Research of Radiating Elements of a Phased Antenna Array

Bagdat Kozhakhmetova[1,2], Aigul Kulakayeva[2], Anatoliy Samsonenko[3], Zhadyra Ongenbayeva[2] and Sungat Koishibay[2]

[1]*Almaty University of Power Engineering and Telecommunications named after G.Daukeev, Baytursynuli St. 126/1, Almaty, 050013, Kazakhstan*
[2]*International Information Technology University, Manas St. 34/1, Almaty, 050040, Kazakhstan*
[3]*Institute of Space Technique and Technology, Kislovodsk St. 34, Almaty, 050061, Kazakhstan*

Abstract

This article presents a study of the radiating elements of a phased array antenna, as well as measurement of the main characteristics of a laboratory layout of a phased array antenna for educational and scientific purposes. This layout provides an opportunity to study the basic properties of phased antenna arrays, the principle of operation of phase shifters and methods of forming a directional pattern. The paper also presents the results of measurements of the standing wave coefficient and the radiation pattern of phased antenna arrays. The results of measurements of the standing wave coefficient show a fairly good result (1.109), indicating good antenna matching at the frequency under study. To obtain more reliable results, all measurements were carried out in an anechoic chamber using a combined ultrahigh frequency analyzer FieldFox Analayser N9915A. The work also provides a measurement scheme. In the work, the antenna under study uses a discrete type of phase shifters, which allows for switching scanning of space. The selected structure of the elements of the phased array antenna allows to achieve a low level of interference between the antenna emitters, and also provides acceptable values of the modulus of the reflection coefficient from the opening in a wide frequency band

Keywords

Active phased antenna array, divider, scanning, amplitude-frequency response, spectrum analyzer, measurement, radiation pattern, SWR.

1. Introduction

Currently, phased array antennas are one of the promising types of antennas used in new radio technologies. This type of antenna is most widely used in mobile communication systems of the new generation 5G and 6G, in satellite communication systems, in radar and radio navigation systems. The main advantages of phased antenna arrays include: the formation of narrow beams of the radiation pattern, electronic scanning of space, high gain (CU), broadband, multi-band, etc. There are many different types of antennas, but of particular interest are phased array antennas (PAA) and its subsequent transition to active PAA (APAA). If an active element in the form of a power amplifier, generator or frequency converter is connected to each emitter of the antenna array, then this PAA will be called an active PAA (APAA).

Many works have been devoted to the use and development of PAA for fifth-generation (5G) mobile communication systems [1-3]. For example, the article [1] presents the advantages and features of using antenna arrays in 5G systems, and the article [2] discusses the technical capabilities and problems of communication systems using antenna arrays. The design and further development of a broadband dual-polarized dipole antenna array for 5G systems is presented in [3]. The operating range of the considered phased antenna arrays is 26 GHz and 28

DTESI 2023: Proceedings of the 8th International Conference on Digital Technologies in Education, Science and Industry, December 06–07, 2023, Almaty, Kazakhstan
kozhahmetova.ba@gmail.com (B. Kozhakhmetova); aigul_k.pochta@mail.ru (A. Kulakayeva); anatolly.sam@yandex.ru (A. Samsonenko); ongenbaeva_zh@mail.ru (Zh. Ongenbayeva); s.koishybay@iitu.edu.kz (S. Koishibay)
0000-0002-9566-3629 (B. Kozhakhmetova); 0000-0002-0143-085X (A. Kulakayeva); 0000-0002-7808-5273 (Zh. Ongenbayeva); 0000-0000-0002-0242-6019 (S. Koishibay)

GHz. Measurements confirm the use of this antenna for 5G base stations due to its compactness and wide scanning in three planes (up to ± 60° in the E, H and D planes).

At works [4-5] present the antenna arrays for 5G Internet of things applications and sixth generation (6G) technology. The possibilities of forming a beam of phased antenna arrays are widely used for Internet of Things applications.

Antenna arrays are widely used in satellite communication systems. Works [8-10] present the development of antenna arrays for use in satellite systems, and work [11] provides an overview of various antenna designs, including antenna arrays, and their application for satellite communication services.

Also, antenna arrays of this type are promising antenna systems that are of the greatest interest for the field of satellite radio monitoring [12-14]. Thus, the works [15-16] consider the process of developing a mobile platform that allows you to study the antenna system using augmented reality technology.

Also in such antenna systems there are many radiating elements that allow to increase the energy potential of the antenna system, as well as to obtain a narrow radiation pattern, compared with a single emitter.

The advantage of APAA is that an active element in the form of a generator, power amplifier or frequency converter is connected to each emitter of the antenna array. Therefore, APAA is of the greatest interest, due to its advantages in higher energy potential, high directivity, electrical scanning of space, etc.

Thus, the use of antenna systems, such as APAA, is promising for modern radio engineering systems. The main requirements for such systems include: expansion of the operating frequency band, provision of high energy potential, multifunctional mode of operation, etc.

2. Research methods

Today, with the rapid development of radio engineering systems, new requirements are emerging for their design. Being an indispensable element of any radio system, antennas play an important role, and the quantity and quality of receiving and transmitting information strongly depends on its effectiveness. Today, with the advent of new radio technologies operating in the range of ultra-high frequencies (UHF) and extremely high frequencies (EHF), modern antenna devices have requirements for broadban, multi-band and high reliability. The most promising in meeting these requirements is the use of antennas of the PAA type, which structurally consist of non-simultaneously emitting antenna elements. The radiation of each element of the antenna array occurs with time delays (phase shift), which accordingly causes the inclination of the beam of the antenna pattern. The shift is provided by a group of phase shifters managed by a controller.

The FieldFox Microwave Analayser N9915A analyzer was used in the work. Portable combined microwave analyzer FieldFox Analayser N9915A, which is designed to perform a wide range of tasks from routine maintenance of equipment to comprehensive diagnostics and troubleshooting. FieldFox microwave analyzer, which provides high-quality measurements, both in the laboratory and in the field.

The main purpose of the combined microwave analyzer is to test cables and antennas. It can also be configured as a vector circuit analyzer and a spectrum analyzer. Additional options:

- include a power meter;
- independent signal generator;
- vector voltmeter;
- interference analyzer;
- adjustable DC power supply and built-in GPS receiver.

The technical characteristics of FieldFox Microwave Analyzer are presented in Table 1.

Table 1
The technical characteristics of Microwave Analayser N9915A

Frequency range	from 30 kHz to 9 GHz
Dynamic range	100 dB
Amplitude measurement error	±0.5 dB
Battery life	3,5 hours
Weight of the device	3.0 kg
Operating temperature range	from –10°C to +55°C

A logoperiodic antenna was also used, which operates in a tenfold and wider wave range. The «Aaronia» test antennas designed for electromagnetic compatibility (EMC) testing include a complete high-resolution measurement protocol. This allows for very accurate EMC measurements using any spectrum analyzer.

The scope of application of such antennas is research on electromagnetic compatibility and analysis of parameters of radio frequency signals: GSM1800/1900, DECT, UMTS, WLAN, Microwave, Bluetooth, WiFi, LTE2.6, WiMAX.

HyperLOG antennas are equipped with a high-tech protective housing. It has a special coating, thanks to which condensate and other types of moisture on the surface of the housing do not affect the measurement results. The housing also has a very low attenuation coefficient. As a result, the antennas have the maximum possible protection from mechanical influences and environmental influences without compromising other characteristics. The technical characteristics of HyperLOG 30180 are presented in Table2.

Table 2
The technical characteristics of HyperLOG 6080X

Frequency range	from 680 MHz to 8 GHz
Impedance	50 Ohms
Gain factor	45 dB
Number of calibration points	733 (step: 10 MHz)
Connector	SMA (F) or N (adapter required)
Operating temperature range	from -10°C to +55°C
Maximum power	100W
Dimensions: (L/W/D)	340x200x25 mm
Weight	0.4 kg

An anechoic chamber was also used in the measurements. Anechoic chamber is a room in which there is no echo. Usually such cameras are built so that they also isolate the camera from external signals (acoustic or radio frequency (RF)). All this makes it possible to measure the signal that came directly from the source, eliminating reflections from the walls and noise from the outside, thus forming the location of the source in an isolated space.

The walls, ceilings and floor of these chambers are covered with a wave-absorbing material. The internal structure of the RF chamber is similar to an acoustic chamber, but here, instead of the sound absorbers used on the acoustic chamber, a radio-absorbing material is used.

Radio frequency cameras are used to plot radiation patterns of antennas, study electromagnetic compatibility.

3. Measurement of the standing wave ratio of the antenna

One of the important parameters when designing antennas is matching their impedance with the power line (feeder). This parameter is called the standing wave ratio (SWR).

When the antenna and the power line do not have matching resistances, the transmitter detects unexpected resistance at which it may not be able to deliver its full power, and in some cases may even damage the transmitter (standing wave ratio (SWR)). In antenna theory [17], the SWR is determined by the formula:

$$SWR = \frac{P_i + P_r}{P_i - P_r}, \quad (1)$$

where P_i is the power of the incident wave, and P_r is the power reflected from the load (antenna). Thus, the maximum value of the SWR is achieved at the maximum value of the reflected signal power.

When measuring SWR (Figure 1), all cable connectors must be properly soldered. Since, oxidation, improperly sealed place is one of the reasons for the poor SWR value. It is important to choose the right cable for the experiment, since part of the energy will be lost in the cable, and this will affect the SWR value. The cable should not introduce phase distortion during bending and have minimal energy losses in the frequency range.

To measure, we use the device in the antenna characteristics mode and set the frequency limit. Then we calibrate the device in the ranges from 0.5 GHZ to 1.5 GHz. We connect the antenna cable port to the analyzer port and measure the SWR of one antenna emitter. We put a marker on the required frequency range, that is, the beginning and the end of the measurement.

Then you can see the SWR in this frequency range. Ideally, the SWR should approach 1. To achieve this result, a method of powering a symmetrical vibrator using a symmetrical bridge has been applied.

When measuring the SWR of the antenna, we connect all the elements together using phase shifters and a divider. Phase shifters are made in the form of delay lines (DL) with discrete switching by logic signals.

Each emitter will be connected to the DL using a cable, respectively, the first to the first, the second to the second, and so all four emitters and the DL are connected to each other. Then all four DL are connected to the power divider. We connect the common port of the divider with a cable to the SWR analyzer. Then we also calibrate in the required frequency range (from 0.5 GHZ to 1.5 GHz).

Figure 1: Measurement of SWR of one antenna element

As mentioned earlier, the SWR should be equal to 1. Figure 2 shows the result of the reduced indicator of the SWR level to 1.109.

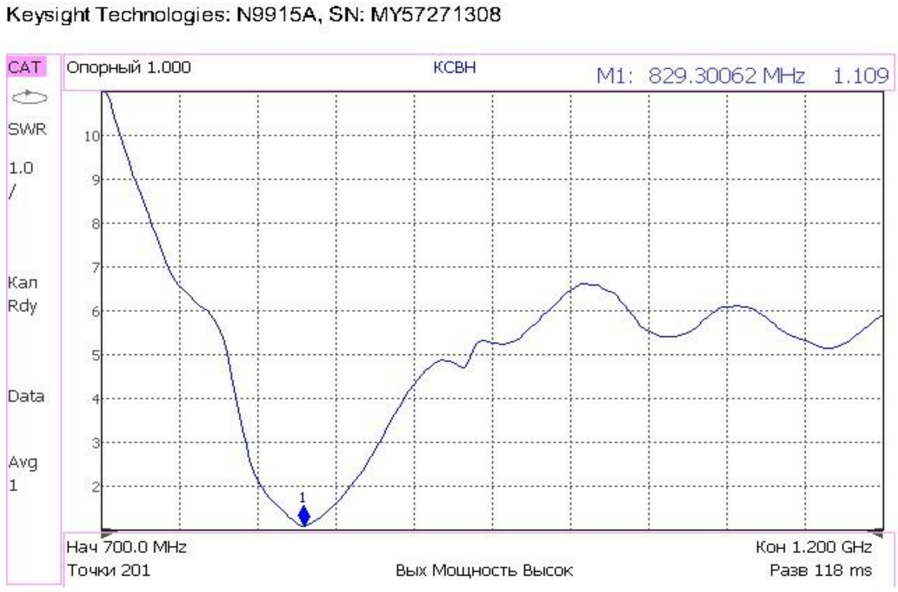

Figure 2: Antenna SWR value

To measure the radiation pattern, the following devices were used: FieldFox Microwave Analayser N9915A, which has a frequency range from 30 kHz to 9 GHz, while the power of the test signal is -15 dBm and, if necessary, you can increase or decrease the power, depending on the location of the antenna being measured. The device is universal because it has three measurement modes: antenna characteristics analysis (SWR, S_{11}), circuit analysis (S_{21}) and spectrum analysis.

As a test (reference) antenna, we use the HyperLOG 30180 logoperiodic antenna operating in the frequency range from 380 MHz to 18 GHz, which makes it possible to make very accurate electromagnetic compatibility measurements with any spectrum analyzer.

The radiation pattern is one of the most important characteristics of the antenna. The definition of the radiation pattern is the dependence of the field strength generated by the antenna at a sufficiently large distance from the observation angles in space. The radiation pattern is characterized by the width of its main beam at the level of 0.5 of its maximum power value and gain, which are related by the relations:

$$\Theta = \frac{\lambda}{d_a} \quad (2)$$

$$G = \frac{4\pi S_a}{\lambda^2} \quad (3)$$

where S_a, d_a - the effective area and length of the antenna aperture, λ – wavelength, G – antenna gain.

The radiation pattern measurement will be carried out in an anechoic chamber. The chamber will ensure the construction of an accurate directional pattern. To measure the radiation pattern, we change the FieldFox Microwave Analyzer N9915A mode from the antenna characteristics analyzer to the circuit analyzer mode. We send the test signal to the antenna, the antenna is in the direct signal mode. The antenna switches are in direct signal mode, so the antenna beam will be formed straight.

We install the measuring antenna at a distance of 3 meters in an anechoic chamber and bring the signal from the measuring antenna to the circuit analyzer. Next, we observe the frequency response of the antenna. At the same time, when the frequency response was recorded, the second action was done – the deviation of the antenna by 180° and with a deviation of every 30°, we record the gain coefficient and thus the radiation pattern was obtained in one direction and in the other. When determining the radiation pattern, it is necessary to take into account the level of the side and back lobes. Since the APAA antenna is mainly used in radar and in the presence of a large level of side lobes, tracking the object will become difficult. Because of the false goals that will be caught by the side lobes, it will be difficult to determine which of the goals is real and which is fake.

In accordance with the principle of reciprocity, the antenna under study can be used both in the radiation mode and in the reception mode. In this work, we use it in the radiation mode. The diagram of the workplace and the composition of the equipment is shown in Figure 3.

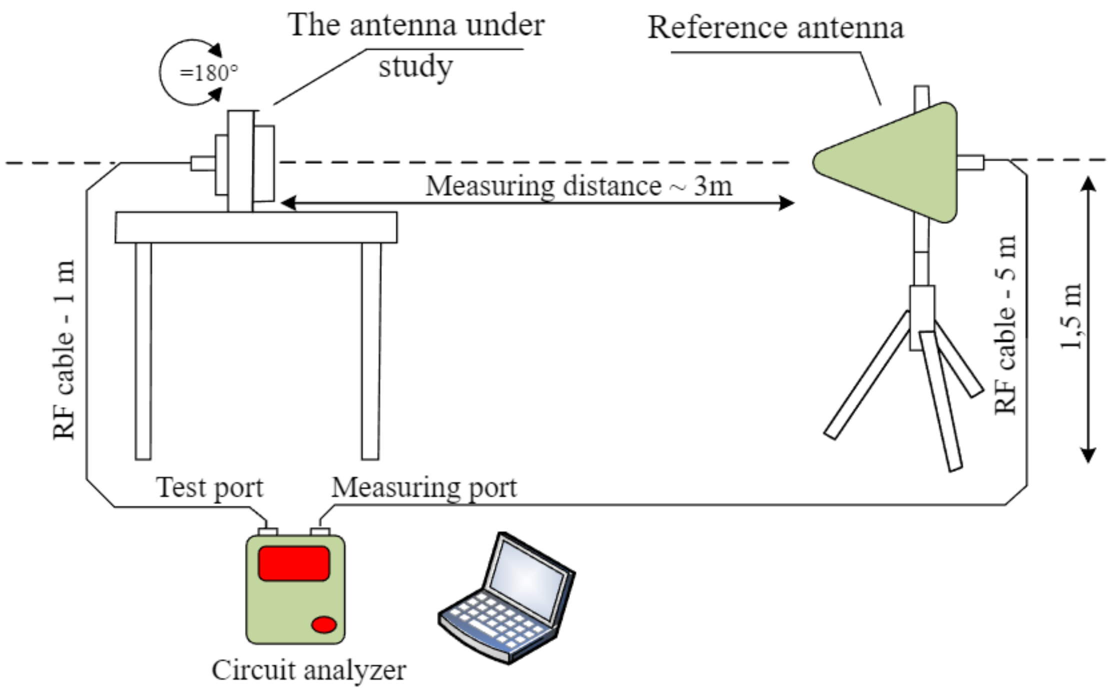

Figure 3: Radiation pattern measurement scheme

As a source of the test signal, as well as a panoramic measuring receiver, the Microwave Analyzer N9915A was used in the (S_{21}) mode of the circuit analyzer (Figure 4). The scanning range is 500 MHz - 2000 MHz. The radio frequency cable of the Huber SuhNer S04272 model is used as connecting cables.

Figure 4: Radiation pattern measurement in an anechoic chamber

The measuring distance in the anechoic chamber is 3 m. The output power level of the test signal is set in such a way as to ensure reliable registration of the received microwave oscillations.

In the process of measuring the radiating pattern, the antenna under study rotates in the azimuthal plane within the angular sector +180°, and then -180°. The level of received microwave oscillations is measured at every 30°.

4. Measuring the radiation pattern of antenna

One of the key characteristics of any antenna is its radiation pattern. Many important parameters and energy characteristics of the antenna, such as gain and directional coefficient, come from the radiation pattern characteristic. Radiation pattern is a dependence of the intensity of the electromagnetic field generated by the antenna at large distances on the viewing angles in space [18].

There are several methods for measuring radiation pattern. Measurements of RP classified depending on the distance are divided into measurements in the far field and near field zone.

The method of measurements in the far field zone involves making measurements at a sufficiently large distance from the antenna, where the signal can be considered almost a plane wave. The amplitude and phase of the signal are measured in different directions, and based on these data, the RP is constructed. The method of measurements in the near field zone is carried out at a distance closer to the antenna than in the far zone. Measuring the antenna bottom in the far field zone is a common method for evaluating the directional characteristics of antennas. The edge of the far field zone is determined by the ratio of the antenna size and wavelength [19].

$$r \geq 2\frac{D^2}{\lambda}, \quad (4)$$

where D - maximum overall size of the antenna, λ - wavelength.

Since the measuring reference antenna in our experience is stationary, the measurement procedure is built in the following order:

- calibrate the circuit analyzer in the required range;
- connect the measuring circuit with the spectrum analyzer;
- send a control logic signal 00 on the delay line, while the same RF signal comes to all 4 emitters without delay and they should form a total lobe of the radiation pattern with an azimuth of 0°;
- deflect the antenna array to the right by +180° and to the left – 180°, while fixing the RF signal level every 30° and getting antenna radiation patterns, which confirms the theory (Figure 5) ;
- send a control logic signal 01 on the delay line, while an RF signal with an increasing delay comes to each emitter from the 1st to the 4th. As a result, the main lobe of the radiation pattern should deviate to the right;
- reject the antenna array as in the previous step and get a radiation pattern with a tilt of the main lobe to the right;
- send a control logic signal 10 to the delay line, now the RF signal with increasing delay comes to the emitters in reverse order from the 4th to the 1st and the radiation pattern should deviate to the left;
- turn the antenna array as in the previous step and get a radiation pattern with the main lobe tilted to the left, as shown in Figure 6.

Table 3 show the measurement results.

Table 3
The results of measuring the radiation pattern at a frequency of 1000 MHz and the control signal on the phase switches - 00

Degrees of measurement (°)	Relative results, dB (+180°)	Obtained results, dB (+180°)
0	-30	0
30	-30.6	-0.6
60	-35.6	-5.6
90	-48.7	-18.7
120	-47.5	-17.5
150	-53.3	-23.3
180	-56	-26
210	-53.3	-23.3
240	-47.5	-17.5
270	-48.7	-18.7
300	-35.6	-5.6
330	-30.6	-0.6
360	-30	0

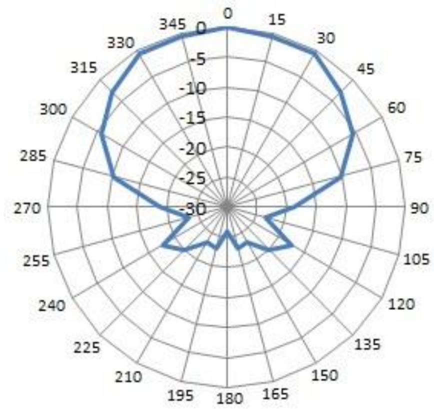

Figure 5: Radiation pattern at a frequency of 1000 MHz and a control signal on the phase shifters 00

As a result of three measurements, a radiation pattern of the antenna array was constructed.

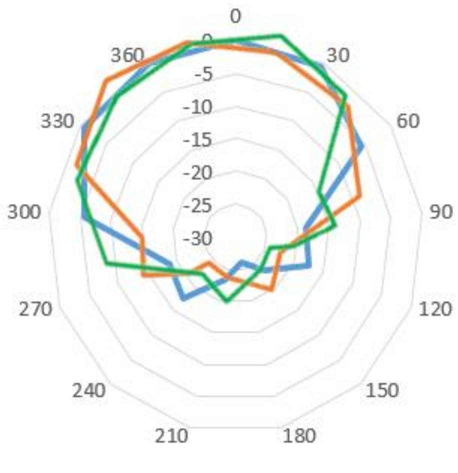

Figure 6: Radiation patterns antenna array with a deviation of ± 20° at a frequency of 1000 MHz

5. Conclusion

In this article, a special case of a large multiport divider of an active phased array antenna is investigated. The amplitude-frequency parameters of the dividers of the active phased antenna array and the aligning characteristics were measured using the Microwave analyzer Analayser N9915A presented by the Institute of Space Engineering and Technology. These studies may be relevant for the next stage of designing an active phased array antenna. Thus, the practical conclusions of this work are as follows.

Phase shifters in the form of discrete delay lines showed operability. However, if you use such technical solutions in 5G networks, you will need a more wide-angle scanning of space than 15-20°, which means long delays in phase shifters.

The scanning angles of space in 5G networks can vary from 5°, which means that delay lines with more detailed discreteness are needed, and therefore with a larger bit depth of the control bus.

Also, when synthesizing an antenna system with a wide-angle scanning sector, weakly directed radiating elements should be used.

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