Linear four-element cylindrical helix antenna array in boreside and scanning radiation modes

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Abstract. A cylindrical equidistant helix antenna has been created. The helix geometry of the antenna determined its central frequency of the operating band, equal to 1 GHz. This frequency corresponds to the maximum spectra of a bipolar voltage pulse with duration of 1 ns. Helixes identical to those of a single antenna were used in horizontal four-element linear arrays. Antenna arrays with different periods of $d$ were studied in the axial mode with simultaneous excitation of elements by a bipolar voltage pulse of 1 ns duration and in the mode of scanning at a fixed angle in the horizontal plane. Experimental measurements were carried out in the frequency and time domains.

1. Introduction

The ability to control the polarization of radiation is important in various fields related to the study of objects and environments under the influence of pulsed electromagnetic fields. The elliptically polarized electric field vector makes it possible to test objects without changing the position of the transmitting antenna. Among the transmitters with elliptical polarization, helix antennas are widely known. The characteristics of cylindrical equidistant helix antennas are well studied in the frequency domain [1]. A number of papers are known [1–3], where arrays consisting of cylindrical helix antennas are studied. In all these studies, a certain distance $d$ between the array elements was chosen for a given wavelength. In this paper, we consider an array of cylindrical helix antennas of 4x1 dimensions with different distances $d$ between the elements $0.5 \lambda_c$, $0.7 \lambda_c$, $1.0 \lambda_c$, where $\lambda_c$ is the wavelength corresponding to the central frequency $f_c$ of the spectrum of a bipolar pulse with duration of 1 ns. The characteristics of the array were studied both in the mode of simultaneous excitation of elements by a bipolar pulse of 1 ns duration, and scanning at fixed angles due to the introduction of time delays in the feeder lines of individual array elements.

2. A single helix antenna and antenna array

A cylindrical equidistant helix antenna was chosen as an element of the antenna array. The appearance of the antenna is shown in Figure 1a. The geometry of the helix antenna (Figure 1b) was chosen so that the axial radiation mode of the antenna corresponded to frequencies near 1 GHz. The average diameter of the helix was equal to $d_{avg} = 9.55$ cm, the inter-turn distance $S = 6.74$ cm, and the number of turns $N = 4.5$. Diameter of the ground plane of the antenna $D = 30$ cm. To reduce the wave impedance of the antenna and increase the rigidity of the structure, the turns of the helix were made of a thick copper tube with a diameter $a = 1$ cm. The total height of the helix was $L = 31.3$ cm.
Figure 1. Photo (a) and schematic (b) of helix antenna.

Linear 4-element antenna arrays made of cylindrical helical antennas were studied (Figure 2). The array elements were installed on rectangular ground planes with a width of $\lambda_c$. The total length of the plane was equal to $3d + \lambda_c$. The distance between the elements of the array $d$ (Figure 2) was 0.5 $\lambda_c = 15$ cm, 0.7 $\lambda_c = 21$ cm, 1.0 $\lambda_c = 30$ cm, and the distance from the outer elements (1 and 4, Figure 2) to the boundaries of the ground plane in all arrays was equal to $\lambda_c/2 = 15$ cm. The helices of the array elements, when viewed from the receiving antenna, ended at 3 o’clock (Figure 2) and at 12 o’clock.

Figure 2. Photo of helical antennas array.

3. Studies in the frequency domain
The Agilent PNA N5227A network analyzer was used for frequency domain studies. Figure 3 shows the voltage standing wave ratio (VSWR) of a single antenna. During the studies of the single array element, the other free inputs were loaded on matched loads with a wave impedance of 50 ohms. The study of the VSWR shows that the VSWR of a single antenna differs from the VSWR of an element, and the change in the distance $d$ does not significantly affect the matching of the array element. For an example, Figure 3 shows the VSWR of an element number 1 (the numbers are shown in Figure 2) for arrays with $d = 15$ cm, 21 cm, 30 cm and helixes ending at 12 o’clock. The VSWR of the array element is more affected by the orientation of the helix (3 or 12 hours) than the distance $d$. As an example, Figure 4 shows the VSWR of element N 1 of the array with $d = 15$ cm, where all the
helixes were oriented at 3, and then at 12 o'clock.

![Graph showing VSWR as a function of frequency for different distances and orientations.](image)

**Figure 3.** VSWR of a single antenna and element N1 of the array, oriented at 12 o'clock.

![Graph showing VSWR as a function of frequency for different orientations.](image)

**Figure 4.** VSWR of element N1 of the array with d = 15 cm, oriented at 3 and 12 o'clock.

The difference in the characteristics of array elements with different orientations is even stronger in the signal response from one element to another. For example, Figure 5 shows the response of the signal (module S21) from the array element N2 to the element N3 in the array with d = 15 cm and different orientation of the helixes. The same parameter (module S21) was also sensitive to the distance d. Figure 6 and Figure 7 show signal response from elements N2 to N3 for array with helixes orientation at 12 o'clock and 3 o'clock, respectively. It can be seen that with increasing d, the signal response tends to decrease. In the frequency range (0.7-1.3 GHz), this trend is almost strictly observed.
Figure 5. Signal response from array \((d = 15\ \text{cm})\) element \(N_2\) to \(N_3\) with different helixes orientation.

Figure 6. Signal response from element \(N_2\) to \(N_3\) for arrays with helixes orientation to 12 o’clock.

Figure 7. Signal response from element \(N_2\) to \(N_3\) for arrays with helixes orientation to 3 o’clock.
4. Studies in the time domain
Antenna arrays with a 3 o’clock helixes orientation (Figure 2) were studied in the time domain. The radiation characteristics of the arrays were measured in an anechoic chamber. The arrays were studied in the radiation mode and rotated in the horizontal plane. To register the radiated pulses, a receiving antenna was used in the form of two symmetrical dipoles crossed at right angles [4]. The antenna simultaneously received the $E_x$ or $E_y$ components of the electric field. A LeCroy WaveMaster 830Zi oscilloscope with a frequency band of 30 GHz was used to record the radiated pulses. Bipolar pulses with a duration of 1 ns and an amplitude of -16/+12 V were fed to the inputs of the array elements from the bipolar pulse generator through a divider (Figure 8). The difference between the peak voltage value on a separate channel and the average one did not exceed 1.5%.

The radiation patterns of the arrays were studied in the horizontal plane. The distance between the ground plane and the receiving antenna was 336 cm. The distance between the receiving antenna and the rotation axis of 320 cm was chosen based on our previous studies [5].

At the first stage of investigation of the peak field ($E_p$) patterns, studies of synchronously excited elements of array were carried out. The maximum deviation of the generator pulse arrival at the input of the array element from the average did not exceed 20 ps. The results for $E_x$ and $E_y$ components are shown in Figures 9 and 10.

Figure 8. Waveform of the voltage pulse at the input of the array element.

Figure 9. Arrays peak field patterns for $E_x$ component.
It is possible to construct hodographs of $E$ vector using the time dependences for the $E_x$ and $E_y$ components registered in the main radiation direction $\theta = 0^\circ$ (Figure 11). Studies have shown that with increasing distance $d$, the ellipticity coefficient $p$ (the inverse value of the axial ratio) decreases. For arrays with periods $d = 15$ cm, 21 cm, and 30 cm, it is 0.6, 0.56, and 0.5, respectively.

The array elements were excited with certain time delays in the studies in the scanning mode. The scanning angle was selected based on the width of the pattern of a single antenna at half the peak power level and was approximately $20^\circ$. Scanning was carried out in a horizontal plane. Figures 12 and 13 show the peak field patterns for the $E_x$ and $E_y$ components of the electric field of a linear array with periods $d = 21$ cm and $d = 30$ cm when scanning towards positive and negative angles, respectively.

The hodographs of the electric field vector in the scanning mode at $\theta = -17.5^\circ$ for arrays with $d = 21$ and 30 cm are presented in Figure 14, and for $\theta = 17.5^\circ$ they are presented in Figure 15. For arrays with $d = 21$ and 30 cm at $\theta = -17.5^\circ$, the ellipticity coefficient $p = 0.59$ and 0.55, respectively, and for the angle $\theta = 17.5^\circ$, the $p$ values were 0.68 and 0.69, respectively.
Figure 12. Peak field patterns for arrays with $d = 21$ and 30 cm for $E_x$ component in scanning mode.

Figure 13. Peak field patterns for arrays with $d = 21$ and 30 cm for $E_y$ component in scanning mode.

Figure 14. Hodographs of the $E$ vector for $\theta = -17.5^\circ$ for arrays with $d = 21$ and 30 cm.
5. Summary
The space-time and polarization characteristics of an ultrawideband radiation wave beam formed by a linear four-element array in the mode of synchronous excitation of the array elements and scanning to the fixed angles were studied. It was shown that the polarization characteristic of radiation weakly depends on the scanning angle.

Acknowledgments
The authors thank M. Y. Zorkaltseva for her help in the measurements and Tomsk Center of Collective Use SB RAS for the provided measuring equipment Agilent N5227A and LeCroy Wave Master 830Zi.

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