Analysis of Impact of the Visibility of Satellites of GNSS Systems on the Process of Digital Signals Processing SIS in the GNSS Receiver

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***Abstract*—**The subject of this article is to conduct selected research in the field of analyzing the impact of visibility of GNSS satellites systems on the digital processing of SIS signals in the navigation system receiver. In the context of considering this problem, special attention has been paid to the main advantages of GNSS systems, where their functionality in applications requiring the best accuracy of the end user's position using several available satellite navigation systems brings a number of benefits. First of all, a larger number of satellites allows continuous and more reliable observation, which will translate into benefits for potential users. This is especially important in areas related to air navigation (e.g. during aircraft approach to landing). In addition, the signals additionally make it possible to increase the reliability of measurements, due to the greater number of observations available. The use of two or more satellite navigation systems also enables measurement control by comparing the autonomous solutions of each system separately. The article presents the results obtained from simulations assessing the availability of satellites in the area of the globe. A larger number of satellites also makes it possible to conduct observations in areas where due to the large obscuration of the horizon, GNSS satellite techniques have not been used so far, as exemplified by urbanized and mountainous areas. Based on the conducted analysis, performed simulations and obtained results, practical conclusions presented in the final part of the article were formulated.

***Keywords*—**analysis, visibility of system satellites, digital SIS signal processing, GNSS receiver

I. Introduction

IN the standard receiver of the global navigation satellite system GPS *(Global Positioning System)*, the signals received by the antenna are subjected to a band pass filtration process and are appropriately amplified.

Usually this process takes place in the active antenna itself, consisting of a low noise amplifier and filters that extract the signal transmission band of one or more GNSS *(Global Navigation Satellite Systems)* systems [1], [2].

Subsequently, the signal in question is imported into the frequency intermediate band or into the baseband by mixing this signal with the local oscillator output signal.

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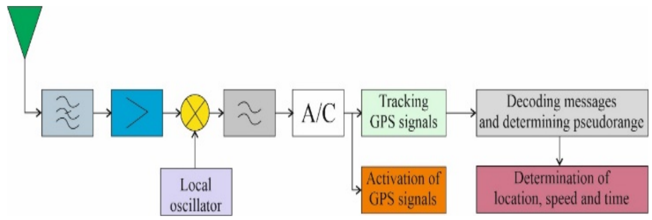

Fig. 1. Processing of signals SIS GNSS in a navigation receiver

The obtained result signal in the SIS *(Signal in Space)* air space, in the next stage subjected to low-pass filtration, has the possibility of further processing in the analog form, or it can be converted into a digital signal.

For the purpose of determining the position of the navigation receiver it is necessary to know the so-called pseudoranges from individual satellites. Also required are the parameter values characterizing the movement of these satellites in their orbits, transmitted in the form of a navigational message.

In addition, it should be noted that in order to be able to reproduce the navigation data placed in the signal of a particular satellite, it is necessary to focus the spectrum of the signal obtained as a result of the operation of multiplication of the input signal by the local replica.

The replica is defined as the product of the course of the pseudo-random sequence C/A *(Coarse Acquisition)* and the frequency of the possibly closest central frequency of the received GPS signal. In order to be able to create a replica correspondingly synchronized with a signal coming from a satellite, it is required to determine the parameters of this signal, obtained through the implementation of subsequent stages of the processing.

It should be noted that in order to make full use of the signal transmission process in all frequency bands, their full use is only possible if they are available to many users at the same time. For this purpose, methods developed in the form of so-called spectrum spreading technique *(spread spectrum)*, implemented in several ways.

The key methods of this technique are:

1. FHSS *(Frequency Hopping Spread Spectrum)* - spectrum spreading with carrier frequency hopping.
2. DSSS *(Direct Sequence Spread Spectrum)* - defining the so-called direct spectrum spreading with a pseudorandom sequence.

In global GNSS satellite navigation systems, the DSSS transmission technique is used in which the reception of this type of signals takes place in two stages.

In view of the above, in the DSSS technique can be mentioned the so-called acquisition phase and the subsequent tracking phase, which will be subjected to detailed analysis later [3], [4], [5].

The first of them, which is the phase of acquisition, is to determine which signals from among all signals broadcast in a given system, currently reach the receiver. With regard to the GPS system, the signals are distinguished based on the forms of their C/A spreading sequences, based on the use of code multiple access technique with direct spectrum spreading DS-CDMA *(Direct Spreading Code Division Multiple Access)*.

This technique, defined as a method of access to a specific transmission medium, is based on allocating to potential users, specific spreading sequences by means of which the navigation receiver is able to uniquely identify a transmission for it.

In the case of the Russian GLONASS *(Global Navigation Satellite System)* system, frequency division multiple access FDMA *(Frequency-Division Multiple Access)* was used [6], [7].

It should be added that in addition to the signal identification process, the *Doppler* deviations of the carrier frequency of signals and the relative time shifts of the spreading C/A sequences, which are parameters enabling the creation of replicas of signals, are determined in the acquisition block.

Due to the variability of these parameters over time, it is required to constantly update these parameters in the navigation receiver. It is the tracking block that is responsible for the simultaneous update of the *Doppler* frequency and the pseudorandom C/A sequence phases.

Then, the signals are multiplied by their replicas and the carrier phase shifts are detected $o \pm \pi$, associated with the change of the bit sign of the message. In other words, the process of focusing the signal spectrum takes place in the tracking phase [8], [9].

Based on the above, pseudorange differences from individual satellites can be determined based on the detection of the change moments of the bit mark, determining the beginning of the navigational message frame. In turn, the orbital parameters of the satellites and pseudo-range information are transferred to the block calculating the position and speed of the receiver and the current system time. The designated navigational parameters are information for the presentation block that can display them, e.g. in a text form or graphic object placed on a map basis.

In the next chapter of this paper, a detailed mathematical analysis of the signal tracking process was considered and made.

II. Analysis and Mathematical Model of the Signals Tracking Process

Signal tracking is a process that takes place after the acquisition phase and consists in maintaining the synchronization received in the acquisition process and its improvement. In navigational satellite systems, i.e. those that use spread spectrum technique, there are two methods of tracking: with trembling tau or with a set delay [10], [11].

A. Tracking with a set delay

The key role in this case plays the tracking loop generator. The system shown in the figure below (Fig. 2) receives a signal C/A, whose shift in time relative to the signal generated in the receiver is smaller than one bit of the sequence.

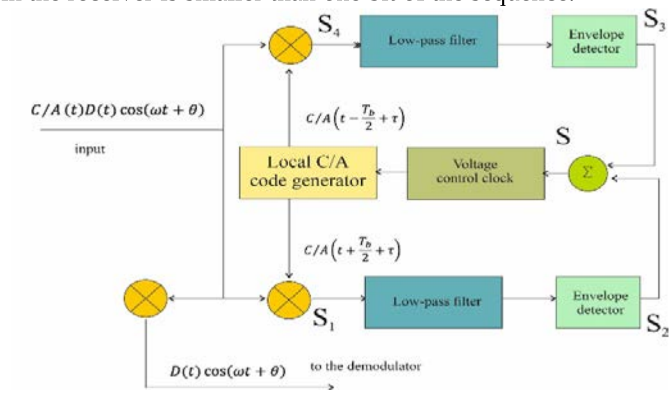

Fig. 2. A loop tracking the phase of the C/A code with a fixed delay [12]

The principle of operation of the tracking system with a set delay consists in the local generator emitting two sequences of a replica of a pseudorandom C/A sequence that are delayed mutually. Delay is the time that one piece of code lasts - T_b.

These sequences, when multiplied with the received signal, can be represented by formulas (1) and (2):

$$s_1 = [C/A(t)D(t)\cos(\omega t+\theta)]C/A\left(t+\frac{T_b}{2}+\tau\right) \quad (1)$$

$$s_2 = [C/A(t)D(t)\cos(\omega t+\theta)]C/A\left(t-\frac{T_b}{2}+\tau\right) \quad (2)$$

Next, both sequences pass through the low-pass filters, where the navigational message $D(t)$is passed and the product C/A and $C/A\left(t\pm\frac{T_b}{2}+\tau\right)$ is averaged. Subsequently, the sequences enter the envelope detector. There, the data signal $D(t)$ is squared and therefore eliminated.

In this way, after exiting the envelope detector, the correlation function between the incoming and the local pseudo-random sequence is obtained, described by the formula (3):

$$s_{3,4} = \left|R_{C/A}\left(\frac{T_b}{2}+\tau\right)\right|. \quad (3)$$

Then both functions are summed - *S(t)*. Due to the negative feedback, when creating a positive phase shift - τ, the voltage controlled clock generates a delay signal, whereas if a negative phase shift is generated, the clock generates a forward signal, which are the basis for the times for s_1 and s_2.

This type of technique continuously maintains the synchronization between the receiver replica signal and the satellite signal [13], [14].

At zero τ at the output of the demodulator an undisturbed data signal is obtained, i.e. a navigational message in the form (4):

$$S_D(t) = C/A^2(t)D(t)\cos(\omega t+\theta) = D(t)\cos(\omega t+\theta). \quad (4)$$

B. Tracking with trembling tau

This type of tracking process is very similar to the one described above, with the difference that it contains only one arm (Fig. 3).

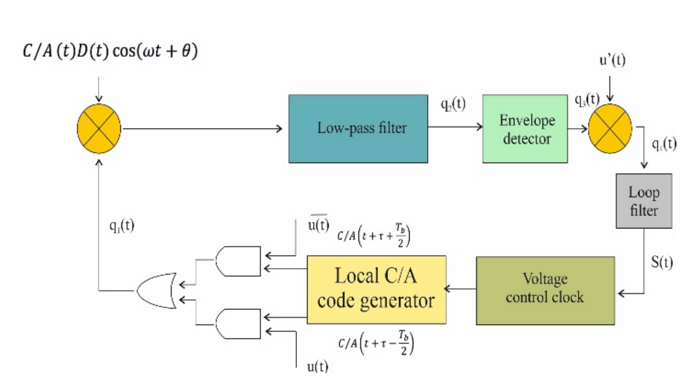

Fig. 3. A tracking loop with trembling tau [15]

The input signal produces two waveforms offset from each other similarly to the tracking with a set delay [16], [17].

The loop is controlled by three waveforms of the tracking loop with trembling tau *u(t)*, *u'(t)* and $\bar{u}(t)$, illustrated in the figure below (Fig. 4):

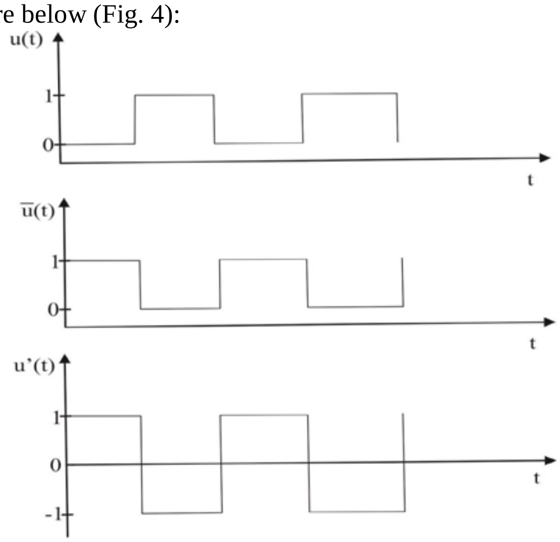

Fig. 4. Control waveforms of the loop with trembling tau

Operation of the above-mentioned loop consists in using by a local generator the signal represented by formula (5):

$$q_1(t) = u(t)C/A\left(t-\frac{T_b}{2}+\tau\right) + \bar{u}(t)C/A\left(t+\frac{T_b}{2}+\tau\right) \quad (5)$$

The logic system only shares one of the two signals from the local generator. By this the signal takes the following form (6):

$$q_2(t) = C/A(t)D(t)\cos(\omega t+\theta)\left[u(t)C/A\left(t-\frac{T_b}{2}+\tau\right) + \bar{u}(t)C/A\left(t+\frac{T_b}{2}+\tau\right)\right]. \quad (6)$$

The low-pass filter plays the role of averaging this signal, leaving only control signals and data [18], [19], [20].

After passing through the envelope detector, the signal takes the form (7):

$$q_3(t) = u(t)\left|R_{C/A}\left(t-\frac{T_b}{2}+\tau\right)\right| + \bar{u}(t)\left|R_{C/A}\left(t+\frac{T_b}{2}+\tau\right)\right| \quad (7)$$

In addition, taking into account (8):

$$q_4(t) = q_3(t)u'(t), \quad (8)$$

thus the following form was obtained (9):

$$q_4(t) = u(t)\left|R_{C/A}\left(t+\frac{T_b}{2}\right)\right| - \bar{u}(t)\left|R_{C/A}\left(t-\frac{T_b}{2}\right)\right|. \quad (9)$$

After passing through the filter, a signal was obtained that controls the clock (10):

$$S(t) = \left|R_{C/A}\left(t+\frac{T_b}{2}\right) - R_{C/A}\left(t-\frac{T_b}{2}\right)\right| \quad (10)$$

As in the case when considering the tracking process with a set delay, the above signal affects the clock, which accelerates or decelerates in relation to the quantity τ.

III. Simulation Studies

The simulations presented in this chapter were carried out in the *Galileo System Simulation Facility* V2.1.11 program (GSSF V2.1), which was illustrated in the following figures (Figures 5-11).

In this chapter, the visibility of satellites and the geometry coefficient of the DOP *(Dilution of Precision)* system of individual systems and the same parameters after combining different systems were examined, while the research analysis focused only on the area of Europe.

A. Visibility of the GNSS system satellites

The following figures illustrate the results obtained from the simulation tests carried out in the GSFF V2.1 program in the field of visibility of GNSS satellites. At the beginning, the visibility of satellites for GPS, Galileo and satellite support system SBAS *(Satellite Based Augmentation System)* was analyzed [21], [22], [23], [24].

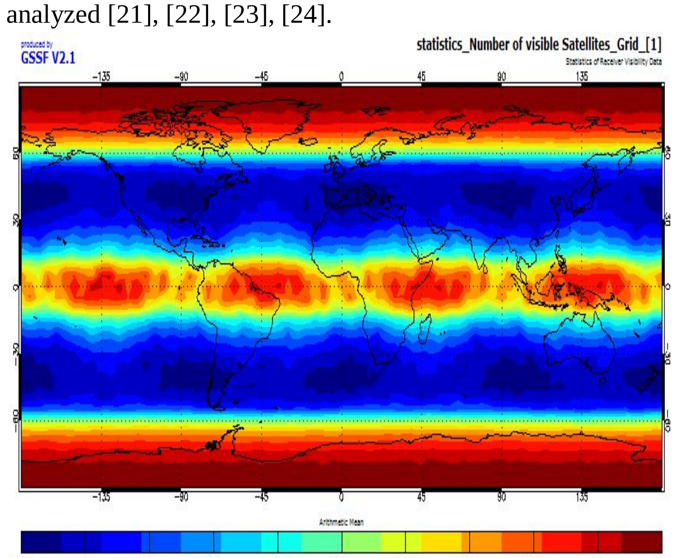

Fig. 5. Visibility of GPS system satellites

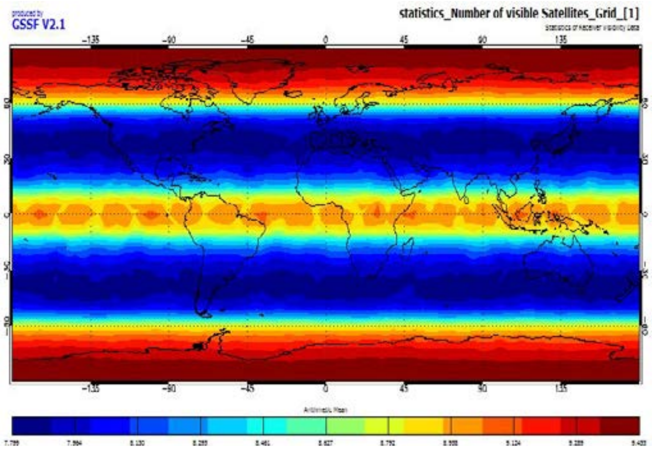

Fig. 6. Visibility of the Galileo system satellites

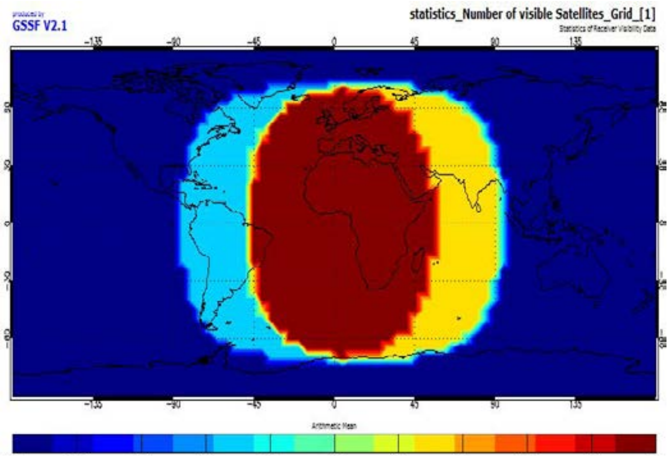

Fig. 7. Visibility of SBAS system satellites

From the above figures (Figures 5-7), it can be concluded that in Europe [25], [26], [27]:

- the average visibility for a GPS system is about 6.9 satellites,
- the average visibility for the Galileo system is about 8 satellites,
- the visibility of SBAS system satellites is 3 satellites in almost the whole area discussed,
- the visibility of the Galileo system satellites is slightly higher than the visibility of the GPS system under the same conditions.

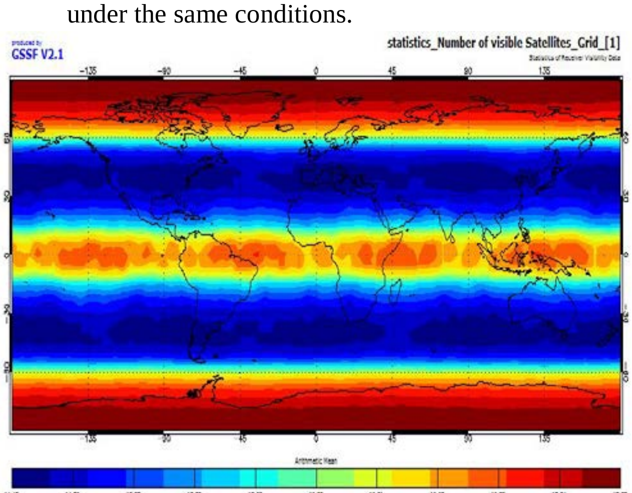

Fig. 8. Visibility of GPS and Galileo systems satellites

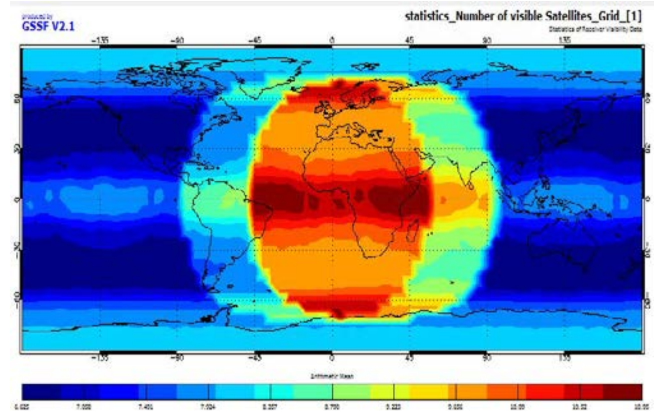

Fig. 9. Visibility of GPS and SBAS systems satellites

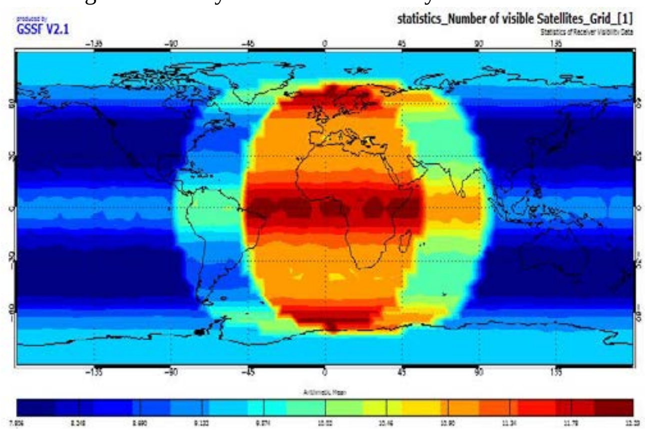

Fig. 10. Visibility of the Galileo and SBAS systems satellites

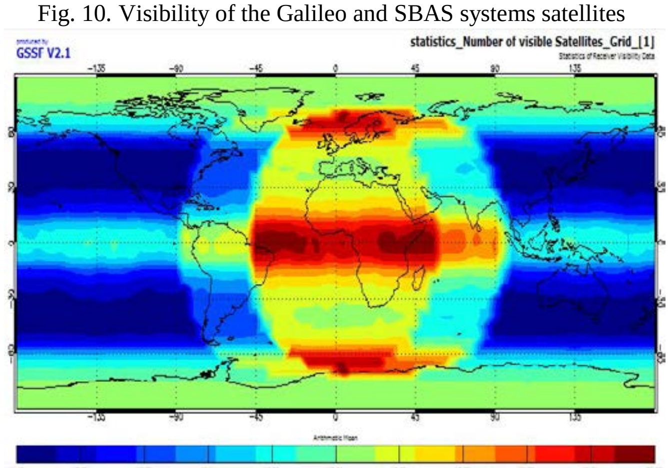

Fig. 11. Visibility of GPS, Galileo and SBAS systems satellites

In addition, from the above figures (Figures 8-11) it can be concluded that in Europe [28], [29]:

- the average visibility of the satellites of the connected GPS and Galileo systems is approximately 14.7 satellites,
- the average visibility of the satellites of connected GPS and SBAS systems is about 9.7 satellites,
- the average visibility of the satellites of the combined Galileo and SBAS systems is approximately 10.9 satellites,
- the average visibility of the satellites of the connected GPS, Galileo and SBAS systems is around 18 satellites,

- the combination of different GNSS systems gives much more visibility than using only one satellite navigation system,
- the highest visibility in the performed simulations was obtained after the combination of all satellite navigation systems used in the studies, i.e. GPS, Galileo and SBAS.

IV. Conclusions

The main purpose of the above research was to check the impact of increasing the number of visible satellites of satellite navigation systems by the user's receiver on such quantites as: visibility and DOP coefficients, which affects the accuracy of position determination by this receiver.

The research considered several strategies for making observations, based on the use of observations derived from two satellite navigation systems (GPS, Galileo) and the system supporting satellite navigation systems (SBAS) in one-day observation sessions [30], [31], [32].

The above studies have shown that visibility and DOP coefficients are very advantageous because their value is less than 6, and the visibility of satellites is always greater than 4. The main limitation of using a single satellite navigation system is the small number of signals sent from satellites to users.

It is therefore beneficial to record signals from all fully operational satellite systems and signals from other systems being in the construction phase. This significantly increases the number of visible satellites, which allows much more accurate positioning than using satellites from only one system.

In addition, attaching observations of the Galileo system to existing GPS signals provides more favorable and more even placement of the satellites over the observer and allows the collection of a much larger number of observations compared to GPS measurements. The combination of these systems has had the greatest positive impact on increasing the accuracy of positioning.

The greatest benefit obtained from adding observations of the Galileo system or other GNSS systems is a process of continuous observation in difficult terrain conditions, where until now it has not been possible to implement them only with the help of a single satellite navigation system. Therefore, it is possible to increase the positioning efficiency of the receiver by increasing the number of satellites seen.

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