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# Timer-Controlled 5 A Constant Current Source

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Bachelor of Engineering

Electronics

Bachelor's Thesis

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<p>The main objective of this project was to build a constant current source with a 5 A output. The project expectation was to create a power source capable of delivering high current output, generating the necessary thermal power to sever medical suture lines. As an end device, loads of the order of 0.5-1 ohm were used. The target was to heat the load and produce high thermal power at the designated part of the load.</p> <p>The main components used in this adjustable current source are LM317, a 3-Terminal Adjustable Regulator alongside transistors 2N3055 and 2N2905. LM317 voltage regulator is used to converting the rectified DC voltage to a constant output voltage which is used to produce high thermal power at the load provided and is connected to a PWM circuit for a power cut-off ranging from 1 to 10 seconds. An enclosed 120 W industrial single output switching power supply adopting the full range of 85-264 VAC input, providing the output of 12 VDC, and the current range of 0-10 A is used for the connection with the AC mains, because of its complete protection function as the design is intended for being used in the medical department.</p> <p>The project was first allocated into small individual tasks, in particular the delivery of constant steady output current, creating a cut-off PWM. Firstly, all the prototypes were designed in the Multisim, a circuit simulator software for the verification, and then tested on the breadboard. The PCBs were then designed through the PADS software package and all the components were mounted and soldered. Lastly, the circuit and the cooling devices were mounted in a plastic enclosure box for the safety precautions and possible contaminations as being used in medical facilities.</p>	
Keywords	Voltage Regulators, PWM, Constant Current, Multisim

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## List of Abbreviations

AC	Alternating Current
DC	Direct Current
PWM	Pulse Width Modulation
BJT	Bipolar Junction Transistor
FET	Field Effect Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
LED	Light Emitting Diode
SMPS	Switch Mode Power Supply
PNP	Positive-Negative-Positive
NPN	Negative-Positive-Negative
DMM	Digital Multimeter
VAC	AC Voltage
VDC	DC Voltage

## 1 Introduction

In recent years, with the scaling down of portable audio equipment, cameras, etc., the demand has increased for constant-current and constant-voltage circuits which are unaffected, by variations in power source voltage, temperature, and so on. From basic transistor and op-amp circuits to complex digital and microprocessor systems, almost all electronic circuits need one or more sources of constant dc voltage. Changes in voltage applied through the terminal are extremely sensitive to these components. Changes in voltage can cause these components to malfunction, resulting in inaccuracies or even permanent damage. Recent developments in integrated circuit technology have developed IC-based voltage regulators that can generate constant reliable voltage to resolve this voltage fluctuation.

Voltage regulators are found in most electronics circuits that require voltage management or voltage regulation such as chargers, power supply units, telecommunications, and automotive applications. Voltage regulators are available in numerous packages depending upon their regulating properties, which can maintain constant voltage in the output.

This thesis project was made for Jani Virtanen as the supervisor from MDS Finland Oy. The main objective of this project was to build a timer-controlled constant current source. The project expectation was to create a power source capable of delivering high current output, generating the necessary thermal power to cut medical suture lines. The target was to heat the nickel-chromium load acting as an end device and produce high thermal power at the designated part and cut off the power after a certain period of time.

## 2 Theoretical Overview

### 2.1 Constant Current Sources

A constant current supply is a power source that provides a constant current to a load regardless of variations or fluctuations in load resistance. It can maintain a constant current flow even though the load varies. When a circuit needs a constant current supply with no variations, it is widely used. For instance, a transistor can behave like one when biased to keep the collector current constant. The voltage and the resistance should vary correspondingly for the current to be constant. The voltage increases to infinity as the load resistance increases to infinity, resulting in an infinite supply of power or energy (1).

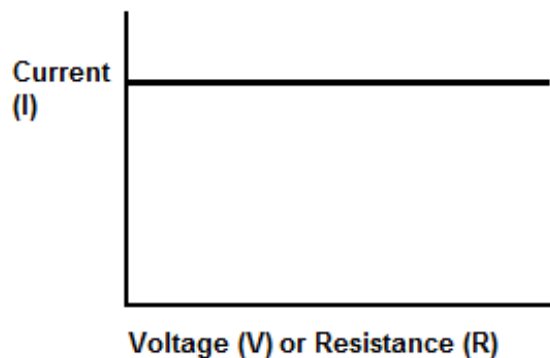


Figure 1: Current vs Voltage graph

In a constant current source, when the current and variable voltage source data is plotted, we get a graph as shown in figure 1.

### 2.2 Introduction to Voltage Regulators

Voltage regulators can be defined as a system to generate a stable and consistent output voltage within a circuit, independent of the input voltage and load conditions. The filtered output of a rectifier generated from ac voltage or a battery is generally the voltage regulator's input voltage. A voltage regulator includes a high gain error amplifier and a voltage



reference, where the reference voltage and the feedback of the output voltage are compared by the error amplifier. As voltage regulators are generally used for DC-to-DC voltage regulation, some can perform AC to AC or AC to DC voltage regulation as well. Voltage regulators are found in most electronics circuits that require voltage management or voltage regulation such as chargers, power supply units, telecommunications, and automotive applications (2).

There are two types of voltage regulators: linear regulators and switching regulators. Linear regulators are furthermore categorized based on the load connected to the circuit, commonly categorized are the series regulator and the shunt regulator. These regulators are usually available in negative or positive output voltage configurations. Both negative and positive outputs are possible with a dual regulator. On the other hand, switching regulators are classified based on various topologies with the three most common as step-up, step-down, and inverting.

## 2.3 Voltage Regulation

Voltage regulation is the rate at which the voltage magnitude between a component's input terminal and output terminal varies. Line regulation and load regulation are two types of voltage regulation. Line regulation maintains a nearly constant output voltage regardless of input voltage changes, while load regulation maintains a nearly constant output voltage regardless of load changes.

### 2.3.1 Line Regulation

Line regulation is defined as the percentage change in output voltage as a function of input voltage change when all other variables remain constant. Line regulation helps the power supply to provide precise output voltage over changes in the input voltage. The line regulation is mostly used when the input voltage source is unstable or unregulated and which results in significant variations in the output voltage. The line regulation for an unregulated power supply is generally very high for most operations, which can be improved by using a voltage regulator. Line regulation can be described in a variety of ways depending on the range of input voltage as

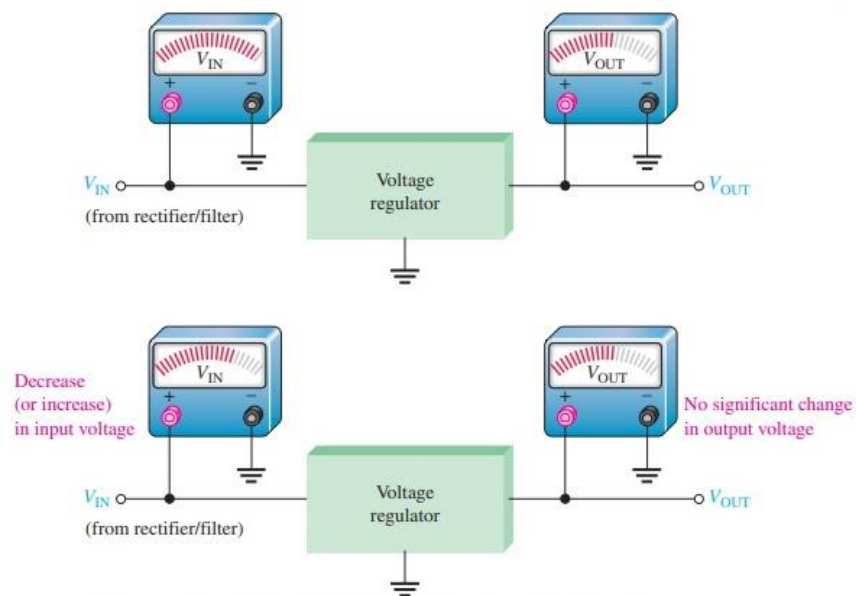
$$\text{Line regulation} = \left( \frac{\Delta V_{OUT}}{\Delta V_{IN}} \right) \cdot 100\% \quad (1)$$

where  $\Delta V_{IN}$  is the change in input voltage and  $\Delta V_{OUT}$  is the corresponding change in output voltage.

Line regulation can also be calculated in a unit of %/V. For instance, a line regulation of 0.04%/V implies that the output voltage alters 0.04% per increase or decrease of input voltage by one volt. Line Regulation can also be determined as

$$\text{Line regulation} = \left( \frac{\frac{\Delta V_{OUT}}{V_{OUT}}}{\Delta V_{IN}} \right) \cdot 100\% \quad (2)$$

where  $V_{OUT}$  is a nominal output voltage.



**Figure 2: Line Regulation. (2)**

As shown in figure 2, the change in input voltage does not have any effect on the output voltage of the regulator.

### 2.3.2 Load Regulation

Load regulation is the capacity of a power supply to produce a constant voltage output regardless of changes in the input load. Load regulation is good when it ensures that the power supply will provide a required and stable voltage to the system. It can also be described as the rate of change in output voltage to provide a change in load current. Load regulation is defined as the percentage change in output voltage from no-load to full-load expressed as

$$\text{Load regulation} = \left( \frac{V_{NL} - V_{FL}}{V_{FL}} \right) \cdot 100\% \quad (3)$$

where  $V_{NL}$  is the no-load output voltage and  $V_{FL}$  is the full-load output voltage.

Load regulation can even be measured in %/mA units. For example, a load regulation of 0.04%/mA implies the change of 0.04% of the output voltage for every 1mA increase or decrease in the load current.

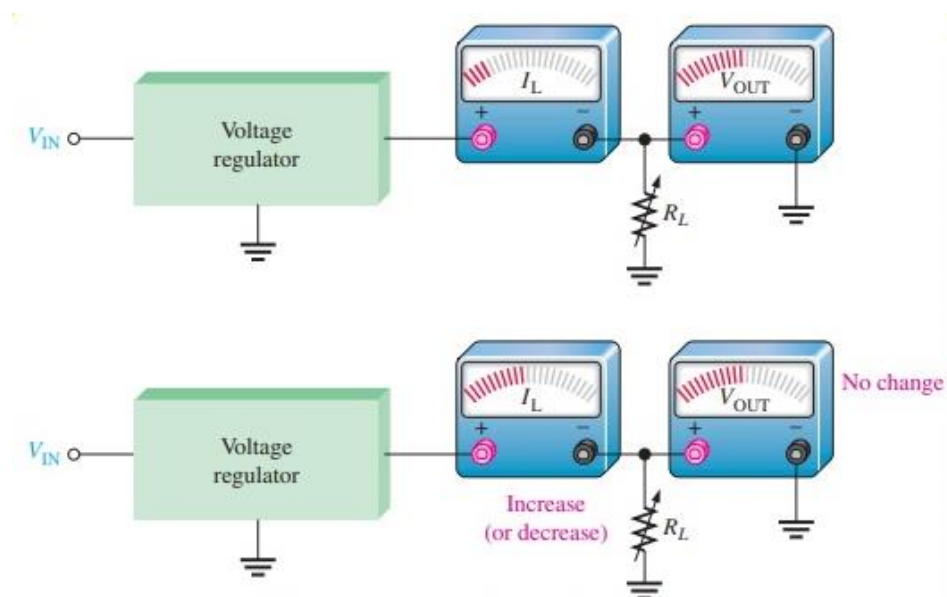


Figure 3: Load Regulation (2)

In figure 3, the output voltage of the regulator is not affected by the change in load current.

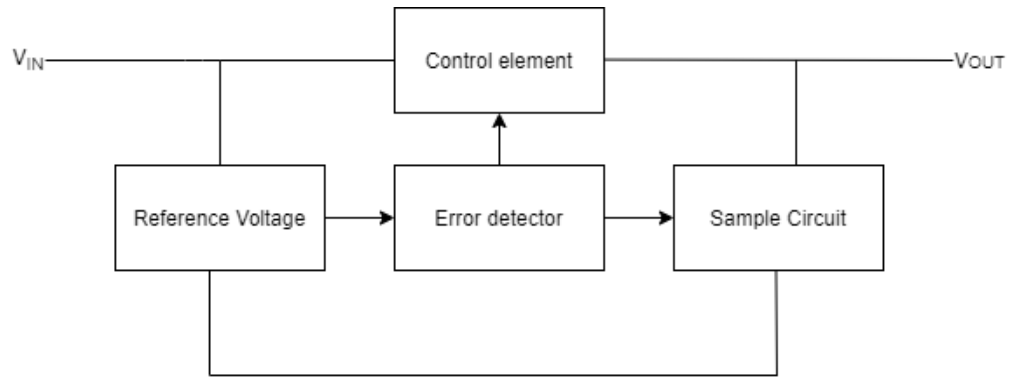
## 2.4 Linear Voltage Regulators

Linear voltage regulators use control elements such as BJT or MOSFET, controlled by a high-gain operational amplifier. A voltage regulator delivers a constant DC output voltage and maintains the voltage continuously at the design value regardless of changes in load current or input voltage in their operating ranges. Linear regulators are generally suitable for the application where the difference in voltage between the input and the output is less. The linear regulator sets the resistance of the pass transistor to maintain a constant output voltage by comparing the internal reference voltage to the sampled output voltage, driving error to zero. The output of the linear voltage regulator is always lower than the input voltage. Linear voltage regulators can have a fixed or an adjustable output (3).

Linear regulators are usually inefficient as the difference between the input voltage and the regulated output voltage of linear regulators is constantly dissipated as heat. These regulators, on the other hand, have a few advantages: they are usually simple to build, cost-effective, respond quickly to voltage fluctuations, and have low noise and output voltage ripple.

### 2.4.1 Series Regulator

Series regulators can be defined as regulators which regulate the output voltage to be constant, despite the input line variations. Series regulator is commonly used for providing the output voltage regulation in a linear regulated power supply. A series regulator performs better when low noise, ripple, and transients are required in the regulated output. In the series regulator, a series-pass transistor acts as the control element.



**Figure 4: Block diagram of series voltage regulator**

As shown in figure 4, between the input and output, the control element is kept in series with the load. A change in the output voltage is detected by the output sample circuit. The error detector compares the sample voltage to a reference voltage, causing the control element to generate a constant output voltage.

#### 2.4.2 Shunt Regulator

Shunt regulators can be defined as regulators which regulate the output voltage to be constant, despite the variations in load at the output. The regulating element in shunt regulators discharges the current to the ground. It operates by maintaining the voltage across the load by providing a constant voltage across its terminals and absorbing the excess current. Shunt regulation is appropriate for low currents and a wide range of fixed, generally low voltages.

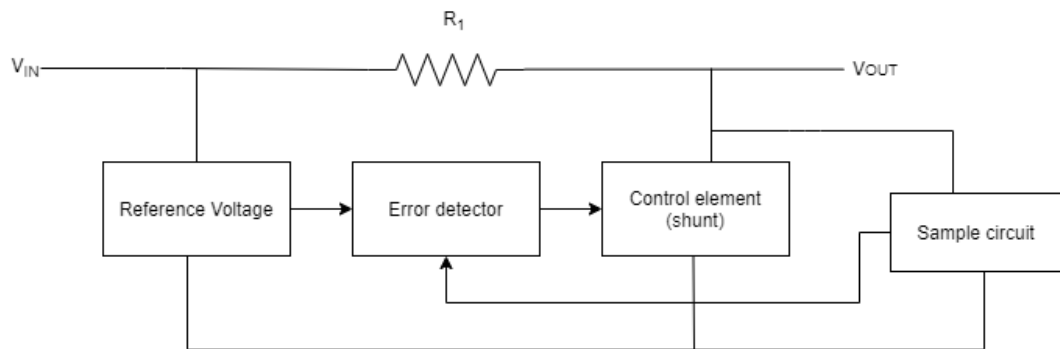


Figure 5: Block diagram of shunt voltage regulator

As shown in figure 5, the control element is kept in parallel, and a resistor  $R_1$  is kept in series with the load. The operation of the circuit is the same as the series regulator, except that the regulation is obtained by limiting the current through the parallel transistor.

#### 2.4.3 Thermal Calculation

The voltage difference between the input and output terminals of the linear voltage regulator releases the extra input power as heat, causing the voltage drop as ICs essentially behave as pseudo-resistors and resulting in inappropriate function or damage in the circuit. So, a proper heatsink is required to increase the device's working surface area and dissipate heat away from the component for a circuit to function properly.

The power dissipated in a regulator can be calculated by

$$P = U * I \quad (4)$$

where  $P$  is the power dissipated from the regulator,  $U$  is the difference between the input and the output voltage, and  $I$  is the output current.

## 2.5 Switching Regulator

A switching regulator is a circuit that transfers energy from the input to the output using a power switch, an inductor, and a diode and requires the selection of external component values, the tuning of control loops for stability, and complex configuration design. A switching controller IC monitors the voltage of the switching regulator in a feedback control loop to maintain a constant output under normal operating conditions, turning on and off the power switch, which is normally a Field Effect Transistor (FET). The field-effect transistor is a discrete component that is external to the switching controller in some switching regulators. The FET and controller are in the same IC in certain types. Since the series element dissipates almost no power and is either completely conducting or switched off, these regulators are considered more effective. Unlike linear regulators, switching regulators may generate higher output voltages than the input voltage or even have the opposite polarity (3).

Switching regulators have higher efficiency, better thermal performance, and can handle higher current and wider  $V_{IN} / V_{OUT}$  applications than linear regulators. Depending on the application requirements, they can achieve greater than 90% performance. Additional external components, such as inductors, capacitors, FETs, or feedback resistors, may be required for a switching power supply.

Switching regulators are categorized based on different topologies, with step-up, step-down, and inverting being the three most common configurations.

### 2.5.1 Step-Down Switching Regulators

A step-down switching regulator, also known as a buck converter, is a power converter that provides an output-regulated voltage that is lower than its input voltage. The operation of these converters is similar to that of linear regulators apart from the fact that the step-down regulators operate at a higher degree of efficiency. A step-down regulator is normally preferable to a linear regulator when the input voltage is significantly higher than the required output voltage.

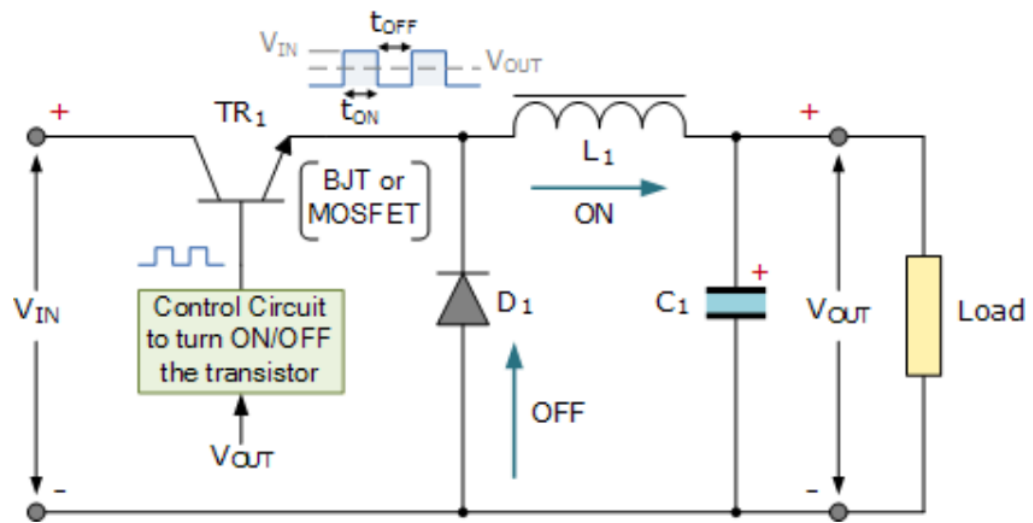


Figure 6: Step-down Configuration (4)

As illustrated in figure 6, a transistor  $TR_1$  (BJT or MOSFET) switches the input voltage at a duty cycle determined by the load requirements of the regulator. To average the switched voltage, the LC filter is used. The power lost in the control circuit is low since the transistor is either on or off. Thus, step-down regulators are mostly useful in high-power applications or in the application where efficiency is of greatest concern.

During the on-time ( $t_{ON}$ ), the capacitor is charged, and discharges during the off-time ( $t_{OFF}$ ). As  $t_{ON}$  is greater than  $t_{OFF}$ , the capacitor charges more, resulting in a higher output voltage. The capacitor discharges further as the  $t_{ON}$  is reduced, lowering the output voltage. The inductor smooths out output voltage fluctuations caused by charging and discharging.

### 2.5.2 Step-Up Switching Regulators

A step-up switching regulator, also known as a boost converter, is a power converter that steps up its input voltage to produce a higher output voltage. Unlike linear regulators, step-up regulators can produce output voltages higher than their input. Since power ( $P=V \cdot I$ ), the current generated at the load is lower compared to the source current.



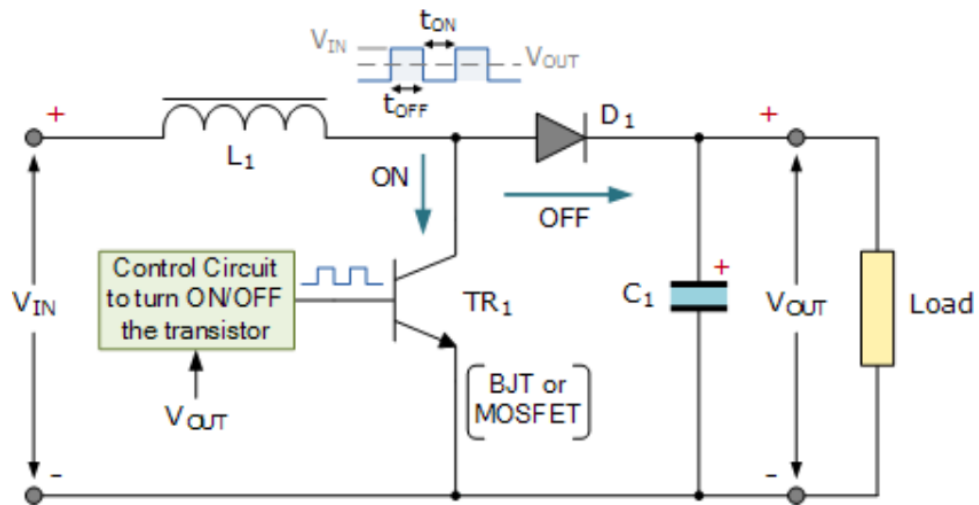


Figure 7: Step-up Configuration (4)

Figure 7 illustrates the configuration of a step-up regulator. TR1 is a transistor that operates as a ground switch. The input voltage is induced through the inductor with a polarity when TR1 is switched on. During on-time of TR1 ( $t_{ON}$ ), the inductor voltage drops from its initial value, and diode D1 becomes reverse-biased. The inductor voltage decreases as the transistor is turned on for longer periods. During  $t_{ON}$ , the capacitor discharges a very small amount through the load. As TR1 is turned off, the inductor voltage instantly reverses polarity and connects to the input voltage, allowing the capacitor to be charged. Since the capacitor is charged to  $V_{IN}$  in addition to the voltage generated through the inductor during  $t_{OFF}$  of TR1, the  $V_{OUT}$  is equivalent to the capacitor voltage and may be greater than  $V_{IN}$ .

The change in Q1's on-time in response to changes in  $V_{OUT}$  due to changes in load or input voltage is used to achieve voltage regulation. As  $V_{OUT}$  attempts to increase, TR1's on-time decreases, resulting in a decrease in the amount of charge in C1. As  $V_{OUT}$  attempts to decrease, TR1's on-time increases, causing the amount of charge in C1 to increase (2).

### 2.5.3 Voltage-Inverter Switching Regulators

The voltage-inverter switching regulator, also known as the buck-boost converter, incorporates the features of a step-up and step-down converter to produce an inverted output voltage (as input voltage) that can be greater or smaller depending on the duty cycle. As a result, these regulators can function in both step-up and step-down modes.

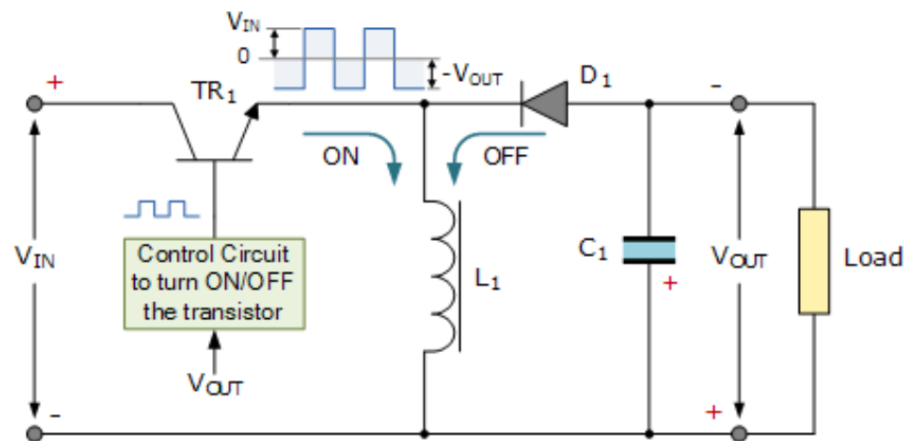


Figure 8: Voltage-Inverter Configuration (4)

The basic configuration of the voltage-inverter regulator is shown in figure 8. As the diode is reverse-biased, the inductor voltage decreases from its initial maximum when the transistor TR1 turns on. As TR1 is turned off, the magnetic field disintegrates and the polarity of the inductor switches, forward-biasing the diode, charging the capacitor C1, and generating a negative output voltage. TR1's constant on-off operation causes repeated charging and discharging, which the LC filter smooths out.

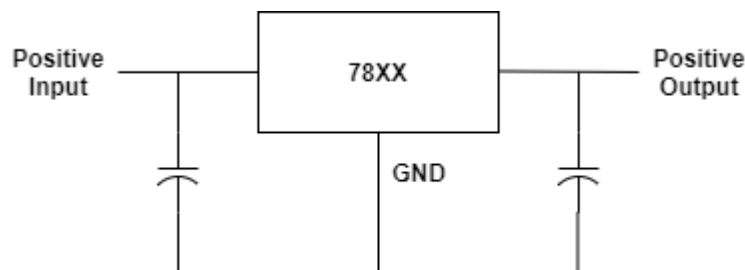
### 2.6 Integrated Circuit Voltage Regulator

Voltage regulator circuits are available in IC having considerably basic power supply design, power handling capacity, various designs, and their reliability have gradually improved. Integrated circuit regulators are readily available in a wide range of current and voltage ratings, for both series and shunt applications, along with complete switched-mode configurations.

In general, linear regulators are three-terminal devices that output either a positive or negative voltage, which can be fixed or adjustable.

### 2.6.1 Fixed Linear Voltage Regulators

The most familiar DC linear fixed voltage regulator ICs used in electronic circuits are 78XX series for positive voltage output. The XX denotes the output voltage ranging from 2.5 V to 35 V and can provide 2 A of current. Internal current limiting, thermal shutdown, and safe area compensation are all features of these regulators, making them more durable. The output voltage of any regulator given can vary by as much as  $\pm 4\%$  of the nominal output. As a result, the output voltage of a 7812 will range from 11.5 to 12.5 V and will remain constant within that range. The LM79XX range of regulators is available in the same range of voltages as the 78xx series but with negative outputs. These regulators share the same features and characteristics except the PINs of the positive regulators. They are mostly used in operational amplifiers in a dual-mode power supply and other various circuits that require regulating negative supply.



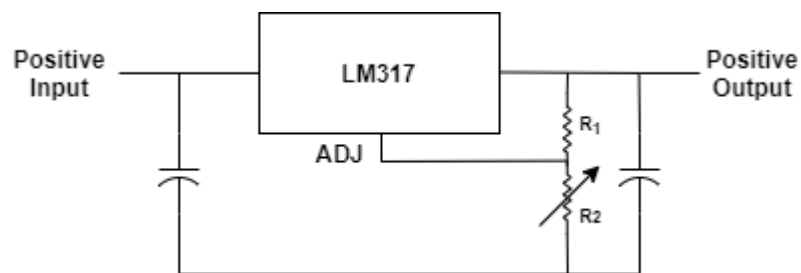
**Figure 9: Configuration of fixed linear voltage regulators**

The basic setup of the 78XX fixed positive voltage regulator can be seen in Figure 9. The capacitors are connected to the input and output. However, the capacitors are not always necessary, input capacitors are used for filtering and preventing unwanted oscillation and the output capacitors act as a line filter for a better transient response.

### 2.6.2 Adjustable Linear Voltage Regulators

The LM317 is the most widely used three-terminal positive regulator with an adjustable output voltage. Depending on the resistor values, it can generate more than 1.5 A over

a voltage range of 1.25 V to 37 V. The terminal pins are input, output, and an adjustment terminal. For voltage adjustment, LM317 requires two external resistors. It comprises thermal overload protection, current limiting, and safe operating area protection. Even if the ADJ terminal is disconnected, overload protection continues to function. To provide regulated negative supplies, LM337 is available in a similar range of voltages as the LM317 series but with negative outputs. As in the LM317, the LM337 needs two external resistors to adjust the output voltage. Depending on the values of the external resistors, the output voltage can be regulated from -1.25 V to -37 V (5).



**Figure 10: Configuration of LM317, an adjustable linear voltage regulator**

In figure 10, we can see the configuration of the LM317. To regulate the output voltage, the external fixed resistor  $R_1$  and the variable resistor  $R_2$  are connected. The capacitors at input and output are for decoupling and do not affect DC operation. The adjustment terminal changes with the voltage across  $R_2$  as not being connected to the ground, so LM317 is regarded as a floating regulator.

## 2.7 Application of IC Voltage Regulator

### 2.7.1 The External Pass Transistor

IC voltage regulators can provide a wide variety of output voltages, but they can only deliver a certain amount of output current to the load. The 78XX series regulator, for example, can tolerate a maximum output current of 1.25 A. The regulator will shut down if the load current reaches the maximum tolerable value due to thermal overload. A thermal overload occurs when a device's internal power supply is overloaded. If the device

needs more current than the regulator's maximum output current, an additional pass transistor may be used.

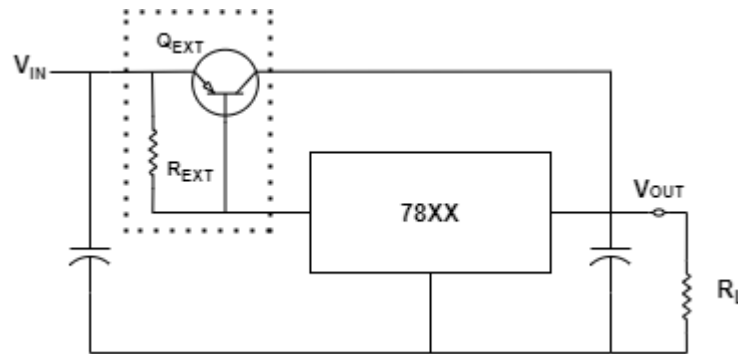


Figure 11: A 78XX-series voltage regulator with an external pass transistor

Figure 11 illustrates a 3-terminal regulator with an external pass transistor for generating current when the required output current is higher than the capacity of the basic regulator. The value of the external current-sensing resistor ( $R_{EXT}$ ), which sets the base-to-emitter voltage of the transistor, determines the current at which  $Q_{EXT}$  begins to conduct.

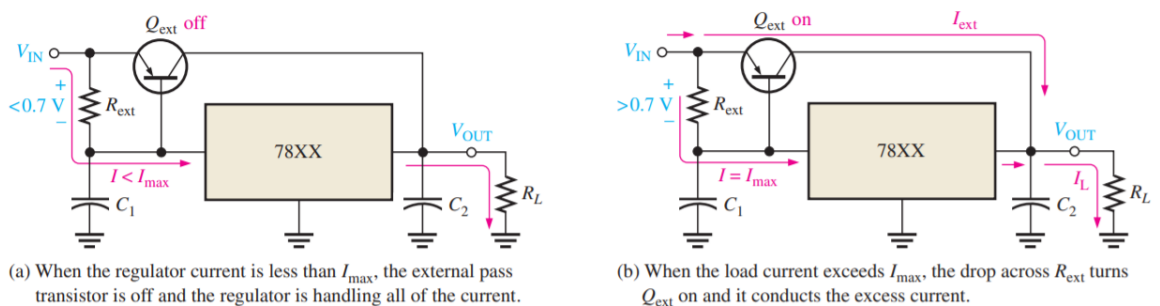


Figure 12: Operation of the regulator with an external pass transistor (2)

If the current is less than the value set by  $R_{EXT}$ , the transistor  $Q_{EXT}$  is turned off, and the regulator operates normally, as shown in figure 12. The regulator's input voltage is 0.7 V less than the emitter voltage of  $Q_{EXT}$ , resulting in a zero base-emitter voltage and the

transistor is off. Since  $R_{EXT}$  specifies the current value at which  $Q_{EXT}$  starts to conduct, the value of  $R_{EXT}$  should be calculated by using the formula,

$$R_{EXT} = \frac{0.7 V}{I_{max}} \quad (5)$$

where  $I_{max}$  is the maximum current handled by the voltage regulator internally.

The transistor  $Q_{EXT}$  switches on and conducts any current greater than  $I_{max}$  when the current is capable to achieve at least a 0.7 V drop across  $R_{EXT}$ , as shown in figure 11. (b).

If the total load current is 5 A and the internal voltage regulator current  $I_{max}$  is 1 A, the external pass transistor will conduct 4 A, much more than the internal voltage regulator current  $I_{max}$ .

### 2.7.2 Current Regulator

When an application needs to supply a precise constant current to a variable load, the three-terminal linear voltage regulator may be used as a current source. The function of a current regulator is the same as of voltage regulator with the major difference being the factor they regulate and the amount they adjust to supply their output. The current in the voltage regulator is adjusted to obtain the required voltage level, whereas current regulators generally involve changes in voltage or resistance to get the required current output. While being possible, it is usually difficult to regulate voltage and current at the same time in a circuit (6).

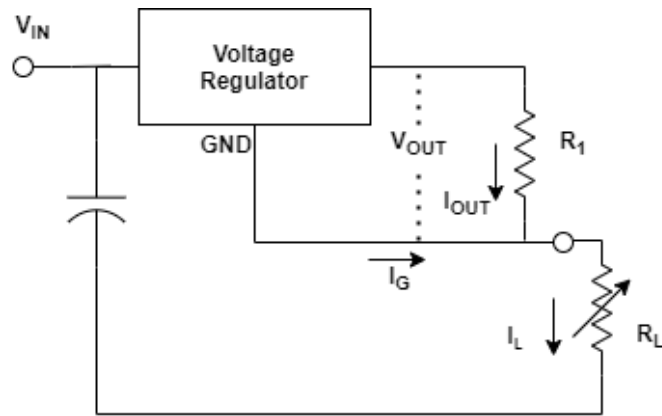


Figure 13: The 3-terminal voltage regulator as a current source

In figure 13, a basic current regulator circuit is designed, where  $R_1$  is the current-setting resistor and  $R_L$  is the variable load. The voltage regulator regulates the constant voltage,  $V_{OUT}$  between the output and ground terminal, determining the constant current supplied to the load.

$$I_L = \frac{V_{OUT}}{R_1} + I_G \quad (6)$$

The current flowing through the ground pin,  $I_G$ , is negligible in comparison to the output current and can be ignored.

## 2.8 Pulse Width Modulation

The concept of reducing the average power generated by an electrical signal by effectively chopping it up into discrete parts is known as pulse width modulation (PWM) or pulse-duration modulation (PDM). The quick on/off switching of supply and load controls the average value of voltage and current supplied to the load (7). PWM is mostly applicable for operating inertial loads like motors, because of its inertia causing them for slow reaction.

A PWM signal varies with time where the signal is on for a certain period and off for the rest. The fraction of one period for which the signal is ON is defined as the duty cycle. A duty cycle ranges from 0% to 100%, 0% being off-state whereas 100% being constantly

on. Hence, a 70% duty cycle signifies that the signal is on 70% of the time being off for 30% of the time. Mathematically, a duty cycle (%) can be expressed as

$$\text{Duty cycle (\%)} = \frac{T_{ON}}{T_{ON} + T_{OFF}} * 100\% \quad (7)$$

where  $T_{ON}$  is the pulse-width and  $T_{OFF}$  is the off-state time of the circuit.

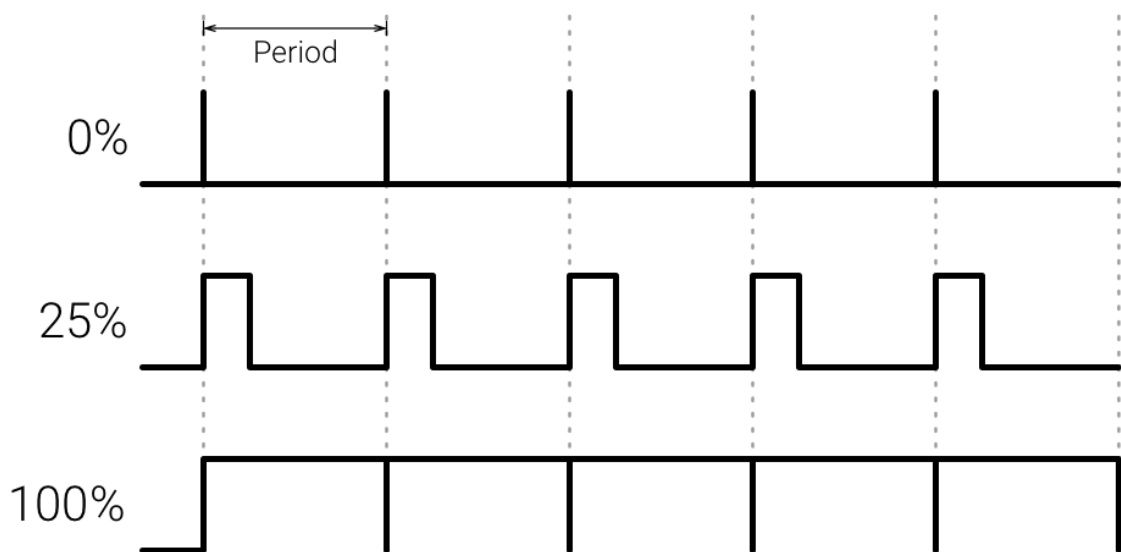


Figure 14: Pulse-width modulation (8)

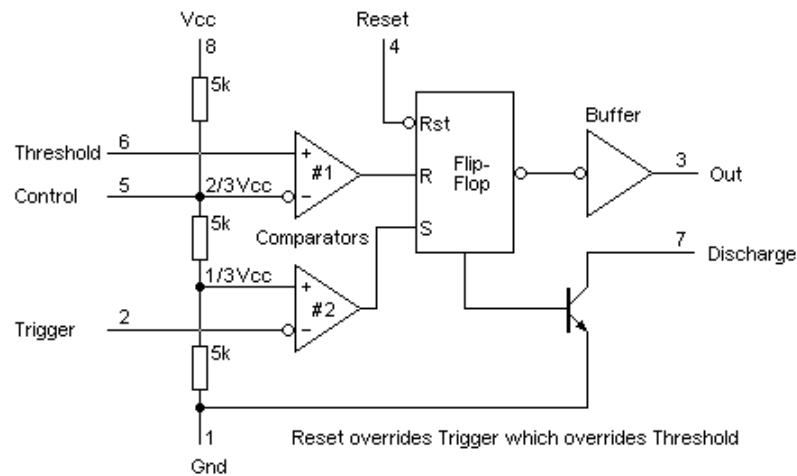
The duty cycle can be adjusted, where the average on-time of the signal can be increased or decreased, to get desired timing. In figure 14, the different duty at 0%, 25%, and 100% are shown.

### 2.8.1 555 Timer

The 555 timer IC is an integrated circuit usually configured to design timers, delays, pulse generators, and oscillators. Two comparators, a flip-flop, a discharge resistor, and a resistive voltage divider make up the circuit. A flip-flop is a two-state system with an output



voltage that can be either high or low. With the proper input signals, the output state can be regulated.



**Figure 15: Internal Schematic Diagram of 555 IC**

Figure 15 illustrates the operation of a 555 timer IC. The comparator levels are set using a resistive voltage divider. Since all three resistors have the same resistance, the upper comparator has a  $2/3 V_{CC}$  reference, and the lower comparator has a  $1/3 V_{CC}$  reference. The state of the flip-flop is regulated by the output of the comparators.

The flip-flop sets and the output rises to its high level when the trigger voltage drops below  $1/3 V_{CC}$ . An external RC timing circuit is usually connected to the threshold input. When the external capacitor voltage reaches  $2/3 V_{CC}$ , the upper comparator resets the flip-flop, which switches the output down to its low level. When the output is minimal, the discharge transistor is triggered, allowing the external capacitor to discharge quickly. This timer has three modes of operation: monostable, bistable, and astable. (9).

#### 2.8.1.1 The 555 Timer Monostable Mode

The 555 timer generates a single pulse of current for a fixed period of time in monostable mode. It is also described as a one-shot pulse. To set up the 555 timer as a monostable,

a resistor and a capacitor are used. The R and C values determine the pulse-width of the output, calculated by the formula,

$$\tau = 1.1 * R * C \quad (8)$$

where  $\tau$  is measured in seconds, R in ohms, and C in farads.

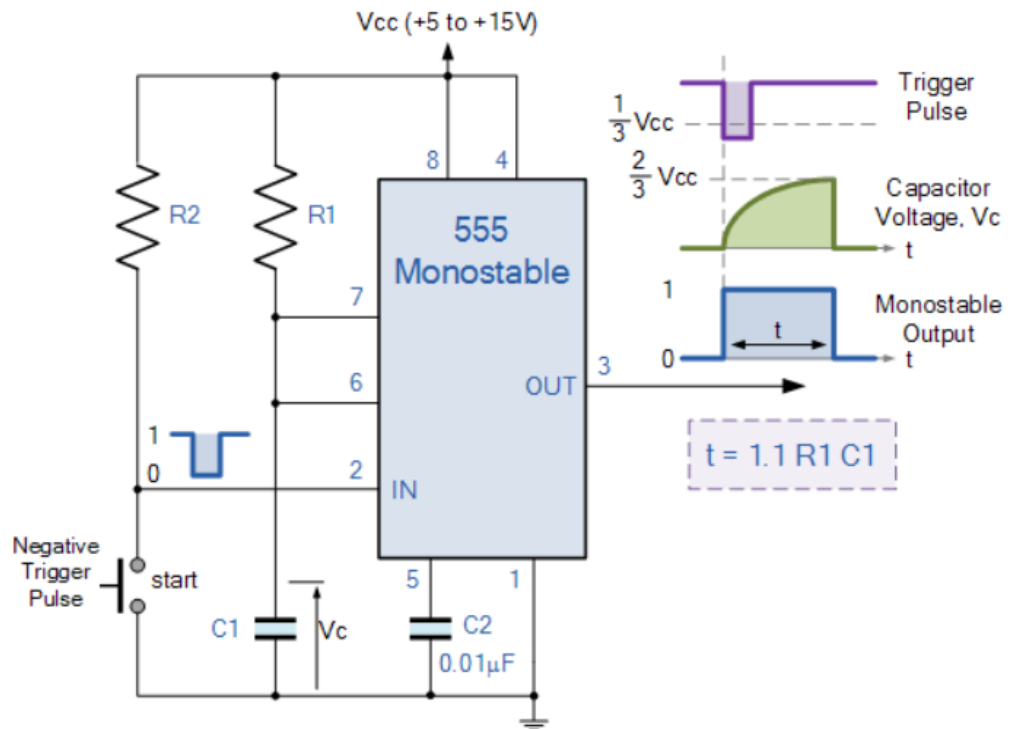


Figure 16 : The 555-timer monostable multivibrator mode (10)

Figure 16 shows the configuration for a monostable mode of 555-timer. The change in resistor R1 and capacitor C1 change determines the on-time of the circuit.

The 555-timer monostable mode was used in the project as a PWM.

### 3 Heating Element

The heating element provided was made of Nikrothal (nickel-chromium alloy) of 0.3 mm thickness. Nikrothal is used at extremely high temperatures up to 1200°C and is known for high resistivity, strong oxidation tolerance, and excellent structural stability. (11).



Figure 17: Loads provided in the project.

As in figure 17, two different loads were provided. Load 1 (1<sup>st</sup> figure) was used in the first half of the project and later another tip, load 2 (2<sup>nd</sup> figure) with different characteristics was provided. The load resistance was calculated using a DMM 4-wire connection, which is suitable for low-value resistance measurements and avoids the effects of the leads without requiring the use of the relative function. This approach provides highly precise, repeatable, and reliable resistance measurements, making it ideal for measuring low resistance values as low as 10 milliohms.

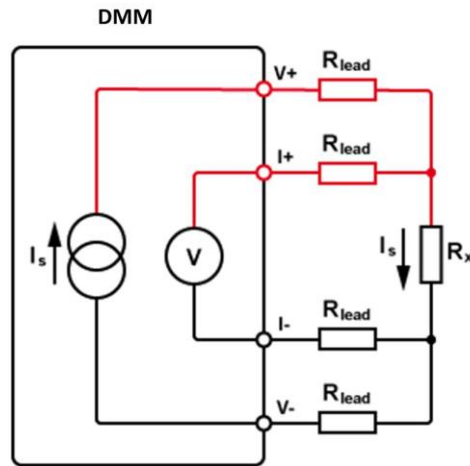


Figure 18: DMM 4-wire measurement (12)

In the configuration shown in figure 18, the provided load was attached as  $R_x$ . The current flow through the test leads from the positive and negative voltage terminals to the resistor. The number of the lead resistance and the external load attached is used to measure the voltage decrease through these voltage terminals.

The sense lines are wired to the terminals of the resistors to calculate the voltage across the resistor, which excludes the voltage across the test leads. The voltmeter's input impedance is so high that it does not generate error voltages or redirect current from  $R_{lead}$ . As a result, the reading is almost completely independent of the test lead resistance and is only dependent on the resistor (12).

Table 1: Resistance value obtained from DMM

Load	Resistance (ohms)
1	0.98
2	0.47

As shown in Table 1, the resistance of load 1 was 0.98 ohms which was used when the project started whereas load 2 had a resistance of 0.47 ohms which was provided later.

Thereafter, a test was carried out across load 1. The load was connected to the power supply and voltage was increased gradually and the current was measured.

**Table 2: Measurement of Current**

Input Voltage (V)	Current (A)	Power (W)
1	1.02	1.02
2	2.04	4.08
3	3.06	9.18
4	4.08	16.31
5	5.1	25.49
6	6.12	36.71
7	7.14	49.96
8	8.16	65.25

The results were obtained as shown in table 2. As the input voltage was increased across the load, the current also increased. Simultaneously, the load started to get heated up and was red hot as 4 A current was passed through it. When the voltage across the load was 8V, the current passing through the load was 8.16 A generating the power of 65.25W which broke the load.

#### 4 Block Diagram

According to the requirements, the following layout is designed in a block diagram. As shown in figure 19, a transistor is used to produce the current for the output load. Alongside a voltage regulator is used for the constant voltage on the output. The resulting output current from the transistor is controlled with the timer circuit. The timer circuit which acts as a PWM (Pulse Width Modulation) switches the transistor on which allows the current to flow through the load.

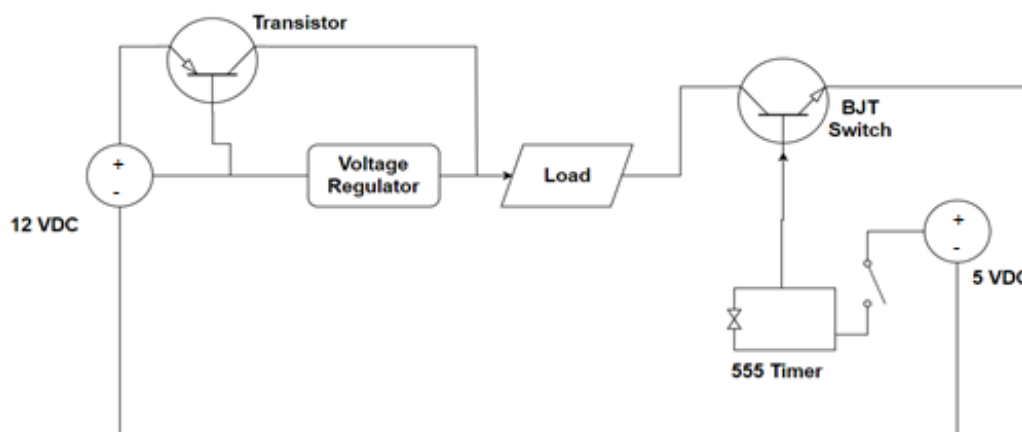


Figure 19: Circuit Layout

## 5 Multisim Simulations and Circuit Design

Various circuits were designed to meet the application requirements and tested and measured in different conditions. Together three prototypes were designed and out of those three, two prototypes were printed on the circuit board and tested.

### 5.1 Prototype 1

In this prototype, a circuit was designed using two main components MJ2955, a PNP power transistor, and LM7805, a 5V DC regulator integrated circuit. To make the circuit more reliable, BC558 and BD140 transistors were added to measure the overload, and LED was added to indicate an overload.

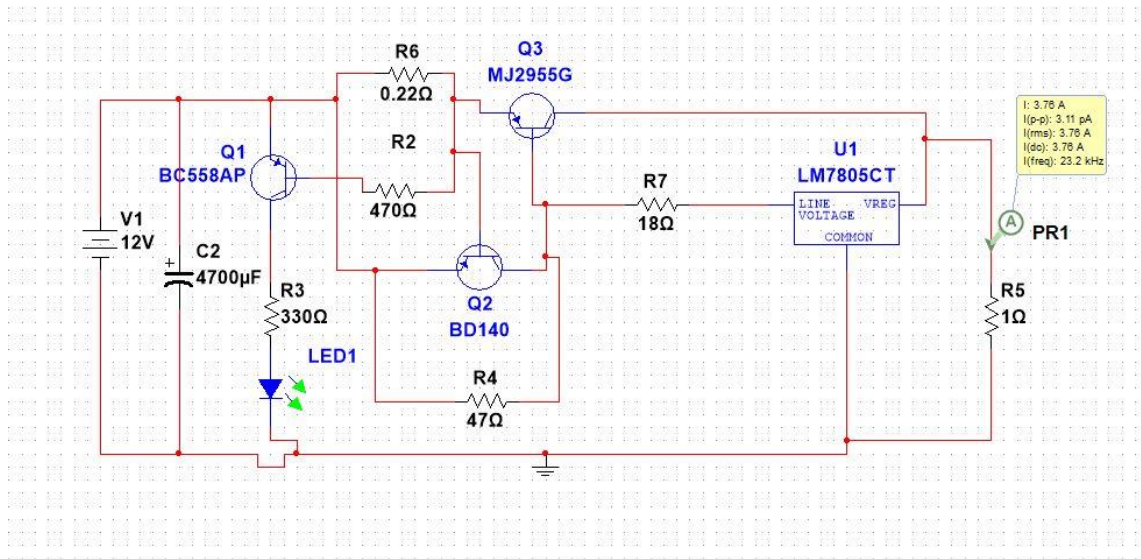


Figure 20: Multisim Circuit - Prototype 1

The circuit was designed and tested in Multisim, a simulation software with promising results as shown in the figure. With the load of 1 ohm in the output, a 3.76A current was obtained.

Then, the circuit was designed on a circuit board (breadboard) and was tested with various loads of different resistance (R5).

Table 3: Current measurement across different loads

Resistance ( $\Omega$ )	Current (A)	Power (W)	Vout
820	0,009	0,066	5
470	0,014	0,09212	4,58
100	0,05	0,25	4,805
56	0,089	0,44	4,715
33	0,159	0,76	4,48
24,81	0,2	1	4,5
22	0,221	1,074	4,82
10	0,45	2,025	4,74
4,7	0,96	4,33	4,67
2,2	1,85	7,52	4,5
1,5	2,88	12,44	4,3
1,33	3,76	18,8	4
1,2	3,2	12,88	3,5
1	3,18	10,11	3,18

The data shown above in Table 3 were obtained from the test carried out. The current obtained across 1-ohm load was 3.18 A. The resulting current was not enough for the project.

The current can be increased across 1-ohm load which can go up to 5 A by changing the value of R7 which controls the input voltage of the regulator. When the R7 is changed to around 4 ohms, the output current across the load is approx. 5 A which heats the regulator. The circuit was also designed to light up the LED to indicate the overload at the output but due to the low load value, the LED lights up when the current at the output is more than 3 A. The circuit can be adjusted so that the output can be 5 A, but the overload circuit cannot function properly.

So, the above circuit is more useful for a load of more than 1.5 ohms.

## 5.2 Prototype 2

In this prototype, a circuit similar to prototype 1 was designed using two main components MJ2955, a PNP power transistor, and LM7805, a 5V DC regulator integrated circuit.

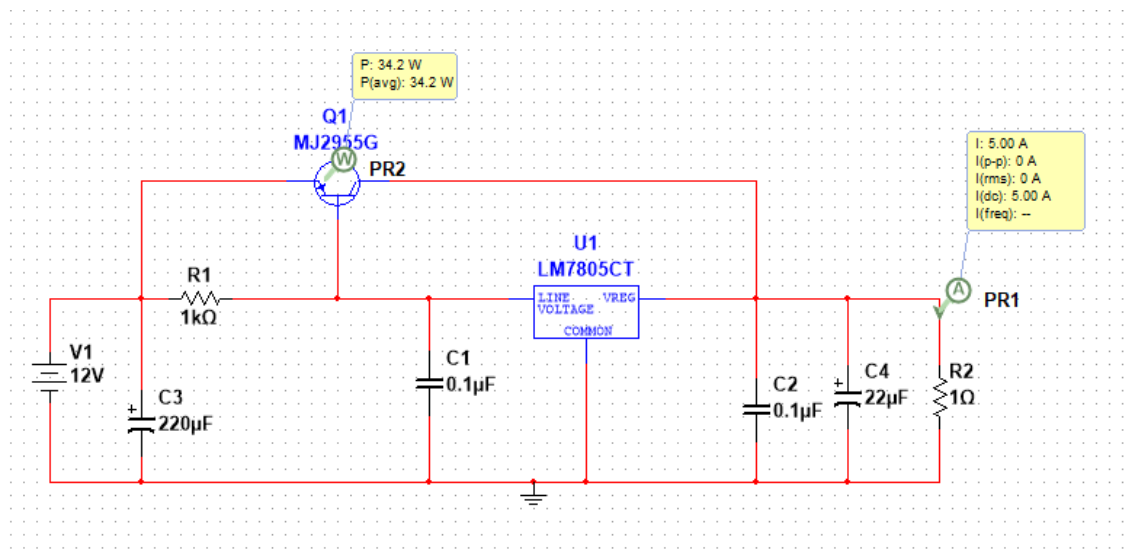


Figure 21: Multisim Circuit - Prototype 2



Solving the problems that occurred in prototype 1, a circuit as shown in figure 10 was designed which can give 5 A output across the load. The voltage drop across the transistor was 7 V producing the power of 35 W ( $P= I \cdot V$ ) generating heat. Hence, a heatsink was used to dissipate the heat away from the transistor to the surrounding.

The circuit was tested and was working ideally, obtaining the desired output of 5 A current across a 1-ohm load. But the different load with developed characteristics (Load 2) with less resistance of 0.47 ohms was handed afterward for the project. Since the circuit designed was a constant current source, it was not ideal for the load with a low resistance to obtain the required result. If the load of 0.47ohms is connected in the circuit, the current of 10.6 A flows through the load, and the load gets broken.

Therefore, the new circuit was designed for the new load.

### 5.3 Prototype 3

In this prototype, a high-current adjustable regulator circuit was designed using LM317, a 3-Terminal Adjustable Regulator alongside transistors 2N3055 and 2N2905. The circuit was then designed in a circuit board and simulation was done in Multisim.

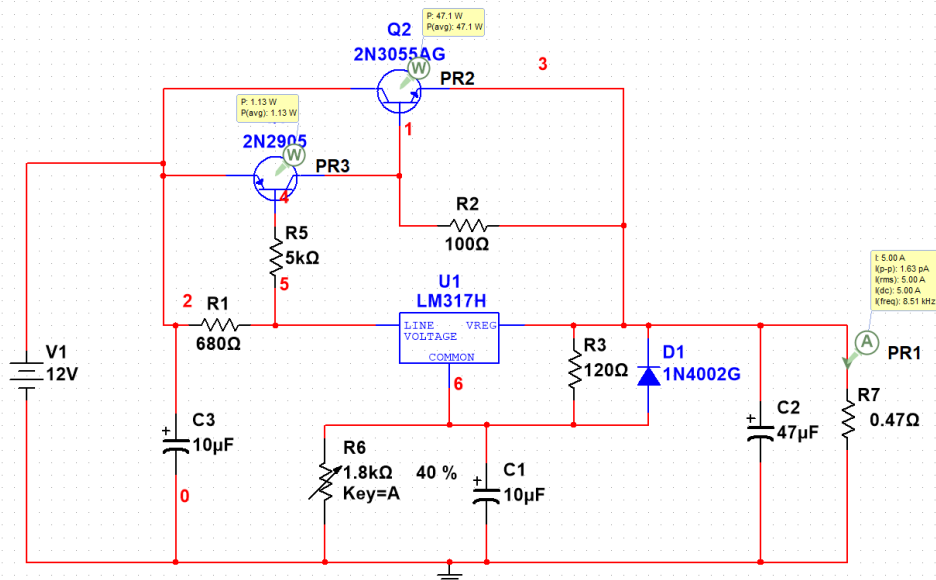


Figure 22: Multisim Circuit - Prototype 3

In figure 14, a potentiometer R6 is used to control the current across the load R7, which can be adjusted from 3.7 A to 5 A. A diode D1 is used as reverse current protection to avoid the high surge in current which may occur due to reversing the polarity of DC supply. The use of the diode in the circuit makes this prototype more reliable than the previous prototypes.

A test was carried out on the circuit board by changing the load R7. To measure the current across R7, a digital multimeter was connected in series. The following readings were obtained.

**Table 4: Current measurement across various loads**

Load(Ohms)	Voltage(V)	Current(A)
0.1	0.48	4.8
0.5	2.375	4.75
1	4.9	4.9
1.5	7.305	4.87
2	9.66	4.83
3	10.8	3.6
5	11	2.2

As illustrated in table 4, the current remains constant through the load range of 0.1 ohms to 2 ohms. The current drops when the load connected is 3 ohms or more. So, the circuit designed is a constant current source for a small load up to 2 ohms.

#### 5.4 Timer Circuit

A PWM circuit was designed to cut off the power in the main circuit when needed. Among various ways to design a PWM, the most common IC 555 timer was used. IC 555 timer is most used, low cost, and easy to work with, alongside different operational modes.

As per the requirement, the monostable mode was the most appropriate mode among others for the project to produce a minimum output time delay of 5 seconds.

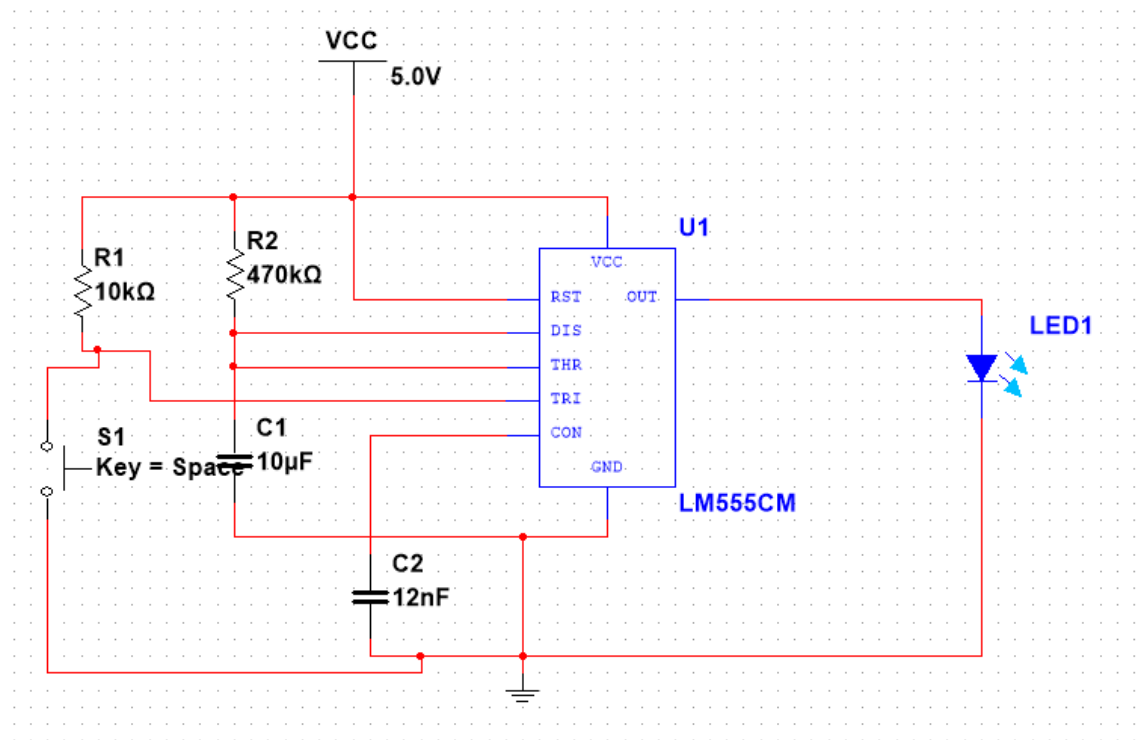


Figure 23 : Multisim Circuit - Monostable 555 Timer

The circuit as in figure 11 was designed in Multisim. Resistor R2 and capacitor C1 be used to adjust the on-time of the circuit. The on-time of the circuit is calculated by the formula below:

$$\tau = 1.1 * 470 * 10^3 * 10 * 10^{-6} \quad (9)$$

Hence, using the resistor of 470 kilo-ohms and capacitor of 10uF, the time delay of 5 seconds was obtained.

## 5.5 Final Circuit

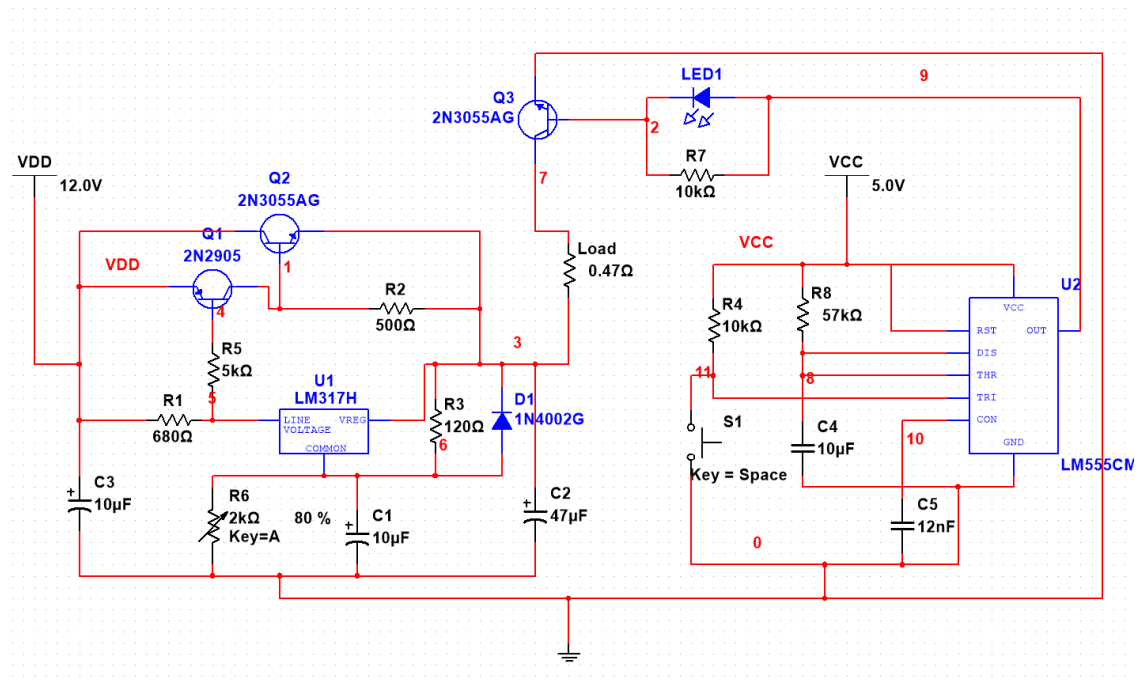


Figure 24: Final Circuit

As shown in figure 24, the main circuit (prototype 3) was connected with the timer circuit with BJT Q3 acting as a switch. When the key S1 is pressed, the timer circuit turns on with 5 V output at U2. The output of the timer is connected to the LED1 and the transistor Q3. The output from the timer turns on the LED1 and transistor Q3. When the Q3 is turned on, the main circuit is grounded, which completes the connection resulting in the flow of current at the load. Due to the monostable properties of the timer circuit, the whole circuit operates for 5 seconds and turns off, indicated by the LED1.

## 5.6 Test of Final Prototype

The final circuit was tested under different circumstances. The main goal of the circuit was to burn the fishing line which has similar properties to the suture lines. The system built in this project is going to be used to burn down the suture line inside a human body,

so the test was needed to be carried out to be sure if it is working. Factors like blood clotting might occur as being used inside a human body and thread may not be cut in time which may cause complications.

So, the test run was done using other animal's blood which showed promising results.

**Table 5: Final Tests**

Current(A)	Power (W)	Success
1	0.47	NO
2	1.88	NO
3	4.23	NO
4	7.52	NO
5	11.75	YES
5.5	14.21	YES

Table 5 shows the results where the current was gradually increased. The heating element was used to cut the fishing line inside the blood. When the current was 5 A the heating element was able to cut the thread within the time limit of 5 seconds.

## 6 Conclusion

A timer-controlled constant current source was successfully simulated in Multisim and then to a PCB. The circuit and the cooling devices were mounted in a plastic enclosure box for the safety precautions and possible contaminations as being used in medical facilities. An enclosed 120 W industrial single output switching power supply adopting the full range of 85-264 VAC input, providing the output of 12 VDC, and the current range of 0-10 A is used for the connection with the AC mains, because of its complete protection function as the design.

Although the system delivers the required output, the power dissipation in the circuit is more resulting in the use of two large heatsinks with the transistors. The circuit can be further developed by using the switching voltage regulators, for higher efficiency and better thermal performance. The switching regulator can also operate in a wide input voltage range, so even at low voltages, switching regulators can deliver higher current

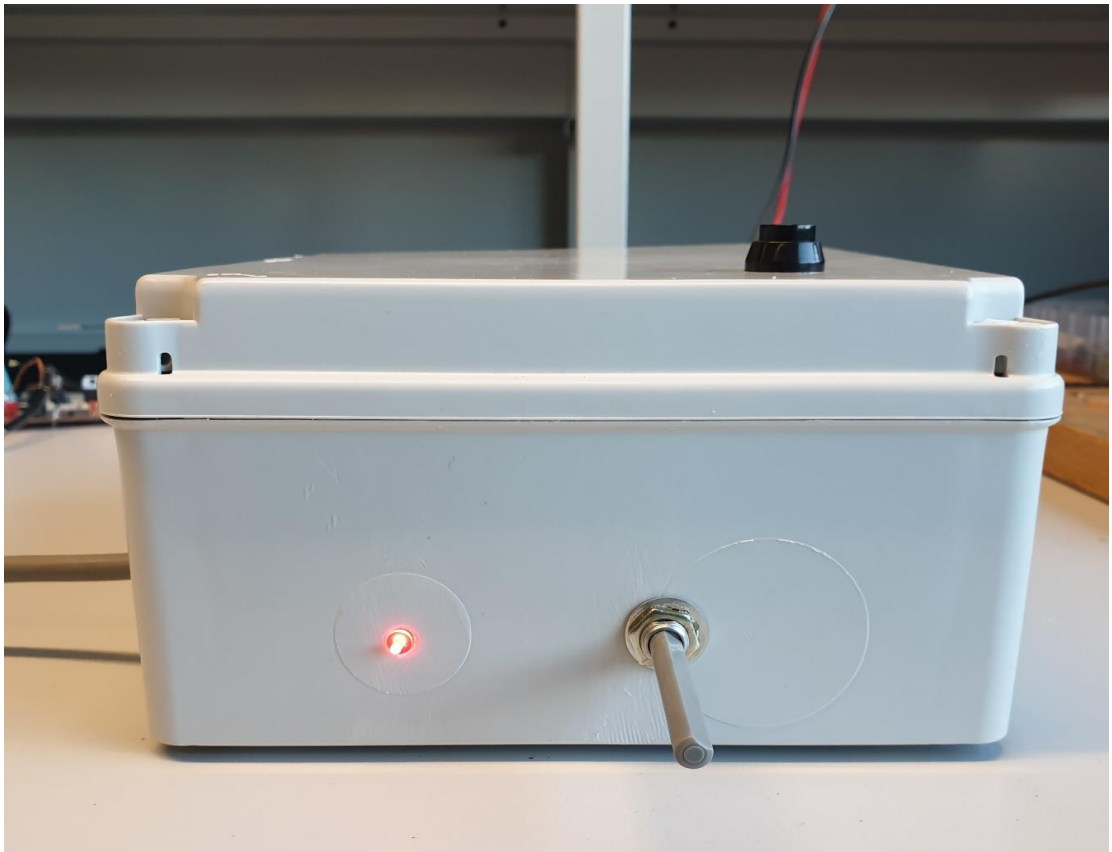
at the load than the linear regulators. Moreover, the use of MOSFET as a switch would be more preferable as of its tolerance properties to heat and higher switching speed.

The development of the heating element can also be taken into consideration. The heating element was not long-lasting, and it was broken after just a few tests carried out. The current handling capacity of the heating element was also an issue as it becomes red hot when the flow of current is 5 A and breaks when goes over 7 A. Instead of keeping the element with a certain amount of current flow inside a human body for a longer period, it might be better to increase the current slightly with less amount of time to cut the suture lines with early precautions and tests carried out before in the normal environment. In near future, the heating element can be made up of a different alloy with high current conducting properties and high operating temperature.

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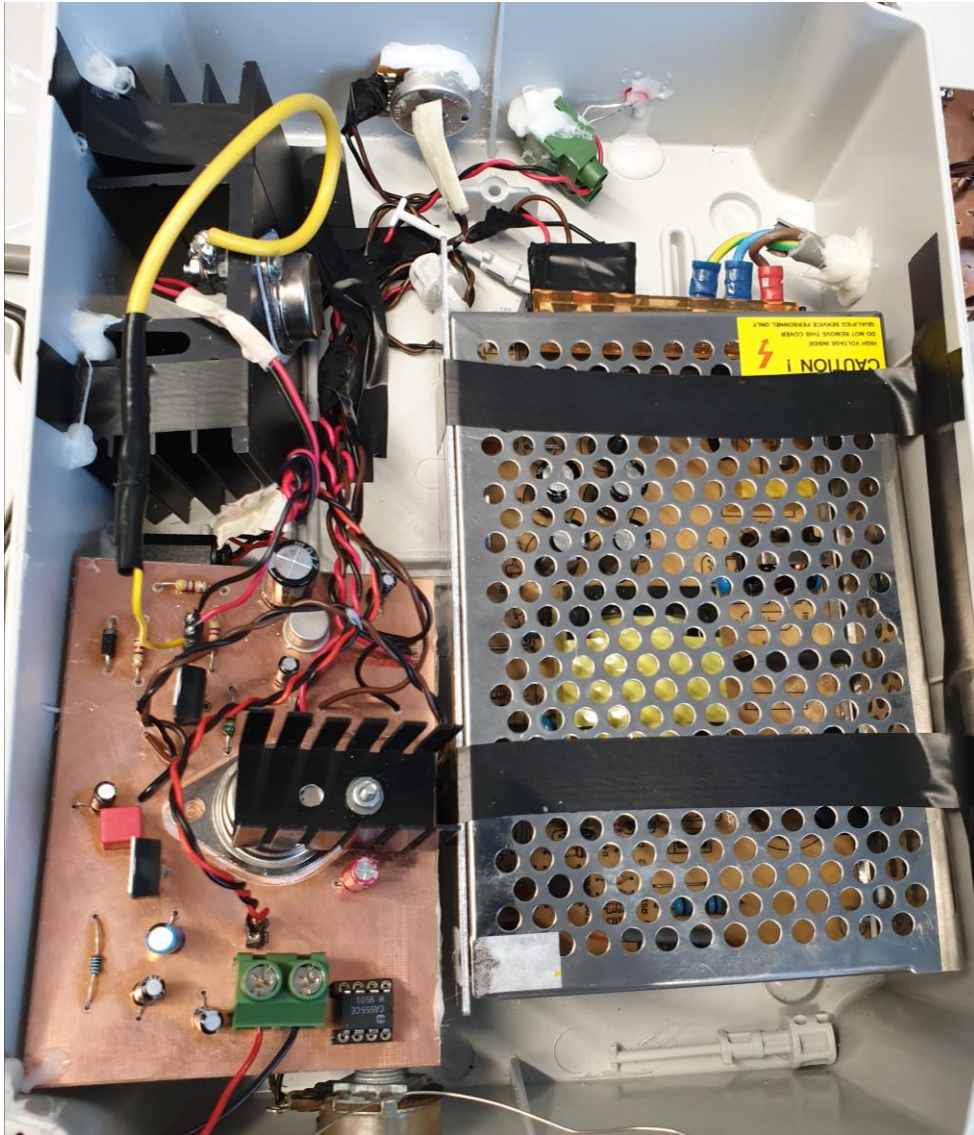
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**Final Product**





**Internal circuitry of the device**



### PCB Layout

