Fiber-optical system for transmitting heterodyne signals in active phased antenna arrays of radar stations

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Abstract: For transmitting reference and heterodyne signals of active phased array antenna is developed a new design of a fiber-optic communication system. In article are considered transmission features of reference and heterodyne signals in is developed by us of new design of a fiber-optic communication system. The data of experimental investigation are presented.

1. Introduction
The radar stations (RLS) are often exploited when in space are grand density of interference various kinds. The tracts through which control and information signals are transmitted to ensure the operation of the station are protected by special system (example, various passive and active screens) [1-6]. The protection level for communication tracts and control is determined the functional tasks which are solved. These tasks should be resolved of used the signals that are transmitted through them. The weight and size of coaxial cables are using of complex access it still doesn’t significantly reduce [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 radio-receivers are exploited. This type of radio-receivers is worked of next principle a received signal is converting in fixed signal to intermediate frequency and after that it intensifies. The superheterodyne receiver has a number of advantages, the main of which is the lack of need of tuning to different frequencies. Very high demands are made in superheterodyne receiver for spectral purity of harmonic oscillations, as well as on the stability of the frequency and amplitude. In transmission tract of data should not be changed a heterodyne signal parameters at different exploitation conditions of the radar (temperature change, the existence of various interference kinds, etc.) [1, 3, 5, 10, 11, 13].

Especially grand problems with maintaining of heterodyne signal parameters when placing the radar or receiving-transmitting station on an aircraft (for example, satellites, aircraft, helicopters, etc.) [2, 3, 8, 14-18]. In addition to external interference in this case a significant role begins to play the interference associated with interference from neighboring channels, etc. 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 which are working in S and X ranges. The APAA of electronic components and feeder paths are dislocated a very high density. The most sensitive to interference in APAA are the feeder paths which are located in superheterodyne receivers. In APAA is used absorbing materials to reduce the effect of induced interference on the feeder paths of superheterodyne receivers. There materials are dislocated on “vulnerable” spots of feeder paths. Operating experience of APAA allowed to get information that this does not solve the problem for long. This is due to the fact that absorbing coatings degrade over time. Their coatings are destroyed. They get damaged during repair work, 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 high density conditions of the channel location. 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 systems which is need to detected by radar. This requires developing new directions for radar modernization to detect such systems. One of the most important directions of this modernization is the development of an APAA with the number of transceiver elements more than 1000. It should be noted that the size and weight of the antenna should be maintained. Using new materials, developers reduce the size of the transmit-receive elements in the antenna. But the use of new materials does not reduce the size of the feeder path. They need to be posted. With their placement in APAA there are big problems.

In our article, we propose to consider the most appropriate solution to this problem. We are replacing feeder paths with fiber optic systems (FOTS) in APAA [10-12, 17-25]. The FOTS has good noise characteristics when transmitting high-frequency signals. In addition, the optical fiber is not affected by high-frequency interference, has high flexibility and low mass [20-27]. Due to the fact that the length of the FOCL is not more than 10-15 meters of many parasitic effects, as well as distortion due to dispersion, during the transmission of the microwave signal does not occur [28-31].

2. The particular qualities of transmission on fiber-optic system in APAA of heterodyne signals

At designing APAA for radar stations, if heterodyne signals are transmitted in them via fiber-optic communication lines, some features of their transmission must be taken into account. In addition, it is necessary to calculate for the fiber-optic system: phase noise, signal-to-noise ratios, temporal stability of the transmission path and temperature stability.

Our studies have shown that due to the small length of the optical fiber in the APAA, nonlinear effects and dispersion losses can be neglected. In addition, the frequency at which the heterodyne signal is transmitted is small compared to the frequencies of the APAA. The value of this frequency does not exceed 100 MHz. This is one of the features of the transmission of heterodyne signals along optical lines in the APAA.

It should also be noted that another of the features of heterodyne signal transmission in the AFAR is associated with the small length of the optical cable L (less than 15 m). This allows you to realize a large number of sharp bends, since nonlinear effects do not have time to influence the signal. These distances L make it possible not to place high demands on the optical transmitting module and the photodetector for their various characteristics. Especially in terms of input power, conversion loss, speed. It is worth noting that the conversion coefficient when transmitting data hydrodynamic signals at frequencies less than 100 MHz is low compared to when microwave signals with frequencies of 40 GHz are transmitted through the FOTS. [4, 7, 8, 11, 12].

The use of the FOTS developed by us made it possible to propose for the design of the APAA a new scheme for transmitting heterodyne signals to receiving and setting modules. It should be noted that each receiving and transmitting module is connected to the AFAR plug element. The scheme we developed using fiber optic link is presented in Fig. 1.

An intermediate frequency signal is generated in one heterodyne receiver. Then it enters the FOTS input, in which it is converted into an optical modulated signal. We can divide this signal with the help of an optical divider into the required number of receiving and setting modules. The limitation of the
signal division number is the minimum output power level and the minimum input optical power of the modules. Since if there will be a lot of channels, where $N$ is the number of channels (optical divider $1/N$), the necessary information may be lost.

![Figure 1. Structural scheme of FOTS: 1 - power supply of heterodyne; 2 - heterodyne; 3 - power supply of driver; 4 - transmitting laser module; 5 - optical isolator; 6 - block housing APAA; 7 - optical divider; 8 - receiving optical module; 9 – power supply of driver; 10 – receiving-transmitting module APAA.](image)

When using the optical fiber splitter developed by us, using the optical divider, it is necessary to take into account the intrinsic noise figure of the optical channel of the $K_n$ line. Its value is a limitation on the number of channels into which the optical signal can be divided. If the signal-to-noise ratios will be small useful information may be lost. We found that for the developed design, the $K_n$ in the channel is less than 4 dBm. It should be noted that for the feeder path the value of the intrinsic noise is not less than 6 dBm. The obtained result shows that in addition to increasing the free space in the APAA and reducing the weight, the transmission coefficient of the channel increases by more than 30%.

Our studies have allowed us to obtain the following results. We measured the dependence of the output power on the input for the developed FOTS. The linear part of this relationship is from $-128$ dBm to $-22$ dBm. In this case, it can be argued that the dynamic range (DD) of the developed FOTS with an optical divider is about 105 dBm. The DD value obtained by us is sufficient for transmitting heterodyne signals via the FOTS. In operating APAA, the dynamic range of feeder paths does not exceed 110 dBm. Therefore, we can conclude that the main characteristic of the heterodyne channel in the APAA has not worsened.

One of the main advantages of the design of the FOTS developed by us is the optical isolation of the channels of the transceiver modules into which the heterodyne signal arrives. Optical isolation eliminates all possible interference signals. In addition, feeder paths do not require additional shielding. Reducing shielding frees up space for the placement of new circuits in the design of APAA.

The use of the FOTS developed by us in the APAA design has identified a number of features that must be taken into account when developing the scheme of a receiving-transmitting module (RTM). The block diagram of the transmit-receive module developed by us is presented in Fig. 2.

Unlike other designs of the transmitting and receiving modules used in the APAA in our proposed design, the RTM phase shifter and attenuator are in the same transmitting and transmitting channel. In other RTM designs, the phase shifter and attenuator are spaced apart on separate channels. This is one of the features of the RTM developed by us. The second feature can be considered the use of a mixer in the RTM. The inclusion in the design of the RTM mixer made it possible to combine the transmission and reception channel in one path. This makes it possible to free up additional space in the design of AFAR and reduces its cost.

This construction of the transmitting and receiving module makes it possible to generate an intermediate frequency signal on the mixer. This signal contains the necessary information to
determine the parameters of the target. On special communication lines, this signal is transmitted to radar processing devices.

![Diagram](image)

**Figure 2.** The design of RTM: 1 - control path; 2 - signal mixer; 3 - phase shifter; 4 - attenuator; 5 - switch; 6 - low noise amplifier; 7 - receiver protection device; 8 - circulator; 9 - receiving and transmitting element APAA.

3. The data of the experiment investigation and discussion

The main parameter that needs to be considered when transmitting the local oscillator signal over the fiber optic link is the change in power at different frequencies. Consider the presence of distortions in the spectrum of the output FOTS signal [4, 11, 17, 18, 25]. Studies were conducted on a model developed by the FOTS. We studied the possible spectral distortions arising from the transmission of the local oscillator signal through the FOTS in the case of an operating frequency of 10 MHz. In Figure 3 shows as an example one of the results of these studies.

![Graph](image)

**Figure 3.** The heterodyne signal spectra at the input (plot 1) and output (plot 2) FOTS.

A study of the available spectra (figure 3) demonstrates the big efficiency of transmitting the local oscillator signal through the FOTS at a carrier frequency of 10 MHz. The spectrum is distorted only on the side parts, which does not interfere with the accuracy of determining the range of the target about the radar.

The APAA with communication system will be used at large temperature differences therefore it is necessary to use the invented FOTS. Thermal expansion or contraction, which is caused by instability of the temperature of the environment, leads to a change in the fiber refractive index and an increase in fiber length. As a result, the phase of the light changes, and the change in the phase of the modulation of the signal transmitted through the communication system depends on it. Therefore, it was necessary to study the temperature instability of the modulation phase obtained from the experiment during signal transmission via FOTS. In Figure 4 shows the experimentally obtained dependence of the phase shift of the light modulation $\Delta \phi_m$ on the temperature of the external medium $T$. 

![Graph](image)
Figure 4. The shift of the modulation phase from the ambient temperature. Charts 1, 2 and 3 relate to the frequencies of the local oscillator signal equal to MHz: 10; 50; 100.

The data of the experiment demonstrate that, at different frequencies of the local oscillator signal, the behavior of the modulation phase depending on the temperature for the G.657 fiber does not exceed 2 degrees when the temperature changes from 213 to 323 K.

4. Conclusion
The data that we were able to obtain demonstrate that the FOTS scheme we proposed can be used with success in the work of radars containing APAA. The results showed that the data obtained as a result of research allow us to reasonably use the proposed design of the FOTS.

This design makes it possible to use in the APAA a new RTM scheme. Now it is possible to place a lot of RTMs more compactly in the APAA as compared to the scheme using feeder paths. It also made it possible to reduce the number of local oscillators used in the new APAA scheme by an order of magnitude.

Due to the fact that it is not necessary to provide optical dividers and fiber with protection against electromagnetic radiation, it is possible not to introduce part of the channel transmitting the local oscillator signal into the APAA housing (a fiber length of 5 m is sufficient for this). Then it will be possible to create free space in the APAA building.

The technical solutions described, which are based on the conducted studies, make it possible to make the number of transceivers elements in the APAA equal to 1024 and not increase the overall dimensions of the antenna complex while maintaining its operability.

The important thing is that in the optical divider $K_n$ in each channel varies in direct proportion to the number of channels. This, as well as a drop in the power of the optical signal in each channel, limits the increase in $N$ in the optical divider during the creation of FOTS. During the experiment, it was found that the best option in now is to use an optical divider consisting of 10 channels in the APAA. This makes it possible to use only 103 local oscillators in the new APAA scheme. In the past, in the APAA scheme, 256 transmit-receive modules were used and there were 256 local oscillators.

5. References
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