A Report on

HIGH VOLTAGE AND HIGH FREQUENCY POWER SUPPLY

At

PULSED POWER AND ELECTROMAGNETICS DIVISION

Bhabha Atomic Research Center, Visakhapatnam

June 2025

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Their expertise was the critical factor in the completion of the project.

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Title of the Project: **Design of High Voltage High Frequency Power Supply**

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Abstract:

In this report, our team would be explaining the schematic and working of HVHFPS overall. We would explain its various components such as the power circuit and control circuit of the system. We would also give an appropriate justification as to why MOSFET’s are used over other switches in the H bridge inverter.

We also provide a detailed explanation of the functioning of the IR2110 gate driver IC, which serves as the core component responsible for driving the high- and low-side MOSFETs in our power conversion circuit. Acting as the 'brain' of the switching stage, the IR2110 ensures proper timing and isolation between the control and power stages. The PWM signal required for controlling the duty cycle is generated using the NE555 timer configured in an astable mode. Through our simulation results obtained in LT_spice IV,

Signature of the Guide ***Signature of the Student***

Date

Table of Content:

1.Introduction

HIGH VOLTAGE HIGH FREQUENCY POWER SUPPLIES OVERVIEW

High Voltage High Frequency Power Supplies (HVPS) are advanced devices engineered to deliver high voltage outputs at elevated frequencies. These specialized power supplies are essential in applications demanding simultaneous high voltage and high frequency performance.

Key Features of HVPS

1. **High Voltage Output**: HVPS units can produce voltages from hundreds to thousands of volts, with some models achieving tens or hundreds of kilovolts, catering to diverse high-voltage requirements.

2. **High Frequency Operation**: These power supplies operate at frequencies ranging from several kilohertz (kHz) to megahertz (MHz), and in certain cases, up to gigahertz (GHz), enabling rapid and precise power delivery.

3. **Efficiency**: Designed with high efficiency to reduce power losses, HVPS systems are optimized for applications requiring substantial power outputs, ensuring reliable and cost-effective performance.

4. **Compact Design**: HVPS units are typically engineered to be compact and lightweight, making them ideal for integration into small and space-constrained systems.

5. **Fast Response**: These power supplies offer rapid response times and swift voltage switching, critical for applications requiring dynamic and precise control.

6. **Precision and Stability**: HVPS systems maintain stable output voltages and currents, even under varying load conditions and environmental factors, ensuring consistent performance.

Applications of HVPS

HVPS are utilized in a variety of high-demand applications, including:

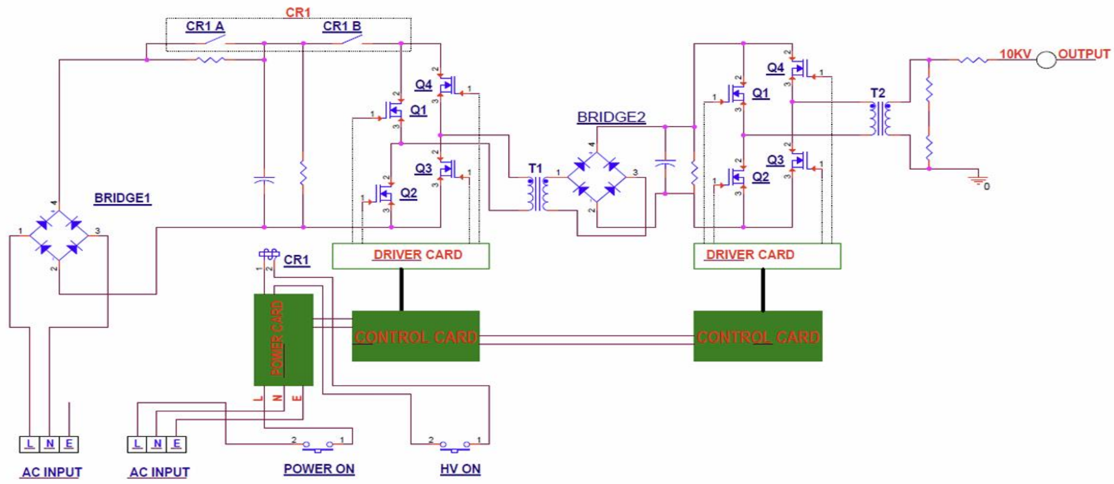
- **Pulsed Power (Short, Intense Bursts)**:
    - *Food Processing*: High-voltage pulses eliminate bacteria, enhancing food safety and extending shelf life.
    - *Water Treatment*: Pulses disrupt microorganisms, enabling disinfection through Pulsed Electric Field (PEF) technology.
- **Plasma Generation (High Voltage Creates Ionized Gas)**:
    - *Material Treatment*: Plasma is used for etching, surface modification, and thin-film deposition in material processing.
    - *Pollution Control*: Plasma-generated radicals decompose pollutants in air and industrial emissions.
- **Ionization for Pollution Control**:
    - High-voltage ionization generates charged particles that neutralize pollutants such as NO_x and SO_x in exhaust gases, aiding in environmental protection.

2.Project Scope

This project focuses on the design and simulation of high voltage power supplies, emphasizing the implementation of **Pulse Width Modulation (PWM)** control and **Metal-Oxide Semiconductor Field Effect Transistor (MOSFET's)**. The study aims to explore the optimization of HVPS performance for enhanced efficiency, precision, and reliability in targeted applications.

3.METHODOLOGY

The project work started by analyzing the existing 10KV, 25KHz power supply model. By looking at the power supply the following conclusions were made and these would be the basis for the future works in designing a supply The Basic schematic is given below.



4.Existing Power Supply System Overview

The power supply system is divided into two main sections for clarity and ease of maintenance:

1. **Power Circuit**

- **AC to DC Conversion**: Converts 230V, 50Hz AC input to 230V DC using a full bridge rectifier and filter capacitor.
- **DC to High-Frequency AC Conversion**: Transforms 230V DC to 230V, 25kHz AC using a Full H-Bridge Inverter with IGBTs.
- **High Voltage Step-Up**: Elevates 230V, 25kHz AC to 10kV, 25kHz AC via a transformer.

2. **Control Circuit**

- **PWM Gate Pulses**: Generates PWM signals for IGBTs to control inverter output voltage and operation, managed by the Control Card.

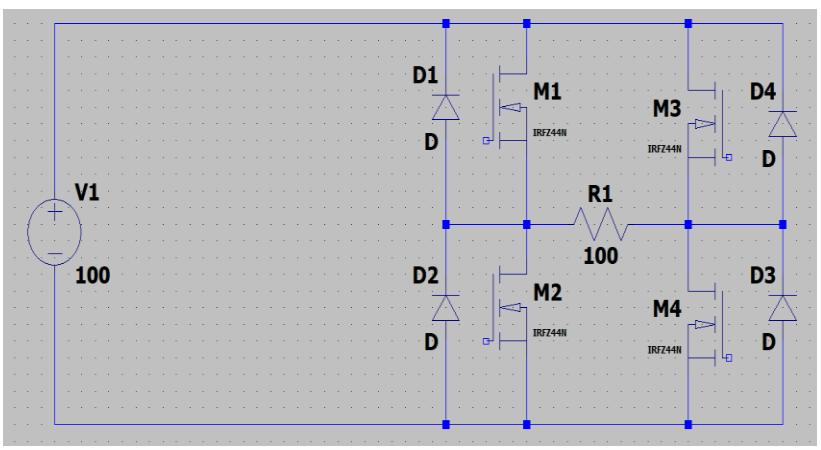
- **Protection Features**: Implements overcurrent protection and shutdown mechanisms to ensure IGBT safety and system reliability, handled by the Protection Card and Control Card.

5.DC To High Frequency AC Using H-Bridge Inverter of MOSFET's

Full Bridge Inverter:

The inverter converts DC to AC. It is comprised of 4 MOSFET's namely M1, M2, M3 and M4. Gate of M1 is connected to M4 and gate of M2 is connected to gate of M3. Together they form 2 legs of the inverter. The AC phase voltage is measured across the load.

The frequency of the AC Voltage is determined by the frequency of the switching of the Legs which is determined by the frequency of PWM signal supplied to the gates.



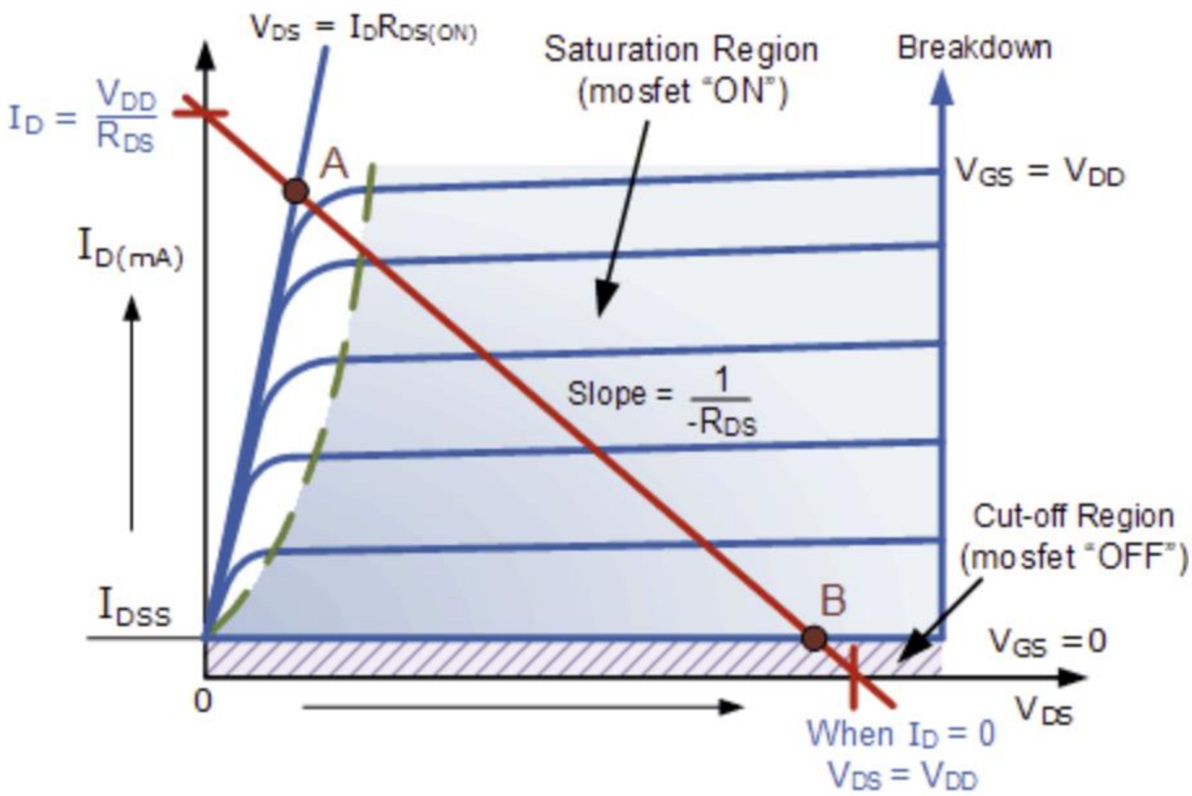
Magnitude of the AC Voltage is determined by the Duty cycle of the PWM supplied to the gates. The maximum AC peak obtained will be the same as the DC voltage

In our case the frequency of PWM pulses given to the MOSFET Gate is of 50% Duty cycle and 20KHz frequency which can be varied by a potentiometer.

MOSFET:

Metal Oxide Semiconductor Field Effect Transistor is a type of field effect transistor mostly fabricated by controlled oxidation of Si. It has an insulated gate, the voltage of which determines the conductivity of the device. This ability to change conductivity with the amount of applied voltage can be used for amplifying or switching. The main advantage of a MOSFET is that it requires almost no input current to control the load current under steady state.

The operation of the enhancement-mode MOSFET, or e-MOSFET, can best be described using it's I-V characteristics curves shown below. When the input voltage, (V_{IN}) to the gate of the transistor is zero, the MOSFET conducts virtually no current and the output voltage (V_{OUT}) is equal to the supply voltage V_{DD}. So, the MOSFET is "OFF" operating within its "cut-off" region

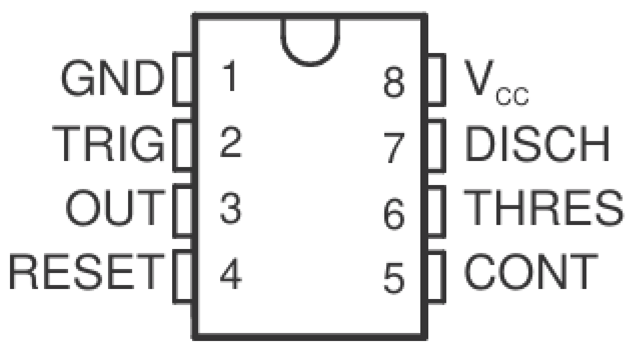


1) **MOSFET CUT-OFF Region:** The operating conditions of the transistor are zero input gate voltage (V_{IN}), zero drain

current I_D and output voltage $V_{DS} = V_{DD}$. Therefore for an enhancement type MOSFET the conductive channel is closed and the device is switched "OFF".

2) **MOSFET SATURATION Region:** In the saturation or linear region, the transistor will be biased so that the maximum amount of gate voltage is applied to the device which results in the channel resistance $R_{DS(on}$ being as small as possible with maximum drain current flowing through the MOSFET switch. Therefore, for the enhancement type MOSFET the conductive channel is open, and the device is switched "ON".

6.NE555 Timer:



The Nx555 devices are precision timing circuits capable of producing accurate time delays or oscillation. In time-delay or monostable operating modes, the timed interval is controlled by a single external resistor and capacitor network. In the astable mode of operation, the frequency and duty cycle are controlled independently with two external resistors and a single external capacitor.

Features

• Timing from microseconds to hours

• Astable or monostable operation

• Adjustable duty cycle

• TTL-compatible output can sink or source up to 200mA

Application

• Pulse-shaping circuits

• Missing-pulse detectors

• Pulse-width modulators

• Pulse-position modulators

NE555 in ASTABLE OPERATION:

The NE555 timer IC can be configured in an astable mode to function as a PWM (Pulse Width Modulation) generator. In this mode, the NE555 continuously oscillates between its high and low states, producing a square wave at its output (pin 3). By modifying the charge and discharge paths of the timing capacitor, the duty cycle of the output waveform can be controlled, making it suitable for PWM applications.

The output high-level duration tH and low-level duration tLare calculated as follows:

$tH \cong 0.693 \times RA+RB \times C$

$tL \cong 0.693 \times RB \times C$

period, frequency, and driver-referred and waveform-referred duty cycle are calculated as follows:

$T = tH+tL \cong 0.693 \times RA+2RB \times C$

$f = 1 / T \cong 1.44 / (RA+2RB \times C)$

Output driver duty cycle = RB/(RA+2RB)

Output waveform duty cycle = (RA+RB)/(RA+2RB)

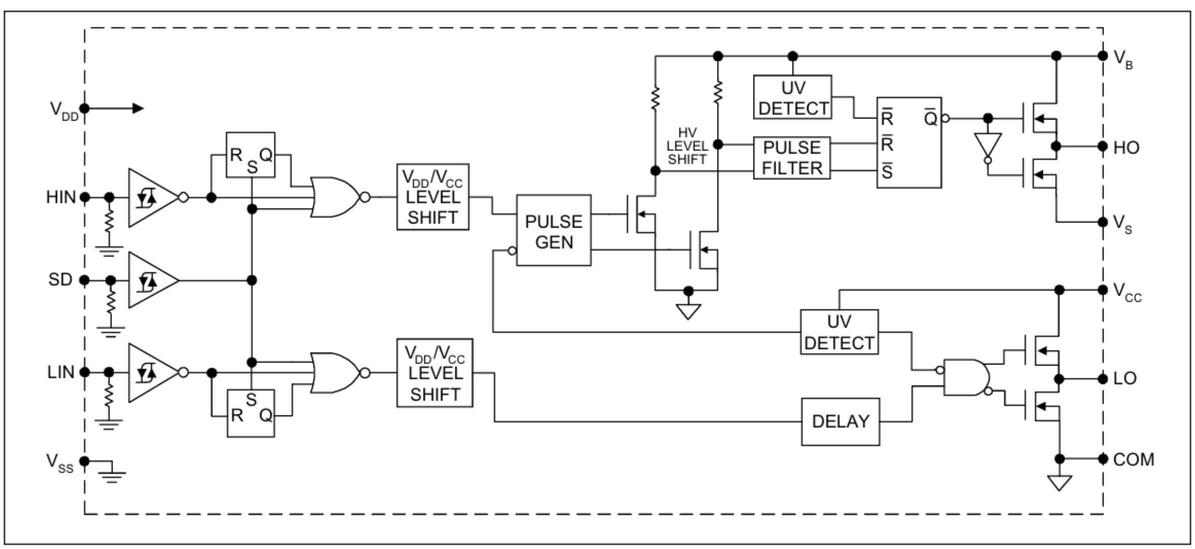
NE555 in MONOSTABLE OPERATION:

Monostable operation is initiated when the TRIG voltage is less than the trigger threshold. After being initiated, the sequence ends only if TRIG is high for at least 10µs before the end of the timing interval. When the trigger is grounded, the comparator storage time can be as long as 10µs, which limits the minimum monostable pulse width to 10µs. As a result of the threshold level and saturation voltage of Q1, the output pulse duration is approximately tw = 1.1 × RAC.

7.IR2110 MOSFET Driver IC:_**IR2110** is a high voltage MOSFET driver IC. It can drive both low side and high side switches in half-bridge and low bridge circuits.

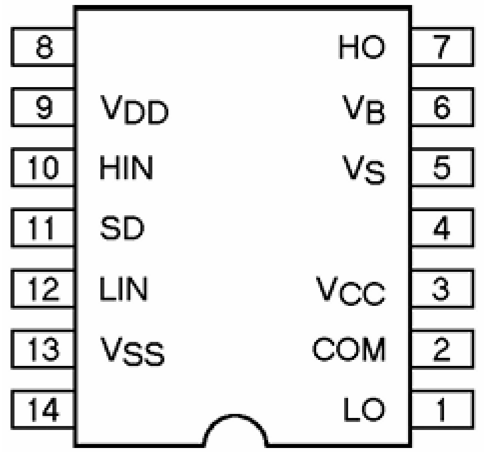
- Pin 1 is the output of low side MOSFET drive
- pin2 is a return path for the low side. It is at the same potential as ground VSS pin 13. Because when an input to the low side at pin 12 Lin is high, LO output will be equal to the value of Vcc voltage at pin 3 with respect to Vss and COM pin. When hen input to low side at pin 12 Lin is low, LO output will be equal to the value of VSS, and it means zero.

Functional Block Diagram



- VDD pin 9 is a logical supply pin. Its value should be between 5 volts. But if you used voltage less than 4 volts it may not give you the required result.
- HIN pin 10 is an input signal for high side MOSFET driver output. It may be from a microcontroller or any other device. But input signal logic level should be between 4-5 volt.
- LIN pin 12 is an input signal for low side Mosfet driver output. It may be from a microcontroller or any other device. But input signal logic level should also be between 4-5 volt.
- SD pin 11 is used as a shutdown pin. you can use it for the protection circuit. For example, in over voltage or over current protection circuit, if any of these values become greater than specified values, you can give a 5-volt signal to shutdown IR2210 driver to stop driving MOSFETS. In return, your circuit will stop working.
- VB pin 6 is used as a high side floating supply of floating circuit to provide floating voltage to high side MOSFET.
- The bootstrap capacitor used between VB and VS to fully operate high side MOSFET. It plays a very important rule in H bridge of pure sine wave inverter. you should use bootstrap capacitor value 22uf-40uf. I have successfully designed H bridge after making many changes in H

bridge with 33uf/50v bootstrap capacitor value



Features

• Floating channel designed for bootstrap operation Fully operational to +500V or +600V Tolerant to negative transient voltage dV/dt immune

• Gate drive supply ranges from 10 to 20V

• Undervoltage lockout for both channels

• 3.3V logic compatible Separate logic supply range from 3.3V to 20V Logic and power ground ±5V offset

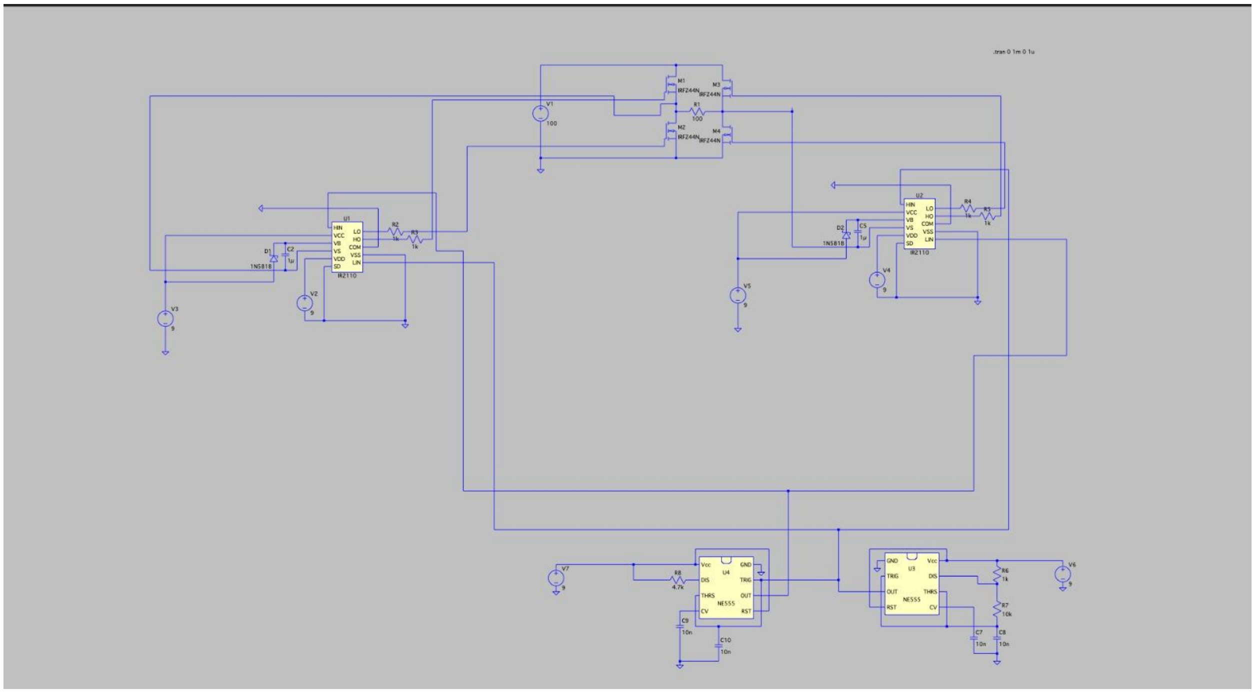
• CMOS Schmitt-triggered inputs with pull-down

• Cycle by cycle edge-triggered shutdown logic

• Matched propagation delay for both channels

• Outputs in phase with inputs

8.Simulation



Schematic Diagram of PCB

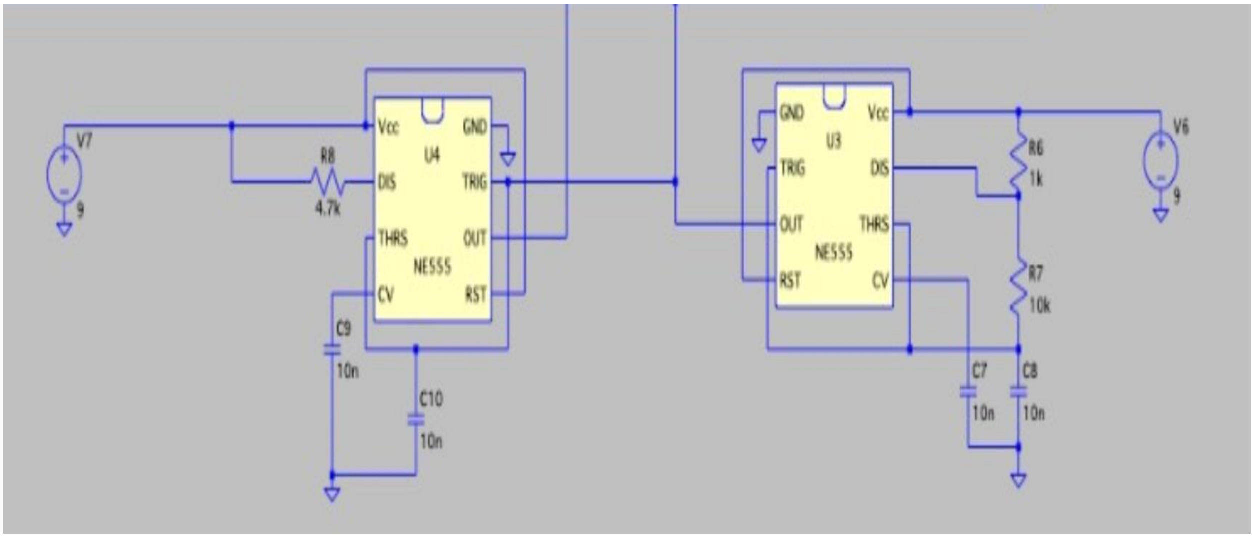
This is a high-frequency full-bridge inverter driver circuit. It's designed to convert a DC input into a high-frequency AC output using MOSFETs.

This system has 3 major components

1) NE555 Timer as PWM Generator
2) IR2110 IC as Driver IC
3) H-Bridge Inverter with a Resistive Load

NE555 Timer as PWM Generator:

PWM (Pulse Width Modulation) is a technique where Switch ON pulse is controlled while keeping frequency constant. PWM controls the timing and switching of the MOSFET's in the full bridge inverter. This NE555 Timer generates this PWM in astable mode.



Let's Define U3

- RA: Resistor between discharge and Vcc = 1K ohm
- RB: Resistor between discharge and threshold pin or a potentiometer of 10 K ohm
- C: Timing Capacitor=10nF

Frequency of the waveform generated

F=1.44/ (RA. C+2RB.C)

ON Time

T_ON=0.693C(RA+RB)

OFF Time

T_OFF=0.693.RB.C

DUTY Cycle:

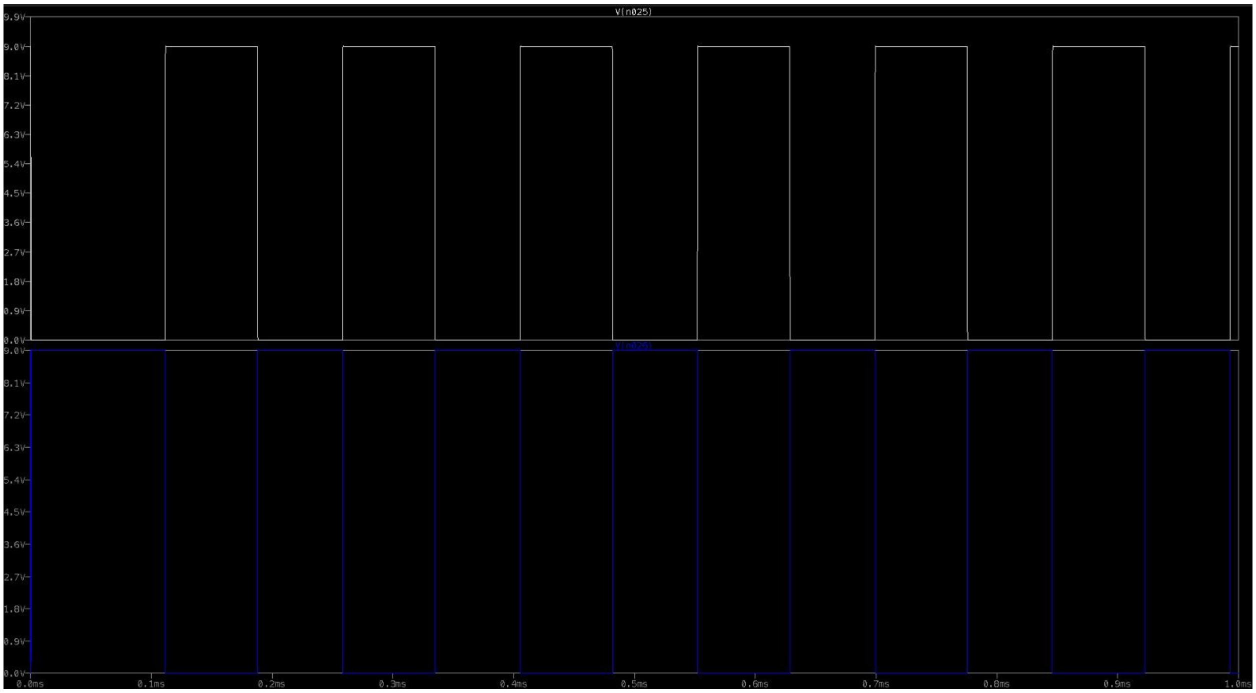
D= T_ON.100/(T_ON+T_OFF) = (RA + RB)100/(RA+2RB)

Using the above formulae

We get

Frequency of PWM close to 6.86 Kilo Hz.

Duty cycle of waveform to be 52.4 percent.



Let’s Define U4

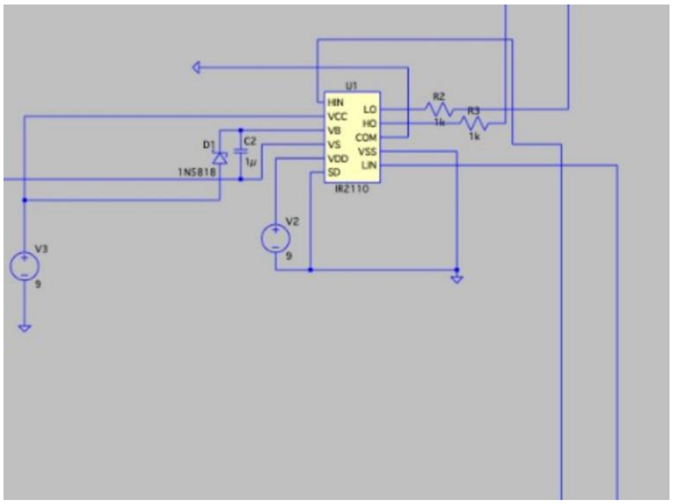
- RC: Resistance between Vcc and Discharge=4.7 K ohm
- C: Timing Capacitance = 10nF
  $T=1.1\cdot 4.7k\cdot 10nF=1.1\cdot 47\mu s=51.7\mu s$
  So, the pulse from U4 is *~51.7 microseconds long*.

To generate synchronized complementary PWM signals, the output of the first NE555 timer (U3, configured in an astable mode) is directly connected to the trigger pin (pin 2) of the second NE555 timer (U4, configured in monostable mode).

This connection ensures that every time the output of U3 transitions from HIGH to LOW, it triggers U4 to produce a single, time-defined HIGH pulse. The result is a complementary waveform where U4's output is HIGH when U3's output is LOW, and vice versa.

IR2110 as Driver IC for MOSFET

To control the switching of the four N-channel MOSFETs in the full-bridge inverter, the circuit uses two IR2110 high- and low-side driver ICs (U1 and U2). These drivers are essential because standard PWM signals from NE555 timers are not sufficient to directly switch high-side N-channel MOSFETs, which require gate voltages higher than their source terminals.



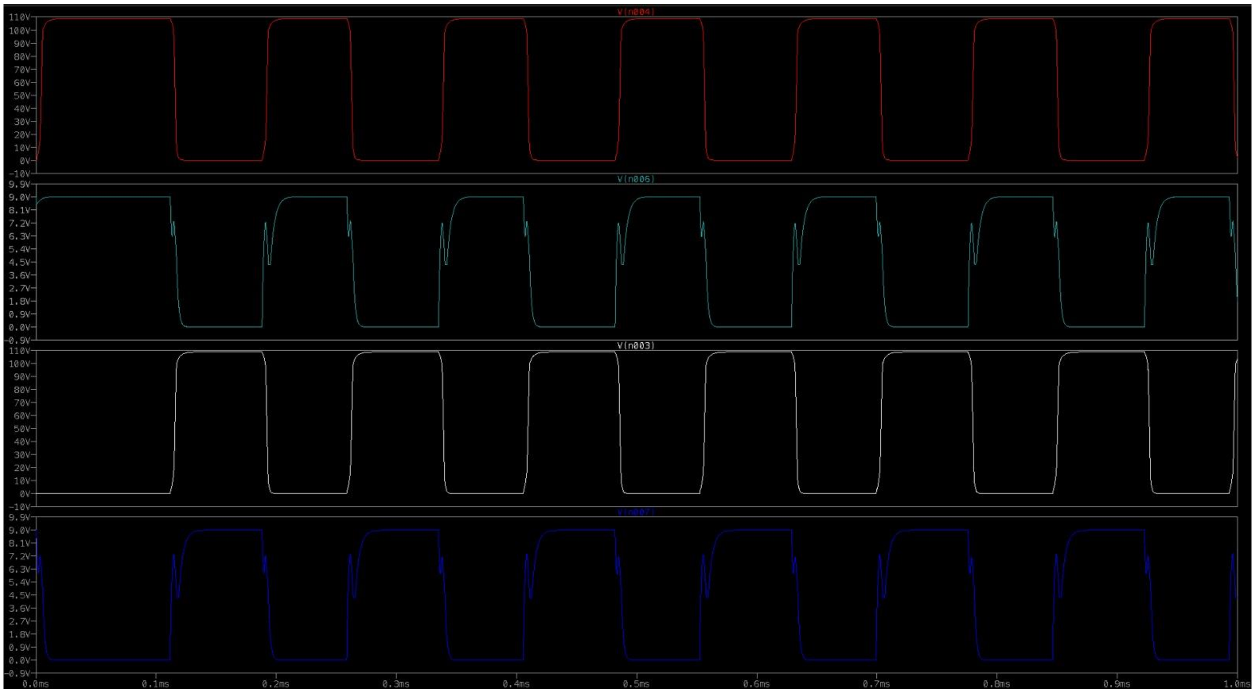
Each IR2110 IC is responsible for controlling two MOSFETs:

- One *high-side MOSFET* (through pin HO)
- One *low-side MOSFET* (through pin LO)

Two IR2110s are used:

- U1 controls the left half of the H-bridge (M1 and M2)
- U2 controls the right half (M3 and M4)

Gate supply of M1 M2 M3 and M4



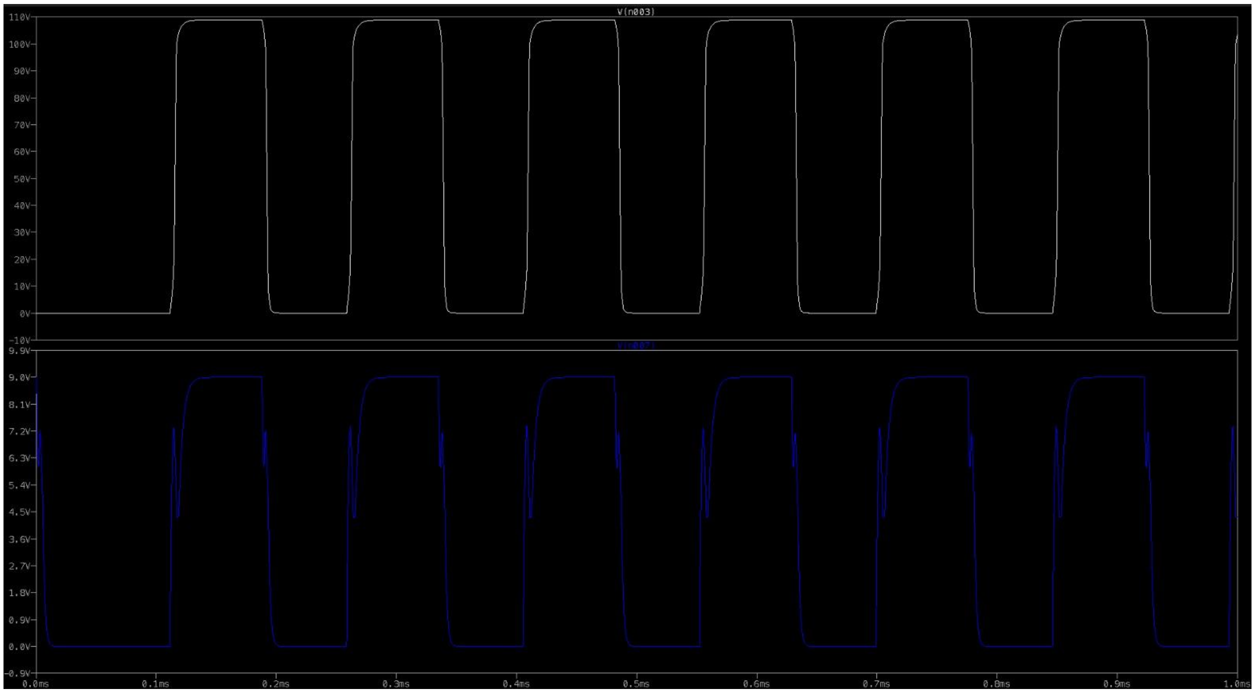
Because the high-side N-channel MOSFET has its source terminal floating (not tied to ground), a special method called bootstrap driving is used to provide gate voltage higher than the source.

Each IR2110 has a bootstrap capacitor and diode connected between the VB (bootstrap supply) and VS (source of high-side MOSFET) pins.

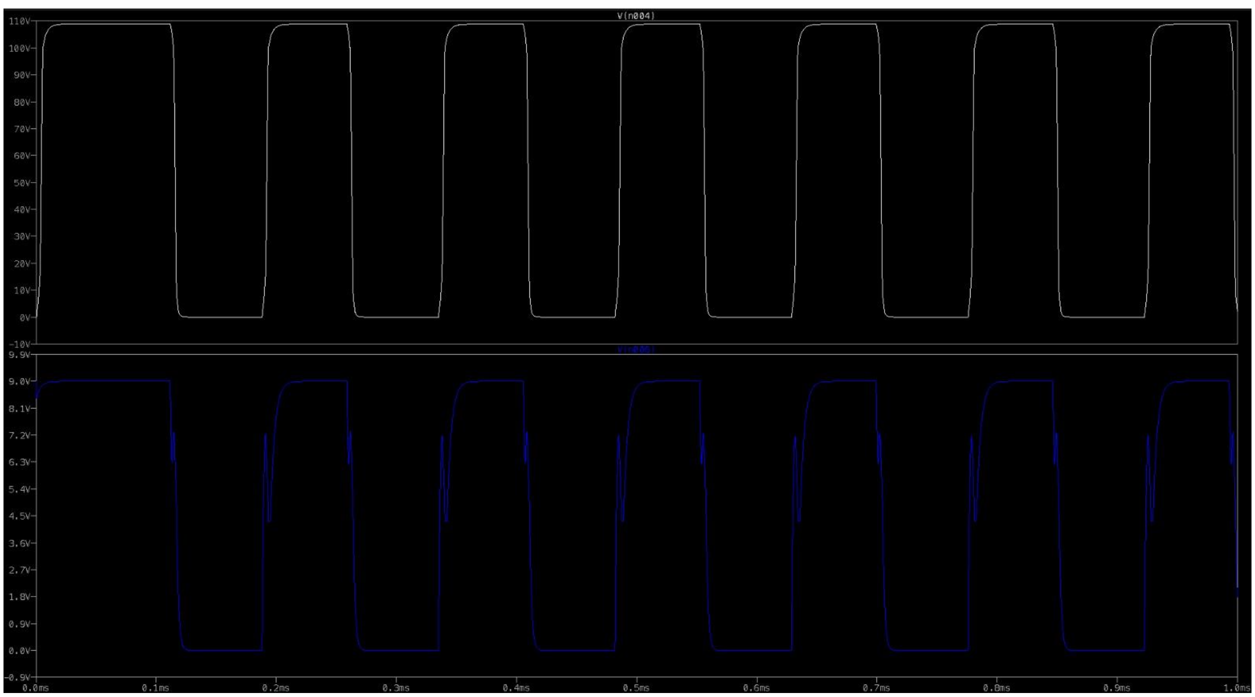
- The bootstrap capacitor (typically 1 µF) charges when the low-side MOSFET is ON.
- When the high-side MOSFET needs to be turned ON, the charge stored in the bootstrap capacitor is used to raise the gate voltage above the source, ensuring proper switching.

This allows safe and efficient control of high-side N-MOSFETs using standard low-voltage PWM signals.

Gate supply of M3 and M2

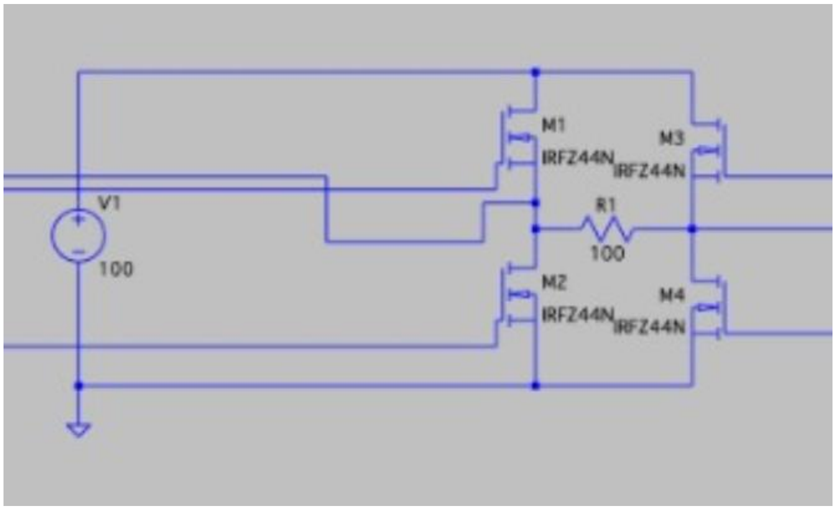


Gate supply of M1 and M4

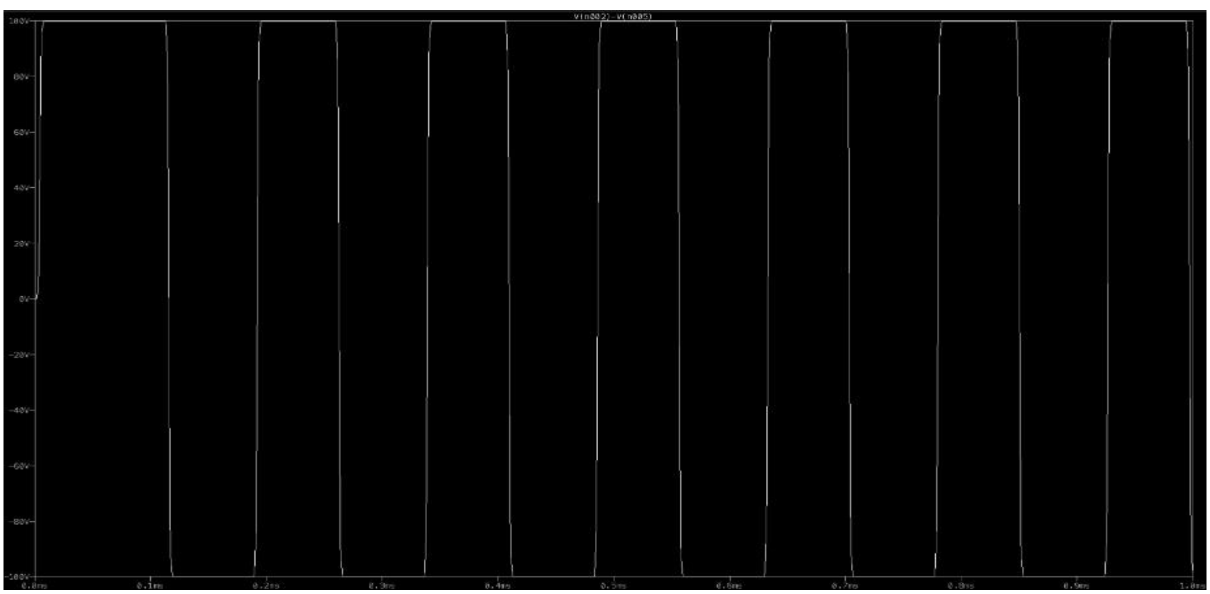


H-Bridge Inverter

An H-bridge is an electronic circuit that switches the polarity of a voltage applied to a load. It is responsible for converting a DC input voltage into a high-frequency AC output voltage. This is accomplished by using four N-channel power MOSFETs (labeled M1 to M4) arranged in an H-bridge configuration.

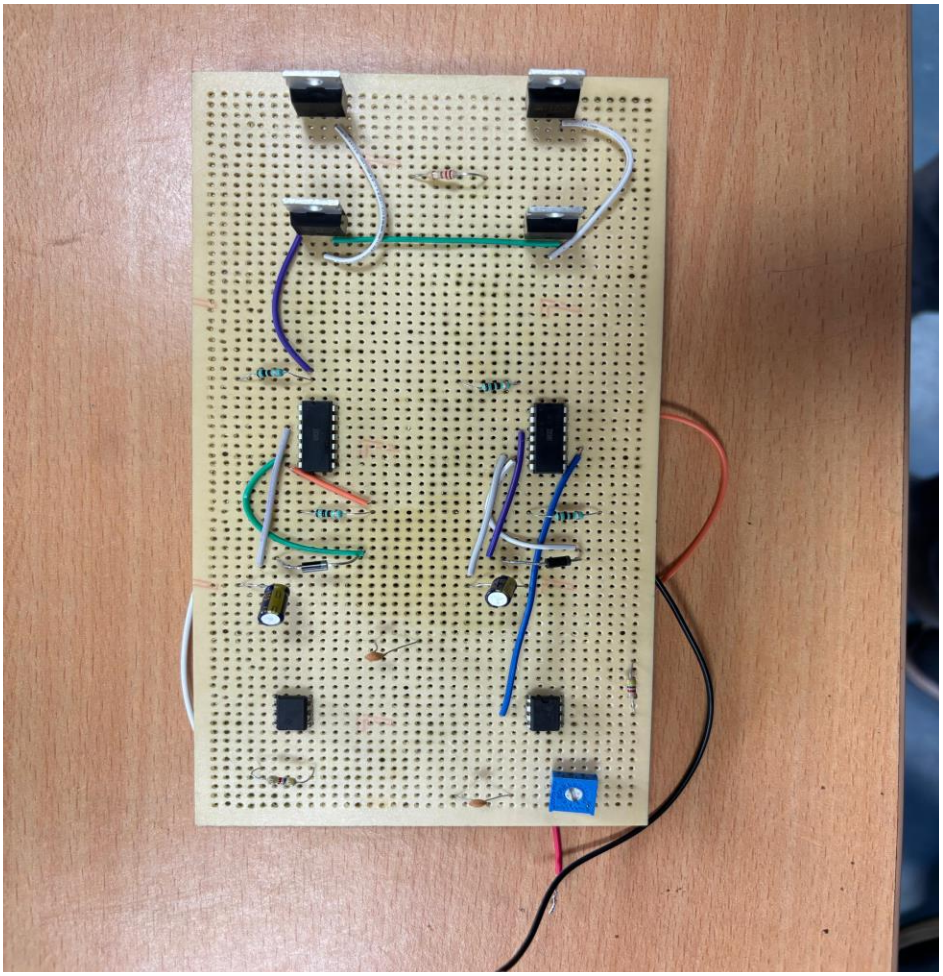


M1–M4 and M2–M3 form the two diagonal switching pairs. At any moment, only one diagonal is turned ON to ensure alternating current flow through the load



A resistive load is used in this circuit. Since the load does not contain inductive or capacitive elements, freewheeling or flyback diodes are not required in this configuration.

9.Experimental setup:



10.Conclusion

We can generate a range of high voltage output(0-10KV) at high frequency(25KHz) which can be used appropriately in various fields such as ionization of gases such as N2, Ar, generation of X ray signals which has various medical applications.

In future we wish to make our circuit on PCB to reduce noise and generate Higher voltage from either regulated power supply or DC Li ion battery.

For H Bridge, we wish to add diodes to reduce inductance from the high frequency voltage and which will also help in reducing noise.

11.References

xx555 Precision Timers datasheet (Rev. J)(Data sheet of NE555)

IR2110(S)-IR2113(S) Datasheet-500V/600V high-side and low-side gate driver IC with shutdown(Data Sheet on IR2110)

1. http://dx.doi.org/10.1063/1.4907359 S. K. Sharma and A.Shyam,"Development of Compact Rapid Charging Power Supply for Capacitive Energy Storage in Pulsed Power Drivers," 2015 IEEE Conference on Pulsed Power Technology and Applications (PPTA), pp. 1-6, Feb. 2015