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Implementation of an Economical and Compact Single MOSFET High Voltage Pulse Generator

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Abstract

The high voltage load applications need very compact generators for the production of fast rising high voltage pulses and are invited in many applications including plasma soft X-ray, ion beam, PEF technology and microwave generators. From the right beginning several technologies have been introduced, Pulse Forming Networks, up to Marx generators. This paper also presents such type of square pulse generator based on power semiconductor device which simplifies the size of the conventional pulse generators. The high electric field intensity square pulses varying in magnitudes in the range of kilovolts with ms to μs pulse widths have been successfully used in many research fields. The advancements in power semiconductor devices, such as power MOSFETs, IGBTs are becoming most suitable for high switching speed high voltage pulse generators. These semiconductor devices are more reliable to control high voltages and currents when implemented in typical circuits. The voltage and current capabilities are increased by connecting the power switches in series and parallel respectively which need aided circuit for protection, equal voltage distributions. This paper presents the design and implementation of such a compact, portable high voltage μs pulse generator based on single power MOSFETs thus avoiding auxiliary circuits. A single CoolMOS™ RF Power MOSFET IXZR08N120B is selected as main switch in this work to produce the high voltage square pulses and is triggered using the suitable high-speed driver DEIC420 with low jitter at higher frequencies. The designed high voltage pulse generator which has variable pulse widths ranging from 2μs to 200μs with a variable pulse magnitude of 1kV is implemented in our laboratory.

Keywords: CoolMOS™ Device, High Speed Driver DEIC420, Power Switch, Pulse Generator, RF Power MOSFET, Schmitt Trigger

1. Introduction

Pulsed power generator has an extremely wider range of applications in defense, medical and civil world. The pulse forming circuits have been designed to generate pulses like exponential decaying waveform, bipolar, unipolar square waveform or oscillating waveforms. The exponentially decaying tail voltage is not useful due to its lower magnitude for the practical applications. The Oscillatory decay pulses produce unnecessary heat. The literature shows that the square pulses are lethal and energy efficient than the other pulses due to constant voltage during on time[1,2]. The conventional developed pulse generators that are in use at present are huge in size with few more challenges of limited switching frequency and synchronization of switches that might be connected in series or parallel[7]. The drastic improvements in the power semiconductor theory might be the revolution technique in the field of pulsed power technology. The pulses have been generated by avalanche transistors and Silicon Controlled Rectifiers (SCRs)[7–9], but their performance in general falls short in one way or another way of that can be obtainable with a properly chosen power MOSFET. The voltage levels are increased by cascading the number of stages[11]. Thus, solid-state devices such as power MOSFETs, IGBTs are turning the attention of researchers towards the design of new pulse generators of high speed with minimized size and cost[3–7]. The advantages of the latest

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semiconductor devices include their high performance, driver complexity reduction and hence easy control. So, the latest food processing technology turns around and developing new pulse generators based on these advanced semiconductors[12–16]. But, it needs custom made devices with required specifications. Hence, alternative techniques are needed and this research details that the high intensity microsecond pulses can be produced by using mass manufactured devices also. A compact and ultrafast RF MOSFET based pulse generator has been developed that produces 1 kV pulses and pulse width in the range of microseconds.

2. CoolMOS™ High Voltage Pulse Generator

The compact, inexpensive circuit to produce the high voltage pulses has been developed with the help of the available power semiconductor devices. The developed pulse generator consists of three system blocks and shown in Figure 1. The single power MOSFET is capable of producing the required high intensity along with proper auxiliary protection circuits.

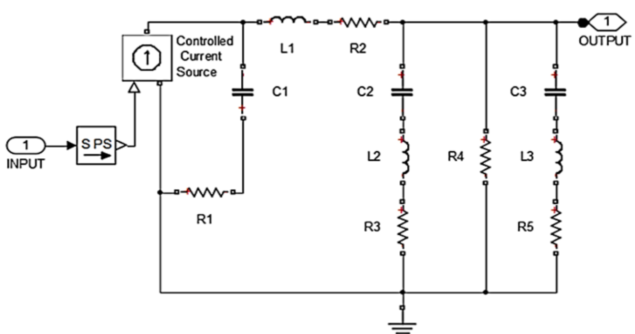

Figure 1. General Block diagram of high voltage pulse generator.

2.1 High Voltage Source

The main goal of this research work was to make the pulse generator as a very compact and portable. The high voltage DC-DC converters could be used to achieve this one. High voltage modules may be any type of available ones in the market, conventional boost converter with voltage doubles stages or cascaded boost converter with advanced topologies. This paper mainly concentrates on the selection of power switch for high frequency operation. So, high voltage supply is made by 1 kV transformer for the present work. The secondary winding is connected to the rectifier with LC filter.

2.2 Power MOSFET Circuit

This work concentrates on the main switch selection to get the required pulses with suitable driver by taking into account of the compactness of the pulse generator. The design specifications require pulse durations as low as possible in the range of µs. Therefore an extremely fast RF MOSFET to meet the requirements has been chosen. The proposed circuit utilizes the CoolMOS™ Technology which further builds upon its advantages. The evolutionary CoolMOS™ transistor family sets new standards in the efficient energy field. As technology advancements in the high voltage MOSFETs, CoolMOS™ brings a significant conduction and switching loss and enables high power density and better efficiency for advanced power conversion systems. The CoolMOS™ products are now introduced in many applications like renewable energy, telecom power supply and adapters. The CoolMOS™ is the ideal solution to meet today's continuously increasing energy demands with appreciable price/performance ratio. This success was achieved by the lowest on state resistance of the MOSFETs in the range of milliohms. In this work, an extremely fast RF MOSFET-IXZR08N120B by IXYs was chosen as the switch. The rated voltage is 1.2 kV. The MOSFET IXZR08N120B RF Power MOSFET has a wide range of features that has over-dominated the use of other conventional MOSFETs. Table 1 shows the features of IXZR08N120B.

Table 1. Features of CoolMOS™ IXZR08N120B

Features	compared to other HF/RF MOSFET	compared to conventional MOSFET
Switching Speed	Equivalent	5-10 times faster
Frequency	Equivalent	5-10 times higher
High gain	3 times higher	Many times higher
Power Dissipation	2 times higher	3 times higher
Low Inductance Packaging	Has the least	Has the least

A high current driver was required to trigger the MOSFET because the input gate capacitance of the MOSFET draws high charging current during initial period. The driver also has to be fast with lower rise and fall time. The MOSFET driver DEIC420 which has 4ns rise time was chosen. The DEIC420 can be operated at higher switching frequency and able to supply high current to trigger the power MOSFET. These gate drivers are suitable to drive class D and E High frequency MOSFETs and other applications where fast rise and fall time with shorter pulse widths are required. The DEIC420 driver is able to supply 20A peak current. The small internal delays in the pulse generation, cross conduction losses and current shoot through are eliminated in the DEIC420 gate driver. These attractive features, wide safety margin in the operating voltage and power make the DEIC420 as popular.

2.3 Gate Triggering Pulse generation

The Schmitt trigger based relaxation oscillator which works as an as table multi vibrator is used here to produce the control pulses. This particular version is useful and produces variable pulse widths. The feedback resistors connected along with MC74AC14 integrated circuit are helpful to adjust the pulse widths in µs scale. The variable resistance range is from 500 Ω and 15kΩ. The feedback capacitor value is 10pF and 1N4148 diode is also used in the feedback path.

3. Simulation Results and Discussions

The gate driver DEIC420 is modeled using MATLAB version. The model schematic is shown in Figure 2 based on the data sheet. V_i is a pulse voltage source. Here the delay time T_D, rise time T_R and fall time T_F should not be changed from their present settings. The passive devices C_1 and R_1 are included to permit the internal power consumption. The L_1 and R_2 devices are used to present the internal impedance of the device. The internal strays of the DEIC420 are represented by using C_2, L_2 and R_3. The resistor R_4 is compulsory to ensure that the Pspice functions properly if the load is removed. The load comprised of C_3, L_3 and R_5. The capacitor C_3 shows the value of the specified load capacitance. The values of L_3 and R_5 represent the stray terms Equivalent Series Inductance and Equivalent Series Resistance. The inclusion of these stray components is essential to work at higher switching frequency. The passive component values are given in Table 2. The pulses generated at 5 kHz and 500 kHz are shown in Figures 3 and 4 respectively. The oscillations are found in the rising edge and falling edge of the pulses at higher frequencies.

Table 2. DEIC420 Driver Model Values

Model components	Values
R_1,R_2	0.1Ω
R_3	1Ω
R_4	1kΩ
R_5	0.5Ω
C_1	6.6nF
C_2,C_3	1000pF
L_1,L_3	1nH
L_2	10nH

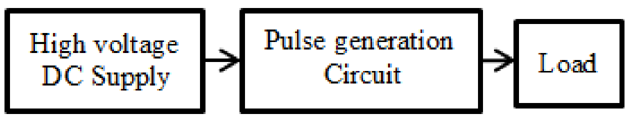

Figure 2. DEIC420 high speed driver model schematic.

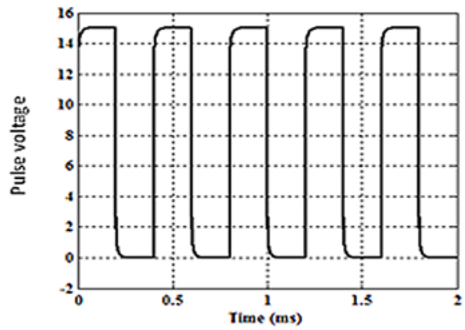

Figure 3. Gate pulse generated by DEIC420 for the frequency of 5kHz.

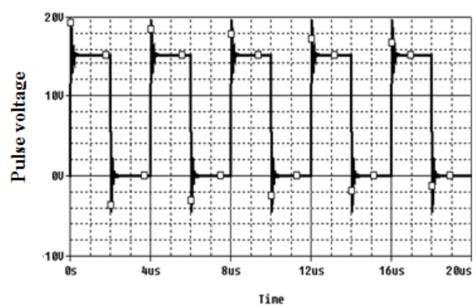

Figure 4. Gate pulse generated by DEIC420 for the frequency of 500kHz.

The designed pulse generator as shown in Figure

5 consists of single n channel enhancement mode connected in common source configuration. The power MOSFET, IXZR08N120B, is capable to withstand voltage of 1.2kV and drain current of 16A. The control pulse of 5V is amplified to 18V by the integrated driver IC DEIC420. Figure 6 shows the simulation output of pulse generator.

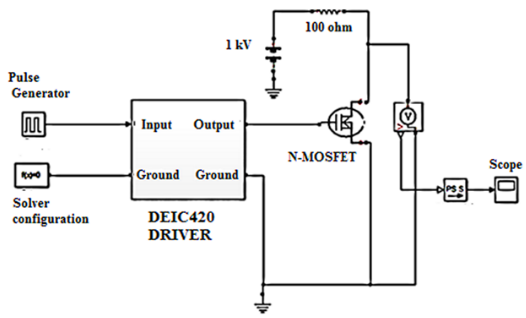

Figure 5. Pulse generator using single N-channel MOSFET along DEIC420.

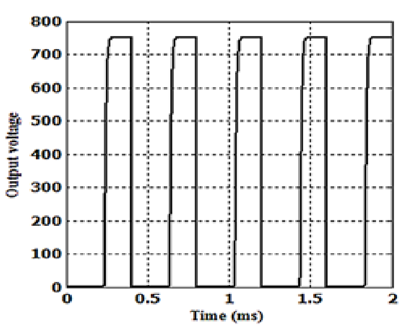

Figure 6. Output square pulse when the input is 750V.

4. Experimental Results and Discussions

The MCIC74AC14 operates from a 5V supply and the DEIC420 driver from 18 V supply. The energy efficiency could be increased by minimizing the pulse width and achieved either by increasing the pulse amplitude or pulse repetition rate for biological applications. The pulse width could be varied by adjusting the feedback resistor from 500Ω to 100kΩ to get pulses in the range of 40ns to 7us. Figure 7, shows the photograph of the pulse generator hardware. The pulsar is tested at our laboratory at 750V and the clock signal generated by MC74IC14 and the output of the compact pulse generator circuit is shown in Figure 8 and Figure 9 respectively. A pulsed waveform of 659V, 2μs was obtained.

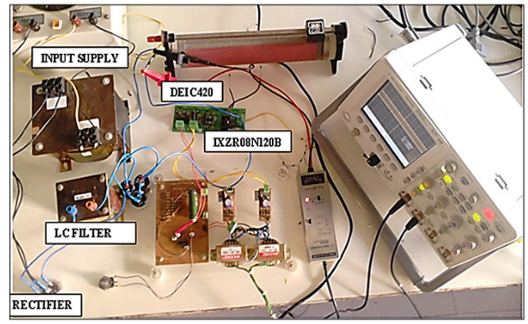

Figure 7. Experimental set up of Pulse Generator using IXZR08120B.

Figure 8. Gate pulse of MOSFET. Pulse width is about 6μs. The waveform was recorded on a Agilent Technologies 6000, 100MHz,2 GSa/s Digital Storage Scope.

Figure 9. Output voltage pulse tested for the input voltage of 750V. The output voltage is 659V at 499 kHz. The pulse width is about 2μs. The waveform was recorded on a Agilent Technologies 6000, 100MHz, 2 GSa/s Digital Storage Scope.

5. Conclusion

The novel simplest economical μs pulse generator based on Schmitt trigger circuit was designed, implemented and tested successfully. The Schmitt trigger produces fast rise time and pulses in the range of μs. The needed electric field intensity for biological applications like electroporation in the range of 5kV/cm to 10kV/cm could be achieved by the designed pulse generator by varying the electrode gap distance. The work may be extended by designing proper high voltage DC-DC converter to supply the designed pulse generator.

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