ECE321 Electronics I
Fall 2006

Professor James E. Morris

Lecture 12

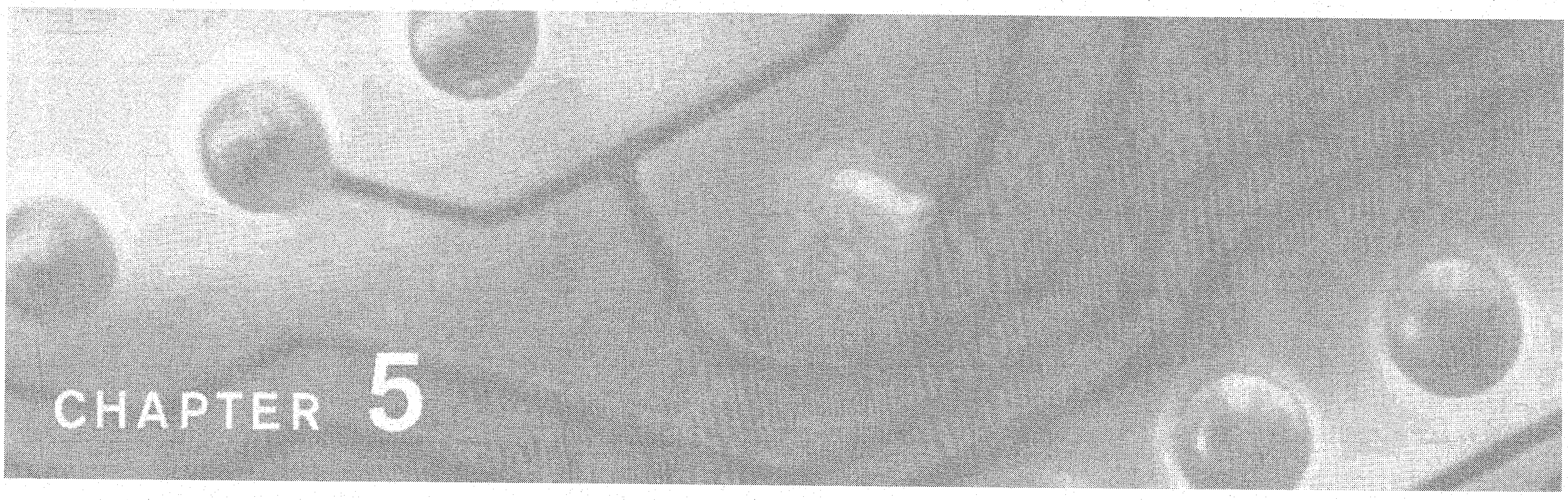
2nd November, 2006

ECE321 ELECTRONICS I
FALL 2006

PROFESSOR JAMES E. MORRIS

Lecture 13

9th November, 2006

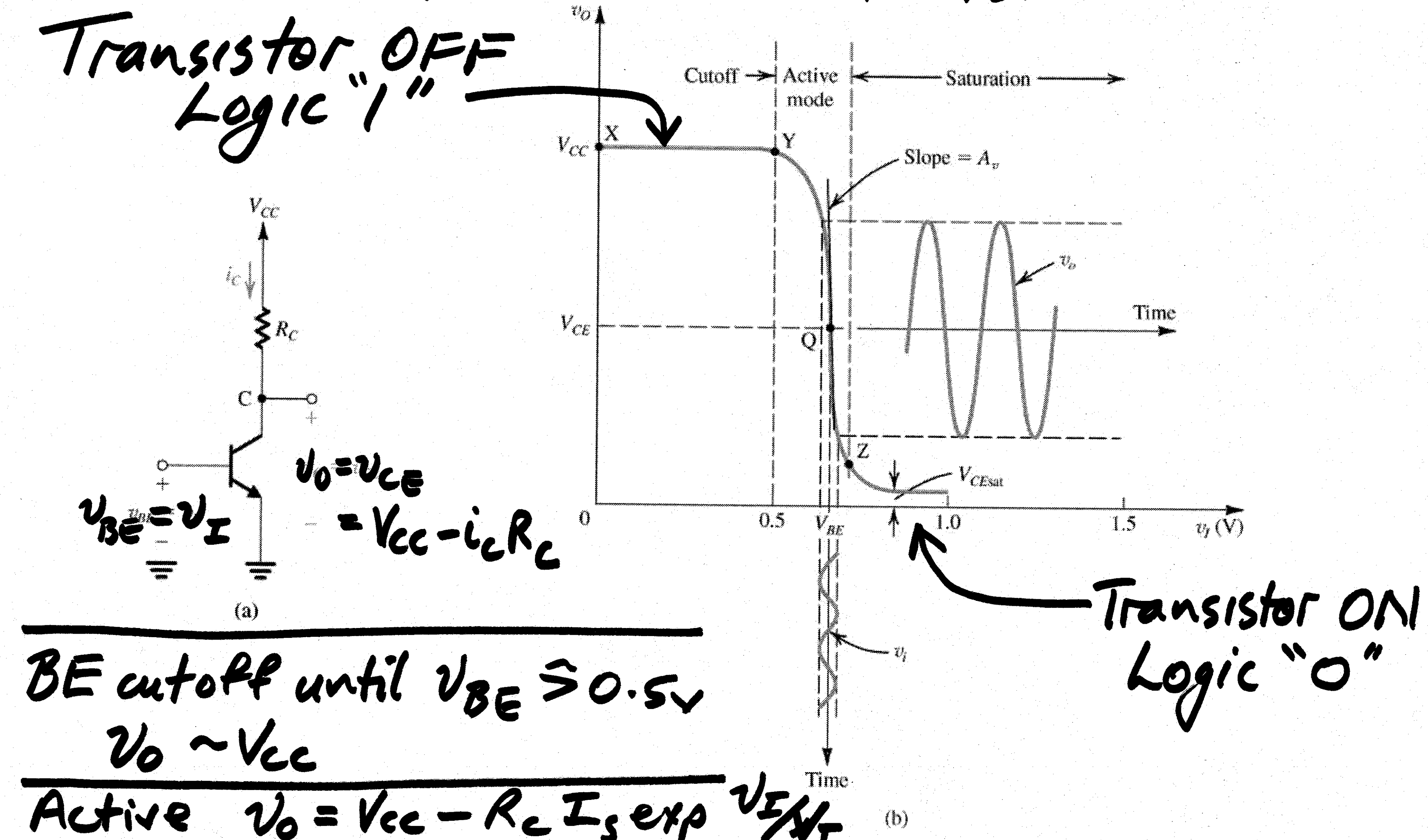


Bipolar Junction Transistors (BJTs)

5.3 Amplifiers & Switches Basic circuits

5.4 DC Circuits → Biasing

CE Transfer Characteristic



BE cutoff until $v_{BE} \gtrsim 0.5v$

$v_O \sim V_{CC}$

Active $v_O = V_{CC} - R_C I_S \exp v_I/V_T$

Figure 5.26 **(a)** Basic common-emitter amplifier circuit. **(b)** Transfer characteristic of the circuit in (a). The amplifier is biased at a point Q, and a small voltage signal v_i is superimposed on the dc bias voltage V_{BE}. The resulting output signal v_o appears superimposed on the dc collector voltage V_{CE}. The amplitude of v_o is larger than that of v_i by the voltage gain A_v.

Saturation $\rightarrow$ $I_C)_{SAT} = \dfrac{V_{CC} - V_{CEsat}}{R_C}$ ~ constant.

Basic CE Amplifier

$$v_O = V_{CC} - R_C I_S \exp^{v_I/V_T}$$

$$A_v = \frac{dv_O}{dv_I}$$

$$= -\frac{R_C I_S \exp \frac{v_I}{V_T}}{V_T}$$

$$= -\frac{I_C R_C}{V_T}$$

$$= -\frac{R_C}{(V_T/I_C)}$$

Note inversion

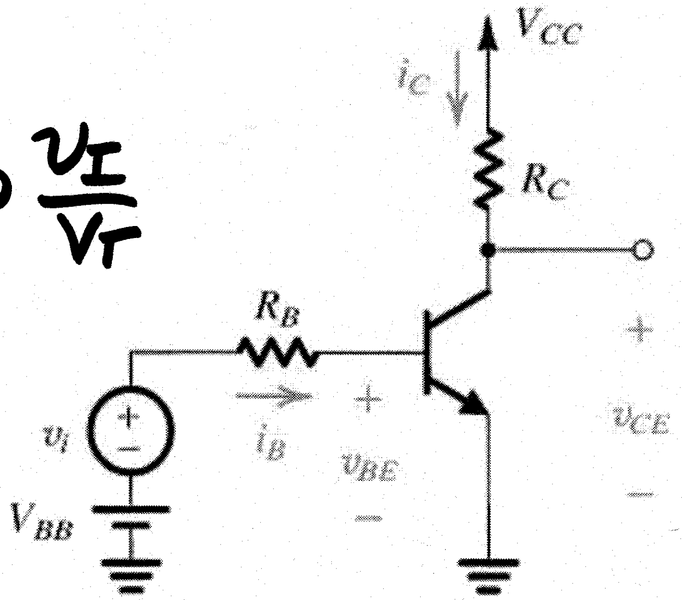


Figure 5.27 Circuit whose operation is to be analyzed graphically.

Graphical (Load Line) approach:

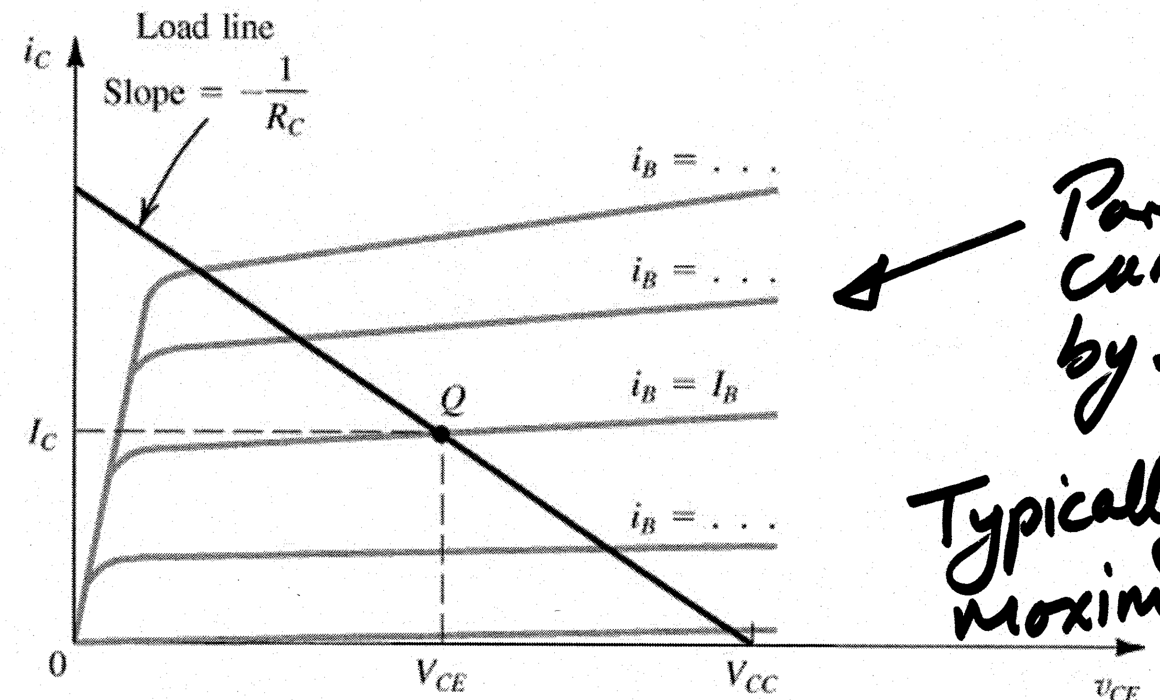
Circuit:

$$v_{CE} = V_{CC} - i_C R_C$$

& Transistor: Characteristics

CE or "Output" characteristics

Need I_B



Particular curve specified by I_B bias.

Typically select for maximum undistorted signal swing.

Ideally at midpoint

$v_o = 0 \rightarrow V_{CC}$

$i_c = 0 \rightarrow V_{CC}/R_C$

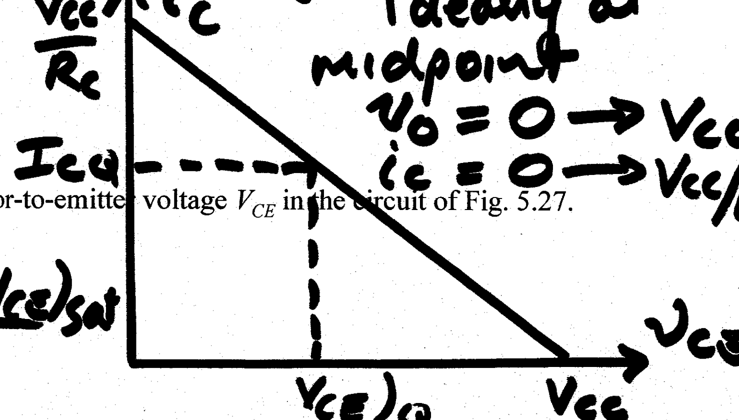


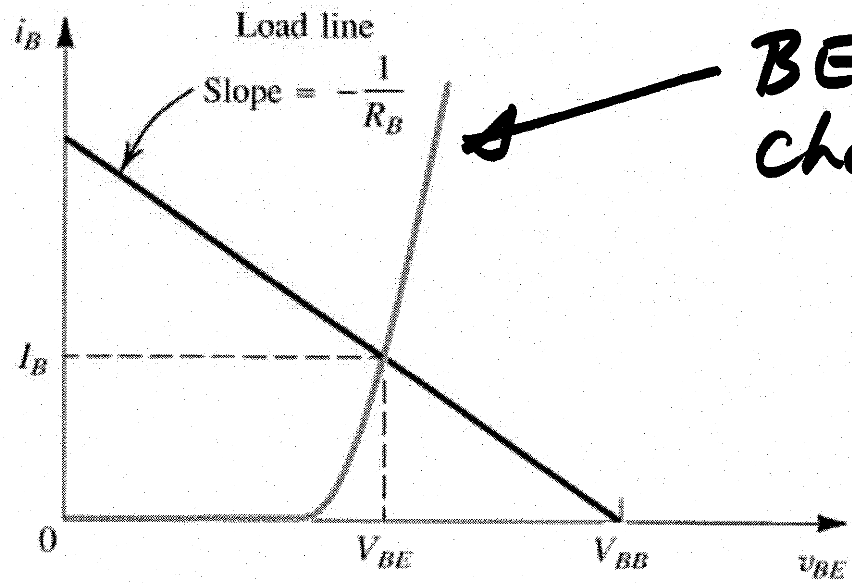
Figure 5.29 Graphical construction for determining the dc collector current I_C and the collector-to-emitter voltage V_{CE} in the circuit of Fig. 5.27.

In practice

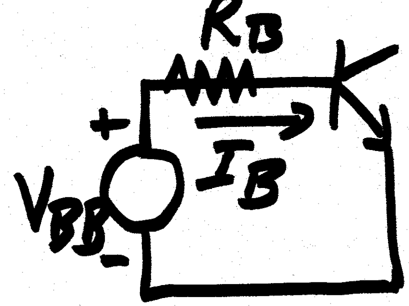
$$V_{CE})_Q = \frac{V_{CC} - V_{CE})_{sat}}{2}$$

B-E or "input" characteristics

Load line — external circuit $I_B = \dfrac{V_{BB} - V_{BE}}{R_B}$



BE diode characteristics



Can use a diode model, as before

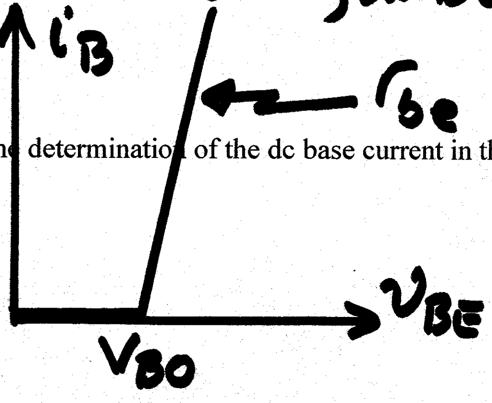
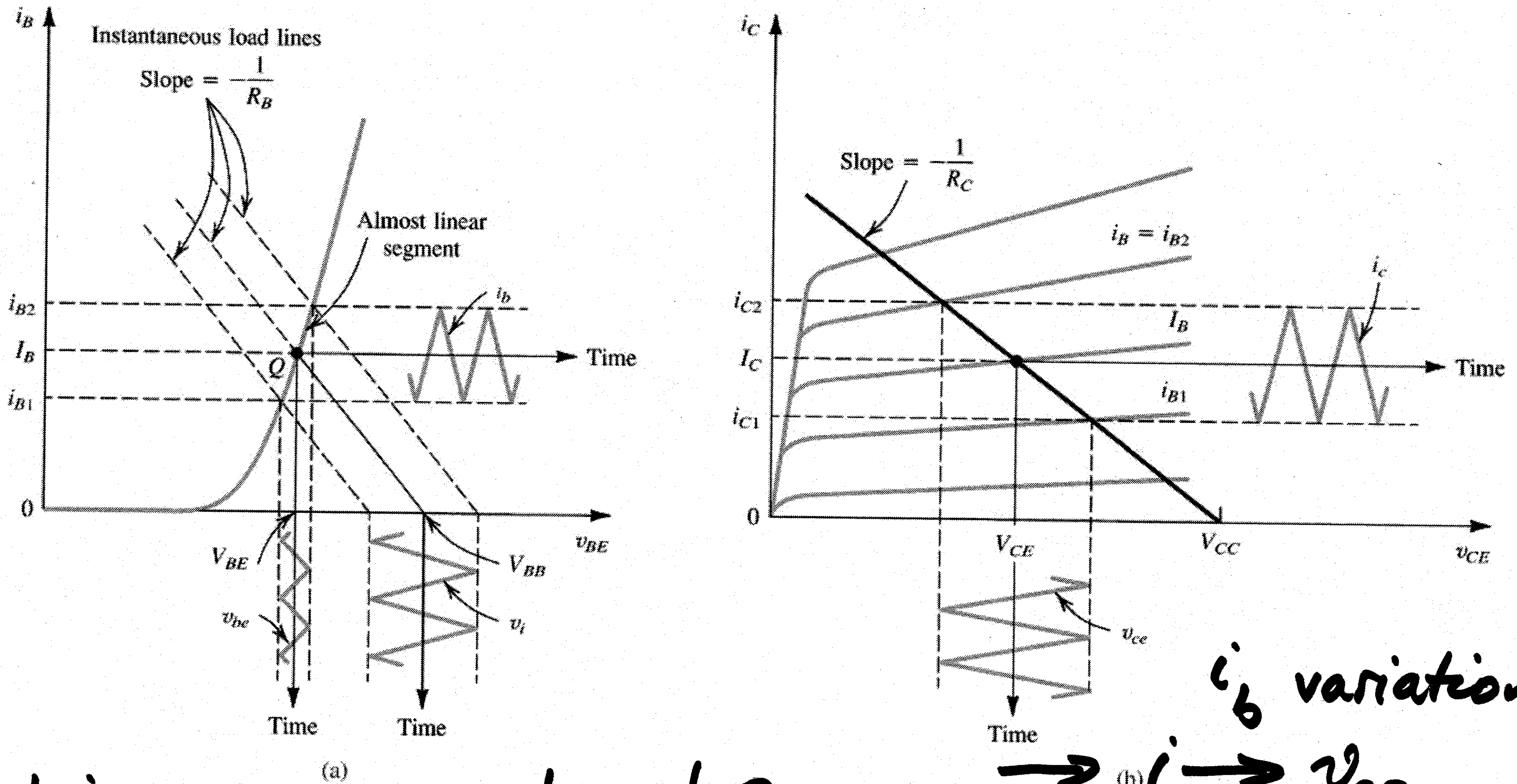


Figure 5.28 Graphical construction for the determination of the dc base current in the circuit of Fig. 5.27.

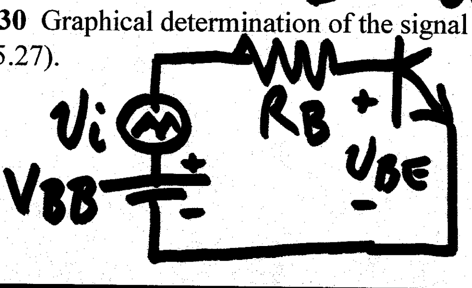
CE Amplifier



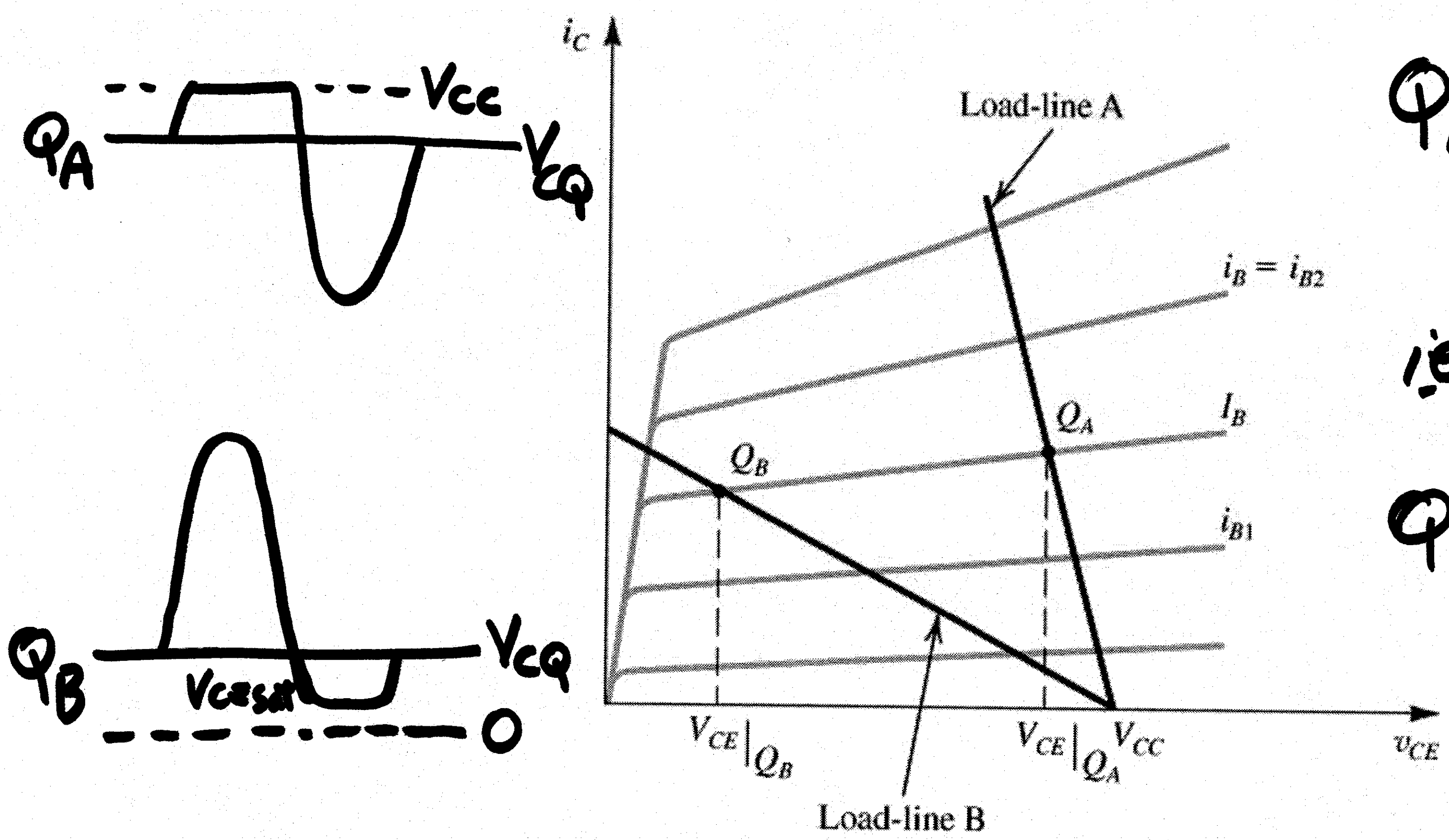
i_b variation $\rightarrow$ i_c $\rightarrow$ v_{ce}

Linear approximation at Q to convert $v_I = v_{BE}$ to i_B

Figure 5.30 Graphical determination of the signal components v_{be}, i_b, i_c, and v_{ce} when a signal component v_i is superimposed on the dc voltage V_{BB} (see Fig. 5.27).



Maximum Signal Swing (again)



Q_A too close to
$i_c = 0$
($v_{CE} = V_{cc}$)
i.e. to cutoff.

Q_B too close to
saturation

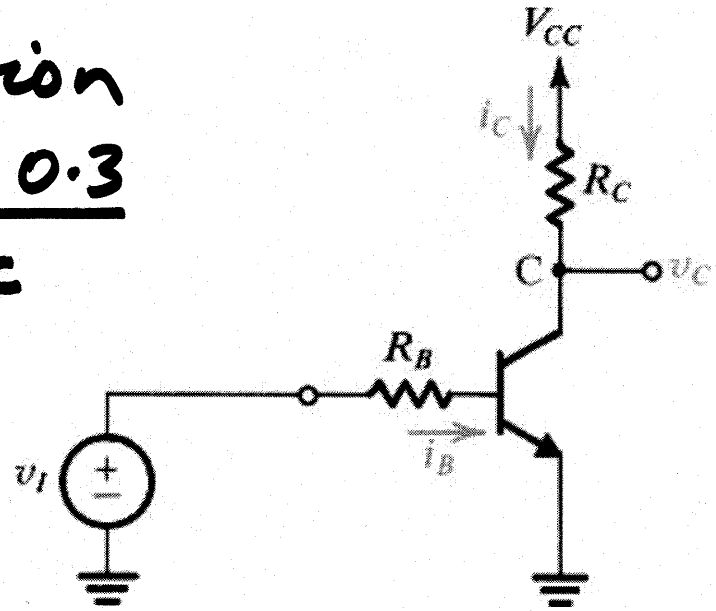
Figure 5.31 Effect of bias-point location on allowable signal swing: Load-line A results in bias point Q_A with a corresponding V_{CE} which is too close to V_{CC} and thus limits the positive swing of v_{CE}. At the other extreme, load-line B results in an operating point too close to the saturation region, thus limiting the negative swing of v_{CE}.

BJT Switch

$$i_B = \frac{v_I - V_{BE}}{R_B} \qquad i_C = \beta i_B \qquad v_C = V_{CC} - i_C R_C$$

Edge of saturation

$$I_C)_{EOS} = \frac{V_{CC} - 0.3}{R_C}$$



$$V_I)_{EOS} = I_B)_{EOS} R_B + V_{BE}$$

Figure 5.32 A simple circuit used to illustrate the different modes of operation of the BJT.

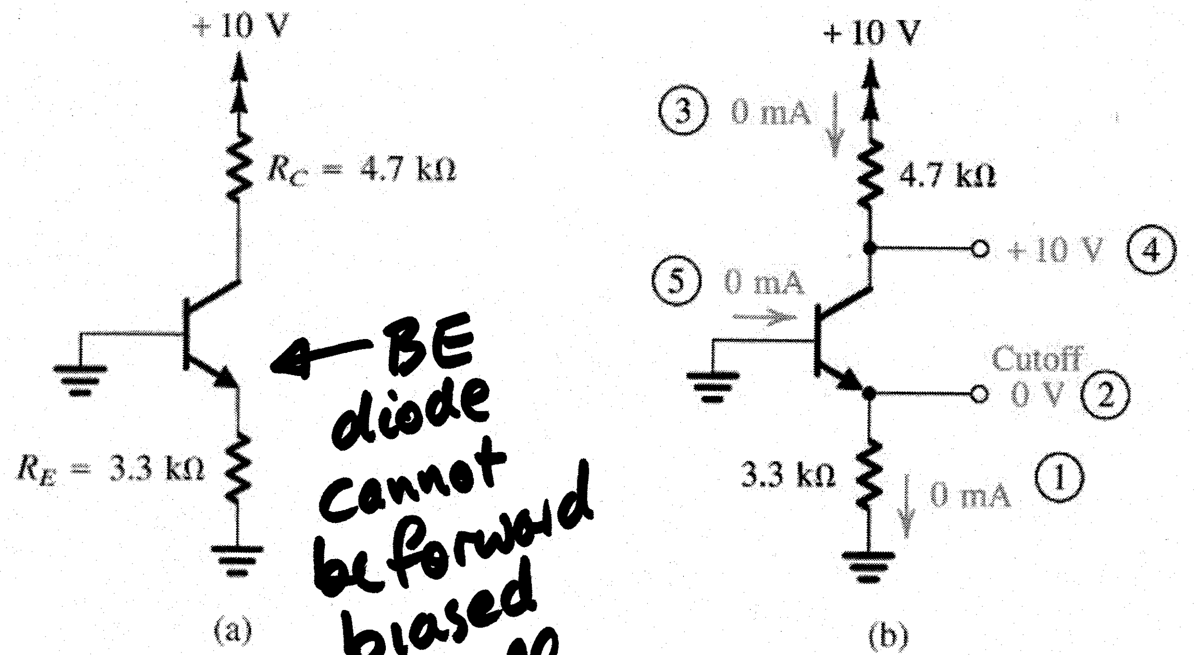
$$I_C)_{SAT} = \frac{V_{CE} - V_{CE\,sat}}{R_C}$$

- Exercise 5.20
  - V_{BB}=1.7V R_{BB}=100kΩ V_{CC}=10V R_C=5kΩ β=100
  - V_I=0.4V pk-to-pk triangle wave
  - Using a graphical approach:
    - (a) Find I_B if V_B=0.7V
    - (b) Show (diode slope)$^{-1}$=V_T/I_B; find value
    - (c) Find approx pk-to-pk i_b, v_{be}
    - (d) Assume horiz i_C-v_{CE} curves, find I_C, V_{CE}
    - (e) Find pk-to-pk i_C, v_{CE}
    - (f) What is A_v?
- Exercise 5.21
  - Fig 3.32 V_{CC}=+5V, v_I=+5V, R_B=R_B=1kΩ, β=100
  - Calculate base current, collector current, & collector voltage
  - If transistor saturated, find β_{forced}.
  - Find R_B to bring transistor to edge of saturation

Exercises

- D5.22
- 5.23
- 5.24

Example 5.6



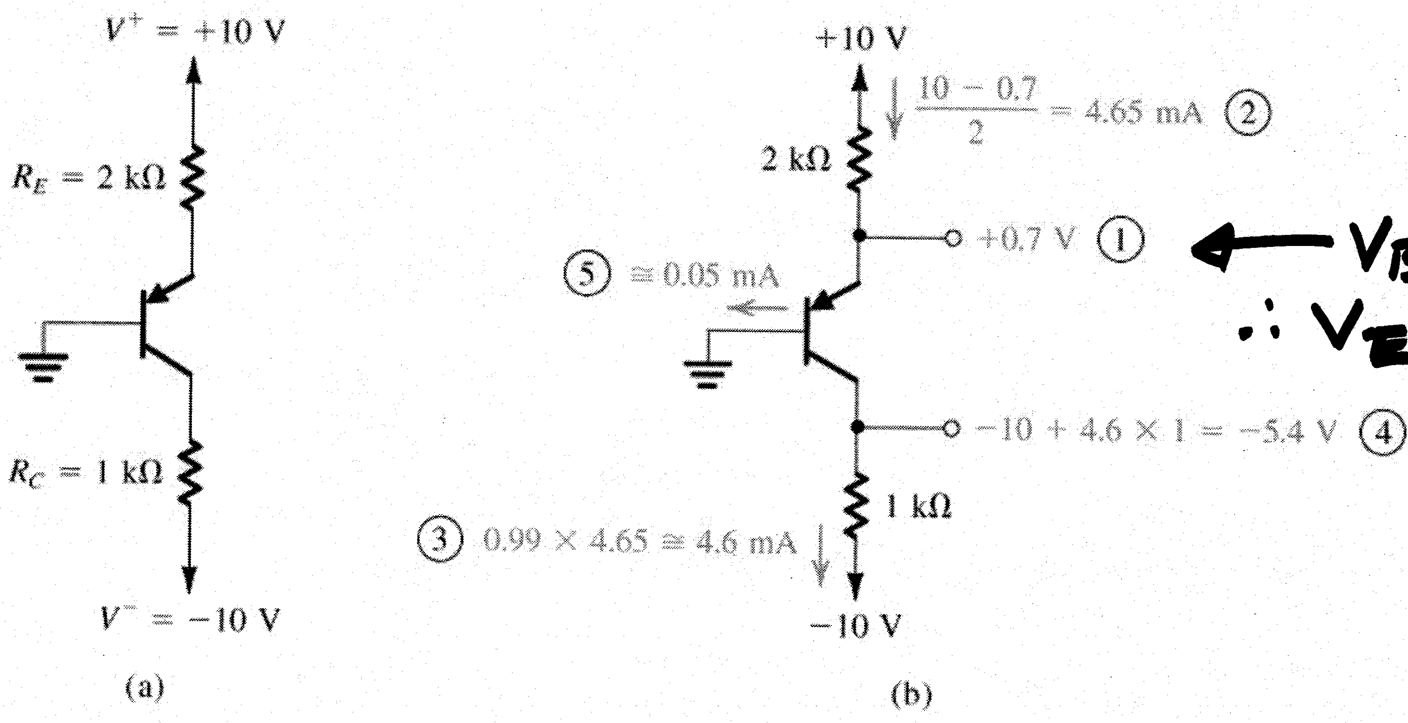
← BE diode cannot be forward biased ∴ Cutoff

$I_C = I_E = 0$ $\quad$ $I_E = 0 \therefore V_E = 0$

$I_B = 0$ $\quad$ $I_C = 0 \therefore V_C = +10V$

Figure 5.36 Example 5.6: **(a)** circuit; **(b)** analysis with the order of the analysis steps indicated by circled numbers.

Example 5.7 PNP



$V_{BE} = -.7v$

$\therefore V_E = +0.7v$

Figure 5.37 Example 5.7: **(a)** circuit; **(b)** analysis with the steps indicated by circled numbers.

Exercises

- D5.25
- D5.26
- D5.27
- 5.28
- 5.29
- 5.30
- 5.31

Assignment #6

5.2

5.50

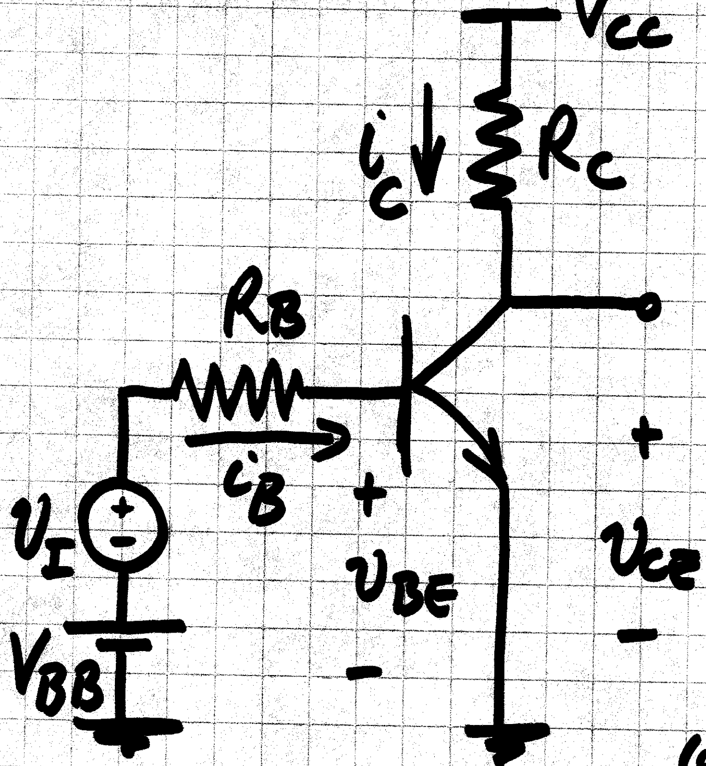
*5.61

5.67

**D5.85

- Exercise 5.20
  - V_{BB}=1.7V R_{BB}=100kΩ V_{CC}=10V R_C=5kΩ β=100
  - V_I=0.4V pk-to-pk triangle wave
  - Using a graphical approach:
    - (a) Find I_B if V_B=0.7V
    - (b) Show (diode slope)$^{-1}$=V_T/I_B; find value
    - (c) Find approx pk-to-pk i_b, v_{be}
    - (d) Assume horiz i_C-v_{CE} curves, find I_C, V_{CE}
    - (e) Find pk-to-pk i_C, v_{CE}
    - (f) What is A_v?
- Exercise 5.21
  - Fig 3.32 V_{CC}=+5V, v_I=+5V, R_B=R_B=1kΩ, β=100
  - Calculate base current, collector current, & collector voltage
  - If transistor saturated, find β_{forced}.
  - Find R_B to bring transistor to edge of saturation

Ex 5.20



$V_{BB} = 1.7v$ $R_B = 100K\Omega$ $V_{CC} = 10v$ $R_C = 5K\Omega$

$\beta = 100$ v_I 0.4v pk-to-pk triangle wave

Using graphical approach:

(a) Find I_B if $V_{BE} = .7v$

(b) Show 1/diode slope = V_T/I_B; find value

(c) Find approximate peak-to-peak i_b, v_{be}

(d) Assume horizontal i_C-v_{CE} curves find I_C, V_{CE}

(e) Find pk-to-pk i_c, v_{ce}

(f) What is A_v?

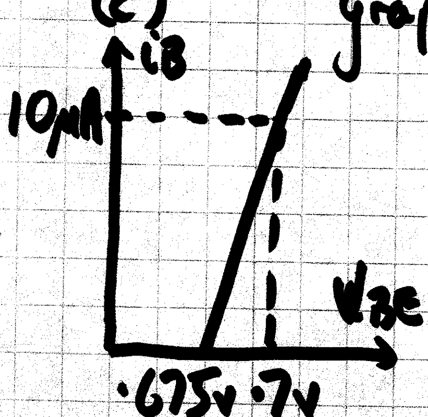
(a) $I_B = (V_{BB} - V_{BE})/R_B = (1.7 - .7)/100K = 10\mu A$

(b) $i_B = I_S/\beta \exp\frac{v_{BE}}{V_T}$ $\therefore \partial i_B/\partial v_{BE} = \frac{I_S}{\beta} \cdot \exp\frac{v_{BE}}{V_T} \cdot \frac{1}{V_T} = \frac{I_B}{V_T}$ $\therefore \frac{\partial v_{BE}}{\partial i_B} = \frac{V_T}{I_B}$

$= \frac{25mV}{10\mu A}$

$= 2.5K\Omega$

(c)



Graphically, or $v_{BB} = 1.5 \rightarrow 1.9v$ $\therefore i_b \sim \frac{.8 \rightarrow 1.2v}{100K}$

or $v_{be} = \frac{r_{be}}{r_{be} + R_B} 0.4\,\text{pk-pk} = \frac{2.5}{102.5}(.4) \approx 10mV$

& $i_b = \frac{(400-10)mV}{100K}$ pk-pk $\approx 4\mu A$ OR $\frac{v_{be}}{r_{be}} = \frac{10mV}{2.5K} = 4\mu A$

(d) $\therefore I_C = \beta I_B = 100 \times 10\mu A = 1mA$, $V_{CE} = 10 - 5 \times 10^3 \times 1mA = 5v$

Ex 5.20 (cont^{d}) (e) Pk-pk: $i_c = \beta i_b = 400\,\mu A$

$v_{ce} = 400\,\mu A \times 5K = 2v$

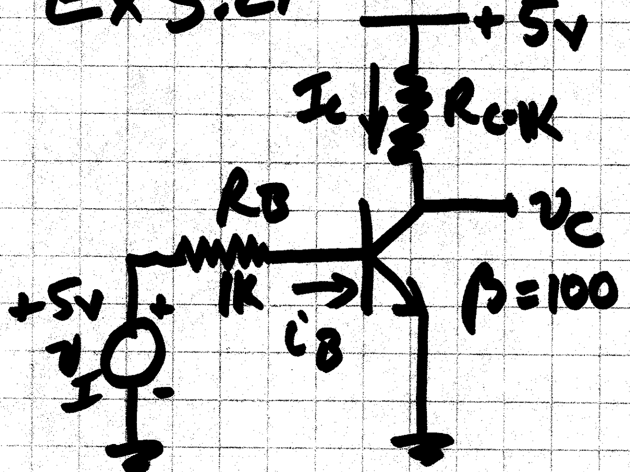
(f) $A_v' = -R_c/(V_T/I_c) = 5K\Omega / \left(\frac{25mV}{1mA}\right) = 200$

$(= v_{ce}/v_{be})$

$$A_v = \frac{v_{ce}}{v_I} = -\frac{\beta i_b R_c}{v_i} = -\frac{100 \times 4 \times 10^{-6} \times 5 \times 10^{3}}{0.4}$$

$= -5\,V/V$

Ex 5.21



Find i_C, i_B, v_C. If transistor saturates, find β_{forced}

Find R_B for edge of saturation.

$I_B \approx \frac{5 - .7}{1}\frac{v}{K\Omega} = 4.3mA$ $\therefore I_C = 430mA$

$\therefore 5 - 1K \times 430mA < 0$

$\therefore$ Saturated.

$\therefore$ Assume $V_{CE}^{sat} = 0.2v$

Then $I_C = (5 - .2)/1K = 4.8mA$

$I_B = (5 - .7)/1K = 4.3mA$

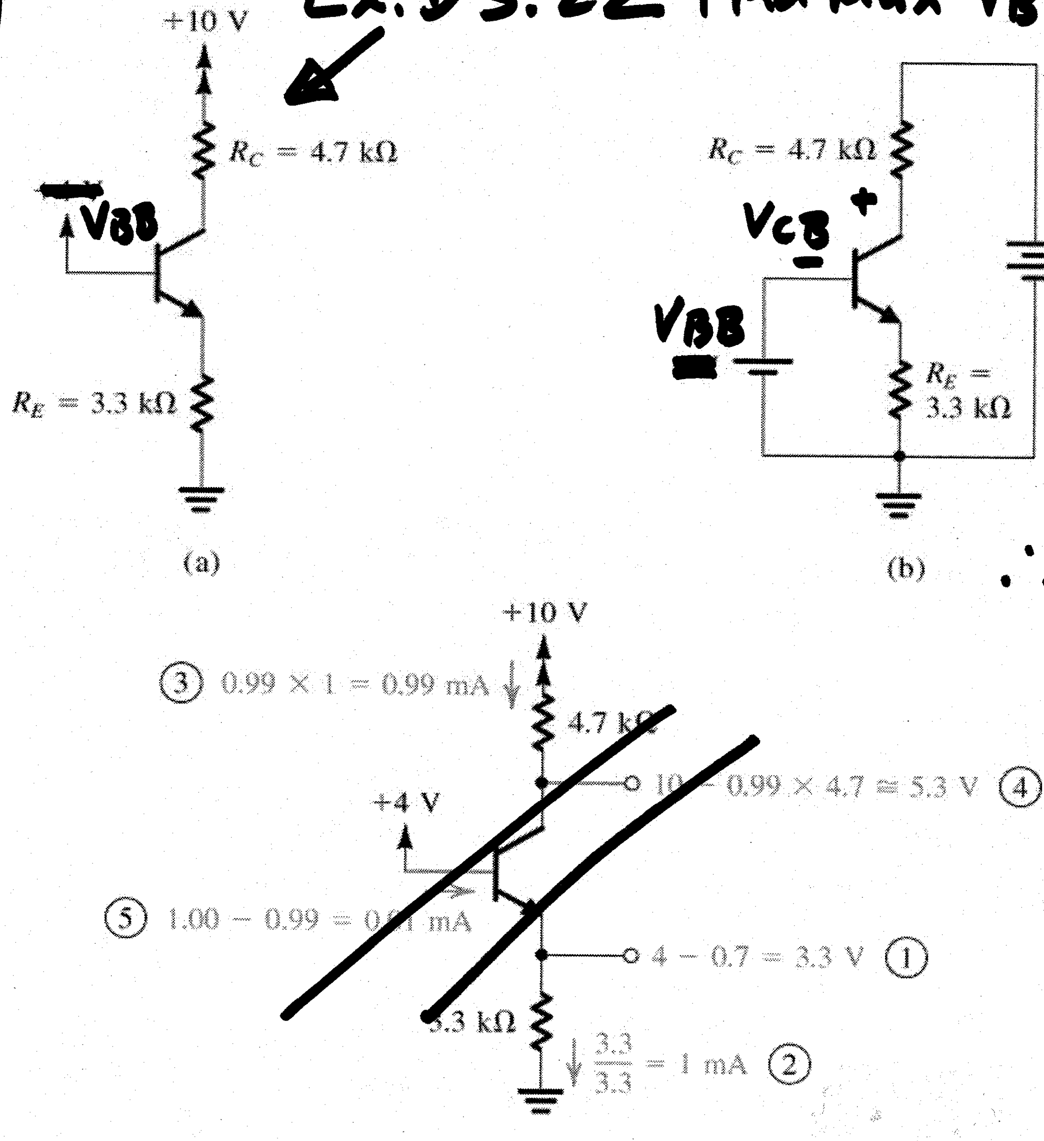
$$\left.\begin{array}{l} I_C = 4.8mA \\ I_B = 4.3mA \end{array}\right\} \beta_{forced} = \frac{4.8}{4.3} = 1.1$$

For edge of saturation — say $V_{CE\,sat} \sim 0.3v$

$\therefore i_C = 4.7mA$, $i_B = \frac{4.7mA}{100} = 47\,\mu A$ $\therefore R_B = \frac{5 - .2}{.047mA} = 91.5K\Omega$

DC BJT Circuits

Ex. D5.22 Find max V_{BB} for BJT active mode $\alpha = 1$



Active mode requires $V_{CB} \geq -0.4V$

Assume $V_{BE} = 0.7V$ & $\alpha = 1$

$\therefore i_E \approx i_C = \frac{V_{BB} - 0.7V}{3.3K}$

Also $V_{CB} = V_C - V_B$

$= 10 - i_C(4.7K) - V_{BB}$

$\geq -0.4V$

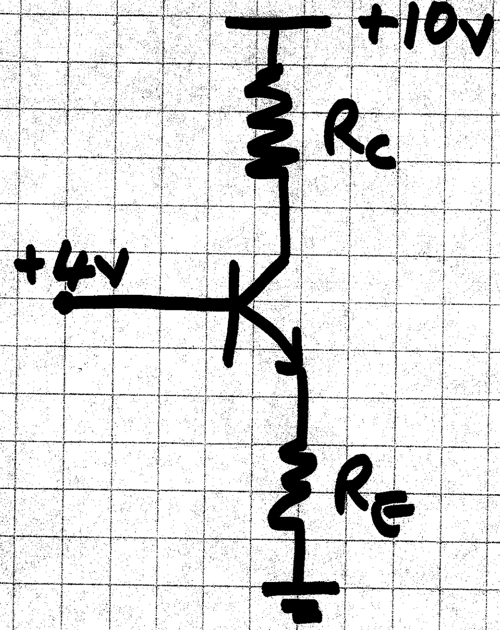
So $10_V - \frac{V_{BB} - .7}{3.3K} 4.7K - V_{BB} \geq -0.4V$

Figure 5.34 Analysis of the circuit for Example 5.4: **(a)** circuit; **(b)** circuit redrawn to remind the reader of the convention used in this book to show connections to the power supply; **(c)** analysis with the steps numbered.

i.e. $V_{BB}\left(1 + \frac{4.7}{3.3}\right) \leq 10V + 0.7\frac{4.7}{3.3}V + 0.4V$

$V_{BB} \leq \frac{33 + 3.29 + 1.32}{8} = \frac{37.61}{8} = 4.7V$

Ex 5.23



Design for $I_C = .5mA$

& $V_{CB} = 2v$

with $\alpha = 1$

$V_B = 4v$ $\therefore$ $V_C = V_{CB} + V_B = 2 + 4 = 6v$

$\therefore$ $R_C = \dfrac{10 - 6v}{.5\ mA} = 8K\Omega$

$V_E = V_B - V_{BE} = 3.3v$ if $V_{BE} = 0.7v$

$\therefore$ $R_E = \dfrac{3.3v}{.5mA}$ if $\alpha = 1$ & $I_E = I_C$

$= 6.6K\Omega$

Ex. 5.24 Find V_B for saturation with $\beta_{forced} = 5$

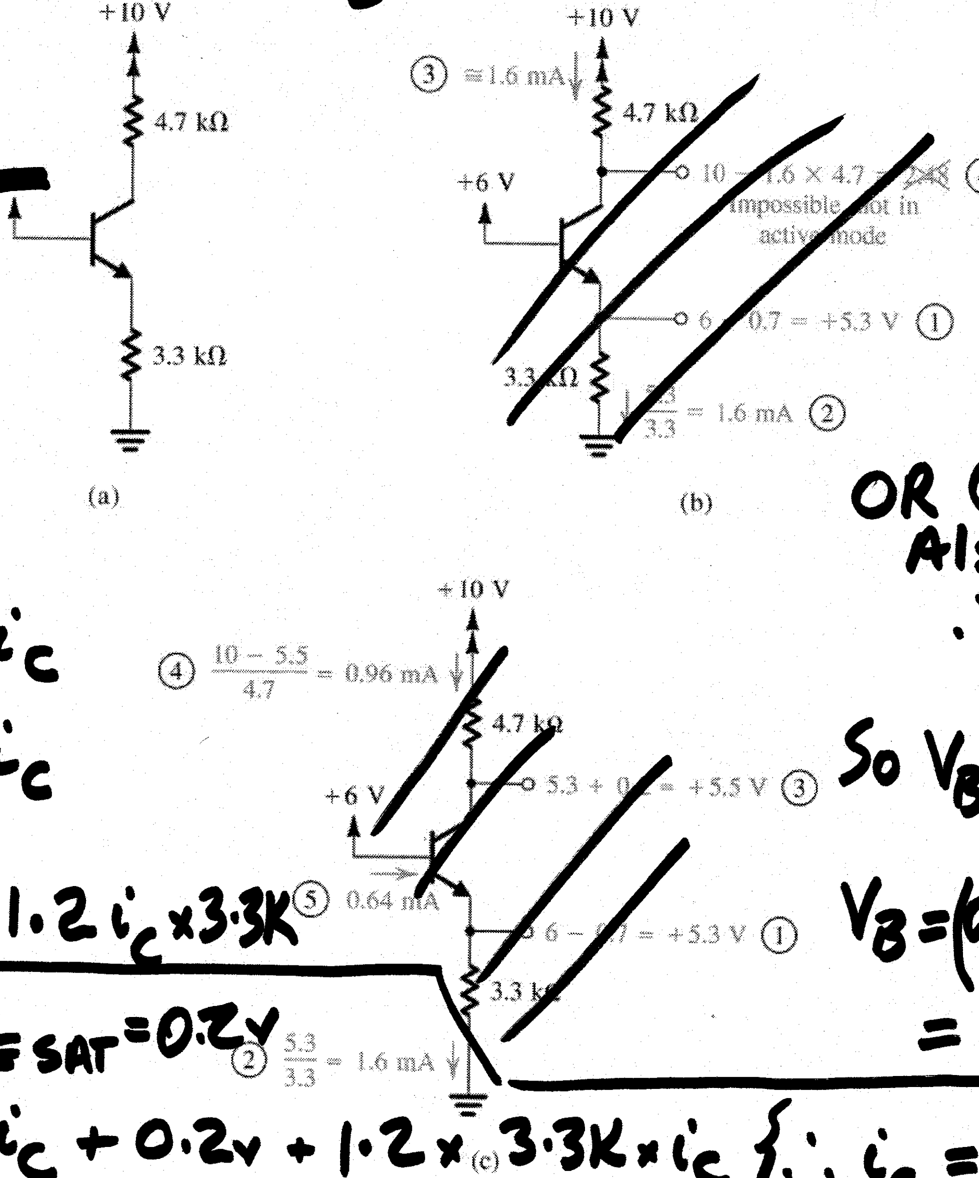


Figure 5.35 Analysis of the circuit for Example 5.5. Note that the circled numbers indicate the order of the analysis steps.

$\frac{i_C}{i_B} = 5$

$\therefore i_B = 0.2\, i_C$

& $i_E = 1.2\, i_C$

$\therefore V_B - 0.7_V = 1.2\, i_C \times 3.3K$

① Also assume $V_{CE\,SAT} = 0.2V$

$\therefore 10 = 4.7K\, i_C + 0.2_V + 1.2 \times 3.3K \times i_C \quad \{\therefore i_C = \frac{9.8_V}{8.7K} = 1.125mA\}$

$\therefore V_B = 0.7_V + \frac{1.2 \times 3.3K\,(10 - 0.2)_V}{(4.7 + 1.2 \times 3.3)K} = 0.7 + \frac{9.8_V}{\left(1 + \frac{4.7}{3.96}\right)} = 5.18_V$

OR ②

Also assume $V_{CB} = -.5_V$

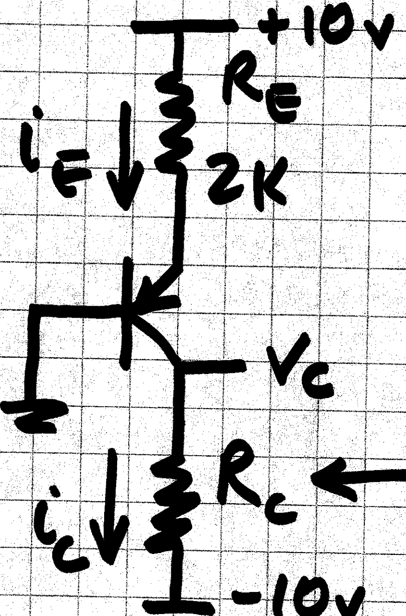
$\therefore i_C = \frac{10 - (V_B - .5_V)}{4.7K}$

So $V_B - .7 = \frac{1.2 \times 3.3K\,(10.5 - V_B)}{4.7K}$

$V_B = \left(0.7 + \frac{3.96}{4.7}\,10.5\right) \Big/ \left(1 + \frac{3.96}{4.7}\right)$

$= 5.18_V$

Ex D5.25 (PNP)



R_C ← Find max for active mode

For active mode limit
CB forward bias $\leq 0.4v$

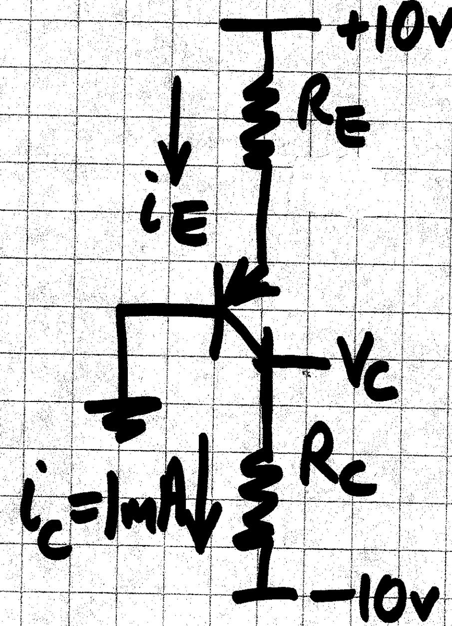
$V_B = 0 \therefore V_C \leq +0.4v$

$\therefore -10v + i_C R_C \leq 0.4$

$\& \; i_C \approx i_E = \dfrac{10 - 0.7}{2K} = 4.65mA$

$\therefore R \leq \dfrac{10.4v}{4.65mA} = 2.24K\Omega$

Ex D5.26



Find R_C, R_E for
$i_C = 1mA$
CB Rev bias 4v
Assume $\alpha = 1$

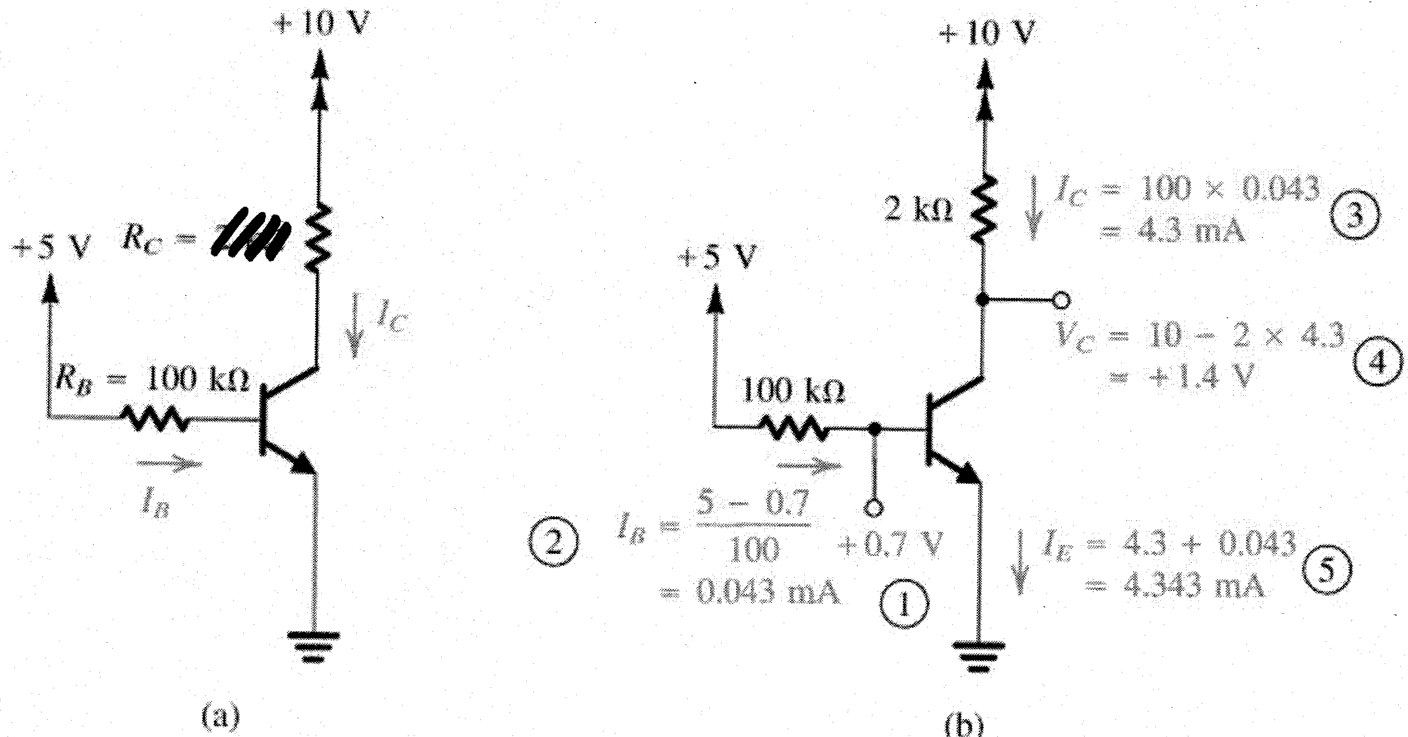
$\alpha = 1 \therefore i_E = i_C = 1mA$

CB rev bias, $V_B = 0$
$\therefore V_C = -4v$

$\therefore R_C = \dfrac{-4v - (-10v)}{1mA}$
$= 6K\Omega$

$\& \; R_E = \dfrac{10 - 0.7v}{1mA}$
$= 9.3K\Omega$ for $V_{BE} = .7v$

Ex D5.27 $\beta = 50$ to 150 Find R_c for all circuits in active mode. Find V_c range for $\beta = 50 \to 150$.



① Assume $V_{BE} = 0.7v$

② $\therefore I_B = \frac{5 - 0.7v}{100K} = 43\mu A$

③ $I_c = \beta I_B$ ④ $V_c = 10 - \beta I_B \cdot R_c$

And for active mode $V_{CB} \geq -.4v$

Figure 5.38 Example 5.8: (a) circuit; (b) analysis with the steps indicated by the circled numbers.

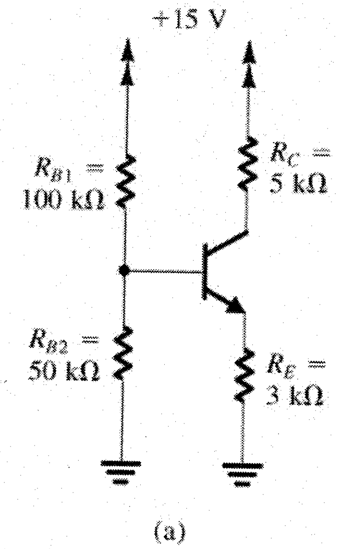
$\therefore V_c = V_{CB} + V_B \geq .3v$

$\therefore 10 - \beta I_B R_c \geq 0.3v$

$R_c \leq \frac{9.7v}{\beta \times 43\mu A} \xrightarrow{\beta = 150} \frac{9.7v}{150 \times .043} K\Omega = 1.5K\Omega$

Max
$V_c = 10 - 50 \cdot 1.5K \cdot 43\mu A$
Min $= 6.775v$
$V_c = 10 - 150 \cdot 1.5K \cdot 43\mu A$
$= 0.325v$

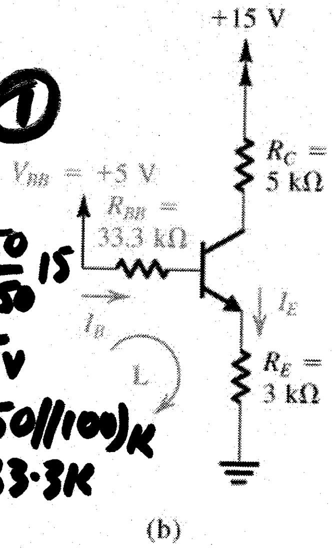
Ex 5.28 $\beta \Rightarrow 50$. Example 5.10 Calculates $i_C = 1.28\,mA$ for $\beta = 100$. Recalculate for $\beta = 50$. What is % change?



①

$$V_{BB} = \frac{50}{150}15 = 5V$$

$$R_{BB} = (50 \| 100)K = 33.3K$$



② Loop L

$$5V = I_B R_{BB} + V_{BE} + I_E R_E$$

$$I_E = \frac{5 - 0.7}{3K + \frac{33.3K}{50+1}} = 1.18\,mA$$

③ $\therefore I_C = \frac{\beta}{1+\beta} I_E = \frac{50}{51} 1.18\,mA = 1.16\,mA$

④ $\therefore$ % change $= \frac{1.16 - 1.28}{1.28} 100\% = -9.375\%$

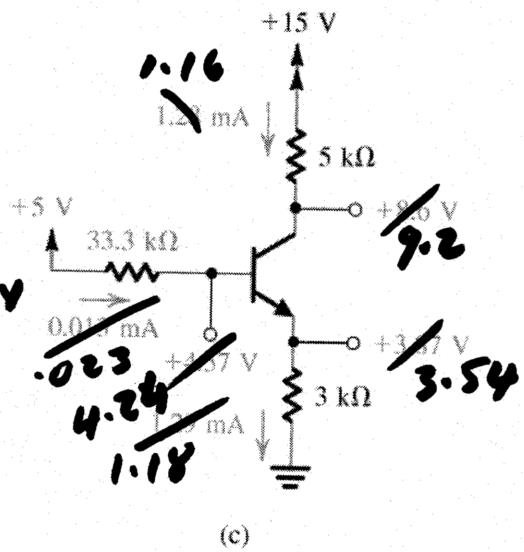
Also:

$$I_B = I_C / \beta = 23.2\,\mu A$$

$$V_E = 1.18 \times 3 = 3.54v$$

$$V_C = 15 - 1.16 \times 5 = 9.2v$$

$$V_B = 3.54 + .7 = 4.24v$$



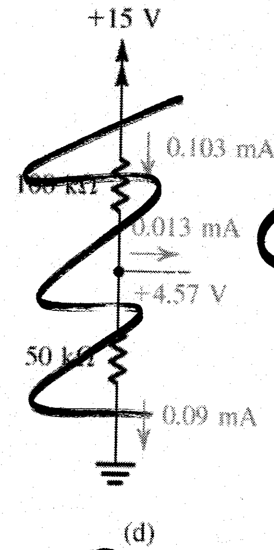
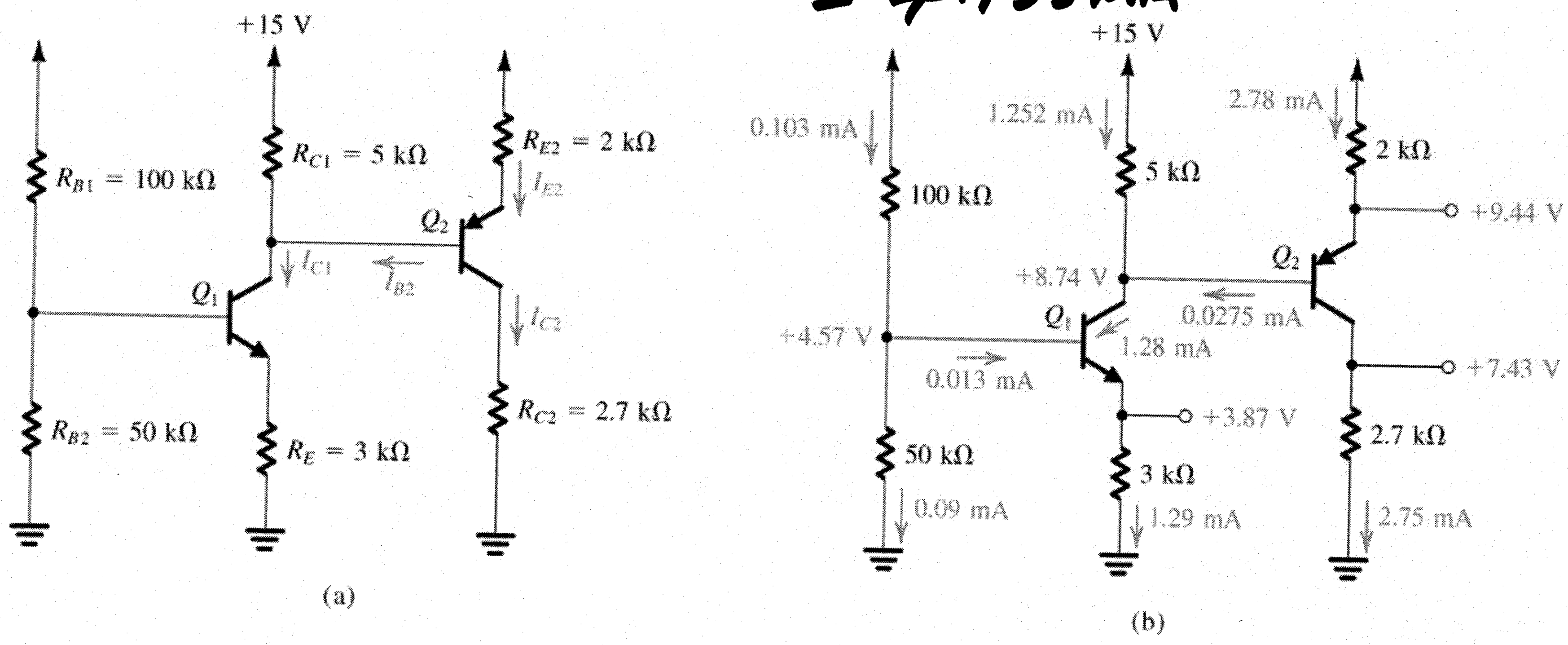


Figure 5.40 Circuits for Example 5.10.

Ex 5.29 Find total current from power supply & power dissipation in the circuit.

See Example 5.11

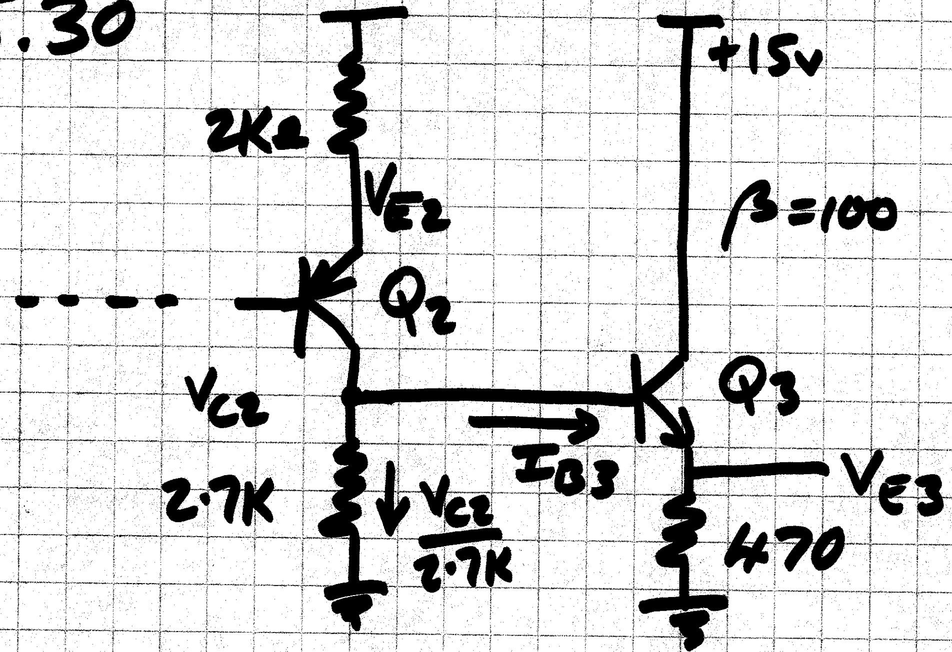
Then $I_{tot} = (2.78 + 1.252 + 0.103)\,mA$
$= 4.135\,mA$



$\therefore P = 15v \times 4.135mA = 62.025\,mW$

Figure 5.41 Circuits for Example 5.11.

Ex 5.30



From Example 5.11

$V_{C2} = 7.43v$

$I_{C2} = 2.75mA$

$I_{E2} = 2.78mA$

$V_{E2} = 9.44v$

Then add Q_3 as shown

Find V_{C2}(new), I_{E3}, V_{E3}

$$V_{E3} = V_{C2} - 0.7v$$

$$I_{E3} = \frac{V_{C2} - 0.7}{470} = 101\, I_{B3} = 101\left(2.75mA - \frac{V_{C2}}{2.7K}\right)$$

Note: I_{E2} defined by V_{B2} if Q_2 in active region

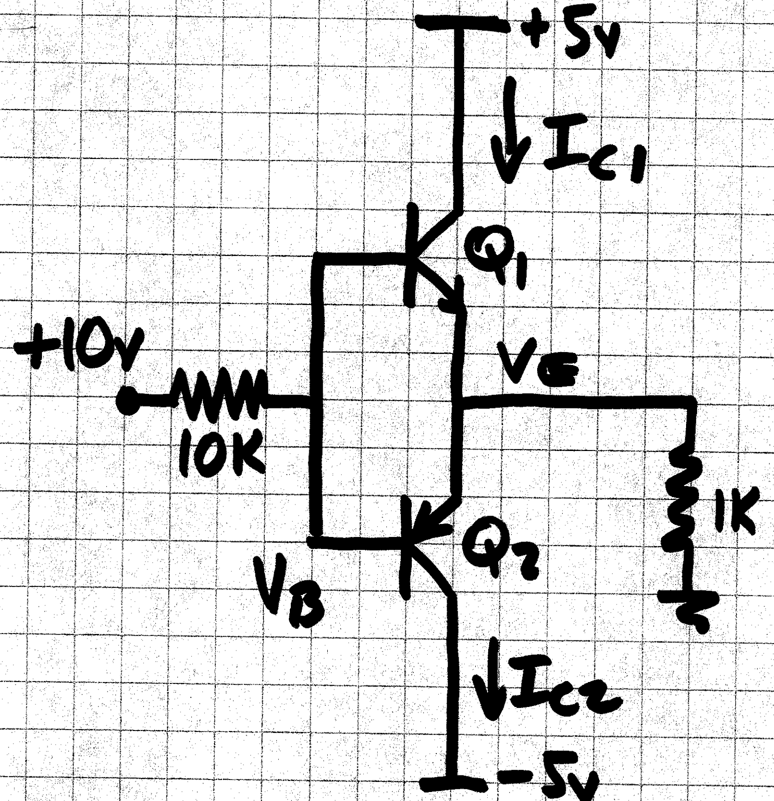
$$\therefore \quad V_{C2} = \frac{101 \times 2.75mA + \frac{.7}{470}}{\frac{1}{470} + \frac{101}{2.7K}}$$

$$= 7.064v$$

$$\therefore V_{E3} = 6.364v \quad \& \quad I_{E3} = \frac{6.364}{.470} mA = 13.54mA$$

Ex 5.31 Find V_E, V_B, I_{C1}, I_{E2}

$\beta_{min} = 30$



$V_{in} = +10v$ ∴ Assume Q_1 saturated, Q_2 cutoff.

$\therefore I_{C2} = 0$

$$10 - 10K I_{B1} - 0.7 - 1K I_{E1} = 0$$

$$\therefore I_{E1} = 9.3mA - 10K I_B$$

$$V_E = 5v - V_{CE\,sat} \approx 4.8v$$

$$\therefore I_{E1} = 4.8mA$$

$$\therefore I_{B1} = \frac{10 - .7 - 4.8}{10K} = 0.45mA$$

$$\& \; I_{C1} = I_{E1} - I_{B1} = 4.35mA$$

Note $\frac{I_{C1}}{I_{B1}} = \frac{4.35mA}{.45mA} = 9.67 < \beta_{min}$

∴ Check saturated.