Development of a device for monitoring and tuning radio-technical parameters of a satellite communications Earth station

A B Gladyshev¹, D D Dmitriev¹, V N Tyapkin¹, V N Ratuschnyak¹
¹Siberian Federal University, 79 Svobodny pr., 660041, Krasnoyarsk, Russia
E-mail: a-glonas@yandex.ru

Abstract. The article describes the existing methods for studying the characteristics of the antennas that are used in satellite earth stations. A variant of the device based on a spherical scanner is proposed. The spherical scanner uses the method of measuring the field in the near field. It has been established that for high efficiency and reduction of measurement time, it is necessary to use the spiral scanning method. The composition and block diagram of the device is presented. Recommendations on the use of software for processing measurement results are given.

1. Introduction

Today, for the national interests of Russia, the development of the Arctic region is of particular relevance. The full development of the Arctic is possible only with the provision of high-quality communication services.

The development of telecommunications in the Arctic based on traditional terrestrial communication networks is fraught with difficulties due to the following factors:

- low population density;
- poor infrastructure development, including the development of transport routes and communication lines;
- huge territory;
- severe climatic conditions are complicating the development of terrestrial communication networks.

The optimal solution for the provision of telecommunication services in the Arctic is the development of a network of earth stations of satellite communication systems. However, ready-made, widely used in the world, solutions require significant study and modification.

At present, Russia does not have its own fully developed satellite communications system that provides uninterrupted service to the entire territory of the country. The high cost of their services distinguishes foreign systems operating in Russia. A significant part of the territory of Russia, including the regions of the Arctic, is outside the coverage of foreign systems [1]. All this limits the possibilities of their application and makes the task of creating domestic satellite communication and data transmission system relevant.

Thus, the task of developing earth stations of promising satellite communication systems with characteristics significantly exceeding the characteristics of world analogues is extremely urgent. In many respects, the characteristics of such stations depend on antenna systems that determine the
energy potential of a communication channel. The characteristics of the antenna systems mainly depend on the irradiating systems and the elements of the microwave supply path.

Antenna systems largely determine the potential properties of a radio link, i.e. signal-to-noise ratio and the following probabilistic characteristics at a given data rate. Of particular interest are the so-called energy characteristics of antennas – directional coefficient, gain, efficiency, noise temperature. This article proposes a variant of the device for monitoring and tuning the antenna parameters of a satellite communications earth station.

2. Methods for measuring antenna directivity

Methods of measuring the directivity of the antennas can be divided into two groups - measurements in the far and near zones. When measuring in the far zone, the required distance between the test and auxiliary antennas depends on the size of their apertures and the working wavelength. According to the required distance, the electromagnetic field emitted by the auxiliary antenna can be considered a plane wave. These methods are the most accurate and allow measurements even of antennas as part of the supporting structures [1]. However, their main drawback is the need to organize long polygons.

When measuring in the near field, the characteristics of the antennas are found by processing the results of measurements of the near field. The near field of the antenna is measured in the plane located in front of the antenna using two-coordinate mechanisms to move the measuring probe. The distance between the antenna and the probe is in the range from several wavelengths to several sizes of the aperture of the antenna and is always much less than the distance to the far zone boundary. Because of the bulkiness of the systems for measuring the characteristics of antennas in the far zone, preference was given to the development of the installation based on measurement methods in the near zone.

Methods for measuring the directional characteristics of antennas based on near-field measurements are divided into:

- amplification method;
- with a collimator (compact polygon);
- method of spiral scanning;

The multiphase method is as follows. A small, slightly directional measuring antenna probe moves mechanically near the antenna under test. For each spatial position of the measuring antenna, the amplitude and phase of the signal at the output of the antenna under test are measured and stored. For simplicity, the vector nature of the field has not yet been taken into account. After completing this procedure, the set of measured data — an array of complex numbers \{En\} (index n corresponds to the n-th spatial position of the measuring antenna) — is processed [2]. Thus, when an amplitude- and phase-sensitive receiver is connected to the antenna under test, the distribution of the complex near field of the antenna along a certain surface S is essentially measured. Knowing the distribution of the complex field \(E(r)\) (r is the vector coordinate of a point on S), we can calculate the field at any point in space outside S, including in the far zone. In particular, one can approximately make such a calculation based on the Huygens principle, according to which the values of the complex field on a certain surface are considered as amplitudes and phases of secondary radiation sources.

The following advantages characterize the near-field measurements:

- the ability to measure in compact rooms;
- weather independent;
- relatively high accuracy of measurements, comparable with similar indicators for measuring instruments of the far zone.

The listed advantages of this method make it possible to measure the parameters of the antennas in a compact anechoic chamber. For measurements, a specialized near-field probe is used, which moves in the aperture of the antenna using a scanner. The meter should be implemented based on a vector network analyzer. The measuring paths will be relatively small. Therefore, the losses will also be relatively small.
Among the shortcomings, it should be noted the difficulties in the metrological support of such devices, the limitation of the measurement range of parameters in azimuth and elevation, and, most importantly for serial products, a sufficiently long measurement time. So, for one antenna with a diameter of 1.2 meters, measurements in the frequency range 44.5 GHz will take about 9 hours without taking into account the time for installation/disassembly and adjustment. Thus, when organizing continuous operation during the day, it will be possible to test no more than 3-4 antennas, which corresponds to the number of antennas from 1095 to 1460 pieces per year, provided that work is carried out without days off and breaks. In addition to the above disadvantages, there are also methodological difficulties in measuring such energy characteristics of antennas as effective isotropically radiated power and quality factor.

Along with the amplitude-phase method, the direct method of obtaining a collimated beam of rays is used in the practice of antenna measurements. It received the name collimator (the term "compact polygon" is also used). In this case, the flat front portion is formed by a special antenna, lens or mirror [3].

The collimator can be considered as a flat in-phase opening emitting a beam of parallel rays, the cross-section of which coincides in shape with the aperture of the collimator. Thus, near the collimator antenna, there is a section of a plane wavefront with a size corresponding to the size of the collimator.

Collimators make it possible to form a plane wavefront at shorter distances than antenna polygons. This circumstance allows organizing measurements in the far zone of the antenna in a compact anechoic chamber. The dimensions of the anechoic chamber are calculated based on the focal length of the collimator and the range of operating frequencies. Algorithms for measuring antenna parameters using a collimator are similar to algorithms for measuring antenna parameters in the far zone.

The measuring device located in the anechoic chamber is a collimator, a rotary support device of the auxiliary antenna (for positioning the antenna at the focus of the collimator) and a rotary support device of the measured antenna. The main advantage of this method is the simplicity and speed of measurements. Measuring the antenna pattern in two main sections takes several minutes. The construction of a three-dimensional radiation pattern is time-consuming - in the Q-frequency range, measurements take about 2.5 hours. The effectiveness of the collimator method is due to the ratio between the reduction in the cost of manufacturing an anechoic chamber by reducing its size and the additional cost of manufacturing a collimator.

However, the requirements for the collimator are very stringent. To achieve acceptable measurement accuracy of the radiation pattern, the linear dimensions of the collimator must exceed the antenna aperture dimensions by at least two times. The fulfilment of this requirement makes it possible to ensure uniformity of the wavefront within the aperture of the antenna under study. To measure the radiation pattern in the angle sector, covering the main and several side lobes closest to it, the tolerance for the production of a collimator should be about (0.01-0.02) \( \lambda \).

Spiral scanning is an alternative method aimed at reducing measurement time while maintaining the necessary accuracy [4, 5]. There are two types of this method:

- measurements on a spherical scanner [6, 7];
- measurements on a planar scanner.

A typical near field spherical scanner is shown in Figure 1. Measurements on a spherical scanner consist of simultaneously measuring both polarizations with a continuous gradual movement of both positioners. Thus, the measurement points form a spiral, described around the measured antenna (Fig. 2). Next, the equivalent surface currents are calculated, followed by recalculation into the radiation pattern of the far zone. The calculation algorithm should support full correction for the probe, as well as correction for reflections from the metal floor for a semi-anechoic chamber. Reception of readings from an external antenna geometry meter in real-time should also be provided.

Based on the analysis of methods for measuring the directivity of antennas based on near-field measurements, the use of a near-field scanner by Rohde & Schwarz is proposed.

3. The block diagram of the device for monitoring and tuning the parameters of the antennas
The block diagram of the device for monitoring and tuning the parameters of the antennas for the satellite earth station is shown in Figure 3.

![Block Diagram](image)

**Figure 1.** Typical Near Field Spherical Scanner.

![Scanning Methods](image)

**Figure 2.** Scanning methods: a – Classic spherical scanning; b – spiral scan.

The principle of operation of the device for monitoring and tuning the parameters of the antennas for a satellite communications earth station is based on measuring the amplitude-phase distribution of the electromagnetic field strength in the near zone of the antenna.

The amplitude-phase distribution is measured using a vector network analyzer. One analyzer port is connected to the emitting antenna, and the second port is connected to the receiving antenna, and the system is bi-directional. As one of the antennas, a near-field probe based on the Vivaldi bipolarization antenna is used, and the second one is the antenna under study. Antennas are mounted on a positioner that mechanically moves the antennas relative to each other. Thus, the points of measurement of the amplitude-phase distribution are located on a spherical surface. Positioner movement control and measurements on the vector network analyzer are automatic and synchronized in time.

Management is carried out from an external computer with special software. Special software receives the results of measuring the amplitude-phase distribution in the near field and, using mathematical algorithms, recalculates the full three-dimensional antenna diagram in the far zone.
From the calculated diagram, the value of the gain of the antenna under study is determined, for which the system is pre-calibrated using a set of horn antennas.

**Figure 3.** Block diagram of a device for monitoring and tuning antenna parameters for a satellite earth station.

In addition, special software provides:
- SWE transform – standard fast Fourier transform and integration, support only the equidistant measurement grid in increments of Kotelnikov’s theorem, and recalculation directly into the radiation pattern of the far zone;
- FIAFTA transformation – calculation of equivalent surface currents with subsequent recalculation into the radiation pattern of the far zone, support for a non-equidistant measurement grid (but with a smaller step), which allows accelerating measurements for spiral scanning of the near field;
- display of the distribution of equivalent currents on the surface specified by the user;
- full correction for the probe and correction for reflections from the metal floor for a semi-anechoic chamber;
- reception of readings from an external antenna geometry meter in real-time.

**4. Conclusion**
The advantage of the device, built according to the stated principles, will be the shorter time required for measuring the parameters of the antennas.

The estimated time of measurements and transformations in the far-field for an antenna with a reflector diameter of 1.2 m using such a device will be 1 hour. In the case of applying the amplifase method, the measurement time will be about 9 hours, with a compact polygon – about 2.5 hours.
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