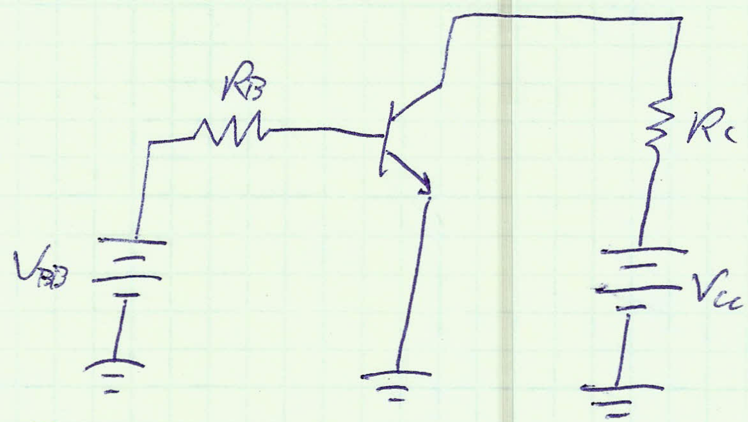
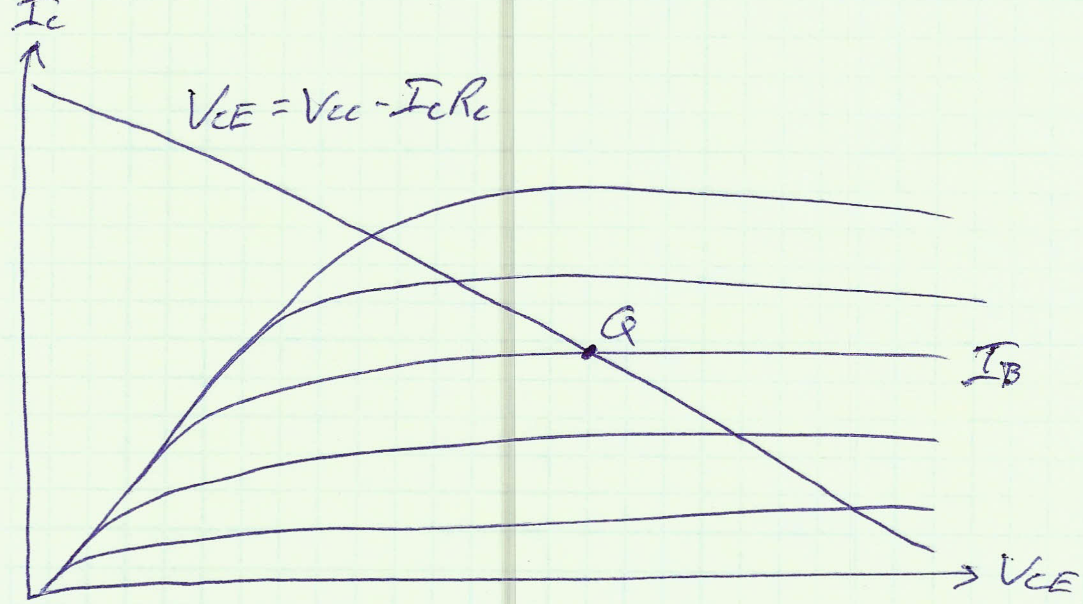
Amplifiers

- Basic component of analog circuits - including opAmps (switches are basic component of digital circuits)



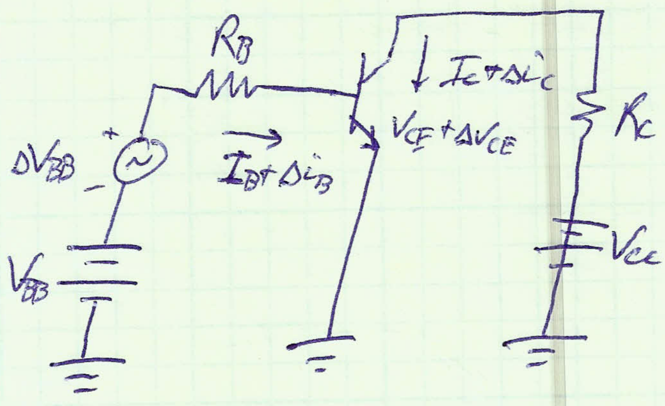


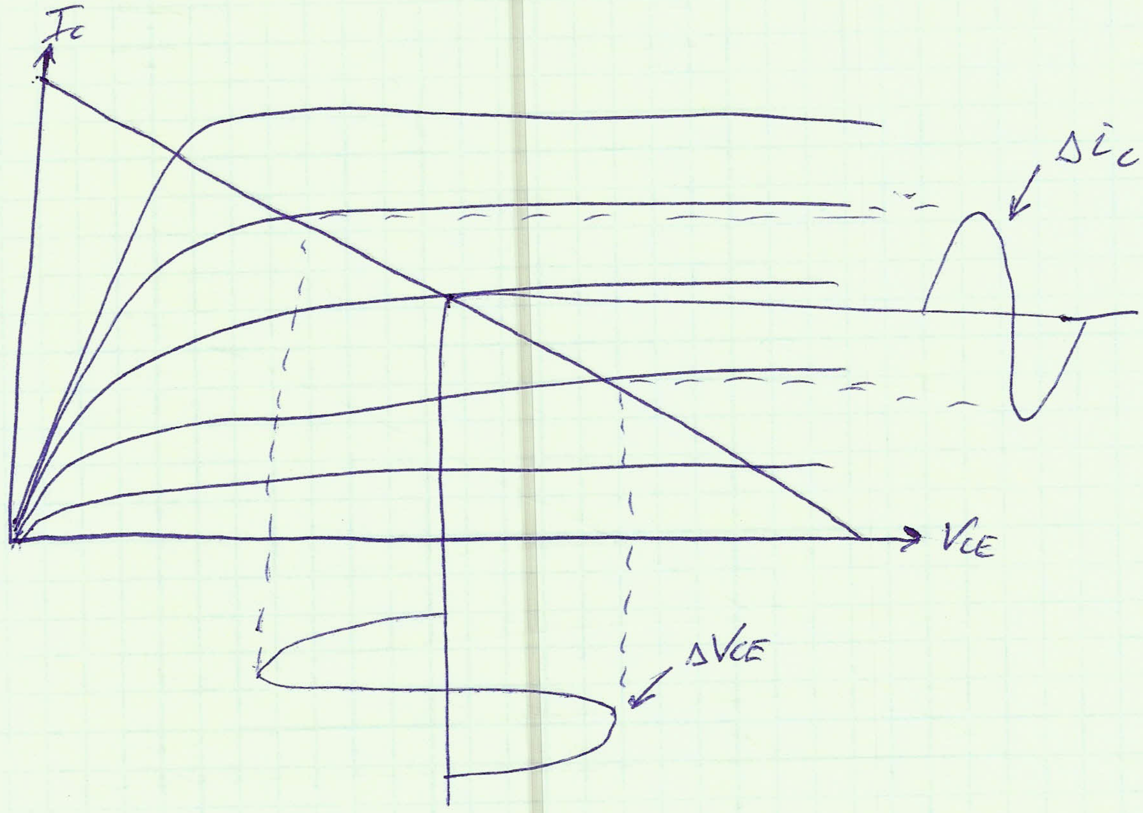
Load Line (Graphical analysis)

Q = quiescent point (operating point)

Q changes as I_B changes

Add sinusoidal source ΔV_{BB} in series with V_{BB}





- Δi_B causes Δi_C, which causes ΔV_{CE}
- I_B may be ~100μA
- Δi_B may be ~10μA
- I_C may be ~10mA (βI_B)
- ΔV_{CE} ~~may~~ will be ~ $R_C \Delta i_C$
- Δi_C may be ~1mA

- Output (ΔV_{CE}) is amplified form of ΔV_{BB}
- β, R_C, and R_B all play a role

Biasing

$$\overset{\text{total}}{v_{CE}} = \overset{\text{DC}}{V_{CE}} + \overset{\text{signal}}{v_{ce}} \gtrsim V_{D0}$$

$$\rightarrow v_{ce} \gtrsim -(V_{CE} - V_{D0})$$

- this limits the negative values of v_{ce}
- transistor will enter saturation beyond that point

$i_C > 0$ and CE-KVL

$$\rightarrow v_{CE} = V_{CE} + v_{ce} < V_{CC} \rightarrow v_{ce} < V_{CC} - V_{CE}$$

- this limits the positive values of v_{ce}
- transistor will enter cut-off beyond that point

For FETs

$$v_{DS} \geq V_{GS} - V_t \rightarrow v_{ds} > v_{gs} - (V_{DS} - V_{GS} + V_t) \simeq -(V_{DS} - V_{GS} + V_t)$$

limits negative values, otherwise enters triode state

$i_D > 0$ and DS-KVL $\rightarrow v_{ds} < \ldots$

depends on DS-KVL, limits positive values, otherwise enters cut-off

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usually choose Q point in the middle of load line

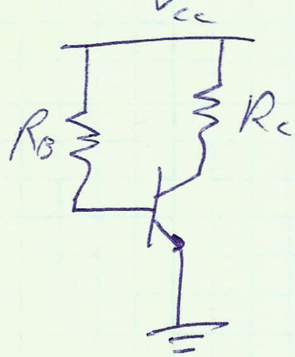
$V_{CE} \simeq 0.5 V_{CC}$ for BJT

Power dissipation is also a consideration

$P = V_{CE} I_C$

BJT fixed bias

V_{cc} supplies both the collector and the base



BE-KVL
$$\begin{cases} V_{cc} = I_B R_B + V_{BE} \longrightarrow I_B = \dfrac{V_{cc} - V_{BE}}{R_B} \\ \star\ I_c = \beta I_B = \beta \dfrac{V_{cc} - V_{BE}}{R_B} \end{cases}$$

CE-KVL
$$\begin{cases} V_{cc} = I_c R_c + V_{CE} \longrightarrow V_{CE} = V_{cc} - I_c R_c \\ \star\ V_{CE} = V_{cc} - \beta \dfrac{R_c}{R_B}(V_{cc} - V_{BE}) \end{cases}$$

$\star$ We can solve these equations to get the Q-point

Design example find R_c, R_B so that $I_c = 25mA$, $V_{CE} = 7.5v$ for $\beta = 100$, $V_{cc} = 15v$

BJT is active ($V_{CE} = 7.5v > V_{D0}$)

$\longrightarrow I_B = I_c/\beta = 0.25mA$

BE-KVL: $V_{cc} - R_B I_B - V_{BE} = 0 \longrightarrow R_B = \dfrac{15v - 0.7v}{0.250mA} = 57k\Omega$

CE-KVL: $V_{cc} - I_c R_c - V_{CE} = 0 \longrightarrow R_c = \dfrac{15v - 7.5v}{25mA} = 300\Omega$

- What happens if $\beta \rightarrow 200$?

$I_B = \dfrac{V_{cc} - V_{BE}}{R_B} = 0.25mA \longrightarrow$ no change

$I_c = \beta I_B = 50mA \quad (\times 2)$

$V_{CE} = V_{cc} - I_c R_c \longrightarrow V_{CE} = 15 - 300 \times 50 \times 10^{-3} = 0$

$\longrightarrow$ transistor is in saturation

β can change due to:

- Manufacturing tolerances
- Temperature variations
  - changes by 9% per °C
  - for 10°C rise, I_c will roughly double

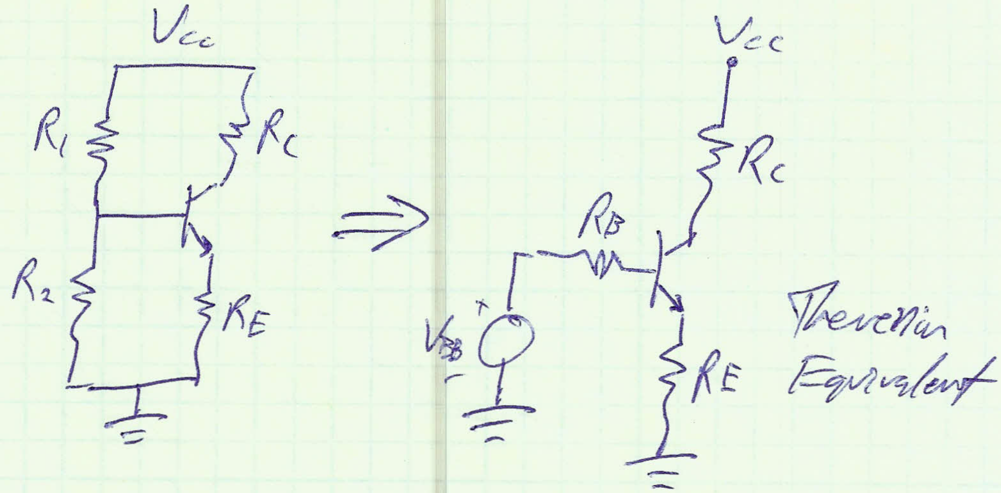
Positive feedback

- Temperature increase makes I_c rise
- I_c rising makes transistor hotter etc.

⇒ Need a biasing scheme that makes Q point independent of β.

BJT "emitter degeneration" bias with voltage divider

- Emitter resistor provides negative feedback



$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{cc} \quad , \quad R_B = R_1 \| R_2$$

Emitter resistor R_E gives negative feedback

- If I_C increases, $V_E = R_E I_E$ increases
  - → BE-KVL shows I_B will decrease
  - → I_C will go back down
  - → This bias scheme is stable, independent of β.

$$I_C = \beta I_B \quad , \quad I_E = (\beta + 1) I_B$$

BE-KVL: $V_{BB} - R_B I_B - V_{BE} - I_E R_E = 0$

$$\longrightarrow I_B = \frac{V_{BB} - V_{BE}}{R_B + (1+\beta) R_E}$$

CE-KVL: $V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$$\longrightarrow V_{CE} = V_{CC} - I_C \left[R_C + \frac{1+\beta}{\beta} R_E \right]$$

* choose $R_B \ll (1+\beta) R_E$

→ necessary for feedback to be effective

→ need I_b to be very responsive to voltage changes → small R_B

$$\rightarrow I_B \simeq \frac{V_{BB} - V_{BE}}{(1+\beta) R_E} \quad , \quad I_C \simeq I_E \simeq \frac{V_{BB} - V_{BE}}{R_E}$$

$$V_{CE} \simeq V_{CC} - \frac{R_C + R_E}{R_E} \left(V_{BB} - V_{BE} \right)$$

* note both I_C and V_{CE} are independent of β

Another look at Emitter Degeneration

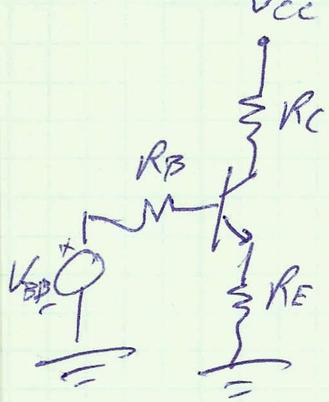
Consider BE-KVL

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

choose $R_B \ll (1+\beta) R_E$

$\simeq \frac{I_E}{I_B} R_E$

or $I_B R_B \ll I_E R_E$



$I_E R_E \simeq V_{BB} - V_{BE}$

* I_E is constant, independent of β. I_C also constant ($\simeq I_E$)

This circuit forces I_E to be fixed, and changes I_B accordingly

* Note: V_{BE} not constant - can vary from 0.6 to 0.8 v for Si BJT

→ need $I_E R_E$ much larger than changes in V_{BE}

$I_E R_E \gg 0.1v$ or $\sim 10 \times 0.1v$

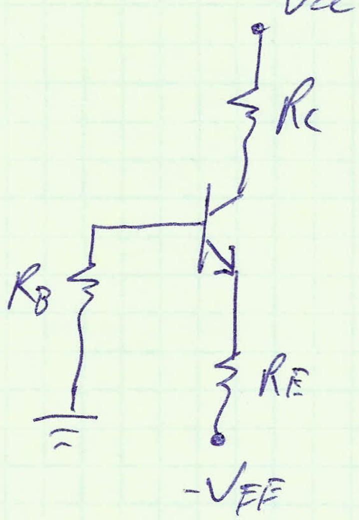
or $V_E \geq 1v$

* Note why R_2 is needed:

- If only one resistor R_B supplied by V_{CC}, it would not be possible to have a small R_B

Students should go through design example on page 4-9

BJT Emitter Degeneration Bias with 2 sources



Same basic idea as with 1 source

stable if $R_B \ll (1+\beta)R_E$

- R_B can be zero if connected directly to signal (DC Amplifier)
- If coupling capacitor is used, base would be open
  - resistor is needed then