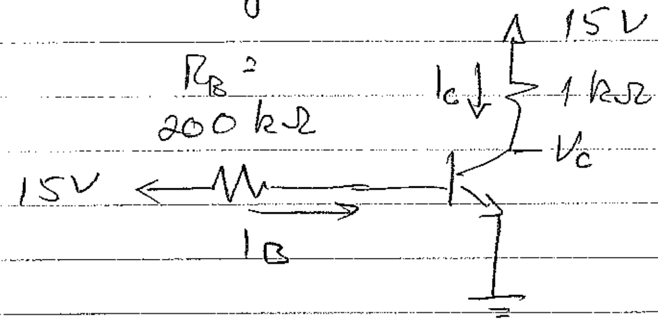
BIASING: VARIATION IN β

We need to account for potentially very large changes in β from one device to the next. Here's why:



GIVEN: β varies between 100 & 300.

Suppose we have designed for forward active mode with $\beta = 100$. We have

$$I_B = \frac{15-0.7}{200\,000} = 71.5\ \mu A$$

$$V_{CE} = V_C = 15 - 1000\beta I_B = 7.85\ V \quad \checkmark$$

Now suppose $\beta = 300$:

$$I_B = \frac{15-0.7}{200\,000} = 71.5\ \mu A$$

$$V_{CE} = V_C = 15 - 1000\beta I_B = -6.45\ V \quad ?!$$

So we are no longer in active mode.

The problem here is that I_B is fixed by R_B and V_{BB}. We need to re-think this design.

BIASING FOR DISCRETE CIRCUIT DESIGN

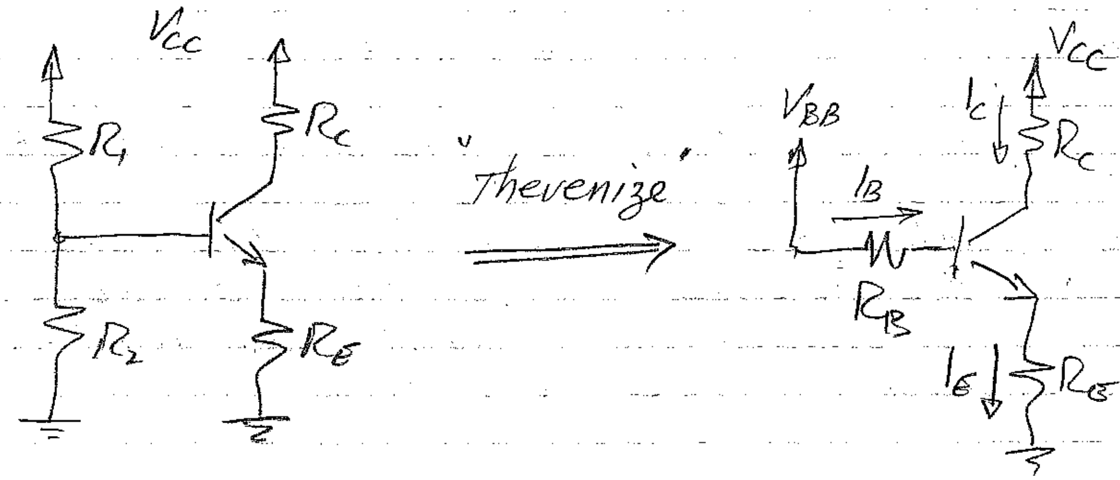
ISSUES:

- β varies dramatically among different discrete BJTs
- Change in temperature affects device operation
- Q-point must allow sufficient "room" for output voltage swing.

We need to consider these issues in designing bias circuits, especially the variation in β.

SINGLE POWER SUPPLY

Four-Resistor Bias circuit:



$$R_B = R_1 \parallel R_2 \qquad V_{BB} = V_{CC}\frac{R_2}{R_1+R_2}$$

Now we have

$$-V_{BB} + R_B I_B + 0.7 + I_E R_E = 0$$

$$I_E = (\beta+1) I_B$$

$$\Rightarrow \qquad I_B = \frac{V_{BB} - 0.7}{R_B + (\beta+1)R_E}$$

Some numbers:

$R_1 = 10\ k\Omega$, $R_2 = 5\ k\Omega$ $\Rightarrow$ $R_B = 3.33\ k\Omega$

$V_{CC} = 15\ V$ $\Rightarrow$ $V_{BB} = 5\ V$

$R_C = R_E = 1000\ \Omega$

Then for $\beta = 100$, $I_B = 41.2\ \mu A$, $I_C = 4.12\ mA$

$\beta = 300$, $I_B = 14.1\ \mu A$, $I_C = 4.24\ mA$

So I_C changes by only 3%. The reason is that an increase in β causes a decrease in I_B, so a change in β is compensated by a change in base current.

Note: We do not mean to imply here that β for a particular BJT can change. What we mean is that different BJTs can have very different β, even though they are nominally the same device.

Another way to look at the circuit is this:

$$-V_{BB} + I_B R_B + 0.7 + I_E R_E = 0$$

$$I_B = I_E/(\beta+1)$$

$$\Rightarrow \qquad I_E = \frac{V_{BB} - 0.7}{R_E + R_B/(\beta+1)}$$

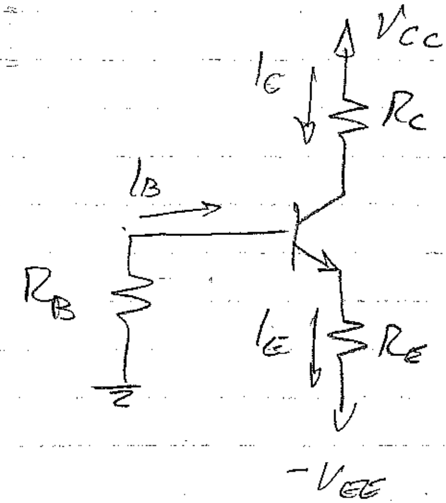
Now I_E will be relatively insensitive to β if

$$R_E \gg R_B/(\beta+1)$$

Also, we want $V_{BB} \gg 0.7\ V$

These conditions will ensure "stability".

DOUBLE POWER SUPPLY

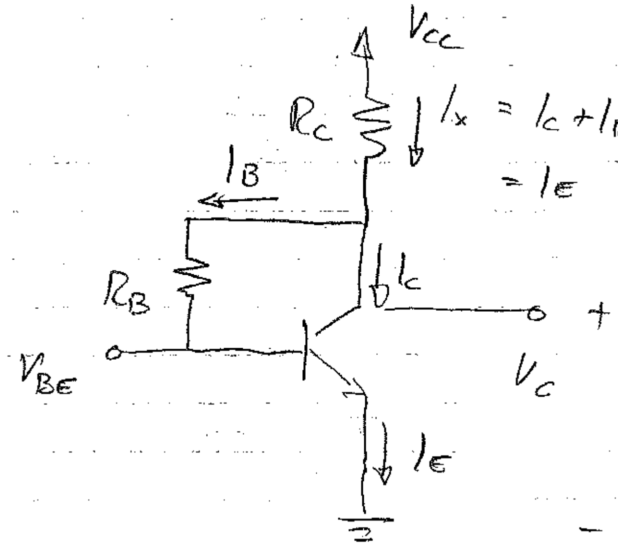


We have an equation similar to the previous one:

$$I_E = \frac{V_{EE} - 0.7}{R_E + R_B/(\beta+1)}$$

so the same stability conditions hold.

... and a couple of others...



Here,

$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_B/(\beta+1)}$$

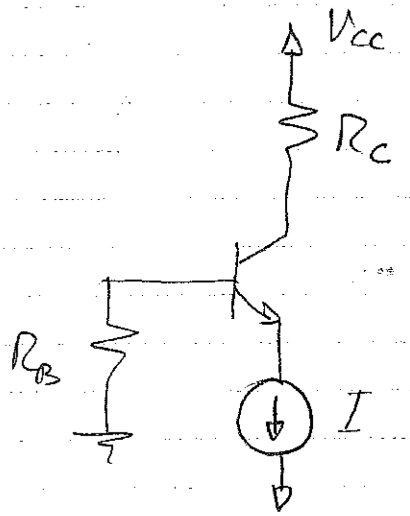
so now we want $R_C >> R_B/(\beta+1)$

Collector voltage "swing" is

$$V_{CB} = I_B R_B = \frac{I_E R_B}{(\beta+1)}$$

so R_B determines this.

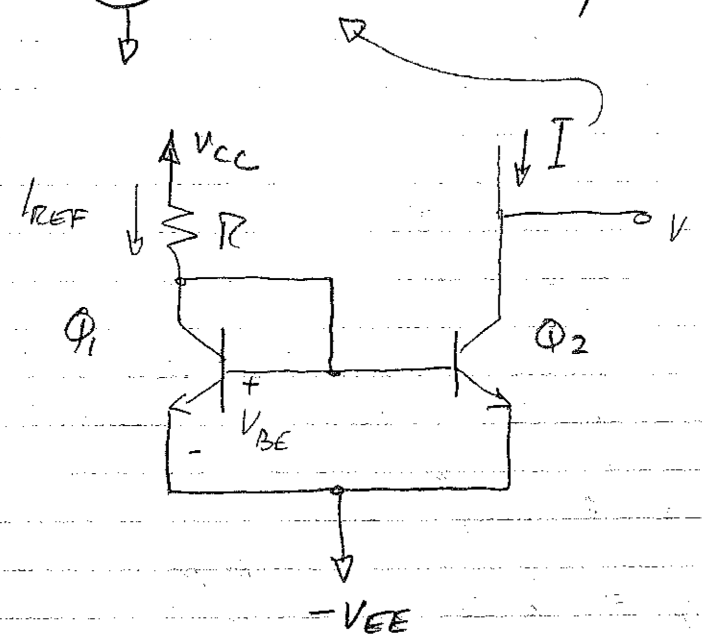
... current- source biasing...



Here, I_E does not depend on β or R_B.

But where do we get the current source??

Try this...



If I_B is negligible for Q_1, Q_2, we have

$$I_{REF} \cong \frac{1}{R}\left(V_{CC} + V_{EE} - V_{BE}\right)$$

If $V_{BE\,Q1} = V_{BE\,Q2}$ (matched BJTS), we must have

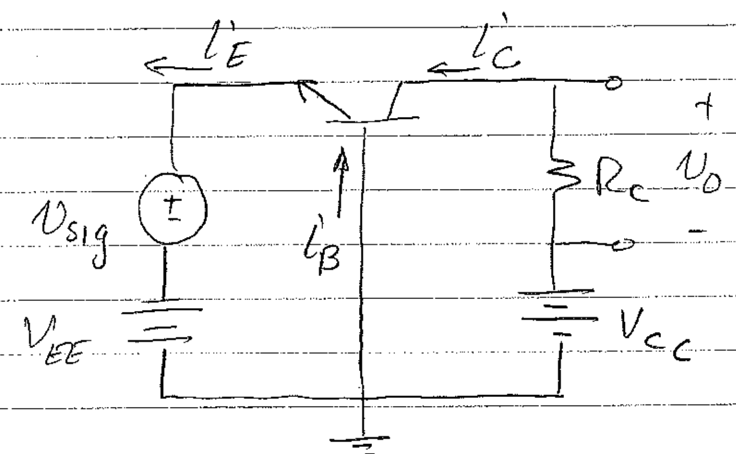
$$I = I_{REF}$$

This is a CURRENT MIRROR.

BJT AMPLIFIER CONFIGURATIONS.

On the following pages, we summarize the basic characteristics of single-stage BJT amps. First, we show simple diagrams indicating input/output parameters and gains. More complete analysis follows.

COMMON BASE



ac gains:

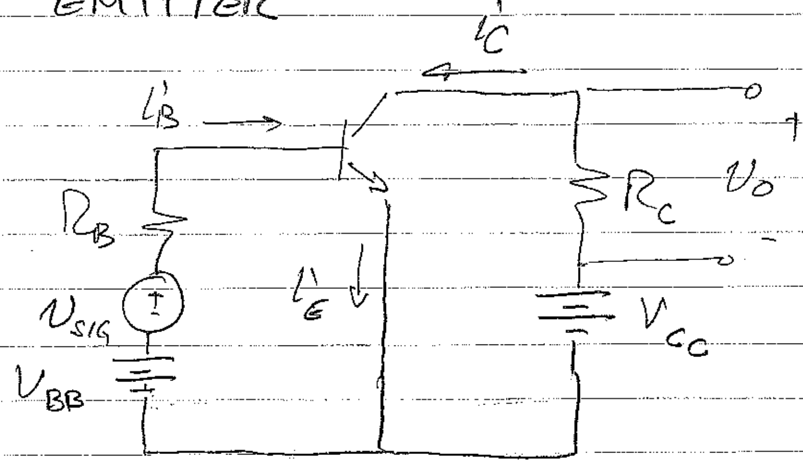
$$A_i = \frac{i_c}{i_e}$$

$$A_v = \frac{v_o}{v_{sig}}$$

Since $i_c \simeq i_E$, $A_i \lesssim 1$.

Since $i_c R_c$ can be large, $A_v > 1$

COMMON EMITTER



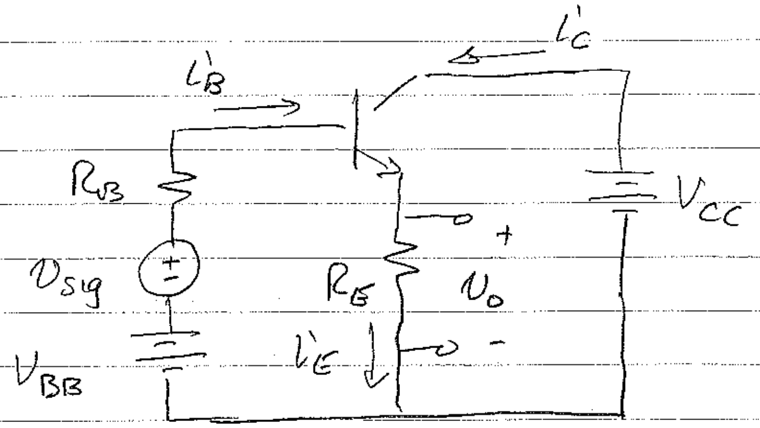
$A_i = \frac{i_o}{i_b}$

$A_v = \frac{v_o}{v_{sig}}$

$i_c > i_B \Rightarrow A_i > 1$

Since $i_c R_c$ can be large, $A_v > 1$.

COMMON COLLECTOR



$A_i = \frac{i_e}{i_b}$

$A_v = \frac{v_o}{v_{sig}}$

$v_B \simeq v_E$ except for B-E voltage drop, so

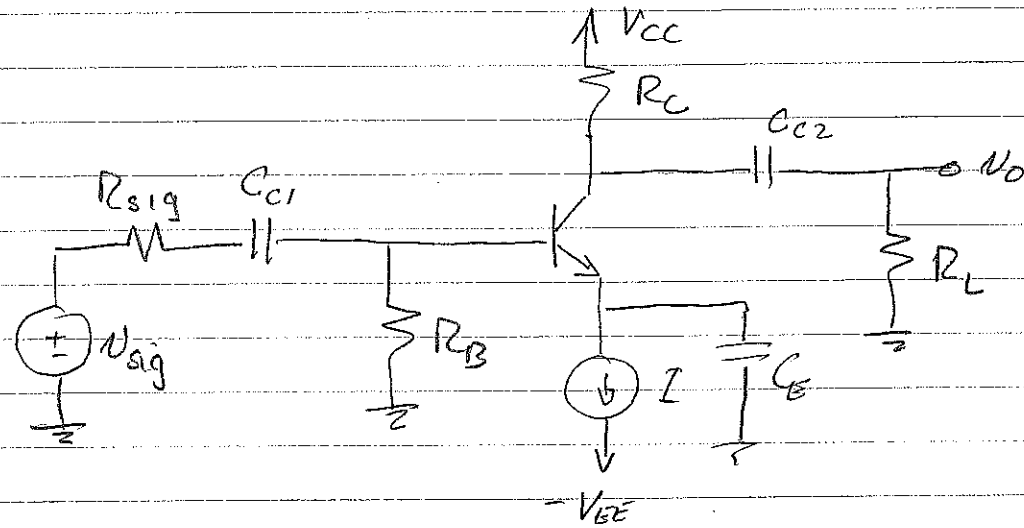
$A_v \simeq 1$.

Since $i_E > i_B$, $A_i > 1$.

SINGLE STAGE BJT AMPLIFIER CONFIGURATIONS

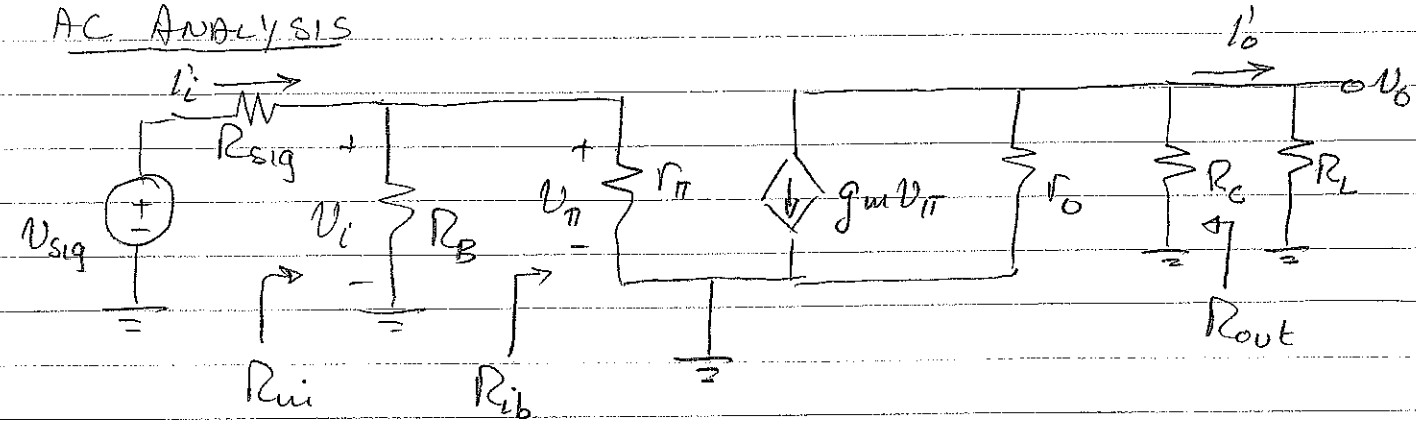
Following Sedra & Smith Section 5.7, we review basic properties of single stage BJT amplifiers. Here we only summarize; Sedra & Smith provide more detail.

COMMON EMITTER (FIG 5.60)



The current source biasing is a convenience, and simplifies the ac analysis.

AC ANALYSIS



A more complete analysis of the CE amplifier circuit is found in the text. Here we summarize important aspects.

Common-Emitter Analysis

- Input resistance $R_{ib} = r_\pi$ (moderately large)
- $A_v \equiv v_o/v_i = -g_m(r_o \| R_C \| R_L)$
- $G_v \equiv v_o/v_{sig}$ If R_B is large, then

$$G_v = v_o/v_{sig} = -\beta(R_C \| R_L \| r_o)/(r_\pi + R_{sig})$$

Note that $\beta = g_m r_\pi$. So for $R_{sig} \gg r_\pi$, G_v is β-dependent. But for $R_{sig} \ll r_\pi$,

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

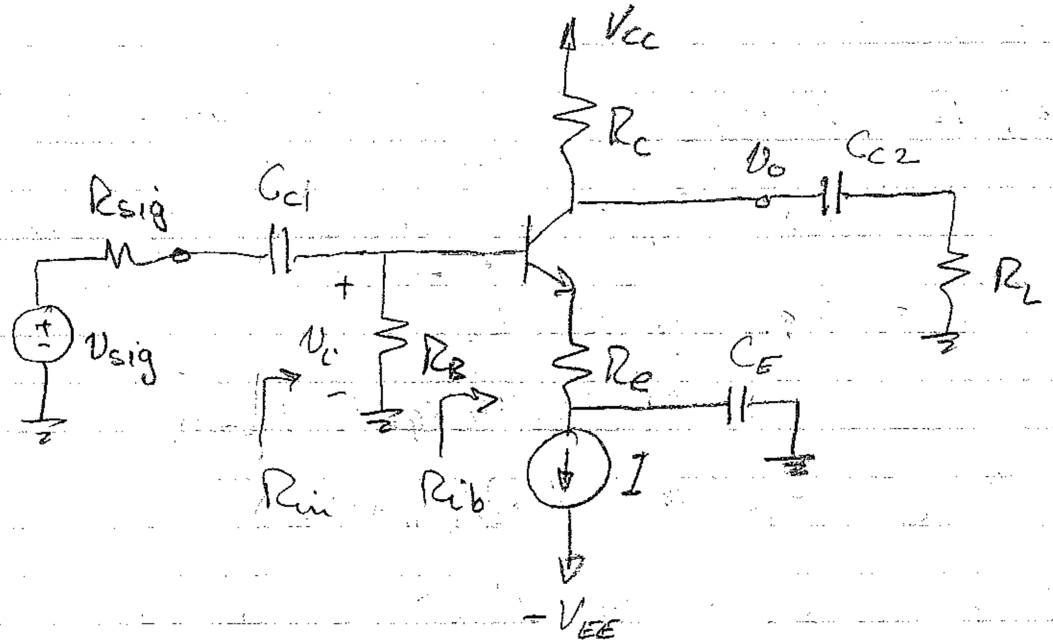
- $A_{is} \equiv \frac{i_{os}}{i_i} = -g_m R_{in} \simeq -\beta$ (short-circuit gain)

with $R_{in} = R_B \| r_\pi$. For $R_B \gg r_\pi$, $A_{is} = -g_m r_\pi = -\beta$.

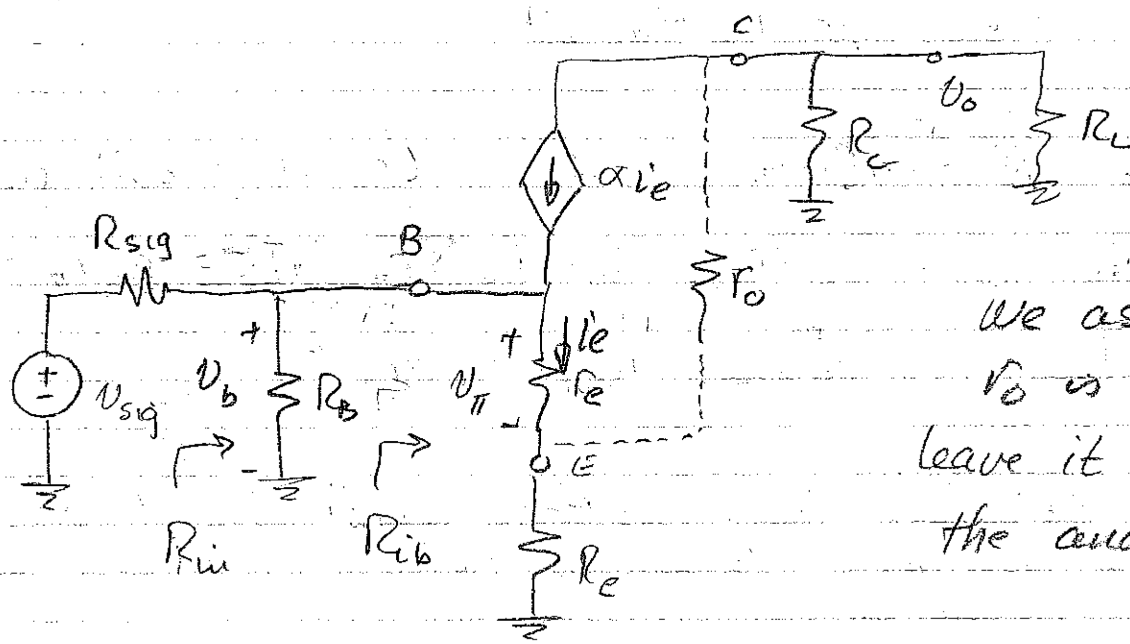
- output resistance $R_{out} = R_C \| r_o$

So the CE has large voltage and current gain, moderate R_i and large R_o (which is a bad thing for a voltage amp).

COMMON EMITTER with R_E (FIG. 5.61)



We use a T-Model here:



We assume r_o is large and leave it out of the analysis.

Analysis:

- Input resistance $R_{ib} = (\beta+1)(r_e + R_e)$

Multiplication by $(\beta+1)$: "resistance reflection rule". This represents a large increase in R_i.

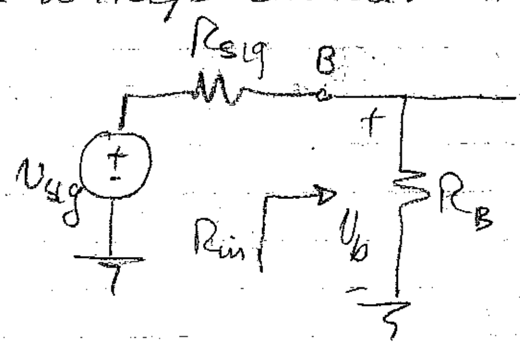
- Voltage gain

$$G_V \equiv v_o / v_{sig} = \frac{-\alpha i_e R_C // R_L}{\frac{i_e}{\beta+1} R_s + i_e(r_e + R_e)} = \frac{-\beta R_C // R_L}{R_s + (\beta+1)(r_e + R_e)}$$

Partial gain "base to collector":

$$\frac{v_o}{v_b} = -\frac{\alpha R_C}{r_e + R_e} \simeq -\frac{R_C}{r_e + R_e} \quad (\text{if } R_L \to \infty)$$

Here's a trick: If we have R_{in} we can use it in a voltage divider to find v_b / v_s:



$$\Rightarrow v_b = v_{sig} \frac{R_{in}}{R_{in} + R_{sig}}$$

and $R_{in} = R_B // R_{in}$

- Increased signal amplitude will not cause saturation:

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

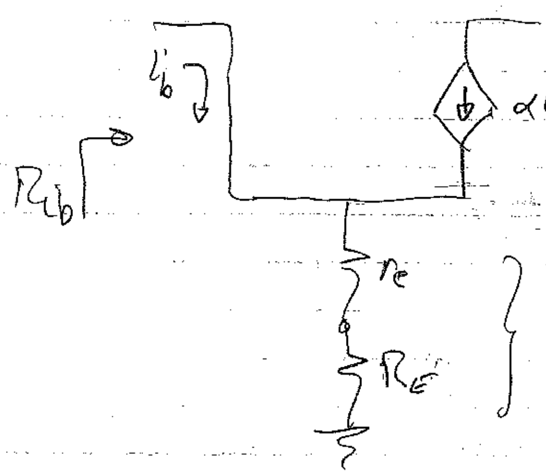
so the base voltage, which was v_π in the

CE with no R_e, is now $v_\pi(1+g_m R_e)$, which is considerably larger.

- output resistance $R_{out} \doteq R_c$
- current gain $A_i = \frac{i_o}{i_b} = -\beta$

Summary: Voltage gain has been reduced, but is less sensitive to variations in β. However, reduced voltage gain has been traded for increased R_{ib}, increased input signal, and better hi f performance (later).

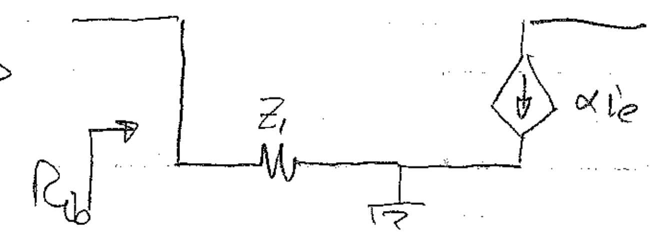
NOTE: The "resistance reflection rule" is nothing more than application of Miller's theorem:



$Z = r_e + R_E$

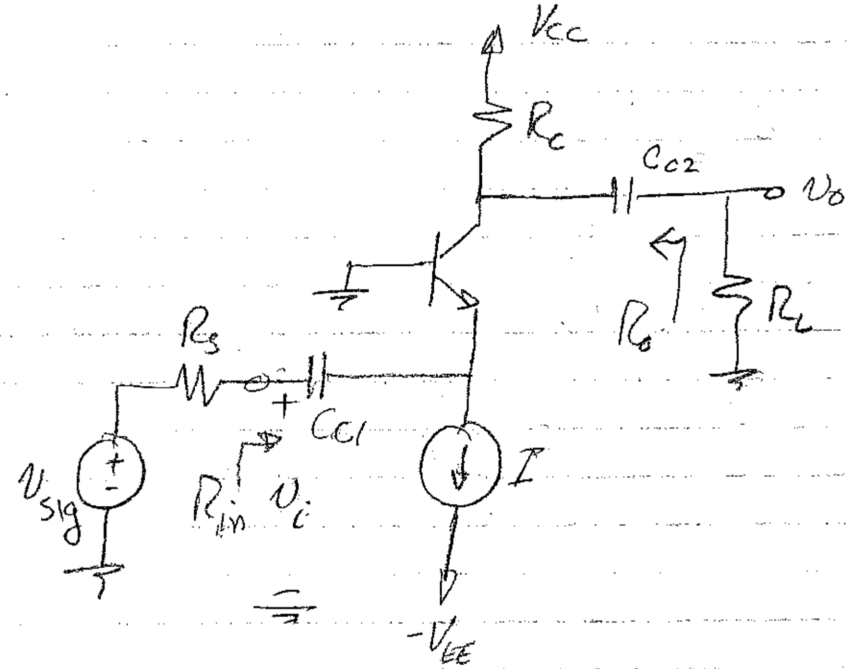
$$J = \frac{\alpha i_e}{i_b} = \frac{\beta}{\beta+1}\,\frac{i_e}{i_b} = \beta$$

$\Rightarrow$

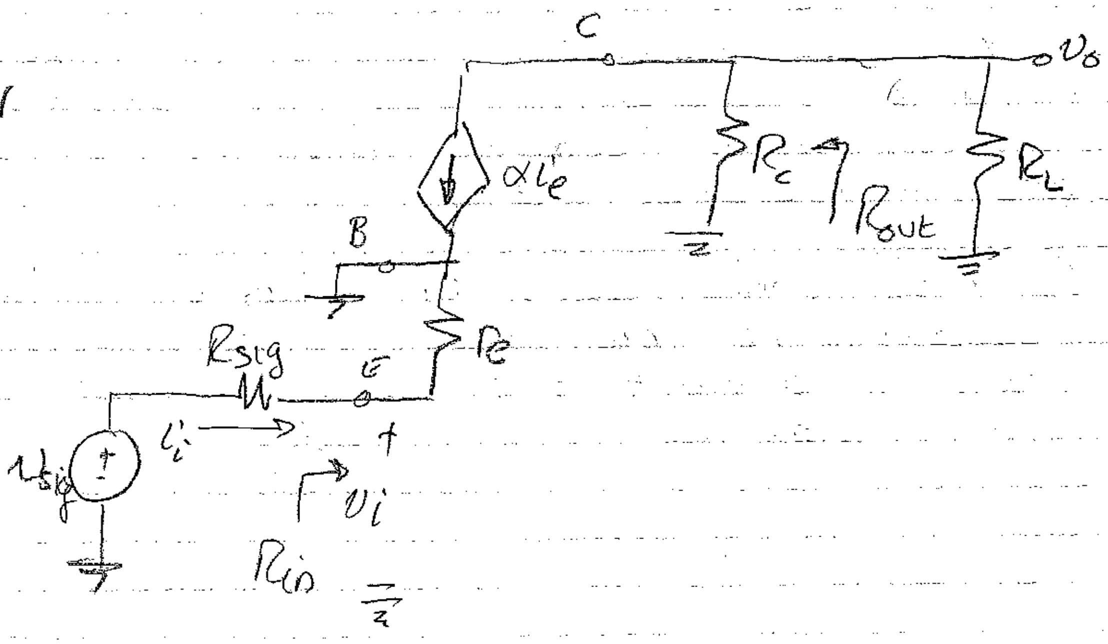


$$Z_1 = (J+1)Z$$
$$= (\beta+1)[r_e + R_E]$$

COMMON BASE (FIG. 5.62)



T-Model



- Input resistance $R_{in} = r_e$
- Voltage gain is non-inverting:

$$A_v \equiv \frac{v_o}{v_{sig}} = \frac{\alpha R_c}{R_{sig} + r_e}$$

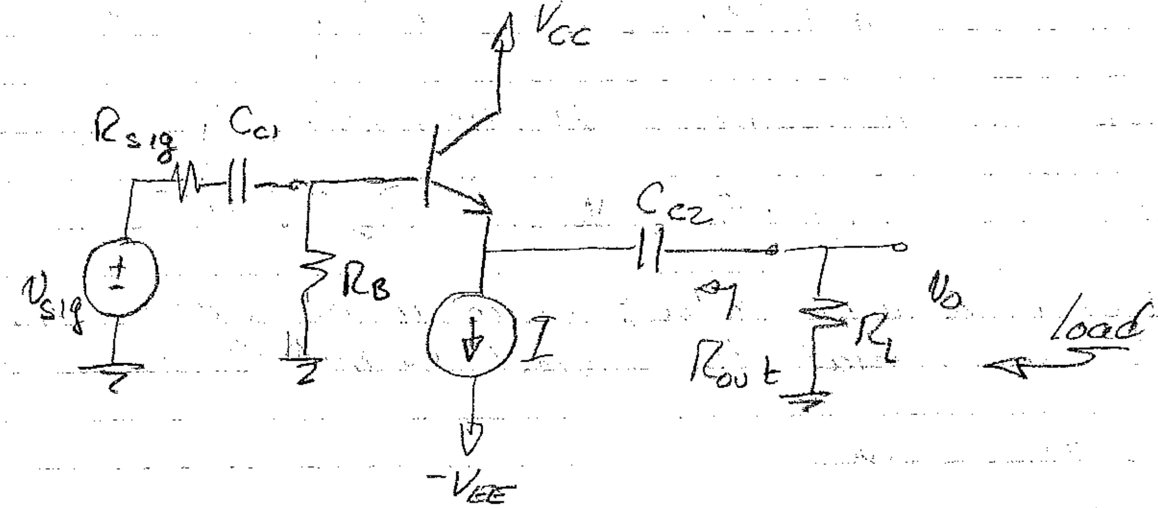
Now, r_e is small, so A_v depends critically on R_{sig}.

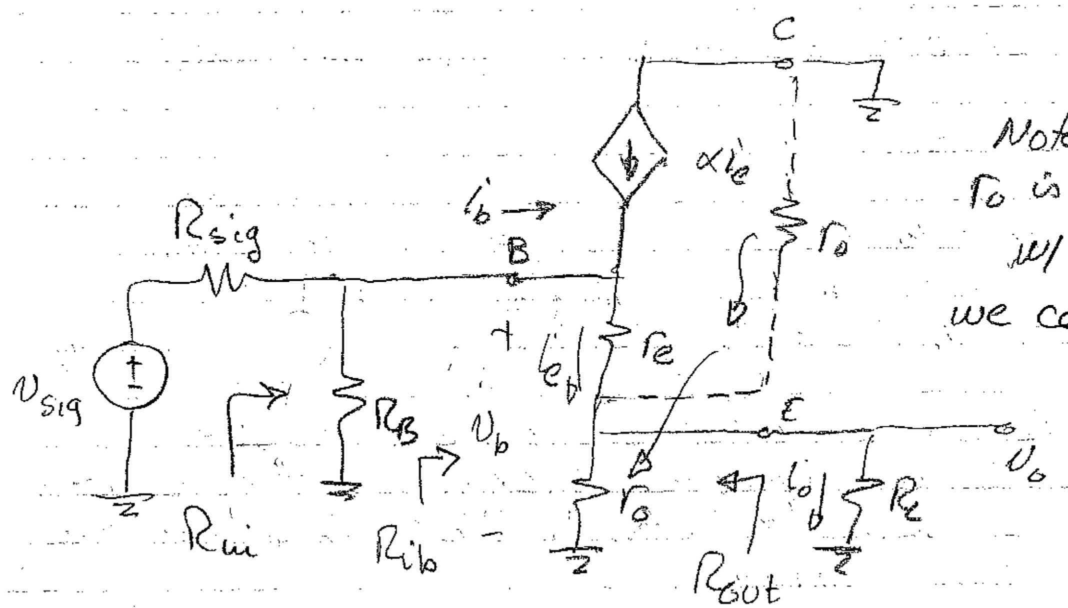
- Current gain is small: $A_{is} \equiv \frac{i_o}{i_i} = \alpha$.
- Output impedance is $R_{out} = R_c$ (large)

So this is not a good voltage amp because R_i is small. However, it is a good unity-gain current amp because R_{out} is large. Also has good f response (later).

Current Buffer: The CB amp accepts a current at low input resistance and delivers almost the same output current to a high resistance load.

COMMON COLLECTOR (FIG. 5.63)





Note that r_o is in parallel w/ R_L, so we can move it.

This looks like the CE amplifier with $R_C = 0$ and

$$R_e \rightarrow r_o \| R_L$$

so we can take some results from that case.

- Input resistance

$$R_{ib} = (\beta+1)[r_e + r_o \| R_L]$$

$$\frac{v_o}{v_s} = \frac{v_o}{v_b}\frac{v_b}{v_s}$$

$$\frac{v_b}{v_s} = \frac{(\beta+1)(r_e + r_o\|R_L)}{R_s + (\beta+1)(r_e + r_o\|R_L)}$$

$$\frac{v_o}{v_b} = \frac{r_o\|R_L}{r_e + r_o\|R_L}$$

from the resistance reflection rule.

if $r_e \ll R_L \ll r_o$, then $R_{ib} \simeq (\beta+1)R_L$

This is a large value; since it depends on R_L, it means that the signal is not "loaded" down.

- voltage gain

$$G_v \equiv \frac{v_o}{v_{sig}} = \frac{(\beta+1)(r_o\|R_L)}{R_{sig} + (\beta+1)[r_e + r_o\|R_L]} = \frac{(r_o\|R_L)}{\frac{R_{sig}}{\beta+1} + r_e + (r_o\|R_L)}$$

This is less than 1.

- output resistance

inverse resistance reflection

$$R_{out} = r_o \| [r_e + \frac{R_{sig}}{\beta+1}]$$

This is r_o in parallel with r_e plus the source resistance reflected back into the emitter (inverse resistance-reflection). Note r_e & $R_s/(\beta+1)$ are small, so R_o is small.

- current gain

$$i_b = (1-\alpha)i_e = \frac{i_e}{\beta+1}$$

$$A_i \equiv \frac{i_o}{i_b} = (\beta+1)\frac{r_o}{r_o+R_L}$$

So we have high R_i, low R_o, $A_v \lesssim 1$ and large current gain. We can connect a high resistance source to a low resistance load.

Emitter "follows" input at base $\rightarrow$ EMITTER FOLLOWER