



Drift-Steps-Recovery diodes based on pulse power circuits and their applications

Seyed Mohammad Hassan Hosseini*¹, Roya Feli¹

¹ Department of Electrical Engineering, Islamic Azad University South Tehran Branch, Tehran, Iran.

Abstract

In this paper, nanosecond pulse power generators and their applications are reviewed. Generally, in pulse generating circuits, the Drift-Steps-Recovery diodes (DSRDs) play an important role as the opening switches. The simulation of a pulse generating circuit using (DSRDs) is done by using MATLAB software. A generating circuit of unipolar and then bipolar pulses are simulated and discussed. Whereas in all simulations we focus on a pulse generator circuit because of its important application.

Keywords: Pulse Power Circuits, Drift-Step- Recovery Devices, Pulse Power Generator, Power Semiconductor Devices, Opening Switches.

1. INTRODUCTION

Nanosecond pulse power generator can be used in different applications like ultra wideband ground-penetrating radars, underground detection, and the study of the effect of severe electrical fields on the biological material [3]. Also electrical pulses with peak power from megawatts to terawatts and pulse duration from tens of picoseconds to tens of microseconds are used in many modern technologies such as power laser and accelerator technologies, super wideband radars, and plasma chemistry. In field of detection of underground anomalies [1]- [2], the transmission of EM shock wave from one borehole to another is used. When an EM pulse is injected into a leaky transmission line (TL) placed along a dielectric bulk, an EM shock wave is radiated inside the bulk if the velocity of the signal inside the leaky TL exceeds the phase velocity in the bulk [2]. In fact, one transmitter is connected to another line. The transmitter gener-

ates an electrical pulse that releases through the leaky TL and therefore the signal radiates outside. The type of the line is chosen such release through the line is faster release through the ground. This shock wave scans the ground around the transmitting TL [2]. If the ground has an anomaly such as a metallic pipeline between the two boreholes, it will disperse the shock wave. In this case the received signal is disturbed according to the shape and the location of the anomaly [2].

It was shown that the electro permeability of a cell membrane occurs when the transmembrane potential induced by an applied electric field reaches a threshold of about 1 V [3]. Traditionally, this critical potential was obtained by using long and relatively low voltage pulses. The electrostatic component of the field applied to the cell results in charge migration within the cellular medium that creates a membrane voltage potential over time [3]. Nowadays, with developing the nanosecond pulse generator technology, generat-

*Corresponding Author's Email: smhh110@azad.ac.ir

ing of pulses which are noticeably shorter than the charging time of the plasma membrane is possible. There is no significant charge migration for these short pulses, and the cell can be modeled as a dielectric shell [3]. It was shown that Nano pulses with megavolt-per meter field strengths result in non-destructively a number of intracellular activities, including calcium bursts and the appearance of apoptotic indicators [3]. There are several reasons to examine the effects of high-peak-power, low-total-energy pulses on biological materials [3]. Nanosecond pulsed electric fields was effective to induce tumor regression in vivo and kill cancer cells in vitro [3]. In addition, research at USC into the sensitivity of cancer cells to nanosecond pulsed electric fields has led to the development of a high voltage Nano pulse system for cancer treatment. So, a new pulse generator architecture that uses a bank of junction recovery diodes as an opening switch to produce pulses with widths as short as 2.5 ns was used [3]. Studying inductive (unipolar) pulse into existent phosphatidylserine in the out section of the cell membrane, give us a model which can be used both for shorter and bipolar pulses. For initial unipolar pulse examination, trans membrane potential is calculated of the dielectric shell model of the cell that reaches voltage of 1v, and that previously has been adequate for providing active transfer energy. ($1 \text{ eV} = 100 \text{ kJ/mol}$); field-gravitation transfer theory with short pulses and strong field, if exiting of phosphatidylserine resulted by plasma membrane electrostatic potential occurs during 7 nanoseconds, 2.5 MV/M pulse and then a very short pulse that could charge the membrane toward conductive potential and then will create a field less than 10-20 MV/m in the made dielectric membrane in each of two experience, that ought not cause fast transfer of phosphatidylserine. But it may have other effects; Results of strong field transferred into the internal environment of cell. Field-gravitation transfer theory forecasts that a series of pulses, in the polarity conversion state, could translocate phospholipid in two sides of membrane. Acquired initial results by help of diodes that pro-

duce unipolar and bipolar pulses are explained at this paper and they are based on homological direct electrical field-gravitation transfer theory.

Sub nanosecond pulses are useful because wide-band antennas can be used for transmitting the electromagnetic fields into tissue with spatial resolution in the range of a centimeter. This is particularly attractive as a means of transmitting electromagnetic fields to localized regions within the body to treat cancer [3]. In many pulse power generators, different kinds of power semiconductor devices such as thyristors, insulated-gate bipolar transistors and etc. are used. In addition, semiconductor opening switches has a key role in generating pulse power via inductive energy storage. Semiconductor switches have extended the scale of pulse power parameters such as the repetition rate and the period and have developed the pulse power applications such as accelerators, and gas lasers. Drift-step-recovery diodes (DSRDs) are fast opening switches which are suitable for use in these generators. DSRDs produce nanosecond pulses with high peak and average power. When high pulse repetition frequency is used to achieve a high average power, the circuit efficiency becomes an important factor. These diodes use a fast reverse recovery characteristic. According to these applications, DSRD-based pulse generating circuits are presented and then simulation results are given.

2. DRIFT-STEP-RECOVERY DIODE CHARACTERIZATION BY A BIPOLAR PULSED POWER CIRCUIT

In generally, DSRDs use a fast reverse recovery characteristic. High-voltage pulses with a rise rate of the order of 1 kV/ns and nanosecond and subnanosecond pulses in range of hundreds of volts to several kilovolts. High voltage operation is achieved by stacking several DSRD dies in series.

According to Fig. 1. [1] for the initial state, two capacitors are charged at first. Then, a first switch closes, enabling the discharge of a capacitor through the diode in the forward direction via a series inductor. The resonance loop causes a

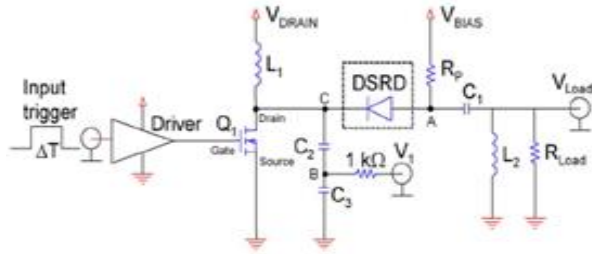


Fig. 1. Bipolar pulsed-power resonant circuit for testing DSRD [1].

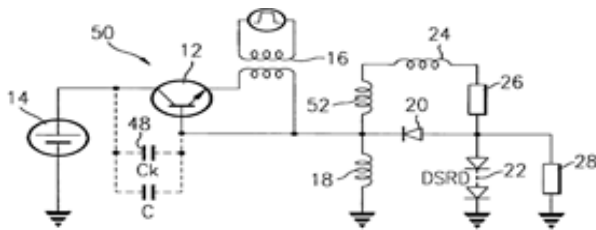


Fig. 2. Pulse generating circuits using DSRDs [4].

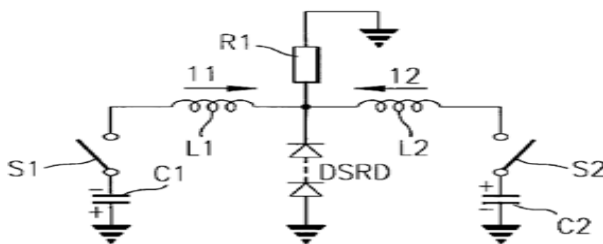


Fig. 3. Simple diagram of a pulse generating circuit by using DSRD [4].

sinusoidal current pulse through the diode. At the end of that pulse, the first switch opens, and a second switch closes, forcing reverse current through the diode. The reverse current loop has a different time constant but great value current. Ideally, the current interruption by the DSRD occurs at the peak of the reverse current at current densities of hundreds of amperes per square centimeter. The current then flows through the load, which is connected in parallel to the diode. In this circuit, MOSFET serves to pump the DSRD in the forward direction and then to pulse it in the reverse direction and a bias voltage source to balance the forward pumping current with respect to the reverse discharge. Placing DSRD in series between the MOSFET and the load results in temporal and polarity separation of

the MOSFET and DSRD pulses at the load, thus allowing viewing of net DSRD signal.

3. PULSE GENERATING CIRCUITS USING DRIFT STEP RECOVERY DEVICES

Current passed via the transistor increases in the storage inductor and the pumping inductor and is blocked by the separating diode to inject electron-hole plasma from the pumping inductor into the drift step recovery diode when the transistor is conducting. The transistor blocks current at the end of the trigger pulse and the storage inductor reverses polarity to bias the separating diode into a conducting state to extract the plasma from the drift step recovery diode. The drift step recovery diode blocks current after the plasma has been extracted to switch current from the storage inductor into the load resistor to generate a pulse. The circuit is shown in Fig. 2 [4].

A simple circuit for a pulse generating by using DSRD is shown in Fig. 3 [4].

4. OPERATIONAL STATE OF UNIPOLAR AND BIPOLAR PULSED POWER GENERATOR

In this Section, two stage voltage booster based on DSRD is presented. A generator produces $\pm 250\text{V}$, 3 ns, and 100 KHz pulses while the load is 50Ω . Bipolar pulses are produced by using unipolar pulses and parallel connection of transmission line. So, the output is the total sum of initial value and inverse delayed pulse. In Section 1, inductive electric field into the cells was explained. Pulses, with longer than $1\mu\text{s}$, charge the out layer of cellular membrane and also cause opening of pores continually or temporarily and finally make the cancer cell death. Pulses, with shorter than $1\mu\text{s}$, influence on interior layer without any effect on out layer. Expectable effects of pulses, with shorter than 0.1ns and voltage domain 5-10 MV/m, are apoptosis and programmed cell death. Studying inductive (unipolar) pulse into existent phosphatidylserine in the out section of the cell membrane, give us a model which can be used both for shorter and bipolar

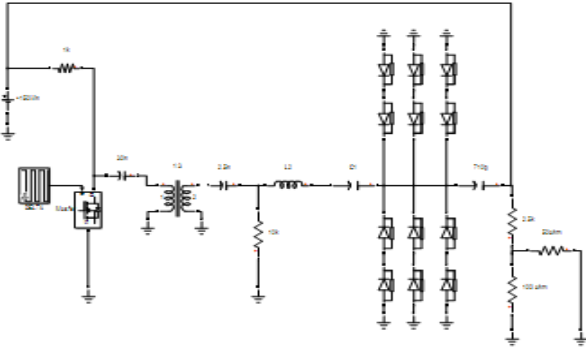


Fig. 4. Pulse power generator (generating bipolar pulses at load).

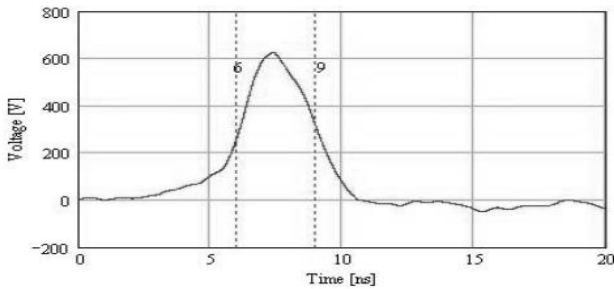


Fig. 5. One generated unipolar output pulse.

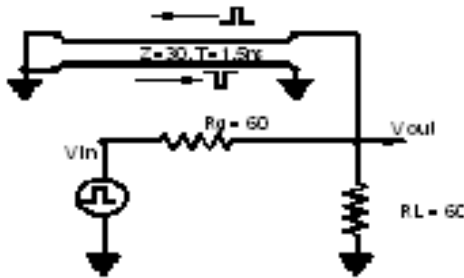


Fig. 6. Operational state of bipolar pulsed power generator.

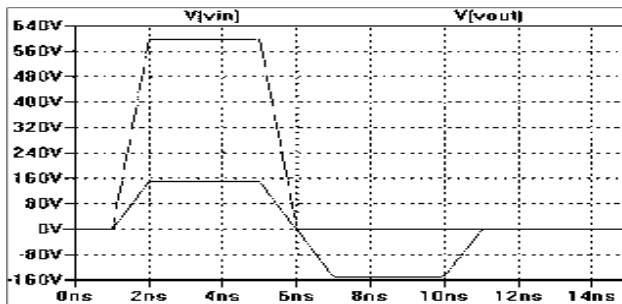


Fig. 7. Input and output diagram of bipolar pulsed power generator (simulation result of Fig. 6).

pulses. Initial results acquired using unipolar and bipolar pulse generating diodes which are explained in following. In this part, a 600v, 3ns and high frequency pulse generating circuit based on a Drift-Step-Recovery Diode is designed and presented.

There are two approaches for generating bipolar pulses; 1. separating unipolar square pulse by using capacitor bank and a MOSFET put on pulse generator, 2. shortened transmission line approach which has application both for square and no square pulses. Pulse is generated by a DSRD which acts as a start switch and interrupts current in one inductor and directs it into load resistor, see Fig. 4.

After simulating pulse generating circuits, as shown in Figs. 2-3, the unipolar output pulse is shown in Fig. 5.

The practical principles of making bipolar pulses are shown in Fig. 6 and the input and output diagram of bipolar pulsed power generator is shown in Fig. 7.

Short circuit transmission line is modeled by an equivalent circuit into a resonant parallel LC-circuit in Fig. 8.

First we approximate the total inductance $L=TZ$ or $L=62.9$ NH, then the total capacity equals $2C=T/Z$ or $C=50$ pF. The input and output voltages obtained via simulation are shown in Fig. 9.

As, it is seen in Fig. 9, there is no symmetry between the positive and the negative parts of bipolar pulse. An appropriate symmetry may be obtained by changing the amounts of inductors and capacitors.

Now, the circuit shown in Fig. 4 is simulated and the output voltages of upward and downward DSRDs are shown in Figs. 10, 11.

At the end, the output voltage on the load is is illustrated in Fig. 12. So, the output is total sum of the initial value and delayed inverse pulse that in facts indicates one bipolar pulse.

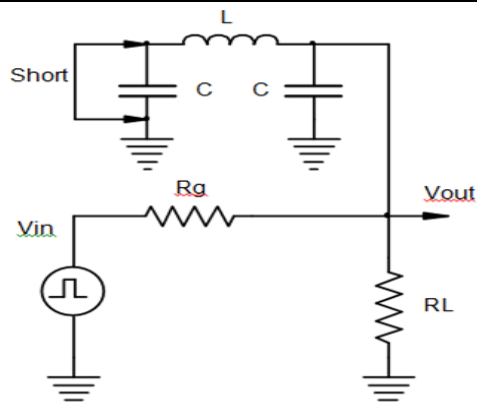


Fig. 8. Generated bipolar pulse at short transmission line caused by LC resonance.

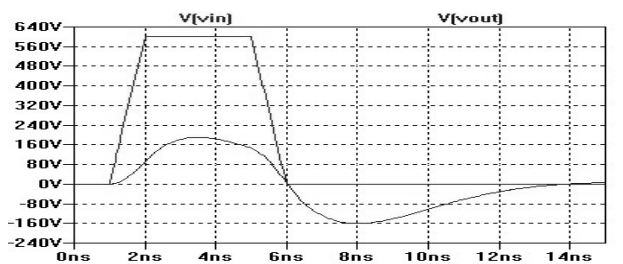


Fig. 9. Generated bipolar pulse at short transmission line (simulation result of Fig. 8).

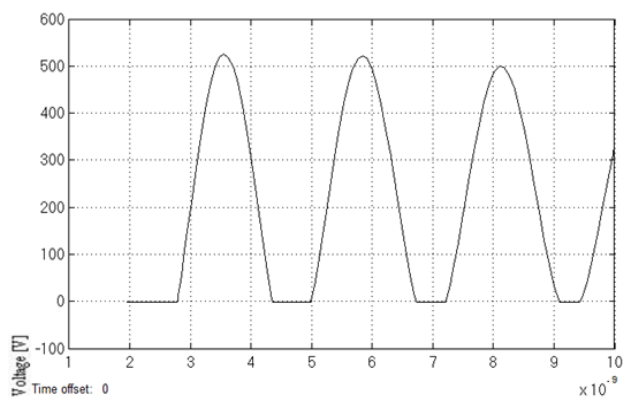


Fig. 10. Output voltage of upward DSRDs.

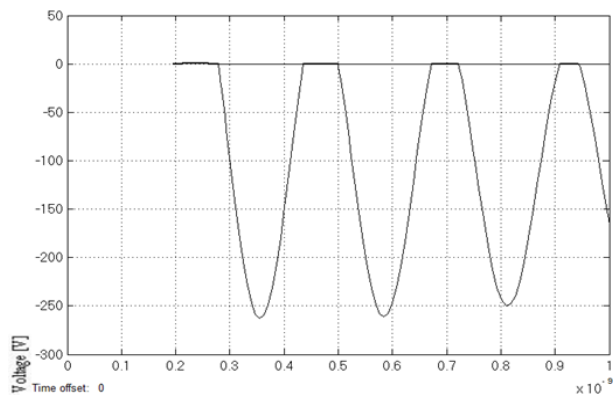


Fig. 11. Output voltage of downward DSRDs.

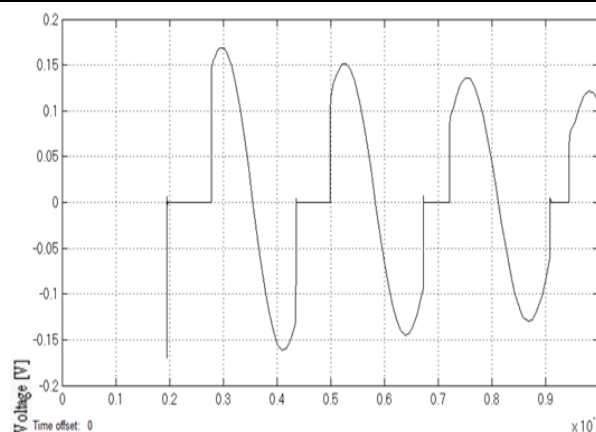


Fig. 12. Load output voltage.

5. CONCLUSION

This paper focuses on Drift-Steps-Recovery diodes based on pulse power circuits and their applications. A pulse power generating circuit was represented. According to the simulation results, bipolar pulses can be generated by using unipolar pulses. In fact, the main purpose of this paper was generating bipolar pulses by using DSRD devices because of the important applications of these pulses.

REFERENCES

- [1] Lev M. Merensky, Alexei F. Kardo-Syssov, Doron Shmilovitz, and Amit S. Kesar, "Efficiency Study of a 2.2 kV, 1 ns, 1 MHz Pulsed Power Generator Based on a Drift-Step-Recovery Diode," IEEE Transaction on plasma science, Vol. 41, No. 11, Nov. 2013.
- [2] A. S. Kesar, "Underground anomaly detection by electromagnetic shock waves," IEEE Transaction on Antennas Propagate, vol. 59, no. 1, pp. 149–153, Jan. 2011.
- [3] J. M. Sanders, A. Kuthi, Y. H. Wu, P. T. Vernier, and M. A. Gundersen, "A linear, single-stage, nanosecond pulse generator for delivering intense electric fields to biological loads," IEEE Trans. on Dielectric and Electrical Insulation, vol. 16, no. 4, pp. 1048–1054, Aug. 2009.
- [4] A. F. Kardo-Syssov, V. M. Efanov, S. V. Zazulin, and I. G. Tchashnikov "Pulse gen-

- erating circuits using drift step recovery devices," U.S. Patent 6 087 871, Feb. 26, 1997.
- [5] A. F. Kardo-Sysoev, "New power semiconductor devices for generation of Nano- and sub nanosecond pulses," in *Ultra-Wideband Radar Technology*, J. D. Taylor, Ed. New York, NY, USA: CRC Press, 2001, Ch. 9.
- [6] A. S. Kesar, Y. Sharabani, L. M. Merensky, I. Shafir, and A. Sher, "Drift-step-recovery diode characterization by a bipolar pulsed power circuit," *IEEE Trans. Plasma Sci.*, vol. 40, no. 11, pp. 3100–3104, Nov. 2012.
- [7] A. Krasnykh (SLAC), "A Working Principle of the DSRD-based Schemes and How this Principle May Be Transformed for the Induction Linac Concept (for SLIM Concept).