Drift Step Recovery Devices Utilization for Electromagnetic Pulse Radiation

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***Abstract*—Utilization of drift step recovery devices for high power electromagnetic short pulse radiation is discussed here. Possibility of powerful impulse radiation is connected with decision of two problems: how to reach stable extremely powerful impulse of nanosecond and subnanosecond duration with repetition rate of dozens and hundreds of kHz; and how to bring to antenna and radiate such energy?**

Among solid-state devices for short pulse generation the drift step-recovery devices look the most suitable ones. Drift step-recovery diodes (DSRD) and transistors (DSRT) are capable to form nanosecond impulses with up to MW peak power and hundreds of kHz repetition rate. High efficiency, compactness, lightweight and reliability of these switches make its very promising devices for UWB radars and communications.

Taking into account nature of drift-step recovery devices the appropriate antenna structure should be found. To combine the drift-step recovery technology with energy accumulation into antenna is proposed and discussed. The DSRD/DSRT switches, interrupting antenna current, are able to hold very high over voltage, taking place at the breaking of antenna current. Therefore a level of electromagnetic pulse radiation is basically determined by antenna current driver capabilities.

Prototype of antenna-generator was developed, manufactured and successfully used in transmitter module of the VIY-2 ground penetrating radar. As high peak voltage as 250…300 Volts with pulse repetition frequency 100 kHz can be achieved with 12 Volts powering. Power consumption of this module didn't exceed 5 Watts.

Description of the transmitting module operation principles and schematics are presented here. It is shown that proposed schematics could be utilized to achieve such impulse peak power as 100 kW and more.

Keywords-drift step-recovery effect; drift step-recovery diode; DSRD; drift step-recovery transistor; DSRT; nanosecond pulse generator; electromagnetic pulse radiation;

I. INTRODUCTION

In general an electromagnetic energy radiating system consists of such basic components as generator, feeder, RF balloon and antenna. Conventional way of the design assumes that the system is divided into separate parts and they are developed under condition of neighboring unit's impedance matching. To determine efficiency of energy transmission along the system a standing wave ratio (SWR) is used. This approach is very good for narrow band system development.

However this algorithm can't be utilized for design of ultra-wide-band (UWB) or impulse systems because of transient operation mode that is the system parameters are time-dependent. As a result connection of the units that operate correctly separately is not allowed to get expected results.

We propose to develop powerful impulse radiating system entirely without it's splitting to separate parts. Following the design concept the shorter way between generator and antenna the smaller power loss and signal disturbance and the higher the system efficiency. Feeder can limit impulse power transfer. It can be omitted if the pulse generator is mounted on the antenna directly. The UWB RF balloon for high power transformation is too bulky and should be leaved out too. It is possible if the impulse generator has balance outputs. Consequently powerful impulse radiating system consists of integrated on single unit pulse generator and UWB antenna.

At this paper we discuss design of power nanosecond pulse generator, principles of high effective transmitting antenna design, and present results of the proposed antenna-generator examination.

II. DSRD GENERATOR WITH BALANCE OUTPUT

To generate powerful nanosecond pulse a novel generation of semiconductor switches – drift step-recovery diodes (DSRD) and transistors (DSRT) are seemed very attractive. The impulse generators based on DSRD/DSRT allow to form nanosecond pulses with hundreds of kilowatts peak power and hundreds kilohertz pulse repetition frequency (PRF) [1], [2].

The drift step-recovery effect (DSR) was discovered by Russian scientists from Ioffe Physic-Technical Institute, St. Petersburg in a middle of 1980s [3]. It observes in power drift rectifier diodes with slow carrier under specific current flow conditions. First some charge is injected into p-n junction and then removed from it. As soon as the charge into p-n junction will be equal zero the diode closes rapidly. There is only one initial condition to obtain the DSR effect – injected into the p-n junction charge should not to reach opposite side of the p-n junction during the injection process. Usually this time is limited by some hundreds of nanoseconds. To simplify the

DSR effect description imagine the DSRD as parametric capacitor with high capacitance in direct biasing and low capacitance in opposite biasing. Using this model we can estimate rise and fall time of generating impulse, and its peak power.

To bring a diode into the DSR regime a special current waveform has to be formed. If forward and reverse current waveforms will be the same the DSRD switches off when the current through the diode is equal zero. And expected effect will be negligible small. To maximize the DSR effect the forward current through the diode should has low magnitude and long duration; and opposite, the reverse current should be high magnitude and short duration. An optimal regime is the DSRD switches off when the reverse current magnitude reaches maximum value.

The current waveform through the DSRD is produced by special driver schemes. There are known schemes based on two switches [4], impulse transformer with saturates core [5], voltage reverse on inductive storage [6], and so on. We propose driver scheme that utilizes both capacitive and inductive storages to produce optimal current waveform.

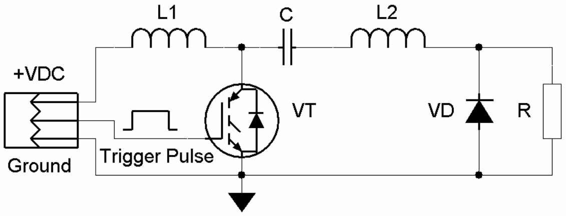

Figure 1. The DRSD current driver scheme

Our DSRD driver (Fig. 1) consists of two circuits joined with power switch VT (for example, MOSFET or IGBT transistor). The first circuit contains inductive storage L1 and the second one contains capacitive storage C, inductive storage L2 and DSRD – VD in serial. Load resistor R is connected with the DSRD in parallel. Before the impulse generation the switch VT is closed and capacitor C is charged up to power supply voltage via resistor R.

The scheme was modeled by Micro-Cap 7.0.0.0 and the results are presented on Fig. 2. As soon as the transistor VT opens, two processes are observed (Fig. 2). Capacitor C discharges through VD and inductance L2, and inductance L1 accumulates the energy. After approximately 1/2 of oscillation period of circuit formed with C and L2, VT switches off. Current flowing through L1 joins with current flowing through C and L2. As soon as injected into p-n junction of VD charge is equal zero, the DSRD switches off. Because it is happened when non-zero current flows through the DSRD a reverse voltage impulse appears on the VD terminals due to self-induction effect. Rise time of the impulse is determined by inductance L2 and reverse capacitance of the DSRD. Kinetic energy accumulated by L2 during the reverse current flowing transforms to potential energy on the DSRD reverse capacitance. Peak power is approximately equal multiplication of the interrupted current magnitude with wave resistance of a circuit formed with inductance L2 and reverse capacitance of the DSRD.

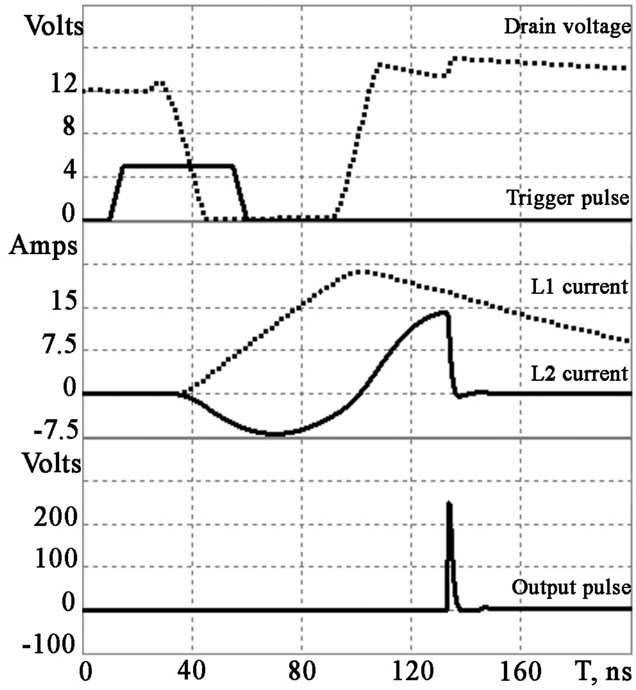

Figure 2. Waveforms of different points of the scheme: trigger pulse (a), MOSFET's drain voltage (b), current through L1 (c), current through L2 (d), load voltage (e).

Known DSRD generators operate with resistive load. To utilize such generators for electromagnetic impulse radiation the special RF wideband balloon is required. In order to connect DSRD generator to the antenna directly the generator should have balance output. The balance output can be realized with single switch or combination of two generators of opposite polarity. It is known single switch nanosecond pulse generator based on avalanche transistor [7]. Utilizing of two generators of opposite polarity combination meets with troubles of opposite impulse parameters synchronizing and adjusting.

The proposed DSRD generator can be easily modified to produce either positive or negative impulses, or both impulses simultaneously. In this case it is enough to double power supplies and L1, L2 and C.

III. ENERGY CLASSIFICATION OF ANTENNAS

It is known a lot of different antennas design that are positioning as electrical or magnetic dipoles, self-augmented or fractal structures, transmission line configurations and so on. We propose to consider electromagnetic radiators from point of view of energy transfer from generator to antenna.

In general electromagnetic radiation is taken place during the energy transformation, potential to kinetic and vice versa. Electromagnetic radiation is observed during charged particles deceleration, changing of antenna current and so on. Antenna system forms radiation pattern however radiation strength is depended on energy, injected into the antenna structure. Therefore to get stronger radiation to bring more energy into the antenna is necessary. In spite of numerous antenna types are known anyone refers to structure with simultaneous energy transfer and transformation, or with separation of these processes (Fig. 3).

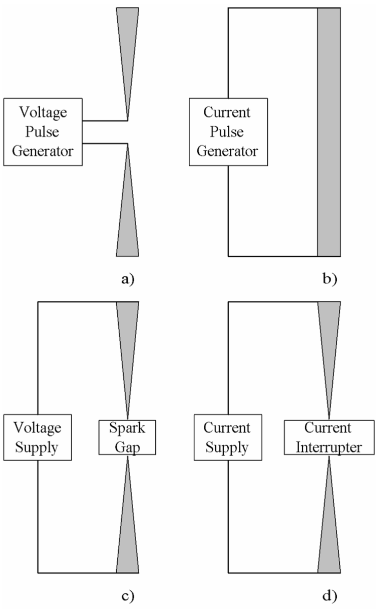

Figure 3. Antenna with voltage (a) and current (b) excitation, potential (c) and kinetic (d) energy accumulation.

Antennas with voltage excitation (Fig. 3a) are most frequently used. They are realized by impulse voltage applying to the antenna terminal. In this case electromagnetic energy radiation are taking place simultaneously with energy transfer from generator to antenna. The antenna radiates injected into it energy only. Therefore impedance matching between generator and antenna should be certainly maintained. Antenna's input impedance is about some hundreds Ohms so high voltage impulse generator is required to get powerful radiation.

Antenna with current excitation (Fig. 3b) or, so-called, large current radiator (LCR), has low impedance and easily matches with impulse generators [8]. However because of small dimensions and low effectiveness to reach high power radiation is very difficult.

Antenna with potential energy accumulation looks very promising for powerful radiation (Fig. 3c) [9]. Since transfer and transformation processes in such antenna are separated it can accumulate long time a lot of energy and radiates it during short time interval. The Hertz dipole is such system, for example. The processes separation eliminates necessity of generator with antenna matching. The antenna accumulates electrical charge at first, and then mounted into the antenna terminal spark gap discharges it. Extremely high power radiation can be reached [10], however pulse repetition frequency and impulse shape stability are strongly dependent on the spark gap parameters.

Antenna with kinetic energy accumulation (Fig. 3d) is seemed more attractive then previous one. In this case energy accumulates by the antenna inductance and operates with comparatively low voltage power supply. Electromagnetic radiation appears during breaking of the antenna current. Impulse shape doesn't depend on the switcher parameter and is exclusively determined by passive components of the antenna system. As a result nonvolatile impulse shape stability can be achieved. However the switch should interrupt large current at nanosecond time and keeps high over voltage because of self-induction effect.

IV. EXPERIMENTAL RESULTS

Since the DSRD can interrupt hundreds amperes current and keep impulse voltage up to dozens kilovolts, it is nature choice for current interrupter of kinetic energy accumulation antenna. To examine proposed concept we designed original configuration antenna and combined it with our DSRD generator. The antenna is symmetric constant impedance TEM horn that is transformed to asymmetric TEM horns through wide dipole sections (Fig. 4). Rear region of the antenna is covered by metal screen. Loop sections and the screen form asymmetric TEM horns that provide additional impulse shape correction because of part energy radiation along perpendicular to main lobe directions.

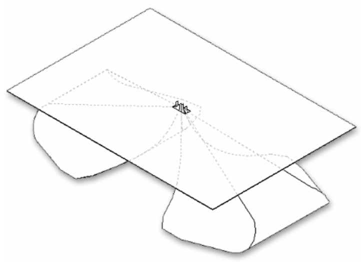

Figure 4. TEM horn with kinetic energy accumulation.

Resultant loops accumulate energy during the DSRD charge injection. They are used instead of inductances L2 of the generator (Fig. 1). The DSRD is connected to the antenna terminals. To avoid "ringing" effects the antenna terminal and loops are arranged by damping resistors.

The antenna-generator design is shown on Fig. 5.

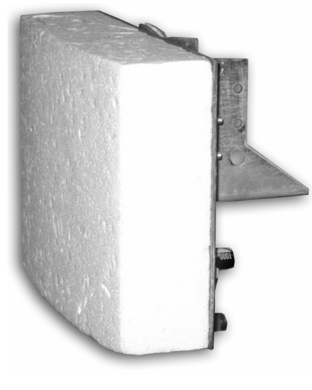

Figure 5. Antenna-generator for nanosecond pulse radiation.

The antenna dimensions are 200 x 160 x 80 mm^3. The antenna plates are fixed by closed-cell foam plastic. It weights about 1 kg.

The DSRD generator and power supply are mounted on the rear surface of the antenna. The generator dimensions are 70 x 60 x 50 mm^3. We obtained 440V_{p-p} voltage on the antenna terminal with 250 kHz PRF under air-cooling condition. Power consumption doesn't exceed 3 Watts at 100 kHz PRF with 12VDC powering.

Received signal waveform is shown on Fig. 6, and power spectrum is shown on Fig. 7. Note that antenna with 150 mm aperture radiates impulse with bandwidth from near 50 up to 600 MHz. Relative bandwidth of the receiving signal is more than 85%.

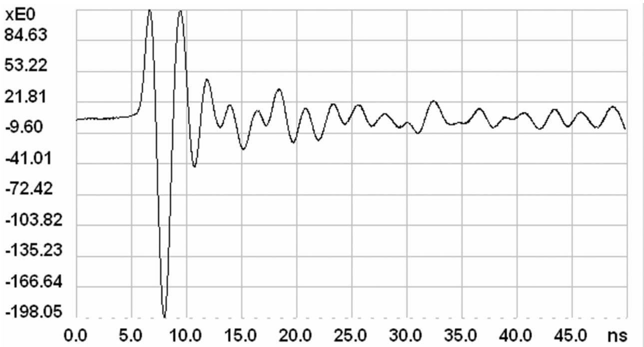

Figure 6. Receiving signal waveform on 4.5 meters distance between transmitter and receiver

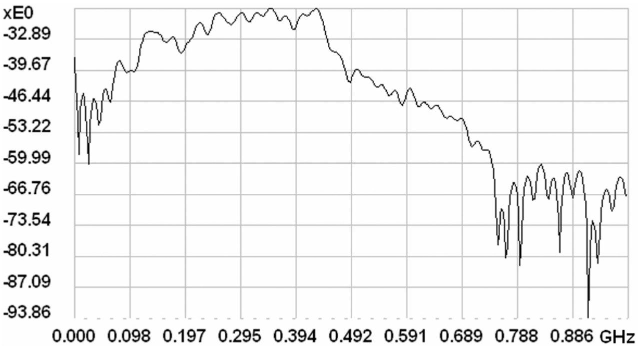

Figure 7. Power spectrum of the receiving signal.

Similar antenna-generator was used with VIY-2 ground penetrating radar (GPR) as transmitter module. Power consumption of the module didn't exceed 5 Watts with 250…300 V_{p-p} at 100 kHz PRF.

V. CONCLUSION

A novel scheme of DSRD current driver is proposed and discussed. It is shown that the DSRD based nanosecond pulse generators can use this driver. Proposed current driver scheme allows building nanosecond pulse generator with balance output that is directly connected to antenna terminals without any RF balloons necessity.

Antennas classification based on energy transfer and transformation is proposed. Antennas with simultaneous and separate processes are discussed. It is assumed that antenna with kinetic energy accumulation is most promising for high power radiation.

A novel antenna with kinetic energy accumulation is designed and built in DSRD generator. Antenna-generator is produced and examined. It is shown that proposed antenna design owns high radiating efficiency with comparatively small antenna dimensions. Electromagnetic radiation bandwidth is more than 85%.

Proposed method of antenna design with kinetic energy accumulation conjointly with DRSD generator can be utilized for generation and radiation powerful nanosecond pulses with high repetition frequency and impulse shape stability.

ACKNOWLEDGEMENTS

The authors would like to thanks Professor Igor Ya. Immoreev for his support of this work and Eduard G. Ziganshin, Sergey N. Pavlov and Sergey V. Samkov for their assistance during field examinations.

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