Features of the transmission of microwave signals at offshore facilities

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Abstract. In the article the capabilities of microwave signals transmission by fiber-optic communication lines on marine objects is considered. The features of constructing a scheme for transmitting a microwave signal from a passive antenna over a fiber-optic communication line are established. The technical solutions for optimizing the design of a fiber-optic communication line are proposed. The results of experimental investigations of fiber-optic communication lines parameters are presented.

Introduction

In the conditions of continuous development of scientific and technical progress, the form and technical parameters of various moving objects that need to be detected and identified are changing [1-5]. This circumstance constantly puts new tasks before the developers of radar stations (RLS). Modern radar designs based on the latest scientific developments allow detecting various objects due to powerful electromagnetic radiation and a specific configuration of the radiating antenna [1, 2, 5-9]. To this end, receiving and radiating (transmitting) antennas are separated at sea objects, as well as in a number of models of ground-based radars. It also allows you to increase the visibility of space and the range of target detection while simultaneously controlling the movement of several targets, as implemented on satellite systems [5, 6, 10-14].

One of the most difficult tasks in the operation of marine radars is the transmission without distortion of microwave signals between the devices included in its composition [1, 2, 11, 15, 16]. Especially from the receiving antenna, located on the upper deck of the mast of the ship to the information processing device, which is located in its case.

In radar stations on offshore facilities that were put into operation earlier and are still operating, coaxial cables and waveguides are used to transmit microwave signals [1, 4, 5, 10, 15-18]. These means of transmitting the microwave signal have major drawbacks. In coaxial cables, the signal attenuation is 1 to 2 dB / m at fc frequencies up to 12 GHz and more than 2 dB / m at higher fc. When transmitting a signal over distances greater than 50 m, the attenuation in the cable will be very large.
To compensate for it in the transmission line, you will need to use additional amplifiers, which also have noise and have band limits. In some cases they will have to be placed in a zone with a high level of interference (between the mast of the ship and the hull). Experience in operating such communication lines shows that the use of an amplifier will further impair the stability of the microwave transmission system to electromagnetic interference. There are a lot of these interferences with the crowding of various radar and electronic systems, both on the masts of the ship and in its area. It should be noted that shielded coaxial cables have poor flexibility. In some cases, their laying on the "straight" is difficult. It is necessary to make a turn. In this case, you have to use connectors, which significantly impairs the protection of the transmission line from interference [5-7, 18, 19].

Unlike coaxial cables, waveguides have better performance. The attenuation of the signal does not exceed 0.11 dB / m. However, their use on offshore facilities under conditions of increasing the amount of equipment is questioned due to the cumbersome design of the waveguide system for transmitting the microwave signal.

One solution to this problem may be the use of fiber-optic communication lines (FOCL) for the transmission of microwave signals — radio-photonic devices. Currently, radiophotonics is one of the promising areas of radiophysics and optics [16, 19-32]. Fiber optic transmission lines surpass coaxial cables and wave paths in their characteristics [17, 18, 20-23, 26, 34, 35]. But when they are used at offshore facilities, features arise that must be taken into account both in the development of the FOCL and in their subsequent operation. Therefore, the aim of our work was to identify these features and take them into account in the design of the FOCL developed by us for sea-based radars in order to increase the reliability of its operation.

2. The design of the fiber-optic communication line and features of its construction.

A feature of the operation of the sea-based radar (for which the FOCL is being developed) is that they use a high-power continuous-wave parabolic antenna with a wide radiation pattern [1, 2, 5] to emit the microwave signal. Reflected signals from various objects are received by the receiving antenna in a non-periodic sequence [2, 4, 5]. Moreover, in addition to the reflected main signal, the object also receives various mirror signals, which are formed as a result of reflections, for example, from the sea surface. In addition, several objects are simultaneously irradiated with a parabolic antenna pattern. Often there is a reflection of the signal from one object to another. Then this signal arrives at the receiving antenna. If additional interference occurs in the communication channels when transmitting such signals, it will be extremely difficult to process the information.

Another feature of the construction of the FOCL data is that the microwave signal must be transmitted at a distance of no more than 100 m. The loss in the amplitude of the signal during its attenuation can be considered insignificant. Different types of dispersion make minor distortions in the form of the transmitted signal due to the short time of its propagation through the optical fiber [10, 15, 17, 18]. The phase shift in the transmitted optical signal can only be due to fluctuations in the temperature T of the fiber [19, 20, 26, 34, 35].

In contrast to ground and radar aircraft in the considered structures of the marine radar for receiving reflected from various targets, several antennas are used. Information is simultaneously transmitted to the processing device from them through various channels. And in some cases for several goals simultaneously. Also in this information are the "tags" created by the signals after several reflections. Some of them have an amplitude below the noise level. In this situation, during processing it will be extremely difficult to isolate signals that go directly from the target with amplitude, also below the noise level. This method is used in single-range radar for long distances.

\[\text{Figure 1. Block diagram of the laboratory layout of a fiber-optic transmission line: 1, 7 - low-noise amplifiers, 2 - power supply, 3 - transmitting optical module, 4 - power supply driver of transmitting optical module, 5 - optical isolator, 6 - receiving optical module, 8, 9 - power sources.}\]
Therefore, after a low-noise amplifier, it does not make sense to install a filter and a mixer with a heterodyne receiver. And immediately the signal from the output of the low-noise amplifier to send a signal to the input of the optical modulator FOCL. This is another feature of the scheme for constructing the registration of a signal in a sea-based radar, in contrast to the classical schemes.

Taking into account these features, as well as previous studies by various authors, we have developed the design of a laboratory model of FOCL. Its structural diagram is presented in Fig. 2.

The optical transmitting module 3 consists of: a laser diode based on InGaAsP/InP nanoheterostructures and a generation wavelength of 1550 nm with a fiber-optic radiation output; LiNbO3-based Mach-Zehnder electro-optic modulator; microwave matching device; control boards and stabilization of the operating points of the laser diode and the electro-optical modulator. It also includes an input coaxial microwave connector and an output optical connector. Receiving optical module 6 consists of: a photodiode based on InGaAsP/InP with a fiber-optic radiation input; Buffer GaAs power amplifier; microwave matching device; power amplifier providing the necessary transmission coefficient; output coaxial microwave connector and input optical connector. Since the optical fiber, while laying it over the ship, has bends, an optical isolator 5 is installed. It prevents the optical signal reflected on the fiber bends from entering the transmitting module 3. The optical isolator and the receiving module are interconnected by an optical fiber cable FC/APC-FC/APC 100 m long. The modules and the optical isolator are connected to the optical fiber by means of special connecting connectors, the loss in each connector is about 0.1 dB. Losses on the optical isolator are not more than 0.6 dB.

3. The results of experimental studies of the operation of the fiber-optic microwave transmission system and their discussion.

One of the most important parameters of any developed FOCL design for the transmission of microwave signals is its amplitude-frequency characteristic (AFC). In fig. 2, as an example, the frequency response of the developed FOCL at different temperatures T is presented, since the operation of the radar station will take place in different climatic conditions.

![Figure 2. Amplitude-frequency characteristic of a fiber-optic transmission line. Charts 1, 2 and 3 correspond to temperature in K: 231.2; 293.1; 333.4.](image)

Analysis of the results showed that the non-uniformity of the frequency response is about 8 dB in the frequency range up to 19 MHz for the operating temperature range of the radar. The main range for all-round radars for which this FOCL is being developed is the X-band. The obtained result shows that the developed FOCL allows transmitting the received reflected signals from various objects with a high degree of reliability.

When developing a FOCL for a sea-based radar, it is necessary to take into account the fact that signals from various targets with different power are received from the receiving antenna to the FOCL due to the characteristics of radar operation. Therefore, in this situation, the dynamic range becomes an extremely important characteristic. In fig. 3, as an example, presents the results of studying the dynamic range of the FOCL from various frequencies of the microwave signal at T = 293.1 K.

The results show that the dynamic range (DD) exceeds 110 dBm. The obtained value of DD is
sufficient for a stable transfer of received reflected signals from targets, even with temperature changes to a critical one. Experiments have shown that DD at $T = 333.4$ K is less than 95 dBm, which insignificantly limits the possibility of operating the radar.

![Figure 3](image)

**Figure 3.** The dependence of the output power of the microwave optical signal from the input. Charts 1, 2 and 3 correspond to the frequency of the input signal in GHz: 6; 12; 16.

In addition, we measured the own FOCL noise figure, which was less than 10 dB. The noise figure of the developed FOCL was determined by the Y-factor method at a frequency of 12 GHz. For the measurements, an Agilent N9030A spectrum analyzer and an Agilent N4002A SNS Series noise source were used. The irregularity of the transmission coefficient $K_p$ FOCL in the frequency range from 1 to 20 GHz is -4 dB. This shows the stability of the FOCL work.

Since the FOCL is intended for sea basing, it will be in different temperature conditions. A change in ambient temperature causes both a change in the refractive index of the fiber and additional lengthening of the fiber due to thermal expansion or contraction. This leads to a change in the phase of the light and, accordingly, to a change in the phase of modulation of the radiation transmitted through the fiber. Therefore, an experimental estimate was made of the temperature deviation of the modulation phase during the propagation of the optical signal in the fiber.

The research results showed that the range of change in the phase modulation shift over the entire temperature range $T$ at which the single-mode Corning SMF-28e single-mode optical fiber is used (extreme conditions — $T$ fibers below 223 K is not considered for the case of using special protective shells) degrees The temperature dependence of the modulation phase change for the Corning SMF-28e fiber is about 6 degrees. When the distance of the optical fiber is 100 m, the influence of this phase shift with a change in temperature on the frequency and amplitude characteristics of the transmitted optical signal will be insignificant.
4. Conclusion
The results show that the developed new FOCL design for sea-based radars is operational and can reliably transmit microwave signals, and the design solutions proposed for its manufacture and the chosen element base on the basis of the conducted studies are justified.

In the case of the use of FOCL at offshore facilities, where the receiving and transmitting part of the radar is submerged under water and an increased intake pressure is created, additional changes will be made to the developed FOCL structure to ensure its stable operation. The principle of transmission and formation of the optical signal will not change.

It should be noted that the obtained value of DD for FOCL is comparable to DD of coaxial cable (no more than 115-120 dBm), differing from it by low dispersion (increase in losses with increasing frequency of the transmitted microwave signal). The transmission coefficient deteriorates by 4 dB, while in the best brands of foreign microwave cable SUCOFLEX 406 with a length of 100 m in the frequency range from 1 to 18 GHz, the difference in attenuation is more than 60 dB. For specialized microwave cables with a high degree of shielding, this value is even higher, in some cases, by an order of magnitude.

This shows that the use of the FOCL design developed by us, besides increasing the degree of protection against interference, reducing the weight and size, and improving the installation possibilities, also makes it possible to increase the characteristics of a microwave signal transmission device in radars.

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