Source of High-Power Ultrawideband Radiation Wave Beams with Orthogonal Polarization

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Investigation results on generation and high-power ultrawideband electromagnetic pulse radiation are presented and possibility to obtain wave beams with orthogonal polarizations of electric field is shown.

1. Introduction

Investigations of generation and radiation of high-power ultrawideband (UWB) pulses with a linear field polarization based on excitation from one generator of array antennas by a 1-ns length bipolar pulse were carried out in the given work. To obtain radiation of wave beams with orthogonal field polarizations, the array made of equal antennas was divided into two sub-arrays with orthogonal position of radiators. Cable feeders of different length were used for a 2-ns time shift of radiation pulses with orthogonal polarizations.

The UWB radiation source was made by the following scheme: a monopolar pulse generator (MPG) – a bipolar pulse former (BPF) – a wave transformer – a radiator (Fig. 1). A 16-element array of combined antennas and a single antenna were used as a radiator.

2. Bipolar voltage pulse generation

A high-voltage pulse generator SINUS-160 described in details in [1] was used as a MPG.

Fig. 2 presents a BPF equivalent scheme previously suggested [2] for a 1-ns length bipolar pulse.

The circuit consists of four coaxial lines FL_0-FL_3, a sharpening S_1 and a cut-off S_2 discharge switches and a load R_L. The lines FL_0-FL_2 have the electric length (single wave run) $\tau = 0.17$ ns. The wave impedance of the lines FL_1 and FL_2 is $\rho = 25$ Ohm. The transmitting line FL_3 with the electric length of 3.7 ns is matched with the load $R_L = 2\rho = 50$ Ohm. The forming line FL_0 having a lower wave impedance of 15.3 Ohm and charged through the charging inductance $L_1 = 250$ nH from the monopolar pulse generator was used in this circuit in order to increase the output voltage. The sharpening discharge switch S_1 operates at the voltages close to the maximum charging one at the line FL_0 while the cut-off discharge switch S_2 operates with the delay of 0.34 ns and a bipolar voltage pulse is formed at the load.
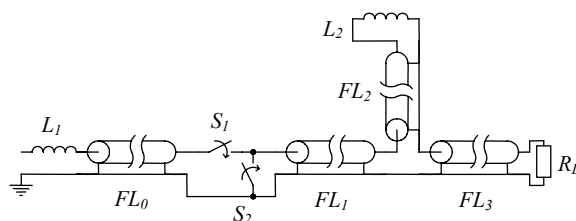

Fig.2. Equivalent circuit of a bipolar pulse former.

In difference from Ref. [2] where a bipolar voltage pulse had the amplitude of the second half-wave U_2 being essentially higher than the amplitude of the first
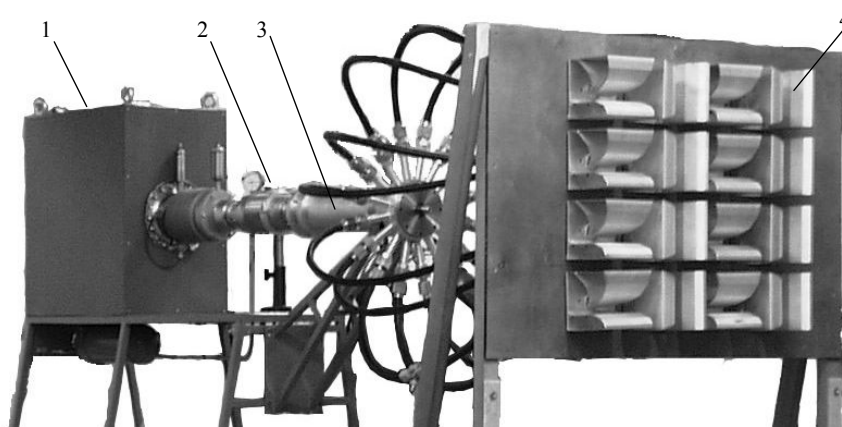

Fig. 1. External view of a radiation source. 1 – monopolar pulse generator, 2 – bipolar pulse former, 3 – wave transformer, 4 – 16-element array antenna.

half-wave U_1, in this work we managed to decrease the pulse waveform asymmetry. By means of computer simulation it was found out that the amplitude U_2 can be decreased in comparison with the amplitude U_1 by tuning the value of the inductance L_2 installed at the end of the line FL_2.

The former design is analogous to the one described in Ref. [2]. A bipolar voltage pulse presented in Fig. 3 was obtained at the former output. The gaps in the discharge switches S_1 and S_2 were equal to 1 and 1.4 mm, respectively, the nitrogen pressure in the former volume was of 9 MPa and the inductance value $L_2 \approx 200$ nH. A bipolar pulse recorded by the oscilloscope TDS7404 by means of the voltage divider at the coupled lines has the amplitudes $U_1 = -185$ kV and $U_2 = 200$ kV and the length of 1.08 ns at the levels of $0.1U_1$ and $0.1U_2$. The observed pre-pulse is related to the passage of the charging pulse of the forming line FL_0 into the load through the discharge switch transfer capacitance.

A wave transformer was used to match the output wave impedance of the former equal to 50 Ohm and the summary wave impedance of the array antenna feeder equal to 3.125 Ohm. The transformer design is described in Ref. [1]. The transformer input was connected to the former output and the transformer output was connected to the array antenna by means of the cables PK-50-17-17. Capacitive voltage dividers were installed to record the output pulse at two cables. Measurements made by means of the low-voltage 1-ns bipolar pulse generator have shown that the summary energy losses in the transformer with feeders are equal to 40% of the incident pulse energy.
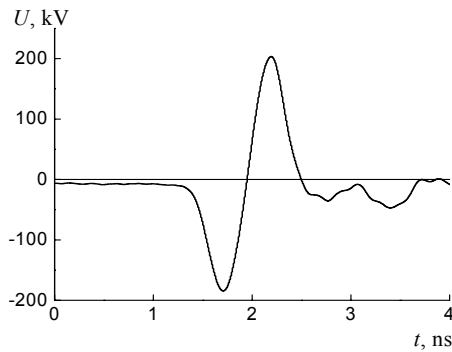

Fig. 3. A bipolar voltage pulse at the former output.

3. Radiating system

A combined antenna close in its design to the one described in Ref. [3] was used as an array element as well as an independent radiator. The antenna dimensions are equal to $15 \times 15 \times 16$ cm and approximately equal to the half of the spatial extension of a 1-ns length bipolar pulse exciting the antenna. To prevent breakdowns at a high voltage operation, a single antenna was placed into a thin-walled polyethylene container filled with SF_6-gas up to the pressure of

0.15 MPa. In difference to the antenna described in Ref. [3], in this design the electric monopole width was enlarged resulting in the pattern narrowing by the peak power at a half-height in a horizontal plane by $20°$ and the electric length of the lower part of the TEM-horn was enlarged allowing decreasing the pattern maximum rise in a vertical plane by $7°$. In the frequency band of 0.3-2.1 GHz where the main part of the 1-ns length bipolar pulse energy is concentrated, the value of VSWR is ≤ 3.

The width of the patterns by the half-power level is $80°$ for the H-plane and $90°$ for the E-plane. In the E-plane the pattern is not symmetric relative to the plane $\delta = 0°$. The antenna directivity in the main direction ($\varphi, \delta = 0°$) is $D_0 \approx 4.7$.

The array antenna presents 16 elements not coupled galvanically between each other that are fixed at a dielectric plate at the equal 18-cm distances from each other. Each radiating element presents the above-described combined antenna. The difference is only in the input design providing the antenna - cable feeder connection. Thanks to the used fastening of the elements, the array allows radiating pulses with the vertical polarization (Fig. 4a) at a synchronous excitation and with the mutually perpendicular polarization vectors (Fig. 4b, c) at the excitation of the perpendicularly oriented elements by the pulses shifted in time by 2 ns. The direction of the electric field polarization is shown by arrows in the pictures. The shift between the exciting pulses is provided by means of cable feeders of different lengths.
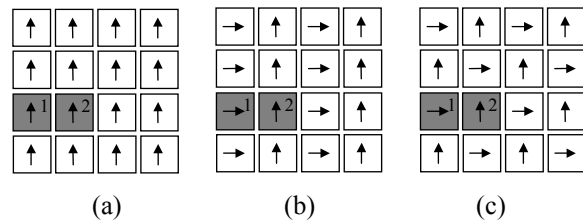

(a)   (b)   (c)

Fig. 4. Variants of elements disposition in the array.

Fig. 5 presents VSWR for two elements of the investigated arrays denoted in Fig. 4 as 1 and 2. VSWR of these elements (curves 4) as single radiating antennas, i.e., outside of the array, are presented here for comparison. Some difference of their VSWR is seen that is related to the accuracy of antenna fabrication. Note, that near the low-frequency boundary, VSWR of the a-type array elements is less than VSWR of a single antenna. As it follows from Fig. 5, VSWR of an element depends both on its position in the array (Fig. 5a, b) and the array configuration (curves 1-3). An average value of VSWR for the internal elements of the array at the frequencies of 0.3 - 1.5 GHz is rather larger than for the external ones. This is testified by the results of measurement of the energy reflected from the energy element inputs. Single elements on average reflect 9% of the bipolar pulse energy incom-

ing into them. The average value of the reflected energy for the arrays of the a-, b-, and c-types is equal to 17%, 16%, and 21%, respectively. The difference in the reflected energies for the arrays of the a- and b-types is in the limits of the measurement error. Increase of the reflected energy and VSWR change are conditioned by mutual influence of the elements in the array.
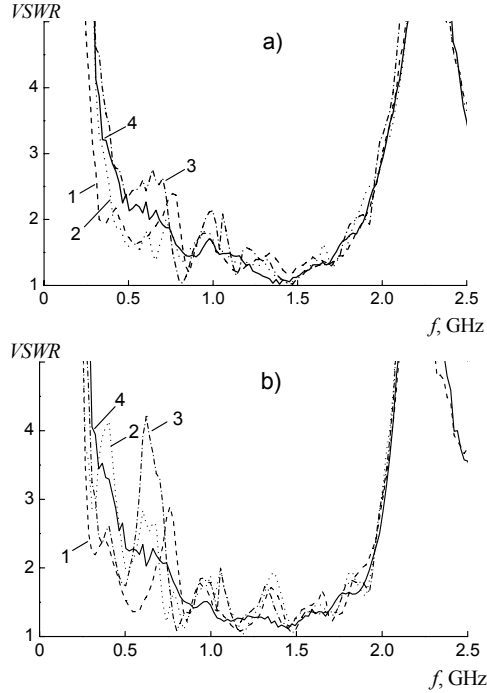

Fig. 5. VSWR of the elements 1 (a) and 2 (b) in the arrays of the a-type (1), b-type (2), c-type (3) and outside (4).
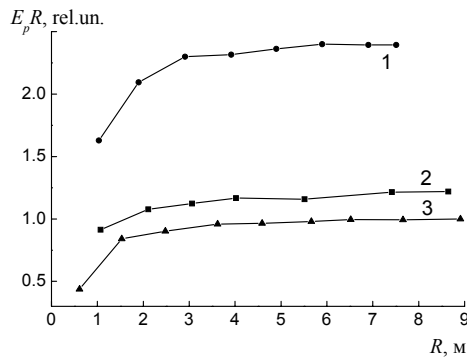

Fig. 6. Efficient potential versus the distance between the receiving antenna and the arrays: 1 – a-type array, 2 – b-type array, 3 – c-type array.

Fig. 6 presents the efficient potential E_pR versus the distance between the receiving antenna and the arrays of different configuration. The data are normalized to the maximum value of E_pR of the sub-array with the vertical polarization of the c-type array. At the distance $R > 3$ m the curves weakly depend on R for all arrays, i.e., the field changes proportionally to $1/R$ that is the far-field zone factor. Moreover, it is

seen from Fig. 6 that the value of E_pR for the c-type (curve 3) is less than for the b-type one (curve 2) though the number of radiating elements in each sub-array is equal. This is explained by more essential influence of the elements to each other in the c-type variant of the array. Note, that for the b- and c-type variants the dependences of $E_pR(R)$ for the horizontal and vertical polarizations coincide in the limits of measurement error.

The pattern width by the half-power level in the E- and H- planes equals to ≈20° for all array types. Fig. 7 presents the patterns of the sub-arrays with the vertical polarization. It is seen that for the b-type array the pattern maximum of the sub-array with the vertical polarization is shifted by $\Delta\varphi \approx 2.5°$ in the H-plane (Fig. 7a, curve 1). This shift is conditioned by interaction of elements in the array. Note as well that the level of background radiation of the b-type array increases essentially for both polarizations that makes difficult its application. The c-type array is characterized by the low level of background radiation. But its drawback is lower energetic efficiency.
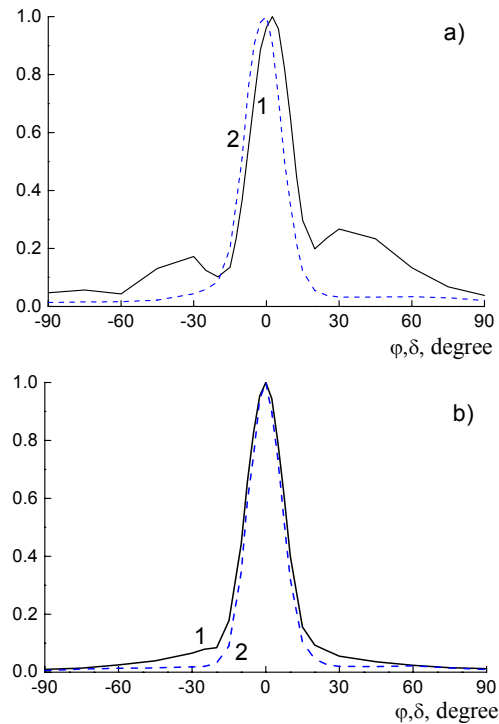

Fig.7. Patterns of sub-arrays with vertical polarization: a - b-type array, b - c-type array; curves 1 - H-plane, curves 2 - E-plane.

4. Radiation of high-power ultrawideband pulses

A high-voltage pulse at the input of a single antenna or a wave transformer is presented in Fig. 3. Fig. 8 presents the electromagnetic pulse radiated by the single antenna excited with a high-voltage pulse at the pulse repetition rate of 100 Hz. The efficient potential E_pR was of ≈300 kV that exceeds more than twice the

previously obtained value of E_pR equal to ≈136 kV [2]. Radiation peak power of the single-antenna source is 780 MW compared with 170 MW obtained in the previous work [2]. The difference with the results of the work [2] is conditioned by increase of the voltage pulse amplitude from 120 kV to 200 kV and of the antenna efficiency both by energy and peak power.
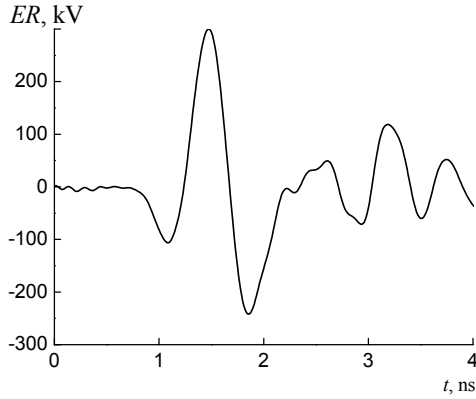

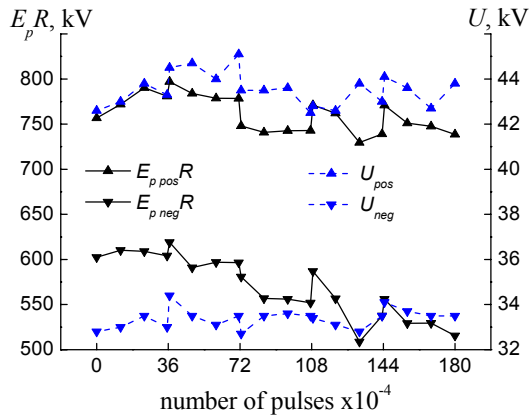Fig. 8. Electromagnetic pulse radiated by a single antenna.

Fig. 9. Amplitudes of the bipolar voltage pulse and efficient potential versus the number of pulses for the a-type array radiation source.

Fig. 9 presents positive and negative amplitudes of the bipolar voltage pulse and efficient potential E_pR versus the number of pulses at the pulse repetition rate of 100 Hz for the a-type array. The averaging was made by 100 pulses. The generator operated in the following mode: 1 hour of continuous operation and a 2-hour break. To decrease the erosion influence of the discharge switch electrodes of the bipolar pulse former on the bipolar pulse parameters, the pressure in them was reduced by 0.2 MPa in every $3.6*10^5$ pulses (1 hour of operation). During $1.8*10^6$ pulses (5 hours of operation) change of amplitudes didn't exceed 6%. Change of the amplitude of a maximum positive time lobe of the radiated pulse ($E_{p\,pos}R$) during 5 hours of operation didn't exceed 9%. The root-mean-square

deviations of the bipolar pulse amplitude and radiated pulse during 100 pulses didn't exceed 6% and 10%, respectively, at the root-mean-square deviation of the monopolar pulse amplitude at the former input not exceeding 1.5%.

Fig. 10 presents waveforms of the pulses with vertical and horizontal polarizations radiated by the b-type array and time-shifted by 2 ns.
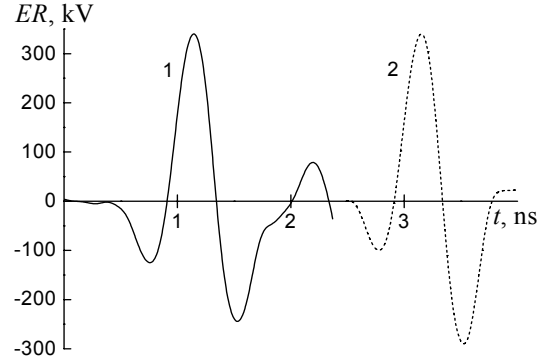

Fig. 10. Waveforms of pulses with vertical (1) and horizontal (2) polarizations of the electric field radiated by the b-type array.

Conclusion

High-power sources of UWB radiation with the bipolar pulse length of 1 ns, amplitude of 200 kV, and pulse repetition rate of 100 Hz have been developed based on a multielement array and a single antenna. The sources based on the multielement array allow obtaining time-shifted electromagnetic pulses with orthogonal polarizations of the electric field.

UWB radiation pulses of nanosecond length with the efficient potentials $E_pR≈800$ кВ at the synchronous excitation of the array and $E_pR ≈300$ kV with orthogonal field polarization were obtained. The change of maximum values of E_pR and instability didn't exceed 10% during 5 hours of summary operation of the source at the pulse repetition rate of 100 Hz.

References

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