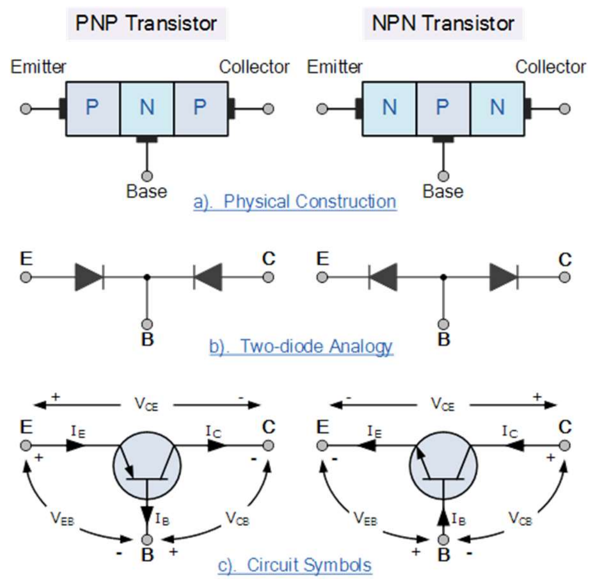
Bipolar Transistor Construction



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Bipolar Transistor Configurations

- Common Base Configuration – has Voltage Gain but no Current Gain.
- Common Emitter Configuration – has both Current and Voltage Gain.
- Common Collector Configuration – has Current Gain but no Voltage Gain.

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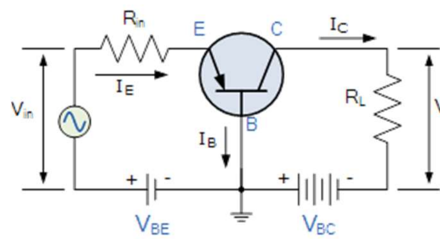
The Common Base Transistor Circuit



- high voltage gain
- Vin and Vout are "in-phase"
- Common Base Voltage Gain

$$A_V = \frac{Vout}{Vin} = \frac{I_C \times R_L}{I_E \times R_{IN}}$$

- single stage amplifier circuits such as microphone pre-amplifier or radio frequency (R*ƒ*) amplifiers due to its very good high frequency response.

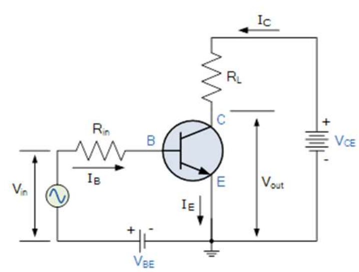
3

The Common Emitter (CE) Configuration

$$\text{Alpha},(\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta},(\beta) = \frac{I_C}{I_B}$$

$$\therefore\ I_C = \alpha.I_E = \beta.I_B$$

$$\text{as:}\ \alpha = \frac{\beta}{\beta+1} \qquad \beta = \frac{\alpha}{1-\alpha}$$



- highest current and power gain
- input impedance is LOW ,output impedance is HIGH
- Vin and Vout has a 180º phase-shift
- greater input impedance, current and power gain

$$I_E = I_C + I_B$$

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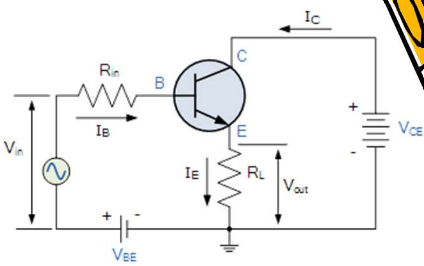
The Common Collector (CC) Configuration

$$I_E = I_C + I_B$$

$$A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1$$



- **Voltage Follower** or **Emitter Follower** circuit.
- useful for impedance matching applications
- very high input impedance, low output impedance
- good current amplification, voltage gain of about "1" (unity gain)

Vin and Vout are "in-phase"

$$A_i = \beta + 1 \qquad I_E = I_C + I_B$$

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The Common Collector (CC) Configuration

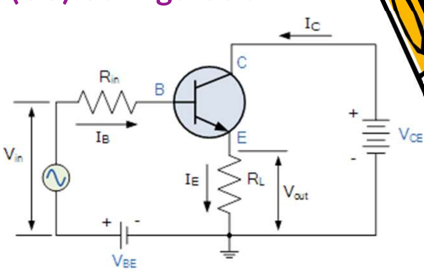
$$I_E = I_B + I_C$$

$$I_C = I_E - I_B$$

$$I_B = I_E - I_C$$

$$\alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta}$$

$$\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}$$



$$I_B = \frac{I_C}{\beta} = \frac{I_E}{1+\beta} = I_E(1-\alpha)$$

$$I_C = \beta . I_B = \alpha . I_E$$

$$I_E = \frac{I_C}{\alpha} = I_B(1+\beta)$$

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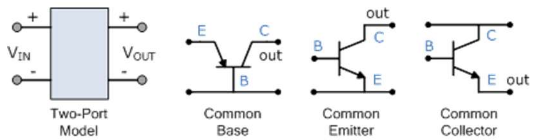
Bipolar Transistor Summary



Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Shift	0°	180°	0°
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

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Bipolar Junction Transistor(BJT) as an Amplifer

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Reference: Thomas L. Floyd, Electronics Devices: Pearson Education Inc

BJT as an amplifier

- DC quantities always carry an uppercase roman (nonitalic) subscript. For example, I_B, I_C, and I_E are the dc transistor currents. V_{BE}, V_{CB}, and V_{CE} are the dc voltages from one transistor terminal to another. Single subscripted voltages such as V_B, V_C, and V_E are dc voltages from the transistor terminals to ground.

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BJT as an amplifier

- *AC* and all time-varying quantities always carry a lowercase italic subscript. For example, I_b, I_c, and I_e are the ac transistor currents. V_{be}, V_{cb}, and V_{ce} are the ac voltages from one transistor terminal to another. Single subscripted voltages such as V_b, V_c, and V_e are ac voltages from the transistor terminals to ground.

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BJT as an amplifier

- The rule is different for *internal transistor resistances*. As you will see later, transistors have internal ac resistances that are designated by lowercase *r'* with an appropriate subscript.
- For example, the internal ac emitter resistance is designated as r'_e.
- For example R_E is an external dc emitter resistance and R_e is an external ac emitter resistance.

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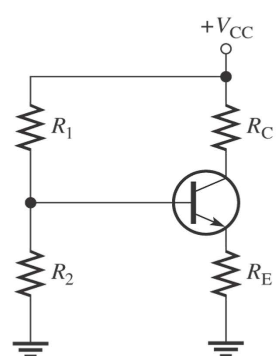
DC Analysis of BJTs

- The voltage divider biasing is widely used
- Input resistance is:

  $R_{IN} \cong \beta_{DC} R_E$
- The base voltage is approximately:

  $V_B \cong V_{CC} R_2 / (R_1 + R_2)$



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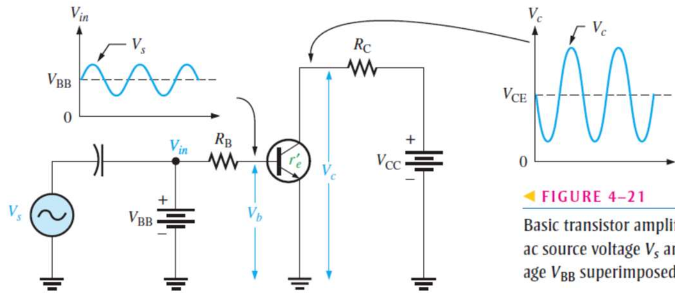
Voltage amplification



◀ FIGURE 4–21

Basic transistor amplifier circuit with ac source voltage V_s and dc bias voltage V_{BB} superimposed.

The forward-biased base-emitter junction presents a very low resistance to the ac signal. This internal ac emitter resistance is designated r'_e in Figure 4–21 and appears in series with R_B. The ac base voltage is

$$V_b = I_e r'_e$$

The ac collector voltage, V_c, equals the ac voltage drop across R_C.

$$V_c = I_c R_C$$

Since $I_c \cong I_e$, the ac collector voltage is

$$V_c \cong I_e R_C$$

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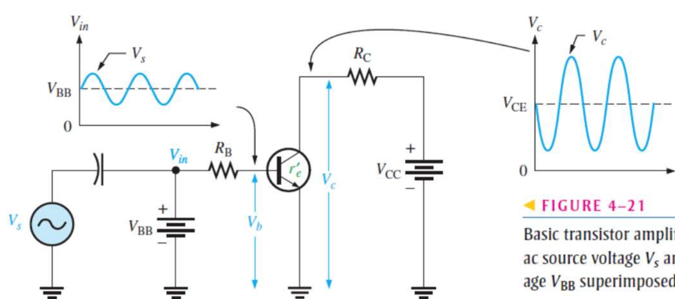
Voltage amplification



◀ FIGURE 4–21

Basic transistor amplifier circuit with ac source voltage V_s and dc bias voltage V_{BB} superimposed.

V_b can be considered the transistor ac input voltage where $V_b = V_s - I_b R_B$. V_c can be considered the transistor ac output voltage. Since *voltage gain* is defined as the ratio of the output voltage to the input voltage, the ratio of V_c to V_b is the ac voltage gain, A_v, of the transistor.

$$A_v = \frac{V_c}{V_b}$$

Substituting $I_e R_C$ for V_c and $I_e r'_e$ for V_b yields

$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r'_e}$$

The I_e terms cancel; therefore,

$$A_v \cong \frac{R_C}{r'_e}$$

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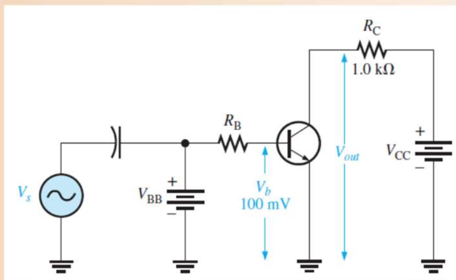
Voltage amplification

Determine the voltage gain and the ac output voltage in Figure 4–22 if $r'_e = 50\ \Omega$.



The voltage gain is

$$A_v \cong \frac{R_C}{r'_e} = \frac{1.0\,\text{k}\Omega}{50\ \Omega} = \mathbf{20}$$

The voltage gain is

$$A_v \cong \frac{R_C}{r'_e} = \frac{1.0\,\text{k}\Omega}{50\ \Omega} = \mathbf{20}$$

Therefore, the ac output voltage is

$$V_{out} = A_v V_b = (20)(100\text{ mV}) = \mathbf{2\ V\ rms}$$

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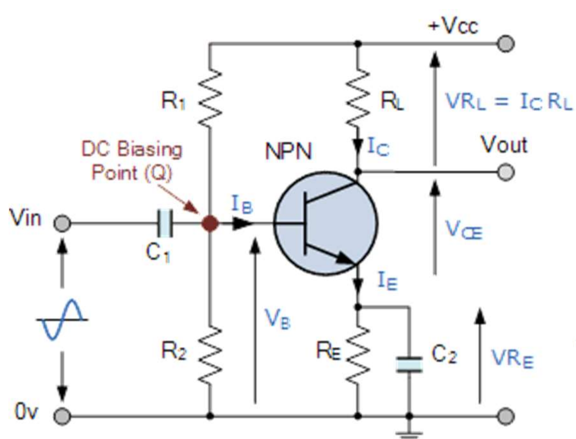
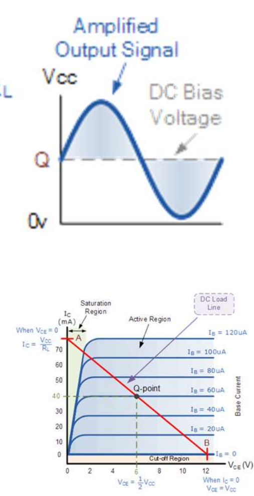
Single Stage Common Emitter Amplifier Circuit





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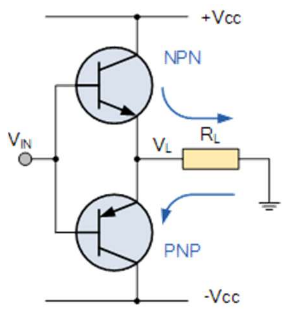
Transistor Matching

- Class-B amplifiers uses "Complementary" or "Matched Pair"
- class B amplifiers use complementary NPN and PNP in their power output stage design. The NPN transistor conducts for only the positive half of the signal while the PNP transistor conducts for negative half of the signal.



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Terminal Resistance Values for PNP and NPN Transistors

Between Transistor Terminals		PNP	NPN
Collector	Emitter	R_{HIGH}	R_{HIGH}
Collector	Base	R_{LOW}	R_{HIGH}
Emitter	Collector	R_{HIGH}	R_{HIGH}
Emitter	Base	R_{LOW}	R_{HIGH}
Base	Collector	R_{HIGH}	R_{LOW}
Base	Emitter	R_{HIGH}	R_{LOW}

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BJT Class A Amplifiers

- In a class A amplifier, the transistor conducts for the full cycle of the input signal (360°)
  - used in low-power applications
- The transistor is operated in the active region, between saturation and cutoff
  - saturation is when both junctions are forward biased
  - the transistor is in cutoff when $I_B = 0$
- The *load line* is drawn on the collector curves between saturation and cutoff

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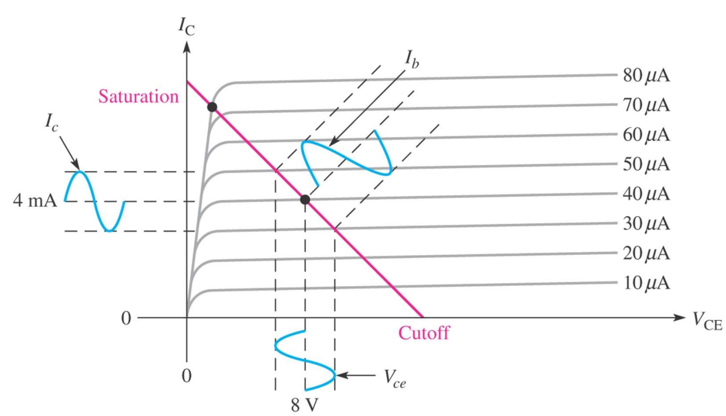
BJT Class A Amplifiers



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BJT Class A Amplifiers

- Three biasing mode for class A amplifiers
  - **common-emitter** (CE) amplifier
  - **common-collector** (CC) amplifier
  - **common-base** (CB) amplifier

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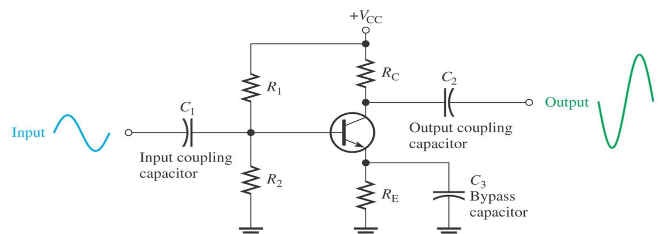
BJT Class A Amplifiers

- A **common-emitter** (CE) amplifier
  - capacitors are used for coupling ac without disturbing dc levels



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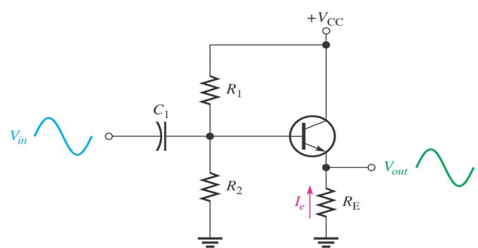
BJT Class A Amplifiers

- A **common-collector** (CC) amplifier
  - voltage gain is approximately 1, but current gain is greater than 1



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BJT Class A Amplifiers

- The third configuration is the **common-base** (CB)
  - the base is the grounded (common) terminal
  - the input signal is applied to the emitter
  - output signal is taken off the collector
  - output is in-phase with the input
  - voltage gain is greater than 1
  - current gain is always less than 1

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BJT Class B Amplifiers

- When an amplifier is biased such that it operates in the linear region for 180° of the input cycle and is in cutoff for 180°, it is a class B amplifier
  - A class B amplifier is more efficient than a class A
- In order to get a linear reproduction of the input waveform, the class B amplifier is configured in a push-pull arrangement
  - The transistors in a class B amplifier must be biased above cutoff to eliminate crossover distortion

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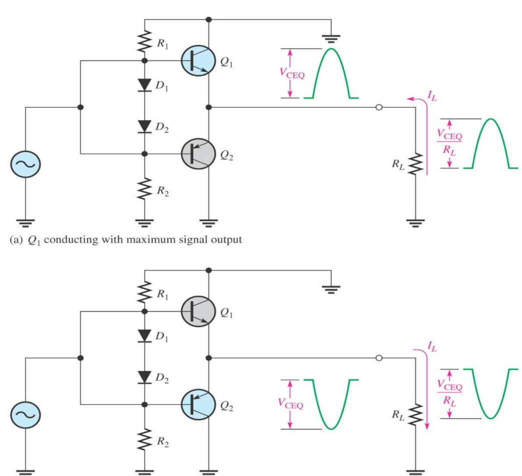
BJT Class B Amplifiers



(a) Q_1 conducting with maximum signal output

(b) Q_2 conducting with maximum signal output

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Bipolar Junction Transistor(BJT) as a Switch

Reference: Thomas L. Floyd, Electronics Devices: Pearson Education Inc

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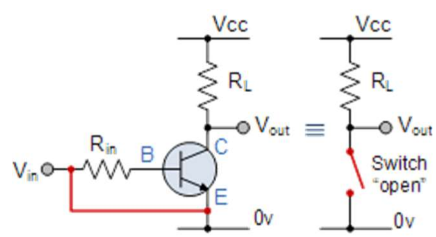
BJT as a Switch

- The transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an *open* between collector and emitter, as indicated by the switch equivalent.



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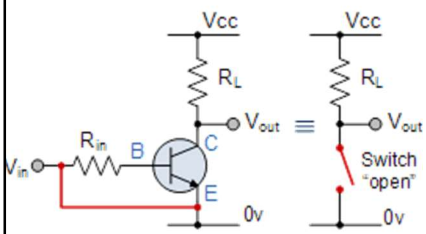
Cut-off Characteristics



- The input and Base are grounded (0v)
- Base-Emitter voltage V_{BE} < 0.7v
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC}$ = "1"
- Transistor operates as an "open switch"

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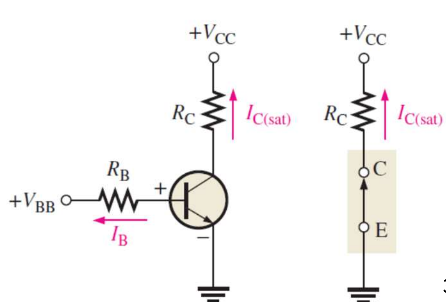
BJT as a Switch

The transistor is in the saturation region because the base-emitter junction and the base-collector junction are forward-biased and the collector current to reach its saturation value. In this condition, there is, ideally, a *short* between collector and emitter, as indicated by the switch equivalent. Actually, a small voltage drop across the transistor, which is the saturation voltage, *VCE*(sat).



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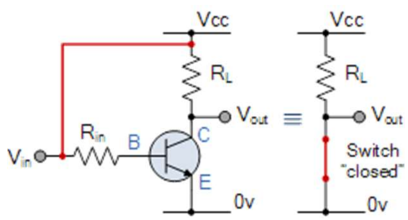
Saturation Characteristics



- The input and Base are connected to V_{CC}
- Base-Emitter voltage V_{BE} > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- V_{CE} = 0 (ideal saturation)
- $V_{OUT} = V_{CE}$ = "0"
- Transistor operates as a "closed switch"

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BJT as a Switch

Conditions in Cutoff As mentioned before, a transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}.

$$V_{CE(cutoff)} = V_{CC}$$

Conditions in Saturation As you have learned, when the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can usually be neglected.

The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Normally, I_B should be significantly greater than $I_{B(min)}$ to ensure that the transistor is saturated.

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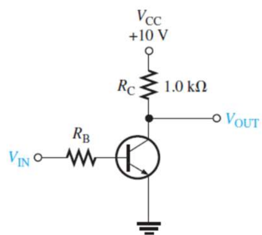
BJT as a Switch

(a) For the transistor circuit in Figure 4–24, what is V_{CE} when $V_{IN} = 0$ V?

(b) What minimum value of I_B is required to saturate this transistor if β_{DC} is 200? Neglect $V_{CE(sat)}$.

(c) Calculate the maximum value of R_B when $V_{IN} = 5$ V.



(a) When $V_{IN} = 0$ V, the transistor is in cutoff (acts like an open switch) and

$$V_{CE} = V_{CC} = \mathbf{10\ V}$$

(b) Since $V_{CE(sat)}$ is neglected (assumed to be 0 V),

$$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{10\ \text{V}}{1.0\ \text{k}\Omega} = 10\ \text{mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{10\ \text{mA}}{200} = \mathbf{50\ \mu A}$$

This is the value of I_B necessary to drive the transistor to the point of saturation. Any further increase in I_B will ensure the transistor remains in saturation but there cannot be any further increase in I_C.

(c) When the transistor is on, $V_{BE} \cong 0.7$ V. The voltage across R_B is

$$V_{R_B} = V_{IN} - V_{BE} \cong 5\ \text{V} - 0.7\ \text{V} = 4.3\ \text{V}$$

Calculate the maximum value of R_B needed to allow a minimum I_B of 50 μA using Ohm's law as follows:

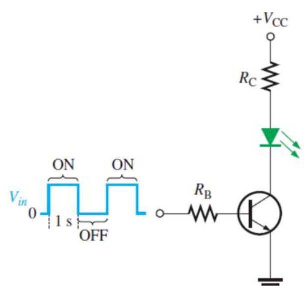
$$R_{B(max)} = \frac{V_{R_B}}{I_{B(min)}} = \frac{4.3\ \text{V}}{50\ \mu\text{A}} = \mathbf{86\ k\Omega}$$

A Simple application of a BJT Switch

The transistor in Figure 4–25 is used as a switch to turn the LED on and off. For example, a square wave input voltage with a period of 2 s is applied to the input as indicated. When

▶ FIGURE 4–25

A transistor used to switch an LED on and off.



the square wave is at 0 V, the transistor is in cutoff; and since there is no collector current, the LED does not emit light. When the square wave goes to its high level, the transistor saturates. This forward-biases the LED, and the resulting collector current through the LED causes it to emit light. Thus, the LED is on for 1 second and off for 1 second.

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A Simple application of a BJT Switch

The LED in Figure 4–25 requires 30 mA to emit a sufficient level of light. Therefore, the collector current should be approximately 30 mA. For the following circuit values, determine the amplitude of the square wave input voltage necessary to make sure that the transistor saturates. Use double the minimum value of base current as a safety margin to ensure saturation. $V_{CC} = 9\text{ V}$, $V_{CE(sat)} = 0.3\text{ V}$, $R_C = 220\ \Omega$, $R_B = 3.3\text{ k}\Omega$, $\beta_{DC} = 50$, and $V_{LED} = 1.6\text{ V}$.

$$I_{C(sat)} = \frac{V_{CC} - V_{LED} - V_{CE(sat)}}{R_C} = \frac{9\text{ V} - 1.6\text{ V} - 0.3\text{ V}}{220\ \Omega} = 32.3\text{ mA}$$

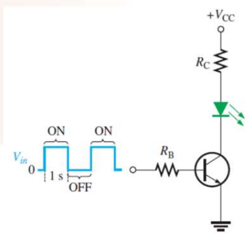
$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{32.3\text{ mA}}{50} = 646\ \mu\text{A}$$

To ensure saturation, use twice the value of $I_{B(min)}$, which is 1.29 mA. Use Ohm's law to solve for V_{in}.

$$I_B = \frac{V_{R_B}}{R_B} = \frac{V_{in} - V_{BE}}{R_B} = \frac{V_{in} - 0.7\text{ V}}{3.3\text{ k}\Omega}$$

$$V_{in} - 0.7\text{ V} = 2I_{B(min)}R_B = (1.29\text{ mA})(3.3\text{ k}\Omega)$$

$$V_{in} = (1.29\text{ mA})(3.3\text{ k}\Omega) + 0.7\text{ V} = \mathbf{4.96\ V}$$



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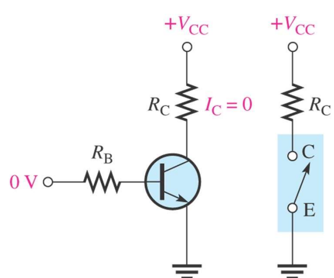
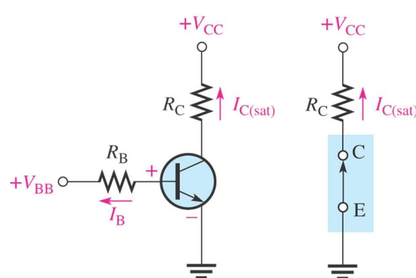
The BJT as a Switch



(a) Cutoff — open switch



(b) Saturation — closed switch

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The BJT as a Switch

- When used as an electronic switch, a transistor normally is operated alternately in cutoff and saturation
  - A transistor is in cutoff when the base-emitter junction is not forward-biased. V_{CE} is approximately equal to V_{CC}
  - When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated

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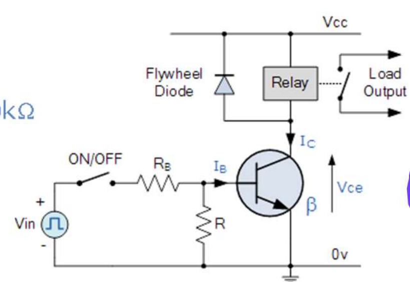
Basic NPN Transistor Switching Circuit

- Using the transistor values from the previous tutorials of: β = 200, Ic = 4mA and Ib = 20uA, find the value of the Base resistor (Rb) required to switch the load fully "ON" when the input terminal voltage exceeds 2.5v.

$$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{2.5v - 0.7v}{20x10^{-6}} = 90k\Omega$$



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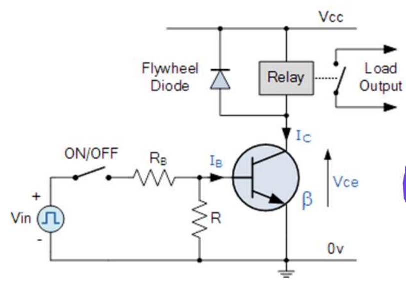
Basic NPN Transistor Switching Circuit

- Again using the same values, find the minimum Base current required to turn the transistor "fully-ON" (saturated) for a load that requires 200mA of current when the input voltage is increased to 5.0V. Also calculate the new value of Rb.

$$I_B = \frac{I_C}{\beta} = \frac{200\text{mA}}{200} = 1\text{mA}$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{5.0\text{v} - 0.7\text{v}}{1\times10^{-3}} = 4.3\text{k}\Omega$$



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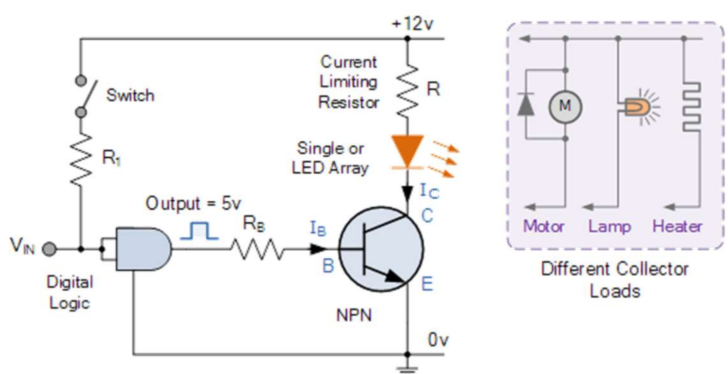
An example -- Digital Logic Transistor Switch



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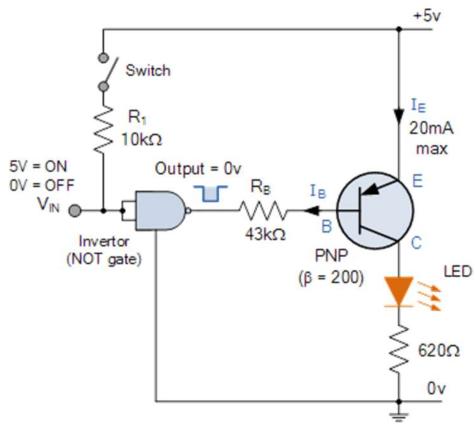
An example --PNP Transistor Switching Circuit



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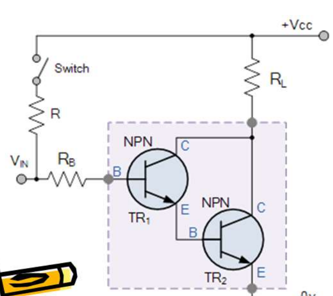
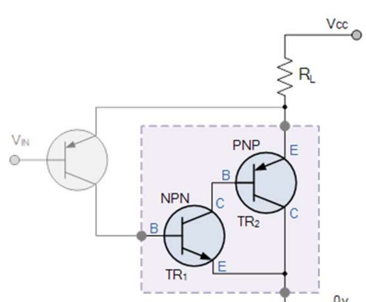
An example --Darlington Transistor Configurations

- high switching speeds
- very high current gain

$$\beta_{TOTAL} = \beta_1 \times \beta_2$$



NPN Darlington Output



Complementary (Sziklai) Output

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Transistor as a Switch Summary

- Transistor switches can be used to switch and control lamps, relays or even motors.
- When using the bipolar transistor as a switch they must be either "fully-OFF" or "fully-ON".
- Transistors that are fully "ON" are said to be in their **Saturation** region.
- Transistors that are fully "OFF" are said to be in their **Cut-off** region.
- When using the transistor as a switch, a small Base current controls a much larger Collector load current.
- When using transistors to switch inductive loads such as relays and solenoids, a "Flywheel Diode" is used.
- When large currents or voltages need to be controlled, **Darlington Transistors** can be used.

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Transistor Categories

Manufacturers generally classify bipolar junction transistors into three broad categories:

- general-purpose/small-signal devices.
- power devices.
- RF (radio frequency/microwave)devices.

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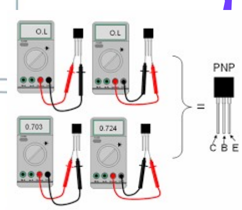
Transistor Categories



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