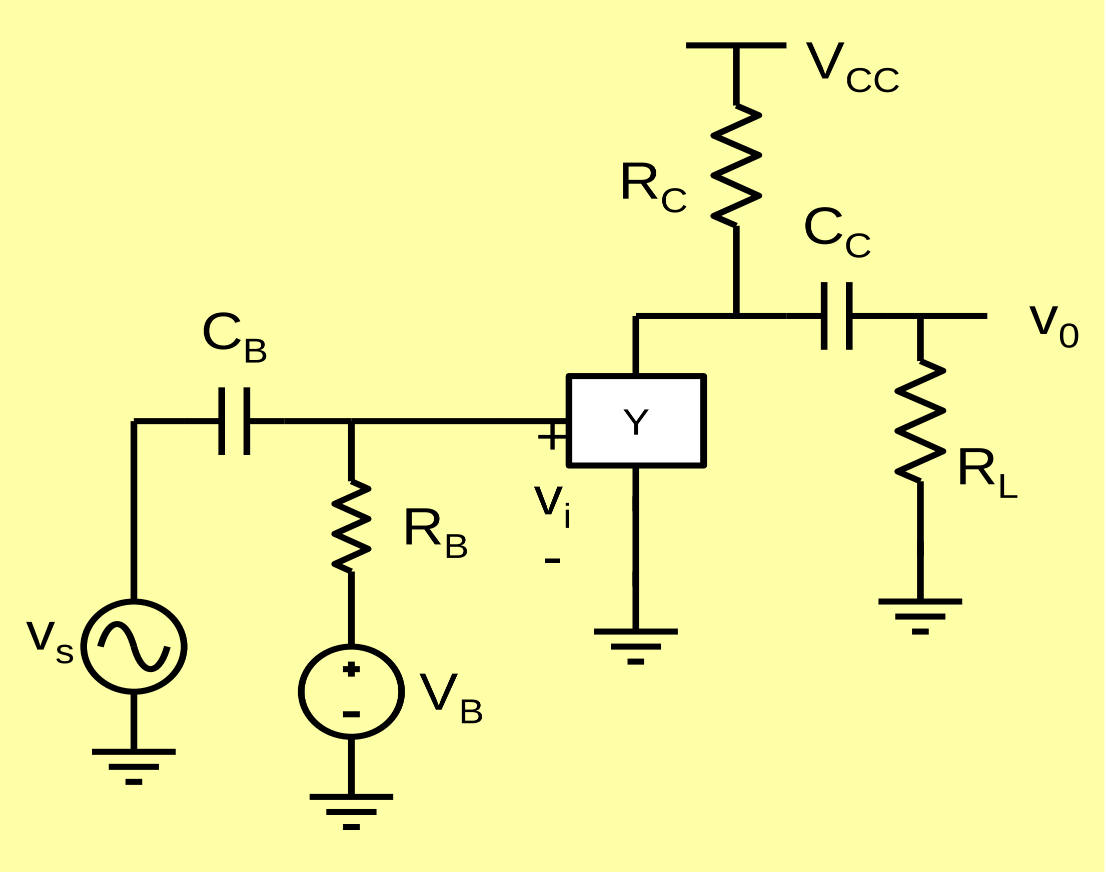
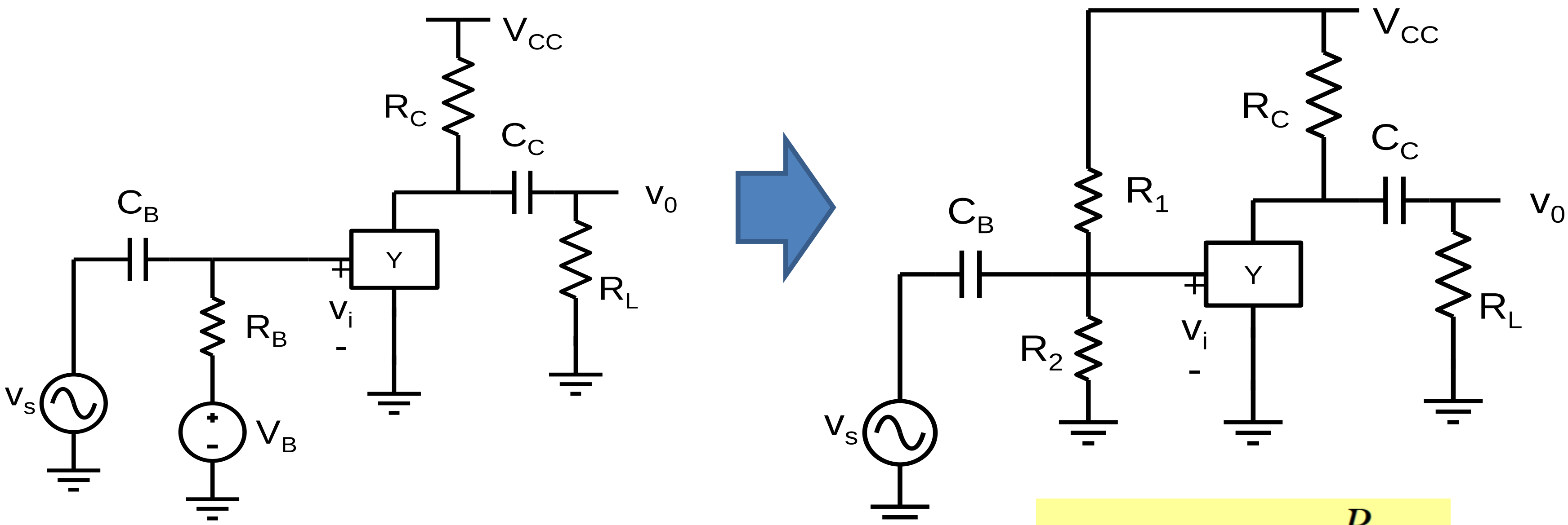




Economising on power supplies

RECAP

Can we implement an amplifying circuit using one dc voltage source only?



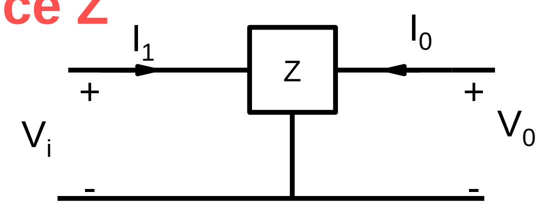
$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2}$$

and $R_B = R_1 || R_2$

A single supply V_{CC} can be used to provide bias to both input and output

High response device Z

Device Z



For $V_o < 0.2$ V ⇨ $I_o = 0$ Output characteristics

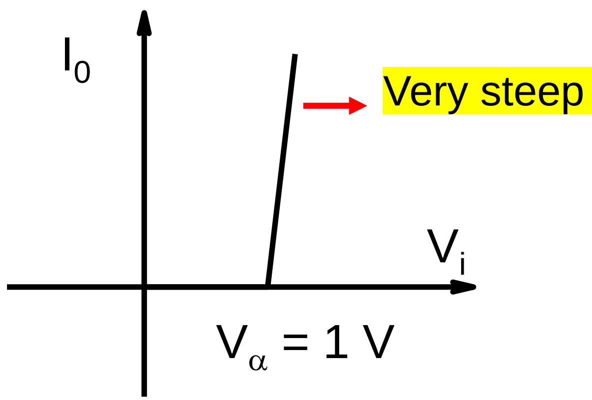
For $V_o \geq 0.2$ V

$I_o = 0$ for $V_i \leq 1$ V

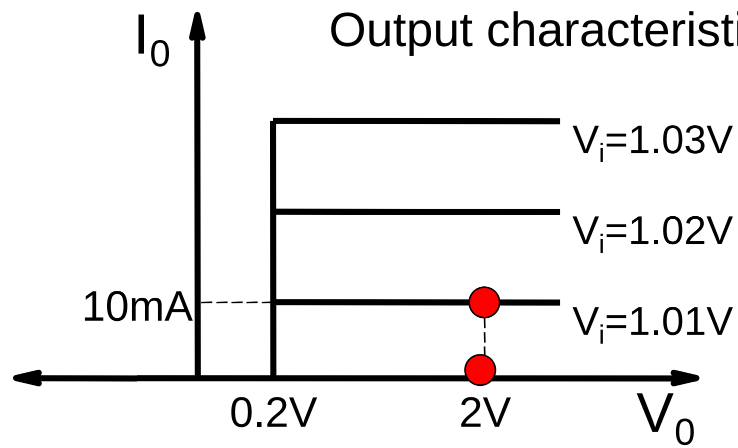
$I_o = 10^3 \cdot (V_i - 1\text{ V})$ mA for $V_i > 1$ V

Transfer characteristics

Transfer characteristics



Output characteristics



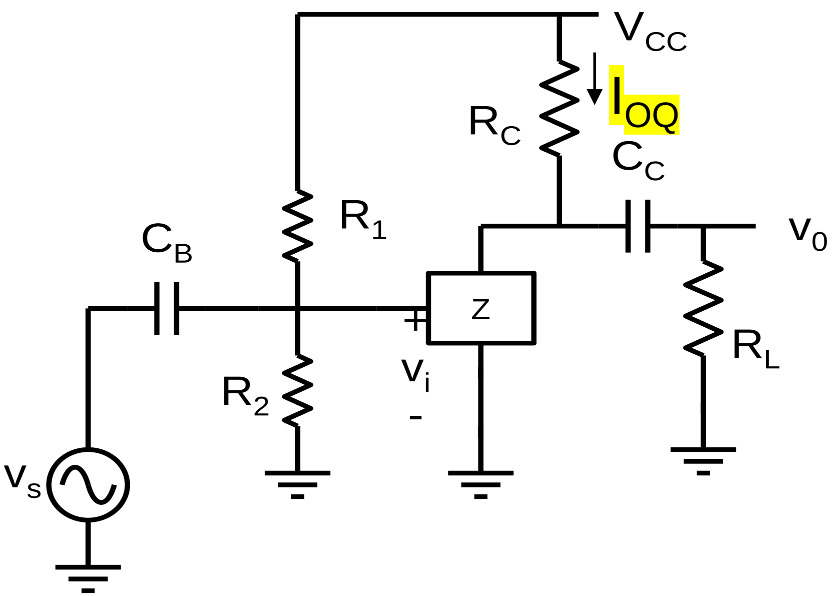
- The voltage gain circuit we designed will be **very sensitive** to:
  - variations in resistor values, power supply, device parameters such as V_α,etc.

Highly sensitive to resistor value

Assume $V_o \geq 0.2$ V by choosing proper bias

$I_o = 0$ for $V_i \leq 1$ V

$I_o = 10^3 \cdot (V_i - 1\text{ V})$ mA for $V_i > 1$ V



Target Quiescent Current:

$V_{CC} = 5$ V; $R_2 = 1$ kΩ; $R_1 = 3.95$ kΩ

⇨ $V_i = 1.01$ V ⇨ $I_{OQ} = 10$ mA

What if R_2 varies?

$V_{CC} = 5$ V; $R_2 = 0.99$ kΩ; $R_1 = 3.95$ kΩ

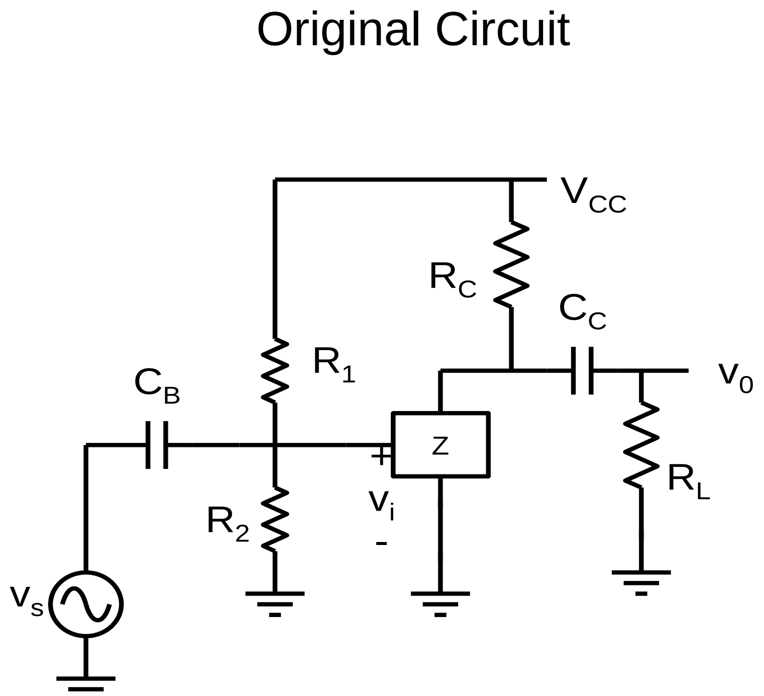
⇨ $V_i = 1.002$ V ⇨ $I_{OQ} = 1.9$ mA

$V_{CC} = 5$ V; $R_2 = 0.98$ kΩ; $R_1 = 3.95$ kΩ

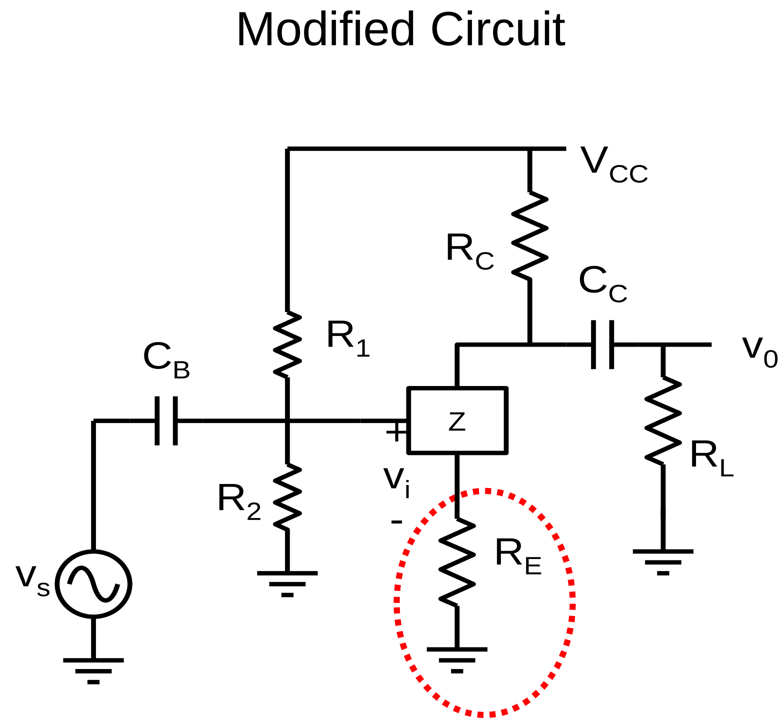
⇨ $V_i = 0.994$ V ⇨ $I_{OQ} = 0$ mA

A 2% drop in R_2 value causes the circuit to become non-operational!

A solution

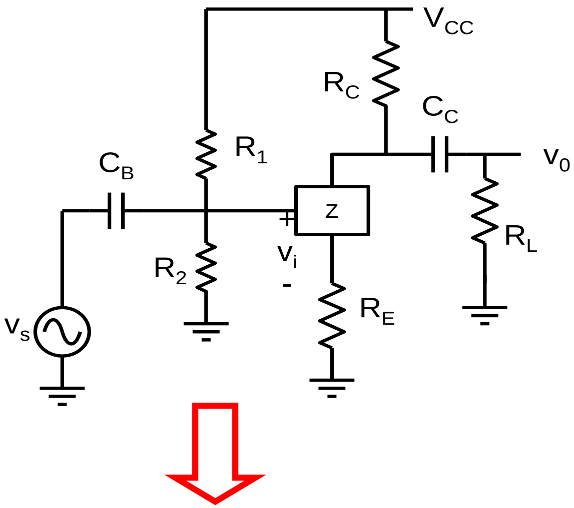


Original Circuit
V_{CC}
R_C
C_C
R_1
C_B
v_0
Z
+
v_i
-
R_L
R_2
v_s

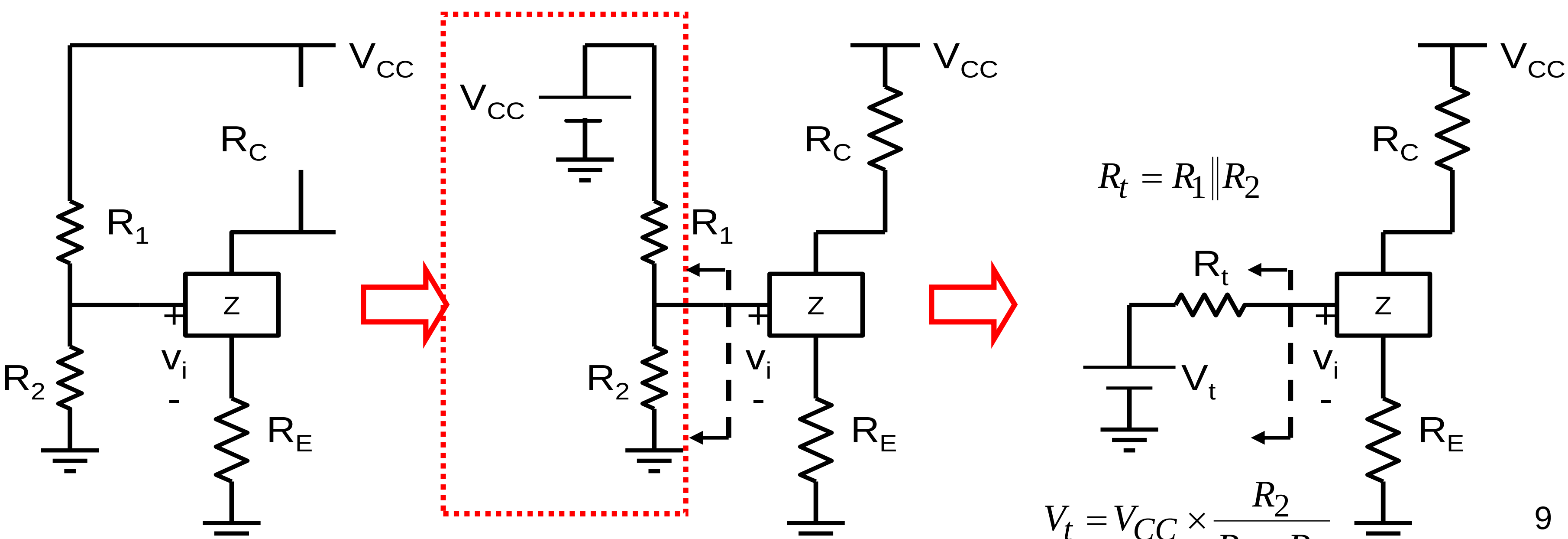


Modified Circuit
V_{CC}
R_C
C_C
R_1
C_B
v_0
Z
+
v_i
-
R_L
R_2
R_E
v_s

DC analysis of modified circuit (1)



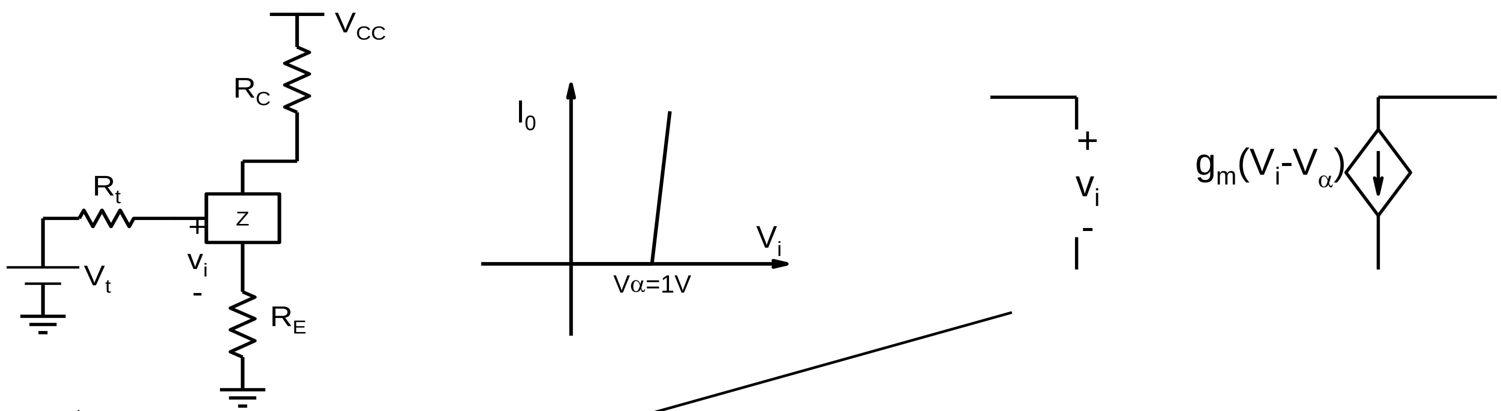
Represent the input bias as:
Thévenin equivalent as seen from input

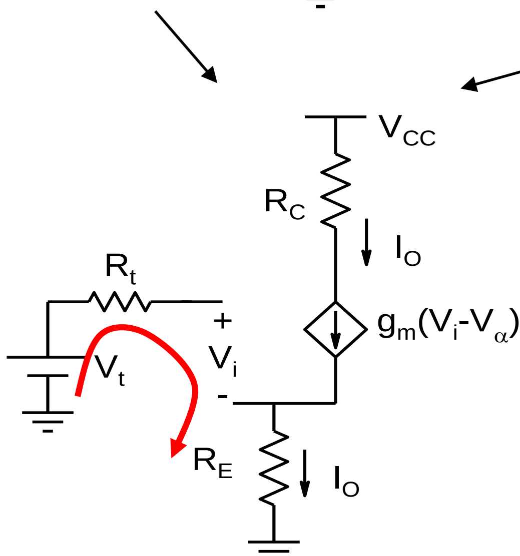


$$R_t = R_1 \| R_2$$

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

DC analysis of modified circuit (2)





$$-V_t + 0 \times R_t + V_i + I_O R_E = 0$$

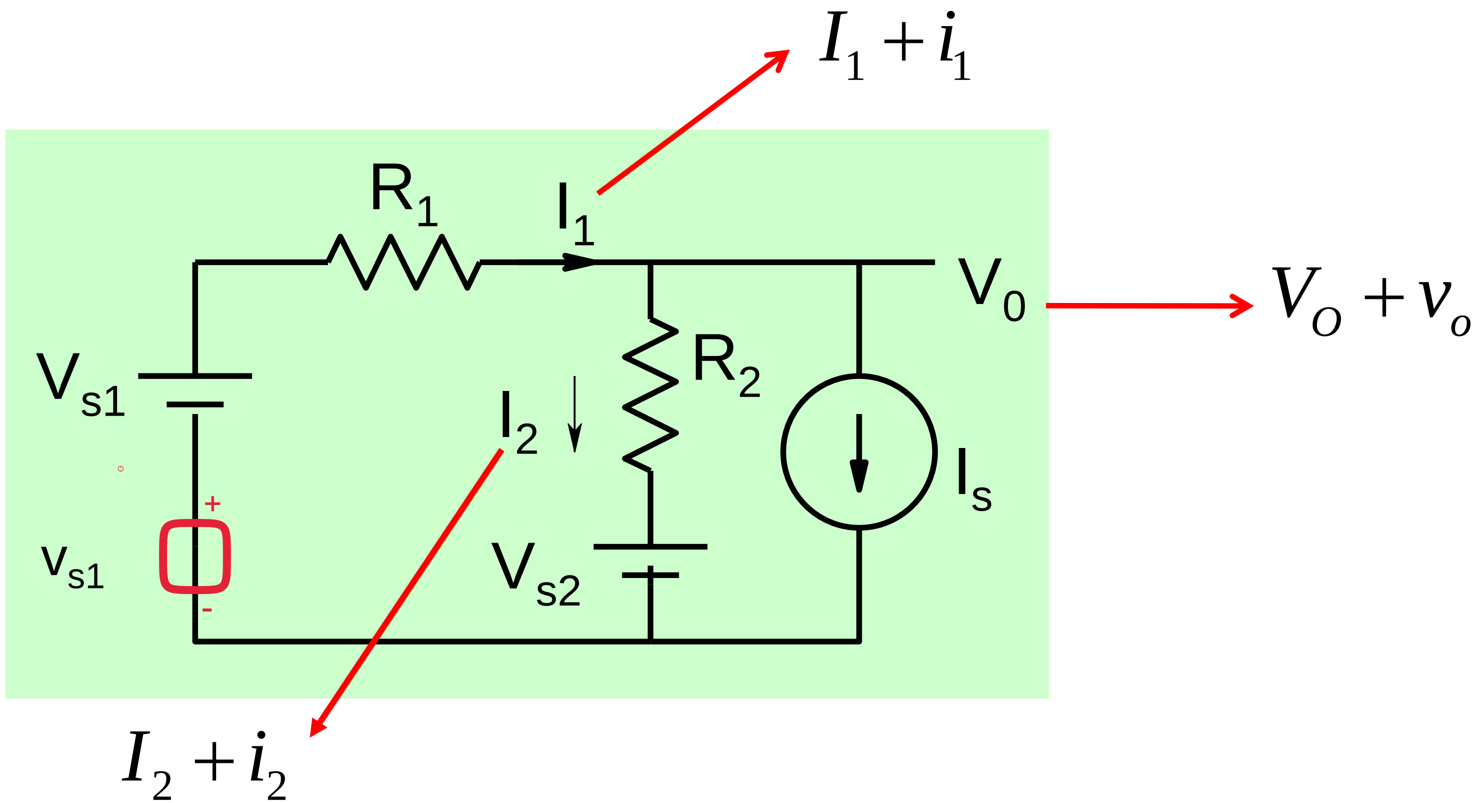
Since I_o vs. V_i characteristics is very sharp, $V_i \sim V_\alpha = 1\text{V}$

$$I_O \cong \frac{V_t - V_\alpha}{R_E}$$

If V_t changes by 1% due to variation in resistor values then the change in output current is proportional.

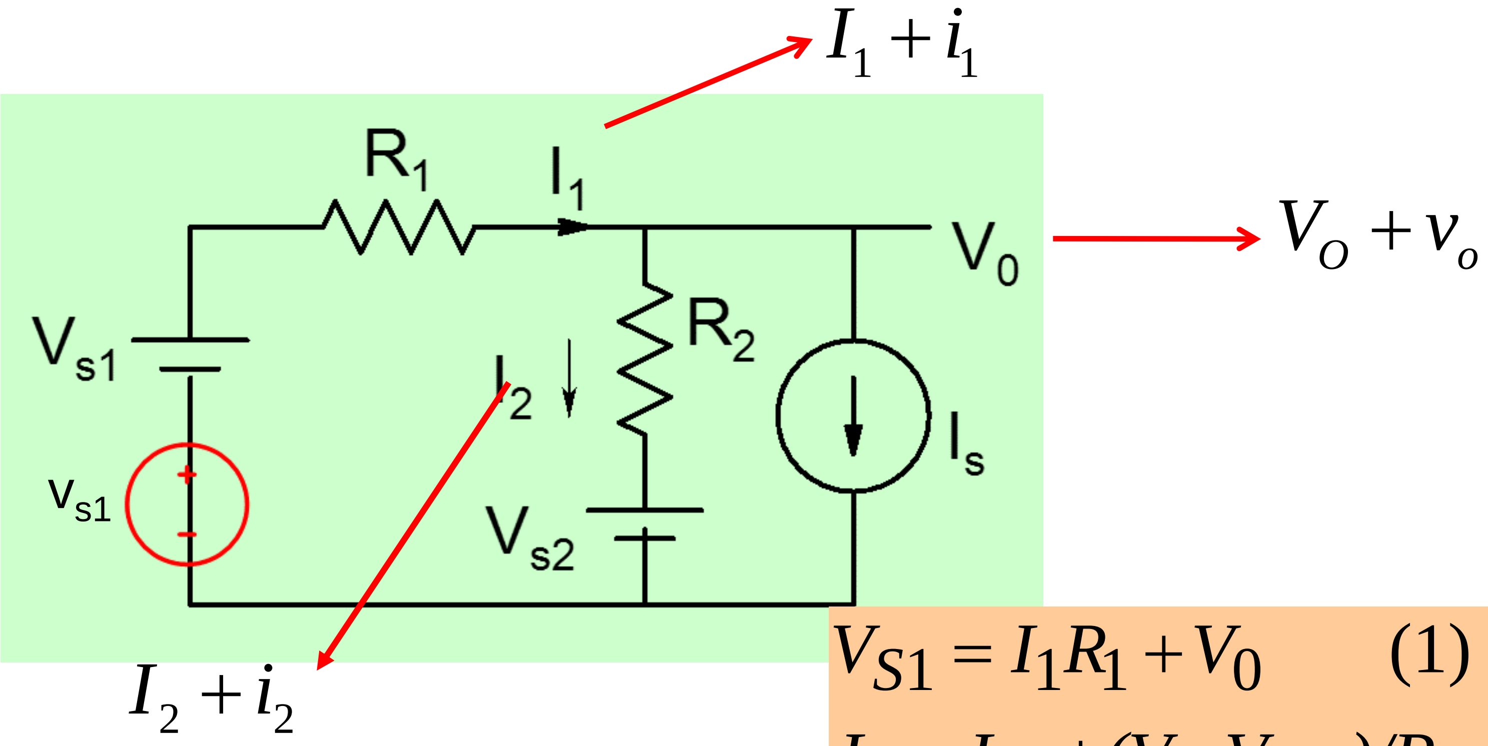
Circuit much less sensitive to variations in circuit parameters

Incremental (ac) Circuit Analysis



Incremental circuit analysis attempts to find the relationships between incremental voltages and currents v_{s1}, i_1, v_o…….

Incremental (ac) Circuit Analysis



$$V_{S1} = I_1 R_1 + V_0 \qquad (1)$$

$$I_1 = I_S + (V_0 - V_{S2})/R_2 \qquad (2)$$

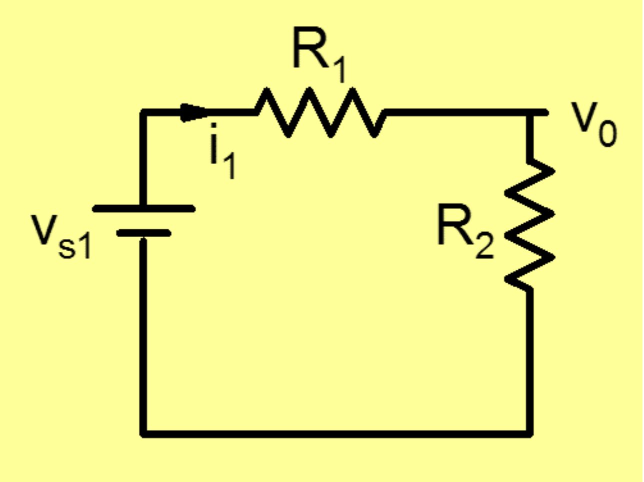
$$V_{S1} + v_{s1} = (I_1 + i_1) \times R_1 + V_0 + v_o \qquad (3)$$

$$I_1 + i_1 = I_S + (V_0 + v_o - V_{S2})/R_2 \qquad (4)$$

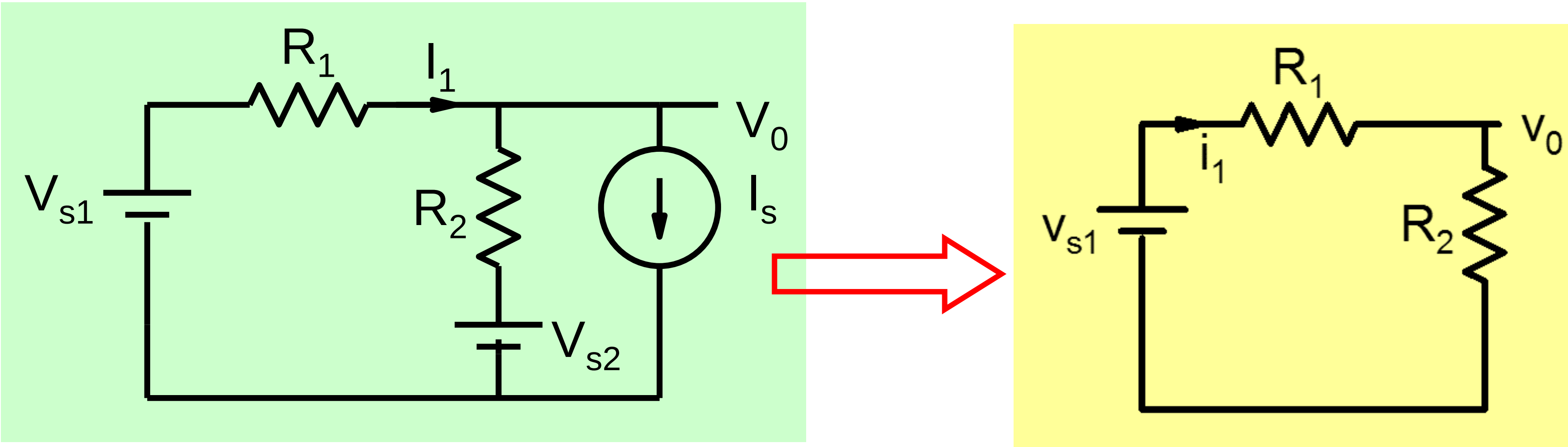
$$(3)\text{-}(1): v_{s1} = i_1 R_1 + v_o$$

$$(4)\text{-}(2): i_1 = v_o / R_2$$

$$v_{s1} = i_1 R_1 + i_1 R_2$$



Method: Incremental equivalent circuit



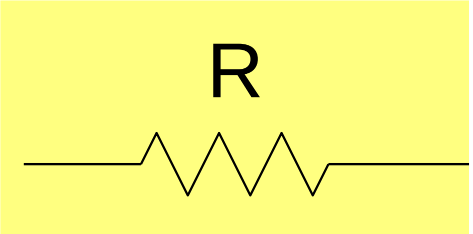
Analyze incremental equivalent circuit obtained by replacing each circuit element by its increment circuit model (sometimes called ac model).

Incremental model

$$I = f(V) \qquad I + i = f(V + v)$$

Relation between *i and v*

Incremental (ac) Models: Resistor



$$V = I \times R$$

$$V + v = (I + i) \times R$$

$$\Rightarrow \quad v = i \times R$$

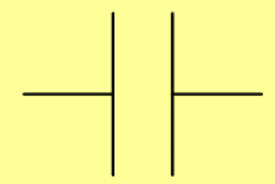
Incremental model of a resistor is a resistor of the same magnitude

Incremental (ac) Models: Capacitor

$$I = C\frac{dV}{dt}$$

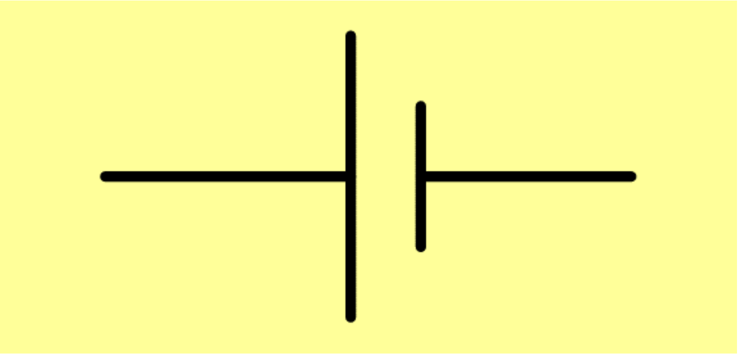
$$I + i = C\frac{d(V+v)}{dt}$$

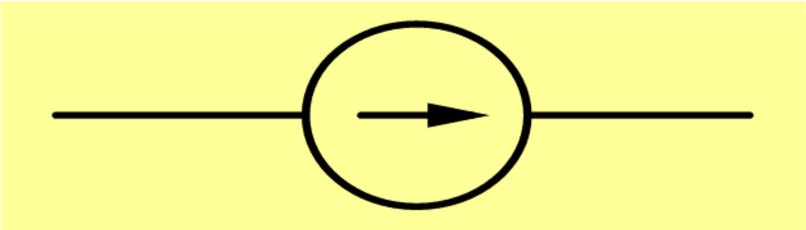
$$i = C \times \frac{dv}{dt}$$



Incremental model of a capacitor is a capacitor of the same magnitude. The same holds for an inductor as well.

Incremental (ac) Models





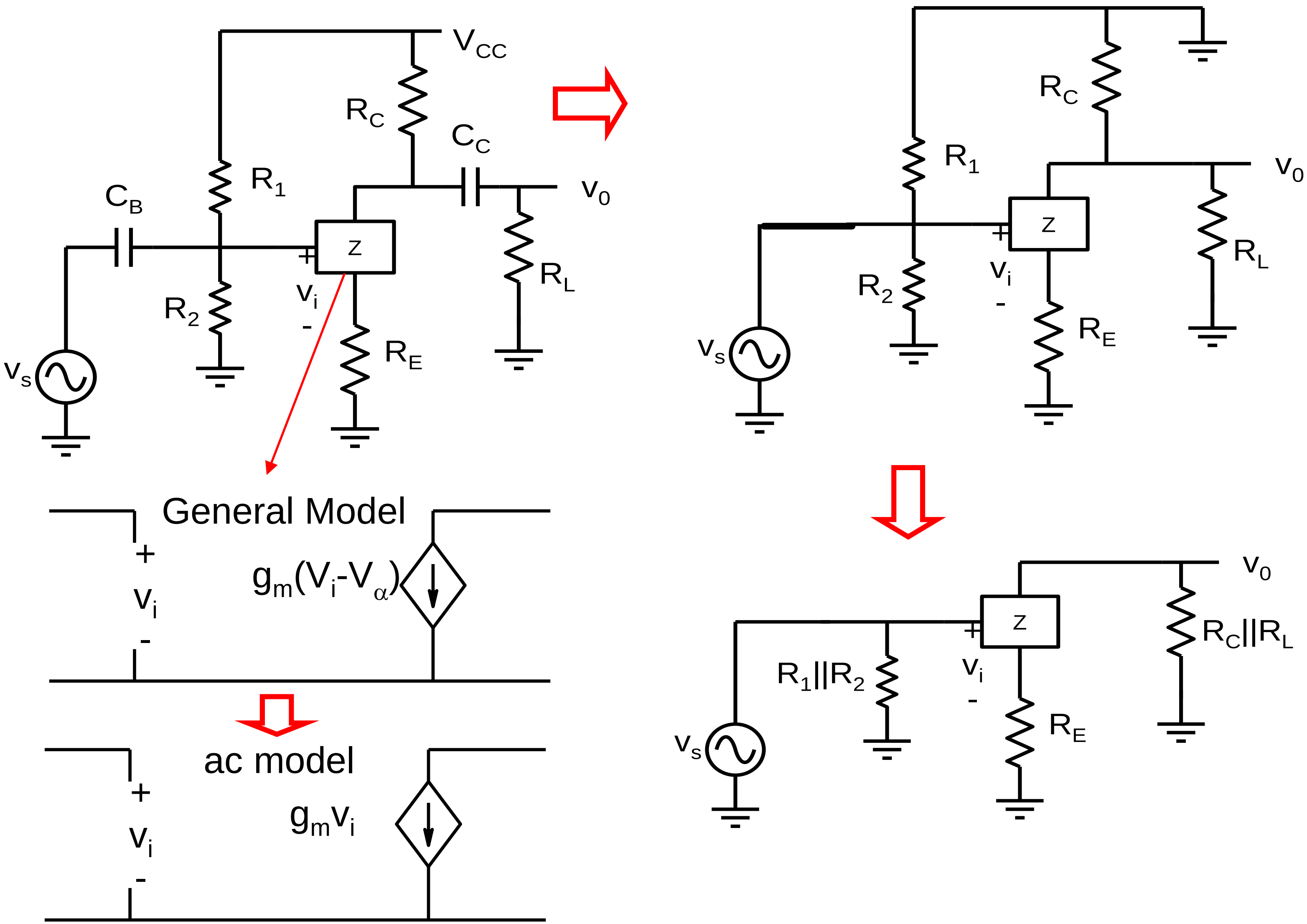
$$V = cons\tan t$$
$$\Rightarrow v = 0$$

$$I = cons\tan t$$
$$\Rightarrow i = 0$$

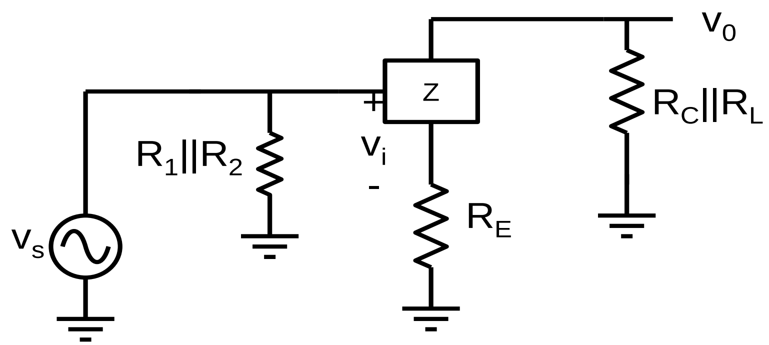
Incremental model of a constant Voltage Source is a short circuit

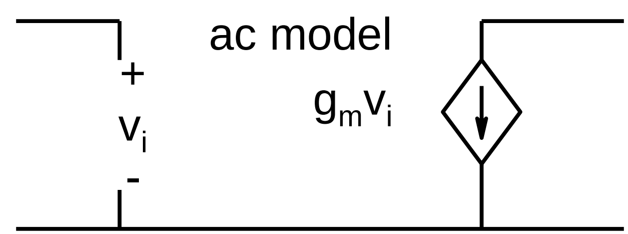
Incremental model of a constant current Source is an open circuit

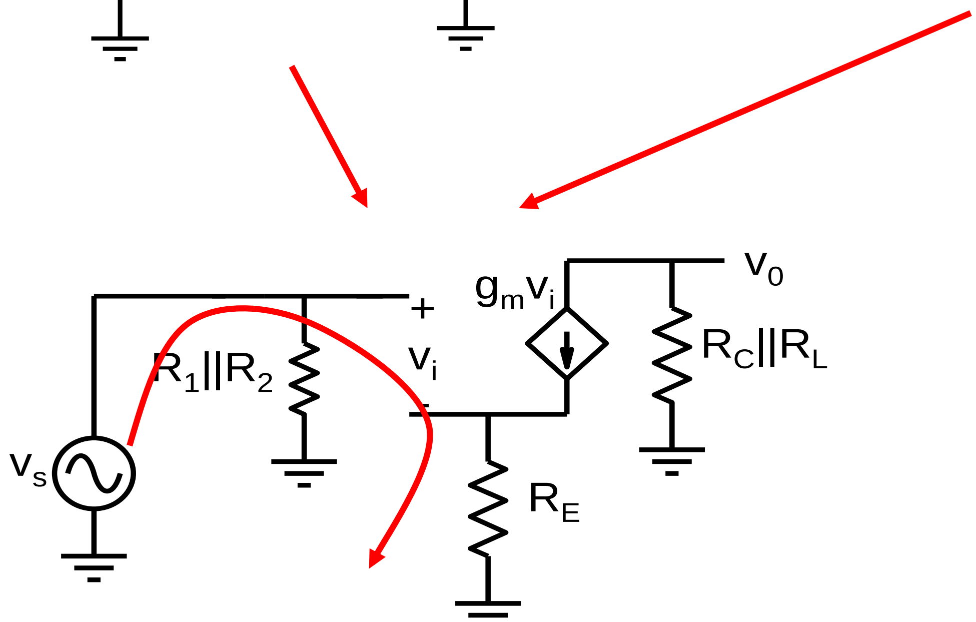
AC analysis of modified circuit (1)



AC analysis of modified circuit (2)







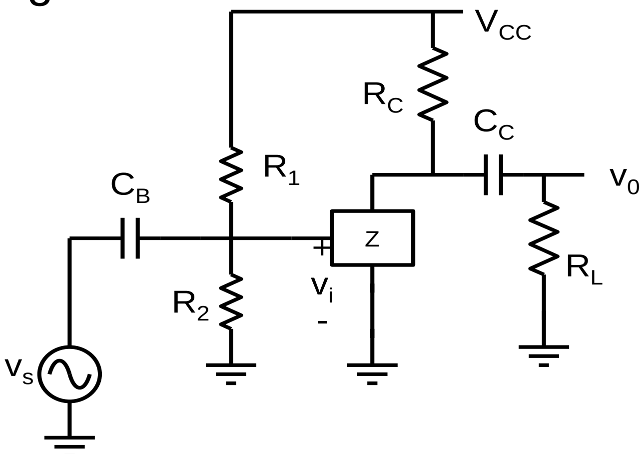
$$v_S = v_i + g_m v_i R_E$$

$$v_O = -g_m \times R_C \| R_L \; v_i$$

$$A_V = \frac{v_o}{v_s} = -\frac{g_m R_C \| R_L}{1 + g_m R_E}$$

Comparsion of circuits

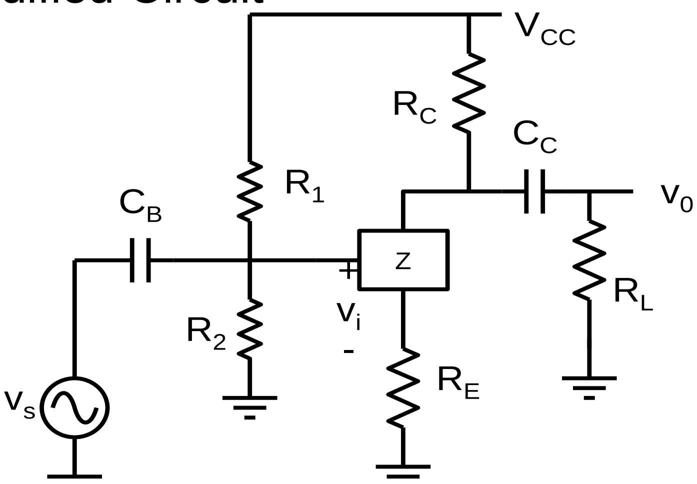
Original Circuit



Circuit very sensitive to variations in resistor values, power supply, device parameters such as Vα

AC signal gain: $$A_V = \frac{v_o}{v_s} = -g_m R_C \| R_L$$

Modified Circuit



Circuit is much less sensitive to variations in circuit parameters

AC signal gain: $$A_V = \frac{v_o}{v_s} = -\frac{g_m R_C \| R_L}{1 + g_m R_E}$$

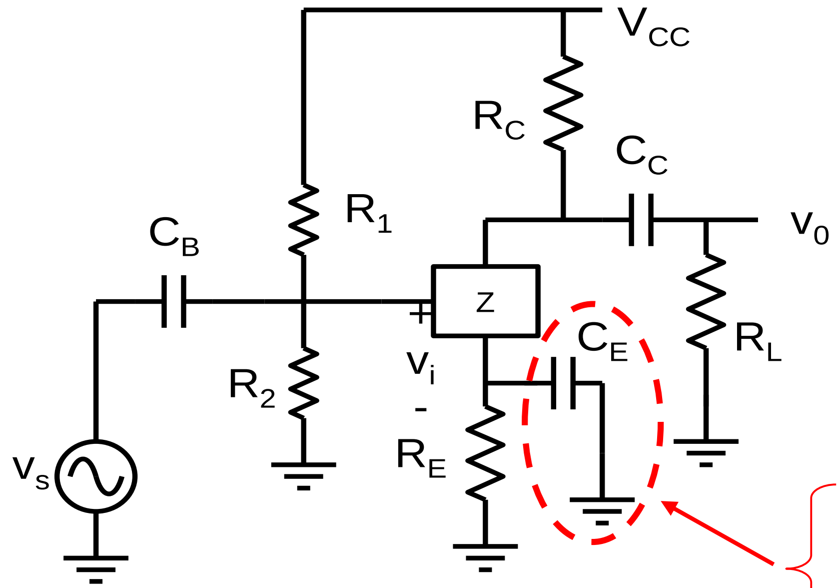
AC gain is smaller

We solved one problem, but have another problem

Is there a way out?

Restoring AC gain

AC signal gain restored to : $A_V = \dfrac{v_o}{v_s} = -g_m R_C \| R_L$



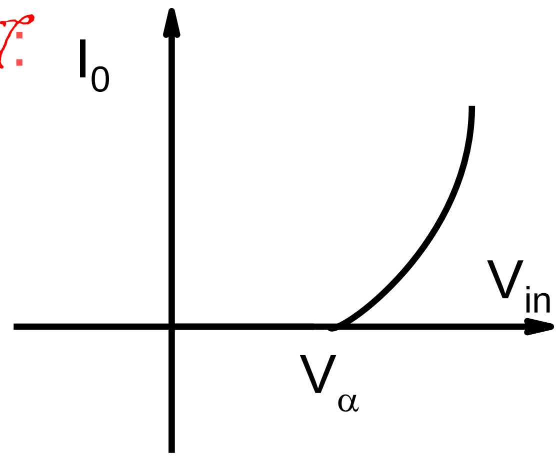
DC signal not affected

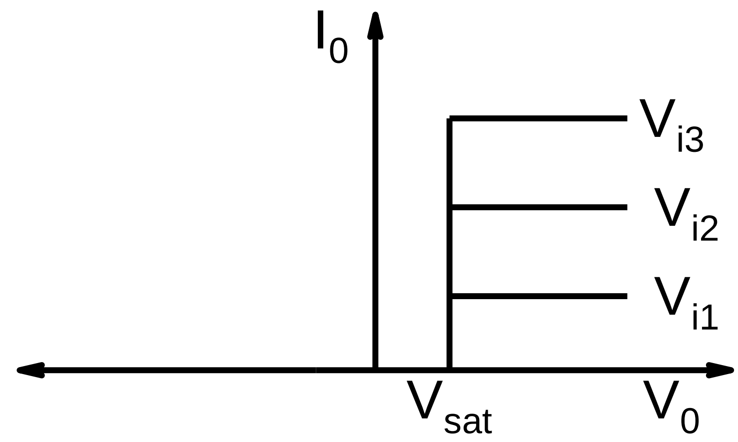
AC signal by-passes R_E

- Attach a capacitor parallel to R_E
- For dc Capacitor C_E acts as open allowing R_E to reduce variations in current
- For ac Capacitor C_E acts as a short circuit ($1/j\omega C \sim 0$)
  - Restores high voltage gain to be obtained for AC signals

A non-linear response device

Device $\mathscr{N}$:



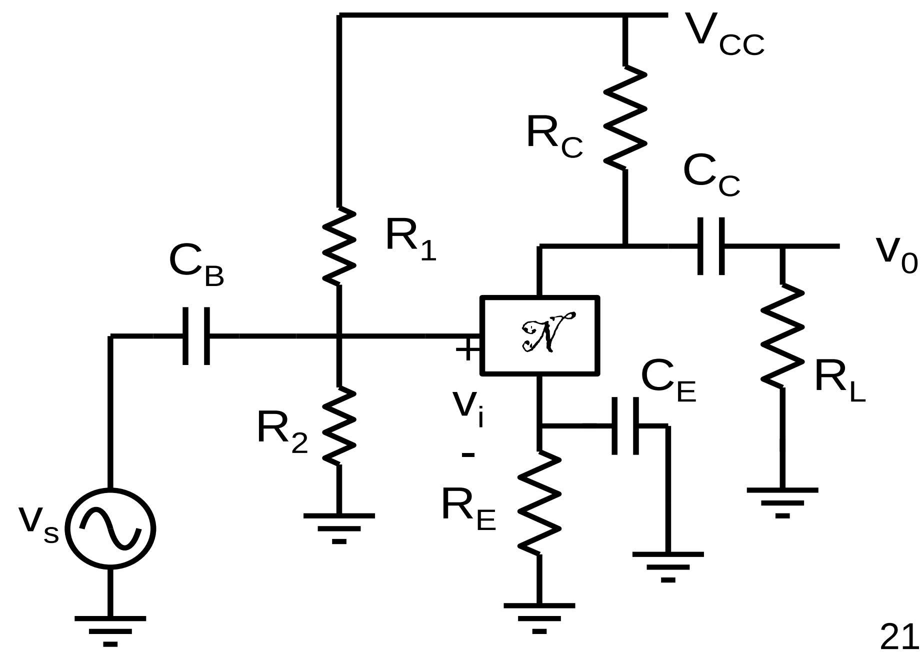


$$I_o = K \times (V_{in} - V_\alpha)^2 \text{ for } V_{in} \geq V_\alpha$$

$V_\alpha = 1.0$ V; $K = 0.01$ A·V^{-2}

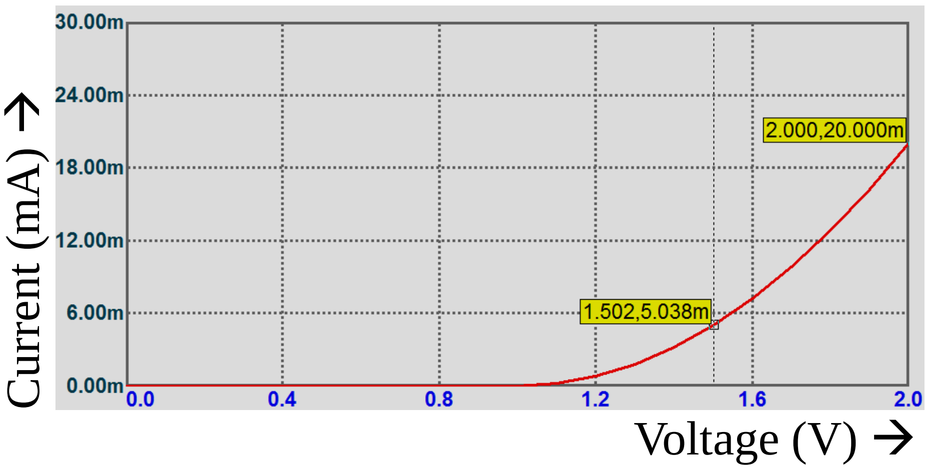
$V_B = 1.5$ V (bias for input)

$v_s = 0.3 \cdot \sin \omega t$ V

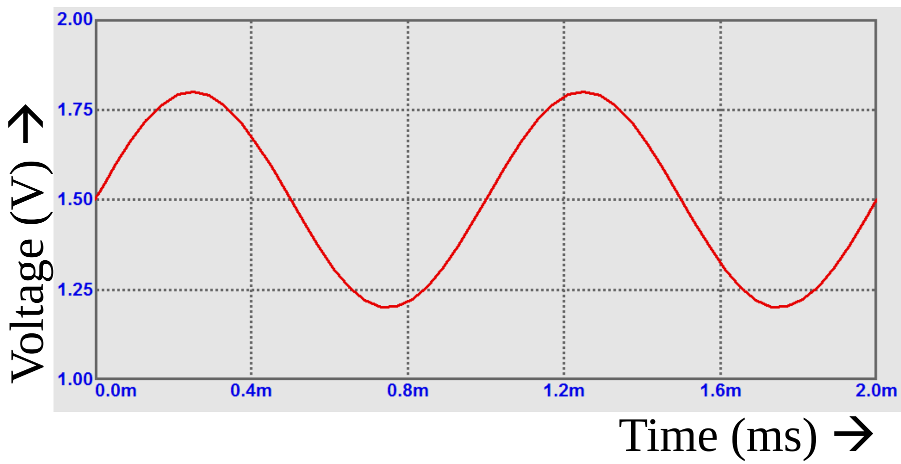


Intermediate signals

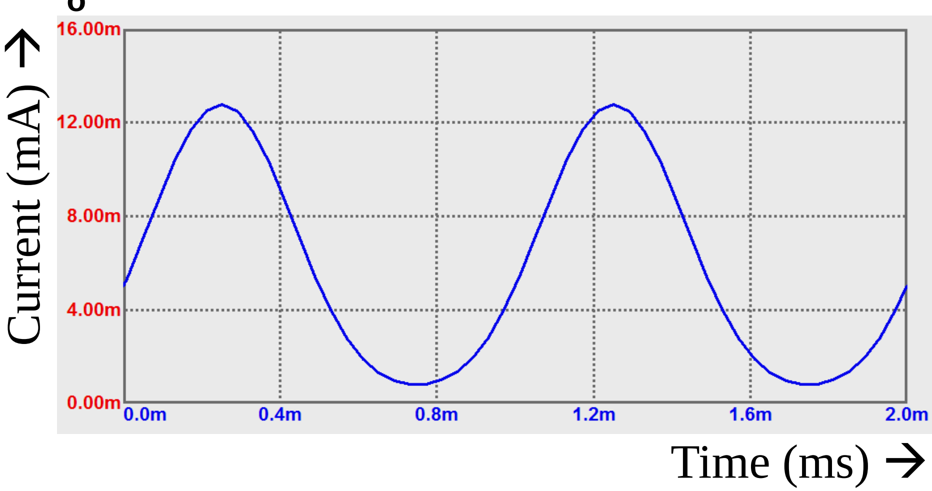
I_o vs. V_{IN}

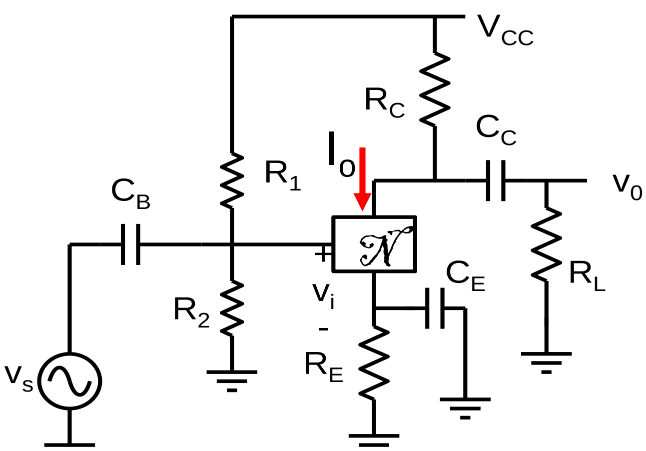


V_I (signal at I/P w.r.t. gnd) vs. time

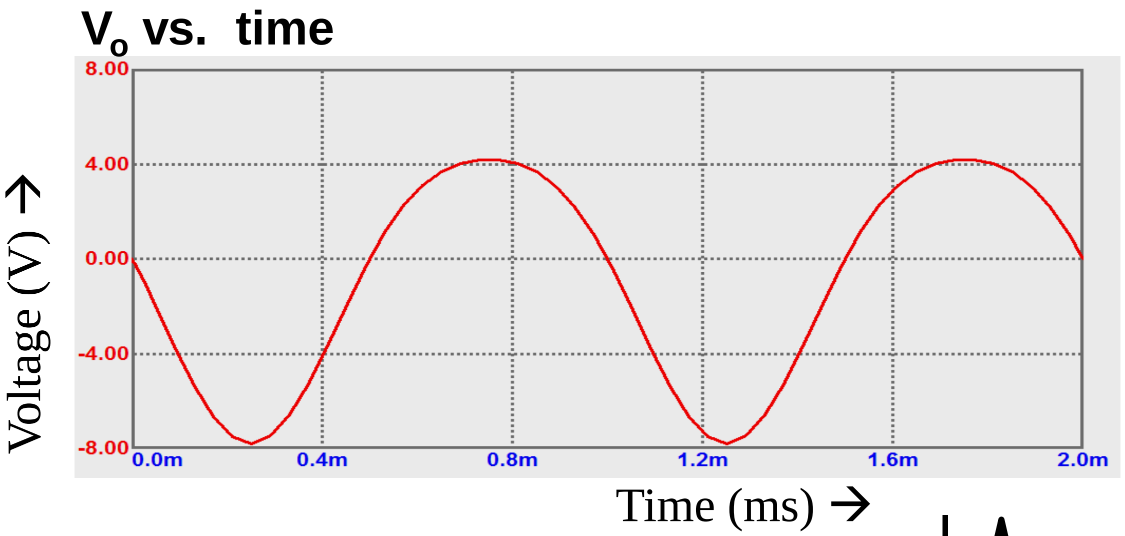


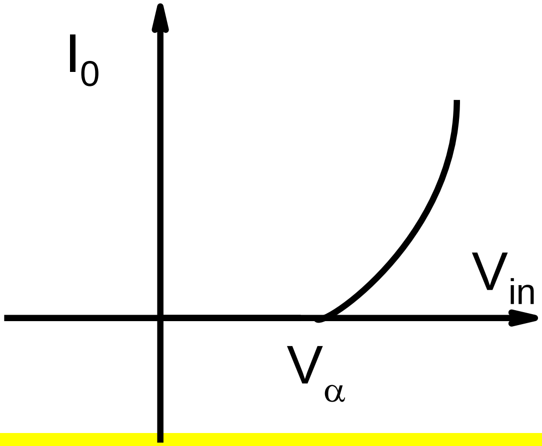
I_o vs. time

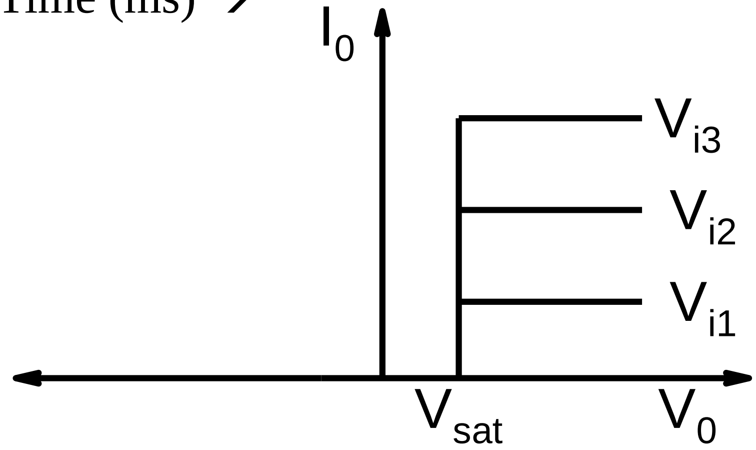




Distorted output





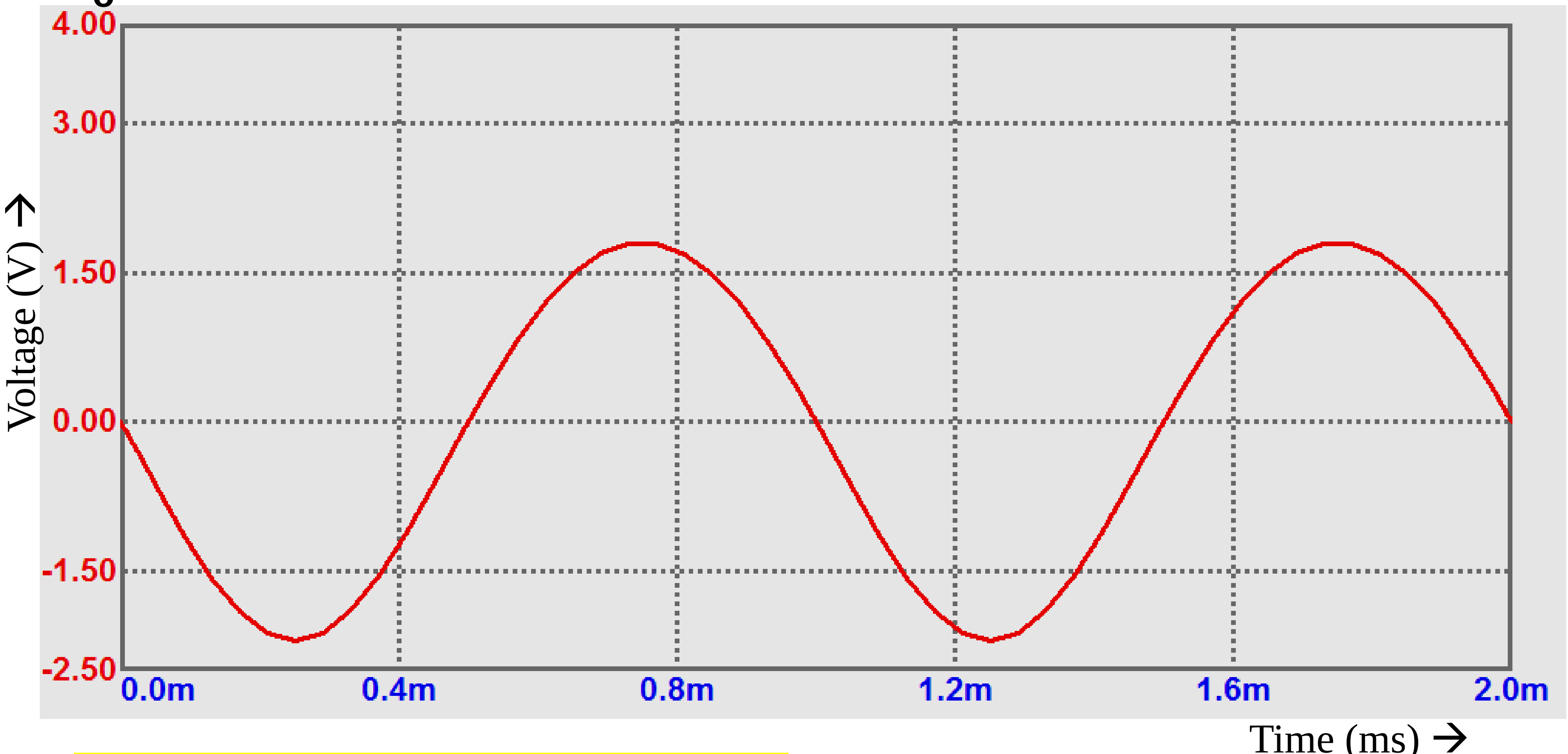


Because of non-linearity in transfer characteristics, the output waveform is distorted !

Output for smaller signals

Suppose input is reduced to $v_s = 0.1 \cdot \sin\omega t \text{ V}$

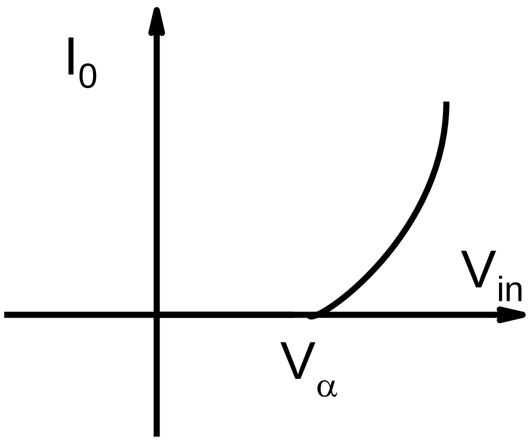
V_o vs. time

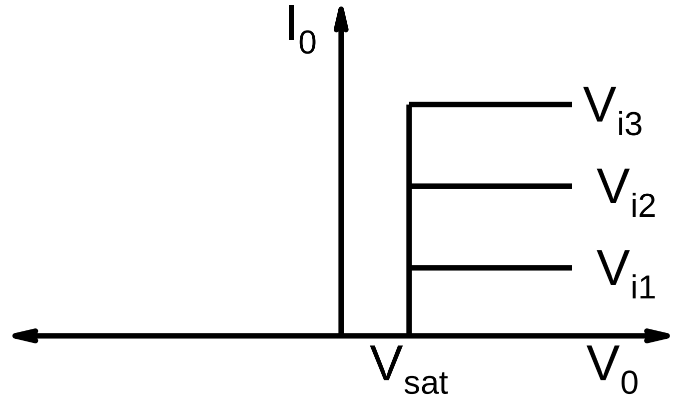


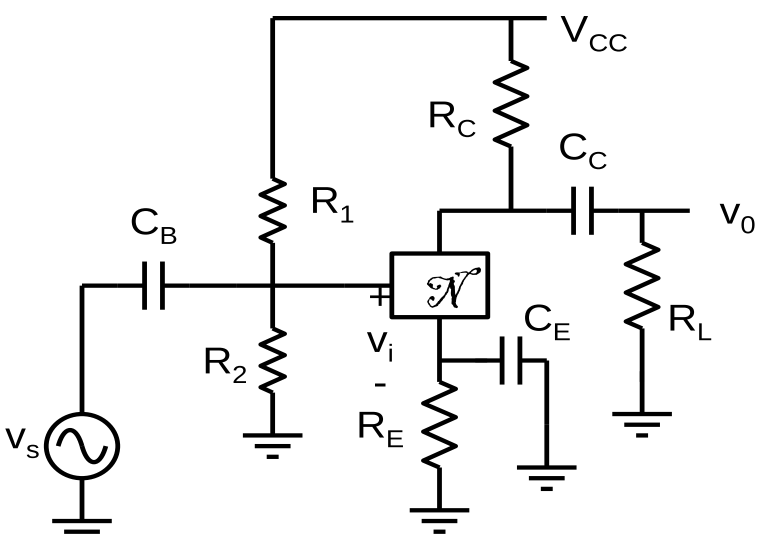
Distortion is much smaller in output

if we restrict input voltage to a small value !

Building amplifiers with non-linear devices



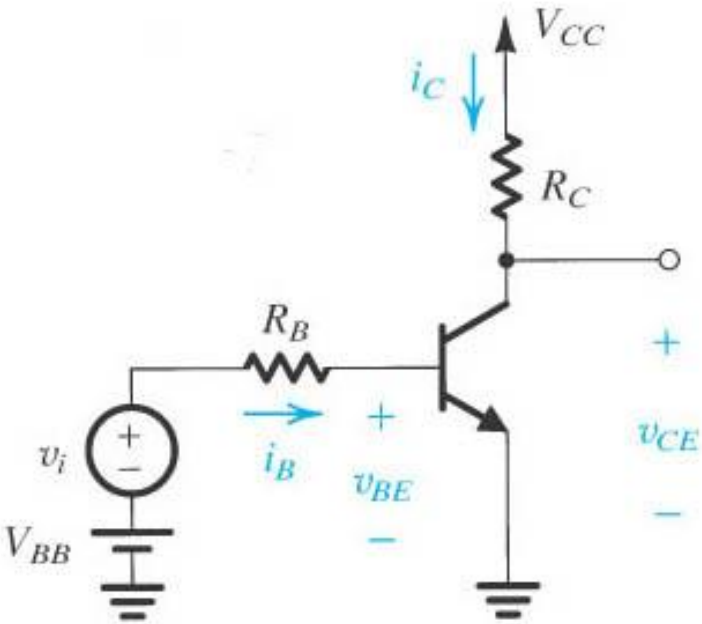


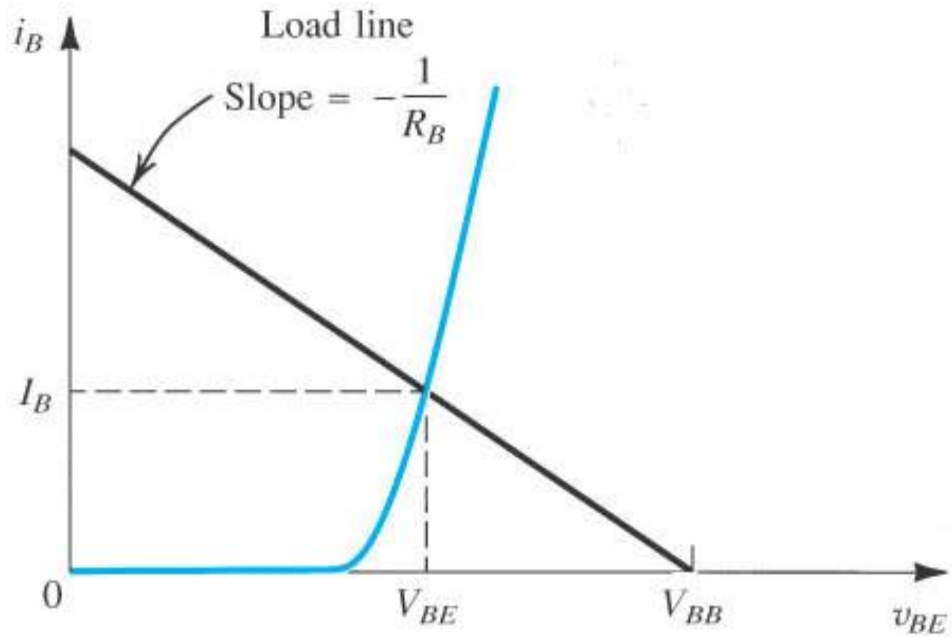


Amplifier will work properly (with small distortion only if we restrict the amplitude of input signal to small values.

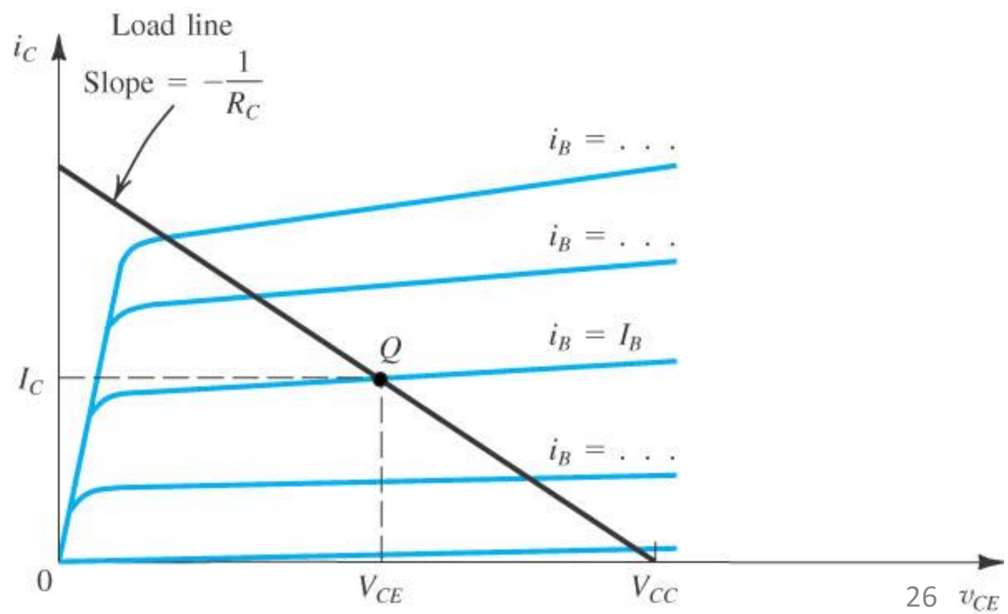
How small depends on the nature of non-linearity. The stronger the non-linearity the lesser the signal amplitude.

Bipolar Junction Transistor: BJT



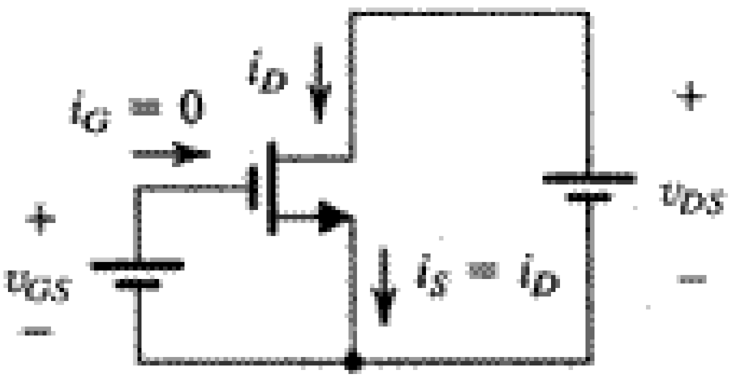


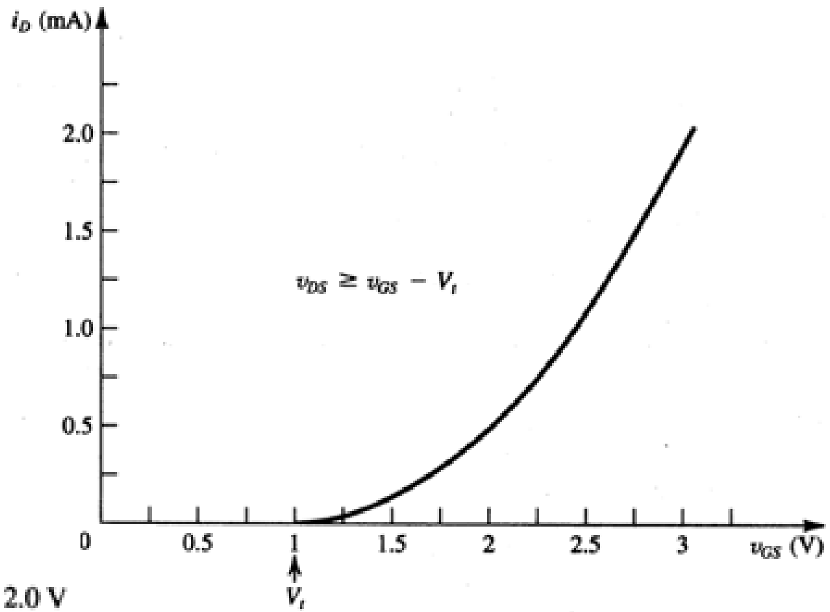
$$I_C = \beta_F I_B$$

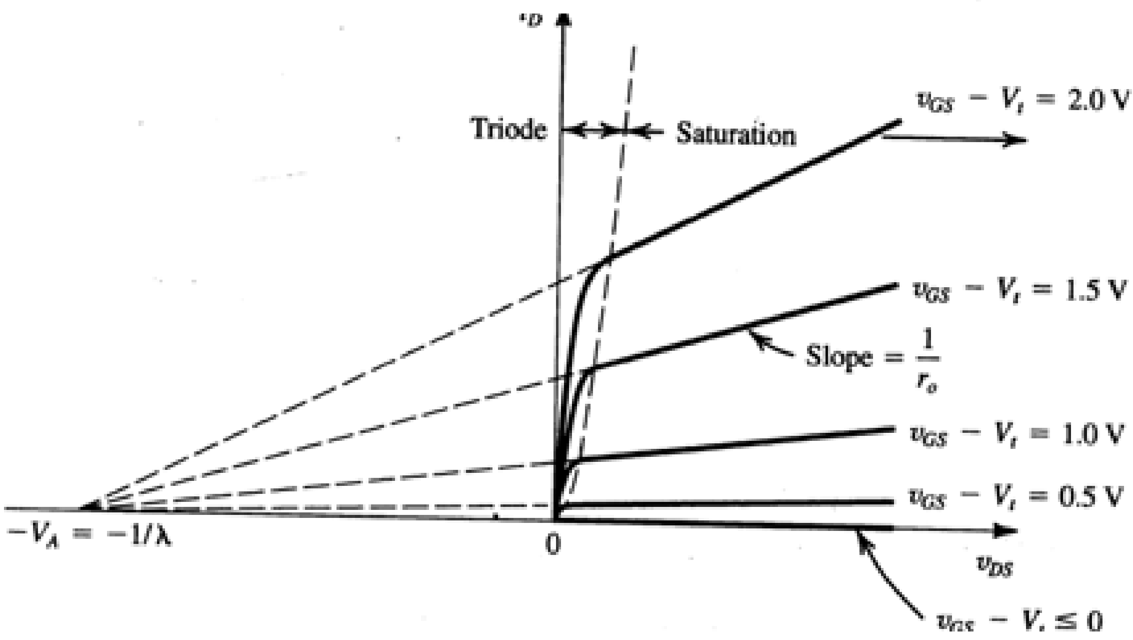


Metal Oxide Semiconductor Field Effect Transistor

MOSFET







Mid-Sem Exam

- Sept. 20, 08.00am-10am
- Syllabus: Lecture 1- Lecture 21
- Detailed seating arrangement would be pasted on doors
- Two part exam (55 mins each)
- Closed notes, closed book. Calculators allowed
- No separate rough sheets allowed
- Write Name and Roll No. clearly in assigned space

Room	Roll No. Range
L01	170032-210104
L07	210105-210314
L16	210315-210447
L17	210448-210592
L18	210594-210769
L19	210770-210951
L20	210952-211208