Usage of the antenna array for radio communication in locomotive engines in Russian Railways

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Abstract. The paper presents the realization of the antenna array for arranging the digital communication in the locomotives of Russian Railways. The provided approach allows setting up steady digital communication without expensive updating of the current technique at the substations. The antenna array described in the article has a gain coefficient from 17dB to 18dB at 150MHz. The paper analyzes the data of possible application of digital standards of data transfer without significant modernization of base-load stations used in Russian Railways.

1. Introduction

The warrant of the usage of digital radio communication in Russian Railways was issued in 2010 (5 February 2010 No. 26), but the switch to the digital standard is not a prompt action. We have two reasons for it - a wide rolling stock and a huge multiple circuit in Russia. But gradually, digital radio communication is spreading by means of purpose-oriented programs of the Russian Federation and by the means of the program of rolling stock modernization.

Digital radio communication will allow one to transfer voice and codograms as well as data and telemetry traffic. Besides, remote control over locomotive subsystems will be available. It will give an opportunity to get to a whole new level of information technique in Russian Railways and raise the security of the infrastructure of the rolling stock.

In Russian Railways, the changeover to a digital communication is realized by the similar ways as the changeover to the digital radio at long waves where analog communication was also applied. In order to preserve the existing infrastructure (and thus to decrease the cost of the implementation of the new standard), a transfer in the digital channels is realized using the same frequencies as in the analog ones. Hence, it helps to avoid a complete replacement of the expensive transmitting equipment. It is only necessary to correct a baseband signal and leave a power amplifier without changing. The digital radio standard must have the same bandwidth (12kHz) as the analog standard.

2. Advantages of digital communications in the Russian Railways infrastructure and difficulties of its organization

The similar approach is used for Russian Railways though there are some peculiarities. The matter is that the dual-range system is used to connect a locomotive with stations: meter-wavelength (150MHz – 160MHz) and medium wavelength (2MHz). The changeover to the digital standard will be realized only at the meter wavelength, the medium wavelength remains analog. We have chosen the DMR digital standard. It supports the required functional and operates with 12kHz bandwidth channels (as in
the analog mode). Thus, we must organize digital radio at the same frequencies as the former standard.

The radio station for the locomotive is an information system which receives data and provides voice communications with subexchange and can handle the components of the locomotive using Ethernet and CAN. Besides, the receiver for GLONASS positioning is embedded in the radio station.

Digital standards allow increasing the information capacity of the locomotive quite safely. But the application of the digital standards of the data transmission without complex reconstruction of a base-load station can lead to certain difficulties. The fact is that analog communication is realized even at a small signal-to-noise ratio. It results in the strong noise background, but it is possible to make out the voice because of a good selectivity of a human ear. The situation is different with the digital channel. Voice transmission keeps distinct up to the certain level of a signal-to-noise ratio and then terminates when the modem cannot correct a large number of errors [1]. That is why, it is necessary to improve receiving but at the same time to keep as much of the installed equipment as possible.

3. Analysis of usage of digital standards without complex reconstruction of base-load stations

It was offered to increase the gain of the locomotive antenna. Thus, the antenna is the same because the construction has been fine-tuned. The gain is achieved by means of simultaneous usage of several antennas and creating the directed transmitting-receiving system. The unit cells of this system are utilized antennas AL/23 which have good mechanical characteristics. In the horizontal plane, the antenna has a diagram close to the circle diagram with a 78-degree angle.

Let us examine the system of two antennas located at the distance of $\lambda/2$ with circle diagram patterns as an example. For this two-component system, the normalized directivity coefficient is equal to [2]:

$$f(\theta) = \cos \left( \frac{\pi}{2} \cos(\theta) \right)$$

(1)

The plot gain versus the bearing angle is shown in Figure 1.

![Figure 1](image.png)

Figure 1. The gain factor of the system of two cophasal components (system 1)

Figure 1 shows that maximum gain is achieved in the direction orthogonal to the line of antennas connection. If we place these components along the locomotive than the maximum amplification is attained in the direction orthogonal to the train’s movement and it is zero in the line with the train’s movement. Thus, this method can be used for the angles in the range of (60;120) degrees. The maximum normalized gain is equal to 1 at 90 degrees, the minimum one is equal to 0.7071 at 60(120) degrees.

We need to alter the phase of one of the antennas to 90 degrees in case the directivity is in line with the locomotive movement. Then, the normalized directivity coefficient is estimated as:
\[ f(\theta) = \sin\left(\frac{\pi}{2} \cdot \cos(\theta)\right) \]  

Figure 2 shows the plot gain versus the bearing angle of this system.

**Figure 2.** The gain factor of the system of two 90-degree shifted components (system 2).

For this system, an absolute gain is achieved in the direction of locomotive moving. In the direction orthogonal to the locomotive moving it is equal to zero. This system can be used for the angles in the range of (-60; +60) degrees.

Thus, this is the system with the normalized gain from 1 to 0.7071 at any angle. There are possible variants of the usage of system 1 (cophased system) and system 2 (90-degree-shifted) in the table below.

| Angle range, degrees | Applied system |
|----------------------|----------------|
| 0 – 60               | System 2       |
| 60-120               | System 1       |
| 120-240              | System 2       |
| 240-300              | System 1       |
| 300-360              | System 2       |

The general direction pattern for this system is shown in Figure 3.
It is necessary to use several antennas disposed at the distance of \( \lambda/2 \) in order to receive higher amplification levels. The length of the locomotive engines used in Russian Railways does not exceed 18 meters. If carrier frequency is 150MHz, then the distance between antennas is 1 meter. Hence, seventeen antennas can be arranged along the locomotive. These antennas will make system 1 or system 2 as it was demonstrated in the example for two elements. If we deal with system 2, then every second element will be 90-degree phase-shifted.

Let us examine system 1 and find its amplification and a beamwidth (by power -3dB).

The beamwidth of the antenna array at the 0.7071 level in the azimuth plane is estimated by the following approximation formula [3]:

\[
2 \cdot Q_\alpha \approx 51 \cdot \frac{\lambda}{N_{\alpha} \cdot d} = 51 \cdot \frac{2}{17 \cdot 1} = 6^\circ
\]  

So the antenna system has a narrow directional pattern and therefore a good gain coefficient:

\[
K \approx \frac{180 \cdot 180}{Q_{\alpha} \cdot Q_{\beta}} = \frac{180 \cdot 180}{6 \cdot 78} = 69
\]  

Hereby, the maximum gain coefficient of our system in the direction orthogonal to the train’s movement is equal to 69 or 18dB.

The directional pattern of the introduced antenna in case of the direction orthogonal to the train’s movement is presented in Figure 4.
4. Conclusion

For the proper operation of the communication system, it is important to know where the beam of the arranged antenna system must be directed. GLONASS positioning in the locomotive and in the railway map is used for these purposes. When a train is moving on the railway, the angle between the traffic route and the station with the combined antenna is estimated. When the angle has been calculated, then the phased receiving system is adjusted so that the beam points to the station. It will allow increasing the signal-to-noise ratio of the receiving system and thus to realize steady digital communication of the locomotive with the station. So there is no need to change the amplification system at the station what results in the decreasing of the costs of the implementation of digital-speech communication in Russian Railways.

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