Analysis for the Effects of Electromagnetic Emission from Stationary Plasma Thrusters on Interference Immunity of the "Earth-SC" Communication Channel

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Abstract: A consideration is given to the mathematical and simulation models for the analysis of effects of self electromagnetic emission from stationary plasma thrusters (SPT) on the immunity characteristics of the digital communication channel "Earth-SC". The area of analytical model application is analyzed, and the use of the simulation modeling method is substantiated. Primary modeling principles are described, as well as the structure of simulation models. Results of assessment for the SPT emission influence on the interference immunity of communication channels with different types of digital modulation are presented and analyzed.

SUCCESSFUL application of stationary plasma thrusters (SPT) while solving a broad range of problems in the near and deep space verified their reliability and efficiency. However, in-depth studies for the SPT characteristics and performance testify that some peculiarities of STP operation should be taken into account while integrating such thrusters with spacecraft (SC) and its systems. Thus, according to the analysis for multiple results of experimental studies for the SPT self electromagnetic emission, in addition to the thermal component such emission comprises a broad-band pulsed random process, the spectral density of which is from some tens of kHz to several GHz.[1, 2] Such emission can represent interference for the "Earth-SC" channel of the space communication systems, especially in the case of deep-space communication, and it is necessary to take it into account while designing such systems. In this context, analysis for the action of such electromagnetic interference on the interference immunity of space communication systems becomes a rather urgent problem.

Analysis, systemization and generalization of the known analytical models used for analyzing interference immunity of digital communication systems, with the BPSK modulation for example, under the conditions of combined action of the additive white noise and random pulsed interference are discussed in the publications of Bello P. A., Esposito R.,[3, 4] Spaulding A. D., Middleton D.[5, 6] and of other authors, Ref. 7, 8, for example, in which generalization of the earlier obtained results is presented for the signals with modulation of M-PSK, M-DPSK and QAM types, respectively.

Examination of analytical methods developed to analyze interference immunity of digital communication systems exposed to pulsed interference revealed that the known methods have limited application area that in many cases does not correspond to the parameters of interference emitted by SPT. So, the most part of analytical methods is applicable for $\mu = T_s/\bar{\tau}_p \ll 1$, while some methods can be used with $\mu \gg 1$. Here T_s is the channel symbol duration,

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and $\overline{\tau}_p$ is the average interference pulse duration. Upon that, analytical solutions for the range of μ values from 0.1 up to 10 are absent.[9] In view of this, it is necessary to find new approaches to this problem; for example, development and application of simulation models.

Statement for the problem of assessing the SPT self-emission effect on the quality of data reception

The validity of data transmission in the digital communication systems is usually assessed using such parameters as the Bit Error Rate (BER) that characterizes the probability of incorrect reception of a useful information bit, and the Symbol Error Rate (SER) that describes the probability of incorrect reception of a channel symbol.

Above probabilities depend on many factors: modulation and demodulation methods, type and algorithm of coding and decoding, type and characteristics of interference, etc.

Interference immunity of communication systems is usually described by the energy penalty of the considered system relative to some reference system. By the energy penalty we mean a parameter defining how many times it is necessary to increase the signal-to-noise ratio at the considered system input for its data transmission validity be equal to that of the reference system.

Approach proposed this paper for assessing validity of data transmission in the digital communication systems operating under the influence of the SPT interfering emission is valid for the communication systems with the most common methods of the carrier signal modulation, for example BPSK, QSPK, 8PSK, 16PSK, 16QAM and 64QAM.

General problem statement

Random process $n_{\Sigma}(t)$ describing the SPT emission can be presented as a sum of the random pulsed process (PP) $u_p(t)$ and the thermal white Gaussian noise $n(t)$ [1, 2, 9]:

$$n_{\Sigma}(t) = u_p(t) + n(t)\,. \tag{1}$$

Or in the complex form:

$$\dot{n}_{\Sigma}(t) = \dot{u}_p(t) + \dot{n}(t) = \left(\dot{U}_p(t) + \dot{N}(t)\right)\exp\left(j\omega_0 t\right) \tag{2}$$

Here ω_0 is the spectrum center frequency, $\dot{U}_p(t) = U_{op}(t)\exp\left(j\varphi_{op}(t)\right)$ is the pulsed process complex envelope, $U_{op}(t)$ is the amplitude envelope of the pulse train, $\varphi_{op}(t)$ is the PP total phase characteristic.

In such a case the pulsed process complex envelope can be presented in the following form:

$$\dot{U}_p(t) = \sum_{i=1}^{\infty} u_o(t - \sum_{l=1}^{i} T_{pl})\exp\left(j\left(\varphi_{oi} + \varphi_{opi}(t)\right)\right) \tag{3}$$

Here $u_0(t)$ is a function describing the form of the single train pulse, φ_{oi} is the initial phase shift for each pulse of the pulsed process, $\varphi_{opi}(t)$ is the law of phase variation within the *i*-th pulse of the train. The following effects can be taken into account by such law:

- random variation of the carrier frequency from pulse to pulse,
- random variation of phase within each pulse,
- determinate variation of phase within each pulse, etc.

Specific characteristics of the SPT emission simulation model were defined by processing the results of test measurements for the characteristics of emission from electric propulsion thrusters, such measurements being made under ground conditions. Such models have rather wide range of application, and can be used for validating digital algorithms of signal processing in the space communication systems.

Mathematical model of the SPT emission, modeling procedure and appropriate hardware and software are described in Ref. 10 in more details.

Simulation model of space communication radio system

A specialized software package was developed for the simulation modeling of the communication radio system operation in view of the influence of the SPT self-emission in the radio-frequency range. Such software package allows assessment for the bit error rate during data transmission depending on the signal-to-noise and signal-to-interference ratios for various parameters of pulsed interference.

The developed software package provides simulation modeling of the digital radio system designed for data transmission and secures regard for the action of the SPT self-emission on such system by forming a sample of the complex envelop of a signal simulating pulsed and thermal components of the SPT self-emission.

Such models are developed in the MATLAB/Simulink environment and can be used to assess the SPT emission influence on the interference immunity of communication channels of the following modulation forms: BPSK, QSPK, 8PSK, 16PSK, 16QAM and 64QAM.

Examples of the BER assessment results, which were obtained using the developed simulation models of communication radio systems and simulation models of the SPT emission for the modulation methods BPSK and 8PSK, are presented in Fig. 1 and Fig. 2. The Bit Error Rate is presented as a function of the total signal-to-noise ratio ($h_{bn}^2 = E_b/N_0$), where E_b is the signal energy per a single data signal bit, N_0 is the spectral density of the additive white gaussian noise taking account of both the SPT thermal emission and the receiver noise. The presented dependences are plotted for different values of the signal-to-pulsed interference ratio (h_{bp}^2). Each figure presents four groups of dependences (a, b, c, d) for four values of parameter $\mu = T_s/\overline{\tau}_p$ = (0.1; 1.0; 10; 100), respectively.

It is obvious that with the reduction of level of pulsed interference caused by SPT, the curves tend asymptotically to the theoretical curves obtained for the Gaussian channel. When the signal-to-pulsed interference ratio h_{bp}^2 is reduced, the BER value grows for each fixed signal-to-noise ratio h_{bn}^2. The higher BER relative increase is, the higher is h_{bn}^2.

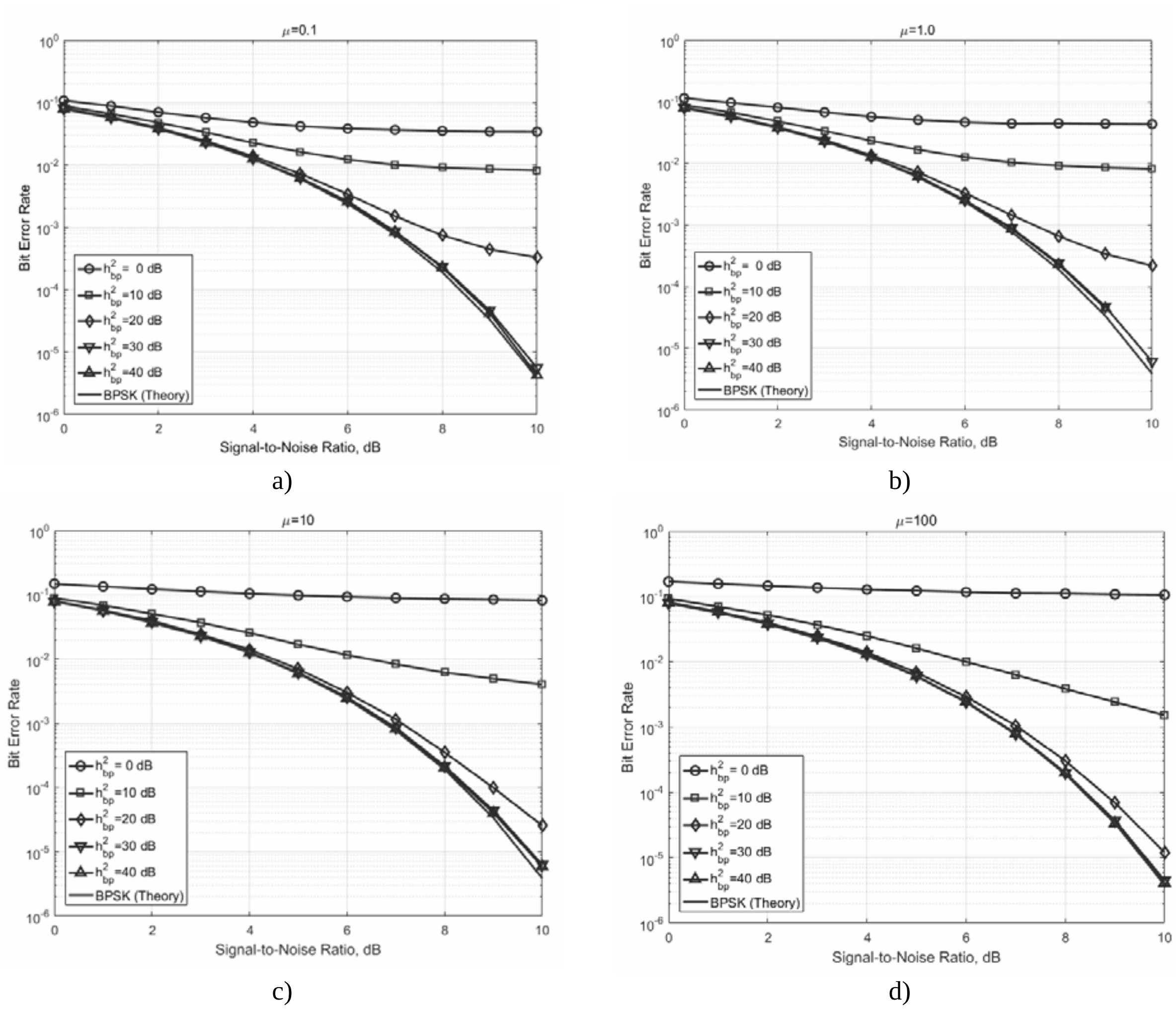

Figure 1. Bit Error Rate for BPSK.

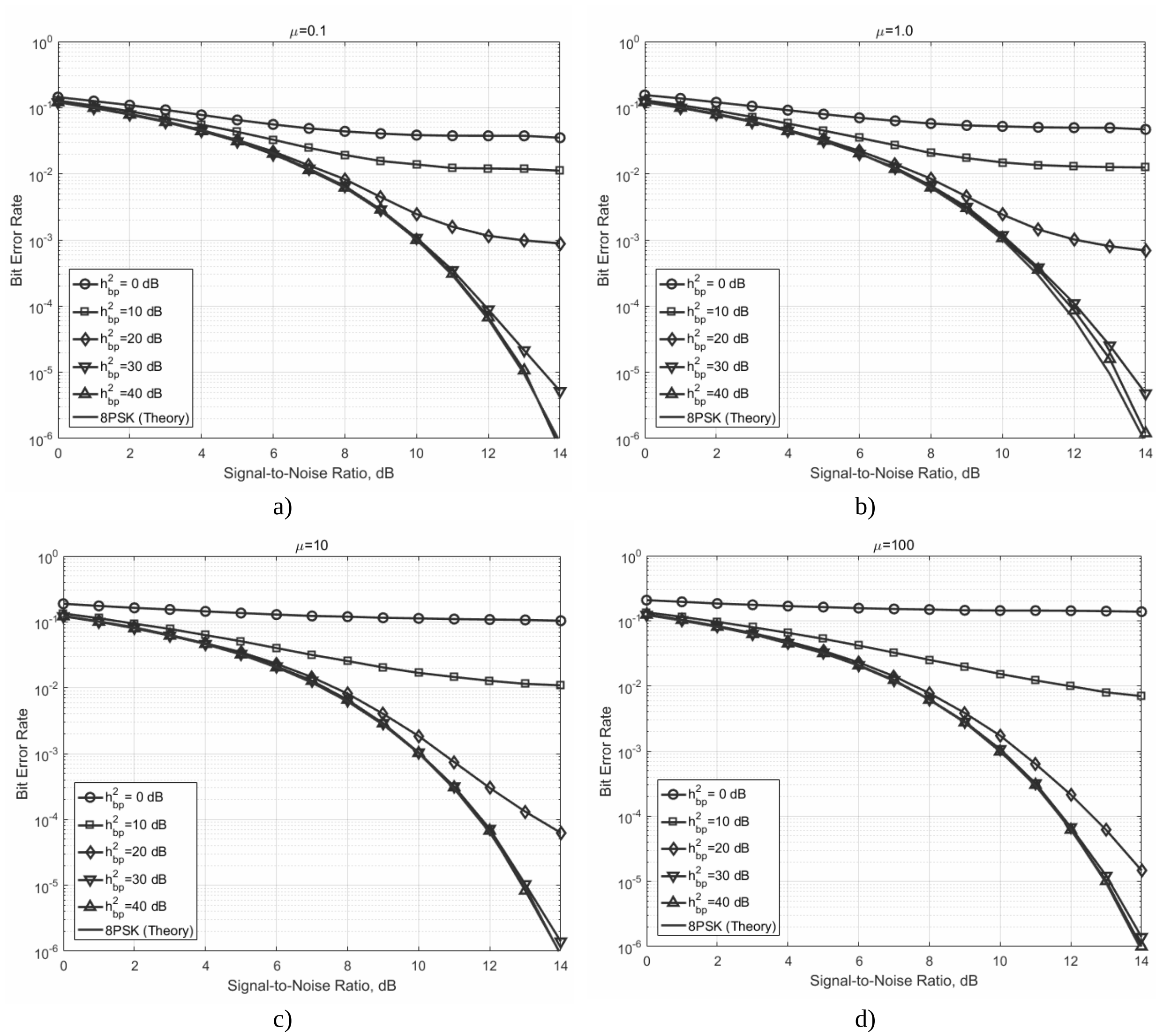

Figure 2. Bit Error Rate for 8PSK.

Fig. 3 and Fig. 4 show variation of energy penalty in dB for a digital radio communication system operating under the influence of SPT emission when compared to a system with the receiver thermal noise as an interference only. Quantitatively, the energy penalty characterizes the factor of the data transmission validity degradation due to the action of interference of the given type.

The lowest energy penalties for the modulation methods BPSK and 8PSK of about 0.1-0.2 dB within the entire considered range of the signal-to-noise ratios take place with the signal-to-pulsed interference ratios of up to 30 dB. While reducing the signal-to-pulsed interference ratio below this value, we observed considerable increase in the energy penalty; and such penalty was higher, the higher current signal-to-noise ratio was.

For the considered examples, the highest energy penalty was recorded for the modulation 8PSK, and depending on the values of signal-to-noise and signal-to-interference ratios it may be as high as 6 dB and over.

According to our analysis, in general case the energy penalty grows with the increase in the number of positions in modulation, for example while changing BPSK to 64QAM. Quantitative value of such penalty is influenced not by the modulation type only, but by the values of signal-to-noise and signal-to-pulsed interference ratios.

For the calculated working values of signal-to-noise and signal-to-interference ratios the curves obtained allow assessment for the noise immunity degradation for a space communication system related to the influence of SPT self-emission in the radio-frequency range, and development of methods for its compensation at every stage of designing.

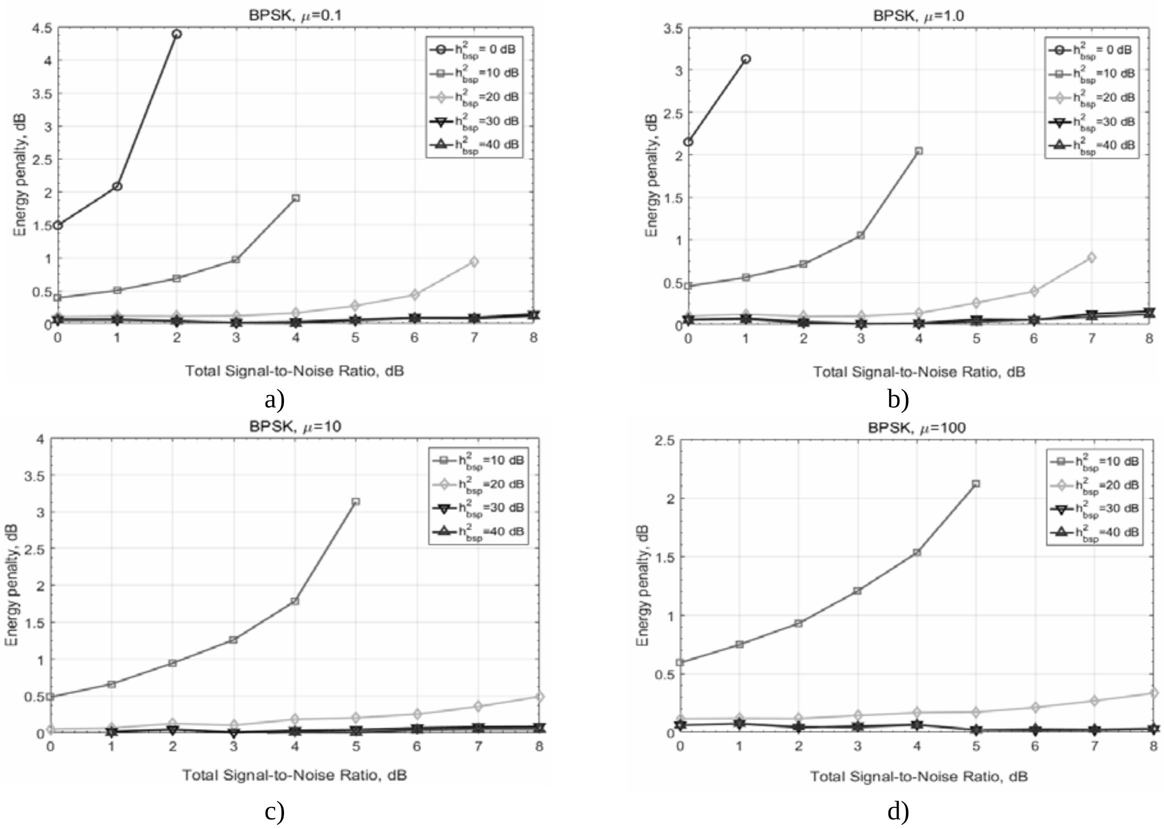

Figure 3. Energy penalty for BPSK.

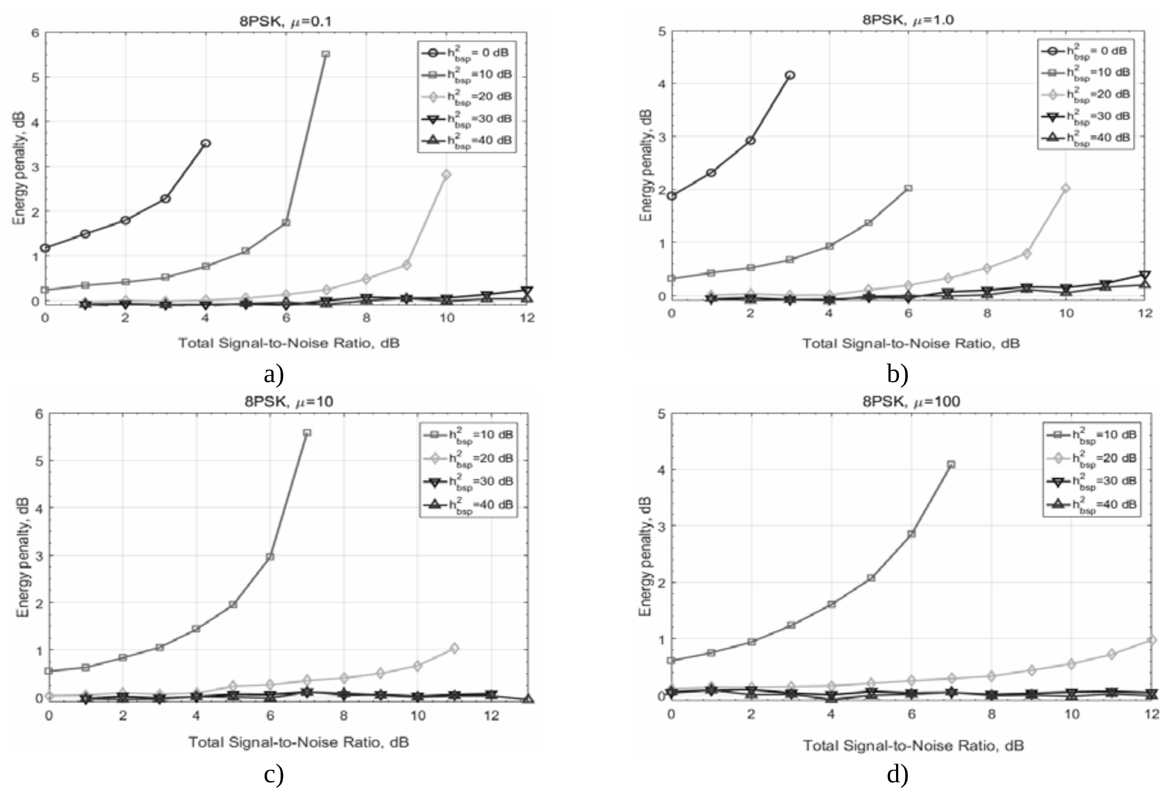

Figure 4. Energy penalty for 8PSK.

Conclusions

1. A mathematical apparatus was developed that is based on representing the SPT emission as a thermal component and a wide-band pulsed random process. A bundled software was developed and simulation modeling was made for the effects of self electromagnetic emission from SPT on the interference immunity of the “Earth-SC” communication channel.

2. According to the results of simulation modeling, the energy penalty caused by the influence of the SPT self-emission in the radio-frequency range, for the modulation methods BPSK and 8PSK varies from some tenth of dB up to 6 dB. The lowest energy penalties of about 0.1-0.2 dB within the entire considered range of the signal-to-noise ratios take place with the signal-to-pulsed interference (from EP) ratios of up to 30 dB. The most essential influence of the SPT self-emission is present within the range of working signal-to noise ratios of about 8…12 dB and signal-to-interference ratios of less than 15-20 dB.

3. The following ways to raise interference immunity of radio links operating under the influence of SPT emission can be proposed: reduction of the SPT emission level in the range of radio link operation by selecting appropriate modes of the SPT operation; selection of SC arrangement (location and orientation of electric propulsion thrusters and receiving antennas); selection of the optimum frequency range for the radio link operation; development and implementation of algorithms for the signal reception and procession that would be stable against the influence of pulsed and thermal emission from SPT; application of methods for pulsed interference suppression in the communication channel, etc.

References

[1]Plokhikh, A., Vazhenin, N., Kim, V., Sidorenko, Ye., Soganova, G., “Study for the Influence of Stationary Plasma Thruster Operating Models on Its Electromagnetic Emission,”. *32nd International Electric Propulsion Conference*. 11-15 September, 2011, Wiesbaden, Germany IEPC-2011-094. 9 p.

[2]Beiting, E. J., Garrett, M. L., Pollard, J. E., Pezet, B., and Gouvernayre, P., “Temporal Characteristics of Radiated Emission from SPT-100 Hall Thrusters in the L, S, and C Bands,” *The 29th International Electric Propulsion Conference*, Princeton University, October 31 -November 4, 2005, IEPC-2005-222.

[3]Bello, P. A., Esposito, R., “A New Method for Calculating Probabilities of Error Due to Impulsive Noise,” *IEEE Trans. on Communication Technology*, v. Com-17, No. 3, 1969, p. 368—378.

[4]Esposito, R., Bello, P. A., “Error Probabilities Due to Impulsive Noise in Linear and Hard-Limited DPSK Systems,”/ *IEEE Trans. on Communication Technology*, v. Com-19, No. 1, 1971, p. 14-20.

[5]Spaulding, A. D., Middleton, D., “Optimum Reception in Impulsive Interference Environment. Coherent Detection,” IEEE *Trans. Commun.*, v. Com-25, No. 9, 1977, Part I: p. 910—923, Part II: p. 924 - 934.

[6]Middleton, D., “Canonical Non-Gaussian Noise Models: Their Implications for Measurement and for Prediction of Receiver Performance,” *IEEE Trans. Electromagn. Compat.*, v. EMC-21, No. 3, 1979, p. 209 - 220.

[7]Huynh, H. T., Fortier, P., Vo, B., “Performance Analysis of M-PSK and M-DPSK in an Electromagnetic Interference Environment,” *IEEE International Symposium on Wireless Communications*, Montréal, May 22-23, 1998.

[8]Miyamoto, S., Katayama, M., Morinaga, N., “Performance Analysis of QAM Systems Under Class A Impulsive Noise Environment,” *IEEE Trans. Electromagn. Compat.*, vol. 37, No. 2, 1995, p. 260–267.

[9]Vazhenin, N., Volkovskiy A. “Interference Immunity of Digital Data Transmission Systems under the Combined Action of Noise and Pulse Interference,” Vestnik *Moskovskogo Aviatsionnogo Instituta (Reporter of the Moscow Aviation Institute)*, No. 6, 2010, v. 17. MAI Publishers, p. 109-119 – in Russian.

[10]Vazhenin, N., Plokhikh, A., “Simulation Modeling for the Radiated Electromagnetic Emission from Stationary Plasma Thrusters,” *Izvestiya Academii Nauk (Proceedings of the Russian Academy of Sciences)*, Energetics, 2014, No. 6, p. 118-131 – in Russian.