Features of the transmission of microwave signals in the range of 8–12 GHz in the maritime radar station over fiber-optic communication line

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Abstract. The presented work demonstrates a new design of a fiber-optic line of microwave signal transmission for the receiving path of the maritime radar station. The features of microwave signals transmission in the maritime radar station are established. New designs of the transmitting and receiving modules have been developed in view of the established features. The transmitting module is based on the Mach-Zehnder electro-optical modulator. The receiving module contains p-i-n diode that is based on heterostructures. The results of experimental studies are presented.

1. Introduction
In the modern world, radar stations play an important role in solving many problems for various purposes. [1-7] The main objective of radar is the detection and identification of various mobile and stationary objects. [2, 5-11] The greatest difficulties in solving this problem arise in the operation of radar on mobile objects. [2, 3, 5, 12-16] They are connected both with the peculiarities of radar operation and with the transmission of various signals in radar stations. [5, 13-18] In addition, several peculiarities of the microwave signals transmission in radar stations are related to the tasks for which the station is used. [1-8, 12-18]

When developing the maritime radar stations, it is necessary to consider the following. The number of antennas and various equipment is growing both to expand the functionality of the ship and to increase the volume of transmitted information. [5, 12, 13] When upgrading a maritime radar, the situation with space on the upper deck masts is especially critical. The sizes of the deck platforms are not changed. In addition, the mass load on the moving element of the upper deck shall not exceed a certain value. This is because the antenna operates in different conditions (e.g. frost, pitching, strong wind, etc.) and it is necessary to provide certain parameters of rotation or scanning of the antenna in a given plane.

The accumulation of various receiving and transmitting antennas as well as the equipment with power systems creates a large number of various kinds of noises on the upper decks and on the location area of the communications for transmitting signals from antennas to signal processing devices. The use of additional shielding systems, as well as the placement of additional waveguide paths or coaxial cables with an increase in the number of antennas, reduces the mobility of scanning devices. The use of fiber-optic communication lines (FOCL) for signal transmission is a solution to many problems. [13, 17-24]
Reducing the space on the upper decks of the ship’s masts to accommodate the receiving and transmitting elements of various radars require the modernization of stations (to reduce its weight and size characteristics while maintaining accuracy characteristics). The process of upgrading the radar parts placed on the upper deck is the most difficult one. FOCL is no exception in this case. The paper proposes one of the possible solutions for the modernization of FOCL taking into account the peculiarities of microwave signals in the frequency range 8 – 12 GHz.

2. Features of microwave signal transmission and laboratory layout of fiber-optic communication line

Articles [10, 12, 13, 17, 19, 20-25] consider in detail the structure and basic elements of FOCL for microwave signals transmission in various types of radar located on mobile objects. The analysis of the results obtained in them showed that the most promising direction of modernization of FOCL for maritime radar stations is the development of a design with a more compact placement of its elements on the upper deck of the mast.

Our studies have allowed us to establish the peculiarity of the use of thermal stabilization mode in the transmission of a microwave signal via FOCL in the case of placing a laser and an electro-optical modulator in one shielded enclosure. During prolonged operation, the laser source is heated, i.e. its temperature changes. The temperature in the shielded enclosure also changes, therefore the operating point of the electro-optical modulator changes. It is necessary to adjust the operating point of the modulator using only the feedback loop without the thermal stabilization of the laser temperature. If the wavelength of the laser radiation changes due to the temperature change, it will not affect the result of microwave signal transmission over the fiber optic. The distance of optical signal transmission by fiber optic cable is less than 300 m. The dispersion does not have time to form in the transmitted optical signal during such a transmission time. This is one of the features of microwave signal transmission.

Another feature is that in the maritime radar station, unlike the air-based radar, FOCL is only used to transmit signals from the receiving antennas. The receiving and transmitting channels of the radar are completely separated. In some cases, other antennas are used to irradiate objects in the radar station, which do not receive signals reflected from the targets.

Taking into account these features, we have developed a new design of the transmitting module, which is located on the upper deck. Figure 1 shows the block diagram of the transmitting module.

![Figure 1](image_url)
The transmitting module consists of a laser with a fiber optic output based on the nanoelectronic heterostructures InGaAsP/InP. [26-28] Radiation through the fiber optic output is fed to the input of the Mach-Zehnder electro-optical modulator. The microwave signal from the receiving antenna enters the connector 7 further along the coaxial cable into the Mach-Zehnder 2 electro-optical modulator made on the basis of the LiNbO₃ connection. The modulation efficiency of the Mach-Zehnder electro-optical modulator depends mainly on the bias voltage, which varies with temperature T. Therefore, it is necessary to stabilize the position of the operating point of the modulator. A photodiode is used 4 with feedback in the design developed by us to solve this problem. The feedback is implemented by feeding part of the output optical radiation from the modulator output to its input using a fiber-optic splitter. According to the signal level on the photodiode 4, the offset voltage value is adjusted.

We have developed a new design of the receiving module to improve the characteristics of FOCL. Figure 2 shows the block diagram of the receiving module.

![Block diagram of the receiving module](image)

**Figure 2.** Block diagram of the receiving module: 1 – p-i-n diode based on InGaAs/InP; 2 – power amplifiers and bandpass filters; 3 – input optical connector; 4 – power connector; 5 – output microwave connector

The intensity-modulated optical signal from the modulator is fed to the input of the receiving module. The receiving module consists of a p-i-n photodiode based on the InGaAs/InP nanoelectronic heterostructure, which is included in the coplanar transmission line matching it with the coaxial microwave connector at the output. The resistance of the coaxial microwave connector is 50 Ohms. A sequence of electric amplifiers and microwave filters is used to obtain the required power of the detected microwave signal. The bias voltage is applied to the photodiode to suppress interference through the pass filter.

3. **Results of experimental studies and their discussion**

The amplitude-frequency response is one of the important parameters that characterize the operation of the FOCL. Figure 3 shows the frequency response of FOCL in the frequency band of 8 – 12 GHz.
The result shows that the irregularity of the frequency response of the FOCL in the frequency band of 8 – 12 GHz is about 4 – 5 dB. Filters that are used after the photodetector to form the frequency response do not cause significant distortion in the unevenness of the characteristics. It allows the transmission of microwave signals from the receiving antenna installed on the upper deck of the ship's mast to processing devices located in the ship's hull with a high degree of reliability.

Another important characteristic of the FOCL is the tangential sensitivity $G$ of the receiving path. It is established that during the connecting to the path of the developed FOCL the value of $G$ has not changed significantly and is about 78 dBm. Figure 4 shows the dependence of the tangential sensitivity $G$ of the receiving path on the frequency of the microwave signal.

In some cases, when transmitting a microwave signal, this allows excluding a low-noise amplifier from the design of the receiving part of the antenna located on the upper deck of the ship's mast. The experiments have shown that a low-noise amplifier in conditions of high level of electromagnetic interference can carry additional distortion in the transmitted signal.

During the study of the developed design of FOCL, its dynamic range was determined. The experimental dependence of the output power of the $P_{out}$ signal on the power of the input signal $P_{in}$ is shown in Figure 5.
The dynamic range of stable operation of FOCL is about 115 dBm. This value of the FOCL characteristic is comparable to the coaxial cable. It should be noted that redispersion of the FOCL is much higher than that of the cable. The redispersion is the lack of increase in losses with increasing frequency of the transmitted microwave signal. Power attenuation at lengths of 200–300 m is an order of magnitude less than in a coaxial cable. There is no sense in comparing flexibility and compactness with cable.

4. Conclusion
The results show that the developed new design of FOCL for sea-based radar is functional and that it can reliably transmit microwave signals. Also, the results justify the proposed design solutions based on the research. The features of transmission of microwave signals via FOCL and their account in the developed design allowed us to obtain the coefficient of transmission via FOCL about 28 dB. The intrinsic noise of the FOCL is about 14 dB. This is significantly less than in devices using a coaxial cable.

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