CMPE 263 ELECTRONIC CIRCUITS PROJECT

PROJECT REPORT

Project No: 4

BJT-Based Comparator

Group 2

Submitted by:

Oussama Tanfouri(CE)

Léa Hijazi(CE)

Muhammad Izaan Ul Haque(CE)

Instructor

Feza Kerestecioğlu

Mentors

Selçuk Öğrenci

Taner Arsan

Teaching Assistants

Umut İlhan Beyaztaş

Sedanur Özdamar

TABLE OF CONTENTS

1 INTRODUCTION

The main focus of this project is the analysis of a BJT-based comparator circuit through the study and implementation of concepts and processes such as the microphone preamplification circuit of an internal communication system.

A BJT or Bipolar Junction Transistor circuit is an electronic circuit employing a BJT to amplify and/or switch electrical signals.

These circuits are formed primarily of three regions, an emitter, a base, and a collector, they can be configured to perform different operations such as signal amplification, voltage regulation, or current switching [4].

Over the course of this project, comparator circuits were broadly studied in order to determine the corresponding output signals with voltage input, viewed via oscilloscope, and measured with a multimeter.

The project includes analyzing the circuit operation, implementing the circuit, verifying its operation, and comparing the experimental results with theoretical expectations. This report outlines the process, outcomes, and framework of the project, including circuit analysis, experimental procedures, results, and conclusions.

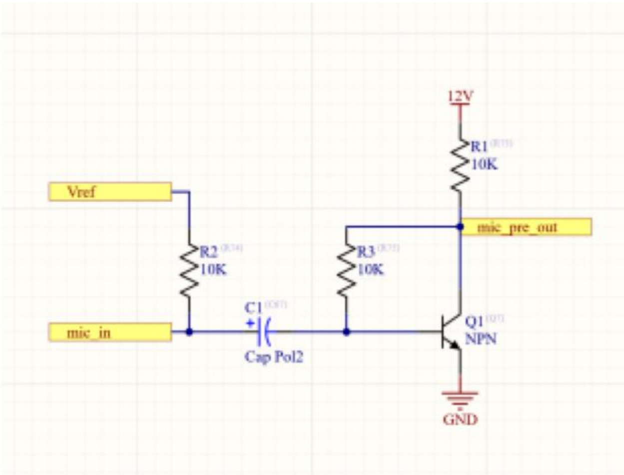

Figure 1.1 Microphone preamplification circuit of an internal communication system

1.1 Objectives

The main objectives of this project were to analyze and explain the operation of a BJT-based comparator circuit, implement and test the circuit, and compare the experimental results with theoretical values.

The focus was on understanding how the circuit produces a ‘high’ signal when the output of the preamplification circuit (mic_pre_out) exceeds a preset threshold.

1.2 Outline

This report will include a detailed analysis of the BJT-based comparator circuit. It starts with a theoretical overview of the circuit, explaining its operation and the relationship between its components.

The Experimental Data and Results section will describe the setup, explain the measurements taken, then outline the implementation process, and compare experimental results with theoretical values.

The Discussions section will analyze the experiment, compare the data, and discuss any issues or errors encountered.

Lastly, the conclusion will summarize the results and insights gained from the project.

1.3 Materials used

The following materials and software were used during the execution of our project:

- Breadboard
- 8 resistors (100k, 10k, 1k, 1k, 0.9k, 1.5k)
- NPN Transistors (2N3903/4)
- Multimeter
- Oscilloscope
- Signal generator (to apply a 1kHz sinusoidal input signal)
- Power supply
- Jumper wires

2 CIRCUIT ANALYSIS

2.1 Circuit Components and Parameters

The circuit studied is the BJT-Comparator circuit, which consists of six main resistor components and two transistors. Two of the unknown resistor values were calculated using voltage divider formulas.

The four known resistors are R_1, R_2, R_3,R_4. The two unknown resistors calculated are R_5, R_6.

The two transistors are npn type of model 2N3903/4.

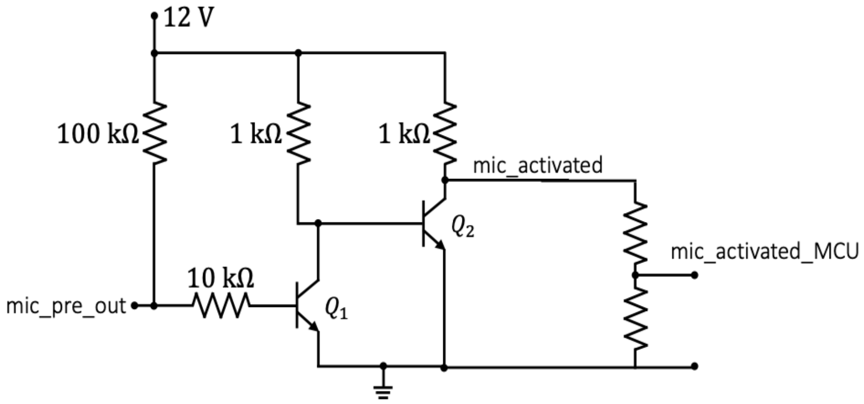

Figure 2.1.1 The Comparator Circuit

Fi

Table 2.1.2 Table of components and their function in the circuits studied.

Component Type	Component Abbreviation	Component Value
Resistor	R1	100k Ω
Resistor	R2	10k Ω
Resistor	R3	1k Ω
Resistor	R4	1k Ω
Resistor	R5	3.3k Ω
Resistor	R6	1.5k Ω
Transistor	Q1	-
Transistor	Q2	-

2.2 Circuit Characteristics

As seen in figure 2.1.1 the circuit studied is the BJT-Comparator circuit, the configuration of the circuit is such that it is suitable for threshold detection as needed for a microphone.

This Circuit provides the capability to transition between High and Low output states depending on the small changes of voltage from the microphone amplifier.

To ensure appropriate design of the circuit, specific resistors are carefully chosen, and the characteristics of Saturation and Cut-off are implemented by the use of transistors to navigate between High and low-output states.

2.2.1 Power Source and Voltage

Three different Voltage Sources are used in this circuit, a stable supply of 12V of DC Voltage is applied to the circuit.

Additionally, 0.4V and 9V DC Voltage are supplied to the circuit at the respective output states of Low and High.

Lastly, An AC Voltage generator was used during the project, the source has a 1kHz sinusoidal signal with a peak-to-peak magnitude of 10V and a DC offset of 5V.

$$Vin\ (t)=5+10\sin(2\pi\cdot 1000\cdot t)$$

2.2.2 BJT – Comparator Circuit Analysis

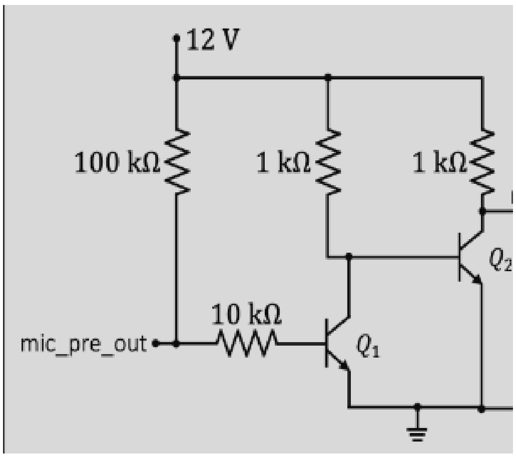

Figure 2.2.1 First Half of the circuit

As seen from the figure 2.2.1 above the first circuit is a BJT-Comparator circuit but without the AC Supply and R_5 and R_6 as that acts as the simulated input of dynamic sound system used in real life.

The figure above shows six components, three resistors are connected in parallel (R_1, R_3 and R_4) and one resistor (R_2) connected from *mic_pre_out* and R_1 to the base of transistor (Q_1) while R_3 is connected to the collector of Q_1 and base of Q_2. R_4 is connected to the collector of Q_2 and the emitter of both Q_1 and Q_2 is connected to the ground.

It is vital to mention that DC Voltages was supplied to the circuit from *mic_pre_out,* of 0.4V and 9V respectively, it represents the Second Supply to the circuit which is used to transition it between High and Low states.

Furthermore, the Voltage between Collector and Emitter (V_{CE}) of each transistor is measured to ensure the appropriate implementation of the circuit and understand when and which transistors go to state of “Saturation” and “Cut-off”. It is represented by the equation:

$$\mathbf{V_{CE} = V_C - V_E}$$

2.2.3 Complete Circuit Setup and Elements

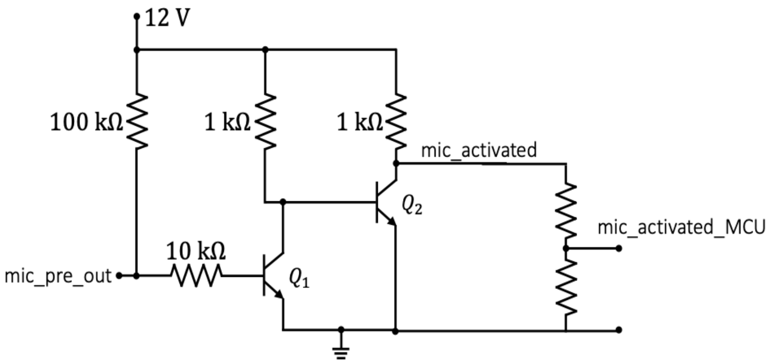

Figure 2.2.2 Completed BJT-base Comparator circuit

As seen from the figure 2.2.2 above, the completed circuit is a BJT-Comparator circuit with eight components, six resistors R_1, R_2, R_3 ,R_4 , R5 and R6, two 2N3903/4 transistors Q_1 and Q_2, resistors R_1, R_3 and R_4 are in parallel, with R2 connected from *mic_pre_out* and R_1 to the base of Q_1, while R3 is connected to the base of Q2 and collector of Q1 and R4 is connected to the collector of Q2. Two new resistors are added in parallel to the transistors and connected from R4. The two new resistors are R5 and R6, which is connected to AC voltage generator to act as a simulated input from a microphone.

It is to be noted that the two new resistor values were determined from the concept of Voltage Divider. The resistor connected through the AC Voltage supply was assumed to be 1.5kΩ and the second resistor's value was calculated.

The formula used for the calculations was:

33V = (R6/1kΩ +R6+R5)

This equation was re-arranged and simplified, by assigning the value of 3.3kΩ to R5.

2.3 Calculation of Resistor Values

Throughout the report, the following formula was used to calculate y values:

$$3.3V = \frac{x}{1k + y + x} \times 12V$$

Assuming x = 1.5 based on the resistor value in the circuit, y was retrieved by plugging in 1.5 as the value of x in the given equation.

$$3.3V = \frac{x}{1k + y + 1.5} \times 12V$$

$$3.3 + 3.3y + 4{,}95 = 18$$

$$8.25 + 3.3y = 18$$

$$y = \frac{18 - 8.25}{3.3}$$

For resistor values not specified in the guidelines, we derived their values through the following formula: $\frac{R2}{R2+R1+1} \times 12 = 3.3.$

R1 and R2 were 100kΩ and 10kΩ resistors respectively.

2.4 Measurements of Sinusoidal input

Figure 2.4.1Mic-Activated (Blue) & 1Mic-Activated MCU (Pink)

A three-channel oscilloscope was used to assess the sinusoidal input, the output from the preamplifier, and the digital output from the comparator interfacing with the microcontroller, in order to assess the functionality of the circuit.

The sinusoidal input was directed to channel 1 (Yellow) of the oscilloscope that was connected to the AC input source.

An analysis of the waveform was conducted in order to determine key parameters such as frequency (1 kHz), peak-to-peak voltage (Vpp), and the DC offset (5 V).

Through this analysis its was confirmed that the input signal adhered to the specified requirements in the guidelines, providing a 10 V peak-to-peak sinusoidal waveform with the appropriate DC offset.

Channel 2 (Blue) was connected to the digital output of the comparator circuit; this output is regulated by the microcontroller (MCU) within the system.

Channel 2 shows the high and low voltage levels that correspond to the threshold crossings of the established sinusoidal input signal.

The output alternated at the expected timing, transitioning between 3.0 to 3.3 V (high) and below 0.3 V (low).

Furthermore, the timing of the transitions, in addition to the pulse width, were thoroughly analyzed to confirm their alignment with the threshold crossings of the sinusoidal wave.

Lastly, channel 3 (Purple) was connected to the microphone-activated section of the circuit. This channel showcased the digitally generated output that was triggered by the microphone.

The signal resulting from the microphone input was amplified and processed before the switch between high and low states, this prepared the data for further comparison and processing.

Via monitoring of channel 3, it can be established that the microphone signal is accurately digitized and is synchronized with the sinusoidal input.

3 EXPERIMENTAL DATA AND RESULTS

3.1 Experimental Setup and Procedure

After all the appropriate components and tools were selected and all appropriate connections were made, the experiment began by verifying the value of the voltage V_{ce1} for the first part of the circuit. Throughout the experiment, one power source, a stable supply of 12V of DC was maintained.

Based on the transistor's regions of the input voltages, V_{CE} values were calculated for Q_1 and Q_2.

For $V_{mic\_pre\_out}$ = 0,4 V, Q_1 was in the cut-off region since V_{BE} < 0,65V and the value of VCE1 was close to the value of V_{CC} and thus V_{CE} was nearly equal to 0.9V.

Q_2 was in saturation due to the absence of base current in Q_1, likewise when $V_{mic\_pre\_out}$ was equal to 9V, Q1 was in saturation as VBE was superior to 0.65V and VCE1 was approximately 0.04V, indicating a saturation voltage.

For Q2 the high voltage present at the Q1 collector impeded base current flow to Q2 and thus placing I in the cut off region and VCE2 was approximately equal to VCC as a result of, with VCE2 being approximately equal to 12V.

3.2 Experimental Result Analysis

These measurements aligned with the expected behavior of the circuit, demonstrating the changes in voltage between the two transistors as they switched states based on the input signal and the thresholds for the high and low states.

3.3 Theoratical Results and Analyiss

To derive theoretical voltage and current values the following calculations were realized:

For Q1 and a $V_{mic\_pre\_out}$ voltage equal to 0.4V:

$V_{BB\ on}$ = 0.05V

$$\mathrm{V}_{BB} < 0.4\mathrm{V} \rightarrow \mathrm{V}_{BB} < 0.05\mathrm{V} \rightarrow \text{cutt off Q1}$$

$$Q1: I_B,\ I_{E1}, I_{C1} = 0\ mA$$

For Q2 and a $V_{mic\_pre\_out}$ voltage equal to 0.4V:

$$V_{BB\ on} = 0.05\ V$$

$$V_{CE} = 0.2\ V$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{12 - 0.05}{1} = 11{,}35\ mA$$

$$I_C = \frac{Vc - V_{CE}}{R_C} = \frac{12 - 0.2}{1} = 11{,}8\ mA$$

$$I_E = I_B + I_C = 11{,}35\ mA + 11{,}8 mA = 23{,}15\ mA$$

For Q1 and a $V_{mic\_pre\_out}$ voltage equal to 9V:

$$V_{BB} = 9\ V$$

$$V_{BB} = mic\_activated > 9V$$

$$V_{BC} = 0.65\text{y}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{9 - 0.05}{10} = 0{,}835\ mA$$

$$V_{CE} = 0{,}12V$$

$$I_c = \frac{V_{cc} - V_{cE}}{R_c} = \frac{12 - 0.2}{1} = 11{,}8\ mA$$

$$I_E = I_B + I_C = 0{,}835\ mA + 11{,}8 mA = 12{,}635\ mA$$

For Q2 and a $V_{mic\_pre\_out}$ voltage equal to 9V:

$$V_{CE} = Q_1 = V_{BE} > 0{,}2V$$

$$V_{BB\ on} > V_{BE} \rightarrow 0{,}65V > 0{,}2V \rightarrow Cut\ off$$

Thus, it can be established that:

$$I_E = I_B = I_C = 0\ mA$$

3.4 Comparison of Theoratical and Experimental results

In this segement of the report we relied on the following formula to calculate the margins of error between experimental measurements and theoratical calculations:

$$Error = \frac{Theoratical\ result - Experimental\ result}{Theoratical\ result} \times 100$$

3.4.1 Comparison of Theoratical and Experimental Voltage Values

The below table will offer a comparison between theoratical and experimental $V_{CE:}$

Table 3.4.1 Table comparing experimental and theoretical values of V_{BE}

V mic_pre_out	**0.4 V**	**9 V**
Q_1	Cut-off	Saturation
Q_2	Saturation	Cut-off
Theoretical Q_1 V_{CE} Value	0.9 V	0.04 V
Theoretical Q_2 V_{CE} Value	0.01 V	12 V
Experimental Q_1 V_{CE} Value	0.804 V	0.021 V
Experimental Q_2 V_{CE} Value	0.027 V	11.7 V
Q_1 Error	4,3 %	25%
Q_2 Error	147%	0.4%

As observed from the table above, theoretical calculations largely conformed with experimental measurements with only slight V_{CE} voltage, except for the Q2 transistor where this transistor reached saturation and a significant error of 147% was observed.

3.4.1 Comparison of Theoratical and Experimental Current Values

The table below will display the previously calculated current values of I_B, I_C, and I_E:

Table 3.4.2 Table of theoretical current values

Transistor	Mic_pre_out	I_B mA	I_C mA	I_E mA
Q1	0,4 V	0	0	0
Q2	0, 4V	11,35	11,8	23,15
Q1	9 V	0,835	11,8	12,635
Q2	9 V	0	0	0

Table 3.4.3 Table of experimental current values

Transistor	Mic_pre_out	I_B mA	I_C mA	I_E mA
Q1	0,4 V	0	0	0
Q2	0, 4V	11,17	10,7	22,17
Q1	9 V	0,81	11,79	12,7
Q2	9 V	0	0	0

Table 3.4.4 Table showing the margin of error between experimental and theoretical values

Error Margin	Mic_pre_out	I_B mA	I_C mA	I_E mA
Q1	0,4 V	0	0	0
Q2	0, 4V	1.59%	4.29%	4.23%
Q1	9 V	2.99%	0.08%	0.51%
Q2	9 V	0	0	0

As we can see from table 3.4.4, it can be established that experimental measurements largely matched theoretical calculations with the highest margin of error being 4.29% for Q2 I_C value.

4 ERROR HANDLING

4.1 Error Analysis

To fully Comprehend differences and variations between theoretical and experimental values, error analysis is crucial.

In both circuits constructed throughout this project differences between theoretical and measured voltages can occur due to various reasons

4.1.1 Sources of Error

Common sources of error include resistor tolerance (±1% or ±5%), inaccuracies in the multimeter, environmental factors like temperature and humidity, and faulty wires or components.

4.1.2 Mic_activated_MCU Error

The mic_activated_MCU was giving a value of 12V instead of the expected range between 3.0V and 3.3V for the high signal.

This error could be caused by improper component connections, incorrect voltage threshold, or an issue with the comparator circuit.

4.2 Outcome in Tackling Error

After correcting the error, by checking component connections and adjusting the circuit, the voltage readings for mic_activated_MCU were corrected to become the expected range of 3.0V to 3.3V range.

5 DISCUSSIONS

This project focused on the analysis and implementation of a BJT-based comparator circuit for threshold detection in a microphone preamplification system. The circuit's ability to switch between high and low output states based on input voltage was successfully demonstrated. Experimental results were mostly aligned with theoretical expectations, giving validity to the experimental arrangement.

The comparator circuit effectively transitioned between states when tested with DC input voltages of 0.4V and 9V, simulating low and high signals, respectively. At 0.4V, the circuit exhibited a low output state, with VCE1 approx 0.804V and VCE2 approx 0.21V , indicating that transistor Q1 was in cutoff and Q2 was in saturation. Conversely, at 9V, the circuit transitioned to a high output state, with VCE1 approx 0.78V and VCE2 approx 0.021V, showing that Q1 had entered saturation while Q2 was in cutoff.

The inclusion of an AC input signal further validated the circuit's dynamic behavior. Using a 1 kHz sinusoidal input, the output successfully alternated between high and low states. To meet the specified VPP = 3.16V requirement, additional resistors (470Ω and 910Ω) were introduced, fine-tuning the circuit to achieve accurate signal conditioning.

Key design considerations included the careful selection of NPN transistors (2N3903/4) for their reliability in small-signal applications and the calculated resistor values, such as R5 = 3.3k Ω and R6 = 1.5k Ω, derived from voltage divider principles. These choices ensured proper biasing and enabled precise threshold detection.

Despite the strong alignment between theoretical and experimental results, minor deviations were observed. For example, a 4.23% error was noted in ie of Q2 at V mic_pre_out = 0.4V , likely caused by resistor tolerances and environmental factors. Measurement noise from external influences also contributed to slight discrepancies. Future improvements could involve the use of higher-precision components and enhanced measurement techniques to minimize errors.

Challenges such as faulty resistors, wiring issues, and fluctuating oscilloscope readings were resolved through testing and adjustments. Overall, the project effectively demonstrated the operation of the BJT-based comparator circuit, validating its theoretical design and showcasing its practical utility in signal detection applications.

6 CONCLUSIONS

The project successfully demonstrated the principles and practical applications of BJT-based comparator circuits through theoretical analysis, experimental work, and simulation. The main concepts such as voltage dividers, transistor saturation, and cutoff states were analyzed and implemented to achieve the project's objectives.

By studying and implementing the circuit, the behavior of output signals in response to input voltage variations was observed and verified using an oscilloscope and multimeter. Resistor values were determined for proper circuit operation, and for an accurate threshold detection for the microphone’s preamplification.

7 REFERENCES

[1] Hambley, A. R. (2024). Electrical engineering: Principles and applications (7th ed.). Pearson Education

[2] Kerestecioğlu, F. (2024). CMPE 263 Lecture Notes. Kadir Has University.

[3] Electronics Tutorials. (2019). Transistor Basics: Bipolar Junction Transistor (BJT). Retrieved from https://www.electronics-tutorials.ws/transistor/tran_2.html

[4] LibreTexts Engineering. (2021). Bipolar Junction Transistor. Retrieved from https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Materials_and_Devices/Bipolar_Junction_Transistor