Microstrip Antenna Topologies for 5G Communication Systems

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Abstract. In this paper the antenna array designs operating at 28 GHz frequency, which is approved by the Federal Communications Commission for 5G communication systems is presented. The antennas are designed on a standard FAF4D microwave material with a dielectric constant of 2.5 and a thickness of 0.5 mm. Since the frequency band is limited both by the radiator itself and the quarter-wave transformers used, passive radiators have increased the band of operating frequencies of the square array antenna, approximately 5-fold. Also in this paper the authors describe the construction of a diagram-forming circuit (DFC) for supplying microstrip radiators. The whole process of designing the proposed antennas was realized in the Anfost HFSS software, specializing in this software, and the design of the DFC was implemented in NI-AWR.

1. Introduction
Today, it is impossible to imagine the world without wireless data transfer between different devices. For this reason, developers around the world try to improve the transmission capabilities of this data every year, so in the near future the fourth generation of mobile communication will be replaced by the fifth generation of 5G. This standard should improve the quality of data transmission, and expand the coverage area of this network, while increasing energy efficiency. The main advantage of the next standard is a higher data transfer rate, namely at least one gigabit per second for a large number of users simultaneously. The Federal Communications Commission (FCC) on July 14, 2016 approved the spectrum of frequencies for the standard mobile communication 5G, including frequencies 28, 37 and 39 GHz. In each generation of mobile communication from 0G to 4G, antennas are used for data transmission, and the 5G standard will not be an exception in this respect. Today, some antenna designs are already available in the literature, which can be used in 5G systems [1–8].

The construction of a multichannel dielectric resonator antenna used for the fifth generation cellular networks operating in the frequency range 10.5-17 GHz is presented in [1]. A compact two-band-bypass antenna, for smartphones operating in 2.5-2.7 GHz and 3.4-3.8 GHz, is considered in [2]. In [3], we investigated a square microstrip radiator, which is tuned for operation at two frequencies of 10.15 and 28 GHz. A two-band PIFA antenna for 5G, with a wide bandwidth in both 28 and 38 GHz, is presented [4]. An adaptive antenna array operating at a frequency of 38 GHz for use in 5G is presented in [5]. MIMO-antenna operating in the frequency band from 3,400 to 3,600 MHz, for use in devices operating using 5G technology, is shown in [6]. In [7], a design operating at a frequency of 28 GHz and consisting of several dielectric substrates is described. Also in [8] two designs of microstrip radiators operating at 28 and 60 GHz, respectively, were investigated. In this paper, two designs of antenna arrays of 4 radiators operating at 28 GHz are presented. The bandwidth of the square grid is increased by the
addition of passive radiators. Also the design of the Butler 4x4 matrix, created to power the radiators in the antenna array is presented.

2. Design
Initially, before designing a single radiator, which will be used in the construction of the antenna array, the authors determine the microwave substrate material for the design of the entire antenna. The three main parameters that must be taken into account when implementing the antenna are the substrate thickness (h), the dielectric constant (ε) and the tangent of the dielectric loss angle (tgδ), which will affect the frequency band of the antenna and the loss in it. A small influence on the bandwidth of the operating frequencies of the antenna is exerted by the shape of the radiating element. The following regularities exist: the bandwidth of the operating frequencies increases with increasing substrate thickness and with a decrease in the relative dielectric constant of the microstrip antenna substrate. However, an increase in the values of the dielectric constant and the substrate leads to a decrease in the efficiency due to the large expenditure of power on the excitation of surface waves.

Initially, for the design of a single radiator, the PHA4D was chosen as the substrate material, with a dielectric constant ε = 2.5, the dielectric loss tangent tan δ = 0.002, and a thickness h = 1 mm. As the operating frequency for the standard 5G was chosen frequency of 28 GHz.

When calculating the geometric dimensions of a quarter-wave transformer, it turned out that when using the selected substrate, the width of the transformer (Wtr) is larger than its length (Ltr), which makes it work differently. For this reason, in order to achieve the ratio Ltr > Wtr, it was decided to change the thickness of the substrate toward its decrease, to a value of 0.5 mm.

The shape of the radiator was chosen rectangular, one of the most common in the application as an element of the antenna array. With the help of these two antenna the arrays of linear and square type will be realized. In Figure 1 an antenna array of a linear type is presented, which consists of equidistant rectangular radiators at a distance less than the wavelength, which avoids the appearance of diffraction maxima.

![Figure 1. Linear array antenna topology for 5G](image1.png)

![Figure 2. Radiation pattern of the proposed antenna array](image2.png)

Antenna gratings are used to increase the directivity factor of the antenna, as a system of radiating elements compared to a single radiator, as well as to control the radiation pattern, for example, the orientation of the main ray in space. The total antenna field consists of the field of a single radiator multiplied by the antenna array multiplier. The geometries of antenna arrays operating in centimeter and millimeter ranges are more complex than the same gratings to a lower operating frequency range, since the dimensions of the antenna are small enough and exact reproduction of the size of each element is required to obtain the same characteristics in practice as in program. The results of numerical simulation of the tuned antenna array were obtained using the software package for electrodynamic analysis of Ansoft HFSS. The radiation pattern is shown in Figure 2, and the SWR from the frequency in Figure 3. From the results obtained, it can be seen that the gain of the antenna array at the central frequency is
13.8 dBm. The band of operating frequencies according to the SWR level = 2 starts at 27.24 GHz and ends at 28.82 GHz.

Figure 3. TE01 propagation ratio-frequency dependence

3. Square array antenna
The square lattice consists of four identical radiating elements, and its design is shown in Figure 4. The antenna is powered by a 50-ohm connector, which is installed in the middle of the branching of the feeding lines.

Figure 4. Topology of the square array for 5G

Also using Ansoft HFSS, the results of numerical simulation were obtained. The radiation pattern is shown in Figure 5, and the SWR from the frequency in Figure 6. It can be seen from the obtained results that the gain of the antenna array at the central frequency is 13 dBm. The band of operating frequencies by the SWR level = 2 starts at 27.13 GHz and ends at 29.25 GHz.

Figure 5. Radiation pattern of the proposed antenna array

Figure 6. Dependence of SWR on frequency
It is worth noting that the increase in the number of elements in the antenna array makes it possible to increase the directivity factor and at the same time the antenna gain factor in comparison with a single radiator. Also, with the increase in the elements in the grating, the main beam is narrowed, which increases noise immunity, and also an increase in accuracy in the radiolocation of the radio wave source.

It also necessary to take into account that the micro-beam emitter and the quarter-wave transformer have the maximum efficiency in a certain band of operating frequencies. Therefore, in order to increase the band of operating frequencies of the antenna array, a multiresonance method is used, its meaning is to use an additional passive radiator that is located above the active radiator at a certain altitude. These emitters can be realized on another microwave material. Due to the fact that the active and passive radiator has two closely spaced resonances, a common wide band of operating frequencies is formed. Such a method of increasing the working band can be used for microstrip radiators of various shapes. In Figure 7, the topology of a square array antenna with added passive radiators is shown.

![Figure 7. Topology of a square array antenna with passive radiators](image)

![Figure 8. Radiation pattern of the proposed antenna array](image)

Adding passive radiators allowed increasing the band of operating frequencies by 2.12 GHz to 11.6 GHz by the SWR level = 2, the graph of which is shown in Figure 8. At the same time, the gain factor decreased by 3.1 dBm. Figure 9 shows the radiation pattern.

![Figure 9. Dependence of SWR on frequency](image)

4. **Control beam beam pattern antenna array**

Antenna gratings can change the direction of the maximum in space. Beam control can be performed by various methods, such as using a phase shifter block that will allow changing the phase on each radiator, or use Butler diagramming schemes (parallel power scheme) or Blass (sequential power scheme). In this paper we will consider the Butler matrix 4x4, with its help it is possible to obtain 4 independent beams in space, and soldering of such microwave elements as pin diodes is not required. The design of the matrix was designed for a working frequency of 28 GHz, in the program NI-AWR.
The Butler matrix consists of four two-bridge bridges and one crossover (directional coupler, which simulates the operation of two intersecting lines). When using the same material as in the design of antennas, it does not allow realizing an efficient bridge. Since the implementation of a two-bridge bridge, the width of the microstrip line of the quarter-wave segment is greater than the length. To solve this problem, it is necessary to increase the length of all quarter-wave segments by the value of the sex of the wavelength in the line. This made it possible to realize the bridge at the desired frequency, however, because of this, the phase difference at the output of such a device changes. Therefore, it was decided to change the substrate material, which will ensure that the length of the microstrip transmission line is greater than its width. To do this, the Rogers RO4350 material was chosen, with a dielectric constant $\varepsilon = 3.48$, a tangent of the dielectric loss angle $\tan = 0.0037$ and a thickness $h = 0.254$ mm. The design of the crossover was chosen in the form of a three-conductor directional coupler, since the two-conductor directional coupler was not realized due to unrealizable lines with the necessary wave impedances. Resistance of quarter-wave segments of the crossover was calculated from the formulas presented in [1]. Also, in order to control the beam electrically, a switch can be installed on the matrix input for 4 outputs. Such a switch consists of one input microstrip line, four output transmission lines, four pin-diodes and power supply for each diode. Figure 10 shows the topology of the resulting Butler matrix.

Also with the help of NI-AWR, the results of numerical simulation were obtained. Figure 11 shows the dependence of the S-parameters on the frequency. Based on the results, it can be seen that the matrix operates at a central frequency of 28 GHz and has a bandwidth of operating frequencies from 27.5 GHz to 28.5 GHz, estimated at a decoupling level of -20 dB.

The dependence of the S-parameters on the frequency for the Butler matrix, where S11 denotes triangular markers, S21 denotes square markers, S31 for diamond markers, S41 denotes round markers, and the remaining transmission coefficients S51, S61, S71, S81.

**Conclusion**

In this paper, antenna arrays operating at a frequency of 28 GHz and designed for use in 5G have been investigated. Lattices consist of equidistant identical rectangular radiators. For the design of antennas, the program for three-dimensional electrodynamic analysis Ansoft HFSS was used. The linear array has a gain of 13.8 dBm, and the band of operating frequencies is 1.6 GHz. The square array antenna has a gain of 13 dBm, and the band of operating frequencies is 2.1 GHz. Since for 5G systems the frequency bands should be 3-4 GHz or higher, this requires increasing the frequency band by adding passive radiators. Using additional radiators it was possible to increase the band of a square lattice by more than 5 times. However, the magnitude of the expansion of the initial frequency band can be regulated by the size of the emitters and their distance from the active radiators. Using the NI-AWR program, a Butler
matrix was designed to supply microstrip radiators. Based on the results obtained, it can be seen that the matrix operates at a central frequency of 28 GHz and has a working frequency band equal to 1 GHz, which can be increased if multi-directional couplers are used. For each radiator comes a signal with amplitude of -7 dB. It is also necessary to take into account the fact that when the frequency at which the information is transmitted decreases, the communications range decreases. Such a law of physics can only be circumvented by increasing the transmitter power, which is limited by sanitary norms. However, it is believed that the base stations of the fifth generation networks will be located denser than the networks of the previous generation, which is caused by the need to create a much larger network capacity. The advantage of tens of GHz bands is the availability of a large amount of free spectrum.

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