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Broadband low-profile antenna array with mechanoelectric scanning based on continuous transverse stubs

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The work is devoted to the development and study of a broadband low-profile antenna array with wide-angle mechanoelectric scanning based on continuous transverse stubs (CTS). In the proposed design, the antenna array is excited by a source of a plane quasi-TEM wave formed in a power divider based on binary dividers implemented on a U-shaped waveguide. Scanning is achieved by rotating the plane wave source relative to the CTS-array. The aperture efficiency of the antenna array was more than 60 % when scanning in a sector of angles of $\pm 30^\circ$ in a frequency band of more than 45 % with VSWR of no more than 1.2. The proposed antenna does not have frequency scanning.

Keywords: Continuous transverse stub, antenna array, satellite communication, wide-angle scanning, VICTS, CTS.

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Modern telecommunication and radar systems require antenna systems with wide-angle scanning of the pattern that are broadband, compact, and highly efficient. Scanning antennas based on active components have a number of advantages over classic waveguide and microstrip antenna systems, but the cost of complex electronic components often makes such antennas inaccessible to the public. Current research in Russia and abroad is aimed at designing and improving antenna systems with wide-angle scanning based on mechanoelectric beam control [1–4].

An antenna array based on continuous transverse stubs (CTSs) has been proposed in the early 1990s [5]. This antenna consists of a waveguide array of wide parallel plates excited by a quasi-TEM wave and offers a high efficiency coefficient (EC) and a wide operating frequency band. Their high efficiency and small number of emitters make such arrays an excellent basis for antenna systems with wide-angle mechanoelectric scanning; in subsequent years, a number of studies focused on this issue have been published.

Ten years after the invention of a CTS antenna array, the same research group has patented a diffraction scanning antenna of the VICTS type [6]. It consisted of a CTS antenna with series excitation and a quasi-TEM wave source, which rotated relative to the emitter system to form a linear phase shift along the width of the waveguide. This made it possible to scan over a wide sector of angles by rotating two disks only: one with emitters and the other with a plane wave source. In recent years, the research into these antennas has been directed toward multi-band designs [7–9] and increasing their efficiency [10]; antenna structures for satellite communication systems [11] have been proposed. In addition, commercial VICTS-based satellite communication terminals are produced by Thinkom [12]. Despite their simplicity and high efficiency, VICTS antennas have an important drawback associated with series excitation: frequency scanning. Among other things, it limits the instantaneous operating frequency band, which becomes narrower the more the antenna gain is required. In addition, such antennas have a blind zone in the direction of the normal to the antenna. The use of a parallel beamforming network (BFN) allows one to circumvent the main drawback of VICTS (frequency scanning). Several scanning antenna systems based on CTS arrays with a parallel BFN have been proposed [13,14]. One common feature of these antenna systems is that their scanning range does not exceed $\pm 40^\circ$. Just as in VICTS, their pattern is controlled by rotating the plane wave source, but the parallel antenna array is fed instead of the series one. Despite the potential of this operating principle, the operating frequency bandwidth in the mentioned studies does not exceed ten percent. The same beam control principle is also used in series CTS arrays [15,16] with an identical scanning sector of $\pm 30^\circ$.

The present study is focused on the design and study of a broadband low-profile antenna array with wide-angle mechanoelectric scanning based on continuous transverse stubs. The transverse section of the proposed antenna array is shown in Fig. 1, *a*. The antenna system features two main parts that have no electrical or mechanical contact with each other: a system of emitters at the top and a source of a plane quasi-TEM wave at the bottom.

Scanning is performed by means of angular rotation of the plane wave source relative to the structure with emitters. The top layer is an antenna array based on continuous transverse stubs that is fed by a TEM wave. The plane wave source is based on binary power dividers built from a U-shaped waveguide; the use of a transmission line of

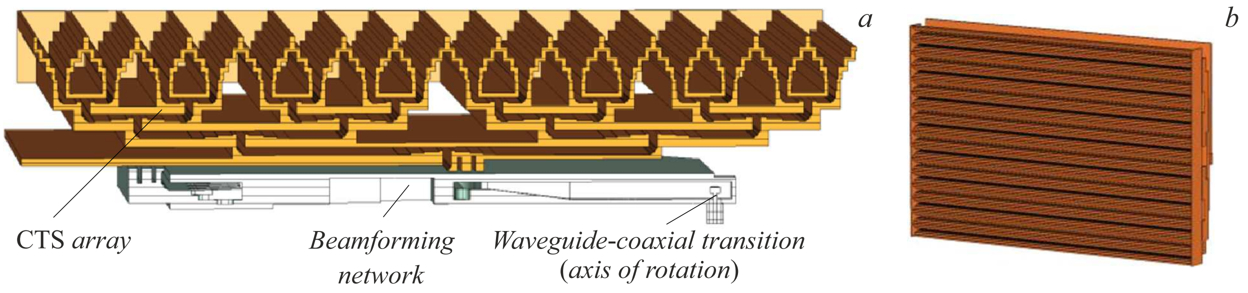

Figure 1. Antenna system with mechanoelectric scanning. *a* — Transverse section; *b* — external appearance.

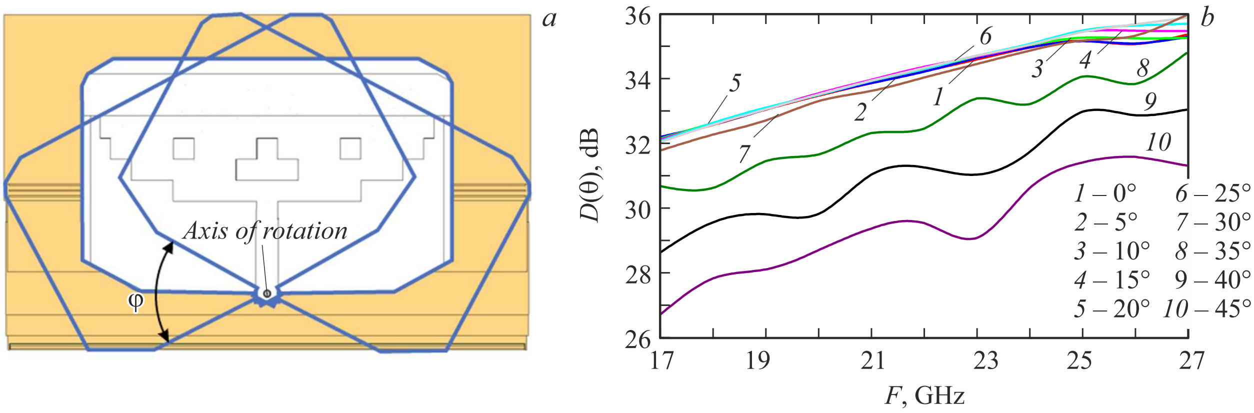

Figure 2. View of the antenna system from the BFN side (*a*) and frequency dependences of the DF at different angles of BFN rotation (*b*).

this type allowed us to achieve VSWR (voltage standing wave ratio) values lower than 1.2 within a frequency band exceeding the operating range of the feed waveguide with a standard cross section (WR 42). The waveguide is, in turn, fed by a waveguide-coaxial transition, which has its axis aligned with the axis of rotation of the entire plane wave source relative to the radiating structure (Fig. 2, *a*). This design allows for the positioning of a rotating microwave transition and ensures practical feasibility. Power is transmitted from the plane wave source to the parallel CTS through three stepped turns of the waveguide line, two of which are implemented without contact between the waveguide walls. The gap width is 0.5 mm. Barrier structures based on choke grooves are used to suppress wave propagation in an undesirable direction. The reflection coefficient of such a turn is no more than -28 dB within the entire operating frequency band.

The aperture size of the designed antenna is 200×312 mm (Fig. 1, *b*) with an array pitch of 12.5 mm, and the profile is within 42 mm; the width of the plane wave source is 220 mm, and the profile is 12 mm. When the source rotates relative to the emitters (Fig. 2, *a*), the plane phase front of the source acquires a linear phase shift, and a wave deflected from the normal propagates in the emitter circuit.

Since the structure has finite dimensions, an additional restriction on the ratio of widths of TEM waveguides of the source and the emitter system arises. If the source and the system of emitters have the same width, the maximum EC is observed in the normal direction of the pattern; however, the directivity factor (DF) decreases sharply in the process of scanning due to the tilt of the source, since a part of the energy propagating at an angle reaches the lateral boundary of the waveguide and is reflected from it. Thus, in order to make scanning efficient, one needs to increase the width of emitters with the effect that the deflected wave propagating in the dividers of the radiating structure does not interact with the waveguide boundaries and the quasi-TEM mode is maintained. The radiating region essentially moves in the antenna aperture during scanning. This approach reduces the overall antenna array EC due to the fact that only a part of the antenna aperture remains active at different tilt angles of the TEM wave source.

The proposed ratio of the source and emitter widths provides an aperture EC higher than 60 % when scanning in the $\pm 30^\circ$ angle sector. With further scanning, the DF of the system decreases significantly; the propagation of a wave is actually blocked by the side wall of the waveguide structure, and a mirror beam is formed. When the BFN is rotated by an angle greater than 30°, the stepped turns bump up against each other. The antenna patterns at angles greater than 30° are shown (Fig. 3, *a*) just for estimation of the DF reduction magnitude and cannot be obtained in actual experiments with the array of the proposed design.

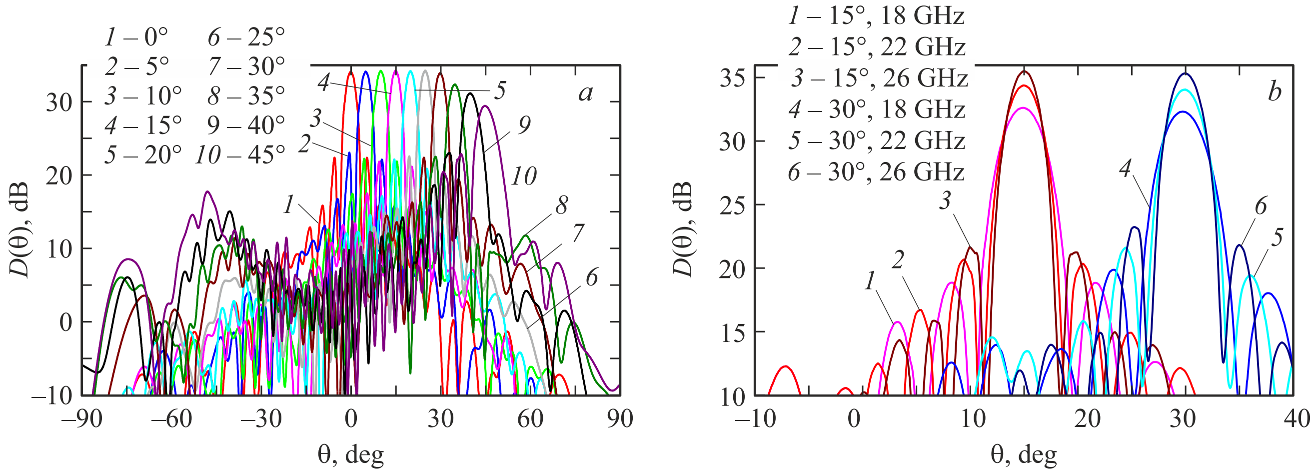

Figure 3. Calculated antenna patterns in the E plane at frequency $F = 22$ GHz with different angles of BFN rotation (a) and at various frequencies with two BFN positions ($\varphi = 15, 30^\circ$) (b). A color version of the figure is provided in the online version of the paper.

The DF fluctuates by no more than 0.3 dB when scanning in the $\pm 30^\circ$ angle sector (Fig. 2, b); the EC is maintained at 60 % at all deviation angles and frequencies. The EC decreases slightly at frequencies above 25 GHz due to the emergence of diffraction maxima; their influence is essentially insignificant.

The calculated patterns at a frequency of 22 GHz are shown in Fig. 3, a. The side-lobe level corresponds to an aperture with a uniform amplitude distribution and does not exceed -13 dB. Calculations were performed using the finite integration method in the time domain.

One of the advantages of the used TEM wave is the lack of dispersion, which translates into virtually non-existent frequency scanning (Fig. 3, b).

Thus, a low-profile antenna array with wide-angle scanning and a virtually constant DF in the $\pm 30^\circ$ angle sector was designed. One of the disadvantages of this array is the fixed linear polarization. An external polarizer, which will increase slightly the size of the antenna, will be needed to generate radiation with circular polarization or control linear polarization. Compared with existing VICTS antennas, the proposed antenna offers such obvious advantages as a wide operating frequency band and the lack of frequency scanning; however, the scanning sector is not as large. If the antenna is installed at an angle of 30° relative to the horizon and rotated mechanically in azimuth, the elevation scanning sector may be expanded to $\pm 60^\circ$. Therefore, this antenna is suitable for use in ground-based satellite communication terminals and radars.

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Conflict of interest

The authors declare that they have no conflict of interest.

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