VIETNAM NATIONAL UNIVERSITY HO CHI MINH CITY
HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
FACULTY OF COMPUTER SCIENCE AND ENGINEERING

Electrical Electronic Circuits

Assignment Report

Advisor(s): Phạm Công Thái

Student(s): Trần Văn Minh Triết 2413603

Nguyễn Phúc Vĩnh 2414001

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1 Introduction

1.1 Introduction about diode

A diode is a two-terminal electronic component that conducts current primarily in one direction; it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other. A diode vacuum tube or thermionic diode is a vacuum tube with two electrodes, a heated cathode and a plate, in which electrons can flow in only one direction, from cathode to plate. Semiconductor diodes were the first semiconductor electronic devices. The most common type of diode today is the semiconductor diode, which is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals. Semiconductor diodes were the first semiconductor electronic devices. The most common type of diode today is the semiconductor diode, which is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals.

Modern electronic systems mainly use semiconductor diodes. A semiconductor diode is typically made from a crystalline semiconductor material forming a p–n junction, with two electrical terminals connected to the p-type and n-type regions. Due to their small size, reliability, and efficiency, semiconductor diodes are widely used in electronic circuits today.

Diodes are widely used in electronic circuits for rectification, voltage regulation, signal demodulation, and circuit protection. For example, rectifier diodes are commonly used in power supply circuits to convert alternating current (AC) into direct current (DC).

1.2 Introduction about BJT

A bipolar junction transistor (BJT) is a type of transistor that uses both electron and hole charge carriers. In contrast, unipolar transistors, such as field-effect transistors (FETs), only use one type of charge carrier. BJTs are made of three layers of semiconductor material, each capable of carrying current. The three layers form two p–n junctions: the emitter-base junction and the base-collector junction.

BJTs are classified into two types based on the arrangement of the p-type and n-type materials: NPN and PNP. In an NPN transistor, a layer of p-type semiconductor (the base) is sandwiched between two n-type semiconductors (the emitter and collector). In a PNP transistor, the arrangement is reversed, with an n-type base between two p-type layers.

BJTs are widely used in electronic circuits for amplification and switching applications.

They can amplify weak electrical signals, making them essential components in audio amplifiers, radio transmitters, and other communication devices. Additionally, BJTs are used as switches in digital circuits, allowing for the control of current flow in various electronic devices.

1.3 Introduction about OPAMP

An operational amplifier (op-amp) is a high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In an op-amp, the output voltage is typically hundreds of thousands of times larger than the voltage difference between the input terminals. Op-amps are widely used in analog electronics for various applications, including signal conditioning, filtering, and mathematical operations such as addition, subtraction, integration, and differentiation.

Op-amps are characterized by their high input impedance and low output impedance, making them ideal for use in voltage amplification circuits. They can be configured in various ways to perform different functions, such as inverting and non-inverting amplifiers, voltage followers, summing amplifiers, and differential amplifiers.

Op-amps are commonly used in audio equipment, instrumentation, and control systems. They play a crucial role in analog signal processing, enabling the amplification and manipulation of electrical signals in a wide range of electronic devices.

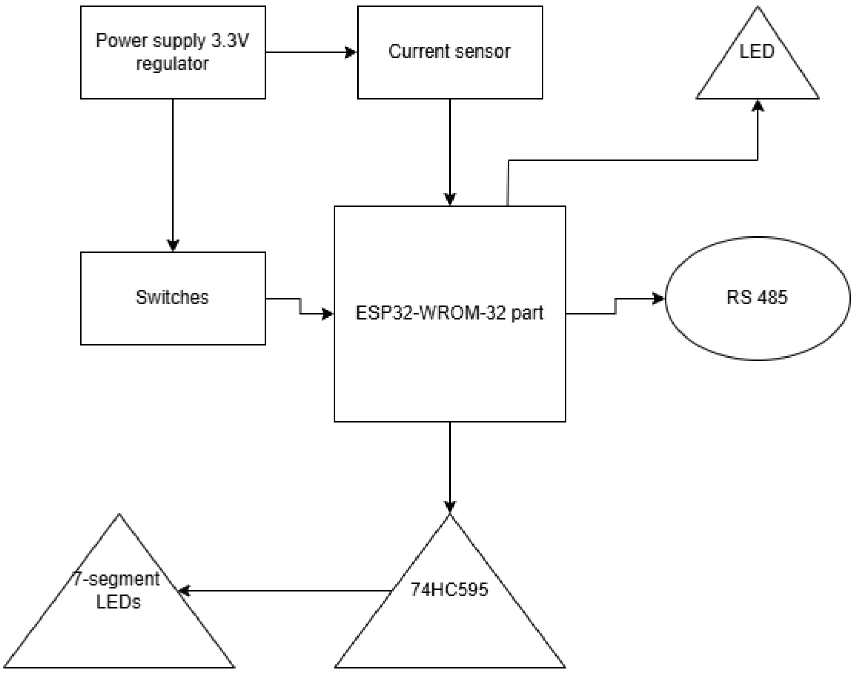
2 Hardware specifications document

2.1 Specification

Component	Description
Power supply 3.3V regulator	Converts input voltage from 3.3V to 5-36V range. Provides stable 3.3V output for the system.
ESP32-WROM-32 part	Microcontroller with 18 ADC channels, SAR ADC on second generation, 9 touch sensors, supports UART, SPI, I2C, I2S, and CAN interfaces. Features PWM, AES encryption, and RSA security.
Switch with an MCU	Provides control interface for the microcontroller.
Current sensor	Monitors current consumption and provides feedback information to ESP32-WROM-32 part.
RS-485 part	Converts UART data to RS-485 transmission protocol.
High-current LEDs	Supports high power and continuous operation without limitations.
PCB dimensions	68.6 mm x 74.7 mm

3 PCB Design using Altium Designer

3.1 Circuit sketching



3.2 Design rule

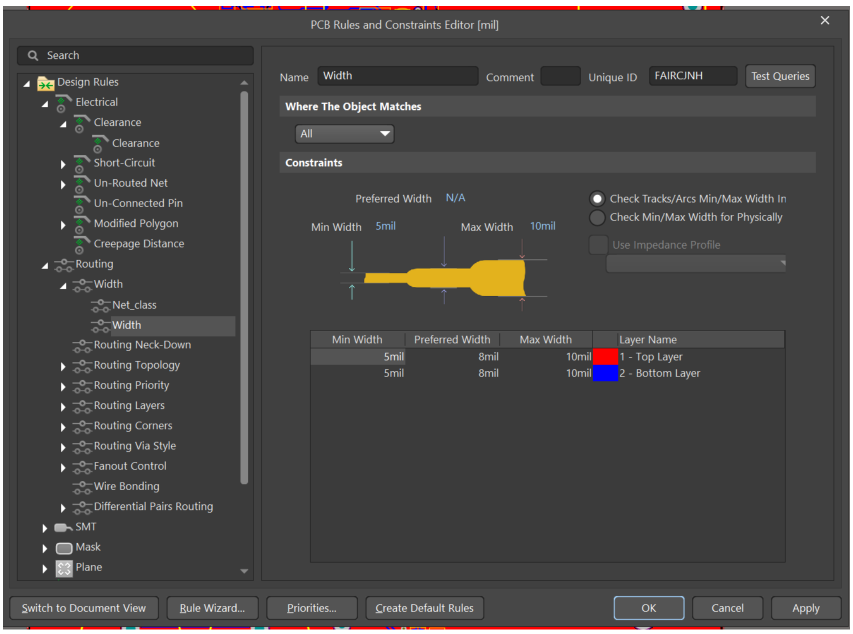


Figure 3.1: Width rule

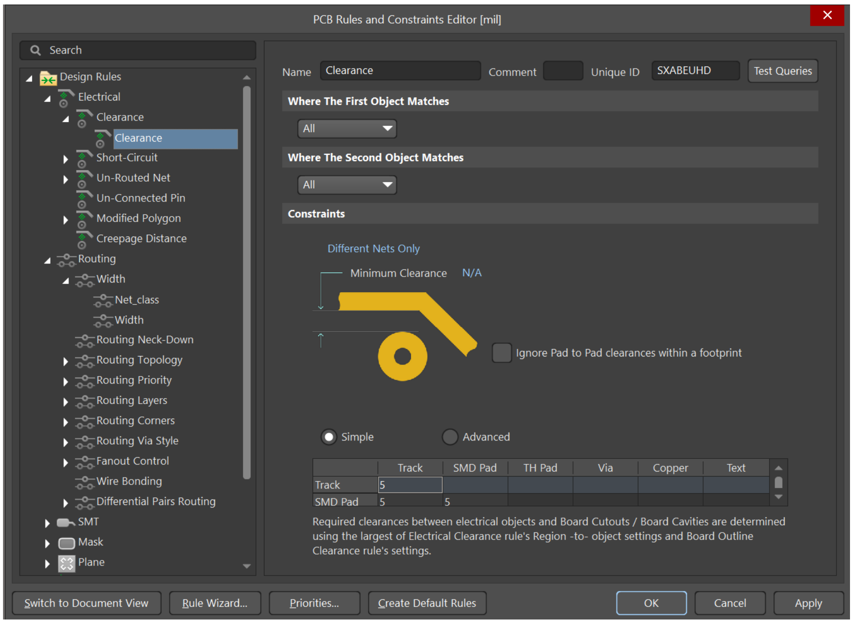


Figure 3.2: Clearance rule

3.3 Schematic of the circuit

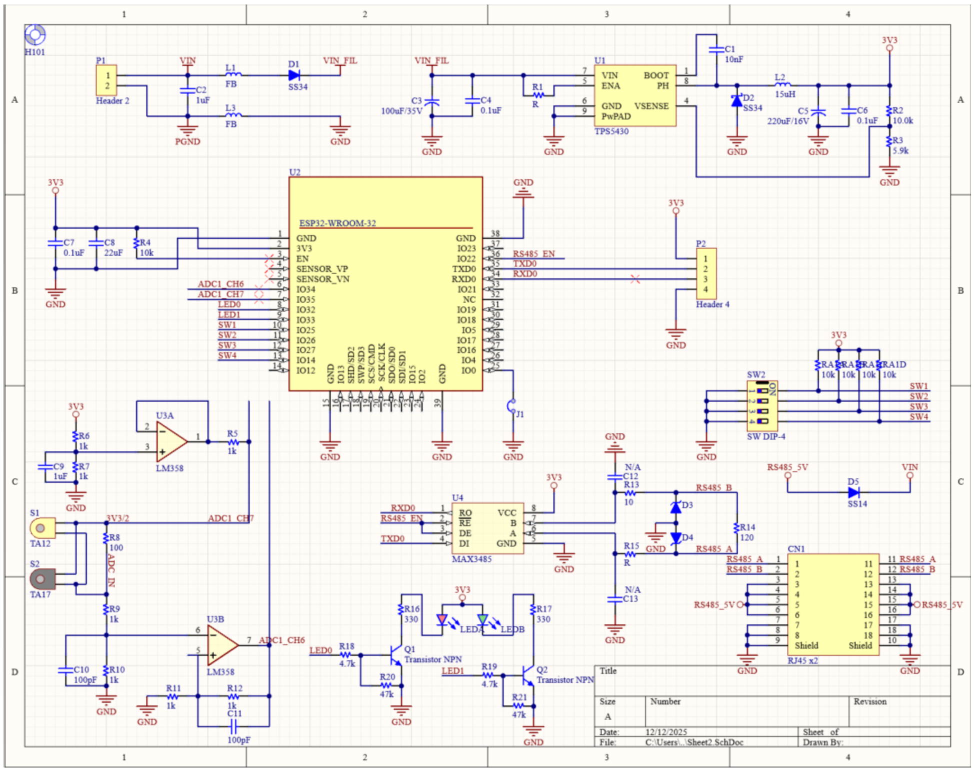


Figure 3.3: Schematic of the circuit

3.4 PCB layout

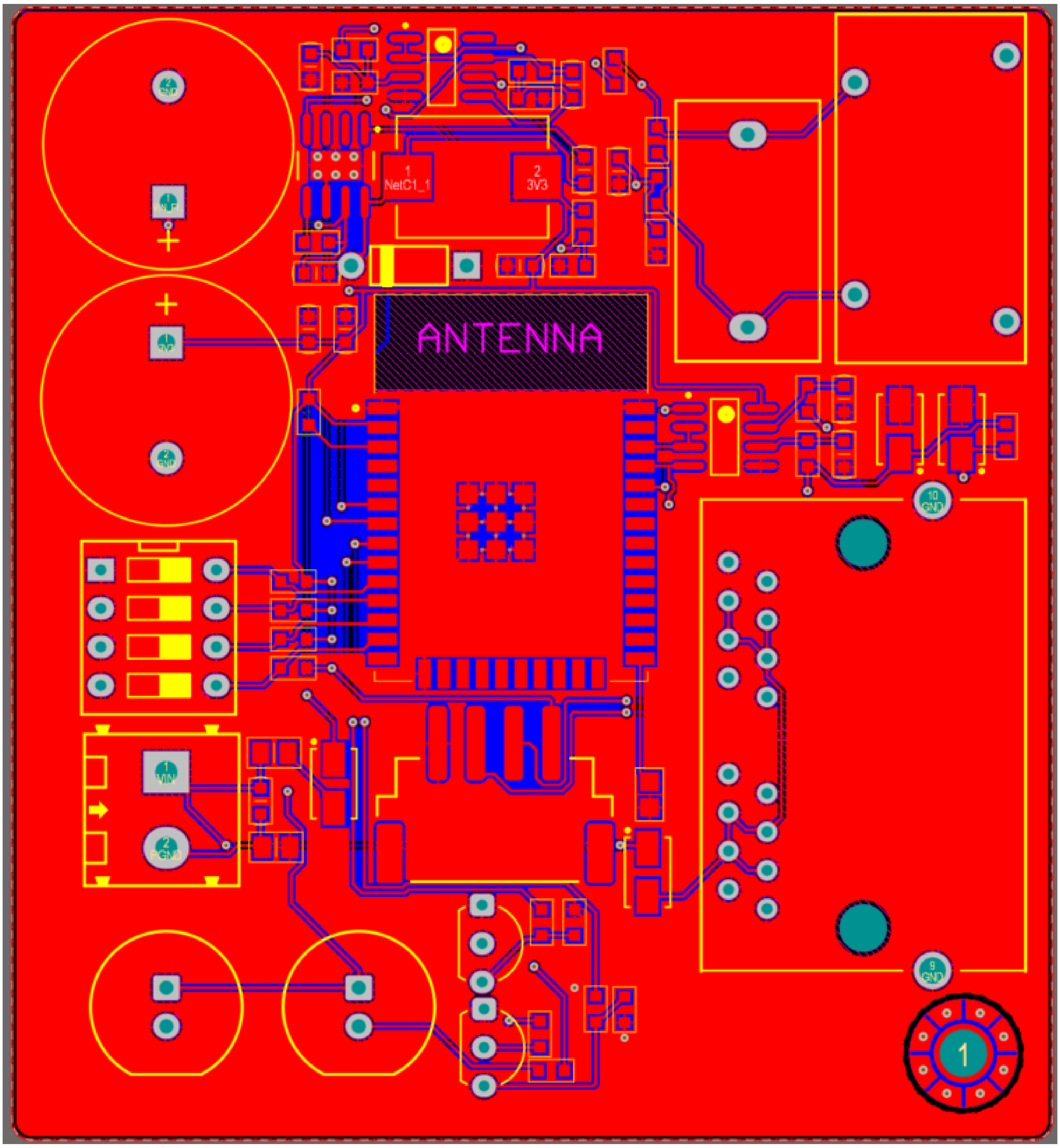


Figure 3.4: PCB top layer

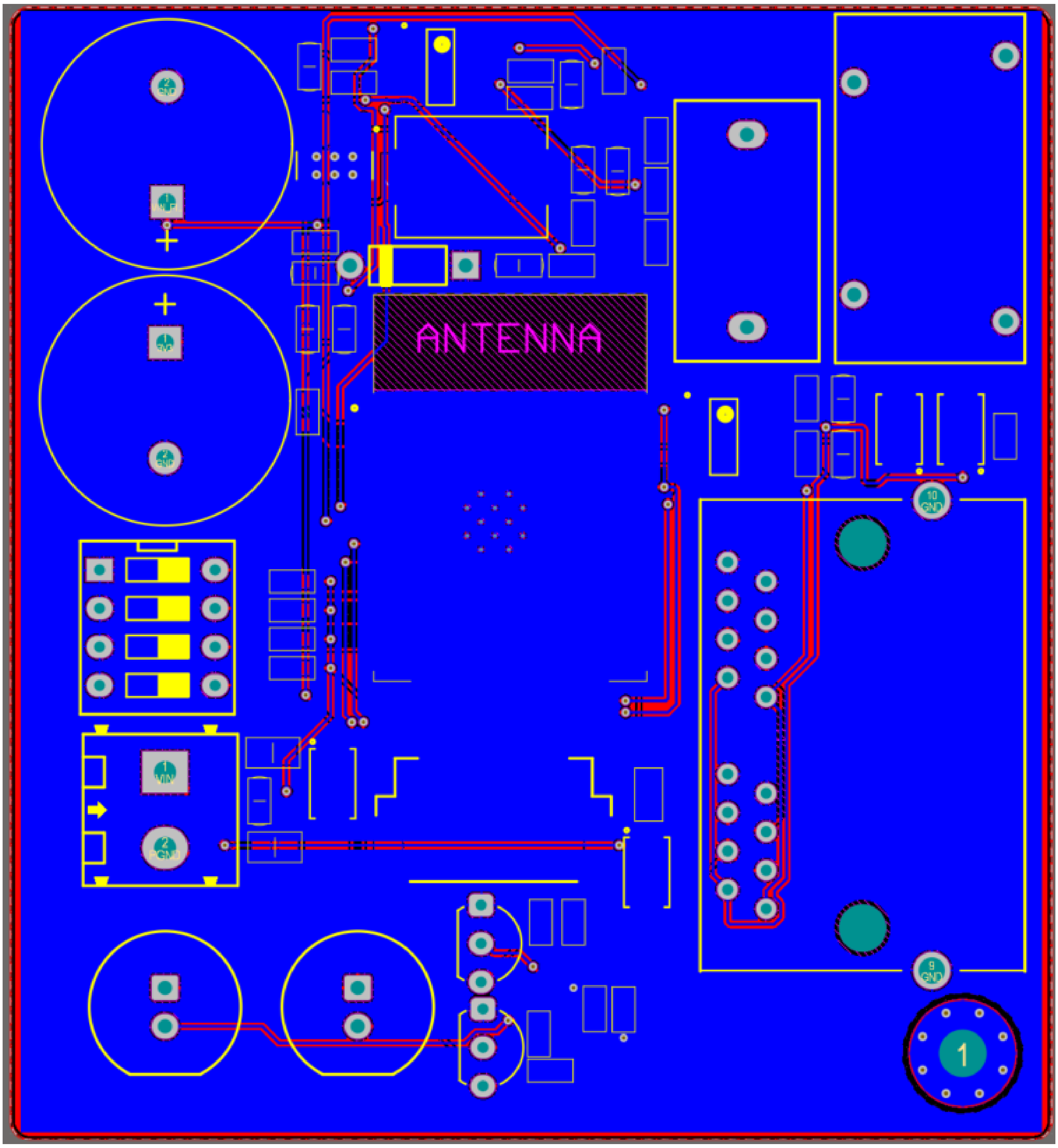


Figure 3.5: PCB bottom layer

3.5 3D view of the PCB

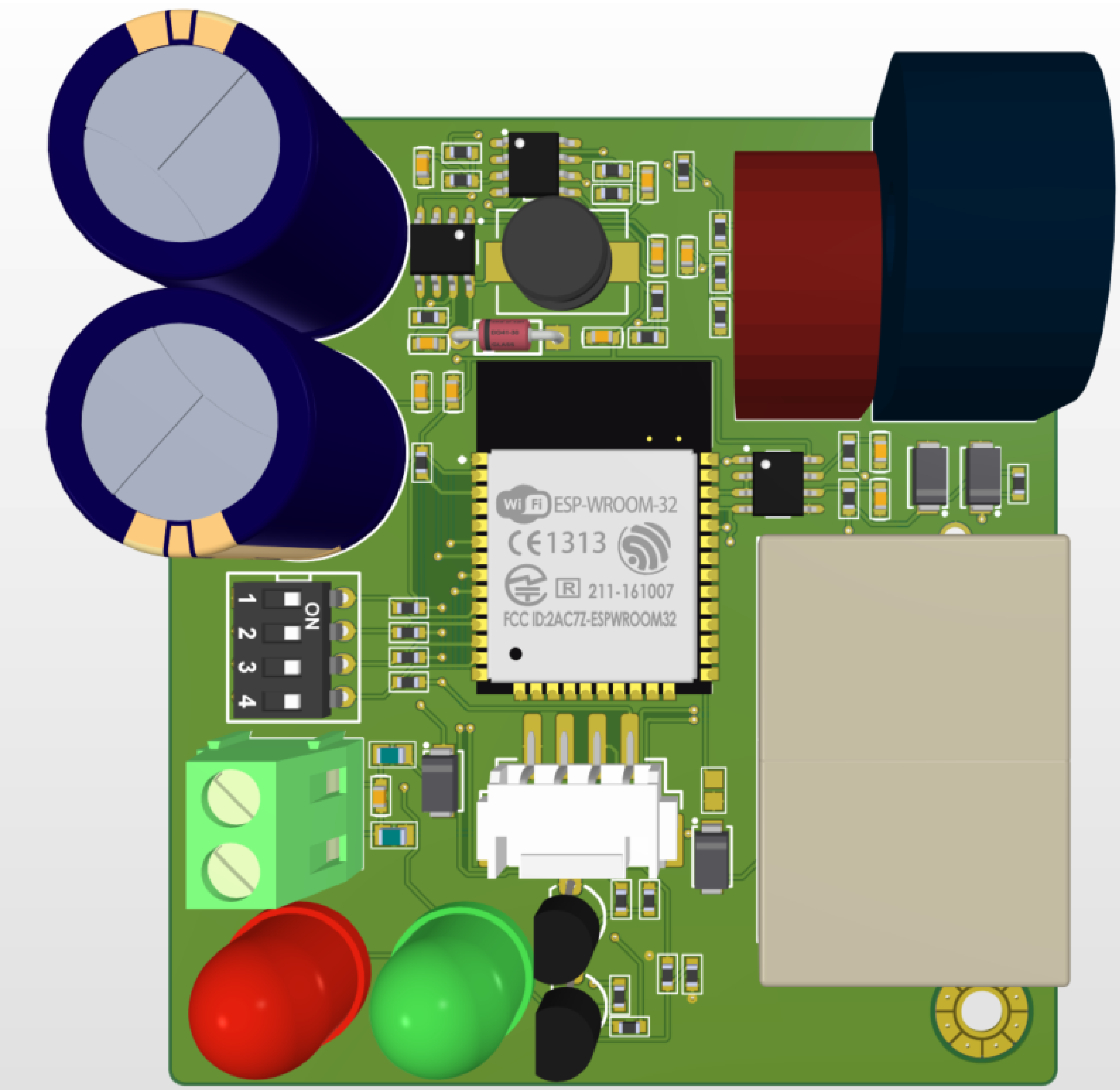


Figure 3.6: 3D top view of the PCB

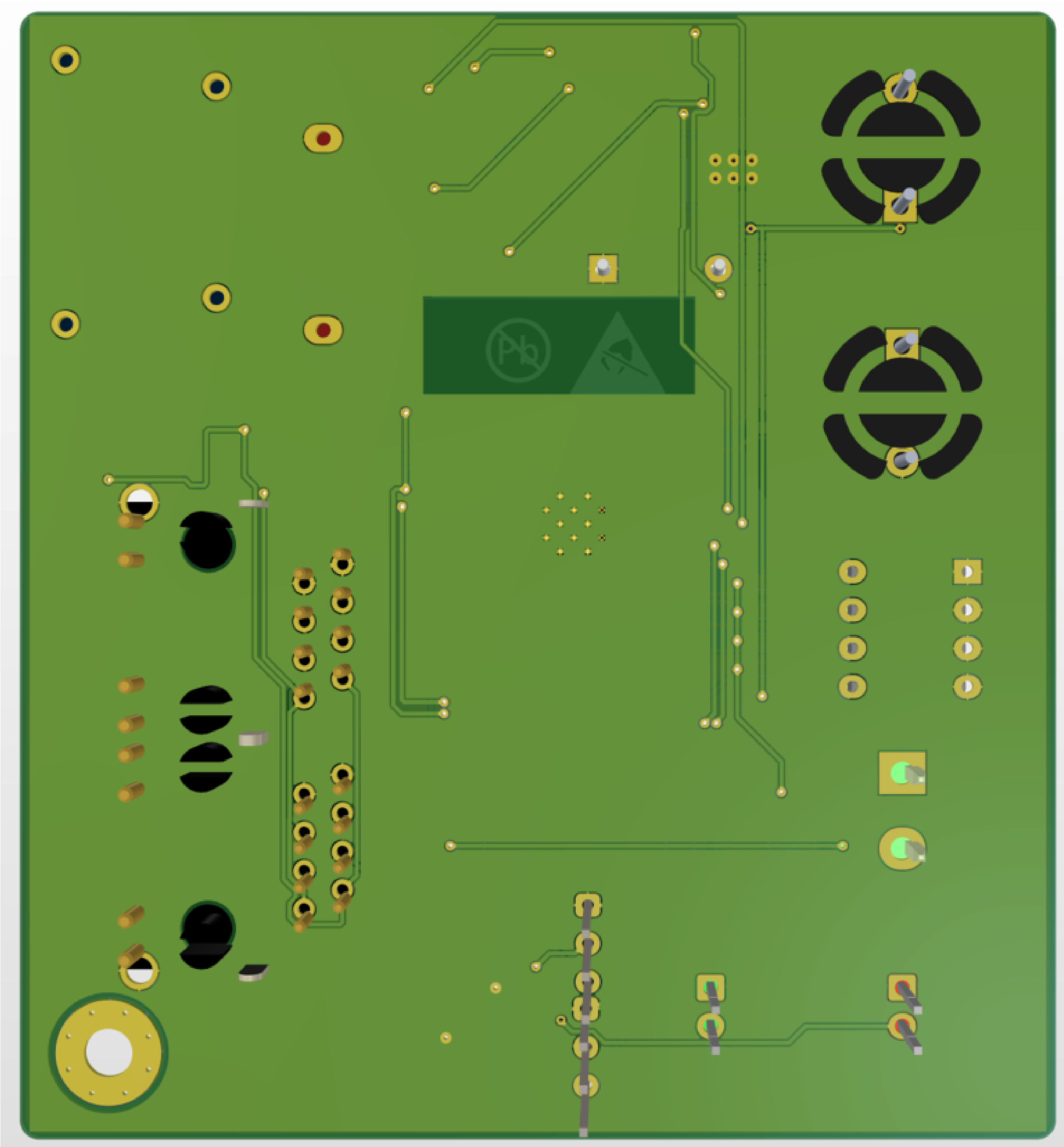


Figure 3.7: 3D bottom view of the PCB

4 PSpice simulation

4.1 3.3V regulator circuit

Circuits function:

The power supply circuit is designed to generate a regulated **3.3 V DC output** from a higher DC input voltage using the **TPS5430 buck converter**. This 3.3 V output is used to supply power for the ESP32 microcontroller and other peripheral circuits in the system.

Simulation:

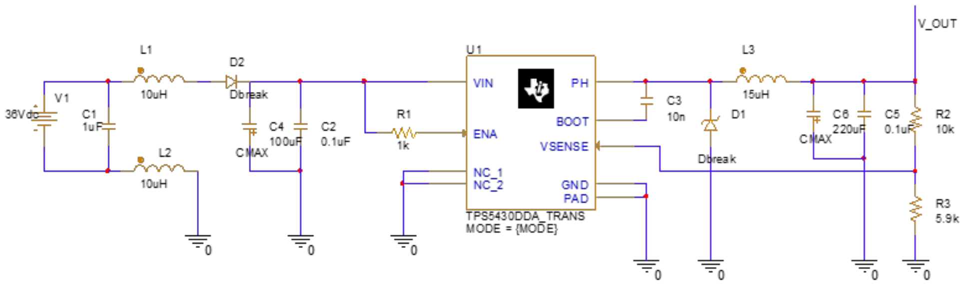


Figure 4.1: Power supply schematic in PSpice

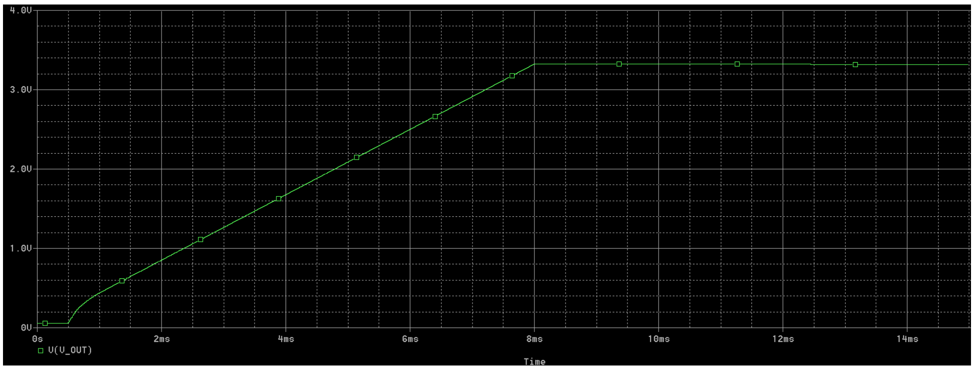


Figure 4.2: Power supply simulation result in PSpice

Figure 4.2 shows the transient response of the output voltage V_{OUT}. When the input voltage is applied, the output voltage rises smoothly from 0 V and reaches approximately **3.3 V after about 8 ms**. No significant overshoot or oscillation is observed during the start-up process. The simulation results confirm that the TPS5430-based power supply operates correctly. The output voltage is stable at 3.3 V and the start-up response is smooth, making the circuit suitable for powering the ESP32 and related modules.

4.2 Current sensor circuit

Circuits function:

The current sensor circuit is designed to measure the AC load current indirectly using a current transformer (TA12/TA17). The sensed current is converted into a small AC voltage, conditioned by operational amplifiers, and shifted to a suitable DC level so that it can be safely measured by the ADC of the ESP32 microcontroller.

In this PSpice simulation, the current transformer is modeled using an AC source to represent the secondary output of TA12/TA17.

Simulation:

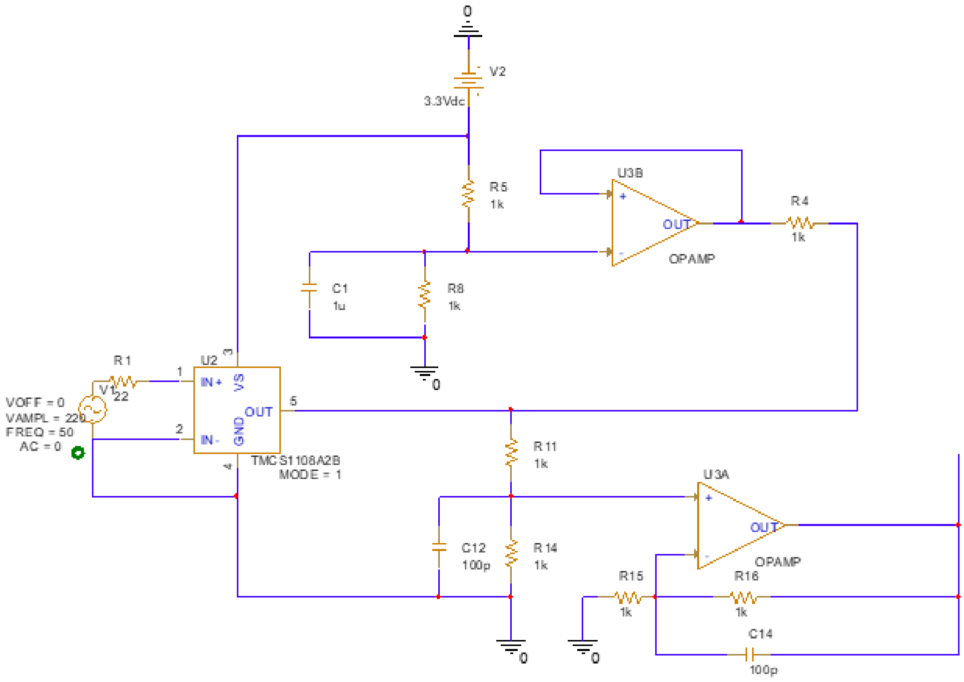


Figure 4.3: Current sensor schematic in PSpice

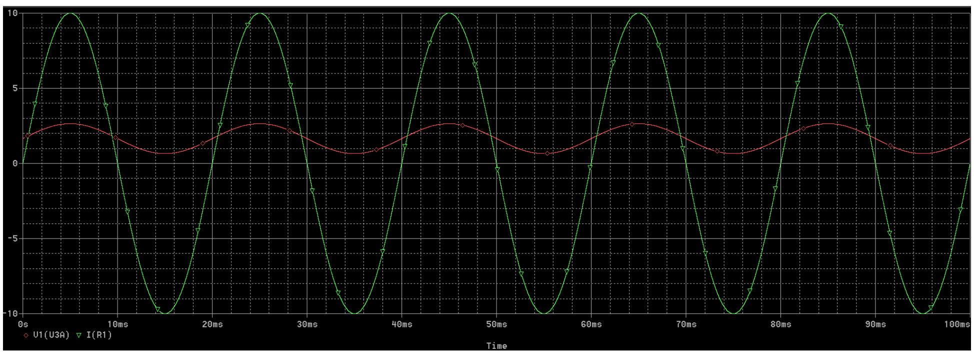


Figure 4.4: Current sensor simulation result in PSpice

The green waveform represents the AC input current, while the red waveform represents the output voltage of op-amp U3A connected to the ADC input. The output is a sinusoidal signal proportional to the input current and shifted by a DC offset to remain within the $0 - 3.3\ V$ ADC range.

The simulation results confirm that the current sensor circuit operates correctly. The input AC current is accurately converted into a stable, scaled voltage signal suitable for ADC measurement without signal clipping.

4.3 LEDs circuit

Circuits function:

The LED driver circuit is designed to control two indicator LEDs using transistor switches driven by digital or PWM signals from the microcontroller. Each LED is connected in series with a current-limiting resistor, while NPN transistors are used to safely switch the LED currents.

In this PSpice simulation, PWM voltage sources are used to emulate the control signals generated by the microcontroller GPIO pins.

Simulation:

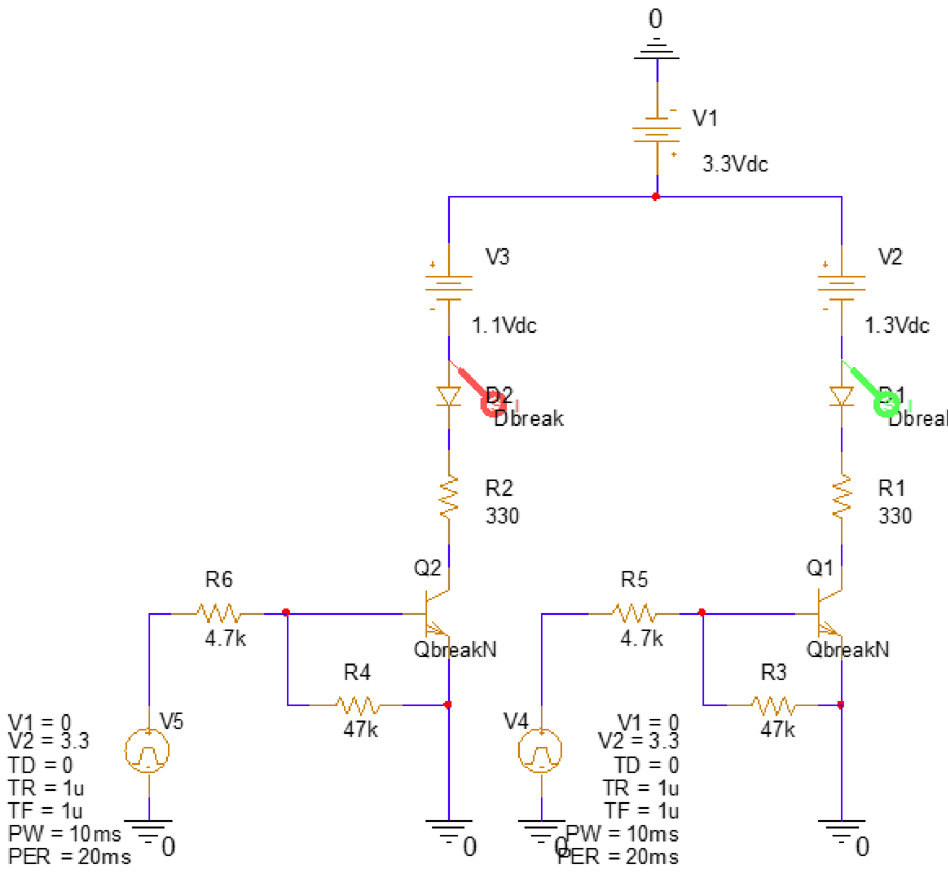


Figure 4.5: LED driver schematic in PSpice

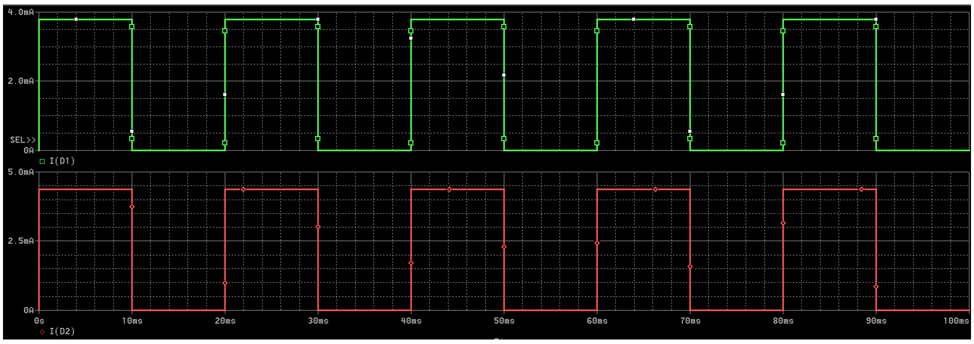


Figure 4.6: LED driver simulation result in PSpice

The green and red waveforms represent the currents flowing through the two LEDs under PWM control. When the control signal is high, the corresponding transistor turns on and allows current to flow through the LED. When the control signal is low, the LED current drops to nearly zero.

The simulation results show that the LED currents are properly limited to approximately 3–4 mA during the on state. This confirms that the LED driver circuit operates correctly and is suitable for status indication applications.

5 Answer to Questions

5.1 Research on Current Sensors

Research on the Internet and list 5 different current sensors that you can find. Along with each current sensor, please:

(1) Give a reference source.

(2) Give the maximum current that the sensor can measure.

(3) Explain how to obtain its values (e.g, using ADC, UART, I2C or SPI and so on).

Current Sensor	**Max Current**	**Interface**	**Source**
WCM3720A	20 A	Digital (UART)	https://evelta.com/wcm3720a-12v-20a-ac-current-sensor-module-digital-data-output-uart/
ACS758	±50 A, ±100 A, ±150 A, ±200 A (IC-dependent)	Analog	https://www.alldatasheet.vn/datasheet-pdf/pdf/533456/ALLEGRO/ACS758_13.html
INA219	Up to ≈ 3.2 A (module-dependent)	I^2C	https://www.ti.com/product/INA219
ACS712	≈ ±8 A (some modules claim ±20 A)	Analog (ADC)	https://www.allegromicro.com/-/media/files/datasheets/acs712-datasheet.ashx
INA226	30 A (module-dependent)	I^2C	https://www.ti.com/lit/ds/symlink/ina226.pdf

5.2 SW1 Voltage in ON and OFF States

When SW1 OFF: $V_{SW1} = 3.3V$ because there is only a single current path.

When SW1 ON: $V_{SW1} = 0V$ because current preferentially flows through paths with lower resistance, while the path from the 3.3 V supply has a relatively high resistance of 10 kΩ.

5.3 Voltage of ADC1_CH7 and ADC1_CH6

1. Voltage calculation at ADC1_CH7 (Reference voltage)

The circuit uses op-amp U3B configured as a voltage follower (buffer). The non-inverting input (pin 5, +) is driven by a voltage divider formed by $R_5 = 1\,\mathrm{k\Omega}$ and $R_8 = 1\,\mathrm{k\Omega}$.

$$V_{\mathrm{ADC1\_CH7}} = V_{CC} \times \frac{R_8}{R_5 + R_8} = 3.3\,\mathrm{V} \times \frac{1}{1+1} = 1.65\,\mathrm{V}$$

2. Voltage calculation at ADC1_CH6 (Measured signal)

The input signal ADC_IN passes through a voltage divider consisting of $R_{11} = 1\,\mathrm{k\Omega}$ and $R_{12} = 1\,\mathrm{k\Omega}$ before entering the non-inverting input of op-amp U3A. Op-amp U3A is configured as a non-inverting amplifier.

- Voltage at pin 3 (non-inverting input):

$$V_+ = V_{\mathrm{ADC\_IN}} \times \frac{R_{14}}{R_{11} + R_{14}} = 1.65\,\mathrm{V} \times \frac{1}{1+1} = 0.825\,\mathrm{V}$$

- Amplifier gain:

$$\mathrm{Gain} = 1 + \frac{R_{16}}{R_{15}} = 1 + \frac{1}{1} = 2$$

- Output voltage:

$$V_{\mathrm{ADC1\_CH6}} = V_+ \times \mathrm{Gain} = 0.825\,\mathrm{V} \times 2 = 1.65\,\mathrm{V}$$

5.4 Low-Pass Filter Design

Consider the signal at pin 3 of the LM358 op-amp (U3A) as shown in Figure 1.5.

The equivalent circuit is:

$$\mathrm{ADC\_IN} \rightarrow R_{11}\,(1\,\mathrm{k\Omega}) \rightarrow (R_{14} \parallel C_{12}) \rightarrow \mathrm{GND}$$

The cutoff frequency of the low-pass filter is given by:

$$f_c = \frac{1}{2\pi} \times \frac{R_{11} + R_{14}}{R_{11} \times R_{14} \times C_{12}}$$

Substituting the initial values:

$$f_c = \frac{1}{2\pi} \times \frac{1000 + 1000}{1000 \times 1000 \times 100 \times 10^{-12}} \approx 3.18\,\text{MHz}$$

Since the desired cutoff frequency is $f_c \approx 10\,\text{kHz}$, three approaches can be considered:

Method 1: Reduce C_{12} while keeping R constant

$$C_{12} = \frac{1}{2\pi} \times \frac{R_{11} + R_{14}}{R_{11} \times R_{14} \times f_c} = \frac{1}{2\pi} \times \frac{1000 + 1000}{1000 \times 1000 \times 10 \times 10^3} \approx 3.18\,\text{nF}$$

Method 2: Increase R while keeping C_{12} constant

$$R = \frac{R_{11} \times R_{14}}{R_{11} + R_{14}} = \frac{1}{2\pi \times f_c \times C_{12}} = \frac{1}{2\pi \times 10 \times 10^3 \times 100 \times 10^{-12}} \approx 159\,\text{k}\Omega$$

Method 3: Compromise between R and C

$$R \times C_{12} = \frac{1}{2\pi \times f_c} = \frac{1}{2\pi \times 10 \times 10^3} \approx 1.59 \times 10^{-5}$$

This approach allows proper scaling while avoiding excessively large resistor values or impractically small capacitor values.

5.5 LED Control

The LED is modeled using a diode in the simulation. The standard diode in PSpice has a forward voltage $V_f \approx 0.65\,\text{V}$. To emulate an LED with $V_f \approx 2\,\text{V}$, a DC voltage source of $1.45\,\text{V}$ is added in series for simulation convenience (not recommended in practical implementation).

The current through each LED is calculated as:

$$I = \frac{V_{CC} - V_f - V_{CE(\text{sat})}}{R} = \frac{3.3 - 2 - 0.2}{330} \approx 3.33\,\text{mA}$$

If a 100 mW LED is required, the following approaches can be considered:

1. Use a constant-current driver.
2. Select a suitable transistor or MOSFET.
3. Adjust the circuit parameters as follows:

We have:

$$I = \frac{V_{CC} - V_f - V_{CE(\text{sat})}}{R} = \frac{V_{CC} - 2 - 0.2}{R} = \frac{100}{0.7}\,\text{mA}$$

Thus:

$$\frac{V_{CC} - 2 - 0.2}{R} = \frac{100}{0.7} \quad (\text{V}/\Omega)$$

Possible solutions:

- Reduce the resistor value R while keeping V_{CC} constant.
- Increase the supply voltage V_{CC} while keeping R constant.
- Increase V_{CC} and reduce R simultaneously.

5.6 Role of Diode D2

Normal operating condition:

- RS-485 operates with a differential voltage range of approximately $-1.5\,\text{V}$ to $+5\,\text{V}$ (MAX485 tolerates up to $\pm 5\,\text{V}$ on A/B lines).
- When the voltage between A and B remains within this range, the TVS diode behaves like an open circuit (non-conductive).

$\Rightarrow$ Result: No impact on RS-485 signal integrity.

During overvoltage events (surge/ESD/lightning):

- If line A rises more than $+3.3\,\text{V}$ relative to line B, the TVS diode enters breakdown mode:
  - Current flows through the diode, clamping from A to B.
  - The voltage is limited to approximately $+1.5$ to $3.3\,\text{V}$ (clamping voltage).

- If line A drops below $-1.5\,\mathrm{V}$ relative to line B, the diode conducts in the reverse direction and clamps the voltage.
- If a large surge occurs relative to GND, the diode conducts and diverts current to ground, ensuring the voltage remains within safe limits for the MAX485.

Conclusion:

Condition	Action of D2
Low voltage	Non-conductive, no signal impact
High positive voltage	Conducts, shunts surge to ground
High negative voltage	Conducts in reverse, clamps voltage

⇒ Result: RS-485 lines are protected against overvoltage and ESD.

5.7 Using the 74HC595 IC to design a display circuit for showing values on four 7-segment LEDs

Objective

The objective of this circuit is to control **four 7-segment LED displays** using the **74HC595 shift register**, thereby reducing the number of I/O pins required from the microcontroller by applying the **multiplexing technique**.

Operating Principle

Each 7-segment display requires eight control signals corresponding to segments *a, b, c, d, e, f, g* and the decimal point (*dp*). Since a single 74HC595 provides only eight output pins, it is insufficient to drive four displays simultaneously.

To solve this problem, the following architecture is used:

- The **first 74HC595** controls the segment lines (*a–g, dp*).
- The **second 74HC595** controls the digit selection signals (*sel0–sel3*).
- The displays are driven using the **multiplexing (scanning)** method, where only one display is enabled at a time, but the switching speed is fast enough to appear continuous to the human eye.

The two 74HC595 ICs are connected in a **daisy-chain configuration** and share the same control signals: `DATA`, `CLK`, and `LATCH`.

Circuit Connections

- The `SDI` pin of the first 74HC595 receives serial data from the microcontroller.
- The `SDO` pin of the first IC is connected to the `SDI` pin of the second IC.
- The `SH_CP` (clock) and `ST_CP` (latch) pins of both ICs are connected together.
- Outputs Q0–Q7 of the first 74HC595 drive segments a–g and dp through 220 Ω current-limiting resistors.
- Outputs of the second 74HC595 (*sel0–sel3*) control NPN transistors that switch the common cathode (K) of each 7-segment display.
- The `OE` pin is tied to ground to enable outputs permanently, while the `CLR` pin is tied to VCC to prevent unintended reset.

Display Scanning Algorithm

The microcontroller performs the following steps repeatedly:

1. Disable all displays by clearing *sel0–sel3*.
2. Shift the segment data (a–g, dp) for the desired digit into the first 74HC595.
3. Shift the corresponding digit select signal into the second 74HC595.
4. Toggle the `LATCH` signal to update all outputs simultaneously.
5. Maintain the state for approximately 1–2 ms.
6. Repeat the process for the remaining digits.

A sufficiently high scanning frequency ensures stable display output without visible flickering.

References

[1] Donald E. Knuth. Literate programming. *The Computer Journal*, 27(2):97–111, 1984.

[2] Donald E. Knuth. *The TEX Book*. Addison-Wesley Professional, 1986.

[3] Leslie Lamport. *LATEX: a Document Preparation System*. Addison Wesley, Massachusetts, 2 edition, 1994.

[4] Michael Lesk and Brian Kernighan. Computer typesetting of technical journals on UNIX. In *Proceedings of American Federation of Information Processing Societies: 1977 National Computer Conference*, pages 879–888, Dallas, Texas, 1977.

[5] Frank Mittelbach, Michel Gossens, Johannes Braams, David Carlisle, and Chris Rowley. *The LATEX Companion*. Addison-Wesley Professional, 2 edition, 2004.