Touch Sensor & NPN Test Module Circuit EE311-Electronics 2 Project Report

Ayşe Ece Akkurt
Electrical-Electronics Engineering
Abdullah Gül University
Kayseri, Türkiye
ayseece.akkurt@agu.edu.tr

Selin Nisa Akgöl
Electrical-Electronics Engineering
Abdullah Gül University
Kayseri, Türkiye
selinnisa.akgol@agu.edu.tr

Melihhan Çınar
Electrical-Electronics Engineering
Abdullah Gül University
Kayseri, Türkiye
melihhan.cinar@agu.edu.tr

***Abstract*—In this study, an analogue circuit design was developed to read a touch sensor exhibiting a capacitance variation between 60 pF and 70 pF. The system generally consists of a Wien Bridge oscillator, a common emitter amplifier, and a rectifier that converts the signal to DC form. In the amplifier block of the design, ready-made integrated circuits were completely avoided in accordance with the task constraints, and the circuit was configured using only discrete transistors. The gain was observed to be around 2, and as the sensor capacitance increased, the amplifier gain increased, and in the converter section, a DC voltage increase was observed along with the capacitance increase. Detailed information about the system is provided under other headings.**

***Index Terms*—sensor interface, transistor-level design, CE amplifier, touch sensing, AC-DC rectifier.**

I. Introduction

Touch sensors are simple and reliable sensing elements that work by detecting small capacitance changes caused by human contact. The sensor used in this project operates in a capacitance range of approximately 60–70 pF and aims to detect very small changes caused by finger contact. Measuring such small changes requires a sensitive and stable signal processing chain. For this purpose, a Wien bridge oscillator is used in the system. The oscillator produces a sinusoidal AC signal that varies depending on the sensor capacitance. A buffer stage is added to prevent the oscillator output from being affected by the load. Then, the signal level is increased with an amplifier and finally converted into a measurable DC voltage using an AC-DC converter. The aim of this study is to design and experimentally verify an analog-based touch sensing system capable of detecting small capacitance changes.

II. Design Concept

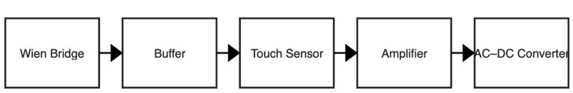

Fig. 1: Block Diagram

In this project, the system consists of five main blocks: a Wien bridge oscillator, a buffer, a touch sensor, an amplifier, and an AC-DC converter. The Wien bridge oscillator is used to provide a sinusoidal AC signal to the system. This signal is transmitted stably, protected from overload by the buffer stage. The touch sensor connected to the buffer output has a capacitive structure operating in the range of approximately 60–70 pF, and small changes in its capacitance occur with finger contact. The weak signal resulting from these changes is amplified in the amplifier stage to a measurable level, and a gain of at least 2 was obtained in the experiments. Finally, to facilitate easier observation of the signal, the AC signal is converted to DC voltage using a half-wave rectifier. Thus, changes related to touch can be clearly observed at the DC level.

III. Working Principle

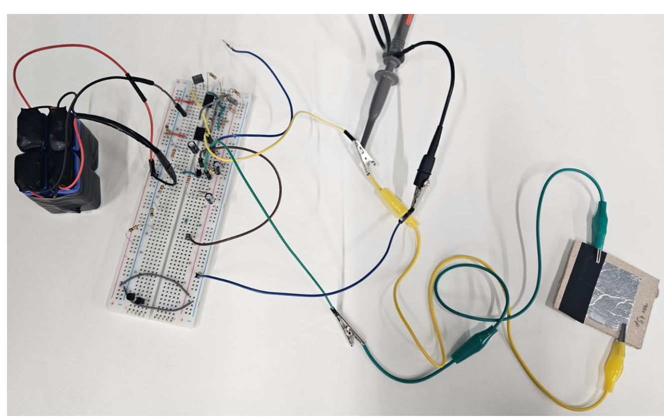

Fig. 2: Whole Circuit

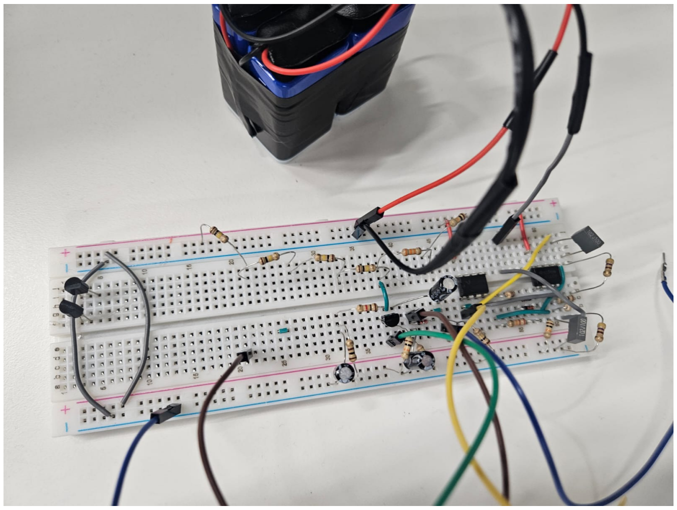

Fig. 3: Close-up of the Entire Circuit

A. *Oscillator*

For oscillations to start, the voltage gain of the amplifier circuit must be equal to or greater than three. The voltage gain is determined by R_1 and R_2, and for a non-inverting amplifier, this ratio is given as

$$A_V = 1 + \left(\frac{R_2}{R_1}\right) \tag{1}$$

When the amplitude approaches the desired level, the circuit itself automatically reduces the gain below 3 to prevent clipping of the signal. When the amplitude of the sine wave increases and reaches the threshold value of the diodes, the diodes conduct. Resistors R_2' and R_2 become parallel to each other. This parallel connection sets the voltage gain to [1]

$$A_V = 1 + \frac{R_2' \parallel R_2}{R_1} \tag{2}$$

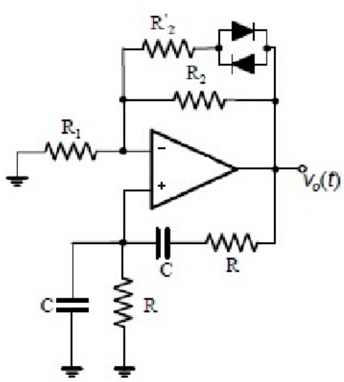

Fig. 4: Oscillator Circuit Schematic

The resonance frequency:

$$f_r = \frac{1}{2\pi RC} \tag{3}$$

$$f_r = \frac{1}{2\pi \times 1500 \times 1 \cdot 10^{-9}}$$

$$f_r = 106\,\mathrm{kHz}$$

Before the diodes enter the conduction region:

$$A_v = 1 + \left(\frac{R_3}{R_9}\right) \tag{4}$$

$$A_v = 1 + \left(\frac{22k}{10k}\right)$$

$$A_v = 3.2$$

When the diodes are switched on:

$$A_v = \left(1 + \frac{R_{10} \parallel R_3}{R_9}\right) \tag{5}$$

$$A_v = \left(1 + \frac{1\,\mathrm{k} \parallel 22\,\mathrm{k}}{10\,\mathrm{k}}\right)$$

$$A_v = 1.09$$

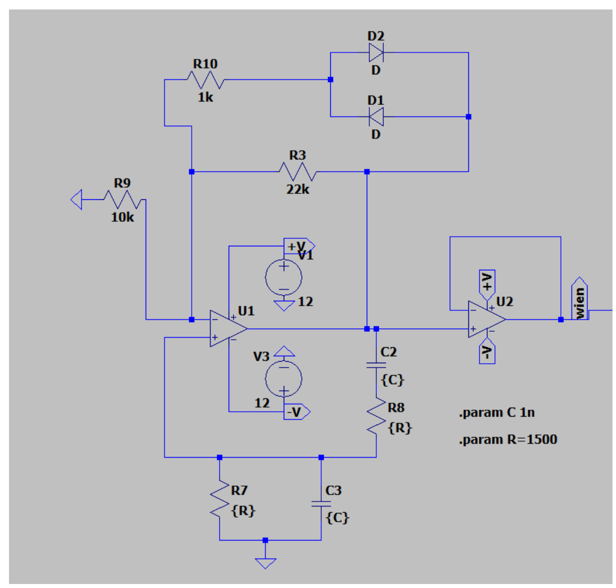

Fig. 5: Oscillator Circuit

The resonance frequency predicted as 106 kHz in theoretical calculations remaining at the 94.34 kHz level in laboratory measurements can be explained by the deviation of real-world components from ideal mathematical models. The most fundamental reason behind this difference is the production tolerances of between 5% and 10% for the resistor ($1.5\,\mathrm{k}\Omega$) and capacitors ($1nF$) used in the circuit. Furthermore, the fact that the circuit was set up on a breadboard caused 'stray capacitance' to form between the connection channels, increasing the total C value and lowering the operating frequency. Finally, the limited gain-bandwidth (GBW) performance of the op-amp used in the high-frequency region and the phase shifts it generated also played a decisive role in deviating from the ideal resonance point.

B. Touch Sensor

As stated in the interim report, a very small capacitance change was observed in the proximity sensor. Although this small difference was seen on LTspice, unfortunately, no change was observed when the circuit was actually set up on a breadboard and the proximity sensor was tested. Multiple proximity sensors were made and tested, but they did not work. Therefore, the sensor was changed. A new amplifier circuit was also designed according to the capacitance range of the touch sensor.The touch sensor's change range is between 60pF and 70pF.

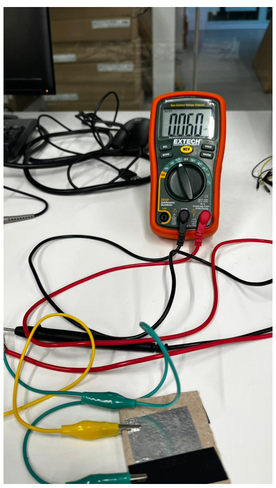

Fig. 6: Touch Sensor When Idle

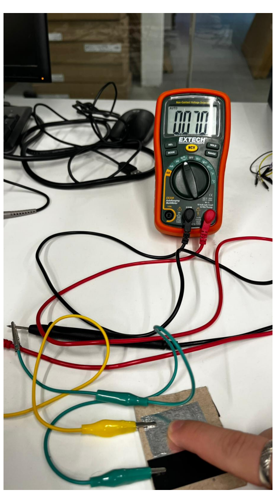

Fig. 7: Touch Sensor Under Finger Contact

C. CE Amplifier

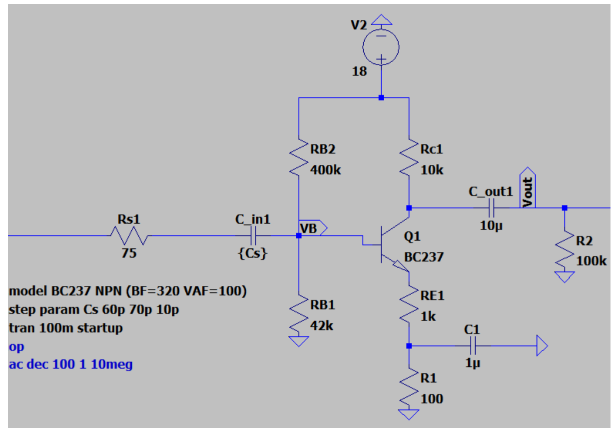

Fig. 8: Amplifier Schematic

A buffer was used to separate the stages before the sensor, or at the oscillator output. In the interim report, a buffer was also used before the amplifier output, or before the AC to DC converter. However, observations made in the laboratory revealed that the buffer at the amplifier output did not alter anything. Therefore, the buffer in that section was removed from the circuit. It was observed that the circuit functioned properly even without the buffer in that section.

The amplifier section in the interim report was created with the necessary calculations, as in the design assignment. Unfortunately, however, during laboratory measurements, it was observed that the circuit, which worked properly in LTspice, did not work as desired in the real environment. Again, all calculations were made as in the design assignment, and the resistance was increased or decreased according to the undesirable conditions seen on the oscilloscope. For example, the saturation condition observed on the oscilloscope disappeared by increasing the R_E resistance in the amplifier circuit. Consequently, the resistance values used in the amplifier were rearranged according to the errors in the laboratory environment.

The reason why the circuit works as desired in the LTspice environment but causes problems when built on a breadboard is that simulation programs assume components have "ideal" and fixed parameters. However, resistors and capacitors used in the laboratory have manufacturing tolerances of around 5-10%, which causes the calculated operating point (Q-point) of the circuit to shift. Since β_f of each transistor differs from the simulation models, the circuit may unexpectedly enter the saturation region. Furthermore, "parasitic capacitances" formed between the metal channels on the breadboard and contact resistances in the cable connections can distort the circuit's characteristics. To fix this situation, the circuit was soldered onto a perfboard; however, due to some problems encountered in the laboratory environment, the soldered circuit was damaged, and the circuit had to be rebuilt on the breadboard.

D. AC to DC Converter

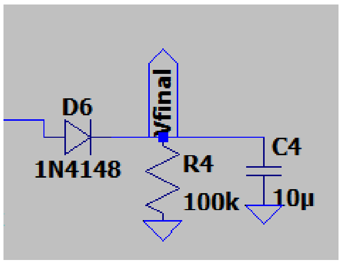

Fig. 9: AC-DC Schematic

Firstly, a half-wave rectifier circuit was used for AC-DC conversion. Later, an RC filter was incorporated as a ripple filter in the circuit. But analysis in the experiment revealed that there was no significant effect due to the inclusion of the RC filter circuit in the design. Moreover, there were no changes in characteristics even after the exclusion of this filter circuit. The primary aim in engineering is to create a system that provides maximum efficiency using a minimum set of elements. Based on this principle, the RC filter circuit that merely added complexity to the design was eliminated. A basic circuit design involving resistors, capacitors, and diodes was adopted. Analysis in real-world scenarios confirmed that this circuit functions effectively without any complications in terms of output.

IV. Simulation Results

The design was improved in our trials so that the circuit was producing meaningful outputs. Therefore, this part of the report will use the final version of the circuit that was presented at the demonstration.

This version of the circuit provided us the best results for our circuit.

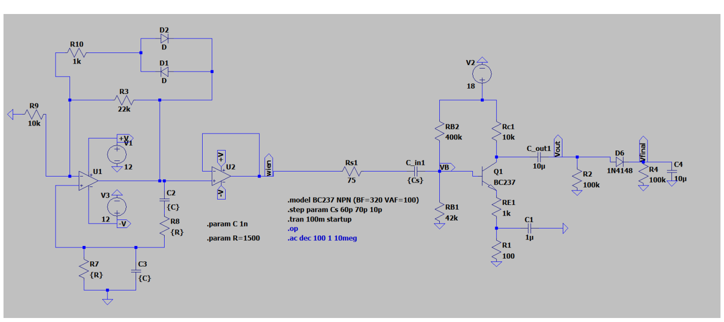

Fig. 10: Complete system

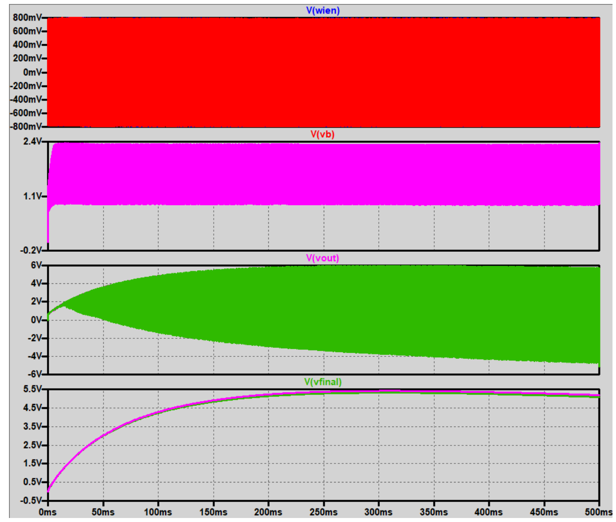

Fig. 11: Simulation results of the complete system

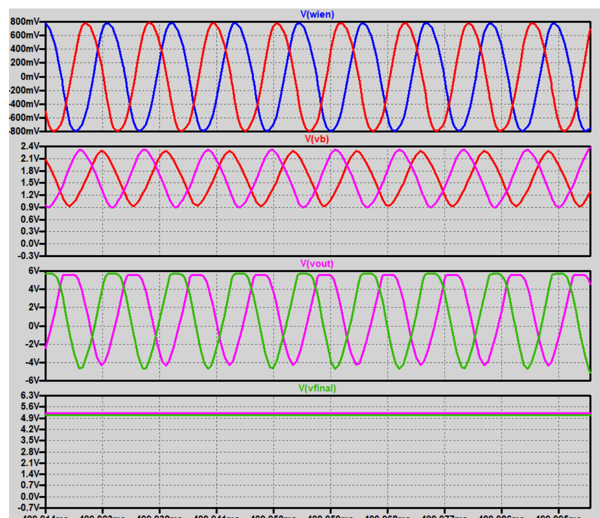

Fig. 12: Zoomed in look of simulation results of figure 11

- **Oscillator:** The oscillator produces around $1.6V_{pp}$ with a frequency around 98kHz in simulation environment .
- **Amplifier:** The most important thing for our design was to have a terminal gain (from base to collector) of 10. However, as visible in figure 12, the output is cut off pretty significantly. This is a bias point problem which did not actually occur as much as this one in real life. The gain can not be calculated with the waves corrupted as much as this.
- **AC to DC Converter:** Even though the amplifier does not operate as desired in simulation, the AC-DC converter is able to produce a noticeable difference, about 105.28562mV according to figure 13.

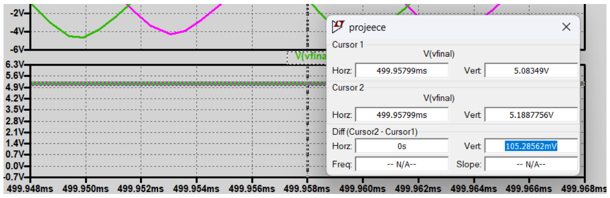

Fig. 13: AC-DC Converter in LTspice

V. Experimental Results

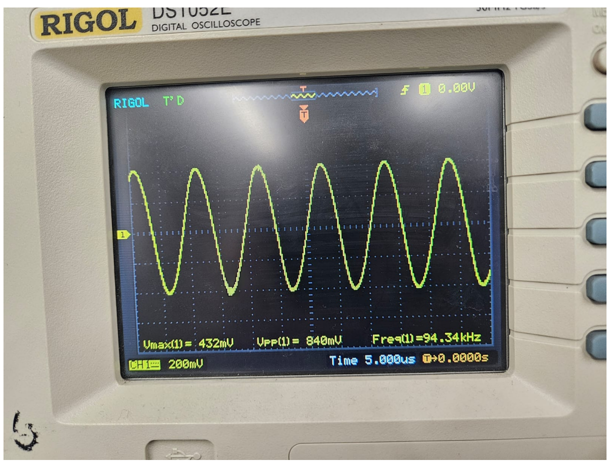

Fig. 14: The Oscillator Measurement

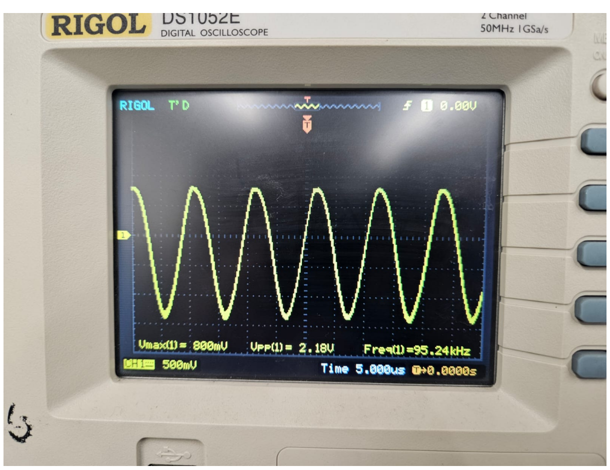

Fig. 15: The Amplifier Measurement without Sensor

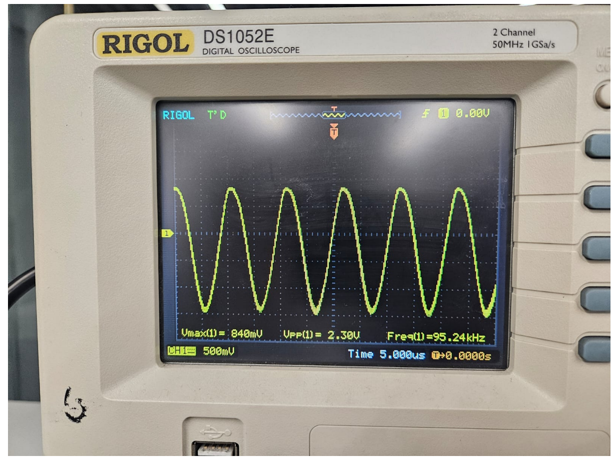

Fig. 16: The Amplifier Measurement with Sensor

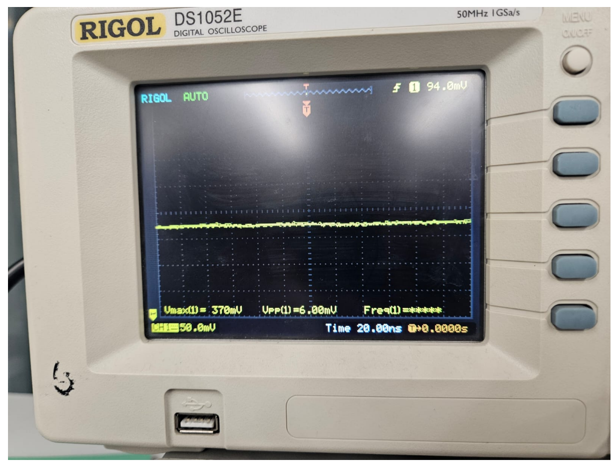

Fig. 17: The AC to DC Measurement when idle

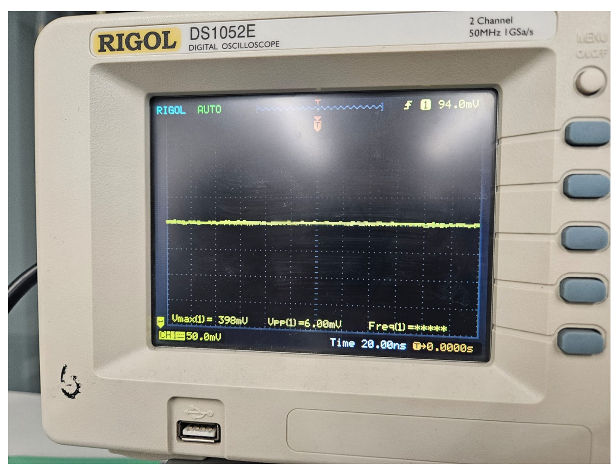

Fig. 18: The AC to DC Measurement when touching

The capacitive sensor reading circuit, oscillator, amplifier, and AC-DC converter designed within the scope of the project were experimentally analysed. During the experiments, the electrical changes in the sensor when idle ($60pF$) and when

a touch action occurred ($70pF$) were recorded using a digital oscilloscope. It was observed that the oscillator stage, which forms the signal source of the system, produced a stable sine wave at a frequency of 94.34 kHz and that the peak-to-peak voltage (V_{pp}) at this stage was 840 mV.
This generated signal was applied as input to the common emitter (CE) amplifier stage designed at the transistor level. At the amplifier output, values of $V_{pp} = 2.18$ V and $V_{max} = 800$ mV were obtained when the sensor was idle. When the sensor was touched, the capacitance increased to 70 pF and the amplifier output amplitude increased to $V_{pp} = 2.30$ V and $V_{max} = 840$ mV.
In the final stage of the system, the amplified signal was transferred to the AC-DC converter stage to produce DC voltage. Measurements showed a DC voltage of 370 mV at the output when the sensor was idle. When the sensor was touched, the output voltage was observed to rise to 398 mV. Consequently, a net DC increase of 28 mV was observed at the output as a result of the touch action.

VI. Discussion

The experimental results indicate that the designed analog touch sensing system in this study can detect changes in capacitance like 60-70 pF by looking at the changes in the DC output. We observed some differences between what we thought would happen, what the LTspice simulations showed, and what we actually measured in the lab. But these differences make sense because things are not perfect in the world like the parts we use are not exactly the same, the breadboard adds extra capacitance, and the transistors do not work exactly the same especially at high frequencies. Perhaps 100KHz is not high enough to cause the same serious problems we faced but it can count as well. Even through these problems, the oscillator made a proper and steady sinusoidal signal, and the CE amplifier was able to amplify the circuit more then the required number, 2. The sensor could have been employed in different positions, such as in parallel to the R_C so that the high impedance of our sensor would have more significant effect on the gain.

The observed 28mV DC output while touching the sensor confirms that the AC-DC conversion is able to detect small signal changes into a readable DC level effectively. Overall, the experimental performance validates the design approach.

VII. Conclusion

In this project, an analog system consisting of a Wien bridge oscillator, buffer, amplifier, and AC-DC converter stages for touch sensing was successfully designed and implemented. Although all the targeted values were not obtained exactly in LTspice simulations, the system was observed to work as expected in experimental measurements. In oscilloscope measurements, at least 2 gains were obtained in the amplifier stage, and this value was found to be consistent with the design goals. When the AC-DC converter stage was reached, it was observed that the peak values of the signal changed within the desired limits when the touch sensor was touched. This shows that small capacitance changes can be successfully detected. Overall, the project met the targeted performance criteria within acceptable limits. The system is designed to be made more stable and sensitive in the future if desired, and is open to further development in this direction.

References

[1] K. Laboratories. (2025) Wien bridge oscillator explained. YouTube video, Accessed: 2025-02-01. [Online]. Available: https://www.youtube.com/watch?v=-AEkdXj2H7A