

Design of patch active electronically scanned antenna for 5G communication system

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Abstract. The article deals with the research and design results of an active electronically scanned antenna (AESA) based on beamforming BiCMOS monolithic integrated circuit (MIC) and patch antenna radiators. The operating frequency band is sub-6 GHz. MIC design is at the stage of transferring files to the manufacture and verification of integrated circuit parameters. In this regard, the current task is the antenna radiators design, that is the main focus of this paper.

1 Introduction

Nowadays a fifth generation mobile communication system (5G) is a promising designing area in radioelectronics. 5G should provide higher bandwidth and data rate compared to 4G, which ultimately should have a positive impact on the technology of the "Internet of things". Since one of the features of this system is the use of the device-to-device mode (direct connection between subscribers), as a result, there is a tendency to design small-size phased antenna arrays.

In the Russian Federation, the 5G communication system frequency range has not been officially defined yet. However, a number of countries is already used bands below 6 GHz in test mode. It is likely that in the Russian Federation for the fifth generation mobile communications this range will also be used. Its advantages include the fact that the Russia Government approved frequency bands for direct visibility relay stations of the range near to 5 GHz [1]. Moreover, this range is also used in radar, radio navigation systems, as well as Wi-Fi, Wi-Max and other communication standards.

According to Sevastopol State University state assignment [2] the design of the transmit/receive modules (TRM) for the active phased antenna arrays is carried out. TRM operating frequency range is corresponding to specified frequency plan [3]. Currently, the design is in the final stage of verification and file transfer to manufacturer. In the near future, the TRM crystal will be made. Thus, the current challenge is the design of antenna radiators.

2 The main requirements for antenna

The main requirements that the antenna must satisfy are its small weight and compactness, at a sufficiently long signal wavelength for such systems, as well as the low cost of

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production. In this regard, it was decided to design a patch antenna. Since it is necessary to use a wider frequency band to ensure a higher data transfer rate, the next requirement for the antenna is its wide bandwidth. The TRM integrated circuit can operate in the 4-6 GHz frequency band, being matched with the 50 Ohm resistance of the next stage. In this regard, it is necessary that the antenna radiators were also matched to 50 Ohm in the entire bandwidth. The operating bandwidth should be at least 500 MHz.

3 Antenna description

3.1 Transmit-receive module

The TRM main parameters, which are obtained as a result of layout simulation, are shown in Table 1.

Table 1. TRM parameters.

Parameter	Value
Maximum output power	6.76 dBm
LNA noise figure maximum value	8 dB
Phase tuning range	360°
Phase shifter resolution	6 bit, 5.625°
Attenuator dynamic range	31 dB
Phase RMS	1.6°
Attenuation RMS	0.33 dB

At a phase tuning step 5.625 degrees, the optimal number of antenna array radiators can be at least 64. This is due to the need to ensure smooth beam scanning with an overlap at a relative level of -1 dB. In this case, the standard deviation of the phase should not exceed 5 degrees, which is satisfied by the obtained TRM parameters. At the same time, the requirements for phase error can be reduced when using a phased array with a large number of radiators. More detailed information on the effect of phase errors on phased array radiation pattern is given in [4].

3.2 Single radiator

The radiators design main objective was to obtain a wideband antenna with a minimum geometric dimensions. For this, the possibility of using low-element antenna arrays in such systems was previously evaluated [5].

In this case, the basis for the radiators construction is the PIFA antenna (planar inverted F-antenna) creation, in which a conductive element is located on the substrate surface, and one of the edges is grounded. This allows you to make the antenna of the smallest size and adjust the matching.

The radiator simulation was carried out with 1 mm thick FR-4 fiberglass substrate. Such an antenna can be easily manufactured according to standard technological process for the manufacture of printed circuit boards. The main advantages of FR-4 are: a high value of relative permittivity, which allows to reduce the radiator dimensions; low cost of production in comparison with microwave materials; high strength; the manufacturing an entire board with a relatively large area (usually up to half a meter) possibility, which is important for antenna arrays. Based on this composite material, the radiator simulation was carried out. The radiator model is shown in Figure 1.

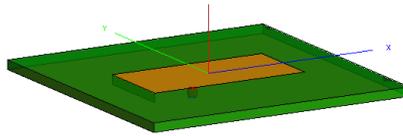


Fig. 1. The antenna radiator model.

Figure 2 shows a three-dimensional beam pattern at the center frequency 5 GHz operating range, and Figure 3 shows the beam pattern in polar coordinates for three frequencies (4.75, 5, and 5.25 GHz).

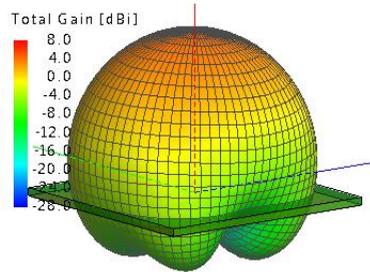


Fig. 2. 3D radiation pattern of a single radiator at a frequency 5 GHz.

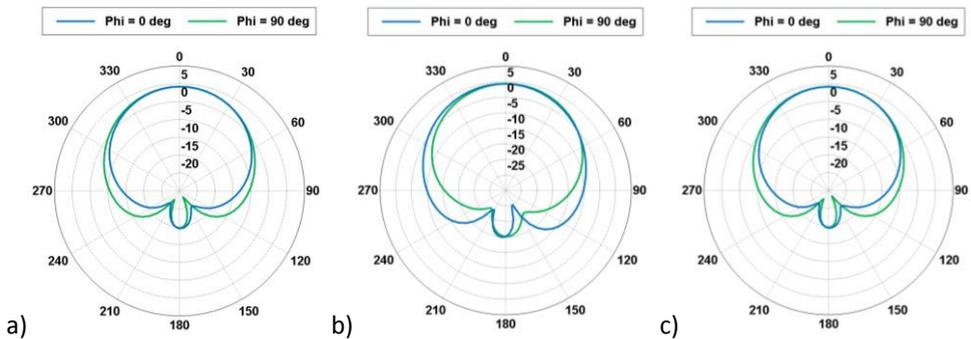


Fig. 3. Radiation patterns of single radiator in polar coordinates at frequencies of 4.75 GHz (a), 5 GHz (b) and 5.25 GHz (c).

Figure 4 shows the radiator input impedance frequency dependence.

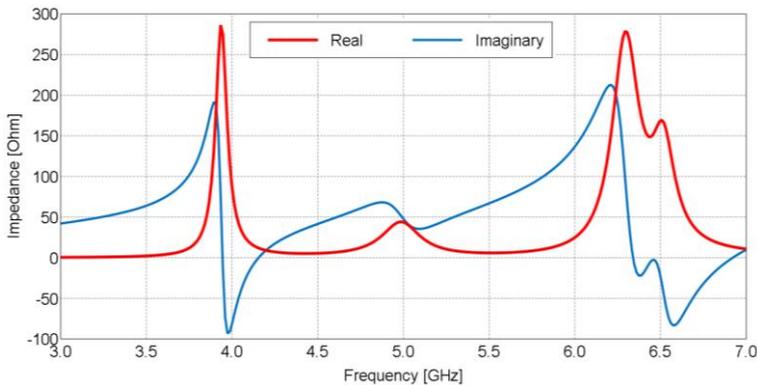


Fig. 4. Radiation patterns of single radiator in polar coordinates at frequencies of 4.75 GHz (a), 5 GHz (b) and 5.25 GHz (c).

Since the imaginary part of the radiator input impedance in the vicinity of the operating frequency range has a different value from zero (see Figure 4), then for the radiator matching with the TRM, it is necessary to use a matching circuit, which is a series connection of 1pF capacitor. Then the standing wave ratio (SWR) at the input will be equal, as shown in Figure 5.

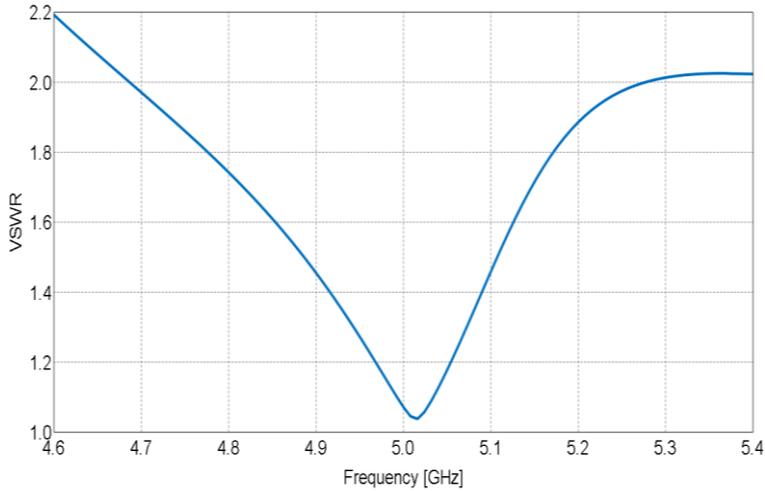


Fig. 5. Single radiator standing wave ratio frequency dependence.

4 Antenna array

The antenna array is a set of radiators with a minimum quantity of 64 pieces, each of which is powered by a separate TRM chip. In this case, taking into account the obtained TRM parameters, an almost smooth scan is achieved. With a step of phase adjustment of 5.625 degrees, a beam scan is provided with an overlap at a relative level < 1dB.

At a distance between the radiators centers of approximately 45 mm the antenna array will be in dimensions of 40x40 cm. The antenna array and its radiation pattern at the beam central position are shown in Figures 6 and 7.

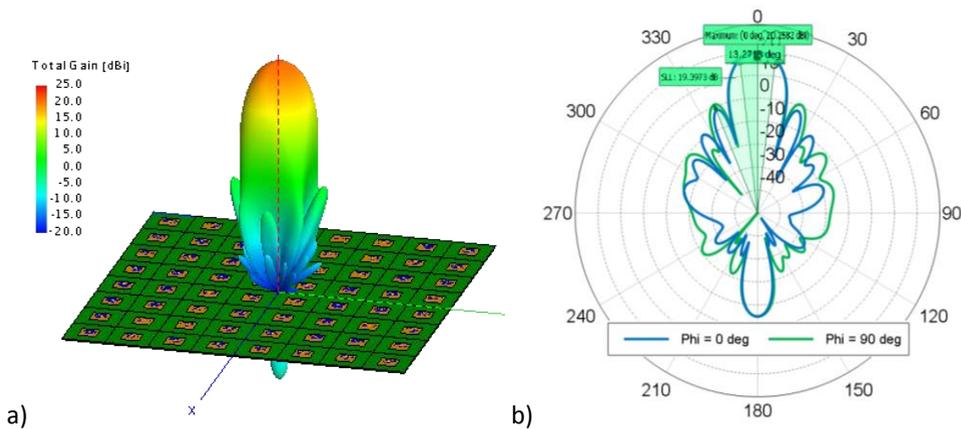


Fig. 6. The antenna array 3D (a) and polar (b) radiation pattern.

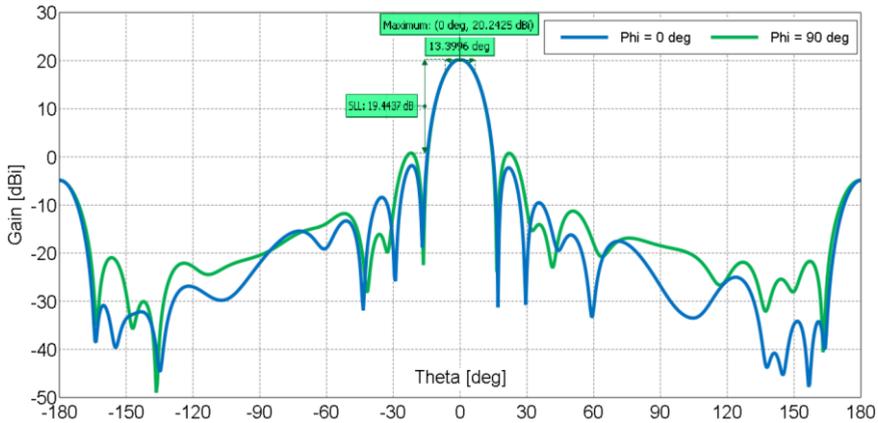


Fig. 7. The antenna array radiation pattern in Cartesian coordinates at central beam position and frequency of 5 GHz.

Figures 8 and 9 show the radiation patterns for the position of the beam deflected to the angle of 35 degrees.

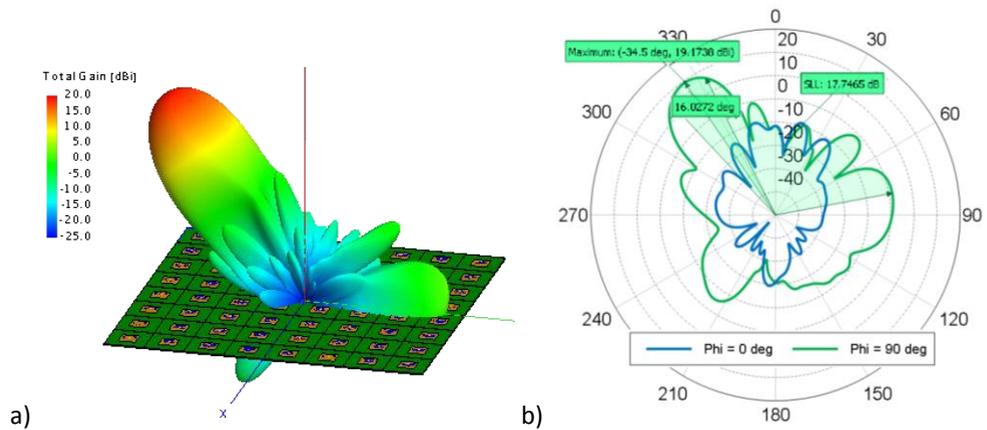


Fig. 8. The antenna array 3D (a) and polar (b) radiation pattern at beam angle of 35 degrees.

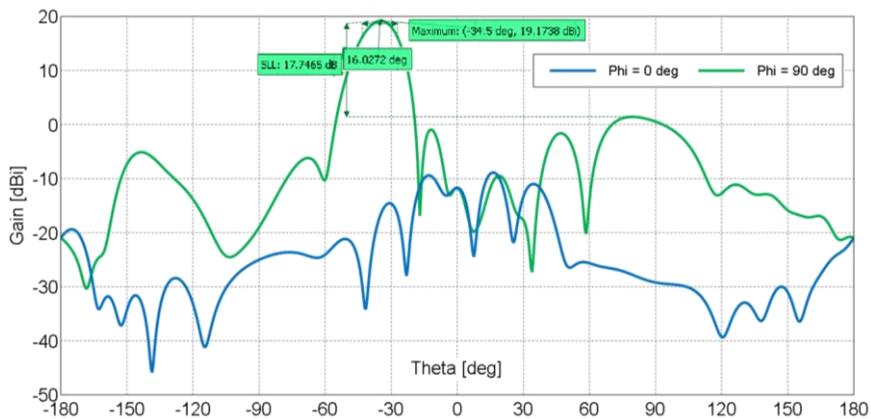


Fig. 9. The antenna array radiation pattern in Cartesian coordinates at beam angle of 35 degrees and frequency of 5 GHz.

5 Conclusion

The paper presents research and development results of AESA for civilian applications. The TRM is designed in silicon-germanium technology, which means it will have a lower cost in comparison with the most common analogues produced in technologies of the connection category A₃B₅. To obtain a low cost AESA, requirements for simplicity of design are also put forward to the antenna array. In this regard, patch antennas made on the FR-4 dielectric material are used as radiators. In this paper, more attention is paid to the design of wideband patch antenna radiators from which the antenna array is formed.

When using the designed AESA in communication systems, taking into account the output power of the TRM (without using additional power amplifiers), as well as the maximum antenna gain of 20 dB (with the beam in the center position), the range is estimated at 25 km.

As a result of the simulation, the following values of the AESA parameters were obtained: the minimum gain is 20 dB, the main lobe maximum width is 16 degrees, the side lobe level is 1.8 dB (18.5 dB less than the radiation value in the main maximum direction), and the scan angle is 70 degrees. To solve special problems, AESA parameters can be optimized by changing the amplitude distribution and arrangement of antenna elements.

After debugging and manufacturing and test of TRM integrated circuit, it is planned to manufacture AESA 64 elements for the frequency range below 6 GHz. The gain optimization, rear and side radiation, as well as the scanning angle is implemented using the TRM, which provides with the attenuator of 31 dB dynamic range and 5 bit resolution.

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