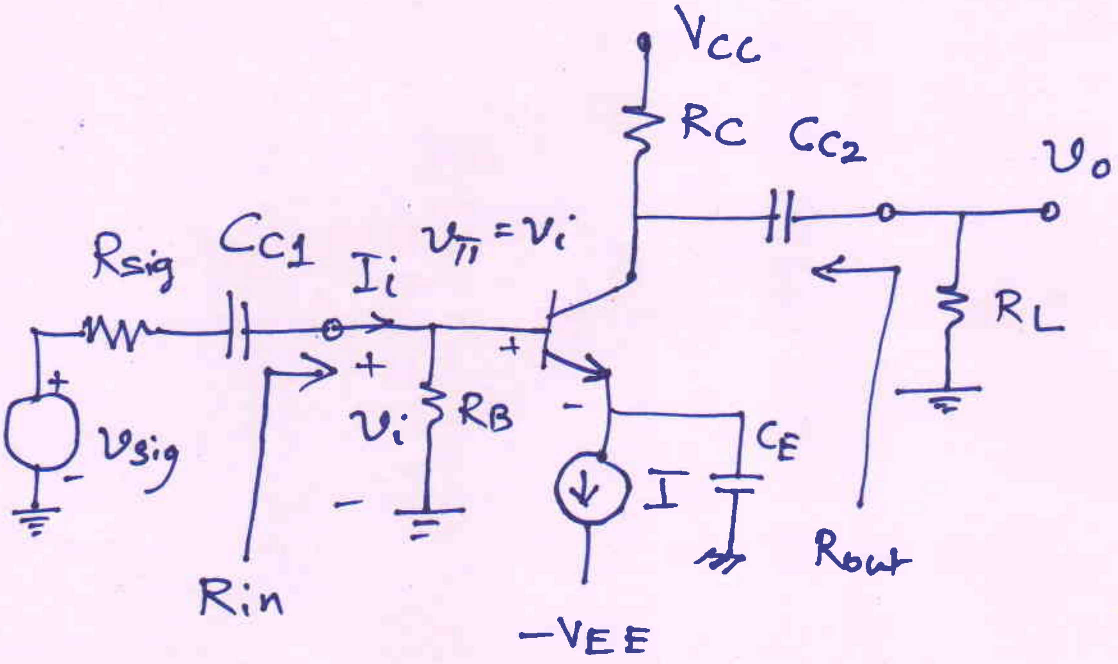
SINGLE STAGE AMPLIFIER (CE)

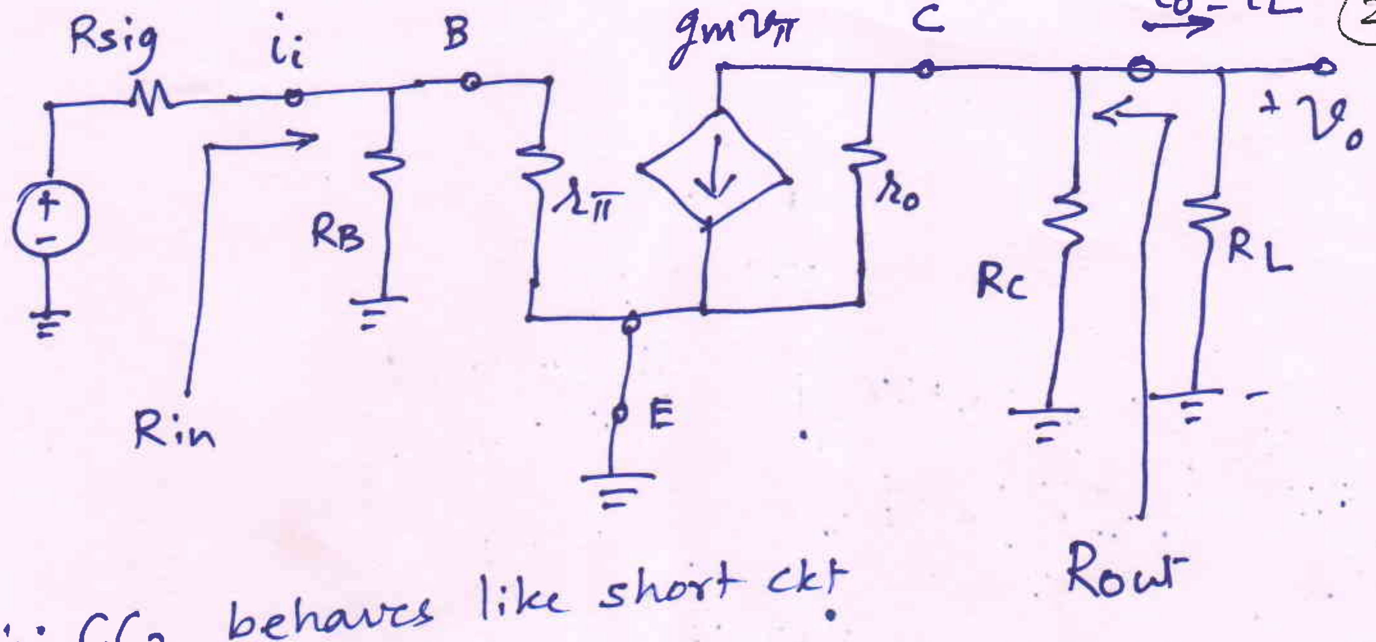


C_{C1} & C_{C2} = inter-stage coupling capacitors
Act like perfect short circuit at
lowest frequency of operation.
Usually $10 \rightarrow 100\,\mu F$

R_B = To provide dc biasing path to I_B. It
reduces $R_{in} = R_B \,||\, r_\pi$.
If signal source can pass I_B then we can
dispense with R_B.

C_E = Emitter Bypass Capacitor to bring Emitter
to 0V as far as AC is concerned.
So it becomes Common Emitter Amplifier.
Usually $100\mu F$ or more.

For AC purposes V_{cc} & $-V_{EE}$ are at same potential
or one end of R_c is grounded.



$\because$ CC_2 behaves like short ckt

$v_o = v_C$

<u>Note</u>: R_L Could be actual load or it cound be Rin of next stage amplifier

$$R_{in} = \frac{v_i}{i_i} = \frac{R_B \cdot r_\pi}{R_B + r_\pi} \quad \left(\text{if } R_B >> r_\pi \atop 100k >> 2.5k\right)$$

then $R_{in} \simeq r_\pi$

$$v_i \simeq v_{sig} \frac{r_\pi}{r_\pi + R_{sig}} = v_\pi$$

Using g_m as transconductance, the output current source $g_m \cdot v_\pi$ drives 3 loads in parallel

$$V_o = -g_m v_\pi (r_o \,||\, R_C \,||\, R_L)$$

Voltage Gain of Amplifier Proper (Base to Collector)

$$A_v = -g_m (r_o \,||\, R_C \,||\, R_L)$$

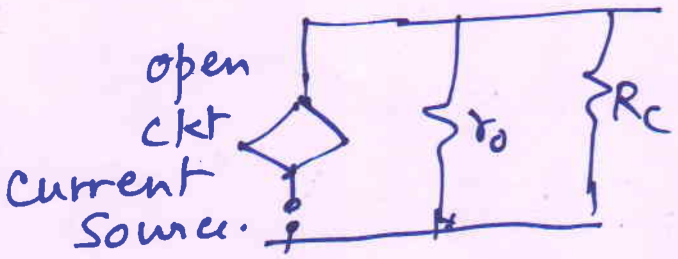
Open Circuit Voltage Gain (when $R_L = \infty$)

$$A_{v_o} = -g_m (r_o \,||\, R_C).$$

$\because$ $r_o \simeq 100k$
$R_C = 1K.$

$A_{v_o} \simeq -g_m \cdot R_C$

Output Resistance Rout can be calculated by (3)
measuring resistance when $v_{sig} = 0$. This gives us only resistors R_C & r_o in parallel



$R_{out} = R_C \| r_o \approx R_C$

Voltage Gain with R_L Connected

$$A_v = A_{vo} \frac{R_L}{R_L + R_o}$$

Overall Voltage Gain — From Source to Load is

$$G_v = \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} \cdot \frac{v_o}{v_i}$$

$$= \left\{ \frac{(R_B \| r_\pi)}{(R_B \| r_\pi) + R_{sig}} \right\} \cdot \frac{g_m \left(r_o \| R_C \| R_L \right)}{1}$$

if $R_B \gg r_\pi$

$$= \frac{(r_\pi \cdot g_m)}{r_\pi + R_{sig}} \left(r_o \| R_C \| R_L \right)$$

$$= \frac{\beta}{r_\pi + R_{sig}} \left(r_o \| R_C \| R_L \right)$$

Thus Voltage Gain is highly dependent upon β if $R_{sig} \approx r_\pi$. If $R_{sig} \ll r_\pi$ then

$$G_v \simeq -g_m (R_C \| R_L \| r_o)$$

In other words, overall voltage gain is nearly the gain of proper amplifier, irresp. of β value & dependence on β reduces.

So it is important to have small R_{sig} as compared to r_π.

Let us calculate Short Circuit Current Gain A_{is}.

When R_L is short circuited, all of current source current $-g_m v_\pi$ flows through it as i_L.

$$i_{os} = -g_m v_\pi$$

$$i_i = \frac{v_\pi}{r_\pi} = \frac{v_i}{R_{in}}$$

$$\therefore A_{is} = \frac{i_{os}}{i_i} = \frac{-g_m v_\pi}{v_i / R_{in}} = -g_m R_{in}$$

So HIGH input impedence R_{in} gets us higher Current Gain. So R_B must be chosen as high as possible.

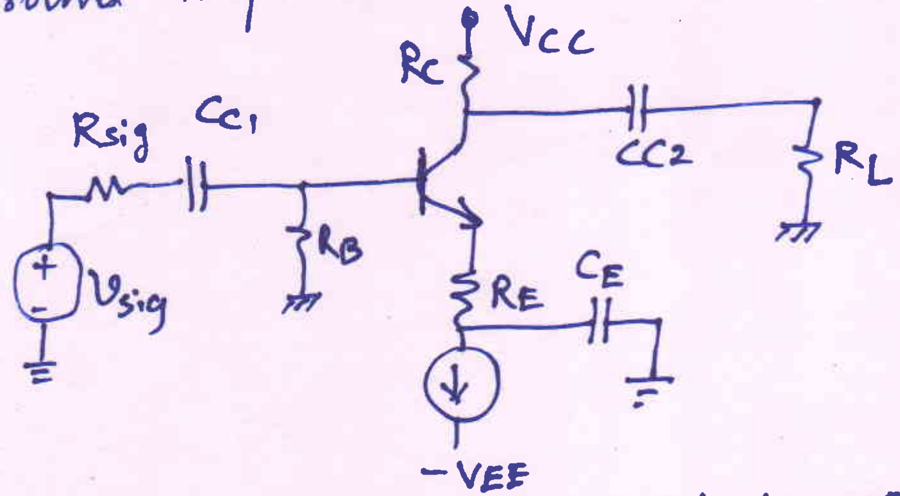
$$A_{is} = -g_m \frac{(R_B \| r_\pi)}{R_B + r_\pi}$$

For $R_B = 100K$, $R_C = 8K$, $\beta = 100$, $\alpha = 0.99$, $V_A = 100V$. $R_L = 5K$, $R_{sig} = 5K$

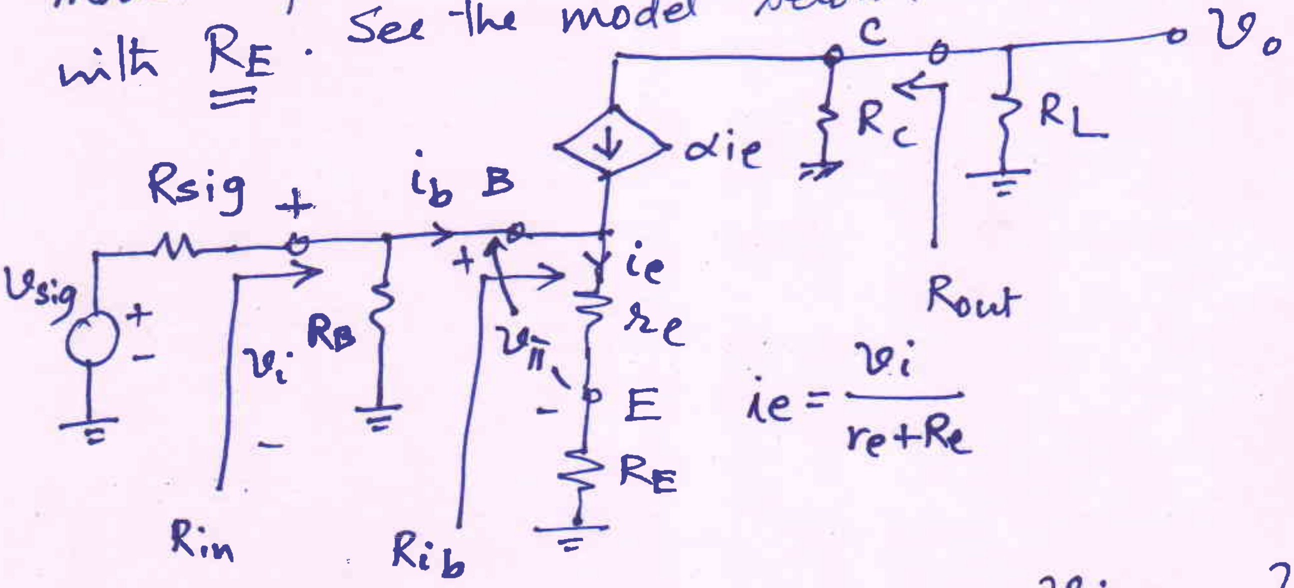
Calculate g_m, r_π, r_o, r_e, R_{in}, A_{vo} (without r_o), R_{out} (with and without r_o). Find Overall A_v.

COMMON EMITTER AMPLIFIER with Emitter Resistance

Adding a resistor R_E between emitter and ground improves characteristics considerably.



We will use T-model as it is more convinient. Its model ~~input~~ emitter resistance r_e will appear in series with R_E. See the model below:



$$i_e = \frac{v_i}{r_e + R_e}$$

$$R_{in} = R_B \,||\, R_{iB} \qquad R_{iB} = \frac{v_i}{i_b} = \frac{v_i}{i_e/(1+\beta)}$$

also, $i_e = \dfrac{v_i}{r_e + R_e}$ $\quad \therefore R_{iB} = (1+\beta)(r_e + R_E)$

Input Resistance looking into Base is β TIMES R_E.

Thus a $R_E = 100\,\Omega$ can add $100 \times 100 = 10k$ to R_{iB} if $\beta = 100$.

INPUT RESISTANCE INCREASED.

R_E effect gets multiplied when viewed from Base.
This is called "Resistance Reflection Rule". (6)

Improvement in R_{ib} by addition of R_E is

$$\frac{R_{ib}(\text{without } R_E)}{R_{ib}(\text{with } R_E)} = \frac{(\beta+1)(r_e+R_e)}{(\beta+1)(r_e} = 1+\frac{R_E}{r_e}$$
$$= (1+g_m R_E)$$

Determine Voltage Gain A_v, we calculate

$$v_o = -i_C(R_C \| R_L)$$
$$= -\alpha i_e (R_C \| R_L)$$

substituting $i_e = \dfrac{v_i}{r_e+R_e}$

$$v_o = -\alpha(R_C \| R_L)\cdot\frac{v_i}{(R_e+r_e)}$$

$$A_v = \frac{v_o}{v_i} = -\frac{\alpha(R_C \| R_L)}{r_e+R_E}$$

VOLTAGE GAIN IS RATIO OF TOTAL COLLECTOR RESISTANCE ($R_C \| R_L$) TO TOTAL EMITTER RESISTANCE (r_e+R_E) and independent of g_m or β.

This is a big advantage.

Open Circuit Voltage Gain (with $R_L=\infty$)

$$A_{vo} = -\frac{\alpha R_C}{r_e+R_e} = -g_m R_C\left(\frac{1}{1+g_m R_e}\right)$$

Note that for amplifier proper the A_{vo} is $-g_m R_C$

$\therefore$ Addition of series resistor R_E reduces Voltage Gain.

This is the cost we pay to enjoy two gains mentioned earlier:
$(1+g_m R_e)$ is the factor by input resistance is increased & by the same factor the Voltage Gain is decreased.

Output Resistance R_{out} can be ~~done~~ seen as

$R_{out} = R_C$ (when Current Source is open circuited) & $v_{sig} = 0$.

Short Circuit Current Gain A_{is} is

$$i_{os} = -\alpha i_e$$

$$i_i = v_i / R_{in}$$

$$\therefore \quad A_{is} = \frac{i_{os}}{i_i} = \frac{-\alpha i_e \cdot R_{in}}{v_i}.$$

$$\because \quad i_e = \frac{v_i}{r_e + R_e}$$

$$A_{is} = -\frac{\alpha R_{in}}{(r_e + R_e)} = \frac{-\alpha}{(r_e + R_e)} \left(R_B \| R_{ib} \right)$$

if $R_B >> R_{ib}$

$$= -\frac{\alpha \ (R_{ib})}{r_e + R_e} = -\frac{\alpha (1+\beta)(r_e + R_e)}{r_e + R_e} \approx -\beta$$

So current gain remains β even though (8)

~~voltagain~~ gain is reduced.

Overall Volta~~gain~~ Gain calculated as:

$$G_v = \frac{v_i}{v_{sig}} \cdot A_v = -\frac{R_{in}}{R_{sig}+R_{in}} \cdot \frac{\alpha\,(R_C \| R_L)}{(r_e + R_e)}$$

$\because R_{in} = R_B \| R_{ib}$ & neglecting R_B $\because R_B >> R_{ib}$

$\approx R_{ib}$

$$G_v = -\frac{\beta\,(R_C \| R_L)}{R_{sig} + (\beta+1)(r_e + R_e)}$$

The gain is lower because of a factor $(1+\beta) R_e$ in denominator.

$$\frac{v_\pi}{v_i} = \frac{r_e}{r_e + R_e} = \frac{1}{1 + g_m R_e}$$

Note: For the given v_i, we get small v_π therefore output voltage is less by factor $(1+g_m R_e)$.

Summary :

Adding a resistor R_E in series of Emitter causes:

1. Input Resistance R_{ib} increases by a factor of $(1+g_m R_e)$.
2. Voltage Gain reduces by factor $(1+g_m R_e)$
3. For the same non-linear distortion, the input signal v_i can be increased by a factor $(1+g_m R_e)$.
4. Overall Voltage Gain is less dependent on β variation or value.
5. Other benefits will be discussed later.