High-Power Source of Ultrawideband Radiation Wave Beams with High Directivity

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Abstract – The paper presents the results of investigation of an UWB radiation source based on excitation of a 64-element array of combined antennas from a bipolar pulse generator of the length 1 ns, amplitude 200 kV and output impedance 12.5 Ω at the repetition rate up to 100 Hz. An effective potential of the UWB radiation source is 2.8 MB.

1. Introduction

Creation of high-power sources of ultrawideband (UWB) radiation with high directivity and multimegavolt effective potential opens new possibilities in the investigations concerning the influence on the objects and media as well as development of UWB radar with high space resolution.

Structurally, the source under study (Fig. 1) consists of a monopolar pulse generator, bipolar pulse former, power divider with impedance transformer and 64-element array of combined antennas.

Fig. 1. Outward appearance of a source

2. A bipolar voltage pulse generator

A bipolar voltage pulse generator consists of a monopolar pulse generator, intermediate sharpening stage, and bipolar pulse former. A high-voltage pulse generator of the SINUS type was used in the given source as a monopolar pulse generator. Constructively, it is similar to the one described in [1]. The difference is that the SF6-gas insulation is changed by the oil and the internal core diameter is enlarged to 100 mm. An equivalent circuit of a bipolar pulse generator is shown in Fig. 2.

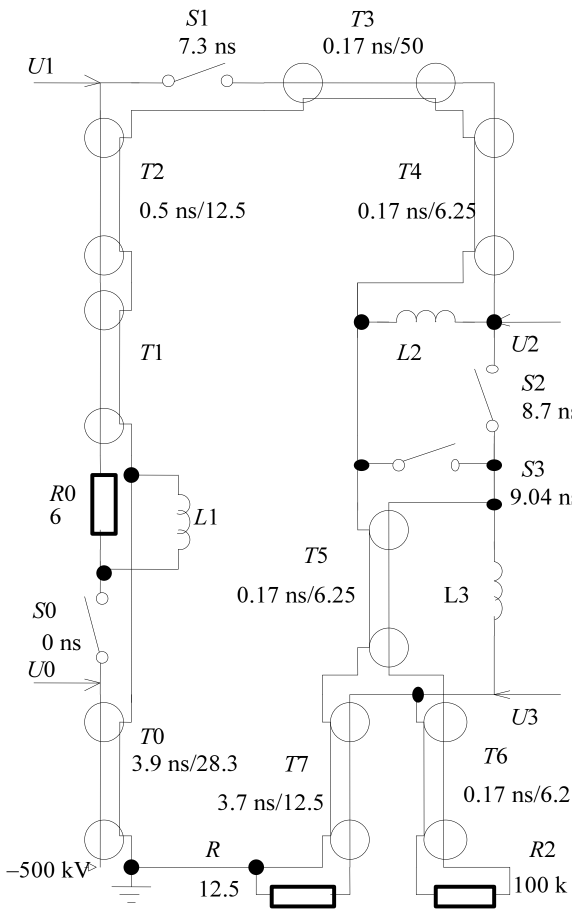

Fig. 2. An equivalent circuit of a bipolar pulse generator

Here a monopolar pulse generator is presented by an output forming line *T*0 with the wave impedance of 28.3 Ω, electric length of 3.9 ns and gas switch *S*0. This line could be charged from the secondary coil of Tesla transformer up to the maximum voltage of 500 kV during 4.2 μs with the pulse repetition rate of 100 Hz. An intermediate sharpening stage consists of the lines *T*1–*T*2, limiting resistor *R*0 and switch *S*1. The line *T*1 presents a set of short lines that model the real coaxial transition from the switch *S*0 to the line *T*2. A bipolar pulse former is assembled by the scheme with an open-circuit line including the lines *T*3–*T*7, the sharpening *S*2 and closing *S*3 switches and the load R. Leakage inductances $L1$–$L3$ are destined to remove a residual charge at the electrodes of the switches $S0$–$S3$ to the moment of generation of the next voltage pulse.

The circuit was simulated by the program PSpice. Fig. 2 presents the parameters of the lines $T0$–$T7$ and the operating time of the switches. A high-impedance resistor $R2$ is included into the circuit only for providing the program operation. Fig. 3 presents calculated pulses of the charge voltages $U1$ and $U2$ at the lines $T2$ and $T4$, respectively, and of the output voltage pulse $U3$ in the transmitting line $T7$.

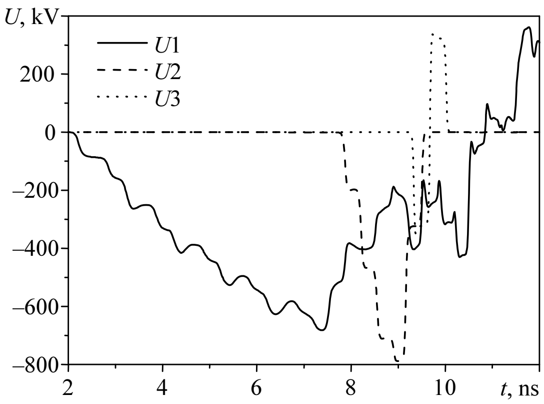

Fig. 3. Calculated pulses of charging voltages $U1$ and $U2$ at the lines $T2$ and $T4$ and output voltage pulse at the line $T7$

At the moment of maximum charging voltage at the line $T0$ the switch $S0$ is operating and this line is discharged through the high-impedance line $T1$ to the intermediate line $T2$ charging the latter up to the voltage of 680 kV during 5.4 ns (curve $U1$, Fig. 3). At the moment of the charging voltage maximum, the switch S1 is operating at the line $T2$ and $T2$ is commutated through the line $T3$ to the forming line $T4$ charging the latter up to the voltage of 780 kV during 1.2 ns (curve $U2$, Fig. 3). At the operation of the sharpening switch $S2$, a bipolar voltage pulse of the amplitudes ± 325 kV is formed in the maximum of charging voltage and closing discharge $S3$ with a 0.34-ns delay in the transmitting line $T7$ and load (curve $U3$, Fig. 3).

Figure 4 shows a design of an intermediate sharpening stage and a bipolar voltage pulse former. The stage consists of two gas volumes and one oil volume. In the first volume, the lines $T1$–$T2$, the switch $S1$ and the capacitive voltage divider $D1$ are disposed in the nitrogen medium under the pressure of 90 atm. The line $T1$ is not shown in Fig. 4. Electrodes of the switch $S1$ are made of copper and installed with a 1.5-mm gap. The divider $D1$ has not been calibrated and served to evaluate the charging time of the line $T2$. In the second volume, under the nitrogen pressure of 100 atm there are placed the lines $T4$–$T7$, the switches $S2$–$S3$, and the leakage inductances $L2$–$L3$. The forming line $T4$ is made of two disk lines. The lines $T3$ and $T6$ have the insulation made of polyamide and plexiglass, correspondingly. The electrodes of the annular switch $S2$ are inserts *2* and *4* at the ends of the internal conductors of the lines $T4$ and $T5$, and the electrodes of $S3$ are a 2-mm thick disk *3* and insert *2*. All the electrodes are made of copper. An interelectrode gap in the switch $S2$ is 0.9 mm and a radial gap in $S3$ is 0.5 mm. The leakage inductances $L2$–$L3$ are winded with a 0.22-mm diameter high-impedance wire on the polyamid rods of 6 and 10 mm diameter, correspondingly. The transmitting line $T7$ is an oil-filled coaxial with the wave impedance of 12.5 Ω. A coupled-line divider $D3$ is installed inside the coaxial to record the output bipolar voltage pulse $U3$ by means of the oscilloscope TDS 6604 with the passband of 6 GHz. A water lossy line was used as a load R. Maximum external diameters of the lines $T2$–$T7$ are equal to 92; 43.8; 70; 76; 64.4, and 65 mm, correspondingly.

The charging voltage pulses arrived to the line $T2$ from a monopolar pulse generator. After successive operation of the switches $S1$–$S3$, the output voltage pulse was extracted through lead-in insulator *1* into the transmitting line $T7$ and further into the load R. The output bipolar voltage pulse $U3$ (Fig. 5) recorded from the divider $D3$ has the amplitudes of –205 kV

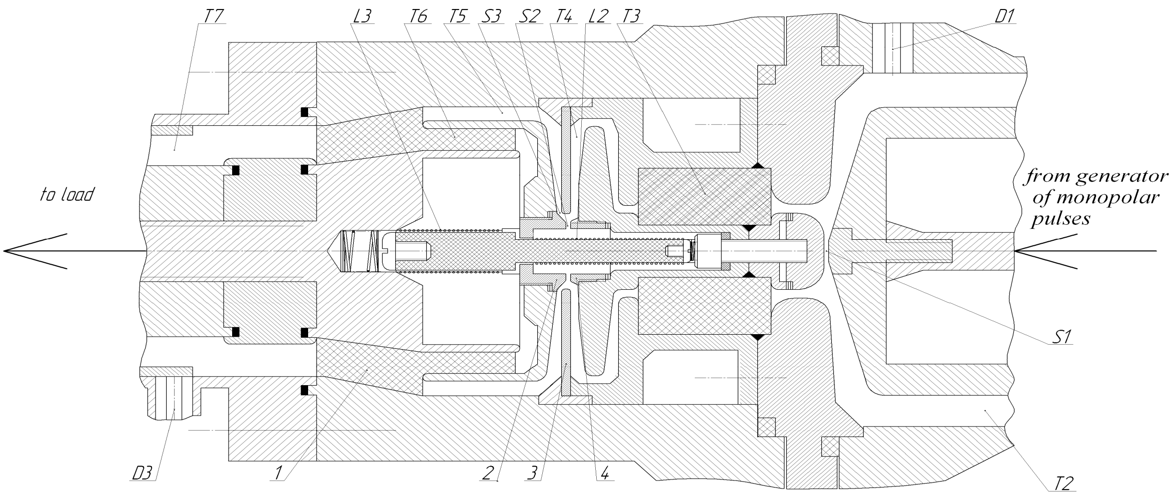

Fig. 4. A design of a preliminary sharpening stage and a bipolar voltage pulse former

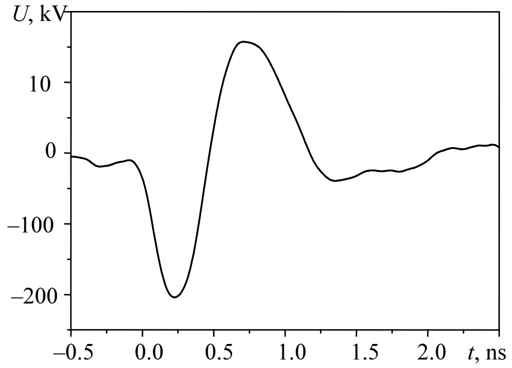

Fig. 5. Waveform of the output voltage pulse $U3$ from the divider $D3$

and +157 kV and the length of 1.15 ns by the level of 0.1 of the amplitude at a pulse repetition rate of 100 Hz. The voltage amplitude spread is no higher than 4%. The pulse energy at a matched load of 12.5 Ω is equal to 1.6 J that is 11.4% of the energy stored in the forming line T0.

3. Power divider

To transfer a bipolar voltage pulse from the generator to the array antenna elements, the design of a 64-channel power divider with simultaneous impedance transformation has been developed. Structurally, the 64-channel power divider consists of three series-connected stages of four-channel dividers. Wave impedance at the first stage is equal to the one at the output of the bipolar pulse generator being of 12.5 Ω. At the beginning of the divider first stage the wave impedance is 12.5 · 4 = 50 Ω. The sum feeder impedance of a 16-element array to which each of the arms of the first stage is loaded is equal to 50/16 = 3.125 Ω, and the sum feeder impedance of 64 elements is equal to 50/64 ≈ 0.78 Ω. In order to transform the impedance, a compensated exponential transition used. The transmission lines are filled with the transformer oil for insulation. Total length of one arm of the divider is 1.2 m. Fig. 6 presents normalized waveforms of voltage pulses at the input U_g and output U_d of one of the divider channels. It is well seen that the pulse waveform is distorted insignificantly. However, the pulse amplitude at the divider output is 6.5 times less than the amplitude at the input whereas in the ideal case it should be decreased by 4 times. This is mainly related to the losses in a dielectric.

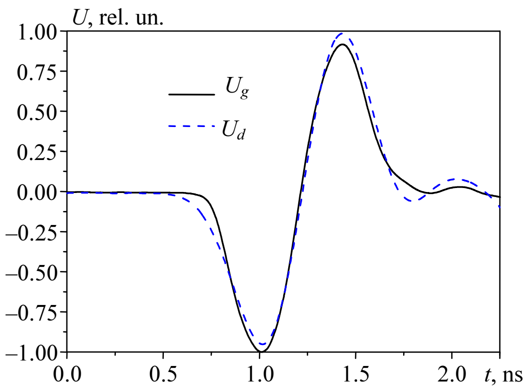

Fig. 6. Voltage pulse waveforms at the input U_g and output U_d of a 64-channel divider

4. Array antenna

A combined antenna [2] optimized to a 1-ns length bipolar excitation pulse is used as an array element. VSWR of the array element is presented in Fig. 7. The array element directivity factor is $D0 = 4.7$ and the coefficient by the field peak strength $k_E = E_pR/U_g \approx$ ≈ 1.38, where E_p is the maximum field strength, R is the distance to the measuring point in the far-field zone, and U_g is the maximum voltage pulse amplitude of the generator.

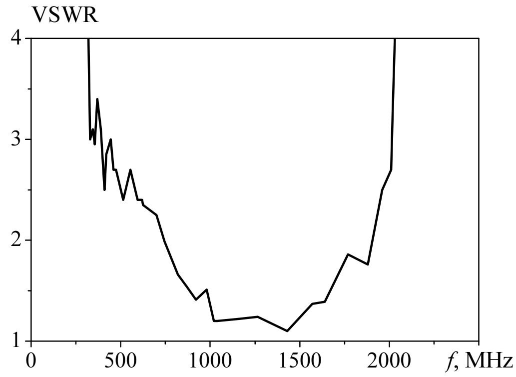

Fig. 7. The array element VSWR

An array consists of 64 (8 × 8) elements fixed at a metal plate. The array aperture is 1.41 × 1.41 m. Fig. 8 presents the pattern of the 64-element array. The pattern width at a peak power half-height is 10° in both planes. The level of the cross-polarized radiation is less than 0.5%.

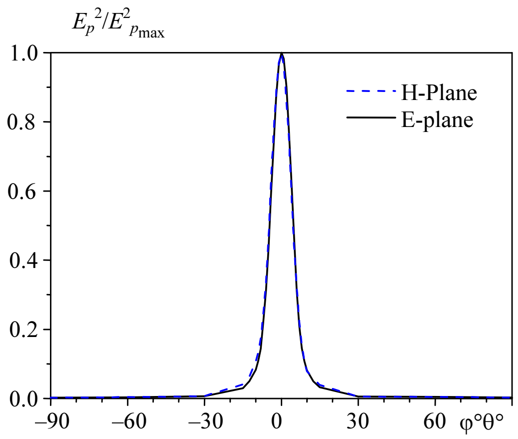

Fig. 8. A 64-element array pattern

Figure 9 presents an array effective potential versus the distance to the receiving antenna.

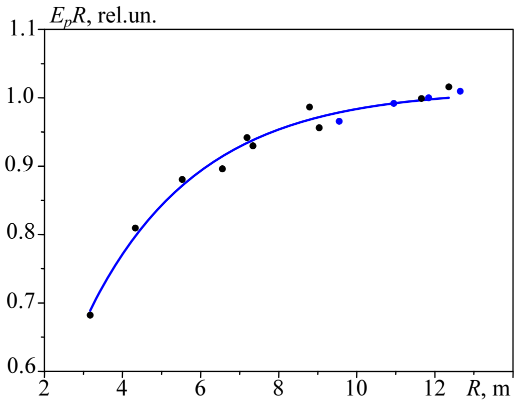

Fig. 9. An effective potential versus the distance between the receiving antenna and array

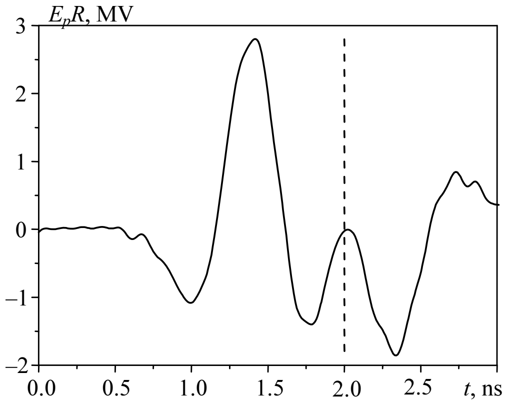

Fig. 10. Waveform of the pulse radiated with a 64-element array

5. Measurement results

The array was excited with a high-voltage pulse presented in Fig. 5. The radiated pulse was recorded by the oscilloscope Tektronix TDS 6604 using a TEM-horn installed at a 10.7-m distance from the array. Fig. 10 presents the radiated pulse waveform where the pulse reflected from the surrounding metal objects is shown after a dashed line. An effective potential was of 2.8 ± 0.2 MV.

6. Conclusion

A high-directivity source of UWB radiation pulses with nanosecond length and effective potential of ~ 2.8 MV at the frequency rate of 100 Hz has been developed.

Acknowledgements

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References

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