XMUT204 Electronic Design

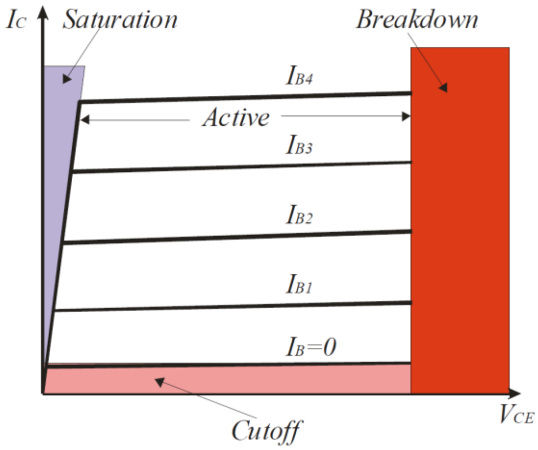
Tutorial 4: BJT Characteristics & Biasing (Solution)

A. BJT Characteristics

1. Determine the region of operations of BJT transistor. [4 marks]

Solution

As shown in the diagram there are four regions existed in BJT transistor operation: active (linear), saturation, cut-off and breakdown.



Active (linear) region is when the BE junction of the transistor is forward biased and its BC junction is reverse biased. Much of the design effort in transistor circuit is to make the transistor in the circuit to operate within this region. This region is considered linear and stable for a given design requirement of the transistor-based circuit.

Most of the design goal is also to avoid transistor to be fall into the breakdown region. The characteristics of this region are non- linear, very unstable and easily turn into problems in performance and quality of the operation.

On the other hand, cut-off region is when the BE junction of the transistor is reverse biased and the BC junction is also reversed bias.

Saturation region is observed when both the BE and BC junctions are forward biased. The following table summarises the regions of operations of a BJT transistor.

Region	BE Junction	BC Junction
Cut off	Reverse biased	Reverse biased
Saturation	Forward biased	Forward biased

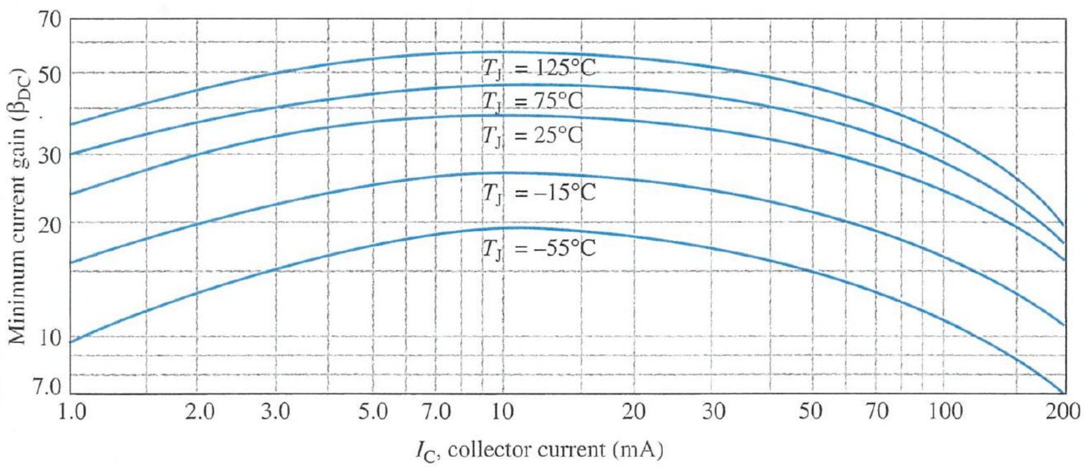
Active (linear)	Forward Biased	Reverse biased
Breakdown	-	-

2. Why it is a bad idea to do the design of a transistor circuit based on a specific (supplied) value of β_{DC}. [4 marks]

Solution

The DC voltage gain of BJT β_{DC} is a function of the transistor temperature i.e. as the temperature increases, the value of β_{DC} also goes up. Data sheets would normally specify a minimum value of β_{DC} at a certain value of IC.

The diagram given below illustrates the cases when operating temperature of the transistor is varied from-55°C to 125°C. The current gain and the collector of the transistor experience considerable changes in their values. This further states the reason why we should not rely on value of β_{DC} for the transistor circuit design.



3. Determine the DC current gain β_{DC} and the emitter current I_E for a transistor where I_B = 50 µA and I_C = 3.65 mA. [4 marks]

Solution

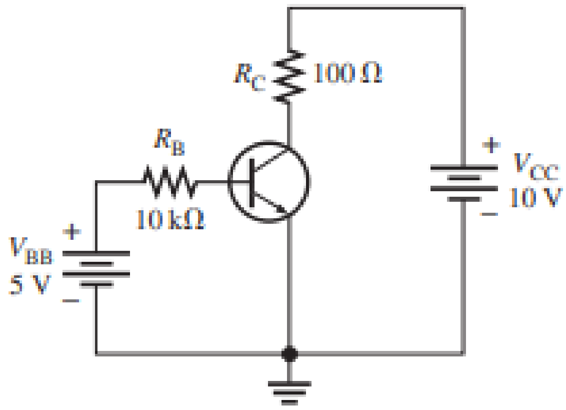
The DC gain of the transistor is found from the following equation:

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65 \text{ mA}}{50 \text{ µA}} = 73$$

The current that flows in the emitter of the transistor is:

$$I_E = I_C + I_B = 3.65 \text{ mA} + 50 \text{ µA} = 3.70 \text{ mA}$$

4. Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of given below. The transistor has a β_{DC} = 150. [12 marks]



Solution

From the equation given below, $V_{BE} = 0.7$ V. Calculate the base, collector, and emitter currents as follows:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = 430\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (150)(430\ \mu\text{A}) = 64.5\text{ mA}$$

$$I_E = I_C + I_B = 64.5\text{ mA} + 430\ \mu\text{A} = 64.9\text{ mA}$$

Solve for V_{CE} and V_{CB}.

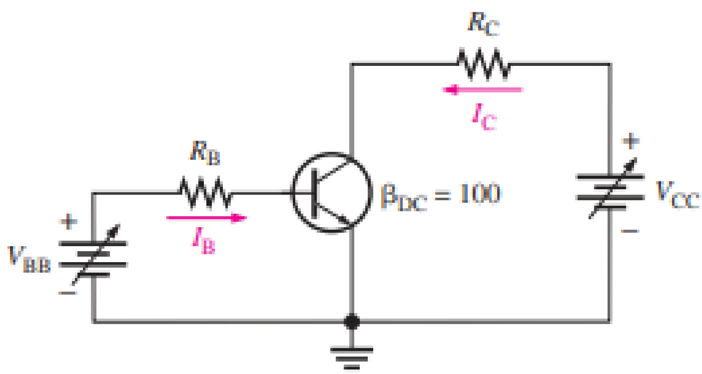
$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (64.5\text{ mA})(100\ \Omega) = 10\text{ V} - 6.45\text{ V} = 3.55\text{ V}$$

$$V_{CB} = V_{CE} - V_{BE} = 3.55\text{ V} - 0.7\text{ V} = 2.85\text{ V}$$

Since the collector is at a higher voltage than the base, the collector-base junction is reverse-biased.

5. Sketch an ideal family of collector curves for the circuit in the figure below for I_B from 5 µA to 25 µA in 5 µA increments. Assume β_{DC} = 100 and that V_{CE} does not exceed breakdown.

[10 marks]

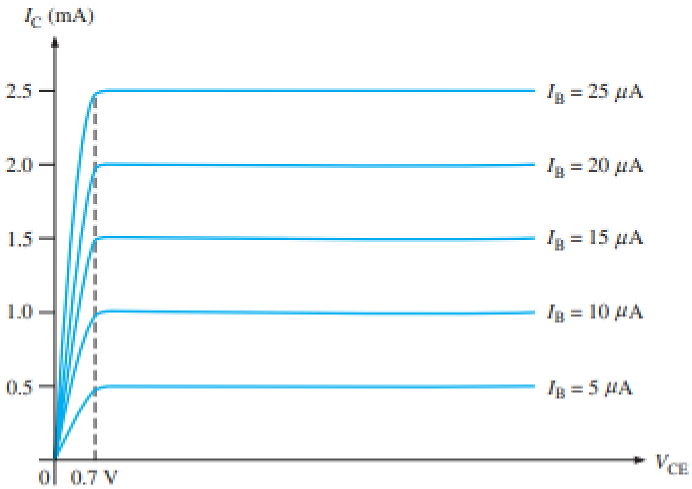


Solution

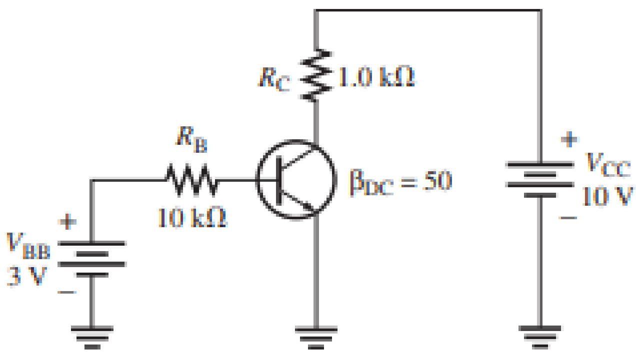
Using the relationship $I_C = \beta_{DC} I_B$, values of I_C are calculated and tabulated in the table given below.

I_B	I_C
5 μA	0.5 mA
10 μA	1.0 mA
15 μA	1.5 mA
20 μA	2.0 mA
25 μA	2.5 mA

The resulting curves are plotted in the figure below.



6. Determine whether or not the transistor in the figure below is in saturation. Assume $V_{CE}(\text{sat})$ = 0.2 V. [8 marks]



Solution

First, determine $I_{C(\text{sat})}$.

$$I_{C(\text{sat})} = \frac{V_{CC} - V_{CE(\text{sat})}}{R_C} = \frac{10\ \text{V} - 0.2\ \text{V}}{1\ \text{k}\Omega} = \frac{9.8\ \text{V}}{1\ \text{k}\Omega} = 9.8\ \text{mA}$$

Now, see if I_B is large enough to produce $I_{C(\text{sat})}$.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = 0.23\text{ mA}$$

$$I_C = \beta_{DC} I_B = (50)(0.23\text{ mA}) = 11.5\text{ mA}$$

This shows that with the specified β_{DC}, this base current is capable of producing an I_C greater than $I_{C(\text{sat})}$.

Therefore, the transistor is saturated, and the collector current value of 11.5 mA is never reached. If you further increase I_B, the collector current remains at its saturation value of 9.8 mA.

7. A certain transistor is to be operated with V_{CE} = 6 V. If its maximum power rating is 250 mW, what is the most collector current that it can handle? [4 marks]

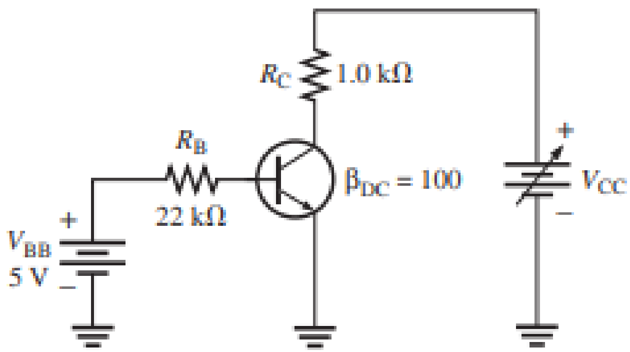
Solution

The current that flows in the collector is found from:

$$I_C = \frac{P_{D(\max)}}{V_{CE}} = \frac{250\text{ mW}}{6\text{ V}} = 41.7\text{ mA}$$

This is the maximum current for this particular value of V_{CE} = 6 V. The transistor can handle more collector current if V_{CE} is reduced, as long as $P_{D(\max)}$ and $I_{C(\max)}$ are not exceeded.

8. The transistor in the figure below has the following maximum ratings: $P_{D(\max)}$ = 800 mW, $V_{CE(\max)}$ = 15 V, and $I_{C(\max)}$ = 100 mA. Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first? [14 marks]



Solution

First, find I_B so that you can determine I_C:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{22\text{ k}\Omega} = 195\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (100)(195\ \mu\text{A}) = 19.5\text{ mA}$$

The I_C is much less than $I_{C(\max)}$ and ideally will not change with V_{CC}. It is determined only by I_B and β_{DC}.

The voltage drop across R_C is:

$$V_{R_C} = I_C R_C = (19.5 \text{ mA})(1 \text{ k}\Omega) = 19.5 \text{ V}$$

Now, you can determine the value of V_{CC} when V_{CE} = $V_{CE(\max)}$ = 15 V

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

So

$$V_{CC(\max)} = V_{CE(\max)} + V_{R_C} = 15 \text{ V} + 19.5 \text{ V} = 34.5 \text{ V}$$

The V_{CC} can be increased to 34.5 V, under the existing conditions, before $V_{CE(\max)}$ is exceeded. However, at this point, it is not known whether or not $P_{D(\max)}$ has been exceeded.

$$P_D = V_{CE(\max)} I_C = (15 \text{ V})(19.5 \text{ mA}) = 293 \text{ mW}$$

Since $P_{D(\max)}$ is 800 mW, it is not exceeded when V_{CC} = 34.5 V. So, $V_{CE(\max)}$ = 15 V is the limiting rating in this case. If the base current is removed causing the transistor to turn off, $V_{CE(\max)}$ will be exceeded first because the entire supply voltage, V_{CC}, will be dropped across the transistor.

9. A certain transistor has a $P_{D(\max)}$ of 1 W at 25°C. The derating factor is 5 mW/°C. What is the $P_{D(\max)}$ at a temperature of 70°C? [4 marks]

Solution

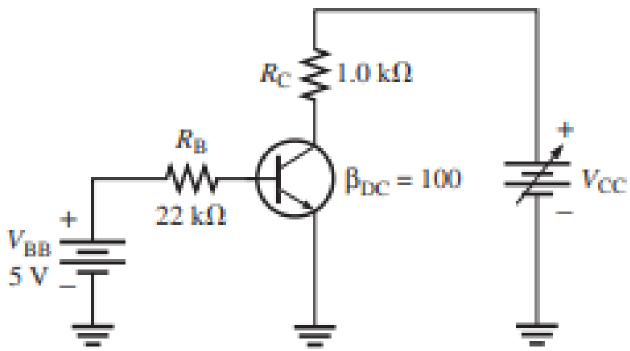
The change (reduction) in $P_{D(\max)}$ is:

$$\Delta P_{D(\max)} = (5 \text{ mW/°C})(70°\text{C} - 25°\text{C}) = (5 \text{ mW}/°C)(45°\text{C}) = 225 \text{ mW}$$

Therefore, the $P_{D(\max)}$ at 70°C is:

$$P_{D(\max)} = 1 \text{ W} - 225 \text{ mW} = 775 \text{ mW}$$

10. A 2N3904 transistor is used in the circuit as shown below (i.e. the same BJT circuit as in Question 6). Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first? Refer to the datasheet of this transistor. [10 marks]



Solution

From the datasheet, we could obtain the maximum values for the device: $P_{D(\max)} = P_D = 625 \text{ mW}$, $V_{CE(\max)} = V_{CEO} = 40 \text{ V}$, and $I_{C(\max)} = I_C = 200 \text{ mA}$.

Assume β_{DC} = 100. This is a reasonably valid assumption based on the datasheet h_{FE} = 100 minimum for specified conditions (β_{DC} and h_{FE} are the same parameter).

As you have learned, the β_{DC} has considerable variations for a given transistor, depending on circuit conditions. Under this assumption, I_C = 19.5 mA and V_{R_c} = 19.5 V as from Question 6.

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_A = 25°C unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."
**Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

Since I_C is much less than $I_C(\max)$ and, ideally, will not change with V_{CC}, the maximum value to which V_{CC} can be increased before $V_{CE}(\max)$ is exceeded is:

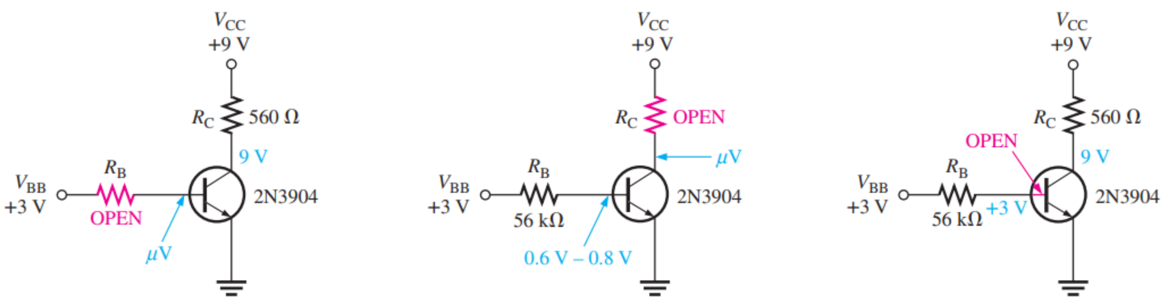
$$V_{CC(\max)} = V_{CE(\max)} + V_{R_C} = 40\text{ V} + 19.5\text{ V} = 59.5\text{ V}$$

However, at the maximum value of V_{CE}, the power dissipation is:

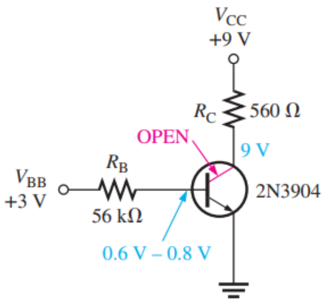
$$P_D = V_{CE(\max)} I_C = (40\text{ V})(19.5\text{ mA}) = 780\text{ mW}$$

Power dissipation exceeds the maximum of 625 mW specified on the datasheet.

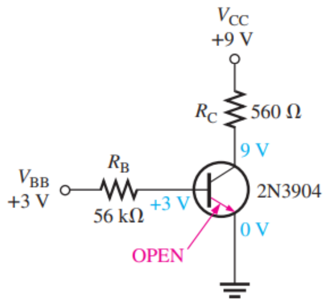
11. Observe the following operational conditions and measured electrical parameters of the 2N3904 NPN BJT transistor-based circuits.



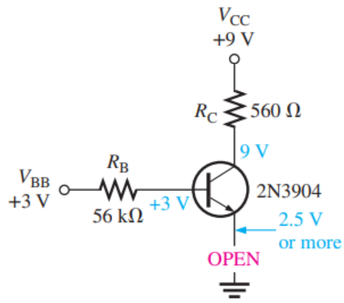
(a) (b) (c)



(d)



(e)



(f)

a. Symptoms: Readings from V to a few mV at base due to floating point and 9 V at collector because transistor is in cut-off. [2 marks]

b. Symptoms: A very small voltage may be observed at the collector when a meter is connected due to the current path through the BC junction and the meter resistance. [2 marks]

c. Symptoms: It is observed that 3 V at base lead and 9 V at collector because transistor is in cut-off. [2 marks]

d. Symptoms: It is observed that 0.6 V – 0.8 V at base lead due to forward voltage drop across base-emitter junction and 9 V at collector because the open prevents collector current. [2 marks]

e. Symptoms: It is observed that 3 V at base lead and 9 V at collector because there is no collector current. Then, we have 0 V at the emitter as normal. [2 marks]

f. Symptoms: It is observed that 3 V at base lead and 9 V at collector because there is no collector current. Then, we have 2.5 V or more at the emitter due to the forward voltage drop across the base-emitter junction. The measuring voltmeter provides a forward current path through its internal resistance. [2 marks]

Solution

a. Fault: Open base resistor.

b. Fault: Open collector resistor.

c. Fault: Base internally open.

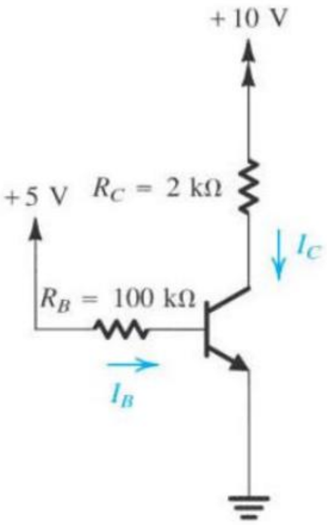
d. Fault: Collector internally open.

e. Fault: Emitter internally open.

f. Fault: Open ground connection.

B. BJT Biasing Circuits

1. Analyse the DC biased NPN BJT transistor circuit below to determine the voltages at all nodes and the currents in all branches. Assume β = 100. [10 marks]



Solution

To determine the voltages and currents in the amplifier, we follow the steps given in the DC biasing design of the BJT transistor.

Step 1

Assuming that V_{BE} of the transistor is around 0.7 V.

Step 2

The base current of the amplifier is found from the following equation:

$$I_B = \frac{V_B - V_{BE}}{R_B} \approx \frac{5\text{ V} - 0.7\text{ V}}{100\text{ k}\Omega} = 0.043\text{ mA}$$

Step 3

The current that flows in the collector is:

$$I_C = \beta I_B = (100)(0.043\text{ mA}) = 4.3\text{ mA}$$

Step 4

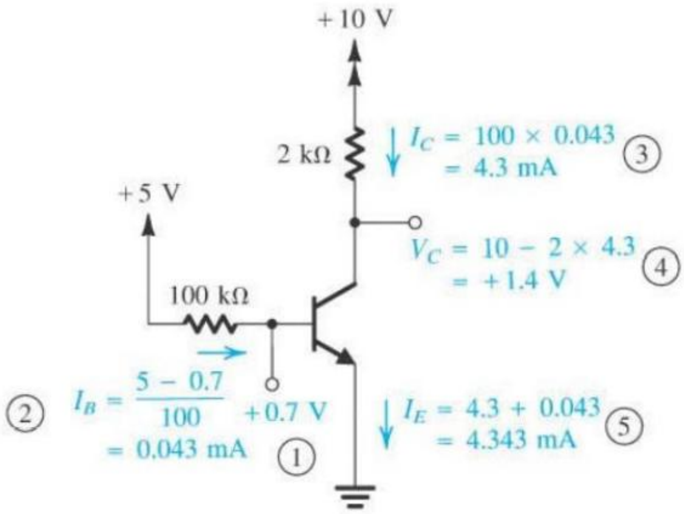
The voltage at the collector is found from the following equation:

$$V_C = V_{CC} - I_C R_C = 10 - (4.3\text{ mA})(2\text{ k}\Omega) = 1.4\text{ V}$$

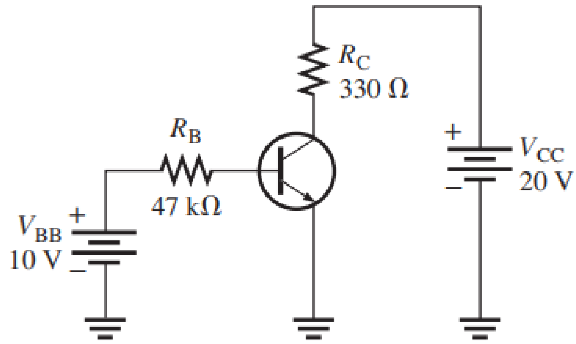
Step 5

The current that flows in the emitter of the amplifier is found from:

$$I_E = (\beta + 1)I_B = (100 + 1) \times 0.043\text{ mA} = 4.343\text{ mA}$$



2. Determine the Q-point for the DC biased NPN BJT transistor circuit in figure given below and draw the DC load line. Find the maximum peak value of base current for linear operation. Assume β_{DC} = 200. [20 marks]



Solution

The Q-point is defined by the values of I_C and V_{CE}.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{47\text{ k}\Omega} = 198\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (200)(198\ \mu\text{A}) = 39.6\text{ mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 20\text{ V} - 13.07\text{ V} = 6.93\text{ V}$$

The Q-point is at I_C = 39.6 mA and at V_{CE} = 6.93 V.

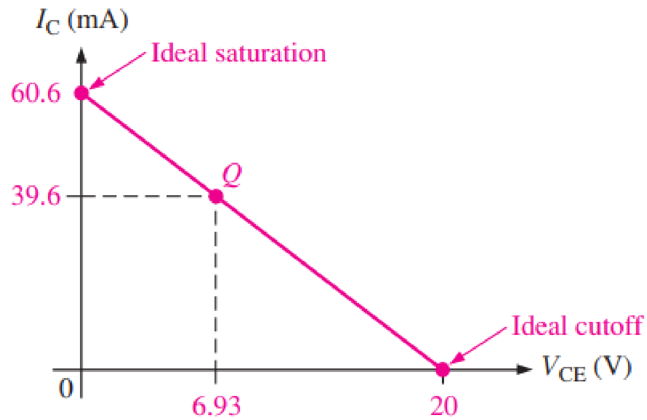
Since I_C(cutoff) = 0, you need to know $I_{C(\text{sat})}$ to determine how much variation in collector current can occur and still maintain linear operation of the transistor.

$$I_{C(\text{sat})} = \frac{V_{CC}}{R_C} = \frac{20\text{ V}}{330\ \Omega} = 60.6\text{ mA}$$

The DC load line is graphically illustrated in the figure below, showing that before saturation is reached, I_C can increase an amount ideally equal to:

$$I_C(\text{sat}) - I_{CQ} = 60.6\text{ mA} - 39.6\text{ mA} = 21\text{ mA}$$

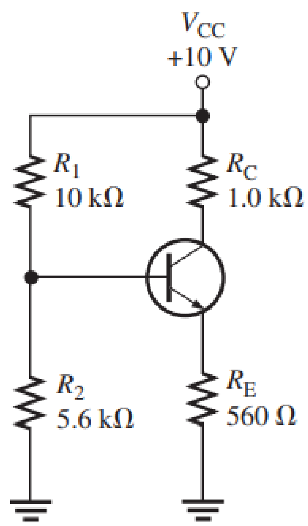
However, I_C can decrease by 39.6 mA before cutoff (I_C = 0) is reached. Therefore, the limiting excursion is 21 mA because the Q-point is closer to saturation than to cut-off. The 21 mA is the maximum peak variation of the collector current. Actually, it would be slightly less in practice because V_{CE}(sat) is not quite zero.



Determine the maximum peak variation of the base current as follows:

$$I_{b(\text{peak})} = \frac{I_{C(\text{peak})}}{\beta_{DC}} = \frac{21 \text{ mA}}{200} = 105 \text{ µA}$$

3. Determine V_{CE} and I_C in the voltage-divider biased NPN BJT transistor circuit of figure given below if β_{DC} = 100. [12 marks]



Solution

The base voltage is found from the following equation:

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{5.6 \text{ k}\Omega}{10 \text{ k}\Omega + 5.6 \text{ k}\Omega}\right) \times 10 \text{ V} = 3.59 \text{ V}$$

So, the voltage at the emitter is

$$V_E = V_B - V_{BE} = 3.59 \text{ V} - 0.7 \text{ V} = 2.89 \text{ V}$$

And the current that flows in the emitter is

$$I_E = \frac{V_E}{R_E} = \frac{2.89\ \text{V}}{560\ \Omega} = 5.16\ \text{mA}$$

Therefore, the current in the collector is found from

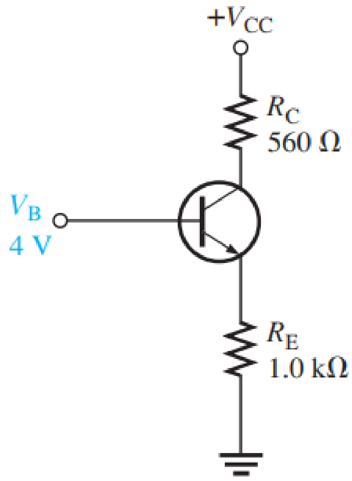
$$I_C \cong I_E = 5.16\ \text{mA}$$

And the voltage at the collector and voltage across the collector-emitter are:

$$V_C = V_{CC} - I_C R_C = 10\ \text{V} - (5.16\ \text{mA})(1\ \text{k}\Omega) = 4.84\ \text{V}$$

$$V_{CE} = V_C - V_E = 4.84\ \text{V} - 2.89\ \text{V} = 1.95\ \text{V}$$

4. Determine the DC input resistance looking in at the base of the transistor in the figure below. Knowing that β_{DC} = 125 and V_B = 4 V. [4 marks]



Solution

The current that flows in the emitter is found from:

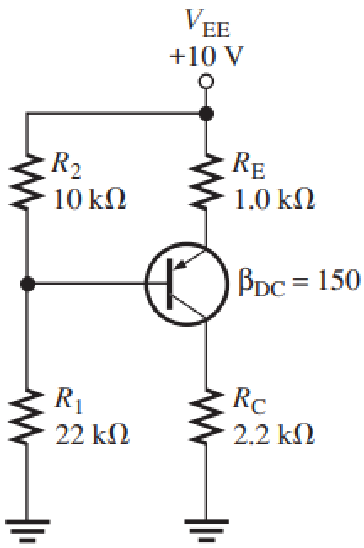
$$I_E = \frac{V_B - V_{BE}}{R_E} = \frac{4\ \text{V} - 0.7\ \text{V}}{1\ \text{k}\Omega} = 3.3\ \text{mA}$$

The DC input resistance looking at the base of the transistor is

$$R_{in(\text{base})} = \frac{V_B}{I_B} = \frac{V_B}{I_E/\beta_{DC}} = \frac{(4\ \text{V})}{3.3\ \text{mA}/125} = 152\ \text{k}\Omega$$

5. Find I_C and V_{EC} for the voltage-divider biased PNP BJT transistor circuit in the figure given below.

[14 marks]



Solution

This circuit has already the configuration of negative collector supply voltage ($-V_{CC}$) transformed to positive emitter supply voltage ($+V_{EE}$) as shown above. Apply Thevenin's theorem.

$$V_{Th} = \left(\frac{R_1}{R_1 + R_2}\right) V_{EE} = \left(\frac{22\ \text{k}\Omega}{22\ \text{k}\Omega + 10\ \text{k}\Omega}\right) 10\ \text{V} = (0.688)10\ \text{V} = 6.88\ \text{V}$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(22\ \text{k}\Omega)(10\ \text{k}\Omega)}{22\ \text{k}\Omega + 10\ \text{k}\Omega} = 6.88\ \text{k}\Omega$$

Use the equation given below to determine I_E:

$$I_E = \frac{V_{Th} + V_{BE} - V_{EE}}{R_E + R_{Th}\beta_{DC}} = \frac{6.88\ \text{V} - 0.7\ \text{V} - 10\ \text{V}}{1\ \text{k}\Omega + 45.9\ \Omega} = \frac{-2.42\ \text{V}}{1.0459\ \text{k}\Omega} = -2.31\ \text{mA}$$

The negative sign on I_E indicates that the assumed current direction in the Kirchhoff's analysis is opposite from the actual current direction. From I_E, you can determine I_C and V_{EC} as follows:

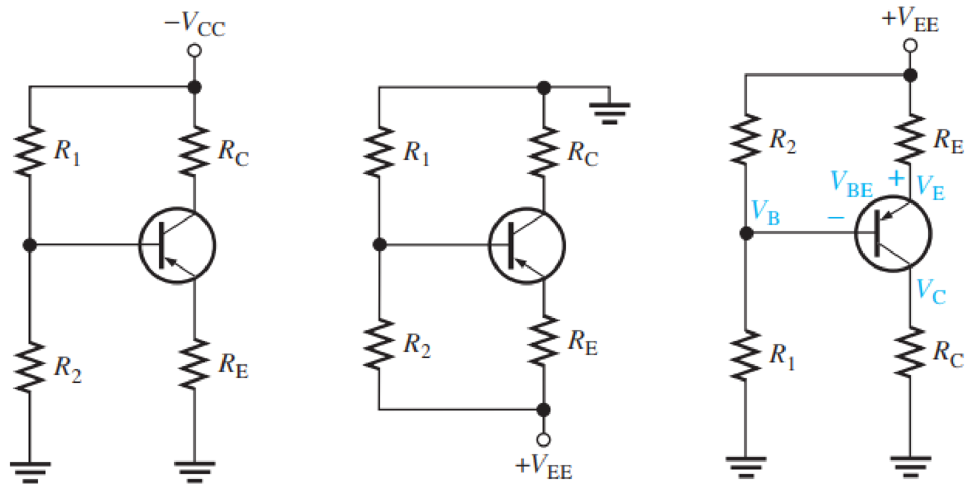
$$I_C = I_E = 2.31\ \text{mA}$$

$$V_C = I_C R_C = (2.31\ \text{mA})(2.2\ \text{k}\Omega) = 5.08\ \text{V}$$

$$V_E = V_{EE} - I_E R_E = 10\ \text{V} - (2.31\ \text{mA})(1\ \text{k}\Omega) = 7.68\ \text{V}$$

$$V_{EC} = V_E - V_C = 7.68\ \text{V} - 5.08\ \text{V} = 2.6\ \text{V}$$

6. Find I_C and V_{CE} for a voltage-divider biased PNP BJT transistor circuit with these values: R_1 = 68 kΩ, R_2 = 47 kΩ, R_C = 1.8 kΩ, R_E = 2.2 kΩ, V_{CC} = -6 V, and β_{DC} = 75. Refer to the figure (a) below, which shows the schematic with a negative supply voltage. [14 marks]



(a) Negative collector supply voltage, V_{CC} (b) Positive emitter supply voltage, V_{EE} (c) The circuit in (b) redrawn

Solution

Apply Thevenin's theorem

$$V_{Th} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{47\ \text{k}\Omega}{68\ \text{k}\Omega + 47\ \text{k}\Omega}\right)(-6\ \text{V}) = -2.45\ \text{V}$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(68\ \text{k}\Omega)(47\ \text{k}\Omega)}{68\ \text{k}\Omega + 47\text{k}\Omega} = 27.8\ \text{k}\Omega$$

Use the equation given below to determine I_E

$$I_E = \frac{-V_{Th} + V_{BE}}{R_E + R_{Th}/\beta_{DC}} = \frac{2.45\ \text{V} + 0.7\ \text{V}}{2.2\ \text{k}\Omega + 371\ \Omega} = 1.23\ \text{mA}$$

From I_E, you can determine I_C and V_{CE} as follows:

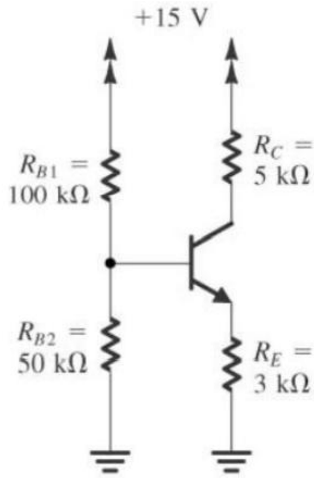
$$I_C = I_E = 1.23\ \text{mA}$$

$$V_C = -V_{CC} + I_C R_C = -6\ \text{V} + (1.23\ \text{mA})(1.8\ \text{k}\Omega) = -3.79\ \text{V}$$

$$V_E = -I_E R_E = -(1.23\ \text{mA})(2.2\ \text{k}\Omega) = -2.71\ \text{V}$$

$$V_{CE} = V_C - V_E = -3.79\ \text{V} + 2.71\ \text{V} = -1.08\ \text{V}$$

7. Analyse the voltage-divider biased NPN BJT transistor circuit below to determine the voltages at all nodes and the currents in all branches. Assume β = 100. [20 marks]



Solution

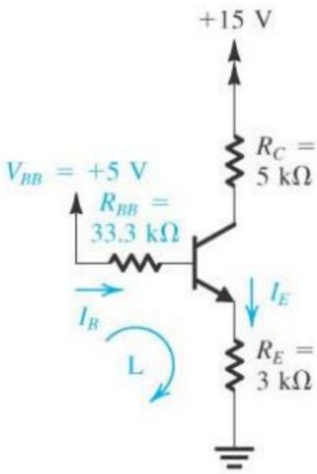
Simplify the base circuit using Thevenin theorem. The voltage across the biasing base of the transistor is given as:

$$V_{BB} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC} = \left(\frac{50\ \text{k}\Omega}{100\ \text{k}\Omega + 50\ \text{k}\Omega}\right) \times 15\ \text{V} = 5\ \text{V}$$

The resistor at the biasing base of the resistor is:

$$R_{BB} = R_{B1} \parallel R_{B2} = 100\ \text{k}\Omega \parallel 50\ \text{k}\Omega = 33.3\ \text{k}\Omega$$

Evaluate the base or emitter current by writing a loop equation around the loop marked L.



The voltage at the biasing of the base of the transistor is given as:

$$V_{BB} = I_B R_{BE} + V_{BE} + I_E R_E \qquad (1)$$

The base current is found from the following equation:

$$I_B = \frac{I_E}{\beta + 1} \qquad (2)$$

Rearranging the equation, substitute for I_B in (1) by (2) gives:

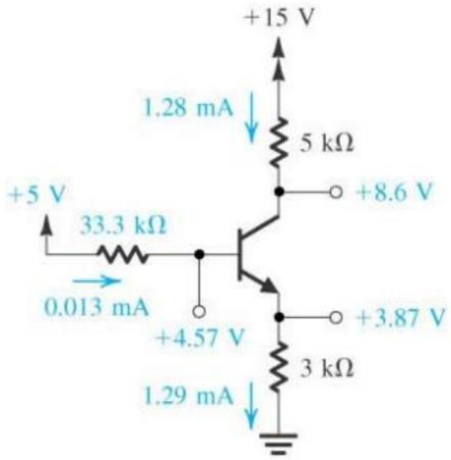
$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \left[\frac{R_{BB}}{\beta + 1}\right]}$$

For the numerical values given, we have

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \left(\frac{R_{BB}}{\beta + 1}\right)} = \frac{5\text{ V} - 0.7\text{ V}}{3\text{ k}\Omega + \left(\frac{33.3\text{ k}\Omega}{100 + 1}\right)} = 1.29\text{ mA}$$

The base current will be

$$I_B = \frac{I_E}{\beta + 1} = \frac{1.29\text{ mA}}{100 + 1} = 0.0128\text{ mA}$$



Now evaluate all the voltages. The voltage at the base of the amplifier is found from the following equation:

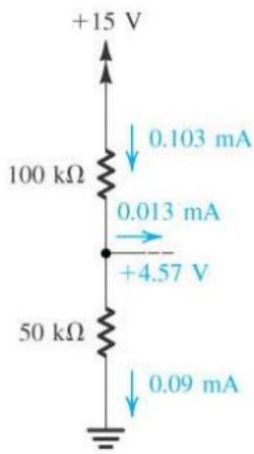
$$V_B = V_{BE} + I_E R_E = 0.7\text{ V} + (1.29\text{ mA})(3\text{ k}\Omega) = 4.57\text{ V}$$

The current that flows in the collector is found from:

$$I_C = \left(\frac{\beta}{1 + \beta}\right) I_E = \left(\frac{100}{1 + 100}\right) \times 1.29\text{ mA} = 1.28\text{ mA}$$

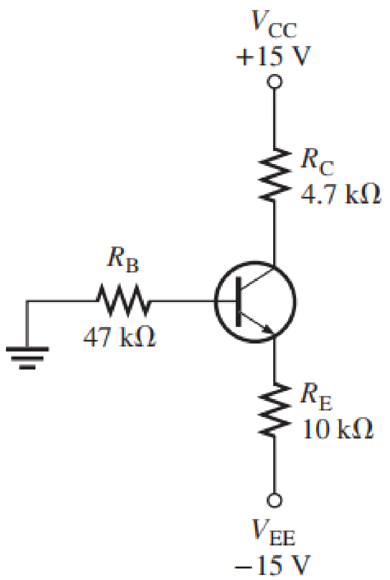
The voltage at the collector is found from:

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.28\text{ mA})(1.29\text{ k}\Omega) = 8.6\text{ V}$$



C. Other BJT Biasing Methods

1. Calculate I_E and V_{CE} for the emitter biased NPN BJT transistor circuit in the figure given below using the approximations $V_E \cong -1\text{ V}$ and $I_C \cong I_E$. [8 marks]



Solution

The voltage at the emitter is found from the following:

$$V_E \cong -1\text{ V}$$

The current that flows in the emitter is:

$$I_E = \frac{V_E - V_{EE}}{R_E} = \frac{-1\text{ V} - (-15\text{ V})}{10\text{ k}\Omega} = 1.4\text{ mA}$$

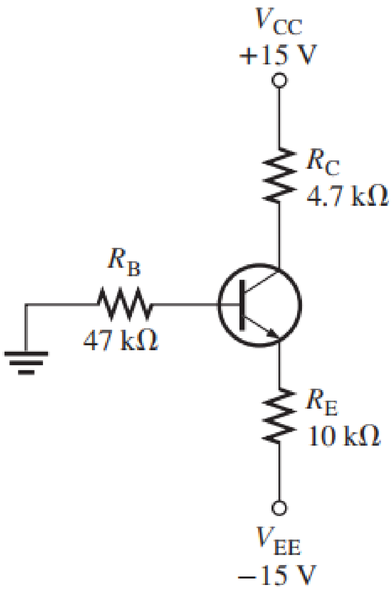
Knowing that $I_C \cong I_E$, the voltage at the collector is:

$$V_C = V_{CC} - I_C R_C = 15\text{ V} - (1.4\text{ mA})(4.7\text{ k}\Omega) = 8.4\text{ V}$$

The voltage across the collector-emitter is found from:

$$V_{CE} = V_C - V_E = 8.4\text{ V} - (-1\text{ V}) = 9.4\text{ V}$$

2. Determine how much the Q-point (I_C, V_{CE}) for the emitter biased NPN BJT transistor circuit in the figure given below will change if β_{DC} increases from 100 to 200 when the given transistor is replaced by another type of BJT transistor. [20 marks]



Solution

For β_{DC} = 100

$$I_{C(100)} \cong I_E = \frac{-V_{EE} - V_{BE}}{R_E + \left(\frac{R_B}{\beta_{DC}}\right)} = \frac{-(-15\text{ V}) - 0.7\text{ V}}{10\text{ k}\Omega + \left(\frac{47\text{ k}\Omega}{100}\right)} = 1.37\text{ mA}$$

$$V_C = V_{CC} - I_{C(100)}R_C = 15\text{ V} - (1.37\text{ mA})(4.7\text{ k}\Omega) = 8.56\text{ V}$$

$$V_E = V_{EE} + I_E R_E = -15\text{ V} + (1.37\text{ mA})(10\text{ k}\Omega) = -1.3\text{ V}$$

Therefore

$$V_{CE(100)} = V_C - V_E = 8.56\text{ V} - (-1.3\text{ V}) = 9.83\text{ V}$$

For β_{DC} = 200

$$I_{C(200)} \cong I_E = \frac{-V_{EE} - V_{BE}}{R_E + \left(\frac{R_B}{\beta_{DC}}\right)} = \frac{-(-15\text{ V}) - 0.7\text{ V}}{10\text{ k}\Omega + \left(\frac{47\text{ k}\Omega}{200}\right)} = 1.38\text{ mA}$$

$$V_C = V_{CC} - I_{C(200)}R_C = 15\text{ V} - (1.38\text{ mA})(4.7\text{ k}\Omega) = 8.51\text{ V}$$

$$V_E = V_{EE} + I_E R_E = -15\text{ V} + (1.38\text{ mA})(10\text{ k}\Omega) = -1.2\text{ V}$$

Therefore

$$V_{CE(200)} = V_C - V_E = 8.51\text{ V} - (-1.2\text{ V}) = 9.71\text{ V}$$

The percent change in I_C as β_{DC} changes from 100 to 200 is:

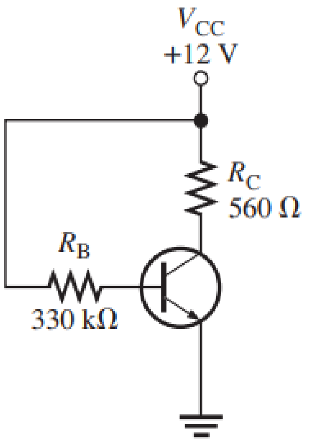
$$\%\Delta I_C = \left(\frac{I_{C(200)} - I_{C(100)}}{I_{C(100)}}\right)100\% = \left(\frac{1.38\text{ mA} - 1.37\text{ mA}}{1.37\text{ mA}}\right) \times 100\% = 0.73\%$$

The percent change in V_{CE} is:

$$\%\Delta V_{CE} = \left(\frac{V_{CE(200)} - V_{CE(100)}}{V_{CE(100)}}\right)100\% = \left(\frac{9.71\text{ V} - 9.83\text{ V}}{9.83\text{ V}}\right) \times 100\% = -1.22\%$$

3. Determine how much the Q-point (I_C, V_{CE}) for the base biased NPN BJT transistor circuit in the figure below will change over a temperature range where β_{DC} increases from 100 to 200.

[14 marks]



Solution

For β_{DC} = 100

$$I_{C(100)} = \beta_{DC}\left(\frac{V_{CC} - V_{BE}}{R_B}\right) = 100\left(\frac{12\text{ V} - 0.7\text{ V}}{330\text{ k}\Omega}\right) = 3.42\text{ mA}$$

Therefore, the voltage across collector-emitter is:

$$V_{CE(100)} = V_{CC} - I_{C(100)}R_C = 12\text{ V} - (3.42\text{ mA})(560\ \Omega) = 10.1\text{ V}$$

For β_{DC} = 200

$$I_{C(200)} = \beta_{DC}\left(\frac{V_{CC} - V_{BE}}{R_B}\right) = 200\left(\frac{12\text{ V} - 0.7\text{ V}}{330\text{ k}\Omega}\right) = 6.84\text{ mA}$$

Therefore, the voltage across collector-emitter is:

$$V_{CE(200)} = V_{CC} - I_{C(200)}R_C = 12\text{ V} - (6.84\text{ mA})(560\ \Omega) = 8.17\text{ V}$$

The percent change in I_C as β_{DC} changes from 100 to 200 is:

$$\%\Delta I_C = \left(\frac{I_{C(200)} - I_{C(100)}}{I_{C(100)}}\right) \times 100\% = \left(\frac{6.84\text{ mA} - 3.42\text{ mA}}{3.42\text{ mA}}\right) \times 100\% = 100\%\text{ (an increase)}$$

The percent change in V_{CE} is:

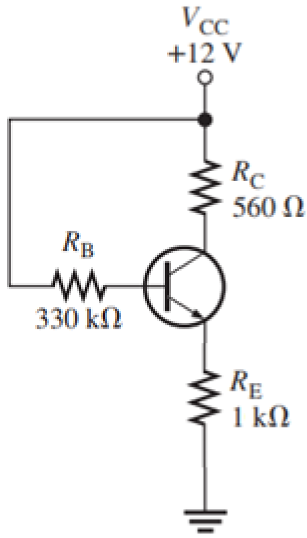
$$\%\Delta V_{CE} = \left(\frac{V_{CE(200)} - V_{CE(100)}}{V_{CE(100)}}\right) \times 100\% = \left(\frac{8.17\text{ V} - 10.1\text{ V}}{10.1\text{ V}}\right) \times 100\%$$

$$= -19.1\%\text{ (a decrease)}$$

As you can see, the Q-point is very dependent on β_{DC} in this circuit and therefore makes the base bias arrangement very unreliable.

Consequently, base bias is not normally used if linear operation is required. However, it can be used in switching applications.

4. The base-biased NPN BJT transistor circuit from previous question is converted to emitter-feedback biased by the addition of a 1 kΩ emitter resistor. All other values are the same and a transistor with a β_{DC} = 100 is used.



Determine how much the Q-point will change if the first transistor is replaced with one having a β_{DC} = 200. Compare the results to those of the base-bias circuit. [14 marks]

Solution

For β_{DC} = 100

$$I_{C(100)} = I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}} = \frac{12\ \text{V} - 0.7\ \text{V}}{1\ \text{k}\Omega + 330\ \text{k}\Omega/100} = 2.63\ \text{mA}$$

Therefore

$$V_{CE(100)} = V_{CC} - I_{C(100)}(R_C + R_E) = 12\ \text{V} - (2.63\ \text{mA})(560\ \Omega + 1\ \text{k}\Omega) = 7.90\ \text{V}$$

For β_{DC} = 200

$$I_{C(200)} = I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}} = \frac{12\ \text{V} - 0.7\ \text{V}}{1\ \text{k}\Omega + 330\ \text{k}\Omega/200} = 4.26\ \text{mA}$$

Therefore

$$V_{CE(200)} = V_{CC} - I_{C(200)}(R_C + R_E) = 12\ \text{V} - (4.26\ \text{mA})(560\ \Omega + 1\ \text{k}\Omega) = 5.35\ \text{V}$$

The percent change in I_C:

$$\%\Delta I_C = \left(\frac{I_{C(200)} - I_{C(100)}}{I_{C(100)}}\right) \times 100\% = \left(\frac{4.26\ \text{mA} - 2.63\ \text{mA}}{2.63\ \text{mA}}\right) \times 100\% = 62.0\ \%\ \text{(increase)}$$

Therefore

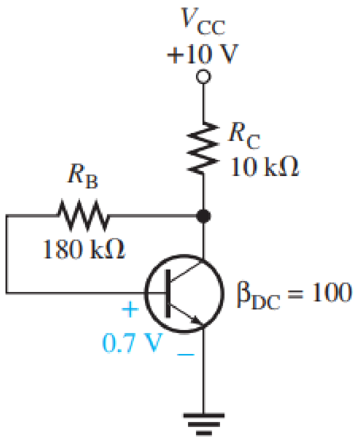
$$\%\Delta V_{CE} = \left(\frac{V_{CE(200)} - V_{CE(100)}}{V_{CE(100)}}\right) \times 100\% = \left(\frac{7.90\ \text{V} - 5.35\ \text{V}}{7.90\ \text{V}}\right) \times 100\%$$

$$= -32.3\ \%\ \text{(decrease)}$$

Although the emitter-feedback bias significantly improved the stability of the bias for a change in β_{DC} compared to base bias, it still does not provide a reliable Q-point.

5. Calculate the Q-point values (I_C and V_{CE}) for the collector-feedback biased NPN BJT transistor circuit in the figure given below. Compare the performance of the circuit with the one in the previous question (e.g. with modified base biased scheme) when β_{DC} is varied from 100 to 200.

[14 marks]



Solution

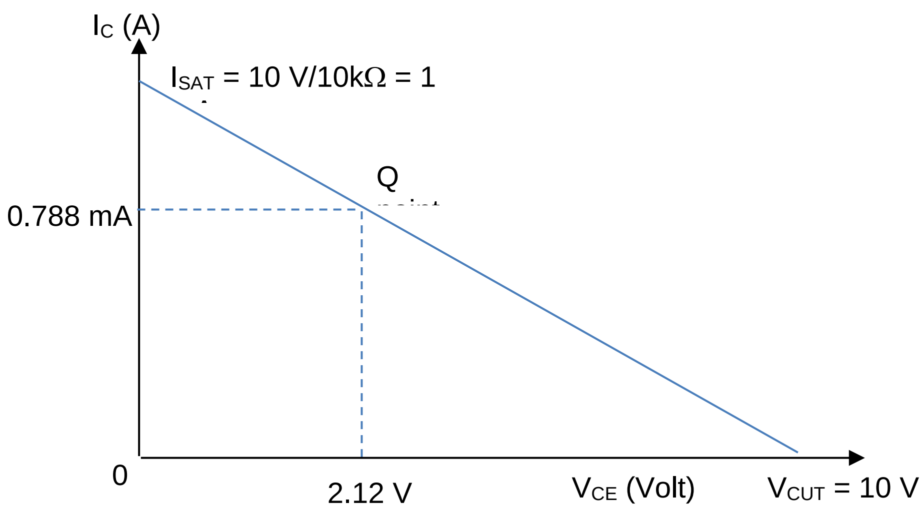
Using the equation given below, the collector current is:

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{DC}} = \frac{10\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega + 180\text{ k}\Omega/100} = 788\ \mu\text{A}$$

Using the equation given below, the collector-to-emitter voltage is:

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (788\ \mu\text{A})(10\text{ k}\Omega) = 2.12\text{ V}$$

The current (I_C) vs. V_{CE} graph and its Q-point of the given BJT transistor circuit.



For $\beta_{DC} = 200$, using the equation given below, the collector current is:

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{DC}} = \frac{10\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega + 180\text{ k}\Omega/200} = 853\ \mu\text{A}$$

Using the equation given below, the collector-to-emitter voltage is:

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (0.853\ \mu\text{A})(10\text{ k}\Omega) = 1.47\text{ V}$$

The percent change in I_C:

$$\%\Delta I_C = \left(\frac{I_{C(200)} - I_{C(100)}}{I_{C(100)}}\right) \times 100\% = \left(\frac{788\ \mu\text{A} - 853\ \mu\text{A}}{853\ \mu\text{A}}\right) \times 100\%$$

$$= -7.6\ \%\ (\text{decrease})$$

$$\%\Delta V_{CE} = \left(\frac{V_{CE(200)} - V_{CE(100)}}{V_{CE(100)}}\right) \times 100\% = \left(\frac{2.12\text{ V} - 1.47\text{ V}}{1.47\text{ V}}\right) \times 100\%$$

$$= 44.2\ \%\ (\text{increase})$$

As seen from the calculation above, there is improvement in terms of the I_C fluctuation from the modified base biased scheme in the previous question as β_{DC} is varied from 100 to 200, but the V_{CE} is worse off than before.