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The Method of Determining the Speed of a Spacecraft in a Low Earth Orbit Personal Satellite Communication Systems

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***Abstract*—The paper considers a method for determining the velocity of the satellite for mobile satellite communication systems at the Low Earth Orbit (LEO). The analysis of errors in determining the velocity of the satellite motion, assess the potential accuracy of the measurement method discussed satellite velocity.**

Keywords—Low Earth Orbit (LEO), Doppler shift, satellite velocity

I. Introduction

In the implementation of missions for the spacecraft important task is to measure the performance of its movement. On the basis of the coordinates and velocity vector components at different times, a determination of the orbit of the spacecraft and its prediction motion required for control and management communications.

It is known that for the determination of the velocity vector is necessary to measure its three components. The greatest precision in the application of this method is achieved when the radius-vectors are crossed at right angles. Thus measuring devices form an equilateral triangle, the apex of which is at a height, the value of which is a $1/\sqrt{6}$ on the distance between the measuring devices. Table 1 and Fig. 1 shows that the only for LEO can be the determination of spacecraft velocity with high accuracy with positioned measurers on the Earth within a coverage area.

Determination of the satellite velocity is particularly relevant for LEO (h = 700 ... 1500 km), where the velocity of the earth relative to the objects is large enough and can lead to significant errors that may not be sufficient to control tasks and performance targets [1].

The personal satellite communication systems (Globaltar, Iridium) for communication with subscribers used the satellites with a multi-beam antenna system based on AESA [2]. Such multi-beam antenna systems allow to arrange on the ground service area diameter of up to 5 thousand kilometers formed independent beams number reaches 48. This beamwidth of each beam is approximately 20° [3].

TABLE I. The optimal distance for different types of orbits

Orbit	System	Height, km	Distance, km
LEO	Iridium, Gonets, Globalstar	780…1410	1912…3456
MEO	GPS, GLONASS	18840…20180	46176…49460
GEO, HEO	Molniya	36000…40000	88235…98039

Given these features of, it is possible to determine the satellite velocity through concurrent measurement of the Doppler frequency shift in the subscriber channels using the user terminals. The transmitted frequency will be different from the received frequency:

$$f_d = f_0 \, v_r / c,$$

where f_0 – operating frequency, c – light velocity, a v_r – radial velocity (between the transmitter and receiver).

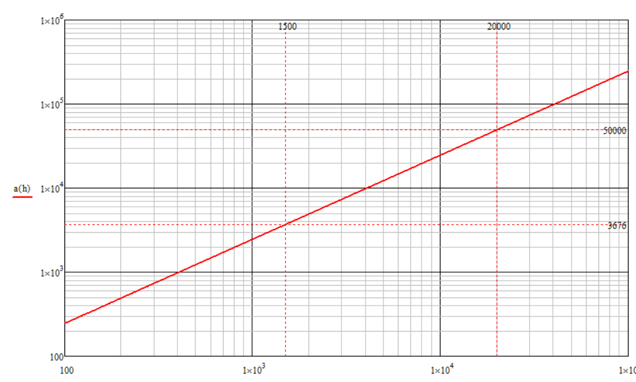

Fig. 1. The optimal distance from orbit altitude

Carry out potential estimation accuracy for determination of the velocity of such a method, taking into account the effect of possible errors.

II. DETERMINATION OF THE VELOCITY VECTOR

In the general case to assess the accuracy of the determination of the velocity vector, used methods similar to the methods of serving the definition position of the object. The accuracy of determining the position and velocity of an object in space depends on the combination of the types of measuring devices, measurement errors and location measurement means relative to the object.

So when evaluating the accuracy of the determination of the velocity vector in the space is necessary find the relationship between the components of the error vector δV and three non-coplanar components of the vector object's velocity **V**, measurable electronic methods.

With regard to the problem of determining the velocity of the spacecraft, we assume that its movement is carried out only in a horizontal direction ($V_z = 0$) and the problem reduces to finding the value and direction of the velocity vector **V** on the plane. Since the calculated value of the velocity vector is determined by the point of intersection of lines perpendicular to the radial component of the two R_1 and R_2.

Destinations of the velocity vector **V** and radial directions are relative to one of the coordinate axes and angles α_V, α_1, α_2. At the same time the existing errors of measurement of radial velocities δV_{R1} and δV_{R2} give rise to errors resulting values of the velocity vector, which is determined by the segment OV* (Fig.2).

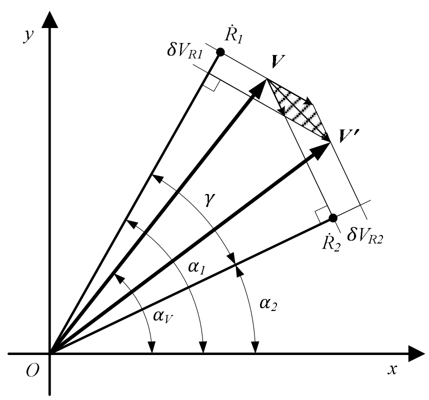

Fig. 2. Impact of the radial components measurement errors

After considering the parallelogram of the velocity vector errors can be found projection error vector **VV'** on δV_x axes and δV_y, which constitute:

$$\delta V_x = \frac{\delta V_{R1}}{\sin\gamma}\cos\left(\alpha_2 - \frac{\pi}{2}\right) - \frac{\delta V_{R2}}{\sin\gamma}\cos\left(\alpha_1 + \frac{\pi}{2}\right),$$

$$\delta V_y = \frac{\delta V_{R1}}{\sin\gamma}\sin\left(\alpha_2 - \frac{\pi}{2}\right) + \frac{\delta V_{R2}}{\sin\gamma}\sin\left(\alpha_1 + \frac{\pi}{2}\right).$$

In addition to these errors due to inaccurate measuring the radial components, resulting in the accuracy of the velocity vector is also influenced and errors caused inaccurate determination of the direction of the object (Fig.3). At the same error in determining the angle of lead to the rejection of the line VR δα direction at an angle, and the emergence of a linear error, which is

$$V\sin(\alpha_V - \alpha)\delta\alpha = V_t\delta\alpha,$$

here V_t – the tangential component of the velocity vector.

Thus, the linear error in a direction corresponding side of the parallelogram errors increases in 1/sin(γ) times. Given this factor, the final expression for the errors in the direction of axes X and Y (1):

$$\delta V_x = \frac{\delta V_R + V\sin(\alpha_V - \alpha)\delta\alpha}{\sin\gamma}\cdot\left[\cos\left(\alpha_2 - \frac{\pi}{2}\right) - \cos\left(\alpha_1 + \frac{\pi}{2}\right)\right],$$

$$\delta V_y = \frac{\delta V_R + V\sin(\alpha_V - \alpha)\delta\alpha}{\sin\gamma}\cdot\left[\sin\left(\alpha_2 - \frac{\pi}{2}\right) + \sin\left(\alpha_1 + \frac{\pi}{2}\right)\right].$$

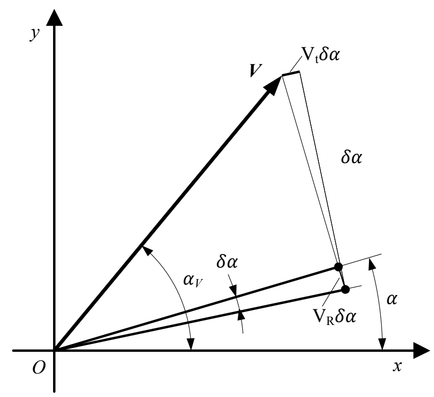

Fig. 3. Impact of the directions measurement errors

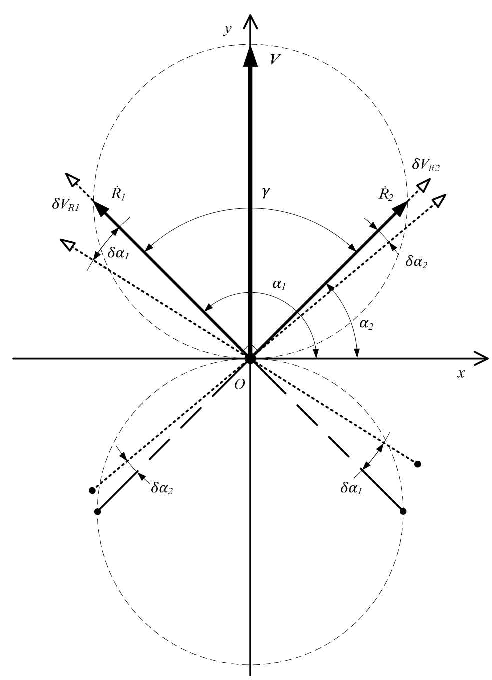

Fig. 4. Measurement of velocity components for errors

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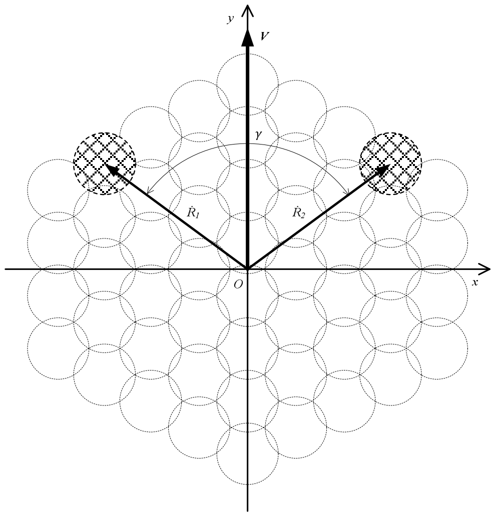

Fig. 5. Measurement of velocity components in selected areas

III. Simulation Results and Analysis

The results of evaluation of accuracy are presented in Fig. 6 and Fig. 7. In calculating the error of measurement accepted of the radial components $\delta V_{R1} = \delta V_{R2} = 1\%$, and the error direction is half the width of the radiation pattern $\delta\alpha = 10°$.

The Fig. 6 shows that the highest accuracy in determining velocity (both axes), corresponds to the case when the radius-vectors intersect at right angles.

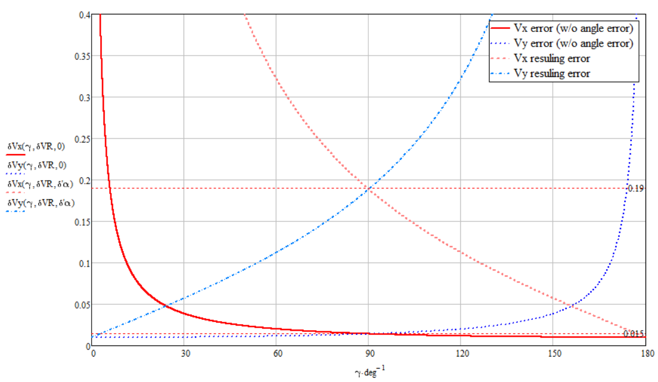

Fig. 6. Velocity error in the direction of the coordinate axes from the intersection angle of measurement directions

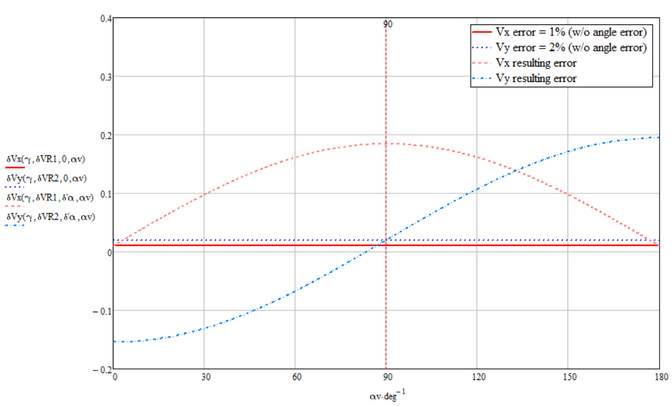

Fig. 7. Velocity error in the direction of the coordinate axes from true direction of the vector velocity

At the same time a significant proportion of errors makes the error due to inaccurate measurement of the direction that tends to decrease with a decrease in the angle between the direction of measurement (γ=90°) and the true direction of the vector velocity of the spacecraft (Fig.7).

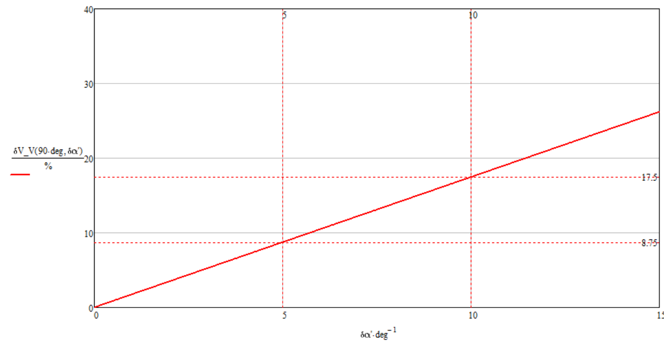

Fig. 8. Dependence of velocity measurement error from beamwidth

In order to study the possibilities to increase the accuracy of this method was plotted relative speed measurement error when you change the width of the beam pattern diagram. The Fig. 8 that the error caused by inaccurate determination of the direction of the measurements, a linear relationship.

IV. Conclusion

The assessment of potential accuracy considered method showed that the resulting accuracy of the satellite velocity vector impact primarily errors due to inaccurate determination of the direction of satellite-user terminal.

To reduce this uncertainty, the uncertainty caused by the radiation source position of the subscriber in the beam, it is possible to take a number of measures, among which are the following:

- reduction of the width of the pattern of the beam, with the general increase in their number to save the service area size;

- use of subscriber location data obtained on the basis of navigation systems (GPS, GLONASS);

- methods based on other measurements and process redundant information;

- combining the methods above.

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