The expediency of fiber-optical communication line used in different schemes of receiver tract of the radio-monitoring complex

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Abstract. In the article the all variants of broadband and narrowband receiver tract design schemes for microwave signal transmission in radio monitoring complexes are considered. The characteristics of receiver tract with use of fiber-optic communication line or microwave cable in its various parts are presented. The features, advantages and disadvantages of fiber-optic communication lines using are marked. The comparison of the investigation characteristics of receiving tract parts with foreign analogues are performed. The results of experimental research and theoretical calculations are presented.

1. Introduction
For the analysis of the electromagnetic environment, functioning control and ensuring of electromagnetic compatibility of radio engineering and telecommunication sources of radio emission, radio monitoring is carried out [1-4]. The radio-monitoring complex (RMC) is operating in a wide frequency range that determines the construction of its receiving tract in the form of a direct gain receiver or a receiver, which is scanning on frequency superheterodyne. At the same time, to increase the coverage area, create a large base for direction finding, and also for the convenience of placing multi-channel equipment for receiving and processing information in one complex, RMC antennas are placed at a considerable distance from the location of signal processing equipment, communications equipment and other elements of the complex, as it is done in various radar [3-9]. Fiber-optical communication line (FOCL) is widely used to transmit various signals between antennas and other parts of the RMC. Similar microwave transmission systems are used on ships and large aircraft [7–15]. There are also particular applications of specialized FOCL both for transmitting microwave signals
and for solving other problems [15-26]. However, there is still no analysis of changes in the characteristics of the RMC when using FOCL in various parts of its receiving tract. For other applications of FOCL associated with their use for microwave signals, this analysis was also not carried out.

In this situation, it is advisable to do this analysis for each option for the introduction of FOCL into the signal transmission tract compared to using new developments in the microwave cable. Because in some cases, practice shows that the efficiency of the microwave cable is higher than the FOCL, as the characteristics, simplicity of design solutions in different transmission of the microwave signal, and at a cost.

The primarily in this analysis will be necessary to consider the frequency dependencies of transfer coefficient and the noise factor for cable and optical part. These characteristics will be different for each frequency band in the transmit path.

Therefore, the purpose of this work is to perform a comparative analysis of two paths (broadband and narrowband) using FOCL and microwave cable in them. Currently, to solve various problems and depending on the antenna system design, the FOCL is located in three parts of the receiving tract (directly at the antenna output to the low-noise amplifier (LNA), after the LNA and at the output of the frequency converter - at the receiver with conversion). The most radar and radio monitoring complexes are working in the operating frequency range from 2 to 18 GHz. In the case of placement of FOCL after the frequency converter, we will conduct research in the frequency range from 1.5 GHz to 2 GHz. In RMC the microwave signal is transferred to this range. For various types of radars, the microwave signal after conversion can be transmitted at lower intermediate frequencies, for example, 90 MHz in the active phased array antenna (APAA). For radio monitoring as an indicator of successful work there are chosen sensitivity and its corresponding maximum range of detection of RMC in free space [1, 2, 4, 8, 9, 27]. The same criteria are used for most radars.

2. Schemes of construction of microwave signal receiving tracts, methods of their calculation and measurement of parameters

For research, we collected typical schemes of broadband and narrowband tract used in radio monitoring equipment. The structure of these circuits included the construction of the optical-electronic path (OEP). This path consists of a laser with an integrated modulator (OTS-2T / 3.5-0518-29-10-FA-1-00-1 transmitter), an optical fiber, optical isolators, and a SIRU 3040 photodetector device from Emcore. The ranges of operating frequencies for the transmitter and photodetector are from 0.5 to 18 GHz and from 0.3 to 40 GHz, respectively.

In figure 1 shown the experimental setup options for investigations of the OET and a microwave cable in the broadband transmitting path.

![Figure 1](image)

**Figure 1.** Structural diagrams of a broadband transmitting path: a) - WA1 - receiving antenna; A1-OET; A2-LNA; Z1-Filter, b) - WA1 - receiving antenna; A1 - LNA; Z1-Filter; A2 - LNA.

We measured the transfer coefficient $K_i$ and noise factor $N_i$ of each circuit scheme. The Rohde & Schwarz ZVA20 vector network analyzer was used for measurements of the gain of an optical path. Due to the high value of the noise factor, a method using a signal generator [7, 10] was selected for its measurement, according to which the noise figure is determined by the following expression:

$$F = \frac{P_g}{kT_0\Delta f},$$

where $P_g$ – generator power at which the output power is 3 dB above the noise level at the matched load in the absence a signal, $\Delta f$ – measurement strip.

The results of these measurements are presented in table 1.
Table 1. Characteristics of the elements of the broadband path.

| Feature | Amplifier dB | Amplifier Times | Filter dB | Filter Times | OET dB | OET Times |
|---------|--------------|-----------------|-----------|--------------|--------|-----------|
| $K_i$   | 14           | 25.1            | -3        | 0.5          | -24.4  | 0.0037    |
| $N_i$   | 3.5          | 2.24            | 3         | 2            | 52.1   | 162181    |

In figure 2 shown the experimental setup options with the OET and a microwave cable in the narrowband transmitting path.

Figure 2. Structural diagrams of a narrowband transmitting path: a) - WA1 - receiving antenna; Z1-filter; A2 - OET; A3-LNA; A4 - mixer; Z2-filter; A5 - LNA, b) - WA1 - receiving antenna; A1 - OET; A2-LNA; Z1- filter; A3 - LNA; A4 - mixer; Z2- filter; A5 - LNA, c) - WA1 - receiving antenna; A1 - LNA; Z1 -filter; A2 - mixer; A3 - LNA; Z2- filter; A4 - OET; A5 - LNA.

For the elements of these schemes, the gain and the noise factor were also measured. The measurement results are presented in table 2.

Table 2. Characteristics of the elements of the narrowband path.

| Feature | Amplifier dB | Amplifier Times | Filter dB | Filter Times | Mixer Amplifier dB | Mixer Amplifier Times | IF filter Amplifier dB | IF filter Amplifier Times | OET dB | OET Times | Amplifier dB | Amplifier Times |
|---------|--------------|-----------------|-----------|--------------|---------------------|------------------------|------------------------|--------------------------|--------|-----------|--------------|----------------|
| $K_i$   | 14           | 25.1            | -3        | 0.5          | 14                  | 25.1                   | -2                     | -24.4                    | 0.0037 | 14        | 25.1         | 25.1           |
| $N_i$   | 3.5          | 2.24            | 3         | 2            | 13                  | 20                     | 3.5                    | 2.24                     | 1.58   | 52.1      | 162181       | 3.5            | 2.24         |
\[ P_0 = kT_0 \cdot \Delta f \left( N_0 - 1 + \frac{T_0}{T} \right)q^2, \]

where \( N_0 \) – total value of noise factor, \( \Delta f \) – the effective noise bandwidth of the receiver, \( T_0 \) – antenna noise temperature, \( q \) – signal-to-noise ratio.

For the detection range, the calculation should be performed using the following formula, for which the value of \( P_0 \) is determined from (1):

\[ R_{\text{max}} = \frac{\sqrt{P_1 \cdot G_{A1} \cdot G_{A2} \cdot \lambda^2 / P_0}}{4\pi}, \]

where \( P_1 \) – power, \( G_{A1} \) and \( G_{A2} \) – gain of transmitting and receiving antennas, respectively, \( \lambda \) – wavelength.

It is worth noting that expression (2) describes the detection distance in free space, i.e. does not take into account the curvature of the earth’s surface, the height of the receiving and transmitting antennas [27, 28], as well as the frequency-dependent attenuation in the atmosphere.

3. The results of experimental studies and discussion of the results

Figure 3 shows, as an example, the experimental dependences of the noise factor \( N_n \) and the gain \( K_t \) on the frequency of the microwave signal, which we use in the construction of the OET in the receive tract circuit of the RMC.

The analysis of the received results shows that in the studied frequency range (2 – 18 GHz) the gain changes ranging from minus 22.3 to minus 19.1 dB, and noise factor – from 40.5 to 52 dB. In the frequency band from 12 to 18 GHz, changes in these parameters of the OET are insignificant compared with the total change in the entire frequency band.

![Figure 3. Dependence of the noise factor \( N_n \) (a) and the transfer coefficient \( K_t \) (b) on the frequency of the microwave OET signal at the ambient temperature \( T = 293.4 \text{ K} \).](image)

The experimentally obtained values of \( N_n \) and \( K_t \) of the studied OET are close to the passport data of similar foreign production tracts of the same frequency range, for example, OTS-2 22 GHz [29, 30], PSI-1601-20L [31]. If we take into account the fact that in some cases the microwave signal must be transmitted over distances of more than 200 m, then these characteristics, considering that its attenuation in the fiber are not more than 0.0001 dB/m [29-34], are quite acceptable.

![Figure 4. 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 \( T = 293 \text{ K} \). Graph 1 corresponds to the brand of cable SF 240, graph 2 - SF 229, graph 3 - SF 404, graph 4 - SF 406.](image)
For comparison, figure 4 presents data on one of the best foreign models of microwave cable brands SUCOFLEX (SF) with low losses. The attenuation in an SF 406 cable at a frequency of 18 GHz is about 0.5 dB/m. With a cable length of 100 m - attenuation will be more than 50 dB.

With use of the received results and chosen based on the conducted researches, ratios (1) and (2) the values of sensitivity and detection range were calculated using the OET and microwave cable in the receiving tract.

It should be noted that, in accordance with accepted methods, the results of calculations for all types of path using a microwave cable are obtained on the basis of a cable length of 1 m. In the calculations in (1), the value $q = 13$ dB. These calculations are presented in table 3.

### Table 3. The results of the calculation of sensitivity and detection range for various designs of the receiving tracts (OET and microwave tract type).

| Tract type          | Option of circuit | Sensitivity, dB (W) | Detection range, km |
|---------------------|-------------------|---------------------|---------------------|
| broadband           | fig. 1.a          | -47.4               | -85.5               |
| $\Delta f = 16$ GHz | fig. 1.b          | -36.4               | -84.9               |
| narrowband          | fig. 2.a          | -62.4               | -99.8               |
| $\Delta f = 0.5$ GHz| fig. 2.b          | -51.4               | -99.3               |
|                     | fig. 2.c          | -61.4               | -96.0               |

Analysis of the results presented in Table 3 allows us to draw a number of conclusions that were not previously established. Depending on the place of inclusion of the OET into the receiving path, the insertion loss in the entire system transmitting the microwave signal is different. In addition, we have established that the losses additionally depend on the gains and noise factors of other elements of the receiving path, which also vary slightly with different inclusions in the presence of the OET. Therefore, it is directly difficult to evaluate the attenuation introduced by the OET. Accordingly, in the case of such a review, it is difficult to assess the need to use fiber optic links in specific receiver circuits.

Therefore, to assess the validity of the use of the OET in RMC, we propose to use the equivalent length of the microwave cable $L$, at which the sensitivity and detection range values will be the same as when used in the receive tract of RMC of the OET. Results of calculation $L$ for various schemes inclusions of OET are presented in table 4.

### Table 4. Characteristic of a path in the equivalent length of microwave cable $L$.

| Tract type          | Option of circuit | $L$, m |
|---------------------|-------------------|--------|
| broadband           | fig. 1.a          | 86.9   |
| $\Delta f = 16$ GHz | fig. 1.b          | 80.9   |
| narrowband          | fig. 2.a          | 75.2   |
| $\Delta f = 0.5$ GHz| fig. 2.b          | 80.0   |
|                     | fig. 2.c          | 81.1   |

The obtained results show that in the case of using the components considered by us for building the OET. It is more expedient to use these tracts compared to a microwave cable over distances of more than 90 m, if there are no sharp bends and difficulties in laying a microwave cable, as well as a powerful background noise of various genus [20, 21, 31-33].

Studies have shown that the use of the MA with built-in amplifiers (preamplifier and output amplifier) reduces the noise factor and increases the gain. But in the aggregate, this leads to a smaller equivalent length of the microwave cable $L$.

### 4. Conclusion

The obtained experimental results of the study of the characteristics of the OET with different ways of its inclusion in the receiving tract allowed us to make comparisons of the sensitivity of the RMC using FOCL and microwave cable. For typical options for constructing a receiving channel RMC calculated
the maximum value of the length of the microwave cable, above which it is advisable to use fiber optic links.

It should also be noted that recent developments [20, 32] in the field of the modernization of the parameters of the OET (K_{OET}=13 dB and N_{OET} =4 dB) show a high potential for their use for the transmission of microwave signals. With such parameters, the equivalent cable length, depending on the operating conditions, is reduced to 2–8 m. This takes the possibility of using the OET system to a new qualitative level.

5. References

[1] Likhachev V P and Pasmurov A Ya 1999 Journal of Communication Technology and Electronics 44(3) 275-280
[2] Bykov V V, Dushkin A V, Kupryashkin I F and Likhachev V P 2005 Radiotekhnika 7 85-87
[3] Mel’nikov Yu P 2000 Radiotechnika 9 27-32
[4] Podstrigaev A S, Smolyakov A V, Davydov V V, Myazin N S and Slobodyan M G 2018 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11118 LNCS 509-515
[5] Lenets, V A, Taraseenko M Yu, Davydov V V, Rodygina N S and Moroz A V 2018 Journal of Physics: Conference Series 1038 (1) 012037
[6] Mashkov G, Borisov E and Fokin G A 2016 Proceedings International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications 7849572 7-12
[7] Mashkov G, Borisov E and Fokin G A 2017 Proceedings 19th International Conference on Advanced Communications Technology 7890254 979-984
[8] Podstrigaev A S, Ryazantsiev L B and Lukashev V P 2016 Measurement Techniques 59(5) 547-550
[9] Podstrigaev A S 2014 Proceedings 24th International Crimean Conference Microwave and Telecommunication Technology 6959682 896-897
[10] Podstrigaev A S, Davydov R V, Rud’ V Yu and Davydov V V 2018 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11118 LNCS 624-630
[11] Davydov R V, Saveliev I V, Lenets V A, Taraseenko M Yu, Yalunina T R, Davydov V V and Rud’ V Yu 2017 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10531 LNCS 177-183
[12] Taraseenko M Yu, Davydov V V, Sharova N V, Lenets V A and Yalunina T R 2017 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10531 LNCS 227-232
[13] Lukashev N A, Petrov A A, Davydov V V, Grebenikova N M and Valov A P 2018 Proceedings of 18th International conference of Laser Optics 8435889 271
[14] Petrov A A, Davydov V V and Grebenikova N M 2018 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11118 LNCS 641-648
[15] Petrov A A, Davydov V V and Myazin N S 2017 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10531 LNCS 561-568
[16] Myazin N S, Smirnov K J, Davydov V V and Logunov S E 2017 Journal of Physics: Conference Series 929(1) 012080
[17] Rykin E V, Moroz A V, Smirnov K J, Davydov V V and Yushkova V V 2018 MATEC Web of Conference 245 12002
[18] Davydov V V, Kruzhalov S V, Grebenikova N M and Smirnov K J 2018 Measurement Techniques 61 365-372
[19] Davydov R V, Antonov V I and Moroz A V 2018 Proceedings of the IEEE International Conference on Electrical Engineering and Photonics 8564378 236-239
[20] Fadeenko V V, Kuts V A, Vasiliev D A and Davydov V V 2018 Journal Physics: Conference Series 1135(1) 012053
[21] Ivanov S I, Lavrov A P and Saenko I I 2016 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 9870 LNCS 670-679
[22] Burdin V A and Bourdine A V 2017 Simulation of a long-haul fiber optic link with a two-mode optical fiber Computer Optics 41(4) 489-493 DOI: 10.18287/2412-6179-2017-41-4-489-493
[23] Gavrilov A V and Pavlyev V S 2017 Integrated fiber-based transverse mode converter Computer Optics 41(4) 510-514 DOI: 10.18287/2412-6179-2017-41-4-510-514
[24] Kutluyarova R V, Sultanov A H and Bagmanov V H 2014 Reduction of wdm-transmission nonlinear impairments due to polarization mode dispersion Computer Optics 38(4) 737-742
[25] Soifer V A, Kotlyar V V and Doskolovich L L 2009 Diffractive optical elements in nanophotonics devices Computer Optics 33(4) 352-368
[26] Soifer V A 2008 Nanophotonics and diffractive optics Computer Optics 32(2) 110-118
[27] Kupryashkin I F and Likhachev V P 2004 Izvestiya Vysshikh Uchebnykh Zavedenii, Radioelektronika 47(9) 62-57
[28] Belkin M E and Sigov A S 2009 Communications Technology and Electronics 54 655-658
[29] Kotov O I, Chapalo I E and Petrov A V 2016 Technical Physics Letters 42(1) 11-14
[30] Kotov O I, Chapalo I E and Medvedev A V 2014 Technical Physics Letters 40(6) 509-512
[31] Davydov V V, Sharova N V, Fedorova E N, Gilshteyn E P, Malanin K Y, Fedotov I V, Vologdin V A and Karseev A Yu 2015 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 9247 712-721
[32] Bisyarin M A, Kotov O I, Hatong A H, Liokumovich L B and Ushakov N A 2017 Applied Optics 56(2) 354-364
[33] Davydov V V, Karseev A Yu, Nepomnyashchay E K, Petrov A A and Velichko E N 2014 Lecture Notes in Computer Science (Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 8638 694-702
[34] Ermolaev A N, Krishpents G P, Davydov V V and Vysochkiy M G 2016 Journal of Physics: Conference Series 741(1) 012171