The research of temperature instability influence of fiber optic communication line in phase direction finder channels on peleng accuracy

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Abstract. In the article the influence of optical fiber temperature change to phase shift between optical signals in transmission channels is considered. The method for influence assessment of temperature phase shift on bearing accuracy is proposed. The results of experimental researchers and calculations are presented.

1. Introduction
The phase direction finder is widely used to search for radio sources of microwave range [1-9]. As you know, phase and amplitude-phase direction finding methods are the most accurate. Therefore, they are widely used in practice in radio monitoring systems [1, 2, 6-11]. Currently, a large number of radio direction finder designs have developed. They are located on various objects, including space [12-17].

When placing the antenna elements on a large-sized carrier often requires significant removal of antenna elements relative to the receiving and processing equipment. This is necessary to create a large base of direction finding, etc. The use of microwave cables in this case leads to unacceptably large losses of signal power. Fiber-optic communication line (FOCL) has a low specific attenuation of the signal [5, 10, 11, 18-20]. Therefore, the following is expedient, it is advisable to transfer the received signal to the optical range, transmitting it via fiber optic and reverse the signal to the microwave range. For comparison: the specific attenuation of a microwave cable in the frequency range up to 18 GHz is 0.7 ... 1.7 dB/m, and up to 40 GHz - 1.7 ... 3.0 dB/m (fig. 1). The attenuation of the optical signal in the FOCL is about 0.1 dB/km.

At the same time, a number of problems arise with the use of FOCL [5, 10, 11, 18-22]. One of them is associated with the appearance of an additional phase shift between the signals transmitted by FOCL. The phase shift occurs due to changes in the temperature of the fiber optic line and equipment. This may lead to an increase in direction finding error. Especially with long-term operation of the direction finder in conditions where frequent changes in ambient temperature are possible.
Figure 1. The dependence of the gain (attenuation) on the frequency of the microwave signal of the microwave cable of various brands at an ambient temperature of $T = 293$ K. Graph 1 corresponds to the brand of cable SF 240, graph 2 - SF 229, graph 3 - SF 404, graph 4 - SF 406.

Therefore, the aim of the work is to study the effect of changes in ambient temperature on the accuracy of direction finding when using FOCL to transmit a microwave signal.

2. The experimental setup and measurement methods
In the radio direction finder, thermal insulation can be performed both for the whole apparatus and separately for FOCL. It depends on the design and permissible weight and size characteristics of the radio direction finder equipment. Therefore, the temperature stability of the phase difference in the channels was investigated for two cases. The first case changes the temperature of the FOCL only. The second case changes the temperature of the entire optical equipment with FOCL. In the figure 2 the block diagram of the experimental setup is presented.

Figure 2. Structural diagram of the experimental setup: 1 - laser module Optilab DFB-C-PM-M-1590-20; 2 – transmitter OTS-2T-0518; 3 – electro-optic modulator Optilab CMP-40-LD-V-PM-TQ; 4 and 5 - optical multiplexer (demultiplexer) CWDM-8-M-47-90-10-FC/APC-DK; 6 and 7 – photodetector SIRU3040-00; 8 – fiber-optic communication line; 9 - vector analyzer; 10 – optic electronic tract.

To optical converters 1, 3 and 2 from the output of the vector network analyzer ZVA40 9 are served the sine wave microwave signals having the same frequency. To transfer these signals to the optical frequency range in the first channel, a laser module 1 and an electro-optical modulator 2 are used. The second channel uses the transmitter 2 to solve this problem. For spectral multiplexing of optical signals, a multiplexer 4 (demultiplexer 5) is used. Using this device allows you to transmit signals from two channels over a single fiber optic cable 8. In the experiment, the length of this cable was 90 m. Signal transmission
through a single cable minimizes the change in the phase difference in the channels due to temperature change. Optical signals are recorded by photodetectors 6 and 7. Analog signals from the photodetector outputs are fed to the inputs of a vector network analyzer 9.

This experimental setup allows you to measure the difference in phase incursions in FOCL channels. It should be noted that this phase difference is not reduced to the range of 0 - 360 degrees. This makes it possible to measure the exact value of the jumps in the phase difference between the channels, even if it exceeds 360 degrees. For the analysis, the selected frequency band is 17.9 - 18.0 GHz. This is due to the fact that the phase shift in the channels in this frequency band is maximum.

The measurements were carried out with a change in temperature for two cases. Changed the temperature of all elements of the optical tract or only FOCL. During the experiment, the ambient temperature increased from 284.5 K to 296.5 K. В ходе эксперимента температура окружающей среды повышалась от 284.5 K до 296.5 K. At the beginning of the measurements, the steady-state temperature of the optical cable and elements of the path was 284.5 K. В начале измерений установившаяся температура оптического кабеля и элементов тракта составляла 284.5 K. At the same time, the value of the difference of phase ramps in the fiber optic channels Δφ1-2 was periodically recorded. The working wavelength is λ = 1590 nm. The working frequency band of the microwave path equipment is 2–18 GHz.

3. Experimental results and their discussion
The analysis of the experimental data showed that the value of the phase shift in the channels with increasing temperature varies significantly. It was found that the phase difference between the channels varied in small limits. With an increase in the temperature of the optical cable, the difference of phase raids in the channels Δφ1-2 changed from minus 3 degrees to plus 8 degrees. For the case of increasing the temperature of all equipment, the difference in phase raids in the channels Δφ1-3 varied from minus 6 degrees to plus 6 degrees. As a result of the experiments, it was found that the maximum change in Δφ1-2 was 8 degrees for the case of fiber optic heating and 6 degrees and in the case of heating all the equipment. The transmission coefficient of the optical path in the process of heating changed slightly. This shows a good internal thermal stabilization in the devices used.

Experiments have shown that one of the main factors that affect the accuracy of direction finding is the value of the phase difference. Therefore, it is necessary to investigate the effect of the resulting phase difference between the Δφ1-3 channels on the direction finding accuracy of the phase method.

To do this, consider the problem of determining the direction of arrival of a signal using two antennas. In figure 3 is shown a diagram which illustrating this task.

![Figure 3. The direction determining of signal arrival by the phase method.](image)

In accordance with figure 3, it is necessary to determine the angle α, indicating the direction of arrival of the signal. The angle α is determined from the measured value of the phase difference of the signals received by the antennas A1 and A2. This difference will be determined by the difference d of the distances that the wave front of the signal traveled in the process of propagation to the antenna points:

$$Δφ = 2π \frac{d}{λ} = 2π \frac{D \sin α}{λ}$$  \hspace{1cm} (1)
In the formula (1) the distance between the antennas (direction finding base), related to the wavelength of the signal $\tilde{D} = D/\lambda$, is, in fact, a scale factor. This scale factor relates the angle of arrival of the signal with the phase difference of the signals received by the antennas. This ratio is determined by the range of possible angles of arrival of the signal, within which it is necessary to provide an unambiguous measurement of the bearing. Unambiguity is ensured when, over the entire range of measured angles $\alpha$, the phase difference $\Delta \phi$ does not exceed $\pi$ in absolute value, that is:

$$\left| \frac{D \sin \alpha}{\lambda} \right| \leq \frac{1}{2}.$$

From this:

$$\tilde{D} = \frac{1}{2} \left| \sin \alpha_{\text{max}} \right|.$$

The resulting ratio shows that it can be seen that the direction finding system is narrowband. The required direction finding base is uniquely determined by the operating frequency of the system. Therefore, in further calculations it is advisable to consider the ratio of the direction finding base to the wavelength. Absolute values of these quantities are impractical to consider.

For a radio direction finder, a characteristic can be obtained which makes it possible to determine the sine of the angle corresponding to the direction of arrival of the signal from the measured phase difference $\Delta \phi$, can be obtained from (1):

$$\sin \alpha = \frac{\Delta \phi}{2\pi \tilde{D}}.$$

Its steepness

$$K_a = \frac{d \sin \alpha}{d \varphi} = \frac{1}{2\pi \tilde{D}}.$$

The error in determining the direction of arrival of the signal $\alpha_e$ for a given measurement error of the phase difference of the signals in the antennas $\varphi_e$ can be determined by the value of $K_a$:

$$\alpha_e = \varphi_e K_a. \tag{2}$$

The relation (2) shows that the error $\alpha_e$ is due to the error $\varphi_e$, completely determined by the slope of direction finding characteristics. The error $\alpha_e$ does not depend on the direction of arrival of the signal. The resulting error in direction finding is the sum of the error $\alpha_e$ and errors caused by other factors. Consideration of these factors lies outside the scope of this work.

In table 1 presents the calculations $\alpha_e$ for different ranges of unambiguous measurement of the direction of signal arrival. Calculations are made for maximum measurement error of the phase difference (equal to 8) which was fixed during the experiments.

| $\pm \alpha_{\text{max}}/2$, degree | $\tilde{D}$ | $K_a$ | $\varphi_e$, degree | $\alpha_e$, degree |
|-----------------------------------|-------------|-------|---------------------|-------------------|
| $\pm 15$                          | 1,93        | 0,08  |                     | 0,64              |
| $\pm 30$                          | 1           | 0,16  |                     | 1,28              |
| $\pm 45$                          | 0,71        | 0,22  | 8                   | 1,76              |
| $\pm 60$                          | 0,58        | 0,27  |                     | 2,16              |

Based on the results presented in table 1 we can draw the following conclusions:
1. For radio systems review (providing direction finding in wide angles ranges from ± 45 to ± 60) additionally introduced error does not exceed 2.5 degrees. It is caused by phase distortions in the optoelectronic path.

2. In accurate direction finding systems (less than ± 15 degrees), the introduced error does not exceed 0.7 degrees.

3. In systems of radio technical review and accurate direction finding the additional phase incursions in the direction finder channels arising from the use of fiber optic lines slightly degrade the accuracy of direction finding.

4. Conclusion

The obtained results show that a change in ambient temperature does not lead to a significant decrease in the accuracy of determining the bearing in the frequency band up to 18 GHz. when spectral seal channels and transfer them over a single fiber optic cable.

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