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Bit Error Ratio, Caused by Doppler Effect, for Systems of Space Diversity Reception

Mikhail G. Polyak*
Academician M.F. Reshetnev Information Satellite Systems
52 Lenin Str., Zheleznogorsk, 662972, Russia

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Today digital data transmission plays a leading role for satellite systems. However, digital data transmission is possible with errors at demodulation, which cause distortion of transmitting information. Errors of digital data transmission are due to three causes. First cause is a low level of signal to noise ratio. Second cause is Doppler Effect. Third cause is symbol-to-symbol interference conditional multipath propagation. Space diversity reception is effective method of bit error resistance.

Doppler Effect is the most significant for bit error probability at satellite communication. Because satellite move very fast in cosmic space. This article show effective of space diversity reception for decrease of bit error probability, which caused by Doppler Effect.

Keywords: satellite communications, bit error ratio, Doppler Effect, space diversity reception.

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Вероятность ошибки, вызванной явлением Доплера, в системах пространственного разнесенного приема

М.Г. Поляк
АО «Информационные спутниковые системы»
имени академика М.Ф. Решетнева»
Россия, 662972, Железногорск, ул. Ленина, 52

Передача цифровой информации в спутниковых сетях играет в настоящее время ведущую роль. Однако передача цифровой информации вследствие воздействия различных факторов может осуществляться с ошибками при демодуляции, которые приводят к искажению

* Corresponding author E-mail address: mpolyak1502@gmail.com

переданной информации. Ошибки при передаче цифровой информации возникают по трем причинам: падение уровня отношения сигнал/шум сигнала; действие эффекта Доплера, ввиду межсимвольной интерференции, возникающей по причине многолучевого распространения сигнала. Эффективным методом борьбы с ошибками при приеме цифровых сигналов признан разнесенный прием сигнала.
В связи с космическими объектами одним из наиболее важных факторов, влияющих на вероятность ошибки, является доплеровское смещение частоты, вызванное движением космического аппарата. В данной статье показана эффективность разнесенного приема с точки зрения снижения вероятности ошибки на один бит, возникающей вследствие эффекта Доплера.

Ключевые слова: спутниковая связь, вероятность ошибки на бит, эффект Доплера, пространственный разнесенный прием радиосигналов.

Introduction

Today digital data transmission plays a leading role for satellite systems. Digital signals are very popular, because they allow transmit information more precisely and faster than analog signals. However, digital data transmission is possible with errors at demodulation, which cause distortion of transmitting information.

Modern digital data transmission systems have to provide bit error ratio (BER) not less than 10^{-5}. So special algorithms for processing signals and coding are often using today.

Errors of digital data transmission are due to three causes. First cause is a low level of signal to noise ratio (SNR), when signal transmit through noisy or fading communication channel. Second cause is Doppler Effect. Third cause is symbol-to-symbol interference conditional multipath propagation. Space diversity reception is effective method of bit error resistance.

Doppler Effect is the most significant for bit error probability at satellite communication. Because satellite move very fast in cosmic space. This article show effective of space diversity reception for decrease of bit error probability, which caused by Doppler Effect.

1. Influence of Doppler Effect on bit error ratio for systems of one and two antennas reception

Doppler effect is very significant for BER especially for low-orbiting satellite systems. For example, if satellite rotates on 700 km circular orbit, then its speed is near 7.5 km/s. Time appearance of these satellites is very limited. Satellite's speed is maximal when satellite to turn up horizon. In this moment its Doppler translation is ultimate. If signal frequency is 1.6 GHz, then maximum Doppler translation is near 7 kHz. Thus signal spectrum shift from nominal value. Nominal value of frequency is generated local heterodyne. Demodulation errors eventuate, in view of the fact that carrier received signal frequency is not equal nominal frequency of local heterodyne.

Today systems of automatic frequency control are very popular for decrease BER caused by Doppler effect. But these systems have lags, which forbid completely except errors. Space diversity reception allow except errors especially when Doppler translation is small. In this case diversity reception allows decrease error probability in two degrees. For example, BER may be decrease from 10^{-8} to 10^{-16}, sub verbo.

BER, caused by Doppler effect, for DBPSK evaluate by using formula [1-3]:

$$P = \frac{\rho_0 \cdot \left(1 - J_0\left(2 \cdot \pi \cdot f_d \cdot T\right)\right)}{2 \cdot \left(\rho_0 + 1\right)}, \tag{1}$$

here ρ_0 – mean SNR; f_d [Hz] – maximum value of Doppler frequency shift; $J_0\left(2 \cdot \pi \cdot f_d \cdot T\right)$ – correlation function in-phased and antiphased components of complex process shifted on T, which is in Gaussian channel. Correlation function is nought-order Bessel function [4]; T [s] – bit duration and delay period of demodulation DBPSK signal.

Diversity reception may be in frequency, in polarization, in angel, in time and in space [1, 5]. Frequency diversity reception and time diversity reception apply for navigation systems, but it require additional frequency band or limit amount of transmitted information. Polarization diversity reception requires two received antennas or have additional loss on 3 dB. Space diversity reception is more beneficent and efficient method of diversity reception. Signals from different diversities antennas are not correlated if between antennas distance is near several wave length.

BER, caused by Doppler effect, for two antennas reception of DBPSK signals evaluate by using formula [1-3]:

$$P = 0{,}25 \cdot \left[1 - J_0\left(2 \cdot \pi \cdot f_d \cdot T\right)\right]^2 \cdot \left[2 + J_0\left(2 \cdot \pi \cdot f_d \cdot T\right)\right]. \tag{2}$$

Fig. 1 demonstrated block diagram of one antenna DBPSK receiver. Fig. 2 demonstrated block diagram of two antennas DBPSK receiver [1, 5].

Research influence of Doppler effect on BER with a different value of Doppler translation and information rate.

2. Research of influence of Doppler effect on bit error ratio

Plot graph of dependence BER from Doppler translation. In case SNR equal 10, information rate equal 32 kb/s and 32 mb/s.

Carry out analyze of obtained dependence. In case small Doppler translation space diversity reception allow decrease error probability in two degreases from 10^{-8} to 10^{-16}. However if value of

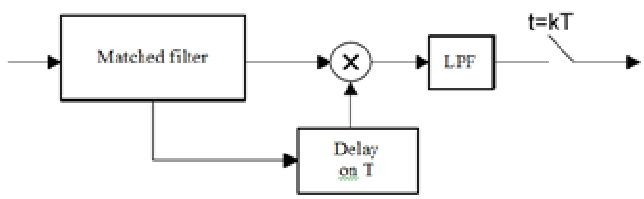

Fig. 1. Block diagram of one antenna DBPSK receiver

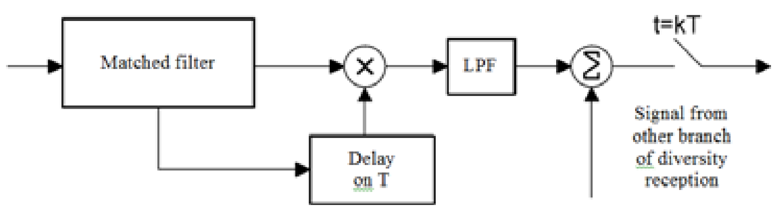

Fig. 2. Block diagram of two antennas DBPSK receiver

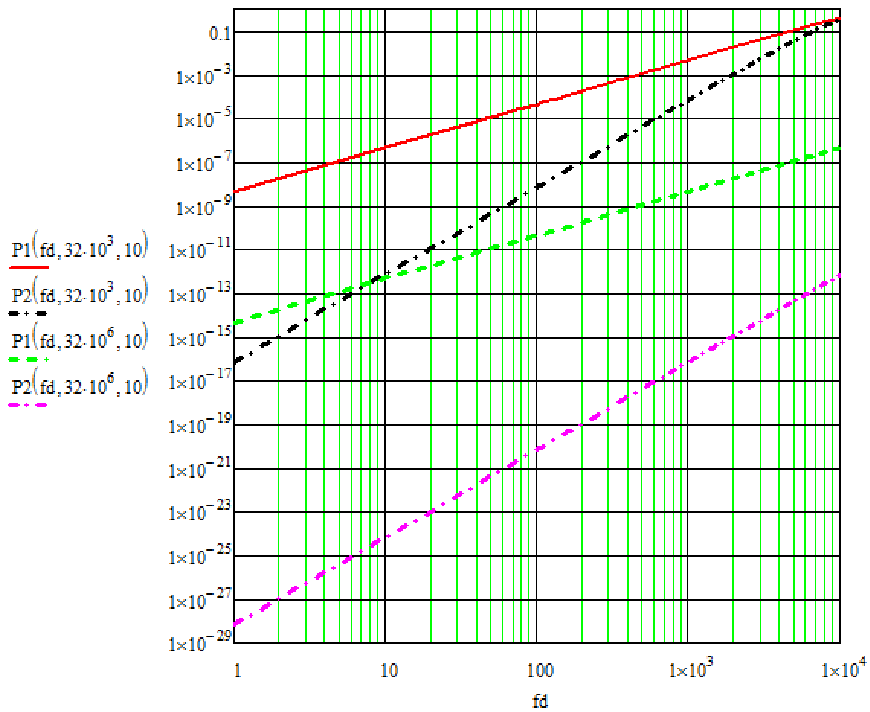

Fig. 3. Dependence bit error ratio from Doppler translation

Doppler translation will be increased, then efficiency of diversity reception will be decreased. For example, in case value of Doppler translation equal 1 kHz and information rate equal 32 kb/s BER will be decreased less in two degrees; and if value of Doppler translation equal 7 kHz BER will be decreased in 1.5. Besides, the faster information rate got the smaller BER, caused by Doppler effect. For example, in case one antenna receiving for information rate 32 kb/s and 32 mb/s BER decrease on 6 degreases, and in case two antennas receiving for information rate 32 kb/s and 32 mb/s BER decrease on 12 degreases.

3. Averaging of influence of Doppler effect on bit error ratio for receiving low-orbiting satellite's signals

For research efficiency of space diversity reception going to average influence of Doppler effect with different information rates. Going to average of momentary value of Doppler translation.

Value of Doppler translation:

$$f_d = \frac{\upsilon_r}{\lambda}, \qquad (3)$$

here $\lambda = \dfrac{c}{f}$ [m] – wave length; c [m/s] – light speed; υ_r [m/s] – radial velocity of satellite to land.

Research momentary value of radial velocity of satellite to land using Fig. 4.

Duration of communication session depend from duration time of line of sight of satellite on horizon line. Radial velocity of satellite is maximal at the moment of satellite appearance. Radial velocity of satellite equal nought at the moment of flight vertical relative to land obtainer (dot "O").

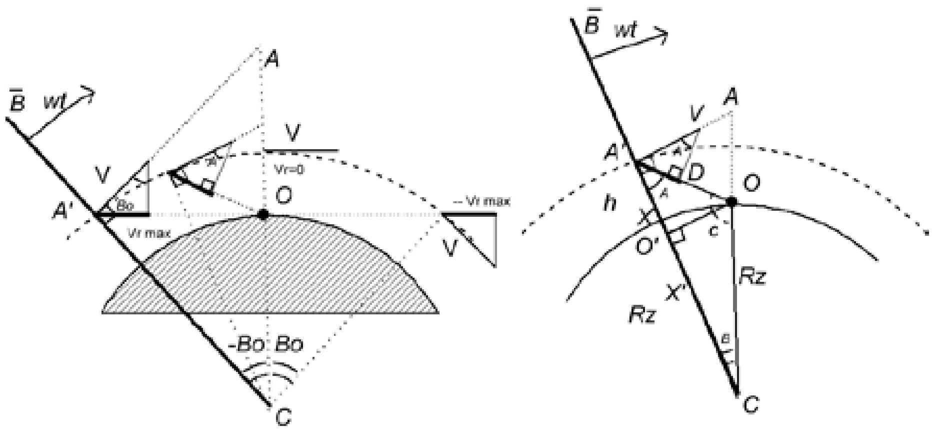

Fig. 4. Research of momentary value of radial velocity

Angle and duration time of line of sight of satellite on horizon line depend from satellite orbit height [6]:

$$\beta_0 = \arccos \frac{Rz \cdot \cos(\alpha_{\min})}{Rz + h} - \alpha_{\min}, \tag{4}$$

here Rz = 6371 [km] – earth radius; h = 700 [km] – satellite orbit height; $\alpha_{\min}$ [rad] – minimal operating angle.

$$\Delta t = \frac{2 \cdot \beta_0}{\omega}, \tag{5}$$

here $\omega = \frac{V}{Rz + h}$ [rad/s] – angular velocity of satellite motion.

Orbital velocity of satellite motion [km/s]:

$$V = \sqrt{\frac{G \cdot Mz}{Rz + h}} = 7,523, \tag{6}$$

here $Mz = 5{,}972 \cdot 10^{24}$ [kg] – earth mass; $G = 6{,}67 \cdot 10^{-11}$ [$m^3\ kg^{-1}\ s^{-2}$] – gravitation constant.

In accord Fig. 4 moment value of radial velocity of satellite motion define by angle *A*. Which is angle between vertical line and satellite direction.

$$\upsilon_r = V \cdot \sin(A), \tag{7}$$

Get analytical dependence for define angle *A* from that:

1) Direction of satellite velocity is perpendicular for direction to earth center (point C) ∠AA'C = $\pi/2$;

2) Direction from earth center to satellite (vector *B*) have uniform angular velocity;

3) Angle *B* move from $-\beta_0$ to β_0.

Initiate reasoning:

1) Angle *A* belong to triangle A'VD, when ∠VA'D= $\pi/2 - A$.

2) Angle ∠ AA'C = *π/2* consist from angles ∠VA'D+∠CA'D. Result from that ∠CA'D = *π/2* – ∠VA'D= *π/2* – *π/2* + *A*= *A*.

3) Define angle *A* =∠CA'D=∠CA'O dependence from angle $B=-B_0+\omega t$.

4) We know two sides CA', CO of triangle CA'O and angle between their sides *B*=∠A'CO. Therefore definition of angle *A* is possible. For that divide triangle on two right-angled triangles CO'O и A'O'O by plot perpendicular O'O.

5) Length of O'O depend from sine of angle *B*: O'O=$Rz \sin(B)=Rz \sin(-B_0+\omega t)$.

6) Length of side CA' equal *Rz*+*h*. Point O' divide side CA' on two parts: A'O' having length X and CO' having length *X'*. Side CO' depend from cosine of angle *B*: $X'=Rz \cos(B)=Rz \cos(-B_0+\omega t)$.

7) Therefore CO'=$X=Rz + h - X'=Rz + h - Rz\cos(-B_0+\omega t)$.

8) Therefore angle *A*=∠O'A'O define arctangent division side O'O on CO':

$$A = \operatorname{arc}tg\left[\frac{O'O}{A'O'}\right] = \operatorname{arc}tg\left[\frac{Rz\cdot sin(-B_0+\omega\cdot t)}{Rz+h-Rz\cdot cos(-B_0+\omega\cdot t)}\right]. \tag{8}$$

Use formulas (7) and (8) for definition of radial velocity of satellite motion subject to time. In view of the fact that additional Doppler frequency shift more nought, when satellite appear on horizon line, and $\sin(-B_0)$ less nought, work in multiply (-1):

$$\upsilon_r(t) = V\cdot(-1)\cdot\sin\left[\operatorname{arc}tg\left[\frac{Rz\cdot\sin(-B_0+\omega\cdot t)}{Rz+h-Rz\cdot cos(-B_0+\omega\cdot t)}\right]\right]. \tag{9}$$

Plot the graph radial velocity of satellite dependence on time (9), using $\alpha_{\min} = 3\frac{\pi}{180}$ [rad] and getting β_0 = 0,399 [rad], Δt = 750,41 [s], $\omega = 1{,}064 \cdot 10^{-3}$ [rad/s].

Average of influence of Doppler effect on BER for session timeout by using formula (9). Average BER get as integral on formulas (1) or (2) according to one and two antennas, in place of Doppler frequency shift use formula (3), in place of radial velocity use formula (9), getting expression average to time:

$$P1 = \frac{1}{\Delta t}\int_0^{\Delta t}\frac{\rho_0\cdot\left(1-J_0\left(2\cdot\pi\cdot\frac{V\cdot(-1)\cdot\sin\left[\operatorname{arc}tg\left[\frac{Rz\cdot\sin(-B_0+\omega\cdot t)}{Rz+h-Rz\cdot cos(-B_0+\omega\cdot t)}\right]\right]}{\lambda}\cdot T\right)\right)}{2\cdot(\rho_0+1)}dt, \tag{10}$$

$$P2 = \frac{1}{\Delta t}\int_0^{\Delta t}\begin{array}{l}0{,}25\cdot\left[1-J_0\left(2\cdot\pi\cdot\frac{V\cdot(-1)\cdot\sin\left[\operatorname{arc}tg\left[\frac{Rz\cdot\sin(-B_0+\omega\cdot t)}{Rz+h-Rz\cdot cos(-B_0+\omega\cdot t)}\right]\right]}{\lambda}\cdot T\right)\right]^2\\ \cdot\left[2+J_0\left(2\cdot\pi\cdot\frac{V\cdot(-1)\cdot\sin\left[\operatorname{arc}tg\left[\frac{Rz\cdot\sin(-B_0+\omega\cdot t)}{Rz+h-Rz\cdot cos(-B_0+\omega\cdot t)}\right]\right]}{\lambda}\cdot T\right)\right]dt\end{array}. \tag{11}$$

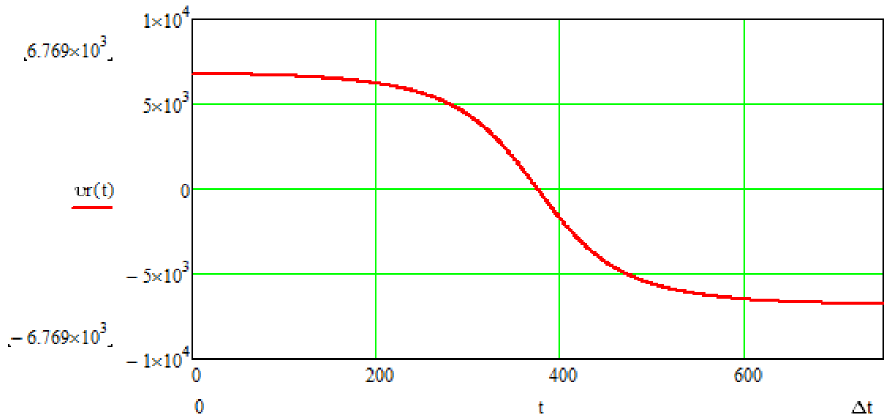

Fig. 5. The graph of the radial velocity of the satellite

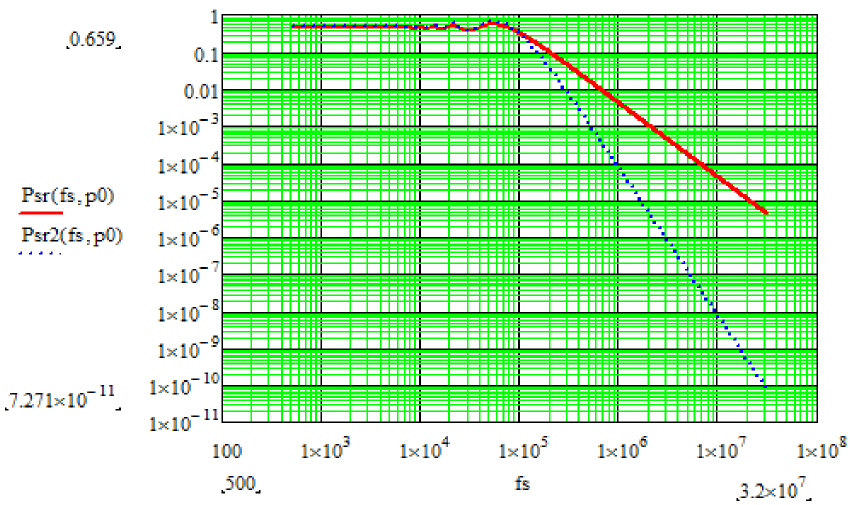

Fig. 6. Average bit error ratio dependence on information rate for one or two antennas receiving

Plot the graph average BER dependence on information rate $f_S = \frac{1}{T}$ on formulas (10), (11).

Carry out analyze of obtained dependence. In case information rate equal 1 mb/s space diversity reception allow decrease average BER in two degreases from 10^{-2} to 10^{-4}. And in case information rate equal 32 mb/s space diversity reception allow decrease average BER in two degreases from 10^{-5} to 10^{-10}.

Summary and Conclusions

Doppler effect increases number of errors at demodulation. In this paper consider efficiency of decreases number of errors at demodulation by using system of space diversity reception. For example of advantage was taken low-orbiting satellite communication system. Satellite orbit height was taken 700 km, type of signal modulation was taken DBPSK.

Fig. 3 was showing by using formula (1) and (2) that space diversity reception allow decrease BER in two degrees from 10^{-8} to 10^{-16} for small value of Doppler frequency shift. And if value of Doppler translation equal 7 kHz BER will be decreased in 1.5.

Besides in this paper was average influence of Doppler effect on BER for session timeout and was getting formulas (10) and (11). In case information rate equal 32 mb/s space diversity reception allow decrease average BER in two degreases from 10^{-5} to 10^{-10}.

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