National Polytechnic Institute
Superior School of Computer Sciences

Analog Electronics.

Practice 4 - Bipolar Junction Transistor.

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Contents

1 Objective:

- Identify the terminal of a transistor using a multimeter fluke.
- Analyze the polarization of a BJT.
- Analyze the bipolar transistor in his commutation state.
- Analyze the cutoff and saturation points of a transistor.
- Implement a application with the commutation transistor.

2 Introduction:

The transistor is a three-layer semiconductor device consisting of either two n- and one p-type layers of material or two p- and one n-type layers of material. The former is called an ***npn transistor***, while the latter is called a ***pnp transistor***. Both are shown in Figure 1.0 with the proper dc biasing.

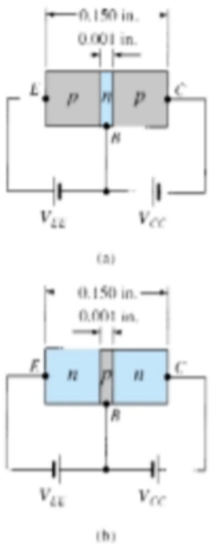

Figure 1.0: Transistor types. (a) pnp and (b) npn.

2.1 Transistor Operation:

The basic operation of the transistor will now be described using the ***pnp transistor*** of Figure 1.0a. The operation of the ***npn transistor*** is exactly the same if the roles played by the electron and hole are interchanged. In Figure 1.1.0 the ***pnp transistor*** has been redrawn without the base-to-collector bias. Note the similarities between this situation and that of the forward-biased diode in Practice 1. The depletion region has been reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from the p- to the n-type material.

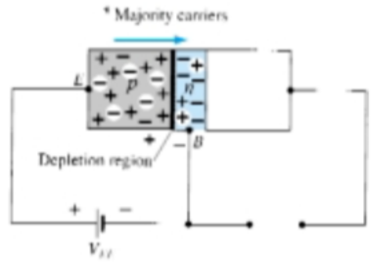

Figure 1.1.0: Forward-biased junction of a pnp transistor.

Let us now remove the base-to-emitter bias of the ***pnp transistor*** of Figure 1.0a as shown in Figure 1.1.1. Consider the similarities between this situation and that of the reverse-biased diode of Practice 1. Recall that the flow of majority carriers is zero, resulting in only a minority-carrier flow, as indicated in Figure 1.1.1. In summary, there- fore:

One p-n junction of a transistor is reverse biased, while the other is forward biased.

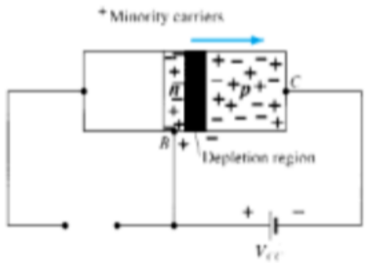

Figure 1.1.1: Reverse-biased junction of a pnp transistor.

In Figure 1.1.2 both biasing potentials have been applied to a pnp transistor, with the resulting majority- and minority-carrier flow indicated. Note in Figure 1.1.2 the widths of the depletion regions, indicating clearly which junction is forward-biased and which is reverse-biased. As indicated in Figure 1.1.2, a large number of majority carriers will diffuse across the forward-biased p-n junction into the n-type material. The question then is whether these carriers will contribute directly to the base current I_b or pass directly into the p-type material. Since the sandwiched n-type material is very thin and has a low conductivity, a very small number of these carriers will take this path of high resistance to the base terminal. The magnitude of the base current is typically on the order of microamperes as compared to milliamperes for the emitter and collector currents. The larger number of these majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal as indicated in Figure 1.1.2. The reason for the relative ease with which the majority carriers can cross the reverse-biased junction is easily understood if we consider that for the reverse-biased diode the injected majority carriers will appear as minority carriers in the n-type material. In other words, there has been an injection of minority carriers into the n-type base region material. Combining this with the fact that all the minority carriers in the depletion region will cross the reverse-biased junction of a diode accounts for the flow indicated in Figure 1.1.2.

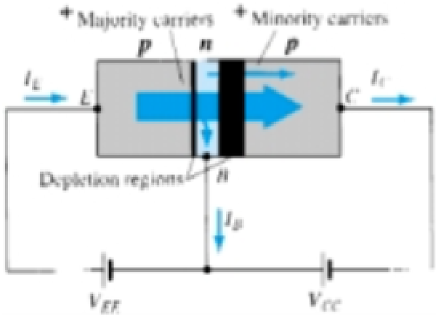

Figure 1.1.2: Majority and minority carrier flow of a pnp transistor.

Applying Kirchhoffs current law to the transistor of Figure 1.1.2 as if it were a single node, we obtain:

$$I_E = I_B + I_C \tag{1}$$

... and find that the emitter current is the sum of the collector and base currents. The collector current, however, is comprised of two components the majority and minority carriers as indicated in Figure 1.1.2. The minority-current component is called the leakage current and is given the symbol I_{CO} (I_C current with emitter terminal Open). The collector current, therefore, is determined in total by Equation (2):

$$I_C = I_{C_{majority}} + I_{CO_{minority}} \tag{2}$$

2.2 Alpha α:

In the dc mode the levels of I_C and I_E due to the majority carriers are related by a quantity called ***alpha*** and defined by the following equation:

$$\alpha_{dc} = \frac{I_C}{T_E} \tag{3}$$

WhereI_C and I_E are the levels of current at the point of operation. Even though the characteristics of the ideal transistor suggest that $\alpha = 1$, for practical devices the level of alpha typically extends from 0.90 to 0.998, with most approaching the high end of the range. Since alpha is defined solely for the majority carriers, equation 2, becomes:

$$I_C = \alpha I_E + I_{CBO} \tag{4}$$

2.3 Common-Emitter Configuration:

The most frequently encountered transistor configuration appears in Figure 1.3.0 for the pnp and npn transistors. It is called the common-emitter configuration since the emitter is common or reference to both the input and output terminals (in this case common to both the base and collector terminals). Two sets of characteristics are again necessary to describe fully the behavior of the common-emitter configuration: one for the input or base-emitter circuit and one for the output or collector-emitter circuit. Both are shown in Figure 1.3.1.

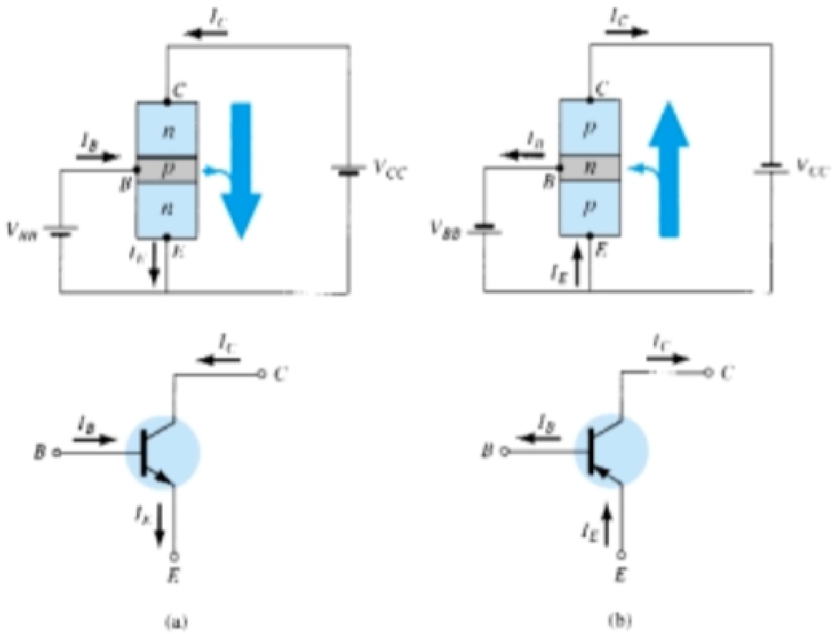

Figure 1.3.0: Notation and symbols used with the common-emitter configuration: (a) npn transistor; (b) pnp transistor.

The emitter, collector, and base currents are shown in their actual conventional current direction. Even though the transistor configuration has changed, the current relations developed earlier for the common-base configuration are still applicable. That is equation 1 and 4. For the common-emitter configuration the output characteristics are a plot of the output current (I_C) versus output voltage (V_{CE}) for a range of values of input current (I_B). The input characteristics are a plot of the input current (I_B) versus the input voltage (V_{BE}) for a range of values of output voltage (V_{CE}).

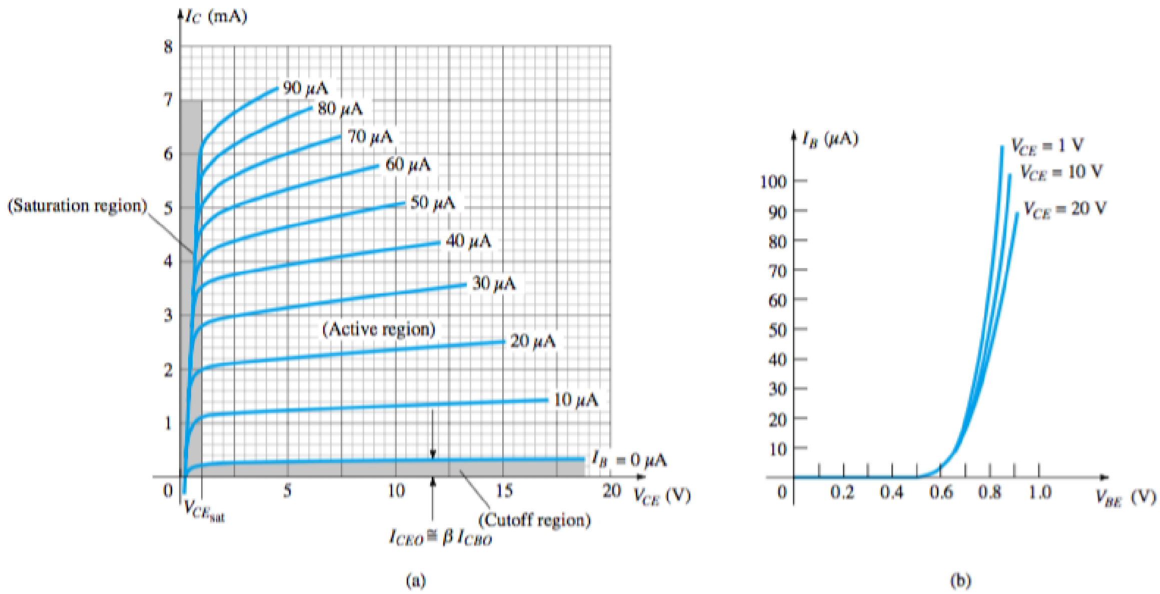

Figure 1.3.1: Characteristics of a silicon transistor in the common-emitter configuration: (a) collector characteristics; (b) base characteristics.

Note that on the characteristics of Figure 1.3.1 the magnitude of I_B is in microamperes, compared to milliamperes of I_C. Consider also that the curves of I_B are not as horizontal as those obtained for I_E in the common-base configuration, indicating that the collector-to-emitter voltage will influence the magnitude of the collector current.

In the active region of a common-emitter amplifier the collector-base junction is reverse-biased, while the base-emitter junction is forward-biased.

You will recall that these were the same conditions that existed in the active re- gion of the common-base configuration. The active region of the common-emitter configuration can be employed for voltage, current, or power amplification. The cutoff region for the common-emitter configuration is not as well defined as for the common-base configuration. Note on the collector characteristics of Figure 1.3.1 that I_C is not equal to zero when I_B is zero. For the common-base configuration, when the input current I_E was equal to zero, the collector current was equal only to the reverse saturation current I_{CO}, so that the curve $I_E = 0$ and the voltage axis were, for all practical purposes, one. The reason for this difference in collector characteristics can be derived through the proper manipulation of 1 and 4:

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha} \tag{5}$$

2.4 Beta β:

In the dc mode the levels of I_C and I_B are related by a quantity called beta and defined by the following equation:

$$\beta_{dc} = \frac{I_C}{I_B} \tag{6}$$

Where I_C and I_B are determined at a particular operating point on the characteristics. For practical devices the level of β typically ranges from about 50 to over 400, with most in the midrange. As for α, β certainly reveals the relative magnitude of one cur- rent to the other. For a device with a β of 200, the collector current is 200 times the magnitude of the base current.

A relationship can be developed between α and β using the basic relationships introduced thus far. Using $\beta = \frac{I_C}{I_B}$ we have $I_B = \frac{I_C}{\beta}$ and from $\alpha = \frac{I_C}{I_E}$ we have $I_E = \frac{I_C}{\alpha}$, such that:

$$\alpha = \frac{\beta}{\beta+1} \tag{7}$$

$$\beta = \frac{\alpha}{1-\alpha} \tag{8}$$

In addition, recall that: $I_{CEO} = \frac{I_{CBO}}{1-\alpha}$, but using the equivalence: $\frac{1}{1-\alpha} = \beta + 1$, we can say:

$$I_{CEO} \cong \beta I_{CBO} \tag{9}$$

As indicated on Figure 1.3.1. Beta is a particularly important parameter because it provides a direct link between current levels of the input and output circuits for a common-emitter configuration. From $I_C = \beta I_B$ and equation 1, we deduce:

$$I_E = (\beta+1)I_B \tag{10}$$

3 Development:

We are going to analyze several circuits with four different transistors.

- ***2N2222A Transistor.***
- ***BC547C Transistor.***
- ***BC557C Transistor.***
- ***TIP41 Transistor.***

And visualize the cutoff and saturation points of each one.

3.1 Beta Value:

To measure the β value using a multimeter or any other device that has the option ***hfe*** it's very simply, once the multimeter it's on this option the only thing you need to do it's search on the device the following section:

Figure 3.1.0: Multimeter NPN - PNP section.

As we can see in Figure 3.1.0, there are at least 8 little holes, on the top we can see the label ***NPN*** and ***PNP*** on the bottom, and beside this two labels we have ***E - B - C - E***. As you can imagine this are shortenings for ***emitter - collector - base***. So, in case you put the terminals of the transistor in this holes, you can figure it out which terminal belongs to the emitter, the base and the collector.

Once we measure the β for the transistors ***2N2222A, BC547C*** and ***BC557C***, the results were captured in the following table:

	2N2222A	BC547C	BC557C
β	241	595	630

Table 1: Beta values for the development transistors.

Observation: *This values are used as well in the* ***Theoretical analysis*** *in section 5.*

3.2 Voltage Divider Bias Circuit:

For the following experiment we assemble the circuit in Figure 3.2.0. The procedure consist in exchange between two ***NPN*** transistors (***2N2222A*** and ***BC547C***) and compare in Table 2 the measured values.

Once we had the circuit, we proceed to measure V_B, V_C, V_{CE}, I_B, I_C, I_E:

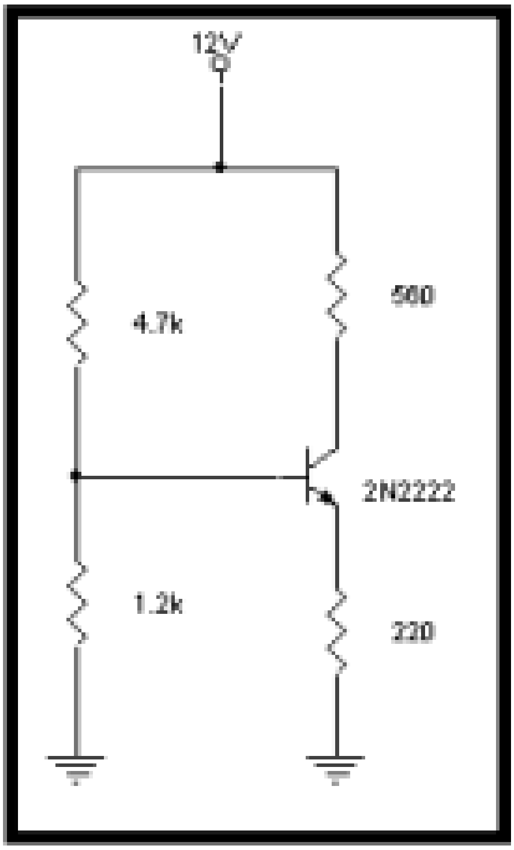

Figure 3.2.0: Voltage divider bias circuit using a 2N2222A transistor.

(i) For V_B: The Base Voltage can be measured by connecting the positive terminal of the voltmeter on the ***Base*** terminal of the transistor, and the negative terminal of the voltmeter on the ***Ground*** reference.

(ii) For V_C: The Collector Voltage can be measured by connecting the positive terminal of the voltmeter on the ***Collector*** terminal of the transistor, and the negative terminal of the voltmeter on the ***Ground*** reference.

(iii) For V_{CE}: The Emitter-Collector Voltage can be measured by connecting the positive terminal of the voltmeter on the ***Collector*** terminal, and the negative terminal of the voltmeter on the ***Emitter*** terminal.

(iv) For I_B: The Base current can be measured by connecting the ammeter in series with the node that connects R_1 and R_2 and the ***Base*** terminal of the transistor.

(v) For I_C: The Collector current can be measured by connecting the ammeter in series with R_C and the ***Collector*** terminal of the transistor.

(vi) For I_E: The Emitter current can be measured by connecting the ammeter in series with R_E and the ***Emitter*** terminal of the transistor.

Observation: *The procedure for measuring this values using the* ***BC547C*** *or the* ***2N2222A*** *transistors it's relative the same.*

	2N2222A	**BC547C**
V_B	2.38 V	2.46 V
V_C	7.6 V	7.4 V
V_{CE}	5.8 V	5.6 V
I_B	2 μA	2 μA
I_C	7.6 mA	8.2 mA
I_E	7.9 mA	8.2 mA

Table 2: Measured values for Figure 3.2.0.

3.3 Cut-off and Saturation Regions:

For the following experiment we assemble the circuit of Figure 3.3.0. The procedure consist in measure V_{CE}, I_B and I_C of ***2N2222A*** using three different resistors and different values for V_i.

> ***Observation:*** *For each circuit we will explain which resistors and voltage were used.*

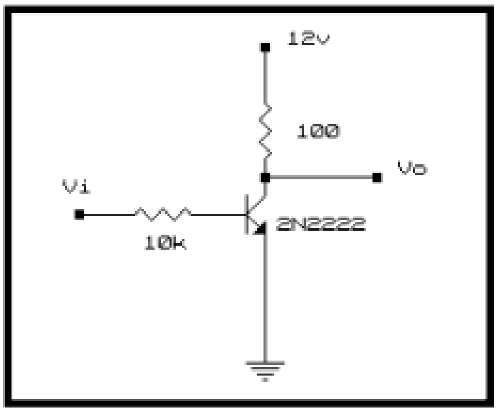

Figure 3.3.0: Transistor in cutoff and saturation region.

(i) For V_{CE}: The Collector-Emitter voltage can be measured by connecting the positive terminal of the voltmeter on the ***Collector*** terminal, and the negative terminal of the voltmeter on the ***Emitter*** terminal.

(ii) For I_B: The Base current can be measured by connecting the ammeter in series with R_B and the ***Base*** terminal of the transistor.

(iii) For I_C: The Collector current can be measured by connecting the ammeter in series with R_C and the ***Collector*** terminal of the transistor.

- For the first circuit we use $R_C = 100\Omega$ and $R_B = 10K\Omega$, such that, we are going to prove it first with $V_i = 5V$, once the values already mentioned were measured, we reduce V_i to $0V$ and we repeated the measures. The results were captured in the Table 3.

	V_i = **5 V**	V_i = **0 v**
V_{CE}	2.5 V	12 V
I_B	0.420 mA	0 A
I_C	89 mA	0 V

Table 3: $R_C = 100\Omega$ and $R_B = 10K\Omega$ resistor values circuit.

- For the Second circuit we use $R_C = 100\Omega$ and $R_B = 22K\Omega$, such that, we are going to prove it first with $V_i = 5V$, once the values already mentioned were measured, we reduce V_i to $0V$ and we repeated the measures. The results were captured in Table 4.

	V_i = **5 V**	V_i = **0 v**
V_{CE}	7.5 V	12 V
I_B	0.204 mA	0 A
I_C	45 mA	0 V

Table 4: $R_C = 100\Omega$ and $R_B = 22K\Omega$ resistor values circuit.

3.4 Other Circuits:

The circuits shown in figures 3.4.0 and 3.4.1 are very similar, both use a ***Square*** signal at a 0.5 H_z frequency that comes from the output of the *functions generator*, which it's connected to a resistor R_B that is in series whit the ***Base*** terminal. The difference lays in the ***NPN*** transistor to which they are connected.

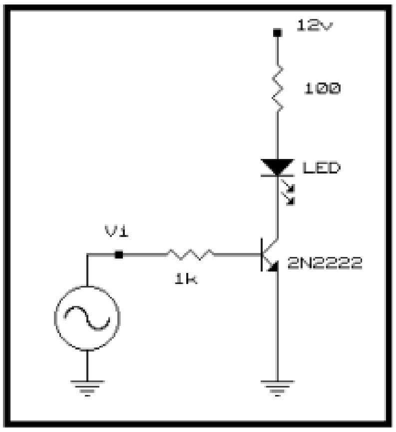

Figure 3.4.0: 2N2222A - LED circuit.

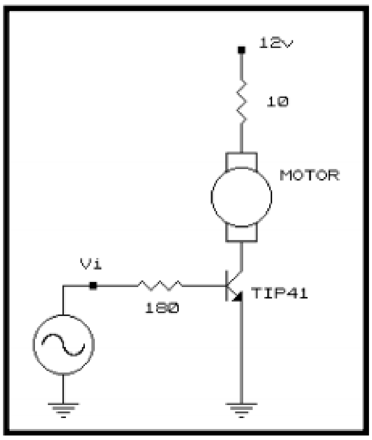

Figure 3.4.1: TIP41 - Motor circuit.

- For the circuit of Figure 3.4.0, as we mention, we connect in series a *Square* signal at 0.5 H_z and the resistor $R_B = 1K\Omega$. In R_C, we use a resistor of 100 Ω at 25w and the transistor used it's a ***2N2222A***. As we can see in Figure 3.4.0, the LED its connected implicitly to the 12 V source, such that, it will be "turned on". But, when the *Square* signal its on the "positive" region, it means that the **Base** terminal it receiving voltage and current, in consequence, the LED will be *brighter* until the positive cycle finishes.

- For the circuit of Figure 3.4.1, same as Figure 3.4.0, we connect in series a *Square* signal at 0.5 H_z and the resistor $R_B = 180\Omega$. In R_C, we use a resistor of 10 Ω at 25w and the transistor used it's a ***TIP41***, this is a power transistor, and the use is identical to the normal transistors, having as special characteristics the high voltages and currents that they have to support and, therefore, the high powers to be dissipated. As we can see in Figure 3.4.1, the Motor its connected implicitly to the 12 V source, but, even that it's receiving voltage and current, this is insufficient to "turn on" the device. But, when the *Square* signal its on the "positive" region the "energy" that the device receives it's enough to turn it on until the positive cycle finish. This because the transistor on ***Common - Emitter*** configuration increase current and voltage.

4 Simulations:

For each circuit that we have analyze in the section 3, we simulate each one of them, and we proceeded to make a comparative table with all the simulated results and the development ones.

4.1 Voltage Divider Bias Circuit:

The circuit of Figure 3.2.0 were simulated with two different ***NPN*** transistors, sames used in the laboratory, this to compare the development results with the simulated. and also, with the theoretical results in section 3.5.

- ***Simulation of a Voltage Divider Bias Circuit implementing a 2N2222A transistor:***

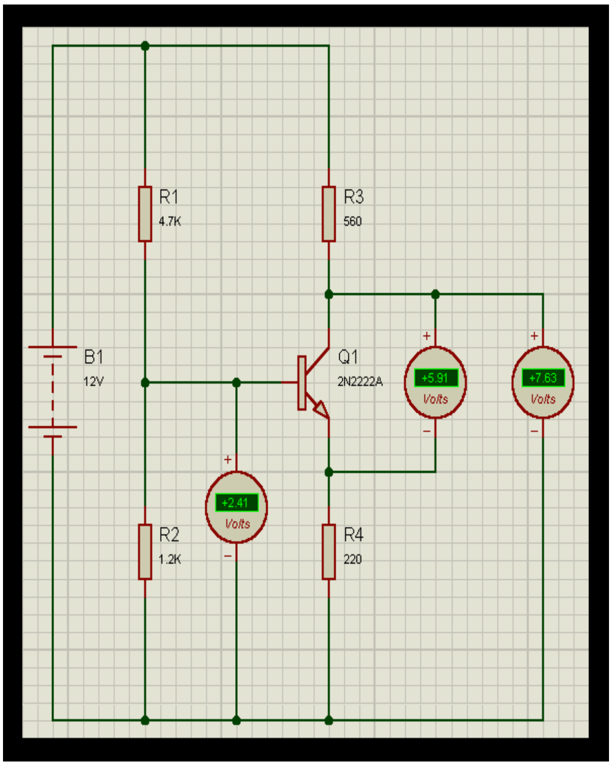

Figure 4.1.0: Simulated voltage measures.

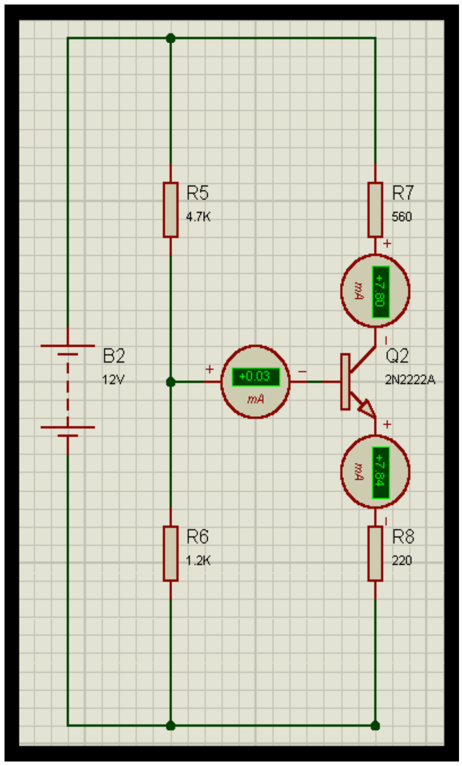

Figure 4.1.1: Simulated current measures.

	2N2222A
V_B	2.41 V
V_C	7.63 V
V_{CE}	5.91 V
I_B	3 μA
I_C	7.8 mA
I_E	7.84 mA

Table 5: Values for simulations in Figures 4.1.0 and 4.1.1.

- ***Simulation of a Voltage Divider Bias Circuit implementing a BC547 transistor:***

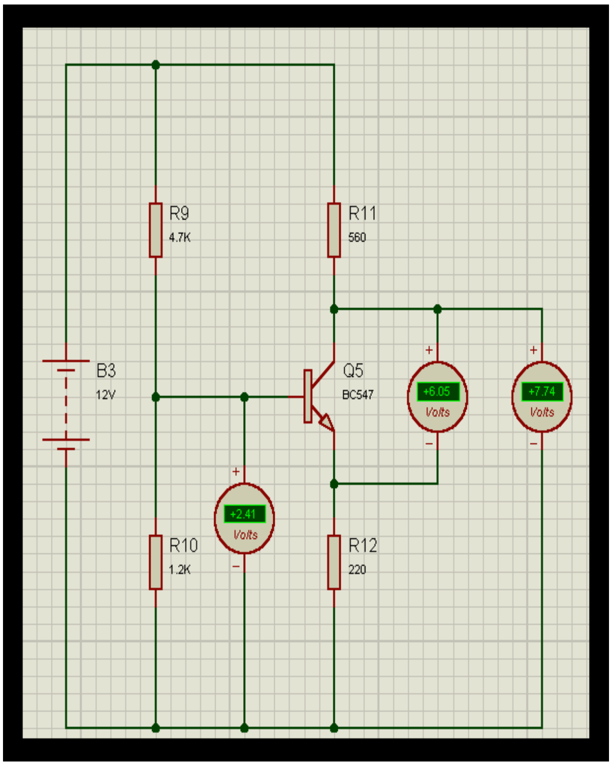

Figure 4.1.2: Simulated voltage measures.

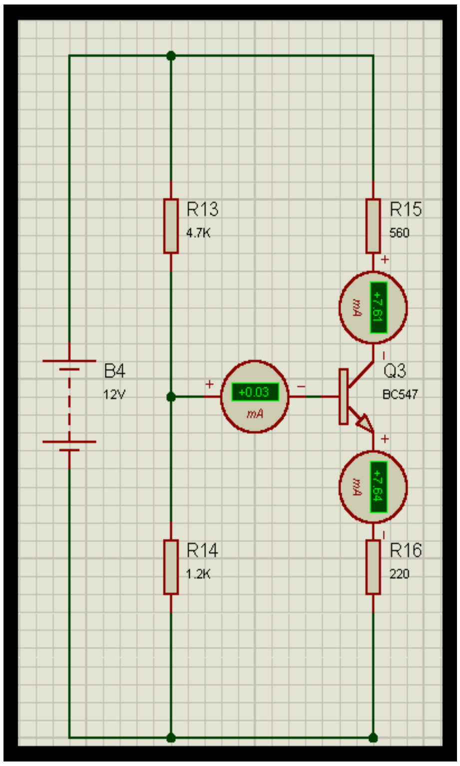

Figure 4.1.3: Simulated current measures.

	BC547
V_B	2.41 V
V_C	7.74 V
V_{CE}	6.05 V
I_B	3 μA
I_C	7.61 mA
I_E	7.64 mA

Table 6: Values for simulations in Figures 4.1.2 and 4.1.3.

4.2 Cut-off and Saturation Regions:

The circuit of Figure 3.3.0 were simulated with the ***2N2222A*** transistora and the resistors used in the laboratory, this to compare the development results with the simulated. and also, with the theoretical results in section 3.5.

- ***Simulation of Cut-off and Saturation points implementing a 2N2222A transistor and a 10K* Ω *resistor in* R_B*:***

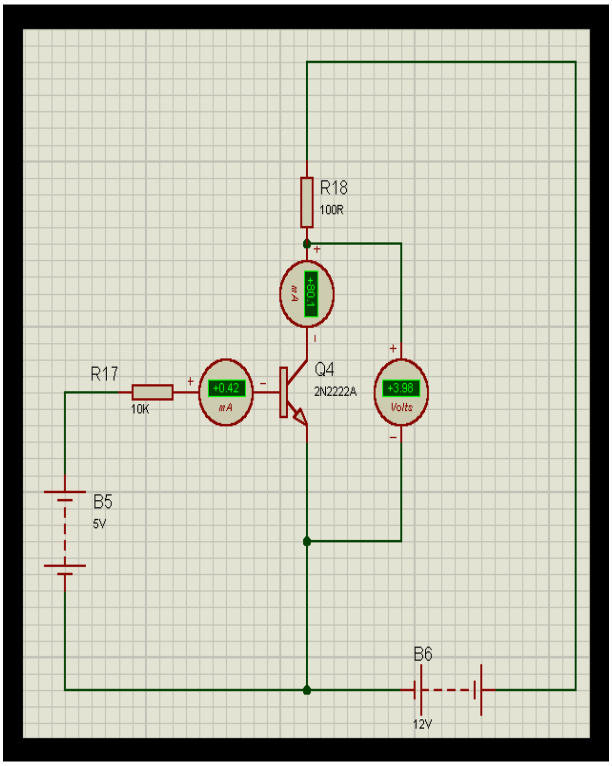

Figure 4.2.0: Simulated measures with a voltage source of $V_i = 5$ V.

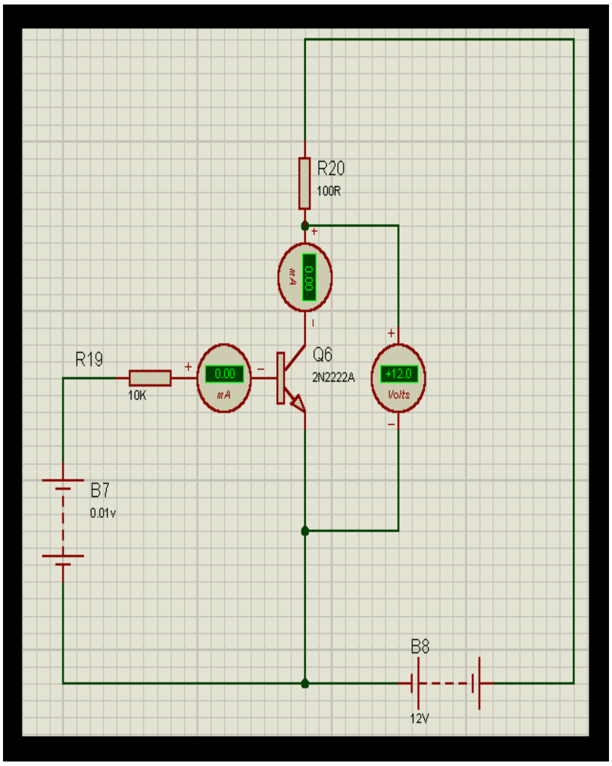

Figure 4.2.1: Simulated measures with a voltage source of $V_i = 0$ V.

	$V_i = \mathbf{5}$ **V**	$V_i = \mathbf{0}$ **V**
V_{CE}	3.98 V	12 V
I_B	420 μA	0 A
I_C	80 mA	0 A

Table 7: $R_C = 100\Omega$ and $R_B = 10K\Omega$ simulated measures.

- ***Simulation of Cut-off and Saturation points implementing a 2N2222A transistor and a 22K Ω resistor in R_B:***

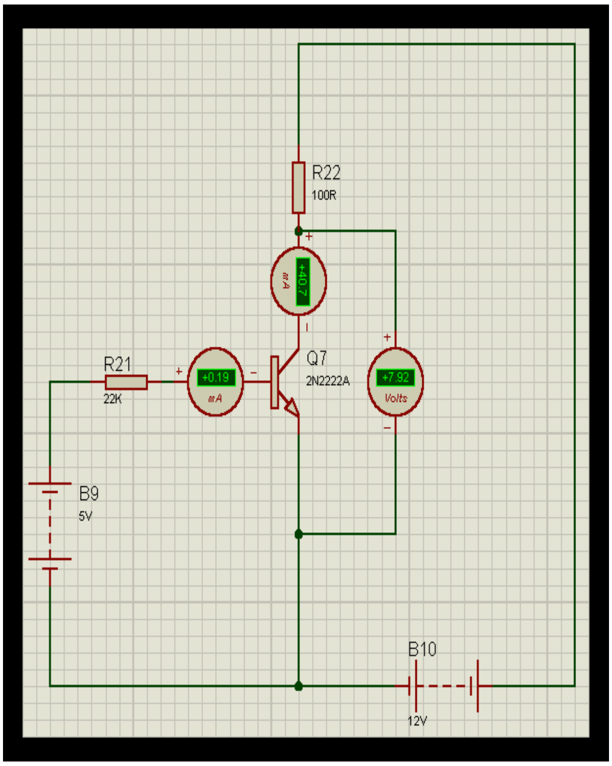

Figure 4.2.2: Simulated measures with a voltage source of $V_i = 5$ V.

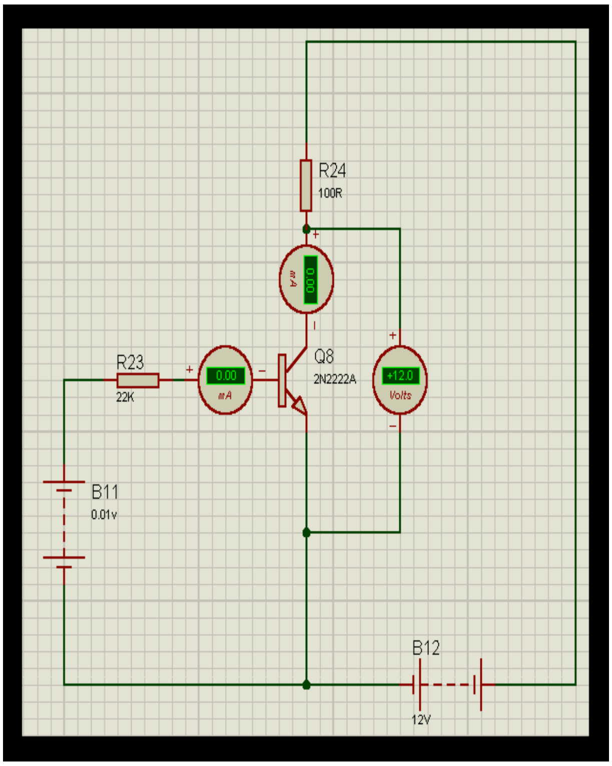

Figure 4.2.3: Simulated measures with a voltage source of $V_i = 0$ V.

	V_i = **5 V**	V_i = **0 V**
V_{CE}	7.92 V	12 V
I_B	190 μA	0 A
I_C	40.7 mA	0 A

Table 8: $R_C = 100\Omega$ and $R_B = 22K\Omega$ simulated measures.

4.3 Other Circuits:

The circuits in section 3.4 were simulated, and, as we can see, the behavior was exactly the same. For circuits in Figures 4.3.0 and 4.3.1, depending the semi-cycle in V_i, that is, if the semi-cycle it's in the positive region, the LED will be brighter, this because the transistor it's receiving voltage in the terminal of the base, in consequence, the voltage it's being empowered, same for current and analogously the power.

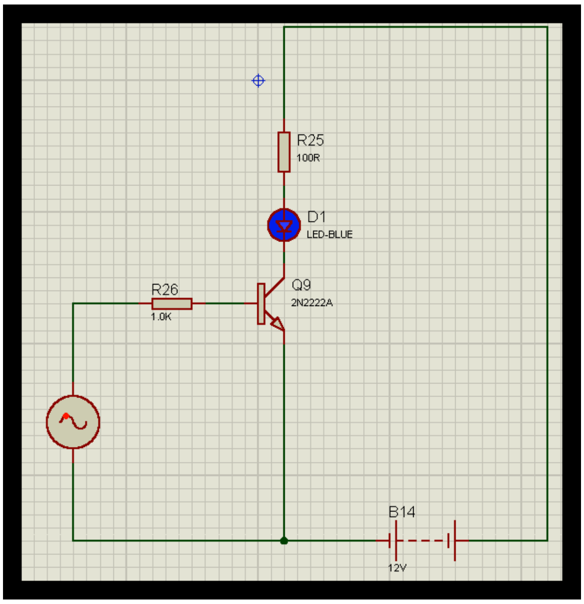

Figure 4.3.0: 2N2222A - LED circuit when V_i it's in the positive semi-cycle.

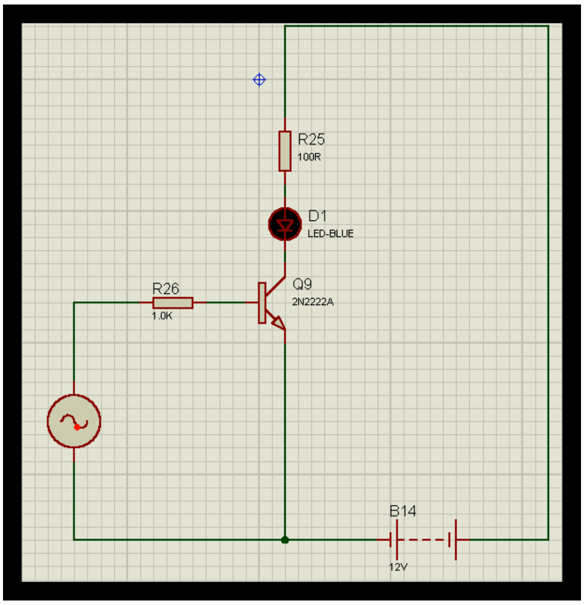

Figure 4.3.1: 2N2222A - LED circuit when V_i it's in the negative semi-cycle.

The same behavior we visualize in Figures 4.3.2 and 4.3.3, instead of using a LED, we are using a DC motor. When V_i it's in the positive semi-cycle the speed in the **RPM** display in the simulation increase, in the other case, when V_i it's in the negative semi-cycle, the speed starts to slow down until V_i reach its positive semi-cycle again.

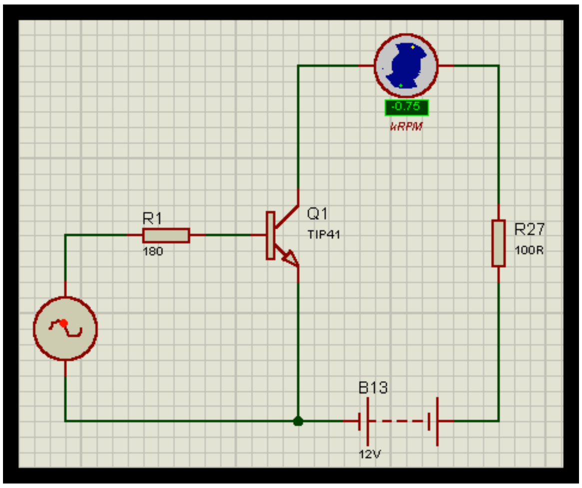

Figure 4.3.2: TIP41 - Motor circuit when V_i it's in the positive semi-cycle.

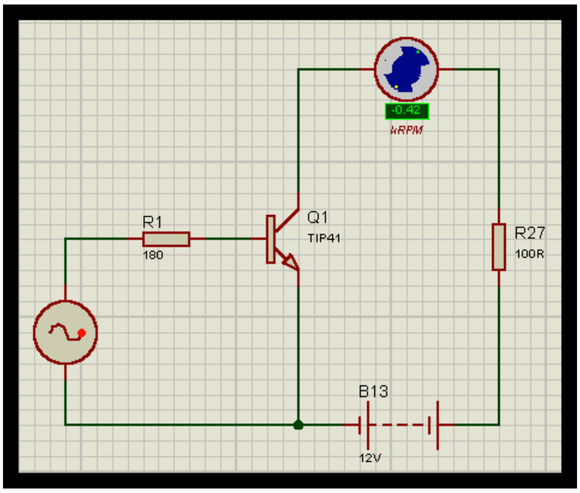

Figure 4.3.3: TIP41 - Motor circuit when V_i it's in the negative semi-cycle.

Observation: *In case that cannot be visualized, the* ***RPM*** *display in Figure 4.3.2 it's up to 0.70, and in Figure 4.3.3 it's near to 0.40.*

5 Theoretical Analysis:

For each circuit that we have analyze in the section 3, we calculate each one of them, and we proceeded to make a comparative table with all the theoretical results and the development ones.

Observation: *For each circuit we are considering* $I_C \cong I_E$.

5.1 Voltage Divider Bias Circuit:

The circuit in Figure 5.1.0 it's the same that Figure 3.1.0, but this time we are going to analyze the circuit converting it first in his ***Basic Polarization*** circuit, and then, proceed to make the respective calculations.

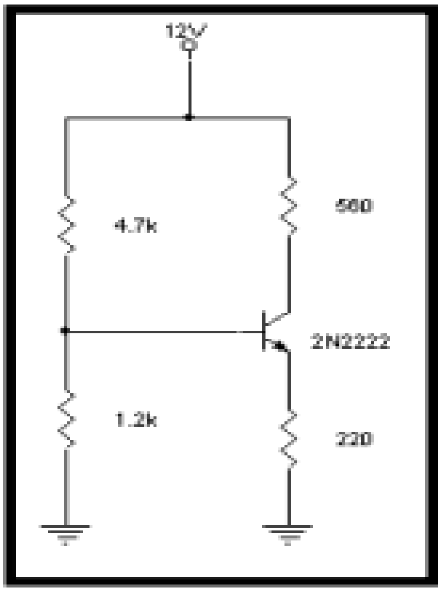

Figure 5.1.0: Voltage divider bias circuit.

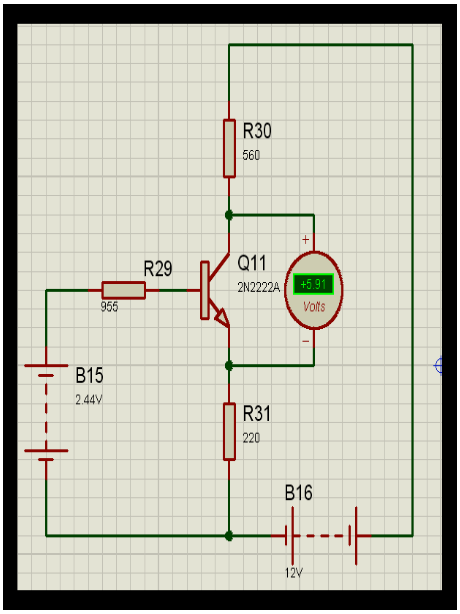

Figure 5.1.1: Equivalent basic polarization circuit.

- **First circuit parameters:**
  - **(i)** $V_{BE} = 0.7V$
  - **(ii)** $R_1 = 4700\Omega$
  - **(iii)** $R_2 = 1200\Omega$
  - **(iv)** $R_C = 560\Omega$
  - **(v)** $R_E = 220\Omega$
  - **(vi)** $\beta = 242$

- ***For*** R_B :

Formula: $R_B = \frac{(R_1)(R_2)}{R_1 + R_2}$:

$$R_B = \frac{(4700\ \Omega)(1200\ \Omega)}{1200\ \Omega + 4700\ \Omega} \tag{1}$$

$$\tag{2}$$

$$= 955.9\ \Omega \tag{3}$$

- ***For*** E_B :

Formula: $E_B \;=\; \frac{(\;E_C\;)\;(\;R_2\;)}{R_1\;+\;R_2}$:

$$R_B \;=\; \frac{(\;12\;V\;)\;(\;1200\;\Omega\;)}{1200\;\Omega\;+\;4700\;\Omega} \tag{4}$$
$$\tag{5}$$
$$=\;2.44\;V \tag{6}$$

- ***For*** I_B :

Formula: $E_B \;=\; \frac{E_B\;-\;V_{BE}}{R_B\;+\;(\;\beta\;+\;1\;)\;R_E}$:

$$E_B \;=\; \frac{2.44\;V\;-\;0.7\;V}{955.9\;\Omega\;+\;(\;243\;)\;(\;220\;\Omega\;)} \tag{7}$$
$$\tag{8}$$
$$=\;3\mu A \tag{9}$$

- ***For*** I_C :

Formula: $I_C \;=\; (\;\beta\;)\;I_B$:

$$I_C \;=\; (\;242\;)\;(\;3\;\mu A\;) \tag{10}$$
$$\tag{11}$$
$$=\;7.7\;mA \tag{12}$$

- ***For*** V_{CE} :

Formula: $V_{CE} \;=\; E_C\;-\;I_C\;(\;R_C\;+\;R_E\;)$:

$$V_{CE} \;=\; 12\;V\;-\;7.7\;mA\;(\;560\;\Omega\;+\;220\;\Omega\;) \tag{13}$$
$$\tag{14}$$
$$= 5.9V \tag{15}$$

- ***For*** V_E :

Formula: $V_E \;=\; I_C\;R_E$:

$$V_E \;=\; (\;7.7\;mA\;)\;(\;220\;\Omega\;) \tag{16}$$
$$\tag{17}$$
$$=\;1.6\;V \tag{18}$$

- ***For*** V_B :

Formula: $V_B \;=\; V_{BE}\;+\;V_E$:

$$V_B \;=\; 0.7\;V\;+\;1.6\;V \tag{19}$$
$$\tag{20}$$
$$=\;2.3\;V \tag{21}$$

The same process previously performed for "converting" the divider bias circuit, into the basic polarization one, it's executed bellow. The difference for the rest of the calculations it's that this time we are contemplating a ***BC547*** transistor.

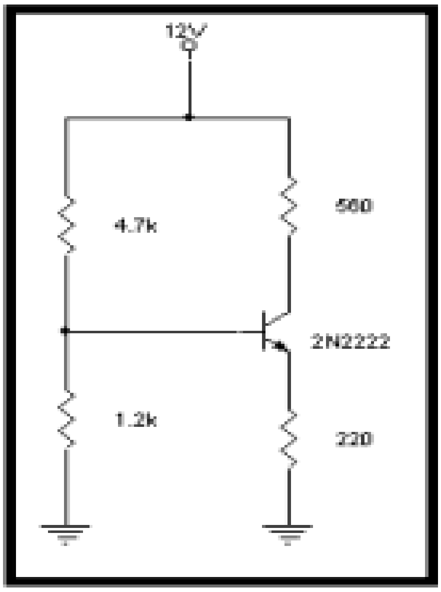

Figure 5.1.2: Voltage divider bias circuit.

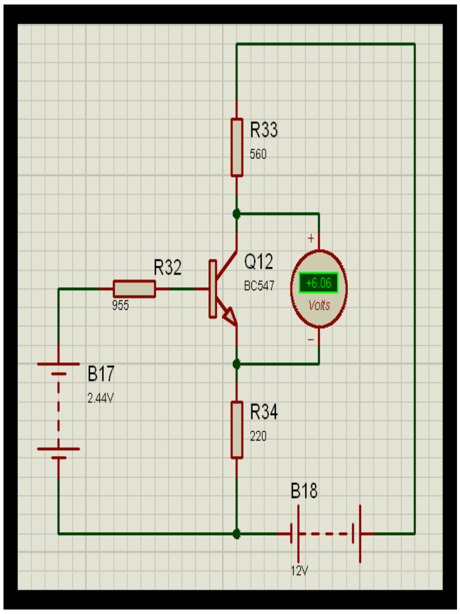

Figure 5.1.3: Equivalent basic polarization circuit.

- **Second circuit parameters:**
  - **(i)** $V_{BE} = 0.7V$
  - **(ii)** $R_1 = 4700\Omega$
  - **(iii)** $R_2 = 1200\Omega$
  - **(iv)** $R_C = 560\Omega$
  - **(v)** $R_E = 220\Omega$
  - **(vi)** $\beta = 595$

- ***For*** R_B :

Formula: $R_B = \frac{(R_1)(R_2)}{R_1 + R_2}$:

$$R_B = \frac{(4700\ \Omega)(1200\ \Omega)}{1200\ \Omega + 4700\ \Omega} \quad (1)$$

$$(2)$$

$$= 955.9\ \Omega \quad (3)$$

- ***For*** E_B :

Formula: $E_B \;=\; \frac{(\;E_C\;)\;(\;R_2\;)}{R_1\;+\;R_2}$:

$$R_B \;=\; \frac{(\;12\;V\;)\;(\;1200\;\Omega\;)}{1200\;\Omega\;+\;4700\;\Omega} \tag{4}$$

$$\tag{5}$$

$$=\;2.44\;V \tag{6}$$

- ***For*** I_B :

Formula: $E_B \;=\; \frac{E_B\;-\;V_{BE}}{R_B\;+\;(\;\beta\;+\;1\;)\;R_E}$:

$$E_B \;=\; \frac{2.44\;V\;-\;0.7\;V}{9.55.9\;\Omega\;+\;(\;596\;)\;(\;220\;\Omega\;)} \tag{7}$$

$$\tag{8}$$

$$=\;1.3\mu A \tag{9}$$

- ***For*** I_C :

Formula: $I_C \;=\; (\;\beta\;)\;I_B$:

$$I_C \;=\; (\;595\;)\;(\;1.3\;\mu A\;) \tag{10}$$

$$\tag{11}$$

$$=\;7.8\;mA \tag{12}$$

- ***For*** V_{CE} :

Formula: $V_{CE} \;=\; E_C \;-\; I_C\;(\;R_C\;+\;R_E\;)$:

$$V_{CE} \;=\; 12\;V\;-\;7.8\;mA\;(\;560\;\Omega\;+\;220\;\Omega\;) \tag{13}$$

$$\tag{14}$$

$$= 5.9V \tag{15}$$

- ***For*** V_E :

Formula: $V_E \;=\; I_C\;R_E$:

$$V_E \;=\; (\;7.8\;mA\;)\;(\;220\;\Omega\;) \tag{16}$$

$$\tag{17}$$

$$=\;1.7\;V \tag{18}$$

- ***For*** V_B :

Formula: $V_B \;=\; V_{BE}\;+\;V_E$:

$$V_B \;=\; 0.7\;V\;+\;1.7\;V \tag{19}$$

$$\tag{20}$$

$$=\;2.4\;V \tag{21}$$

5.2 Cut-off and Saturation Regions:

The circuit in Figure 5.2.0 it's the same that Figure 3.2.0, but this time we are going to proceed to make the respective calculations.

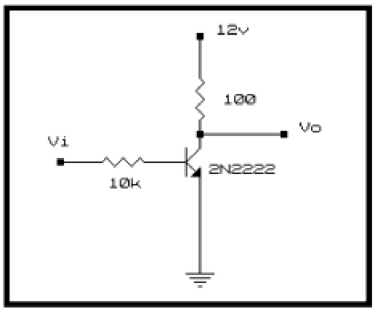

Figure 5.2.0: Cut-off saturation points of a transistor.

- ***Setting*** V_i ***= 5 V Analysis, and using:***
  - ***(i)*** $V_{BE} = 0.7V$
  - ***(ii)*** $R_C = 100\Omega$
  - ***(iii)*** $R_B = 10K\Omega$
  - ***(iv)*** $R_E = 0\Omega$
  - ***(v)*** $\beta = 242$

- ***For*** I_B :

Formula: $I_B \; = \; \frac{E_B \; - \; V_{BE}}{R_B \; + \; (\; \beta \; + \; 1 \;) \; (\; R_E \;)}$:

$$I_B \; = \; \frac{5 \; V \; - \; 0.7 \; V}{10 \; K\Omega \; + \; (\; \beta \; + \; 1 \;) \; (\; 0 \; \Omega \;)} \tag{1}$$
$$\tag{2}$$
$$= 430\mu A \tag{3}$$

- ***For*** I_C :

Formula: $I_C \; = \; (\; \beta \;) \; I_B$:

$$I_C \; = \; (\; 242 \;) \; (\; 430 \; \mu A \;) \tag{4}$$
$$\tag{5}$$
$$= \; 0.10 \; A \tag{6}$$

- ***For*** V_{CE} :

Formula: $V_{CE} \ = \ E_C \ - \ I_C \ (\ R_C \ + \ R_E \ ):$

$$
\begin{align}
V_{CE} \ &= \ 12 \ V \ - \ 0.10 \ A \ (\ 100 \ \Omega \ + \ 0 \ \Omega \ ) \tag{7} \\
&\tag{8} \\
&= \ 2V \tag{9}
\end{align}
$$

- ***Setting V_i = 0 V Analysis, and using:***
  - ***(i)*** $V_{BE} = 0.7V$
  - ***(ii)*** $R_C = 100\Omega$
  - ***(iii)*** $R_B = 10K\Omega$
  - ***(iv)*** $R_E = 0\Omega$
  - ***(v)*** $\beta = 242$

- ***For*** I_B :

Formula: $I_B \;=\; \frac{E_B \;-\; V_{BE}}{R_B \;+\; (\;\beta\;+\;1\;)\;(\;R_E\;)}$:

$$I_B \;=\; \frac{0\;V \;-\; 0.7\;V}{10\;K\Omega \;+\; (\;\beta\;+\;1\;)\;(\;0\;\Omega\;)} \tag{10}$$

$$\tag{11}$$

$$\cong 0A \tag{12}$$

- ***For*** I_C :

Formula: $I_C \;=\; (\;\beta\;)\;I_B$:

$$I_C \;=\; (\;242\;)\;(\;0\;A\;) \tag{13}$$

$$\tag{14}$$

$$=\; 0\;A \tag{15}$$

- ***For*** V_{CE} :

Formula: $V_{CE} \;=\; E_C \;-\; I_C\;(\;R_C\;+\;R_E\;)$:

$$V_{CE} \;=\; 12\;V \;-\; 0\;A\;(\;100\;\Omega\;+\;0\;\Omega\;) \tag{16}$$

$$\tag{17}$$

$$=\; 12V \tag{18}$$

The same process previously performed for calculating I_C, I_B, V_{CE} will be repeated bellow, the difference lays this time in the resistor R_B that we will use.

- ***Setting V_i = 5 V Analysis, and using:***
  - ***(i)*** $V_{BE} = 0.7V$
  - ***(ii)*** $R_C = 100\Omega$
  - ***(iii)*** $R_B = 22K\Omega$
  - ***(iv)*** $R_E = 0\Omega$
  - ***(v)*** $\beta = 242$

- ***For*** I_B :

Formula: $I_B = \frac{E_B - V_{BE}}{R_B + (\beta + 1)(R_E)}$:

$$I_B = \frac{5\ V - 0.7\ V}{22\ K\Omega + (\beta + 1)(0\ \Omega)} \tag{19}$$

$$\tag{20}$$

$$= 195\mu A \tag{21}$$

- ***For*** I_C :

Formula: $I_C = (\beta)\ I_B$:

$$I_C = (242)(195\ \mu A) \tag{22}$$

$$\tag{23}$$

$$= 0.047\ A \tag{24}$$

- ***For*** V_{CE} :

Formula: $V_{CE} = E_C - I_C(R_C + R_E)$:

$$V_{CE} = 12\ V - 0.047\ A(100\ \Omega + 0\ \Omega) \tag{25}$$

$$\tag{26}$$

$$= 7.2V \tag{27}$$

- ***Setting V_i = 0 V Analysis, and using:***
  - ***(i)*** $V_{BE} = 0.7V$
  - ***(ii)*** $R_C = 100\Omega$
  - ***(iii)*** $R_B = 22K\Omega$
  - ***(iv)*** $R_E = 0\Omega$
  - ***(v)*** $\beta = 242$

- ***For*** I_B :

Formula: $I_B \;=\; \frac{E_B \;-\; V_{BE}}{R_B \;+\; (\;\beta\;+\;1\;)\;(\;R_E\;)}$:

$$I_B \;=\; \frac{0\;V \;-\; 0.7\;V}{22\;K\Omega \;+\; (\;\beta\;+\;1\;)\;(\;0\;\Omega\;)} \tag{28}$$

$$\tag{29}$$

$$\cong 0A \tag{30}$$

- ***For*** I_C :

Formula: $I_C \;=\; (\;\beta\;)\;I_B$:

$$I_C \;=\; (\;242\;)\;(\;0\;A\;) \tag{31}$$

$$\tag{32}$$

$$=\;0\;A \tag{33}$$

- ***For*** V_{CE} :

Formula: $V_{CE} \;=\; E_C \;-\; I_C\;(\;R_C\;+\;R_E\;)$:

$$V_{CE} \;=\; 12\;V \;-\; 0\;A\;(\;100\;\Omega\;+\;0\;\Omega\;) \tag{34}$$

$$\tag{35}$$

$$=\;12V \tag{36}$$

6 Comparisons:

In this sections we will compare the development, simulated and theoretical results for each circuit in each configurations.

6.1 Voltage Divider Bias Circuit:

- **Implementing the transistor *2N2222A*:**

	Development	Simulated	Theoretical
V_B	2.38 V	2.41 V	2.3 V
V_C	7.6 V	7.63 V	
V_{CE}	5.8 V	5.91 V	5.9 V
I_B	2 μA	3 μA	3 μA
I_C	7.6 mA	7.8 mA	7.7 mA
I_E	7.9 mA	7.84 mA	7.7 mA

Table 9: Comparison values for the voltage divider bias circuit implementing a transistor ***2N2222A***.

- **Implementing the transistor *BC547*:**

	Development	Simulated	Theoretical
V_B	2.46 V	2.41 V	2.4 V
V_C	7.4 V	7.74 V	
V_{CE}	5.6 V	6.05 V	5.9 V
I_B	2 μA	3 μA	1.3 μA
I_C	8.2 mA	7.61 mA	7.8 mA
I_E	8.2 mA	7.64 mA	7.8 mA

Table 10: Comparison values for the voltage divider bias circuit implementing a transistor ***BC547***.

6.2 Cut-off and Saturation Regions:

- **Implementing a resistor of 10K Ω in R_B and V_i = 5 V:**

	Development	Simulated	Theoretical
V_{CE}	2.5 V	3.98 V	2 V
I_B	420 μA	420 μA	430 μA
I_C	89 mA	80 mA	100 mA

Table 11: Comparison values using a source of $V_i = 5\ V$.

- **Implementing a resistor of 10K Ω in R_B and V_i = 0 V:**

	Development	Simulated	Theoretical
V_{CE}	12 V	12 V	12 V
I_B	0 A	0 A	0 A
I_C	0 A	0 A	0 A

Table 12: Comparison values using a source of $V_i = 0\ V$.

- **Implementing a resistor of 22K Ω in R_B and V_i = 5 V:**

	Development	Simulated	Theoretical
V_{CE}	7.5 V	7.92 V	7.2 V
I_B	204 μA	190 μA	195 μA
I_C	45 mA	40.7 mA	47 mA

Table 13: Comparison values using a source of $V_i = 5\ V$.

- **Implementing a resistor of 22K Ω in R_B and V_i = 0 V:**

	Development	Simulated	Theoretical
V_{CE}	12 V	12 V	12 V
I_B	0 A	0 A	0 A
I_C	0 A	0 A	0 A

Table 14: Comparison values using a source of $V_i = 0\ V$.

7 Questionnaire:

- ***What is the reason for the polarization of the transistor?***

For a bipolar transistor to function properly, it is necessary to polarize correctly. For that:

(i) The BASE - EMITTER junction must be directly polarized.

(ii) The junction COLLECTOR - BASE must be reverse biased.

- ***What represents the β of the transistor?***

The Beta parameter of a bipolar transistor or BJT indicates the efficiency of the transistor, relating the collector current with the base current, While the β it's greater, more efficient the transistor will be. i.e with a small base current it is capable of delivering a big collector current. Thus, the current gain of a transistor is the relationship that exists between the variation or increase of the collector current and the variation of the base current. Then, β it's the gain in the common emitter configuration.

- ***What does the α of the transistor represent?***

The parameter α of a transistor indicates the similarity relation that occurs in the collector current and the variations of the emitter currents. Since the base current is usually very small, in most transistors the parameter $alpha$ approaches the unit. Then, α it's the gain in the common base configuration.

- ***Mention the points of operation of a transistor:***

Obtaining the working point Q of a device basically consists of obtaining the value of the different tensions and currents that are established as unknown in the operation the same.

- ***What is the saturation zone of a bipolar transistor?***

The collector diode is directly polarized and is transistor behaves as a small resistor. In this zone an additional increase of the base current does not cause an increase of the current of collector, this depends exclusively on the voltage between emitter and collector. The transistor resembles in its emitter-collector circuit to a closed switch.

- ***What is the cut-off zone of a bipolar transistor?***

The fact of making the base current void is equivalent to keeping the emitter base circuit open, in these circumstances the collector current is practically null and therefore can be considered the transistor in its circuit Collector - Emitter as an open circuit breaker.

- ***What is the difference between the transistor 2N2222 and the TIP41?***

Despite of both are NPN BJT's, the TIP41 it's designed to withstand higher levels of current, voltage and analogously power.

- ***Mention 3 applications of circuits in commutation:***

(i) Bipolar transistor as switch in ON and OFF states.

(ii) Bistable multivibrator (FLIP-FLOP).

(iii) Astable multivibrator.

8 Conclusion:

The transistor, as far, are the most complicated and important device that we think, we analyze in this course, this because, they have a lot of applications and 3 different configuration for a so tiny and simple device. Its functionality it's based on the diode principle and we have seen and demonstrated that the ***Common - Base*** configuration has the particularity of increment in potential the output voltage, power, and resistance but not the current. As well, for the ***Common - Emitter*** configuration it's very effective for increasing current, voltage, resistance and of course, power. Finally, the ***Common - Collector*** configuration increase current, but not the voltage. As well, we also analyze how to convert from a ***Basic Polarization Circuit*** to a ***Voltage Divider Bias Circuit*** and vice versa. Seen a little applications for the transistor was a very interesting part of the practice, we also read about the ***H-Bridge*** that has a lot of applications in the industry and its configuration it's based in transistor.

9 Bibliographic References:

[1] BOYLESTAD, Robert L. "Electronic Devices and Circuit Theory". Edit. Prentice Hall. 2009.