BILKENT UNIVERSITY

ENGINEERING FACULTY

DEPARTMENT

OF

ELECTRICAL and ELECTRONICS ENGINEERING

EEE 299

SUMMER TRAINING REPORT

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Performed at

Siyah Research and Development

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1 Introduction

In this report, the information about my internship company and project can be found. I have done my internship at Siyah R&D. As I was unsure about whether to focus on software or hardware on my internship, I had decided it would be best to discover the field of microprocessors that combines both fields. As Siyah R&D is a company that specialized in the field of embedded technologies it was a valuable experience for me to learn about this sector during my internship.

The main aim of my project I was given to is to be able to power an Arduino UNO Board when the input voltage is higher than what Arduino can handle, use Arduino to measure the current flowing into a certain device, in this case a load, and finally decided to close a relay manually to stop the current flow into to load. To achieve this I built a reverse voltage and overvoltage protection circuit. Then implemented a switching regulator and a capacitor bank after which I powered the Arduino. I used an Hall Effect sensor and electrical relay for the load. I decided to use a load which would symbolize the device itself.

I will start this report by giving information about Siyah R&D, company's working fields, the department I had worked in and my internship supervisor, Önder Arık. Then I will give more details about the project I had done, the path that led me to final decision and what I learnt during these steps. Afterwards, I will show the final version of the project and its test run according to wanted requirements. Finally, I will talk about how I worked during the project, how I earned the knowledge needed, how I decided to turn my knowledge into application, my ethical and professional responsibilities, diversity, equity and inclusion exercises I have observed during my internship. I will finish this report with a conclusion about the internship.

2 Company Information

2.1 About the company

Siyah R&D is a company founded in 2007 by Özgür Barış Akan, Önder Arık, Gökhan Moral. The company has a lot of knowledge regarding Information Technology and encompasses a variety of technologies including embedded systems, mobile systems, telecommunication systems and cloud computing. The company has several collaborations such as Bilkent University, TAI, BARMEK, Beko, Koç University, Innova and Avea. It is located in Gazi University Technolgy Development Area where only high-tech firms are hosted. [1]

2.2 About the products and production systems of the company

Siyah R&D's primary focuses are research and development. The company's research and development interests are:

- Embedded System hardware and software design & development (Real time systems, multi-processing/ multi-threaded systems, Assembler, C/ C++, ARM/ PowerPC/ MIPS)
- Mobile Systems (Low level Android customizations and security enhancements, custom Android ROMs, Android applications)
- Telecommunication Systems (Digital Signal Processing, Modem Design, Electromagnetic Propagation Modelling & Simulation, Powerline Communication, Protocol design & implementation)
- Cloud Computing (forming simple cloud computing environment for SMEs, developing mobile application for cloud computing environments) [1]

A general process of production in Siyah R&D begins after a project is chosen. The management team holds a meeting with the administrative staff and chief engineers after they have the project in hand. This meeting allows the company to determine which engineers are capable for the project according to their field of expertise. Regularly the team formed reflects to work done for the project and change their working style in a more efficient way.

Works and projects could not be added due to the internal confidential policy.

2.3 About your department

I completed my internship at embedded systems department. In this department there are several electrical and mechanical engineers who have sufficient knowledge about embedded system hardware and software through their education and years of experience. These engineers usually work on one or several projects at the same time. Main work done here is to design and develop embedded systems according to project's needs. Engineers usually code embedded systems right to the system's registers to create the project as efficiently as possible. During development, a strong hierarchal embedded system is pursued for efficiency, cost and availability purposes.

2.4 About your supervisor

Name and Last Name:	Önder Arık
Job Title:	CTO of Siyah R&D
University of B.S. Graduation:	Bilkent University
Department of B.S. Degree:	Electrical and Electronics Engineering
Year of B.S. Graduation:	1998
Email:	onder.arik@siyah.arge.com
Phone Number:	05337665415

3 Work Done

For this internship, my aim was to build several types of circuits where each circuit has a designated task to achieve and connect these circuits successfully to see whether I can power an Arduino with the result.
As the supervisor, Önder Arık specified that input voltage will be between 12V and 24V that made the following circuits necessary: a reverse voltage protection circuit, an overvoltage protection circuit, a switching regulator and a capacitor bank.

Essentially the aim is to eliminate the chance of causing any harm to the device, Arduino and power Arduino with the same circuit as well.

Moreover, I also aimed to use Arduino to decide whether to deliver current to a specific device, which is a load, and measure the current it draws for both of which I wrote a code in the Arduino IDE.
Energy efficiency was given a priority throughout the whole project.
Here is the project schematic:

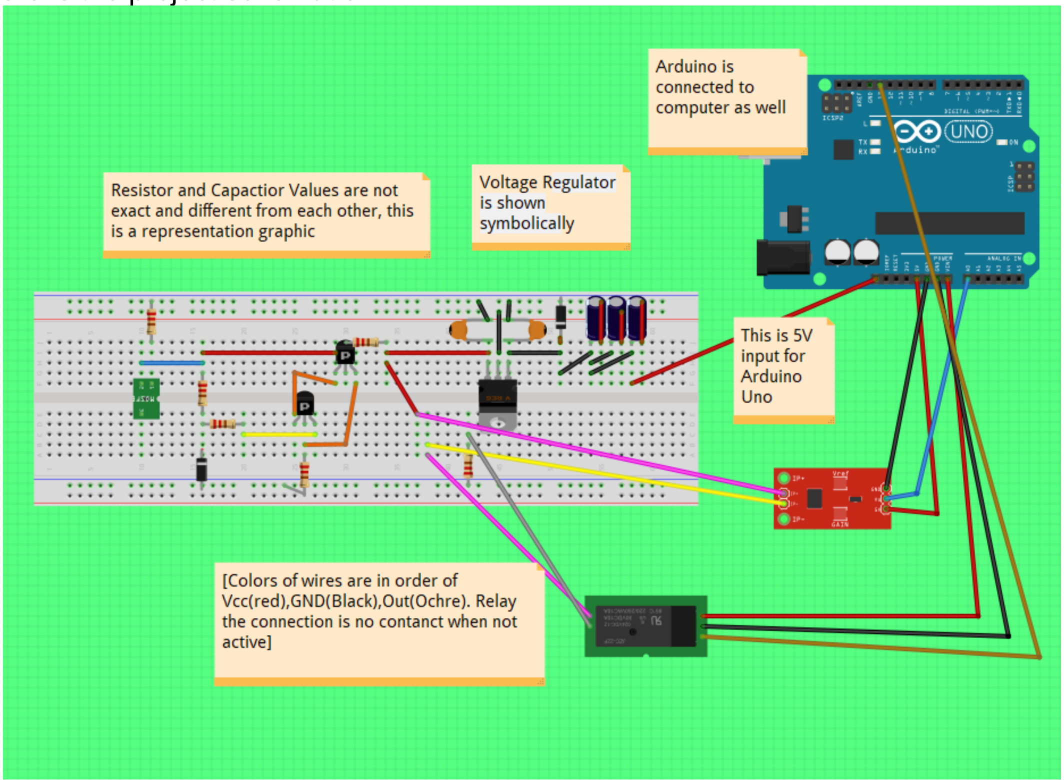

Figure 1: General Schematic of the Project

3.1 Theoretical Part of the Project

In this section I explain the steps I took during the design of the project until I decided on the project and explain each of these steps.

3.1.1 Reverse Voltage Protection Circuit (RVP)

RVP essentially cuts of the circuit when there is a case of reverse voltage application on the input or output terminals, thereby protecting power supplies and electronic circuits. It is usually implemented right after the input of the circuit [2].

For the design of this circuit, there are generally two different paths one can use. One is a simple diode circuit that will only pass current in the preferred direction whereas the other path utilizes a P channel MOSFET as a simple switch. For the design of this project both ways were examined in LTSpice and MOSFET circuit was chosen due to its high performance. As 24V is the highest supply voltage that will be chosen for this project, circuits were analyzed according to this constraint.

3.1.1.1 *RVP Using Diode*

Essentially a forward biased diode is used which will only allow circuit to pass current through one way. In the case of a reverse voltage application the diode will disconnect input from the remaining circuit.

However, this circuit was not considered a rational choice due to its lower energy efficiency in forward bias case. Moreover, diode also causes a voltage drop due to its threshold voltage in forward bias. Here is an example circuit:

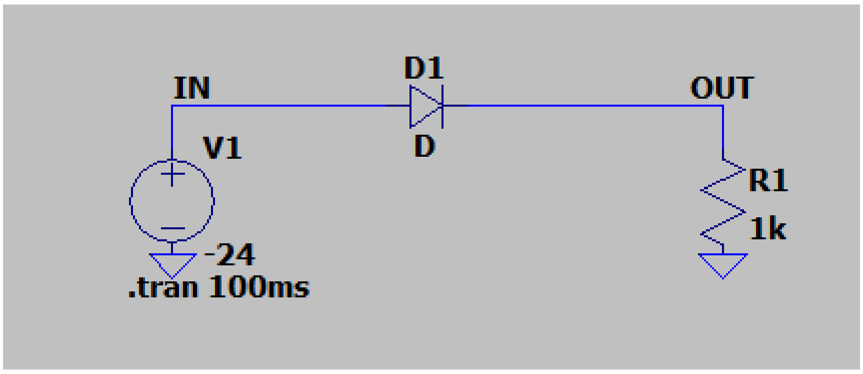

Figure 2: RVP Schematic

- The load resistance was chosen 1k ohm for the sake of simplicity.

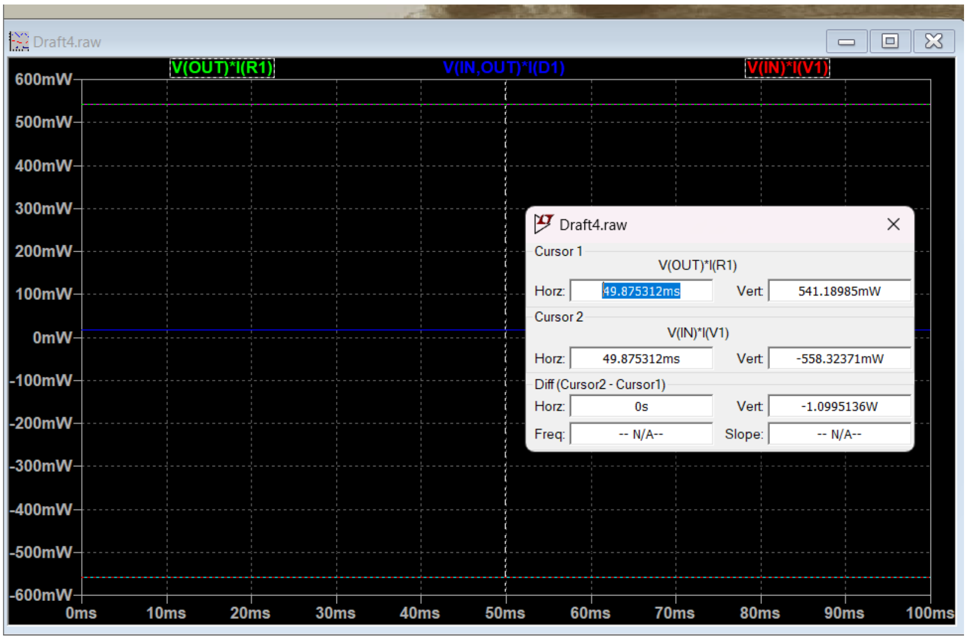

Figure 3: RVP Using Diode, LTSpice Schematic

As one can see, in forward bias case there seems to be no complications as %96.9 percent of the energy is being delivered to the output(see Appendix A). However, if one looks out the output voltage, they can see 0.736 Volt drop which may be undesired, especially if the desired circuit consists of several circuits that all cause minimal voltage drops. Accumulated drop in the voltage may become insufficient for the device in the output. To minimize the voltage and energy drops, it is smarter to use a different type of circuit.

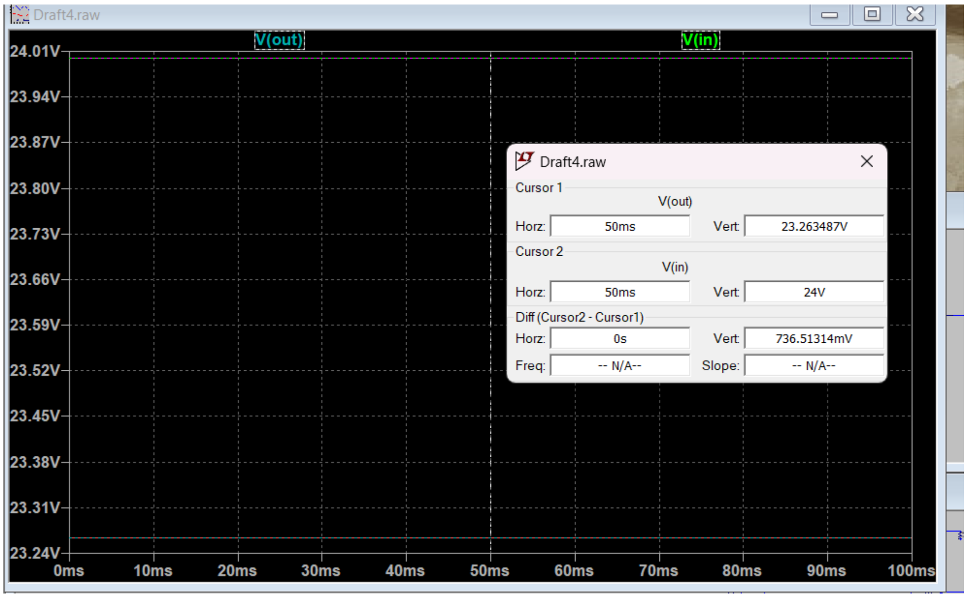

Figure 3: Vin vs Vout of RVP circuit

3.1.1.2 RVP Using PMOS FET

MOSFETs are a four terminal device which have source(S), gate(G), drain (D) and body (B). Source and body are connected which makes it a three-terminal device. MOSFETs can be categorized in 4 ways which are [3]:

- N-type enhancement MOSFET
- N-type depletion MOSFET
- P-type enhancement MOSFET
- P-type depletion MOSFET

As P type depletion MOSFET is used for the RVP, MOSFETs' working principle will be explained through PMOS FETs.

A depletion MOSFET can be considered as normal on MOSFET without any voltage application to the gate. In a depletion PMOS FET, the drain and the source are doped p region and body is n region. When negative voltage is applied to the gate, the electrons in the n region move towards the p region and the depletion MOSFET becomes conductive [4]. In other words, depletion PMOS FET becomes more resistive when positive voltage is applied. This case is reversed for depletion NMOS FET.

Essentially this circuit utilizes depletion PMOS FET's ability to turn off when positive voltage is applied to the gate. Reverse voltage application is essentially positive voltage application to the ground node. In other words, if one connects PMOS FET's gate terminal to the ground, in the event of reverse voltage application the depletion PMOS FET will cut off the circuit from the rest protecting it from any possible harm. For real life application, IRFD9010 was the chosen MOSFET.

Moreover, this RVP circuit wastes little to no energy and has no voltage drops across the circuit making it a better choice over the diode circuit.

Here is the example circuit:

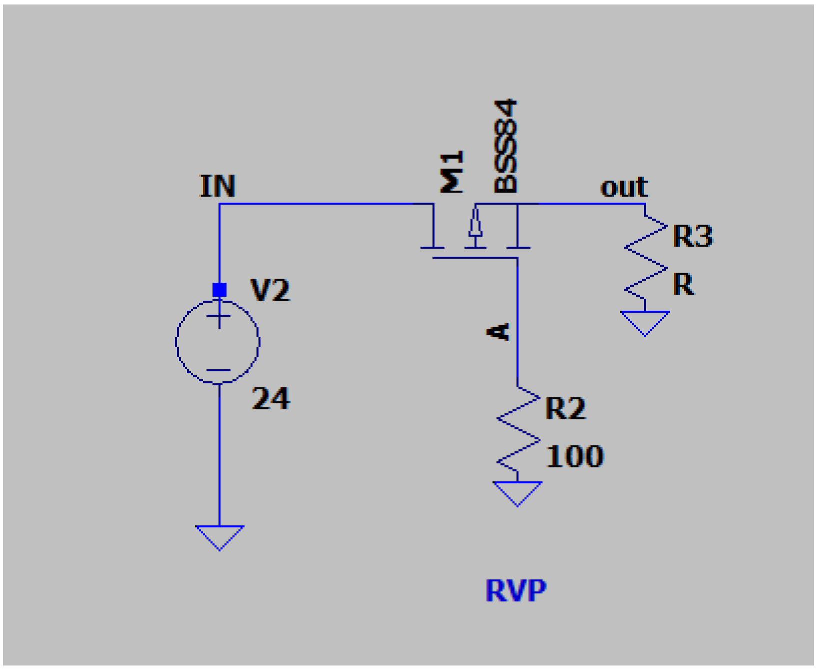

Figure 4: RVP using depletion PMOS FET

- BSS4 PMOS FET is enhancement type MOSFET that can withstand, which is the closest to IRFD9010 PMOS FET as both have 50 drain to source voltage (V_{ds}) [5].

When reversed, PMOSFET's gate to source voltage (V_{gs}) is positive which inhibits the current flow. The device will only work when the voltage is forward bias condition. In this circuit only 0.105 Volt drop was observed, and this circuit has 99.47% energy efficiency. Both values are better compared to that of diode circuit (see Appendix B).

3.1.2 **Overvoltage Protection Circuit**

Overvoltage protection (OVP) is a feature that clamps or shuts down the output to prevent any excessive voltage from being supplied to the other electric elements in the circuitry. For this protection to activate, voltage should exceed the predetermined value [6].

There were two types of overvoltage circuit that were considered for the project:

- Simple Zener Circuit,
- PNP BJT Overvoltage Protection Circuit

3.1.2.1 ***Simple Zener Circuit***

This circuit relies on Zener diode's breakdown voltage to clamp the voltage to the preset level. In other words, Zener diode can only operate in breakdown voltage for this circuit. As 24V is the absolute maximum input planned, a Zener diode with 24V breakdown voltage was sufficient for the software test. Here is the LTSpice schematic:

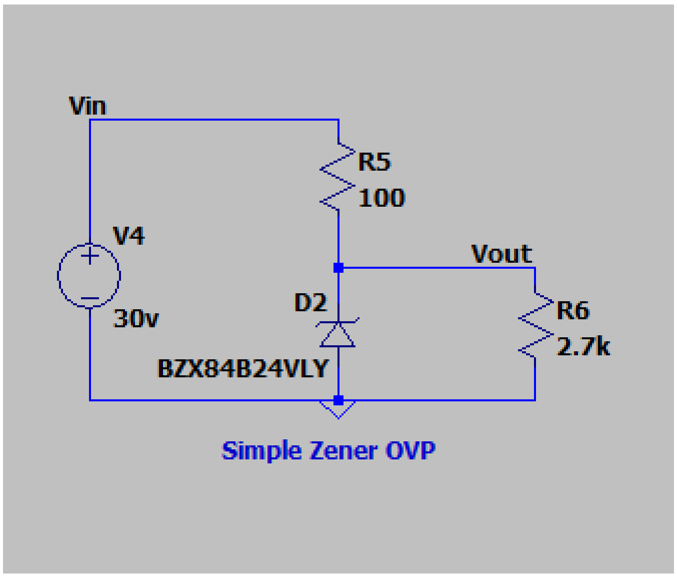

Figure 5: Simple Zener OVP Circuit Schematic

- BZX84B24VLY is a Zener diode with 24.5V breakdown voltage in LTSpice library which is connected in parallel to output voltage. A small drop in voltage was also taken into consideration for output voltage to stay around 24V.
- The resistances allow most of voltage to remain in the output through voltage divider.

When input voltage is higher than 24.5V Zener diode starts regulating the output voltage. Essentially diodes parallel connection allows Zener to clamp the voltage to 24V, including the voltage drop. This circuit's main advantage is that it doesn't cut the connection between the input and output. However, regarding energy concerns, this circuit is highly ineffective. (see appendix C)

- When input voltage is 24V, output has 198mW power and 96% of the energy is transferred. Output voltage drops to 23.14V.
- When input voltage is 30V, only 12% of the power is transferred and output has 214mW power. Output voltage is clamped to 24.08V.

Though the energy transferred to output has risen. The energy loss has also risen significantly with most of the energy being spent by the Zener diode, which is 1.2W. This can be a problem as a Zener diode mostly operates on low-power systems. As Zener diodes have a low power rating, the component is not an appropriate fit for high power systems [7].

3.1.2.2 *Zener and PNP BJT Overvoltage Protection Circuit*

This circuit relies on PNP BJT's off state when exposed to positive voltage from the base. It utilizes Zener's breakdown voltage to cut off the circuit. When this circuit is active, it cuts off the input from the output therefore no voltage gets transferred protecting the rest of the circuit. Here is the example circuit:

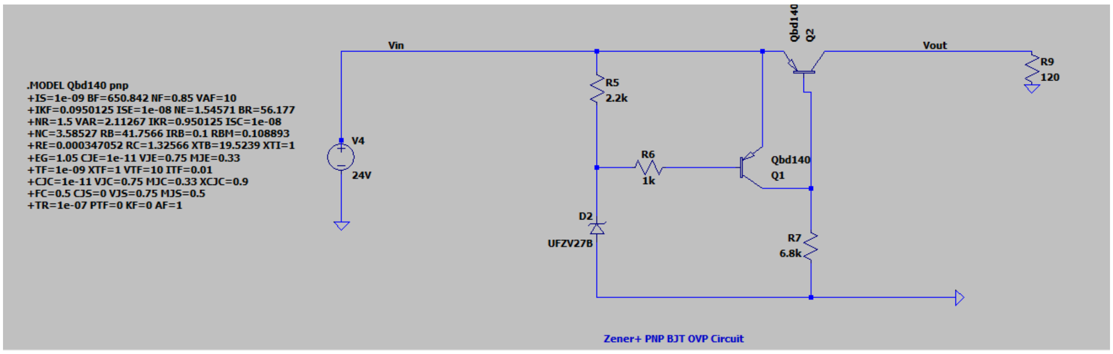

Figure 6: BJT Overvoltage Protection Circuit

- The model for the PNP BJT is the same as the one that is used in the project which goes under the name as BD140L-16-T60-K. This component was picked as it can withstand up to 80Volts and has an easily implementable library [8, 9].
- UFZV27B is a Zener diode that was picked as an alternative to SMBJ5359B-TP. Though the first one is 26.5V Zener diode [10], SMBJ5359 is a 24V Zener Diode [11]. While the former can withstand 500mW [10], latter can withstand up to 5W power [11] making it a better choice for real life application.

The working mechanism of this circuit can be explained in two steps:

1. When input voltage is less than 24V, Zener diode is not conducting which means Q1 transistor's base has positive voltage meaning it is off. As Q1 is not conductive, Q2's base is connected to ground through R7, which indicates that current can pass through the BJT. Current can be observed in Q2's collector terminal.
   It was seen when 24V was delivered by the voltage supply, 23.99 Volt was observed in the output. As for energy conservation, 98% of the energy is conserved during transfer. (see Appendix D)
2. When input is higher than 24V, Zener diode is on breakdown voltage and starts conducting. As Zener is connected to the ground, it activates Q1's Base terminal. When Q1's Base terminal is activated and allows current to pass, there will be positive voltage across Q2's Base terminal due to R7 which will cut the rest of the circuit from Q2. In other words, no current will be delivered to the collector terminal.

   When 30V was used, there was only 1.32uV measured on the output voltage. Almost as close to 0. Regarding energy problems, voltage supply only delivers only 300mW of energy meaning it is unlikely that any component will get harmed [8]. (see Appendix D)

3.1.3 **DC-DC Converter**

As Arduino Uno can be powered from an external power supply, one needs to step down the voltage input within the requirements. Arduino Uno can be powered in several spots which are:

- USB Type B Port,
- Arduino Power Jack
- Vin Port of Arduino UNO
- Direct Powering from 5V [12]

Direct powering from a 5V port was chosen as this port doesn't have overvoltage protection, reverse voltage protection which means one needs to be extra careful while using this port [12]. If the voltage exceeds 5.5V the board can be damaged [12]. However, as the project itself required an RVP and an OVP circuit, these risks were considered a challenge to be overcome.

To power Arduino Uno with 5V, a step-down regulator is necessary that can convert any voltage input between 12 and 24V to 5V. For this a DC – DC converter, a linear regulator that can step-up or step down the input voltage [13], is necessary. There were several circuit designs that was considered:

- Simple Voltage Divider with Zener Diode
- Buck Converter
- R78C5.0-1.0 Switching Regulator

3.1.3.1 *Simple Voltage Divider with Zener Diode*

A simple voltage divider utilizes resistors in serial to step down voltage itself. The voltage output in a simple voltage divider can be calculated through:

$$V_A = V_{inp} \cdot \frac{R_2}{R_1 + R_2}$$

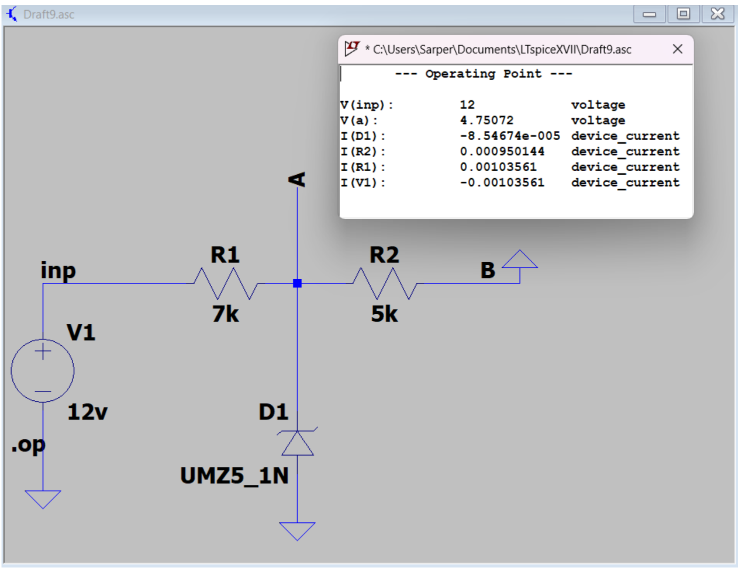

Figure 7: 12V Input 4.75V output

For instance, one can use 7k and 5k for R1 and R2 respectively, which can be seen in the figure, to get a 5V across the R2 resistor. However, as voltage input may vary, the output can vary as well. One cannot constantly change the resistors used so a Zener diode can be used on node A. UMZ5_1N is a 5.1V Zener diode [14].

A small loss in this case is caused by the Zener diode which causes a 0.25V drop. This loss will not stop Arduino from being powered, however it may not be able to deliver enough power to other devices powered by Arduino [12].

When voltage is increased to 24V, the Zener Diode is active which clamps the voltage to 5.08Volts. A value that is not necessarily harmful to Arduino Uno [12]. (see Appendix E)

However, one flaw of this circuit is the excessive energy consumption. When 24V is delivered by the power supply, only 7% of the energy is delivered to the load resistor R2. Out of 64.8W supplied by the power source only 5.8W is used on the load with most of them, which is 51.3W, being spent by R1 (see Appendix E for figures). As a result, it was decided that this is not an applicable solution.

3.1.3.2 ***Buck Converter***

Buck converter is a DC – DC converter that is used for gadgets that need a smaller voltage than the input voltage. It effectively converts a high voltage input to a low voltage through utilizing NMOS as a switch [15]. The idea is to open and close NMOS in a shorter period than inductor and capacitor’s time constant so that the energy delivered by the inductor stays relatively same throughout the process. In other words, the aim is to have such a short period that one can consider that fluctuations in output voltage caused by inductor and voltage charge and discharge are small enough to be considered linear so that small ripple approximation is apparent [16].

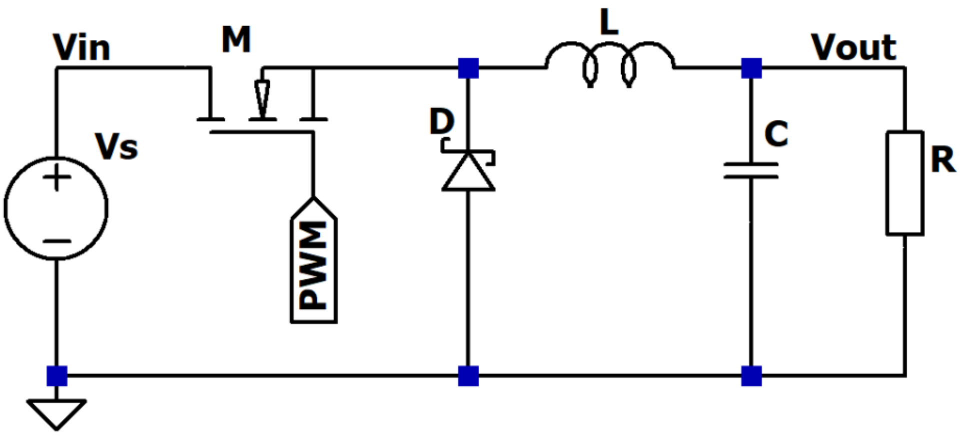

Figure 8: Buck Converter [17]

The working mechanism of Buck Converter can be explained in three steps:

1. Let’s assume that the MOSFET is on, since the diode is reverse-biased one will get a circuit like this:

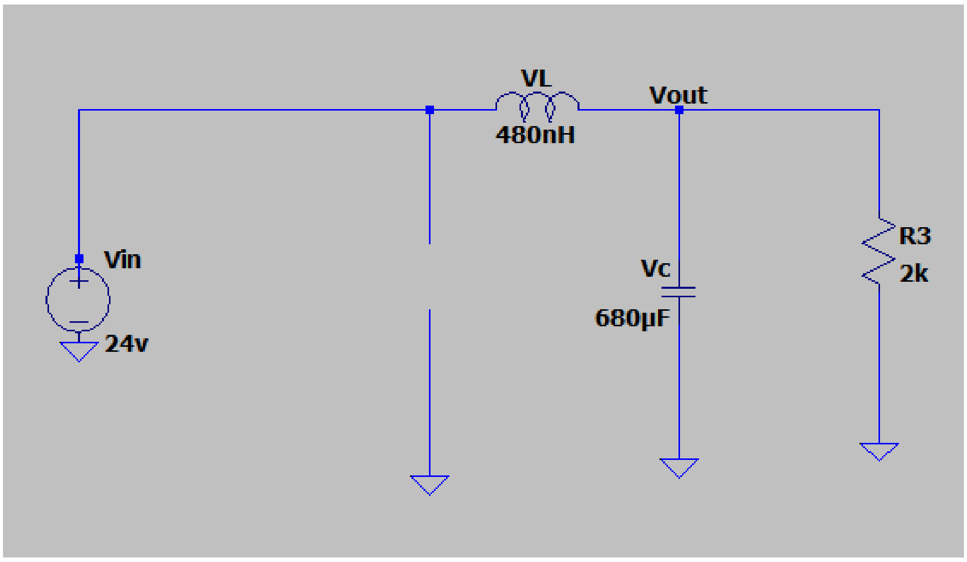

Figure 9: MOSFET's ON State

As it relies on Duty Cycle, let's assume that it is on for T_{on} in period T which means duty cycle (D) can be described as

$$D = \frac{T_{on}}{T}$$

In on state, by using KVL it can be seen that:

$$V_{in} = V_L + V_C, \text{ and } V_C = V_{out} = V_{load}$$

Which means,

$$V_{in} = L\frac{di}{dt} + V_{out}$$

2. When the MOSFET is in its OFF state, the diode is forward biased and allows stored energy to flow through it. The circuit schematic will look like this:

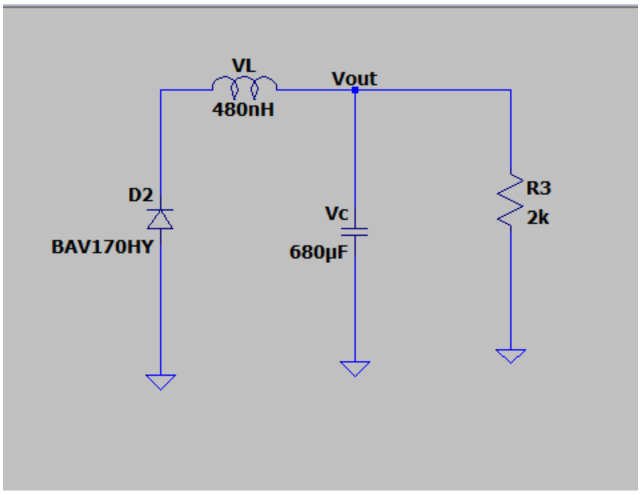

Figure 10: MOSFET's OFF State

When MOSFET is off the KVL on the circuit would be written as:

$$V_L + V_{out} = 0 \text{ or } L\frac{di}{dt} = -V_{out}$$

As mentioned before, by assuming that small ripple approximation can be used we can that V_{out} is a constant value. This can be described as,

$$\frac{di}{dt} = -\frac{Vout}{L}$$

This means that the slope of the inductor current is constant.

3. Being aware that V_{out} and V_{in} are both constant values and through small ripple approximation inductor current's increment and decrement should be equal as that is the only way to have a steady voltage source on the output.

Current increases when MOSFET is on, which brings the equation:

$$Current\ increment = \frac{V_{in} - V_{out}}{L}(D)T$$

Current decreases when MOSFET is off, which brings the equation:

$$Current\ decrement = -\frac{V_{out}}{L}(1-D)T$$

These two equations' magnitudes should be equal for the steady state to function properly.

$$\left|\frac{V_{in} - V_{out}}{L}(D)T\right| = \left|-\frac{V_{out}}{L}(1-D)T\right|$$

$$Vout = DVin$$

As a result, output voltage depends on the duty cycle and input voltage.

Here is the LTspice schematic of the full circuit:

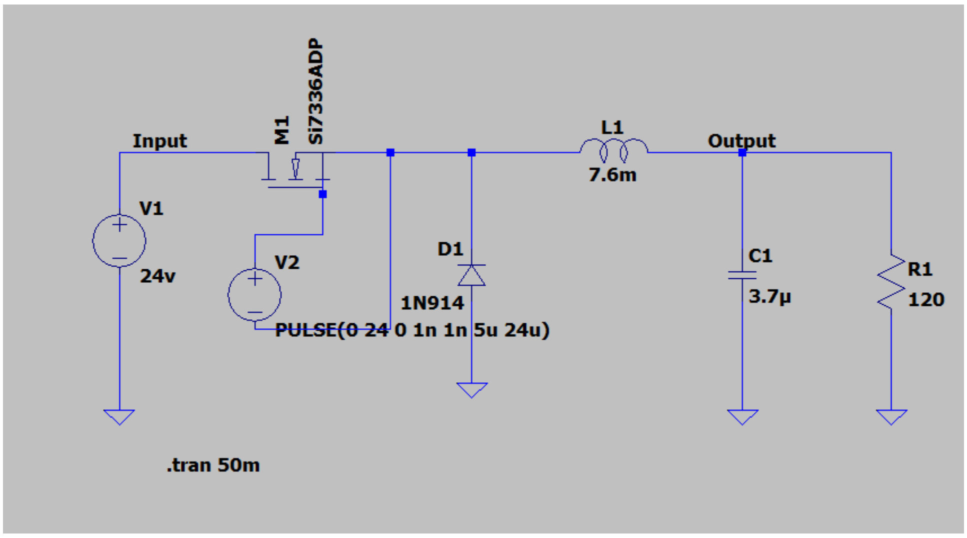

Figure 11: Buck Converter Schematic

- Pulse voltage source works as a PWM that opens and closes the NMOS by creating voltage difference between gate and source.
- Diode's function is to allow current to pass from inductor when NMOS is disconnected the voltage source from the rest of the circuit.

- The resistor's choice is up to the user and does influence the overall circuit as it impacts current flow and power relations in the circuit [18]. 120 Ohm resistor was picked in this case.
- The inductor and capacitor values are important for the ripple approximation. The inductor value is given by the formula,

$$L = 3.33V_{out}(T - T_{on})/I_{out}$$

As the V_{out} is known to be 5V one can calculate I_{out} from Ohm's Law,

$$V_{out} = I_{out} \cdot R\,, which\ means\ I_{out} = 41.66mA$$

From here one can find that L=7.59mH

$$\Delta V_c = \frac{V_{out}(V_{In} - V_{out})}{8LCf^2V_{In}}$$

ΔV_c needs to be a value that is smaller than 1V as a small ripple indicates a smaller change in the voltage in the output. For this ΔV_c was chosen to be 0.01 V. In such case only 0.01V change is expected in the output.
The result of this circuit is like this:

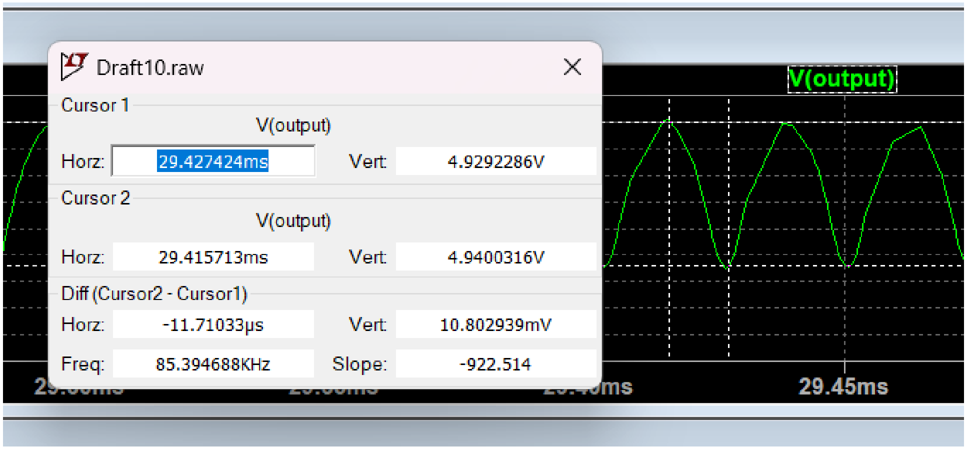

Figure 12: Voltage Fluctuation on the Output

As one can see$\Delta V_c = 10.8mV$, which is 8% off from the intended fluctuation of 10mV. One can say that the voltage output can be median of these two values which is 4.934V.

As one can see, the buck converter effectively converts 24V input into 4.934V, which means there is 0.066V extra loss. This circuit is quite effective at converting high voltage to low voltage, but it is not an adequate choice for constantly changing input voltage as one needs to change the duty cycle alongside it. The component values are also chosen to ensure this specific case so in other cases the voltage loss may increase or decrease.

Here are two cases:

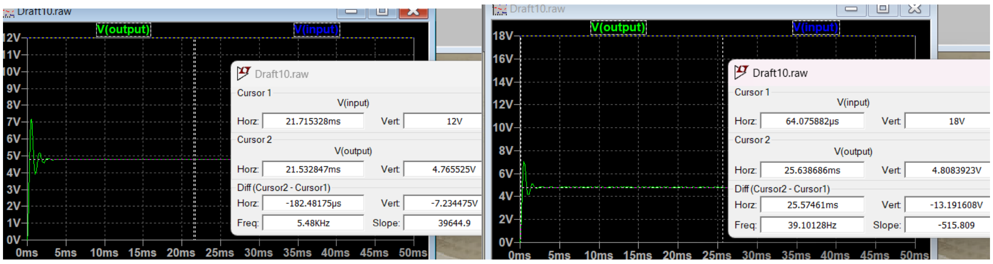

Figure 13: 12V input and 18V input case

When 12V with 10 microseconds on time and 18V with 6.66 microsecond ontime was used, the loss in voltage increased to 0.24V and 0.20V respectively. One can increase the duty cycle to fix this problem, however this circuit proves to be quite impractical as the constant need of calibration to achieve wanted voltage. Moreover, there was no available voltage generator that could create the pulse at the time of the project, so this idea was later scraped.

3.1.3.3 ***R-78C5.0-1.0 5V Step Down Converter***

As a final choice, an IC had to be used due to its efficient energy transfer and voltage regulation. R-78C5.0-1.0 is a switching regulator model that converts any input between 8V-42V to 5V output [19]. This IC promises up to 93% energy efficiency [8]. An ideal usage of the IC looks like this:

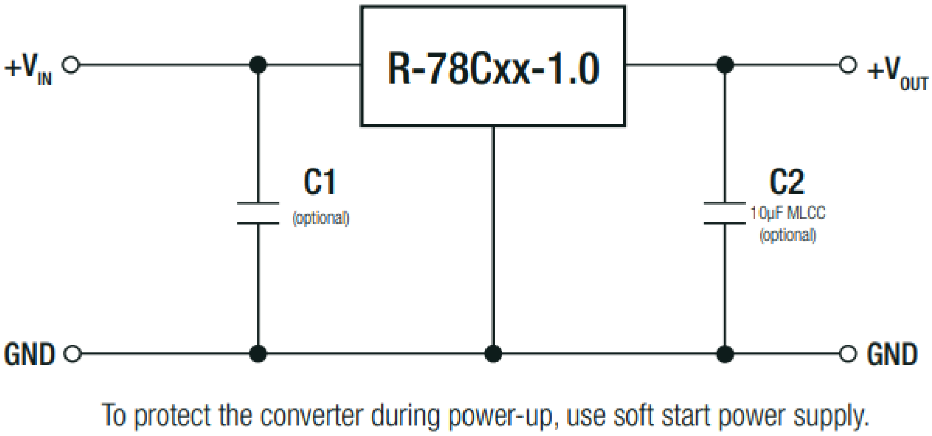

Figure 14: Standard Application Circuit [19]

A Zener diode of 5.6V is also recommended as a means of overvoltage protection whose schematic looks like this [19]:

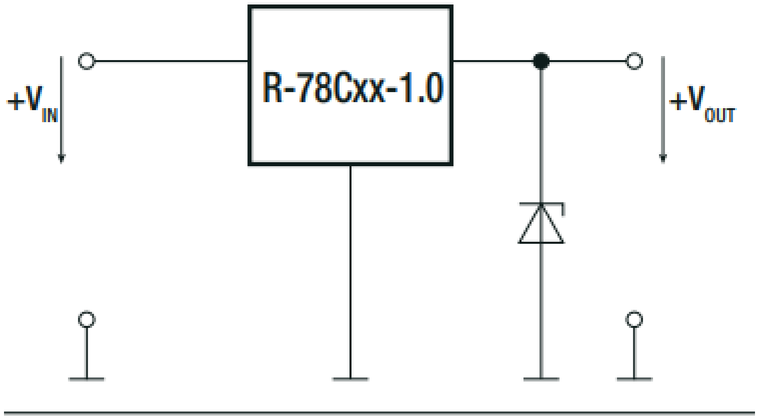

Figure 15: OVP protection from Zener [19]

It was decided to combine these two circuits together as the capacitors can suppress rapid voltage changes and filter out AC noise that could be caused by the voltage supply. In the case of a voltage spike whose duration is longer than the capacitors' handling capability, a Zener diode with 5.6V breakdown voltage can prevent the long-term spikes which will protect Arduino UNO from being damaged.

3.1.4 **Capacitor Bank**

The purpose of this capacitor bank is to compensate for the reactive power and correct the power factor before powering the Arduino Uno [20]. Most electrical devices need reactive power to be able to operate correctly but reactive power may cause strain on the circuitry [20]. Moreover, most switching regulators carry an inductive load, which is caused by the inductor that draws reactive power from the supply to operate properly [20], [21]. Therefore, A capacitor bank was implemented to the circuit as a precaution to prevent the possible strain caused by the reactive power. As a result, three 10 microfarad capacitors were connected in parallel right before power was supplied to the Arduino Uno.

3.1.5 **ACS712 – Current Sensor Carrier –5A to +5A**

ACS712 is a current sensor that can measure current up to 5A in both directions [22]. This sensor utilizes hall effect to be able to measure current. Hall effect is a principle that needs a current passing through a wire to apply perpendicular magnetic field [23]. When this magnetic field is applied it separates the electrical charges and creates a potential difference at the sides to the current path. The measurable voltage is called hall effect voltage.

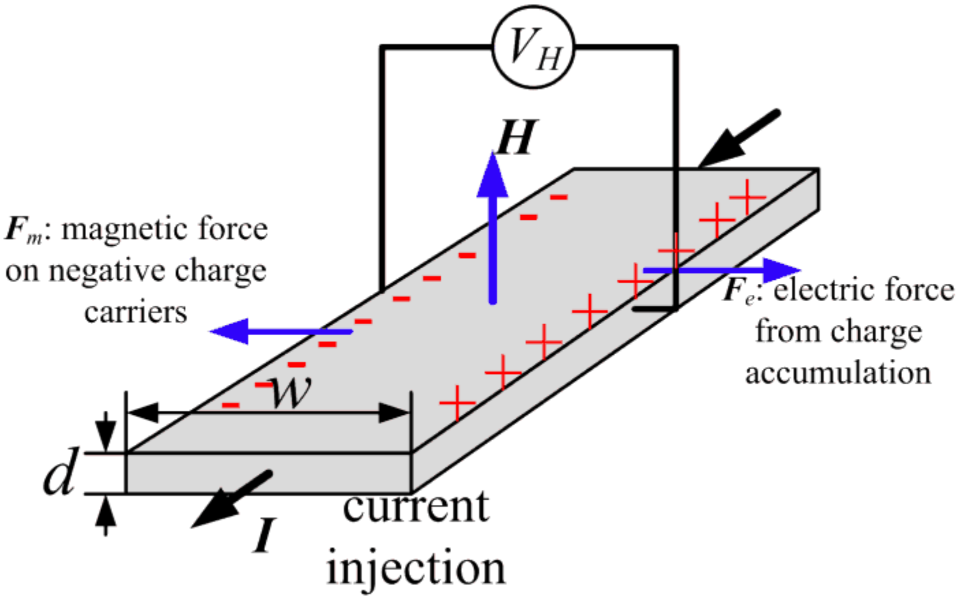

Figure 16: Hall voltage [24]

As can be seen in the figure, hall voltage is measured through the potential difference that occurs at the sides of the current path.

Figure 17: ACS712 [25]

ACS712 needs 5V input to be able to work appropriately [22]. This can be supplied from Arduino to its VCC input. One needs to connect the circuit in series, which is the green ports in the circuit. A Hall Effect current sensor uses the current that passes through the green ports to increase or decrease the reference voltage or in other words the output. When there is no current passing through the green ports the reference voltage is half of Vcc. Which means there would be V_{ref}= 2.5V on the output node of ACS712 [22].
The reference voltage, the output, increases or decreases depending on the current passing through the circuit. ACS712, +5A to –5A version has the sensitivity rate of 185mv/A [22]. This means the output voltage will change between 5.925V and 4.075V depending on the current passing through the green ports.

This current sensor will measure the total current that passes through the circuit.

3.1.5.1 ***Arduino Code for ACS712***

Arduino has a 10bit ADC that I needed to connect the output of the sensor to. After knowing this all I needed to do is to use “analogread()” command from the pin. Arduino’s 10-bit ADC can read up to 5 Volts. Therefore, we need to transform this read value to Voltage so that to find how much voltage is supplied to the ADC. After finding that voltage, we need to subtract it from the reference voltage 2.5V and divide it by the sensitivity to find the current passing through the circuit.

```
void loop() {
volatile int a;


  int ADC == analogRead(A0);
  float voltage = ADC * 5  /1023.000;
  float current = (voltage - 2.500)/ 0.185;
  delay(1000);
  Serial.print("Voltage: ");
  Serial.println(voltage);
  Serial.print("Current: ");
  Serial.println(current);
```

Figure 18: Arduino Code for the Hall Effect Sensor

3.1.6 **SRD-05VDC-SL-C Relay**

The relay’s main function in this circuitry to allow whether a certain load in the circuit gets current flown in or not. The aim is to look at the current flow and decide whether to close or open the relay depending on the current flow.

Figure 19: SRD-05VDC-SL-C Relay [26]

This relay needs 5V to work which can be supplied from the Arduino’s pins [27]. The Relay’s state changes through the voltage given to the IN port. If wires are connected to the top left 2 ports in the relay, the relay in the open circuit state and it will turn on when there is voltage supplied from the input pin [28].

3.1.6.1 ***Arduino Code of Relay***

The aim is to have a working electronic switch, I used states to achieves this as long as the number typed is lower than 8, the relay will turn on. It will be off when a number bigger than 7 is typed.

```
}
if (Serial.available())
{
int b;

int state = Serial.parseInt();
if (state >0){
  b = state;
}
if (b > 7) {
  a = 2;
}
if (b<8 ){
  a= 1 ;
}
if (a == 1)
{
  digitalWrite(13, HIGH);
  Serial.println("Command completed relay turned ON");
}

if (a == 2)
{
  digitalWrite(13, LOW);
  Serial.println("Command completed relay turned OFF ");
}
```

Figure 20: Relay Code

The whole code can be seen in appendix F.

3.2 Hardware Results

I was given these tasks on the hardware part:

- A Working Reverse Voltage Protection Circuit
- A Working Overvoltage Protection Circuit
- A Working Voltage Regulator and a Powered-Up Arduino
- A Working Relay and Current Sensor

Here is the overall circuit for reference:

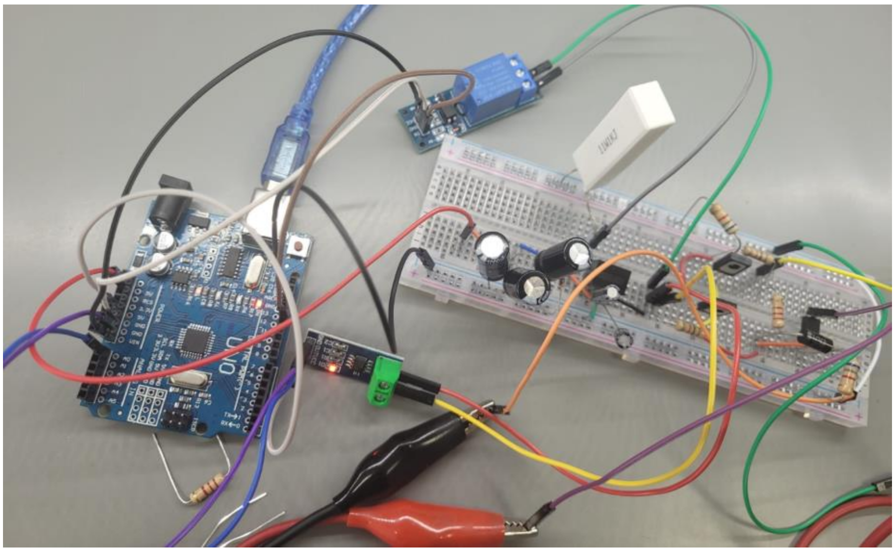

Figure 21: Overall Circuit

Each circuit was checked in a sequential fashion where after confirming one circuit worked properly the next circuit was implemented while being connected to the checked circuit. As reverse voltage protection and overvoltage protection protect the overall circuit this is a necessary choice to protect components like switch regulator, capacitors and Arduino itself.

3.2.1 Reverse Voltage Protection

The best way to check reverse voltage protection is to connect an LED with 120k Ohm connected to the ground so that the LED will not burn even at 24V [10]. LED can withstand up to 20mA current [10].

When 20V was applied correctly, LED lighted up without any issues. However, when the voltage was reversed, the LED's light went out instantly.

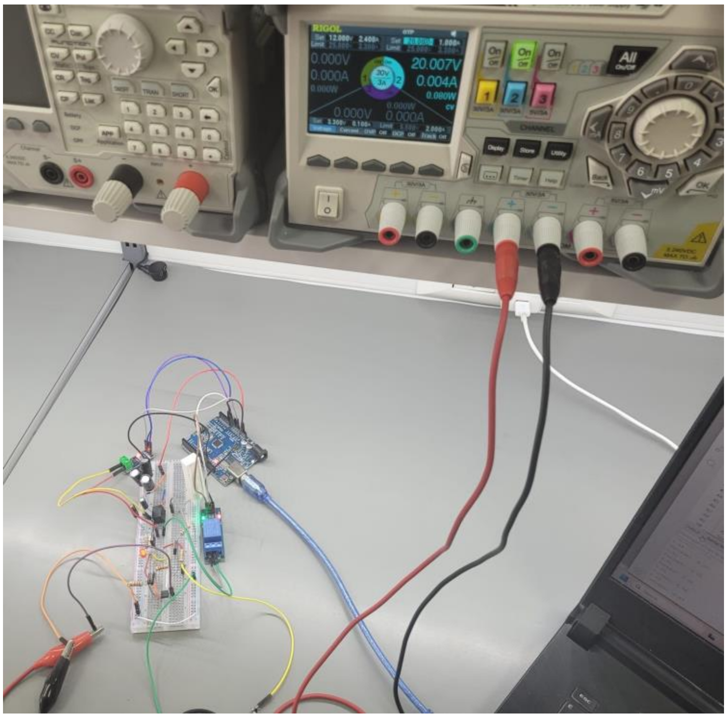

Figure 22: Correct 20V Application

As can be seen in the figure, the red clip is connected to MOSFET and black clip is connected to the ground. LED gives of a bright light due to correct application

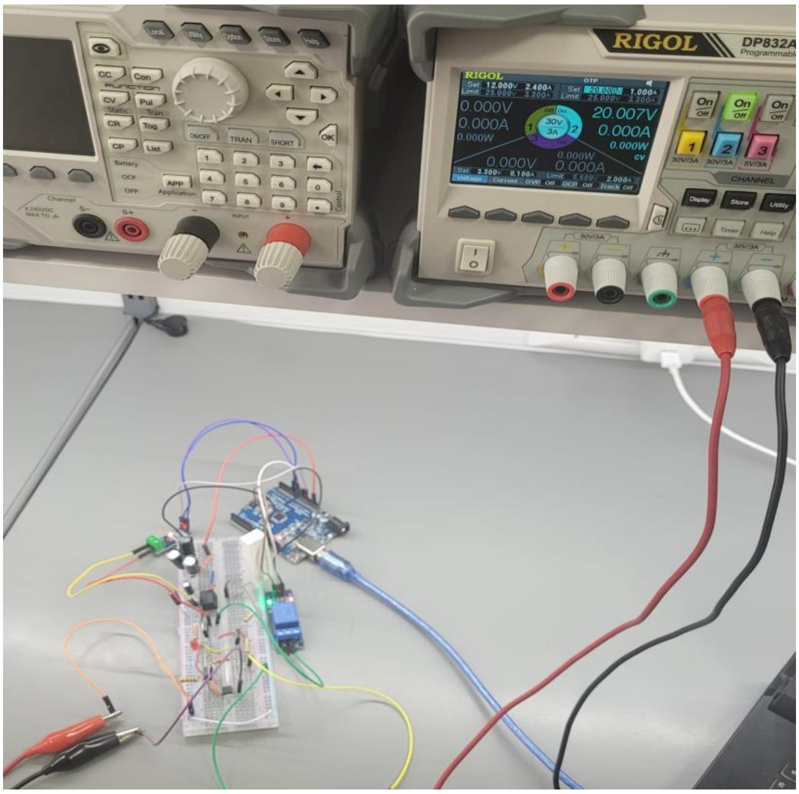

Figure 23: Reverse 20V Application

When reverse voltage was applied, black clip to MOSFET and red clip to ground, the LED can be seen as off in the figure. This indicates that RVP circuit is working properly, and Overvoltage Protection Circuit can be tested.

3.2.2 **Overvoltage Protection Circuit**

The overvoltage protection circuit will cut the connection with rest of the circuit when voltage surpasses 24.1V.

To test this, the same LED circuit was moved to the output of OVP and was tested for voltage values of 5V,20V and 25V.

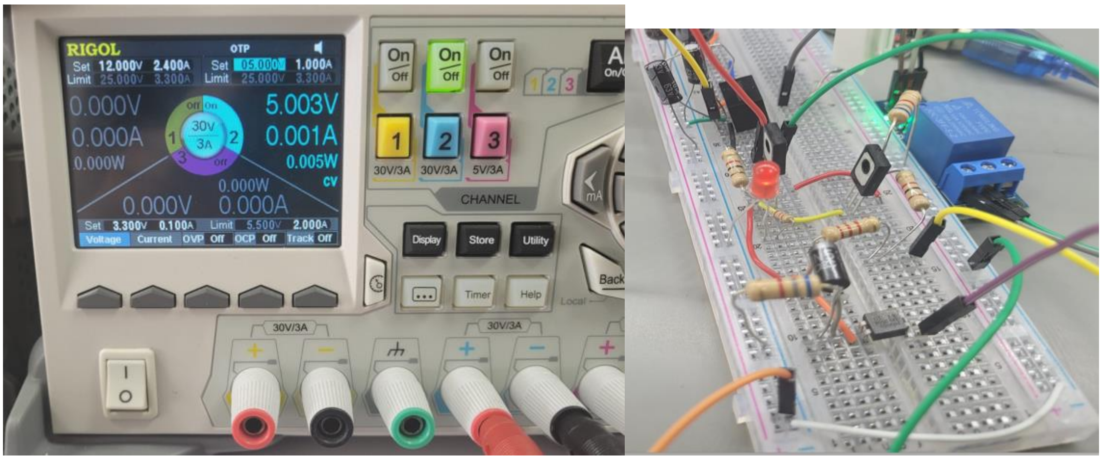

Figure 24: 5V Input and LED

A weak light can be seen at the output of the OVP circuit at 5V.

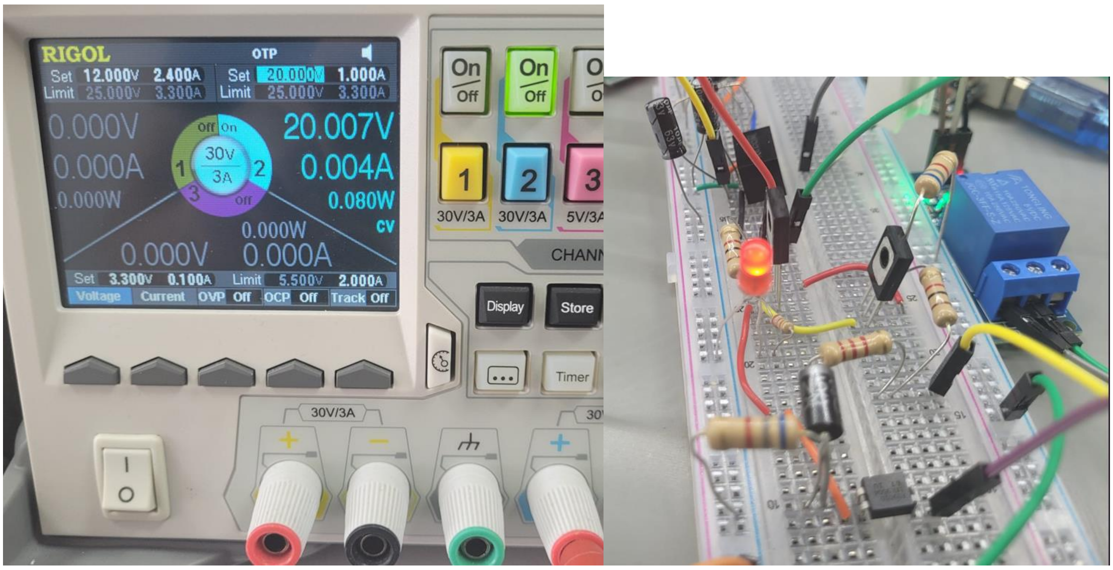

Figure 25: 20V Input and LED

When 20V was applied the LED's light gets stronger as expected.

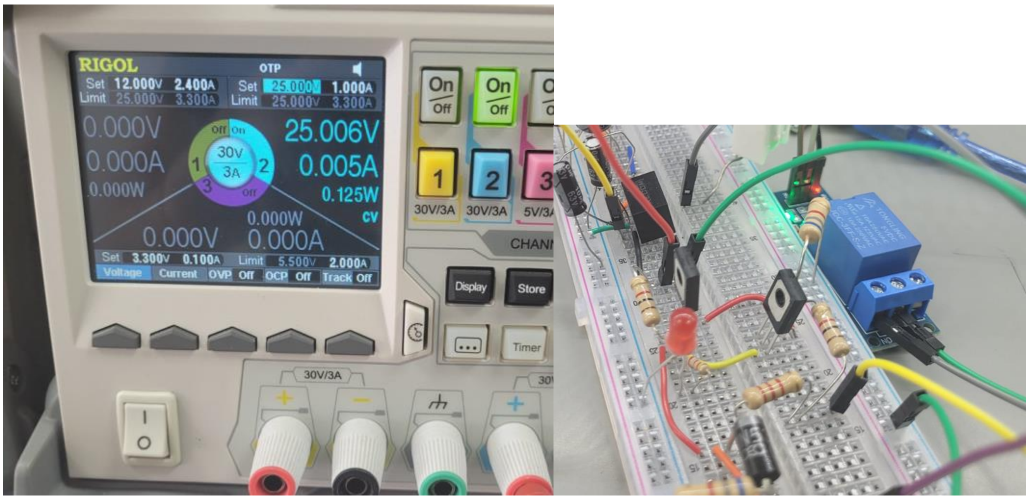

Figure 26: 25V Input and LED

When 25V was applied the OVP activates as expected and LED turns off. Confirming that OVP circuit is working, the step-down converter can be checked.

3.2.3 R-78C5.0-1.0 5V Step Down Converter and Working Arduino

Since RVP and OVP circuits are confirmed to be working it was decided to go ahead and check the output after capacitor bank. A resistor was connected to the end of circuit before it was connected to Arduino to check whether 5V is supplied appropriately. A multimeter was used to check voltage across the resistor. The test was made for 12V and 24V input.

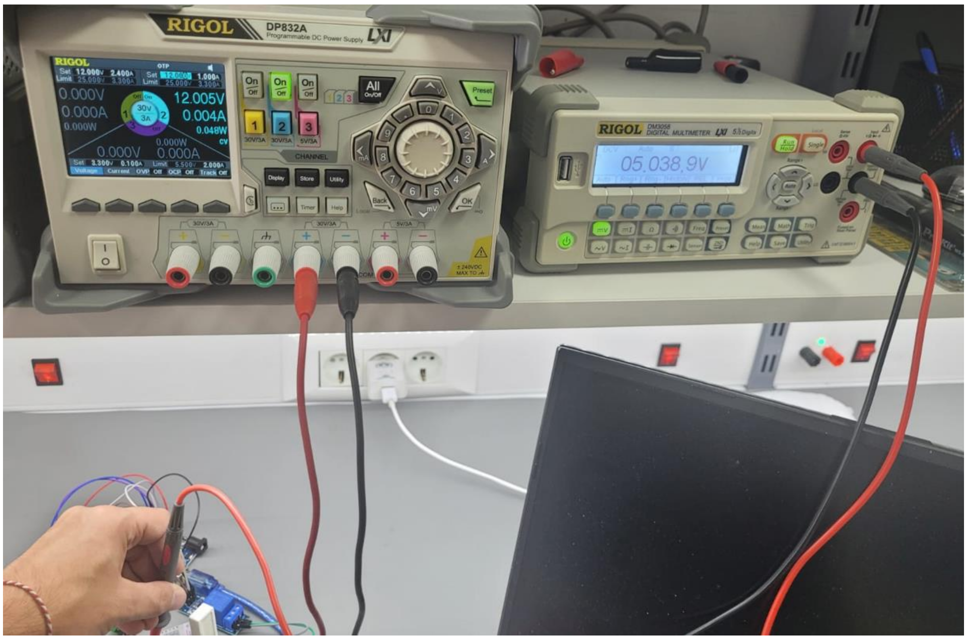

Figure 27: 12V Input

When 12V was given from the input,

V_{out}=5.038 V

Arduino shouldn't have any problems working with this voltage as specified earlier.

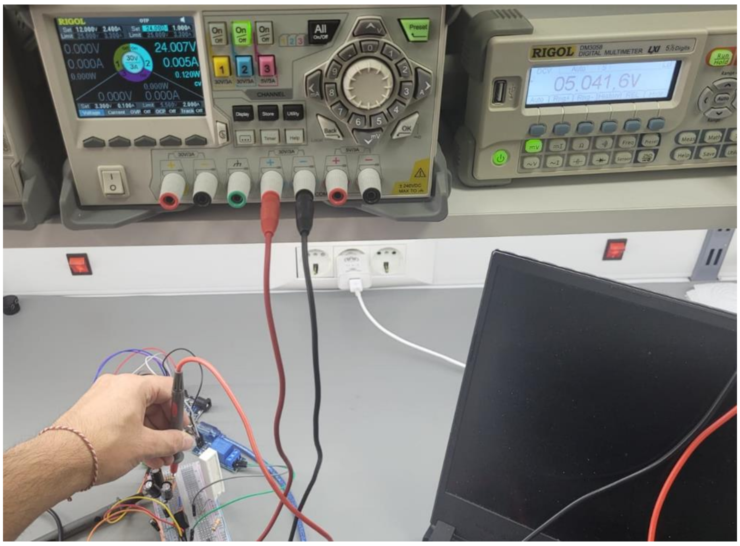

Figure 28: 24V Input

When 24V was given from the input the step-down regulator lowered the value to

V_{out}=5.041 V

This value is still appropriate to power Arduino. Since this circuit is confirmed to be ready, we can connect the circuit to Arduino's 5V pin.

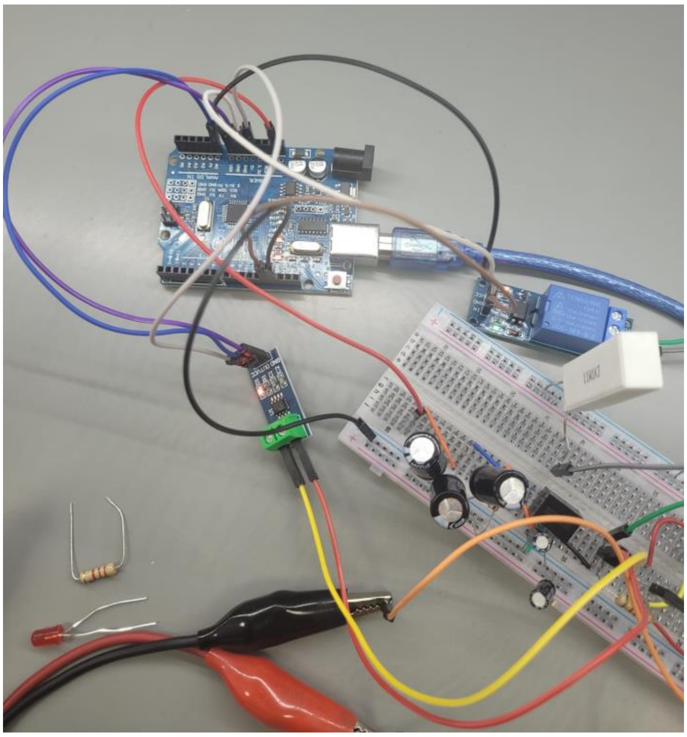

Figure 29: Arduino being powered when Vinput is 12-24V

As can be seen in the figure, Arduino seems to work properly as the LED’s of it shown to be on.

3.2.4 **Working Relay and Current Sensor**

When 20 Volt was applied to the device, which is a 100 Ohm with 11W Power rate, Arduino gave:

```
Voltage: 2.54
Current: 0.20
```

Figure 30: 2.54 Reference Voltage and 0.2A current

Which makes sense as 0.2A should pass through 20V

When relay was closed Arduino gave this data:

```
Voltage: 2.50
Current: 0.01
```

Figure 31: 2.50 Reference Voltage and 0.01A Current

Though the reference voltage makes sense, the current is caused by Arduino’s IDE’s itself as the numbers are approximated rather than having infinite precision.

4 Performance and Outcomes

4.1 Solving Complex Engineering Problems

The task given to me during my internship required me to combine my knowledge from several areas such as circuit theory and microprocessors. The task required me to move step by step so that I could power an Arduino Board without the risk of burning the board. To achieve this, I designed and implemented RVP and OVP circuits using LTSpice. Furthermore, I implemented a step-down regulator to be able to lower the voltage and power the Arduino.

Using Arduino, I implemented a current sensor and relay to the created circuit using my knowledge from microprocessors. The overall circuit allowed me to decide on whether a certain load should flow to the load or not where load symbolizes a certain device.

4.2 Recognizing Ethical and Professional Responsibilities

During my internship I made sure to find several researched on the circuit I was implementing. I have used the findings of the research to find my own personal solution and made sure the circuits I implemented were as efficient as possible. I got feedback from my supervisor to understand the mistakes or problems I have faced more clearly. On the cases where I got stuck, the supervisor guided me without giving the answer. I recognize that it is my ethical and professional responsibility to create my own work.

Since the workplace has ties with the defense industry, there were some rules I had to follow during my internship. I was not allowed to learn about any work or projects the employees were working on. I was only allowed to learn how they do their work rather than what they do. Though I was allowed to bring my own computer, I was not allowed to connect to the main internet of the company and used the guest internet during my time. I was informed on these topics during my first day in internship

4.3 Making Informed Judgments

The main issue, especially in the beginning, was understanding what to do. As the field I was doing my internship on has vast number of sources I had to find the most efficient way to finish the tasks. To achieve that I divided the task into several small tasks and tackled them one by one through research and software experimentation if I could. For microprocessor part, I analyzed several codes on the internet and came up with my own code in the end to meet the task's requirements

4.4 Acquiring New Knowledge by Using Appropriate Learning Strategies

Though I had prior knowledge regarding the task, my knowledge wasn't sufficient for me to finish the tasks by itself. My previous circuit theory and microprocessors knowledge weren't enough for me to understand circuits like RVP, OVP or switching regulators. To understand these circuits, I first studied microelectronics and power electronics to understand and use components of these circuits as efficiently as possible. I created several circuits in LTSpice and compared their energy efficiency to see which would be a better fit for implementation. After making sure the circuit was energy efficient enough, I moved on to the implementation part.

4.5 Applying New Knowledge As Needed

I used LTSpice mostly with which I was familiar. This allowed me to apply new knowledge I acquired as fast as possible. These tools allowed me to analyze new circuits at a faster rate so that I could implement and test them as early as possible. Though I had no prior knowledge regarding Arduino my prior knowledge regarding microelectronics and Arduino's simple interface allowed me to finish the project efficiently.

4.6 Diversity, Equity, and Inclusion (DEI)

The company I worked in employed engineers from different cities of Turkey, creating cultural diversity inside the workplace. Moreover, there were engineers from every age, gender and experience which created a dynamic work environment where one could learn from others. Regardless of the experience each engineer's ideas were valued and listened to for the project creating an inclusive workspace and increasing equity among employees. During my internship, I noticed that Siyah R&D prioritizes efficient engineers regardless of their cultural background, gender, religion and creates a space for these engineers to discuss and work on several projects.

5 Conclusions

The most informative part about the internship was to be able to learn several types of circuits that can connect with each other and understand how each has to do their part to be able reach the wanted outcome. In short, I designed and implemented a reverse voltage protection circuit, overvoltage protection circuit, a capacitor bank and switching regulator to power an Arduino Uno, from which I measured the current flowing into a load and decide on whether to close a relay depending on the current.

During my internship, I managed to build upon my foundation of circuit theory and microprocessors through research and implemented a circuit that can be used in real life. Overall, I was glad to be able to learn on several topics during my internship.

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Appendices

Appendix A – RVP Using Diode

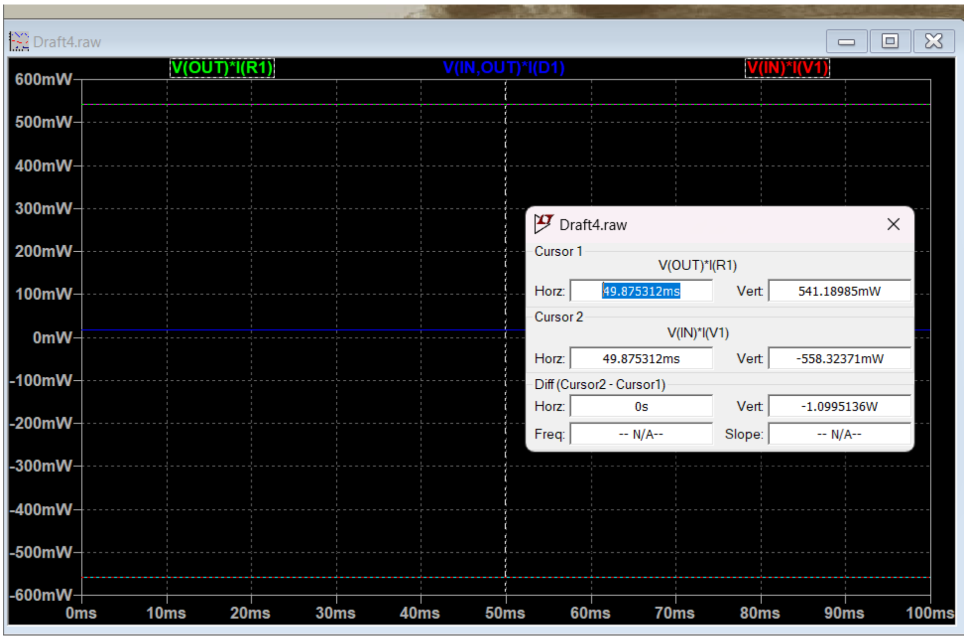

Figure 32: RVP Using Diode, LTSpice Schematic

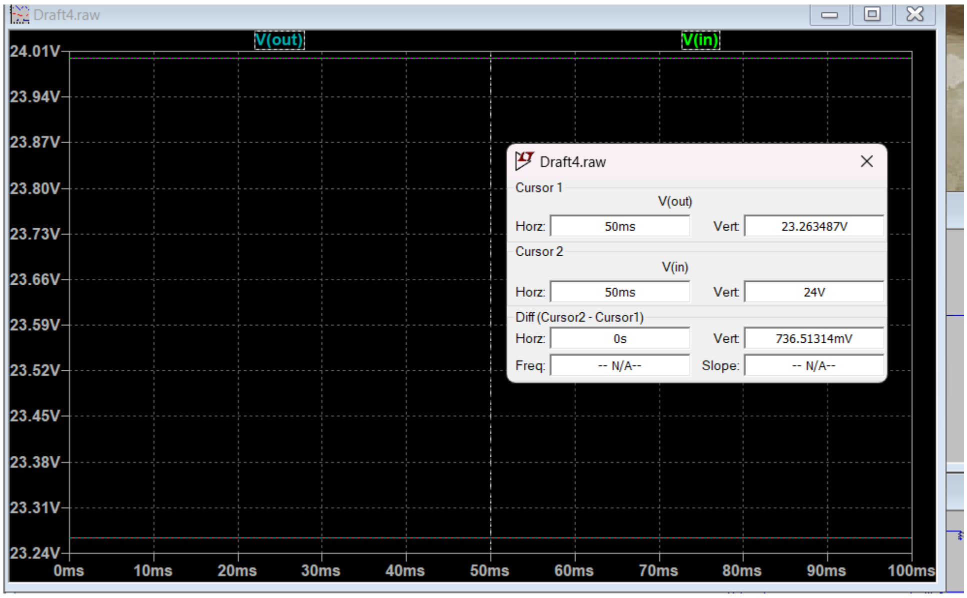

Figure 33: Vin vs Vout of the Diode Circuit

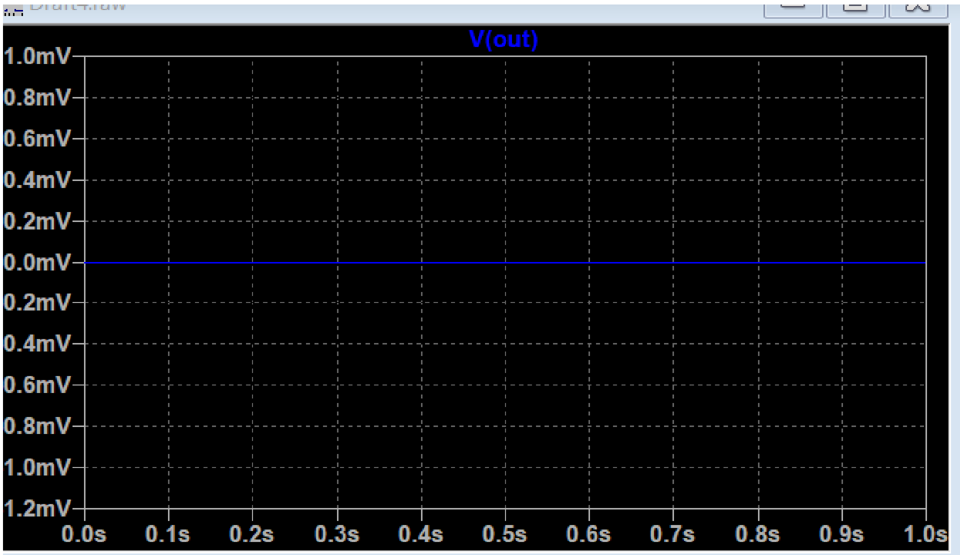

Figure 34: Diode Behavior in Negative Polarity

Appendix B – RVP Using PMOS FET

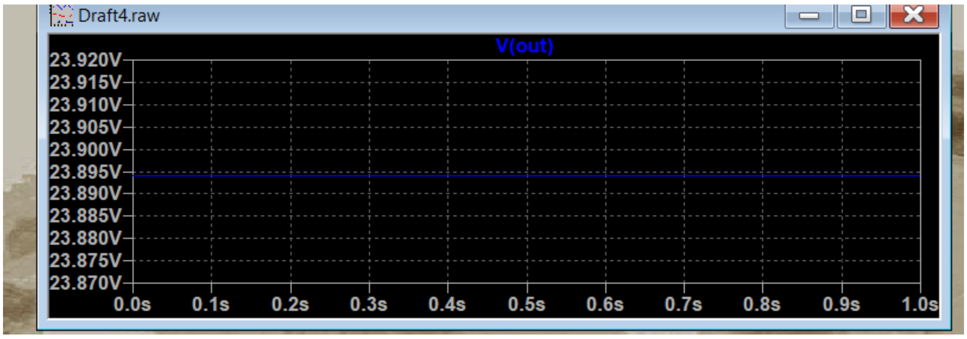

Figure 35: 24 Volt input, 23.895 Volt Output

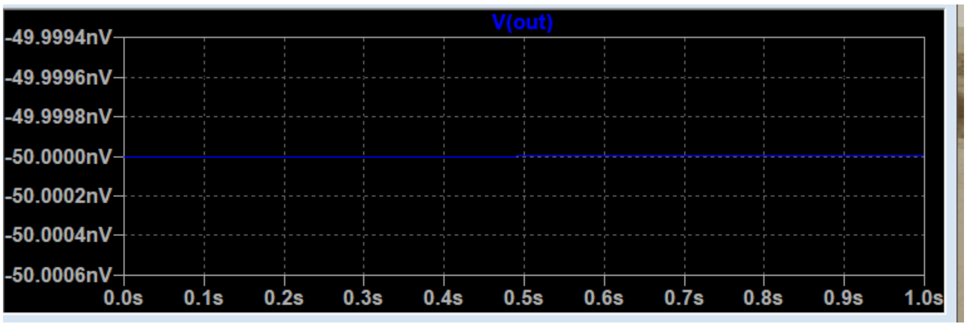

Figure 36: -24volt input, -50nV Output

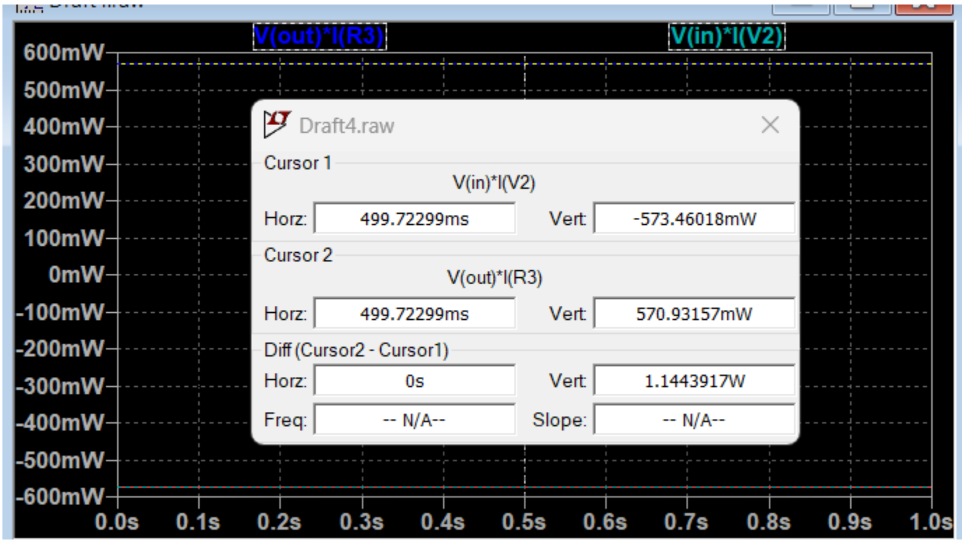

Figure 37: Power Efficiency of the PMOS Circuit

Appendix C – OVP Circuit Using Zener Diode

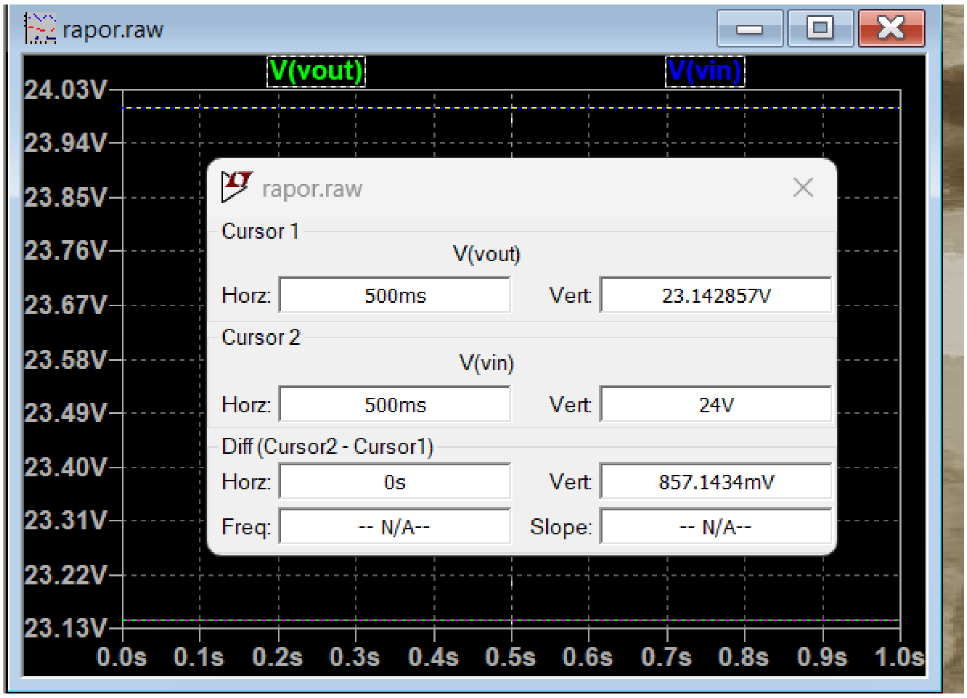

Figure 38: Input vs Output Voltages on Zener's off state

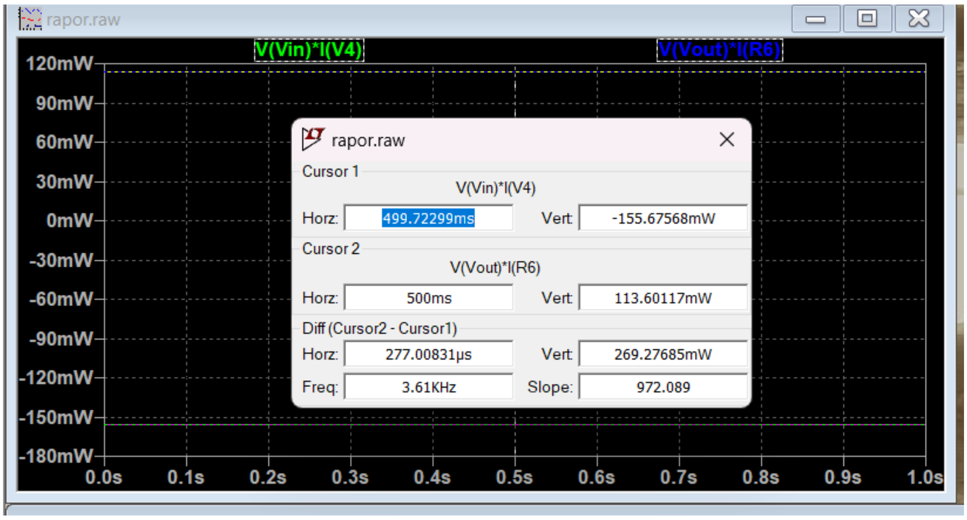

Figure 39: Energy comparison between Input and Output

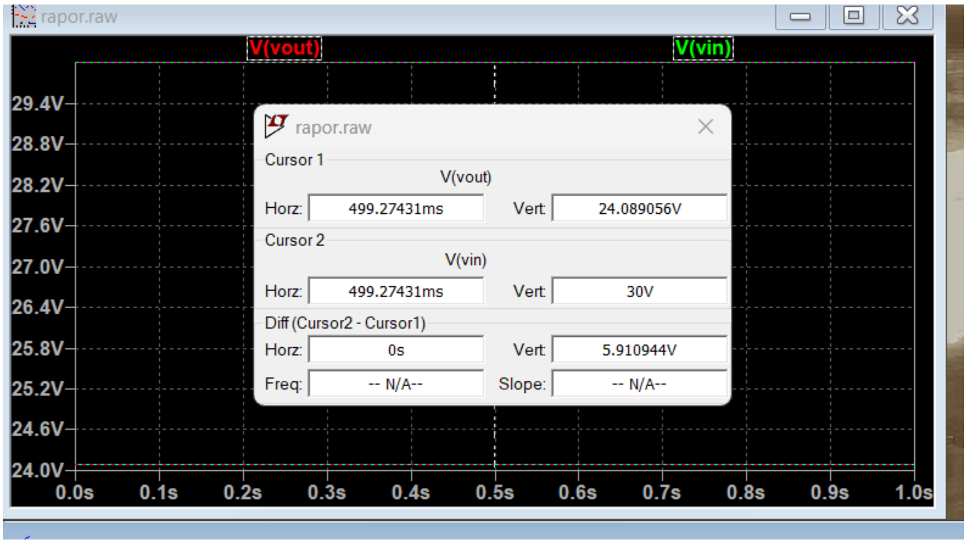

Figure 40: Input vs Output when Zener is in Breakdown State

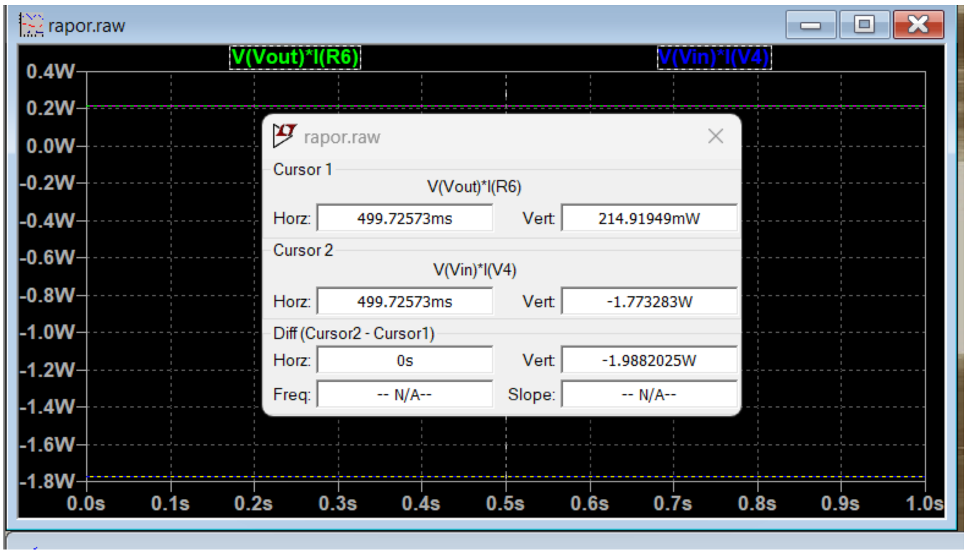

Figure 41: Energy Comparison between Input (30V) and Output

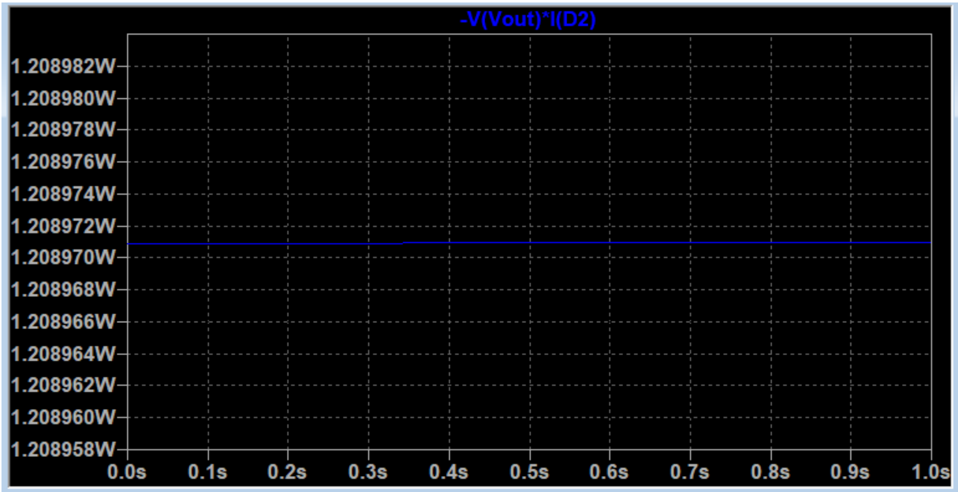

Figure 42: 1.2W Energy Spent by the Zener Diode on Breakdown

Appendix D – OVP Using Zener and PNP BJT

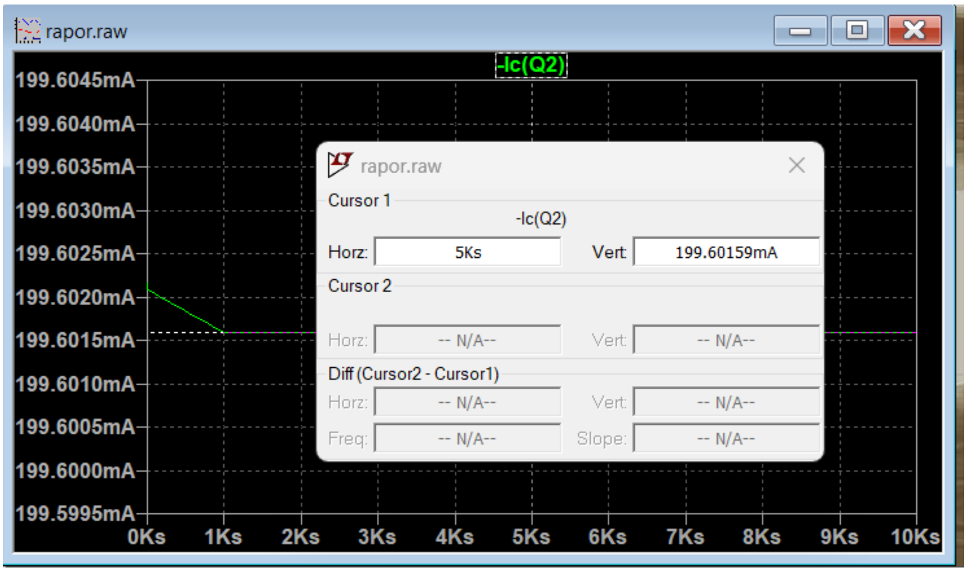

Figure 43: Current Passing Through when OVP is Inactive

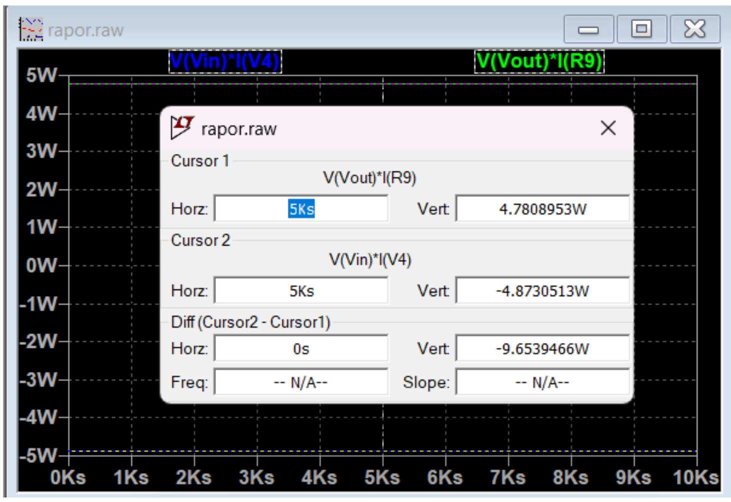

Figure 44: Energy Conservation for OVP Circuit

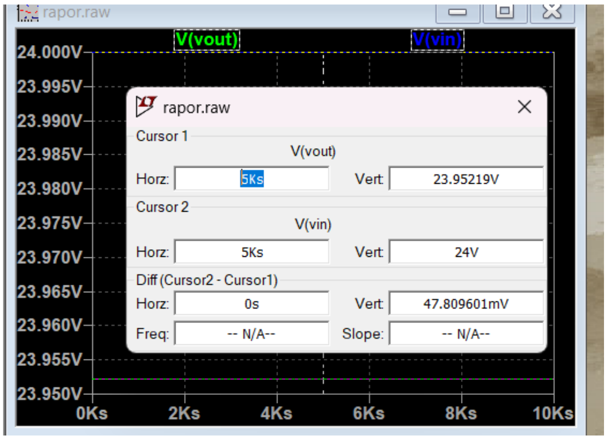

Figure 45: Voltage Conservation for OVP Circuit

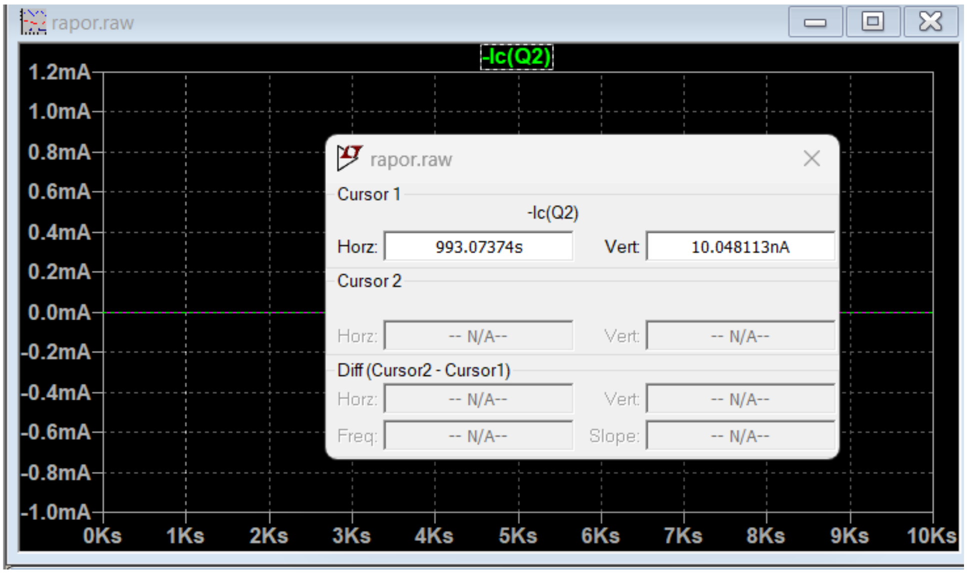

Figure 46: Current Flow to R9 when OVP is Active

Appendix E – Simple Zener Circuit OVP

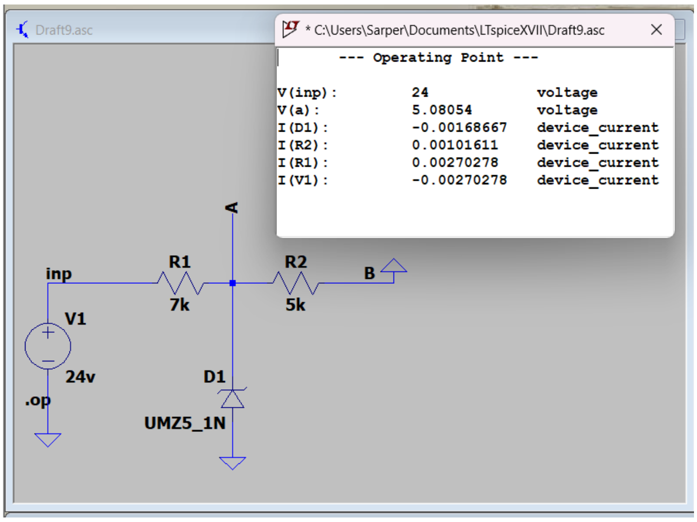

Figure 47: 24V input for Simple Zener Voltage Regulator

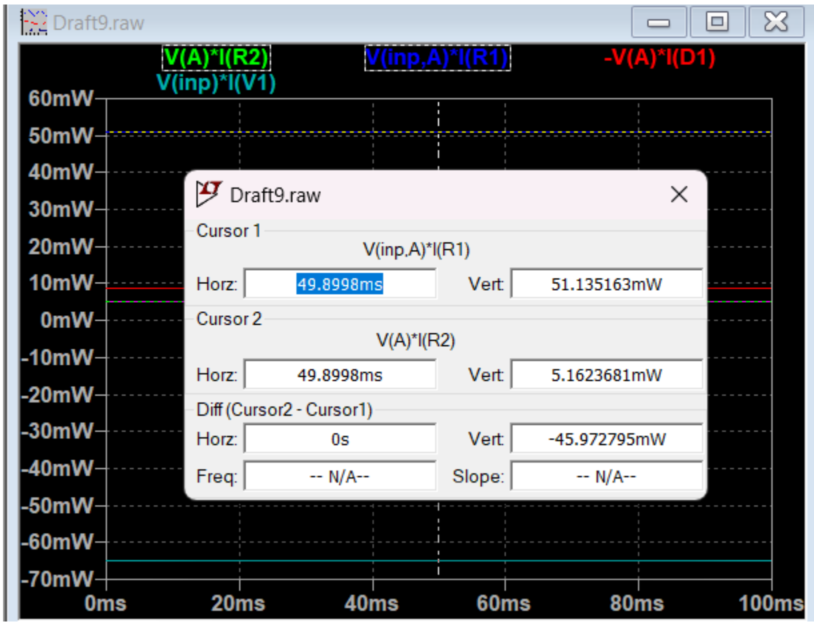

Figure 48: Energy Efficiency of simple Zener Circuit for 12V

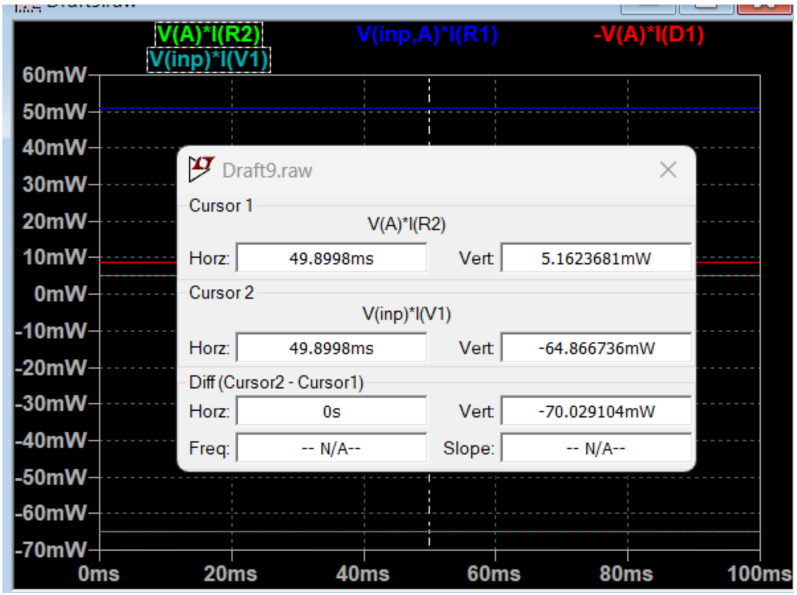

Figure 49: Energy Efficiency of Simple Zener Circuit for 24V

Appendix F – Arduino Code

```
void setup()

{

pinMode(13, OUTPUT);

Serial.begin(9600);

while (!Serial);

Serial.println("Input:");

}

void loop() {
volatile int a;


  int ADC == analogRead(A0);
  float voltage = ADC * 5  /1023.000;
  float current = (voltage - 2.500)/ 0.185;
  delay(1000);
  Serial.print("Voltage: ");
  Serial.println(voltage);
  Serial.print("Current: ");
  Serial.println(current);


if (Serial.available())
```

Figure 50: Arduino Code Part 1

```
if (Serial.available())
{
int b;

int state = Serial.parseInt();
if (state >0){
  b = state;
}
if (b > 7) {
  a = 2;
}
if (b<8 ){
  a= 1 ;
}

if (a == 1)
{

  digitalWrite(13, HIGH);

  Serial.println("OFF");
}

if (a == 2)

{

  digitalWrite(13, LOW);
  Serial.println("ON ");
}
}
}
```

Figure 51: Arduino Code Part 2

Self-Checklist for Your Report

Please check the items here before submitting your report. This signed checklist should be the final page of your report.

- ☑ Did you provide detailed information about the work you did?
- ☑ Is supervisor information included?
- ☑ Did you use the Report Template to prepare your report, so that it has a cover page, has all sections and subsections specified in the Table of Contents, and uses the required section names?
- ☑ Did you follow the style guidelines?
- ☑ Does you report look professionally written?
- ☑ Does your report include all necessary References, and proper citations to them in the body?
- ☑ Did you remove all explanations from the Report Template, which are marked with yellow color? Did you modify all text marked with green according to your case?

Signature: ____________________

While writing your summer internship reports, you should follow the rules of ethical writing. You can find an extensive guide on ethical writing at:

https://ori.hhs.gov/content/avoiding-plagiarism-self-plagiarism-and-other-questionable-writing-practices-guide-ethical-writing