A study of temperature dependence of phase shift in optoelectronic path of direction finder channels

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Abstract. The need to study the temperature dependence of phase difference between optical signals in information transmission channels for direction finder stations is justified. The method is proposed how to determine the phase difference. The experimental results are presented for different cases of temperature change influence on optoelectronic path of direction finder.

1. Introduction
Currently, a large number of methods have been developed and practically implemented for determining the coordinates of various objects [1-7]. By the principle of the station work, these methods can be divided into three types, which are active, passive and combined. The combined methods are mainly used in space systems for determining the coordinates of an object on Earth or in the solar system [2, 4, 5, 8]. The active methods are mostly used in radar stations (RLS) of various locations for solving a wide class of tasks [7, 8-12]. The passive methods are used in ground-based receiving stations and very rare in air-based ones. In most cases, these stations operate in direction finding mode [1, 13]. Such stations are actively used in radio monitoring systems, in search and rescue systems, etc. This is due to the fact that the phase and amplitude-phase direction finding methods used are the most accurate as compared to others [1, 7, 13].

The determination of the object coordinates with high accuracy needs a large base for direction finder. For this, the receiving antenna elements are to be placed on considerable distance (more than 100 m) from each other. In addition, the equipment for receiving and processing information should also be located at a considerable distance from the antennas. With this arrangement of devices at the station, the use of microwave cables for information transmitting leads to unacceptably large signal losses. At low signal / noise ratio, using the amplifier for compensation for these losses is highly undesirables, especially at phase direction finding. The use of the microwave signals transmission of fiber-optic communication lines (FOCL) is one solution to this problem [8, 13-17]. It should also be noted that at present the FOCL and laser systems are applied for different tasks solving [18-25]. The results of relevant studies highlight the advantages of the information transmission method with using FOCL [16, 17, 26-30]. The using FOCL for analog microwave signals transmitting significantly reduces signal attenuation and the interference effect on measurement results [12, 13, 16, 17, 26-30].
It should be noted that most stations for direction finding are mobile in contrast to stationary radars. In stationary radar for FOCL, the regime of temperature stabilization is applied. The direction finders are constantly moving to solve various problems or move out of the object on the platform. The systems for information transmission (microwave cable, optical cable, etc.) are located in open air or water space where the temperature changes occur. This leads to a change in temperature of the fiber, which causes an additional phase shift $\triangle \phi$ in optic fiber. In case of large value of $\triangle \phi$, the difficulties arise when using the phase and amplitude-phase method of direction finding for object coordinates determination.

At the same time the temperature stability of phase difference in optic signals transmission channels for direction finding, which has an impact on the bearing determination accuracy, has not still investigated. This circumstance does not allow us to develop the requirements for temperature stability for optic channels of the direction finding that leads to errors in the station work during the signals processing from different antennas. Therefore, the aim of our work is to investigate the influence of temperature on phase shift during microwave signal transmission over FOCL.

2. Experimental setup and measurement technique

The features of the equipment operation in the direction finding station in the experimental setup for the research developed by us have taken into account. These features are related to the facts, that the depending on the station design and the conditions of its location in a number of radio direction finder units, it is possible to provide a thermal insulation, including optical fiber. In some cases the stable temperature regime are provided only in processing blocks and information transmission. The optical fiber with active temperature stabilization regime is used only in stationary stations of direction finder on far North and the Arctic [26]. Therefore, we investigated for two cases of temperature stability of the phase difference in the channels for microwave signal transmission. In the first case research were carried out only for the temperature changes in FOCL. In the first case research were carried out for the temperature changes for all optoelectronic path. The optoelectronic path in addition to optical fiber includes equipment for transferring the signal from the microwave range to the optical and back. In the figure 1 is presented the block diagram of the experimental setup.

![Figure 1. Structural diagram of the experimental setup: 1- laser module; 2 – transmitter; 3 – optic modulator; 4 and 5 - optical multiplexer (demultiplexer); 6 and 7 – photodetector; 8 – fiber-optic communication line; 9 - vector analyzer; 10 – optic electronic tract.](image)

The analog microwave sinusoidal signals (equal frequencies) are supplied to optical converters from the output of the network analyzer 9. To convert analog microwave signals to optical we used in one channel: Optilab DFB-C-PM-M-1590-20 laser module – 1 and Optilab CMP-40-LD-V-PM-TQ modulator – 3. In the another channel we used the transmitter OTS-2T-0518 – 2. For spectral multiplexing of optical signals, a multiplexer (CWDM-8-M-47-90-10-FC/APC-DK) is used. Its use
has allowed us to transmit optical signals from the two channels on one cable with waterproofing. The FOCL length in the experiment was 90 m. The transmission of signals through one cable allows us to minimize the phase difference change in the channels under the temperature influence. Optical signals are recording by photodetectors (SIRU3040-00) with increased photosensitivity [31]. The analog signals are fed with photodetector outputs to the inputs of the network analyzer (Rohde & Schwarz ZVA 40) – 9.

Such a construction scheme of the experiment for research of FOCL characteristics with using a vector network analyzer (Rohde & Schwarz ZVA 40) allows to measure the self-noise level of FOCL. For this purpose the output of the vector network analyzer is apply to the modulator and the microwave signal transmitter with a power of 0 dBm. In addition, the experimental setup allows us to investigate the intrinsic noise dependence of the entire optoelectronic tract from temperature.

3. Experimental results and their discussion

In figure 2 as an example is presented the dependence of microwave signal phase advance $\delta \phi$ in optic channels from temperature change (only for FOCL or for all equipment of optoelectronic tract. The temperature varied from 284.3 to 294.4 K in the time interval 926 s.

![Figure 2](image)

**Figure 2.** The time dependence of the phase shift $\delta \phi$ of the optical signal due to the temperature T increase. Graph 1 corresponds to heating after cooling only FOCL, graph 2 - after cooling all equipment of optoelectronic path.

The analysis of the obtained results shows that at a frequency 18 GHz the value $\delta \phi$ for each of the channels is more than 9400 degrees with the initial cooling only FOLC. In the case of cooling all equipment, the value $\delta \phi$ is more than 9200 degrees.

The experiments have shown that the obtained numerical values of $\delta \phi$ are quite difficult to explain. This is due to the large number of contradictions. Therefore, it will be necessary to continue research in this direction. It should also be noted that the obtained values of phase difference $\Delta \phi$ between channels are in limits, which are corresponding to reliable work of detector finder.

The obtained values for $\delta \phi$ show that if the FOCL of direction finder will be located in different waterproofing cables (antennas spaced at a long distance and are used without platform), it is necessary to ensure the thermal stabilization of FOCL. Since the temperature change is even 1-2 K between the optical fibers in these FOCLs will lead to very big mistakes in during the bearing in a few
hours. In addition, the bearing is most appropriate to carry out in a wide frequency band, for example, 18 GHz and above.

In figure 3 as an example is presented the dependence of changing the phase difference \( \Delta \phi \) between the signals in the photodetector devices after passing through the optical communication channels. The conditions of this experiment correspond to the conditions of experiments for the graphs in figure 2.

![Graph](image)

**Figure 3.** The time dependence of the phase difference \( \Delta \phi \) of optical signals due to the increase in temperature \( T \). The graph 1 corresponds to heating (an increase in \( T \)) after cooling only FOCL, graph 2 - after cooling all equipment of optoelectronic tract.

The analysis of the obtained dependences in figure 3 shows that the phase difference \( \Delta \phi \) varies within 8 degrees, when cooled only the FOCL. When we cooled all the equipment of the optic electronic tract – value \( \Delta \phi \) varies within 11 degrees. The maximum allowable change \( \Delta \phi \) with bearing is 12 degrees.

These phase difference values \( \Delta \phi \) are obtained taking into account the fact that we used in the channels for transmitting the optical signal of different types of optical modules. In the case of using in optical channels the equipment of one type, the fluctuations of the phase difference \( \Delta \phi \) will be less.

One of the important characteristic of optic electronic tract is the transmission coefficient because the direction finder antennas are often used to register weak signals. The transmission coefficient \( P \) of optoelectronic path using a laser module, modulator, FOCL and photodetector device operating at a wavelength of 1590 nm in the frequency range from 2 to 20 GHz, is presented in figure 4. The research of transmission coefficient \( P \) are implemented for two cases. One case to change the temperature only the FOCL. In another case to change the temperature all of optoelectronic path.

The obtained experimental results showed that the transmission coefficient \( P \) does not change in equipment cooling process. This is due to a good internal thermal stabilization which is used in device of optoelectronic path.
Figure 4. The frequency dependence of the transmission coefficient $P$ change from $f_{\text{os}}$. Graph 1 corresponds to the change in the transmission coefficient when only the FOCL temperature changes, graph 2 – when the temperature of all equipment of optoelectronic path changes.

4. Conclusion
The obtained research results show that the prolonged significant temperature changes at 18 GHz do not create a phase difference $\Delta \phi$ between the channels of more than 11 degrees. This value of phase difference $\Delta \phi$ is acceptable for coarse direction finding systems, when performing an instant overview of the radio engineering space. At lower frequencies $f_{\text{os}}$, the $\Delta \phi$ value decreases accordingly. At frequencies up to several GHz, the temperature instability of the phase difference due to fiber is few tenths of degree. This practically does not affect the accuracy of direction finding. The data obtained allow us to recommend the considered technical solution for use in accurate direction finding systems with antennas placed on a single base.

In phase direction finding it is necessary to ensure high temperature stability in FOCL for the case of transmitting signals over FOCL from antennas separated by a large distance (over 100 m). To establish the limit values for this temperature stability, it is necessary to carry out a number of studies with using of additional equipment. This important question will be the direction of our future work.

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