Direction Finding in Satellite Systems

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In article the method allowing to determine coordinates of a source a radio emission located on a terrestrial surface in satellite systems with use of the geostationary satellite is stated.

Keywords: determination of coordinates, radio emission source, satellite systems, difference of phases

Introduction

In satellite technologies the problem determination of coordinates a source a radio emission (SRE) which can settle down both on Earth surface, and on the aero-space carrier [1] is actual.

Method determination of location SRE

For measurement of coordinates the SRE (corners α and β in topocentric system of coordinates, Fig. 1), Bg located in a point the phase radio direction finder established onboard a communication...
artificial satellite (ASE), has to have two couples antennas 1-2 and 3-4 with mutually perpendicular bases. Shift of phases between E.D.S., induced in antennas 1-2 and 3-4, [2]:

\[
\Delta \psi_{1-2} = \frac{2 \cdot \pi \cdot d}{v} \cdot \sin \alpha \cdot \cos \beta, \quad \Delta \psi_{3-4} = \frac{2 \cdot \pi \cdot d}{v} \cdot \cos \alpha \cdot \cos \beta \quad (1)
\]

Where: \(d\) – base of antennas 1-2 and 3-4; \(v\) – length of a wave an accepted signal.

Corners \(\alpha\) and \(\beta\) from (1):

\[
\alpha = \arctg \frac{\Delta \psi_{1-2}}{\Delta \psi_{3-4}}, \quad \beta = \arccos \frac{v}{2 \cdot \pi \cdot d} \cdot \sqrt{\Delta \psi_{1-2}^2 + \Delta \psi_{3-4}^2}. \quad (2)
\]

Having placed an antenna arrays on a geostationary ASE it is possible to define the direction on SRE concerning an ASE [3 … 6]. For determination of coordinates SRE it is necessary to calculate its coordinates in geocentric system of coordinates taking into account ellipticity of Earth.

For calculation of required width and longitude of a source signal we will address to Fig. 2 [7]. Transition to the geocentric demands modification of expressions (2) therefore corners \(\alpha\) and \(\beta\) pay off on formulas from topocentric system of coordinates:

\[
\alpha = \arctg \frac{\Delta \psi_{3-4}}{\Delta \psi_{1-2}}, \quad \beta = \arcsin \frac{v}{2 \cdot \pi \cdot d} \cdot \sqrt{\Delta \psi_{3-4}^2 + \Delta \psi_{1-2}^2}. \quad (3)
\]

Here \(\alpha = 90 - \alpha\); \(\beta = 90 - \beta\).

The point \(D_0\) lies in the plane of the equator and is the projection of a point \(B_0\). The angle \(\varphi\) of the triangle \(B_0OD_0\) is the breadth of the signal source. The longitude \(\lambda\) of the signal source is \(\lambda = \lambda_{\text{sp}} + \lambda_s\), where \(\lambda_s\) – angle triangle \(C_0OD_0\); \(\lambda_{\text{sp}}\) – longitude of the satellite. If the satellite is on the Greenwich Meridian, \(\lambda_{\text{sp}}=0\). The point \(C_0\) on the line \(R1\) is a projection of a point \(D_0\) on the meridional plane. Note that \(R1=42253,135\) km [8].

To determine \(\lambda_s\) refer to the section of the Earth meridional plane (Fig. 3b). In the triangle \(K_0ON_0\) angle \(\alpha\) is calculated according to the formula

Segment \(K_0N_0\) is perpendicular to the plane of the equator. Required in this triangle is the n-end. Fig. 3a shows the plane spheroid with minor radius \(n\), at an angle \(\alpha\) to the plane of the equator. Semi-minor axis \(n\) intersects the plane of a triangle \(B_0AO\) at the same angle \(\alpha\) to the plane of the equator. In...
The point $g_D$ lies in the plane of the equator and is the projection of a point $g_B$. The angle $\phi$ of the triangle $ggODB$ is the breadth of the signal source. The longitude $\lambda$ of the signal source is $g_{sp} \lambda + \lambda = \lambda$, where $g\lambda$ – angle triangle $ggODC$; $sp\lambda$ - longitude of the satellite. If the satellite is on the Greenwich Meridian, $sp\lambda = 0$. The point $g_C$ on the line $R_1$ is a projection of a point $g_D$ on the meridional plane. Note that $R_1 = 42253.135$ km [8].

To determine $g_\lambda$ refer to the section of the Earth meridional plane (Fig. 3b). In the triangle $ggONK$ angle $\alpha$ is calculated according to the formula

\[
\text{Fig. 3. Additional geometric constructions to calculate the coordinates of SRE with regard to the ellipticity of the Earth}
\]

Segment $gg NK$ is perpendicular to the plane of the equator. Required in this triangle is the n-end. Fig. 3a shows the plane spheroid with minor radius $n$, at an angle $\alpha$ to the plane of the equator. Semi-minor axis $n$ intersects the plane of a triangle $AOBg$ at the same angle $\alpha$ to the plane of the equator. In the triangle $AOBg$ angle $\beta$ is calculated according to the formula (3). The required Fig. 3a is a $gR$ party in the triangle $AOBg$.

Calculation of latitude $\phi$ and longitude $\lambda$ includes the following 7 stages.

1. Is the point of intersection (Fig. 3b) minor axis $n$ and arc spheroid, the solution of systems of two equations

\[
\begin{align*}
-q_k r_1 q_k & = \alpha, \\
-q_k r_2 q_k & = \alpha,
\end{align*}
\]

where the first equation describes the minor axis, and the second is arc of a spheroid. The solution (4) has two roots

\[
2221 + \cdot = \alpha, 2222 + \cdot - = \alpha
\]

the triangle $B_gAO$ angle $\beta$ is calculated according to the formula (3). The required Fig. 3a is a $R_g$ party in the triangle $B_gAO$.

Calculation of latitude $\varphi$ and longitude $\lambda$ includes the following 7 stages.
1. Is the point of intersection (Fig. 3b) minor axis n and arc spheroid, the solution of systems of two equations

\[ k = q \cdot \tan \alpha \]
\[ k = r \cdot \sqrt{1 - \frac{a^2}{R^2}}. \]  
(4)

where the first equation describes the minor axis, and the second is arc of a spheroid.

The solution (4) has two roots

\[ q_1 = r \cdot R \cdot \sqrt{1 - \frac{1}{\tan^2 \alpha \cdot R^2 + r^2}}, \quad q_2 = -r \cdot R \cdot \sqrt{1 - \frac{1}{\tan^2 \alpha \cdot R^2 + r^2}}. \]  
(5)

Further used only positive root, since a negative value belongs to the opposite part of a spheroid.

Substituted \( q_1 \) in any of the equations (4), we obtain the value of \( K \). The semiminor axis \( n \) of a right triangle \( K_{g}O_{g}n_{g} \) is equal to:

\[ n = \sqrt{k^2 + q_1^2}. \]  
(6)

2. Is the point of intersection (Fig. 3a) direct \( R_l \), which is given by the equation \( a_g = \tan(R_l - f_g) \) and arc spheroid by solving the system of two equations:

\[ a_g = \tan(R_l - f_g) \]
\[ a_g = n \cdot \sqrt{1 - \frac{f_g^2}{R^2}}. \]  
(7)

Solution of the quadratic equation

\[ \left( \frac{\tan^2 \beta + \frac{n^2}{R^2}}{R^2} \right) \cdot f_{g1}^2 - 2 \cdot R_l \cdot \tan^2 \beta \cdot f_{g1} + \left( \tan^2 \beta \cdot R_l^2 - n^2 \right) = 0, \]  
(8)

are the two roots \( f_{g1} \) and \( f_{g2} \)

\[ f_{g1} = \frac{2 \cdot R_l \cdot \tan^2 \beta + \sqrt{D}}{2 \cdot (\tan^2 \beta + \frac{n^2}{R^2})}, \quad f_{g2} = \frac{2 \cdot R_l \cdot \tan^2 \beta - \sqrt{D}}{2 \cdot (\tan^2 \beta + \frac{n^2}{R^2})}, \]  
(9)

where \( D = (2 \cdot R_l \cdot \tan^2 \beta)^2 - 4 \cdot (\tan^2 \beta + \frac{n^2}{R^2}) \cdot (\tan^2 \beta \cdot R_l^2 - n^2) \).

From Fig. 3a and (9) follows that, in further calculations will need the root \( f_{g1} \) meaning equal side \( OC_g \). Substituting \( f_{g1} \) into any equation of system (7), we obtain the value of the side \( a_{g1} \), then from a right-angled triangle \( B_gOC_g \) we find \( R_{g1} \):

\[ R_{g1} = \sqrt{a_{g1}^2 + f_{g1}^2}. \]  
(10)

3. From right-angled triangle \( B_gC_gD_g \) (Fig. 2) we find \( o_g \):

\[ o_g = a_{g1} \cdot \sin \alpha. \]  
(11)

4. From right-angled triangle \( B_gOD_g \) we find latitude \( \phi \) of SRE:

\[ \phi = 658 \]
Thus, the described technique relying on use onboard the spacecraft of an antenna arrays, allows to solve a problem determination of coordinates of the Source a radio emission.

Conclusion


References