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

Electrical Electronic Circuits-CO2037
Assignment's Report

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HO CHI MINH CITY, 5^{th} January 2022

Contents

1 Altium Designer

The Altium project will be packed together with this report in a zip file.

1.1 Schematic Design

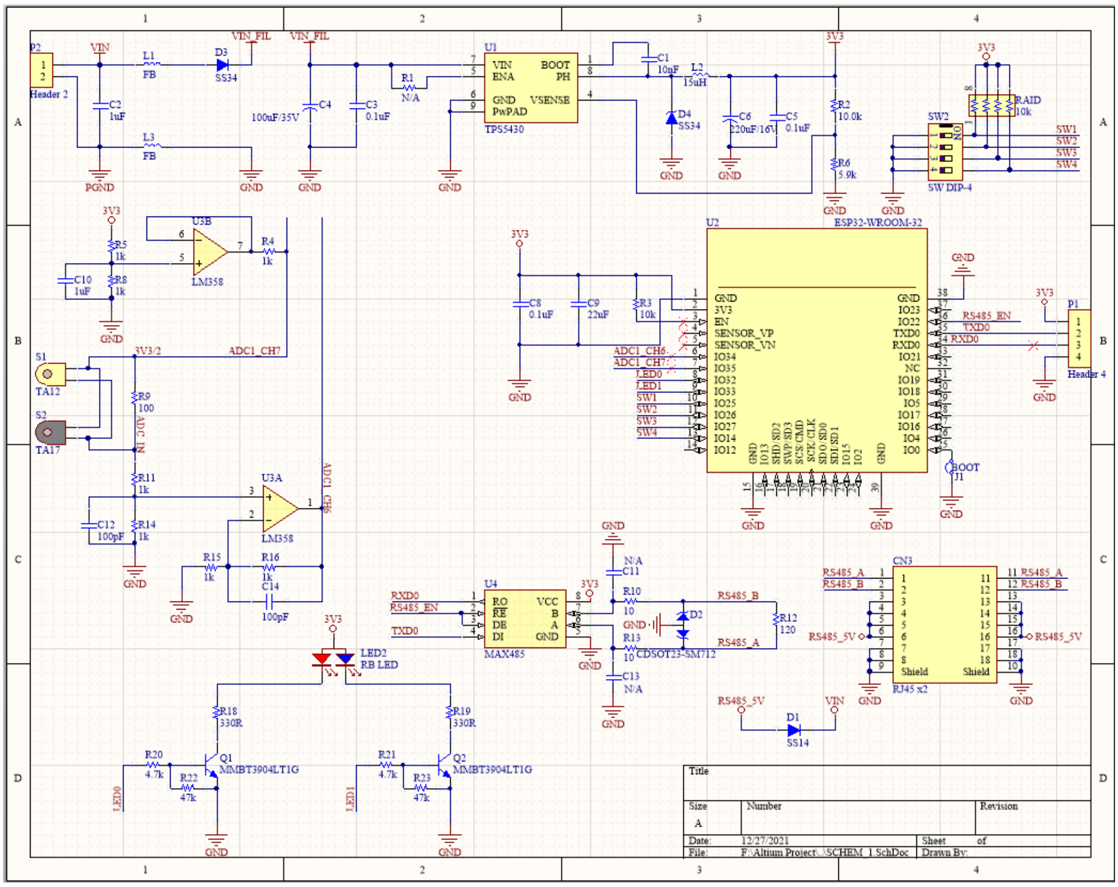

Figure 1: The schematic design of the circuit.

1.2 PCB Layout

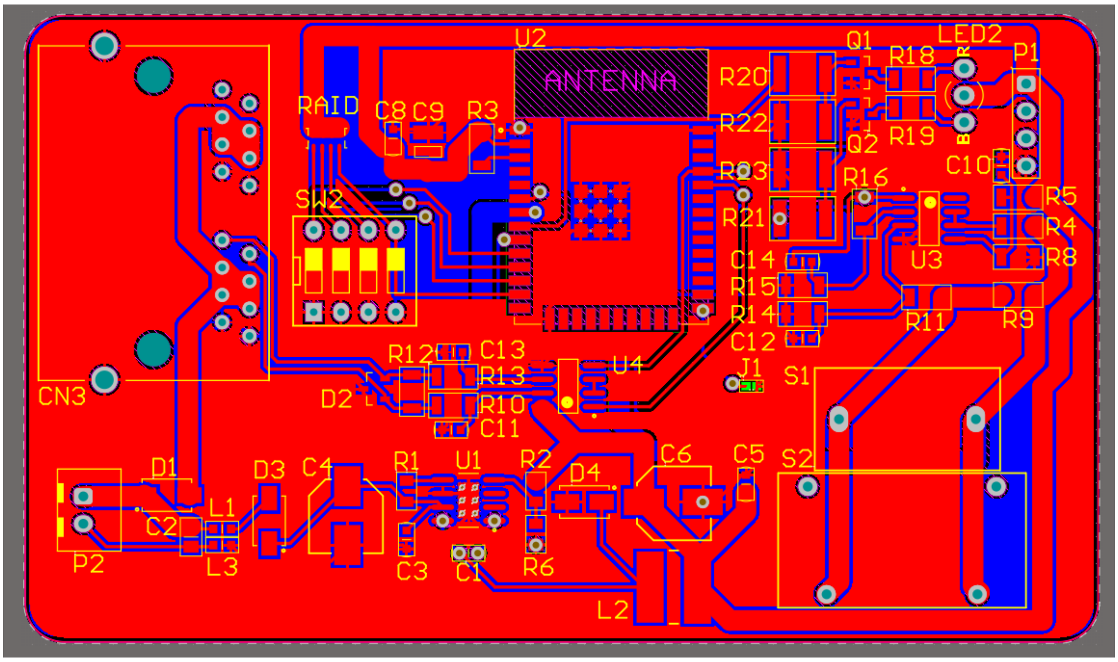

Figure 2: The top layer of the PCB layout.

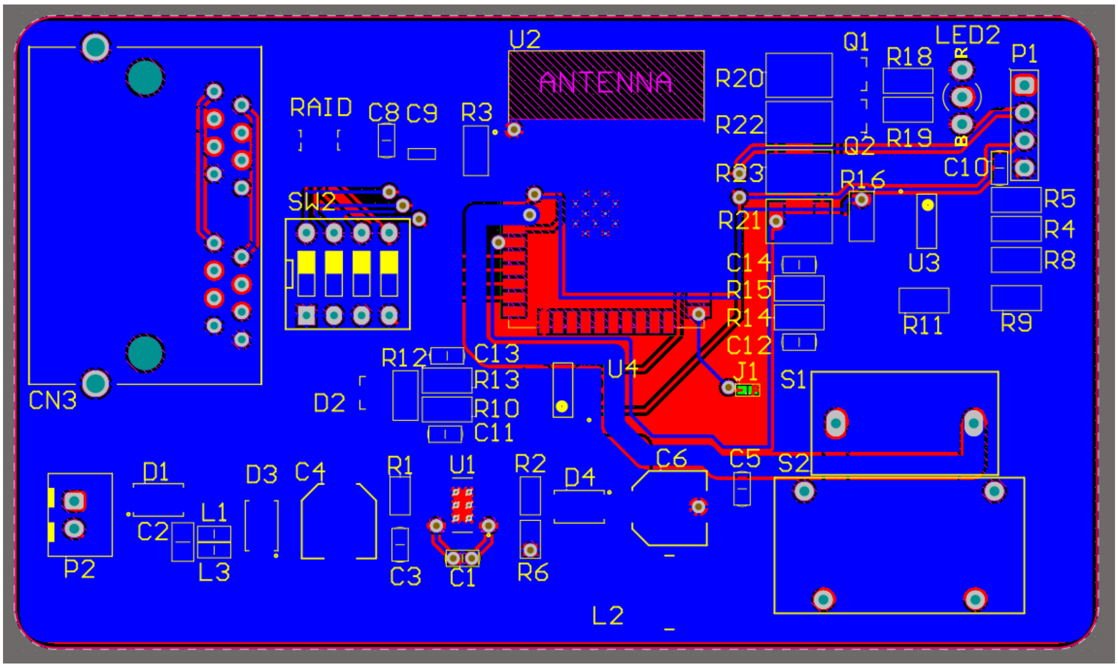

Figure 3: The bottom layer of the PCB layout.

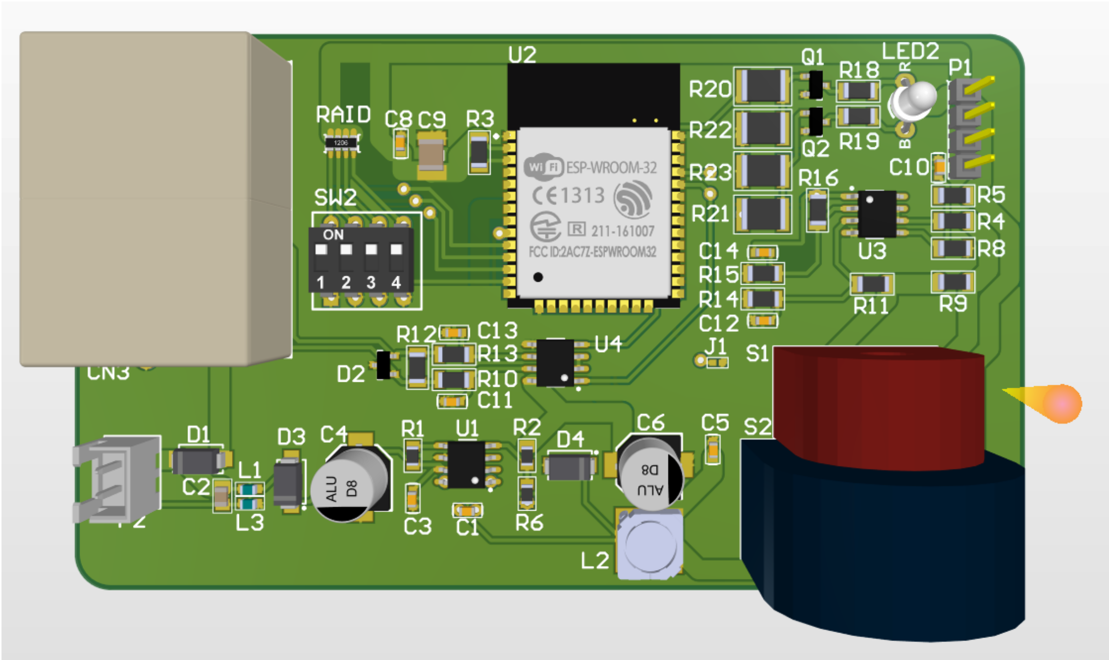

Figure 4: The top view of the circuit in 3D.

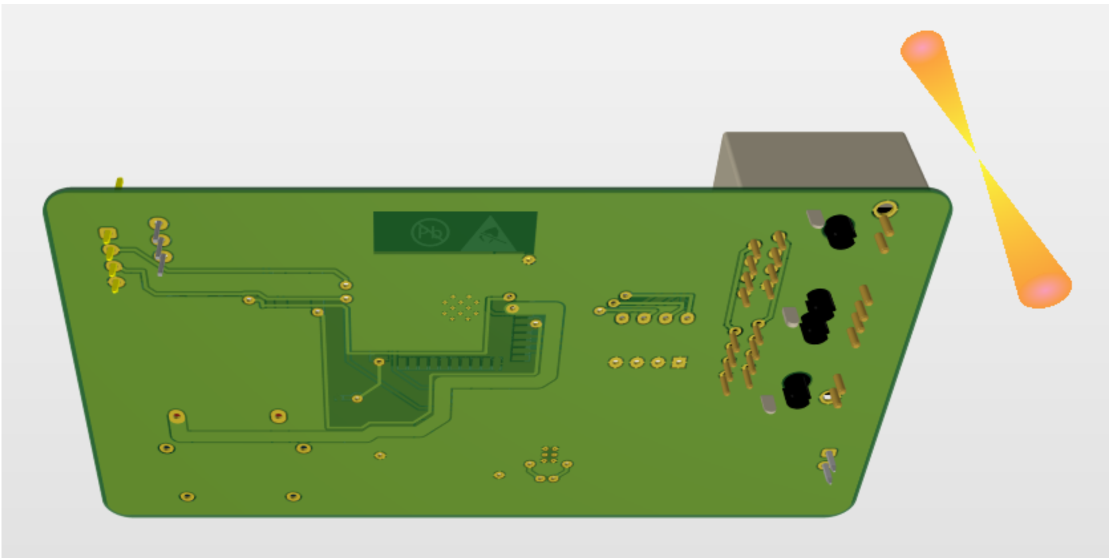

Figure 5: The bottom view of the circuit in 3D.

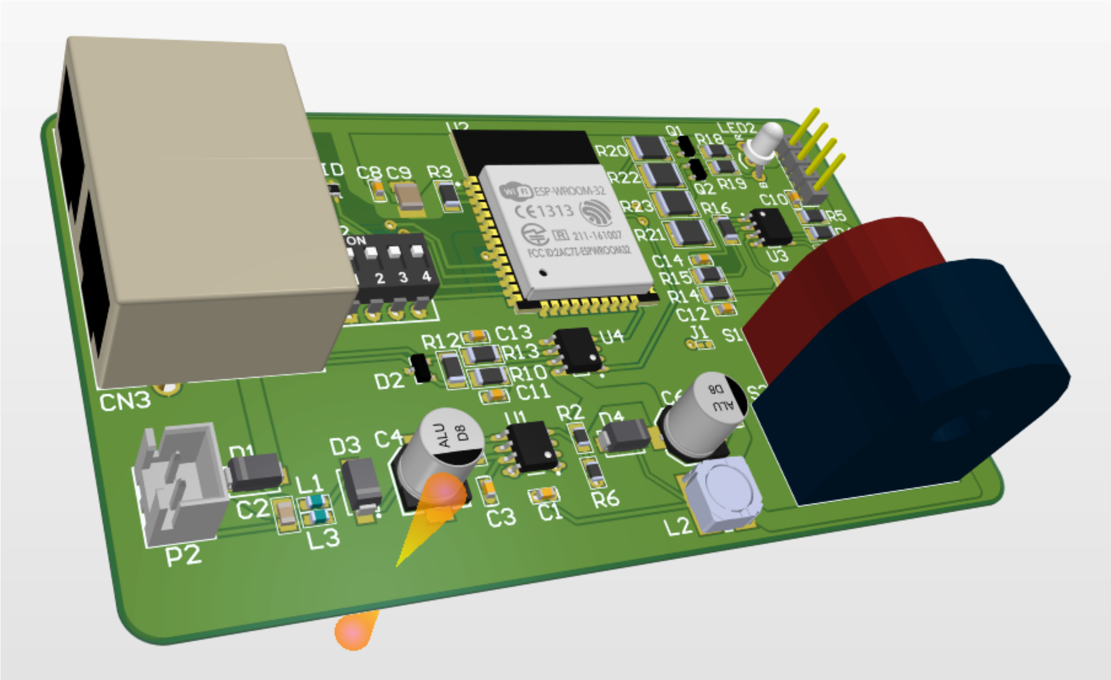

Figure 6: The circuit in 3D.

2 Questions to answer

2.1 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) maximum current that the sensor can measure, and (3) how to obtain its values (e.g, using ADC, UART, I2C or SPI and so on)

2.1.1 Current Shunt Monitor

- Current shunt monitor is a simple and easy way to measure current. It measure the voltage across a sense resistor placed in the conduction path between a power source and a load. This voltage is multiplied by a gain either fixed in the IC or programmable by external resistor.

  One of the example of the current shunt monitor that we are going to take a look at is the INA260 IC. For further information, please access this link to get the detailed product description from Texas Instrument: https://www.ti.com/lit/gpn/INA260

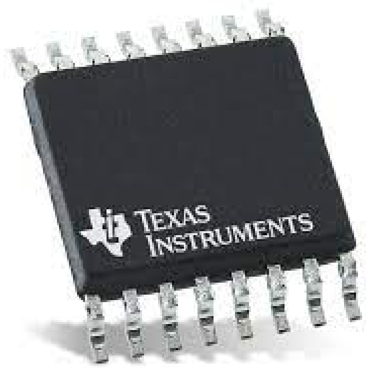

Figure 7: INA260 Digital Current/Power Monitor.

- The INA260 enables high-accuracy current and power measurements and over-current detection at common-mode voltages that can vary from 0 V to 36 V, independent of the supply voltage.

  The device is a bidirectional, low- or high-side, current-shunt monitor that measures current flowing through the internal current-sensing resistor. The maximum analog input current is $\pm15A$ continuous from -40^oC to $+85^oC$ with high accuracy of 0.15% system gain error (maximum) and 5 mA offset (maximum).

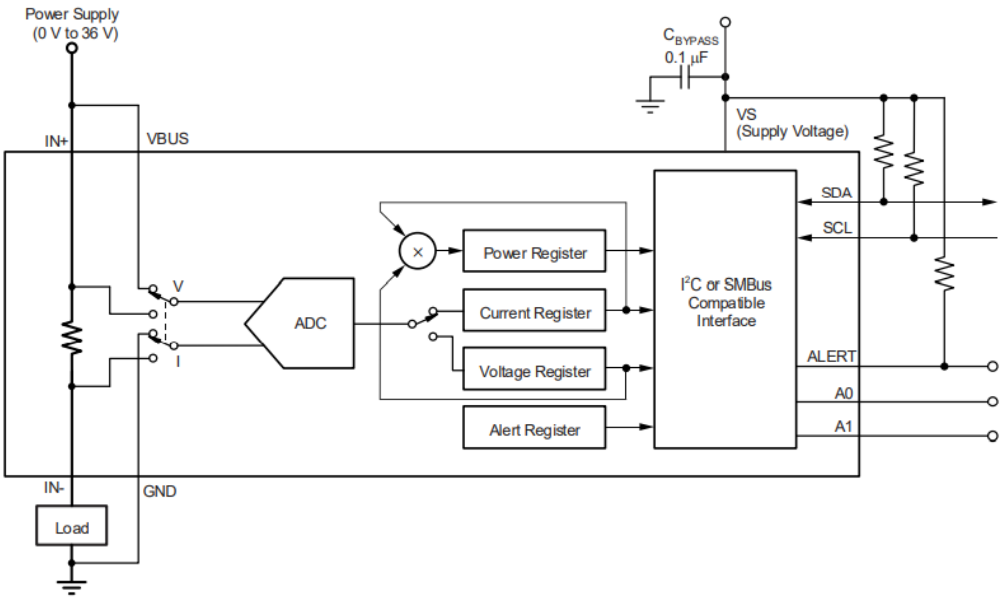

Figure 8: Typical Circuit Configuration,INA260.

- The INA260 offers compatibility with both I^2C and SMBus interfaces. The I^2C and SMBus protocols are essentially compatible with one another. The device features up to 16 programmable addresses on the I^2C-compatible interface. The digital interface allows programmable alert threshold, analog-to-digital converter (ADC) conversion times, and averaging. To facilitate ease of use, an internal multiplier enables direct readouts of current in amperes and power in watts.

2.1.2 Current Transformers (CTs)

- Current transformers accurately sense and measure current flow in power supply circuits in a non-invasive way. Ideally, they shunt a very small sample of the current to measure while dissipating minimal energy.

  The sensed current information is typically used to prevent over-current conditions and to monitor and control circuits in power supplies and other powered applications.

- The maximum current that CTs can measure varies from 1A to 100kA depending on the type and series.

  For example, the Coilcraft CST2020 series current transformers can sense the current upto 40A. For further information, please access: https://www.coilcraft.com/en-us/products/transformers/power-transformers/current-sensing/cst2020/#physical

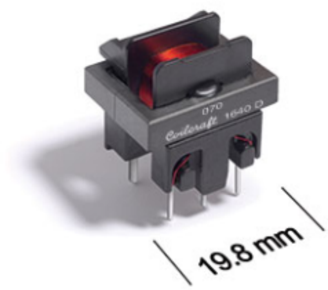

Figure 9: CST2020 series.

The T6522 surface mount high frequency current transformers can measure maximum of 3A. (https://www.coilcraft.com/en-us/products/transformers/power-transformers/current-sensing/t6522/).

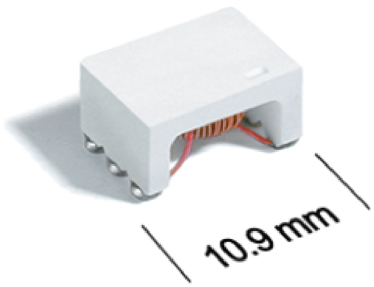

Figure 10: T6522 Surface Mount CT.

For many other types of Colicraft CTs, please access: https://www.coilcraft.com/en-us/products/transformers/power-transformers/current-sensing/

Another example is the SXMMT5-Multifunction Measuring module for CT which is dedicated to Nemo SX System has the maximum CTs primary current of 32kA.(https://catalogue.bticino.com/app/webroot/low_res/509398_509427_IDP000165EN_04.pdf)

Figure 11: Nemo SX–Multifunction Measuring module for Current Transformers (CT).

- About obtaining values from the CTs, we will examine an AC measurement Arduino ciruit using HWCT-5A/5mA Current Transformer. The full project can be viewed at: https://iotdesignpro.com/projects/detect-and-measure-ac-current-using-current-transformer-and-arduino

Figure 12: HWCT-5A/5mA.

The schematics below show the block diagram and circuit diagram for current measurement using the current transformer.

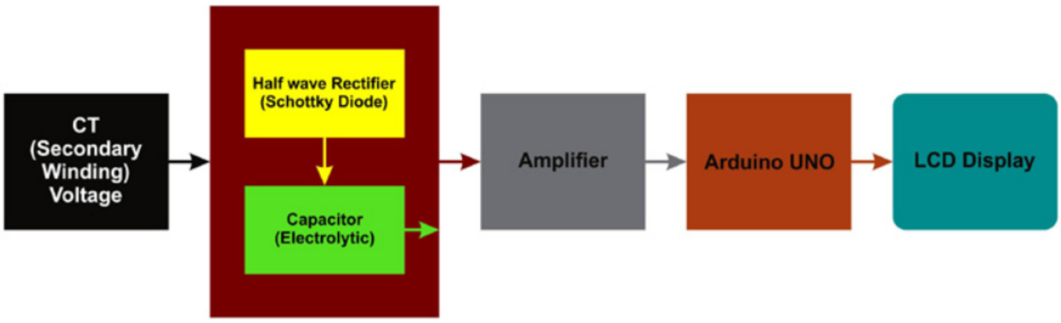

Figure 13: HWCT-5A/5mA.

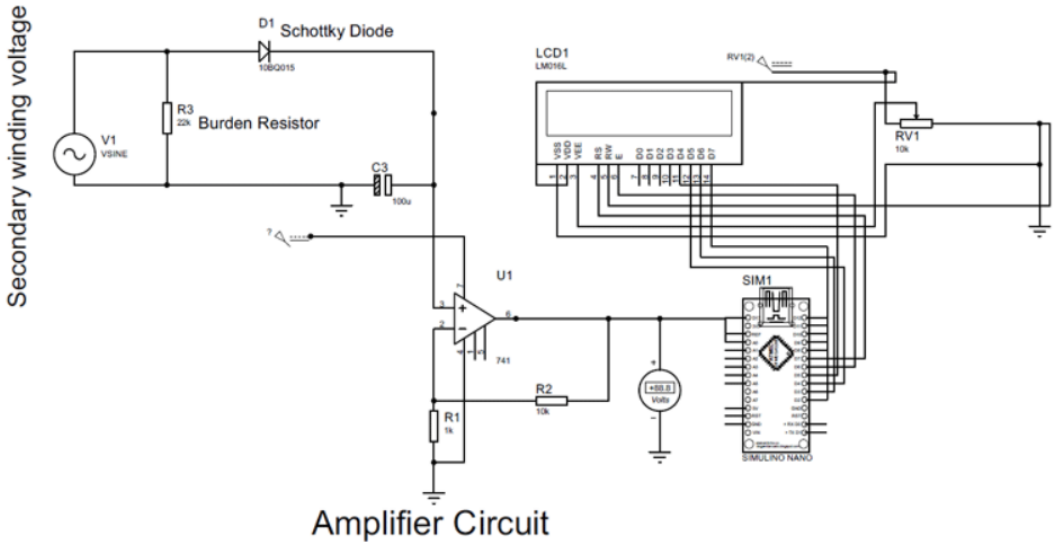

Figure 14: HWCT-5A/5mA.

The I^2C LCD display is used to output the values. As the voltage is varied from the Auto transformer, the value of the current in the primary winding changes, which we measure with a digital multi-meter. Change in the value of the primary winding current is also visible in the LCD screen. As we can see in the figure below, the actual current value and measured current value is almost same.

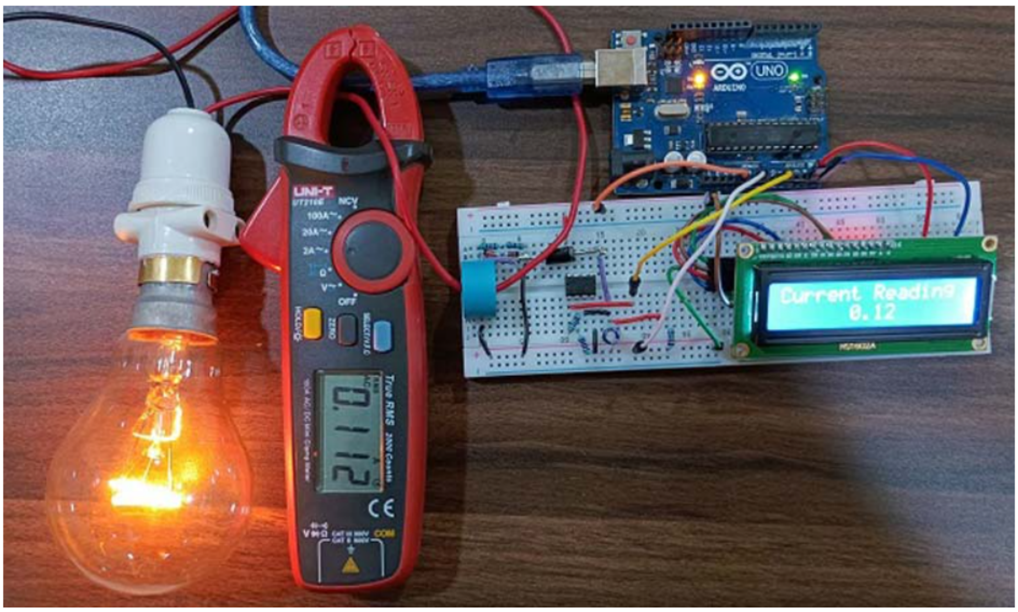

Figure 15: The circuit implementation.

Measuring a small value (less than 0.2 A) shows a fluctuation in measured value at second decimal place. This happens because of the very small value of AC current but if we measure a large value (more than 0.5A), then fluctuation does not appear. Here, we used metal film resistor but we can get more accurate results by using precision metal film resistor.

2.1.3 PCB Rogowski Coil Sensor

- A Rogowski coil is an electrical transducer used for measuring AC currents such as high speed transients, pulsed currents of a power device, or power line sinusoidal currents at 50 or 60 Hz. The Rogowski coil has a flexible clip-around sensor coil that can easily be wrapped around the current-carrying conductor for measurement and can measure up to a couple thousand amperes of very large currents without an increase in transducer size.(https://www.rs-online.com/designspark/what-is-a-rogowski-coil-current-probe)

Figure 16: Rogowski coil current probe.

- Next, we're going to take a deeper look into the TIDA-01063 High Accuracy AC Current Measurement Reference Design using PCB Rogowski Coil Sensor.(https://www.ti.com/lit/pdf/TIDUBV4A)

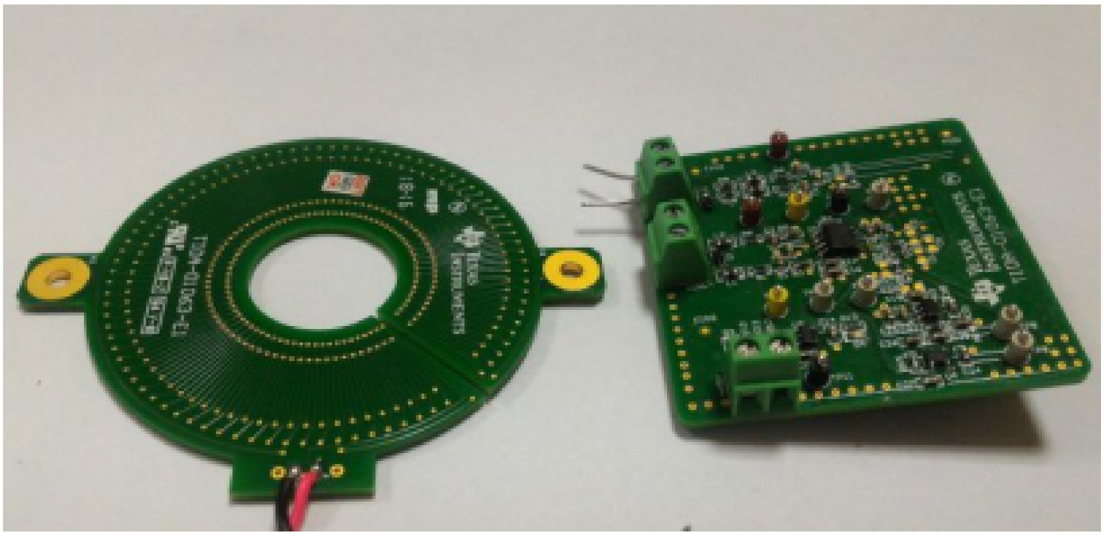

Figure 17: TIDA-01063 PCB Rogowski Coil Current Sensor.

The TIDA-01063 is a reference design for current sensing using a PCB Rogowski coil sensor to achieve very good linearity for wide measurement range at a very low system BOM cost

The PCB Rogowski sensor is advantageous for isolated current measurement due to its very high bandwidth of 20 MHz and fast settling time of 50 ns.

The auto-zeroing, 12 nV/Hz noise density of the INA188 makes it suitable to achieve a 12-bit system resolution for a full-scale current of 1 kA.

Using a simple IIR digital integration algorithm and scalable sampling rate, it is possible to achieve better magnitude and phase response.

- To obtain the measured value, the TIDA-01063 TI Design is easily interfaced to the ADS1256 EVM or ADS131E08 EVM. There are two PCBs as shown in figure 17. The circular PCB is the Rogowski sensor and the square PCB is the interface board for the sensor.

The board consists of two analog input channels, one for reference voltage signal and another for the PCB Rogowski sensor input. The voltage reference signal is to compute phase error only. An AC voltage of 1.5 to 2.5 V needs to be applied externally.

Connecting to the ADS131E08 EVM: Test point TP3 and TP9 of the interface board is connected to connector J11 of the ADS131E08 EVM for capturing Rogowski Coil signal.

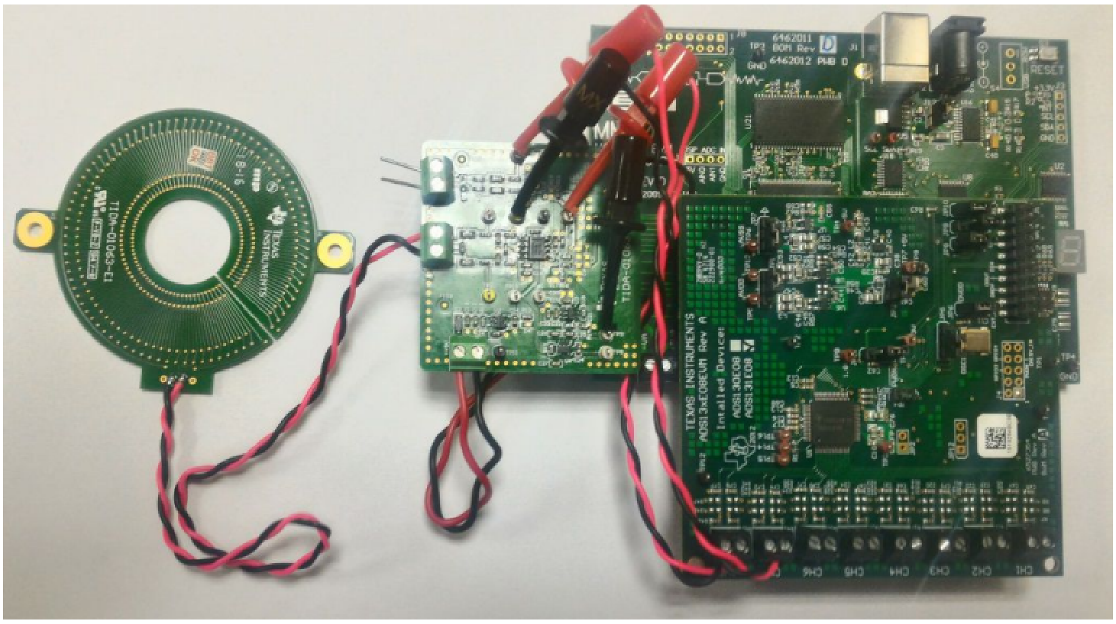

Figure 18: Connecting to the ADS131E08 EVM.

Connecting to the ADS1256 EVM

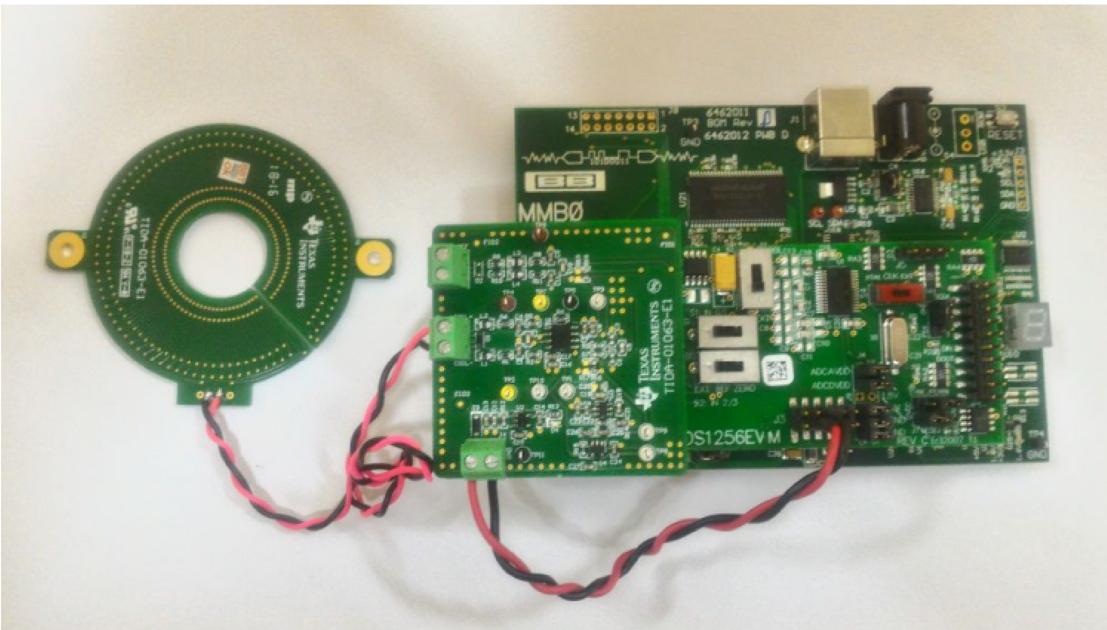

Figure 19: Connecting to the ADS1256 EVM.

2.1.4 Hall-effect Current Sensor

- Hall-effect current sensors provide high accuracy combined with low drift, enabling accurate current measurements over both time and temperature.

  Additionally, Hall-effect current sensors offer high working voltage levels with different levels of isolation to help address varying use-case conditions.

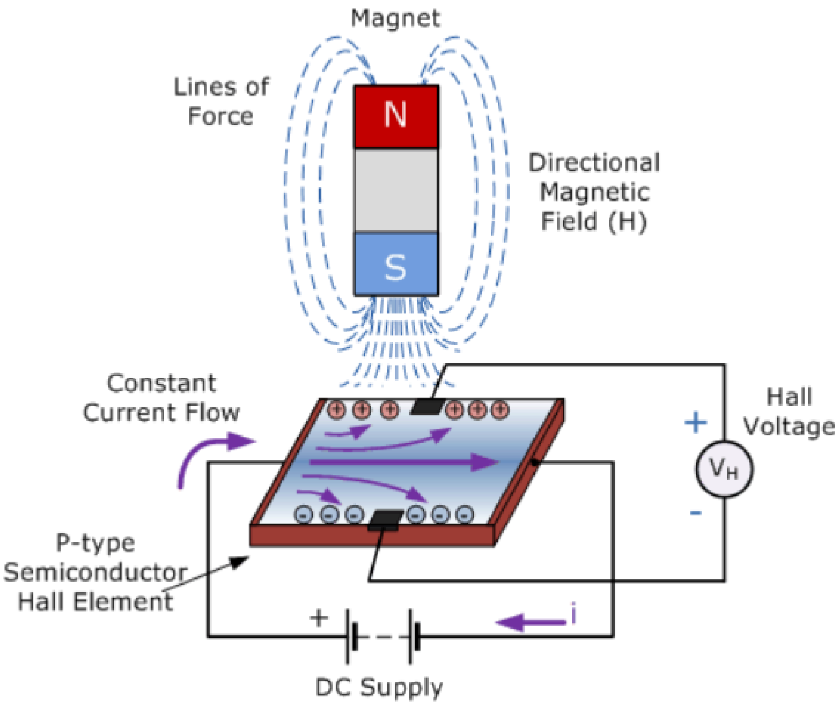

Figure 20: Hall-effect Sensor Principles.

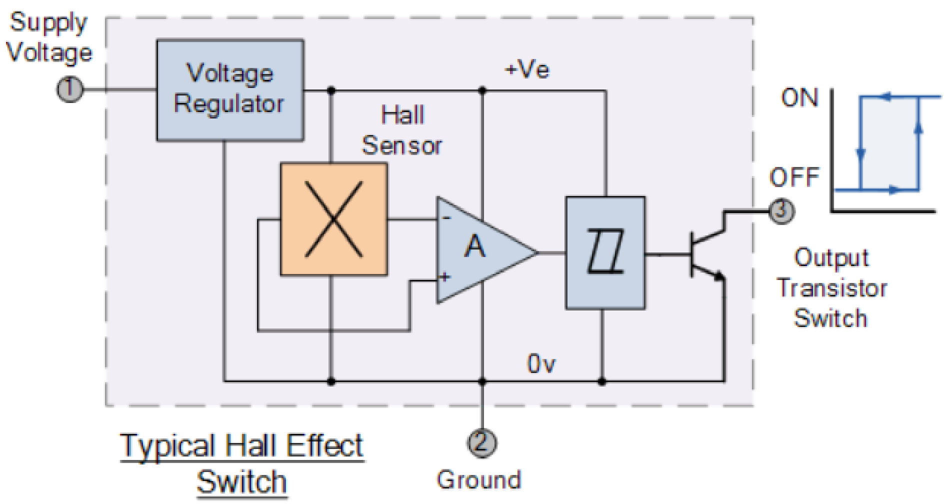

Figure 21: Typical Hall-effect Sensor.

(https://www.electronics-tutorials.ws/electromagnetism/hall-effect.html)

Maximum current can be measured varies from 10mA to 35kA depending on types and series.

- One of the example of Hall-effect current sensor is the TMCS1100 1% High-Precision, Basic Isolation Hall-Effect Current Sensor designed by Texas Instruments.(https://www.ti.com/lit/gpn/tmcs1100)

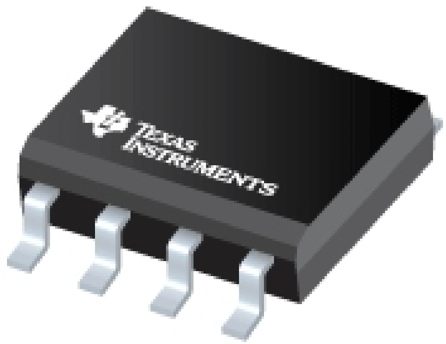

Figure 22: Texas Instruments TCMS1100.

The TMCS1100 is a galvanically isolated Hall-effect current sensor capable of DC or AC current measurement with high accuracy, excellent linearity, and temperature stability. A low-drift, temperature-compensated signal chain provides $< 1\%$ full-scale error across the device temperature range.

The input current flows through an internal $1.8m\Omega$ conductor that generates a magnetic field measured by an integrated Hall-effect sensor. This structure eliminates external concentrators and simplifies design. Low conductor resistance minimizes power loss and thermal dissipation. Inherent galvanic insulation provides a 600 V lifetime working voltage and 3-KV_{RMS} basic isolation between the current path and circuitry. Integrated electrical shielding enables excellent common-mode rejection and transient immunity.

The output voltage is proportional to the input current with four sensitivity options. Fixed sensitivity allows the TMCS1100 to operate from a single 3 V to 5.5 V power supply, eliminates ratiometry errors, and improves supply noise rejection. The current polarity is considered positive when flowing into the positive input pin. The V_{REF} input pin provides a variable zero-current output voltage, enabling bidirectional or unidirectional current sensing.

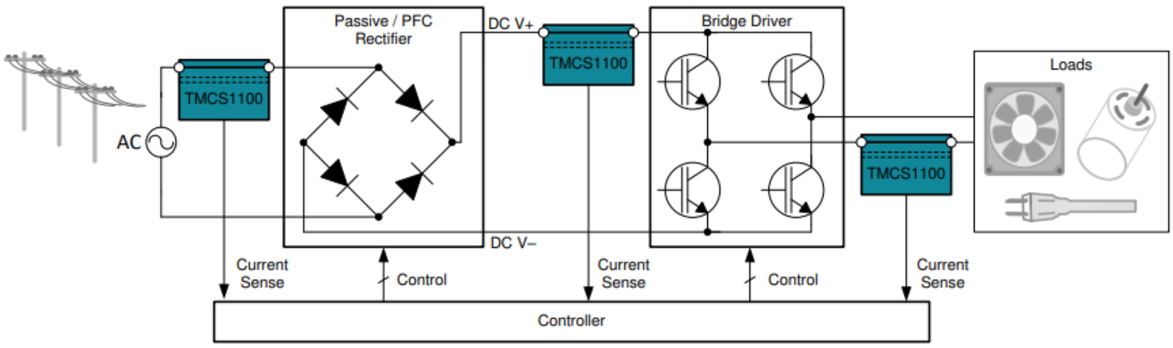

Figure 23: Typical Application of TCMS1100.

The TMCS110 draws a maximum supply current of 6 mA and all sensitivity options are specified over the operating temperature range of -40^oC to $+125^oC$.

2.1.5 Flux Gate Current Sensor

- Flux Gate Sensors or Saturable Inductor Current Sensors work on the same measurement principle as Hall-effect-based current sensors: the magnetic field created by the primary current to be measured is detected by a specific sensing element. The design of the saturable inductor current sensor is similar to that of a closed-loop Hall-effect current sensor; the only difference is that this method uses the saturable inductor instead of the Hall-effect sensor in the air gap.

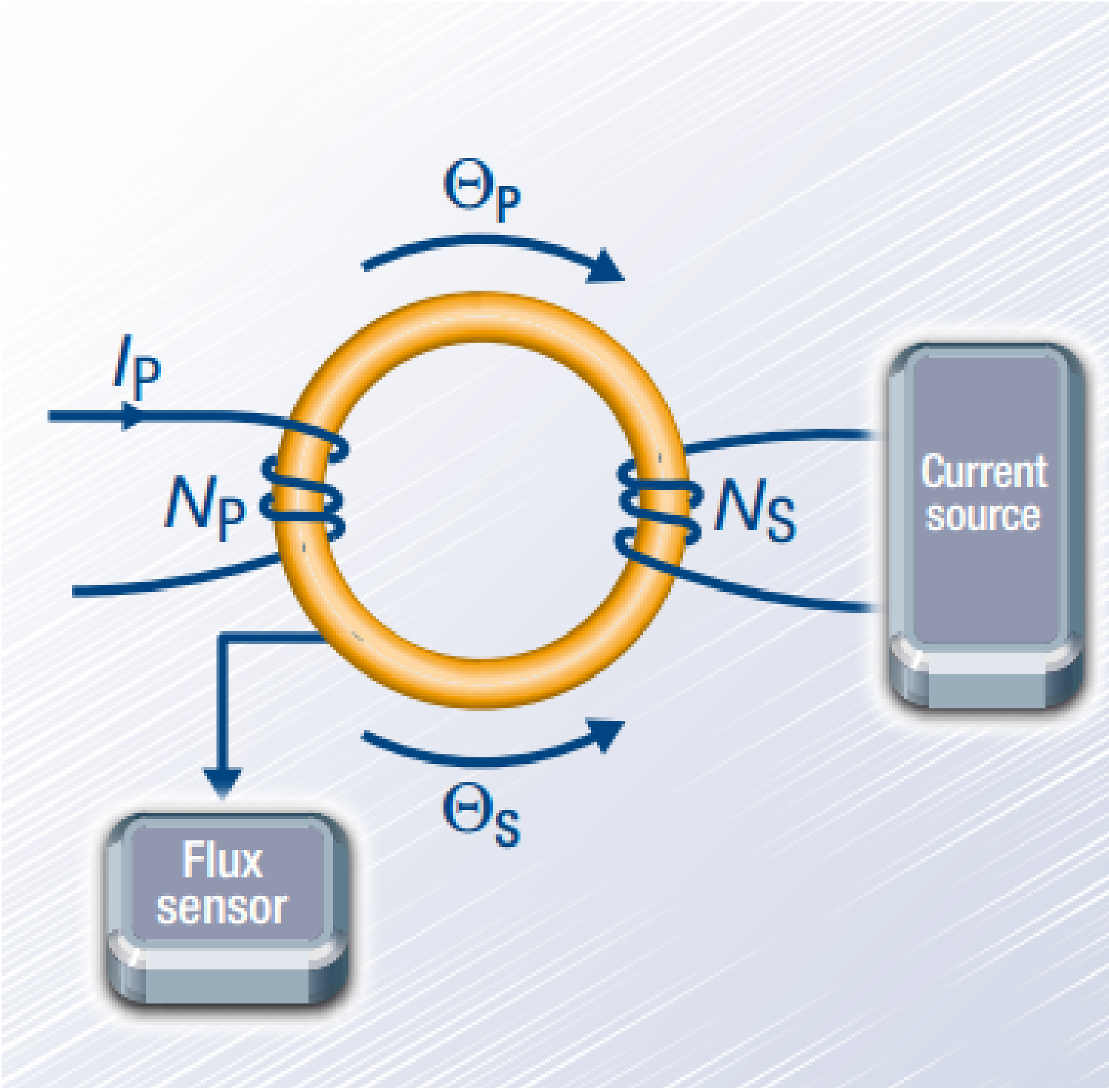

Figure 24: Flux Gate Technology Principles

Depending on types and series, the flux gate current sensor's maximum measured value can vary from 1A to 10kA.

- Next, we are going to delve into an example of the flux gate sensor which is the DRV421 Integrated Magnetic Fluxgate Sensor for Closed-Loop Current Sensing designed by Texas Instruments.(https://www.ti.com/lit/gpn/drv421)

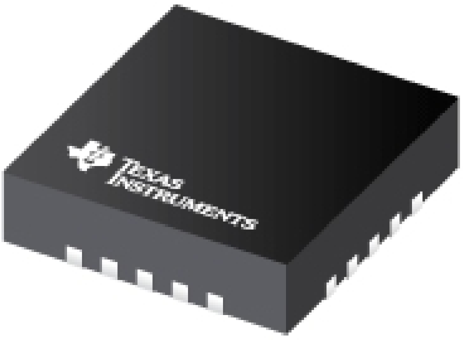

Figure 25: TI DRV421.

The DRV421 is designed for magnetic closed-loop current sensing solutions, enabling isolated, precision DC and AC current measurements. This device provides both, a proprietary integrated flux gate sensor, and the required analog signal conditioning, thus minimizing component count and cost. The low offset and drift of the flux gate sensor, along with an optimized front-end circuit results in unrivaled measurement precision.

The DRV421 provides all the necessary circuit blocks to drive the current-sensing feedback loop. The sensor front-end circuit is followed by a filter that can be configured to work with a wide range of magnetic cores. The integrated 250 mA H-Bridge drives the compensation coil and doubles the current measurement range, as compared to conventional single-ended drive methods. The device also provides a precision voltage reference and shunt sense amplifier to generate and drive the analog output signal.

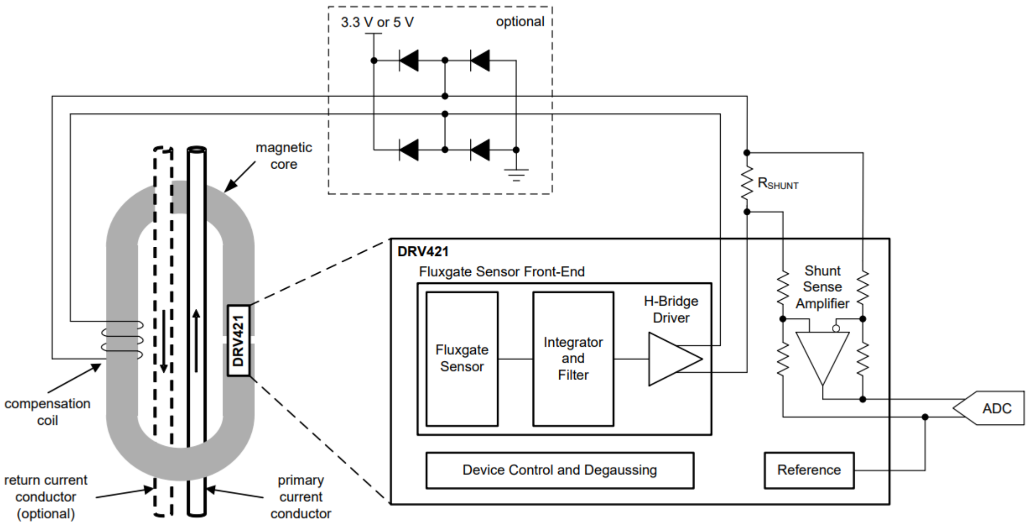

Figure 26: Typical Application of the DRV421.

2.2 In the interfacing slide switch with an MCU, what is the voltage of SW1 when slide switch 1 is ON? and is OFF ?

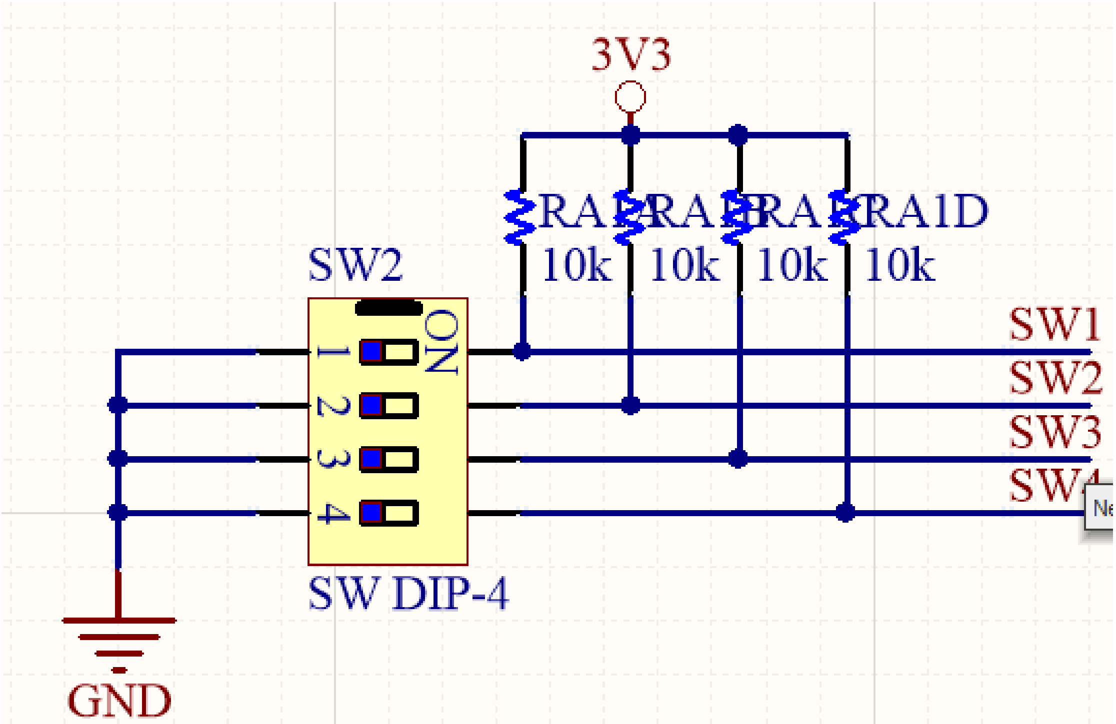

Figure 27: The slide switch.

- In case the switch 1 is on, we have a connection from the source through the $10k\Omega$ resistor across the switch to the ground. Then, it is obvious that SW1 is one end of the resistor that connect to the ground, so $V_{SW1} = 0(V)$.
- When the switch 1 is off, the connection above becomes open and there is no current passing through the resistor. Thus, it acts as a wire. At a result, we can conclude that $V_{SW1} = 3.3(V)$

2.3 In the current sensor circuit, what is the voltage of ADC1_CH7 and ADC1_CH6 ?

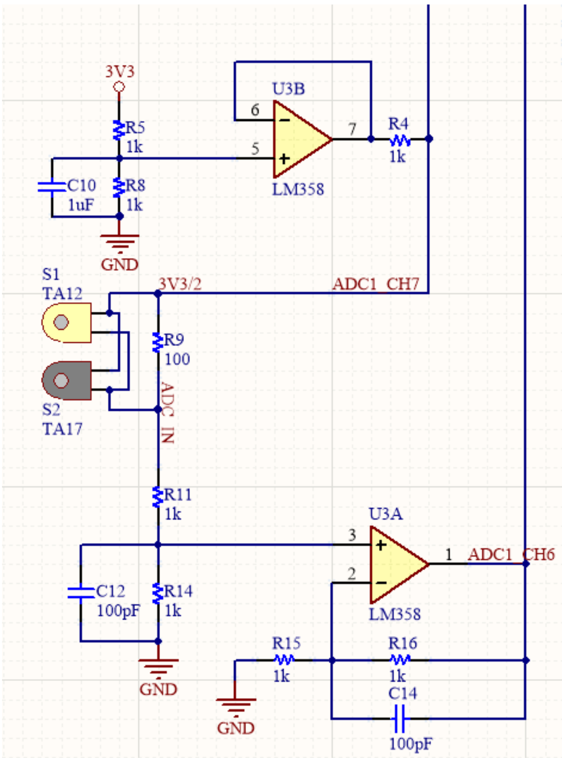

Figure 28: The ADC input.

- Let the point between R_5 and R_8 be A.

  We have: $\dfrac{3.3 - V_A}{R_5} = \dfrac{V_A - 0}{R_8}$

  $=> \dfrac{3.3 - V_A}{1000} = \dfrac{V_A}{1000} => V_A = 1.65(V)$

  The U3B op-amp is in negative feedback configuration, so $V_A = V_5 = V_6 = V_7 = 1.65(V)$

  According to Ohm's law, we have an equation: $V_7 - I \times R_4 - I \times R_9 - I \times R_{11} - I \times R_{14} = 0$

  $=> I = \dfrac{V_7 - 0}{R_4 + R_9 + R_{11} + R_{14}} = \dfrac{1.65}{3100} = 532(\mu A)$

- $V_{ADC1-CH7} = V_7 - I \times R_4 = 1.65 - 532 \times 10^{-6} \times 1000 = 1.118(V)$

- $V_{ADC-IN} = V_{ADC1-CH7} - I \times R_9 = 1.118 - 532 \times 10^{-6} \times 100 = 1.0648(V)$

  $$\frac{V_{ADC-IN} - V_3}{1000} = \frac{V_3 - 0}{1000} => V_3 = 0.5324(V)$$

  The U3A op-amp is in negative feedback configuration. We have the closed-loop gain for U3A is $A_{CL} = 1 + \frac{R_{16}}{R_{15}} = 2$

  $=> V_{ADC1-CH6} = A_{CL} \times V_3 = 2 \times 0.5324 = 1.0648(V)$

- The bias-point simulation on Pspice verifies our theoretical calculation above.

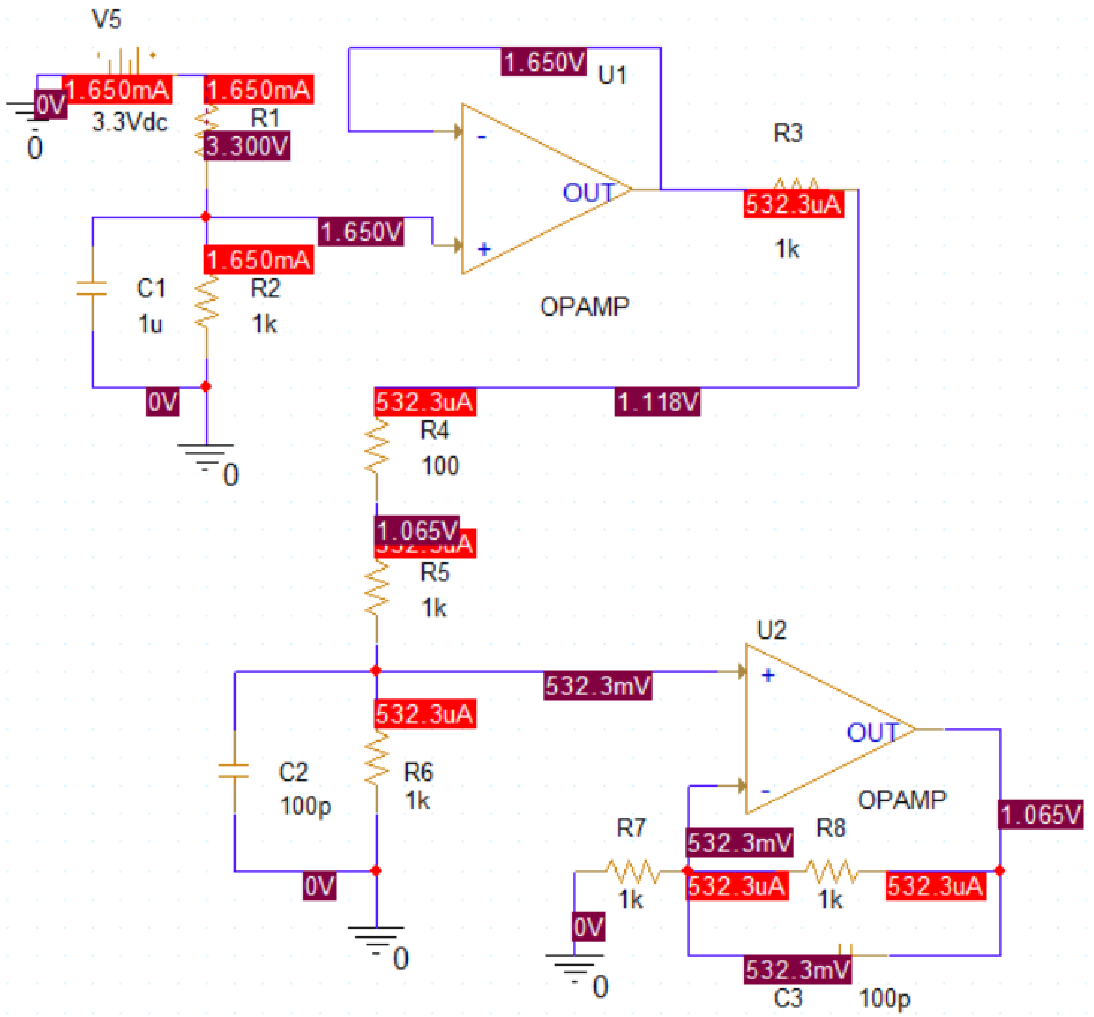

Figure 29: The bias point simulation.

2.4 In the current sensor circuit, we apply a low pass filter to the signal ADC_IN. What is the cutoff frequency of this low pass filter ? If we want to set a cutoff frequency is about 10kHz, what should we change in the circuit of U3A ?

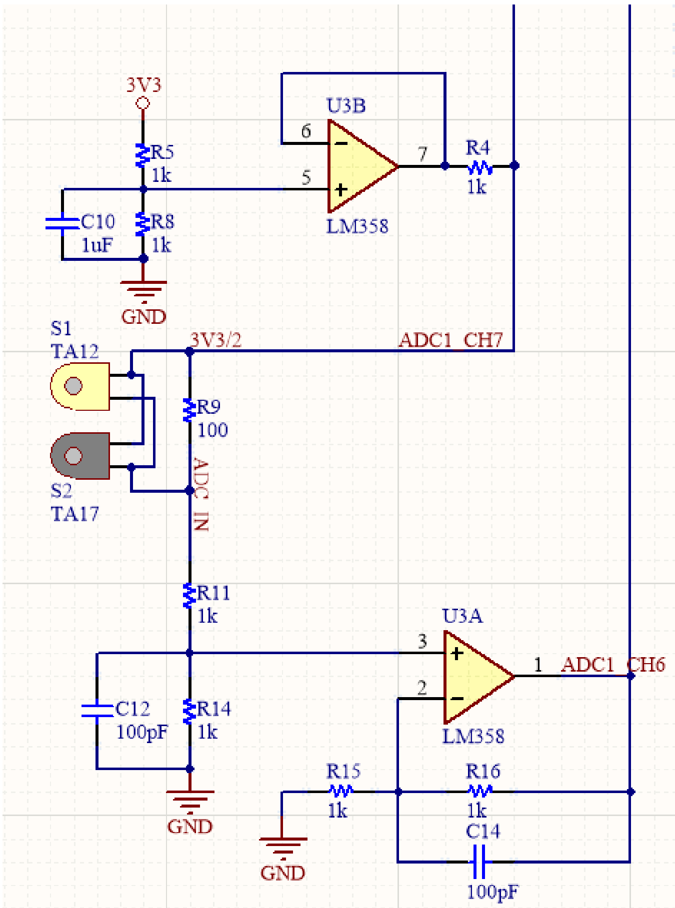

Figure 30: The ADC input.

- The cut-off frequency for this low pass filter is: $f_c = \dfrac{1}{2\pi \times R_{14} \times C_{12}} = \dfrac{1}{2\pi \times 1000 \times 100 \times 10^{-12}} = 1.6(MHz)$

- Rechecking the result with the AC sweep mode on Pspice gives us the same number:

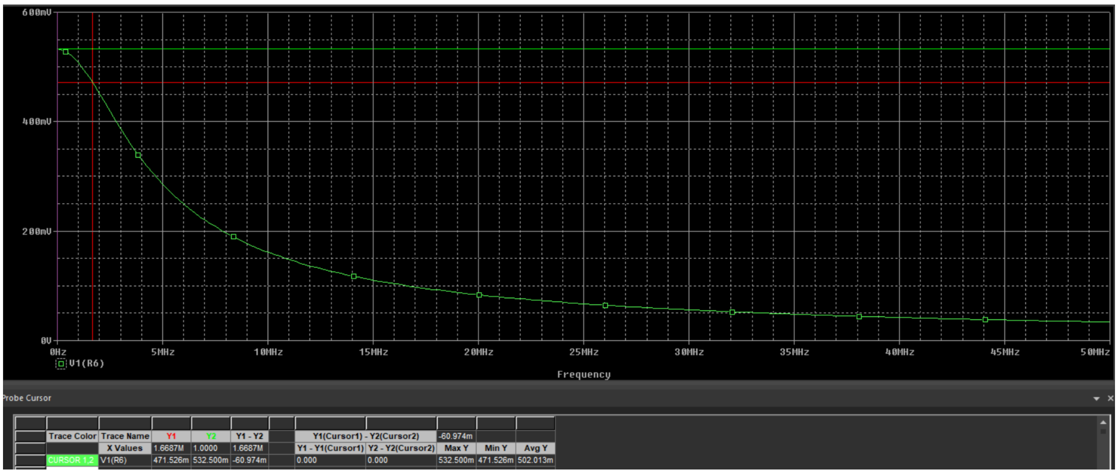

Figure 31: The AC sweep simulation.

- In order to adjust the cut-off frequency to 10kHz, we can keep the resistance unchanged and modify the capacitance or do reversely.
- If the resistance remain the same, we have $C_{12} = \dfrac{1}{2\pi \times f_c \times R_{14}} = \dfrac{1}{2\pi \times 10000 \times 1000} = 16(nF)$
- Or we can do the other way round, $R_{14} = \dfrac{1}{2\pi \times f_c \times C_{12}} = \dfrac{1}{2\pi \times 10000 \times 100 \times 10^{-12}} = 160(k\Omega)$
- Checking the changes with AC sweep simulation gives us the same result.

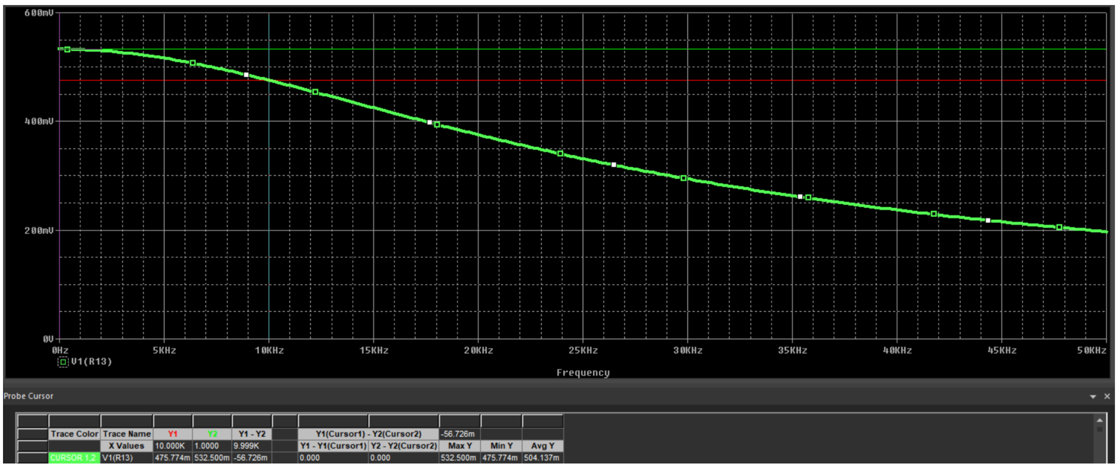

Figure 32: The AC sweep simulation when changing C_{12} to $16nF$.

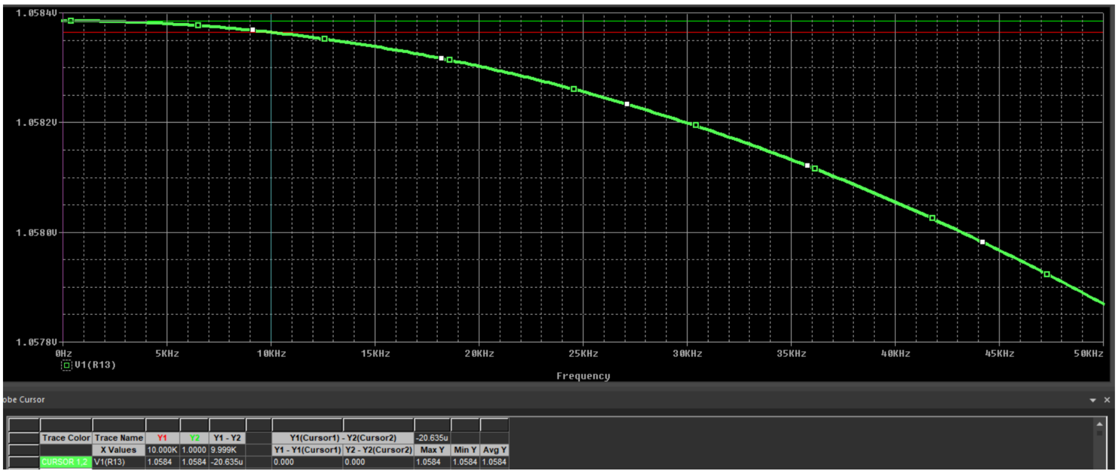

Figure 33: The AC sweep simulation when changing R_{14} to $160k\Omega$.

2.5 How much do the currents go through each LED in the interface with high-current LEDs ? What should we do if we want to control a 100mW LED ?

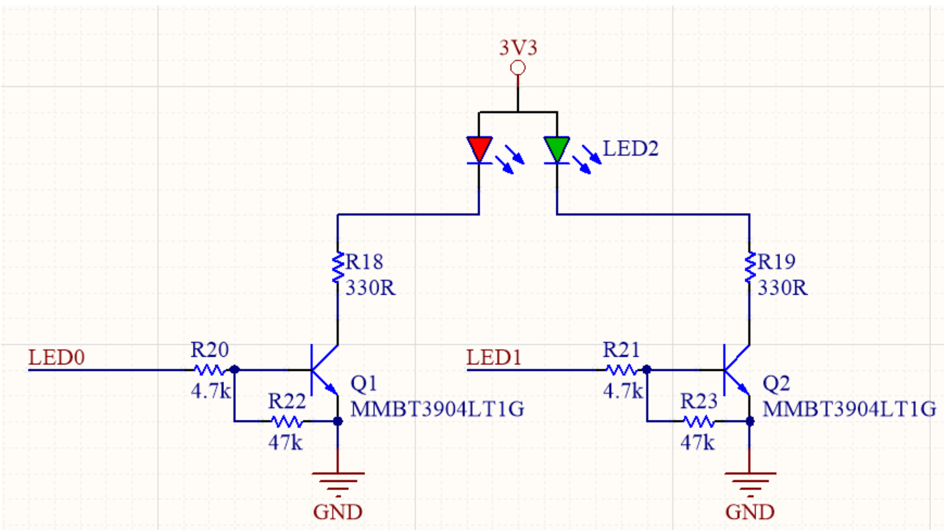

Figure 34: The interface with high-current LEDs.

- The forward voltage drop of LEDs differs by their colors. According to the table below, we can choose the voltage drop of the red LED is 1.5 V and the green one is 2.5 V for the following calculation.

CircuitBread | LED COLORS AND MATERIALS

Color	Wavelength Range (nm)	Forward Voltage (V)	Material
Ultraviolet	< 400	3.1 - 4.4	Aluminium nitride (AlN) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)
Violet	400 - 450	2.8 - 4.0	Indium gallium nitride (InGaN)
Blue	450 - 500	2.5 - 3.7	Indium gallium nitride (InGaN) Silicon carbide (SiC)
Green	500 - 570	1.9 - 4.0	Gallium phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Yellow	570 - 590	2.1 - 2.2	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
Orange / Amber	590 - 610	2.0 - 2.1	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaUInP) Gallium phosphide (GaP)
Red	610 - 760	1.6 - 2.0	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
Infrared	> 760	> 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)

Figure 35: LED Color and Forward Voltage based on the material.

- **Considering the green LED branch:**

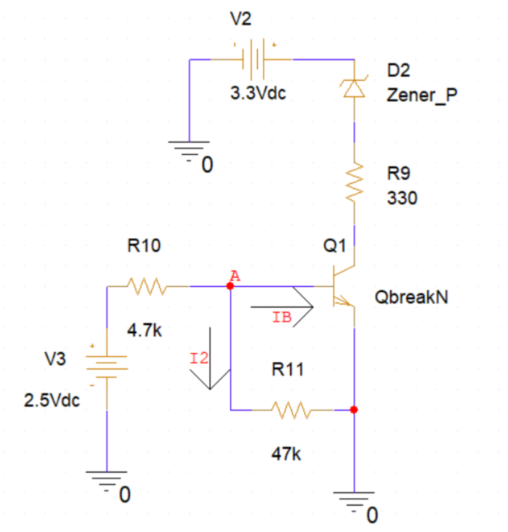

Figure 36: The deducing circuit.

Assume that the transistor is working on linear mode. According to the Ohm's law we can obtain a system of two equation with two variables:

$$\begin{cases} V_3 - 4700.(I_B + I_2) - 0.7 = 0 \\ V_3 - 4700.(I_B + I_2) - 47000 I_2 = 0 \end{cases} => \begin{cases} 4700 I_B + 4700 I_2 = 1.8 \\ 4700 I_B + 51700 I_2 = 2.5 \end{cases} => \begin{cases} I_B = 368.08(\mu A) \\ I_2 = 14.89(\mu A) \end{cases}$$

$$=> I_C = \beta \times I_B = 100 \times 368.08 \times 10^{-6} = 36.808(mA)$$

$$V_{CE} = V_2 - 2.5 - 330 \times I_C = 3.3 - 2.5 - 330 \times 36.808 \times 10^{-3} = -11.35(V)$$

Obviously, $V_{CE} < 0$ then the transistor is working on saturation mode.

Hence, $I_{LED_{Green}} = I_{C_{sat}} = \dfrac{V_2 - V_{LED_{Green}} - V_{CE_{sat}}}{330} = \dfrac{3.3 - 2.5 - 0.2}{330} = 1.81(mA)$

– Pspice simulation tool shows the result that is quite close to which we has obtained by theoretically calculations.

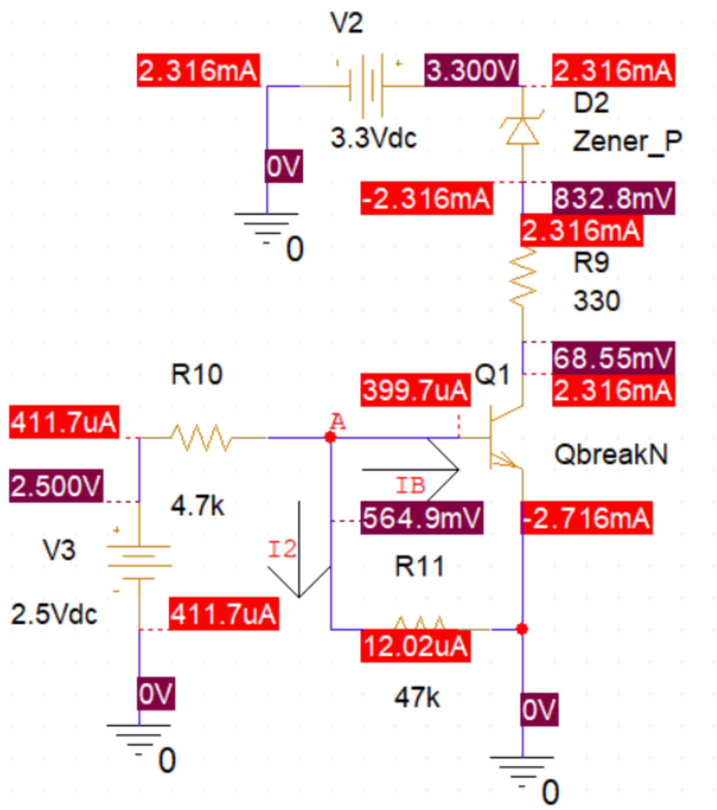

Figure 37: The bias point simulation.

- **Considering the red LED branch:**

  Assume that the transistor is working on linear mode. According to the Ohm's law we can obtain a system of two equation with two variables:

$$\begin{cases} V_3 - 4700.(I_B + I_2) - 0.7 = 0 \\ V_3 - 4700.(I_B + I_2) - 47000 I_2 = 0 \end{cases} => \begin{cases} 4700 I_B + 4700 I_2 = 1.8 \\ 4700 I_B + 51700 I_2 = 2.5 \end{cases} => \begin{cases} I_B = 368.08(\mu A) \\ I_2 = 14.89(\mu A) \end{cases}$$

$$=> I_C = \beta \times I_B = 100 \times 368.08 \times 10^{-6} = 36.808(mA)$$

$$V_{CE} = V_2 - 1.5 - 330 \times I_C = 3.3 - 1.5 - 330 \times 36.808 \times 10^{-3} = -10.35(V)$$

Obviously, $V_{CE} < 0$ then the transistor is working on saturation mode.

$$\text{Hence, } I_{LED_{Red}} = I_{C_{sat}} = \frac{V_2 - V_{LED_{Red}} - V_{CE_{sat}}}{330} = \frac{3.3 - 1.5 - 0.2}{330} = 4.84(mA)$$

– Pspice simulation tool shows the result that is quite close to which we has obtained by theoretically calculations.

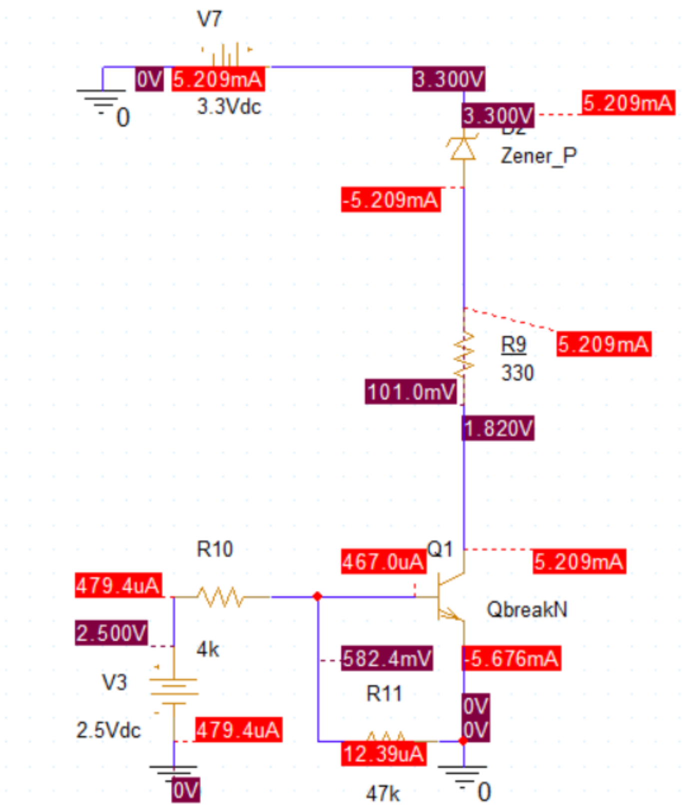

Figure 38: The bias point simulation.

- Combining two branches together:

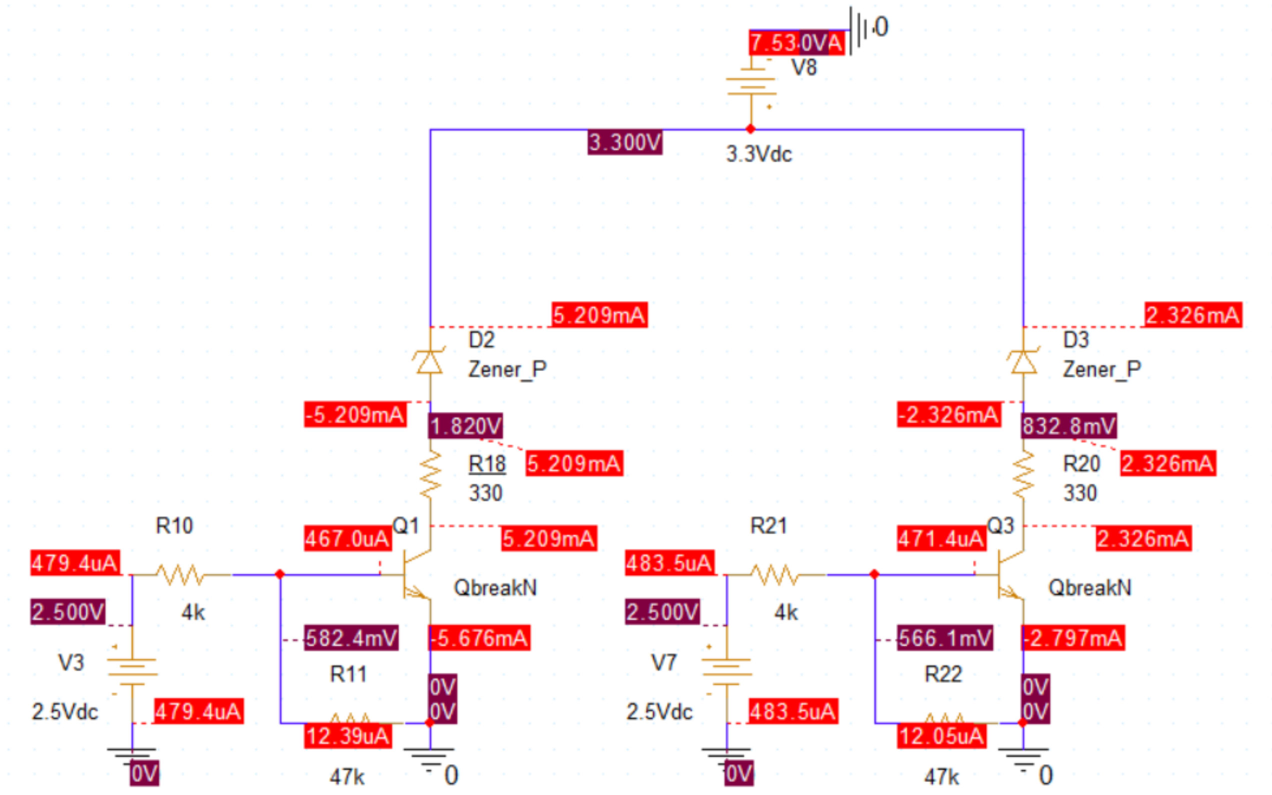

Figure 39: The bias point simulation.

- A $100mW$ LED would require a current of $\dfrac{100 \times 10^{-3}}{2.5} = 40(mA)$.

  In order to control this LED, we can use a voltage follower circuit to apply a voltage as our will to the high-currents LED circuit and at the same time, adjust the resistor to get a wanted current

  The circuit can be implemented as following:

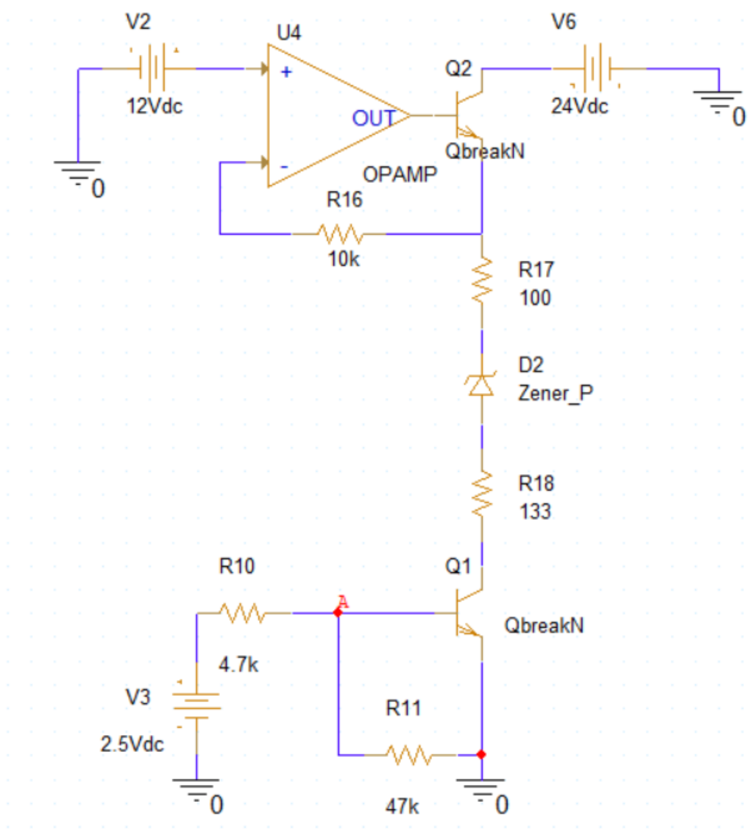

Figure 40: The circuit to control a 100mW LED.

The voltage follower's low output impedance makes it a good circuit for driving current into a low-impedance load. The E pin of the Q2 op-amp is connected to output of the op-amp so the voltage at the positive pin is copied to V_E. No matter how much is the voltage supply at the C pin, V_E still remains the same.

- Here we want to maintain a current of 40 mA through the LED. One of the solution is that to force the transistor Q1 working on saturation mode then it would be easier for us to reach 40 mA since we only need to modify resistor R_{17} and R_{18}

We have $I_{C_{sat}} = 40(mA) => I_{B_{min}} = \dfrac{I_{C_{sat}}}{\beta} = 400(\mu A)$. Anytime, $I_B > I_{B_{min}}$, Q1 will be on saturation mode. Let adjust the value of R_{10} to obtain our goal.

- **Considering the green LED branch:**

According to the previous calculation, we have a system of two equation:

$$\begin{cases} V_3 - R_{10}.(I_B + I_2) - 0.7 = 0 \\ V_3 - R_{10}.(I_B + I_2) - 47000 I_2 = 0 \end{cases} => \begin{cases} R_{10} \times I_B + R_{10} \times I_2 = 1.8 \\ R_{10} \times I_B + (47000 + R_{10}) I_2 = 2.5 \end{cases}$$

Let say we want $R_{10} = 4(k\Omega)$ then $\begin{cases} I_B = 435.11(\mu A) > I_{B_{min}} \\ I_2 = 14.89(\mu A) \end{cases}$

– Next, we can use the bias point simulation mode in Pspice to choose the appropriate value for R_{17} and R_{18} to set $I_C = 40(mA)$. After some trials, we can see that $R_{17} = 105(\Omega)$, $R_{18} = 120(\Omega)$ makes $I_C = 40.32(mA)$ which is pretty close to our goal.

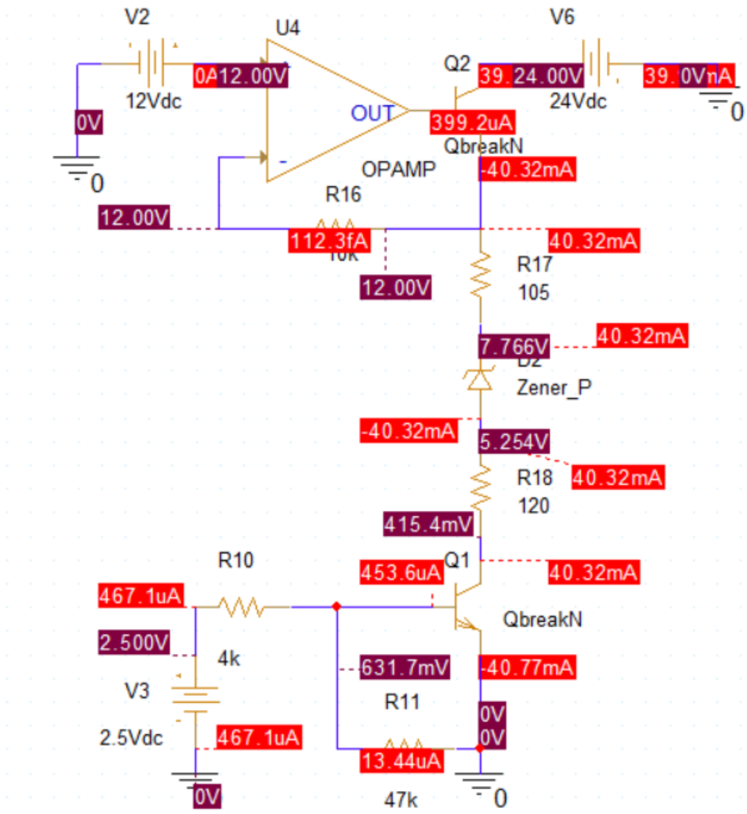

Figure 41: The bias point simulation.

- **Considering the red LED branch:**

According to the previous calculation, we have a system of two equation:

$$\begin{cases} V_3 - R_{10}.(I_B + I_2) - 0.7 = 0 \\ V_3 - R_{10}.(I_B + I_2) - 47000 I_2 = 0 \end{cases} => \begin{cases} R_{10} \times I_B + R_{10} \times I_2 = 1.8 \\ R_{10} \times I_B + (47000 + R_{10}) I_2 = 2.5 \end{cases}$$

Let say we want $R_{10} = 4(k\Omega)$ then $\begin{cases} I_B = 435.11(\mu A) > I_{B_{min}} \\ I_2 = 14.89(\mu A) \end{cases}$

– Next, we can use the bias point simulation mode in Pspice to choose the appropriate value for R_{17} and R_{18} to set $I_C = 40(mA)$. After some trials, we can see that $R_{17} = 100(\Omega)$, $R_{18} = 150(\Omega)$ makes $I_C = 40.29(mA)$ which is pretty close to our goal.

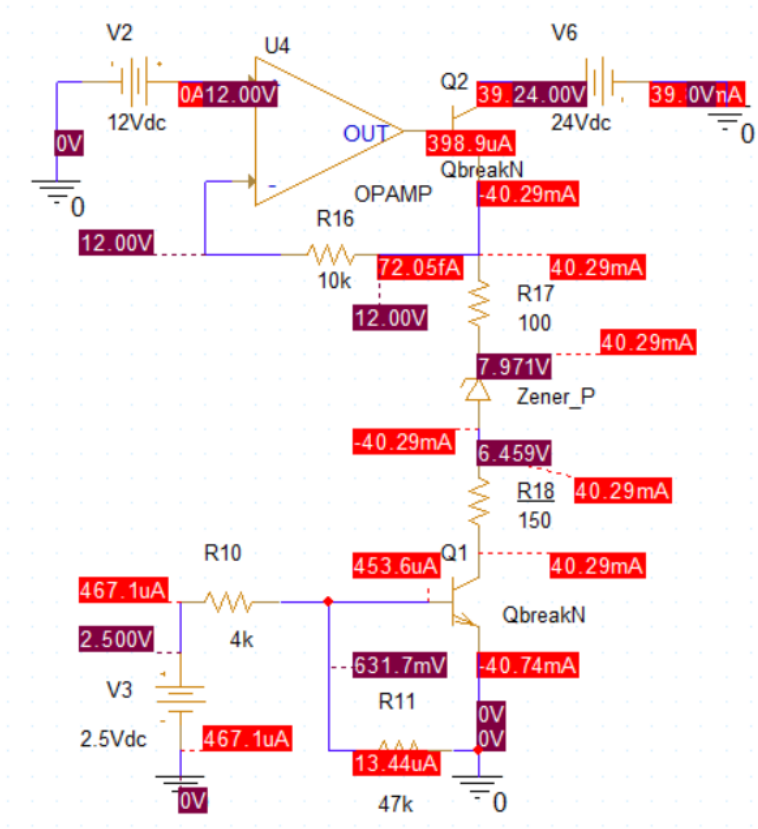

Figure 42: The bias point simulation.

- Combining two branches together:

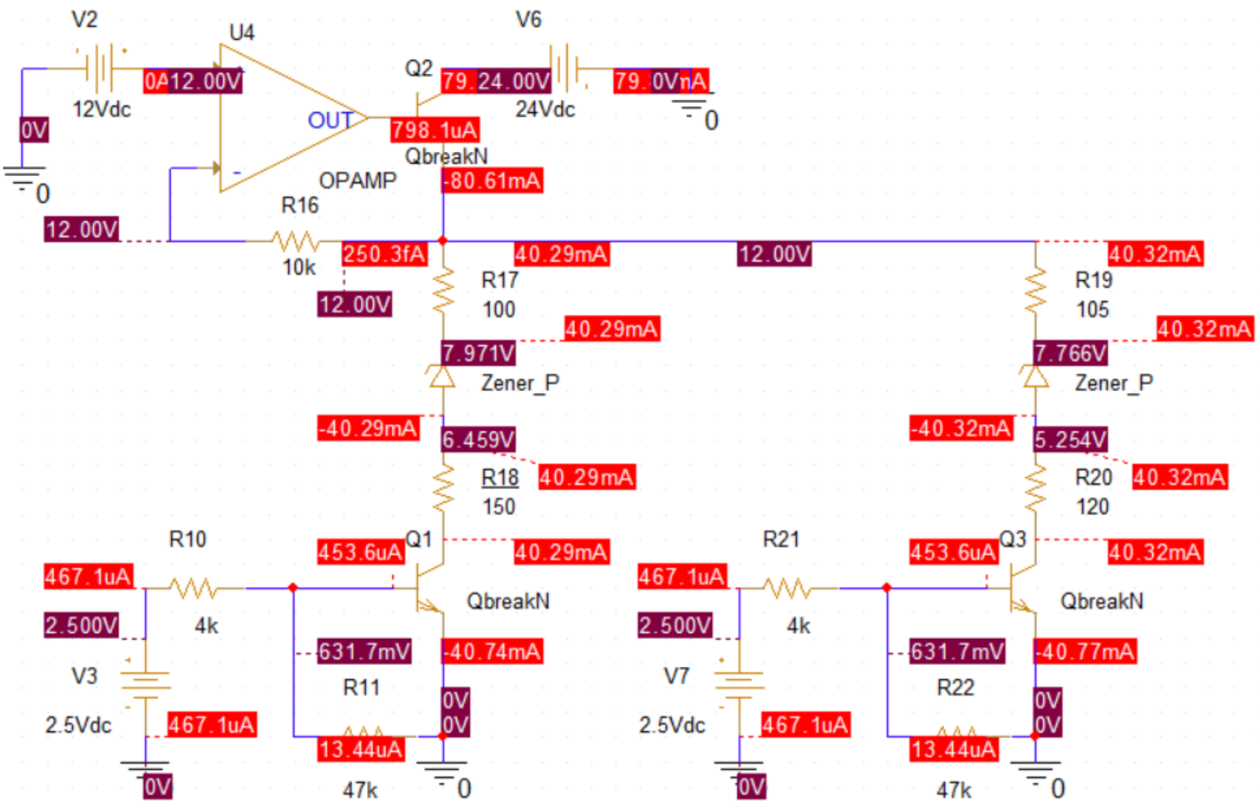

Figure 43: The bias point simulation.

2.6 What is the main purpose of D2 in the RS-485 part ?

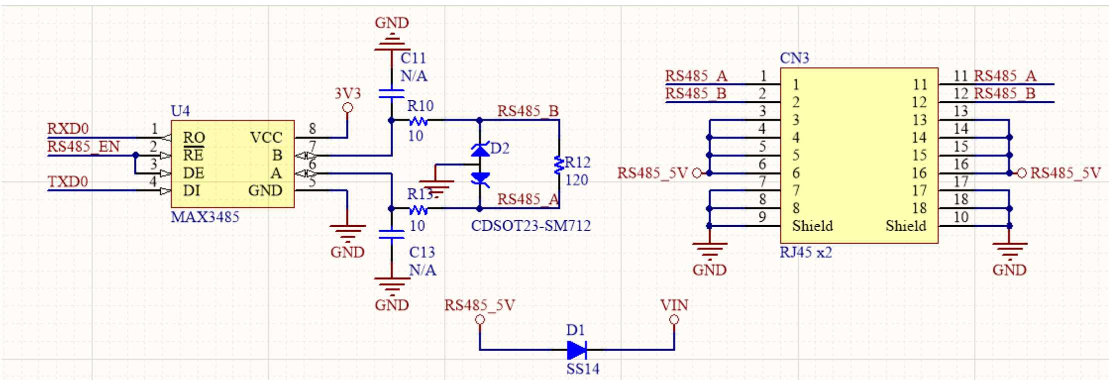

Figure 44: The RS-485 part.

- The main purpose of D2 is to provide protection for RS-485 ports. A general protection scheme for an RS-485 network usually includes a TVS diode array such as D2 with the name CDSOT23-SM712 device on each node. This single-stage bidirectional device provides asymmetrical over-voltage protection for the RS-485 transceiver across the entire -7 V to +12 V common mode voltage range. For RS-485 parts with limited exposure, this TVS diode array may be all that is needed for reliable operation.

- Furthermore, the single-stage TVS diode solution will provide effective clamping of the transient signal up to the peak impulse current, I_{PP}, of the TVS diode. I_{PP} is the maximum current the TVS diode can be subjected to without failure. As the TVS diode is exposed to higher transient voltages, concern for exceeding this device's current limitation rises as well. Current limiting must be used to keep I_{PP} within its rated limit. A TVS diode with series resistance R_x, shown in figure 45, is effective for low level transients. As the transient voltage increases, the power rating (and physical size) of the TVS diode and series resistance also must increase to limit the TVS diode's current below the device's I_{PP} (peak pulse current rating).

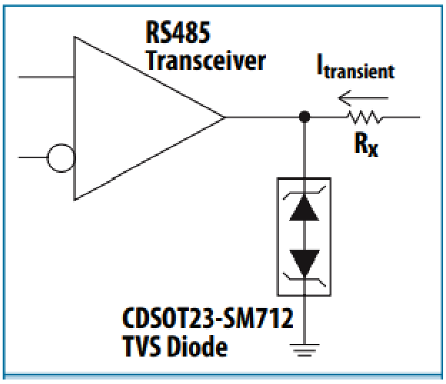

Figure 45: TVS diode plus resistor.

2.7 (Optional) How to use IC 74HC595 to design a circuit to display value on four 7-segment LEDs ?

2.7.1 Introduction

- A circuit of a 4-digit 7-segment LED display module can be driven by many microprocessors and development boards. Apart from a 5V power supply, the module requires three I/Os of the micro-controller, and one header is needed to connect power and data lines to the module.

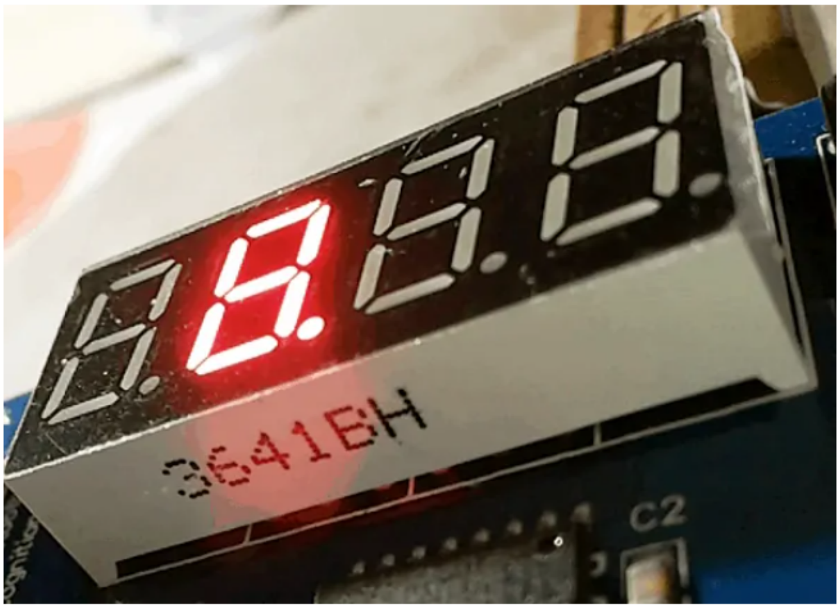

Figure 46: 4-digit 7-segment LED.

- **Key Components**
  - Two 74HC595 ICs
  - One 4-digit 7-segment LED Display
  - Two 100nF Capacitors
  - Two 1$k\Omega$ Resistors
  - One 5-pin Header

- **The use of 74HC595 IC in the circuit**
  - The 74HC595 IC consists of an 8-bit shift register and an 8-bit D-latch with 3-state parallel outputs. The IC directly interfaces with the SPI serial data port on today's micro-controllers, accepts serial data and provides serial output. The shift register also puts up parallel data to 8-bit latch. The shift register and latch also have independent clock inputs. The IC has operating voltage range of 2 to 6 V.

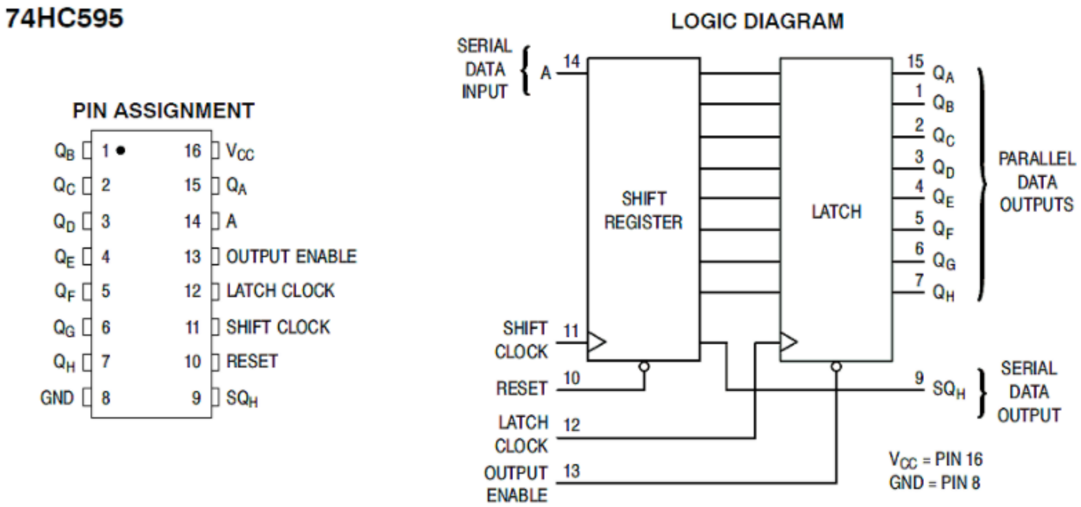

Figure 47: Pins assignment and logic diagram of IC 74HC595.

– In the circuit, 74HC595 IC uses the standard SPI interface, and thus accepts 3 serial control signals from the external micro-controller - Serial Data In, Serial Clock, and Latch Clock.
  * Pin 14 of 74HC595 is the serial data input pin. Data on this pin is shifted into the 8-bit serial shift register.
  * Pin 11 is the shift register clock input pin. A low to high transition here causes the data at serial input pin to be shifted into the 8-bit shift register.
  * Pin 12 is the storage latch clock input pin. A low to high transition here latches the shift register data.
  * Pins 15, 1, 2, 3, 4, 5, 6, 7 (Q_A-Q_H) are non-inverted, 3-state, latch output pins.
  * Pin 9 is the non-inverted serial data output pin. This is the output of the 8^{th} stage of the 8-bit shift register (without tri-state capacity).
– Making a 16-bit shift register by 74HC595 is quite simple as it just need a 74HC595 daisy chain. In the circuit diagram, two 74HC595 ICs share common clock and latch pins but with the data output pin of the first shift register to the data input pin of the second one. In principle, the two daisy-chained shift registers operate like a single 16-bit register where the first device in the chain is the MSB, so it is the last to be filled while the second is the LSB, i.e. the first to be filled by the micro-controller's serial data set.

2.7.2 Altium Design

- Schematic Design:

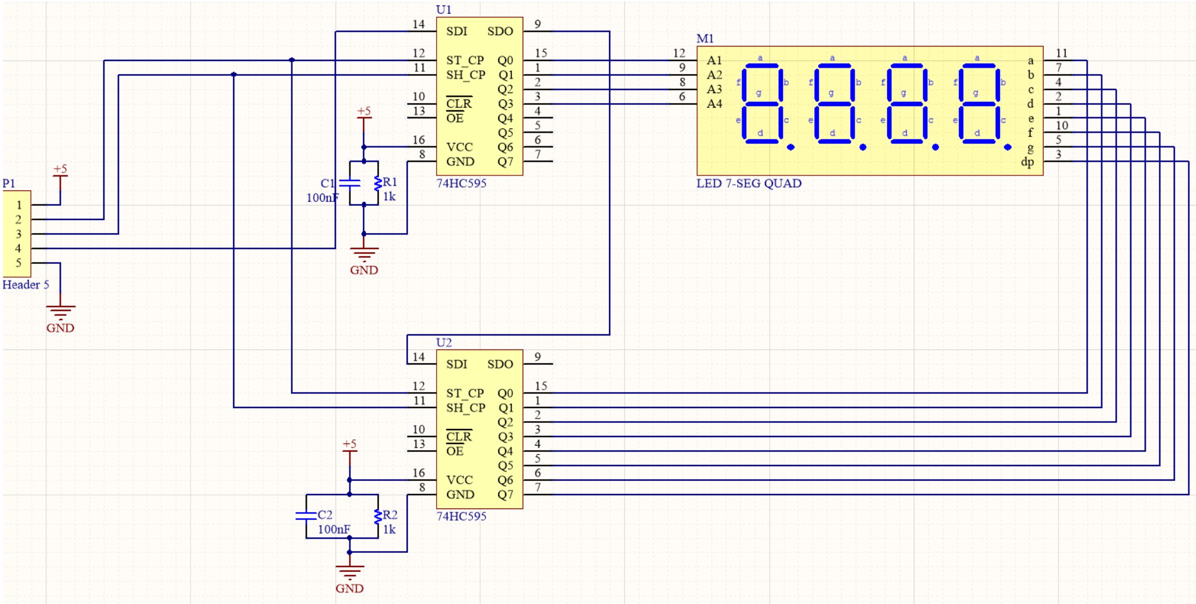

Figure 48: The schematic design.

- PCB Layout:

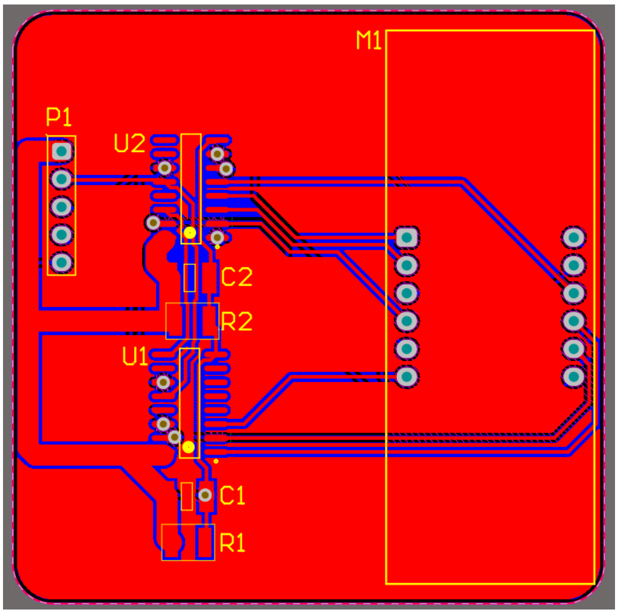

Figure 49: The top layer of PCB layout.

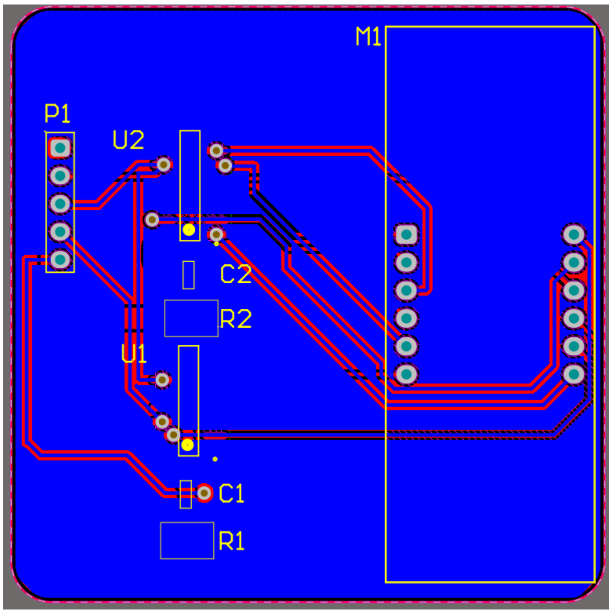

Figure 50: The bottom layer of PCB layout.

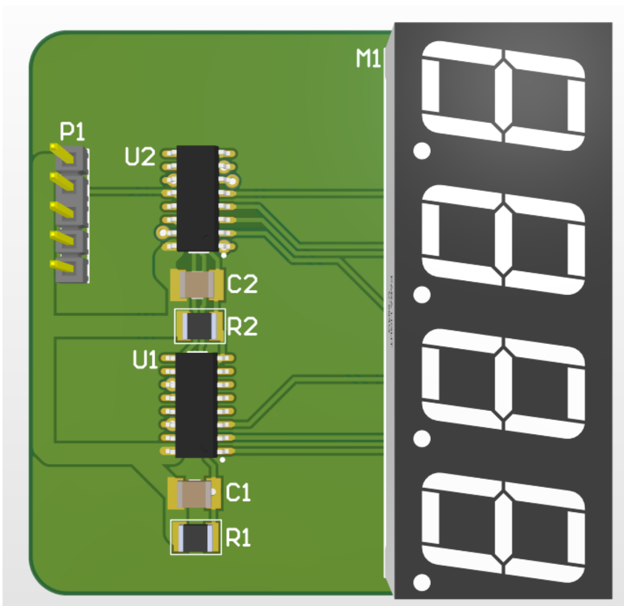

Figure 51: Top view of the circuit in 3D.

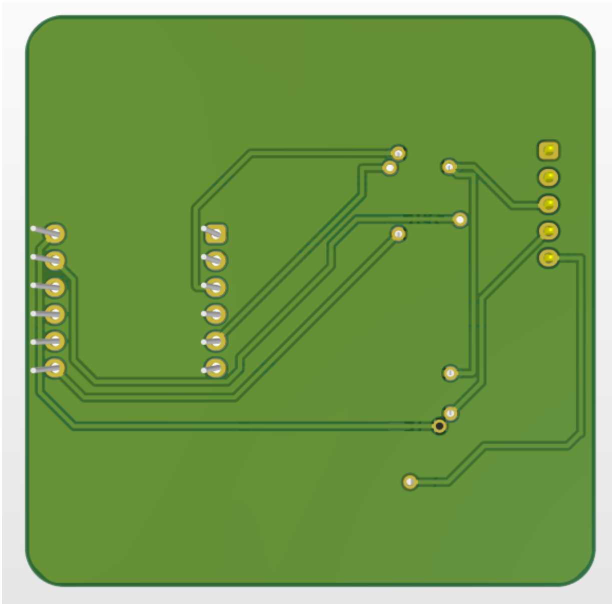

Figure 52: Bottom view of the circuit in 3D.

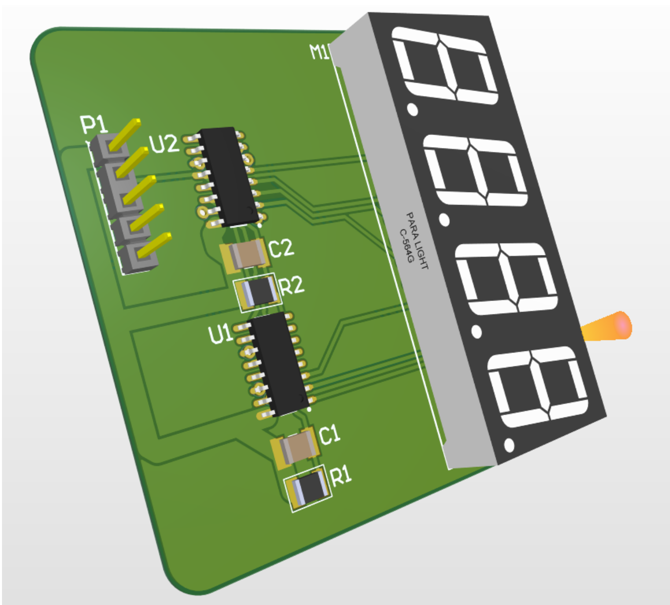

Figure 53: Side-view of the circuit in 3D.

3 References

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