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Improving the reliability of data transmission on the communication line spacecraft–ground tracking station: intermittent emission mode

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Received September 25, 2024
Revised October 24, 2024
Accepted October 27, 2024

The dependence of the reliability of data reception under conditions of tropospheric lognormal amplitude fluctuations of millimeter radio waves on the line "spacecraft–ground tracking station" on the threshold level in the intermittent radiation mode with coherent signal reception is considered. It is shown that with a fixed energy of the bit of the signal from the output of the transmitting device, a monotonic decrease in the probability of erroneous data reception is ensured depending on the threshold level.

Keywords: tropospheric channel, millimeter waves, dispersion, Fraunhofer diffraction, lognormal amplitude fluctuations, intermittent communication, radio line usage coefficient.

DOI: 10.61011/TPL.2025.02.60642.20131

As it was previously shown [1,2], using the millimeter range and increasing the radio signal bandwidth significantly increases the speed of wireless data transmission in ground-space radio interferometry on the spacecraft.ground tracking station line. Implementing the intermittent emission mode can enhance the noise immunity of transmitted messages. In [3] the dependence of error probability reduction on the signal-to-noise ratio (SNR) at the threshold level γ_t), normalized to the average value of SNR (γ_0) ($q = \gamma_t/\gamma_0$). In practice, however, there are situations where the average SNR varies a little, such as in Lagrangian point transmission ($L2$), where the distance from the spacecraft to the ground tracking station varies slowly.

In this case, analyzing the noise immunity of data transmission from q at a fixed symbol energy of the signal at the transmitter output is relevant and of significant scientific and practical interest.

In this paper, the probability density of the envelope distribution of the millimeter-wave signal in the turbulent troposphere channel is characterized by a lognormal law [2] due to small dispersion values (less than one).

Let us determine the SNR value at the receiver input for the distance from the spacecraft at the Lagrangian point ($L2$) to the ground tracking station ($1.75 \cdot 10^9$ m). The diameters of the transmit and receive antennas are 2.2 and 15 m, their surface efficiency factors are 0.5 and 0.95, respectively. Using the basic radio-communication equation [1] with these parameters, we obtain that the signal power at the receiver input equal $6.186 \cdot 10^{-10}$ W.

The noise temperature of the receiving system includes the antenna noise and the receiver's own noise.

The noise temperature of antenna, in turn, also includes:

— atmospheric noise, which at a characteristic antenna elevation angle of 30° is approximately 97 K [4] in the E-band (Fig. 1);

— the noise of cosmic microwave background radiation with a temperature of about 3 K;

— the Planck correction for the $h\nu/k$, temperature, which at the $\nu = 80$ GHz frequency is 3.8 K (h and k — the Planck and Boltzmann constants, respectively).

Thus, the total noise temperature of the antenna will be 103.8 K.

The intrinsic noise temperature of the uncooled receiver (∼ 300 K) taking into account the losses due to overexposure by the antenna mirror horn (∼ 0.49 dB), losses in the antenna path (∼ 0.1 dB) and the receiver noise figure of 0.6 dB [5] will be 94.77 K.

Thus, the total noise temperature of the T_{sys} receiving system is found to be 198.57 K.

The noise power at the receiver input with a total E-band signal bandwidth of 10 GHz (5 GHz at segment 71–76 GHz and 5 GHz at segment 81–86 GHz) will be $3.334 \cdot 10^{-11}$ W.

Then the SNR at the receiver input will be 8.8 dB with the following values of additional parameters:

— required power reserve to compensate for fluctuations in the signal level 3 dB;

— maximum signal attenuation in the troposphere 1.7 dB at an inclined range of 20 km, antenna position angle $\theta = 30°$ and tropospheric attenuation at zenith 0.85 dB [6].

Fig. 2 shows the dependences of signal reception error probabilities on the normalized threshold level q at a fixed signal symbol energy at the transmitter output and different dispersion values, obtained according to the expression

$$P_e(q) = \left[\frac{1}{4\eta(q)\sqrt{2\pi\sigma_\chi^2}}\right] \int\limits_{q\gamma_0}^{\infty} \frac{1}{\gamma} \times \exp\left[-\frac{\left(\ln\sqrt{\frac{\gamma}{\gamma_0}} + \sigma_\chi^2\right)^2}{2\sigma_\chi^2}\right] \operatorname{erfc}\sqrt{\alpha\gamma}\, d\gamma, \quad (1)$$

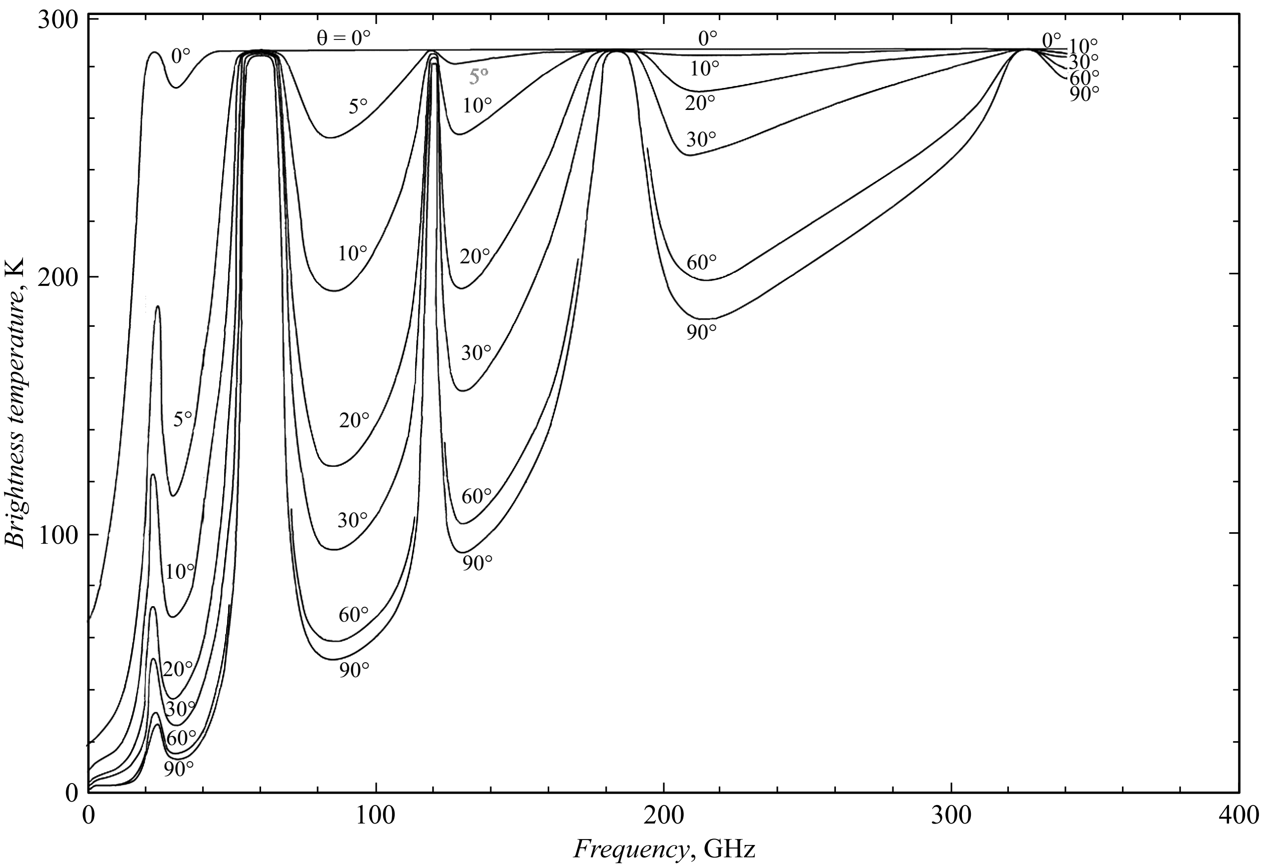

Figure 1. The brightness temperature of the atmosphere as a function of frequency at different antenna site angles [4].

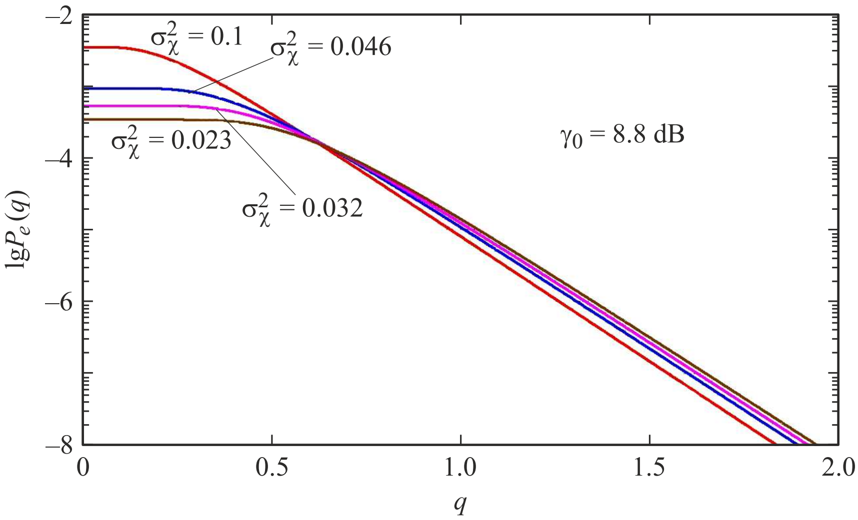

Figure 2. Signal reception error probabilities in intermittent emission mode as a function of the normalized threshold level q at constant symbol energy of the signal at the transmitter output and different dispersion values σ_χ^2.

where $\alpha = 1$ for phase-manipulated signals [7].

The analytic expression (1) is obtained by averaging the error probability in Gaussian noise ($0.5\mathrm{erfc}\sqrt{\alpha\gamma}$) in the lognormal fluctuation statistics [2] for threshold levels above $q\gamma_0$. In formula (1) and Fig. 2, the value of $\gamma_0 = 8.8\,\mathrm{dB}$ corresponds to the average value of the SNR in the absence of intermittent communication.

From Fig. 2, it follows that at $q \approx 1.31$ the error probability decreases to values less than 10^{-5}. However, in this case, the radio link utilization factor [3] is no more than $\eta(q) = 0.23$, and the data transmission time is reduced by more than 4 times.

To implement a high-performance scenario in the considered communication channel [3], it is necessary to increase the instantaneous data rate inversely proportional to changes in $\eta(q)$. In this case, the duration of the signal symbol is reduced proportionally to $\eta(q)$ and in order to preserve its energy, the transmission power must be increased inversely proportional to this factor. At the same time, the energy of the signal symbol from the transmitter output remains unchanged and under more favorable conditions of signal propagation (increasing the threshold level), the symbol energy at the receiver input and the SNR increase, and the error probability decreases in accordance with (1) (Fig. 2).

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Translated by J.Savelyeva