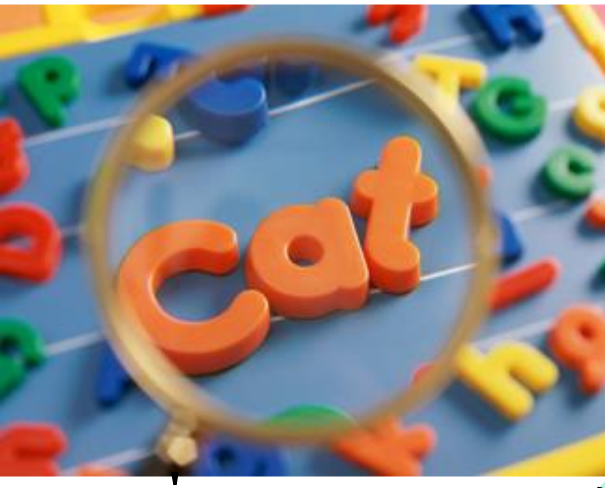
EN2042102 วงจรไฟฟ้าและอิเล็กทรอนิกส์

Circuits and Electronics



บทที่ 7 ทรานซิสเตอร์

Bipolar Junction Transistor

สาขาวิชาวิศวกรรมคอมพิวเตอร์

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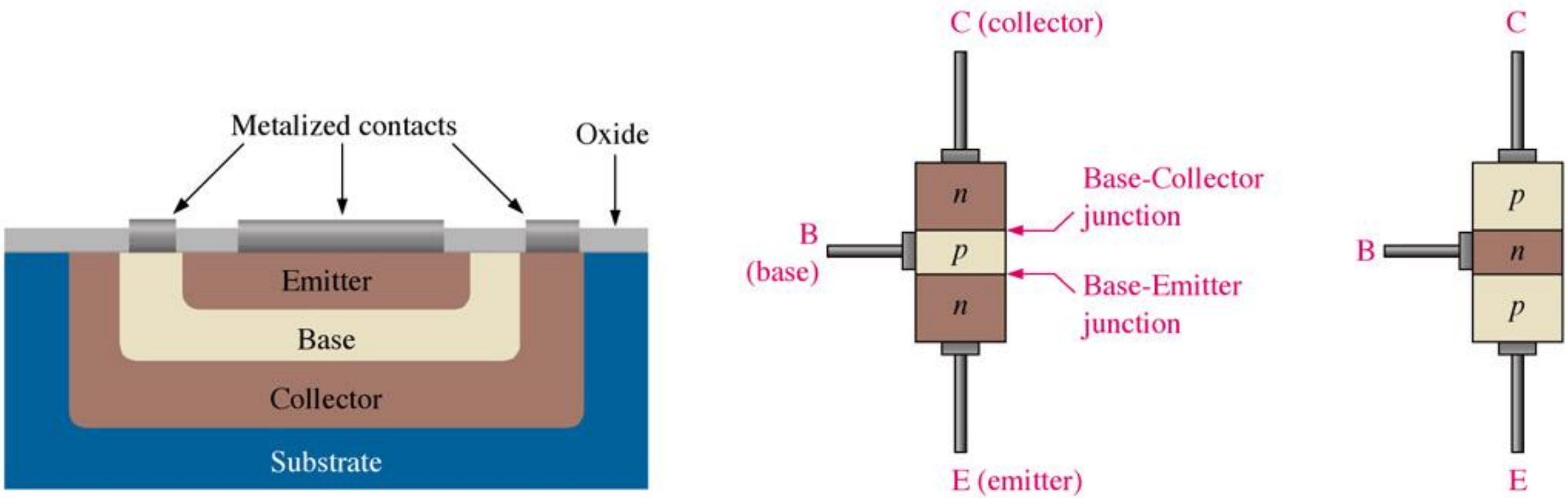
Objectives

- Describe the basic structure of the bipolar junction transistor (BJT)
- Explain and analyze basic transistor bias and operation
- Discuss the parameters and characteristics of a transistor and how they apply to transistor circuits
- Discuss how a transistor can be used as an amplifier or a switch
- Troubleshoot various failures typical of transistor circuits

BJT Construction

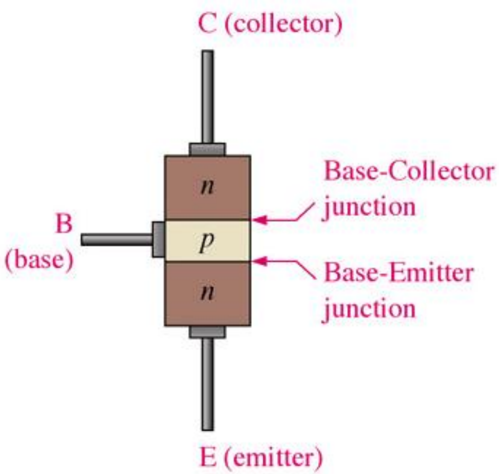
- With diodes there is one p-n junction. With **bipolar junction transistors (BJT)**, there are three three layers and two p-n junctions. Transistors can be a either **pnp** or **npn** type.
  - The emitter (E) and is heavily doped (n-type).
  - The collector (C) is also doped (n-type).
  - The base (B) is lightly doped with opposite type to the emitter and collector (i.e. p-type in the npn transistor).
  - The base is physically very thin.
- The p-n junction joining the base and emitter regions is called the base-emitter (B-E) junction. (or emitter-base, it doesn't really matter)
- The p-n junction between the base and collector regions is called the collector-base (C-B) junction.(or base-collector)

BJT Construction

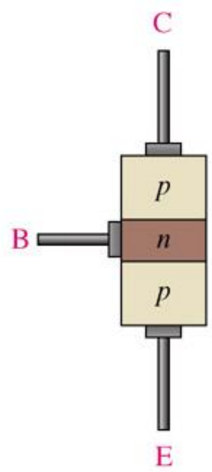


(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

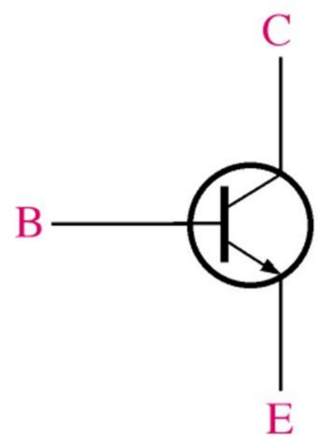
Symbols



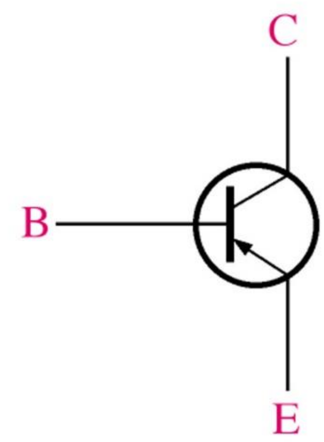
(b) *npn*



(c) *pnp*



(a) *npn*

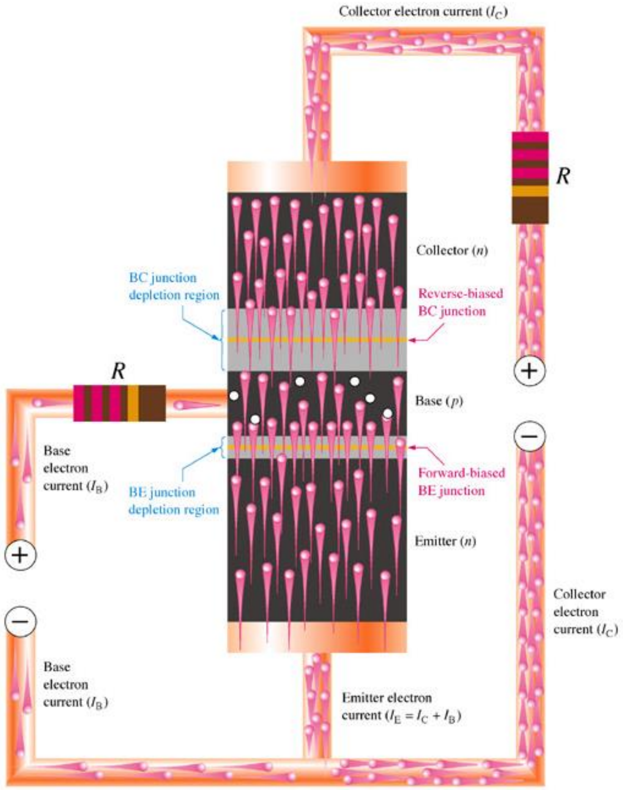


(b) *pnp*

Current Flows

- The forward bias between the base and emitter injects electrons from the emitter into the base and holes from the base into the emitter.
- As the emitter is heavily doped and the base lightly doped most of the current transport across this junction is due to the electrons flowing from emitter to base
- The base is lightly doped and physically very thin.
- Thus only a small percentage of electrons flowing across the base-emitter (BE) junction combine with the available holes in this region.

$$I_E = I_C + I_B$$

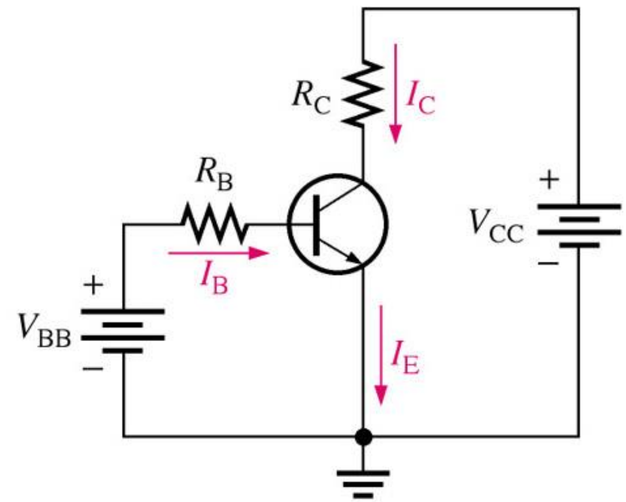


BJT Operation

- A transistor is a device which can be used as either an:
  - Amplifier
  - Switch
- Let’s first consider it’s operation in a more simple view as a current controlling device.

BJT Operation

- Look at this one circuit as two separate circuits:
  - base-emitter(left side) circuit
  - collector-emitter(right side) circuit.
- Note that the emitter leg serves as a conductor for both circuits.
- The amount of current flow in the base-emitter circuit controls the amount of current that flows in the collector circuit.
- Small changes in base-emitter current yields a large change in collector-current.
- I_C is approx 100 times I_B (ratio is called beta β)



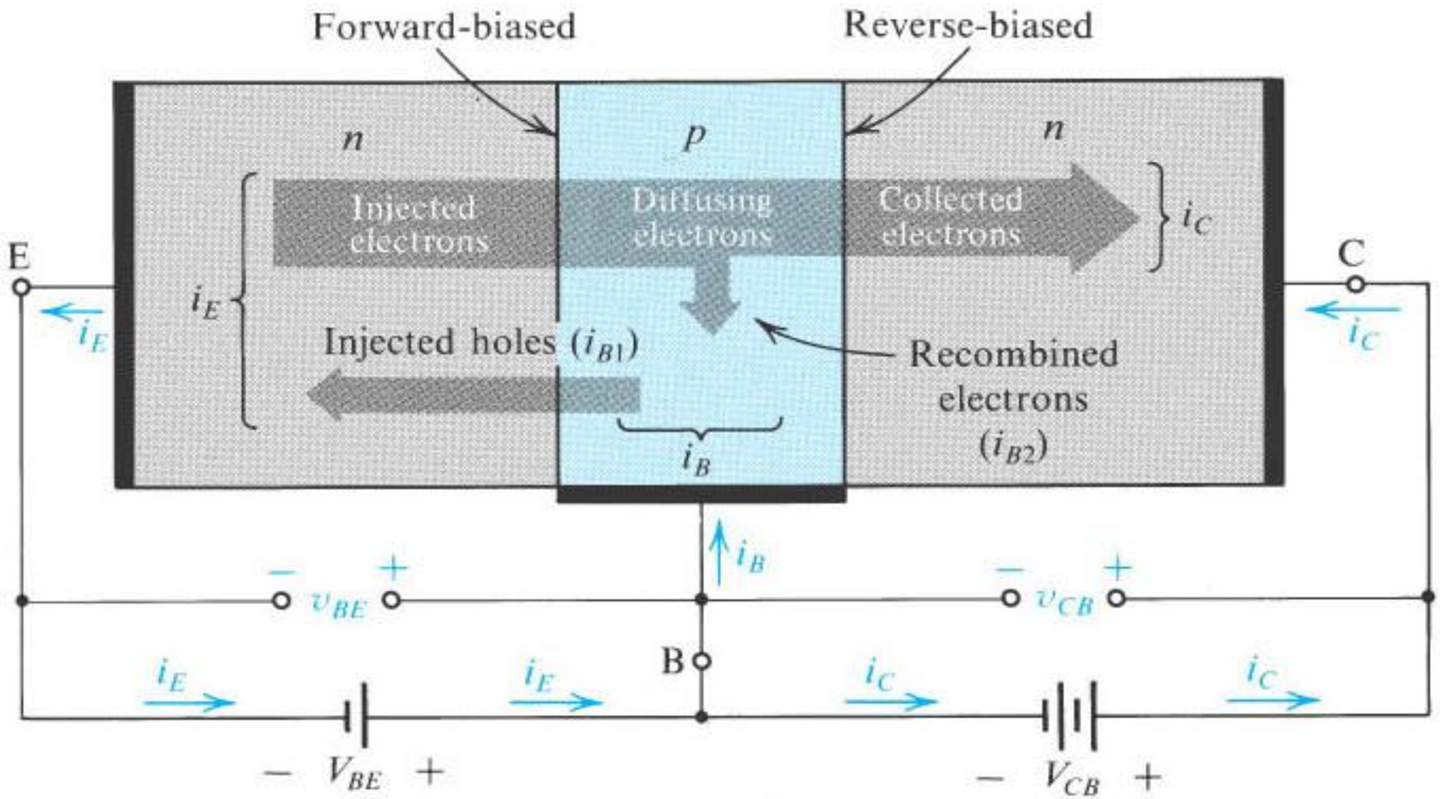
(a) *npn*

Modes of Operation

- Depending on the bias condition (forward or reverse) of each of the two junctions, there are different modes of operation of the BJT.

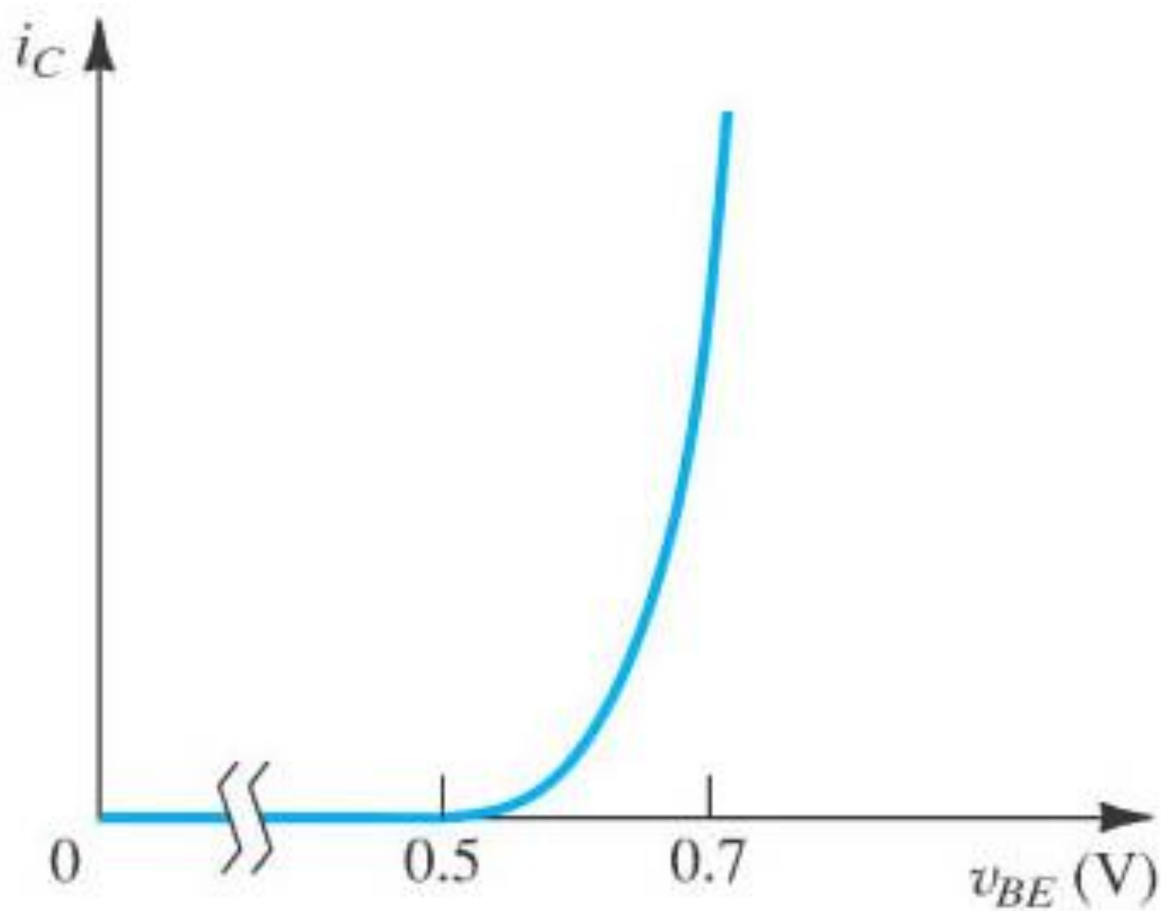
Modes	EBJ	CBJ	Application
Cutoff	Reverse	Reverse	Switching application in digital circuits
Saturation	Forward	Forward	
Active	Forward	Reverse	Amplifier
Reverse active	Reverse	Forward	Performance degradation

Amplification

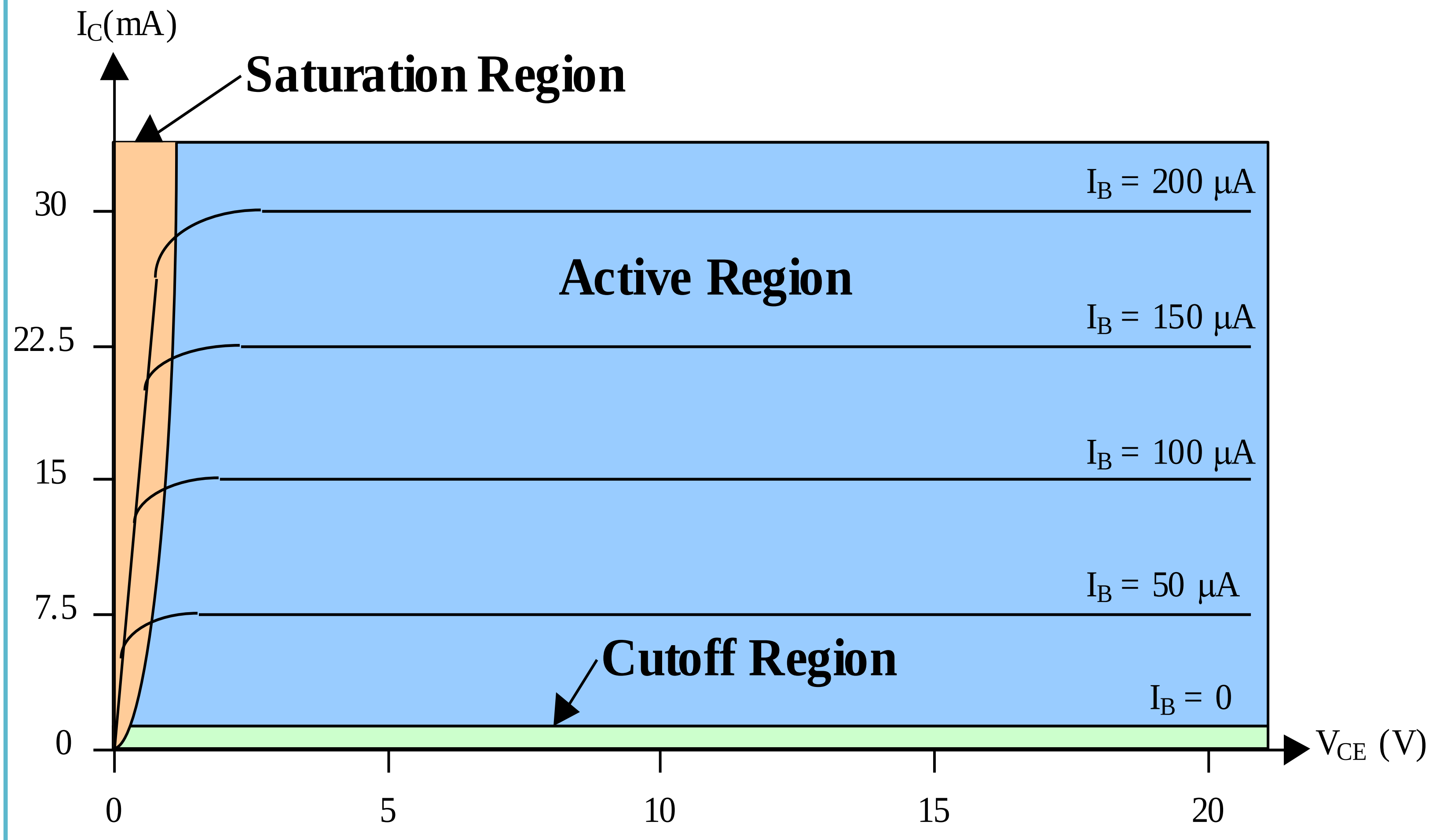


Input Characteristics

- The ic-*v*BE characteristic for an npn transistor



Output Characteristics

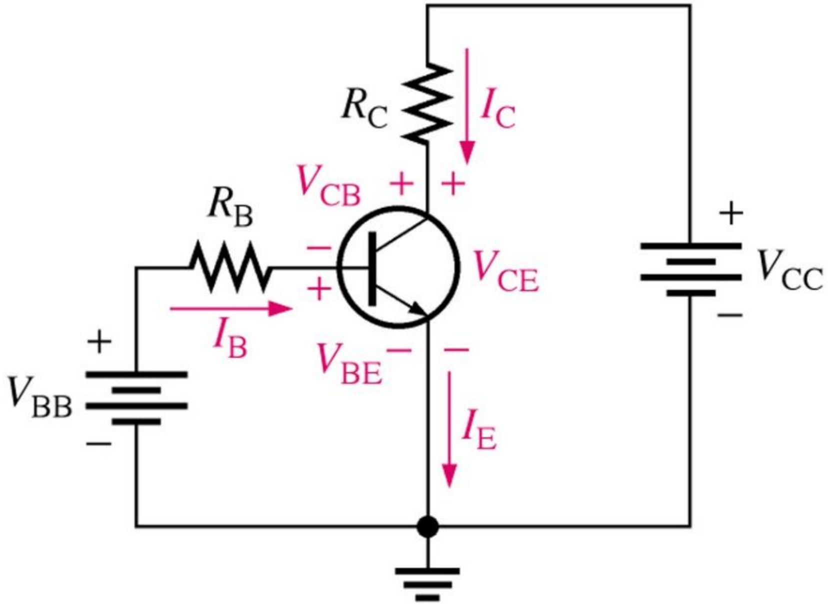


Transistor Characteristics and Parameters

- As previously discussed, base-emitter current changes yields large changes in collector-emitter current. The factor of this change is called ***beta***(β).

$$\beta_{DC} = I_C / I_B$$

$$\alpha_{DC} = I_C / I_E$$

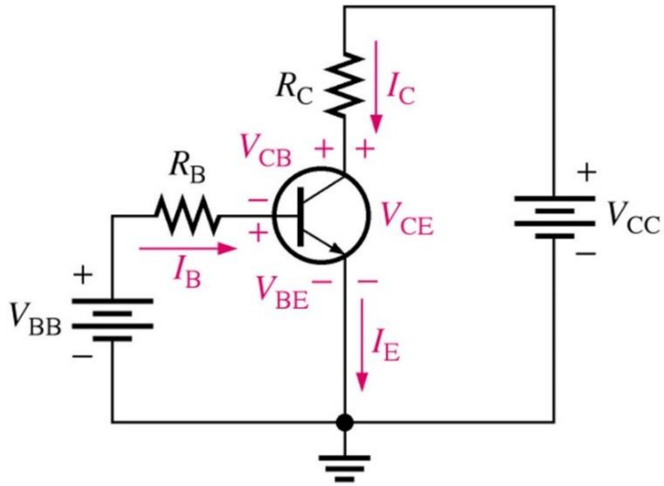


Transistor Characteristics and Parameters

- There are three key dc voltages and three key dc currents to be considered. Note that these measurements are important for troubleshooting.

Transistor Characteristics and Parameters

- I_B: dc base current
- I_E: dc emitter current
- I_C: dc collector current
- V_{BE}: dc voltage across base-emitter junction
- V_{CB}: dc voltage across collector-base junction
- V_{CE}: dc voltage from collector to emitter

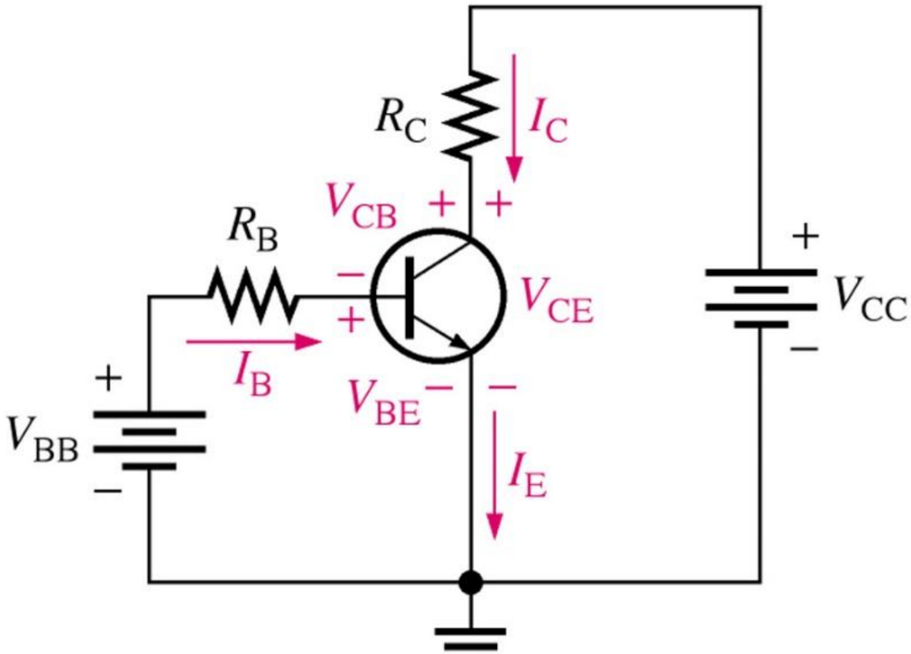


Transistors Characteristics and Parameters

- For **proper operation** the base-emitter junction is forward biased by V_{BB} and conducts just like a diode.
- The collector-base junction is reverse biased by V_{CC} and blocks current flow through it’s junction just like a diode.

Transistors Characteristics and Parameters

- Remember current flow through the base-emitter junction will help establish the path for current flow from the collector to emitter.



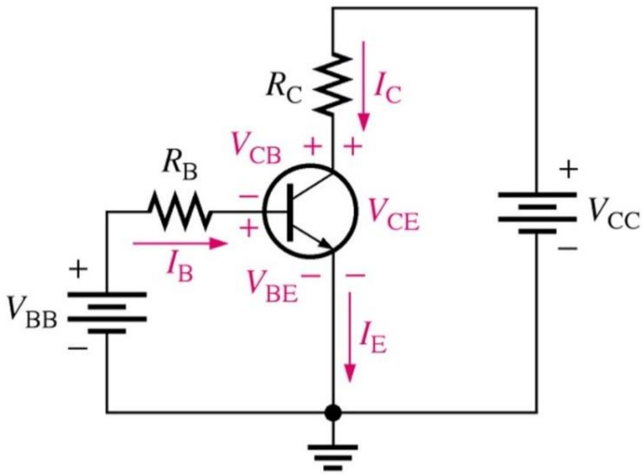
Transistor Characteristics and Parameters

- Analysis of this transistor circuit to predict the dc voltages and currents requires use of Ohm's law, Kirchhoff's voltage law and the beta for the transistor.

- Application of these laws begins with the base circuit to determine the amount of base current. Using Kirchhoff's voltage law, subtract the 0.7 V_{BE} and the remaining voltage is dropped across R_B. Determining the current for the base with this information is a matter of applying of Ohm's law. $I_B = (V_{BB} - V_{BE})/R_B$

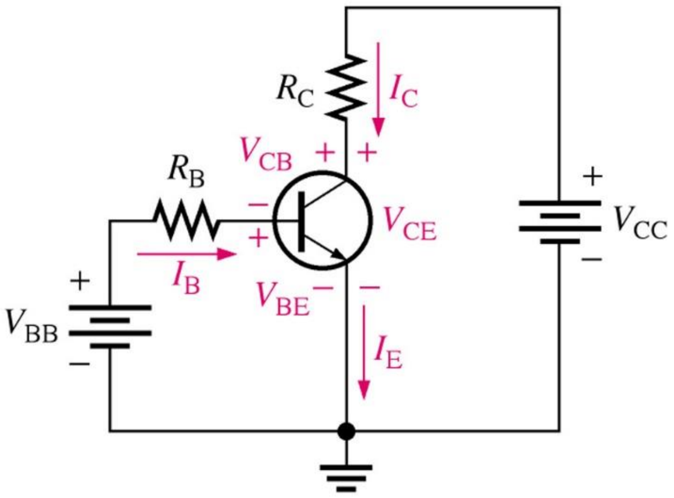
Transistor Characteristics and Parameters

- $I_C = \beta I_B$
- $I_E = I_C + I_B$
- $V_{BE} = 0.7$ (Will be used in most analysis examples)
- $V_{CE} = V_{CC} - V_{RC} = V_{CC} - I_C R_C$
- $V_{CB} = V_{CE} - V_{BE}$



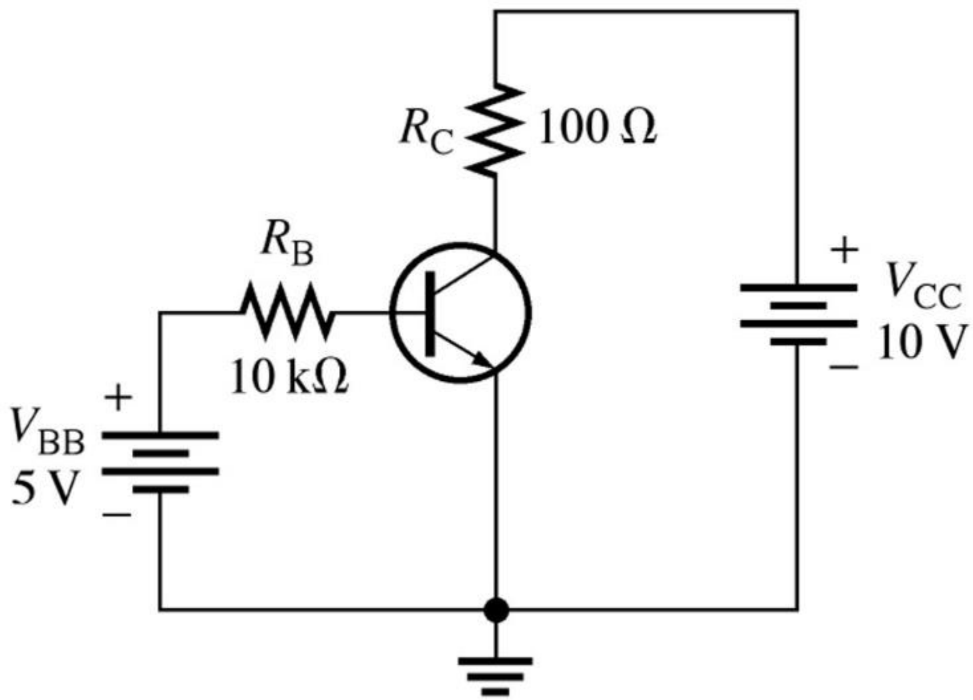
Transistor Characteristics and Parameters

- What we ultimately determine by use of Kirchhoff's voltage law for series circuits is that in the base circuit V_{BB} is distributed across the base-emitter junction and R_B in the base circuit. In the collector circuit we determine that V_{CC} is distributed proportionally across R_C and the transistor(V_{CE}).



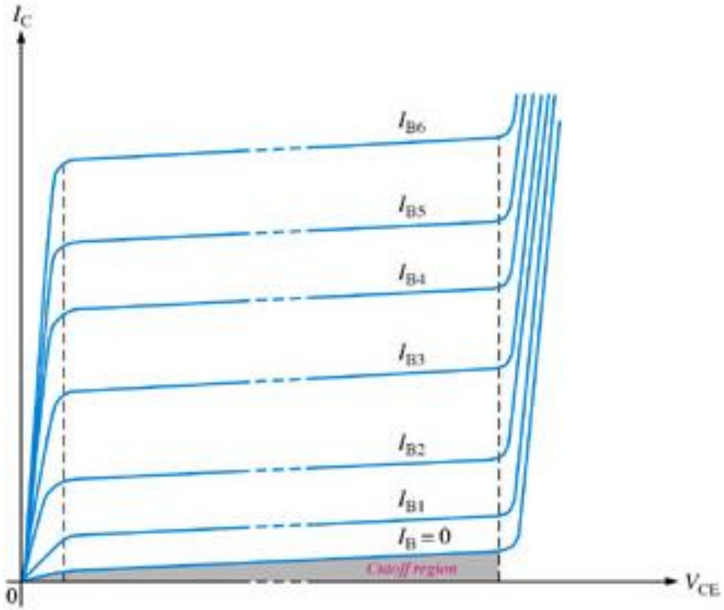
Example

- Find out the DC Currents and Voltages in the CCT.



Transistor Characteristics and Parameters

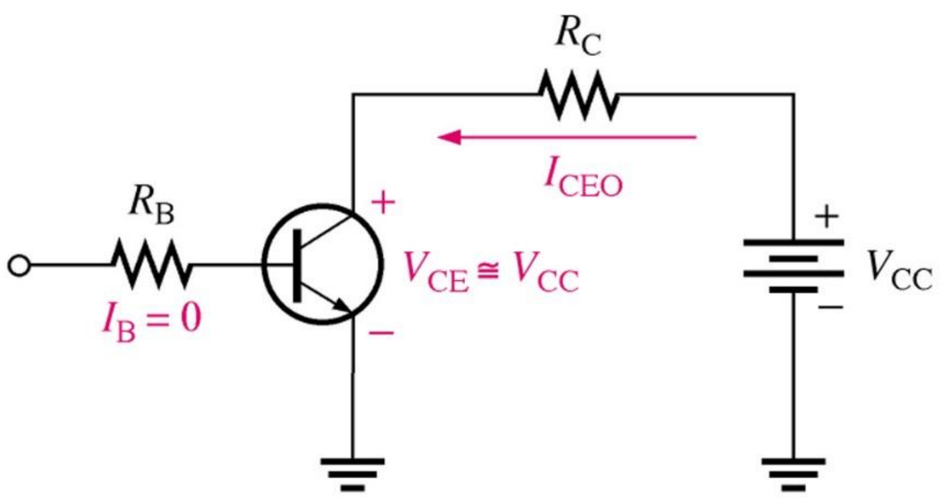
- **Collector characteristic curves** gives a graphical illustration of the relationship of collector current and V_{CE} with specified amounts of base current. With greater increases of V_{CC}, V_{CE} continues to increase until it reaches breakdown, but the current remains about the same in the **linear** region from .7V to the breakdown voltage.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

Transistor Characteristics and Parameters

- With no I_B the transistor is in the **cutoff** region and just as the name implies there is practically no current flow in the collector part of the circuit. With the transistor in a cutoff state the the full V_{CC} can be measured across the collector and emitter(V_{CE})

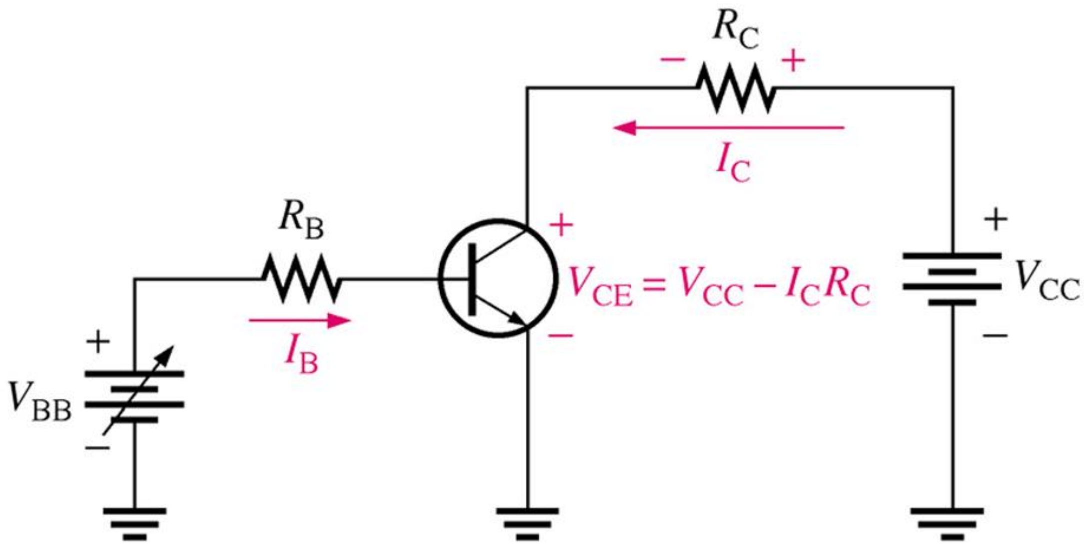


Transistor Characteristics and Parameters

- Current flow in the collector part of the circuit is, as stated previously, determined by I_B multiplied by β. However, there is a limit to how much current can flow in the collector circuit regardless of additional increases in I_B.

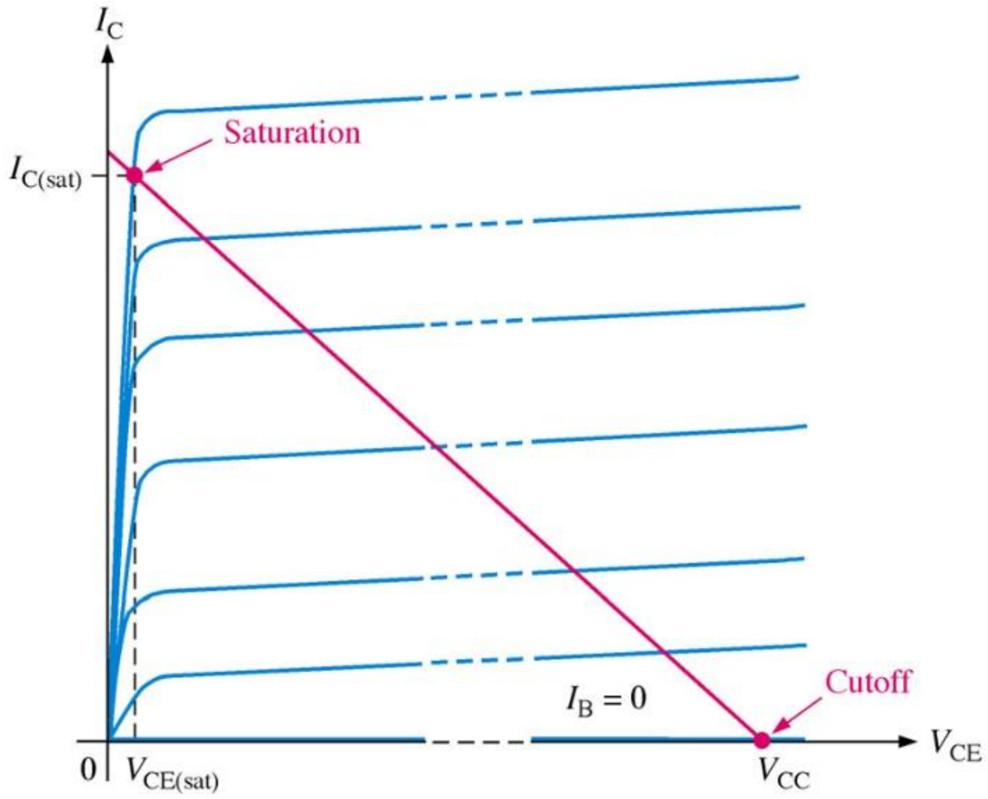
Transistor Characteristics and Parameters

- Once this maximum is reached, the transistor is said to be in **saturation**. Note that saturation can be determined by application of Ohm's law. $I_{C(sat)}=V_{CC}/R_C$ The measured voltage across this now seemingly "shorted" collector and emitter is 0V.



Transistor Characteristics and Parameters

❖ The **dc load line** graphically illustrates $I_{C(sat)}$ and Cutoff for a transistor.



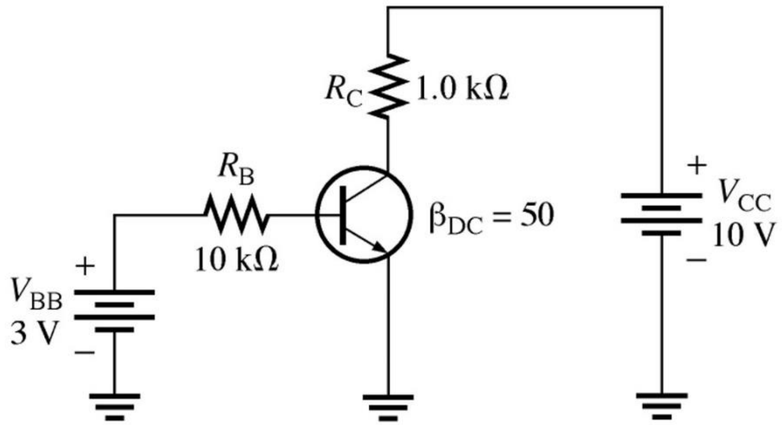
Example

- Determine whether or not the transistor is in saturation region. Assume $V_{CE(sat)}$=0.2V.

<u>Steps:</u>

1. Find $I_{C(sat)}$
2. Find I_B
3. Find I_C for I_B
4. If $I_C > I_{C(sat)}$

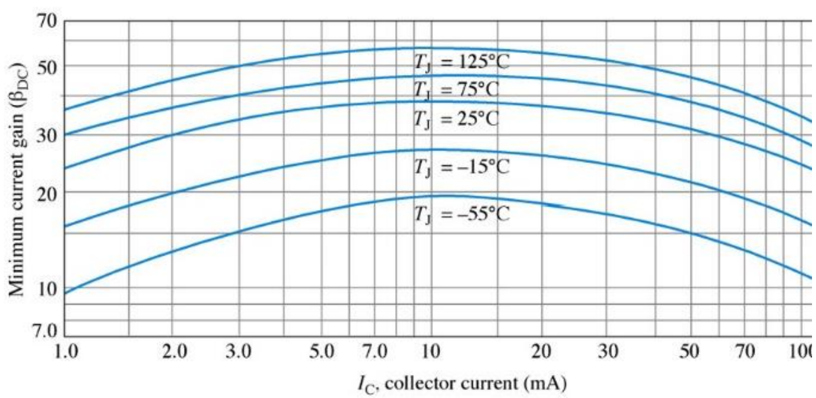
The BJT is in saturation region.

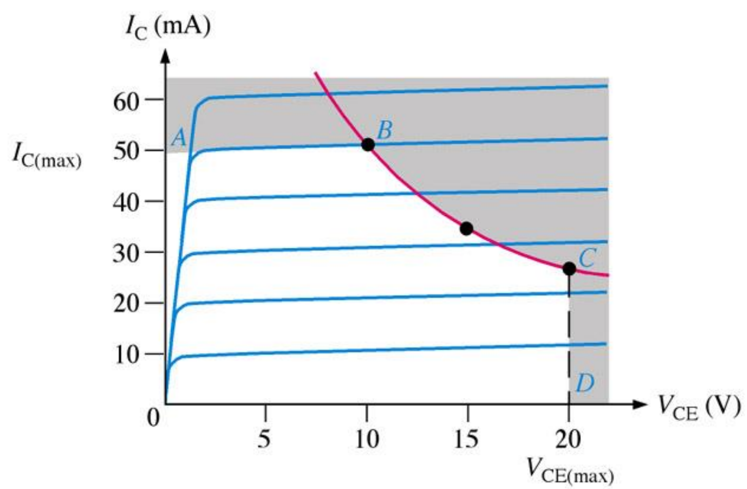


Can I_C ever exceed $I_{C(sat)}$ in normal operation ????

Transistor Characteristics and Parameters

- The beta for a transistor is not always constant.
- **Temperature** and **collector current** both affect beta, not to mention the normal inconsistencies during the manufacture of the transistor.
- There are also maximum power ratings to consider.
- The data sheet provides information on these characteristics.



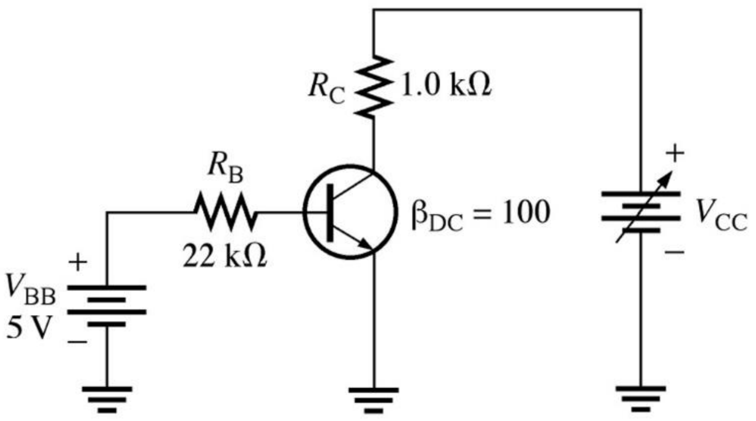


Example

- $P_{D(max)}$=800mW, $V_{CE(max)}$=15V, $I_{C(max)}$=100mA
- Determine the maximum value of V_{CC} that can be adjusted without exceeding a rating.
- Which rating will be crossed first?

Steps:

1. Determine I_B
2. Determine I_C for I_B
3. $I_C > I_{C(max)}$???
4. What will be the max value of V_{CC} for which V_{CE} = 15V for calculated value of I_C ??
5. Calculate P_D
6. $P_D > P_{D(max)}$???
7. What if V_{BB} is cut out???



Transistor Amplifier

- Amplification of a relatively small ac voltage can be had by placing the ac signal source in the base circuit.

- Recall that small changes in the base current circuit causes large changes in collector current circuit.

- The small ac voltage causes the base current to increase and decrease accordingly and with this small change in current the collector current will mimic the input only with greater amplitude.

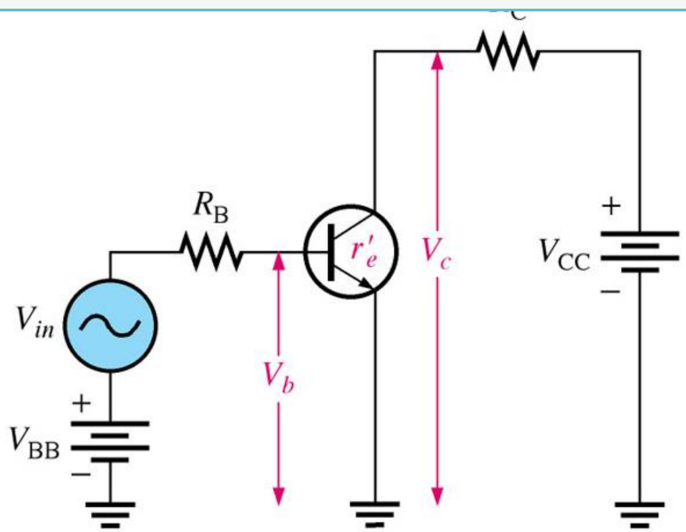
Transistor Amplifier

$I_e = V_b / r_e = I_c$

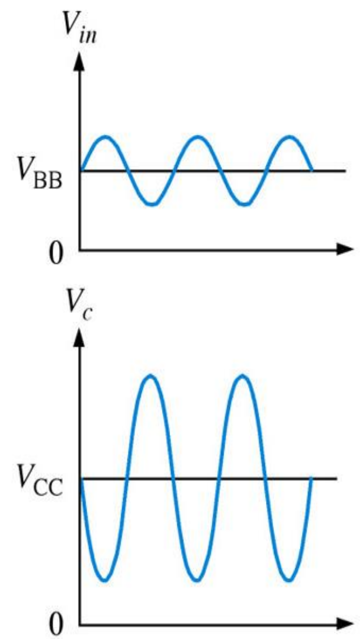
$V_c = I_c R_C$

$A_v = V_{out} / V_{in} = V_c / V_b = I_c R_C / I_e r_e$

$\mathbf{A_v = R_C / r_e}$



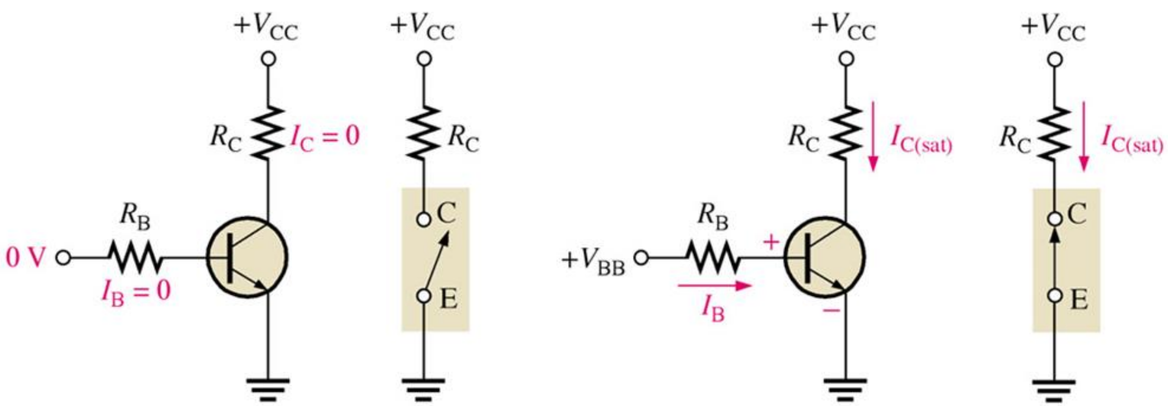
(a) Circuit with ac input voltage V_{in} and dc bias voltage superimposed



(b) Waveforms

Transistor Switch

- A transistor when used as a switch is simply being biased so that it is in cutoff (switched off) or saturation (switched on). Remember that the V_{CE} in cutoff is V_{CC} and 0V in saturation.



(a) Cutoff — open switch

(b) Saturation — closed switch

<u>Cut off:</u>

$I_B = 0$

$I_C = 0$

$V_{CE} = V_{CC}$

<u>Saturation:</u>

$I_C = (V_{CC} - V_{CE(sat)})/R_C$

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

$V_{CE} = 0$ ideally or few tens of a volt.

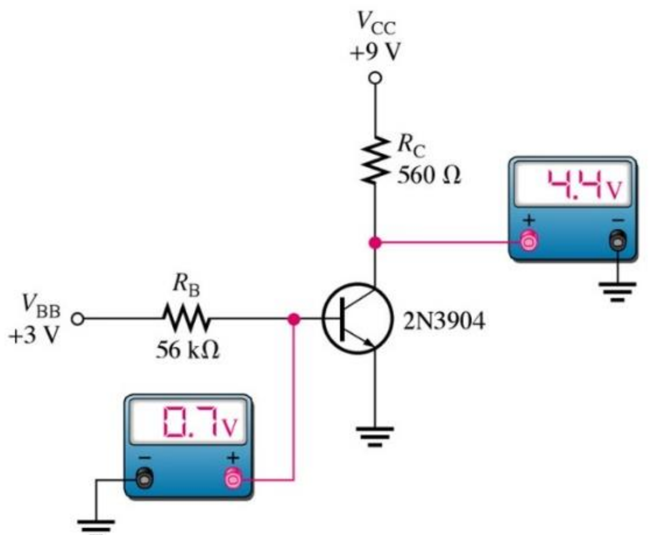
Some text assume $V_{CE(sat)} = 0.2V$

Troubleshooting

- Troubleshooting a live transistor circuit requires us to be familiar with known good voltages, but some general rules do apply. Certainly a solid fundamental understanding of Ohm’s law and Kirchhoff’s voltage and current laws is imperative. With live circuits it is most practical to troubleshoot with voltage measurements.

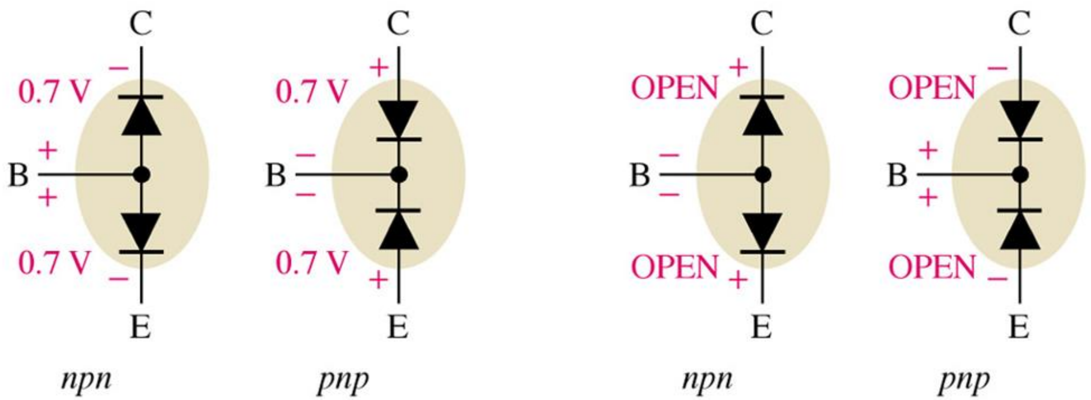
Troubleshooting

- Opens in the external resistors or connections of the base or the circuit collector circuit would cause current to cease in the collector and the voltage measurements would indicate this.
- Internal opens within the transistor itself could also cause transistor operation to cease.
- Erroneous voltage measurements that are typically low are a result of point that is not "solidly connected". This called a **floating point**. This is typically indicative of an open.
- More in-depth discussion of typical failures are discussed within the textbook.



Troubleshooting

- Testing a transistor can be viewed more simply if you view it as testing two diode junctions. Forward bias having low resistance and reverse bias having infinite resistance.

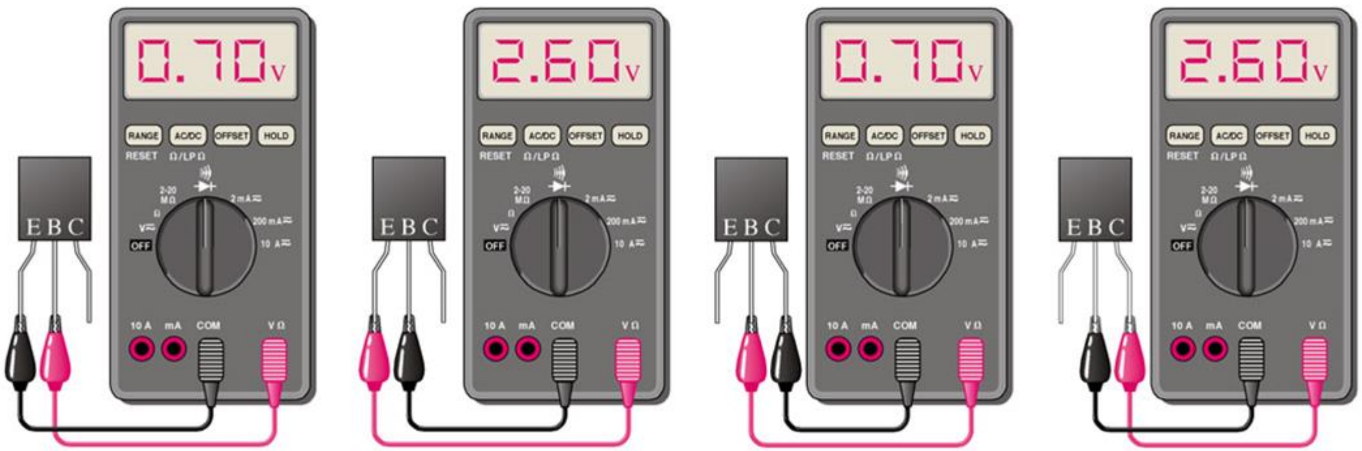


(a) Both junctions should read 0.7 V ± 0.2 V when forward-biased.

(b) Both junctions should ideally read OPEN when reverse-biased.

Troubleshooting

- The diode test function of a multimeter is more reliable than using an ohmmeter. Make sure to note whether it is an npn or pnp and polarize the test leads accordingly.



(a) Forward-bias test of BE junction

(b) Reverse-bias test of BE junction

(c) Forward-bias test of BC junction

(d) Reverse-bias test of BC junction

Troubleshooting

- In addition to the traditional DMMs there are also transistor testers. Some of these have the ability to test other parameters of the transistor, such as leakage and gain. Curve tracers give us even more detailed information about a transistors characteristics.

Summary

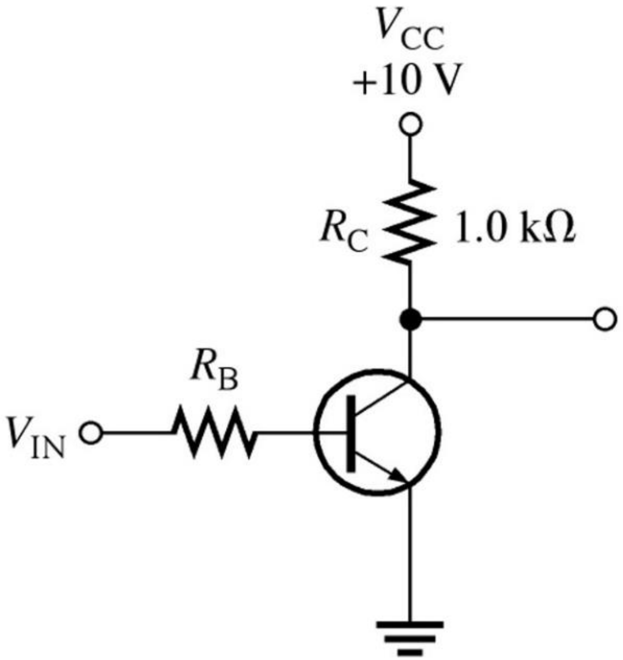
- The bipolarjunction transistor (BJT) is constructed of three regions: base, collector, and emitter.
- The BJT has two pn junctions, the base-emitter junction and the base-collector junction.
- The two types of transistors are pnp and npn.
- For the BJT to operate as an amplifier, the base-emitter junction is forward biased and the collector-base junction is reverse biased.
- Of the three currents I_B is very small in comparison to I_E and I_C.
- Beta is the current gain of a transistor. This the ratio of I_C/I_B.

Summary

- A transistor can be operated as an electronics switch.
- When the transistor is off it is in cutoff condition (no current).
- When the transistor is on, it is in saturation condition (maximum current).
- Beta can vary with temperature and also varies from transistor to transistor.

Quiz

1. If $V_{IN} = 0$, $V_{CE} = ??$
2. $I_{B(min)} = ??$ for saturating transistor. $\beta_{DC} = 200$, $V_{CE(sat)} = 0V$
3. $R_{B(max)}$ when $V_{IN} = 5V$



Thank You !