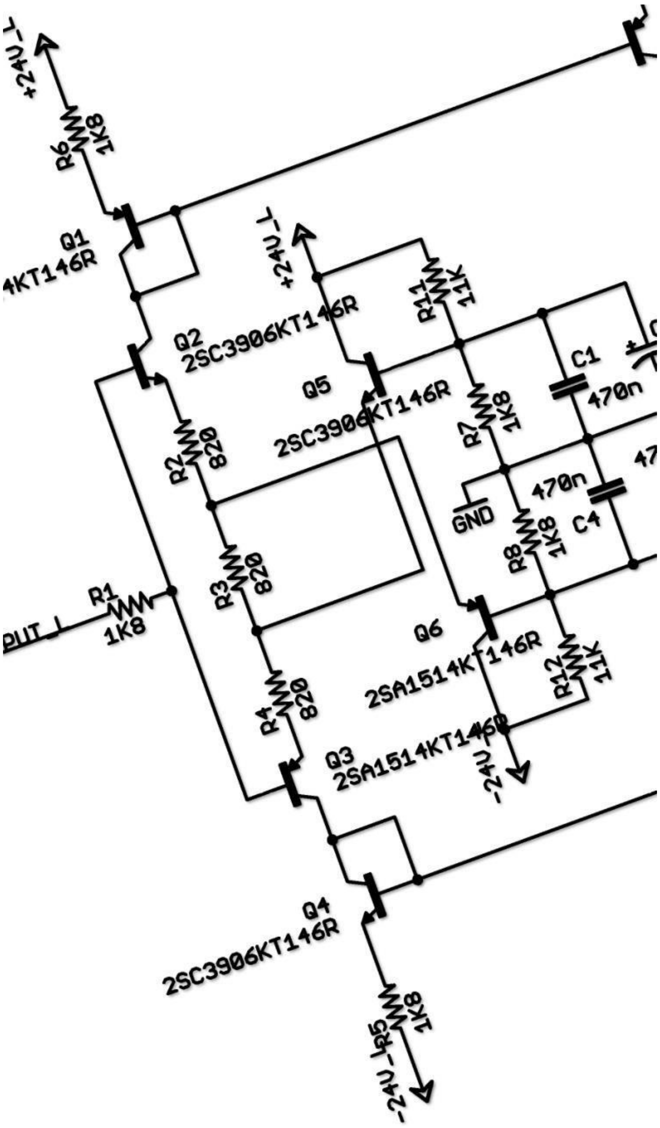
MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

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11 Bipolar Junction Transistors

11.1 Learning Objectives and Introduction

Transistors form the foundations of virtually all modern electronics, and as such it is something of an understatement to say that they are an important component to understand! The aim of this experiment is to explore, in depth, the operating regions and characteristics of Bipolar Junction Transistors (BJTs), operating as analogue devices.

At the conclusion of this lab, you should be comfortable with the different operating regions and characteristics of a BJT transistor. You will also get the opportunity to learn how to use the digital storage oscilloscope to easily capture more information about active devices.

By the end of this lab you should:

- Experimentally measure the basic characteristic of BJT transistors
- Observe the difference in modes of operation for BJT transistors, and how these can be achieved
- Trace a characteristic curve for a BJT transistor

11.2 Equipment and Components

- Breadboard.
- Transistor: BC 547.
- Resistors: 1 Ohm, 100 Ohm, 10 kOhm, 100 kOhm.

11.3 Important Notes

All circuit calculations will be done in the preliminary quiz for this lab. Ensure you have the formulas you developed for the quiz on hand!

Besides the specially mentioned components and instruments, you may assume that standard passive components will be available (resistors and capacitors). Note that the BJT transistors used have a nominal current gain β_N of ≈150, but the gain specified in the data sheet can vary between 110 and 800.

Some measurements to be made in this experiment involve measuring switching times in the order of 10's of nanoseconds. Second order effects can affect these measurements significantly, and must be accounted for in your simulations and workings. In particular, the rise and fall times of the signal generator can be significant, and the oscilloscope probe capacitance can also have a significant influence. Try and make some allowance for these effects when comparing measured, simulation and calculated results.

Please note that the notes for this experiment are not intended to provide a complete recipe of the procedure to be followed, and you are encouraged to make whatever measurements you consider necessary to get better results. Electronics is about THINKING about what you are trying to achieve, UNDERSTANDING the basic theory, and APPLYING this knowledge to achieve a result.

You will use the BC547A transistor in this experiment. You will need to use the datasheet you found as part of your preliminary quiz, ensure you have a copy of it available.

11.4 EXPERIMENTAL SECTION

11.4.1 PART A – MEASURE BJT β_F

The principle proposed to measure the BJT β_F is to energise the transistor using the circuit shown in Figure 1 below, where the excitation source is a relatively slow triangular waveform with peak limits adjusted to just cycle the transistor between cutoff and saturation. This will cause a fairly slow turn on and turn off process, allowing the point at which the transistor becomes saturated to be easily determined. The base and collector currents are determined by measuring the voltages across R1 and R2, and the current gain (β_F) can then be measured by dividing the collector current by the base current, for various parts of the excitation waveform.

NOTE: you cannot directly use the voltages across the 10k and 100k resistors. For V_{100k}, you must measure the input triangular voltage and subtract v_{be}, the base-emitter voltage. For V_{10k} you must measure V_{ce} and subtract this voltage from the 15V supply to find the voltage across the 10k ohm resistor.

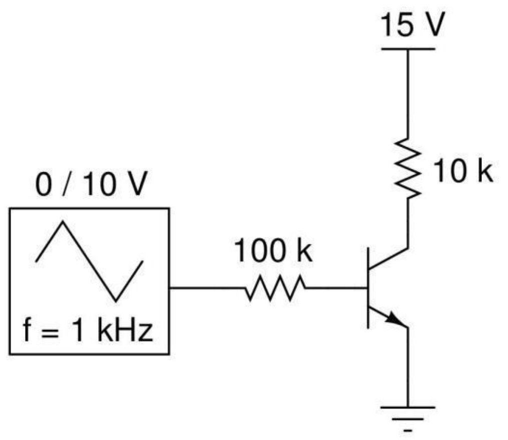


Fig. 1: Test Circuit to measure transistor βF

11.4.1.1 Setup the circuit shown in figure 1, and then adjust the **upper** and **lower** triangle waveform limits using amplitude and DC offset settings in Scopy. <u>Adjust the triangle waveform</u> so that the BJT just goes into saturation and cut-off at the upper and lower limits of the waveform respectively. To help you with this, connect one oscilloscope channel at V_{BE} and another oscilloscope channel at V_{CE}. <u>Record</u> the values of your triangle waveform.

HINT: We want the operation of the transistor to be in the forward-active region for most of the time. Saturation occurs when $V_{BE} \geq 0V$ and $V_{CE} \leq V_{BE}$, while cut-off occurs when $V_{BE} \leq 0V$; and $V_{BC} \leq 0V$ or $V_{CE} \leq V_{BE}$

Theoretical Calculations (5 V is used due to the limitations of Scopy)

First, we need to know the conditions for the circuit to be in saturation which is given above ($\beta Ib > Ic$). β is assumed to be 400 and V_{BE} is assumed to be 0.7V.

From the datasheet, at saturation, the collector-emitter junction voltage is 90mV (0.09 V)

Using a saturated transistor model and an input voltage of 1V (p-p) with an offset of 0.5 V, we will get Ic to be

$$Ic = \frac{1-0.09}{10\ k\Omega} = 0.091 \text{ mA}$$

Assuming that $\beta Ib > Ic$

$$\frac{400 * (V_{in} - V_{BE})}{100\ k\Omega} > 0.091\ mA$$

Since V_{BE} = 0.7 V, we can substitute into our equation

$$\frac{400 * (V_{in} - 0.7)}{100\ k\Omega} > 0.091\ mA$$

$$V_{in} > 0.72 \text{ V}$$

The transistor enters the saturation mode when V_{in} exceeds 0.72 V

Note that the datasheet also stated the minimum turn-on voltage for V_{BE} is 0.58 V. If it is less than this voltage, the transistor will be in the cut-off region.

So theoretically we can conclude that the forward active region is between the range of 0.58 V and 0.72 V.

It is also stated that Saturation occurs when $V_{BE} \geq 0V$ and $V_{CE} \leq V_{BE}$, while cut-off occurs when $V_{BE} \leq 0V$; and $V_{BC} \leq 0V$ *or* $V_{CE} \leq V_{BE}$.

Measured Value

Saturation Point

To obtain the saturation point, we need to measure the point when $V_{BE} > V_{CE}$ and obtain the value of V_{input} and V_{BE}.

Based on our measured voltage values, saturation will occur when V_{input} is 741.272 mV and Vbe is 590.280 mV. As we can see here, the values match quite well with the theoretical assumption that we have made previously for the condition of saturation to occur.

Cutoff Point

Measure the point where Vbe goes close to 0V and get the Vinput.

When V_{BE} goes close to 0V (5.188 mV), the V_{input} obtain is 42.936 mV. The measured value of V_{input} is quite consistent with the theoretical value where cut-off would occur which is when the value of voltage is less than 0.58 V

11.4.1.2 Measure the triangular source upper peak voltage (V_{peak}) and the BJT collector voltages (V_C) at the **same time**. Use these measured values to calculate the base current (I_B) and the collector current (I_C), and then use these values to find β_F.

The triangular source peak voltage, V_{peak} is approximately 628.028 mV and the value of V_{BE} is 571.406 mV.

Using the value that we have obtained, we can calculate the value of the base current (I_B) and and the collector current (I_C). The two values will allow us to find the value of β_F.

$$I_B = \frac{V_{peak} - V}{100k} = \frac{0.63 - 0.44}{100k} = 1.9\ \mu A$$

$$I_c = \frac{V_{supply} - Vc}{100k} = \frac{5 - 0.09}{10k} = 0.491\ mA$$

$$\beta_F = \frac{I_C}{I_B} = \frac{0.491\ m}{1.9\ \mu} = 258.4$$

11.4.1.3 <u>Repeat</u> the measurement process of 11.4.1.2 when your triangular source is at half of V_{peak}. <u>Compare</u> the two values of β_F. <u>Explain</u> the differences between the two values of β_F.

Since our V_{peak} has a value of 628.028 mV, we will place our cursor at the value of 0.5*628.028 mV = 0.314 V. The closest value that we can get to 0.314 V in Scopy would be 0.307 V.

The measured Vce is about 4.95 V

The measured Vbe is about 212.801 mV

$$I_B = \frac{V_{peak} - V}{100k} = \frac{0.307 - 0.213}{100k} = 0.94\ \mu A$$

$$I_c = \frac{V_{supply} - Vc}{100k} = \frac{5 - 4.95}{10k} = 5\ \mu A$$

$\beta_F = \frac{I_C}{I_B} = \frac{5\ \mu}{0.94\ \mu}$ = 5.32 (Definitely wrong need to do again) Should be around 260++

11.4.1.4 Which value of β_F is more appropriate for operation of the transistor in the forward active region?

The β_F value of 5.32 in 11.4.1.3 is more appropriate for operation of the transistor in forward active region. This is because the measurement is taken at forward-active region and not at the edge between the saturation region and forward active region. The measured current gain is also within the range of manufacture value.

11.4.1.5 Measure the BJT base-emitter voltage and collector-voltage as the BJT goes into saturation. How do these values compare with the data sheet for the BC547?

Datasheet Value
The base-emitter voltage at saturation in datasheet is 0.7V.
The collector voltage at saturation in datasheet is 0.09V.

The measured base-emitter voltage is 522.952 mV and the measured collector voltage is 93.376 mV.

As we can see from the differences between the datasheet value and the measured value, the measured base-emitter voltage is close to the expected value and the measured collector voltage is also close to the expected value. There is a slight difference between the datasheet value and the measured value which could be due to the systematic error made by humans during the extraction of value from the graph. The testing conditions could also be different, resulting in the difference in value.

11.4.1.6 Reverse the BJT connection by swapping the emitter and collector pins, and repeat the test to measure β_R (using similar steps that you have done in 11.4.1.2). How does this value compare with β_F?

As we can see from the graph above, the measured value of the voltage at the peak is 950.266 mV and the voltage at the base is 493.207 mV.

As we can see from the graph above, the measured value of the voltage at the emitter is 13.852 mV.

$$\mathrm{I_B} = \frac{V \quad - V_{base}}{100k} = \frac{0.53 \;\; - 0.49}{100k} = 0.4\ \mu\mathrm{A}$$

$$\mathrm{I_E} = \frac{V_{supply} - V_{emitter}}{100k} = \frac{1 - 0.95}{10k} = 5\ \mu\mathrm{A}$$

$$\beta_F = \frac{I_E}{I_B} = \frac{5\ \mu}{0.4\ \mu} = 12.5$$

The value β_R in reverse-active mode is much lower than the value β_F in forward active mode. This is the due to the current flowing in opposite direction (emitter to collector junction). The difference in the doping concentrations between each junction of NPN transistor limits the current that can be drawn from the supply at the emitter junction and to the collector junction. The emitter is heavily doped meaning that the emitter has a high number of free electrons. The base and the collector are lightly doped, so it has small number of positive holes. This would mean that current can easily flow from collector to emitter if there is current applied to the base junction, but not the other way round.

11.4.2 PART B – MEASURE BJT ACTIVE REGION CHARACTERISTICS (I_C–V_{CE} plot)

The aim of this part of the experiment is to plot the transistor active region static characteristics using the digital oscilloscope. The principle proposed is to use an adjustable voltage feeding through a 100k resistor to create an adjustable base current, and then to apply a triangular voltage to the BJT collector. In theory, for any particular base current, the collector current should be independent of the collector-emitter voltage when this voltage is greater than about 0.7V.

NOTE: in this part of the experiment we are using the oscilloscope in a mode you are not familiar with, please read the instructions carefully to avoid frustration!

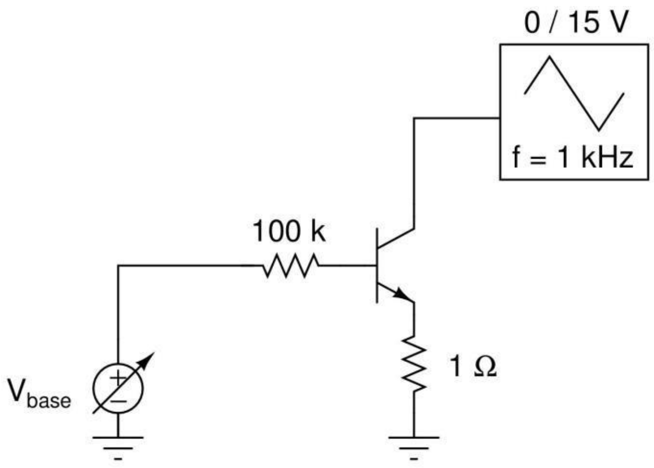


Fig.2: Test Circuit to measure I_C – V_{CE}.

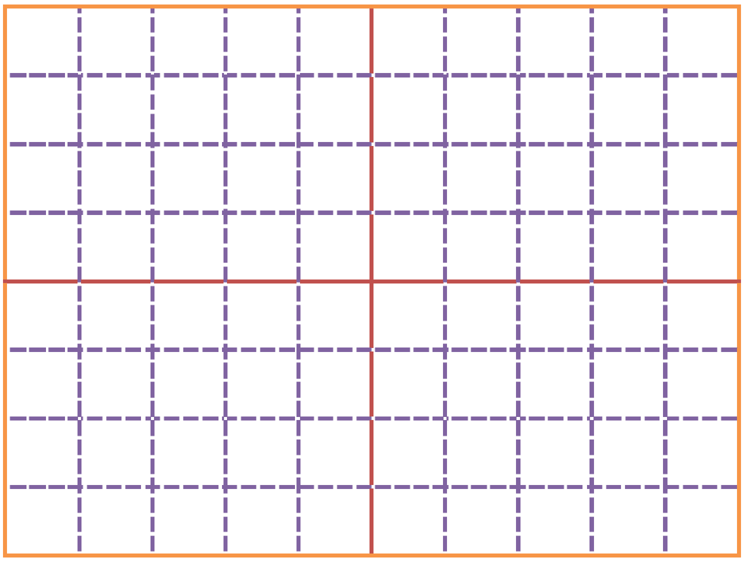
11.4.2.1 Setup the circuit shown in Figure 2 and place the probe for channel #1 on the BJT collector (with the ground on the ground as shown in figure 2). Attach channel #2 to emitter terminal next to the 1 Ohm resistor. **Since the voltage across channel #2 is very small, you should set the oscilloscope probe to X1 mode (and change the attenuation setting in the channel mode options) to get a better measurement.**

11.4.2.2 Adjust the oscilloscope timebase to display 2-3 cycles of triangular waveform.

11.4.2.3 Switch the oscilloscope to X-Y mode. You should now see one trace of the "Static characteristics" shown in the BC547 data sheet (I_C – V_{CE} characteristic). This characteristic should move vertically (increasing/decreasing collector current) as iBase is varied by adjusting the voltage feeding the 100k base resistor. *NOTE: you will probably have to swap between TIMEBASE and X-Y modes several times to get this trace effectively. You will need to adjust channel gains and offsets, and the time base, and some of these controls do not work effectively in X-Y mode.*

11.4.2.4 When you are confident you have captured a sensible result, sketch out the oscilloscope display on the axes below (you may also want to take picture of the DSO display with your phone, to record additional details).

Attempt to match several performance curves to those shown in the BJT data sheet by adjusting I_{Base}. Remember to allow for the base-emitter voltage when calculating the base current using the voltage drop across R2 (it may be easier to measure this voltage using a multimeter). Add the matching characteristics to the graph above. **(UNABLE TO DO WITH SCOPY)**



☐ CHECKPOINT: Get a demonstrator to check your answers, and initial here

LAB ASSESSMENT

Given Circuit

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ASSESSMENT

Student Statement:

I have read the university's statement on cheating and plagiarism, as described in the *Student Resource Guide*. This work is original and has not previously been submitted as part of another unit/subject/course. I have taken proper care safeguarding this work and made all reasonable effort to make sure it could not be copied. I understand the consequences for engaging in plagiarism as described in *Statue 4.1 Part III – Academic Misconduct*. **I certify that I have not plagiarized the work of others or engaged in collusion when preparing this submission.**

Student signature:_____Tan Jin Chun______Date:18/5/ 22

TOTAL: ________(/7)

ASSESSOR: ________