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# UWB locating system in semi-open space

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**Abstract.** Simulation of the processing of navigation signals and estimation of the noise immunity of the receiver of an ultra-wideband positioning system in difficult conditions for receiving GNSS signals with dense taiga vegetation was performed. Experimental data were obtained on microwave interference and the conditions for the propagation of radio waves at real production facilities, including operating mountain taiga geophysical profiles.

## 1. Introduction

Given the mountain-taiga topography of the Krasnoyarsk Territory, conducting mobile prospecting seismic exploration for oil and gas (without stopping the seismic emitter (SI) at the point of excitation, currently working out one point of excitation takes about 1 minute) will lead to faster and cheaper search operations. However, to achieve a given economic indicator (10 km / day instead of 5 km / day), there is a very specific scientific and technical barrier associated with the impossibility of high-precision coordinate-time reference of SI (up to 1 m) in motion in the conditions of high Siberian taiga during felling profiles up to 3 m wide. The standard deviation in the determination of coordinates of 5-10 m gives a big error when constructing the geological section of the field in post-processing.

Currently, countries such as Canada, India and China are actively conducting research in the field of constructing optimal communication channels and transmitting broadband signals in mine workings, as well as developing positioning systems based on UWB signals [1].

In 2012, a study was conducted in the application of various types of antennas for data transmission using UWB signals with a band up to 7 GHz, both in direct visibility and in the absence of direct propagation of radio waves [1]. The results of these studies were the analysis of the signal attenuation gradient for direct and multipath propagation of radio waves and the analysis of the signal intensity in the channel with fading, as a function of time delay. It is concluded that for conditions of lack of direct visibility, omnidirectional antennas are more suitable, since they guarantee better signal coverage, while highly directional antennas allow increasing channel throughput.

In 2015, the National Institute for Occupational Safety and Health in Pittsburgh, PA, USA, obtained analytical ratios of the complex transmission coefficients and impulse response of channels in mines and tunnels at different frequencies, based on the model of the determined UWB channel [2]. The data channel is considered as an infinite delay line with taps.

Semi-open space is defined as a space semi-confined by partitions in an open space environment. Most of the previous indoor environmental researches were focused on the open space environment, while only a few of them looked into the performance of the semi-open space. The aim of the work is to study the propagation processes of ultra-wideband (UWB) microwave signals in the half-open areas



with difficult reception conditions for global navigation satellite systems (GNSS), in particular, on geophysical seismic profiles in a wooded mountainous taiga area.

The principle of constructing a positioning system involves the use of ultra-wideband signals in the frequency range from 3 to 7 GHz with a band from 500 to 1300 MHz [3]. A large base of signals in this range allows increasing the resolution of time interval meters and, consequently, the difference in the time of arrival of signals. In addition, an ultra-wideband pulse is the most suitable probe signal for studying the time and frequency characteristics of the studied radio channel in relation to the propagation of microwave signals in the half-open spaces of mine workings and geophysical profiles, respectively.

Generally speaking, the problems associated with the propagation of waves in physical media are quite difficult to theoretically analyze and rigorously describe mathematically, especially if the environment cannot be likened to open space (for example, as a satellite or inter-satellite communication channel). A key parameter that affects reception quality is signal strength (or signal-to-noise ratio) [4]. Therefore, the ability to predict the signal level at some point in space remote from the transmitting antenna is critical. However, it is known that even the propagation model in terrestrial radio systems is much more complex, and the main factors influencing the signal intensity are shadowing and multipath fading [5]. In the framework of the goals and objectives of this research, in the case of the studied wireless paths in half-open and closed locations, there is a much greater variety of influencing factors associated with the presence of "guide lines" in the form of metal structures, highly conductive layers of the rock mass, passive sources of shadowing and re-reflection of microwave radio waves-range. The target function of the studied system of high-precision local positioning in the final version assumes multi-positioning and location of objects using various methods, including rangefinder, pseudo-rangefinder and difference-rangefinder.

## 2. Environment conditions on the semi-open space set

The reliability of presented results is confirmed by a set of verification data obtained experimentally on real objects that is sufficient for statistical averaging.

The transmitter includes a buffer stage, which generates short video pulses lasting about 0.5 ns. These pulses produce shock excitation of the antenna circuit. A radio pulse with a frequency of 1250 MHz is formed in the antenna. The transmitter performs amplitude manipulation. When a unit is received at the digital input, a video pulse of negative polarity with an amplitude of 4 V, duration of 0.5 ns, is formed, when a zero signal is received, the video pulse is not formed. The maximum frequency of the input signal coming from the encoder is 10 MHz. Level of spectral density of isotropically radiated power: not more than  $-45$  dBm / MHz; antenna gain:  $-3$  dBV for omnidirectional and  $+6$  dBV for directional.

From the receiving antenna, the signal enters the receiver input circuit, which determines the operating frequency band. Using the key device, the input circuit is connected to the detector immediately before the expected signal arrival. A window is a time interval (of the order of 13–15 ns) during which the detector is connected to the input circuit. Windows in the receiver open at a frequency of about 10 MHz (equal to the maximum pulse repetition rate of the received signal). When the window is opened, the system is in a state of alert for signal detection. Detection means receiving an information unit, the absence of detection means receiving information zero.

Synchronization adjusts the position of the window so that the received signal is always in the center of the window [6]. In this regard, the circuit adjusts the frequency of the reference oscillator of the receiver in accordance with the repetition rate of the received pulses. Synchronization occurs only when a unit is received.

The microcontroller enables or disables the operation of the synchronization system and adjusts the threshold voltage that is supplied to the detector in accordance with a given detection criterion. From the decoder to the consumer the output digital and clock signals. The system operates in simplex mode, while data transfer is carried out in one direction.

It was decided to use the modified model adopted by the IEEE working group in 802.15.4a standard for modeling [3]. The impulse response can be represented as:

$$h_i(t) = X_i \sum_{l=0}^{L-1} \sum_{k=0}^{K-1} \alpha_{kl}^i \delta(t - T_l^i - \tau_{kl}^i) \quad (1)$$

where  $l$  – number of cluster,  $k$  – number of pulse of the cluster,  $\alpha_{kl}^i$  – amplitude of  $k$ th pulse of the  $l$ th cluster,  $T_l^i$  – delay of the  $l$ th cluster,  $\tau_{kl}^i$  – delay of the  $k$ th pulse relatively to the first pulse in the cluster,  $X_i$  – normal distribution.

Modeling was carried out in the case of direct and indirect visibility for three different ranges. The propagation model in terrestrial radio systems is much more complex, and the main factors influencing the signal intensity are shadowing and multipath fading. In the framework of the goals and objectives of this research, in the case of the studied wireless paths in half-open and closed locations, there is a much greater variety of influencing factors associated with the presence of "guide lines" in the form of metal structures, highly conductive layers of the rock mass, passive sources of shadowing and reflection of microwave radio waves range.

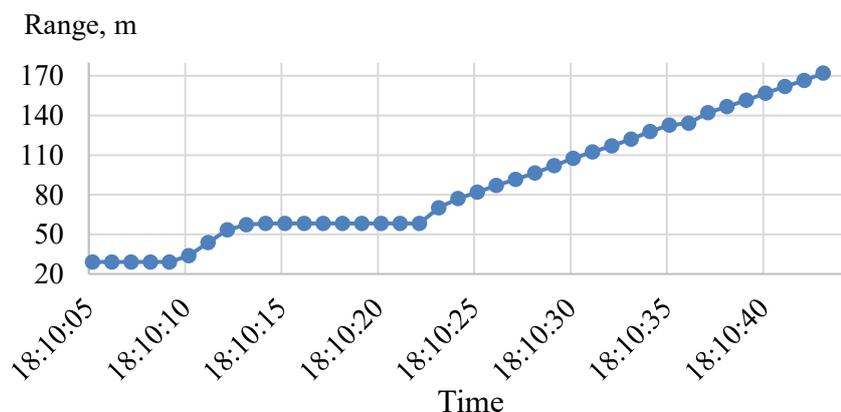
### 3. Positioning accuracy investigation

To solve the direct problem, in the framework of this research, a regression model has been created that describes the laws governing the formation of a microwave field at a given point in space based on the methods and approaches of statistical radio engineering, electrodynamic equations. The reliability of scientific results is confirmed by a set of verification data obtained experimentally on real objects that is sufficient for statistical averaging.

The pulse sequence is formed by modulating the analog pulse generator with the transmitted data. The pulse sequence is transferred using a double balanced mixer to the carrier generated by the synthesizer and centered on one of the selected channels. The modulated signal is amplified before being fed to an external antenna.

The receiver contains a low noise amplifier and a subsequent frequency conversion path (superheterodyning). The baseband signal is demodulated, and the received data is sent to the microcontroller via SPI.

Considering that the maximum speed of movement of positioned objects (equipment) is no more than 10 km / h, smoothing filters of PLL systems and delay tracking are configured. As field tests of the model show, positioning accuracy of not worse than 0.5 m is ensured at object speeds of up to 12 km / h at distances of up to 120 m in open space. Figure 1 shows a graph of the distance between the mobile and one base station.



**Figure 1.** Pseudorange dependency on moving object with speed of 5.2 m/s.

#### 4. Results

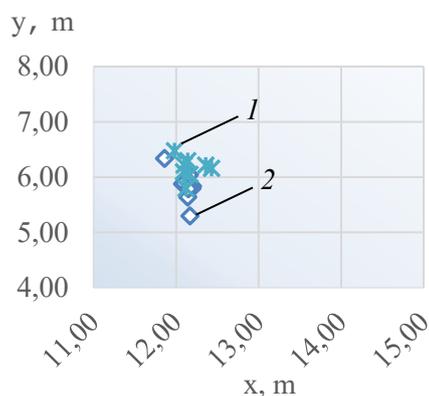
The solutions to the navigation problem were tested using the ranging and differential ranging methods. The ranging method is based on two-way communication between two devices (mobile and base stations or between base stations). During the measurement session, the devices measure the propagation time of the signal between them. The difference-ranging method provides for the presence of several base stations that are deployed at the work site and also synchronized in time. The arrival time of the signal emitted by the mobile station is recorded by the base stations and transmitted to the server, which implements mathematical algorithms for calculating the location by the difference in the arrival time of the signals and the known location of the base stations.

Taking into account the received characteristics of the transceiver equipment, the area of the working area (cells from 4 base stations) is determined, which ensures accuracy of location no worse than 50 cm in conditions of simulated interfering signals and multipath interference – 500 sq. m

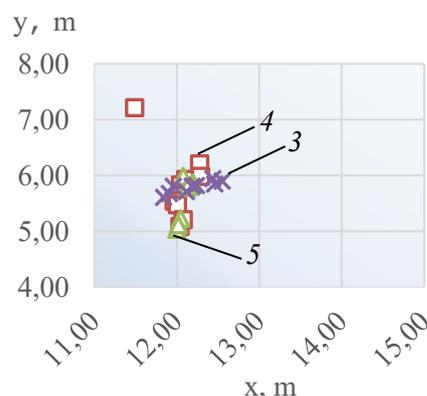
After testing the model on the laboratory bench, experimental work was carried out on the geophysical profile. After successful debugging of the system operation algorithms, the system was confirmed to be operational in a wooded mountain taiga area.

With a decrease in the area of the working area to 400 square meters. m. accuracy indicators are achieved when working at the laboratory bench. When deploying the system, the base stations are first linked to the terrain and the relative position of the stations is determined. Verification of range-finding methods for linking base stations was carried out with an accuracy of 0.5 cm using a special laser range finder.

The accuracy of the positioning of the mobile station was also checked by measuring the distance from the mobile station to each base station with a special laser range finder. The results show the bias of the estimate of the coordinates of the mobile station relative to the geometrically calculated coordinates, as well as the root-mean-square error of the coordinates is 0.24 m. When working in the forest, the root-mean-square error of the coordinates is 0.29 m. In order to bring a clean result, the 1000 samples are grouped by 100 samples within a 15 cm distance. Figure 2 and figure 3 show grouped samples of each experiment.



**Figure 2.** Mobile tag coordinates: model and experiment.



**Figure 3.** Mobile tag coordinates: open space and guided lines, reflectors.

On the figure 2 curves shown are: 1 – tests on a laboratory bench with simulated interference; 2 – forest testing. On the figure 3 curves shown are: 3 – work in open space; 4 – the presence of guide lines at different points on one shoulder of the mobile station-base station; 5 – the presence of flat reflectors at various points on one shoulder of the mobile station-base station.

## 5. Conclusion

In the course of a series of experimental works, the influence of objects of scattering of radio waves, leading to the appearance of multipath, was studied, an initial assessment of the reliability of the developed mathematical model of the radio channel was made.

In particular, an experimental assessment was made of the influence of “guide lines” of metal structures in various orientations to a plane attached to base stations; The impact of the presence of reflecting faces at various orientations and distances from the mobile station was estimated (figure 3). The critical effect on the contour of the working area with the greatest reliability of the coordinates of such factors as: the presence of a linear conductor normal to the plane of the working area, the lack of direct visibility between the mobile station and any base station, the presence of one or more reflected rays in the direction to the base station is revealed. These factors lead to abnormal errors in the measurements and require the use of filtering algorithms for coordinate measurements (for example, the Kalman filter). The obtained experimental data are highly correlated with the obtained computer simulation data.

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## References

- [1] Rissafi Y, Talbi L and Ghaddar M 2012 Experimental Characterization of an UWB Propagation Channel in Underground Mines **60** *IEEE Antennas and Propagation Magazine* 240-6
- [2] Zhou C 2015 Physics-based Ultra-Wideband Channel Modeling for Tunnel/Mining Environments *IEEE Radio and Wireless Symposium (RWS)* doi: 10.1109/RWS.2015.7129760
- [3] IEEE Std 802.15.4™-2015 *Revision of IEEE Std 802.15.4-2011*
- [4] Chehri A, Fortier P and P 2018 M. Tardif, “Time delay estimation for UWB non coherent receiver in indoor environment from theory to practice *EURASIP Journal on Wireless Communications and Networking* **4** 264-76 DOI: 10.1186/s13638-018-1306-z
- [5] Gigl T, Preishuber-Pfluegl J, Arnitz D and Witrisal K 2009 Experimental characterization of ranging in IEEE802.15.4a using a coherent reference receiver in *Proceedings of the IEEE 20th International Symposium in Personal Indoor and Mobile Radio Communications* 92-6 DOI: 10.1109/PIMRC.2009.5450363
- [6] Bondarenko V 2006 Self-adjustment in delay time of the noise-like signal with frequency-keying *Radioelectronics and Communications Systems* **49(5)** 36-41