电子科技大学
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Communication Circuits Design

Academic year 2018/2019 – Semester 2 – Week 1

Lecture 1.4: Bipolar Junction Transistor (BJT)

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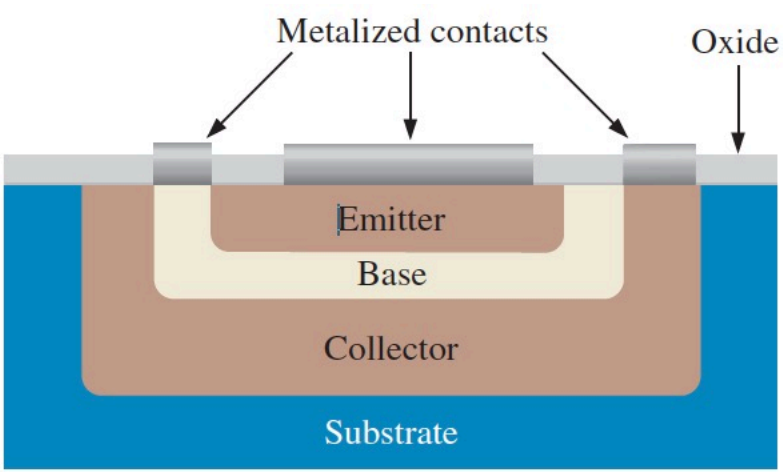
Objectives

- After completing this lecture, you will be able to:
  - Describe the structure of the BJT
  - Discuss basic BJT operation
  - Discuss important BJT parameters and characteristics and analyze transistor circuits
  - Discuss how a BJT is used as a voltage amplifier
  - Discuss how a BJT is used as a switch
  - Discuss the phototransistor and its operation
  - Identify various types of transistor packages
  - Troubleshoot faults in transistor circuits

BJT Structure (1)

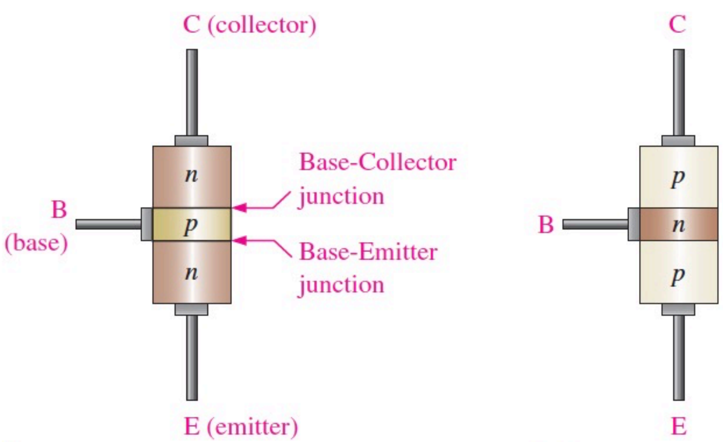
The BJT has three regions called the emitter, base, and collector. Between the regions are junctions as indicated.

The base is a thin lightly doped region compared to the heavily doped emitter and moderately doped collector regions.

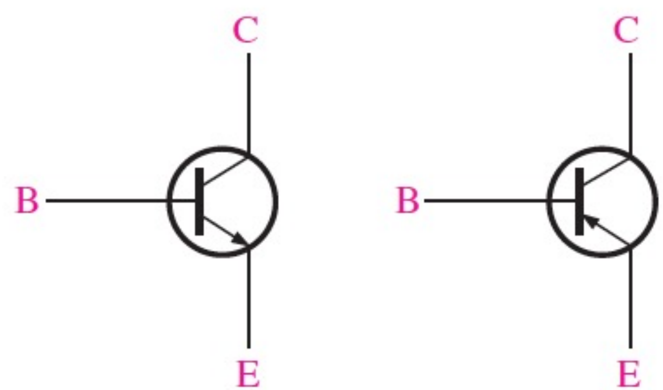


BJT Structure (2)

- Physical representations of the two types of BJTs are shown in Figure below.
- One type consists of two *n* regions separated by a *p* region (*npn*), and the other type consists of two *p* regions separated by an *n* region (*pnp*)..
- The term bipolar refers to the use of both holes and electrons as current carriers in the transistor structure.

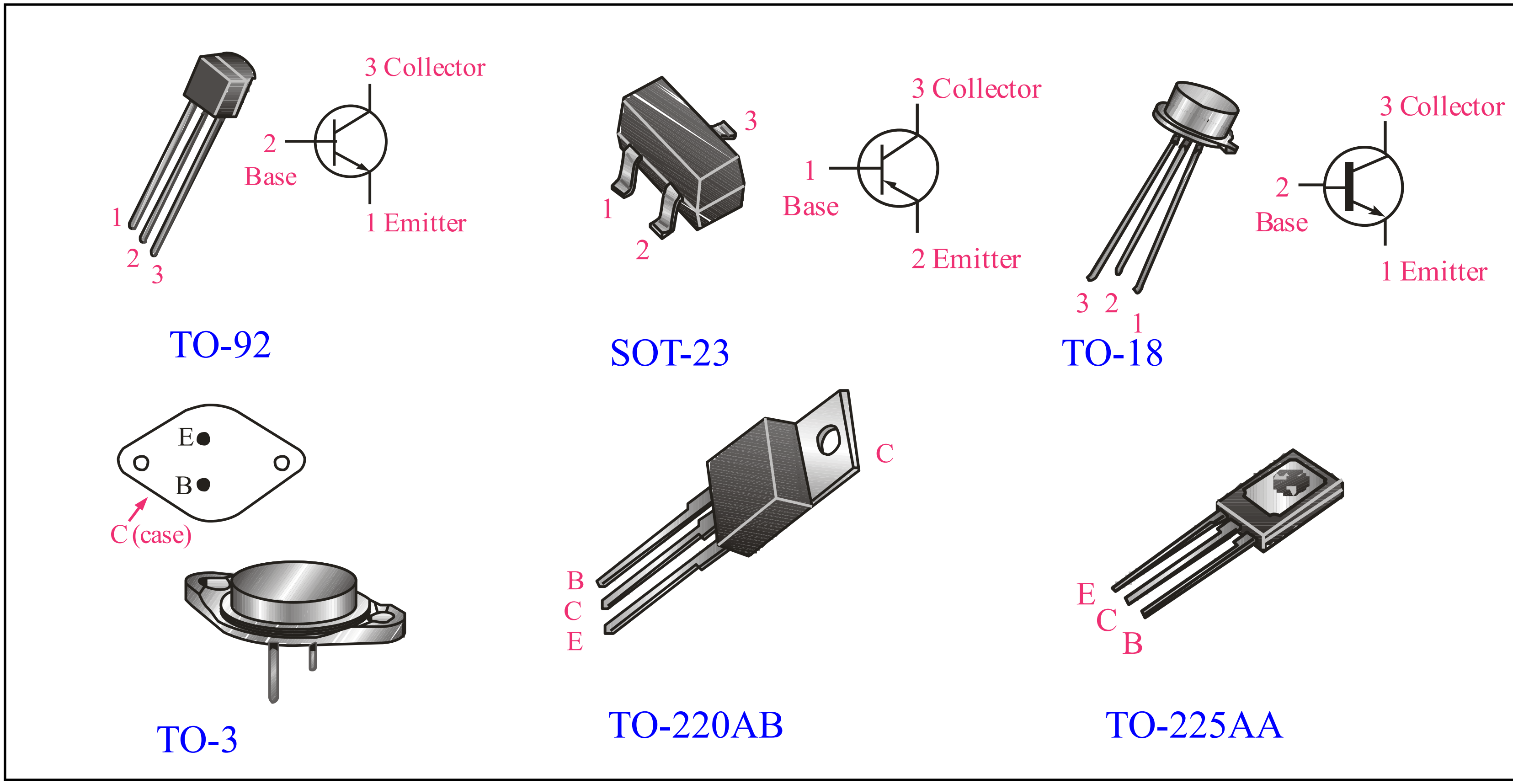


(b) *npn* (c) *pnp*



(a) *npn* (b) *pnp*

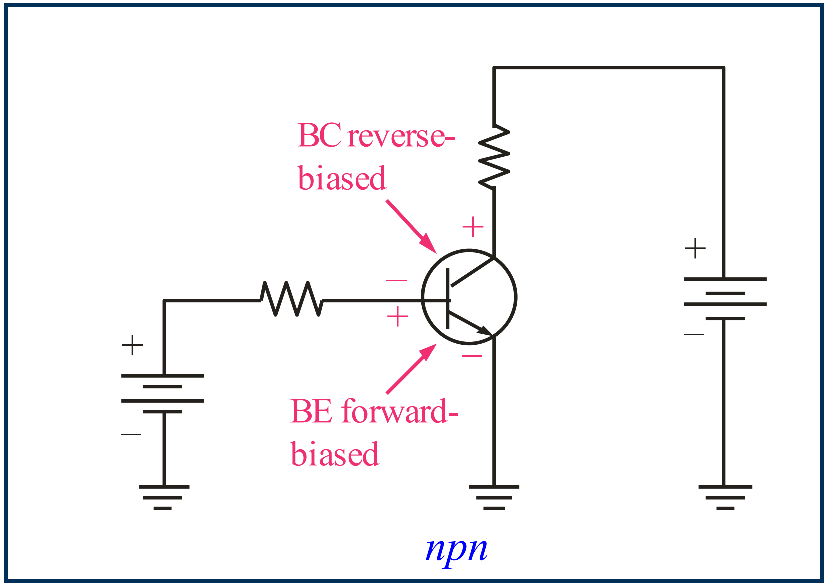
Transistor Categories and Packaging



Basic BJT Operation

In normal operation, the base-emitter is forward-biased and the base-collector is reverse-biased.

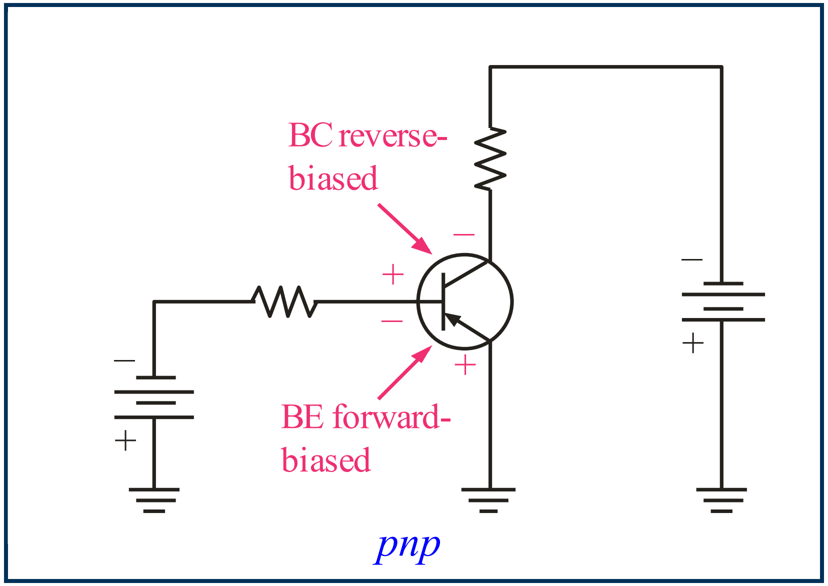
For the *npn* type, the collector is more positive than the base, which is more positive than the emitter.



Basic BJT Operation

In normal operation, the base-emitter is forward-biased and the base-collector is reverse-biased.

For the *pnp type*, the voltages are reversed to maintain the forward-reverse bias.



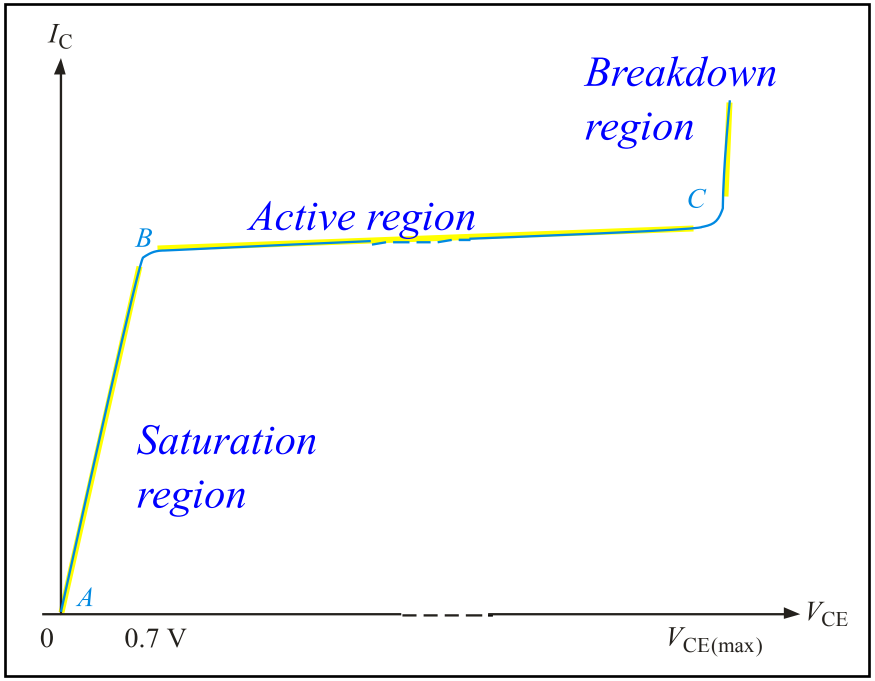
Collector Characteristic Curves

The collector characteristic curves show the relationship of the three transistor currents. The curve shown is for a fixed based current

The first region from *A* to *B* is the **saturation region**. As V_{CE} is increased, I_C increases until *B*.

After reaching *B*, the curve flattens between points *B* and *C*, which is the **active region**.

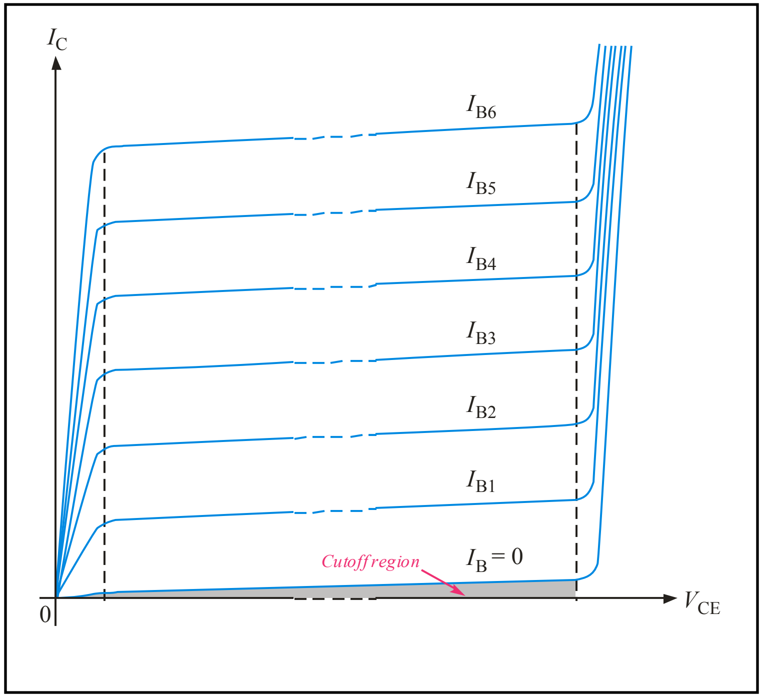
After *C*, is the **breakdown region**.



Collector Characteristic Curves

The dc current gain of a transistor is the ratio of the dc collector current (I_C) to the dc base current (I_B).

By setting up other values of base current, a family of collector curves is developed.



β_{DC} **is the ratio of collector current to base current.**

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

It can be read from the curves. The value of β_{DC} is nearly the same wherever it is read.

Typical values of β_{DC} range from less than 20 to 200 or higher. β_{DC} is usually designated as an equivalent hybrid (*h*) parameter, h_{FE}, on transistor datasheets.

Collector Characteristic Curves

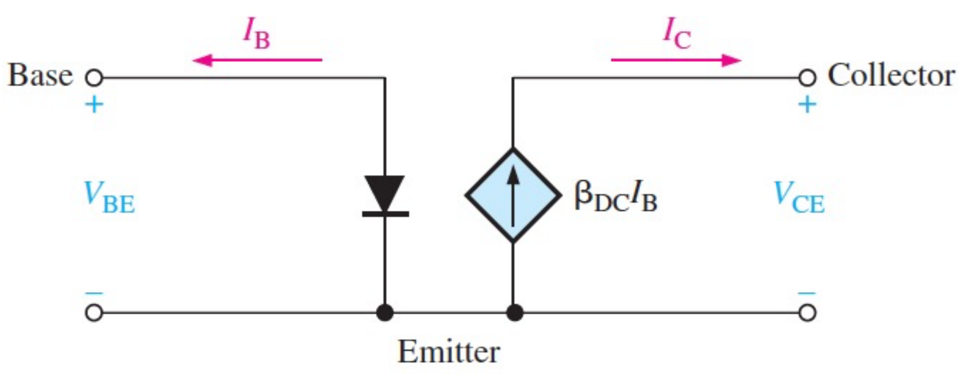
- The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc alpha (α_{DC}). The alpha is a less-used parameter than beta in transistor circuits.

$$\alpha_{\mathrm{DC}} = \frac{I_{\mathrm{C}}}{I_{\mathrm{E}}}$$

- Typically, values of α_{DC} range from 0.95 to 0.99 or greater, but α_{DC} is always less than 1. The reason is that I_C is always slightly less than I_E by the amount of I_B .

Transistor DC Model

- You can view the unsaturated BJT as a device with a current input and a dependent current source in the output circuit.
- The input circuit is a forward-biased diode through which there is base current.
- The output circuit is a dependent current source (diamond-shaped element) with a value that is dependent on the base current, I_B , and equal to $\beta_{DC} I_B$. Recall that independent current source symbols have a
- circular shape.



Example - Collector Characteristic Curves

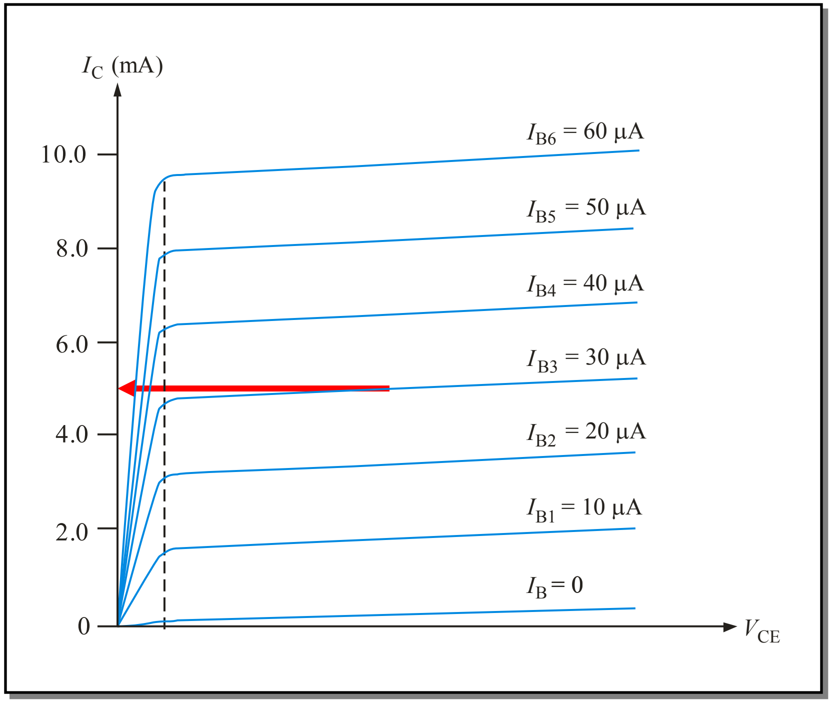
Question: What is the β_{DC} for the transistor shown?

Solution:

Choose a base current near the center of the range – in this case I_{B3} which is 30 μA.

Read the corresponding collector current – in this case, 5.0 mA. Calculate the ratio of collector current to base current.

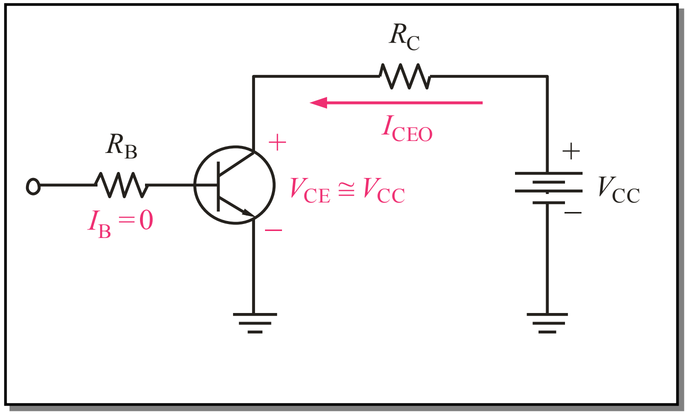
$$\beta_{DC} = \frac{I_C}{I_B} = \frac{5.0\ \text{mA}}{30\ \mu\text{A}} = 167$$



Cutoff Region

In a BJT, **cutoff** is the condition in which there is no base current, which results in only an extremely small leakage current (I_{CEO}) in the collector circuit. For practical work, this current is assumed to be zero.

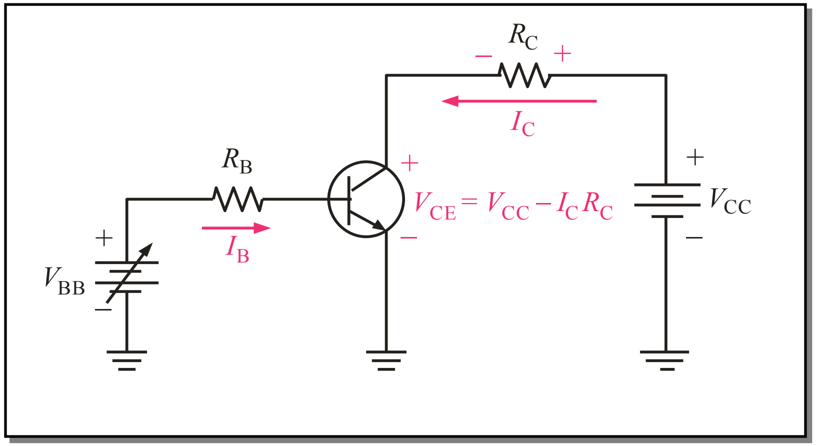
In cutoff, neither the base-emitter junction, nor the base-collector junction are forward-biased.



Saturation Region

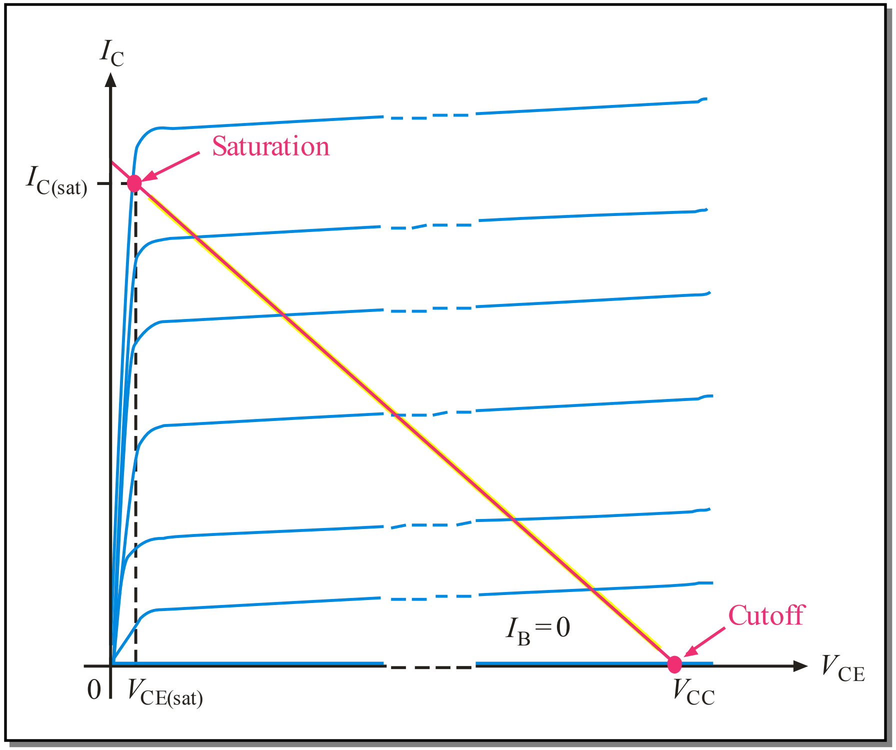
In a BJT, **saturation** is the condition in which there is maximum collector current. The saturation current is determined by the external circuit (V_{CC} and R_C in this case) because the collector-emitter voltage is minimum ($\approx$ 0.2 V)

In saturation, an increase of base current has no effect on the collector circuit and the relation $I_C = \beta_{DC} I_B$ is no longer valid.



DC Load Line

The **DC load line** represents the circuit that is external to the transistor. It is drawn by connecting the saturation and cutoff points.

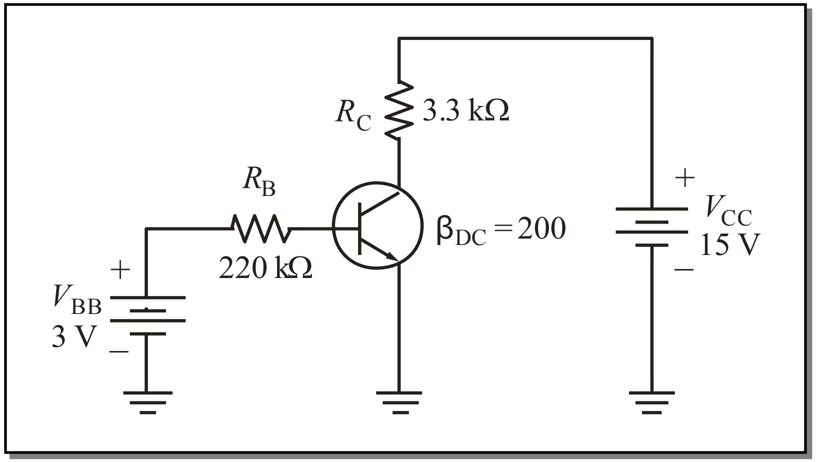


The transistor characteristic curves are shown superimposed on the load line. The region between the saturation and cutoff points is called the **active region.**

Example 1

Question:

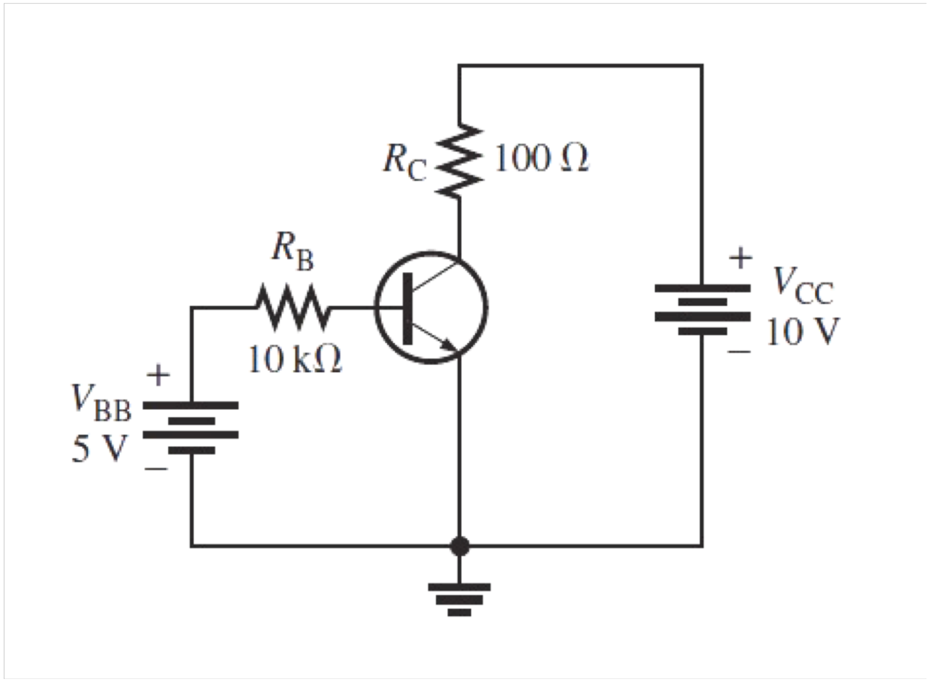
What is the saturation current and the cutoff voltage for the circuit? Assume $V_{CE} = 0.2$ V in saturation.



Example 2

Question:

Determine I_B , I_C , I_E , V_{BE} , V_{CE} , and V_{CB} in the circuit of Figure below. The transistor has a β_{DC} = 150.



Data Sheets

Data sheets give manufacturer's specifications for maximum operating conditions, thermal, and electrical characteristics. For example, an electrical characteristic is β_{DC}, which is given as h_{FE}. The 2N3904 shows a range of β's on the data sheet from 100 to 300 for I_C = 10 mA.

Characteristic		Symbol	Min	Max	Unit
ON Characteristics					
DC current gain		h_{FE}			–
(I_C = 0.1 mA dc, V_{CE} = 1.0 V dc)	2N3903		20	–	
	2N3904		40	–	
(I_C = 1.0 mA dc, V_{CE} = 1.0 V dc)	2N3903		35	–	
	2N3904		70	–	
(I_C = 10 mA dc, V_{CE} = 1.0 V dc)	2N3903		50	150	
	2N3904		100	300	
(I_C = 50 mA dc, V_{CE} = 1.0 V dc)	2N3903		30	–	
	2N3904		60	–	
(I_C = 100 mA dc, V_{CE} = 1.0 V dc)	2N3903		15	–	
	2N3904		30	–	

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(I_C = 1.0 mA dc, V_{CE} = 1.0 V dc)	2N3903		35	–	
	2N3904		70	–	
(I_C = 10 mA dc, V_{CE} = 1.0 V dc)	2N3903		50	150	
	2N3904		100	300	
(I_C = 50 mA dc, V_{CE} = 1.0 V dc)	2N3903		30	–	
	2N3904		60	–	
(I_C = 100 mA dc, V_{CE} = 1.0 V dc)	2N3903		15	–	
	2N3904		30	–	

DC and AC Quantities

The text uses capital letters for both AC and DC currents and voltages with rms values assumed unless stated otherwise.

DC Quantities use upper case roman subscripts. Example: V_{CE}. (The second letter in the subscript indicates the reference point.)

AC Quantities and time varying signals use lower case italic subscripts. Example: V_{ce}.

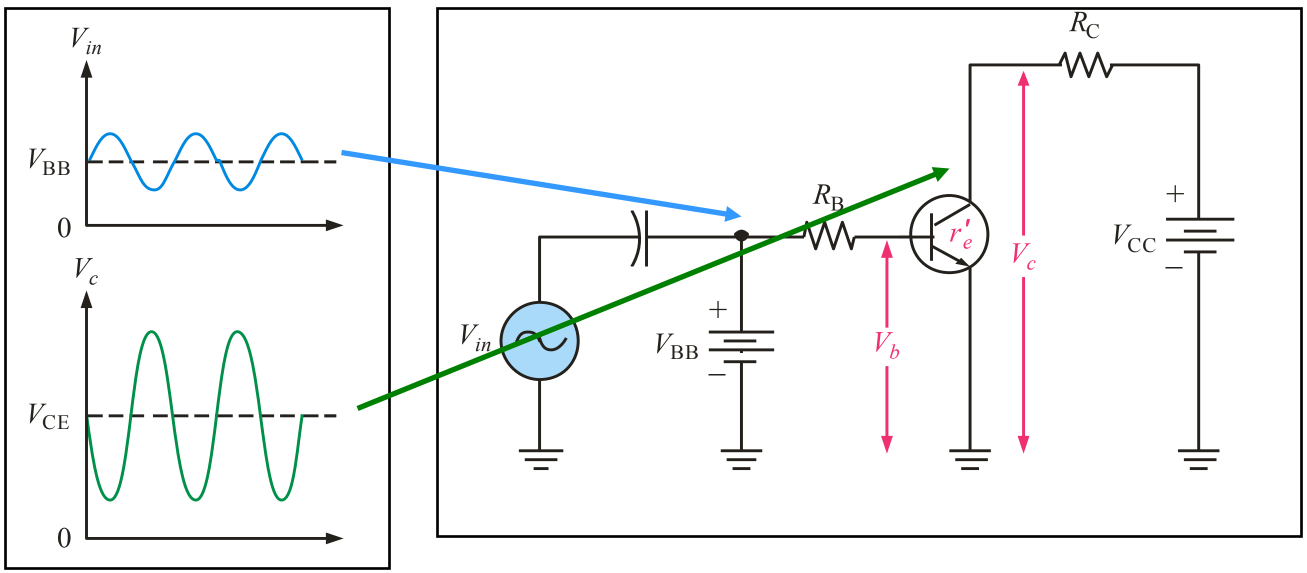
Internal transistor resistances are indicated as lower case quantities with a prime and an appropriate subscript. Example: r_e'.

External resistances are indicated as capital R with either a capital or lower case subscript depending on if it is a DC or ac resistance. Examples: R_{C} and R_{c}.

Voltage Amplification

A BJT amplifies AC signals by converting some of the DC power from the power supplies to AC signal power.

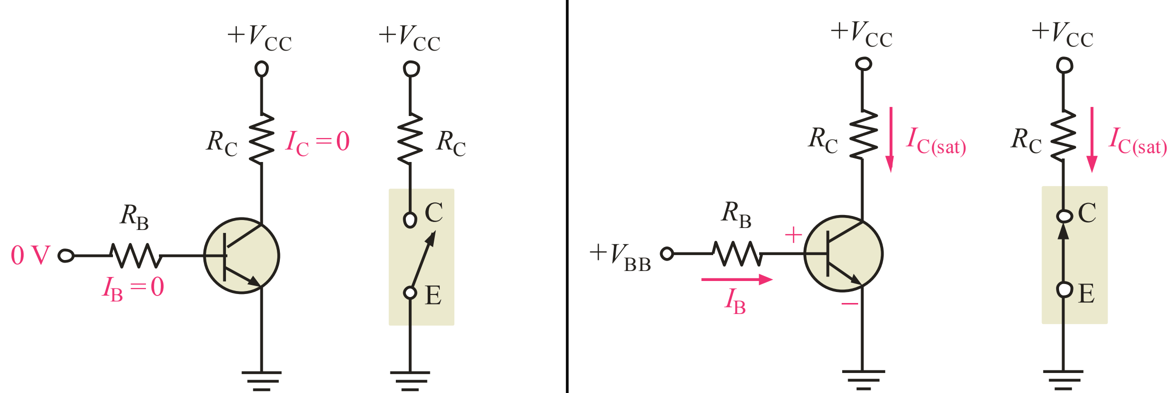
An ac signal at the input is superimposed in the dc bias by the capacitive coupling. The output ac signal is inverted and rides on a dc level of V_{CE}.



Switching Operation

A BJT can be used as a switching device in logic circuits to turn on or off current to a load.

As a switch, the transistor is normally in either cutoff (load is OFF) or saturation (load is ON).

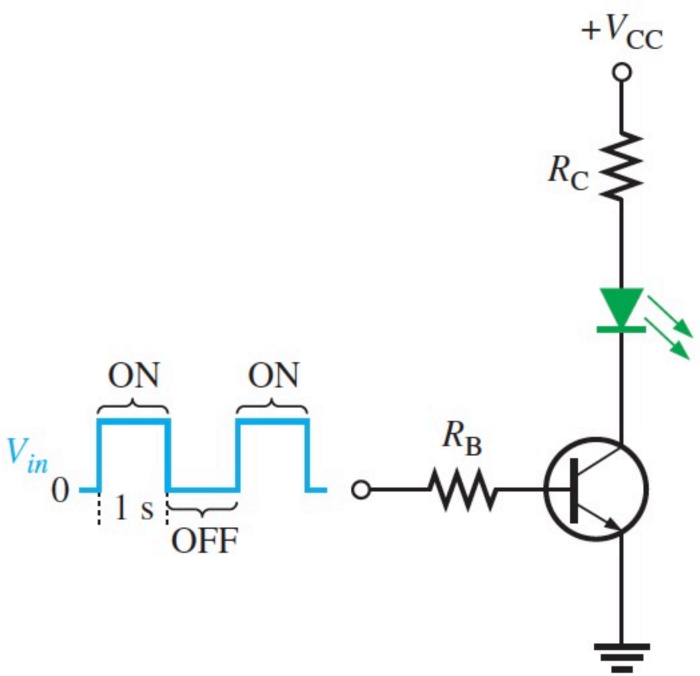


In cutoff, the transistor looks like an open switch.

In saturation, the transistor looks like a closed switch.

Application of a Transistor Switch

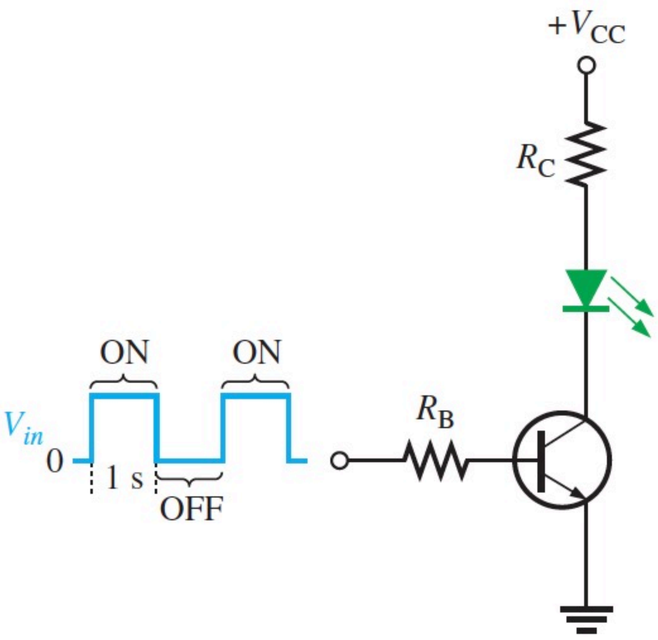
- The transistor in Figure below is used as a switch to turn the LED on and off.
- For example, a square wave input voltage with a period of 2 s is applied to the input as indicated.
- When the square wave is at 0 V, the transistor is in cutoff; and since there is no collector current, the LED does not 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



Example 3

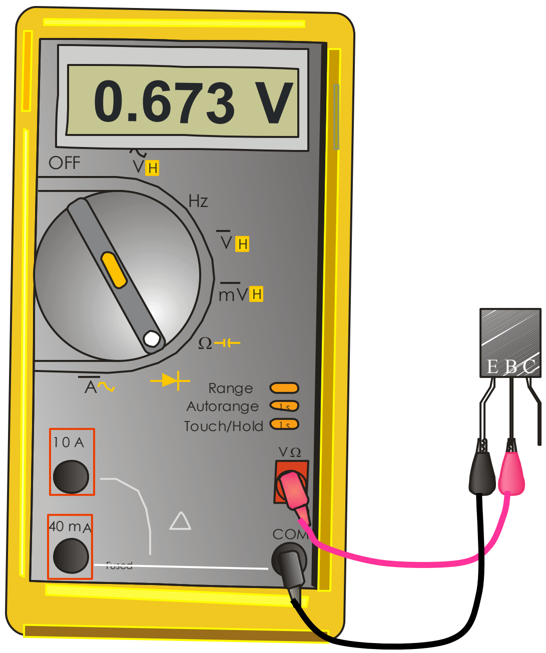
Question:

The LED in Figure 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 V, V_{CE}(sat) = 0.3 V, R_C = 220 Ω , R_B = 3.3 kΩ, β_{DC} 50, and V_{LED} = 1.6 V.



Diode Test

A basic test for a BJT is to use the **Diode Test** function of your DMM.



To test the base-emitter junction of a BJT, connect the positive lead to the base and the negative lead to the emitter. You should see a voltage close to 0.7 V for an *npn* transistor.

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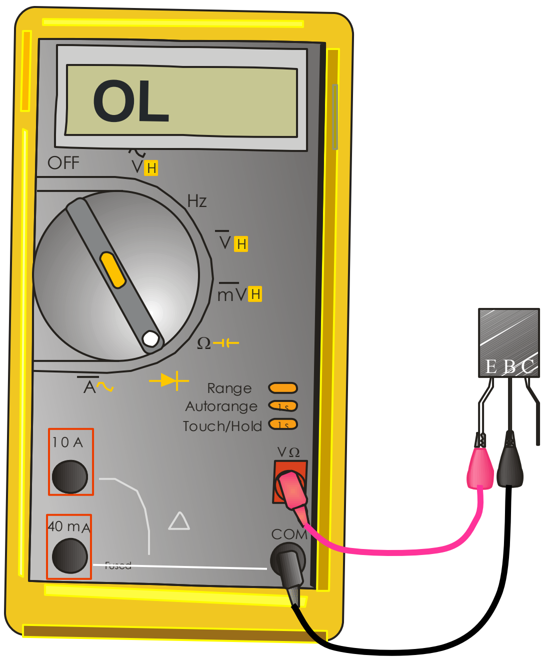

To test the base-emitter junction of a BJT, connect the positive lead to the base and the negative lead to the emitter. You should see a voltage close to 0.7 V for an *npn* transistor.

Reversing the leads will show OL for “overload”.

The procedure is repeated to test the base-collector junction.