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Application of a fiber-optic communication line for transmitting RF-signal in system for measuring parameters of active phased antenna arrays

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Abstract. The necessity of using fiber-optic communication lines (FOCL) for transmitting microwave signals in radar complexes is substantiated. The advantages of the use of FOCL when working with microwave signals and testing various antennas are noted. A system with a fiber optic system has been developed to measure the parameters of an active phased array antenna (APAA) in the far zone. The choice of the components of the system is justified and their characteristics are measured. The results of research on the operation of the developed system are presented.

Keywords: fiber-optic communication line, active phased array antenna, radiophotonics, frequency range, microwave signal, far zone

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Материалы конференции
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Использование волоконно-оптической линии связи для передачи РЧ-сигнала в системе измерения параметров активных фазированных антенных решеток

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Аннотация. Обоснована необходимость использования волоконно-оптических линий связи (ВОЛС) для передачи сигналов СВЧ в радиолокационных комплексах. Отмечены преимущества использования ВОЛС при работе с СВЧ-сигналами и тестировании различных антенн. Разработан комплекс с волоконно-оптической системой для измерения параметров активной фазированной антенной решетки (АФАР) в дальней зоне. Обоснован выбор компонентов системы и измерены их характеристики. Представлены результаты исследования работы разработанной системы.

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Ключевые слова: волоконно-оптическая линия связи, активная антенная фазированная решетка, радиофотоника, диапазон частот, СВЧ сигнал, дальняя зона

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Introduction

The development of efficient high-speed optoelectronic devices has aroused great interest in the use of optoelectronic and optical technologies in microwave technology [1–9]. Various developments of laser systems also contributed to the emergence of radiophotonics [10–14], which allows to create devices and systems of the microwave range with parameters unattainable by traditional electronic means. The main advantages of radiophotonics devices and systems are related to the properties of optical fiber: ultra-low losses during transmission of a microwave signal, a wide frequency band, immunity to electromagnetic interference, complete galvanic isolation, mechanical flexibility, low weight and dimensions [13, 15–20]. A during are solving various tasks in radar, the use of FOCL allows obtaining the necessary results [15–25]. It should be noted that the transmission of microwave signals is carried out mainly at distances less than 1000 m. In this case, different types of dispersion do not have time to form in the fiber and affect the transmitted signal [22–27]. This greatly simplifies the design of the FOCL [20–30].

One of the most difficult tasks is to set up various radar antenna systems in an enterprise environment. The greatest difficulties arise when setting up an air-based radar with APAA operating in review mode. In this mode precise measurements of radiation diagram are very important, in the far zone especially [21, 28, 30]. The far zone of the radar is determined by the following ratio:

$$R_0 \gg 2L^2 / \lambda, \tag{1}$$

where R_0 is the distance between antennas, L is the distance between the marginal transmitting elements of the antenna array, λ is the wavelength of the radiation.

The angular distribution of the field in the far zone does not significantly depend on the change in the distance to the antenna. In most APAAs in operation, the far zone corresponds to a distance of about several hundreds meters. This creates big problems when setting up and testing the radars in an anechoic chamber (AEC). Therefore, field tests are necessary. In the conditions of the polygon, the amount of interference of various kinds can be very large, which will lead to signal distortion and errors in the antenna setup. The use of fiber-optic communication lines can help solve this problem.

Fiber optical communication system

In analog fiber-optic information transmission systems, modulation methods are used, characterized by a continuous change in one of the parameters of the signal carrier (optical radiation power during intensity modulation, the position of the optical pulse during positional pulse modulation or its duration during pulse width modulation, etc.).

One of the ways to transmit a microwave signal to a FOCL is direct modulation. The principle of direct modulation is as follows: the input of a laser diode with direct modulation receives a microwave signal that modulates the output optical signal of the laser diode. The modulated optical signal is transmitted with the help of a fiber-optic line to an optoelectronic receiving module, in which it is converted into a microwave signal. The developed direct-modulated FOCL can be used to transmit an analog signal over long distances (more than 500 m) in the frequency band from 0.1 to 12 GHz (currently unknown direct-modulated FOCL in the diapason from 0 to 40 GHz).

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Similar FOCL have two main disadvantages: limited bandwidth and significant nonlinear distortions caused by the direct arrival of the microwave signal to the laser. In order to avoid these disadvantages, it is recommended to use a FOCL with external modulation. The principle of external modulation is as follows: the electro-optical modulator receives an optical signal from a semiconductor laser module, which is modulated by an input microwave signal. The modulated optical signal is transmitted via a fiber-optic line to an optoelectronic receiving module, in which it is converted into a microwave signal.

The peculiarity of analog transmission in comparison with digital is the need to ensure a large signal-to-noise ratio at the output of the optical receiver and high linearity along the entire path, since otherwise mutual interference from various frequency components of the transmitted analog signal is possible.

Fig. 1 shows a block diagram of a system in transmitting mode for measuring APAA parameters in the far zone.

The system includes two antenna posts:

- antenna post 1 (AP I) includes the studied APAA, optoelectronic converters (receivers) and spectrum analyzers.

- antenna post 2 (AP II) includes receiving antennas - horns 1 and 2, low-noise amplifiers, transmitters, as well as a power source.

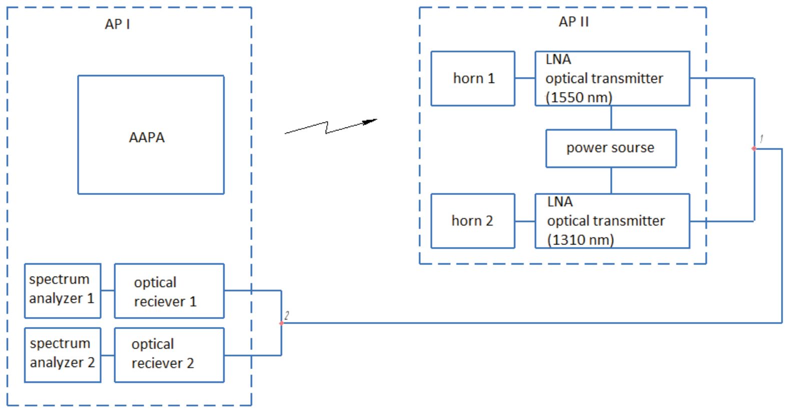

Fig. 1. Block diagram of the developed system

Two different devices were selected as transmitters - transmitter with direct modulation in the 1310 nm window and with external modulation for the 1550 nm wavelength. Direct modulation is a cheap solution used for 1310 nm window. Because 1310 nm wave is not subject to amplification by EDFA (Erbium Doped Fiber Amplifiers) amplifiers at longer lengths, there are problems with optical noise and, in particular, with signal attenuation. It has one big drawback: the presence of a chirp effect, which occurs only in lasers with direct modulation. That is why the length of the emitted lightwave is volatile and depends on the current of light source. The corruption created by this is very high in the 1550 nm window. Therefore, external modulation is usually used for transmission on the 1550 nm and direct modulation is used for 1310 nm, so the signal covering distances are increased up to 20 km. External modulation is much complex modulation type that provides attenuation of the optical signal of a laser in accordance with the RF input signal, but through the use of amplifiers, it allows covering distances up to 120 km.

Devices paired with transmitters were selected as receivers. In optical networks they must have a large dynamic range, good linearity, high sensitivity, even sensitivity in its spectral waveband. The photodetector must be fully compatible with the transmitting device, in terms of spectral sensitivity, transmission wavelengths and temporal modulation characteristics. High resistance to errors occurring in the signal when passing through the medium and other optical components is also important.

A single-mode fiber was chosen to transmit the analog microwave signal. Multi-year fiber has much more loss and multi-year dispersion is present, and the most important disadvantage is the small broadband coefficient.

For the developed FOCL, the main factors are high reverse losses and the strength of the connector. The best reverse losses of connectors with APC polishing, one of the most reliable and convenient are FC connectors. Therefore, FC-APC connectors were used in the FOCL. Also, an optical insulator was used to reduce the possible reflection of the signal along the entire length of the line.

The concept of the microwave path operation of the VOLS is as follows: the microwave signal received by the horn goes to a broadband low-noise amplifier, then the amplified microwave signal goes to an optical modulator and modulates the light beam coming from the laser module. From the modulator, the modulated optical signal is transmitted across a fiber-optic line to the optoelectronic receiving module, in which the light signal is converted back into a microwave signal with minimal distortion. Then the converted microwave signal is sent to the measuring receiver for further processing, after which it is sent to the spectroanalyzer.

The principle of operation of the microwave path of the FOCL is as follows: the microwave signal received by the horn goes to a broadband low-noise amplifier, then the amplified microwave signal goes to an optical modulator and modulates the light beam coming from the laser module. From the modulator, the modulated optical signal is transmitted through a fiber-optic line to the optoelectronic receiving module, in which the light signal is converted back into a microwave signal with minimal distortion. Then the converted microwave signal is sent to the measuring receiver for further processing, after which it is sent to the spectroanalyzer.

Results and Discussion

Fig. 2 shows, as an example, the radar radiation diagrams in a rectangular coordinate system, measured using an electrical cable and designed FOCL in landfill conditions.

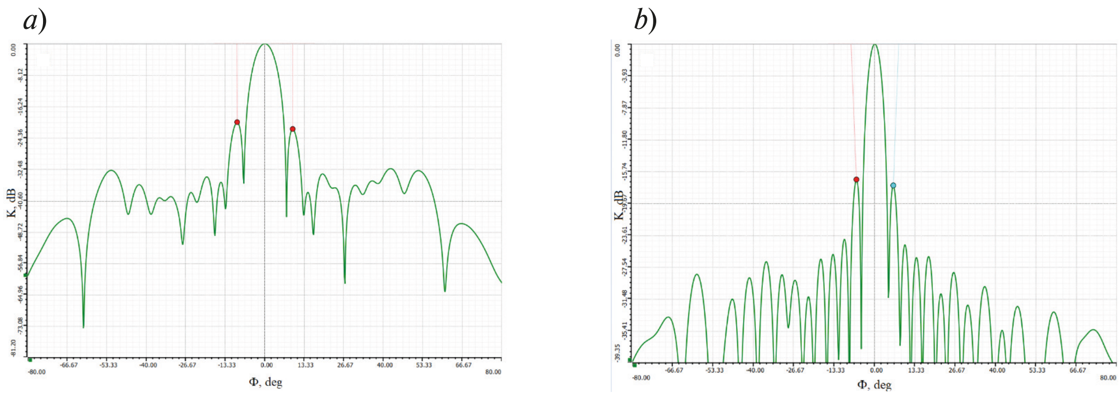

Fig. 2. AFAR directional diagram: electrical cable is used to transmit signal (*a*), FOCL is used to transmit the signal (*b*)

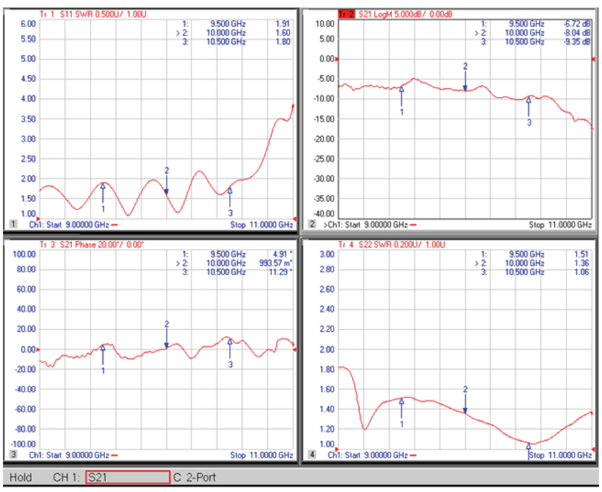

Fig. 3. Frequency characteristics of the experimental stand

Results show that the radiation pattern measured with FOCL allows an approximation to be performed to assess the stable APAA radar survey zone. Allows you to adjust the APAA to the maximum suppression of the side lobes for reducing the impact on the determination accuracy for the coordinates of moving objects, repeatedly reflected electrical signals.

Fig. 3 shows the frequency characteristics of the stand measured by the analyzer.

The usage of designed FOCL made it possible, as experiments have shown, to study, in addition to the radiation spectrum of the entire APAA in various operating modes, as well as the radiation spectra of its single active elements. These studies were previously not possible because of the presence of interference and noise in the transmission path.

As an example, in Fig. 4 shows the emission spectra of a single active element (rod) of the APAA transmitted to the control sector from the microwave signal recording device via a coaxial cable and the perceived.

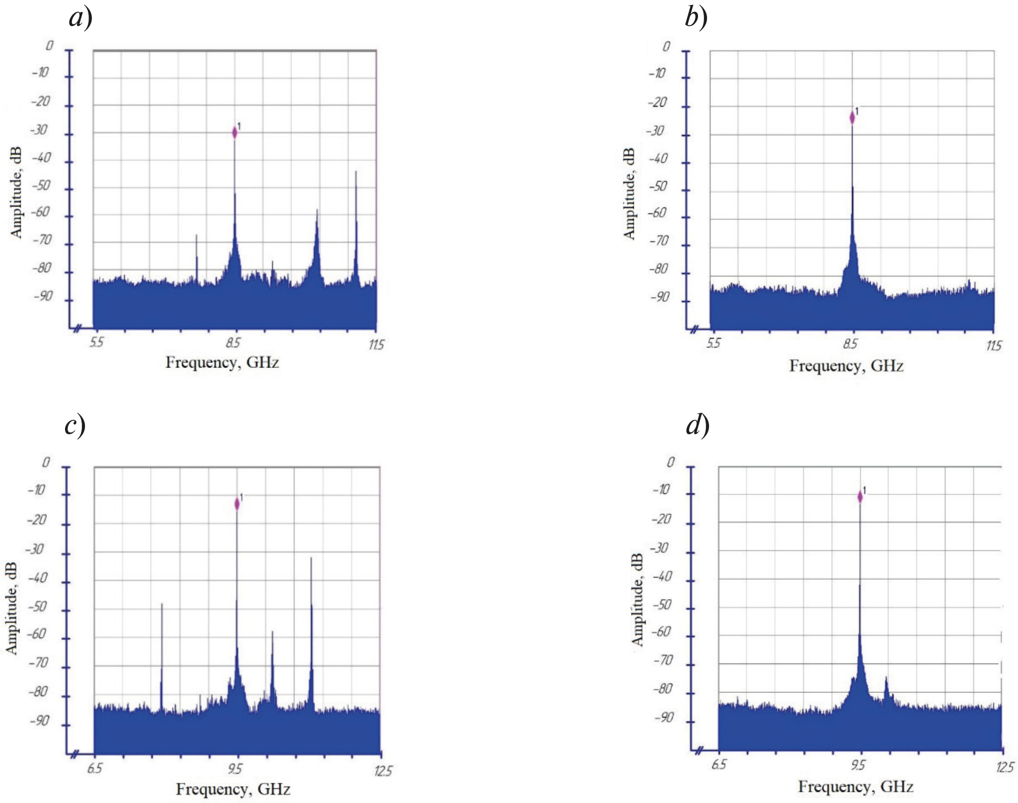

Fig.4. Radiation spectra transmitted via coaxial cable (*a*, *c*) and optical fiber (*b*, *d*)

The obtained graphs show that the measured spectra of the transceiver modules transmitted via a coaxial cable contain parasitic components in the spectrum, whereas the spectra obtained by the fiber optic have no interference. This fact indicates the expediency of using FOCL for APAA testing.

Conclusion

The results obtained demonstrate that our designed FOCL makes it possible to make insignificant the effect of distortion when transmitting a microwave signal over the territory of the landfill over long distances to the equipment for subsequent processing. It also allows to identify different mistakes in the radar elements that cannot be established when using electrical cable.

REFERENCES

1. **Davydov R., Antonov V., Moroz A.,** Parameter Control System for a Nuclear Power Plant Based on Fiber-Optic Sensors and Communication Lines, In: IEEE International Conference on Electrical Engineering and Photonics (EExPolytech), Saint Petersburg, Russia, 13-15 October 2019. Vol. 8906791 (2019) 295–297.

2. **Dyumin V., Smirnov K., Myazin N.,** Charge-coupled Device with Integrated Electron Multiplication for Low Light Level Imaging, Proceedings of the 2019 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech. Vol. 8906868 (2019) 308–310.

3. **Grebenikova N. M., Davydov R. V., Rud V. Yu.,** Features of the signal registration and processing in the study of liquid flow medium by the refraction method, Journal of Physics: Conference Series. 1326(1) (2019) 012012.

4. **Grebenikova N. M., Smirnov K. J., Rud V. Yu., Artemiev V. V.,** Features of monitoring the state of the liquid medium by refractometer, Journal of Physics: Conference Series. 1135(1) (2018) 012055.

5. **Skidanov R.V., Blank V.A., Morozov A.A.,** Study of an imaging spectrometer based on a difraction lens, Computer Optics. 39(3) (2015) 384–392.

6. **Kuzmin M. S., Rogov S. A.,** On the use of a multi-raster input of one-dimensional signals in two-dimensional optical correlators, Computer Optics. 43(3) (2019) 391–396.

7. **Myazin N.S., Smirnov K.J., Logunov S.E.,** Spectral characteristics of InP photocathode with a surface grid electrode, Journal of Physics: Conference Series. 929(1) (2017) 012080.

8. **Nalimov A.G., Kozlova E.S.,** Inversion of the longitudinal component of spin angular momentum in the focus of a left-handed circularly polarized beam, Computer Optics. 44(5) (2020) 699–706.

9. **Kozlova E.S., Kotlyar V.V.,** Refined dispersion model for quartz glass, Computer Optics. 38(1) (2014) 132–138.

10. **Stafeev S.S., Kozlova E.S., Nalimov A.G.,** Focusing a second-order cylindrical vector beam with a gradient index mikaelian lens, Computer Optics. 44(1) (2020) 29–33.

11. **Davydov V. V., Kruzhalov S. V., Grebenikova N. M., Smirnov K. J.,** Method for Determining Defects on the Inner Walls of Tubing from the Velocity Distribution of the Flowing Fluid, Measurement Techniques. 61(4) (2018) 365–372.

12. **Davydov V. V.,** Determination of the Composition and Concentrations of the Components of Mixtures of Hydrocarbon Media in the Course of its Express Analysis, Measurement Techniques. 62(2) (2020) 1090–1098.

13. **Dmitrieva D.S., Pilipova V.M., Rud V.Y.,** Fiber-optical communication line with a system for compensation of radiation-induced losses during the transmission of information. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 12526 LNCS (2020) 348–356.

14. **Fadeenko V.B., Kuts V.A., Vasiliev V.D.,** New design of fiber-optic communication line for the transmission of microwave signals in the X-band, Journal of Physics: Conference Series. 1135(1) (2018) 012053.

15. **Petrov A. A.,** Digital Frequency Synthesizer for ^{133}Cs-Vapor Atomic Clock, Journal of Communications Technology and Electronics. 62(3) (2017) 289–293.

16. **Davydov V.V.,** Some specific features of the NMR study of fluid flows, Optics and Spectroscopy (English translation of Optika i Spektroskopiya). 121(1) (2016) 18–24.

17. **Pchelkin G.A.,** Features of the transmission of microwave signals at offshore facilities, Journal of Physics: Conference Series. 1368(2) (2019) 022045.

18. **Fadeenko V.B., Pchelkin G.A., Rud V.Yu.,** Features of the transmission of microwave signals in the range of 8-12 GHz in the maritime radar station over fiber-optic communication line, Journal of Physics: Conference Series. 1400(4) (2019) 044010.

19. **Lenets V.A., Tarasenko M.Yu., Rodygina N.S., Moroz A.V.,** New method for testing of antenna phased array in X frequency range, Journal of Physics: Conference Series. 1038(1) (2018) 012037.

20. **Davydov V., Fadeenko V., Fadeenko I., Popovskiy N., Rud V.,** Multifunctional method for remote monitoring of the environment in the area of nuclear facilities, E3S Web of Conferences. 140 (2019) 07006.

21. **Moroz A.V., Malanin K.Y., Krasnov A.A.,** Development of a Compensation System Based on Horn Antennas for an Active Phased Antenna Array, Proceedings of the 2019 Antennas Design and Measurement International Conference, ADMInC 2019, vol. 8969090 (2019) 114–116.

22. **Moroz A.V.,** Features of transmission bearing and heterodyne receivers for signals in fiber-optic communication line in active phased array antenna, Journal of Physics: Conference Series. 1410(1) (2019) 012212.

23. **Filatov D.L., Galichina A.A., Vysoczky M.G., Rud V.Y.,** Features of transmission at analog intermediate frequency signals on fiber - Optical communication lines in radar station, Journal of Physics: Conference Series. 917(8) (2017) 082005.

24. **Petrov A. A., Grebenikova N.M.,** On the Potential Application of Direct Digital Synthesis in the Development of Frequency Synthesizers for Quantum Frequency Standards, Journal of Communications Technology and Electronics. 63(11) (2018) 1281–1285.

25. **Fadeenko V.B., Pchelkin G.A., Beloshapkina O.O., Rud V.Yu.,** Features of construction of the scheme of fiber-optic communication system for transmission of analog signals in the frequency range from 0.135 to 40 GHz, Journal of Physics: Conference Series. 1410(1) (2019) 012238.

26. **Moroz A. V., Davydov R. V.,** A New Scheme for Transmitting Heterodyne Signals Based on a Fiber-Optical Transmission System for Receiving Antenna Devices of Radar Stations and Communication Systems, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics).11660 (2019) 710–718.

27. **Fadeenko V.B., Vasiliev D.A.,** Multifunctional radar system for remote control of environment and the Earth's surface, Journal of Physics: Conference Series. 1745(1) (2021) 012023.

28. **Moroz A.V.,** Fiber-optical system for transmitting heterodyne signals in active phased antenna arrays of radar stations, Journal of Physics: Conference Series. 1368(2) (2019) 022024, December 2019.

29. **Petrov A. A., Shabanov V. E., Zalyotov D. V., Bulyanitsa A. L., Shapovalov D. V.,** Modernization of the frequency synthesizer of cesium atomic clock, IEEE International Conference on Electrical Engineering and Photonics, EExPolytech 2018, Saint Petersburg, October 2018. vol. 8564389 (2018) 52–55.

30. **Moroz A.V., Krasnov K.Yu.,** Features of the construction of the noise compensation circuit of a small-sized active phased antenna array, Journal of Physics: Conference Series. 1400(4) (2019) 044009.

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