ELECTRONICS LABORATORY

PART 4

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Contents

TRANSISTORS

4.1 INTRODUCTION

Transistor is the main circuit component in electronics. There are different transistors in terms of production type and working principle. Thus, they are defined with various names. Some of them are BJT, UJT, FET and MOSFET. We will examine BJT (**B**ipolar **J**unction **T**ransistor) in this chapter. In common usage, transistor means BJT.

BJT's are produced as NPN type by placing a thin P plate between two N plates or as PNP type by placing a thin N plate between two P plates. The material used in the middle has a thickness as much as 1/150 of total thickness. The symbols and structures of PNP and NPN type transistors are shown in Figure 4. 1

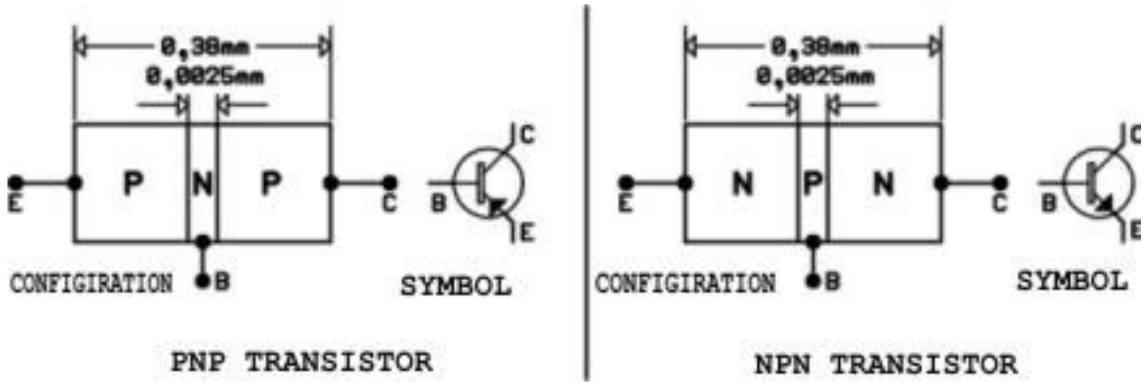


Figure 4. 1

4.2 OPERATION OF TRANSISTORS

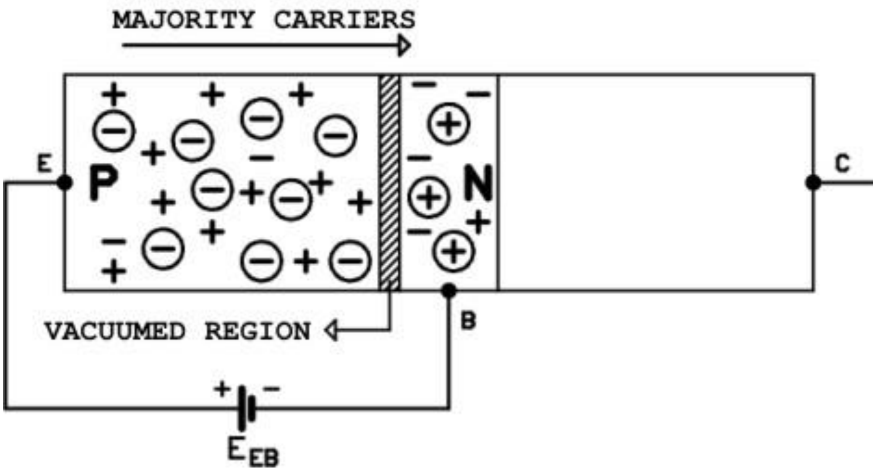


Figure 4. 2

The forward bias of PNP transistor's base-emitter terminals by supply E_{EB} is shown in Figure 4. 2 PN combinations behaves like diode and current starts to pass. (**E_{EB}, expresses the forward bias of PN combination. It is not valid to connect a direct supply to B-E terminals)**

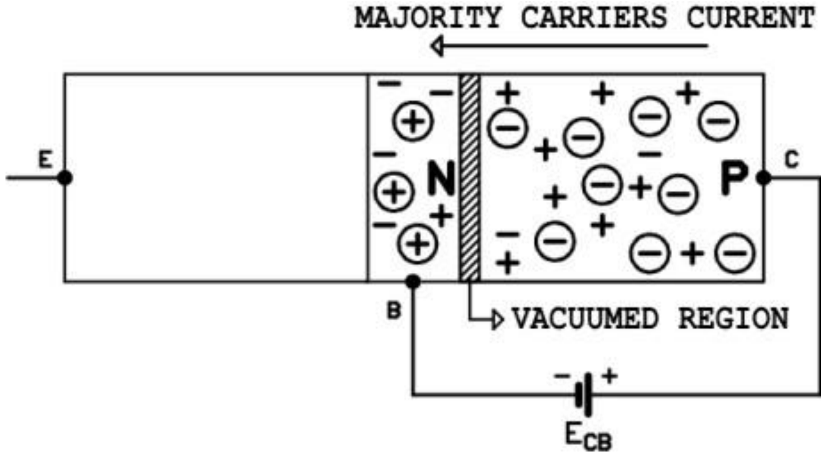


Figure 4. 3

The forward bias of PNP transistor's base-collector terminals by E_{BC} supply is shown in Figure 4. 3 P-N combination behaves like a diode.

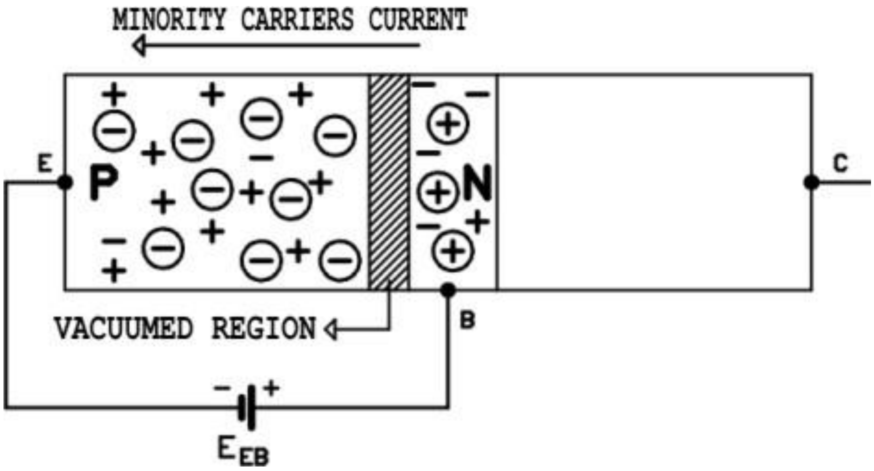


Figure 4. 4

The inverse bias of PNP transistor's base-emitter terminals by supply E_{EB} is shown in Figure 4. 4 Compared to Figure 4. 2, it is observable that vacuumed region is widened and the passage of majority carriers is prevented. Minority flow occurs only at nA level of NP combination.

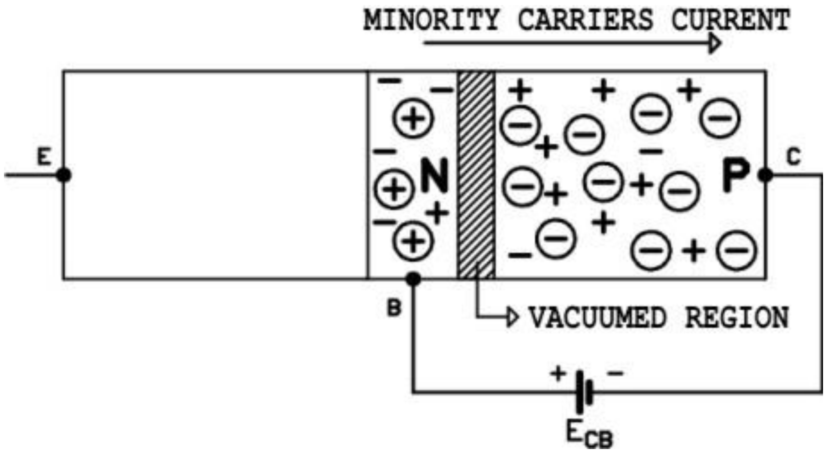


Figure 4. 5

The inverse bias of PNP transistor's base-collector terminals by supply E_{CB} is shown in Figure 4. 5 Compared to Figure 4. 3, it is observable that vacuumed region is widened and the passage of majority carriers is prevented. Minority flow occurs only at nA level of NP combination.

Now, let's apply the biases in Figure 4. 2 and Figure 4. 5 at the same time.

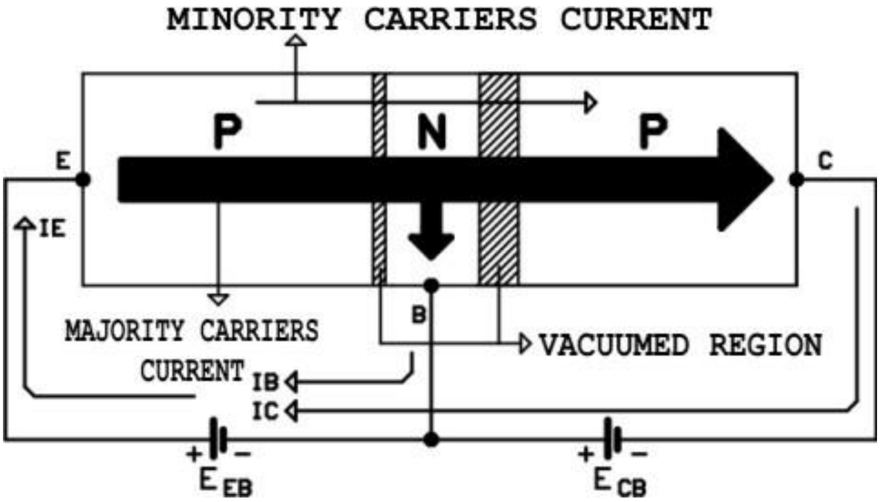


Figure 4. 6

It is observable from the width of the vacuumed region that which junction is forward biased and which junction is inverse biased. A small base current passes through the forward biased PN junction (**E-B**). Flow of a great magnitude of majority carrier starts between the collector-emitter terminals when the PN voltage set is broke. The initiator of the flow is the base current.

E_{BE} and E_{CB} supplies (connected to terminals E-C) are serial. $E_{BE} + E_{CB}$ is applied to C-E terminals. Majority carrier flow starts between E-C as a result of base current passing. There is no current flow between B-C because B-C is inverse biased. If base current is cut during majority carrier flow it will stop forward bias of PN junction which forms E-B. So the vacuumed region of PN junction will be widened. Therefore, E-C current will also stop.

Magnitude of I_C current depends on I_B current. I_E current is the sum of I_B and I_C currents. (**$I_E=I_B+I_C$**)

Let's see the operation of NPN transistor circuit:

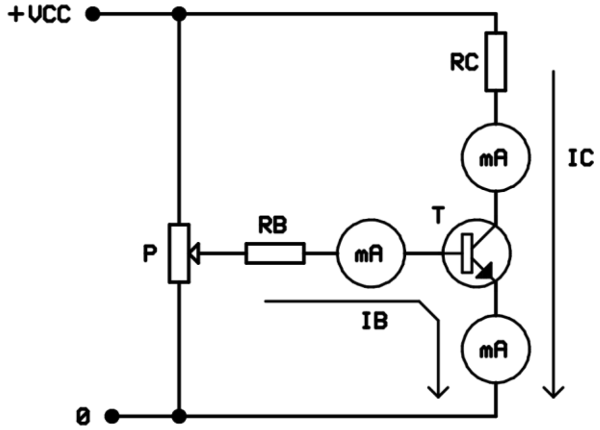


Figure 4. 7

Mid-terminal of potentiometer should be on chassis level.

So, E_{BE}**=**0 and I_B**=**0. I_C depends on I_B, so I_C**=**0.

If the mid-terminal of potentiometer moved slowly to E_{CC} level than there will be an increasing I_B. Depending on I_B, there will be an I_C greater than I_B. Increase of I_C results in the increase of voltage on R_C resistor. Simultaneously, E_{CE} voltage decreases. If I_B is continued to increase I_C will also increase and E_{CE} will be approximately zero. At that value of E_{CE}, I_C will be constant even if the I_B continued to increase. So the transistor will work at saturation (**that means the non-increase of I_C**).

If the mid-terminal of potentiometer moved towards the chassis level, I_B will decrease and depending on it, I_C will also decrease and E_{CE} will increase. If I_B is zero (0) then I_C=0 and E_{CE}=E_{CC} because there wont be voltage decrease on R_C

Outside the cut-off and saturation situations of transistor, the ratio of I_C differences for different levels of I_B gives the current gain ratio of β (**beta**). I_B, I_C and β values are as follows:

$$\beta = \frac{\Delta Ic}{\Delta Ib} \quad \text{Or} \quad \beta \cong \frac{Ic}{Ib}$$

Outside the cut-off and saturation situations of transistor, the ratio of I_C differences for different levels of I_E gives the current gain ratio of α (**alfa**). I_E, I_C and α values are as follows:

$$\alpha = \frac{\Delta . I_C}{\Delta . I_E} \quad \text{or} \quad \alpha \cong \frac{I_C}{I_E}$$

α (**alfa**) current gain is always lower than 1 (one).

Various types of transistor are shown in Figure 4. 8.

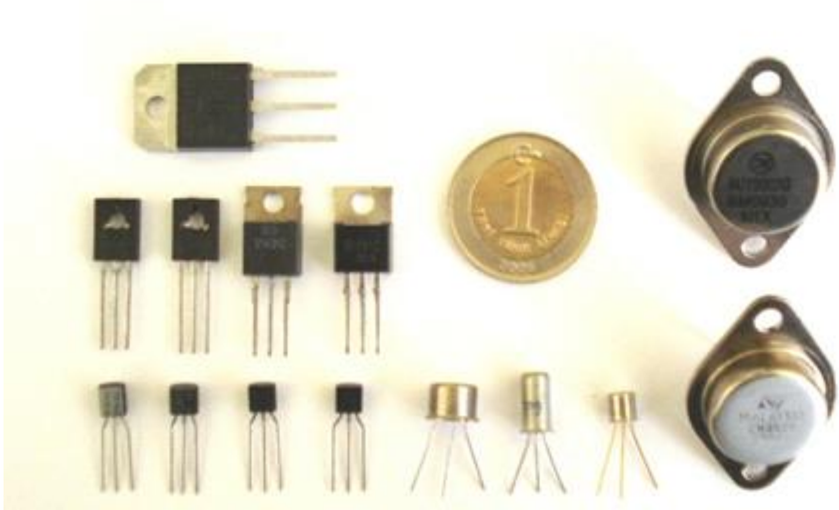


Figure 4. 8

4.3 MEASUREMENT OF TRANSISTORS

Transistors, like diodes, can be measured by analog or digital avometers. Durability of transistor is measured by analog avometers through the resistance value between terminals; measured by digital avometers through the voltage value decrease by the current flowing between terminals. as we know, digital avometers are more reliable than analog. In avometer measurements, transistor is assumed to consist of two diodes. The equivalent circuits of PNP and NPN transistors are shown in Figure 4. 9. They are made of diodes.

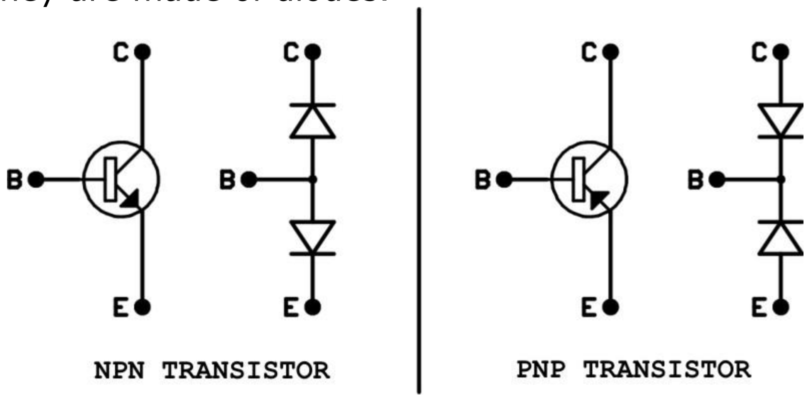


Figure 4. 9

Whatever the type of transistor, there are two diodes (opposite to each other) serially connected between the collector-emitter terminals. One of the resistances between the collector-emitter terminals is very big because one of two diodes is inverse biased. Because of that, there will not be any current flow. Whatever the bias of measurement there will be (**OL**) on display (just like there is no component between probes). Measurement in both ways between collector-emitter terminals are shown in Figure 4. 10

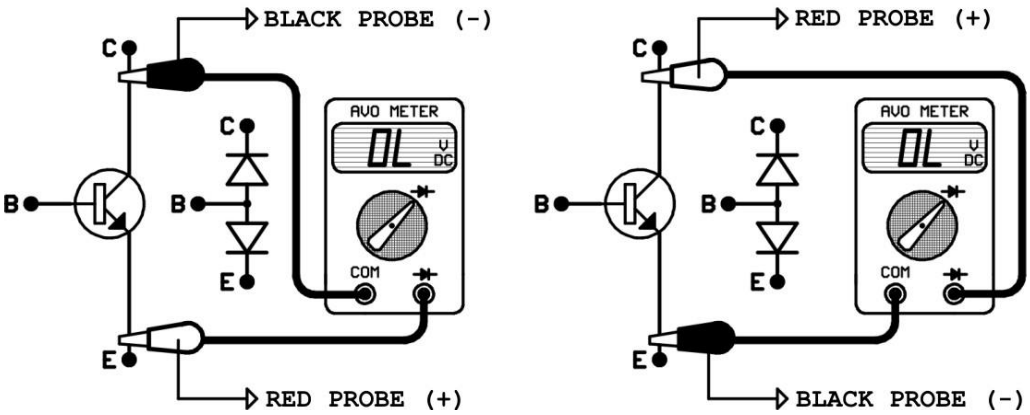


Figure 4. 10

The measurements to be made between base-collector and base-emitter are the same as diode measurement. Because of that, direction of bias is important. When “**base**=**positive, collector=negative”** and “**base=positive, emitter=negative**”, diodes are forward biased. In forward bias, the resistance between base-collector terminals is low. When measuring with digital avometer, it is observed that a DC current flows from base to collector and from base to emitter. In silisium transistors “**0,6Volt-0,7Volt**” and in germanium transistors “**0,1Volt-0,3Volt**” is displayed on avometer. In Figure 4. 11, measurements of an NPN type silisium transistor at three forward biases are shown.

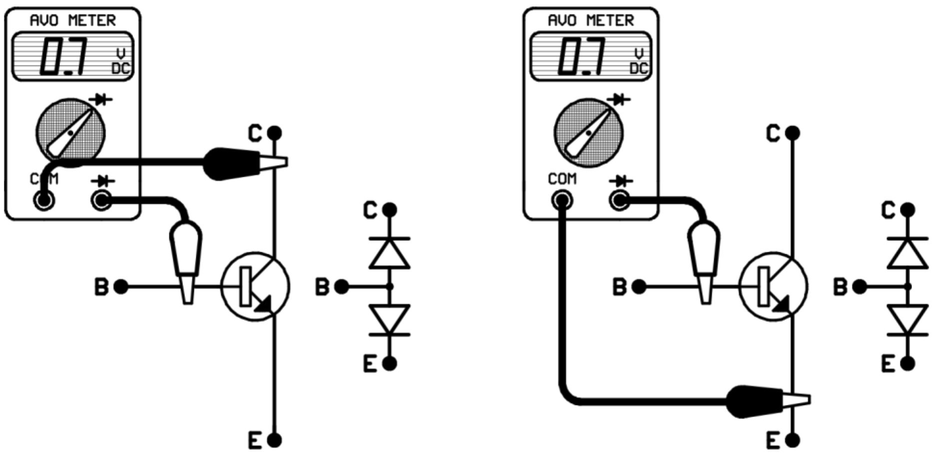


Figure 4. 11

Base-collector junction is larger than the base-emitter junction in the structure of transistor. As a result, the resistance between base-collector terminals is lower than resistance between base-emitter terminals. So, voltage between base collector terminals is lower than the voltage between the base-emitter terminals. It can be seen by the help of avometer.

When “**base**=**negative, collector=positive”** and “**base=negative, emitter=positive**”, diodes are inverse biased. In inverse bias, the resistance between base-collector terminals and the resistance between base-emitter terminals are low. When making measurement with digital avometer, you will see the shape (**OL**) when there are no components between probes on display of avometer. Measurement at inverse bias is shown in Figure 4. 12

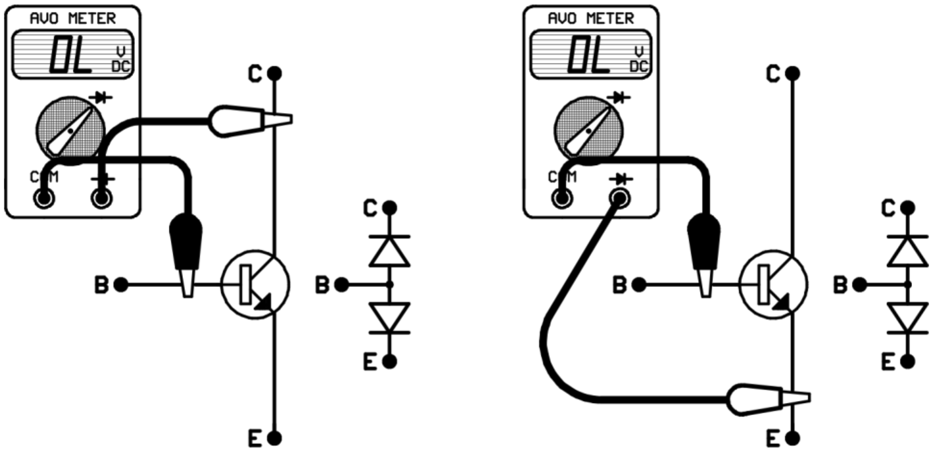
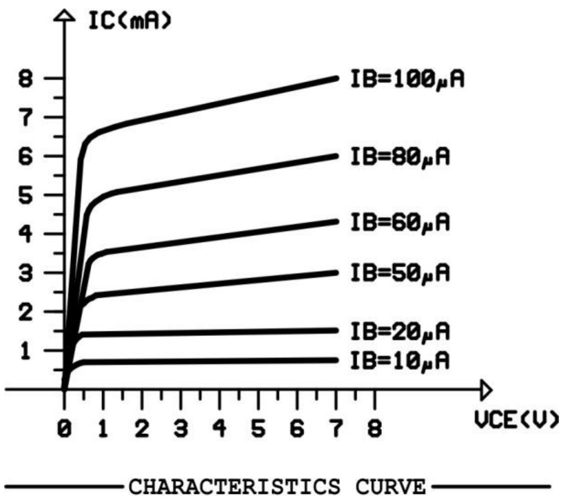


Figure 4. 12

If the measured transistor is an NPN type silisium transistor, the same results should be displayed when the direction of probes is opposite. If the results are not the same or very similar then the transistor is damaged.

4.4 REGION I CHARACTERISTICS OF TRANSISTOR

In a specific base current (**I_B=constant**) of transistor, the curve (**I_C=f.**(**V_{CE}**)) of change of collector current (**I_C**) depending on the collector-emitter voltage (**V_{CE}**) is called 1.region characteristics of transistor. This curve and the connection schema to derive that curve are shown in Figure 4. 13



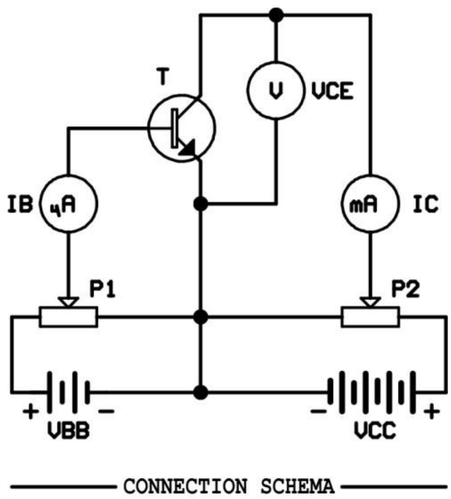


Figure 4. 13

Current gains of Beta (**β**) and Alfa (α) can be calculated using the 1.region curve. Load line can be drawn according to a specific resistance value.

4.5 CALCULATIONS OF β AND α CURRENT GAINS for TRANSISTORS

This method is used for calculating the current gains of small and potent transistors. Current gains in such transistors are same for a given V_{CE} voltage. As we know, beta (**β**) current gain for a transistor with its emitter is chassis:

$$\beta = \frac{IC}{IB} = \frac{\Delta IC}{\Delta IB}$$

Example: β current gain of transistor is calculated as following. Assume that V_{CE} voltage is constant at 5V; a perpendicular line is drawn from 5V upwards. In order to find I_C currents, perpendicular lines are drawn from the points where that line intersects 10μA and 20μA base current curves. This is shown in Figure 4. 14

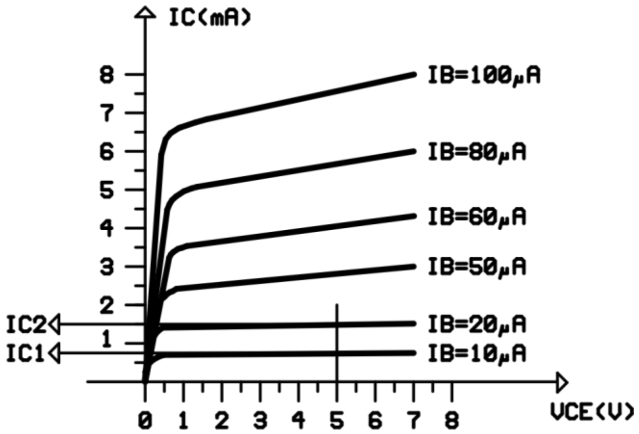


Figure 4. 14

From characteristics curve:

I_C2 = 1,5mA=1500μA
I_C1 = 0,7mA=700μA
I_B1 = 10μA
I_B2 = 20μA
$\Delta I_C = I_C2 - I_C1$=1500-700=800μA
$\Delta I_B = I_B2 - I_B1$=20-10=10μA

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{800}{10} = 80$$

α Current gain is calculated as following:

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

The schema is used in calculating β current gain will also used here.

From characteristics curve:

ΔI_C**=** $I_C2 - I_C1 = 1500-700 = 800\mu A$

ΔI_B**=** $I_B2 - I_B1 = 20-10 = 10\mu A$

ΔI_E**=** $\Delta I_B + \Delta I_C = 800+10 = 810\mu A$

$\alpha = \dfrac{\Delta I_C}{\Delta I_E} = \dfrac{800}{810}$ = 0,988

NOT: α current gain in transistors is always smaller than 1.

4.6 LOAD LINE FOR A SPECIFIC RESISTANCE VALUE

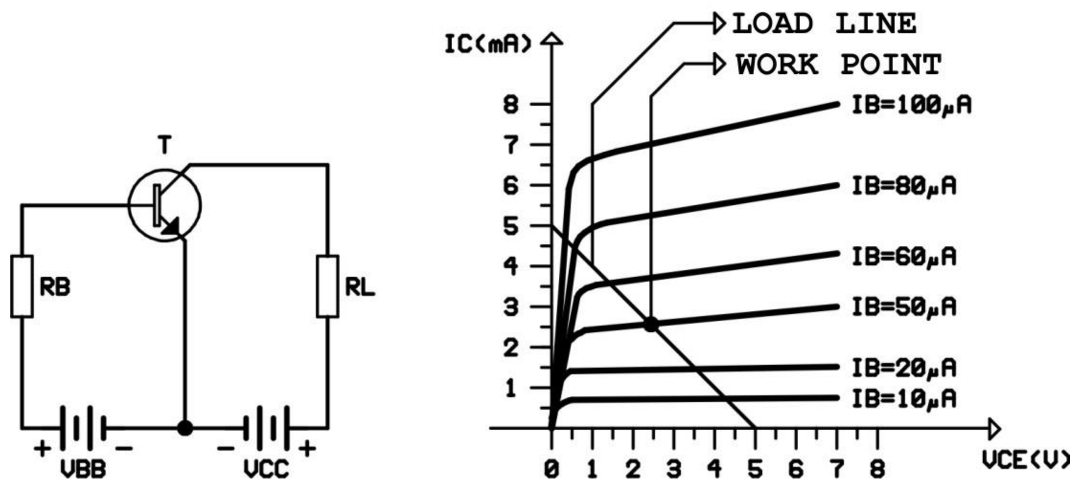


Figure 4. 15

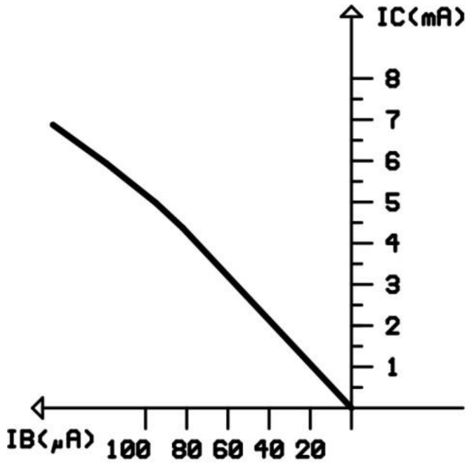
In Figure 4. 15, V_{CC}**=**5V and R_L**=**1KΩ; maximum current to pass through R_L:

$I_{C\ max} = V_{CC}/R_L = 5/1000 = 0{,}005A = 5mA$.

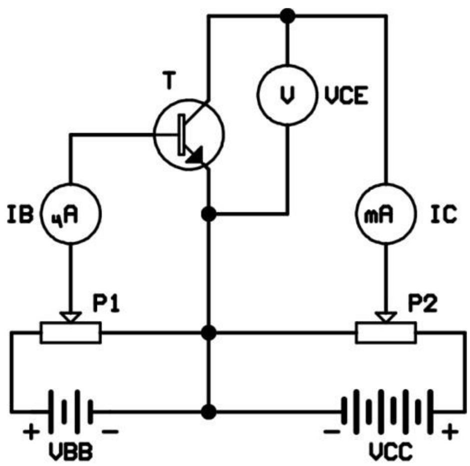
On characteristics, mark V_{CC}**=**5Volt on V_{CE} axis and $I_{C\ max}$=5mA on I_C axis. Link those two points with a line. This line is called load line and the mid-point of this line is work point.

4.7 REGION II CHARACTERISTICS OF TRANSISTOR

In a specific collector-emitter voltage (**V_{CE}=constant**) of transistor, the curve (**I_C=f.**(**I_B**)) of change of collector current (**I_C**) depending on the base current (**I_B**) is called 2.region characteristics of transistor. This curve and the connection schema to derive that curve are shown in Figure 4. 16.



CHARACTERISTICS CURVE



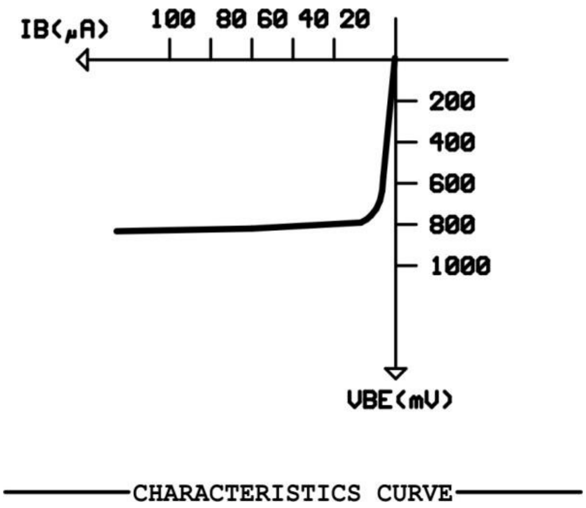
CONNECTION SCHEMA

Figure 4. 16

Current gains of Beta (**β**) can be calculated benefiting from the 2.region curve.

4.8 REGION III CHARACTERISTICS OF TRANSISTOR

In a specific collector-emitter voltage (**V_{CE}=constant**) of transistor, the curve (**I_B=f.**(**V_{BE}**)) of change of base current (**I_B**) depending on the base-emitter voltage (**V_{BE}**) is called 3.region characteristics of transistor. This curve and the connection schema to derive that curve are shown in Figure 5. 17



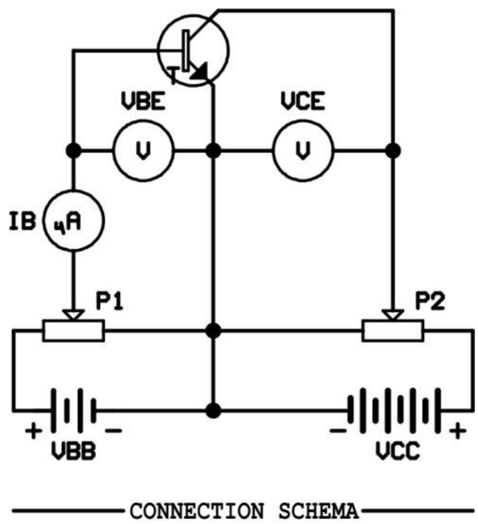


Figure 4. 17

Input impedance can be calculated using 3.region characteristics.

4.9 REGION IV CHARACTERISTICS OF TRANSISTOR

In a specific base current (**I_B=constant**) of transistor, the curve (**V_{BE}=f.(V_{CE})**) of change of base-emitter voltage (**V_{BE}**) depending on the collector-emitter voltage (**V_{CE}**) is called 4.region characteristics of transistor. This curve and the connection schema to derive that curve are shown in Figure 4. 18

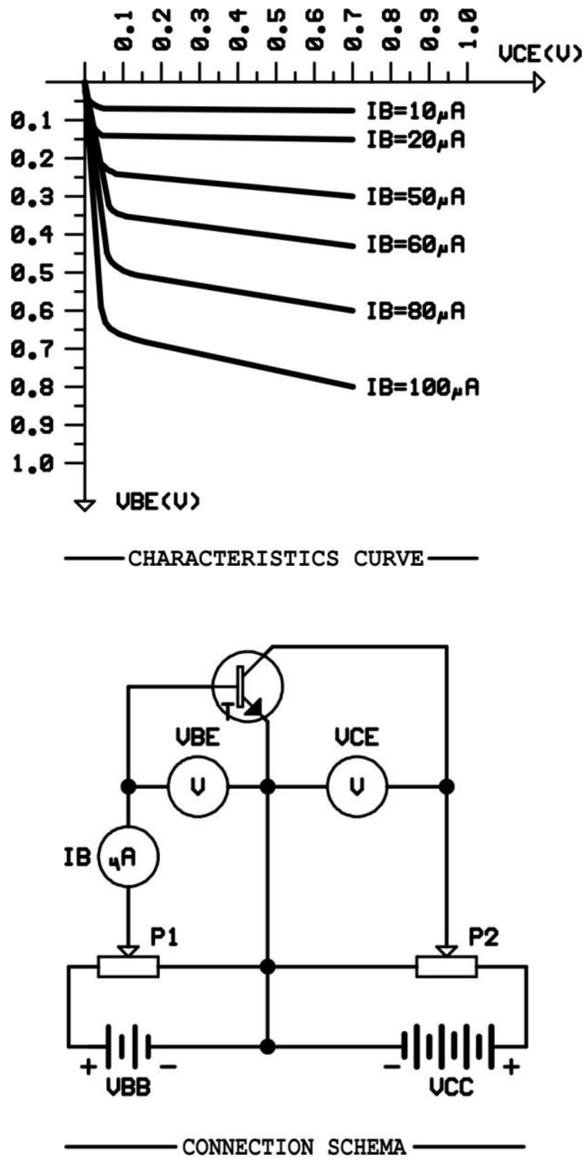


Figure 4. 18

Voltage feedback ratio between collector-base can be calculated using the 4.region curve.