Design and implementation of 50 KV DC power supply using Cockcroft Walton Voltage Multiplier

Submitted by:

Arslan Siddique 2014-EE-064

Muhammad Imran 2014-EE-086

Yasir Ali Khan 2014-EE-096

Kaleem Khan 2014-EE-097

Supervised by: Dr. Sidra Farid

Department of Electrical Engineering

University of Engineering and Technology Lahore

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Declaration

I declare the content written in thesis is my own. This work has not been submitted at any other forum to obtain some degree or any other professional qualification.

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Acknowledgments

First of all, we are very thankful to Allah Almighty who gave us enough courage and ability to work on this final year project and complete it successfully. All this was not possible without the support of certain people. We would like acknowledge them and express our thanks to them.
We are very thankful to the advisor of our project, Dr. Sidra Farid for giving important ideas and instructions about this project. She gave us the motivation and encouragement to work on the project and complete it successfully. A special thanks is dedicated to high voltage engineering lab staff for their coordiation and helping us while working in high voltage engineering lab. We are also thankful to Dr. Farhan Mahmood for his guidance.
We would also like to express oury thanks to our beloved parents who supported us always.

Dedicated to our parents and teachers
May their world be filled with love and peace

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Abstract

A high voltage DC Power supply is an essential component of a high voltage engineering laboratory. It is used for the testing of insulation of cables, high voltage direct current (HVDC) equipments testing and generation of X-rays. The circuit design uses a center tapped AC transformer, NAND gate based PWM generation electronic circuit, Flyback converter and Cockcroft Walton Multiplier circuit. Center tapped AC transformer steps down WAPDA AC mains to positive and negative 12 V which is applied to the input of NAND gate based PWM generation electronic circuit. The circuit sends PWM signals to the input of Flyback converter which produces a high frequency high voltage signal. The output voltage of Flyback converter increases and decreases with the increase and decrease in the frequency of PWM signal. In this way, variable output functionality is being achieved. This high frequency high voltage signal is fed to our Cockcroft multiplier circuit. This circuit works by the charging and discharging of capacitor and increases the voltage up to 50 KV. Electrostatic Voltmeter can be used to measure the output voltage. A resistive potential divider circuit can also be calibrated and designed to measure output voltage.Simulation work has been carried out in MATLAB and satisfactory results have been obtained.

Chapter 1

Introduction

In IEC Standards and its national counterparts (IET, IEEE, VDE, etc) high voltage circuits are defined as those circuits with more than 1000 V for AC and at least 1500 V for DC. In electric power transmission engineering high voltage is usually considered any voltage over approximately 35 kV. In DC systems, 600 kV and voltages below it are known as HVDC levels. Voltage levels above 600 kV are called UHVDC levels.

1.1 Classification of High Voltages

There are three main kinds of voltages in power system:

AC , DC and Impulse Voltage

1.2 High Voltage Engineering

High voltage engineering include various phenomenon like dielectric discharges, generation, overvoltages , measurements and control of high voltages, breakdown of electrical insulation and their protection etc.

- Examples of HV Equipment

Some examples of HV equipment include winding of 220 kV transformer, 750 kV transmission line, SF6 gas insulated switchgear and substation, oil filled transformer, metal oxide arrestors, AC testing transformer, DC voltage generator and impulse voltage generator.

1.3 Testing Voltages

It is mandatory to test the HVDC and other related electrical equipment before launching them for utilization in commercial. There are various kinds of testing voltages. These testing voltages are classified as:

- Testing with power frequency AC voltages
- Testing with switching impulse voltages
- Testing with very low frequency AC voltages
- Testing with lightening impulse voltages
- Testing with DC voltages

1.4 Voltage Stresses in HVDC systems

In HVDC systems, voltage stresses arise from various overvoltages. External overvoltages associate with lightening strokes on lines. Internal overvoltages are generated by certain changes in the operating power systems. Such environmental changes include swithing operations, faults on systems and fluctuations in loads.

No.	Type of Overvoltage	Shape Designation	Causes
1.	Temporary overvoltages	Low-frequency oscillations	Electric faults Sudden changes of load
2.	Switching overvoltages	Slow front surges	Fault interruption De-energization of capacitor banks Energization of lines Energization/de-energization of transformers
3.	Lightning overvoltages	Fast front surges	Lightning—cloud-to-ground flashes
4.	Restrike overvoltages, GIS	Very fast front surges	Opening or closing of circuit breakers, disconnecting switch and earthing switch etc.

Figure 1.1: Shape and Reasons of Voltage stresses

1.5 HVDC Generation Methods

Generation of high voltages is required for two main purposes

- Testing of Power equipment
- To study the breakdown characteristics of insulating material.

There are various methods which are used to generate HVDC. Some methods are discussed here.

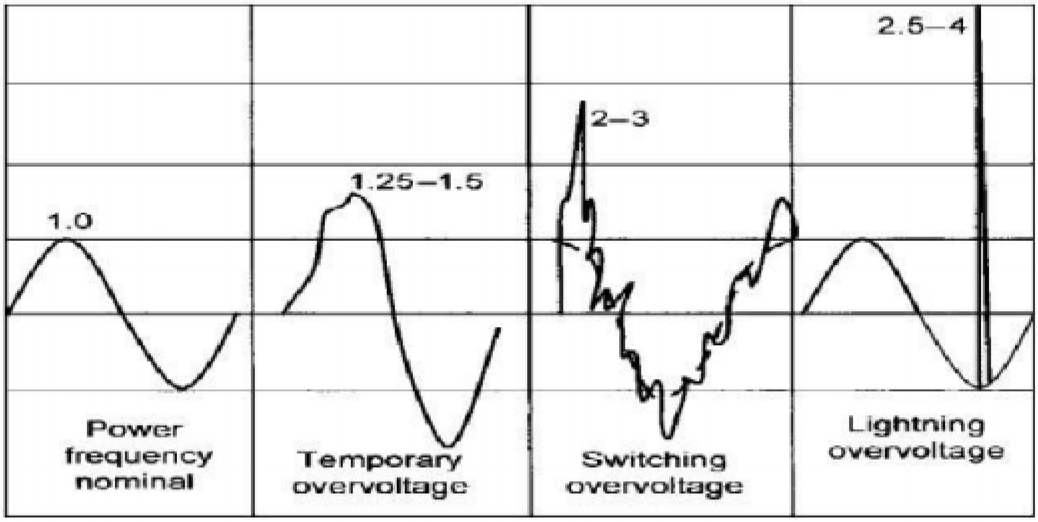

FIGURE 1.2: Voltage Stresses Waveform

- Rectifiers
- Voltage Multiplier circuits
- Electrostatic generators

Ripple is an important factor which should be considered in high voltage generation. In our project, we are using voltage multiplier circuits. Highly efficient method used for the generation of high voltages is Cockcroft Walton Voltage Multiplier circuit. This cascaded circuit reduces the ripple and produces ripple free high voltage.
Insulation of the power equipment is a major factor which should be taken into consideration. Insulation of an electrical equipment should be able to withstand

- Normal system voltage
- Abnormal voltages

1.6 Testing in High voltage engineering

In high voltage engineering, testing can be done by two method:

1.6.1 High voltage testing

In high voltage conditions, current under faulty conditions should be very small. Typically it should be less than 1A for AC/DC voltages and few amperes for transient voltages.

1.6.2 High current testing

In high current testing, current should be very high especially while testing surge arrester and switch gear.

Chapter 2

Generation of PWM Signal

A particular signal of low voltage with varying frequency is applied at the input of Flyback Converter which converts this low voltage signal into high voltage and high frequency signal. This particular signal is called PWM signal. Usually the magnitude of PWM signal lies in the range of 0-5 v. Duty cycle of PWM signal is defined as the ratio of time for which it remains ON to the time interval for which it remains OFF. ON condition means signal is at the position of 5v and OFF condition means signal is at the position of 0v. Duty cycle of our PWM signal generated is 50.

2.1 PWM Signal Generation Methods

There are various techniques which are used to generate PWM signal. Each method has its own limitations of producing PWM signal. PWM signal should be efficient such that it may be suitable for the working of Flyback Converter. There should not be any distortion in the PWM signal. Otherwise it may affect the working of Flyback Converter and desired results will be obtained. If the PWM signal is smooth signal, output of Flyback Converter will be highly efficient. There are two main methods used for the generation of PWM signals. These methods are based on microcontroller and analog circuits.

2.2 PWM Signal Generation by Microcontroller

Different type of microcontrollers are used for the generation of PWM signals. In microcontrollers there are various kind of ports which can be configured with the help of different types of software. PWM signals are produced in these ports whose frequency can also be varied by programming the ports. The PWM signal generated by the microcontrollers are highly efficient and smooth. No noise will be observed in the PWM signal produced by such methods. The frequency of PWM signal can be easily varied from few Hz to Mega Hertz and Giga Hertz. Different typed of functionalities can also be implemented with the help of microcontrollers. Some microcontrollers used for this purpose are:

- STM 32
- Stellaris and Tiva

There are few limitations of using microcontroller.

- Opto-coupler is required to isolate the microcontroller from the remaing circuit. Otherwise microcontroller may be damaged by reverse currents.
- Microcontroller is highly costly as compared to analog circuit. From an external source an extra power supply is needed for the operation of microcontroller.

Due to the limitations, we prefer analog circuits over microcontroller.

2.3 PWM Signal Generation by Analog Circuits

Analog circuit consists of various types of transistors, capacitors, resistors, diodes, ICs etc. Different types of analog circuits have been designed to generate PWM signal depending upon the required efficiency. PWM signals generated by analog circuits is not highly smooth as that was generated by microcontroller. However PWM signal generated by analog circuits can be made smooth and efficient by introducing modern analog circuits. Some of these analog circuits are discussed below:

- 555 Timer
- Eriks Fly back driver circuit
- NAND gate based analog electronic circuit

  555 Timer is a chip used for pulse generation and oscillation applications. It can also be used for time delay purposes.

2.3.1 555 Timer

555 Timer is a chip used for pulse generation and oscillation applications. It can also be used for time delay purposes.

Pin configuration There are 8 pins in one IC of 555 Timer. Pin configuration is shown below.

There are two types of 555 timer.

2.3.1.1 555 timer as astable multivibrator

Astable multivibrator acts like an oscillator. It generates rectangular wave without any help of external trigger. It can be called as free running multivibrator.

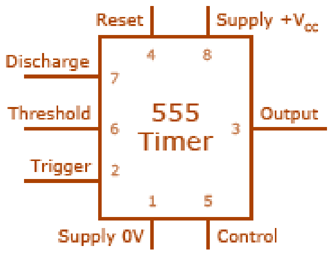

FIGURE 2.1: Pin Configuration of 555 Timer

2.3.1.2 555 timer as monostable multivibrator

When trigger is low, monoatable multivibrator generates high pulse output. By this high output, comparator output can be easily switched.
If the input signal applied at the input of 555 timer is varied, there will be a considerable distortion in PWM signal. This distorted PWM signal does not meet the requirements. So we need an efficient analog circuit which produces suitable PWM signal to operate Flyback converter. This distortion issue can be solved by Eriks Flyback driver circuit.

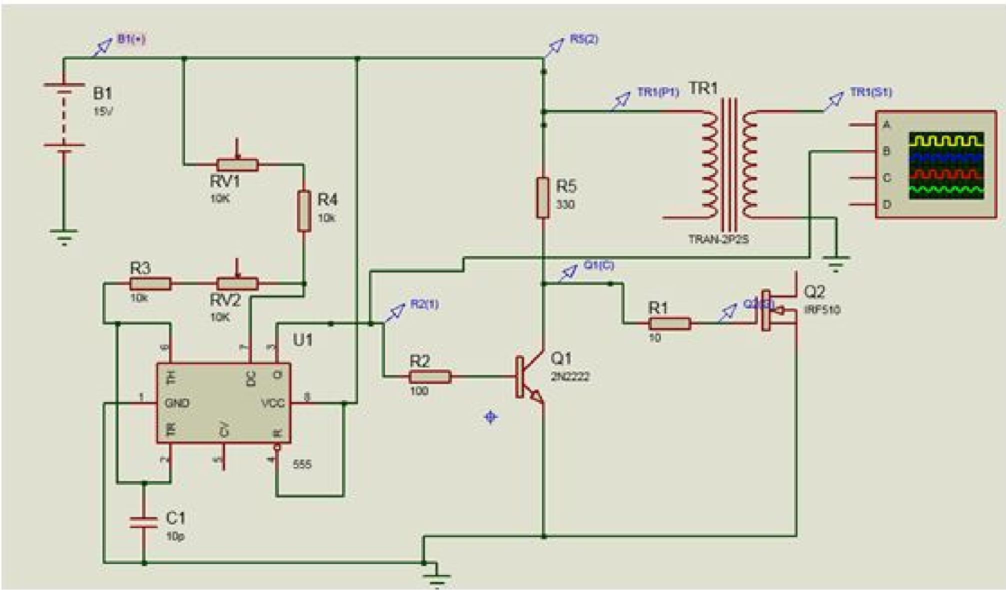

FIGURE 2.2: Simulation of 555 Timer Circuit

2.3.2 Eriks Flyback driver circuit

Circuit configuration of Eriks Flyback driver circuit consists of one 555 timer and a voltage regulator. 7804 is an IC of voltage regulator. At the input of this circuit, we apply AC supply. 7804 IC regulates the voltage. There are normally three input, output and ground terminals in the configuration of this IC. Output of this IC is always constant. If we vary the input, the output remains 5v always. To make the PWM signal more smooth, two capacitor are used. These capacitors make the PWM signal little bit efficient. However, there will be a considerable noise in the final output. This noise is

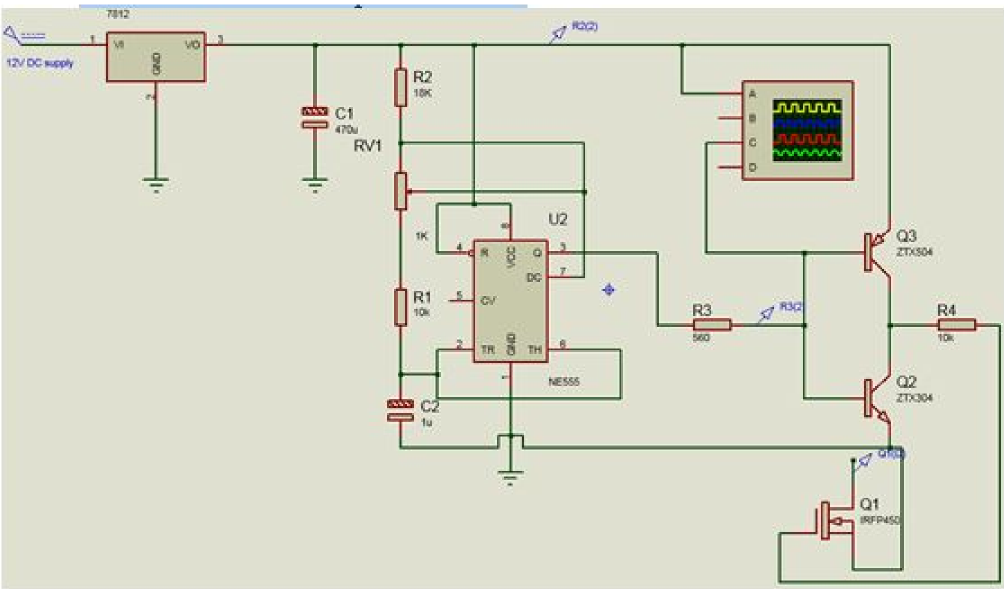

FIGURE 2.3: Simulation of Eriks Flyback PWM signal generater circuit

due to the use of 555 timer. Further, this noise can be removed by use of modern high efficient NAND gate based analog electronic circuit. The PWM signal produced by this circuit will be highly efficient and smooth. This circuit is suitable for Flyback converter.

2.3.3 NAND Gate Based Analog Electronic Circuit

NAND gate based analog electronic circuit is the highly efficient circuit as compared to the circuits discussed above. It generated noise free PWM signal. By apply this noise free PWM signal at the input of Flyback converter, it will operate efficiently. This is reason that we are using NAND gate based analog electronic circuit in our project to generate PWM signal. PWM signal generated by this electronic circuit is noise free.
Flow chart of Nand Gate based analog electronic circuit is given below:

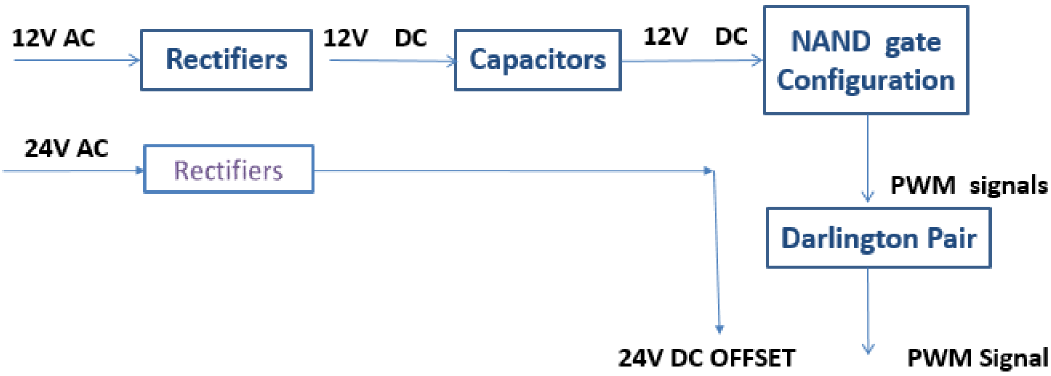

FIGURE 2.4: Flow Chart of NAND Gate Based Analog Electronic Circuit

2.3.3.1 Generation of 12V and 24V for Electronic Circuit

12V and 24V are fed at the input of NAND gate based analog electronic circuit. This low voltage is generated by using a center-tapped transformer. Center-tapped transformer converts 220V AC to 12V and 24V.
There are various components in this circuit which perform various operations.

- Rectifiers
- Series Configuration of NAND gates
- Variable Resistor
- Voltage Regulator
- Darlington pair
- Heat sinks

2.3.3.2 Rectifiers

At the beginning of this electronic circuit, there are two full wave rectifiers. Basically from the output of center tapped transformer, two output voltages of 12 and 24v are obtained. These voltages are fed at the input of NAND gate based analog electronic circuit. Basically analog electronic circuit operates on DC input. To obtained DC signal, we rectify the AC output of center tapped transformer. For this purpose, diodes are used. Current rating for diodes used to rectify 12v is 1A, but current rating of diodes used to rectify 24v is 4A. 12V DC is fed to series configuration of NAND gates. 24V DC acts as a DC offset. This 24V adds up with final PWM signal generated.

2.3.3.3 Series configuration of NAND gates

To generate PWM signal, an IC 4001 is used. There is a series configuration of 4 NAND gates in this IC. These NAND gates can be connected in any configuration. But in our designed IC, these NAND gates are configured in series. These NAND gates produce PWM signal.

2.3.3.4 Variable Resistor

Variable resistor plays a role model for the variable functionality of final output voltage. The frequency of PWM signal can be varied by using this variable resistor in this circuit. Range of variable resistor used in our designed circuit is 0-500 K. By varying the resistance of this variable resistor, the frequency of PWM signal is varied. By varying the frequency of PWM signal generated, the output magnitude of Flyback converter can also be varied. Hence the final output can be varied from 0-50 kV.

2.3.3.5 Voltage Regulator

Voltage regulator is used to regulate the voltage levels. IC 7408 performs this operation.

2.3.3.6 Darlington Pair

Darlington pair is constructed from two bipolar transistors. These transistors are connected in such a way that current amplified by first transistor is fed to the base of second transistor. This second transistor amplifies it further. Basically the PWM signal produced by series configuration of NAND gates is low magnitude signal. To increase the current of PWM signal, Darlington pair of transistors is used. Darlington pair acts as a single transistor. But its current gain very large as compared to single transistor.
A general expression representing the gain is given by:
Gain of Darlington Pair = Gain OF transistor T1. gain of T2 + gain of T1+ gain of T2
Where T1 and T2 are transistor1 and transistor2.

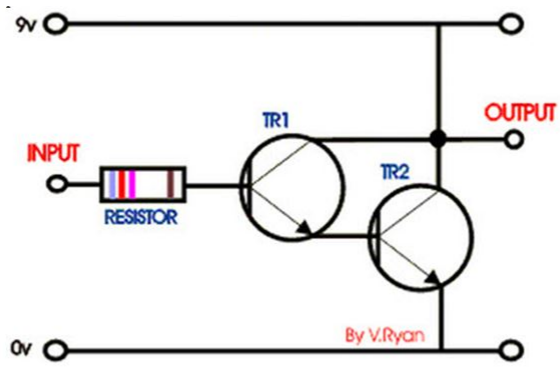

FIGURE 2.5: Darlington Pair

2.3.3.7 Heat Sinks

There are two heat sinks in NAND Gate Based Analog Electronic circuit. When the load is applied at the end terminals of Power Supply, heat is produced in this electronic circuit. This heat may damage the electronic analog circuit. Heat sinks absorb this heat and save this electronic circuit.

2.4 Simulations of NAND gate based Analog Electronic Circuit

Simulations of NAND gate based analog electronic is shown below. Output at various stages is shown here:

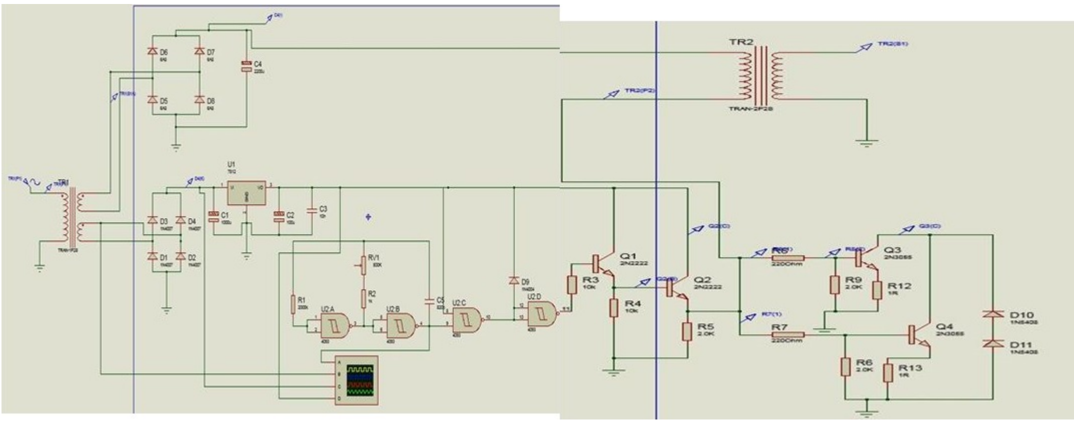

Figure 2.6: Simulated circuit of NAND Gate based Analog Electronic Circuit

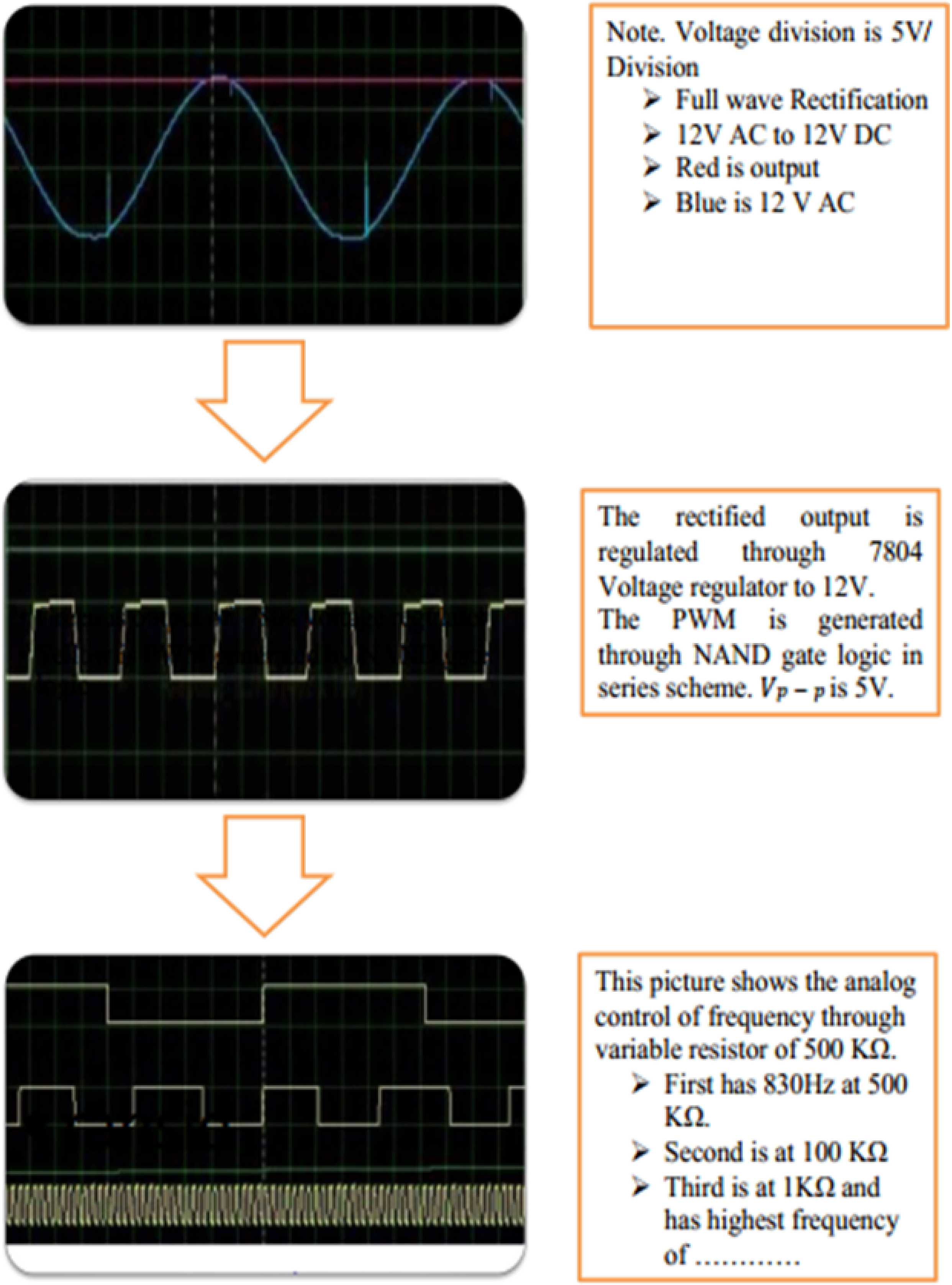

FIGURE 2.7: Simulation Results of NAND gate based Analog Electronic Circuit

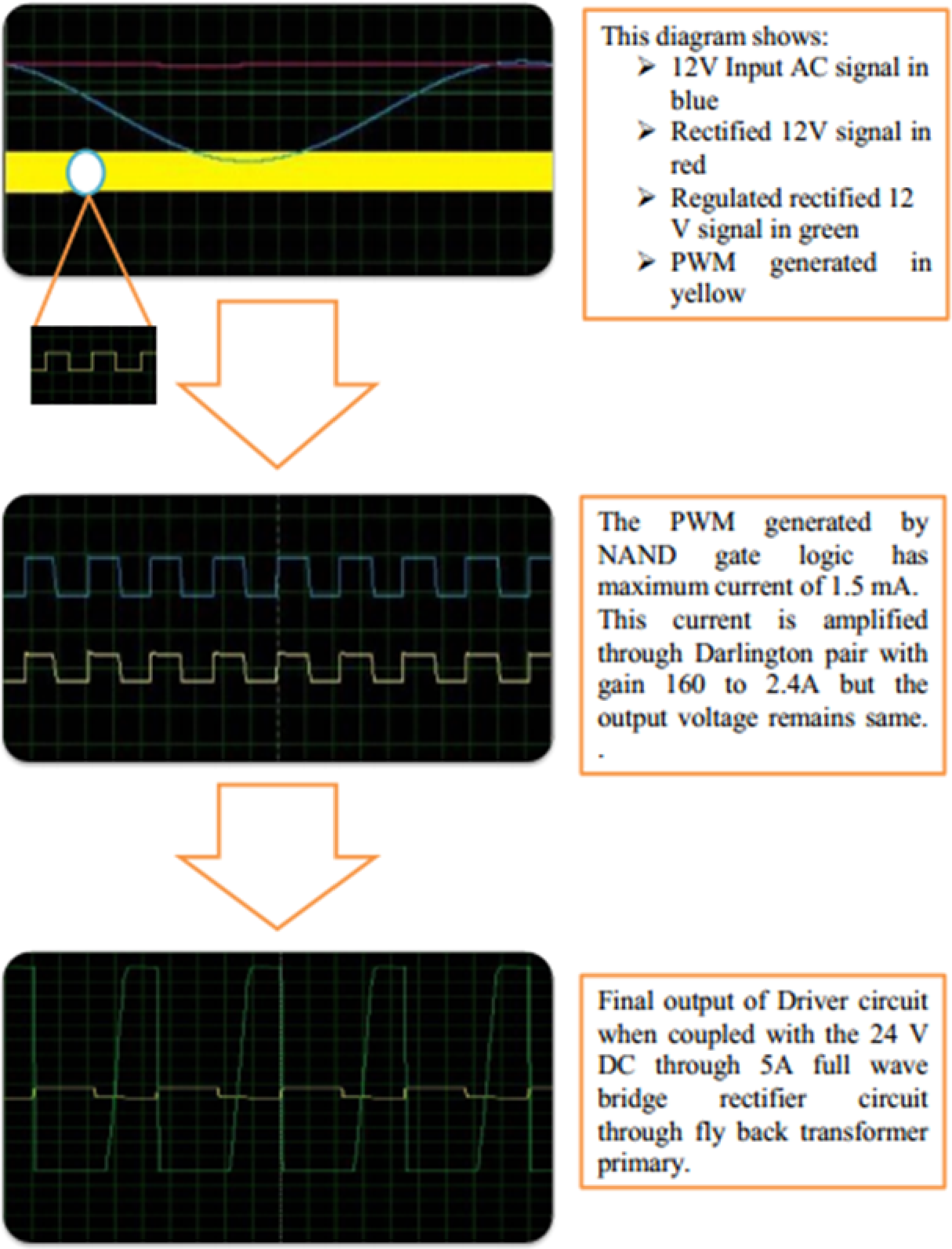

FIGURE 2.8: Simulation Results of NAND Gate based Analog Electronic Circuit

Chapter 3

Flyback converter

3.1 Transformer

Transformer is a electrical or electronic device depend upon the use ability which is used to convert voltages from on level or transition to other level or state.It will have windings and the principle followed is electromagnetic or mutual induction. It does not step up or step down power here power also remain same in ideal case or some power is lost in transformer.

3.1.1 Background

Micheal Faraday invented the first transformer during the mid of 19th century some induction ring using electromagnetic induction. Also later Power transformer was introduced and special attention was paid towards transformer and advancements is being made with time.

3.1.2 Contribution of transformer

Basically transformer contributes very much in the field of transmission where voltage is change upto desire and transmit with minimum power losses. Here current is minimized as power losses are directly proportional to current losses.

3.1.3 Losses

In transformer losses are classified as hytsterisis losses, copper losses, core losses. Hysteresis losses are also represented by a curvature type graph. Basically hysteresis losses occurs due to domain alignment when electric field is created at first it align all the domain which were unaligned so it costs power and hence power loss occurs. Copper losses occurs due to primary windings and secondary windings as current flows across these windings and these coppers have resistance as current is directly proportional to resistance. Copper losses can be reduced by using high quality and low resistance copper wires. Core losses occurs when current starts flowing in the core due to mutual induction phenomena here the core has also resistance which interrupt the current flow and some of power is lost here. Use of high quality lamination or insulation can minimize core losses.

3.1.4 Ideal Transformer

As it has been the fact that in engineering ideal means working at full efficiency. So in ideal transformer there is no resistance such that core provides no resistance or we consider zero reluctance to the current flow. Also Windings provides no resistance to the flow of current in short we can say that power at the input equals to the power at output.

3.1.5 Working of Transformer

Basically transformer has two coils which are isolated from each other electrically and mechanically and it operates on principle of faraday law of electromagnetic induction. When voltage is applied at the primary side current starts to flow in the primary windings and this current produce its own magnetic flux which induces an emf in the secondary windings so the induce voltage is directly proportional to flux. In this way induced voltage can be vary with no of turns in secondary to primary turns.As these two coils always connected magnetically not electrically.

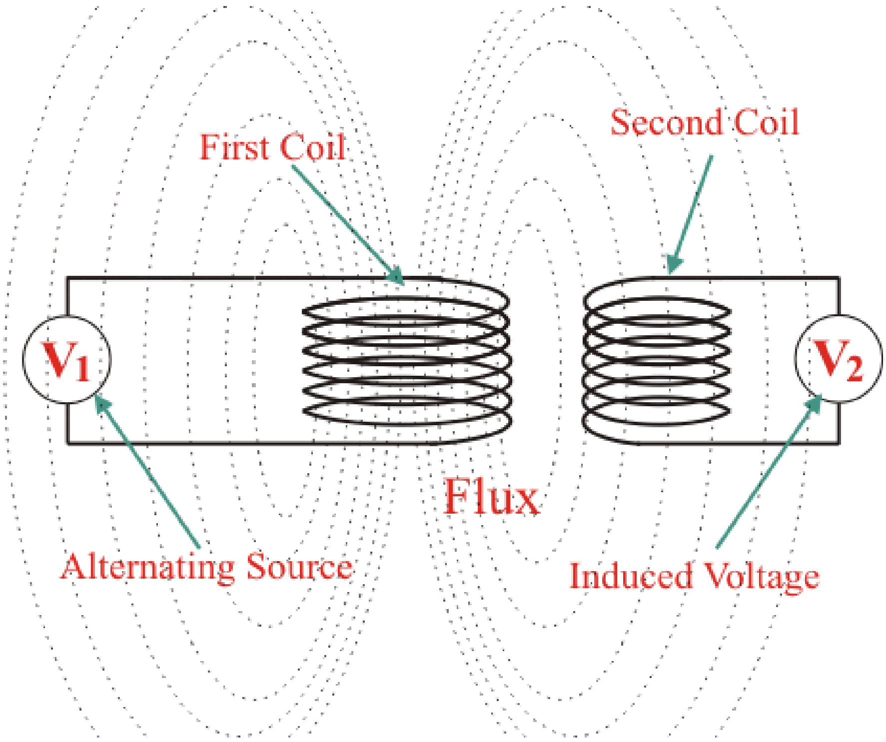

FIGURE 3.1: Magnetic field linkage

3.1.6 Description of transformers

If transformers are divided on the core basis then it can have three types.

- Air Core
- Iron Core
- Ferrite Core

3.1.6.1 Air core

This type of transformer uses no magnetic material. As we have iron in iron core but here we use air instead of air. This is also being used in low frequency applications.

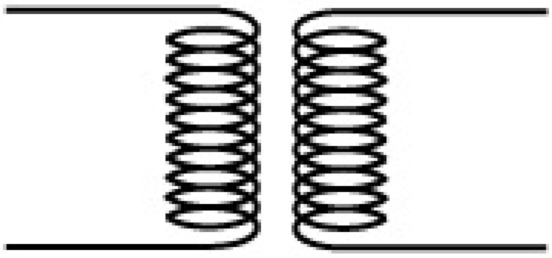

FIGURE 3.2: Air core transformer

3.1.6.2 Iron core

Basically the core used in transformer are made up of conducting material, So here the raw material used is iron in iron core type of transformer. Devices which has low frequency mostly uses iron core transformer.

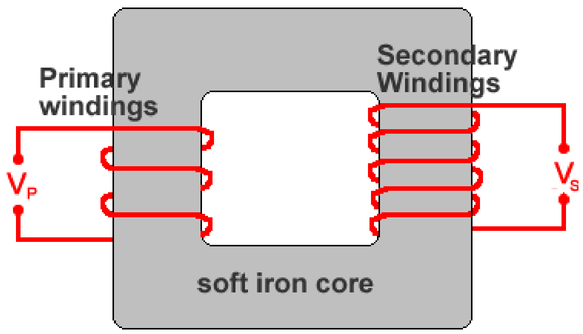

FIGURE 3.3: Iron core transformer

3.1.6.3 Ferrite core

Air core or iron core cannot be used in application where high frequencies are needed. If high frequency is applied then there is early saturation so thats not what is required. So to avoid saturation Ferrite core is used for applications where high frequencies are needed. They are dense, structure of homogenous ceramic made by mixture of iron oxide with carbonates or oxide of metals such Zinc, Nickel, Manganese or magnesium. The fly back transformer we have used in the project is made up of Ferrite core because we need high frequency device to change dc voltage levels.

3.2 Flyback converter

Flyback transformer are very simple in design and cheaper and its intrinsic efficiency has made it very popular solution in the electrical world where design of power supply have power less than 200W.

3.2.1 Applications

In CRTs, TVs and monitors it is used as high voltage supply. Horizontal deflection drive is often combined with flyback converter. Also uses for high voltage generation as we have used for the generation of 5 kVs.

- In output power supplies where low cost is required it is used.
- It can be also used as isolated gate driver.
- In low-power power supplies which is operated in switch mode.

3.2.2 Why it is needed

As we know that in the windings with the flow of DC component of current flowing the transformer get saturated. And we also want to avoid these saturation with the step up voltage. So when in the windings DC of such a chokes which will produce such a large mmf that will saturate iron or we can say the core so largely, that low inductance will be observed correspondingly. So as a result to obtain the alternating part of current we need a big size of choke.to make dc saturation negligible an air gap in inserted in series with flux path.as we avoid small value of inductance if air gap length is very much then we will a high magnetic reluctance which left us with low inductance. The other core transformer get saturated except ferrite core so thats why we it in high frequency application.

3.2.3 Working of Flyback converter

The fly back converter is based on the principle of buck boost converter. Its diagram is represented here. The diagram is of step down converter. Is is the current in secondary and Ip is the current in primary when Q1 conduct and during Q1 is OFF respectively. The output can be increased by using Cock Croft or capacitor and diode in series of the secondary and thats its simplicity. Sometimes this device we can call it flyback transformer. As in ideal transformer current flows in both windings but here current simultaneously does not flow in both the windings. To allow best converter optimization ratio is being kept at 1:n. To simplify the gate side circuit a MOSFET is introduced on the primary side to have a better handling of the circuit and as we know it is a high frequency device so it provide is convenient way to handle the circuit.

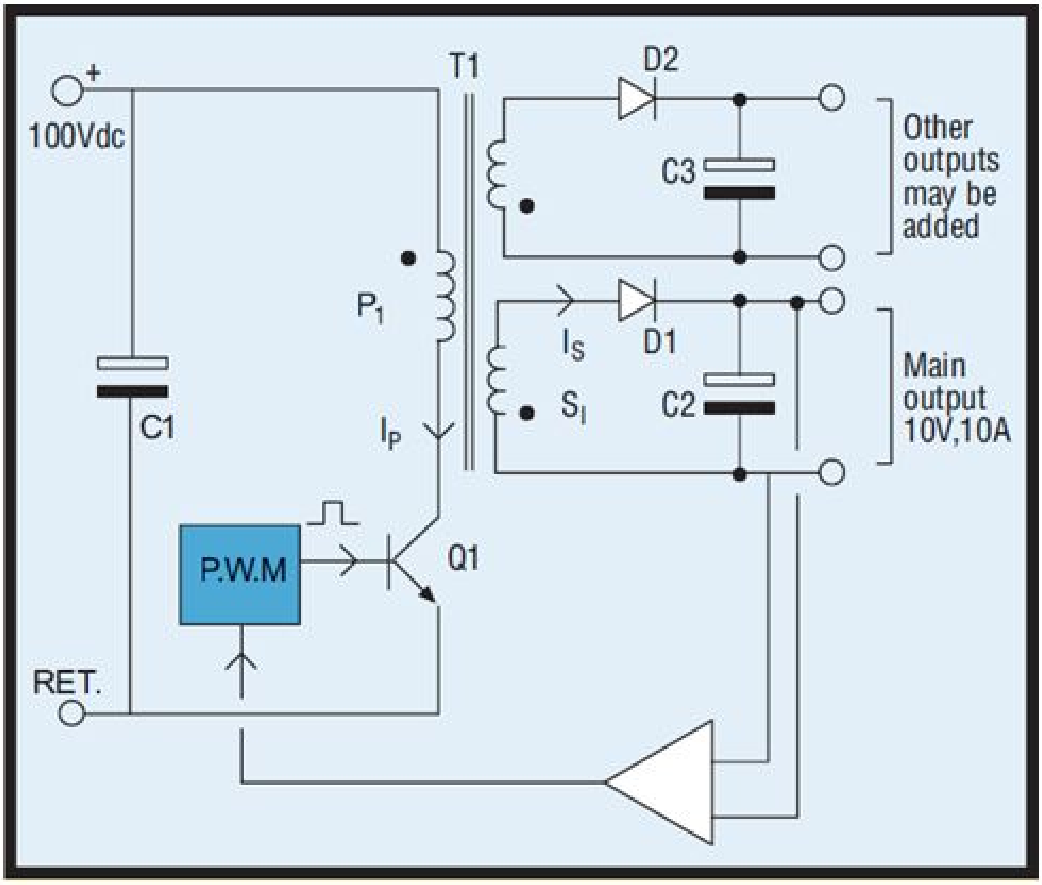

FIGURE 3.4: Iron core transformer

3.2.4 Operations

Continous mode and Discontinous mode is been standard for flyback converter operations. It is a converter with isolated power. Voltage control-mode and current control-mode are two controlling schemes. A signal is required to generate output voltage. Optocoupler can be used to generate signal to required output voltage. The other technique is on the coil a separate winding is winded to control output voltage. Voltage sampling amplitude is the third technique to control output. All these techniques are very reliable and easily understood by every electrical engineer. An advance technique is microcontroller with the help of microcontroller we can control the frequency which control the output voltage and this technique is very advance which also provide many other facilitations.

When the transistor start conducting the DC voltage from the source is stored in the P1 inductance and when diode D1 is on the voltage is delivered to load. The continuous mode of operation is show below in the figure

In discontinuous mode of operation all of the energy stored in primary winding is transferred to secondary winding before the next Q1 on condition. The waveform of this

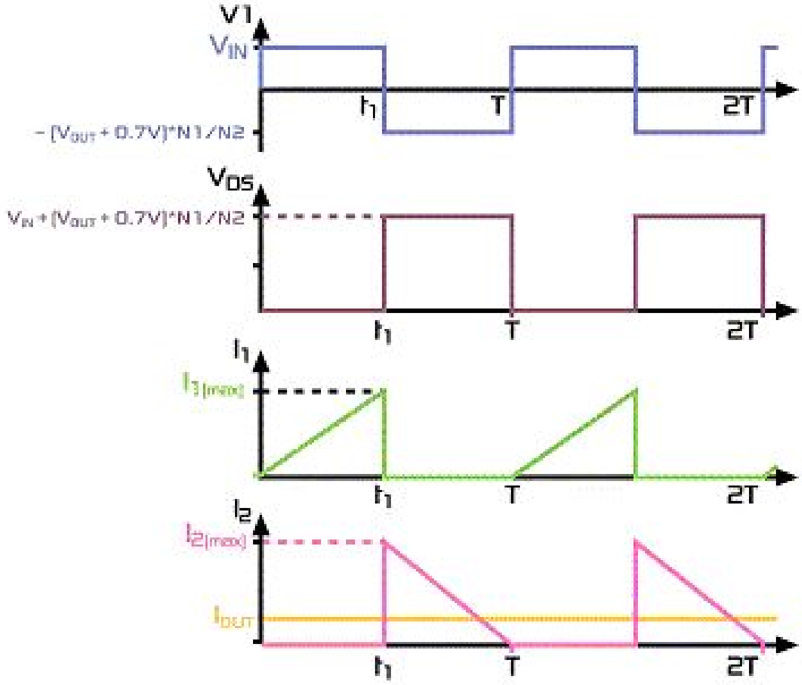

FIGURE 3.5: Discontinuous mode of operation

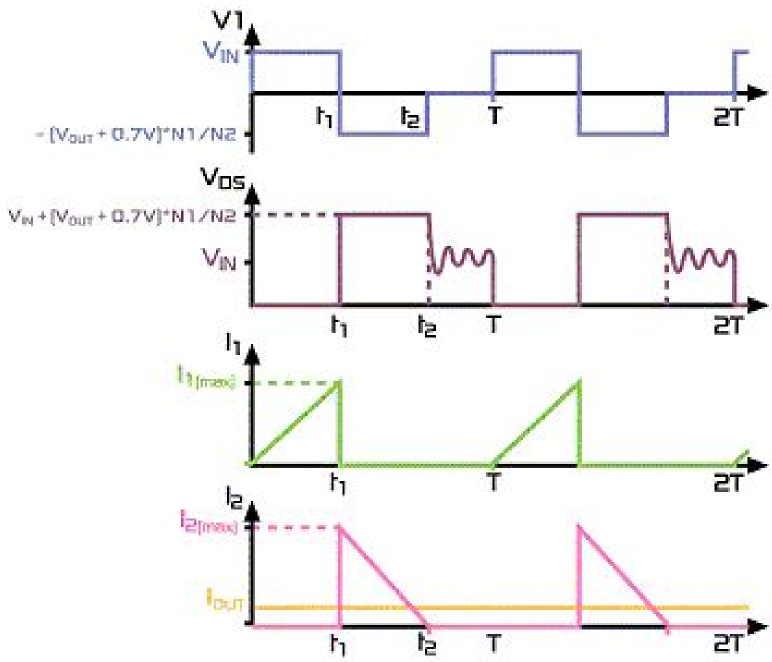

FIGURE 3.6: Continuous mode of operation

mode of operation is shown below

In the windings, capacitors and diodes ripple current with high peak is produced which is its one of limitations. So it is always used in applications with low power. While in continuous method this ripple peak current is very low which gets advantage over discontinuous method.

The flyback we have used in our project has the output frequency of 1.8kHz and output voltage is 5.5 kVs.At the input we have provided 36 volt and 0-100 variable frequency.The output frequency of 1.8 hz also equals to 18000 pulses. 15 mJ per pulse energy is required. Maximum duty cycle was 50 percent.The capacitor of 16uF were used. Charge time is 12 second and maximum on time is 312 u sec. The input voltage is maximum 80 V. The total energy storage of capacitor is 242 Joule. The inductances are of 17mH and the turns ratio are calculated according to the transformer turns ratio formulae.

3.2.5 Limitations of Flyback converter

As discussed earlier the continuous mode of operation has disadvantages which make the circuit complex.
With positive point power switches which means a lot of loss of power. When duty cycle is above 50 percent above the current control mode needs compensation.
In discontinuous method there is very high ripple current peak which is a very big limitation for the circuit.
In inductor there is high flux junkets.

Chapter 4

CockCroft Walton multiplier ircuit

The output of Flyback converter is fed to a Cockcroft Walton Muliplier circuit which increases its output to our desired voltage. The circuit works on the principle of charging and discharging of capacitors. The same purpose can be achieved by using some step-up transformer and then high voltage rectifiers but the cost of the circuit will be increased considerably. That is why, we are going to use this circuit. Let us look at some basic theory about this circuit.

4.1 Introduction to Cockcroft Walton multiplier circuit

It is actually AC to DC converter which works by the charging and discharging of capacitors. It takes a signal with symmetric waveform at its input and produces a DC signal. A single stage of this circuit consists of two diodes and two capacitors. Voltage can be increased by connecting more and more stages of this circuit.

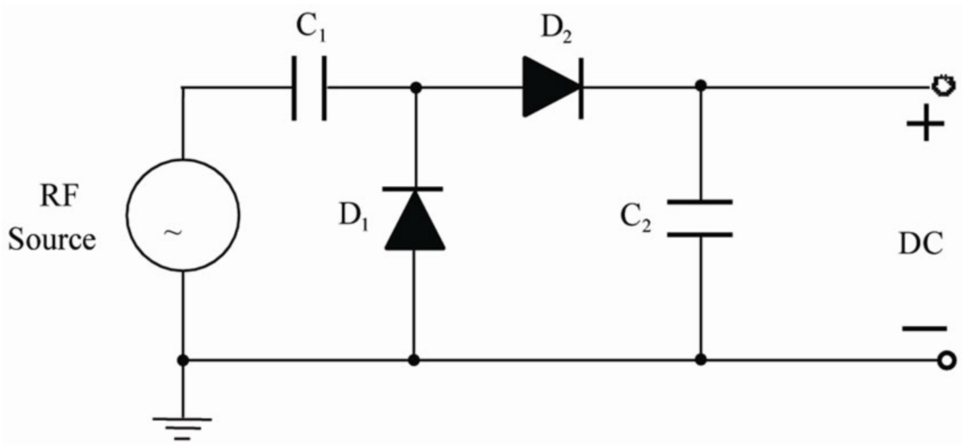

FIGURE 4.1: Single stage of multiplier circuit

4.2 Basic Working Principle

A single stage of this multiplier circuit uses two diodes and two capacitors. The basic working principle of diode and capacitors explains the working of this multiplier circuit.

4.2.1 Doubler

A doubler circuit is actually a single stage of Cockcroft Walton voltage circuit. Its working principle can be explained by looking the below figure.In the positive half cycle, C1 is charged upto Vpeak and in the negative half cycle, C1 is discharged and C2 is charged upto 2 times Vpeak.

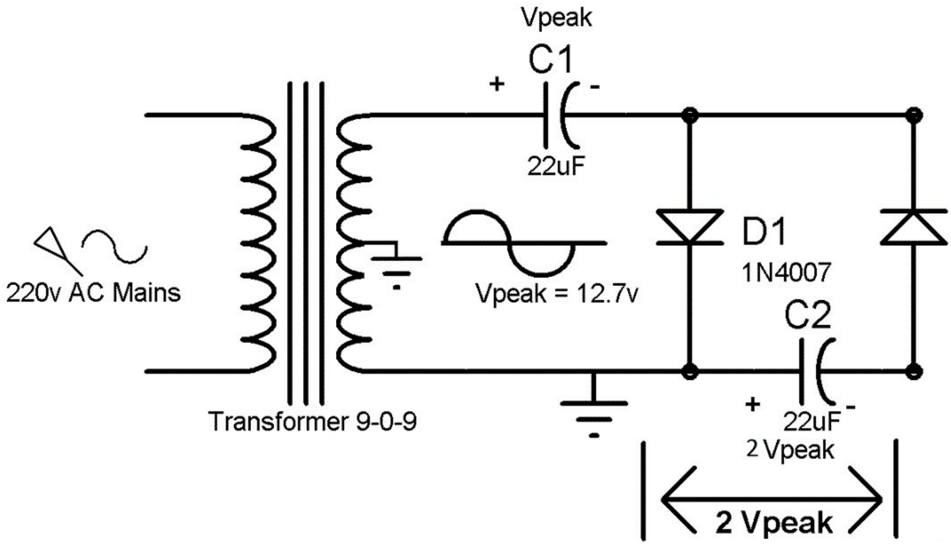

FIGURE 4.2: Doubler circuit

4.2.2 Two stages

The output can be increased by cascading more stages of multiplier circuit. Triplers and quadruples consist of two stages of Cockcroft mutiplier circuit. The below figure shows these circuits.

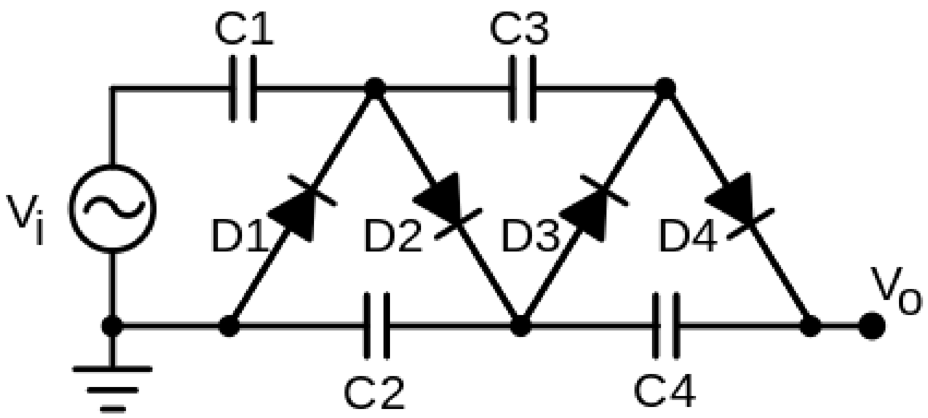

FIGURE 4.3: Two stages of multiplier circuit

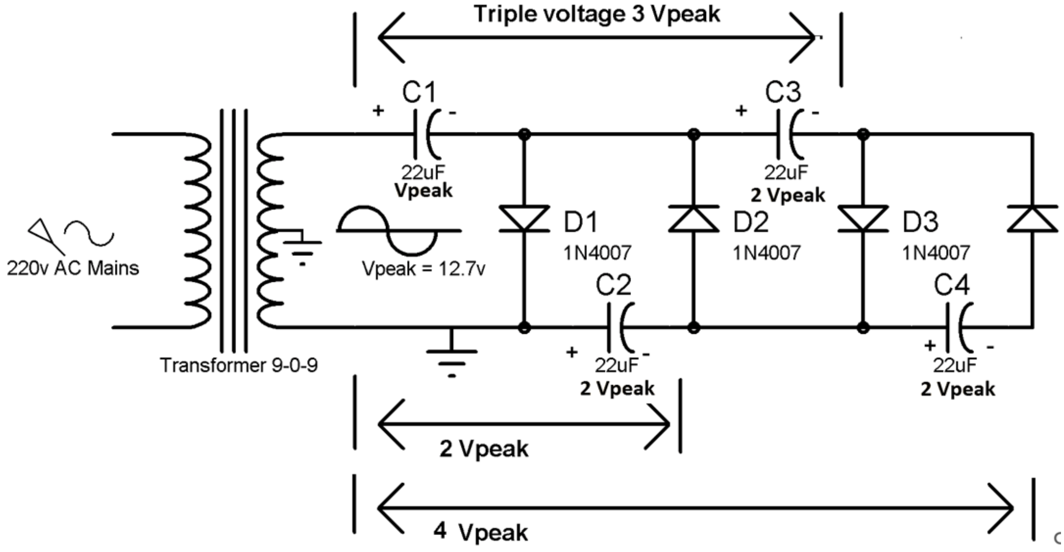

FIGURE 4.4: Triplesr and quadruplsr

Similarly, voltage can be further increased by cascading more mutiplier stages.

4.2.3 Cockcroft Walton Multiplier Circuit

In a Cockcroft circuit, output voltage depends upon the number of stages being cascaded. It consists of series of diodes and capacitors. Capacitors are continuously charged and discharged. The following diagrams elaborate its structure and formation.

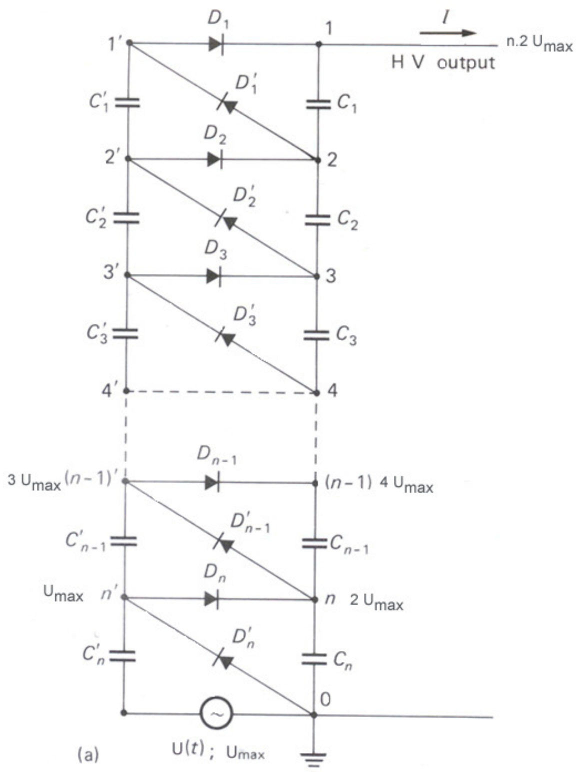

FIGURE 4.5: Cockcroft Walton Voltage Multiplier

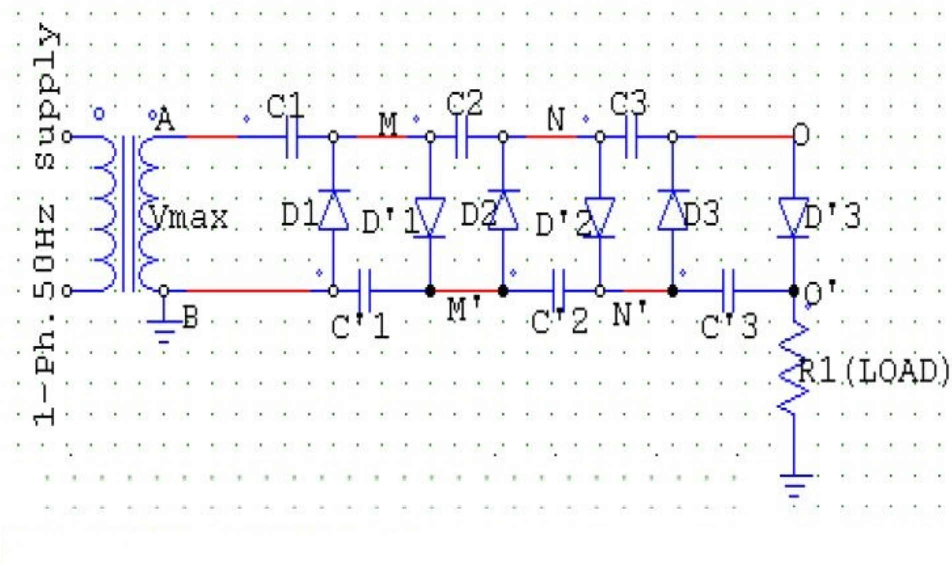

Figure 4.6: Multiplier circuit

In the above figure, capacitors C1, C2 and C3 are called oscillating column, because it is charged and discharged as input signal oscillates in its cycle. While capacitors C1,C2and C3 are called smoothing column, because their voltage remain constant.

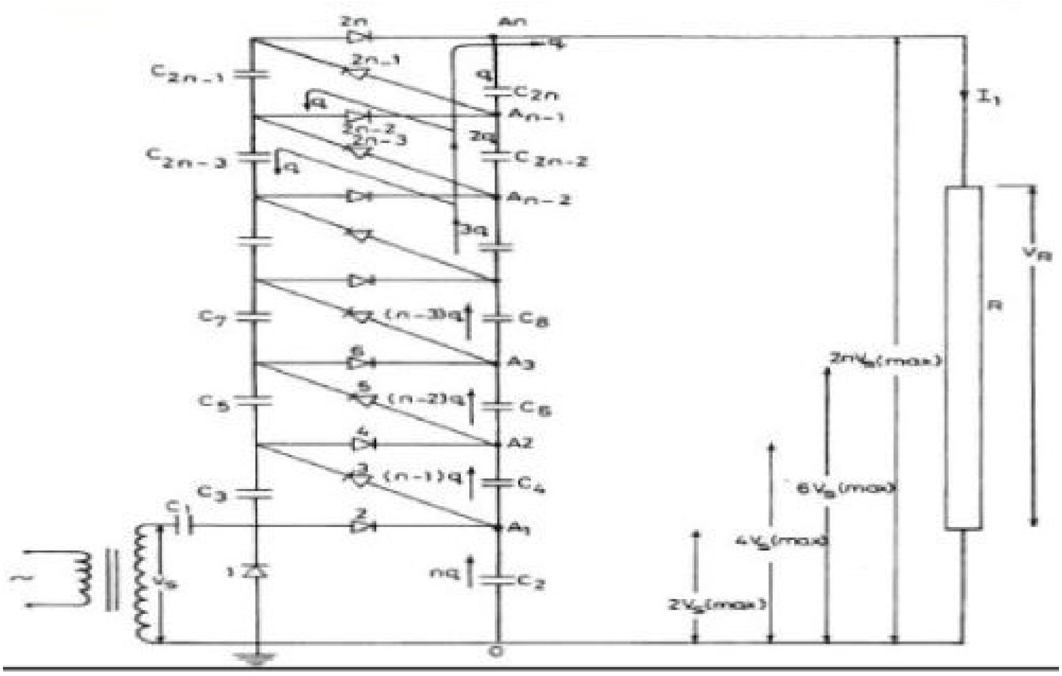

Figure 4.7: Cascaded stages

4.3 Multiplier Circcuit design

There are many important parameters related to the design of multiplier circuit. It is very important to know about these parameters and consider them for designing multiplier.

4.3.1 Ripple and decrease in voltage

4.3.1.1 Ripple

The unwanted periodic variation of signal at a DC voltage output is called ripple. Ripples should always be kept as minimum as possible. Capacitors of cockcroft multiplier circuit also suffer from ripple. Output voltage waveform is distorted as soon as a load is connected at the output. The following diagram shows ripples pictorially.

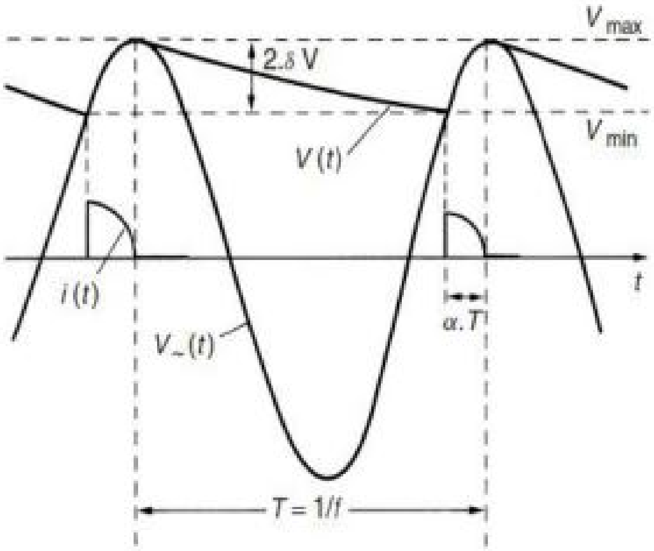

FIGURE 4.8: ripples

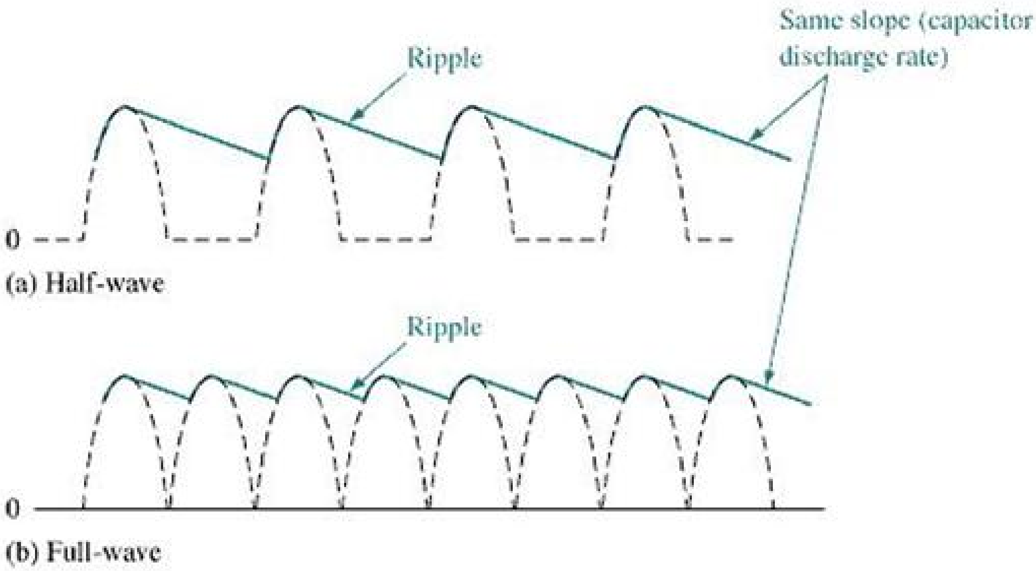

FIGURE 4.9: ripples

4.3.1.2 Decrease in voltage

When a load is connected at the output of mutiplier, voltage gets reduced due to the ripple. This voltage drop should be kept as minimum as possible.

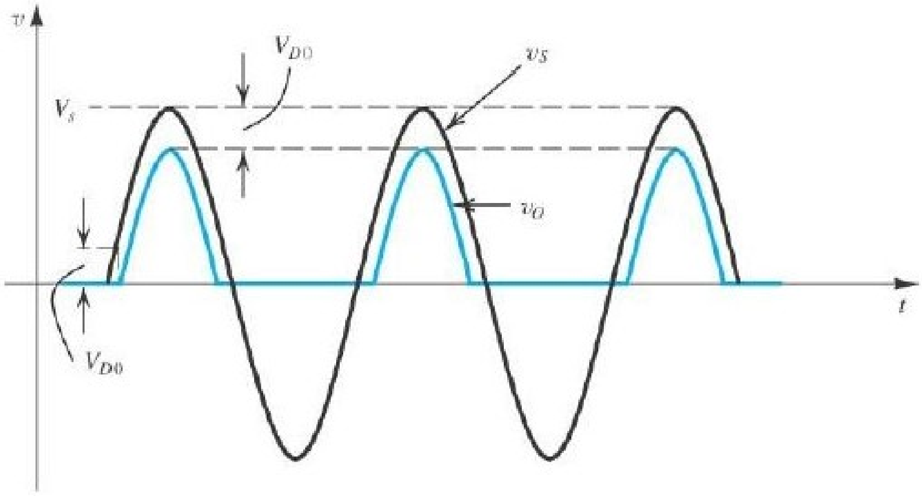

FIGURE 4.10: Voltage drop

4.3.2 Choice of capacitor

4.3.2.1 Size of capacitor

Capcitance required is inversely proportional to the input frequency. This means by increasing the frequency of input signal, lesser capcitance will be required and high capacitance will be required for a low frequency signal. High voltage capacitors are extremely costly. So it is suggested to increase the frequency of input signal. We are giving 1.68 KHz signal at the inut of multiplier circuit. We are using two 0.22nF capacitors in series.

4.4 Design of our project

4.4.1 Design of capacitor

4.4.1.1 Rating of voltage

The specifications for our project are

$$Vpeak = 5kV$$

So Maximum voltage applied voltage across the capacitor=2*Vpeak

$$= 2 * 5kV$$

$$= 10kV$$

Thus rating of our capacitor should be greater than 10 kV. Such a high voltage capacitor is not available in the market.
Voltage rating of capacitor (Market availability) =8 KV.
So we connect two resistors in series to increase the voltage rating of capacitor.
The below figure shows the hardware implementation.

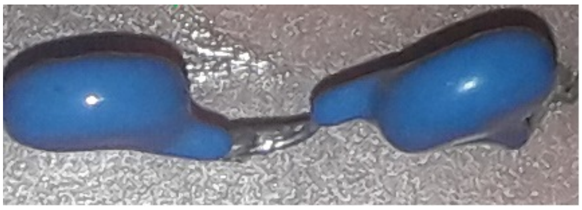

Figure 4.11: Capacitors in series

So
The total voltage rating of a capacitor = 2* 8 kV = 16 kV

4.4.1.2 Size

We are using capacitors of 0.22 nF Capacitance.
When two capacitors are in series so
Resultant capacitance = (0.22/2)nF =0.11 nF

4.4.2 Diode

The model of our diode being used is G10FS.
Its repetitive peak reverse voltage is 10kV
Average Forward Current is 25 mA
Maximum Forward Voltage Drop is 25 V.

Figure 4.12: G10FS Diode

4.4.3 Hardware implementation of a single stage

The single stage of a multiplier circuit has two diodes and two capacitors. This single stage is called a doubler because it doubles voltage. Following are the figures of a doubler voltage circuit simulated doubler circuit and PCB hardware Implementation.

Looking at the two figures, C1 will charge upto Vpeak = 5 KV during the positive half cycle at which diode D1 is forward biased whereas D2 is reversed biased. While C2 will charge upto 2*Vpeak = 10 kV during the negative half cycle at which D1 is reversed biased whereas D2 is forward biased.

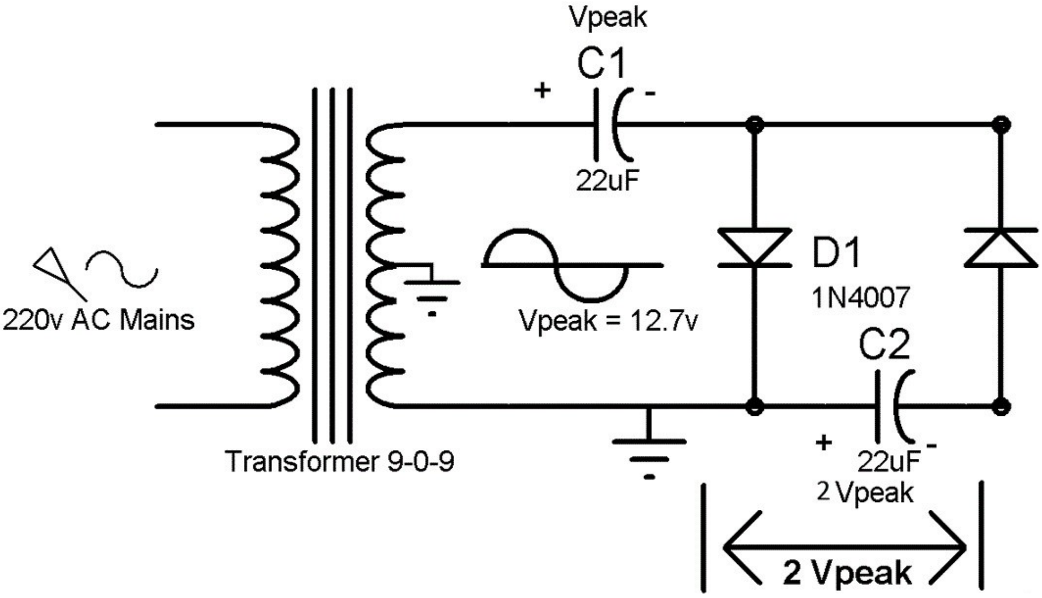

FIGURE 4.13: Doubler circuit simulation

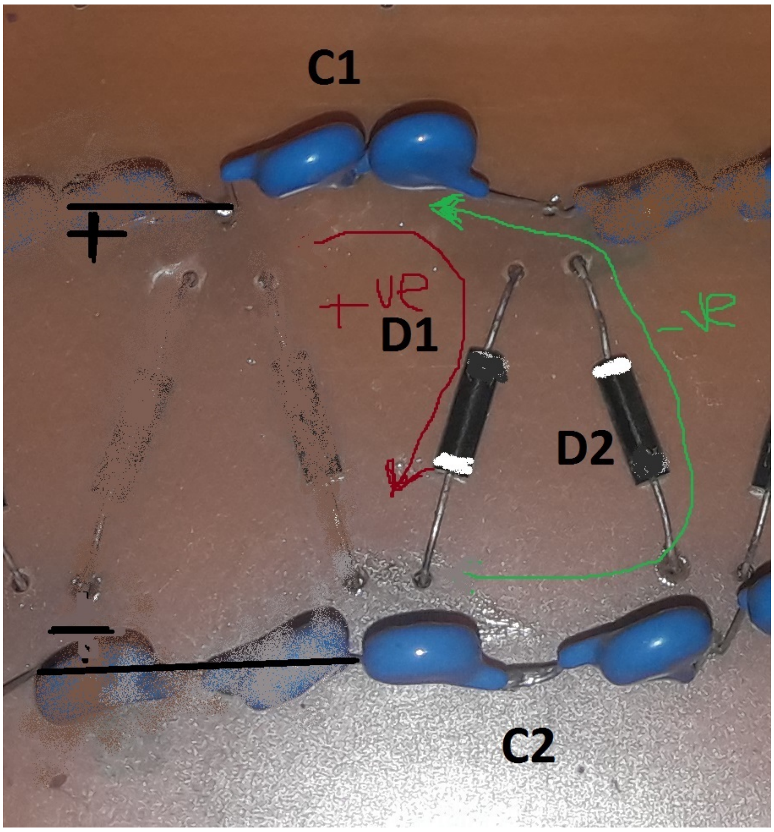

FIGURE 4.14: Hardware implementation of a doubler

4.4.4 Five-stage circuit

In order to achieve, 50 kV from 5 KV we will have to connect five stages of Cockcroft Walton Voltage multiplier circuit.
Now

$$Vin = 5kV$$

$$Vout = 50kV$$

For a cockcroft walton voltage multiplier circuit, Number of required stages = Vout/(2*Vpeak) where 2 is the factor for a doubler circuit.
Number of Stages = 50 kV/(2*5 kV)
Number of stages = 5
So
Let us calculate the output voltage at every stage of the multiplier circuit.

Voltage at the output of 1st stage = 1*10 kV

$$= 10kV$$

Voltage at the output of 2nd stage = 2*10 kV

$$= 20kV$$

Voltage at the output of 3rd stage = 3*10 kV

$$= 30kV$$

Voltage at the output of 4th stage = 4*10 kV

$$= 40kV$$

Voltage at the output of 5th stage = 5*10 kV

$$= 50kV$$

The following figures show simulation and hardware implementation of 5 stages of multiplier circuit.

4.5 Simulations of the project

We have simulated our circuit design on MATLAB simulink. Output is viewed at every stage of multiplier circuit. Simulation results satisfy hardware results. The following

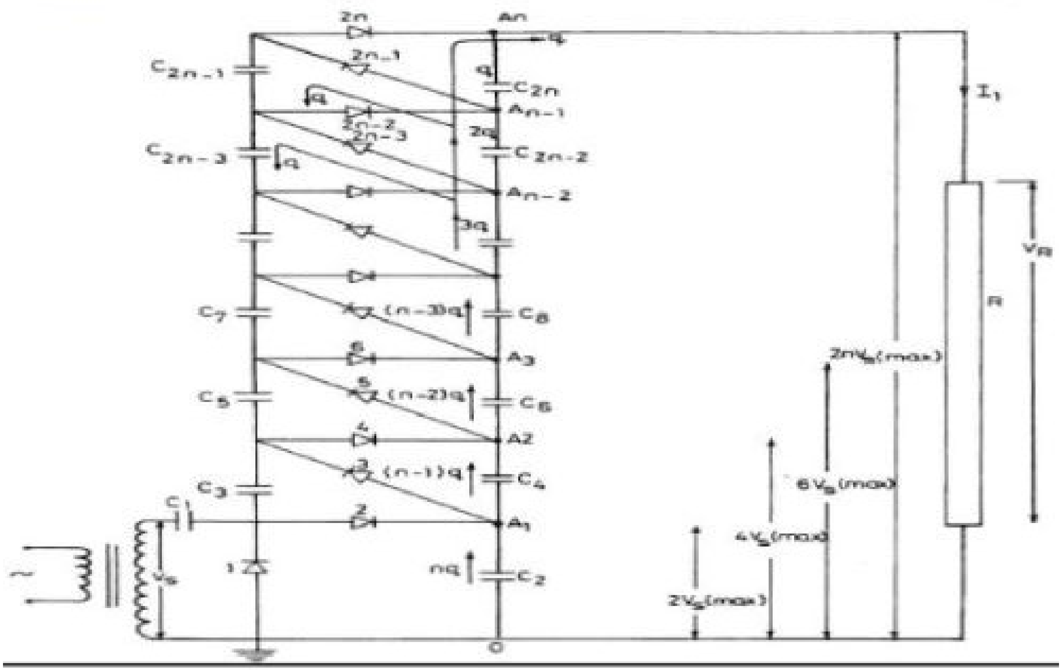

FIGURE 4.15: Multiplier circuit

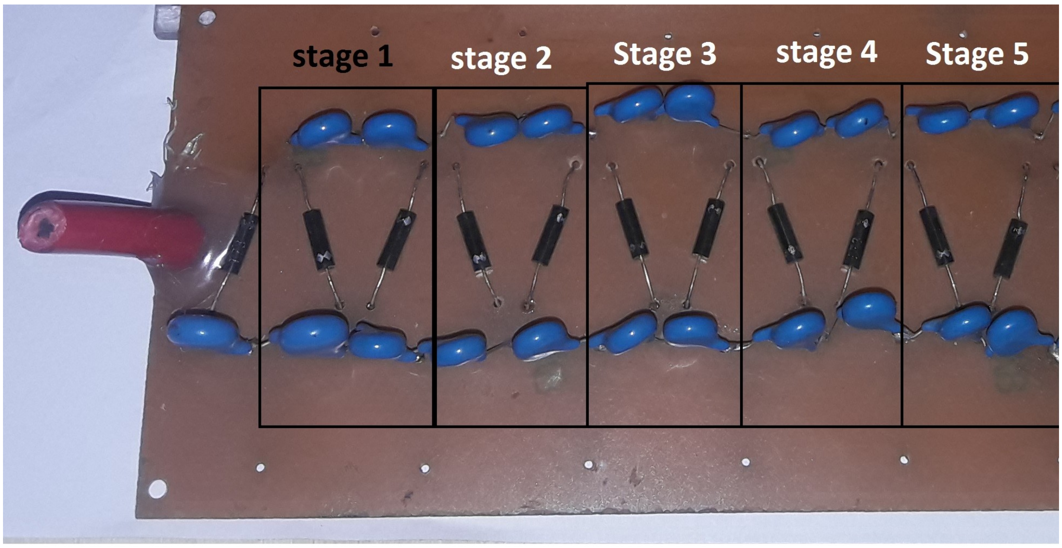

FIGURE 4.16: Hardware implementation of multiplier circuit

figure shows the snapshot of circuit drawn on MATLAB simulink.

4.5.1 Results of simulation

The following figure shows the snapshot of Simulation results.

- Blue illustrates voltage graph after 1st stage
- Green illustrates voltage graph after 2nd stage
- Red illustrates voltage graph after 3rd stage

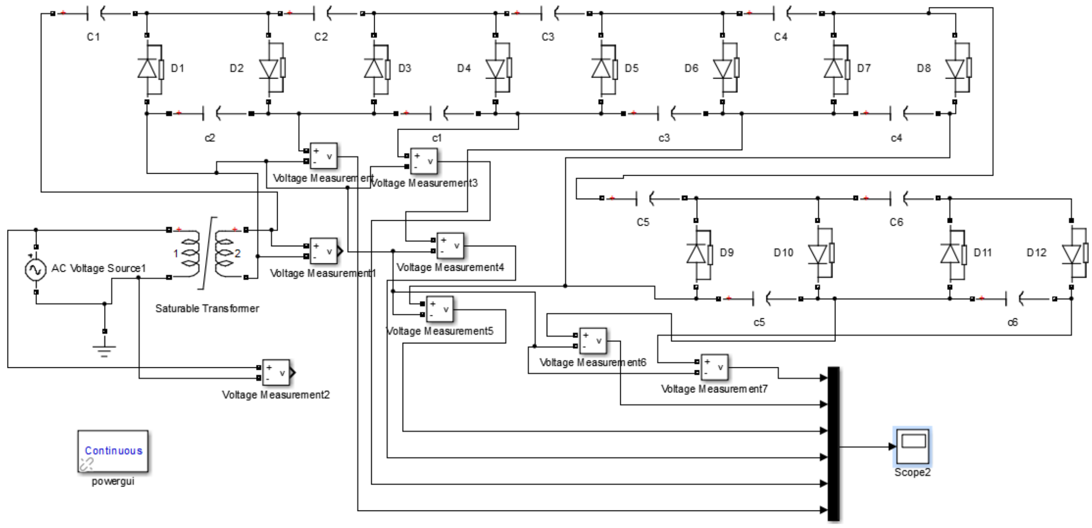

FIGURE 4.17: MATLAB simulation of the circuit design

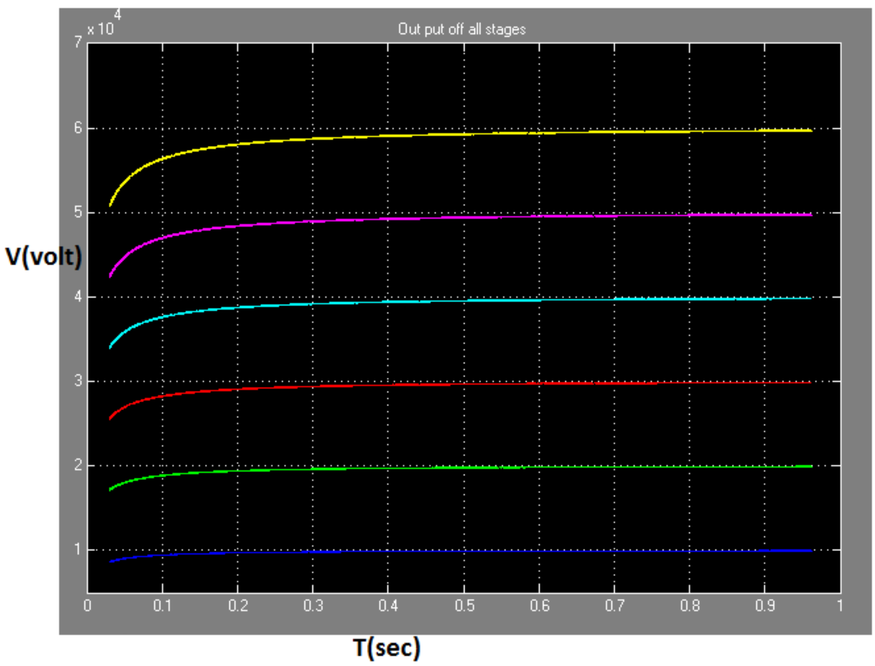

FIGURE 4.18: MATLAB simulation results

- Torquoise illustrates voltage graph after 4th stage
- Magneta illustrates voltage graph after 5th stage

4.6 Insulation

Designing of insulation is very important in high voltage engineering. High voltage is extremely dangerous which can cause damage to human beings. A high voltage engineer must be familiar with the importance and technques of insulation. Corona and air breakdown can be very serious. Our Cockcroft Walton voltage multiplier circuit also needs proper insulation before being used. If we do not do insulation, circuit may be short circuited. Following figure shows multiplier circuit after insulation.

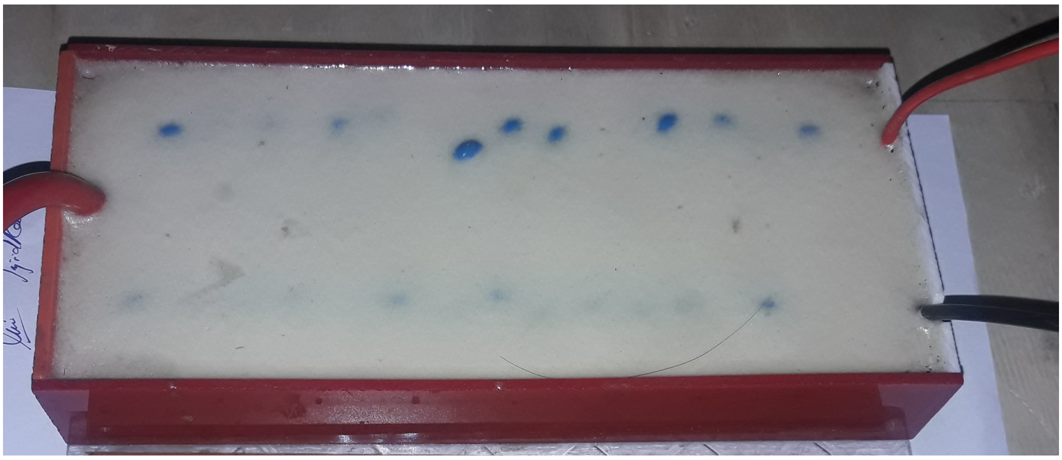

FIGURE 4.19: Insulated Cockcroft Walton Voltage Multiplier

Chapter 5

Validation Chapter

According to IEC, High voltage is 1500 as a standard for DC and 1000V and more for A.C. High Voltages and its measurement is getting important eld in the observation and study of Electrical and Electronics Engineering. There are various ways through which we can measure high voltage. Some of them have been described below.

5.1 Electrostaic voltmeters

Such devices are helpful and are often used to measure the high voltages directly with accuracy and efficiently. Coulombs law is basis and principle for such voltmeters. Besides, the area there could be a is a force F corresponding with that eld E that can be numerically calculated by evaluating the derivative of electrical energy accumulated in the applied direction of the electrical eld. Above equation, it could be judged that

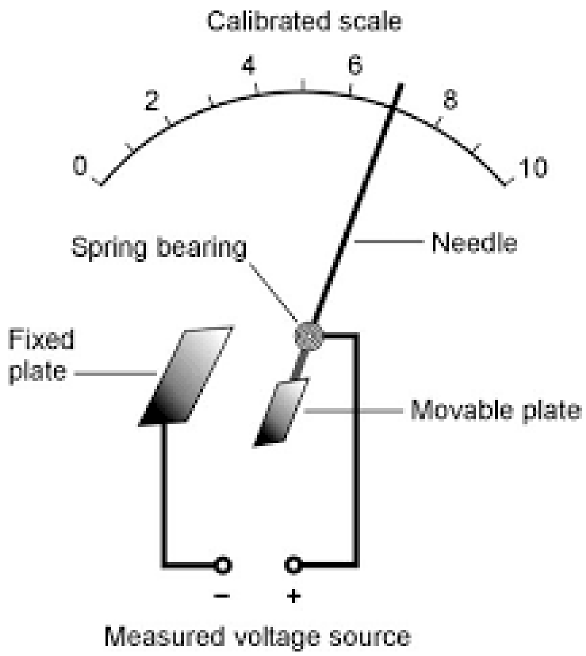

Figure 5.1: Illustration of Electrostatic voltmeter

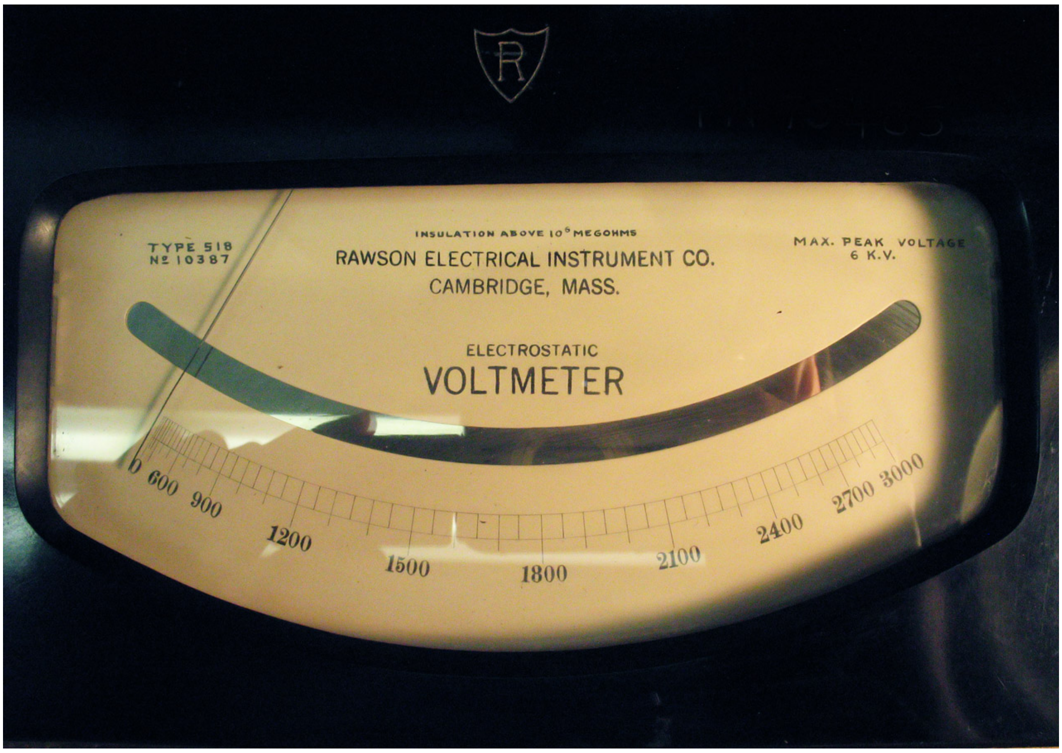

FIGURE 5.2: Electrostatic voltmeter

electrostatic voltmeters could be broadly used to calculate and measure the r.m.s value by scaling the meter. They are high voltage calculating meters and could mark and measure voltage level up to 200kV by using them in the circuit.

5.2 Resistive Potential Divider circuit

This circuit can also be used to measure high voltage. In this circuit, two resistors are connected in series and voltage is measured across one of them. The resistance across which voltage is measured has a very low value as compared to other resistor.
This circuit is the most economical and easy to design. Since current passes through both circuits equally, so this voltmeter is insensitive to temperature. When temperature increases due to passage of current then both resistor values increase and overall their ratio remains same. So scaling factor also remains same.

5.3 Abraham Voltmeters

Abraham voltmeter is also a very widely used voltmeter. It consists of two plates and the device and could harm the voltmeter so such plates which is attached to the electrodes positions gives high security.The diagram of they Abraham Voltmeter are placed below and is literally clearly showing the working of the Abraham Voltmeter as shown

5.4 Sphere gaps

Sphere gaps are also being widely used to measure voltage. Other factor which is being take under observation are that this spark over voltage are aected by density in the

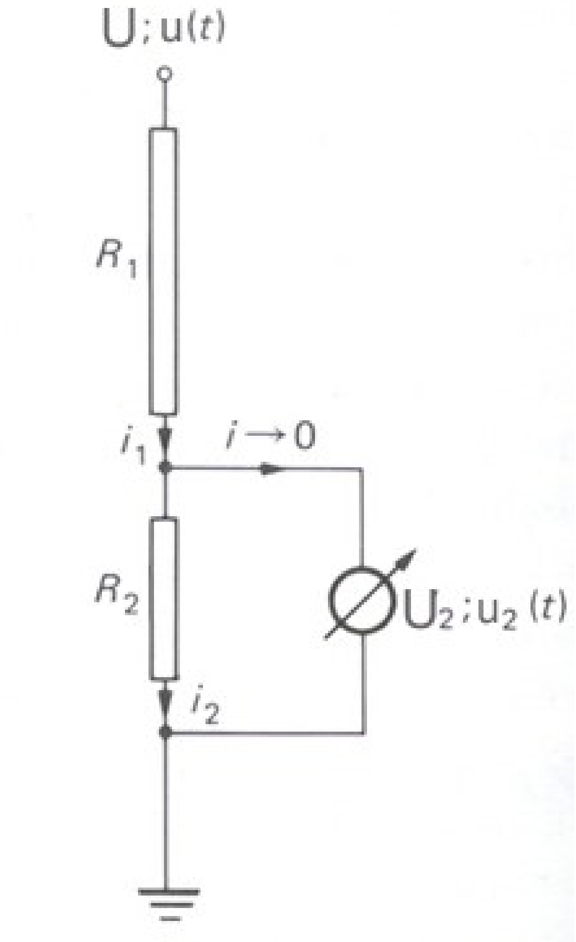

FIGURE 5.3: Potential divider circuit

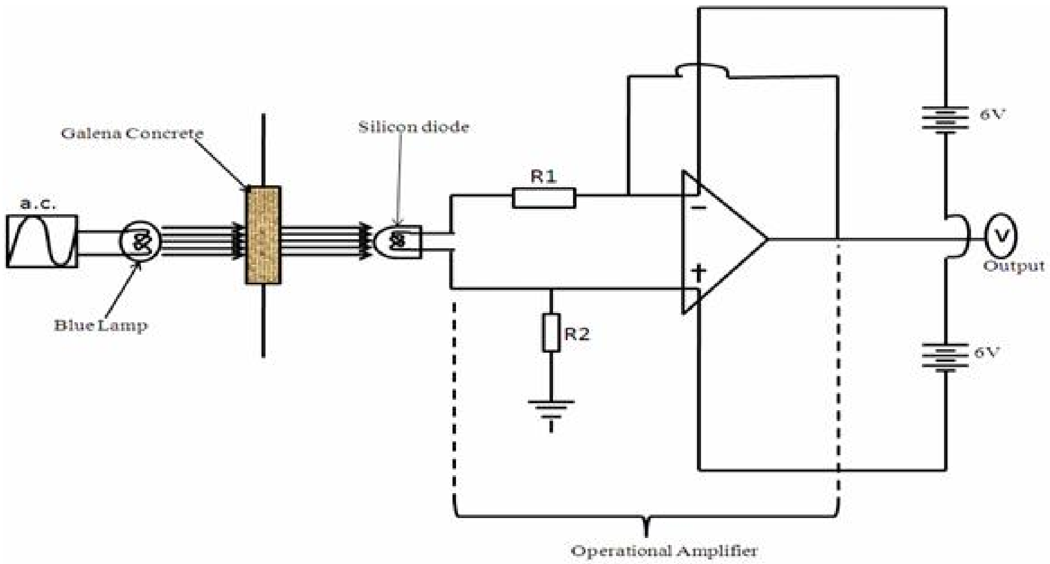

FIGURE 5.4: Abraham voltmeter

gas so we will use correction factor in the density of for the acute measurement are the voltage and Mathematically it are given as following ;
= P/760(273 + 20)/(273 + t)
= 0.386(P/(273 + t))
In the presence of humidity do not perfectly aect the breakdown volt but if here is few

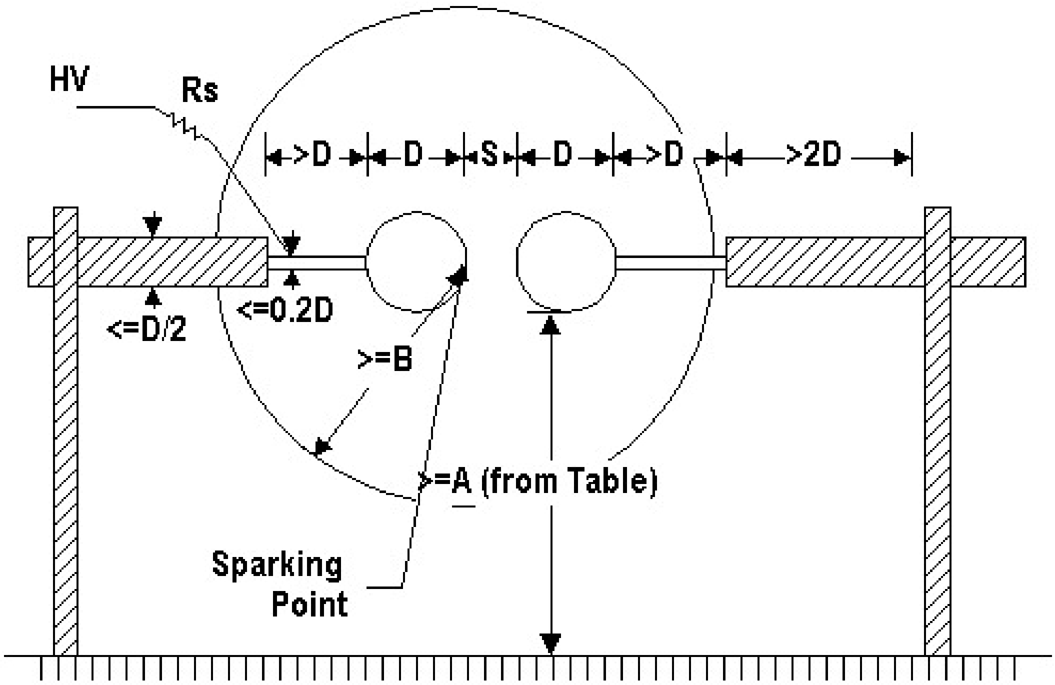

Figure 5.5: Sphere gaps

on the above surface of the spheres then this breakdown voltage would be lowered and here would be uncertainty on the measurement of that voltage. Here is two kinds of gaps when we classified them in the basic of polarity of voltage in the sphere.
Sphere gaps can either be used in horizontal configuration or in vertical configuration.

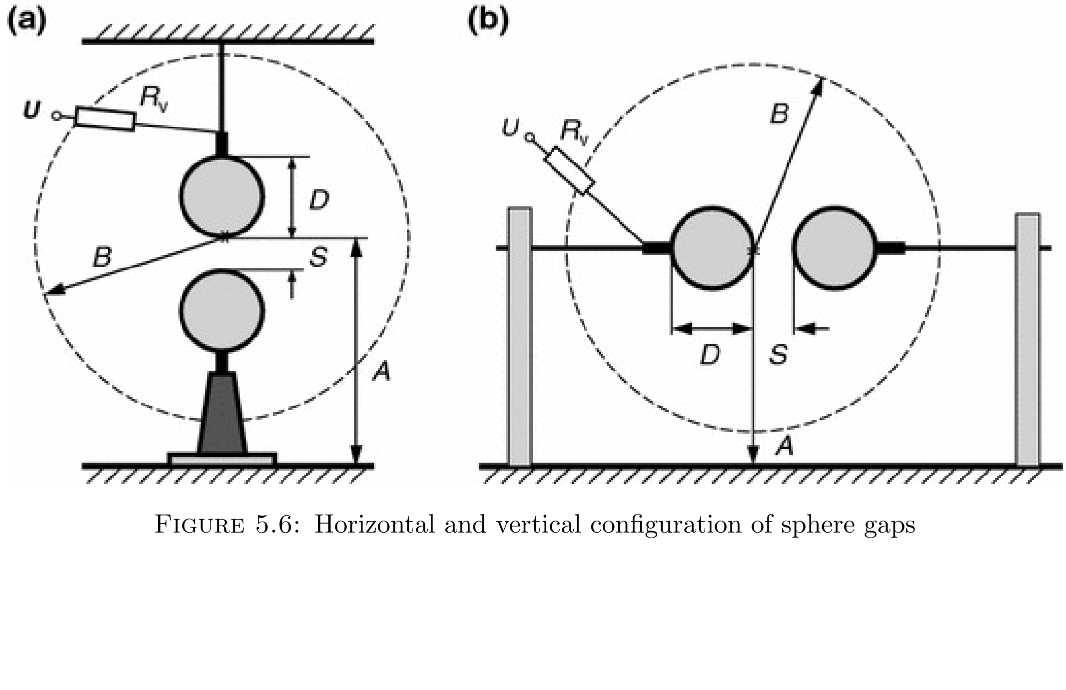

Figure 5.6: Horizontal and vertical configuration of sphere gaps

5.4.1 Limitations of sphere gaps

Following is the limits of using Sphere Gaps in the voltage measurement.

- Here are full uncertainty in the measuring of D.C voltage using spherical gaps cause in the present of dust and another ber particle on the atmosphere.
- Volt measuring by using spherical gaps are generically time consuming cause off the establishment off they high voltage on they circuits hat are being measureable by that spherical gap and that measuring show by measurement device as voltmeter etc that is easily available on that controls circuitry or that measurement.

Chapter 6

Results and discussions

To conclude, we have simulated high voltage DC power supply circuit in MATLAB and then implemented the circuit on hardware. Simulation results are found to be matched with the hardware results.

6.1 Future Recommendations

This project can be further improved to get higher DC voltage and output power. Following are the future recommendations

Microcontroller can be employed instead of NAND gate based electronic circuit for the generation of PWM signals to be given to Flyback converter.

The DC output voltage can be further increased if we increase the number of stages in Cockcroft multiplier circuit. In order to increase number of stages, we can either increase the frequency of signal being given at the input of multiplier or increase the capacitance of capacitors being used in multiplier.

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