Common emitter

\[ V_{\text{out}} = V_{\text{ce}} - R_c \cdot I_c = V_{\text{ce}} - R_c \cdot I_s \frac{V_{\text{be}}}{V_{\text{il}}}. \]

starts flowing when \( V_{\text{be}} > 0.5 \text{ V} \)

\[ V_{\text{ce}} = V_{\text{ce}}^{\text{sat}} \approx 0.2 \text{ V} \]

AC voltage gain near bias point \( V_{\text{b}}^Q, V_{\text{ce}}^Q \)

\[ A_v = \frac{\Delta V_{\text{out}}}{\Delta V_{\text{in}}} = \frac{V_{\text{ce}}}{V_{\text{b}}} = -R_c \cdot I_c \left( \frac{V_{\text{b}}^Q, V_{\text{ce}}^Q}{V_{\text{il}}} \right) < 0. \]
BJT bias

Voltage gain is defined by $I_C^0$, i.e by bias.

In example we stabilized DC value of $V_{BE}$ by using $V_{BB}$

$$V_{BE} \approx \frac{R_1}{R_1 + R_2} \cdot V_{CC}$$

This type of bias (stable $V_{BE}$) has problem.

Consider example.

$$V_{CC} = 10\,V$$

$$R_1 + R_2 \approx 100\,\Omega \quad \& \quad n = 7 \cdot R_0$$

Now assume that $R_1$ is not 7k but 6.9k due to normal value variation among resistors.

$$I_B \propto \exp \left( \frac{V_{BE}}{V_{TH}} \right)$$

$$I_B' = I_B \cdot \exp \left( \frac{V_{BE}' - V_{BE}}{V_{TH}} \right) = I_B \cdot \exp \left( -\frac{0.01}{0.025} \right)$$

$$\frac{\Delta I_B}{I_B} > 30\%, \quad I_C = \beta \cdot I_B, \quad \frac{\Delta I_C}{I_C} > 30\%$$

BAD BIAS: < 2 % variation of resistance results into > 30 % variation of gain
BJT bias

*Let’s stabilize $I_B$ rather than $V_{BE}$.*

$$I_B = \frac{V_{cc} - 0.7V}{\beta_R}$$

$\beta_R = 1 \text{M} \Omega \& V_{cc} = 10V \rightarrow I_B \approx 9.3 \mu A$

For $\beta_R = 0.98 \text{M} \Omega \rightarrow I_B \approx 9.5 \mu A$

However, we care about $I_C^Q$, not $I_B^Q$ and here:

$$I_C^Q = \beta \cdot I_B^Q$$

It is rather normal to have variation of common emitter current gain $\beta$ of about 50% of its value.

*BAD BIAS: relies on value of $\beta$.*

We need better than that – we need feedback to stabilize our circuit bias!
BJT bias

Stabilized $I_B$ with feedback

$J_B = \exp \left( \frac{V_{BE}}{V_{TH}} \right) ; \Delta V_{BE} \to \Delta J_B$

$J_C = \beta \cdot J_B$ & $\Delta J_C = \beta \cdot \Delta J_B$

What if we use $\Delta J_C$ to adjust $V_{BE}$?

Means: $I_C \uparrow \to V_{BE} \uparrow$ to keep $I_C \downarrow I = \Delta I = 0$ in turn!

Sailston!

Once $J_C \approx J_E$ hence when $I_C \uparrow$ then $V_E \approx I_C \cdot R_E \uparrow$ hence $V_{BE} = V_B - V_E \downarrow$ when $I_B \downarrow.$ & hence $I_C \uparrow$, i.e. stabilized!
Here we neglected base current assuming that it is much smaller than currents through $R_1$ and $R_2$. 

**BJT bias**

*Stabilized $V_B$ with feedback*
BJT bias

Exact analysis

\[ V_{eq} = \frac{R_1}{R_1 + R_2} \cdot V_{cc} \]
\[ V_{eq} = \frac{R_1 \cdot R_2}{R_1 + R_2} \]

\[ I_e = \frac{I_C}{\alpha} = \frac{\beta I_B}{\alpha} = (1 + \beta) I_B \]
\[ \alpha = \frac{\beta}{1 + \beta} \]

\[ V_{eq} = I_B \cdot R_{eq} + V_{BE} + R_E (1 + \beta) I_B \]

\[ I_B = \frac{V_{eq} - V_{BE}}{R_{eq} + R_E (1 + \beta)} \]
and

\[ I_C = \beta \cdot I_B \]

\[ I_C = \frac{V_{eq} - V_{BE}}{R_E} \cdot \frac{1}{1 + \frac{1}{\beta} \left( 1 + \frac{R_{eq}}{R_E} \right)} \leq \frac{V_{eq} - 0.7 V}{R_E} \]

for \( \beta \gg 1 + \frac{R_{eq}}{R_E} \)
BJT bias

*Feedback resistor from collector*

\[ V_{CC} = I_E \cdot R_C + I_B \cdot R_S + V_{BE} \]

In FA mode:  \[ I_E = (\beta + 1) I_B \]

\[ I_E = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_S}{\beta+1}} = \frac{V_{CC} - V_{BE}}{R_C} \cdot \frac{1}{1 + \frac{R_S}{V_S}} \]

Limited output swing
BJT bias

Bipolar power supply

* \( R_B \) cannot be too small not to short circuit input \( V_{in} \) to ground.

Case 1: \( R_B = 0 \) and \( V_{EE} = 5 \) V. Design \( R_E \) to have \( I_C = 1 \) mA.

\[
R_E = \frac{V_{EE} - V_{BE}}{\beta R_B + R_E (\beta + 1)}
\]

\[
I_C = \beta I_B = \frac{V_{EE} - V_{BE}}{R_E} \cdot \frac{1}{1 + \frac{\beta R_B}{R_E}}
\]

\[
I_B = \frac{V_{EE} - V_{BE}}{R_B + R_E (\beta + 1)}
\]

\[
R_E \geq 4.3 k\Omega
\]

Case 2: \( R_B < \beta R_E = 430k \) for \( R_E = 4.3k \) and \( \beta = 100 \).

Let's use \( R_B = 40 \mu \Omega \) then for \( I_C = 1 \) mA; \( I_R = 10 \mu \)A

\[
V_B = -10 \mu \text{A} \cdot 40 \mu \Omega = -0.4 \text{ V}
\]

\[
I_E = \frac{5V - 0.7V - 0.14V}{4.3k\Omega} = 0.9 \mu \text{A}
\]
BJT bias

*Current source*

One can use large $R_B$ since condition is always satisfied for current source

As long as BJT in FA mode

* Need to have bypass capacitor to ground emitter for signal, otherwise no gain.