Mini Project
on

Multi-level Voltage Detector using LV-25P Sensor

Linear integrated circuit laboratory (EELR14)

Submitted by

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Table of Contents:

Sl. No.	Section	Page
1	Abstract	3
3	Introduction	4
4	Methodology	4
5	Design	6
6	Simulation and Experimental Analysis	9
7.	Results and Discussion	14
8.	Conclusion	22
9.	Datasheets and References	23

Abstract

This report details the design, simulation, and analysis of the Signal Conditioning Circuit to measure AC voltage, an electronic circuit engineered for meticulous monitoring of voltage levels across a broad spectrum. The circuit is uniquely designed to provide three distinct outputs indicating overvoltage, undervoltage, and normal voltage conditions, making it a useful tool in safeguarding electrical systems against voltage irregularities. The heart of the system lies in its use of the ZMPT101B voltage sensor for initial voltage sensing which converts the input voltage in the range of (0-300V) to an output of (0-1V), followed by a non-inverting amplifier which amplifies the AC voltage to the range (0-5V) suitable for further processing and a precision rectifier with filters to convert it into a dc voltage in the range of (0-5V). The core functionality is achieved through a series of comparators (Inverting and Non-inverting) to detect high (235V-300V) and low voltage (0-180V) levels and then using two inverting amplifiers connected to the comparators given to an AND gate to produce the complement of the two for the normal voltage range (180V-235V). The high, low and normal voltage ranges are indicated by the Leds of colour Yellow, Green and Red respectively. To ensure reliability and safety, the design includes a robust power supply system with a backup path, as well as protective features like electrical isolation and Zener diode-based safeguards. Through detailed simulations and experimental analysis, the report demonstrates the circuit's ability to accurately detect and indicate varying voltage levels. The results highlight the circuit's potential in various applications, ranging from industrial to commercial power systems, where precise voltage monitoring is critical.

1. Introduction

This report presents a comprehensive account of a mini project aimed at developing a voltage monitoring system. The purpose of this system is to continuously monitor the voltage levels within electrical circuits, ensuring they remain within the safe operating range.

1.1 Purpose of the Project

The project's primary purpose is to create a robust monitoring system that accurately detects and indicates any deviation from predefined voltage levels. This includes the detection of overvoltage and undervoltage conditions in real-time, which is crucial for the protection of electrical equipment and maintaining system stability.

1.2 Background Information

Voltage fluctuations in power systems can lead to severe consequences, including equipment failure, data loss, or even fire hazards. A reliable voltage monitoring system is therefore essential for preventing damage and ensuring the longevity and reliability of electrical systems.

1.3 Scope of the Project

The scope of this project encompasses the design and fabrication of a voltage monitoring system that can measure AC voltage ranges from 0-300V and indicate normal, high, or low voltage conditions. It includes the conditioning circuit to scale the voltage appropriately and the integration of visual indicators to convey the voltage status clearly to the user.

1.4 Objectives of the Project

The objectives of this project are outlined as follows:

- To develop a signal conditioning circuit that scales down an AC voltage from 0-300V to a more manageable level of 0-5V, suitable for processing and indication.
- To implement a set of LED indicators that provide immediate visual feedback on the voltage status: green for normal operating conditions, yellow for overvoltage, and red for undervoltage.
- To integrate protection mechanisms within the circuit to prevent damage from reverse polarity and overvoltage conditions.
- To design a self-powered system that does not rely on external power sources, thereby increasing the circuit's versatility and deployment potential.

2. Methodology

The development of the signal conditioning circuit to measure AC voltage was guided by a structured approach that encompassed design, simulation, and experimental verification. This section describes the methodologies used in each phase of the project.

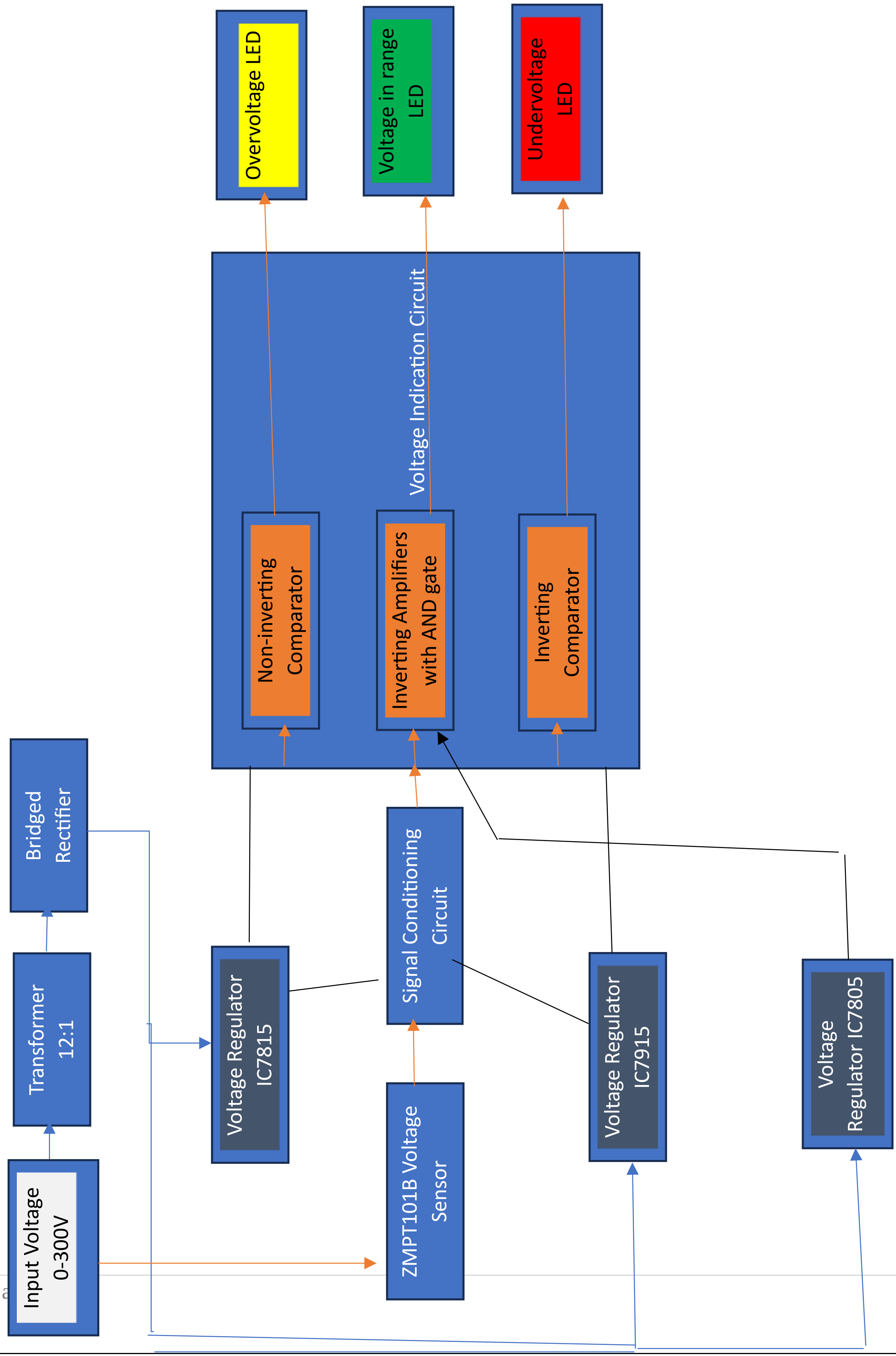
Let us divide the circuit into 3 sub-circuits for easier design and implementation.

1) Self-power generation circuit

2) Signal conditioning circuit

3) Comparator circuit

2.1 Block Diagram (The capacitors and diodes are not represented in the below block diagram) (Fig.1)



3. Design

3.1. Self-power generation circuit:

To power the sensitive op-amp circuitry, a self-sufficient power supply is integrated within the design. This power supply begins with a step-down center tapped transformer which transforms a 220V supply to +24/0/-24 V, appropriately sizing the voltage to be rectified by a bridge rectifier. The rectified voltage, while now DC, contains an AC ripple which is subsequently smoothed out by input and output decoupling capacitors. This smoothed DC voltage is then fed into voltage regulators, which output a stable ±15V and +5V, crucial for the op-amps' optimal performance.

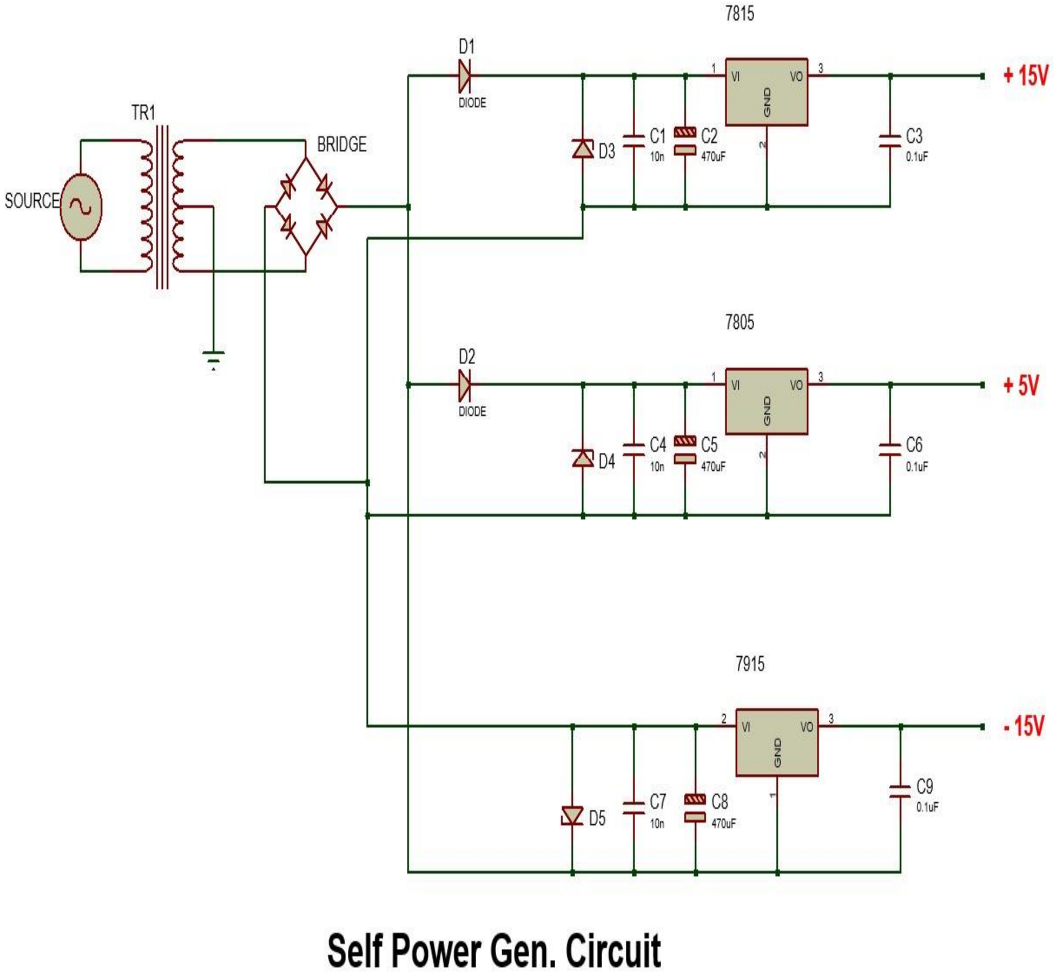


Fig: 2

Calculation of C – values, Zener diode ratings:

1) Calculation of input and output decoupling capacitances:

- The output decoupling capacitor (C_{out}) can be approximated using the ripple voltage and the load current:

  $C_{in} = I_{Load} / (f * V_{Ripple})$

- For the input decoupling capacitor (C_{in}), a commonly used approach is:

$C_{out} = (I_{Load} * V_{dropout}) / (f * V_{InputRipple})$

where $V_{Dropout}$ is the voltage difference between the unregulated input and the regulated output.

Estimating the load current:

- From the circuit, the load is primarily the current consumed by the operational amplifiers (741) and the sensor output.
- The 741 operational amplifier typically has a quiescent current (no load current) of about 1.5 mA to 2.5 mA. Assuming there are no other significant loads on its output, we'll consider the higher value of 2.5 mA for each op-amp. So, for two op-amps, the current is 5 mA.
- The sensor output is given as 12.5 mA.
- Combining the two, the total load current is:

I_{Load} = 5mA (forop-amps) + 12.5mA (sensor-output) = 17.5mA

Using the following values:

- For C_{in} (assuming 7815 as an example): C_{Out}

= 17.5mA / 50Hz * 10mV = 350μF

We can use the nearest higher standard value, such as 470μF.

- For C_{out}, assuming V_{Input} ripple is also 10mV and a $V_{Dropout}$ of 3V (typical for 7815 under max load):

C_{in} = 17.5mAx3V / 50Hz x10mV = 1.5μF

We can use a 10μF capacitor or the nearest higher standard value.

Breakdown Voltage Ratings of Zener diodes to be used:

For IC 7815 and IC 7915 – A 35 V rated Zener diode
For IC 7815 – A 25 V rated Zener diode.

3.2. Signal conditioning circuit:

In this sub-circuit, the input voltage (0-300V) is fed to the ZMPT101-B sensor and is converted to a voltage range of (0-1.44V).

The ZMPT101B is an AC voltage sensor module that measures the AC voltage of a single-phase power supply. It has an output voltage that is proportional to the measured AC voltage. The ZMPT101B is a small, low-power module that is easy to use. It is a popular choice for applications such as power monitoring, voltage measurement, and control systems.

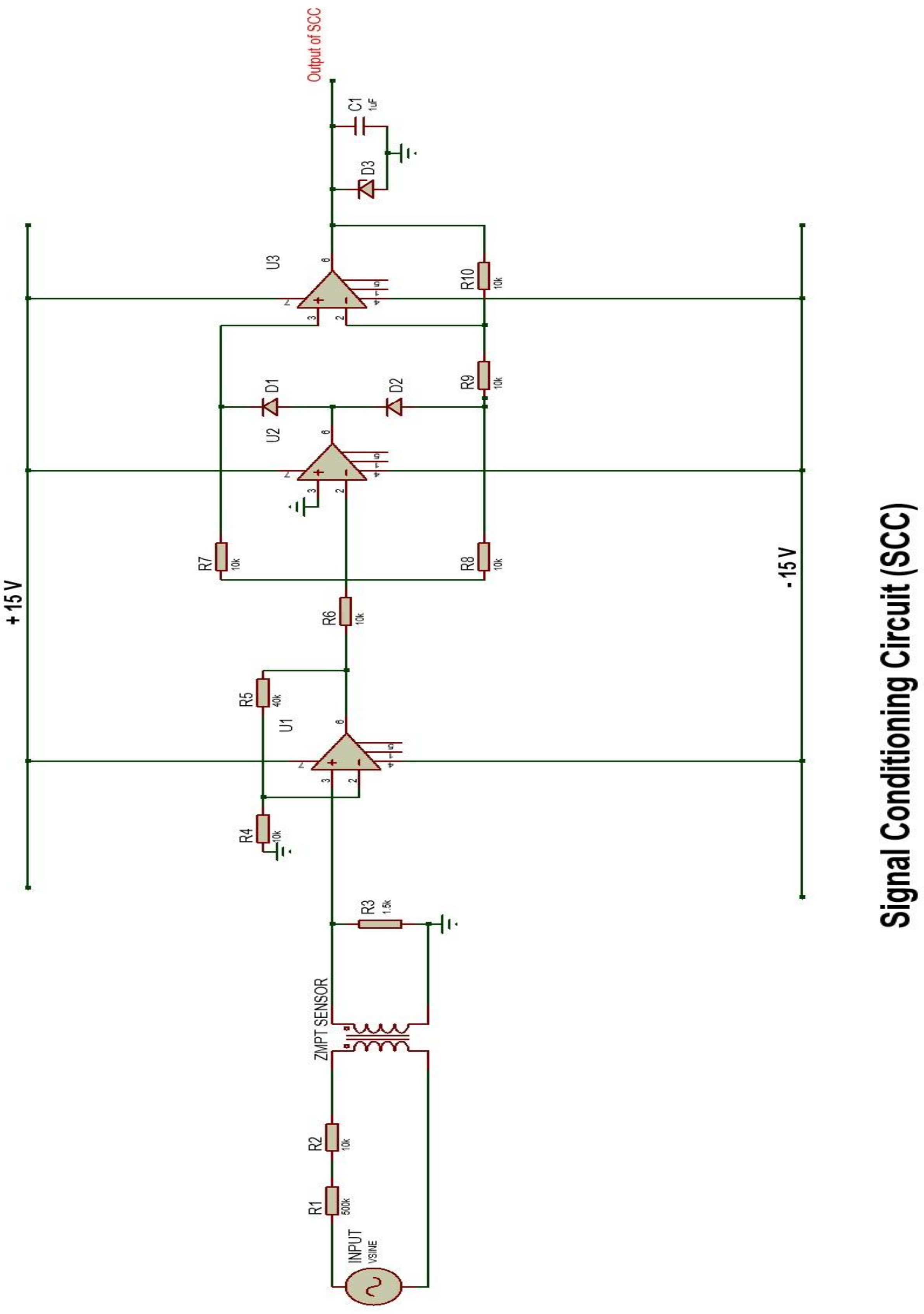
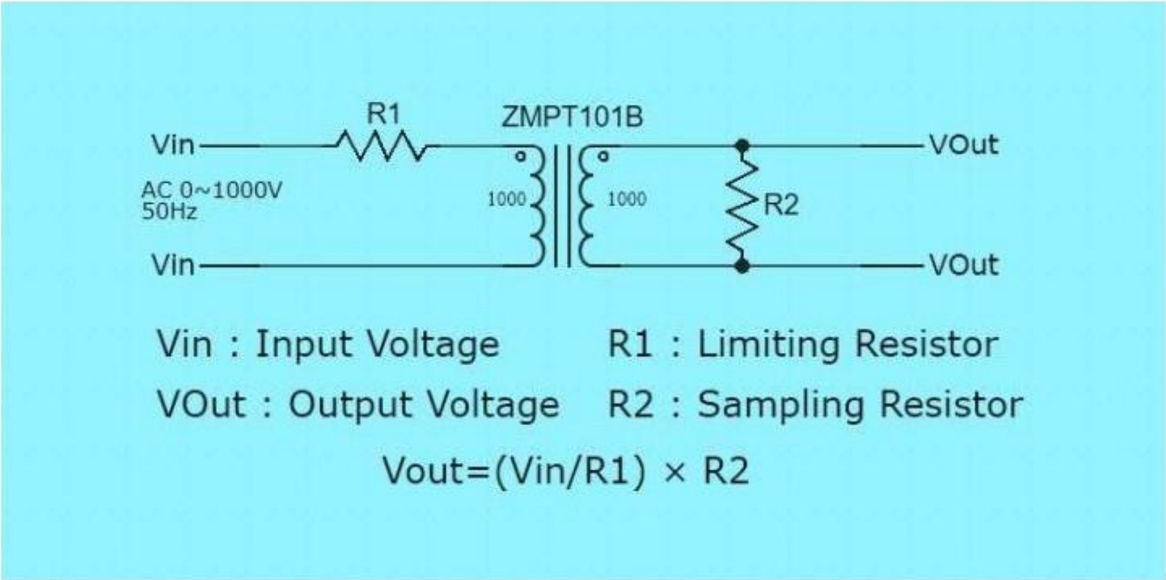

Output of SCC
C1
1uF
D3
U3
R10
10k
D1
D2
U2
R9
10k
R7
10k
R8
10k
+15 V
-15 V
R6
10k
R5
40k
U1
R4
10k
R3
1.5k
ZMPT SENSOR
R2
10k
R1
500k
INPUT
VSINE
Signal Conditioning Circuit (SCC)

Fig: 3

ZMPT101B schematic/ Wiring Diagram



Calculation of R1 and R2:

Due to the use of capacitor, there is a voltage drop in the final output of the precision rectifier, not giving us the required 5V output, thus, to compensate for it, we have increased the output voltage of the ZMPT sensor to 1.44V

Maximum current is 2mA so

$R_1 = \frac{300\,V}{2 \times 10^{-3}} = 150\ \text{K}\Omega$ $\qquad$ $R_2 = \frac{1.44\,V}{2 \times 10^{-3}} = 720\ \Omega$

$V_{out} = \frac{(Vin)}{R1} \times R2$

$V_{out} = \frac{300\,V}{150 \times 1000} \times 720 = 1.44\ \text{V}$

Next the output from the sensor is amplified 5 times

For that the value of resistances are

$R_2 = 3.3\ \text{k}\Omega$ $\quad$ $R_1 = 820\Omega$

as the formula for gain of non-inverting amplifier is $1 + \frac{R_2}{R_1} = 1 + \frac{3300}{820} = 5.004$ so the output after amplification is 7.2 V

Now this 7.2V AC should be converted to DC for proper working of the the next part of the circuit i.e, the comparator circuit. For that we have used a precision rectifier circuit. After the precision rectifier due to addition of capacitive filter we get 5V DC as output with a small ripple which can be seen in the simulation graphs Here a precision rectifier was preferred over normal bridge rectifier because Precision rectifiers provide more accurate DC output voltage compared to standard rectifiers. This is because they compensate for the inherent voltage drop across diodes, which can significantly distort the output waveform. Precision rectifiers offer high accuracy in rectifying the AC signal. This is important in applications such as instrumentation, where precise signal conditioning is necessary without introducing additional errors. Standard rectifiers produce ripple, which is an unwanted AC component superimposed on the DC output. Precision rectifiers incorporate additional filtering stages to minimize ripple, resulting in a smoother and cleaner DC output.

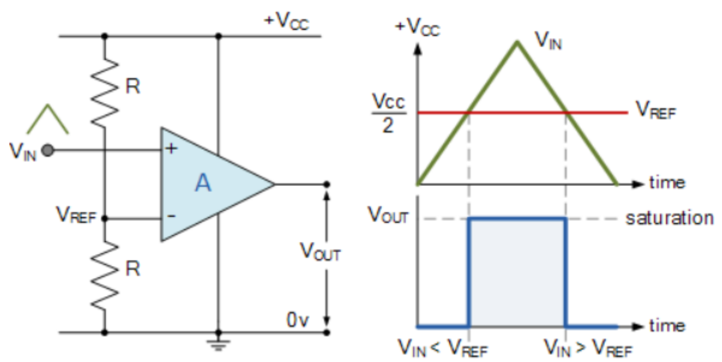
3.3 Comparator circuit:

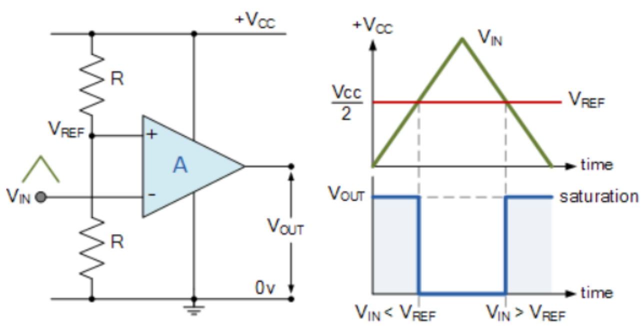
In this part of the circuit, the maximum voltage that will go to the comparator circuit which corresponds to 300 V is 5 V . The core functional block of the circuit comprises a duo of comparator circuits, 2 inverting op amps and an AND gate each designated to handle a specific voltage monitoring task:

- **The Inverting Comparator:** This comparator circuit is designed to detect when the input voltage falls below the threshold of 180V (when actual voltage < 3V), indicative of an undervoltage condition. The inverting comparator inverts the sense of the input signal, producing a high output when the input voltage is below the set point, thus driving the connected LED to indicate an undervoltage state.

- **The Non-Inverting Comparator:** Conversely, this comparator is responsible for identifying an overvoltage situation, which occurs when the input surpasses 235V (when actual voltage > 3.917V). In this case, the non-inverting nature of the comparator results in a high output when the input voltage exceeds the reference voltage, triggering the corresponding LED to signal an overvoltage condition.

- **Inverting op amps with AND gate**: To illuminate an LED only when the input voltage is within the normal operating range (180V to 235V) (when actual voltage is in the range of (3-3.917) V, we use the help of 2 inverting op amps with inputs taken from the 2 comparator circuits respectively , and the output from 2 op amps is fed to an AND gate. AND gate will give positive output only when both the inputs are positive. When the input voltage range is in between 3V and 3.917V the outputs of both the comparator circuit will be negative and with the help of inverting amplifiers with gain as -1 we can convert them to positive voltages and give it to AND gate. For any other case the output from both the comparators will not be negative, which means AND gate will not receive two positive voltages and the LED connected to it will not glow.





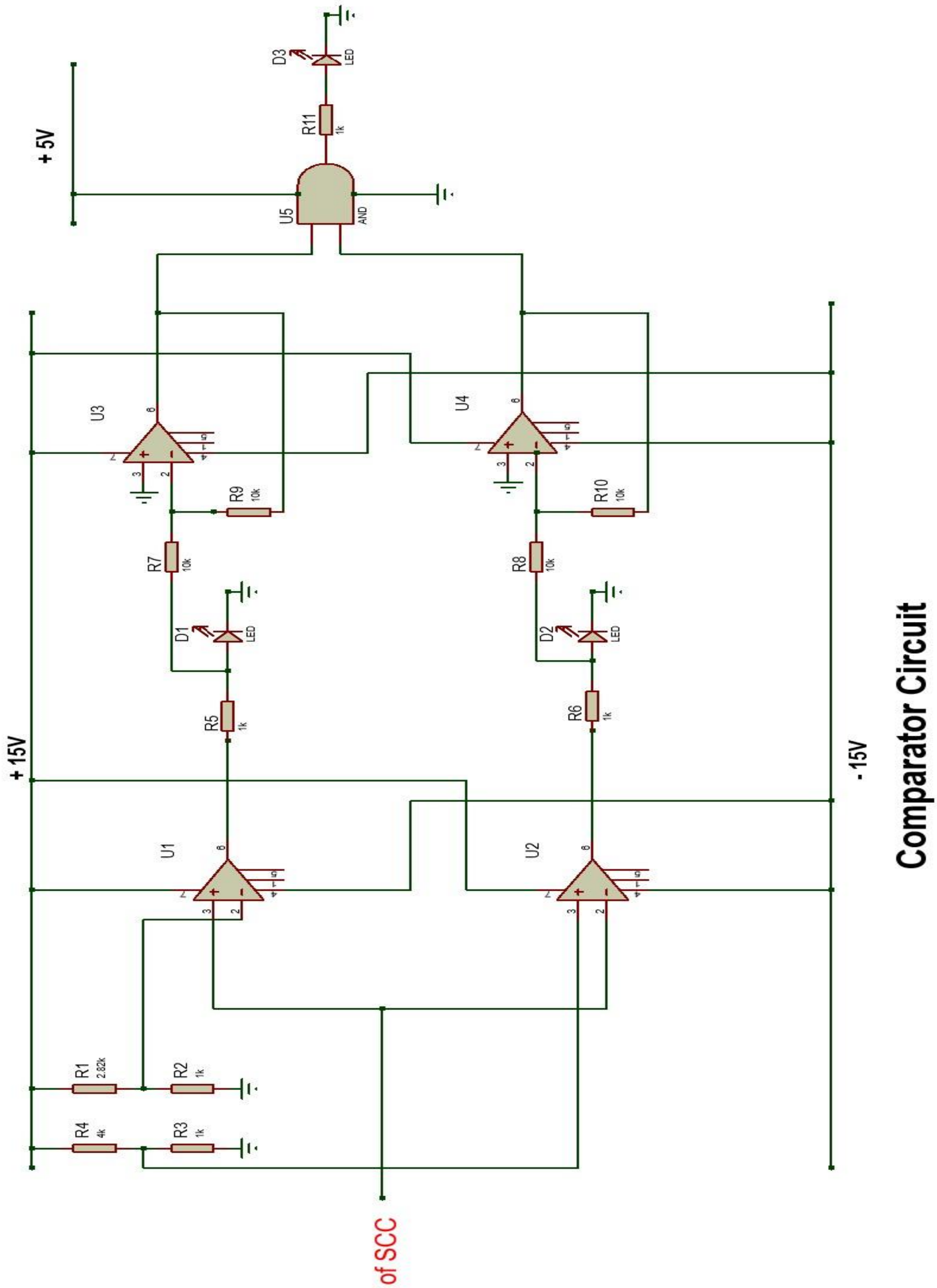

Comparator Circuit
+ 5V
+ 15V
- 15V
Output of SCC
U1
U2
U3
U4
U5
AND
R1
2.82k
R2
1k
R3
1k
R4
4k
R5
1k
R6
1k
R7
10k
R8
10k
R9
10k
R10
10k
R11
1k
D1
D2
D3
LED

Fig: 4

Calculation of Resistances for inverting and non-inverting amplifiers:

for non inverting comparator(overvoltage)

300 V corresponds to 5 V so 235 V corresponds to 5/300 ×235 = 3.9 V

To get 3.9 V we use a potential divider circuit with input as +15 V from 7815 IC

We use two resistors of value 2.82 KΩ and 1kΩ

for inverting comparator(overvoltage)

300 V corresponds to 5 V so 180 V corresponds to 5/300 ×180 = 3 V

To get 3 V we use a potential divider circuit with input as +15 V from 7815 IC

We use two resistors of value 4 kΩ and 1 kΩ

For the inverting comparators with gain as -1 we will just use two resistors with values 1 KΩ as the formula for gain is $-\frac{R_2}{R_1}$.

We have to limit the current that enters the LED to ensure it doesn't get damaged for that we use a 1 KΩ resistor in series with LED.

3.4 Safety Features and Reliability

The design includes several safety features, such as the electrical isolation provided by the LV-25P sensor and the Zener diode's overvoltage protection for the voltage regulators, ensuring that the circuit does not operate under conditions that could damage the components or produce unreliable outputs.

The sensor and signal conditioning unit is also protected from reverse supply polarity using a diode in series from the output of the bridged rectifier and the voltage sensor.

The below circuit combines all 3 sub-circuits and represents out Signal Conditioning Circuit to measure AC voltage:

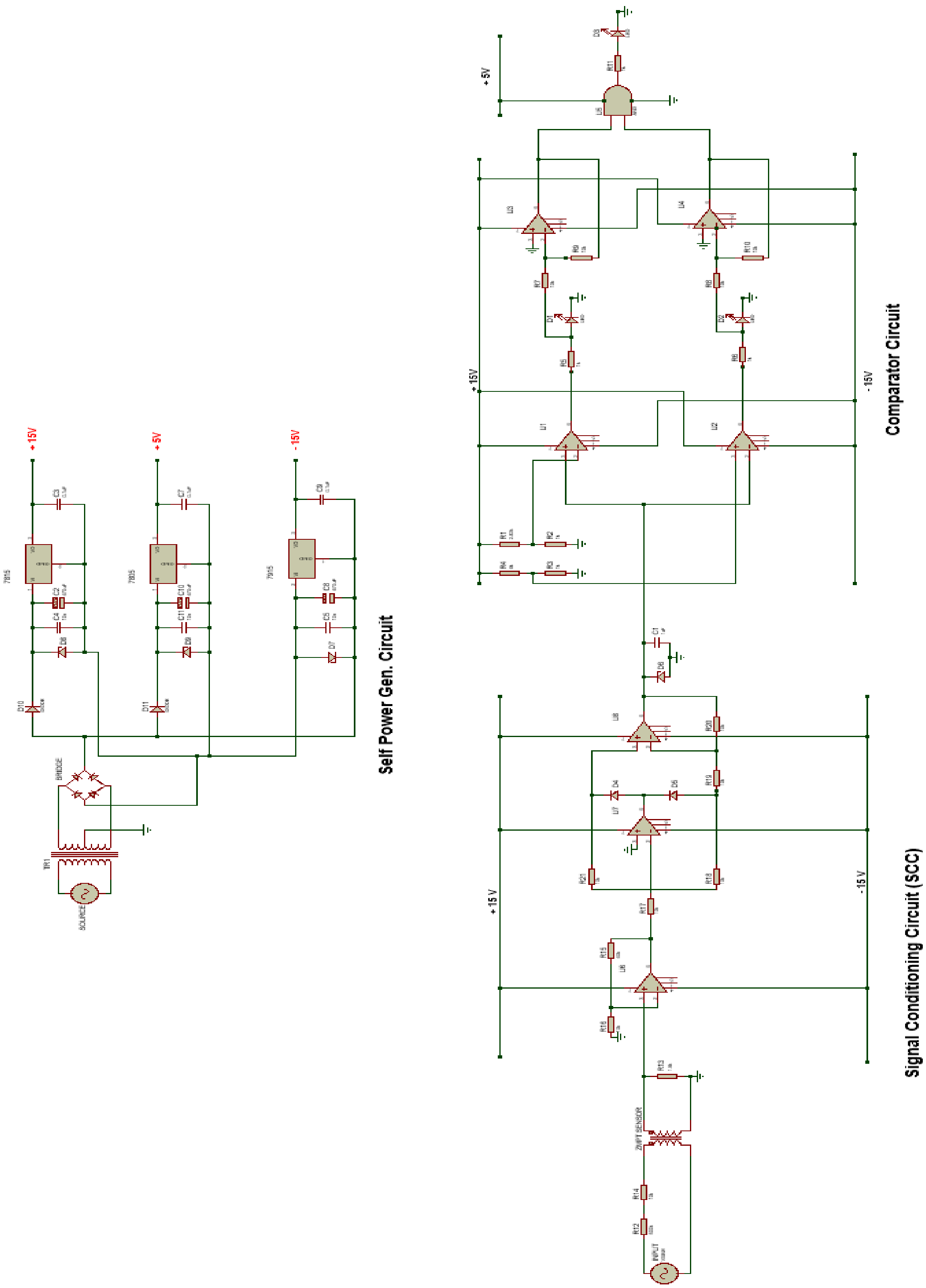
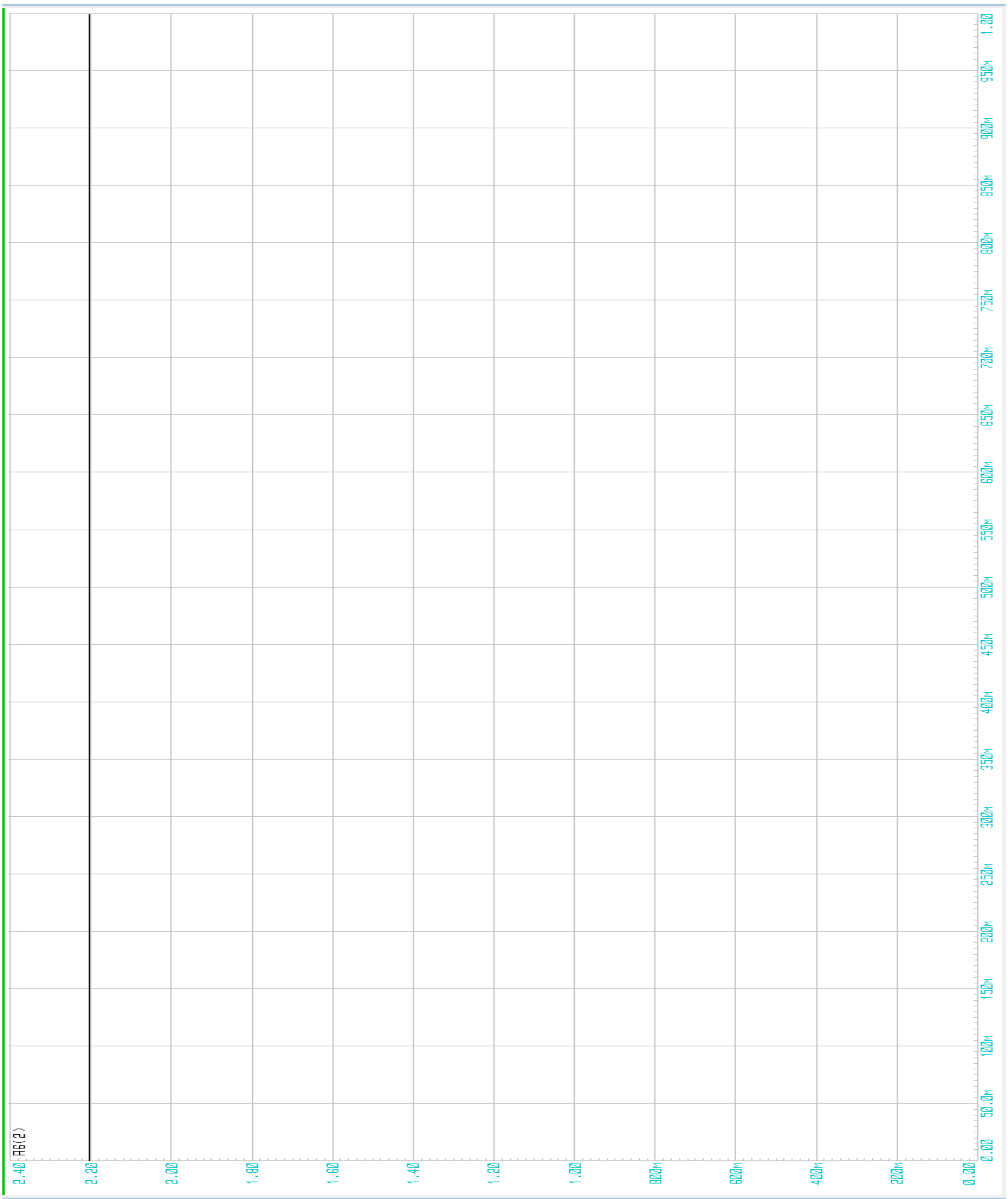


Fig: 4 – Complete circuit

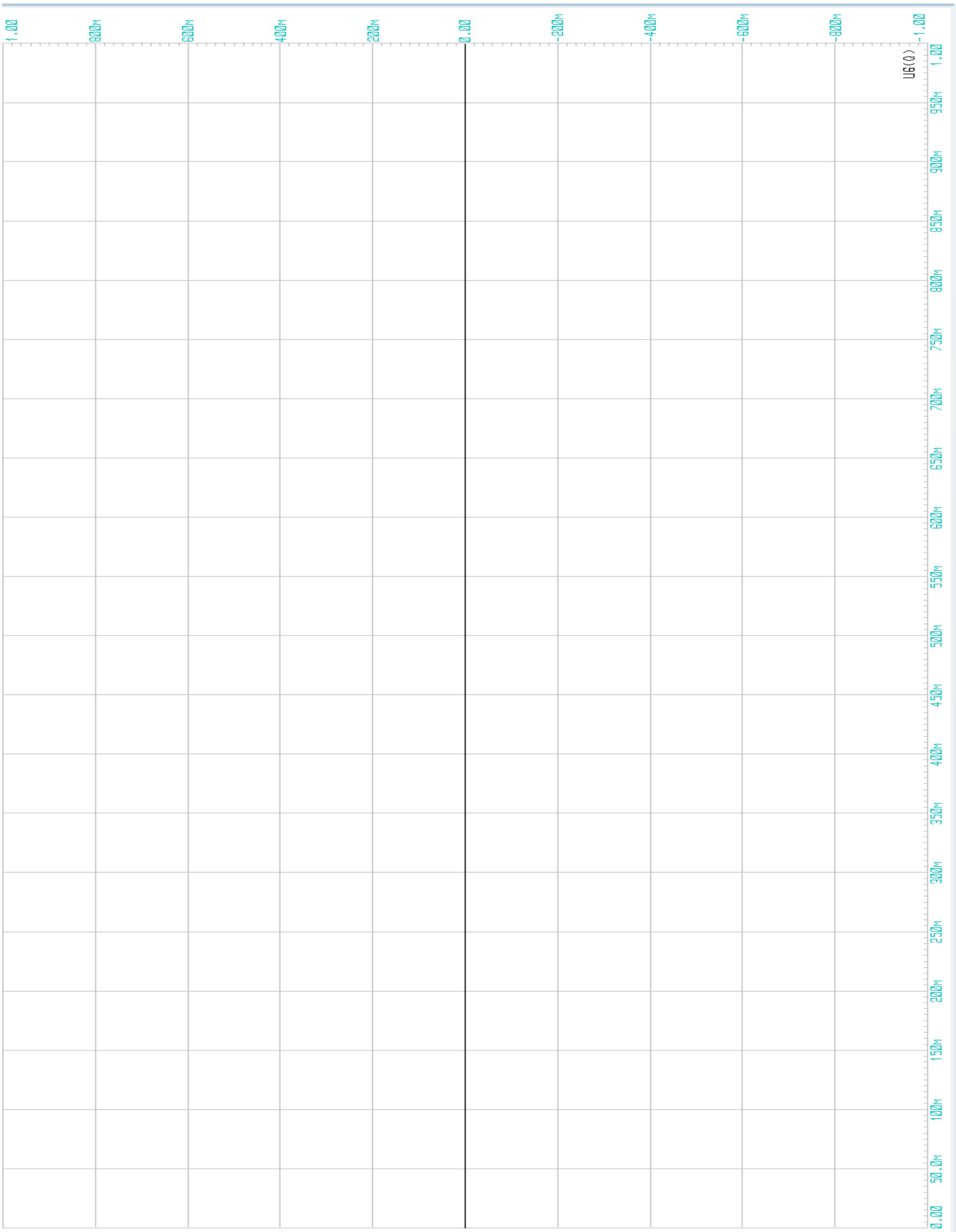
4. Simulation and Experimental results:

Voltage across LEDs for inverting comparator when input voltage is less than 3V and for non inverting comparator when input voltage is more than 3.9V

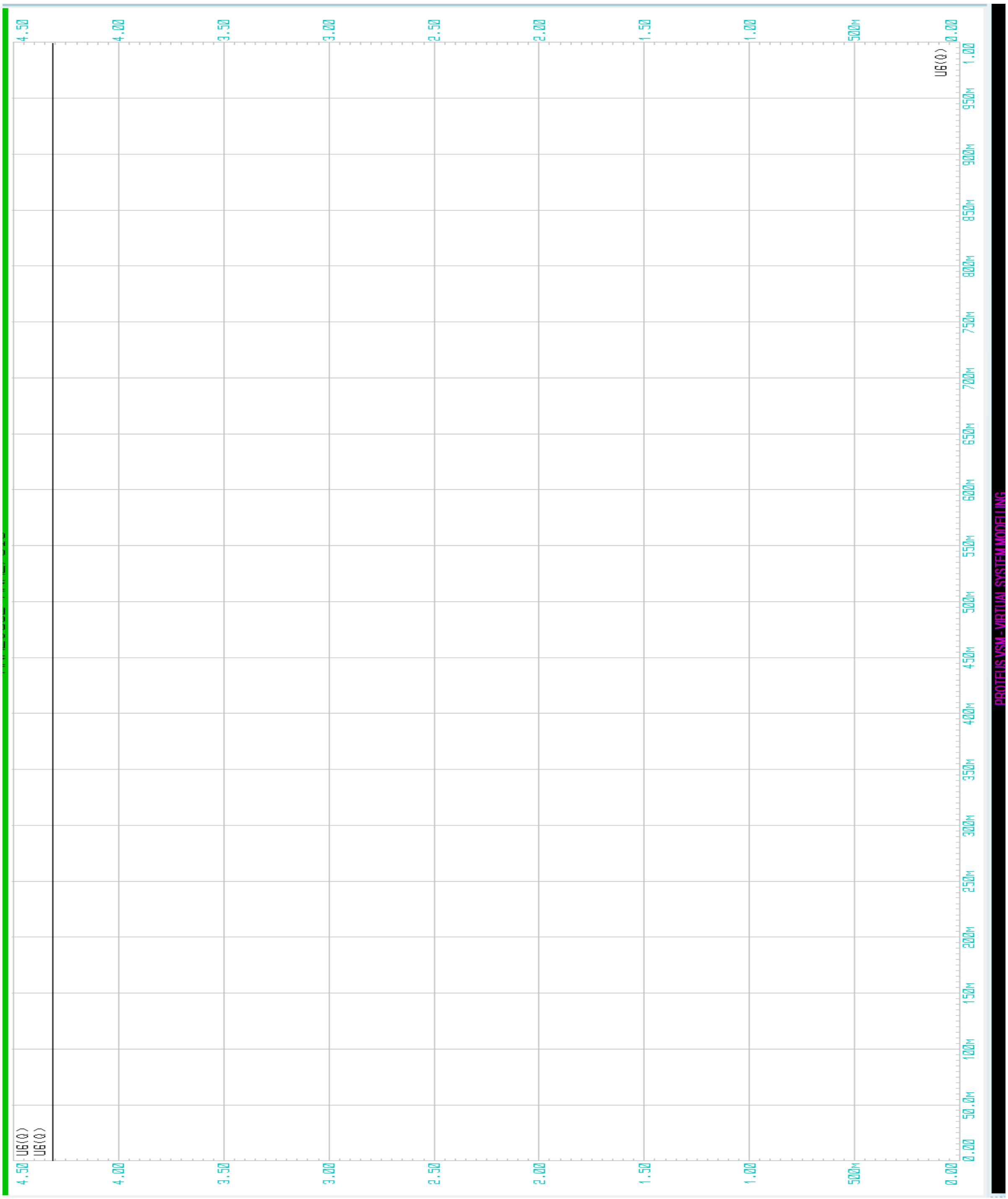


Voltage across LEDs for inverting comparator when input voltage is more than 3V and for non inverting comparator when input voltage is less than 3.9V

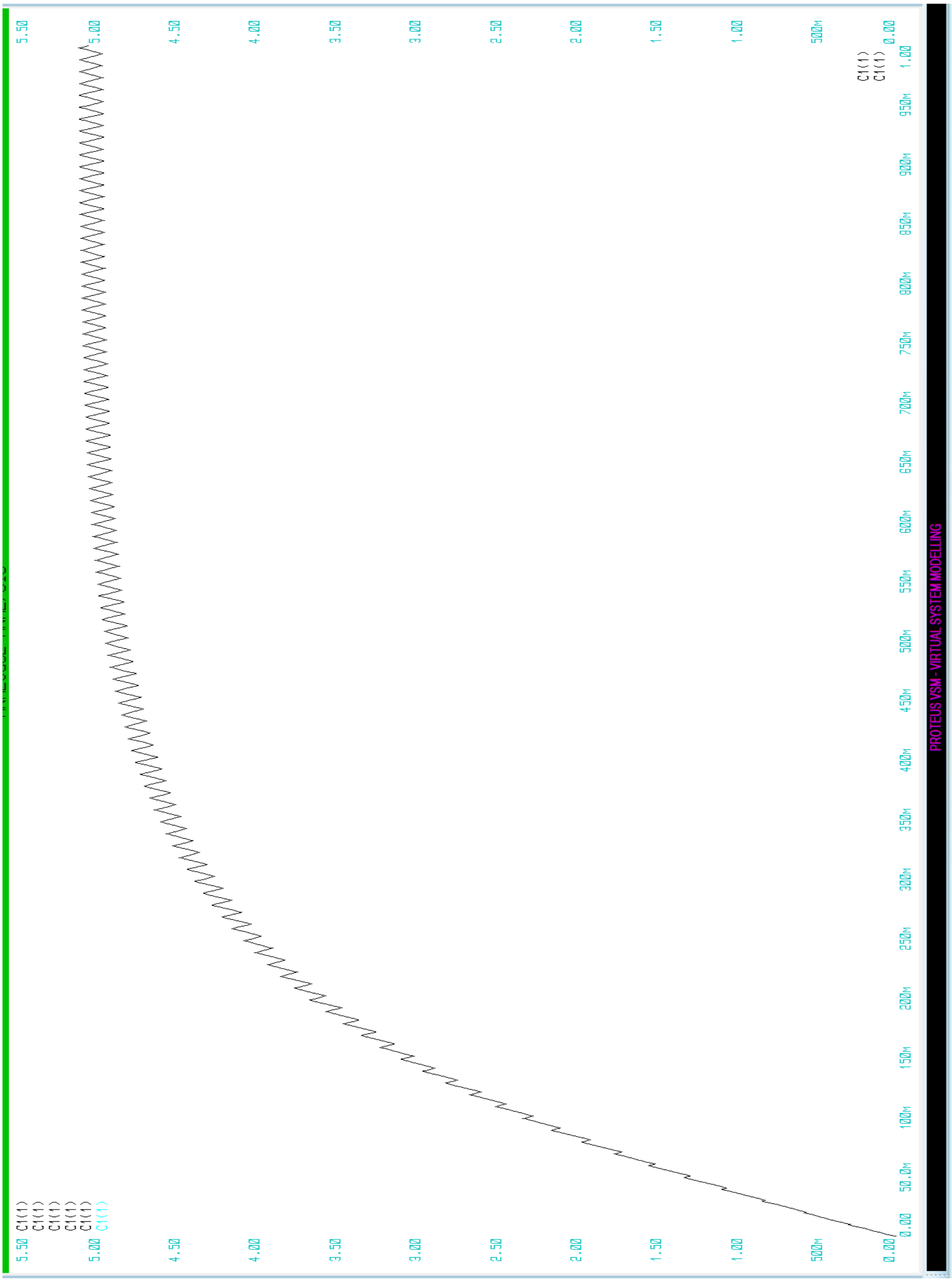
Voltage across LED for AND gate when input voltage is not in between 3V and 3.9V



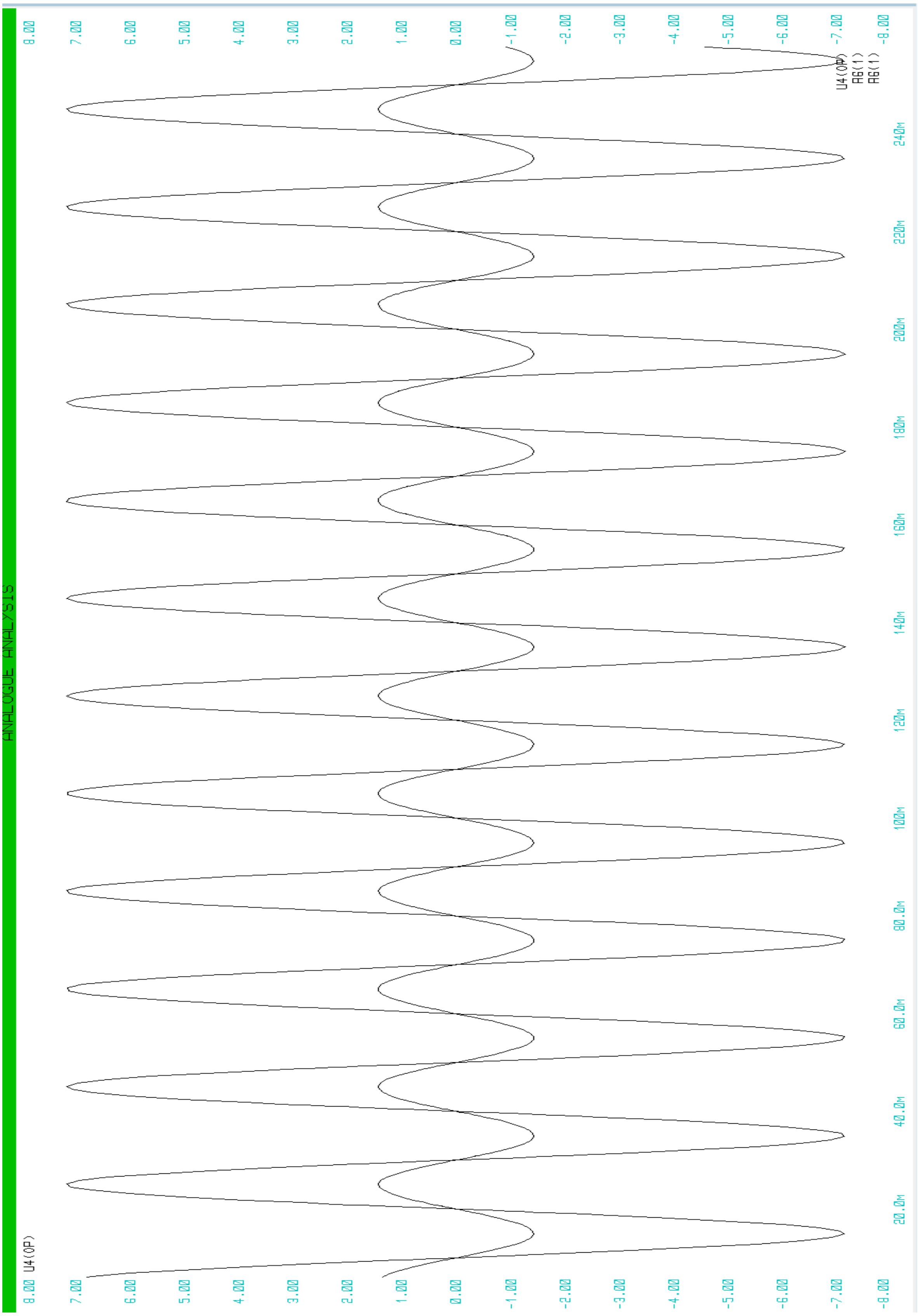
Voltage across LED for AND gate when input voltage is in between 3V and 3.9V



Output voltage from precision rectifier with capacitive filter:



Voltage from ZMPT sensor and the amplifier with gain = 5



4.1 Components used: (as in the circuit)

1. **Resistors**: The resistance values and their corresponding locations are marked by R followed by a number (e.g., R2, R3, etc.). Their resistance values are as follows:

   Signal Conditioning Circuit

   - R1: 500 kΩ
   - R2: 10 kΩ
   - R3: 1.5 kΩ
   - R4: 820 Ω
   - R5: 3.3 kΩ
   - R6, R7, R8, R9, R10: 10 kΩ

   Comparator Circuit

   - R1: 2.82 kΩ
   - R2, R4, R5, R6, R11: 1 kΩ
   - R3: 4 kΩ
   - R7, R8, R9, R10: 10 kΩ

2. **Capacitors**: Capacitors are labeled C followed by a number (e.g., C1, C2, etc.):

   Self-power Generation Circuit

   - C1, C3, C5, C7, C8, C9: 1 μF
   - C2, C4, C6: 470 μF

   Signal Conditioning Circuit

   - C1: 470 μF

3. **Diodes**:

   Comparator Circuit

   - D1, D2, D3: Light Emitting Diodes (LEDs) for indication purposes.

   Self-power Generation Circuit

   - D1, D2: Diode for reverse voltage protection.
   - D3, D4, D5: Zener diodes for voltage regulation and protection.

   Signal Conditioning Circuit

   - D1, D2: Diodes used in precision rectifier.

4. **Integrated Circuits**:

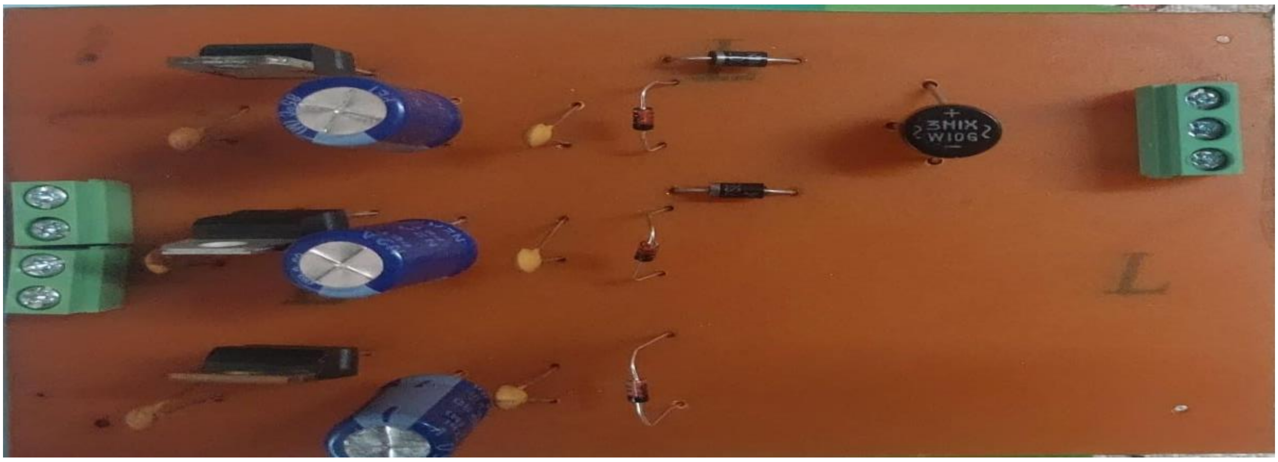
   - Op741: 741 operational amplifiers used in amplification, precision rectifiers and various comparator configurations.

- IC7804: It is used to convert the output of the LV-25P voltage sensor to the required voltage signal of (0-5)V
- IC7815 positive voltage regulators to provide a stable +15V output for +Vcc,
- IC7915 negative voltage regulator to provide a -15V output for -Vcc.
- IC7408 (And Gate) used in detection of normal voltage range.

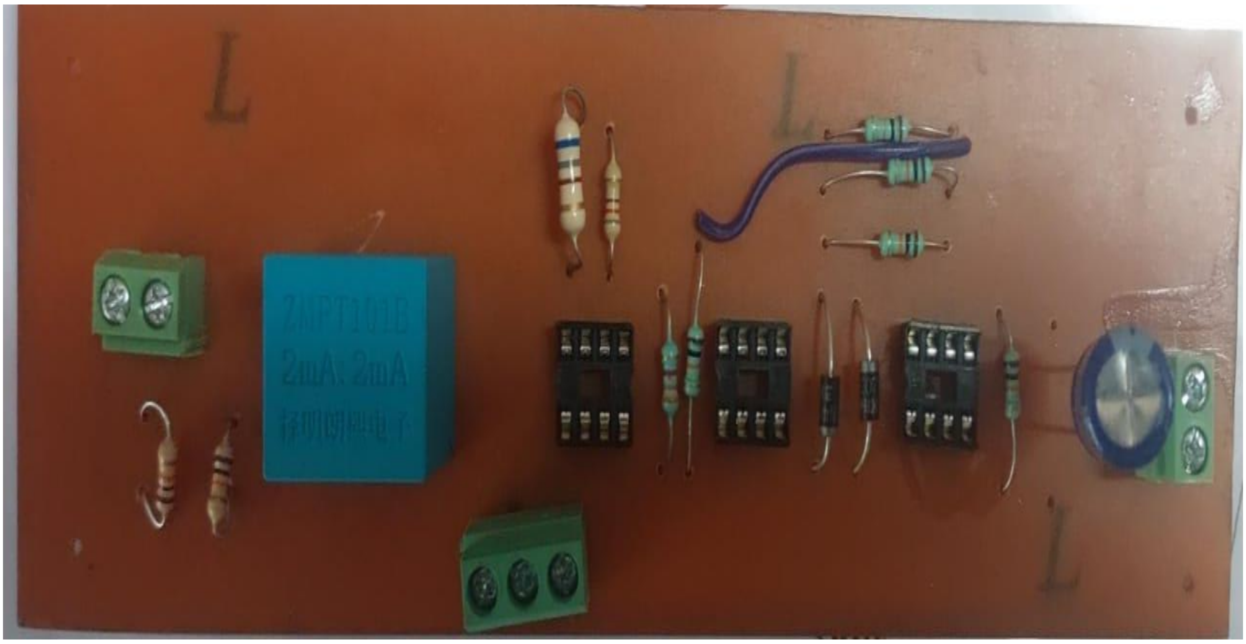
5. **Transformer**:
   - TR1: A step-down transformer, with Vin = 220V, Vout = +24/0/-24V
6. **Bridge Rectifier**:
   - BR1: A full-wave bridge rectifier, which contains four diodes to convert AC to DC.
7. **AC Source**:
   - V1: The AC voltage source, denoted as V_SINE, which can vary from (0 – 300)V
8. **ZMPT101-BVoltage Sensor:**
   - As it was not available in proteus, we have modelled it using a dependent current source.

9. **Connector/Wire Links**:
   - The unmarked lines represent electrical connections/wires.

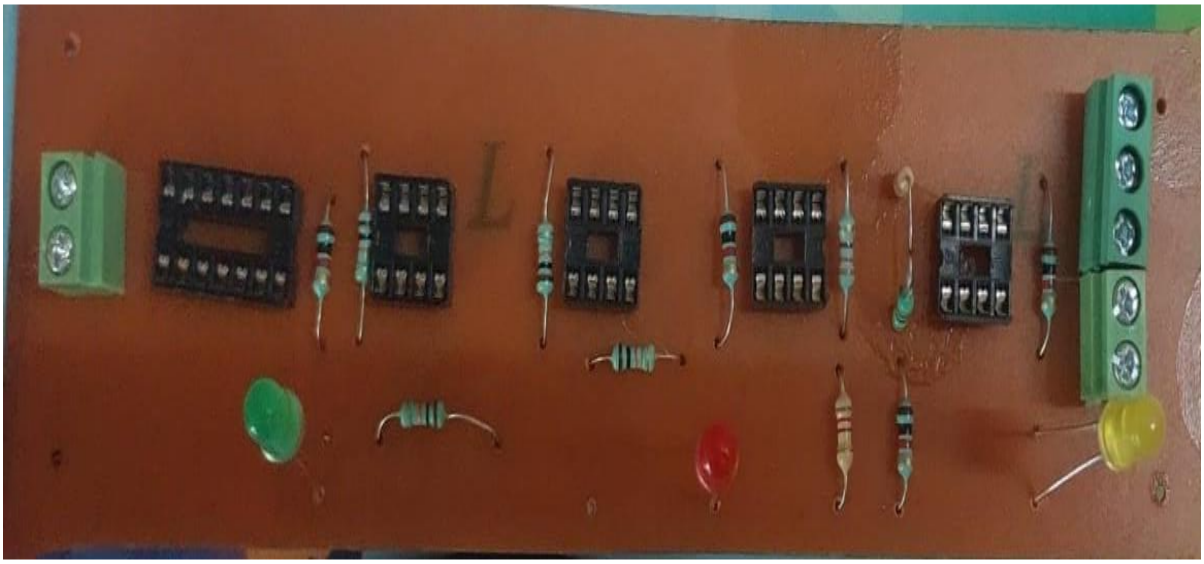
4.2 Final PCB designed circuits:



Self-power Generation Circuit



Signal Conditioning Circuit



Comparator Circuit

5. Results and Discussion:

The simulation of the "Signal Conditioning Circuit to detect AC Voltage " circuit in Proteus yielded successful outcomes. Testing across a span of voltage inputs confirmed the circuit's functionality, with each LED indicator illuminating correctly in response to its corresponding voltage condition. The undervoltage LED (Red) activated when the input was below the threshold, the overvoltage LED (Yellow) lit up upon exceeding the upper limit, and the normal voltage LED (Green) indicated proper voltage levels within the specified range. These results validate the circuit's design, demonstrating its potential efficacy in real-world voltage monitoring applications.

5.1 Developments in the circuit:

Usage of logic gates instead of window comparator:

Logic gates and window comparators are both electronic circuits that perform comparisons of input signals. However, they have different functionalities and are used in different applications. Window comparators are specialized circuits that compare an input signal to two reference voltages. They output a high signal if the input signal is within a specified range (the "window") and a low signal if the input signal is outside the window. Window comparators are often used in analog-to-digital converters (ADCs) to convert analog signals into digital representations.

In general, logic gates are used for digital applications, while window comparators are used for analog applications. However, there are some cases where it is possible to use logic gates instead of a window comparator. For example, if you need to compare an input signal to two fixed reference voltages, you can use two comparators and an AND gate to create a window comparator circuit. Logic gates can be combined in many different ways to create complex circuits. This makes them very flexible and adaptable to different applications. Logic gates can be very fast, especially when compared to window comparators. This makes them well-suited for applications that require high-speed operation. Logic gates are typically more power-efficient than window comparators. This makes them a good choice for applications where power consumption is a concern.

6. Conclusion:

In conclusion, the voltage monitoring circuit presented in this report exemplifies a comprehensive solution to monitoring and managing voltage levels in high-voltage systems. Its meticulous design integrates a series of electronic components, including the ZMPT101-B voltage sensor for initial voltage transformation and operational amplifiers for subsequent signal conditioning. The decision to employ a logic gates over a window comparator is a testament to the circuit's capacity to handle a full spectrum of analog voltages, ensuring precise monitoring with less complexity .

The circuit's ability to provide immediate visual feedback through LEDs for overvoltage, undervoltage, and acceptable voltage range conditions, adds to the robustness of the monitoring process. Additionally, the inclusion of a self-regulating power supply, complete with a backup path activated by a Zener diode, ensures that the circuit maintains its operational integrity, even in the face of power supply fluctuations.

Safety and reliability are woven into the fabric of the design, with features like electrical isolation and protection circuits safeguarding against conditions that could potentially harm the system or compromise its performance. The redundancy of visual indicators serves not just as a failsafe but also as a clear and immediate method of communicating the system's status to operators.

7. Datasheets:

The major components which we used are ZMPT101-B voltage sensor, Op-amp 741, Voltage regulators IC7815 and IC7915, we will link the datasheets of these components in this section;

1. Op-amp 741 - µA741 General-Purpose Operational Amplifiers datasheet (Rev. G)
2. IC 7815 - LM7815.XLS (tme.eu)
3. IC 7915 - LM79XX Series 3-Terminal Negative Regulators datasheet (Rev. C)
4. ZMPT101B - https://pdf1.alldatasheet.com/datasheet-pdf/view/1131993/ETC2/ZMPT101B.html

References:

1. Sedra, A.S., and Smith, K.C. "Microelectronic Circuits." Oxford University Press, 6th Edition, 2009.
2. Gayakwad, R.A. "Op-amps & Linear Integrated Circuits." Prentice Hall of India, 4th Edition, 2009.
3. Smith, John A., and Doe, Jane. "Design and Analysis of Window Comparator Circuits for Voltage Monitoring." Journal of Electrical Engineering
4. Op-amp Comparator and the Op-amp Comparator Circuit (electronics-tutorials.ws)
5. Voltage Sensor: What is it And How Does it Work? (Circuit Diagram Included) | Electrical4U
6. Datasheets of all the components used as mentioned in the previous section.