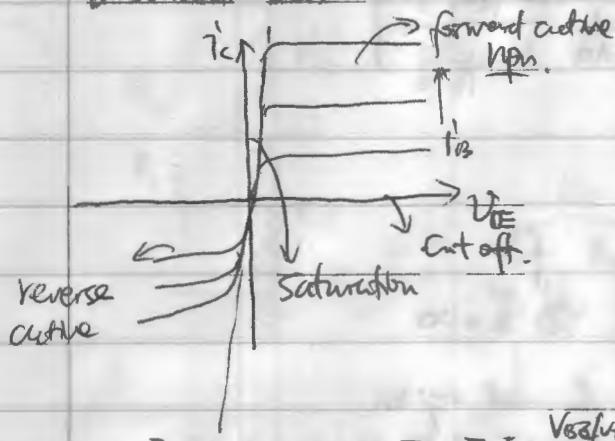
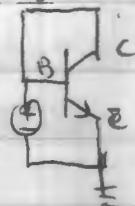


Discussion Session #5.



BE	Forward	Reverse
Forward	Saturation	Reverse
Reverse	Forward	Cutoff

① Forward



$$\begin{cases} I_c = I_s (e^{\frac{V_{be}}{V_T}} - 1) \\ I_b = I_c / \beta_F \\ I_e = (1 + \frac{1}{\beta_F}) I_c \end{cases}$$

② Reverse



$$\begin{cases} I_e = -I_s (e^{\frac{V_{be}}{V_T}} - 1) \\ I_{bR} = \frac{I_s}{\beta_R} (e^{\frac{V_{be}}{V_T}} - 1) \\ I_c = -(1 + \frac{1}{\beta_R}) I_s (e^{\frac{V_{be}}{V_T}} - 1) \end{cases}$$

~~Complex mode~~ Complex mode

$$\begin{aligned} ①+②: \quad & \begin{cases} I_c = I_s (e^{\frac{V_{be}}{V_T}} - e^{-\frac{V_{be}}{V_T}}) - \frac{1}{\beta_R} I_s (e^{\frac{V_{be}}{V_T}} - 1) \\ I_e = I_s (e^{\frac{V_{be}}{V_T}} - e^{-\frac{V_{be}}{V_T}}) + \frac{1}{\beta_R} I_s (e^{\frac{V_{be}}{V_T}} - 1) \\ I_{bR} = \frac{1}{\beta_R} I_s (e^{\frac{V_{be}}{V_T}} - 1) + \frac{1}{\beta_R} I_s (e^{\frac{V_{be}}{V_T}} - 1) \end{cases} \end{aligned}$$

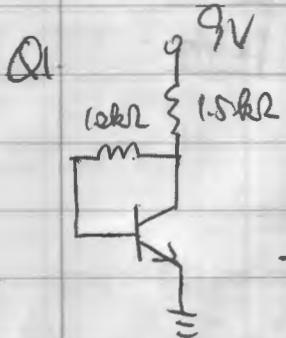
③ At cutoff. $V_{be} \approx 0, V_{ce} < 0$

$$\begin{cases} I_c = I_s / \beta_R \\ I_e = -I_s / \beta_R \\ I_{bR} = -I_s / \beta_R - I_s / \beta_F \end{cases}$$

④ Saturation

$$U_{CE,ST} = U_T \ln \left[\frac{I_C}{I_S} \frac{1 + \frac{I_C}{\beta_E I_S}}{1 - \frac{I_C}{\beta_E I_S}} \right]$$

$$\rightarrow \frac{I_C}{\beta_E} < I_S$$



Find Q-point for
① $\beta_F = 40$, ② $\beta_F = \infty$

Assume in forward region
 $\rightarrow V_{CE} = 9 = 1.5k\Omega \times (I_C + I_B) + V_{BE}$

$$I_C = \frac{\beta_F V_{BE}}{1.5k\Omega + (\beta_F + 1)k\Omega}$$

① $\beta_F = 40$, assume $V_{BE} = 0.7V$

$$\left\{ \begin{array}{l} I_C = 40 \times \frac{0.7}{1.5k\Omega + 41k\Omega} = 4.65mA \\ V_{CE} = V_{CC} - (I_C + I_B) \times 1.5k\Omega = 2.04V \end{array} \right.$$

$V_C > V_B$. \rightarrow assumption is correct.

$$\textcircled{2} \quad \beta_F = 200, \quad I_C = \frac{9 - V_{BE}}{1.5k\Omega} = 5.53mA$$

$$\textcircled{2} \quad V_{CE} = 9.705V > V_{B2}$$

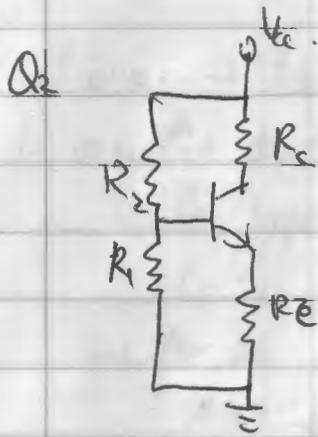
If given I_C use numerical iteration

$$\left\{ \begin{array}{l} I_C = \frac{\beta_F (9 - V_{BE})}{1.5k\Omega + (\beta_F + 1)k\Omega} \\ V_{BE} = U_T \ln \frac{I_C}{I_S} \end{array} \right.$$



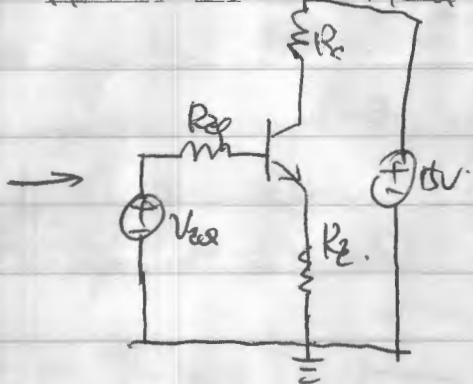
$$I_S = \beta_F \frac{9 - U_T \ln \frac{I_C}{I_S}}{1.5k\Omega + (\beta_F + 1)k\Omega} \quad \text{put in an initial } I_S$$

Iterate \rightarrow converge



$$R_1 = 120\text{k}\Omega, R_2 = 270\text{k}\Omega, R_L = 150\text{k}\Omega, R_E = 100\text{k}\Omega$$

$\beta = 100$, $V_{CE} = 15\text{V}$, f_{Tc} at 750Hz.



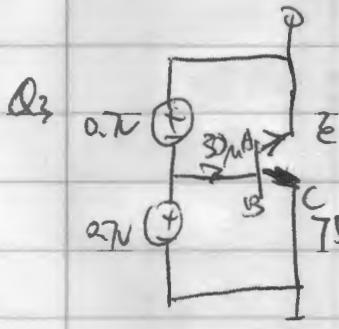
$$\left\{ \begin{array}{l} V_{BEQ} = \frac{R_1}{R_1 + R_E} V_{in}, \\ V_{CE} = 4.62\text{V} \end{array} \right.$$

$$\left\{ \begin{array}{l} R_{EQ} = R_1 \parallel R_E = 83.1\text{k}\Omega \end{array} \right.$$

$$I_C = \beta_F \frac{V_{BE} - V_{BEQ}}{(R_E + R_2) + R_L}$$

$$= 100 \times \frac{4.62 - 0.7}{(100 + 83.1) + 150} = 38.1\text{mA}$$

$$V_{ce} = 15 - R_L I_C - R_2 I_C = 3.38\text{mV}$$



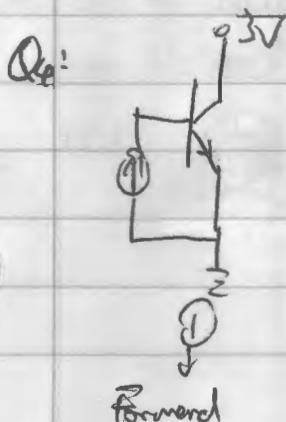
what is I_S and β_R ?

$\rightarrow \beta_F$

$$\text{① } (1 + \frac{1}{\beta_F}) I_B = I_C \therefore 1 + \beta_F = \frac{I_C}{I_B} = 2.5 \therefore \beta_F = 0.5$$

$$\text{② } I_S e^{\frac{V_{BE}}{V_{Tc}}} = I_B$$

$$\therefore I_S = \frac{I_B}{\beta_F e^{V_{BE}/V_{Tc}}} = 31.1\text{nA}$$



For both circuits, $I = 17\text{mA}$.

$$I_S = 4e^{-6}\text{A}, \beta_F = 50, \beta_R = 0.5$$

which region does the transistor work in?

V_{BE} ? V_{CEsat} ?

$$\text{① } I_C = \beta_F I_B = I_S e^{\frac{V_{BE}}{V_{Tc}}} \rightarrow V_{BE} = 2.76\text{mV}$$

$i_c = 0 < \beta_F I_S$
Saturation

$$\text{② } V_{CEsat} = V_C \ln \frac{I_C}{I_S} = 27.5\text{mV}$$