

## Electromagnetic compatibility of ground system of near navigation, based on the use of GNSS and pseudolites

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**Abstract.** Article describes the results of modeling the allowable power pseudolites in the ground system of near navigation, working together with GLONASS. Was justified pulsed operation of pseudolites and using weighting windows to improve electromagnetic compatibility of pseudolites signals with GNSS signals.

### 1. Introduction

At present days, more and more attention is paid to radio communications or navigation systems. The most widely used is a global navigation satellite systems (GNSS). They are characterized by high availability and sufficient for ordinary consumers accuracy. However, the possibilities offered by GNSS is insufficient for activities requiring continuous high-precision navigation support. This is to ensure aviation safety in airport areas; ensuring flights of unmanned aircraft; navigation in port areas, the narrowness of the rivers; provision of geodetic, cartographic and special works. The reason for this is the low noise immunity of GNSS, and their lack of accuracy in the mountains or urban areas.

One of the ways to resolve this contradiction is augmentation of GNSS signals by ground-based radio navigation system near range navigation, which allows you to create a navigation field in a given region of space with the help of ground-based pseudolites [1, 2]. High precision measuring consumer navigation parameters in a radio navigation system provides high precision geodetic reference and mutual synchronization of pseudolites, which are stationary emitters navigation signals similar to the signals of navigation satellites (NS) GLONASS.

This short-range navigation architecture is significantly different from the local, regional or wideband differential GNSS subsystems. If the use of the latter is possible only with a stable receiving GLONASS signals, using a navigation system based on pseudolites can ensure the navigation even in the absence of signals from the NS. In addition, such system allows to ensure the required accuracy of measurement of coordinates and angles of spatial orientation of the consumer at the design stage [3].

One of the main problems faced in the development of such systems - is the problem of electromagnetic compatibility of pseudolites signals and navigation satellites. [4] In the



operating frequency channel, it is necessary to implement them additional isolation. This can be done in three ways:

- add a small shift in operating frequency pseudolites within the working channel frequency;
- add artificial offset pseudorandom sequence ranging code pseudolites to ensure minimal cross-correlation between the signal pseudolite and GLONASS signal on the same frequency [5];
- use pulsed pseudolites mode. In this case the receiver must be made pseudolites blanking pulse in the channel receiving the signal on one frequency GLONASS [6].

To achieve the best cross-correlation may use a combination of these methods.

Together with EMC problems that must be solved in the local navigation augmentation systems based on pseudolites, also necessary to solve a "near-far" problem. This problem is that when an over-power signal pseudolites 20 dB and it creates more interference for receiving GLONASS signals. The same effect occurs when working with several pseudolites user approaching one of them.

## 2. Allowable power pseudolites calculation

Consider a pair of pseudolite – GLONASS satellite operating at the same frequency and define the parameters of the signals, at which it is possible to avoid the "near-far" effect. Navigation satellites signals received by the antenna apparatus of the consumer, have an average power:

$$P_{GNSS} = P_G - L_F - L_{AT} - L_{POL} - L_0 \approx -161 \dots -163 \text{ dBW}, \quad (1)$$

where  $P_G$  – effective transmitter power (28...30 dBW);  $L_F$  – free space loss  $20\lg(\lambda/4\pi R) \approx 182.2 \dots 184.2$  dB for GLONASS signals);  $L_{AT}$  – atmospheric losses ( $\approx 2$  dB);  $L_{POL}$  – polarization losses ( $\approx 1$  dB);  $L_0$  – other losses ( $\approx 3 \dots 4$  dB).

Given that pseudolites signal loss associated with propagation in the atmosphere, and the polarization losses are negligible, the conditions under which the "near-far" effect can be avoided, is described by the inequality:

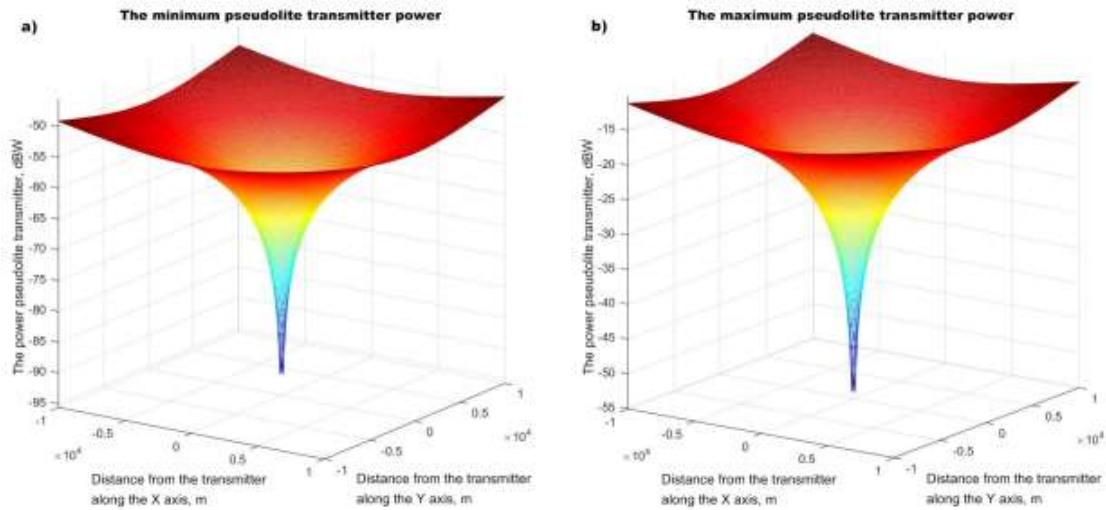
$$|P_{PL} - P_{GNSS}| \approx |P_{GTX,PL} - P_{GTX,GNSS} + 20\lg(R_{GNSS}/R_{PL}) - 3 \text{ dB}| < 20 \text{ dB}, \quad (2)$$

where  $P_{PL}$  – pseudolite transmitter power;  $P_{GNSS}$  – GNSS satellite transmitter power;  $P_{GTX,PL}$  – pseudolite effective transmitter power;  $P_{GTX,GNSS}$  – GNSS satellite effective transmitter power;  $R_{GNSS}$  – distance from the satellite to the GNSS consumer receiver equipment;  $R_{PL}$  – distance from the pseudolite to the GNSS consumer receiver equipment.

Thus we arrive, in order to eliminate the "near-far" effect in the entire range of possible power signals of the GLONASS space navigation devices must be observed the following inequality:

$$(11 \dots 13) - P_{GTX,PL} < 10\lg(R_{GNSS}/R_{PL}) < (51 \dots 53) - P_{GTX,PL}. \quad (3)$$

The range of power pseudolites signals by 2 dB is due to some scatter the power of the transmitted signal space navigation unit and the change in the value of its attenuation at different elevations. The results of modeling the allowable power pseudolite transmitter radiation range are shown in Fig. 1.



**Figure 1.** Dependence pseudolite allowable power of the transmitter of the distance in the plane of the Earth's surface:  
*a* – minimum power value; *b* – maximum power value.

You can see a big difference gradient power depending on the distance from the transmitter pseudolite that limits the working range of the signals pseudolite. To improve the performance of the consumer equipment pseudolites signals are usually transmitted in the pulse mode. To assess the degree of influence of pulse mode pseudolite transmission signal on the GLONASS signal, consider the correlation operation on the  $T$  accumulation interval in the  $i$ -th channel.

$$\begin{aligned}
 I_{i,PL}(t) &= \int_0^T h_{i,DC}(t) h_{PL}(t - \tau) \cos(\Delta\omega_{i,DC}t + \Delta\varphi_{i,DC}) dt, \\
 Q_{i,PL}(t) &= \int_0^T h_{i,DC}(t) h_{PL}(t - \tau) \sin(\Delta\omega_{i,DC}t + \Delta\varphi_{i,DC}) dt,
 \end{aligned} \tag{4}$$

where  $h_{i,DC}$  – a pseudo-random sequence ranging code of  $i$ -th channel;  $h_{PL}$  – code sequence of the received signal;  $\Delta\omega_{i,DC}$  – the difference between the local oscillator frequency and the frequency of the received signal  $i$ -th channel;  $\Delta\varphi_{i,DC}$  – the phase difference between the local oscillator and the received signal phase  $i$ -th channel.

Let pseudolite signal is a weighted by Henning window (with default parameter  $\alpha = 1$ ) normalized delta pulse with  $\tau_p$  duration, the signal at the output of the correlator will be presented in (5).

For the analysis we assume that the received signal pseudolite and GLONASS signals are completely correlated with the code sequence of the receiver, but also do not have Doppler frequency shift.

$$\begin{aligned}
I_{i,PL}(t) &= \int_0^{\tau_p} h_{i,DC}(t) h_{PL}(t-\tau) \sin\left(\frac{\pi t}{\tau_p}\right) \cos(\Delta\omega_{i,DC}t + \Delta\varphi_{i,DC}) dt, \\
Q_{i,PL}(t) &= \int_0^{\tau_p} h_{i,DC}(t) h_{PL}(t-\tau) \sin\left(\frac{\pi t}{\tau_p}\right) \sin(\Delta\omega_{i,DC}t + \Delta\varphi_{i,DC}) dt.
\end{aligned} \tag{5}$$

Then, according to (5) a pulse signal pseudolite and GLONASS correlated signals will have a real component only is equal to

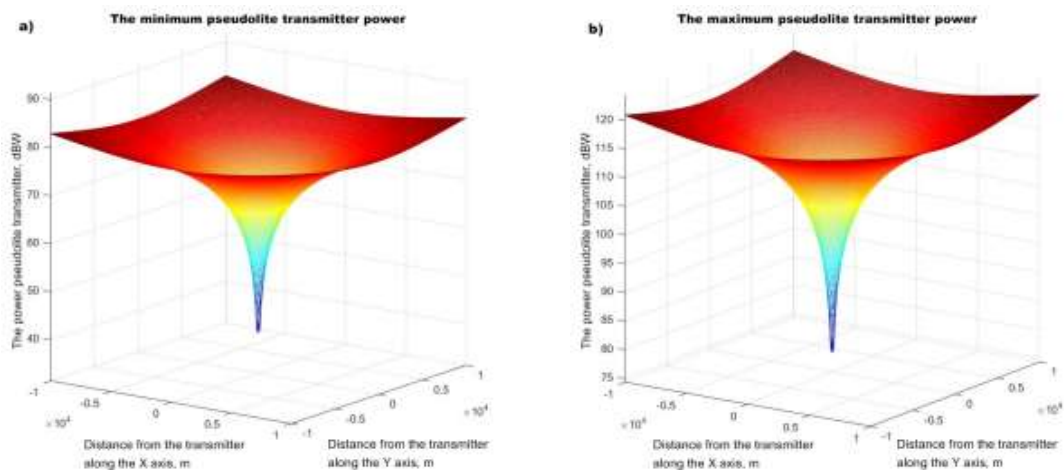
$$\begin{aligned}
I_{i,PL}(t) &= \frac{\tau_p}{\pi} \sum_{k=1}^{\tau_p/\tau_e} h_{ik,DC}(t) h_{k,PL}(t-\tau) \left[ \cos\left(\frac{(k-1)\pi\tau_e}{\tau_p}\right) - \cos\left(\frac{k\pi\tau_e}{\tau_p}\right) \right], \\
I_{i,GNSS}(t) &= \sum_{k=1}^{T/\tau_e} h_{ik,DC}(t) h_{k,PL}(t-\tau),
\end{aligned} \tag{6}$$

where  $\tau_p$  – pseudolite pulse duration;  $\tau_e$  – duration of the chip code sequence.

System health condition (2) in view of (6) is equal to

$$\left| 20\lg \frac{I_{i,PL}(t)}{I_{i,GNSS}(t)} + 20\lg \frac{R_{GNSS}}{R_{PL}} - 3 \text{ dB} \right| < 20 \text{ dB}. \tag{7}$$

When pseudolite signal pulse duration equal to 2 ms and interval accumulation of the correlator equal to 10 ms then allowable power range boundaries pseudolite radiation signal depicted in Fig. 2.



**Figure 2.** Dependence pseudolite allowable transmitter power in a pulsed mode of operation of the distance in the plane of the Earth's surface. Used Hanning window, parameter  $a = 1$ :  $a$  – minimum power value;  $b$  – maximum power value.

Despite the fact that the calculated output power of the pulse signal can have values pseudolite 40 dBW above, the actual radiation power permissible dynamic range is limited to the automatic gain control and analog-to-digital converter of the receiver. To ensure isolation of pseudolites and GLONASS signals taken receiver on the same frequency using only code division will not be enough, as the GLONASS signal will be simply muted by pseudolite signal. At the same time ensuring reliable receive signal on the same channel and knowing pseudolite pulse signal width we can compensate pseudolite signal in the second channel on the same frequency.

Thus, the first correlator will collect samples over the entire range of the pseudolite signal accumulation interval  $T$ , the second correlator in the interval  $T - \tau_p$  accumulation will collect a signal of the GLONASS navigation system.

### 3. Using the weighting windows to improve the coherence of signals pseudolites and navigation spacecraft

The disadvantage of the above approach is the influence of the side lobes of the spectral characteristics of a pulsed signal pseudolite to adjacent frequency channels of GLONASS. To improve the frequency response of the working channel in consumer navigation equipment can use weighting window.

So, for the Hanning window with parameter value  $\alpha = 1$ , the level of the first side lobe is  $-23$  dB, which corresponds to the level of interference from adjacent frequency channels of the receiver. Using Hanning window function with parameter  $a = 4$  to forming a pulse pseudolite provides a side-lobe level  $-46.8$  dB.

To estimate the allowable power of the radiation pulse pseudolite range using this Hanning window function can estimate the signal at the output of the consumer navigation equipment correlator. Let us assume that the receiver does not have Doppler frequency shift and the received signal is completely correlated with the code sequence

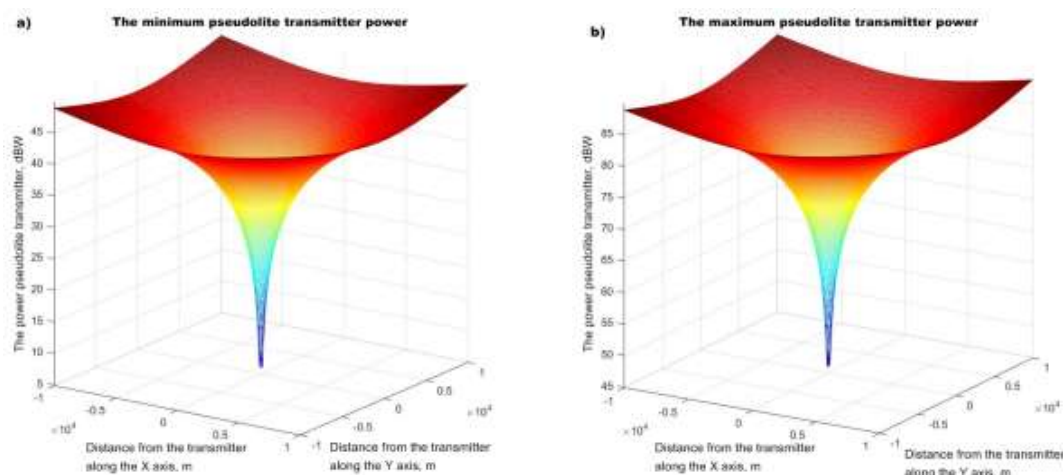
$$I_{i,PL}(t) = \int_0^{\tau_p} h_{i,DC}(t) h_{i,PL}(t - \tau) \frac{(3 + 4\cos(2\pi t) + \cos(4\pi t))}{8} \cos(\Delta\omega_{i,DC}t + \Delta\phi_{i,DC}) dt. \quad (8)$$

### 4. Conclusion

An analysis of pseudolites permissible power range modeling results allows us to conclude that when pseudolites are used together with the GLONASS system, the impulse mode of operation of pseudolites is most appropriate.

When a pseudolite is pulsed possible to implement time division of the GLONASS signals and pseudolites signals received by one frequency channel on the basis of data on the pulse duration. Since the "near-far" effect is arises due to difference between the power of the received GLONASS signals and pseudolites signals, to reduce the interference pulses adjacent channels on each other, the pulses should be formed through the weighting windows, side lobes which have a level below the minimum level of signal reception pseudolite.

Fig. 3 shows that the dynamic range of operation of the receiving channel without the appearance of the effect of "near-far" should be about 40 dB. Using a Hanning window with parameter  $a = 4$  pulse weighing provides a side-lobe level of 6 dB below the minimum power level pseudolite pulse signal, thus providing isolation adjacent frequency channels.



**Figure 3.** Dependence pseudolite allowable transmitter power in a pulsed mode of operation of the distance in the plane of the Earth's surface. Used Hanning window, parameter  $a = 4$ :  $a$  – minimum power value;  $b$  – maximum power value

The research had been conducted with financial support from the Russian Science Foundation. Grant No 16-19-10089.

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