Faculty 4

M.Sc. in Electronics Engineering

Measurement and Instrumentation

Project Report

Output Characteristics of Bipolar Junction Transistor(BC547) using LabView

Submitted by

Md Shahriar Dipto (5227587)

&

Nikhil Shrikrishna Sanga (5366338)

Submitted to

Prof. Dr.-Ing. Friedrich Fleischmann

E-Mail: Friedrich.Fleischmann@hs-bremen.de

WiSe 2024/25

Date of Submission

16th March 2025

Table of Contents

List of Figures

List of Tables

1. Introduction

One of the most important inventions of the 20th century, the transistor has completely redefined the world of electronics. Electronic circuits used to be built using vacuum tubes before transistors were invented—bulky devices where the minimum switching capacity needed many watts, and life was extremely limited by the need to dissipate heat, need to keep things mechanically intact, etc. This resulted in the development, in 1947, of the transistor, invented by John Bardeen, Walter Brattain, and William Shockley at Bell Laboratories, which offered a much more efficient, compact, and reliable alternative. This invention marked the beginning of the semiconductor era, enabling the development of smaller, faster, and more energy-efficient electronic devices [1].

Transistor is a semiconductor device, which conducts electricity in a semi-enthusiastic way, falls somewhere between a real conductor like copper and an insulator such as the plastic wrapped around wires. While most transistors are made of silicon, transistors are also constructed from other materials such as germanium and gallium arsenide [1].

Silicon, a chemical element typically associated with sand, isn't a conventional conductor of electricity. A chemical procedure named doping is utilized to add impurities into a semiconductor to tune electrical, optical and structural properties. This allows silicon to acquire free electrons that conduct electric current. The silicon either becomes an n-type semiconductor, where the electrons flow out of it, or a p-type semiconductor, where electrons flow into it. In either case, the semiconductor allows the transistor to act as a switch or amplifier [1].

Transistors are three terminal devices – the Base, Collector and Emitter. the base is lightly doped and thin, the collector is moderately doped and larger, and the emitter is heavily doped and moderate. A transistor works on the very basic principle of controlling the flow of current through the Collector and Emitter terminals, by applying a smaller current or voltage at the Base terminal. It then modulates this base current flow, effectively allowing the transistor to amplify weak signals or function as an electronic switch, which underpins contemporary electronic circuits [2].

Transistors basically can be divided into two main types; Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET). Specifically, BJTs—current-controlled devices that conduct using both electrons and holes—are referred to as "bipolar." Based on the configuration of doping, they are further classified as NPN and PNP types. The most common transistor configuration is the NPN transistor configuration that has a high gain and is much more efficient at using the power to amplify signals; The BC547 NPN transistor was used in this experiment [3].

The invention of the transistor made the development of vacuum tubes obsolete, it founds the basis for the Integrated Circuits (I_C), where millions of transistors are fabricated into a single silicon chip. This advancement, driven by Moore's Law, has led to exponential growth in computing power and the miniaturization of electronic devices. Now, transistors go everywhere, from phones and computers to medical devices and cars [4].

This report examines BC547 output characteristics through the use of LabVIEW software. The purpose of the experiment is to investigate the relationship between collector current (I_C) and collector-emitter voltage (V_{CE}) for different base currents (I_B). By studying these characteristics, we can gain insights into the transistor's behaviour in different operating regions, such as the cut-off, active, and saturation regions, which are essential for designing and optimizing electronic circuits.

2. The aim of the experiment

- To become familiar with and investigate the use of LabVIEW as a programming language and measuring tool.

- Use LabVIEW software to examine the NPN Bipolar Junction Transistor's (BC547) output characteristics.

- Create a LabVIEW VI file to measure the Collector-Emitter Voltage (U_{CE}) and Collector Current (I_C) by varying the Collector Voltage (U_C) and Base Voltage (U_B) while maintaining a constant Base Current (I_B). Plot the graph for forward characteristics based on the data obtained with the DAQ and become accustomed to it.

3. Theorem

3.1 Transistor with Bipolar Junction

A three-terminal semiconductor device with two p-n junctions that may magnify a signal is called a bipolar junction transistor (BJT). Because the BJT is a current-controlled device, we may regulate the output current at the collector by providing a voltage and input current at the base. As was previously mentioned, the base, collector, and emitter are the three terminals of the BJT. Because both holes (+)

and electrons (-) contribute to the current flow through the transistor, BJT is also referred to as a bipolar device. Free electrons (negative charge carriers) are found in the N-type area. Holes (positive charge carriers) are present in the P-type area [5].

Bipolar transistors can be classified as either NPN or PNP based on their structure. Thin and lightly doped P-type bases are positioned between strongly doped N-type emitters and additional N-type collectors in NPN transistors, whereas thin and lightly doped P-type bases are positioned between heavily doped P-type emitters and additional P-type collectors in PNP transistors [5].

Below are the fundamental schematics for the two varieties of bipolar junction transistors that were previously discussed.

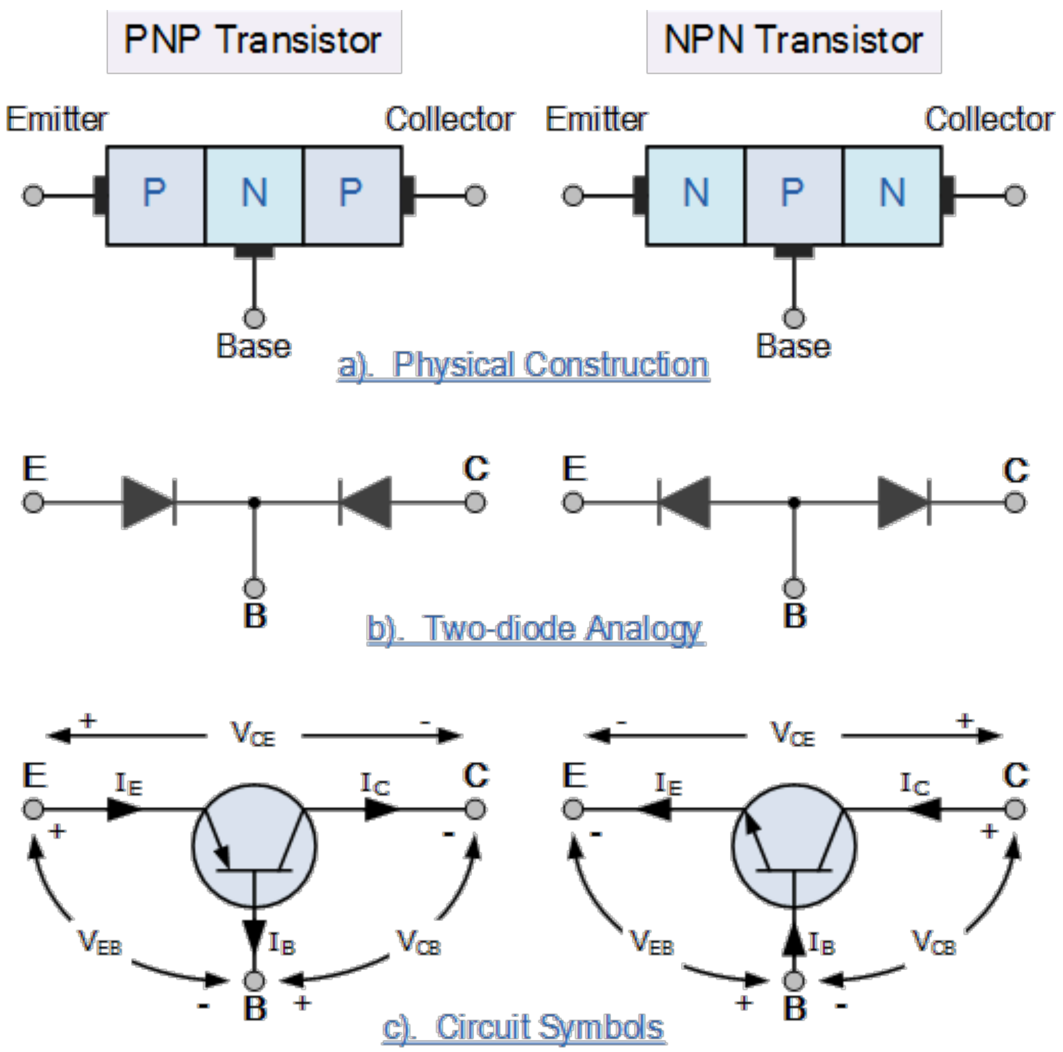


Figure 1: Types of BJT [6].

Because the Bipolar Transistor has three terminals, it can be connected to an electronic circuit in three different ways. One terminal serves as common ground to both the input and the output [6].

The Base, Emitter, or Collector are examples of this common component. The static properties of the Bipolar Transistor vary with each circuit configuration, hence each connecting technique reacts differently to its input signal inside a circuit [6].

The three BJT configurations are as follows:

- Common Base Configuration: No Current Gain, Voltage Gain [6].
- Common Emitter Configuration: Gain in both voltage and current [6].
- Common Collector Configuration: No Voltage Gain, Current Gain [6].

Due to its high-power gain (from both voltage and current gain), the Common Emitter Mode configuration of an NPN transistor—the most popular—will be employed. A low input current might produce a big output current when the transistor acts as an amplifier [7].

The circuit for the BJT's common emitter is an inverting amplifier. This indicates a 180^{o} phase shift in the output signal compared to the input voltage signal. Common emitter configurations are mostly utilized in radios and as low voltage amplifiers [7].

Table 1 below shows how the three configurations compare to one another in terms of their features.

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Angle	0^{o}	180^{o}	0^{o}
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

Table 1: Comparison of different configurations of BJT [6].

3.2 Common Emitter Configuration

As seen in the diagram below, in the common emitter or grounded emitter arrangement, the input signal is applied between the base and the emitter, and the output is obtained between the collector and the emitter [6].

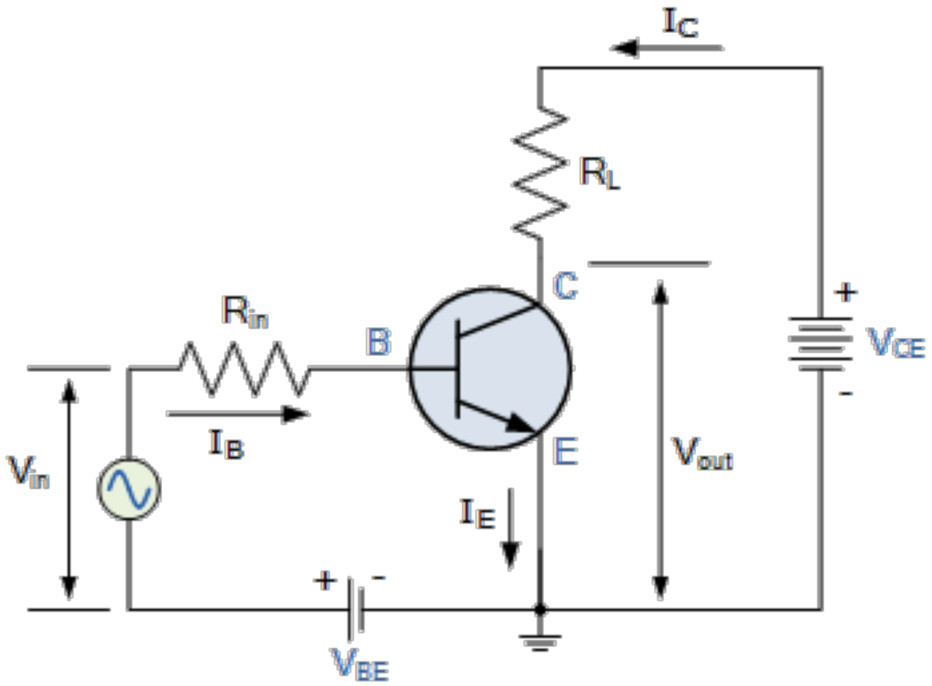


Figure 2: Common Emitter Configuration [6].

This arrangement provides the base terminal with the AC input signal Vin, collects the output at the collector terminal Vout, and grounds the emitter terminal. This kind of setup, which embodies the "normal" approach to bipolar transistor connection, is the most widely used circuit for transistor-based amplifiers. The common emitter amplifier configuration generates the maximum power gain and current among the three bipolar transistor configurations [7].

This is mostly due to the fact that the output impedance is extremely HIGH since it is drawn from a reverse-biased PN-junction, whereas the input impedance is extremely LOW since it is connected to a forward-biased PN-junction. With an 1800 phase shift, the common emitter amplifier arrangement produces an inverted output [7].

3.2.1 Working Principle of Bipolar Junction

Figure 2 shows that, the collector base junction is reversed biased and the base emitter junction is forward biased when a supply voltage is applied. As a result, the Base Emitter junction's depletion region is narrower than the Collector Base junction. Electrons go from the emitter to the base as a result of the forward bias at the base-emitter junction, which lowers the barrier potential. Some of the electrons from the emitter recombine with the holes in the base area and flow out of the base terminal as base current IB since the base is small and has very few holes due to its mild doping [6].

As a result of electron and hole recombination, base current IB flows. The collector current (IC) is made up of the remaining huge number of electrons that transit the base area and the reverse biased collector junction [7]. Therefore, via KCL,

$$I_E = I_B + I_C \qquad (1)$$

In addition, the base current pales in comparison to the emitter and collector currents.

$$I_E \approx I_C$$

Because the load resistance (R_L) is connected in series with the collector, the common emitter transistor arrangement has a rather substantial current gain (I_C / I_B). The current gain of a transistor is determined by its beta (β). Additionally, the ratio of I_C to I_E is known as Alpha (α), and its value is always less than unity because the emitter current for a typical emitter design is defined as (1).

Any small change in the base current (I_B) will cause a much bigger change in the collector current (I_C), as the physical structure of the transistor itself determines the electrical interaction between these three currents, I_C, I_B, and I_E. As a result, slight variations in the base's current will regulate the emitter-collector circuit's current. Beta typically ranges from 20 to 200 for the majority of general-purpose transistors [6].

Combining the formulas for Alpha (α) and Beta (β) yields the transistor's current gain and the mathematical relationship between these parameters, which is as follows:

$$\alpha = \frac{I_C}{I_E} \qquad (2)$$

$$\beta = \frac{I_C}{I_B} \qquad (3)$$

$$\therefore\ I_c = \alpha . I_E = \beta . I_B \qquad (4)$$

$$\text{Also}, \alpha = \frac{\beta}{1 + \beta} \qquad (5)$$

$$\beta = \frac{\alpha}{1 - \alpha} \qquad (6)$$

In an NPN transistor, electrons make up the bulk of the charge carriers, while holes make up the minority. Electrons make up the minority of charge carriers in a PNP transistor, while holes make up the majority [6].

3.2.2 Output characteristics of BJT

The V_{CE} versus I_C graph illustrates the BJT's output characteristics. The Collector Emitter Voltage (V_{CE}) determines the Collector Current (I_C) for the output characteristics, while the Base Current (I_B) remains constant (i.e., V_{BE} remains constant).

Several BJT properties are displayed in the graphs above. The three primary phases of a BJT are cut-off, active, and saturation. The next section discusses the three BJT stages.

- **Cut-off Region:** $V_{BE} < V_B, I_B = 0, I_C \approx I_E \approx 0$

Transistors are off when the base-emitter junction is reversed-biased, meaning that no charge carriers enter the base and go to the collector when the base emitter voltage is lower than the base voltage (0.7 V in silicon). There is no impact from the voltage that is placed between the emitter and collector. The cut-off region is the name given to this area. The transistor behaves as an open circuit in the cut-off area because the effective resistance between the collector and emitter is quite high (hundreds of MΩ), despite the fact that the collector and emitter currents are very modest for any [5].

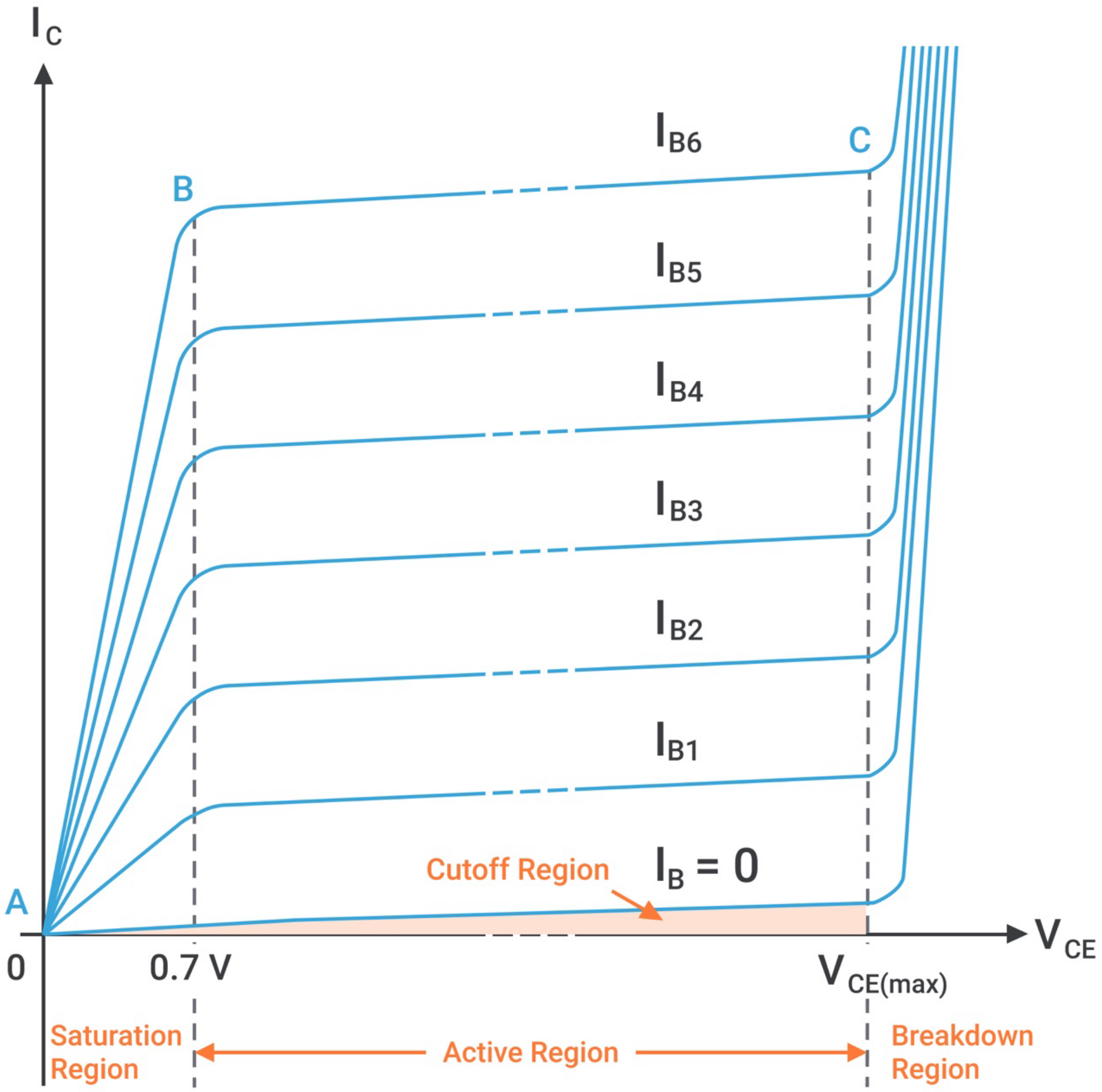


Figure 3: Output Characteristics of BJT [8].

- **Active Region:** $V_{BE} = V_B, I_B > 0, I_C/I_B = \beta, V_{CE} > V_B$

The transistor is turned on when the base-emitter junction is forward-biased. However, the amount of voltage supplied between the collector and the emitter determines how the transistor behaves. The base collector junction is reverse-biased and the transistor is in the active-linear zone if $V_{CE} > V_B$. The base emitter junction is forward biased. In this area, the transistor functions as an amplifier and the I_C varies linearly with I_B but with a gain of β [8].

- **Saturation Region:** $V_{BE} = V_B, I_B > 0, I_C/I_B < \beta, V_{CE} \approx V_{sat}$

Both the Base Collector and Base Emitter junctions are forward biased if $V_{CE} < V_B$. The saturation region is the name given to this area. Since the I_C is high and the V_{CE} is low in this instance, the BJT functions as a closed circuit and the effective resistance between the collector and emitter in the saturation region is low. The saturation voltage, $V_{CE} \approx V_{sat}$, is thus specified by the model [8].

Additionally, there is a breakdown region where transistor damage is possible and the value of the I_C rises rapidly. This may occur if:

- A high reverse voltage is supplied between any two terminals;
- The product of the I_C and V_{CE} exceeds the transistor's power handling capacity;
- A high positive voltage is put across the Collector Emitter junction (breakdown zone) [8].

4. Setup of the experiment

The following elements make up the experimental setup:

- PC running NI Software LabVIEW [9].
- Transistor BC547 [10].
- National Instruments USB-6001 [11].
- DAQ module for automated data gathering [12].

4.1 USB – 6001

The NI USB-6001 is a compact, multifunctional data acquisition (DAQ) device manufactured by National Instruments (NI), designed for a low-cost measurement and automation applications. It offers 8 analog inputs, 2 analog outputs, 12 digital I/O lines, and a 32-bit counter, making it suitable for a wide range of laboratory and industrial tasks [13].

With a maximum sampling rate of 20 kS/s and 14-bit resolution, the USB-6001 provides sufficient accuracy for many low-speed signal acquisition and control applications. Its plug-and-play functionality, powered entirely by the USB bus, ensures ease of use and portability. Additionally, the device is compatible with LabVIEW, enabling seamless integration for data acquisition, analysis, and visualisation. The USB-6001 is widely used in educational, research, and prototyping environments due to its affordability, reliability, and versatility [13].

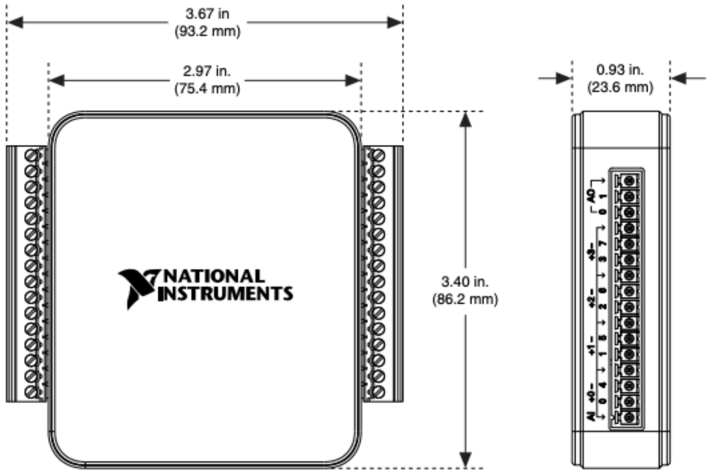


Figure 4: NI USB-6001 Dimensions [13].

Specifications for NI USB-6001:

The NI USB-6001 is a versatile data acquisition device with robust analog and digital capabilities. On the analog front, it features four differential and eight single-ended analog input channels and also providing flexibility for various signal measurement configurations [13].

Additionally, it includes two analog output channels with an operating voltage range of 0 to 5V, suitable for generating control signals in low-voltage applications [13].

On the digital side, the device offers 12 digital I/O lines, divided into Port 0 (P0.0-P0.7) with 8 configurable lines and Port 1 (P1.0-P1.3) with 4 lines, supporting a high output voltage of up to 5.8V. It also provides an external voltage output of +5V with a maximum output current of 200mA, enabling it to the power external sensors or peripherals [13].

Furthermore, USB-6001 includes a 32-bit event counter for precise timing and counting applications. The device is equipped with a USB 2.0 full-speed interface (12 Mb/s), ensuring fast and reliable data transfer between the DAQ and the host computer [13].

4.2 BC547 Transistor

To begin with, the BC547 is a common NPN bipolar junction transistor (BJT) that is known for its dependability and versatility in low-power applications. Here are its main specifications and features [10]:

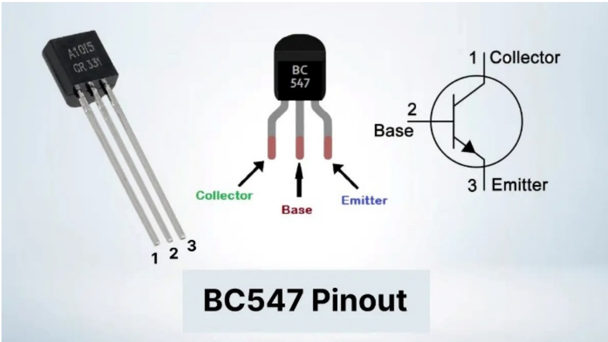


Figure 5: BC547 Pinout [10]

Operation:

When the base pin is grounded, the collector and emitter remain open (reverse-biased). Applying a signal to the base pin forward-biases the transistor, allowing current to flow between the collector and emitter [10].

The current gain (h_{FE}) of BC547 is 110 to 800, which means it can amplify the input. The maximum collector current (I_C) is 100 mA, making it suitable for low-power circuits. The base current (I_B) should not exceed 5 mA to avoid damaging the transistor [10].

Operating Regions:

Saturation Region: Under full biasing the BC547 allows 100 mA of maximum current flow between collector and emitter. However, the base-emitter voltage (V_{BE}) is around 900 mV, and the collector-emitter voltage (V_{CE}) is around 200 mV [10].

Cut-off Region: When the base current is removed, the transistor turns off, and the base-emitter voltage drops to around 660 mV [10].

Key Features:

Type: Bi-Polar NPN-Transistor [10].

Current Gain (h_{FE}): Up to 800 [10].

Collector Current (I_C): 100 mA maximum [10].

Emitter-Base Voltage (V_{EB}): 6 V maximum [10].

Package: Available in **the To-92** package, which is compact and easy to use [10].

4.3 Data Acquisition (DAQ) System

The National Instruments DAQ module is Ideal for Data Acquisition as it can measure electrical or physical phenomena such as voltage, current, temperature or pressure or sound. A DAQ system generally includes some combination of:

Sensors: To detect physical or electrical signals.

DAQ Hardware: Such as the USB-6001 [11], to digitize the signals.

Software: Like LabVIEW, to analyse, save, and present the data.

The DAQ system digitizes signals from the experimental setup, performs analysis, and presents the results to the user, making it an essential tool for automated measurements [12].

5. Development of Output Characteristics of Bipolar Transistor (BC547) in LabView

5.1 Overview

National Instruments LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a system-design platform and development environment with a visual programming language. It employs a graphical programming language for data acquisition, instrument control, and industrial automation. This experiment used LabVIEW to find the output characteristics of an NPN Bi-polar Junction transistor (BC547). LabVIEW programs are called Virtual Instruments (VIs) and include three primary parts [10], [13].

Front Panel: This is the user interface, containing controls (inputs) and indicators (outputs).

Block Diagram: This contains the graphical source code, where the programming logic is implemented.

Connector Panel: This allows VIs to be used as subroutines within larger programs.

The experiment consisted of designing a LabVIEW programme to study the dependency of the collector current (I_C) with respect to the collector−emitter voltage (V_{CE}) for a BC547 transistor. The Implementation section describes how this program was developed through a series of graphical programming blocks and data acquisition tools.

5.2 Flow Diagram:

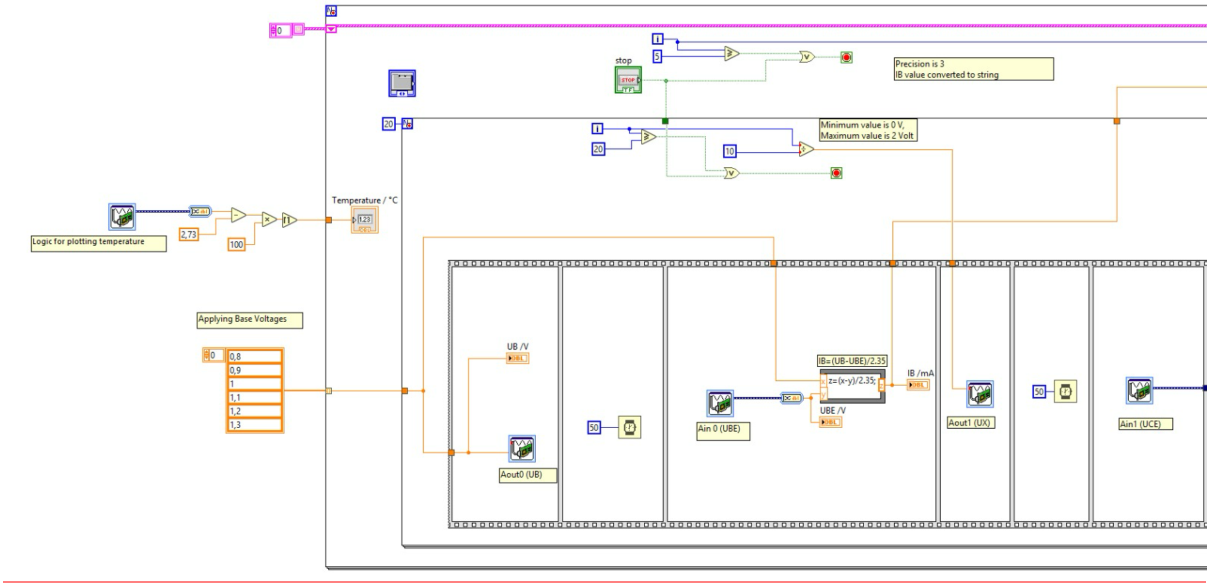


Figure 6: LabView program (part 01).

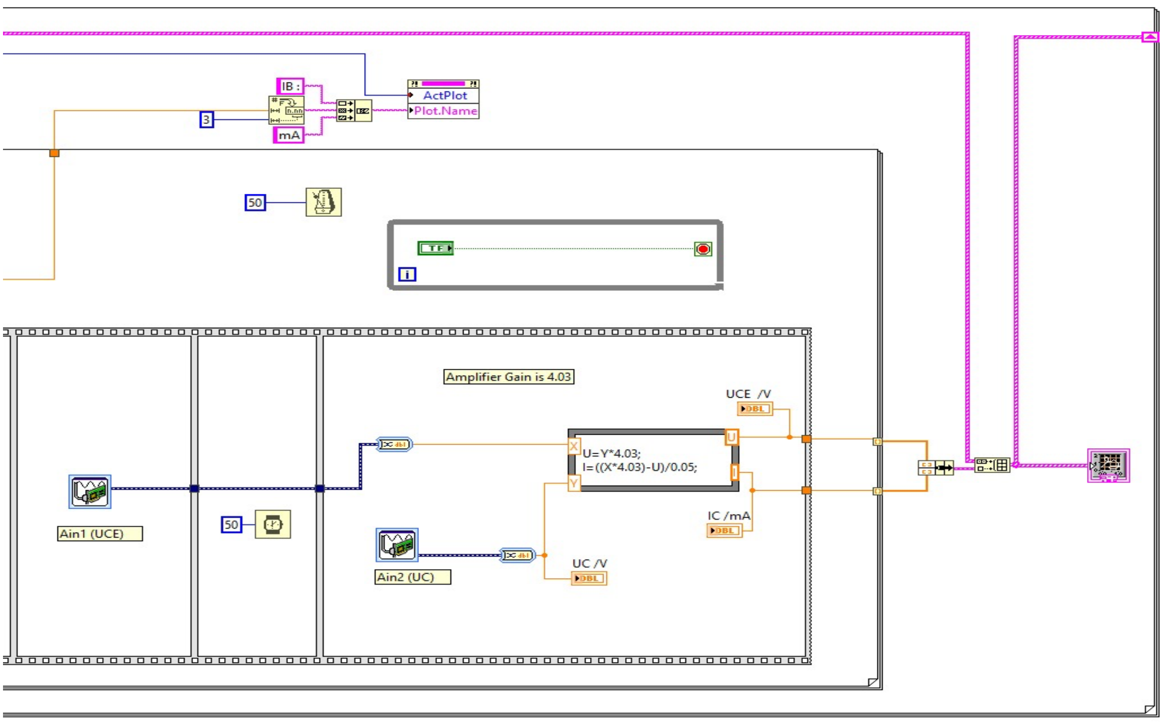


Figure 7: LabView program (part 02).

5.3 Program Development

For the development of Output Characteristics of Bipolar Transistor (BC547) in LabView has following basic steps:

1. Input Signal Acquisition: Base Voltage, Base-Emitter Voltage (U_{BE}) and Collector-Emitter Voltage (U_{CE})
2. Signal Processing & Calculations: Base Current (I_B) Calculation, Collector Current (I_C) Calculation
3. Data Output and Visualization: Real-time plotting of I_C vs. U_{CE} for different I_B values, Display U_B, U_{BE}, I_B, U_C, U_{CE}, and I_C numeric values

5.3.1 Start Button Implementation

The Start Button in the LabVIEW program serves as a user-controlled trigger to initiate the data acquisition and measurement process for analysing the output characteristics of the BC547 transistor. When the START button is pressed, the program begins executing, allowing real-time data collection and plotting of collector current (I_C) vs. collector-emitter voltage (U_{CE}) for different base currents (I_B).

The program allows users to start the experiment with the button which ensures that the experiment begins only when the user Is ready.

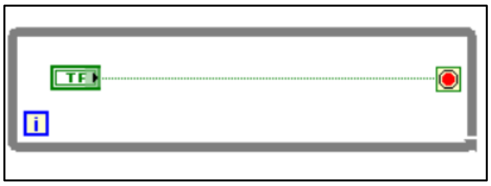


Figure 8: Start button logic.

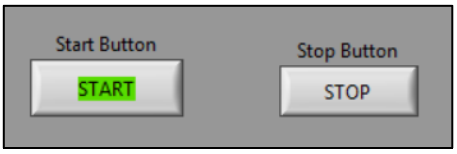


Figure 9: Start/Stop button at front panel.

5.3.2 Applying Base Voltage (U_B)

The input base voltage (U_B) is applied to the base terminal of the BC547 transistor through the NI-USB 6001 DAQ module. In the LabVIEW program, different values of (U_B) are generated and stored in an array. These values are passed through the DAQ module sequentially after each iteration of the for loop. The base voltage is varied in steps within the range of 0.8V to 1.3V to observe the transistor's behaviour under different biasing conditions. This process ensures accurate control of the base current (I_B), which in turn influences the collector current (I_C) .

The base voltage (U_B) is applied to the BC547 transistor in incremental steps. The values used in the experiment are:

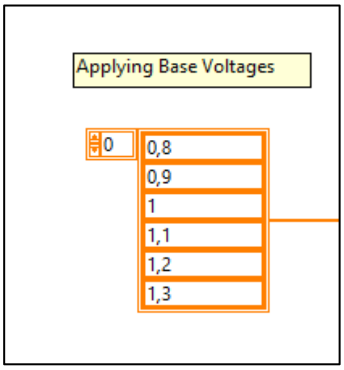


Figure 10: Input Base Voltage UB.

These voltages are applied sequentially to analyse the transistor's behaviour in different operating regions.

The DAQ Assistant block is used to configure and send the Base Input Voltage (U_B) through the AOut0 pin of the NI-USB 6001 DAQ module. This is done so that, the base voltage can be given to the transistor according to the program.

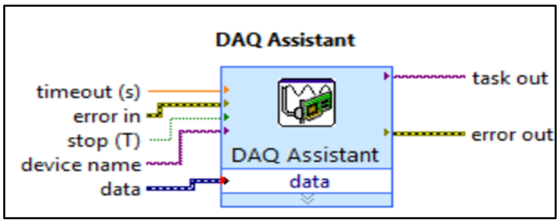


Figure 11: DAQ Module.

The inner loop counter will, take 21 different points to draw the graph I_C Vs V_{CE} according to the different I_B for each iteration of outer for loop 6 times. The inner loop operation will start again for the next iteration until outer loop stop condition satisfies or STOP button is pressed.

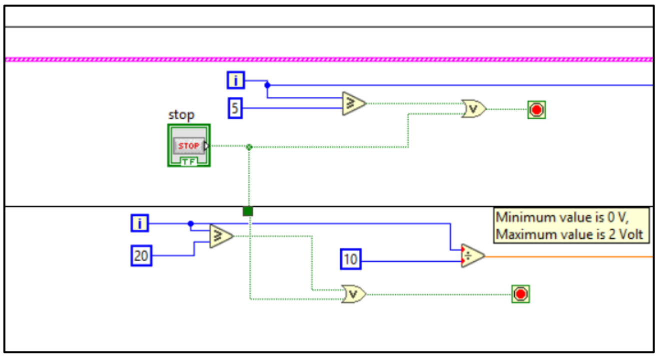


Figure 12: Inner and outer for loop circuit.

For Loop is used to repeat the code until it meets the last indexing of (U_B).

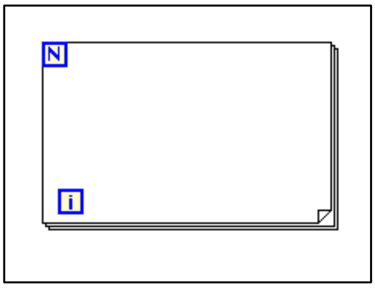


Figure 13: Basic for loop block.

5.3.3 Base Current Calculation (I_B)

This section of the LabVIEW program is responsible for calculating the base current (I_B) using the measured base-emitter voltage (U_{BE}). The analog input channel (Ain 0) acquires the (U_{BE}) value from the circuit. The base current is then determined using the equation:

$$I_B = \frac{(U_B - U_{BE})}{R_B}$$

Where RB is equivalent resistance of two parallel resistances of 4.7 kΩ. So, R_B is given by,

$$R_B = \frac{4.7 \times 4.7}{4.7 + 4.7} \text{ k}\Omega$$

$$I_B = \frac{(U_B - U_{BE})}{2.35}$$

This calculation ensures accurate determination of (I_B), which plays a crucial role in analysing the transistor's characteristics. The computed (I_B) value is then sent to an indicator for real-time monitoring and further processing.

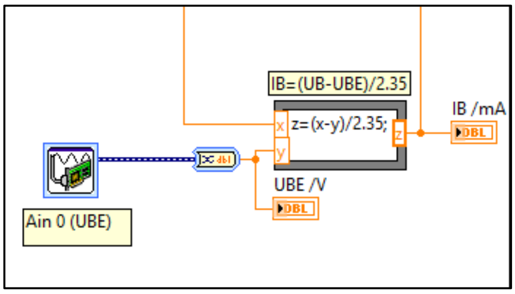


Figure 14: Base Current Calculation.

5.3.4 Input Collector Voltage (U_C)

The measurement system defines for each value of input base voltage (U_B), enables the acquisition of (U_C) collector voltage values. The operational amplifier (LM324) applies the calculated gain value of 4.03 using the resistor ratio 10K and 3.3K to process input values.

$$\text{Gain} = 1 + \frac{10\text{ k}}{3.3\text{ k}} = 4.03$$

The amplification process properly adjusts measured collector voltage values before they become available for subsequent calculation operations. The output characteristics plot of the transistor requires the acquired (U_C) values together with calculations to determine the (U_{CE}) and (I_C) parameters.

Function Block	Use in circuit
	Converts the dynamic data type to numeric, Boolean, waveform, and array data types for use with other Vi's and functions. In our case, used to convert the data acquired from the DAQ to scalar for further calculations.

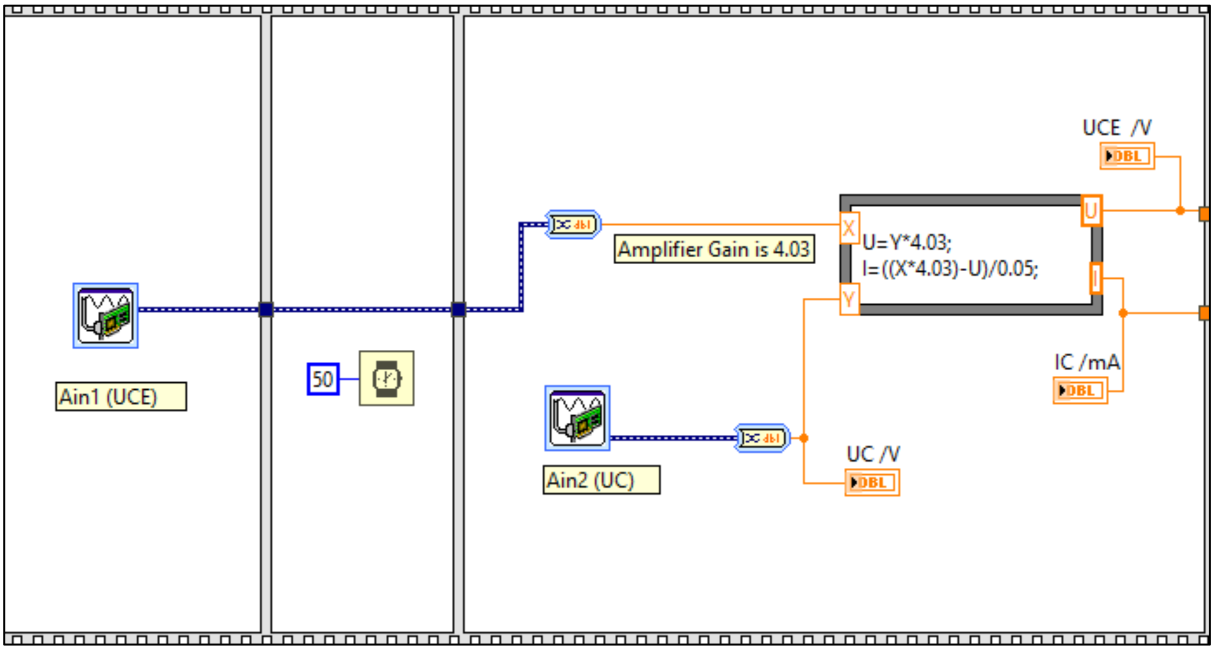


Figure 15: Collector Voltage Uc.

5.3.5 Measurement of Collector-Emitter Voltage (U_{CE}) and Collector Current (I_C)

The DAQ acquires the output voltage measurement through the collector-emitter voltage parameter (U_{CE}), allowing real-time monitoring of the transistor's output voltage. Based on this voltage, collector current (I_C) is evaluated from the measured voltage.

$$I_C = \frac{(U_C - U_{CE})}{R_C}$$

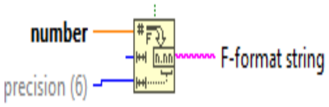
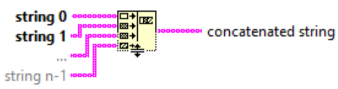
Whereas the calculation of (R_C) involves the collector path resistance. Four 200Ω resistors connected in parallel form an effective resistance aspect which results from,

$$R_C = \frac{200}{4} = 0.05 \text{ k}\Omega$$

The plot of transistor output characteristics can be plotted by calculating collector current (I_C), providing insights into its electrical performance under different conditions.

5.3.6 Displaying I_B with Base Current values on Front Panel

At this juncture of the LabVIEW program, the base current values (I_B) (orange line) are reformatted into a string format with three decimal precision to label the plot correctly. This function assigns each curve in the graph to its matched (I_B) value thus improving clarity about the transistor output characteristics.

Function Block	Use in circuit
	Formats numerical values of (I_B) into a string with a precision of 3 for display.
	Concatenates multiple string inputs to generate a properly labelled plot name for base current value I_B.
	Assigns the formatted and concatenated string as the label for the plotted graph, which is used to display base current value I_B on front panel.

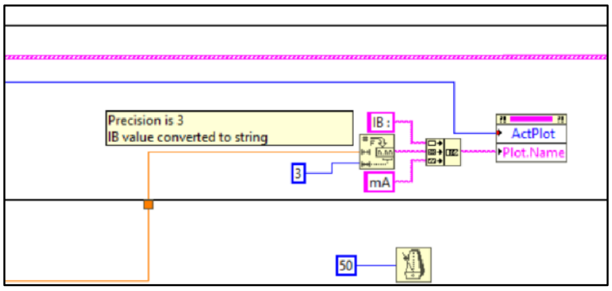


Figure 16: Logic to Displaying Base Current values (I_B).

5.3.7 Plot Characteristic Curve of (I_C) vs. (U_{CE})

The measured values need conversion through this section to create data that can be displayed by an XY Graph in the LabVIEW block diagram. Program components incorporate measured (U_{CE}) and (I_C) values which the circuit turns into data points to produce the transistor characteristic curve through the XY Graph.

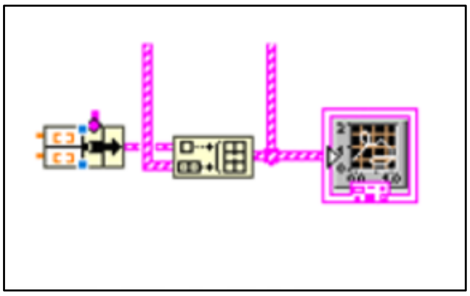
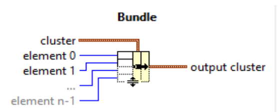
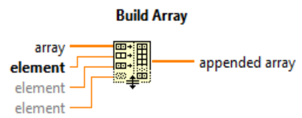
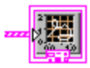


Figure 17: Plot Ic Vs Uce graph.

Function Block	Use in circuit
	The Bundle function groups the measured values of (U_{CE}) and (I_C) into cluster format, making them compatible with XY graph input.
	The Build Array function arranges the voltage (U_{CE}) and current (I_C) values into a structured dataset, allowing continuous plotting of the transistor's characteristic curve.
	The XY Graph block takes the bundled data and plots (I_C) vs. (U_{CE}), enabling real time visualisation of the transistor's behaviour.

This experimental arrangement ensures that the transistor's output characteristic curve is dynamically plotted, providing a clear representation of how collector current (I_C) varies with collector-emitter voltage (U_{CE}) at various base voltages.

5.3.8 Outer for loop logic

The highlighted part of the LabVIEW program controls the loop execution out outer loop and stopping condition. A stop button serves to terminate the loop operation by manual intervention. A comparison procedure tests the loop criteria. Conditions state that if the loop count surpasses 5 (i.e. total 6 iteration) the loop concludes while it will be in operation if the loop count is below 5 (i.e. below 6 iteration). The programming strategy enables workflow management by providing safe termination of execution during specific requirements.

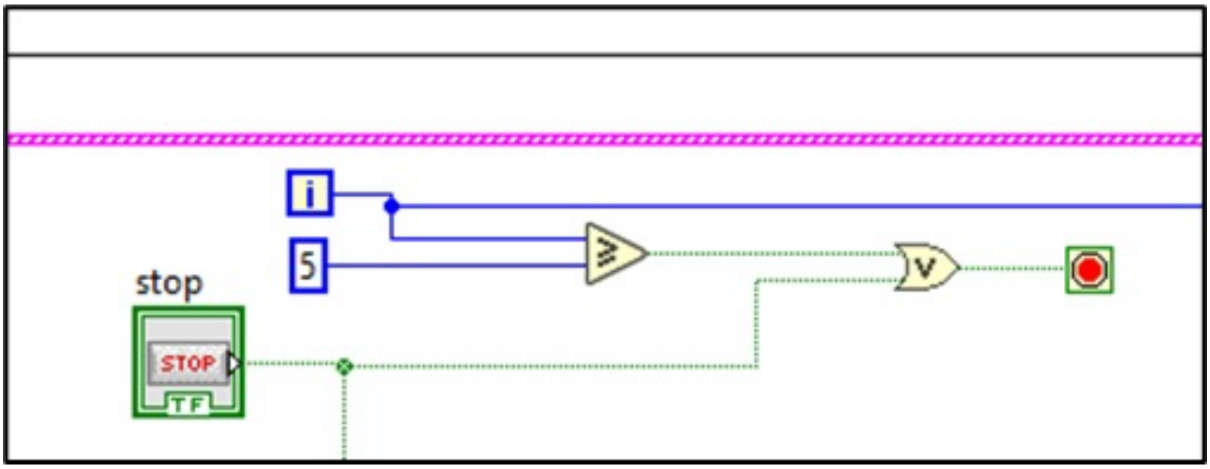


Figure 18: Outer for loop.

5.3.9 Logic for Plotting Temperature

The temperature data acquisition takes place during this segment of the LabVIEW program through analog input signals. The received voltage signal gets analysed against a reference value (2.73 V) which defines the temperature calibration baseline. An appropriate temperature value in degrees Celsius results from multiplying the difference value by 100 after which it scales the voltage reading. Finally, the processed temperature is displayed in numeric format, allowing for real-time monitoring and visualization.

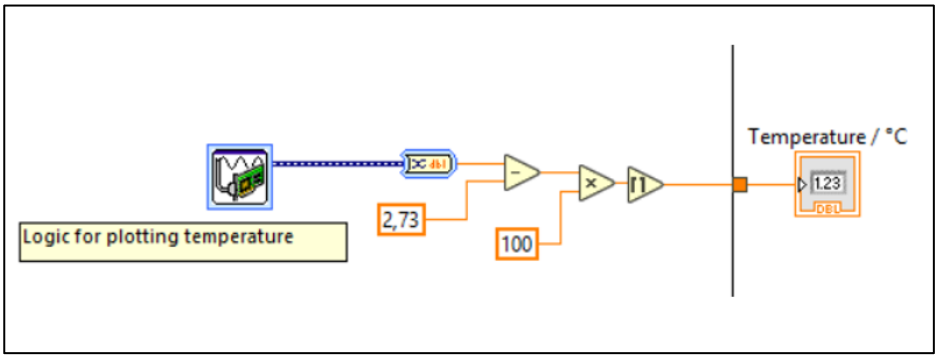


Figure 19: Logic for Plotting Temperature.

5.4 Front Panel Overview

5.4.1 Graphical Representation of Transistor Characteristics

The Output Characteristics feature on Front Panel displays the (I_C) variation against (U_{CE}) for different values of (I_B) . User can view (I_C) response to (U_{CE}) changes at different base currents via the graphical representation in the Front Panel. The specific value of base current determines the amplification characteristic of transistor shown through each curve.

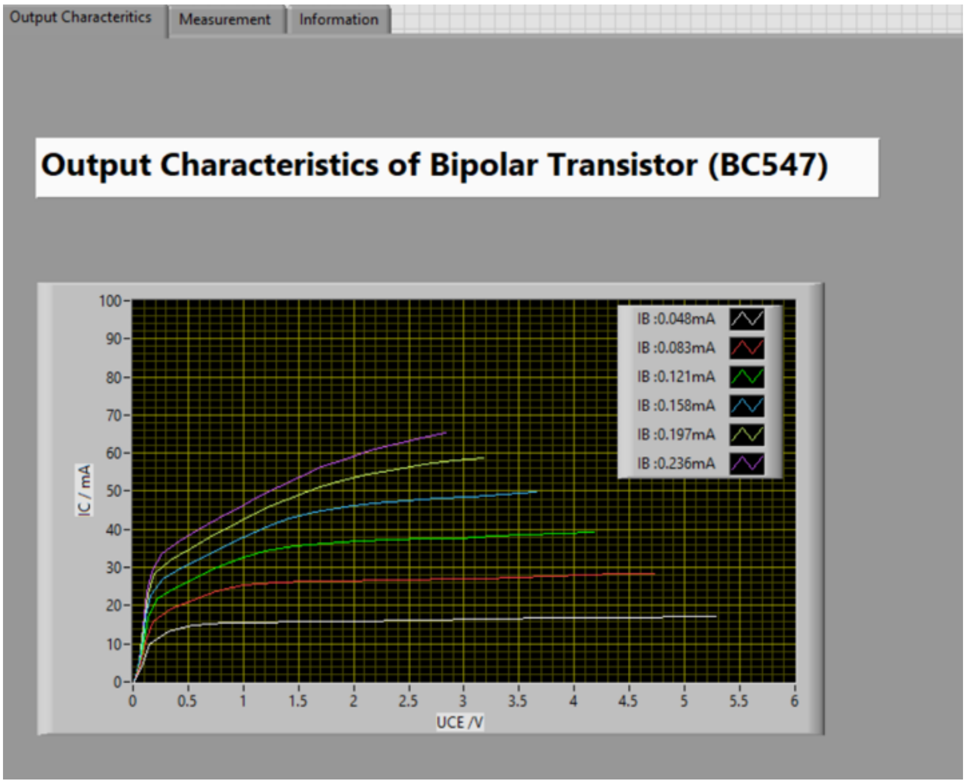


Figure 20: Front Panel of the LabView Program.

5.4.2 Measurement Display Section

The measurement tab provides real-time numerical values of key electrical parameters, including:

- Base Voltage (U_B) – The applied voltage at the base terminal.
- Base-Emitter Voltage (U_{BE}) – The voltage drop across the base-emitter junction.
- Base Current (I_B) – The current flowing through the base terminal.
- Collector Voltage (U_C)– The applied voltage at the collector terminal.

- Collector-Emitter Voltage (U_{CE}) – The voltage drop between the collector and emitter.
- Collector Current (I_C) – The output current through the collector.

These values are displayed dynamically, updating based on real-time measurements from the DAQ module.

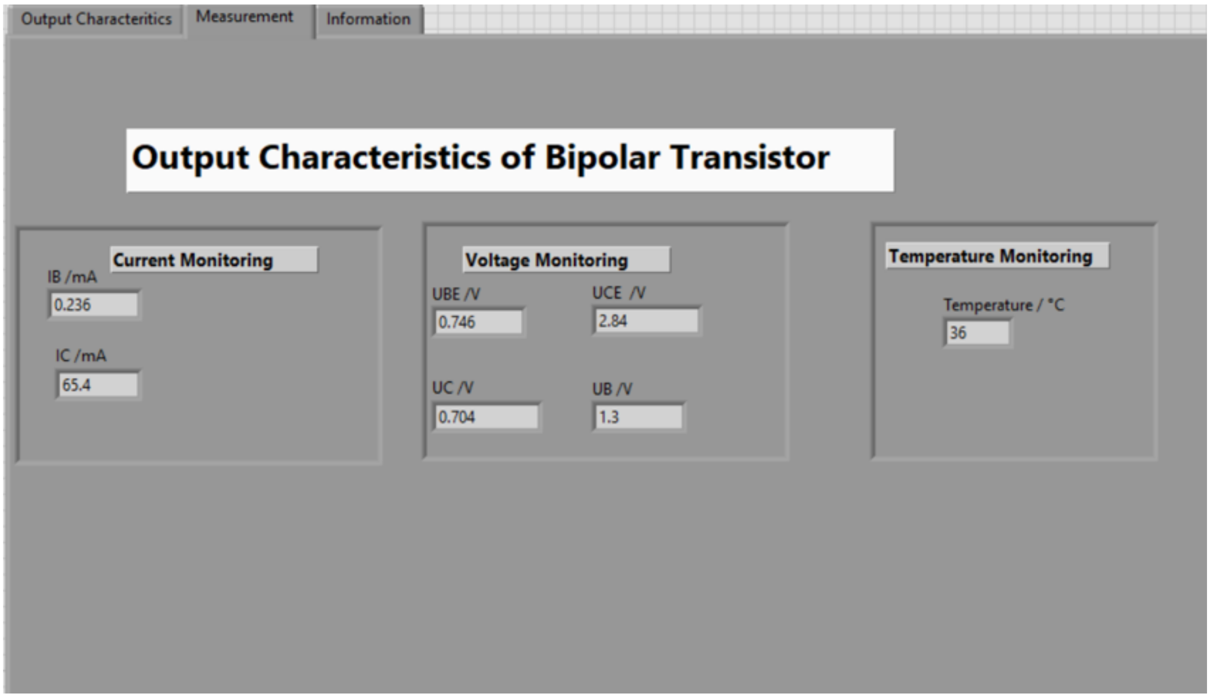


Figure 21: Front Panel of the LabView Program shows Values of Parameters of Transistor.

5.5 Understanding the Output Characteristics of the Transistor

The LabVIEW simulation depicts transistor behaviour changes that occur during different operational stages through graphic representations. The applied base voltage (U_B) determines the base current level (I_B) which directly influences the value of collector current (I_C). The presented curves display the transistor's reactions to voltage modifications so we can evaluate its different operating zones.

The plot shows as increase of collector-emitter voltage (U_{CE}), collector current (I_C) initially rises rapidly but the current reaches a steady state at high voltage levels. This indicates that after a certain point, the transistor reaches its active region, where collector current (I_C) remains almost constant for a given base current (I_B) . The experimental results demonstrate BJT (Bipolar Junction

Transistor) operation in amplification mode since collector current mainly depends on base current instead of collector-emitter voltage.

The system behaviour shifts toward another phenomenon when (U_{CE}) takes lower values. The collector current (I_C) start to drop, when collector-emitter voltage (U_{CE}) falls below specific threshold value. The transistor's conductive efficiency decreases because forward bias of the collector-base junction takes effect. The transition of charge carriers becomes difficult between emitter and collector at this point which results in current reduction. Charge recombination in the base region simultaneously minimizes the overall current movement in the circuit.

As the (U_{BE}) voltage falls below 0.7V the transistor enters the cutoff region in which almost no current flows through the collector. Base-emitter voltage control is essential for transistor switching operations because devices can turn between on and off states through voltage modifications.

A BJT undergoes three distinct operational regions consisting of cutoff where it operates as an off state, the active region (where it functions as an amplifier), and the saturation region (where it behaves as a closed switch). Both observations match transistor theories which validates the correctness of the LabVIEW simulation together with the experimental method.

6. Applications

Amplifiers: BJTs power most current amplifier devices that work at both audio frequencies and radio frequencies to boost signal strength [14].

Switching Circuits: They are used in digital circuits as switches to turn currents on and off, which is fundamental in computers and other digital systems [14].

Oscillators: BJTs enable oscillator functions by producing constant waveforms such as sine waves or square waves for radio transmitter applications as well as signal generator systems [14].

Signal Modulation: In communication systems, BJTs are used for modulating signals, which involves varying a carrier wave in accordance with the information signal [14].

Voltage Regulators: BJTs function as Voltage Regulators that preserve continuous output voltage by regulating input voltage changes along with adjusting to load conditions [14].

Analog Circuits: BJTs maintains its position in different analog circuits as key component in filters when combined with comparators and analog-to-digital converters [14].

7. Conclusion

It proved possible to successfully measure Bipolar Junction Transistor static output characteristics through the combination of NI USB-6001 DAQ module with LabVIEW software. An analysis of the collector current (I_C) through different base currents (I_B) was conducted under varying base voltages (U_B) with respect to the collector-emitter voltage (U_{CE}). The experimental outcome verified the theoretical properties of BC547 transistors because the setup showed precision in measurement.

The active region amplifier characteristics of the transistor can be seen from the graphs since (I_C) shows minimal change beyond (U_{CE}) thresholds. As (U_{CE}) moves toward lower values, (I_C) decreases because the transistor transitions to the saturation region that acts as a closed switch. The transistor transformed into its cutoff mode when (U_{BE}) reached below 0.7V while simultaneously blocking almost all collector current flow.

The experimental setup gives insights to BJT operation and its behaviour across different working regions. Base current control acts as the main determinant which allows the transistor to function correctly. The implementation of LabVIEW for data collection and real-time display was highly beneficial because it led to more exact and interactive characterization of the data.

The experiment verified the primary operational features of BJT models for their use in amplification as well as switching systems which are essential in modern electronic technology.

8. References

[1] M. Riordan and L. Hoddeson, Crystal fire: the invention of the transistor and the birth of the information age, WW Norton & Company, 1998.

[2] United States. Dept. of the Army, "Transistor Amplifier Fundamentals (Chapter 3)," in *Basic Theory and Application of Transistors*, vol. 86, Michigan, Dover Pubs., 1959, pp. 45-50.

[3] R. Teja, “Classification and Different Types of Transistors | BJT, FET, NPN, PNP,” Electronicshub, 16 09 2024. [Online]. Available: https://www.electronicshub.org/transistors-classification-and-types/. [Accessed 14 03 2025].

[4] D. C. Brock, Understanding Moore's law: four decades of innovation, Philadelphia: Chemical Heritage Foundation, (Ed.) 2006.

[5] I. J. Nagrath, “Electronic devices and Circuits,” *PHI Learning Pvt. Ltd.,* pp. 80-82, 2007.

[6] AspenCore, Inc., “Electronics Tutorials,” Bipolar Junction Transistor (BJT), [Online]. Available: https://www.electronics-tutorials.ws/transistor/tran_1.html. [Accessed 05 03 2025].

[7] H. L. Fernandez-Canque, “Bipolar Junction Transistor,” in *Analog electronics applications: fundamentals of design and analysis*, London, CRC Press, 2016, pp. 95-106.

[8] J. Magoncia, “CircuitBread,” Intermediate Electronics, a SwellFox project, 08 05 2020. [Online]. Available: https://www.circuitbread.com/tutorials/different-regions-of-bjt-operation. [Accessed 12 03 2025].

[9] National Instruments, “LabVIEW,” Emerson, 23 01 2025. [Online]. Available: https://www.ni.com/de/support/downloads/software-products/download.labview.html?srsltid=AfmBOoqvBdEMuooN87_lMmVkdQ_KvkU_PjbVbQutmxA9FGxrpfCp5C-P#559067. [Accessed 12 03 2025].

[10] Fairchild Semiconductor, “BC547 NPN general-purpose transistor datasheet,” SparkFun Electronics, 08 2002. [Online]. Available: https://cdn.sparkfun.com/assets/d/5/e/5/d/BC547.pdf. [Accessed 12 03 2025].

[11] National Instruments, “NI USB-6001 Specifications,” Emerson, 2025. [Online]. Available: https://www.ni.com/de-de/shop/model/usb-6001.html. [Accessed 12 03 2025].

[12] Hochschule Bremen (HSB), “Aulis HSB learning platform,” [Online]. Available: https://aulis.hs-bremen.de/ilias.php?baseClass= ilrepositorygui&cmdNode=yl:no&cmdClass=ilObjFileGUI&cmd=sendfile&ref_id=2133539. [Accessed 12 03 2025].

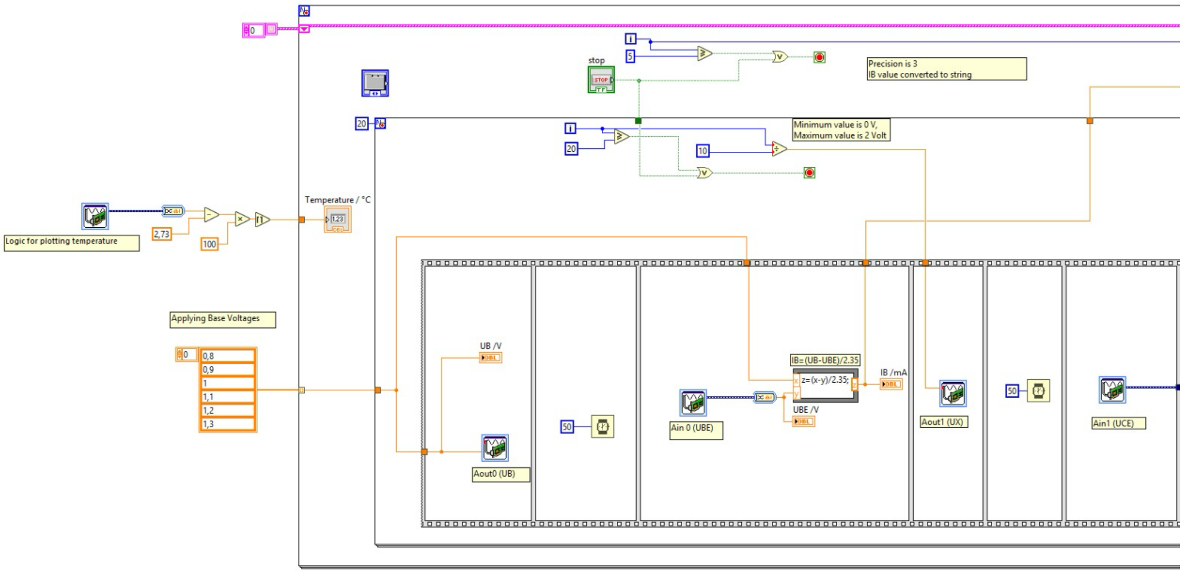
[13] National Instruments, “NI USB-6001 Specifications,” Emerson, 2025. [Online]. Available: https://www.ni.com/docs/de-DE/bundle/usb-6001-specs/resource/374369a.pdf. [Accessed 12 03 2025].

[14] J. O. Bird, Electrical Circuit Theory and Technology, Newnes, 2007.

9. Appendix

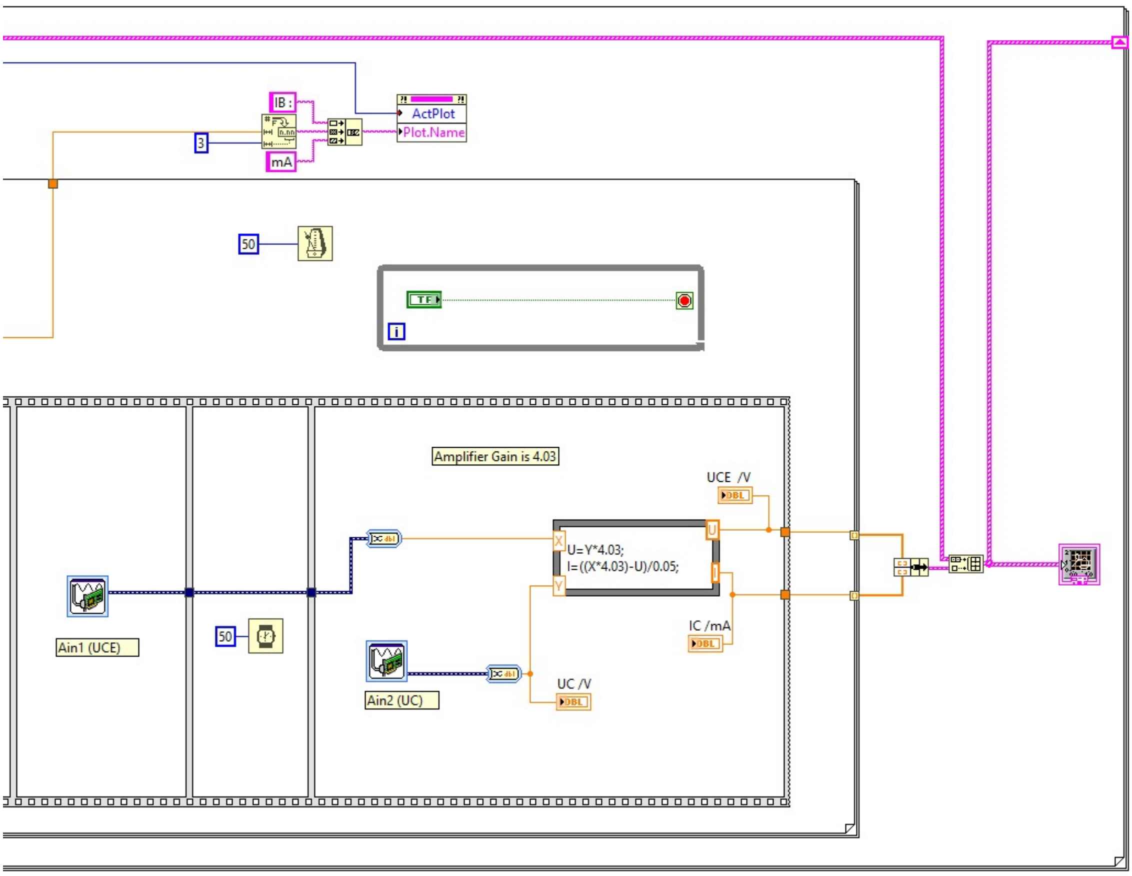
9.1 Block Diagram

Part 01:



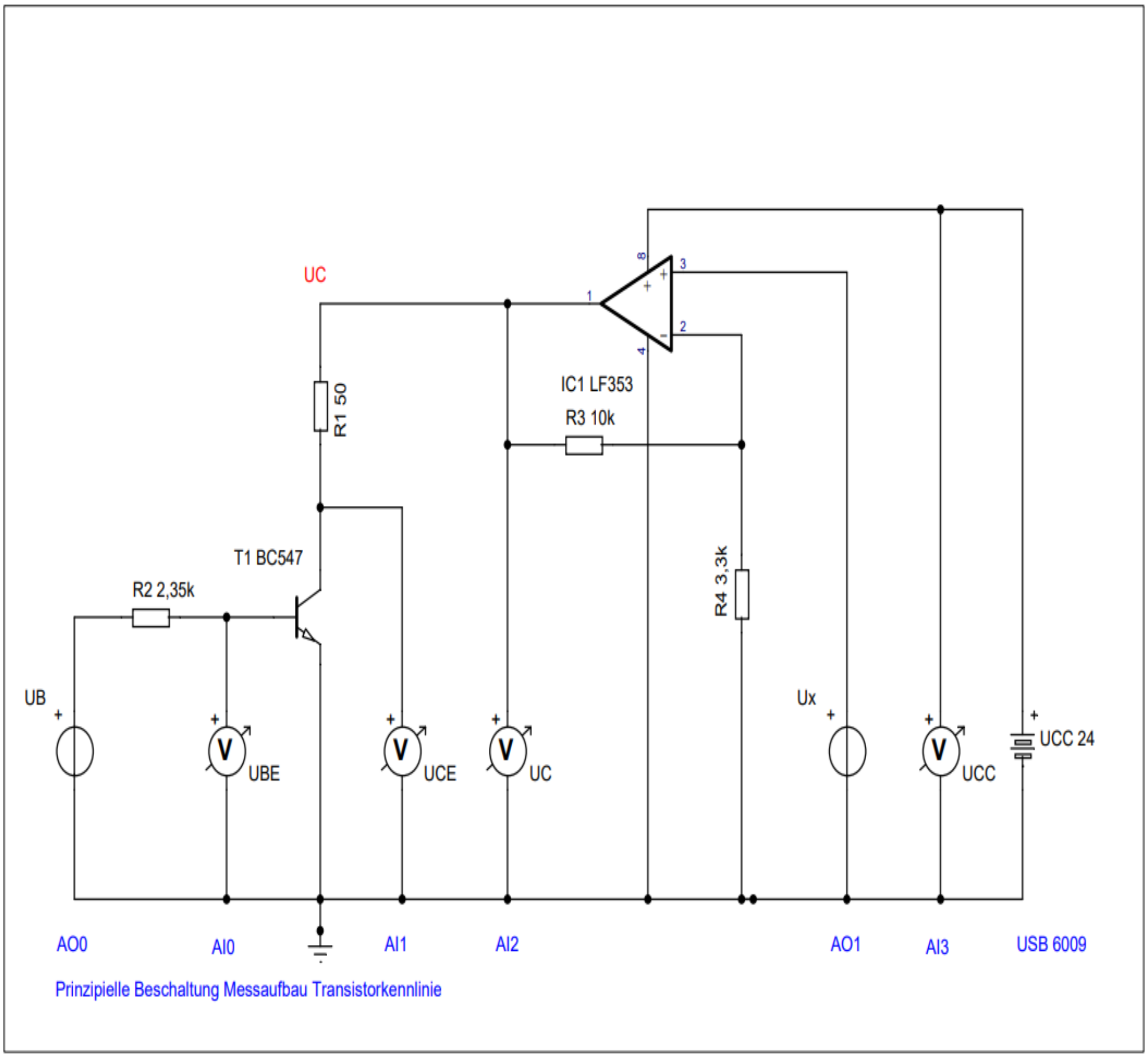
stop
Precision is 3
IB value converted to string
Minimum value is 0 V,
Maximum value is 2 Volt
Logic for plotting temperature
Temperature / °C
Applying Base Voltages
UB /V
Aout0 (UB)
Ain 0 (UBE)
IB=(UB-UBE)/2.35
z=(x-y)/2.35;
IB /mA
UBE /V
Aout1 (UX)
Ain1 (UCE)

Part 02:

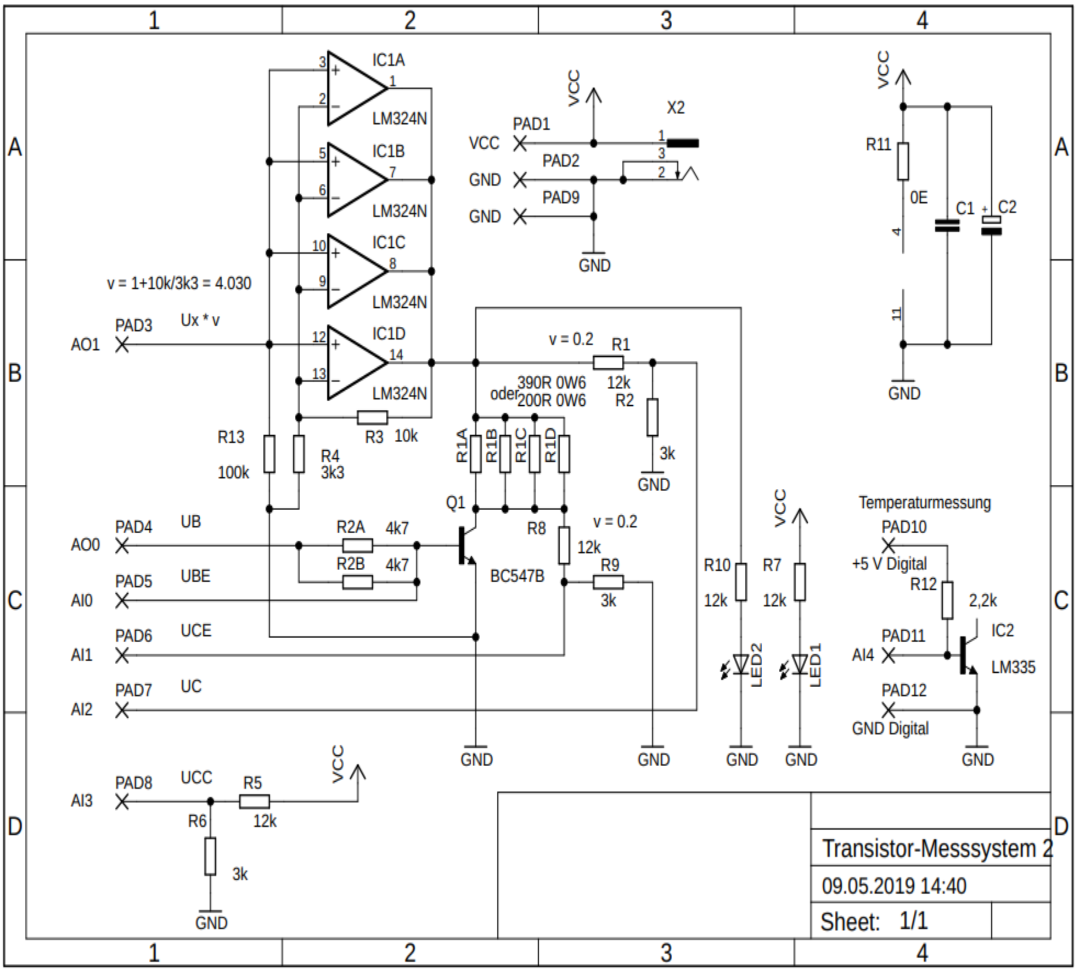


IB :
mA
ActPlot
Plot.Name
Amplifier Gain is 4.03
UCE /V
U=Y*4.03;
I=((X*4.03)-U)/0.05;
IC /mA
UC /V
Ain1 (UCE)
Ain2 (UC)

9.2 Transistor Base (provided by Dipl.-Ing. Rene Ramson)



9.3 Transistor Measuring System USB(provided by Dipl.-Ing. Rene Ramson)



9.4 Data sheet of BC547

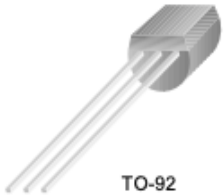
FAIRCHILD SEMICONDUCTOR®

BC546/547/548/549/550

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, V_{CEO}=65V
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560



1

TO-92

1. Collector 2. Base 3. Emitter

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BC546 : BC547/550 : BC548/549	80 50 30	V V V
V_{CEO}	Collector-Emitter Voltage : BC546 : BC547/550 : BC548/549	65 45 30	V V V
V_{EBO}	Emitter-Base Voltage : BC546/547 : BC548/549/550	6 5	V V
I_C	Collector Current (DC)	100	mA
P_C	Collector Power Dissipation	500	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	-65 ~ 150	°C

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
I_{CBO}	Collector Cut-off Current	V_{CB}=30V, I_E=0			15	nA
h_{FE}	DC Current Gain	V_{CE}=5V, I_C=2mA	110		800	
V_{CE} (sat)	Collector-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		90 200	250 600	mV mV
V_{BE} (sat)	Base-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		700 900		mV mV
V_{BE} (on)	Base-Emitter On Voltage	V_{CE}=5V, I_C=2mA V_{CE}=5V, I_C=10mA	580	660	700 720	mV mV
f_T	Current Gain Bandwidth Product	V_{CE}=5V, I_C=10mA, f=100MHz		300		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		3.5	6	pF
C_{ib}	Input Capacitance	V_{EB}=0.5V, I_C=0, f=1MHz		9		pF
NF	Noise Figure : BC546/547/548 : BC549/550 : BC549 : BC550	V_{CE}=5V, I_C=200μA f=1KHz, R_G=2KΩ V_{CE}=5V, I_C=200μA R_G=2KΩ, f=30~15000MHz		2 1.2 1.4 1.4	10 4 4 3	dB dB dB dB

h_{FE} Classification

Classification	A	B	C
h_{FE}	110 ~ 220	200 ~ 450	420 ~ 800

Rev. A2, August 2002

9.5 Output Characteristics of BJT

Typical Characteristics

BC546/547/548/549/550

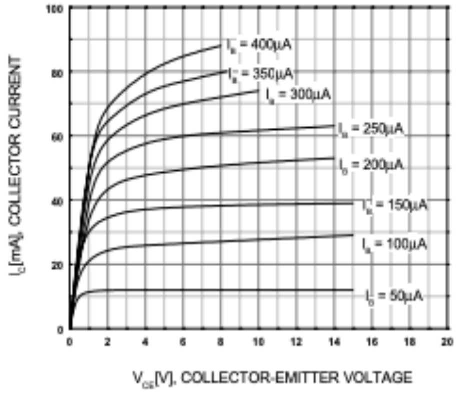


Figure 1. Static Characteristic

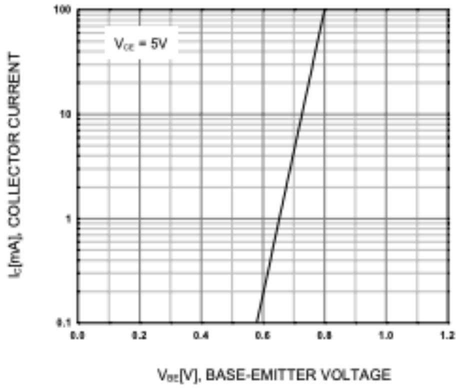


Figure 2. Transfer Characteristic

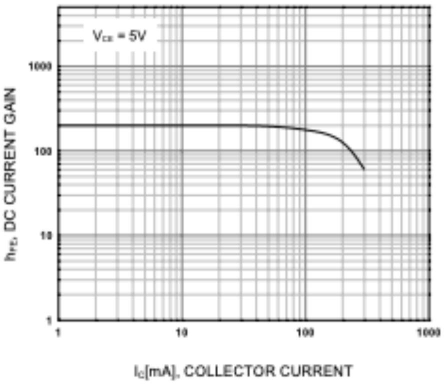


Figure 3. DC current Gain

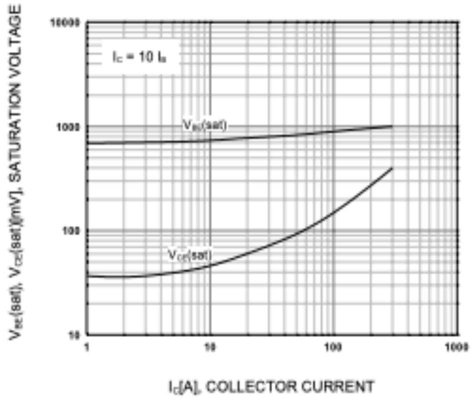


Figure 4. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

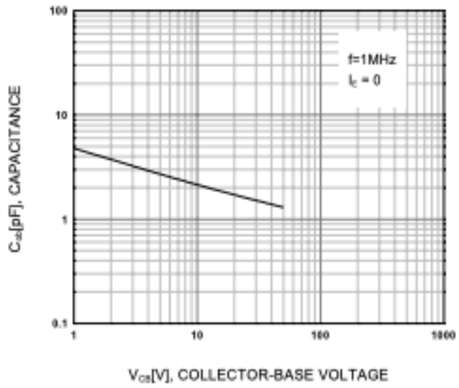


Figure 5. Output Capacitance

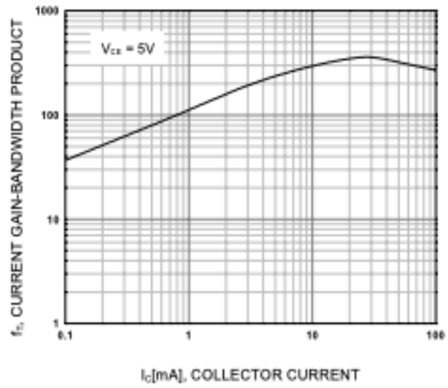


Figure 6. Current Gain Bandwidth Product

Rev. A2, August 2002