
DESIGN PROJECT 3

ELECENG 2E14 – Electronic Devices and Circuits I

Section C01

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The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

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Summary

The main goal of this project is to design and test a single-transistor amplifier. The circuit is to be able to receive an input of ± 0.5 V from a $100\ \Omega$ source and provide output to a $100\ \Omega$ load with minimal loss and maximum performance. The aim was to create an analog amplifier circuit using a single BJT in a common-collector configuration, which is known for its higher performance and lower output impedance. To meet the design requirements, calculations were performed to determine the precision of the biasing, gain, and input impedance.

The circuit was simulated first using LTSpice to understand how it would function theoretically. Then the actual circuit was built and tested using the Analog Discovery 3 and WaveForms software. Quantities such as time-domain waveforms were measured, and spectral analysis was performed to ensure the amplifier was functioning well and linear at the appropriate input level. In this report, the step-by-step process of design from researching concepts to selecting parts, testing, assembling, and verifying the final output using lab tests is detailed.

What type of transistor did you choose (MOSFET/BJT)? Why?

A Bipolar Junction Transistor (BJT) was selected for this circuit because it performs better in small-signal, low-voltage applications. BJTs offer greater transconductance at the same bias current as MOSFETs, so they can deliver more voltage gain in a single-stage amplifier. BJT devices are generally more reliable and easier to work with low DC supply voltages, so they are well-suited for this one-transistor circuit.

What amplifier topology (CE/CS/CD/etc.) did you choose? Why?

A Common-Collector configuration was used. The configuration is an effective signal-buffering circuit due to the high input impedance, low output impedance, and approximately the same voltage gain. The internal impedance of the signal source is $100\ \Omega$, and the amplifier has to deal with a $100\ \Omega$ load without reducing the signal level. The CC configuration facilitates power transfer with effective impedance matching without affecting the signal. It also shows effective linearity and stability due to the local feedback from the emitter resistor. It is easier to observe the linearity between the input and output with a CC topology since the gain is equal to about 1.

What calculations did you use to determine the required component values?

1) Output Swing Requirement:

$$V_{in} = 0.2 \cdot V_T \cdot (1 + g_m R_L) \geq 0.5$$

Assuming:

$$V_T = 0.025, R_L = 100\Omega$$

Substitute :

$$0.2 \cdot 0.025 \cdot (1 + 100gm) \geq 0.5V$$

$$0.005(1 + 100gm) \geq 0.5$$

$$1 + 100gm \geq 100$$

$$gm \geq 0.99S$$

$$V_T = 0.025, R_L = 100\Omega$$

2) Attenuation Requirement:

We want total gain ≥ 0.9 :

$$\frac{gmRL}{1 + gmRL} * \frac{R_{in}}{R_s + R_{in}} \geq 0.9$$

Let:

$$gm = 0.99, R_L = 100\Omega, R_S = 100\Omega$$

Substitute:

$$\frac{99}{100} * \frac{R_1}{0.1 + R_1} \geq 0.9$$

$$0.09R_{in} \geq 0.091$$

$$R_{in} \geq 1.01k\Omega \approx 1k\Omega$$

3) Input Resistance of Amplifier

$$r_\pi = \frac{gm}{\beta} = 990100 = 0.101k\Omega$$

$$R_{in}' = r_\pi(1 + gmRL) = 0.101 \cdot (1 + 990) = 10.1k\Omega$$

Total Input Resistance:

$$R_{in} = R_1 \parallel R_2 \parallel R_{in}'$$

$$R_{in} \geq 1k\Omega$$

Parallel Resistor Condition:

$$\frac{1}{R_{in}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{10.1k\Omega}$$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{1k\Omega} - \frac{1}{10.1k\Omega} = 0.90099$$

$$R1 \parallel R2 \geq 1.11k\Omega$$

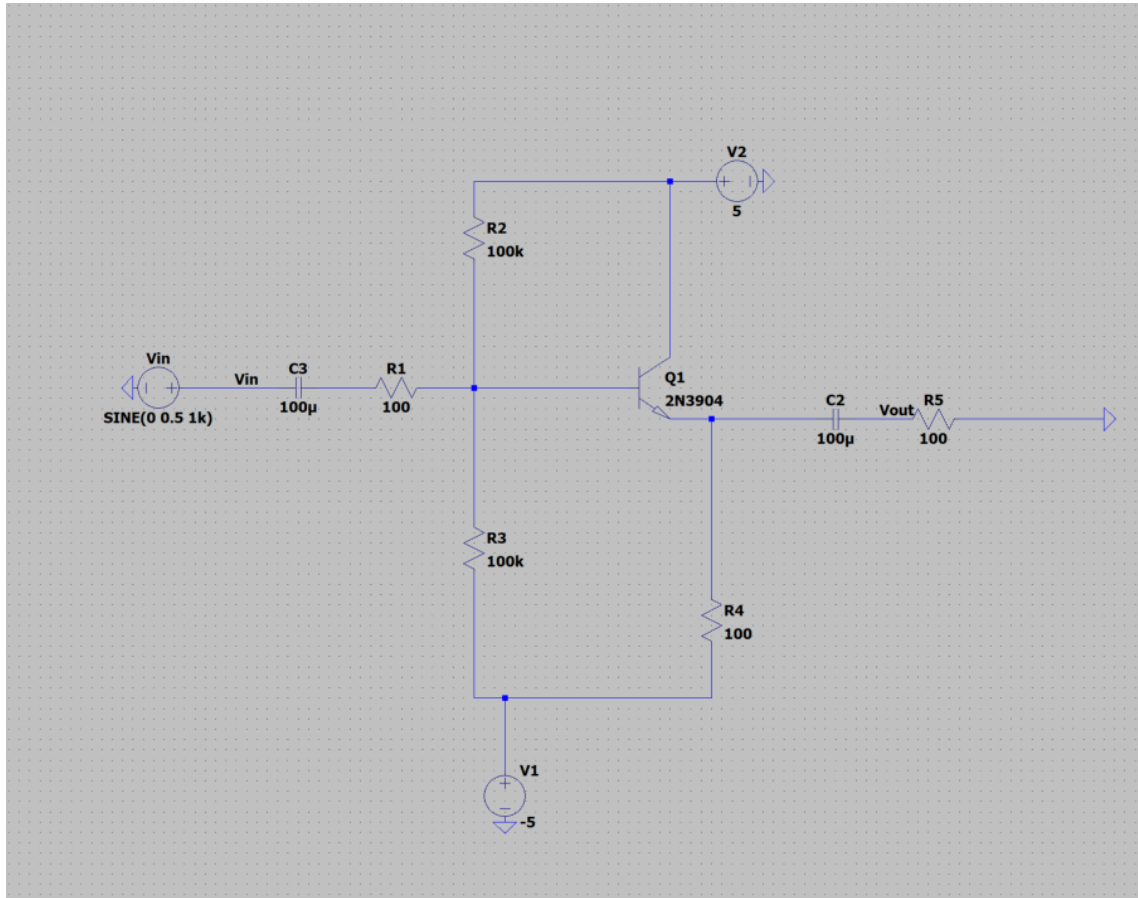


Figure 1: Circuit Schematic

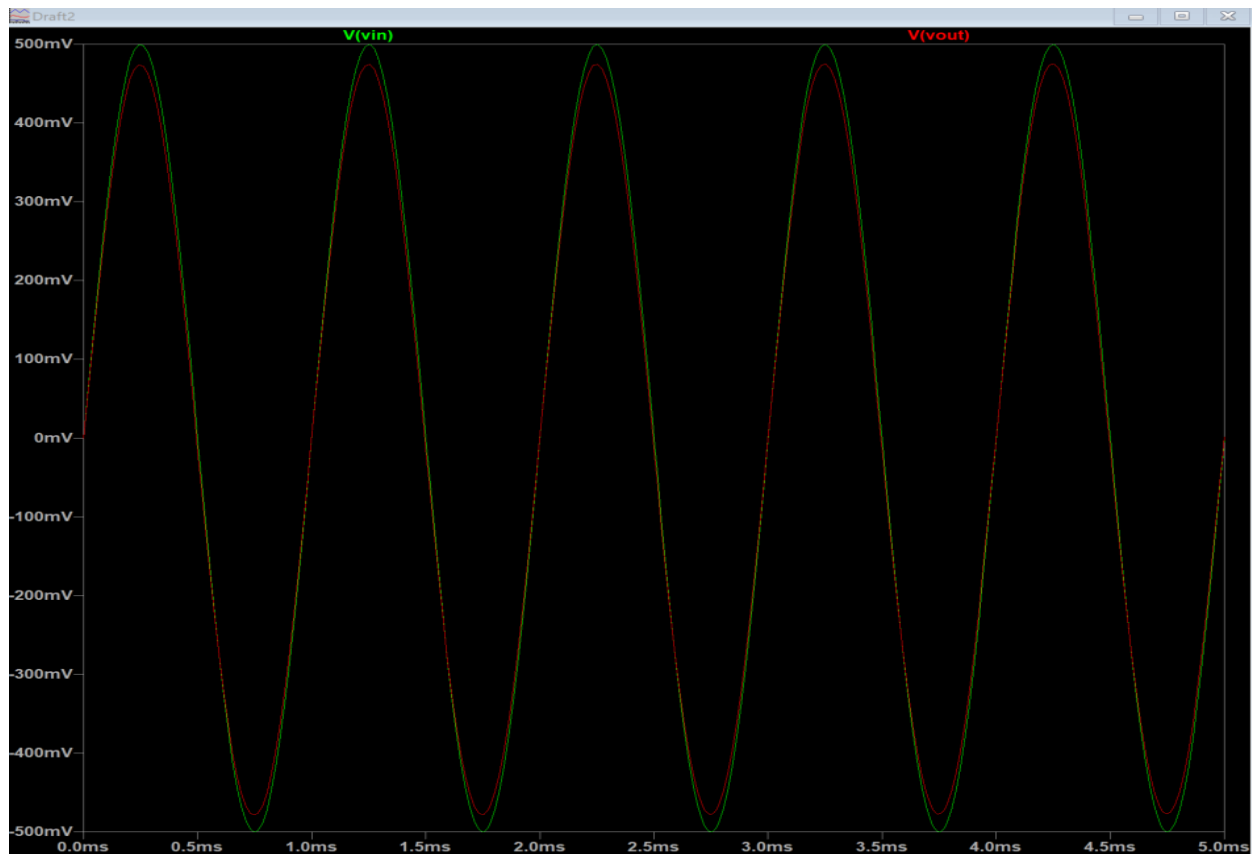


Figure 2: LTSpice Simulation for Input and Output Voltage

How did you model the transistor in the simulator you used?

I modelled my transistor using the LTSpice software. I used the 2N3904 NPN BJT for this schematic. This BJT is ideal for low signal analog applications and accurately captures real world behaviour of a BJT.

What settings did you use for each simulation (transient/dc sweep/frequency sweep/etc.)?

For each simulation, I used transient analysis with a stop time of 5ms and a timestep of 10 micro seconds. The Y-axis was set between 500 mV and -500 mV to be able to observe the full sine waves.

The overall gain determined from the simulations.

$$Gain = \frac{V_{out}}{V_{in}}$$

$$\begin{aligned}
 &= \frac{453.29 \text{ mV}}{500 \text{ mV}} \\
 &= 0.90658
 \end{aligned}$$

Since the calculated gain of 0.9066 exceeds the required minimum of 0.9, the amplifier meets the design specification and is considered effective and properly functioning

Other performance parameters determined from the simulations

One key performance parameter determined from the simulations was the input resistance which was calculated using the ratio of input voltage to input current (found using the simulation)

$$\begin{aligned}
 R_{in} &= \frac{V_{in}}{I_{in}} \\
 &= \frac{500 \text{ mV}}{47.94 \text{ uA}} \\
 &= 10.43 \text{ k}\Omega
 \end{aligned}$$

This value confirms that the amplifier has a high input resistance, an important attribute for minimizing signal attenuation from the $100 \text{ }\Omega$ source. The high input resistance allows the amplifier to pick up most of the input signal, greatly improving overall efficiency while complying with the design requirements.

Physical Circuit

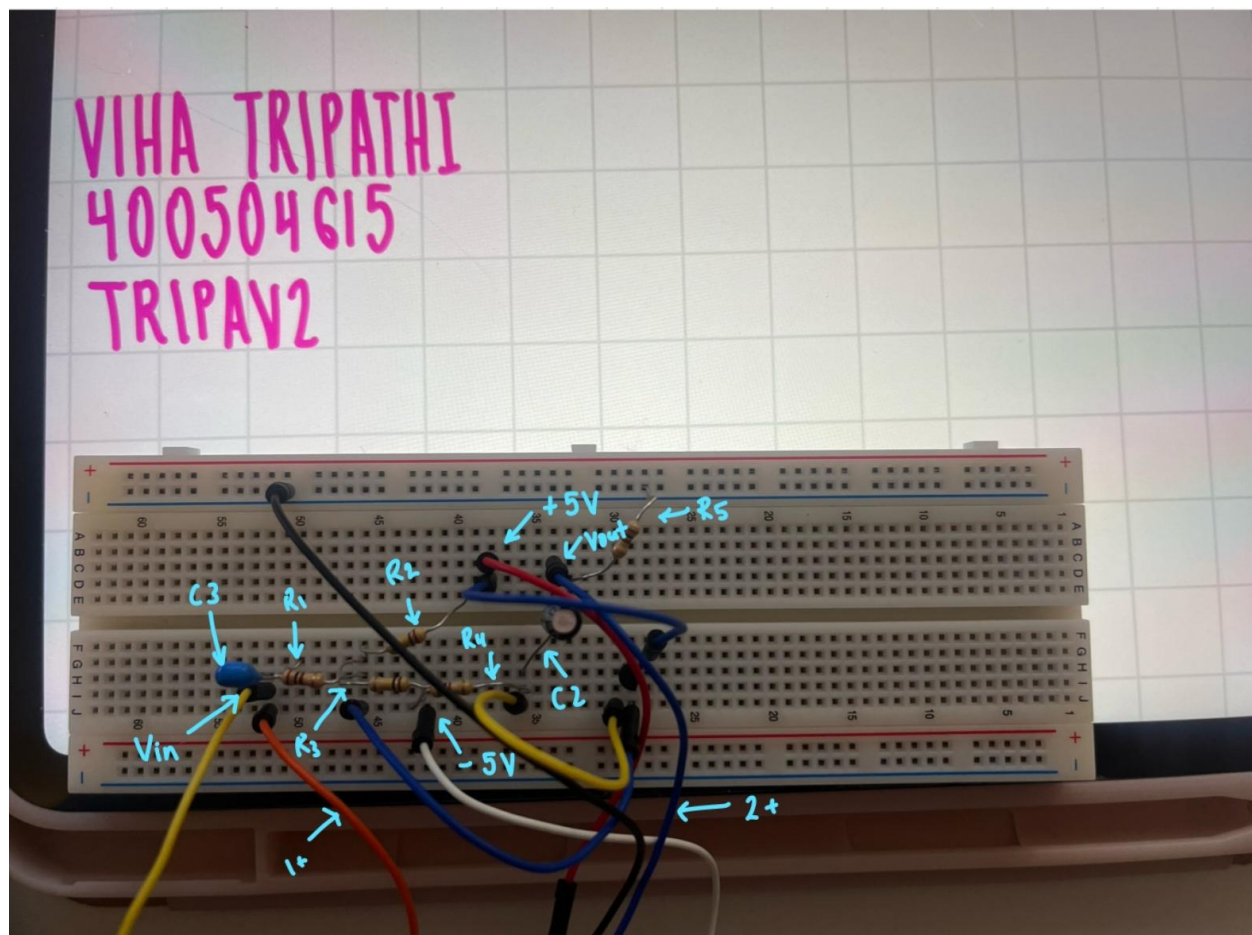


Figure 3: Physical Circuit

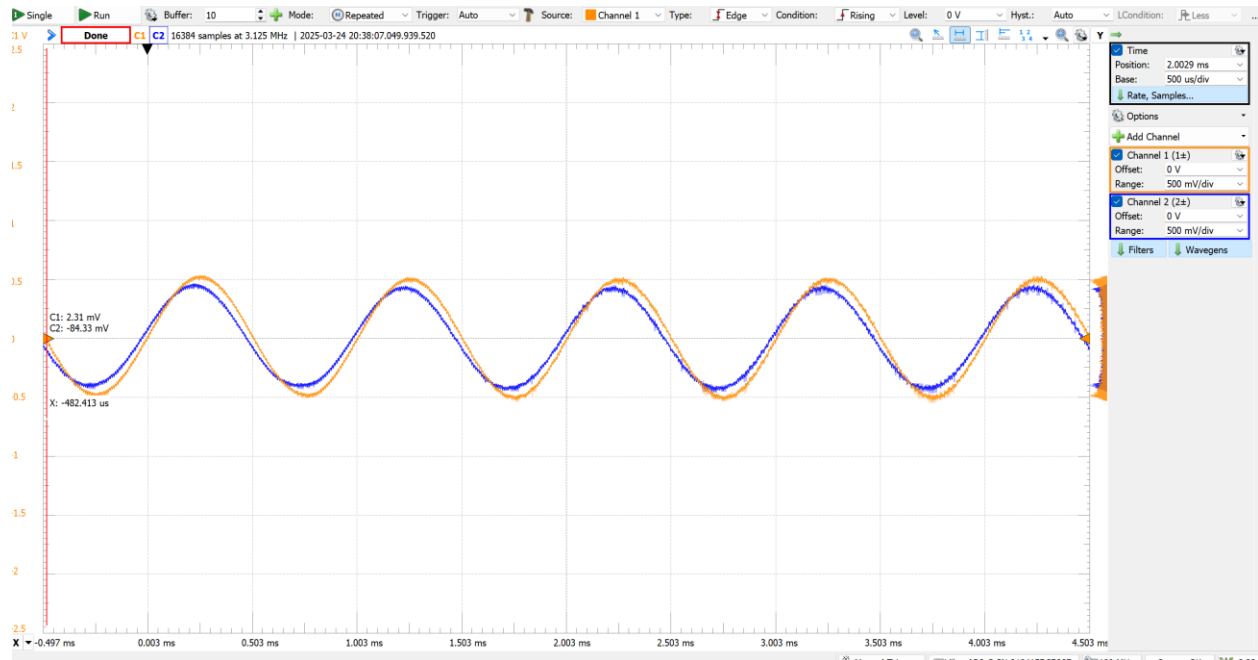


Figure 4: Waveform Simulation of Input And Output Voltage

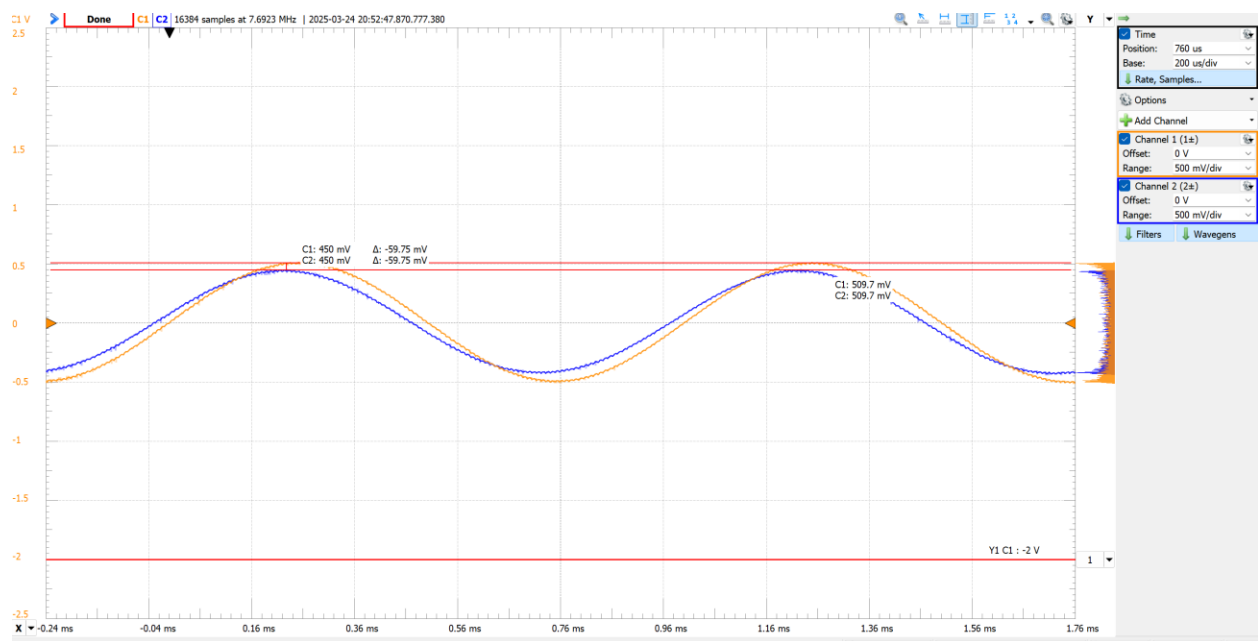


Figure 5: Measurement of Input and Output Voltage Using Cursors

What measurements did you do? (E.g. waveforms as functions of time, XY plot,

network analyzer, etc. You decide which measurements are beneficial and explain why you used them.)

Using Y-cursors, I measured the maximums of V_{in} and V_{out} which happened to be 509.7 mV and 507.9 mV, respectively. These measurements help determine the voltage gain, which is a key parameter in verifying signal amplification and checking whether the circuit meets design requirements.

How did you determine the midband gain for your amplifier? What value did you obtain? Compare your value with what was expected from calculations and simulations.

The midband gain was determined by measuring the peak amplitude of the input and output waveforms

$$\text{Gain} = V_{out}/V_{in}$$

$$\frac{507.9}{450} = 1.13$$

This gain is above the minimum of 0.9, thus guaranteeing that the amplifier performs the signal retention design specification adequately. While the gain is marginally above the expected range of around 0.90658, this deviation can be attributed to slight measurement fluctuations, waveform offset, or simulation noise.

The measured gain usually signifies that the amplifier is working well in the midband, providing a clean in-phase output signal, thus meeting the functional and design requirements.

Demonstrate linearity at an input amplitude of 0.5V

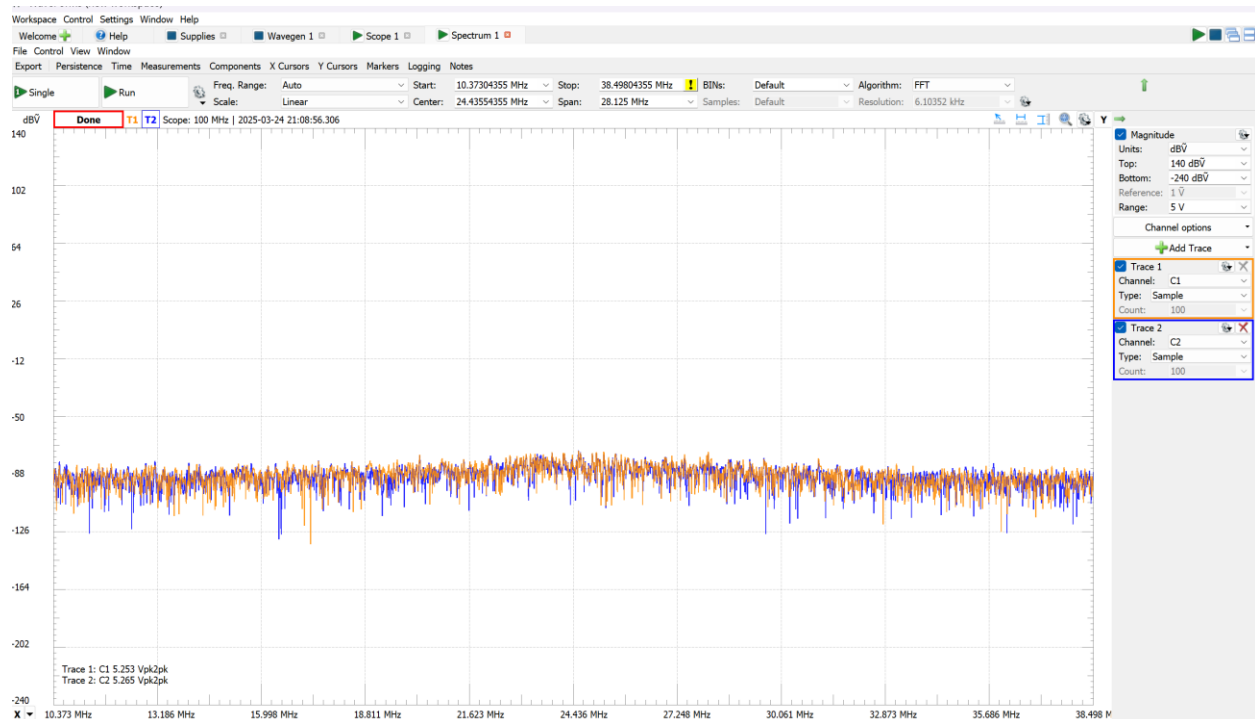


Figure 6: Demonstrating Linearity Using the Spectrum Analyzer

To verify how linear the amplifier is with an input of 0.5 V, a spectrum analysis was performed. Measurements of the input (C1) and output (C2) signals in the frequency domain were taken.

The graph of the spectrum indicates that both the signals maintain a constant level of noise without large distortions or additional spikes. The input and output traces are identical for all the frequencies, indicating that the amplifier will not introduce distortion or alter the frequency of the signal.

There are no major visible harmonics, so the resulting wave is merely a clean and direct amplification of the original without alteration such as clipping or compression.

Overall, the identical spectrum profiles of the input and output signals indicate that the amplifier is performing well with an input of 0.5 V. The absence of distortion in the spectrum analysis confirms the notion that the amplifier maintains excellent linearity in this configuration.

Conclusion

In conclusion, the single-transistor amplifier was constructed to achieve all significant objectives. The amplifier's gain of 1.13 was more than the required minimum gain of 0.9, and the input resistance was 10.43 k Ω with minimal loss of signal. Simulations and actual circuit tests

demonstrated that the amplifier performs well in the midband range when properly configured and has an excellent output match. Linearity was tested with spectrum analysis, and no significant harmonic distortion was evident. This indicates that the amplifier preserves the input signal shape and frequency even at 0.5 V. Generally, the design performs satisfactorily, accurately, and fulfills the requirements of a common-collector amplifier.