# CHAPTER FOUR

## *Bipolar Digital Circuits*

*Digital Electronics.*

# Introduction



Ch 4

- This chapter describes:
  - Basic types of logic circuits:
    1. D-R-L
    2. BJT inverter
    3. T-T-L

# Terminal Currents and Voltages



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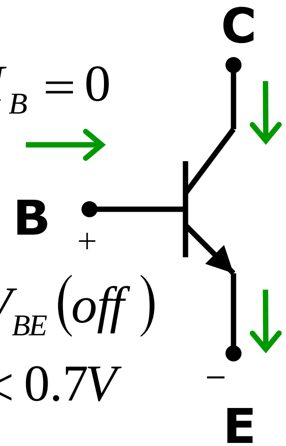
## Cut-off Mode



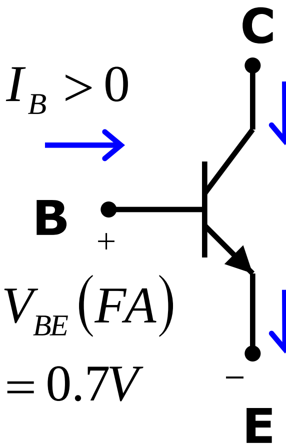

$I_B = 0$

$I_C = 0$

$I_E = 0$

$V_{BE}(off) < 0.7V$

## Forward-Active Mode



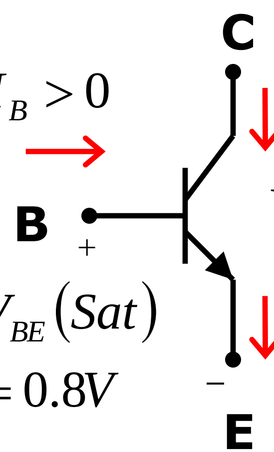

$I_B > 0$

$I_C > 0 = \beta_F I_B$

$I_E > 0 = (1+\beta) I_B$

$V_{BE}(FA) = 0.7V$

## Saturation Mode




$I_B > 0$

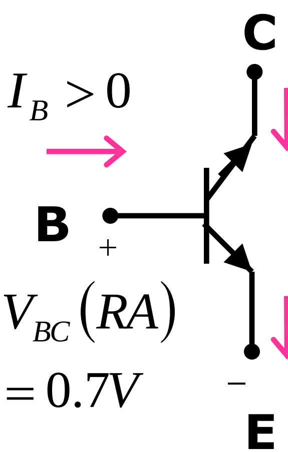
$I_C > 0 = \sigma \beta_F I_B$

$V_{CE}(Sat) = 0.2V$

$I_E > 0 = I_B + I_C$

$V_{BE}(Sat) = 0.8V$

## Inverse-Active Mode




$I_B > 0$

$-I_E = \beta_R I_B$

$-I_C = (1+\beta_R) I_B$

$V_{BC}(RA) = 0.7V$

# Terminal Currents and Voltages



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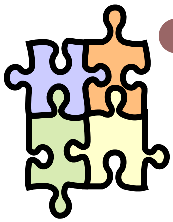


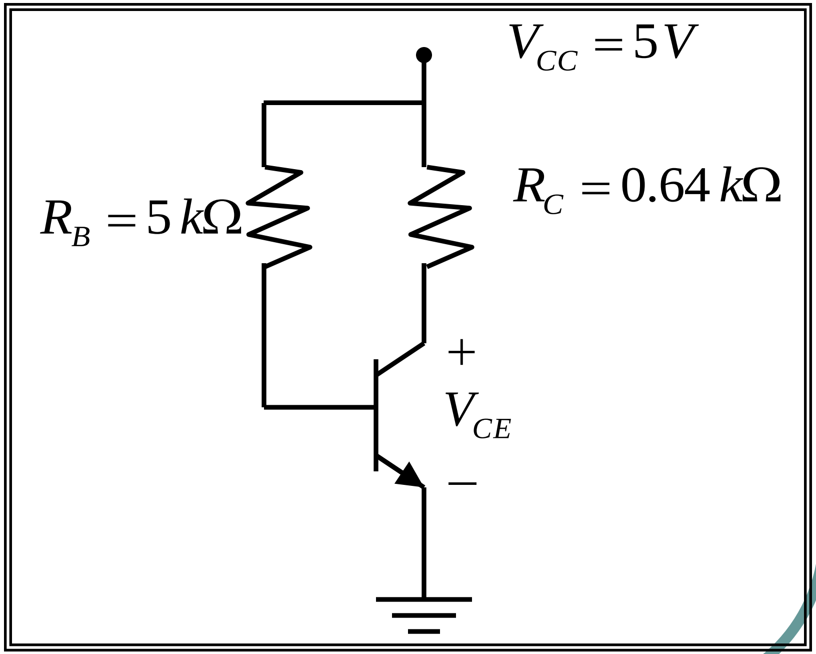
- Example

Determine $I_C$, $I_B$, and σ for the BJT shown in the following circuit, assuming $\beta_F=65$

- Solution

Assume FA, $V_{BE}=0.7V$ and then calculate $V_{CE}$. If $V_{CE}<=0.2$ then the BJT operates in saturation mode

$$V_{CE} << 0.2$$




The BJT operates in saturation mode i.e.

$$V_{CE}(sat)=0.2V \qquad V_{BE}(sat)=0.8V$$

$$I_B=\frac{V_{CC}-V_{BE}(sat)}{R_B}=0.84mA$$

$$I_C=\frac{V_{CC}-V_{CE}(sat)}{R_C}=7.5mA$$

$$\sigma=\frac{I_C}{\beta_F I_B}=0.137$$

# Terminal Currents and Voltages With Known States





- **Example**

Determine the terminal voltages of the transistors shown in the following circuit, assuming $Q_1$ operates in saturation mode while $Q_2$ and $Q_3$ operate in forward-active mode

- **Solution**

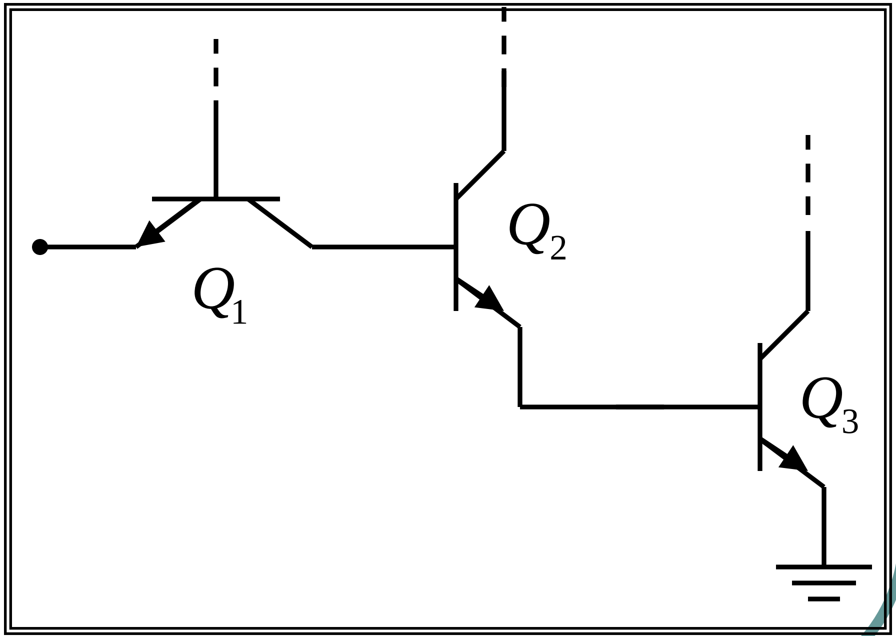
$$V_{E3} = 0.0V$$

$$V_{B3} = 0.7V$$

$$V_{B2} = 0.7 + 0.7 = 1.4V$$

$$V_{B1} = 0.6 + 1.4 = 2V$$

$$V_{E1} = -0.2 + 1.4 = 1.2V$$

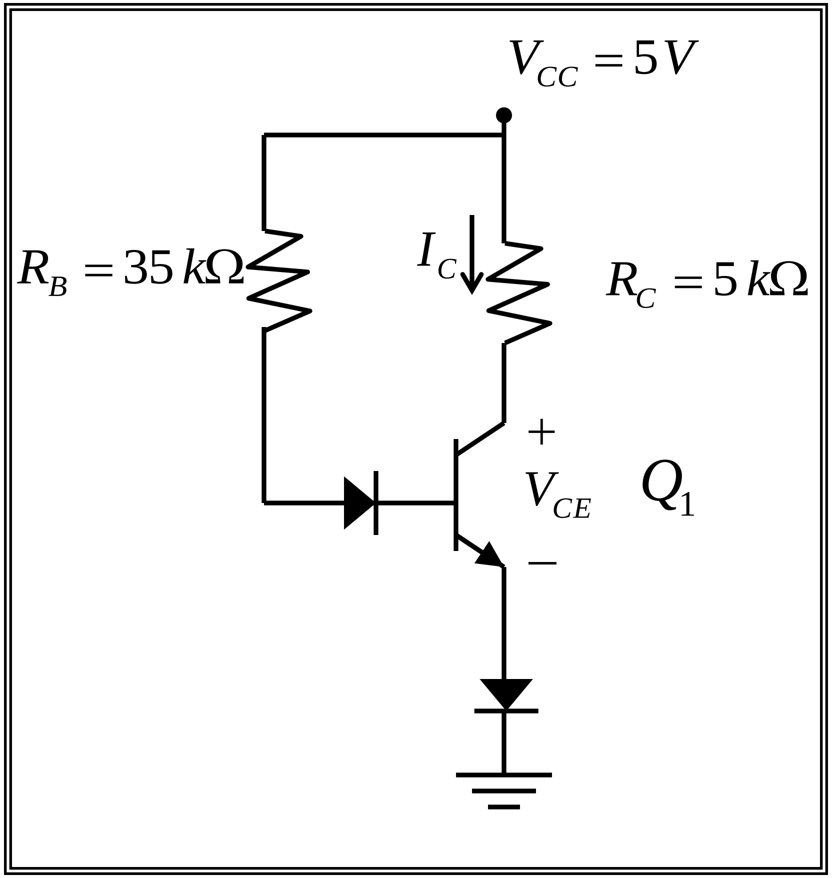


# Terminal Currents and Voltages With Known States




- **Example**

  Determine the dissipated power $P_{CC}$ in the following circuit, given that the BJT operates in saturation mode




- **Solution**

$$P_{CC}=V_{CC}\times\left(\frac{V_{CC}-V_{CE}(sat)-V_D(ON)}{R_C}+\frac{V_{CC}-V_{BE}(sat)-2V_D(ON)}{R_B}\right)$$

$$P_{CC}=5\times(0.82+0.08)=4.5mW$$

$I_{CC}$ (OL)

# Terminal Currents and Voltages With Known States



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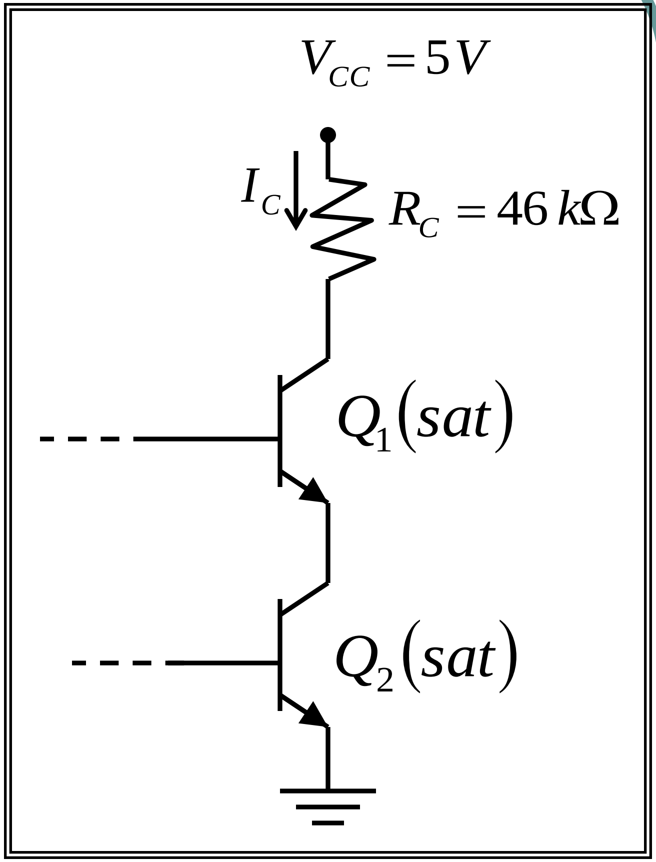
- Example

Determine the current $I_C$ in the following circuit.



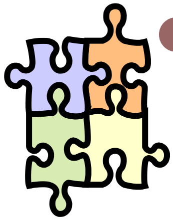

- Solution

$$I_C = \frac{V_{CC} - 2V_{CE}(sat)}{R_C} = 0.1mA$$

# Terminal Currents and Voltages With Known States

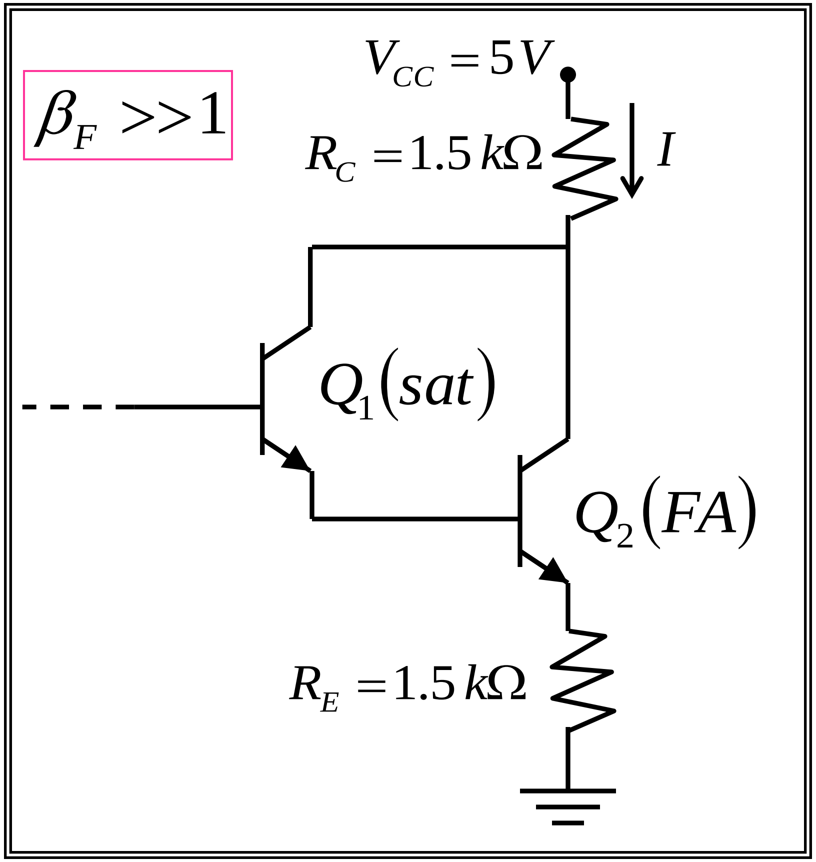






- Example

Determine the current $I$ in the following circuit neglecting the base currents.




- Solution

$I_{C2} = I_{E2}$ Since $\beta_F >> 1$

$I_{C2} = I$ Since $I_{B2} <<$ i.e $I_{E1} <<$ & $I_{C1} <<$

$$I = \frac{V_{CC} - V_{CE1}(sat) - V_{BE1}(FA)}{R_C + R_E}$$

$$I = 1.367\,mA$$

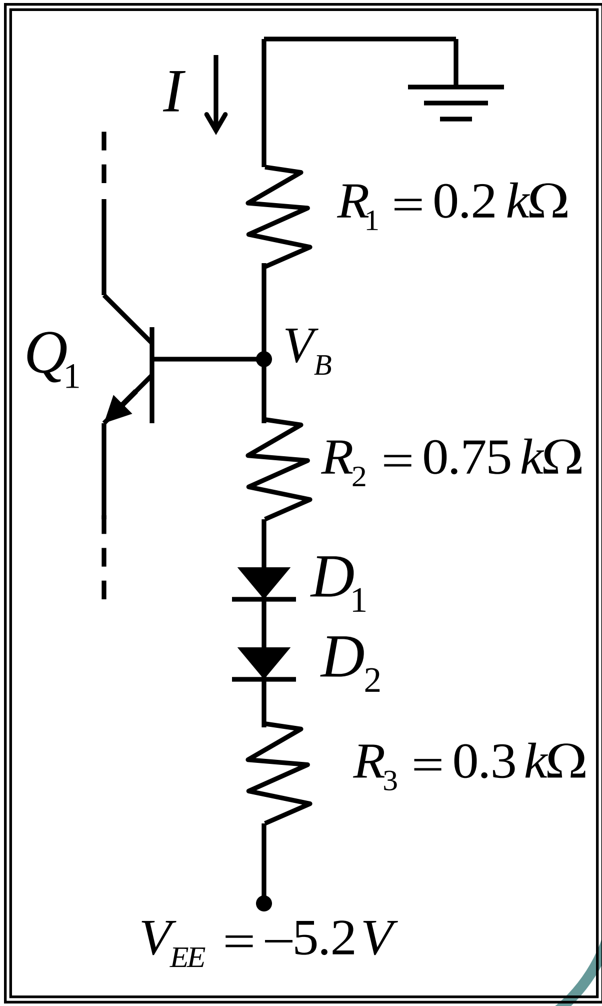
# Terminal Currents and Voltages With Known States



Ch 4

- **Example**

Determine the voltage $V_B$ and the current $I$ indicated the circuit shown below assuming the base current of $Q_1$ is negligible.




- **Solution**

$$I = \frac{0 - V_{EE} - 2V_D(ON)}{R_1 + R_2 + R_3}$$

$$= \frac{5.2 - 1.4}{0.2 + 0.75 + 0.3} = 3.04mA$$

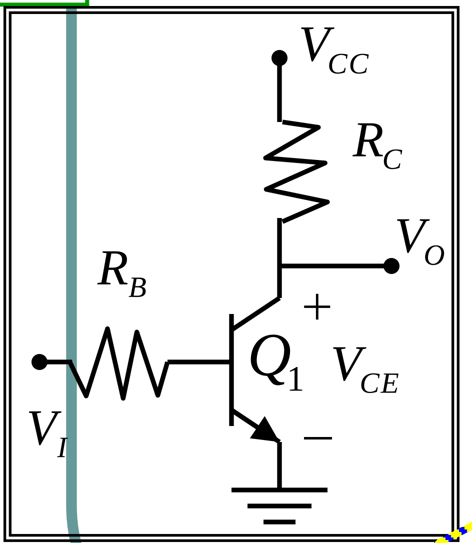
$$V_B = 0 - IR_1 = -3.04 \times 0.2 = -0.608V$$

- Voltage-Transfer Characteristics

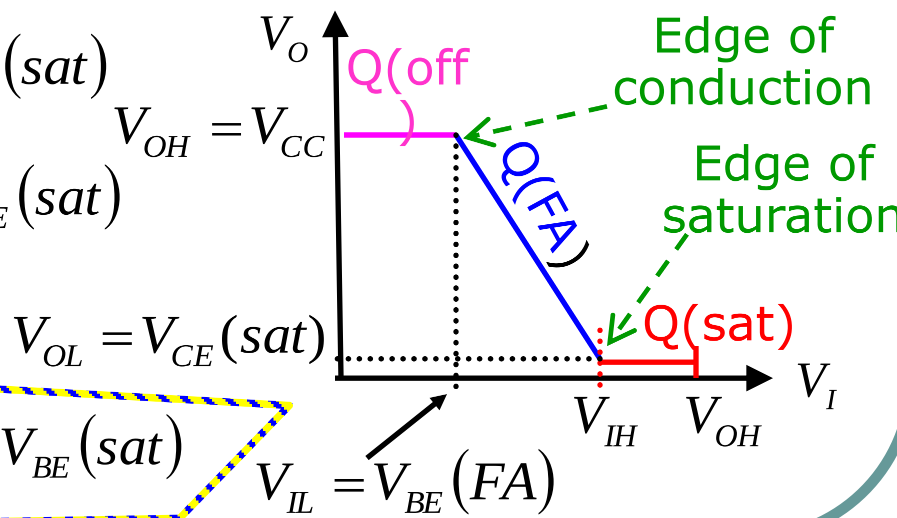
For $V_I - GND < V_{BE}(FA)$ ⇨ $I_B=0, I_C=0, V_O=V_{CC}=V_{OH}$

For $V_I - GND \geq V_{BE}(FA)$ ⇨ $I_B=(V_I-V_{BE}(FA))/R_B, I_C=\beta_F I_B, V_O=V_{CC}-I_C R_C$

For $V_I - GND \geq V_{IH}$ ⇨ $I_B=(V_I-V_{BE}(sat))/R_B$, $I_C=(V_{CC}-V_{CE}(sat))/R_C$, $V_O=V_{CE}(sat)=V_{OL}$




$$V_{IH} = I_B(sat)R_B + V_{BE}(sat)$$
$$= I_B(EOS)R_B + V_{BE}(sat)$$
$$= \frac{I_C(EOS)}{\beta_F}R_B + V_{BE}(sat)$$



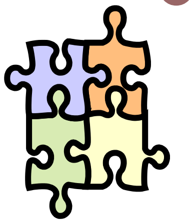

$$V_{IH} = \frac{V_{CC} - V_{CE}(sat)}{\beta_F R_C}R_B + V_{BE}(sat)$$

# BJT Inverter (Basic RTL Inverter)





- Example



Assume $V_{CC}$= 5 V, $R_C$= 1kΩ , $R_B$= 10 kΩ, $\beta_F$=60;

**Determine the <u>VTC</u> parameters and the low and high noise margins**

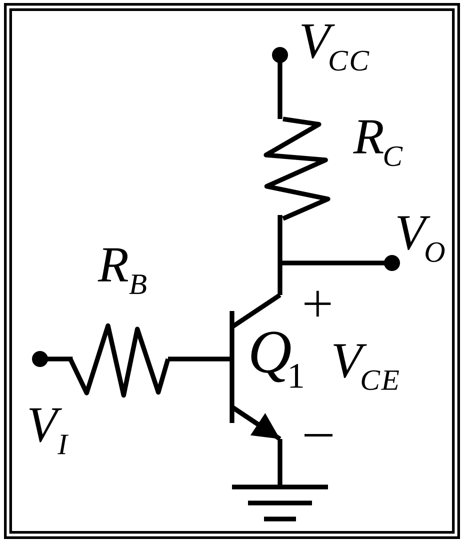
- Solution

$V_{IL}$= 0.7 V, $V_{IH}$= 1.6 V,
$V_{OL}$= 0.2 V, $V_{OH}$= 5 V,

$$N_{ML} = V_{IL} - V_{OL} = 0.5V$$

Small value

$$N_{MH} = V_{OH} - V_{IH} = 3.4V$$



- HW #4:Solve Problems: 4.1 (a)&(d), 4.3, 4.11, 4.12, 4.13, 4.21

Skip sections 4.3-4.6