Characterization of Active Ultrawideband Array Antennas with Dual Polarization

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Abstract – The results of investigations of an ultrawideband receiving dual-polarized 2 × 2 array antenna are presented. The antenna array is designed for investigation of a polarization structure of nanosecond and subnanosecond electromagnetic pulses. Each element of the 2 × 2 array consists of two crossed active dipole antennas with one-stage FET amplifiers. The results of investigation of the pattern, the effective length and the waveforms of the recorded pulses versus the distance between the array elements are presented.

1. Introduction

On solving the problems of object detection and recognition in ultrawideband (UWB) radar, an essential information feature is a polarization structure of the pulses reflected from objects [1]. When designing high-power UWB radar, it is assumed that transmitting and receiving antennas are separated in space. A receiving dual-polarized antenna should have the following properties: small distortion of the waveform of recorded pulses and simultaneous registration of orthogonal components of a pulsed electric field. A receiving array antenna consisting of crossed dipoles satisfies these conditions.

In order to record UWB electromagnetic pulses with small distortions, all elements of the array antenna should have a passband being no less than the frequency band occupied by the pulse spectrum. The set of devices formed feeder line of antenna array comprises summation units and balancing units. Previous investigations showed that single active receiving dipoles allow to record waveform of the pulses at the distortion no more than 15% by the root-mean-square criterion [2]. Well-known multiring Wilkinson power dividers used as summation units provide a sufficient passband for in-phase summation of signals of antenna elements. The main problem in application of dipole antennas as UWB array elements is extraction of an antiphase signal in a wide frequency band. An UWB balancing unit consisting of a 180° phase shifter and summation unit has been developed to be used in the array structure.

A four-element 2 × 2 array has been developed to investigate a dual-polarization array antenna with application of the above-indicated components. A distribution of the signals of each antenna elements consists of two parts. The first step is a summation of the signals of analogous dipole arms and the second step is an extraction of an antiphase signal.

The design and characteristics of the developed array antenna (Fig. 1) intended for receive and investigate a polarization structure of nano- and subnanosecond electromagnetic pulses are presented below. The presented antenna array can serve as a module for construction of multielement dual-polarized array antennas.

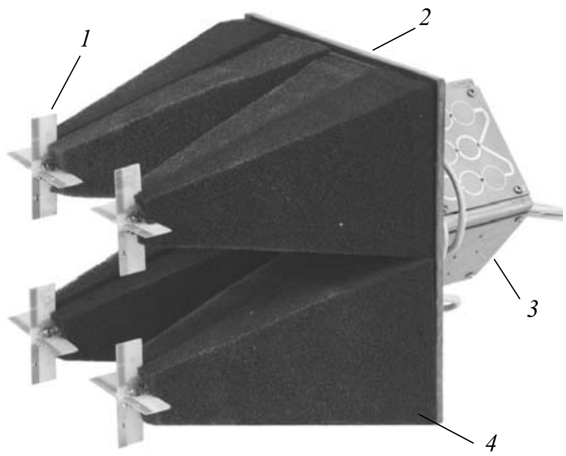

Fig. 1. Array antenna design: *1* – crossed active dipoles; *2* – dielectric base; *3* – group of summation units; *4* – absorbing material

2. Array antenna design

An antenna array (Fig. 1) consists of four crossed 48×48 mm-dimension active dipoles *1*, 160×160 mm-dimension dielectric base *2*, group of summation unit *3*, and feeder lines covered with absorbing material *4*. The distance between the centers of the dipoles d varied in the limits of 48–100 mm, the distance from the dipole arms to the dielectric base was 140 mm.

Figure 2 presents the design of the crossed active dipoles. The dipoles are made by the printed-circuit method on a 1-mm thick foil-clad glass-fiber plastic. Each arm of the dipole *1* is loaded directly to active element *2* presenting a one-stage FET amplifier [2]. Each of four active elements has separate coaxial output *3*. A power supply wire is laid separately (not shown in the picture). The supply voltage equals to 3 V. The consumption current of the array antenna is 400 mA.

The array antenna block diagram is shown in Fig. 3. Initially, the signals of the similar arms of

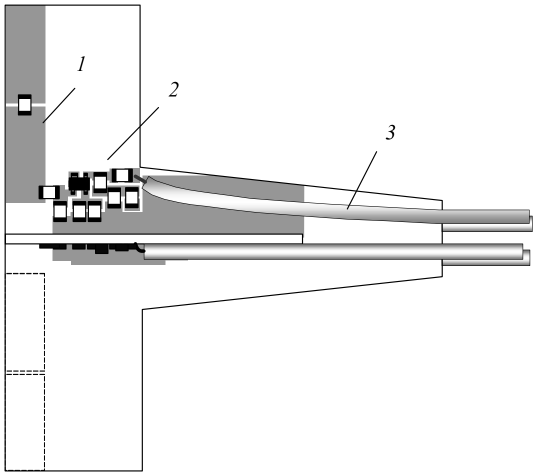

Fig. 2. Crossed active dipoles: *1* – dipole arm; *2* – active element; *3* – coaxial output of active element

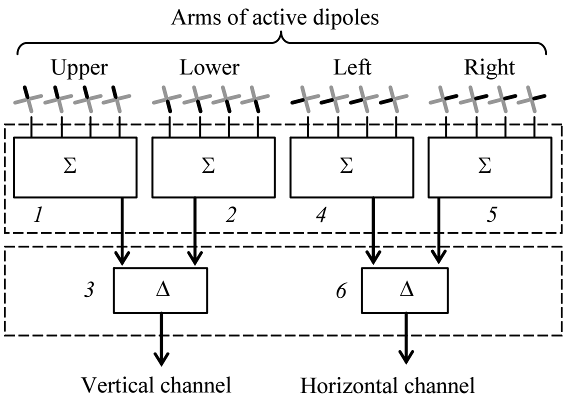

Fig. 3. Array antenna block diagram: *1*, *2* – vertical channel summation units; *4* and *5* – horizontal channel summation units; *3* and *6* – balancing units of vertical and horizontal channels, respectively

active dipoles are summed in-phase and then the antiphase component is extracted. The set of crossed dipoles has four vertical and four horizontal dipoles. The dipoles of vertical channel have four upper and four lower arms. The signals of four upper dipole arms are summed in-phase in summation unit *1* and the signals of four lower arms are summed in summation unit *2*. To extract an antiphase component corresponding to the vertical polarization, balancing unit *3* is used. Summation units *4* and *5* and balancing unit *6* are used, similarly, for the horizontal channel.

Figure 4 presents the summation unit physical configuration. Four similar printed-circuit boards are used. The three-ring summation units are placed at each 60 × 67-mm dimensional printed-circuit boards made of a 1-mm thick foil-clad dielectric FLAN-5. Wave impedances of semi-ring lines have the following values: $\rho_1 = 57\ \Omega$, $\rho_2 = 71\ \Omega$, $\rho_3 = 87\ \Omega$. The length of the lines corresponds to a quarter of the wavelength at the frequency of 2 GHz. Nominal values of the resistors R_1, R_2, and R_3 are equal to 400, 200, and 100 Ω, respectively. The passband of the summation unit equals to 0.3–3.5 GHz at VSWR ≤ 1.5 at each of the four input ports. An amplitude response from each input ports to output port is not less than –7 dB in the indicated frequency band.

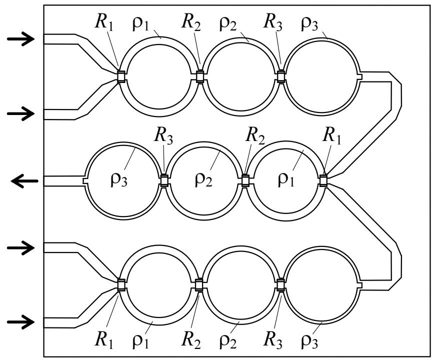

Fig. 4. Physical configuration of the summation unit printed-circuit board

A developed balancing unit consists of an UWB 180° phase inverter and a summation unit. Fig. 5 presents the design of one channel of the balancing unit. Input connectors *1*, *2* and output connector *3*, phase inverter *4* of the length $L = 100$ and two-stage ring summation unit 6 are disposed on the printed-circuit board of dimension 162 × 98 mm made of a 1-mm thick foil-clad dielectric FLAN-5. Dashed lines indicate the elements disposed at the rear side of the plate. The elements of second channel are placed at the same dielectric plate as a mirror image relative to the horizontal axis.

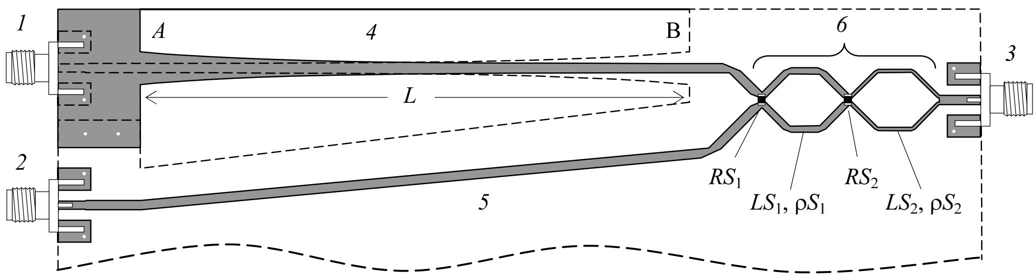

Fig. 5. A balancing unit design: *1* and *2* – input connectors; *3* – output connector; *4* – phase inverter; *5* – uniform section strip line; *6* – two-stage annular summation unit

Phase inverter *4* consists of two exponential transitions from the microstrip line to the double-wire line joined towards each other. As a result of this connection, the "strip" at point A becomes the "ground" at point *B* and the "ground" at point *A* becomes the "strip" at point *B*. This tapered transition provides the 180° phase inversion in a wide frequency band. The electrical length of uniform microstrip line *5* is equal to electrical length of line *4*. The elements of the two-stage ring summation unit have the following parameters: $RS_1 = 240\ \Omega$, $RS_2 = 100\ \Omega$, $\rho S_1 = 61\ \Omega$, $\rho S_2 = 82\ \Omega$, the length of the lines $LS_1 = LS_2$ corresponds to a quarter of the wavelength at the frequency of 2 GHz. Measured passband of a separately manufactured phase inverter is 0.15–10 GHz at VSWR ≤ 2.

The developed balancing unit has the following characteristics. The amplitude response from input port *1* to output port *3* (Fig. 5) is not less than –3.5 dB in the range of 0.4–3.3 GHz except a narrow resonance at the frequency of 1.25 GHz where the amplitude response descends to –6 dB. The isolation between input port *1* and port *2* is no more than –10 dB in the range of 0.5–3.5 GHz. Measured VSWR at ports *1* and *2* is not higher than 2 in the frequency range of 0.2–4.8 GHz.

3. Array antenna characteristics versus the distance between the elements

Investigations of antenna array characteristics were made in time domain. A combined antenna [3] excited by a 0.5-ns length bipolar voltage pulse generator was used as a source of UWB radiation pulses with linear polarization. A TEM-antenna of dimension 1200 × × 500 × 80 mm and effective length of 4 cm was used as a reference one to compare the waveforms of recorded pulses. Fig. 6 presents the pulse waveform recorded by the TEM-antenna (curve *1*).

Pulse waveforms recorded by the array antenna at $d = 48$, $d = 64$, and $d = 80$ mm are presented in Fig. 6

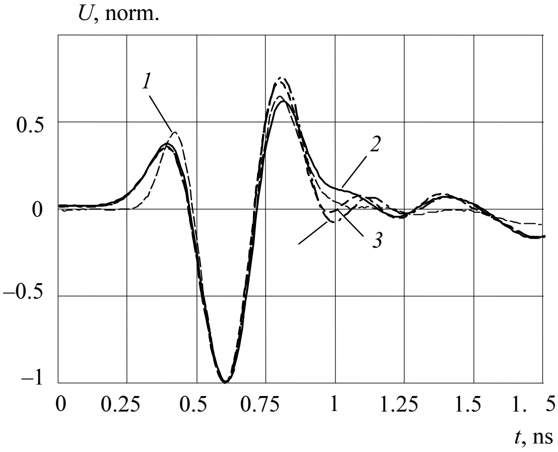

Fig. 6. Waveforms of recorded pulses: *1* – TEM-antenna; *2–4* – array antenna at d equal to 48, 64, and 80 mm, respectively

(curves *2–4*, respectively). At $60 \le d \le 100$ mm, the waveform of the recorded pulses and the effective length of the array were changed insignificantly. At $48 \le d < 60$ mm there were observed the pulse waveform change and increase of the array antenna effective length (Fig. 7). This effect can be explained by mutual influence of neighboring dipoles. At the minimum value of $d = 48$ mm the electric insulation between the arms of the neighboring dipoles was provided. The root-mean-square deviations of the pulse waveforms recorded by TEM-antenna and the array antenna are $\sigma = 0.24$, $\sigma = 0.34$, and $\sigma = 0.36$ at $d = 48$, $d = 64$, and $d = 80$ mm, respectively. Polarization isolation between the channels is not less than 25 dB.

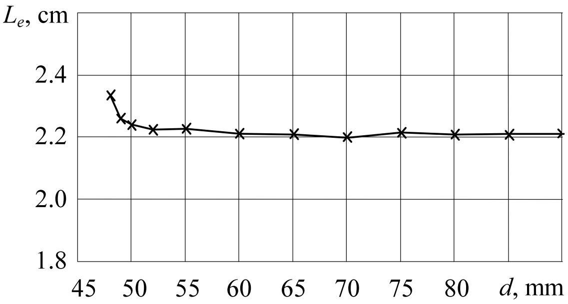

Fig. 7. The array antenna effective length versus the distance between the centers of crossed dipoles

Figure 8 presents measured patterns of the array antenna in two planes. Here, a pattern is an angular dependence of the square of maximum voltage value at the array antenna output during a pulse.

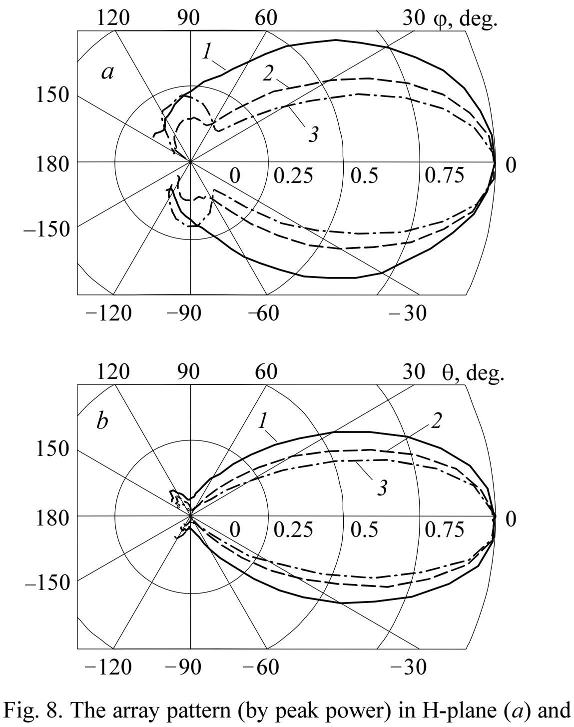

Fig. 8. The array pattern (by peak power) in H-plane (*a*) and E-plane (*b*). Curves *1–3* correspond to *d* equal to 48, 64, and 80 mm

Increase of the distance between the elements results in increase of the array directivity and decrease the range of angles where the waveform of the recorded pulses is preserved. Fig. 9 presents the root-mean-square deviation of the recorded pulse waveforms in different directions versus the pulse waveform in the main direction. These distortions are additional besides the waveform distortions in Fig. 6.

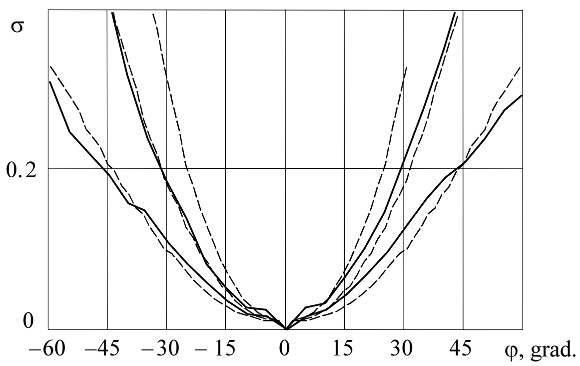

Fig. 9. Root-mean-square deviation of recorded pulse waveforms in different directions versus pulse waveform in the main direction. Measured (solid) and calculated (dashed) curves *1–3* correspond to *d* equal to 48, 64, and 80 mm

4. Noise responses and array antenna dynamic range

Direct connection of the array antenna to the digital oscilloscope Tektronix TDS 6604 in a shielded room has shown that the oscilloscope noises essentially exceed the antenna ones. The voltage corresponding to the oscilloscope noise level was 450 μV. Connection of UWB linear amplifier between the array output and oscilloscope input increased the noise level up to 3 mV. Taking into account that the gain of the linear amplifier is equal 36 dB, the noise level at the output of array antenna can be evaluated as 50 μV. The saturation of active circuits of array elements occurs at high field strength. The root-mean-square deviation of the waveforms of recorded pulses at the field strength of 50 V/m (this value corresponds to 1.1 V output voltage of array antenna) versus the waveform at small field strength is equal $\sigma = 0.1$. Assuming that a pulse can be recorded at the signal/noise ratio of 10 dB, the array antenna dynamic range can be evaluated at the level of 70 dB. The array antenna keeps its working capacity after the influence of a ~ 6 kV/m pulsed field.

5. Conclusion

A four-element active dual-polarized 2×2 array antenna intended for simultaneous and independent recording of two orthogonal components of a pulsed electromagnetic field with the spectrum occupying the band of 0.3–4 GHz has been created.

To record low-distortion pulses in a wide range of angles, it is necessary to use the minimum distance between the elements. The array antenna effective length weakly depends on the distance between the elements.

The array antenna that has been developed can be used as a module at construction of dual-polarized array antennas of $2n \times 2m$ elements.

References

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