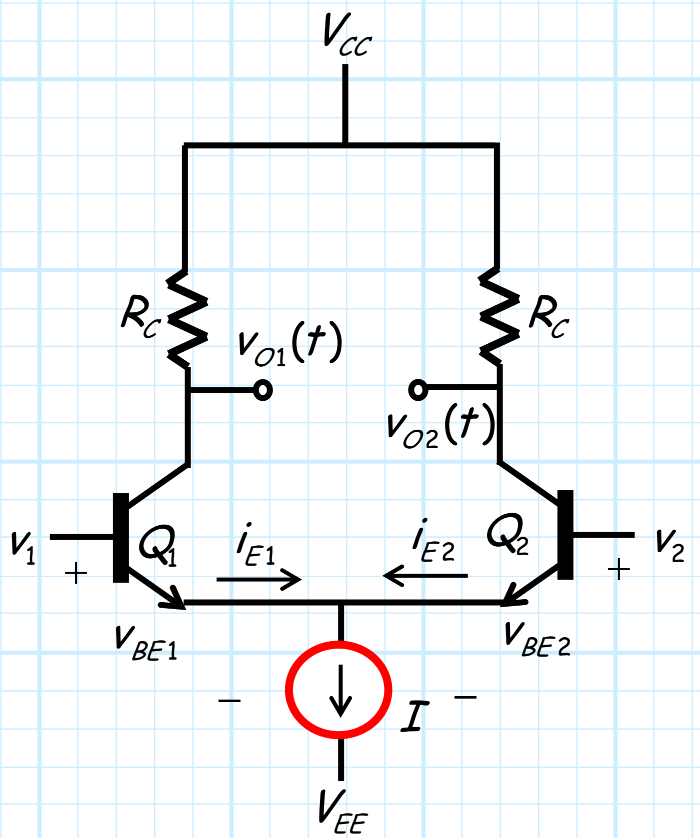
Large-Signal Operation of BJT Differential Pair

Consider the **BJT differential pair**:



Note:

$$v_{E1} = v_{E2} \doteq v_E$$

and:

$$i_{E1} + i_{E2} = I$$

Also, we know that:

$$i_{E1} = \frac{I_s}{\alpha}\, e^{v_{BE1}/V_T} \qquad\qquad i_{E2} = \frac{I_s}{\alpha}\, e^{v_{BE2}/V_T}$$

where

$$v_{BE1} = v_1 - v_E \qquad \text{and} \qquad v_{BE2} = v_2 - v_E$$

Therefore, the **emitter currents** can be written in terms of the **base voltages** as:

$$i_{E1} = \left(\frac{I_s}{\alpha}\, e^{-v_E/V_T}\right) e^{v_1/V_T} \qquad\qquad i_{E2} = \left(\frac{I_s}{\alpha}\, e^{-v_E/V_T}\right) e^{v_2/V_T} \qquad \textbf{(A)}$$

Of course, we know that $I = i_{E1} + i_{E2}$, thus:

$$I = \left(\frac{I_s}{\alpha}\, e^{-v_E/V_T}\right)\left(e^{v_1/V_T} + e^{v_2/V_T}\right)$$

And **rearranging** we find:

$$\frac{I_s}{\alpha}\, e^{-v_E/V_T} = \frac{I}{e^{v_1/V_T} + e^{v_2/V_T}} \qquad \textbf{(B)}$$

Now, we can insert equation **(B)** into equation **(A)** and find:

$$i_{E1} = \frac{I\, e^{v_1/V_T}}{e^{v_1/V_T} + e^{v_2/V_T}} = \frac{I}{1 + e^{-(v_1 - v_2)/V_T}}$$

as well as:

$$i_{E2} = \frac{I\, e^{v_2/V_T}}{e^{v_1/V_T} + e^{v_2/V_T}} = \frac{I}{1 + e^{+(v_1 - v_2)/V_T}}$$

Now, let's define a **differential voltage**:

$$v_D = v_1 - v_2$$

We can now (finally) write the emitter currents in terms of this differential voltage v_D **only**!

$$i_{E1} = \frac{I}{1 + e^{-v_D/V_T}}$$

$$i_{E2} = \frac{I}{1 + e^{+v_D/V_T}}$$

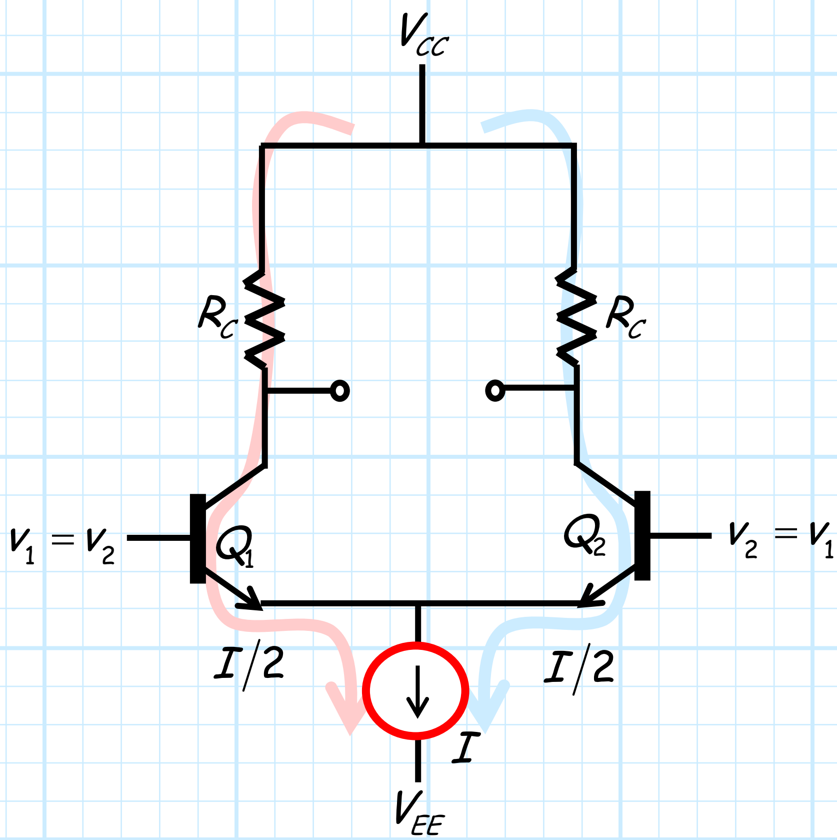
In other words, the emitter current in a differential pair is **independent** of the **common-mode** voltage $v_{cm} = (v_1 + v_2)/2$!

Now, let's examine this result more closely. We will consider **3 cases**, $v_D = 0$, $v_D \gg V_T$, and $v_D \ll -V_T$.

$v_D = 0$

When $v_1 = v_2$ (i.e., $v_D = 0$), we find that the **emitter currents are equal**, with each taking **half** of the available current I:

$$e^{v_D/V_T} = e^{-v_D/V_T} = 1 \,, \qquad \therefore \quad i_{E1} = i_{E2} = \frac{I}{1+1} = \frac{I}{2} \;.$$



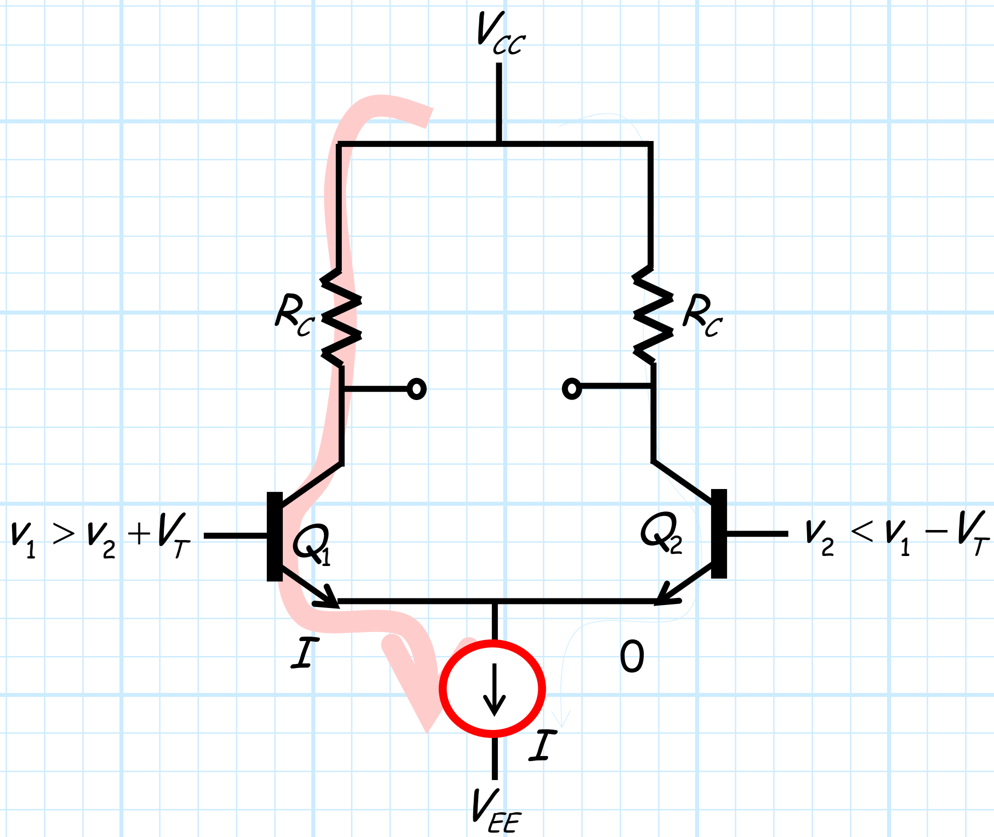
$v_D \gg V_T$

When $v_D \gg V_T$ (i.e., $v_D \gg 25mV$), we find that the emitter current i_{E1} takes **all** the available current, leaving emitter current i_{E2} with **none**:

$$e^{-v_D/V_T} \approx 0 \,, \qquad \therefore \qquad i_{E1} = \frac{I}{1+0} = I$$

and

$$e^{v_D/V_T} \approx \infty \,, \qquad \therefore \qquad i_{E2} = \frac{I}{1+\infty} = 0$$



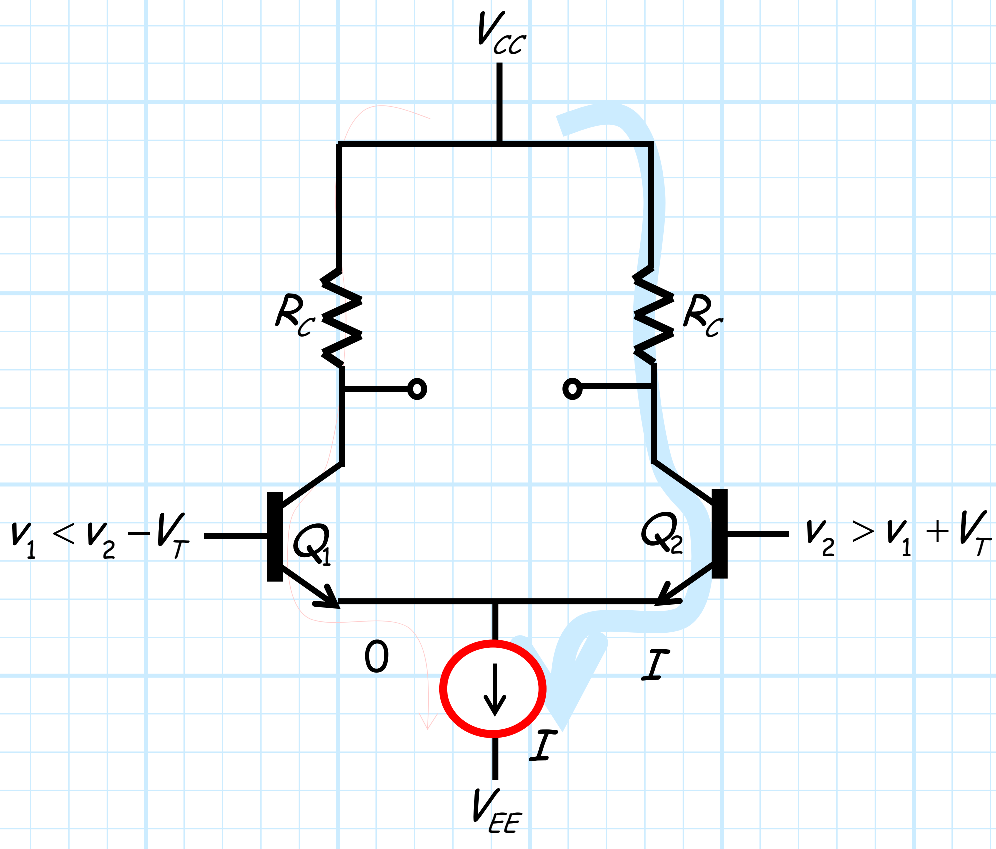
$v_D \ll -V_T$

When $v_D \ll -V_T$ (i.e., $v_D \ll -25mV$), we find that the emitter current i_{E2} takes **all** the available current, leaving emitter current i_{E1} with **none**:

$$e^{-v_D/V_T} \approx \infty \, , \qquad \therefore \qquad i_{E1} = \frac{I}{1+\infty} = 0$$

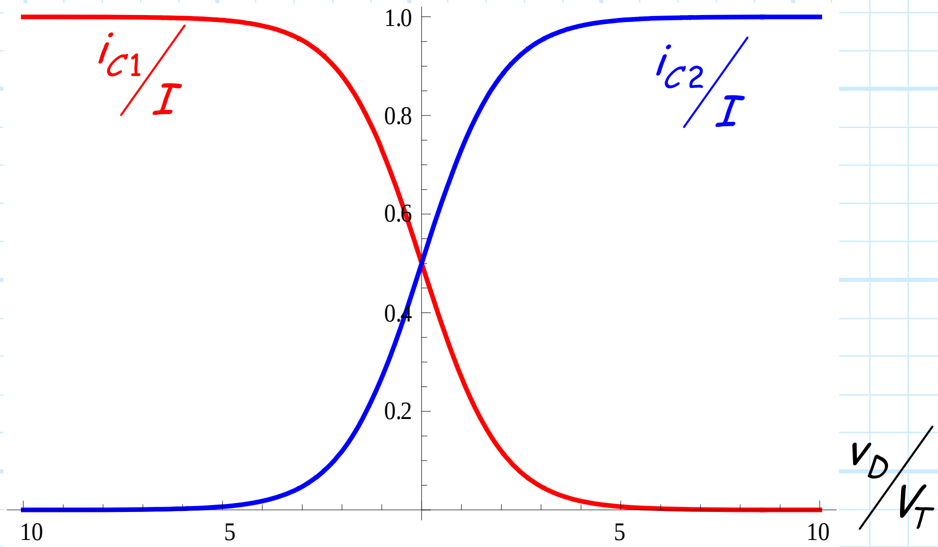
and

$$e^{v_D/V_T} \approx 0 \, , \qquad \therefore \qquad i_{E2} = \frac{I}{1+0} = I$$



Recall that for BJTs in the active mode, the **collector** current is related to the emitter current by $i_C = \alpha\, i_E$.

Thus, we can **plot** the collector currents i_{C1} and i_{C2} as a function of differential voltage v_D:



Note for $|v_D| <\approx 2V_T$:

$$\left|\frac{d\, i_C}{d\, v_D}\right| \gg 1$$

Q: *Is this important? What does this mean?*

A: