# Variable Voltage, Variable Frequency Regulated High Voltage Power Supply for Coulomb crystallization Base on Microcontroller

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## ABSTRACT
**Coulomb crystallization in dusty plasmas is of great interest in recent years. The Control of fine particle behavior in Coulomb Crystallization Experiments requires low frequency particle driving, which involves injection of alternating voltages at low frequencies. With a repetition period shorter than the particle response time, the particles feel only time-averaged force because of large mass. Also in case of dusty plasma, one needs to excite dust acoustic wave for which low frequency perturbation of higher amplitude are required, depending upon the dust size. To perform such experiments, High Voltage power supply with variable voltage and variable frequency is required. Moreover, the power supply should be highly regulated and short circuit protected. Such low frequency, high voltage pulse generator are not commercially available and hence requires special design. To satisfy the above requirements a microcontroller based variable frequency, variable amplitude, regulated high voltage power supply is designed and developed indigenously in RF Group. The paper deals with the Design, Development and Testing of 0 to1000V (p-p), 1 to 10Hz, 10mA regulated power supply.**

*Keywords* **- About five key words in alphabetical order, separated by comma**

## I. INTRODUCTION
Coulomb crystallization in dusty plasmas is of great interest in recent years. The experiments generally involve a parallel plate capacitor arrangement for RF plasma generation. Plasma temperature and density is varied with the gas (typically Argon) pressure, RF frequency and power. Once the plasma is stabilized SiH4 and O2 gas are injected to generate SiO2 particles of size 2-3\mum. Occasionally 10-15 \mum sized quartz crystals are also formed [1]. The charged particles arrange themselves in a regular geometrical array in the groove of the bottom plate of the capacitor. This array formation is known as **Coulomb crystallization**. The Control of fine particle behavior in Coulomb Crystallization Experiments requires low frequency particle driving, which involves injection of alternating voltages at low frequencies. With a repetition period shorter than the particle response time, the particles feel only time-averaged force because of large mass [2]. To perform such experiments, High Voltage power supply with variable voltage and variable frequency is required. Moreover, the power supply should be highly regulated and short circuit protected. Such low frequency, high voltage pulse generator are not commercially available and hence requires special design.

## 2. SPECIFICATIONS OF VVVF POWER SUPPLY
Specifications for VVVF power supply are given in Table 1 below.

Table 1. SPECIFICATIONS OF VVVF POWER SUPPLY

| Sr.No. | Specification | Value |
|---|---|---|
| **A** | **Input** | |
| | Voltage | 1-ph, 230V (+/-10 %) |
| | Frequency | 50Hz |
| | Isolation | 1.5kV |
| **B** | **Output** | |
| | Voltage | 0 to 1000V (p-p), settable (floating) |

| | | |
|---|---|---|
| | Current | 10 mA |
| | Frequency | 1 Hz to 10 Hz |
| | Regulation | < 1% |
| | Ripple | < 0.5% at full load |
| C | Protection | -Overload protection<br>-O/P Short Circuit Protection @10mA |
| **D** | **Control** | |
| | Control Parameter | Output Voltage |
| | Voltage setting | 0-5V control signal through POT |
| | Frequency setting | Pushbutton/ POT |
| **E** | **Metering** | |
| | O/P Voltage | 1kV (p-p) Analog Voltmeter |
| | Frequency | 20 Character LCD |
| F | **Programmability** | |
| | In-Circuit Reprogrammable-ICP | 16-bit |
| | | |
| | Mode of operation | Variable Voltage, Variable Frequency (VVVF) |

## 2. Design

### 2.1 Topology Selection

The two important requirements of the power supply are:

(a) Variable Alternating Voltage (Square Wave shaped)

(b) Variable Low Frequency

The transformer design becomes critical if it is to be operated at very low frequencies (1 to 10Hz) as the core gets saturated and hence a special design needs to be implemented. To avert the above problem, a low frequency, transformer-less H-bridge Topology is selected. The H-bridge topology provides the following advantages: -

(a) It allows the current to be fed to a load in all four quadrants of voltage and current.

(b) The frequency and amplitude can be easily controlled through control pulses from a low voltage circuit.

Also, as the frequency and time period are inversely proportional to each other, the non-linear time period generation (1sec for 1Hz and 100ms for 10Hz) introduces another issue. Based on the above requirements it is decided to go for H-bridge topology controlled by a microcontroller-based frequency controlled driver [3].

The reasons for using microcontroller are as follows:

(a) Most of the PWM controllers available in the market generally have lower frequency range, starting from few hundreds of Hertz and hence are not fit for our requirements. Such low frequencies can be precisely generated using the inbuilt timers provided in the microcontroller.

(b) Another important requirement of frequency driver is to generate Dead Time; time delay between the complimentary pairs *Q* and *Q*. A precise dead time can be easily generated through a microcontroller

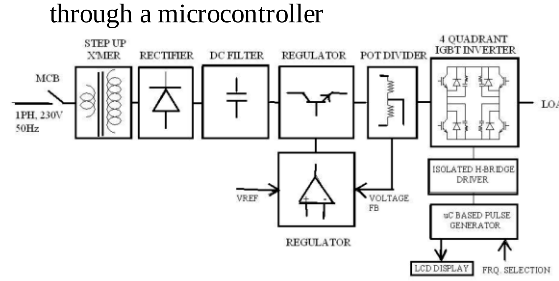



Fig.1 Block Diagram of VVVF Power Supply

Fig.1 shows the block diagram of the VVVF power supply. The voltage requirement specified for the supply is 500V peak to peak. However, the total circuit has been designed with a design value of 1000V peak to peak. The H-bridge topology has been used for switching. Consequently, in the power part the input voltage is stepped up to using a step up transformer. This obtained value of AC is converted to an equivalent DC output using a full wave bridge rectifier using HV diodes [4]. A DC filter is designed to reduce the output ripple content. The regulated output of the filter is fed to the H-bridge circuit. The regulator is a power BJT based series pass regulator, which provides closed loop control of the total power supply. The controller is fed with a reference signal, which is compared with the feedback signal at the output, the difference of which forms the error signal for the regulator. The error signal is amplified and is fed to the base of the BJT and hence the required regulation as well as variation is achieved. The amplitude of the power supply is set using a potentiometer and its value is displayed on an analog voltmeter calibrated to show peak-peak output voltage. The H-bridge is IGBT based (Fig. 1) and its switching is controlled by a buffered isolated driver card that in turn is controlled by a micro-controller. The microcontroller adjusts the timing sequence for switching requirements of IGBT including the Dead Time. This is achieved by programming its 16bit timers, to generate pulsed waveforms of desired frequency (1-10Hz). The frequency is varied using a push button interfaced to the microcontroller. An LCD is also interfaced with the microcontroller to display the online frequency [5].

## 2.2 Design Description

### 2.2.1 Power Circuit

The power circuit (Refer Fig.2) is divided among the following parts: -

(a) Step up transformer
(b) Rectifier
(c) DC Filter
(d) Short Circuit Protected Linear Regulator
(e) H-bridge
(f) Snubber design

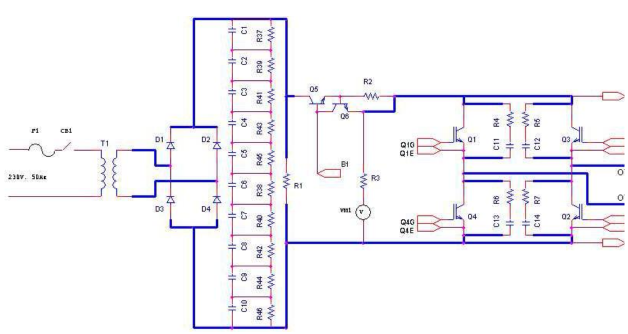


Fig. 2 Power Circuit

### 2.2.2 Control Circuit

A dedicated driver (developed for low power IGBTs used in inverter section) with inbuilt isolation (through opto-couplers) is designed and developed for the power supply. For the purpose of safety and low voltage control, the driver part is isolated from the power part. While the driver part works at a maximum voltage of 15 volts, the power part works at a maximum voltage of 1000 volts peak to peak and hence the isolation is a must. The block diagram of the driver and control card is given in Fig. 3. The basic function of the driver part is to periodically, as determined by the operator, generate triggering pulses *Q* and _ *Q*_ through the microcontroller to govern the ON and OFF switching of the IGBT switches that constitute the H-bridge. The separate 15V power supplies needed to run the 4N35 IC's is also mounted on the driver card. The function of the driver and control is categorized into four levels as: (refer Fig.3, Fig. 4)

(a) Buffering
(b) Isolation
(c) Conditioning
(d) Level translation

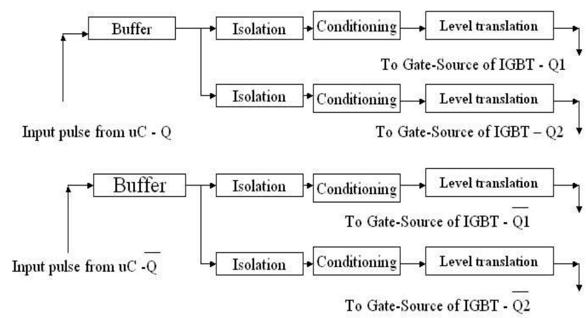



Fig. 3 Block Diagram of Driver and Isolation Card

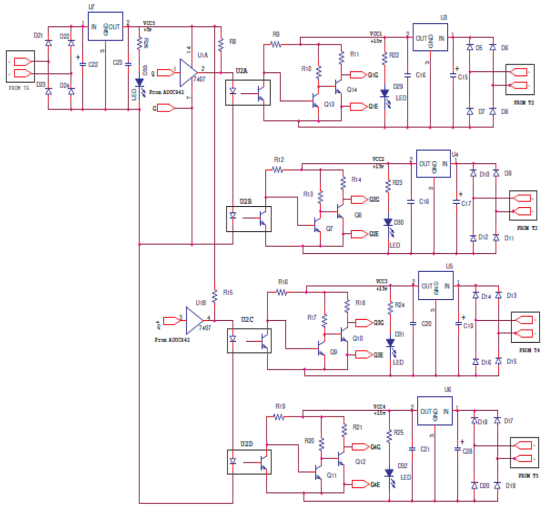


Fig. 4 Driver and Isolation Card

The buffers used in the system are two of the six in built buffers of a 7407 IC. The need for a buffer arises because during the driver operation by the microcontroller the current generated by it is not sufficient enough to feed the primary of optical isolator. The isolation function is desired to separate the L.V and the H.V circuits. In an Hbridge circuit for turning on the diagonally opposite switching devices would lead current flow through the load and lead to its reversal of direction of flow alternately.
This method requires that each of the four switches receive its own control input. Since our voltage requirement at the load is high we need to provide electrical isolation and a level shifter to match the micro controllers output voltage/current requirements, as a standard practice. IC 4n35 is used for both the purposes. The SL 100 transistors provide the signal conditioning. The provision of inversion is a control measure. Inversion of the waveform is necessary because during input from the microcontroller all the pulses are high just a moment before switching starts happening, this can create a short circuit within the switching circuit. The level translation is required because up to the isolators in the driving circuit the operating voltage is 5 volts, however in order to drive the IGBT gates in hard saturation 15V supply is used. The output of 4n35 drives the Conditioning and level translation circuits, which finally drives the gates of the IGBTs.

### 2.2.3 MICRO-CONTROLLER BASED LOW FREQUENCY GENERATOR DESIGN

For generating programmable low frequency witching pulses, Micro-converter ADUC842 from Analog Devices is used. This controller is a part of the Micro-controller Kit developed at RF Group (Fig. 5), and is provided with all the features to interface LCD, Keypads and external peripherals. The kit size is around 5.5" x 4" and is in-circuit programmable (ICP).

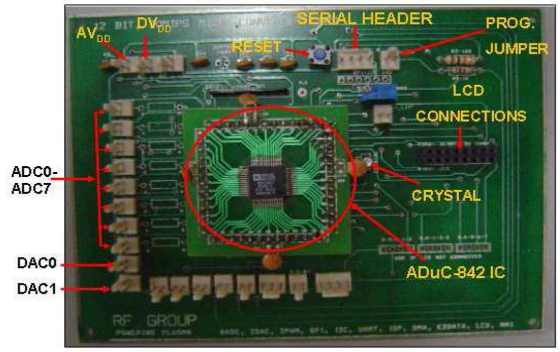



Fig. 5 Micro-Converter Kit Developed at RF Group

### 2.2.4 EXTERNAL DEVICE INTERFACING

A 2 line, 20Character LCD is interfaced with the ADUC842 kit using a FRC connector and cable.

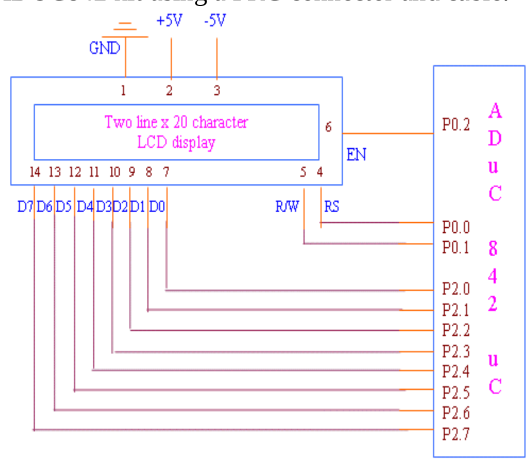



Fig. 6 Interface of LCD with Microcontroller

The connection diagram of LCD to Microcontroller is given in Fig. 6. Port 2 of the microcontroller is used as the Data Bus for the LCD. Port pins p0.1, p0.2 and p0.3 are used for controlling the data flow and Display on the LCD. The Connection between ADUC842 and LCD is through 14-wire FRC cable. The LCD is housed in a separate control box of the power supply [6]. A push button is connected to the port 'P0.5' and is used for frequency selection. The pin 'P0.5' is polled for active low (when the push button is pressed) and causes change in the output frequency with simultaneous display over the LCD.

## 3. Flow Chart

The program flow is shown in Fig. 7. The default frequency of the output pulse is set to 1Hz. As soon as the system is started, the output generates 1Hz. This is simultaneously displayed over the LCD. The frequency is generated using Timer 1 in 16-bit mode. The program then waits for the push-button to be pressed (for a change in frequency). Once the push button is pressed, the program counter increments to the new value in the look up table (LUT) and collects the data and starts generating the new frequency with the simultaneous display over LCD. A circular programming loop is used for frequency increments i.e. after reaching 10Hz the frequency rolls back 1Hz.

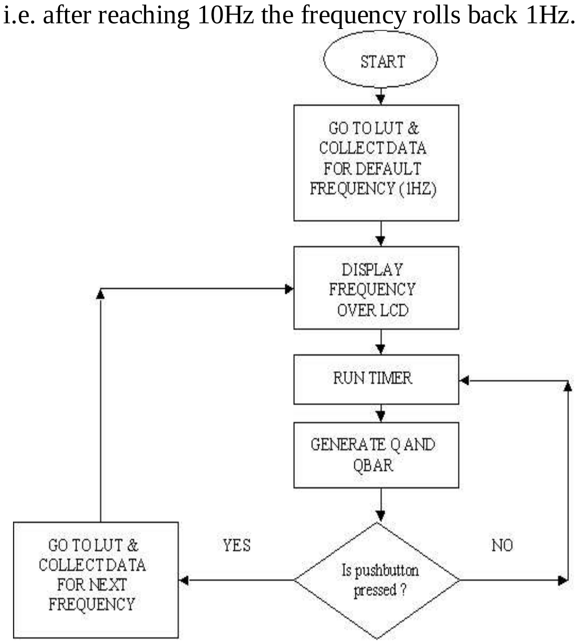



Fig. 7 Flow Chart

## 4. Software

The software used is divided in three categories: -
(a) Assembler
(b) Simulator
(c) Downloader

### 4.1 Assembler

The program is written in an ASCII text editor in assembly format. Once the code is written it is assembled using an assembler. The assembler used is 2-pass (cross) assembler from Metalink Corporation (Fig. 8). Once the code is assembled, Intel compatible hex file is generated. Fig. 9 gives a screen shot of the Intel Compatible hex file for the program used.

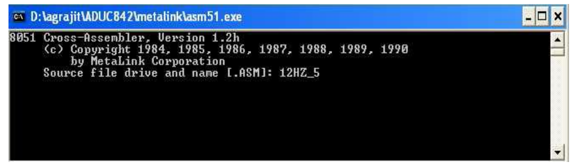
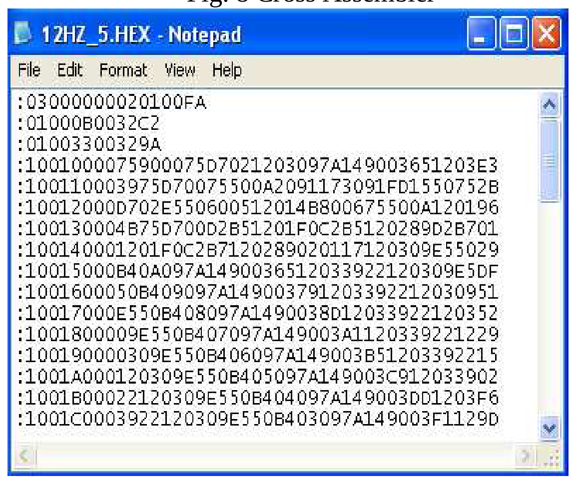



Fig. 8 Cross Assembler


12HZ_5.HEX - Notepad

File Edit Format View Help

```
:03000000020100FA
:01000B0032C2
:01003300329A
:10010000759000075D7021203097A149003651203E3
:1001100003975D70075500A2091173091FD1550752B
:10012000D702E550600512014B800675500A120196
:100130004B75D700D2B51201F0C2B5120289D2B701
:100140001201F0C2B7120289020117120309E55029
:1001500B40A097A1490036512033922120309E5DF
:10016000050B409097A149003791203392212030951
:10017000E550B408097A1490038D12033922120352
:1001800009E550B407097A149003A1120339221229
:100190000309E550B406097A149003B51203392215
:1001A000120309E550B405097A149003C912033902
:1001B00022120309E550B404097A149003DD1203F6
:1001C00039221203 09E550B403097A149003F1129D
```

Fig. 9 Intel-Compatible Hex Code file

### 4.2 Simulator

Before downloading the program, the hex file is loaded in a simulator. The simulator used is ADSim Simulator from Analog Devices. Fig.9 shows the screen shot of the ADSim simulator with different simulation windows like RAM Simulation, Port simulation, Timer Simulation etc. The simulator provided the facility of stepped simulation and facilities like external simulated interrupts.

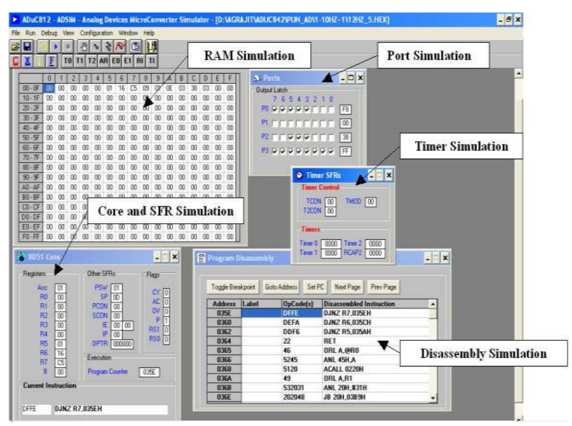



Fig. 9 AD Sim Simulator

### 4.3 DOWNLOADER

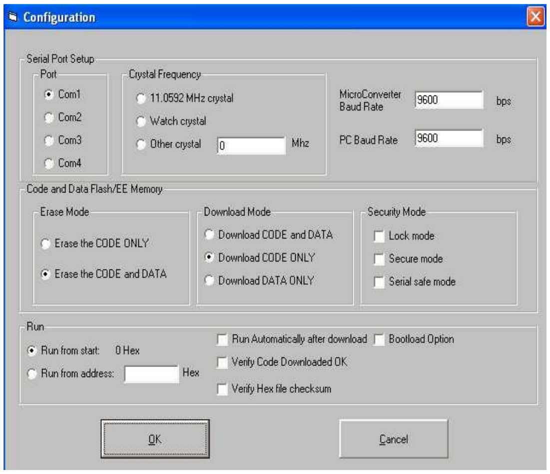



Fig. 10 Screen Shot of the Configuration Menu of Serial Downloader

For downloading the hex code into the flash of microcontroller, Serial Downloader v6.06 from Analog Devices is used. Some of the configuration capabilities (Fig. 10) of the downloaded are listed as follows: -

(a) Downloading Port Selection facility
(b) Crystal frequency selection
(c) Baud rate selection for both PC and microcontroller
(d) Erase Modes for Code and data
(e) Download Modes for Code and data, Verification and Bootload options

## 5. RESULTS

### 5.1 TESTING OF DRIVER CARD

The IGBT driver is tested for its maximum operating frequency range. It works well up to 4 kHz, which is well above the requirement.

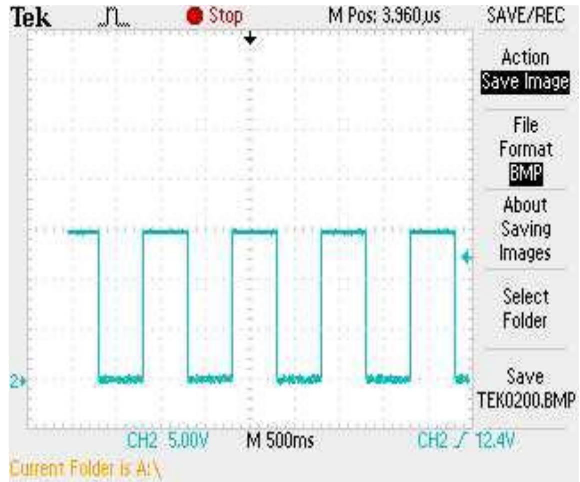



Fig. 11 Input Through Function Generator

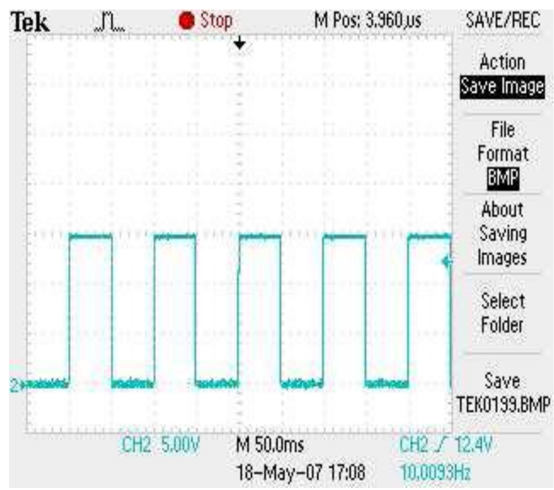



Fig. 12 Input through Function Generator

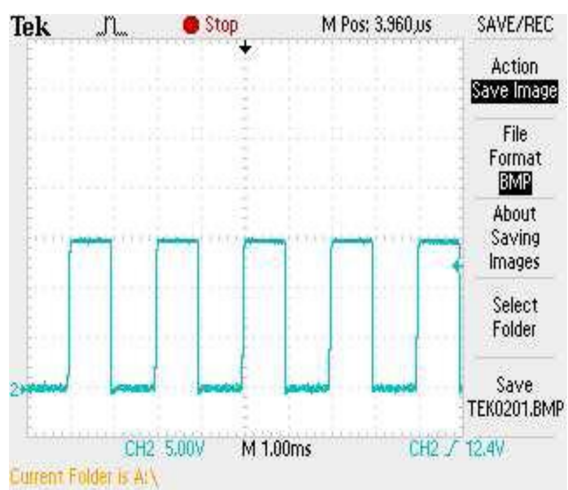



Fig. 13 Input through Function Generator

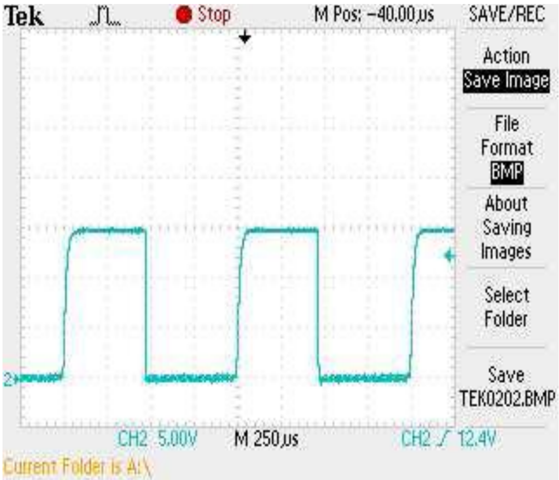



Fig. 14 Input through Function Generator

5.2 TESTING OF POWER SUPPLY

The Power Supply is tested on a resistive dummy load for a load current of 10mA.

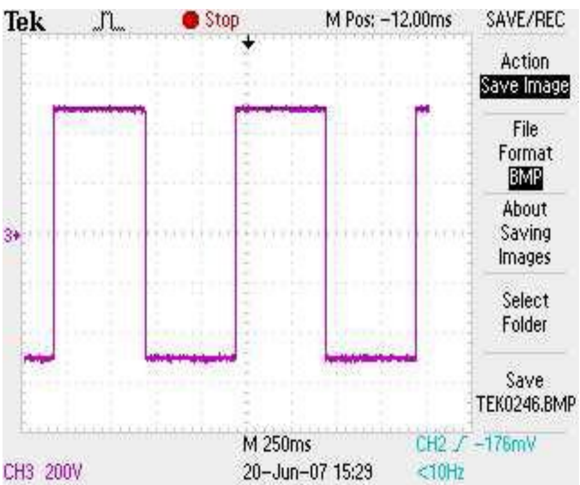



Fig 15 Voltage Output at 1Hz, 1kVp-p

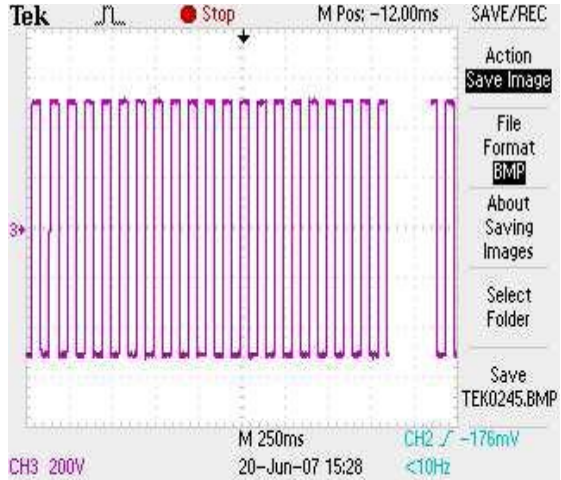



Fig 16 Voltage Output at 10Hz, 1kVp-p

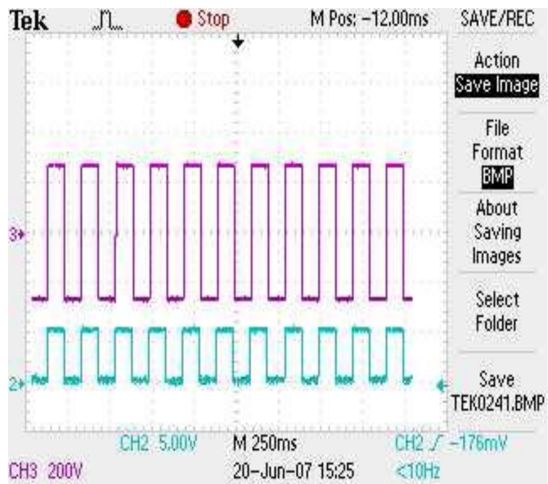



Fig 17 Voltage Output at 5Hz, 500V p-p

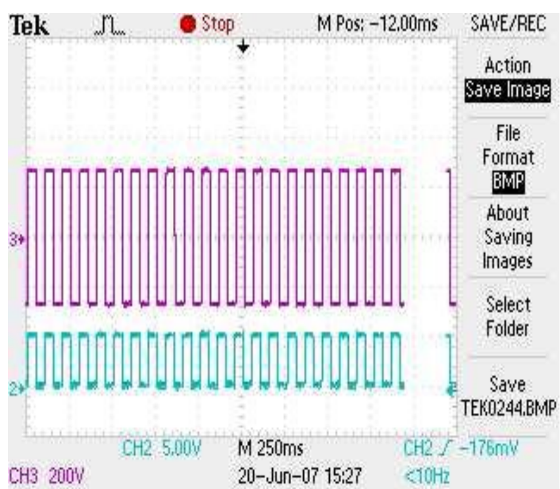


Fig 18 Voltage Output at 10Hz, 500V p-p

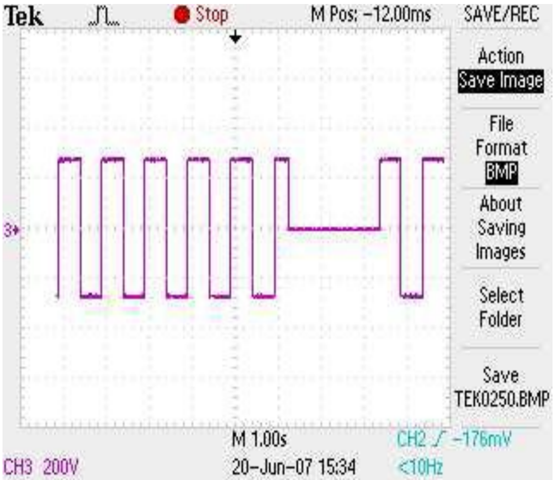



Fig 19 Voltage Output at 1Hz, 500V p-p

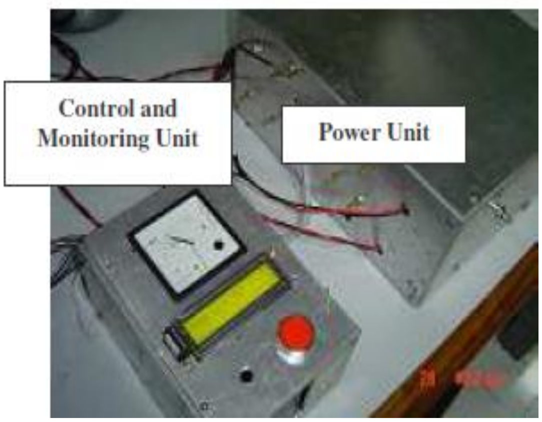



Fig. 20 Shows a view of the assembled power supply

## 6. Conclusion and Future Scope

- The power supply is designed and tested successfully as per the given requirements on a resistive dummy load.
- The power supply is made indigenously with the available components in a time scale of ~ 25 days
- The estimated cost of the power supply is ~ Rs10,000/-
- The power supply can be optimized for the components, size and power
  density as most of the components used are over rated.
- The program can be modified for higher frequency resolution.
- Features like remote programmability can be incorporated in future designs.
- Owing to the constraint of time the wiring layout can be optimized in future by designing a lanned wiring layout to avoid any interference between power and control circuits

## Acknowledgements

Firstly, the authors would like to pay their respectfully thanks to God, their beloved family, teachers and their admirer supervisor. Special thanks to Mr. R. K. Patel Head of department of Kirodimal .Government Polytechnic, Raigarh for his encouragements. The authors also express their greatly thanks to all persons who had concern to support in preparing this paper.

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