Prototype Pulse Power Modulator

Development of Solid State Pulse Modulator for Biological Applications

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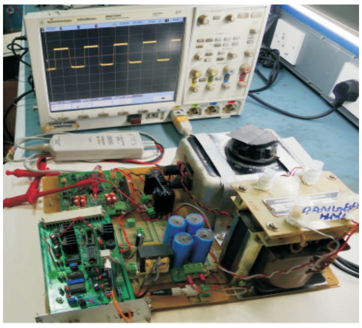

Pulse Modulator

ABSTRACT

Solid state pulse modulators have many industrial and scientific applications. The pulse modulator developed in our laboratory has flexibility in terms of the peak voltage (20V-2 kV), pulse repetition rates (DC-10 kHz) and duty cycle (0.1-100 %). The topology used enables reduced form factor of the system for low current drawing loads by modifying the solid state switch and capacitors. MOSFET and IGBT are used as the switches depending upon the application and load requirements. The fiber-optic cable integration ensures trigger source isolation. The driver circuit based on the M57962L operates as an isolation amplifier and provides required electrical isolation between input and output. The optical fiber integration ensures remote trigger control operation of the system. This pulse power supply developed has application in Electroporation and gene delivery of biological cells and tissues and food sterilization.

KEYWORDS: *MOSFET, Optical Fiber, HFBR, Transformer, Gate Driver.*

Introduction

Pulse modulator is an electronic circuit which provides high voltage pulsed power for many industrial and scientific applications. The advances in the device capabilities with respect to the switching speed and the power handling capacity has ensured the performance rivaling that of thyratron switched line-type modulators and hard tube modulators[1]. The new generation solid state switches have been developed with higher efficiencies and longer lifetime. The on-off timing sequence of solid state switches can be controlled by the low voltage and low power trigger circuit. There can be complete pulse width and duty cycle flexibility on a pulse-to-pulse basis. The MOSFETs and IGBTs have insulated gate thus requiring very low drive current thus eliminating the need for cascaded stages of bipolar junction transistors of low betas. Behrend *et al*[2] have described three pulse generator topologies namely a spark gap switched Blumlein, a spark gap switched coaxial cable and a solid state modulator, for developing electrical pulse less than 10ns rise time catering to the requirements of biological materials in culture. The transmission line based topologies have the advantage of higher voltages and faster rise times while the solid state modulators have the advantage of varying the pulse parameters namely the pulse width and the switching frequency. Kumar Gyanendra *et al*[3] have implemented the pulse generator based on the tesla transformer driven pulse forming line; in which the coaxial cable is used as the pulse compressor to generate the nanosecond duration pulse. The pulse generator providing the electric field of 18kV/cm, rise time of 25ns and repetition rate of 1.5Hz has been used to expose the cancer cells in a 2mm electroporation cuvette. The different topologies of generating high voltage fast rise time pulses and the effects of nanosecond pulses in bioelectric experiments emphasize the importance of the electric field in the biomedical domain[4-6]. The rectangular high voltage pulses can also be generated using the flyback technique and the Bouncer modulator methods[7]. These methods are appropriate for low power levels. The topology used for development of pulse modulator provides flexibility in terms of peak voltage levels, repetition frequencies and duty cycle.

Schematic of Topology

Power circuit: The block diagram of the pulse modulator for delivering the rectangular flat top pulses to the load is shown below in the Fig.1. The Topology involves generation of high voltage DC and switching the energy stored in the filter capacitor (C) into the load through the solid state switch *viz.* MOSFET. The input voltage (V) is derived from the 230 V/50 Hz AC mains. In order to achieve voltage variation from 20V to 2kV, the AC main is fed to step up transformer T2 (230V/2.5kV) through autotransformer (T1). The auto transformer provides input voltage variation from 0-260V to the input of step up transformer.

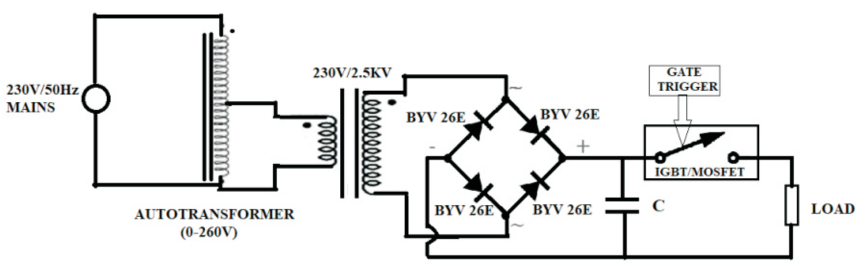

Fig.1: Schematic of the topology.

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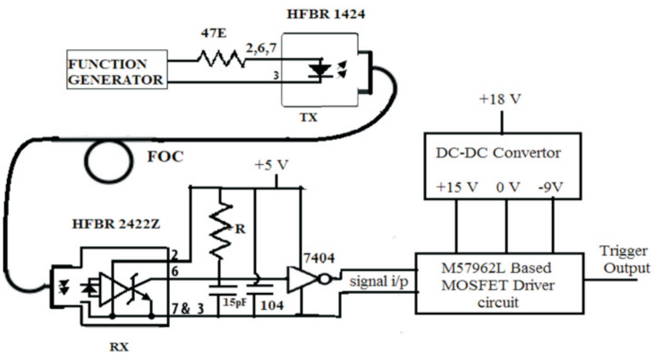

Fig.2: Trigger circuit for solid state switch.

The core material used in the transformer (T2) is CRGO steel. The High voltage AC is converted to high voltage pulsating DC using a bridge rectifier with two BYV26E diodes (1kV PIV & 1A average current) in each arm of the bridge. The pulsating DC voltage is converted to smooth DC voltage by connecting a filter capacitor at the output of the bridge rectifier. This filter capacitor itself acts as the energy storage element. The capacitor was selected depending upon the current drawn by the load. Lower the capacitance value, higher will be the droop during the ON time of the pulse.

Trigger circuit for solid state switch: The trigger system has been designed in such a way that the system can be triggered using the external reference signal or can operate in the standalone mode. The standalone mode of operation is shown in Fig.2. The interconversion between the electrical and the optical signal takes place at the transmitter and the receiver end coupled by the Fiber optic cable. The signal generated at the receiver end is then used as the trigger signal to the driver circuit. The driver circuit is designed to provide the required drive current to turn on the MOSFET IXTH04N300P3HV. In the standalone mode, the timing signal is provided using the, Agilent make Function Generator AFG3052C. The 5V rectangular pulse signal at desired pulse repetition frequency and duty cycle is generated and fed to the HFBR transmitter circuit through a coaxial cable. In order to limit the current input to the HFBR, a 47Ω resistor is connected in series. The electrical pulses are converted to optical pulses and the output of HFBR is coupled with the fiber-opticlink. The optical fiber has FC connectorization at both ends. The 62.5/125μm fiber patch cord has a length of 2m. This optical isolation in between the two electrical circuits makes the system immune from the electromagnetic interference noise. The optical fiber integration ensures remote trigger control operation of the system in restricted areas. The optical signal received from the fiber is converted back to the electrical signal by HFBR 2422z. This IC has with inbuilt opto-transistor in open collector mode. A pull up resistance is connected to Vcc. The output TTL signal is obtained at the collector terminal is in the inverted form. This inverted signal is connected to the logic Inverter IC 7404. The input voltage to the driver circuit is +18 V.

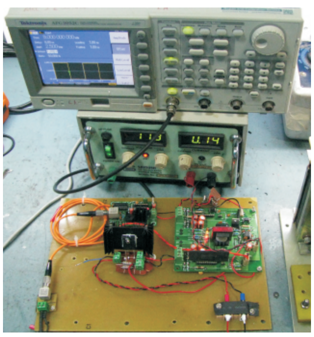

Fig.3: Trigger circuit assembly.

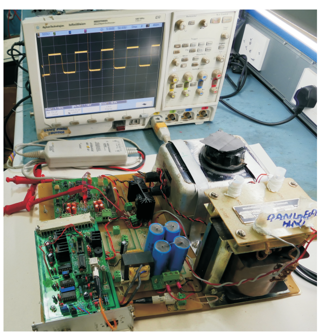

Fig.4: Pulse Modulator.

The output of the optical to electrical receiver circuit is given to the Driver circuit. The driver IC M57962L is a hybrid integrated circuit designed for driving n-channel IGBTs and MOSFETs in any application. This device operates as an isolation amplifier for these modules and provides the required electrical isolation between the input and output with an opto-coupler. Short circuit protection is provided by a built-in desaturation detector. A fault signal is provided if the short circuit protection is activated. The drive current of 500mA is provided by the Driver IC at 50% duty cycle. This drive current capability of the driver IC is higher than the requirement of the IGBT and the MOSFET used. The driver PCB consists of the driver IC M57962L whose primary function is to drive the gate of the MOSFET. This IC requires a dual power supply. The input 18 V is converted to dual power supply of (+15 V) and (-9 V) using a dc-dc flyback convertor topology. The dc-dc converters provide isolated gate drive power. The gate drive power supplies are decoupled using the low impedance electrolytic capacitors. It is very important that these capacitors have low enough impedance and sufficient ripple current capability to provide the required high current gate drive pulses. The switching action provided by the MOSFET IRF530 enables the energy storage in the primary winding (when MOSFET is ON) and energy transfer in the secondary circuit (when MOSFET is OFF). The dot notation of the two secondary winding indicates complementary actions w.r.t ON and OFF times. IC 3844 drives IRF530 ON and OFF at frequency of 172kHz. The output from the Inverter IC 7404 of the receiver circuit is connected to input of the driver IC through a current limiting resistor. The hybrid gate driver amplifies the control input signal and produces high current gate drive at the output terminal. The gate drive current is adjusted by selecting the appropriate series gate resistance. The gate resistance will and normally be adjusted to provide suitable drive for the module being used considering dynamic performance, losses and switching noise. The photograph of the trigger circuit assembly is shown in Fig.3. The entire prototype is depicted in the Fig.4. The experiment was done by powering the trigger circuit and slowly varying the DC input to the energy storage capacitor. This variation was done using the auto-transformer connected to the input of the 230 V/ 2.5 kV transformer.

The final output voltage was measured across the load using the Differential probe: Agilent Technologies (N2790A) which can measure maximum of 1.4kV peak voltage in 500:1 attenuation setting. For measurement of higher voltages i.e. up to 2kV, the HV probe: Tektronix P6015A was used having 1000:1 attenuation setting. Fig.5 and Fig.6 depict the output voltage across the load obtained with variable voltages and duty cycles measured across 47kΩ resistive load.

Selection of Solid State Switch: The IGBTs and MOSFETs are the two solid state switches considered based upon their power handling capacities, switching frequencies, on state voltage drop and the miller capacitance between input and output. The IGBT has higher power handling capacity, lower switching frequency, slower rise and fall times, higher miller capacitance and lower on state voltage drop as compared to the MOSFET. In the switch used in the series configuration as in this topology, the entire load current flows through the switch, hence under higher load condition the voltage drop across the MOSFET becomes significant and impacts the output load voltage. When the resistive load was kept at 200Ω, the current drawn was high enough to reduce the voltage across the load to half of what could be achieved with IGBT as the switching element. The property of lower on state voltage drop makes IGBT the better option during the electroporation experiments in the cuvette where the equivalent load resistance in the

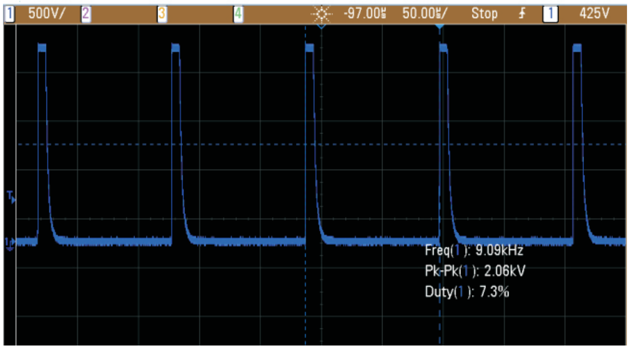

Fig.5: Output voltage of 2kV @ 7.3% duty cycle & 9kHz pulse repetition frequency.

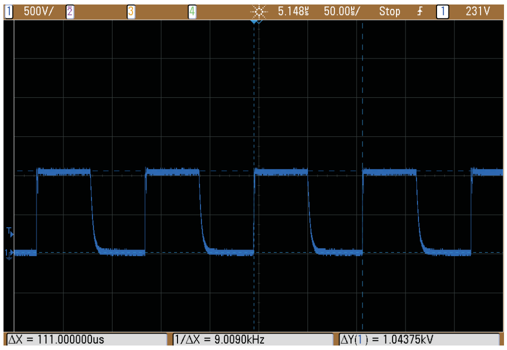

Fig.6: Output voltage of 1kV @ 50% duty cycle & 9kHz pulse repetition frequency.

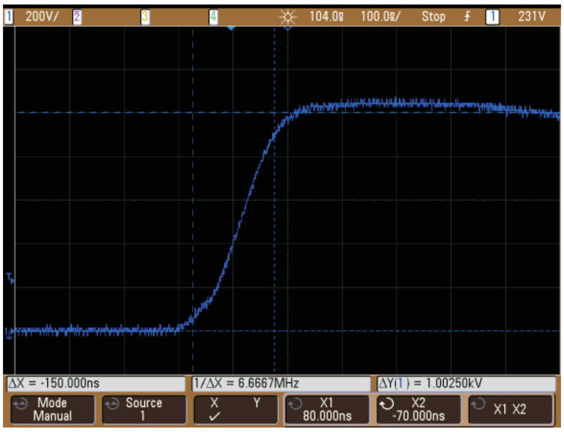

Fig.7: Rise time of pulse with MOSFET.

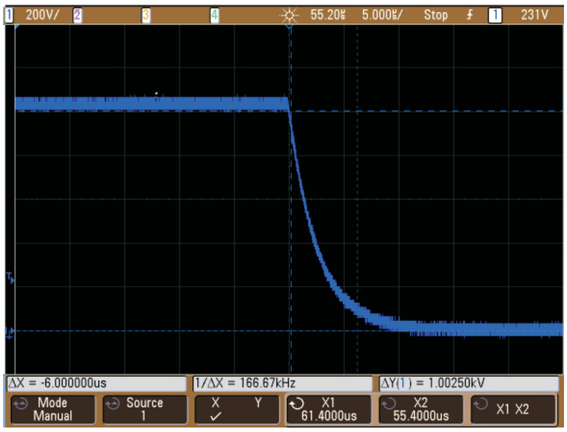

Fig.8: Fall time of pulse with MOSFET.

range of 20-100Ω. On the other hand, when the current drawn by the load is in the mA range, the drop across the device is negligible; in that case the MOSFET provides the advantage of faster switching and faster rise and fall time due to lower miller capacitance compared to the IGBT. This feature of faster switching makes MOSFET a preferable device in the pulsed ion extraction from plasma. Fig.7 and Fig.8 show rise time and fall times of the pulse under 47kΩ load.

Since the current requirement is less, the switching device used to switch the capacitor voltage in to the load is MOSFET. IXTH04N300P3HV having voltage rating of 3kV, continuous current of 400mA and miller capacitance of 23 pF between drain and source. The rise time of the pulse across the load is 150nsecs as shown in the Fig.7. The fall time of the pulse is 6μsecs as shown in the Fig.8. The value is in close approximation of the calculated value; i.e. (5 x load resistance x miller capacitance value) ≈ (5 x 23pF x 47kΩ) ≈ 5.4μsecs.

Conclusion

The working prototype of the pulse power supply has been developed with peak voltage of 1kV, pulse repetition rate of 9kHz and 50% duty cycle. The supply developed has the flexibility in terms of voltage variation up to 1kV, Duty cycle up to 50 percent and pulse repletion rate DC- 9kHz. The prototype can be used as a standalone system and also can be synchronized from the external trigger pulse. The external trigger pulse can be fed to the system through the optical fiber enabling remote operation. The incorporation of the optical fiber based trigger system ensures isolation between the incoming trigger system and the pulse power supply. This also ensures proper synchronization in the electromagnetic noisy environment. This pulse power supply developed, has application in effective Ion extraction of the isotopes in separation process, Electroporation and gene delivery of biological cells and tissues and food sterilization.

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