Novel Tunable Ultrashort Pulse Generator With High Amplitude and Low Ringing Level

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***Abstract*— A new design of the ultrashort pulse generator based on a step recovery diode (SRD) is presented in this letter. The design schematic features allow us to increase the pulse amplitude, decrease the ringing level, and realize pulse duration tuning. The signal amplitude increase results from the use of an additional inductive energy storage, which accumulates energy of the magnetic field during both charge storing and extraction phases of the generator duty cycle. The ringing level is reduced by including the ringing reduction subcircuit in the design. This subcircuit consists of the Schottky diode to block the negative half-waves of ringing oscillation and the resistor to force oscillation fading. The electronic tuning of the pulse duration is based on the relation between the SRD recovery time and the forward current. In the experiments ultrashort pulses with the duration in a range from 350 ps to 1.5 ns and the 40-V amplitude were obtained for a 50-Ω load by varying the diode forward current. The output signal has a good symmetry shape, which is shown both in simulation and experimentally. The measured ringing level was −20.5 dB.**

***Index Terms*— Pulse generator, ultrawideband (UWB).**

I. Introduction

SUBNANOSECOND video pulses are used as signals for various ultrawideband (UWB) radar and wireless communication systems [1]–[4]. The performance of these systems depends on the signal parameters. Thereby, the signal generation with desirable characteristics is an important issue for the development of UWB technologies. Numerous papers have been aimed at solving this problem. Some of them were focused on ringing reduction [2]. Other researchers dealt with the electronic tuning of the pulses parameters [1], [4]. Low pulse amplitude is the main drawback with reliability and sensing performance of radar applications. Many of the previously designed generators suffer from this disadvantage. We have developed a novel design of the low-cost ultrashort pulse UWB generator based on a step recovery diode (SRD) which includes some schematic features that allow generating pulses with tunable duration, low ringing, high amplitude, and a high repetition rate.

So far, the SRD is, probably, the most commonly used semiconductor device for pulse generation. It can be considered as a P+-I-N+ semiconductor structure, where minority carriers are accumulating in the intrinsic I layer in the case of a positive bias. If then it is biased in a negative direction, the storage charge will be removed. When the extraction of electrons and holes has finished, the SRD high resistance recovers abruptly. The ultrafast change of the diode conductivity is a physical basis of subnanosecond pulse generation.

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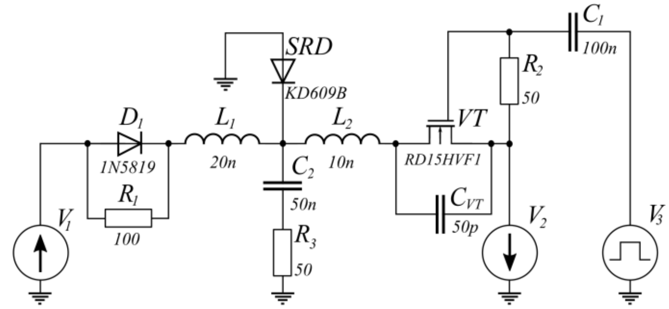

Fig. 1. Circuit of the ultrapulse generator.

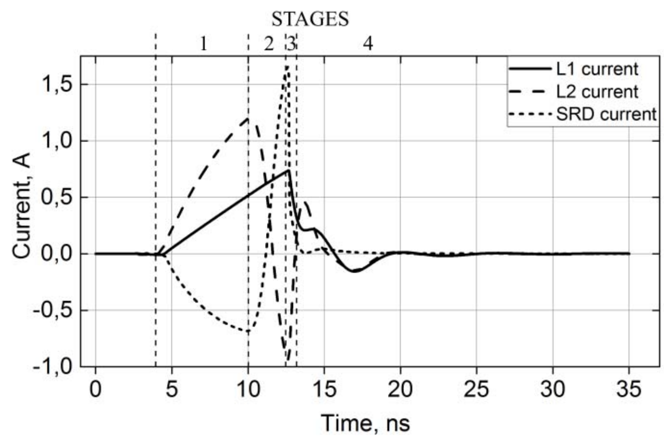

Fig. 2. Simulated inductors and SRD currents.

II. Design of Ultrashort Pulse Generator

The circuit of the designed generator is shown in Fig. 1. Time-domain simulation has been made for the circuit with the parameter values indicated in Fig. 1. The currents through the SRD and inductor energy storages are illustrated in Fig. 2. The generator duty cycle consists of four consecutive stages. The first stage starts when the transistor VT is turned ON by applying a trigger signal from V_3. So, the currents through the inductors L_1 and L_2 increase and the capacity C_{VT} voltage rises to the value V_2. As can be seen from the generator circuit, the SRD biases positively if the inductor L_2 current (I_{L2}) is greater than the inductor L_1 current (I_{L1}). For convenience, this condition can be written as $L_2/L_1 < V_2/V_1$. If it is satisfied, the diode conductivity rises up due to the carriers accumulation in the I layer.

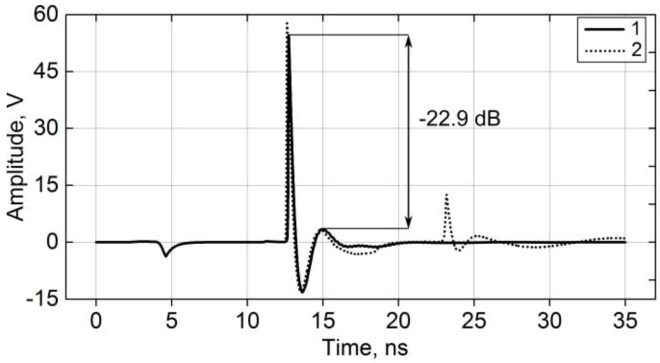

Fig. 3. Simulated impulse signal from the generator output. 1—with ringing reduction subcircuit. 2—without ringing reduction subcircuit.

When the trigger pulse ends, the VT turns OFF (stage 2) and an oscillation process between the capacity C_{VT} and the inductor L_2 begins. First, the current through the inductor L_2 falls down to zero, then it changes the direction and rises. Meanwhile, the current I_{L1} keeps increasing. At this stage, according to the Kirchhoff's current law, the SRD current (I_d) equals to the difference between the currents I_{L1} and I_{L2}. Thereby, the storage charge will be removing from the SRD after I_d changes its direction to the opposite one.

As soon as the storage charge has been extracted from the I layer, the high reverse resistance recovers abruptly and the diode current falls down to zero (stage 3). Wherein, the currents I_{L1} and I_{L2} are switched to the load (R_3) and an ultrashort pulse generates on it. Finally, relaxation processes, which are the oscillations between the capacity C_{VT} and the inductors L_1 and L_2, occur (stage 4).

A. Low Ringing

The oscillation process after pulse generation is known as ringing. To avoid signal distortion, a new pulse has to be generated when the ringing ends. This condition limits the generator repetition rate.

The main causes of ringing are the signal reflection and parasitic oscillation processes between the reactivity elements in the circuit. The signal reflection depends only on the matching between the generator and the load, while parasitic oscillations result from transient processes in the generator and can be reduced by the improvements in its design.

For this design our simulation allows us to claim that the minimal ringing is achieved if at the end of the third stage of the generator duty cycle the currents through the inductors L_1 and L_2 are equal to zero and the capacity C_{VT} voltage is equal to the source V_1 voltage. However, in practice, it is hard to find a mode to satisfy this condition. Therefore, the ringing reduction subcircuit was introduced to decrease the ringing level in the generator circuit. It is made up of the Schottky diode D_1 and the resistor R_1, connected in parallel. The Schottky diode passes the positive half-waves of ringing and does not conduct the negative ones, while the resistor causes fading of oscillations during the fourth stage of the generator duty cycle.

The statements mentioned above have been checked by the designed generator time-domain simulation. The SRD capacity model was used. The results of the modeling are illustrated in Fig. 3. As appears from the graph, the ratio between the pulse amplitude and the peak value of the parasitic oscillations equals 14. So, the ringing reduction subcircuit reduces the level of ringing by 22.9 dB. The experimental results are given in Section III.

TABLE I
SOURCE VOLTAGES AND PULSEWIDTH CORRESPONDENCE TABLE

Pulse width, ps	350	500	700	900	1100	1300	1500
V_1, V	3	4	5	6	7	8	9
V_2, V	2.2	2.9	3.8	4.5	5.4	6.1	6.8

B. High Amplitude

There are two conditions that must be met to achieve a high output pulse amplitude. The first one requires a large amount of the magnetic field energy to be accumulated in the inductor energy storage. To meet this requirement, the inductor current must flow within a period long enough to reach its maximum value. In the designed generator, two inductors were used for energy storing. The magnetic field energy accumulates in the inductor L_2 just as in the classic ultrashort pulse generation circuit: while the storage carriers are being extracted from the SRD. Energy amasses in the inductor L_1 when the current flows through it during both the storing and the extraction phases of the generator duty cycle. Thereby, the additional inductor L_1 allows increasing the total amount of stored energy, which is then switched to the load. Hence, the output signal amplitude increases.

The second condition is the rapid transfer of the stored energy to the load by an ultrafast current switching from the inductors. It requires the SRD recovery time to be as short as possible. Otherwise, the pulsewidth increases and its amplitude decline.

C. Electronic Tuning

UWB radar system penetration depth and range resolution can be changed by varying the pulsewidth [1], [4]. A long pulse has large energy and, consequently, deep penetration. At the same time, its range resolution is poor due to the signal's narrow bandwidth. On the other hand, a UWB system which uses a narrow pulse signal produces good range resolution at the expense of penetration depth [1]. Thus, generators with tunable signal parameters are preferable for these systems.

The width of generated pulses depends on the dynamics of the SRD transient processes. Its minimal value is limited by the SRD recovery time. In the course of our experiments, we figured out the diode recovery time dependence on the forward current. It is illustrated in Fig. 4. This dependence was used to control the SRD recovery time and, consequently, the pulse duration in the designed generator. The forward current through the SRD is adjusted by setting the V_1 and V_2 voltages. The values of the pulsewidth and the corresponding source voltages are given in Table I.

III. EXPERIMENTAL RESULTS

The generator prototype has been realized as a double-sided printed circuit board using a 1-mm-thick FR-4 glass epoxy substrate (Fig. 5). The ground planes were utilized to reduce interferences. The width of the output trace has been

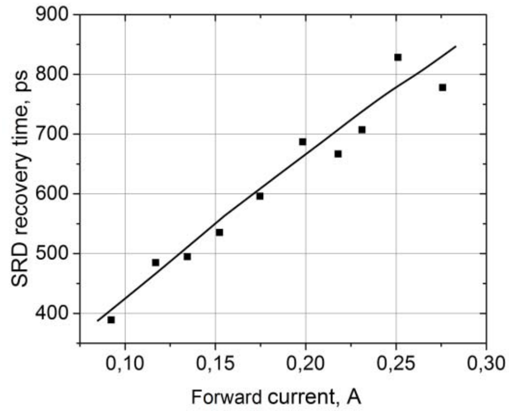

Fig. 4. Dependence of the SRD recovery time on the forward current.

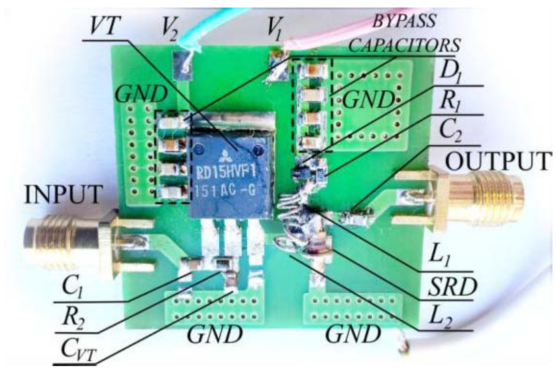

Fig. 5. Photograph of the ultrashort pulse generator.

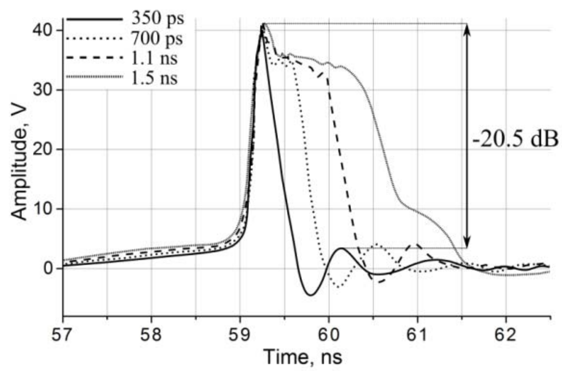

Fig. 6. Measured ultrashort pulse signal with different durations from the generator output.

chosen for impedance matching with a 50-Ω coaxial cable. The stroboscopic input of the oscilloscope DCA-X 86100D with the plug-in module 86112A (50-Ω resistance and 20-GHz bandwidth) was used as the load R_2 in the experiments. The pulsewidth was measured at the half-amplitude level. The amplitude of the trigger signal was 5 V, and its duration was 10 ns. It was generated by the external pulse generator Agilent 81104A.

Fig. 6 shows the measured output pulse waveforms of the generator when it was operating in different modes. The ultrashort pulse duration varied from 350 ps to 1.5 ns, while the amplitude was constant and equaled to 40 V. Thereby,

TABLE II

SUMMARY OF ULTRASHORT PULSES GENERATORS CHARACTERISTICS

№ references	[2]	[3]	[4]	[5]	[6]	[7]	THIS PAPER
Amplitude, V	0.4	2.5	0.3	0.32-0.85	8.3	3.2	**40**
Duration (tuning range), ps	300	1000	550-1750	290	400	225-440	**350-1500**
Ringing level, dB	-17	-17.8	-	-21.8	-	-15.2	**-20.5**
Repetition rate, MHz	10	100	20	40	1	40	**60**
Signal type*	MC	MP	MP	MC	MP	MC	**MP**

* MC – Monocycle, MP - Monopulse

the designed generator allows generating pulses with a larger amplitude in comparison with the generators published previously (Table II). The ringing level was relatively low and equaled to −20.5 dB. The pulse duration tuning was observed in the mentioned range with the repetition rate up to 60 MHz. So, all transient processes related to the change of the generator operation mode terminated during the interpulse interval. It is important to note that the speed of adjustment can be significantly limited by the speed of supply sources.

IV. CONCLUSION

The new design of the ultrashort pulse generator has been described in this letter. The new approach to pulse duration electronic tuning based on the dependence between the forward current and the SRD recovery time has been proposed. The variation of the ultrashort pulse duration in a range between 350 ps and 1.5 ns was achieved experimentally. In addition, this design allows obtaining a low ringing level and provides a higher pulse amplitude in comparison with the generators mentioned in Table II.

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