Lab Report 2: Amplifiers and Comparators

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DECLARATION

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Abstract

The behaviour of analog circuits built with bipolar junction transistors and operational amplifiers were examined in this experiment. Understanding the impact of emitter bypass capacitors on amplifier gain, the switching capacity of comparators to input voltage levels, and the effect of negative feedback in inverting amplifiers were the main objectives. LM741 op-amps and BC109 transistors were used in the circuit's development, and a waveform generator and digital oscilloscope were used to measure the signals. Despite small measurement differences due to instrument tolerance and human error, the actual results closely matched theoretical predictions, verifying fundamental ideas of analog circuit operation.

Aims

The main goal of this report is to analysis of analog circuit performance are to examine switching behaviour in comparators, gain changes in BJT amplifiers with and without emitter bypass capacitors, and negative feedback in inverting amplifiers.

Introduction

Analog circuits are crucial for processing continuous signals in a wide range of electronic applications. Three fundamental analog components are examined in this experiment: the common-emitter BJT amplifier, comparator, and inverting amplifier. Systems like voltage level detectors, signal conditioners, and audio amplifiers depend on these parts. The experiment aims to connect theoretical understanding with actual circuit behaviour and performance by applying these circuits into practice and testing them.

Background

In the design of analog circuits, operational amplifiers, sometimes known as op-amps, are high-gain voltage amplifiers. In an inverting amplifier, the resistor ratio determines the gain, and the output is opposite of the input:

$$A_v = -\frac{R_f}{R_{in}}$$

Op-amp circuits known as comparators are designed without feedback and change their output states in response to a comparison between an input signal and a reference value. They are crucial for analog-to-digital conversions and control systems.

Transistor biasing is how BJT amplifiers operate in the active area. An emitter bypass capacitor efficiently shorts the emitter resistor for AC signals, increasing AC gain. Without it, emitter resistance rises, reducing gain. The gain in AC voltage is approximately:

$$A_v = \frac{R_C}{R_E}$$

when the resistance of the internal transistor is very low.

Ideal op-amp behaviour and a constant V_{BE} for the BJT of 0.7 are assumed. Because of actual component tolerances, slight variations are anticipated.

Equipment

- 1 × Waveform generator
- 1 × Digital Storage Oscilloscope (DSO) and probes
- 1 × LM741 Op amp IC
- 2 × 1 kΩ resistors
- 1 × 10 kΩ resistor
- 1 × 1.2 kΩ resistor
- 1 × 20 kΩ resistor
- 1 × 200 Ω resistor
- 1 × 3.3 kΩ resistor
- 3 × 4.7 µF/50V electrolytic capacitors
- 1 × BC109 NPN transistor

Procedure

1. Inverting amplifier

1. Implement the given inverting amplifier circuit using the LM471 op amp.
2. Connect a $\pm 12V$ DC power supply to the circuit.
3. Apply a 1 KHz , $20m$Vp-p sinusoidal signal to inverting input through 1 k Ω resister.
4. Connect feedback resistor of 10kΩ between the output and inverting input.
5. Ground the non-inverting input
6. Observe the output waveform on DSO.
7. Calculate the voltage gain $\boldsymbol{V_{out}/v_{in}}$
8. Remove the 10kΩ feedback resistor
9. Note the modification in the output waveform.

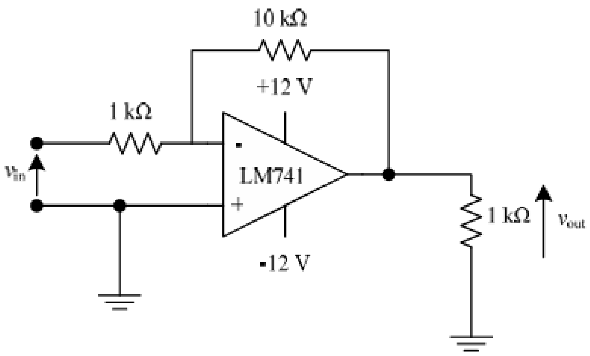

Figure 1 Inverting Amplifier

2. Comparator

1. Build the given circuit shown in figure 2 using the LM741 op-amp.
2. Connect a $\pm 12V$ DC power supply to the circuit.
3. Apply a 1 KHz , $5V_{\ p-p}$ sinusoidal signal with a +2.5V offset to the inverting input.
4. Observe the output waveform on DSO.

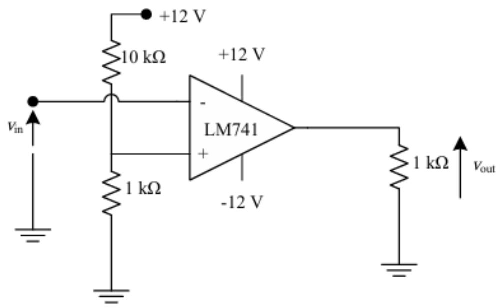

Figure 2 Op amp comparator

3. DC biasing of a BJT amplifier

1. Build voltage-divider biased amplifier shown in figure 3 using a BC109 transistor.
2. Use 20 kΩ and 3.3 kΩ for the base voltage divider.
3. Then use 1.2 kΩ and 200 Ω resistor for the collector and emitter respectively.
4. Connect a 4.7 µF capacitor across the emitter resistors.
5. Connect + 12 V DC power supply to the circuit.
6. Measure DC bias values: I_B, I_C , V_{BE}, V_{CE} and record them.
7. Apply a 1 KHz 20m V_{p-p} sinusoidal signal to V_{in}.
8. Observe the output waveform on DSO.
9. Remove the emitter bypass capacitor C_E.
10. Record the output waveform and compare voltage gains in both scenarios using the formula $\boldsymbol{V_{out}/v_{in}}$

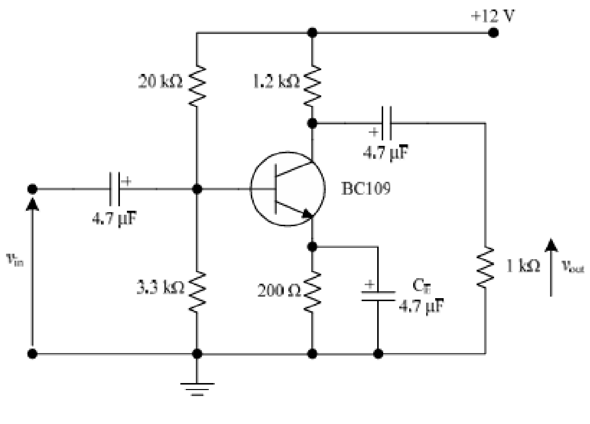

Figure 3 BJT Amplifier

Results and Observations

Pre-laboratory work

1. Voltage gain of the inverting amplifier = -10
2. a. V_{CE} = 5 V
   b. V_{BE} = 0.7 V
   c. I_B = 0.05 mA = 50 μA
   d. I_C = 5mA

3.1 Inverting Amplifier

Voltage gain of the inverting amplifier = -10

Observation: This value is assigned a negative sign in mathematics since the waveforms that were produced were inverted.

3.2 Comparator

Observations: When V_{in} crosses V_{ref} , the output changes phrase and the behaviour is consistent with the ideal comparator.

3.3 DC Biasing of a BJT amplifier

DC Bias point values:

a. V_{CE} = 1.90 V

b. V_{BE} = 0.65 V
c. I_B = 4.67 mA
d. I_C = 29.7 μA

Voltage gain with R_E in place = 5
Voltage gain with R_E removed =2.5

Observations: A higher voltage gain was achieved by effectively grounding the emitter resistor for AC signals when the emitter bypass capacitor was included. The output amplitude dropped by half when the capacitor was removed, which also caused the voltage gain to decrease. The expected effect of the capacitor on amplifier performance was confirmed by this noticeable change in waveform height.

Calculations

Pre Laboratory:

Voltage gain (Av) = $\frac{V_{out}}{V_{in}}$ = $\frac{-10\ k\Omega}{1\ k\Omega}$ = -10

Explanation: The experimental result is consistent with the theoretical voltage gain of -10, which is achieved by using a 1 kΩ input resistor (R_{in}) and a 10 kΩ feedback resistor (R_f). An output that is inverted is indicated by the negative sign.

Base voltage (V_{BB}):

$$V_{BB} = \left(\frac{R_2}{R_2+R_1}\right) \times V_{CC}$$

$$= \left(\frac{3.3\ k\Omega}{3.3\ k\Omega + 20\ k\Omega}\right) \times 12\ V$$

=1.67 V

≈ 1.7 V

Base-Emitter voltage (V_{BE}):

V_{BE} = 0.7 V

$V_E = V_{BB} - V_{BE}$

= 1.7 V – 0.7 V

= 1.0 V

Emitter current (I_E):

$$I_E = \frac{V_E}{R_E} = \frac{1.0\ V}{200\Omega} = 5.0\ \text{mA}$$

Assuming β= 100: $I_C \approx I_E = 5.0$ mA

$$I_B = \frac{I_C}{\beta} = \frac{5.0\ mA}{100} = 0.05\ \text{mA} = 50\ \mu A$$

Collector resistor voltage drop (V_{RC}) :

$$V_{RC} = I_C \times R_C$$

= 5.0 mA × 1.2$k\Omega$

= 6.0 V

Collector -Emitter voltage (V_{CE}) :

$V_{CE} = V_{CC} - V_{RC} - V_E$

=12 V – 6V – 1V

= 5.0 V

1.Inverting Amplifier gain:

V_{out} = 200mV

$V_{in} = 20mV$

Voltage gain = $\frac{V_{out}}{V_{in}} = \frac{200mV}{20mV}$ = - 10, as waveforms were inverting

2. Op-Amp Comparator:

Using voltage divider with 1 kΩ and 10 kΩ resistors powered by +12V

Voltage Reference (V_{ref}) = $(\frac{1\ k\Omega}{1\ k\Omega + 10\ k\Omega}) \times 12\ V$

$= \frac{1}{11} \times 12\ V$

= 1.09 V

Explanation: When the comparator changes, the cutoff value is set by the reference voltage at the non-inverting terminal. When the input sine wave exceeds 1.09 V, the output shifts.

3 .DC Biasing of a BJT amplifier:

Voltage gain $\boldsymbol{with\ R_E}$ in place:

V_{out} = 100mV

V_{in} = 20mV

Voltage gain = $\frac{V_{out}}{V_{in}} = \frac{100mV}{20mV}$ = **5**

Voltage gain $\boldsymbol{without\ R_E}$ in place:

V_{out} =50mV

V_{in} = 20mV

Voltage gain = $\frac{V_{out}}{V_{in}} = \frac{50mV}{20mV}$ =2.5

Discussion

Figure 4: Waveform of inverting op-Amp Configuration

Figure 4 shows the inverting amplifier's input and output waveforms. The input signal is represented by the yellow waveform, and the output by the green waveform. As expected in an inverting amplifier configuration, the output signal is opposite of the input. Voltage measures for each waveform are displayed in the upper-left corner of the oscilloscope screen. These values are color-coded to correspond with the relevant traces for convenient identification.

Op-amp topologies come in two main varieties: inverting and non-inverting. The terminal to which the input signal is applied determines this classification. The circuit operates as an inverting amplifier if V_{in} is put to the op-amp's negative terminal. In contrast, the circuit operates as a non-inverting amplifier if V_{in} is connected to the positive terminal.

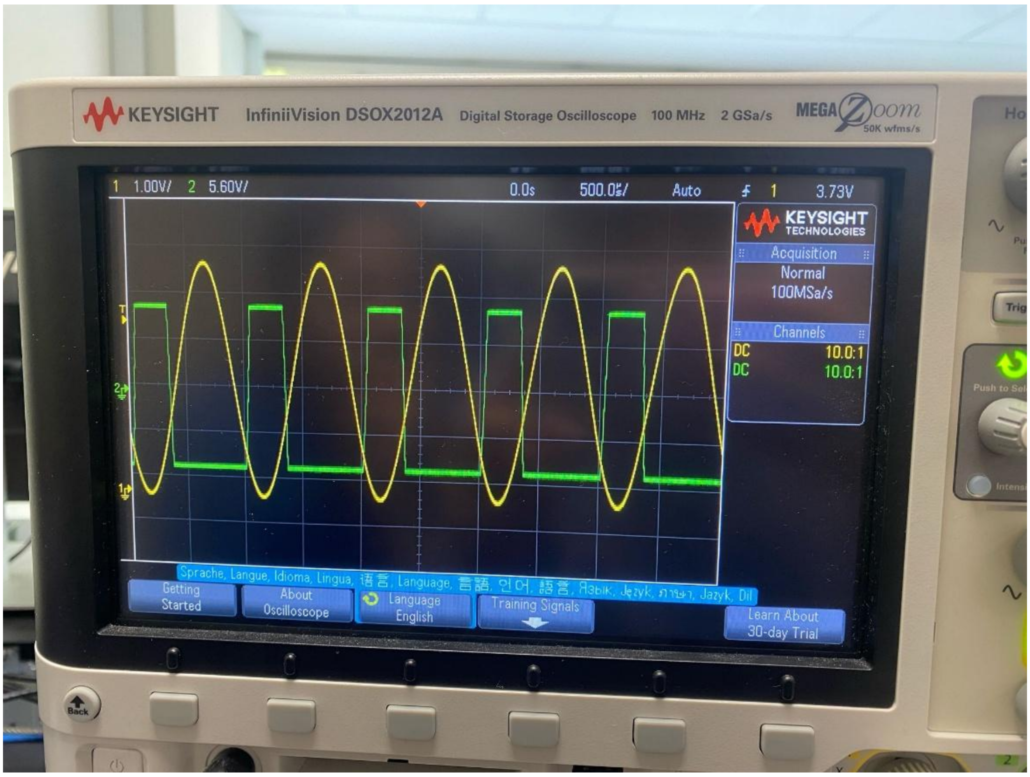

Figure 5: input and output Waveform of inverting comparator

The waveforms of an inverting comparator's input and output are shown in Figure 2. The input signal is represented by the yellow waveform, while the output is displayed by the green waveform. The comparator displays inverted behaviour when the input is applied to the op-amp's negative terminal. Every time the input signal reaches a predetermined reference voltage—in this case, roughly 1.09 V—the output changes phases due to this setup. Because of this, the output waveform shows up as a square wave that follows the input sine wave inversely.

Depending on the outcome, the comparator will either produce a high or low voltage after comparing the input signal to the reference voltage. The output jumps to a high state when the input falls below the reference, and flips to a low state when the input rises above the reference. As a result, the output signal is clear and has two levels, making the edge crossing simple to see. A square wave for the output and a sinusoidal signal for the input makes it easier to see how the comparator reacts to variations in voltage around the reference point.

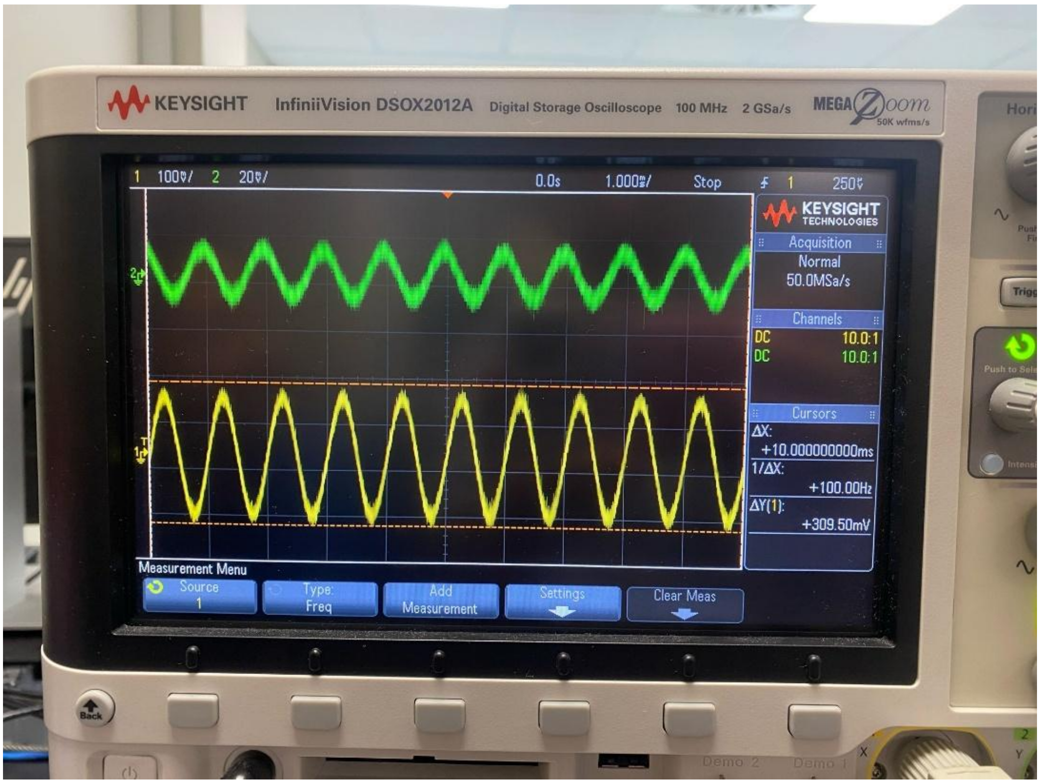

Figure 6 :Waveform of BJT amplifier

The above figure 6 displays the waveforms of BJT amplifier where the yellow waveform is the output signal, and the green one is the input signal.

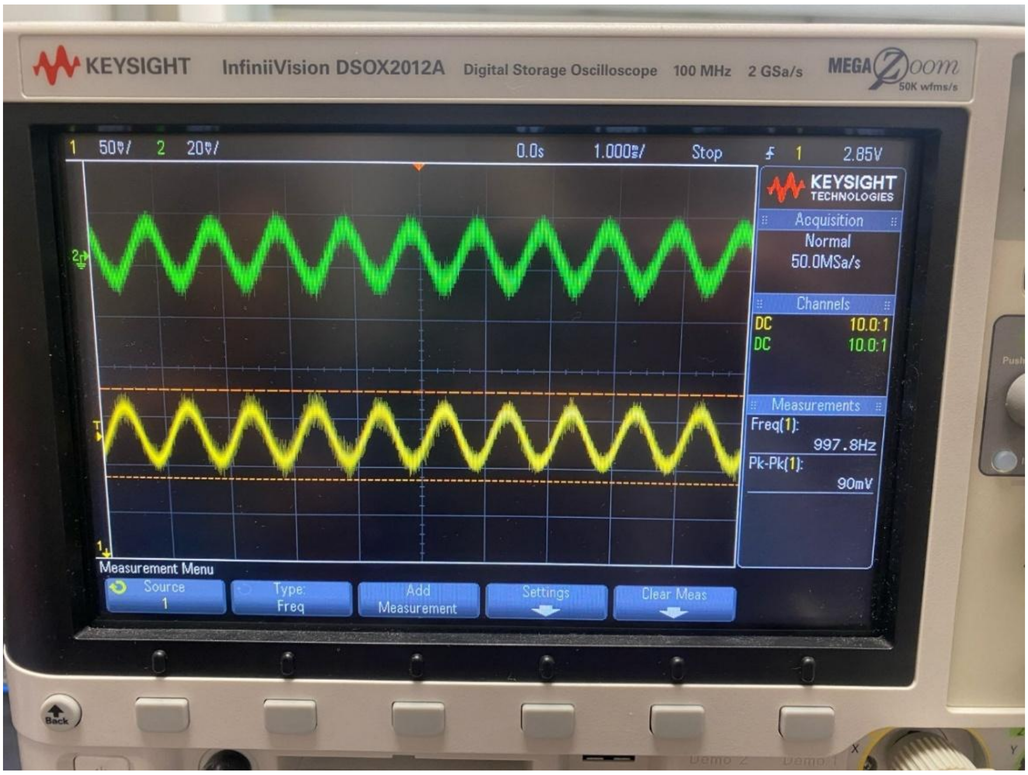

Figure 7: Waveform of BJT amplifier after removing the emitter bypass capacitor.

After removing the emitter bypass capacitor from the identical BJT amplifier circuit, the waveform displayed above was recorded. As can be seen, the output signal's amplitude has significantly decreased in comparison to the earlier state. This occurs because the emitter resistor may impact AC signals when the bypass capacitor is removed, decreasing the amplifier's total voltage gain. The gain in this case decreases to roughly 2.5, according to calculations.

There were a few variations in the measured DC bias levels, which were probably caused by small setup errors made by people or by the digital multimeter's accuracy limitations. Even still, most of the readings remained relatively near to their theoretically predicted values, especially when rounding errors are taken into consideration.

Conclusions

In conclusion, there were only minor differences between the theoretical calculations and the lab measurements, as real-world instruments and components are not ideal. Despite this, the inverting amplifier's measured voltage gains accurately matched the theoretical value, demonstrating proper circuit execution. Additionally, the comparator experiment’s waveforms and lab instructor both confirmed that the output correctly responded to changes in the input signal relative to the reference voltage. When the BJT amplifier's DC bias values were measured; two out of the four readings were approximately 93.1% accurate, while the remaining values displayed flaws due to technical and human error during measureme1nt. Overall, the experiment successfully confirmed key theoretical ideas, especially the impact of the emitter bypass capacitor on AC voltage gain, which was effectively observed and learned through hands-on testing.

References

Lecture notes.

Appendix

Nil.