Using GLONASS for precise determination of navigation parameters under interference from various sources

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Abstract. This article discusses the main approaches to the designs of systems for determining location and spatial attitude based on satellite navigation equipment. The article describes possible solutions for constructing an angular attitude measurement system capable of spatial interference selection on the basis of a single antenna system.

Keywords: object angular attitude, phased antenna array, interference stability, GLONASS, algorithms and equipment of broadband interference suppression

1. Introduction

Modern signal receivers utilized in global satellite radionavigation systems have one significant drawback – low immunity to interference. The modernization of existing receivers by reducing the bandwidths of their tracking systems, integral tracking of a full set of signals from navigation satellites at all frequency bands, narrowband filtering of (in the limit – harmonic) interferences, providing direct entry into the synchronization with a high precision GLONASS signal (this is effective against narrowband interference), and other methods enable the operation of navigation equipment with an interference to signal relation at input of the receiving antenna at no more than 60 – 65 dB. Further improvements to interference immunity for navigation equipment (to a level of 80 – 85 dB) are possible only with the application of spatial methods to resist interference.

Nowadays the widespread implementation of satellite navigation systems requires substantial improvement of equipment responsible for interference immunity. This includes deliberate interference (jamming). Estimates show that the required level for interference immunity to broadband interference in the useful signal band is \( J/S \approx 90 \) dB. Although there

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are many methods for suppressing interference, they are all based on utilizing distinctions
(amplitude, temporal, frequency, angular, polarizing, etc) in useful and disturbing signals. The
idea of making these distinctions useful consists in the formation of minima (nulls) in angular,
polarizing, frequency and other receiver parameters in corresponding directions towards the
source of interference and maxima in direction of a useful signal. This suppresses or compensates the interference and accumulates the useful signal.

The final effect of the processing is defined by the level and completeness of use of
available distinctions and the corresponding methods, their implementation into the unit
diagram models for the satellite navigational user equipment.

The following approaches should be considered as the main methods for improving
interference immunity for the studies equipment [1-7]:
- reducing the tracking systems bandpass; these systems measure satellite signal
parameters using available aprioristic data on the dynamic movements of the user antenna
system (one source of such data can be inertial navigation devices which is found in the
satellite navigation user equipment);
- integral tracking for a full set of signals from the satellite at all frequency bands;
- filtering narrow-band (at its limit – harmonic) interference in the signal to correlator
processing chain by means of adaptive digital filters or by utilizing spectral filtration; this
includes measuring the parameters of interference and its compensation in the digital sector of
the equipment to the correlators;
- providing direct access into the synchronization with a high precision GLONASS
signal (effective for narrow-band interference).

Estimates [1] show that the aforementioned methods may provide the operability of
satellite navigation user equipment at the following level for interference / signal relation
upon input of the receiving antenna \( J/S \approx 60 \ldots 65 \text{ dB} \). Further interference stability
improvement to \( J/S \approx 80 \ldots 90 \text{ dB} \) is possible by using spatial methods for interference
suppression. These methods require the spatial structure of signal wave fronts, generated
either by navigation satellites or by the source of interference, to be tracked as do methods for
determining spatial attitude (orientation). Regarding this, the anti-interference and the angular
receivers should be equipped with antenna arrays. Tracking the structure of spatial signals on
the array elements enables us to reduce the multibeam reception error. Thus, in the long term,
the angular receiver should be developed on the basis of a low-element antenna array (6 to 12
elements). This will provide a solution for the following triune problem:

1) determining spatial attitude of objects;
2) increasing interference stability amplification with spatial selection methods;
3) suppressing multibeam signal distribution.

The design for of such equipment may vary in terms of antenna array configuration and
the receiving and measuring unit layout.

2. Application of three identical low-element antenna arrays dispersed in space.

The simplest layout for anti-interference equipment capable of detecting spatial attitude
has been suggested by V. N. Kharisov [1]. It is based on three identical low-element antenna
arrays (Fig. 1) that are dispersed in space. A design like this is the modernization of a typical
angular antenna system where each antenna has been replaced with an anti-interference
antenna array.
Figure 1. Anti-interference angular satellite navigation user equipment based on three identical low-element antenna arrays.

For interference suppression the same weighting coefficients are used in each antenna array as the interference situation is identical for all elements of the interferometer. In this case, the carrier phase shifts equally for all antenna arrays; the phase shifts between output signals are identical to single antennas.

3. Application of an angular system antenna array for interference suppression

The main drawback of this first anti-interference antenna system for navigation equipment, capable of determining spatial attitude, is the excessive number of antennas. The system is equipped with 12 antennas. However during interference suppression only 4 antennas are employed for each case; for spatial attitude determining there are only two bases – this is equivalent to the application of three antennas. If $N$ number of antennas is required for determining spatial attitude and $M$ number of antennas are required for interference suppression then the total number of antennas for this variant is $N \times M$, i.e. the low application efficiency of the antenna array is obvious.
To increase the exploitation efficiency of the antenna array, another layout (Fig. 2) is suggested. It has several interference suppression routes equipped with an allocated channel, different reference antennas [5] are used for each channel. The remaining antennas of the array are used as additional channels for interference suppression.

**4. Building an angular system on the basis of antenna arrays with a large number of elements**

In the first two proposed layouts, a minimum number of antenna array elements were supposed to be utilized. However, nowadays we have an opportunity to build antenna arrays with large numbers of elements – up to 8 or 12. Due to the redundancy of the antenna system, this allows us to further develop methods for both interference suppression and determining spatial attitude.
Figure 3. Layout of angular satellite navigation user equipment based on antenna arrays with a large number of elements.

The redundancy of the antenna array can be used for eliminating additional diffraction nulls during interference suppression and to improve accuracy and reliability when determining spatial orientation.

A drawback of the third variant is the equipment becoming increasingly overcomplicated for both antenna array and the receiving and measuring unit.

However, the application of arrays for a simultaneous solution of the aforementioned problem for all proposed layouts demands some features to be considered.

When the anti-interference radionavigation equipment is arranged, one antenna is always added to the minimum number of antennas: there is always one antenna more than the estimated number of suppressed interference signals. So, if it is necessary to suppress interference from three directions the antenna array should contain at least four antennas. The interference suppressor represents a complex gravimetric adder of signals from all elements of the array. Weighting coefficients are selected so that interference signals are completely compensated during addition.

The arrangement of satellite navigation equipment that is capable of determining spatial attitude requires no less than \(n+2\) and \(n+3\), in certain cases, for the design of anti-interference satellite navigation user equipment capable of determining spatial attitude.

To determine the angles, the phase shift of signals between antennas is measured. This determines the spatial attitude of an object. The first two layouts require utilizing a null beamformer in the directions of the interference source. Another requirement is for the phase of satellites signals to be corrected.
after adapting. The third layout suggests the employment of a beamformer in direction of the satellites; in this case it is necessary to be aware of the spatial configuration of the antenna system.

5. Conclusion

Thus, a theoretical justification for the principal decisions on improving the accuracy and interference immunity of the developed modifications for angular receivers allows us to make the following conclusions:

Anti-interference modifications should be built on the basis of the adaptive antenna arrays that include the functions of a null beamformer pointed in the direction of the source of interference. They provide a considerable (exceeding 35 dB) reduction of interference; it is possible to achieve a higher amplification of the signal (∼8 … 15 dB) if the beamformer function of the radiation pattern is realized in the direction of each satellite. This will also minimize the error from the multibeam reception signal, which proves to be an integral part of the error for determining spatial attitude.

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