23ECE286 CIRCUITS AND COMMUNICATION LAB

Design and implementation of a circuit using op-amps to find the frequency of a sinusoidal signal

TERM PROJECT REPORT

Submitted by

CB.EN.U4ECE23010	**BATTULA UDAY VENUGOPAL**
CB.EN.U4ECE23016	**EZHILKIRTHIK M**
CB.EN.U4ECE23018	**SRUJANA KARRI**

AMRITA SCHOOL OF ENGINEERING AMRITA VISHWA VIDYAPEETHAM

COIMBATORE 641112

April 2025

Date of Submission

(01/04/2025)

Students signature

Faculty **Lab Staff**

Table of Contents

Introduction

The ability to determine the frequency of a given input signal is essential in various applications such as communication systems, instrumentation, and signal processing. This project aims to design and implement a circuit that can detect the frequency of a sinusoidal signal without prior knowledge of its frequency. The key approach is to convert the frequency into a measurable DC equivalent, which varies with changes in frequency.

Problem Statement and Explanation

The primary challenge in this project is to develop a method to detect the frequency of a sinusoidal signal and represent it as a DC voltage output. This allows for an easy and precise measurement using a multimeter. The circuit must maintain linearity between the frequency and the output voltage, ensuring an accurate and predictable response.

Objectives

- To design a circuit that converts frequency into a readable DC voltage output.
- To ensure the output voltage varies proportionally with the input signal frequency.
- To maintain linearity in the frequency-to-voltage conversion.
- Validating the circuit performance through simulation, analysis and hardware implementation.

Breakup of Goals

1. Implement a differentiator circuit to extract frequency-dependent amplitude variation.
2. Use a precision rectifier to obtain a measurable DC output.
3. Evaluate circuit performance through LTSpice simulations.
4. Validate linearity of the circuit’s frequency response.
5. Optimize the design for improved accuracy and reliability.

Methodology

To achieve the project objectives, the following approach was taken:

1. **Circuit Design**: A differentiator circuit followed by a precision rectifier was designed to achieve frequency-to-voltage conversion.
2. **Simulation**: The circuit was simulated using LTSpice to validate its performance.
3. **Analysis**: The output voltage was measured at different input frequencies to establish a frequency-to-voltage relation.
4. **Optimization**: The circuit was fine-tuned to maintain linearity and stability.

Why a Differentiator Circuit?

A differentiator circuit was used because differentiation of a sinusoidal input results in an output where the frequency component appears as a multiplying factor in the amplitude. Mathematically, if the input is given by $A_c \sin(\omega t)$, the differentiated output becomes $\omega A_c \cos(\omega t)$. This means that the amplitude of the output is directly proportional to the frequency, making it easier to extract a frequency-dependent signal. The differentiated signal is then processed further to obtain a readable DC output.

Why a Precision Rectifier?

A precision rectifier was used to convert the AC signal obtained from the differentiator into a DC voltage. Standard diode rectifiers introduce voltage drops that affect accuracy, especially for low-amplitude signals. Using an op-amp-based precision rectifier eliminates these losses and ensures accurate rectification. This allows for a reliable DC representation of the frequency-dependent signal, which can be measured with a multimeter.

Circuit Design and Components

The circuit consists of:

1. **Differentiator Circuit**
   - Converts the sinusoidal signal into a frequency-dependent amplitude-modified waveform.
   - Based on the principle: $d/dt\ [A \sin(\omega t)] = \omega A \cos(\omega t)$, where the frequency component ω appears in the amplitude.
2. **Precision Rectifier Circuit**
   - Converts the differentiated AC signal into a DC output.
   - Provides accurate rectification even for low-amplitude signals.

3. **Key Components and Their Roles**:

Component	Specification	Quantity
Op-Amp	LM741	2
Resistors	1kΩ, 10kΩ	1, 3
Capacitors	10nF	1
Diodes	1N4148	2
Power Supply	+15V, -15V	1
Digital Storage Oscillator		1
Probes		3

Bread board		1
Connecting wires		as required

- Op-Amps (LM741): Used for differentiation and precision rectification.
- Resistors (1kΩ, 10kΩ): Define circuit response characteristics.
- Capacitors (10nF): Used in the differentiator for frequency-dependent behavior.
- Diodes (1N4148): Provide rectification in the precision rectifier stage.
- Power Supply (+15V, -15V): Powers the op-amps.

Implementation

The circuit was built and tested in LTSpice simulation software. Initially, a peak detector was considered for generating the DC output, but it was found to distort the linearity in frequency analysis. The peak detector was replaced with a precision rectifier to maintain linearity.

- The simulation results showed a clear relationship between the output voltage and input frequency.
- AC analysis confirmed the linearity of the circuit.
- Frequency-to-voltage mapping was established for practical measurement.

Results:

Simulation:

Initial Implementation (With Peak Detector):

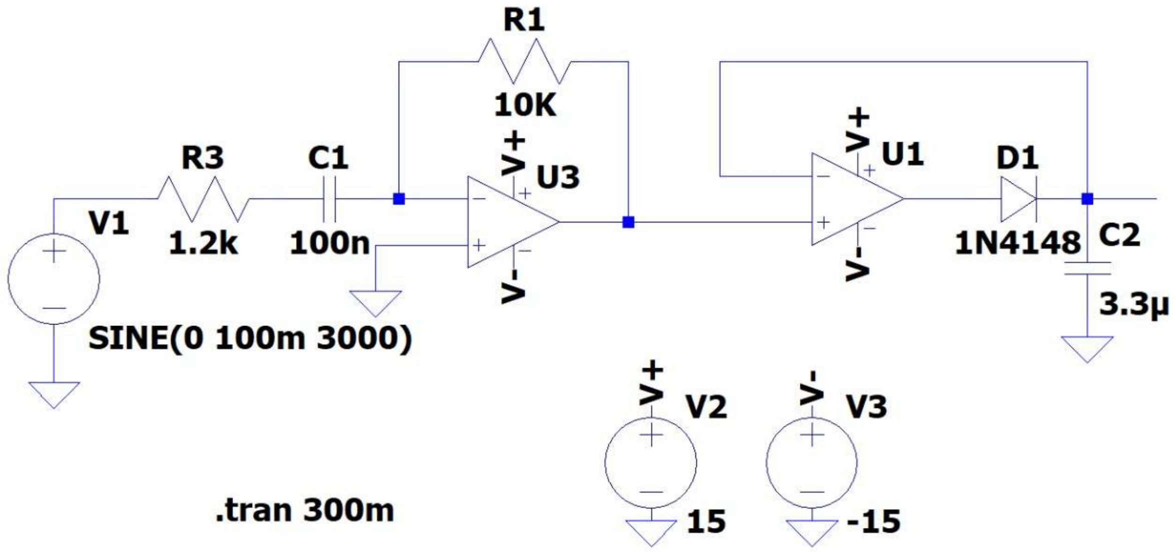


Figure 1: Circuit using peak detector

Intermediate Results:

Differentiator output:

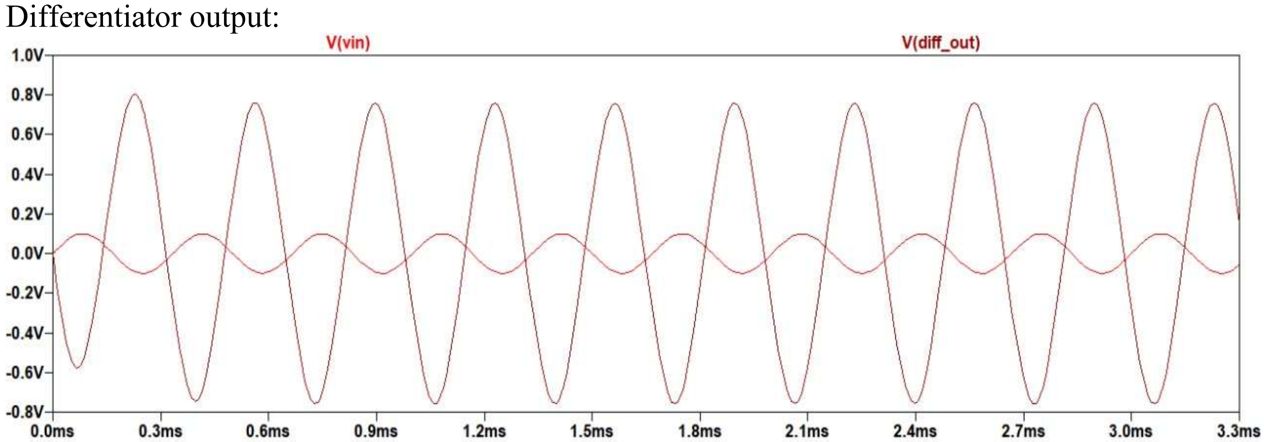


Figure 2: Differentiator output

Peak detector Output:

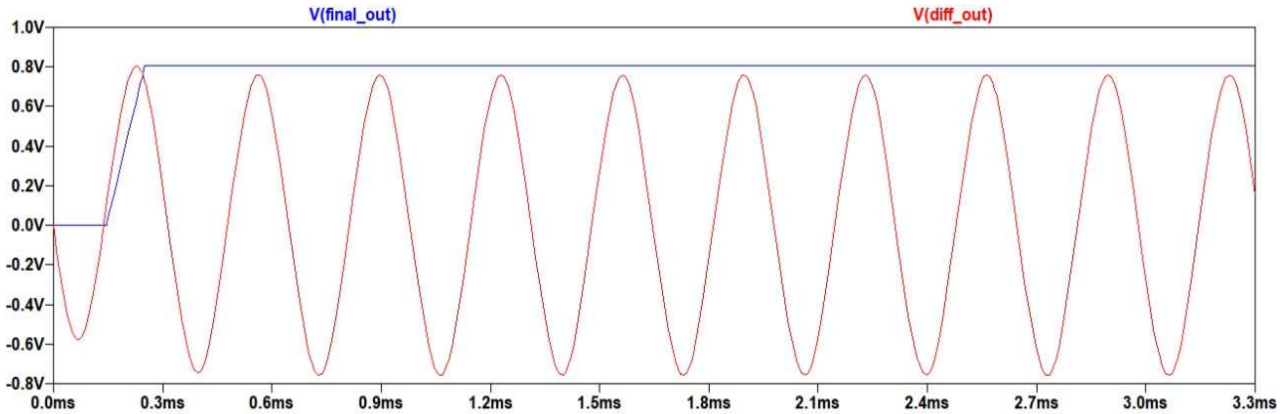


Figure 3: Peak Detector Output

AC Analysis:

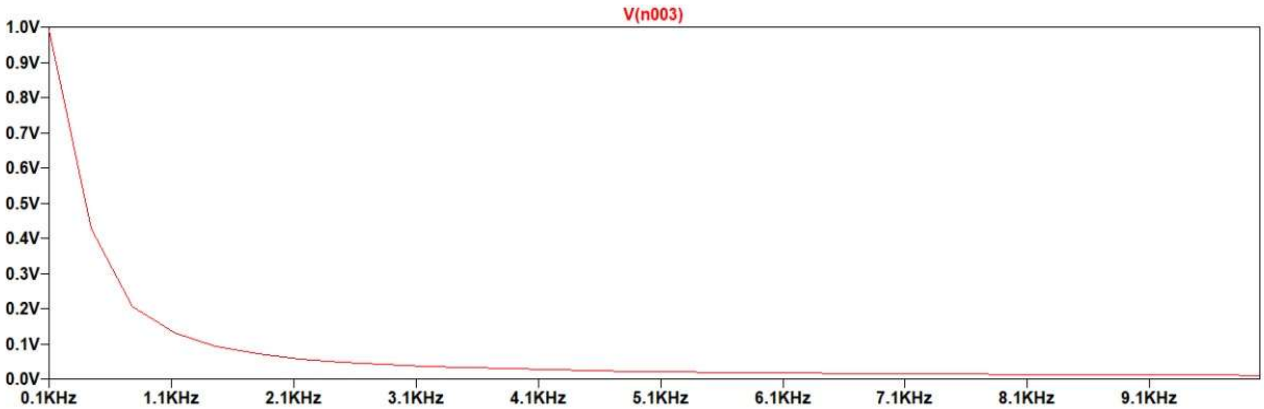


Figure 4: AC Analysis

Refined implementation (With precision rectifier):

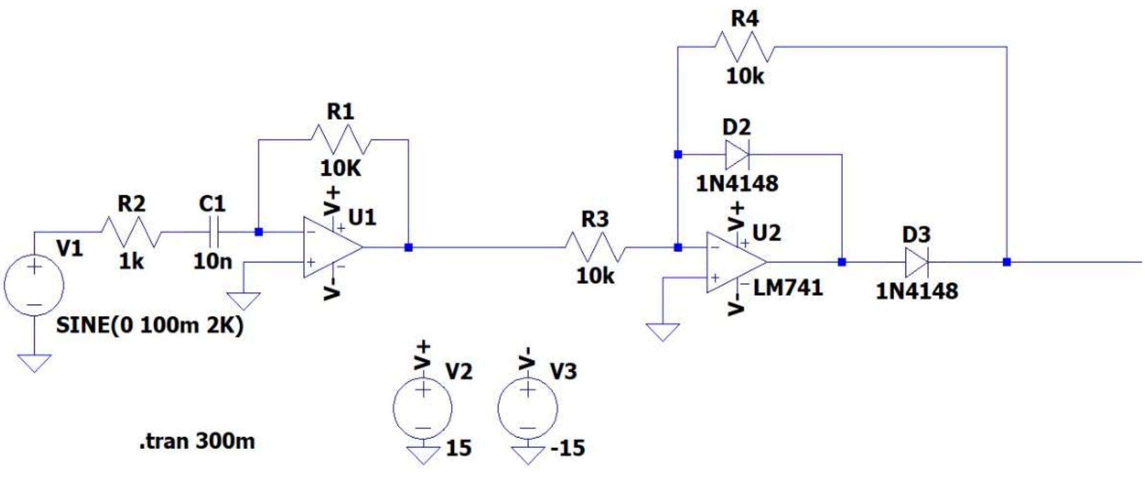


Figure 5: Implementation with precision rectifier

Differentiator output:

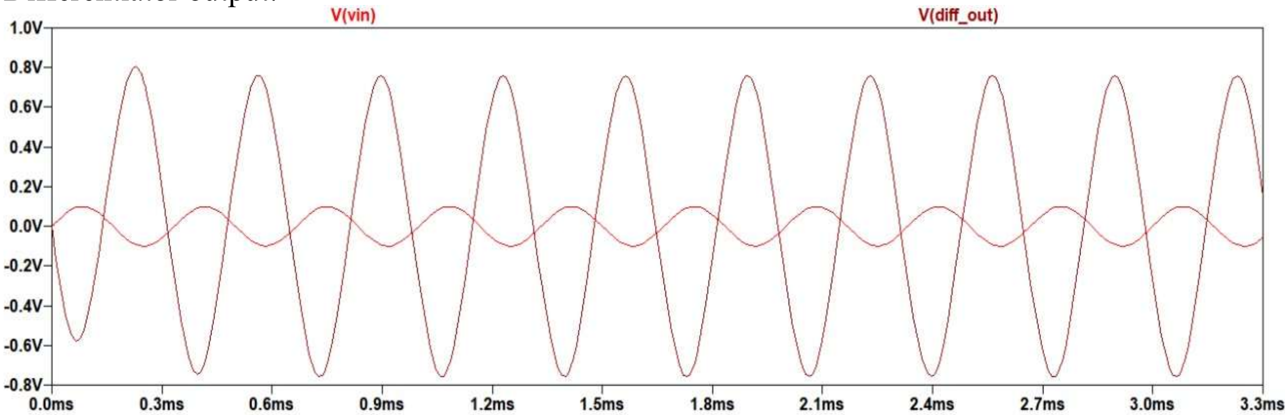


Figure 6: Differentiator output

Precision Rectifier Output:

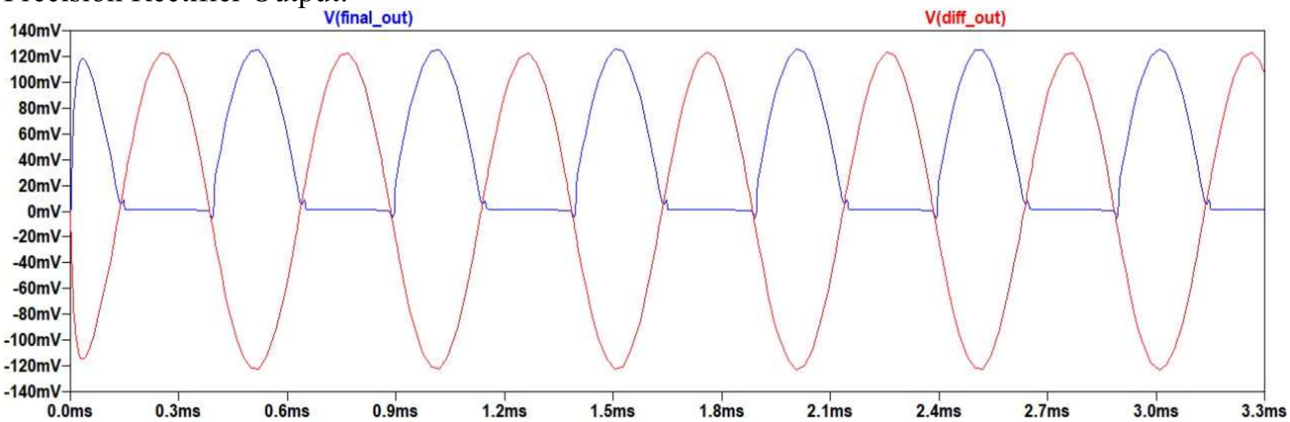


Figure 7: Precision Rectifier Output

AC Analysis:

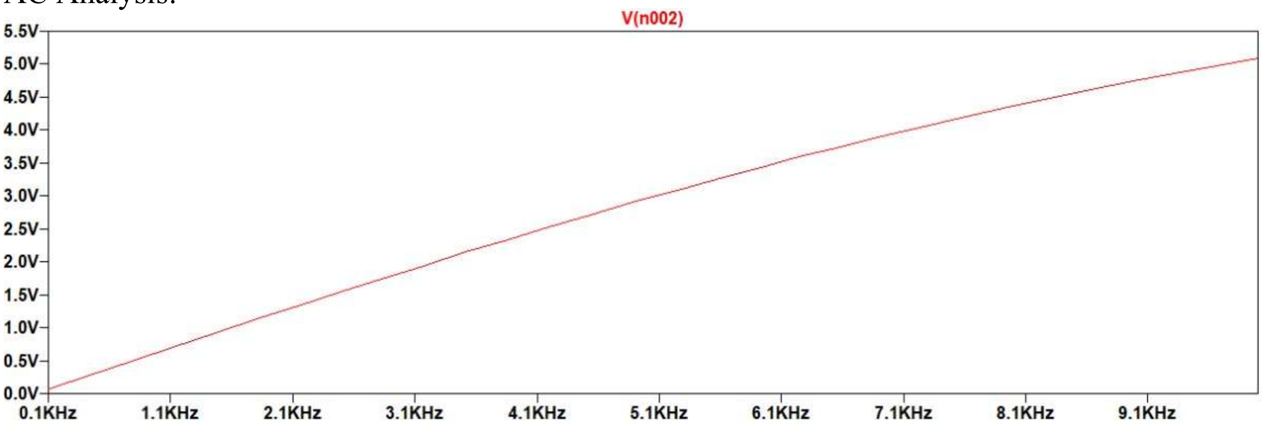
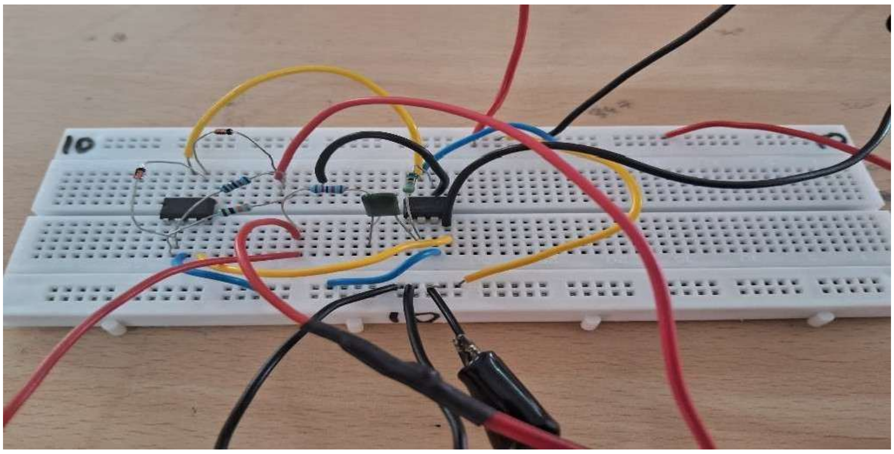
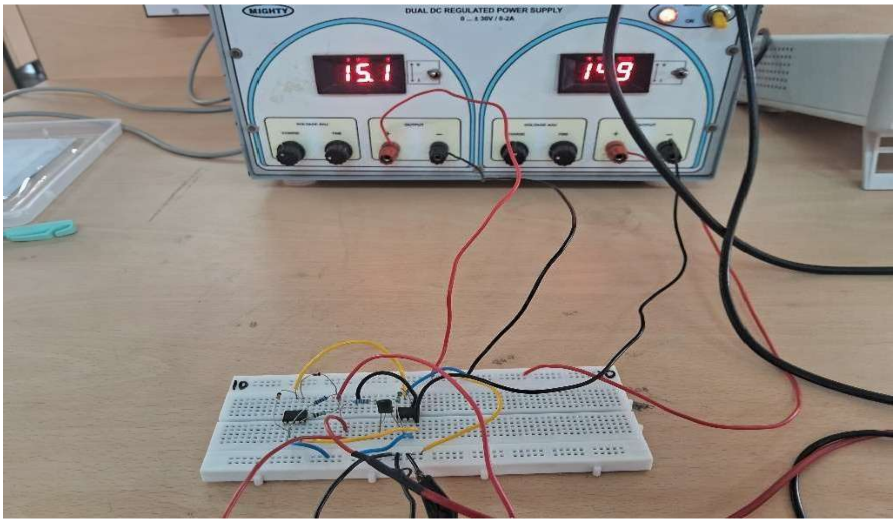


Figure 8: AC Analysis

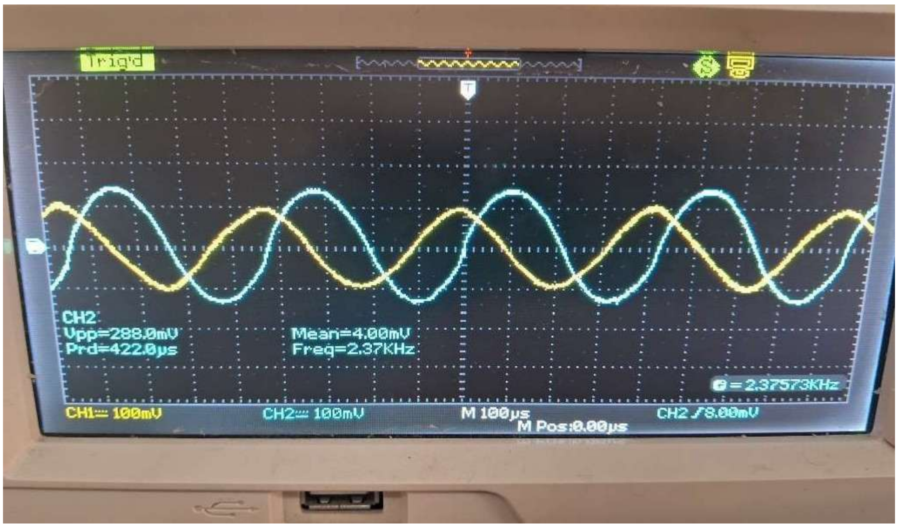
Hardware Implementation

Circuit:

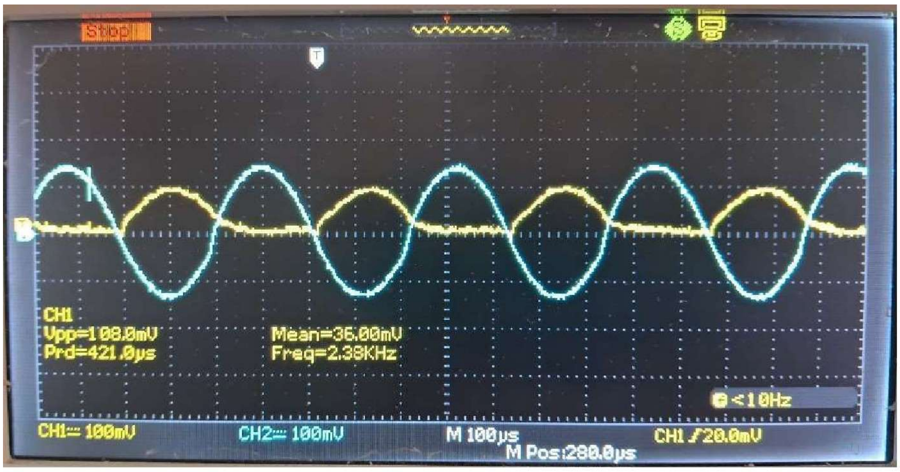




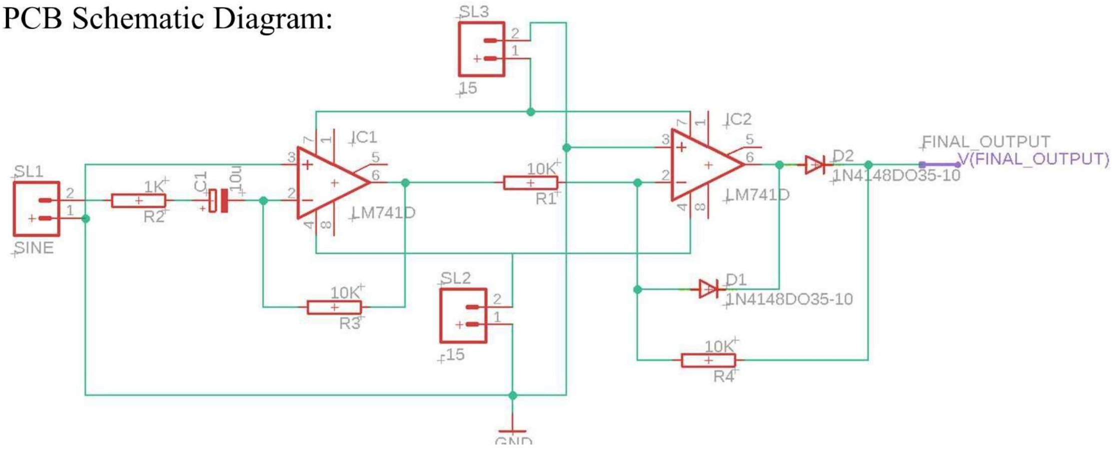
Differentiator output:



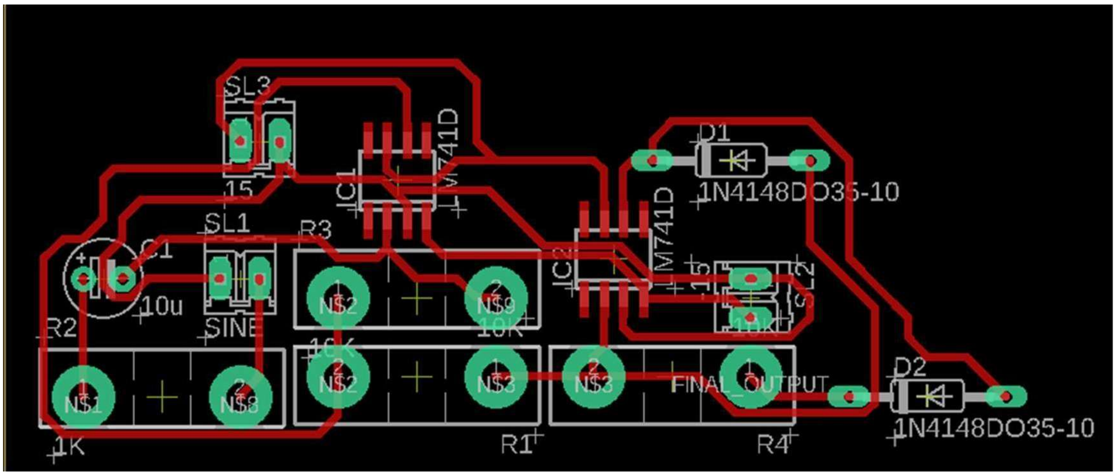
Precision Rectifier Output:



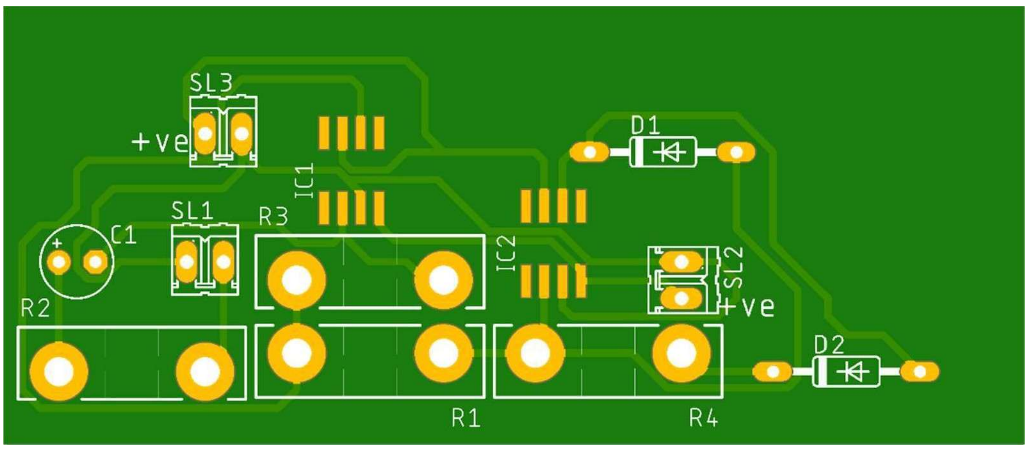
PCB Schematic Diagram:



PCB Layout:



PCB Board after Manufacture:



Results (Tabulated for frequencies and their corresponding DC outputs):

Frequency(Hz)	Voltage(mV)
300	6.6
500	11.1
700	15.6
900	20.2
1000	22.5
1200	27
1400	31.5
1600	35.9
1800	40.3
2000	44.7
2500	55.7
3000	66.3
3500	76.9
4000	87.1
4500	97.1
5000	106.8
5500	116.3
6000	125.4
6500	134.2
7000	142.6
7500	150.6
8000	158.4
8500	165.7
9000	172.9

Table 1. Output from Hardware implementation

Graph:

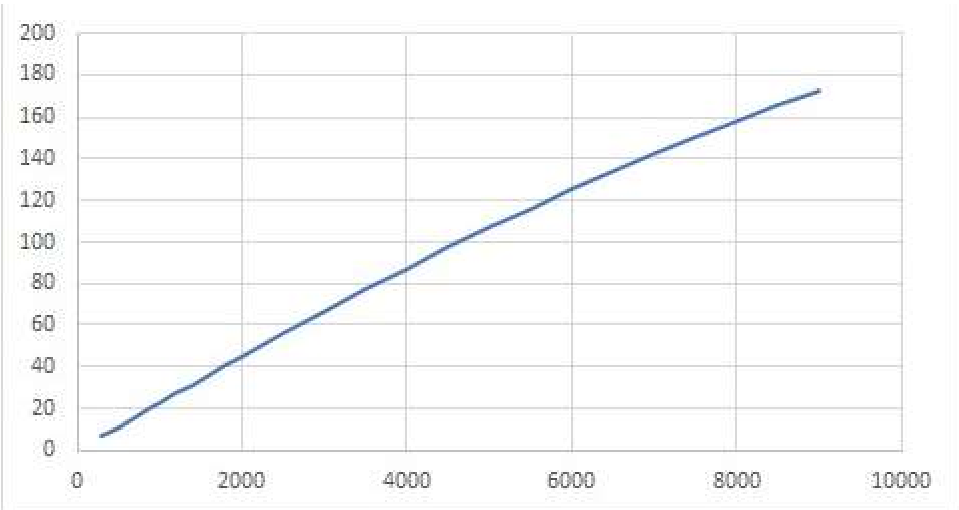


Figure 13: AC Analysis

Relation:
Linear Equation:

$$\text{Voltage (mV)} = 0.01952 \times \text{Frequency (Hz)} + 4.8803$$

Nonlinear Equation:

$$\text{Frequency (Hz)} = 28.99 * (\text{Voltage (in mV)})^{1.1096}$$

Quadratic Relation:

$$\text{Frequency (Hz)} = 0.0743(\text{Voltage (in mV)})^2 + 38.0884(\text{Voltage (in mV)}) + 106.78$$

The quadratic equation and nonlinear equation are a better representation because the circuit contains a diode, which introduces a strong non-linearity. Additionally, the RC filter's frequency-dependent behavior also contributes to the non-linear relationship. The combination of these effects makes the quadratic equation a more accurate model of the circuit's output. The exact nature of the nonlinearity depends on the specific operating conditions and component values. However, in this case, the quadratic fit is clearly superior to the linear fit.

Discussion

- The circuit effectively detected frequency variations by converting them into a proportional DC voltage.
- The differentiator approach provided a frequency-dependent amplitude variation, which was successfully rectified.
- Eliminating the peak detector improved the curve fitting, ensuring accurate frequency estimation.

Challenges and Solutions

1. **Initial Peak Detector Issue**
   - Problem: It introduced distortion in the frequency response.
   - Solution: Replaced with a precision rectifier for accurate rectification.

2. **Maintaining Linearity**
   - Problem: Non-uniform frequency response in the initial tests.
   - Solution: Optimized component values and simulation parameters.

Conclusion

The designed circuit successfully converted the input sinusoidal frequency into a measurable DC voltage output with good curve fitting. Future work can include implementing a peak detector and getting a DC output without intermediate distortions.

References:

1. A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, 7th ed. New York, NY, USA: Oxford University Press, 2014, pp. 1012-1015. (**For differentiator and precision rectifier circuit principles**)

2. B. Razavi, *Design of Analog CMOS Integrated Circuits*, 2nd ed. New York, NY, USA: McGraw-Hill, 2016, pp. 254-257.