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Optimization of the threshold level in the intermittent emission mode according to the criterion of the minimum probability of erroneous data reception on the communication line „spacecraft–ground tracking station“

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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 reception of signals is considered. An estimate of the optimal threshold level of the transmitting device is made according to the criterion of the minimum probability of error. It is shown that at the estimated level not only the minimum probability of errors in the received data is ensured, but also the energy requirements for the transmitter are reduced. The presented results can be used in the practical implementation of effective broadband communication channels „spacecraft–ground tracking station“ in the mm range.

Keywords: tropospheric channel, millimeter waves, lognormal amplitude fluctuations, intermittent communication, radio link utilization factor, optimal threshold level, transmitter energy consumption.

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As shown in [1], the intermittent data transmission mode over a wireless communication channel with a fixed energy of the signal symbol at the transmitter output allows monotonously reducing the probability of erroneous data reception at the output of the demodulator.

Also, as described in [2,3], the use of the millimeter range significantly increases the speed of wireless data transmission in ground-space radio interferometry on the spacecraft –ground tracking station line. In the following paper [4] the dependence of error probability reduction is obtained on the signal-to-noise ratio (SNR) at the threshold level (γ_t), normalized to the average value of SNR (γ_0): $q = \gamma_t/\gamma_0$. It should be noted that the coefficient of radio line use (η) depends only on q and does not depend on γ_0 [1]. The probability density of the envelope distribution of the millimeter-wave signal in the turbulent troposphere channel is characterized by a lognormal law [3] due to small dispersion values (less than one).

In contrast to [1], the present work provides a theoretical analysis of the dependence of the error probability for coherent data reception on the normalized threshold level at constant transmitter power, when the energy of the signal symbol at the transmitter output varies with a change of γ_t.

In [2] it was shown that the signal power at the receiver input for the distance from the spacecraft (in Lagrange point L_2) to the ground tracking station is $6.186 \cdot 10^{-10}$ W.

With account of the atmospheric noise 97 K at the specific antenna elevation angle 30° [1,5] and the noise coefficient of receiver 0.6 dB [1,6] SNR at the receiver output would make 8.8 dB at the following values of the 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 elevation angle $\varphi = 30°$ and tropospheric attenuation at zenith 0.85 dB [7]. The common signal band in E-range in this case will be 10 GHz (5 GHz in segment 71–76 GHz and 5 GHz in segment 81–86 GHz).

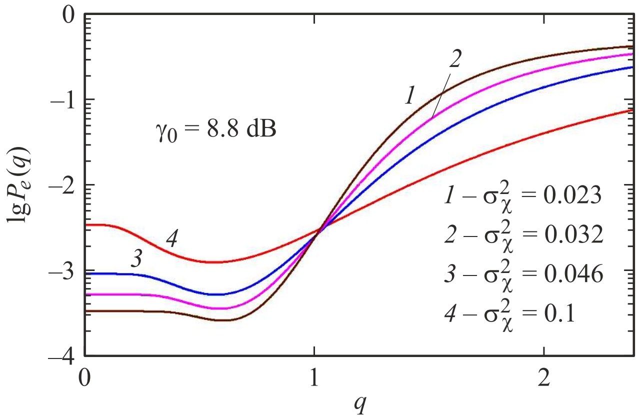
The figure shows the dependences of signal reception error probabilities on the normalized threshold level (q) at a fixed signal power at the transmitter output and at different dispersion values, obtained according to the expression

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

where $\alpha = 1$ for phase-manipulated signals [8].

The analytic expression (1) is obtained by averaging the error probability in Gaussian noise ($0.5\operatorname{erfc}\sqrt{\alpha\gamma}$) in the lognormal fluctuation statistics [3] for threshold levels above $q\gamma_0\eta(q)$. The value of $\gamma_0 = 8.8$ dB accepted in (1) and accordingly in the figure corresponds to the average value of the SNR in the absence of intermittent communication.

To maintain the average transmission speed, it is necessary to increase the instant speed of transmission in inverse



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

proportion to the coefficient of radio line use $(\eta(q))$ [1]. Besides, the energy consumption of the transmitter due to its intermittent operation reduces in direct proportion to $\eta(q)$.

Increased level of the threshold provides for more favorable conditions of data transmission. Therefore, at the fixed power, despite the lower energy of the signal at the transmitter output with the reduced duration of the signal symbol, the SNR at the receiver input increases, and the error probability decreases. As the threshold level increases further, the balance will be achieved, when the favorable conditions will not be able to compensate the reduction in the signal symbol energy, the duration of which continues decreasing. At a certain value of the threshold, the optimal (minimum) value of the error probability is achieved (see figure). The SNR at the receiver input reaches the maximum and is not increasing further. Despite the favorable transmission conditions, further increase of the threshold level as a result of further decrease of the signal symbol energy provides for decrease of the SNR at the receiver input and increase in the error probability up to the value of 0.5.

Use of the intermittent data transmission algorithm at the fixed power of the transmitter in the tropospheric channel with log-normal fluctuations of the signal levels makes it possible to determine the optimal level of the normalized threshold (q_{opt}) by the criterion of minimization of erroneous data reception probability.

The obtained estimate of the optimal normalized threshold provides for the minimum error probability, despite the reduced energy consumption by the transmitter — the relevant factor for the autonomous scientific systems in the conditions of far space and deficit of the project energy resource. The energy consumption of the transmitter decreases with an increase of the normalized threshold q.

In the cases under consideration, providing a fixed transmitter power in the environmental conditions of deep space ensures high reliability of uninterrupted operation of the transmitting devices.

Conflict of interest

The authors declare that they have no conflict of interest.

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