Features of transmission bearing and heterodyne receivers for signals in fiber-optic communication line in active phased array antenna

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Abstract: The article discusses the problems arising from the modernization of active phased antenna arrays (for example, an increase in the number of transceiver active elements, a decrease in the weight and size of the antenna system, etc.). It has been substantiated that the most rational solution of these problems is the use of fiber-optical communication systems for transmitting heterodyne signals. A new design of the transmit-receive module with a fiber-optic transmission system for an active phased antenna array has been developed. The results of experimental investigations are presented.

1. Introduction

In most cases, the operation of radar stations (RLS) is carried out in conditions of high density of interference of various kinds. Therefore, communication and control channels in radar are protected by various screens (passive and active) [1-6]. The degree of protection of communication channels and control is provided depending on the functional tasks. These tasks should be solved using the signals that are transmitted through them. But it still does not significantly reduce the weight and dimensions of coaxial cables [1-3, 5-11].

The greatest difficulties in radar arise when transmitting signals reflected from various targets from the antenna to processing devices [1, 3, 5, 7, 10-13]. To solve this problem, as well as more convenient processing of the microwave signals reflected from various targets, received by the antenna in radars, superheterodyne radios are used. This type of radio receivers is based on the principle of converting the received signal into a fixed signal of an intermediate frequency with its subsequent amplification. The main advantage of the superheterodyne receiver is the absence of the need for tuning to different frequencies. To the local oscillators make high demands on the stability of the frequency and amplitude, as well as the spectral purity of harmonic oscillations. In the data transmission channel, the parameters of a heterodyne signal in different operating conditions of the radar (temperature differences, the presence of interference of various kinds, etc.) should not change [1, 3, 5, 10, 11, 13].

Especially many problems with maintaining the parameters of the heterodyne signal arise when placing the radar or receiving-transmitting station on an aircraft (for example, satellites, aircraft, helicopters, etc.) [2, 3, 8, 14-18]. In this case, in addition to external interference, interference associated with interference from neighboring channels, etc., begins to play a significant role. These tasks are solved depending on the design of antenna systems. The most difficult are technical solutions in active phased array antennas (APAA) for radars operating in the S and X ranges. APAA has a very
high density of electronic components and feeder paths. The most sensitive to interference in APAA are the feeder paths of superheterodyne receivers. To reduce the effect of induced interference on the feeder paths of superheterodyne receivers, their “vulnerable” spots in APAA are covered with absorbing materials. Operating experience of APAA shows that this is a temporary solution to the problem. Absorbent coatings for various reasons fail, lose their integrity during repairs, etc.

Therefore, for each receiving-transmitting element APAA uses its own local oscillator. This partially allows to reduce the pickup of the feeder paths at each other in conditions of high density of the location of channels. Such a construction of the transmission channels of heterodyne signals led to the fact that in the existing designs of APAA there is no space for new nodes.

Currently, new absorbing coatings are used in the manufacture of various objects that need to be detected using radar. In this connection, modernization of the APAA in operation is required. One of the most important directions of this modernization is the development of an APAA with the number of transceiver elements more than 1000 while maintaining the weight and size characteristics of the antenna. The dimensions of the transceiver elements can be reduced and their characteristics retained using new materials in their manufacture. But with the placement of additional feeder paths, especially superheterodyne receivers in APAA, great difficulties arise.

One of the solutions to this problem is considered in our article. We propose to replace feeder paths transmitting microwave signals with fiber optic transmission systems (FOTS) in APAA [10-12, 17-25]. Optical fiber is not affected by high-frequency interference and has good noise characteristics when transmitting high-frequency signals, it has high flexibility and low mass [20-27].

2. Features of the transmission of heterodyne signals on a fiber-optic system and its design.

In the case of heterodyne signals for transmission in FOTS radar APAA necessary in its design to take into account a number of features and calculate the following parameters: phase noise, the signal / noise transmission path temporal stability and temperature stability.

The values of the frequencies of heterodyne signals are small (no more than 100 MHz) compared with the frequency of the radar emission (more than 8 GHz). Therefore, nonlinear effects in an optical fiber and dispersion losses can be neglected. This is one of the features of the transmission of these signals to APAA.

In addition, another distinctive feature of the transmission of heterodyne signals is the small length of the optical fiber L (not more than 15 m). This circumstance also makes it possible to neglect the previously noted nonlinear effects. It should be noted that at such distances L the requirements for the optical transmitting module and photodetector are not high in terms of input power, conversion loss, speed, conversion coefficient when transmitting these signals at frequencies less than 100 MHz compared to when FOTS transmits microwave signals from 40 GHz frequency [4, 7, 8, 11, 12].

The use of FOTS has allowed us to develop a new scheme for the transmission of heterodyne signals to receiving modules that are each connected to an APAA receiving element. In figure 1 shows the structural scheme developed by us.

The proposed design of the FOTS allows you to generate a signal using a single local oscillator. Further, it is converted into an optical modulated signal, which can be divided into a specified number of receiving and specifying modules using an optical divider. The only condition for this transmission implementation is the choice of optical transmitting (with a given output power level) and receiving (minimum input optical power) modules, so that with a large number of N channels (optical divider 1/N) the information is lost.

With this construction of a FOTS with an optical divider, the intrinsic noise factor of a channel on a K_n line becomes an important characteristic. When transmitting heterodyne signals, it limits the number of channels into which the optical signal can be divided. The measurements performed showed that K_n in the channel of the developed FOTS is less than 4 dBm. The intrinsic noise of the feeder path for transmitting the heterodyne signal to APAA is not lower than 6 dBm. This shows that
the new design not only significantly increases the free space in the APAA unit, but also improves the characteristics of the transmission channel by more than 30%.

Figure 1. Structural diagram of a fiber-optic transmission system: 1 - local oscillator power supply; 2 - a local oscillator; 3 - power driver; 4 - transmitting laser module; 5 - optical isolator; 6 - block housing AFAR; 7 - optical divider; 8 - receiving optical module; 9 - power driver; 10 - receiving and transmitting module APAA.

In addition, we found that in the newly developed FOTS design, the dependence of the signal power at the system output on the signal power at its input is linear from –128 dBm to –22 dBm. This allows us to conclude that the dynamic range (DR) developed by FOTS with an optical divider exceeds 105 dBm. This value of DR is sufficient for transmitting heterodyne signals via the FOTS. Standard DR feeder paths is not more than 110 dBm. One of the main characteristics of the heterodyne communication channel in APAA has not deteriorated.

It should be noted that the channels of the transceiver modules, where the heterodyne signal enters, are optically isolated. This eliminates possible interferences from one another, and also does not require additional screening, as in feeder paths. The latter also frees up space for the introduction of additional elements in the design of APAA.

The use of the developed FOTS in the design of AFAR imposes a number of features on the construction of the receiving-transmitting module (RTM) scheme. In figure 2 shows the structural diagram of the receiving-transmitting module developed by us.

The main feature of the new scheme is that the phase shifter and attenuator developed by us are located in one receiving and transmitting channel, when in other designs they are spaced apart along separate channels. The second feature is the use of a mixer in RTM. This allows you to combine the channel of reception and transmission in one path, which significantly saves space in the design of APAA and reduces its cost. A heterodyne signal arrives at the mixer input from the output of the FOTS. The mixer also receives a signal from the receiving antenna reflected from the target.
Figure 2. Structural diagram of the receiving-transmitting module: 1 - control bus; 2 - mixer; 3 - phase shifter; 4 - attenuator; 5 - switch; 6 - low noise amplifier; 7 - receiver protection device; 8 - circulator; 9 - receiving and transmitting element APAA.

This allows the mixer to generate an intermediate frequency signal, which contains information about the movement of the target. This signal is transmitted to radar processing devices.

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

The most important characteristic that needs to be investigated when transmitting a heterodyne signal via a FOTS is the dependence of power on frequency. Let us determine the presence of distortions in the spectrum of the signal at the output of the FOTS [4, 11, 17, 18, 25, 28-32]. On the laboratory model of FOTS developed by us, possible distortions in the spectrum when transmitting a heterodyne signal via FOTS at an operating frequency of 10 MHz were investigated. In figure 3, one of the results of these studies is presented as an example.

Figure 3. Spectra of a heterodyne signal at the input (graph 1) and output (graph 2) FOTS.
Comparison of the obtained spectra (figure 3) shows the high efficiency of the transmission of the heterodyne signal at a carrier frequency of 10 MHz 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 developed FOTS is intended for APAA, which are located on the aircraft, it will be operated 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. In figure 4 shows the experimental dependence of the phase shift of the modulation of light $\Delta \varphi_m$ on the ambient temperature $T$.

![Figure 4](image)

**Figure 4.** The phase shift modulation of the medium temperature. Graphs 1, 2 and 3 correspond to the frequency of the heterodyne signal in MHz: 10; 50; 100.

The research results showed that the temperature dependence of the modulation phase change for G.657 fiber is no more than 2 degrees in the selected temperature range from 213 to 323 K for various frequencies of the heterodyne signal.

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

The use of the FOTS design developed in APAA made it possible to implement a new construction of the RTM. This allowed for a more compact placement of a large number of RTMs in APAA compared with the case when feeder paths were used. In addition, the number of used local oscillators
in the new design of APAA decreased by an order of magnitude compared with the case of using feeder paths.

Since optical dividers and fiber do not need to be protected from electromagnetic radiation, a part of the channel for transmitting a heterodyne signal with these elements can be placed behind the APAA housing from its rear part (the fiber length of 5 m allows you to do this). In this case, additional space is made available in the APAA housing.

The technical solutions we proposed on the basis of the conducted research allowed us to increase the number of transceiver elements in APAA to 1024 and to ensure reliable operation of the antenna complex while maintaining its weight and size characteristics within specified limits.

It should also be noted that with an increase in the number of channels in the optical divider, $K_n$ in each channel increases. This fact together with a decrease in the optical signal power in each channel is a limitation on the increase in $N$ in the optical divider during the development of FOTS. As a result of research, it was found that the most optimal at present is the use of an optical divider with 10 channels in APAA. This allows the use of a total of 103 local oscillators in the APAA design. Previously, 256 local oscillators were used in the design of an APAA with 256 transceiver elements.

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