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

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Abstract. The paper presents the design of a fiber-optic microwave signal transmission line. The use of the developed design of a fiber-optic microwave transmission line allows the radar operating frequency range to be at least doubled. In addition, the number of functional blocks is reduced to ensure the operation of the radar in this frequency range. The results of experimental studies are presented.

1. Introduction

Nowadays, fiber optic communication lines (FOCL) are an important element in the transmission of various information [1-7]. The structure and technical characteristics of fiber optic links change depending on the tasks to be solved, for example, high-speed fiber optic links or transmission of information on fiber optic lines at enterprises of the agricultural industry segment [6-10]. The principle of construction of the work of fiber optic lines for transmitting information remains unchanged [4-16]. The main elements in the FOCL design are the transmitting laser module, the electro-optic modulator, the receiving module and optical isolators [11-16]. Optical amplifiers are used depending on the distance to which information is transmitted via fiber optic links. It should be noted that in the construction of many fiber optic links there are a number of features that depend on the type of information transmitted via fiber optic links and the conditions of operation of fiber optic links. The greatest number of features is present when using fiber optic lines for transmitting various microwave signals and controls in radar stations (radars) for various purposes [11–20].

Studies and operating experience of the radar showed that it is most appropriate to use single-mode fiber to transmit microwave signals and control. In addition, each channel uses its own signal transmission system with fiber optic communication line. This has its own advantages and disadvantages [11, 12, 16, 21, 22]. The disadvantages include the fact that the currently developed various systems for transmitting microwave signals from fiber optic lines work stably in a certain frequency range, for example, X-band. This is due to the structural features of the modulation of the optical signal of the microwave signals in an electro-optical modulator and the sensitivity when receiving weak antenna signals and the speed of the photodetector elements in the receiving module at a high frequency of the
transmitted signal via a fiber optic communication line. In addition, based on new technologies and materials, as well as the results of scientific research, receiving and transmitting antennas that operate in a wide range of microwave frequencies have been developed. In some cases, these are tunable devices based on the microwave frequency. For these radars, it became necessary to create a universal system using fiber optic lines, which allows transmitting microwave signals in the frequency range from 0.135 to 40 GHz.

Figure 1 presents the standard modular design of this system, which consists of 8 previously used individual channels. In comparison with previous developers, systems were developed for transmitting microwave signals using fiber optic communication lines.

![Figure 1. The scheme of fiber-optic transmission line microwave signals in the radar frequency range from 0.135 to 40 GHz](image)

Our studies have shown that this design of the microwave signal transmission system is not rational to use for several reasons:

1. the scheme contains a large number of expensive optical elements to ensure the operation of the system in a narrow frequency range, for example, 1-2 GHz;
2. it is necessary to provide temperature stabilization for each optical element or the entire unit (all optical elements are in one large design) when placing them, for example, on the upper decks of the mast racks of ships [4, 11, 12, 15];
3. difficulties arise if this design is used in active electronically scanned array (AESA), for example, on a moving object (where there are significant limitations on the volume and weight of the blocks and temperature stabilization is necessary).

Therefore, there is a need to upgrade this universal system of microwave signal transmission in order to reduce its size and cost. One of the solutions to the considered problem is presented in our work.

2. New design of fiber-optic microwave transmission system in the radar and features of its work

Studies have shown that the amplitude-frequency characteristics (AFC) of fiber optic communication line in the frequency range from 0.135 to 2.0 GHz do not differ between communication channels when
transmitting a microwave signal using direct or external modulation. The absence of an electro-optic modulator in the FOCL channel reduces the transfer ratio $K_t$ by 20-25%. Therefore, it is more efficient to use in the design of fiber optic transmission system a new model of a transmitting module with direct modulation and to combine two channels into one (from 0.135 to 2.0 GHz). Figure 2 presents the new design of the FOCL for the transmission of microwave signals.

![Figure 2](image_url)

**Figure 2.** The new scheme of fiber-optic transmission line microwave signals in the radar frequency range from 0.135 to 40 GHz: 1 and 2 – microwave channel switches; 3 – receiving laser modules; 4 – optical isolator; 5 – transmitting laser module; 6 – electro-optical modulator; 7 – photodetector module; 8 – power amplifier

Other channels were also converted into one channel with a frequency range from 2 to 8 GHz and from 8 to 18 GHz. In the new design due to the use of an optical divider by 4, the number of laser transmitting modules was reduced to two. The study showed that the use of a single transmitting module with direct modulation simultaneously on all 5 channels using microwave switching devices creates additional noise. This noise reduces the dynamic range of the fiber optic transmission system. In the case of the transmission of weak signals creates additional problems.

In the new design of the fiber optic transmission line, the number of electro-optical modulators (EOM) has decreased from eight to five. These devices are most sensitive to temperature changes. For their stable operation in a wide range of temperature variations, a thermal stabilization scheme with adjustment of the operating point is necessary [12, 16, 21, 22]. This scheme can be implemented for several EOMs, but it will take a lot of space. The working point of each modulator is different. Reducing the number of EOM reduces the size and weight of the thermal stabilization system, as well as its cost.

It is also necessary to implement reliable thermal stabilization in the photodetector modules [23-31].

Such a construction of the fiber optic transmission system design is justified, since the distances over which the signal must be transmitted do not exceed 300 m. Losses in the optical fiber at such distances are insignificant. Different types of dispersion on the bends of the optical fiber do not have time to form due to the short propagation time of the optical signal through it. The important characteristics in this case remain the purity of the spectrum of the transmitted signal and the magnitude of the temperature deviation of the modulation phase during the propagation of the optical signal in the fiber, since FOCL can also transmit signals from the local oscillator and control.

### 3. The results of experimental studies and their discussion

Experience in operating a radar with a fiber optic communication line showed that in some cases distortions in the spectrum [18–20, 32–36] of the transmitted signal can lead to errors in determining the position of the object’s coordinates or loss of control of the station’s operation. On the developed laboratory model of FOTS, we investigated possible distortions in the spectrum when transmitting a heterodyne signal over FOTS at an operating frequency of 150 MHz. Figure 3 presents one of the results of research for the microwave transmission channel in the frequency range from 0.135 to 2.0 GHz.
Figure 3. Spectra of input (continuous) and output (dashed) signal of FOTS

Comparison of the obtained spectra (Fig. 3) shows a high efficiency of transmission of the heterodyne signal at the carrier frequency over FOTS. Distortions in the spectrum are present only on the lateral components, which does not affect the accuracy of determining the distance to the target in the radar.

Since the fiber optic transmission system is designed for AESA, which are placed on aircraft, the FOTS 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 assessment was made of the temperature drift of the modulation phase during propagation in the fiber. Figure 4 shows the experimental dependence of the phase shift of the modulation of laser radiation $\Delta \phi_m$ on the ambient temperature $T$.

Figure 4. The shift of the phase of modulation $\Delta \phi_m$ from the temperature $T$. Graphics 1, 2 and 3 correspond to the frequency of the heterodyne signal in MHz: 50; 100; 150
The experimental research results showed that the temperature dependence of the modulation phase change for G.657 fiber is no more than 3.0 degrees in the selected temperature range from 213.1 to 323.3 K for different heterodyne signals transmission frequencies. The influence this phase shift value on the frequency and amplitude characteristics of the transmitted optical signal will be negligible for optical fiber distance of less than 120 m.

4. Conclusion
The obtained results showed that the design developed by us can be successfully operated as part of a radar with an AESA. It has been established that design solutions implemented in the manufacture of FOTS are justified on the basis of the conducted research.

In addition, we found that the technical characteristics (dynamic range, transmission coefficient, etc.) did not deteriorate in the newly developed FOTS design. And in some cases, for some channels have become better. This made it possible to expand the number of tasks that can be solved during the operation of the radar using the new developed FOTS compared to the previously used FOTS designs.

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