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Laboratory complex for simulation of navigation signals of pseudosatellites

Laboratory complex for simulation of navigation signals of pseudosatellites

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Abstract. In the article, features of the organization, structure and questions of formation of navigation signals of pseudosatellites of the short - range navigation system based on the hardware-software complex National Instruments are considered. A software model that performs the formation and management of a pseudo-random sequence of a navigation signal and the formation and management of the format transmitted pseudosatellite navigation information is presented. The variant of constructing the transmitting equipment of the pseudosatellite base stations is provided.

1. Introduction

Current trends in the development of radio navigation systems (RNS) based on «pseudosatellites» (PS) require complex computer modeling of the interaction base stations of the PS with the environment for the formation and propagation of navigation signals [1–3]. The main goal of the software-hardware model creation based on «pseudosatellites» is to investigate the options for the formation of radio navigation signals based on the code M-sequences and the creation of a single radio navigation field. The main requirements for the formation of navigation signals, various code pseudorandom sequences (PRS) with different correlation properties are frequency stability, low phase noise and the level of nonharmonious components of the generator, strict correspondence to the polynomial and a change in the signal modulation law and ensuring high spectral purity. The quality of fulfilling the requirements ultimately affects the accuracy of the coordinate-time determination of consumers. [4–6].

2. The format of the pseudosatellite navigation frame

To solve the problem of navigational definitions, the user should transmit navigation data including the coordinates of all base stations of the PS, frequency-time corrections (for synchronization of time scales), etc. In the course of the work, composition and format operational information (OI) of the PS navigation message was developed. The OI PS consists of information collected from five lines of operational information of the PS navigation message (Figure 1).

Row information 1 OI PS (10 byte)	HC	TS
Row information 2 OI PS (10 byte)	HC	TS
Row information 3 OI PS (10 byte)	HC	TS
Row information 4 OI PS (10 byte)	HC	TS
Row information 5 OI PS (10 byte)	HC	TS

Figure 1. The format of the operational information of the navigation message of the PS

The beacon frame has a duration of 10 seconds and consists of five lines with a duration of 2 seconds each. Within each frame, the total volume of the operational digital information (DI) for the given PS is transmitted. The information line of 2 seconds (100 bits) is divided into 2 parts. The first part of the line (1,7 s) contains the navigation information (85 bits), of which the top 77 bits (transmitted first) contain the operational information, and the lower 8 digits - the verification symbols (the Hamming code (HC)). In the second part of the line (0,3 s), PRS time stamp (TS) consisting of 30 symbols with a duration of 10 ms is used as a sequence. Separation of digital information strings is carried out using timestamps. Words of the DI are written with the higher order bit digits on the left. The highest order bit forward carries out the transmission of the DI from the PS to the consumer. All the data of the navigation message PS are presented in the direct code [7].

3. Formation of navigation signals of pseudosatellites

The generation of the pseudo-random sequence of the navigation signal and the transmission of operational information of the pseudosatellite base station on the basis of the National Instruments hardware and software complex are considered [8]. The base station of the base station is the hardware platform PXI of National Instruments operating under the control of the central computer center. The PS model consists of the following functional nodes (Figure 2):

Vector signal generator NI PX1e-5673E;
- High Frequency attenuator NI PXI-5695;
- Computing controller NI PXIe-8880;
- Chassis NI PXIe-1085;
- NI PXIe-7976R FlexRIO FPGA module;
- GNSS receiver (such as MRK-101).

Figure 2. Appearance of the layout of the pseudosatellite base station

The digital signal synthesizer, located in arbitrary waveform generators NI PXIe-5450, is formed by a digital code in phase I (t) and quadrature Q (t) components of the modulating sequence of the navigation signal. This code is generated by the algorithm specified in special software module (subVI) LabVIEW (Figure 3). At the same time, a pseudo-random ranging code is generated in the FPGA and fed to sibVI. By changing the algorithm, it is possible to create a variety of the navigation signal structures and explore their effectiveness.

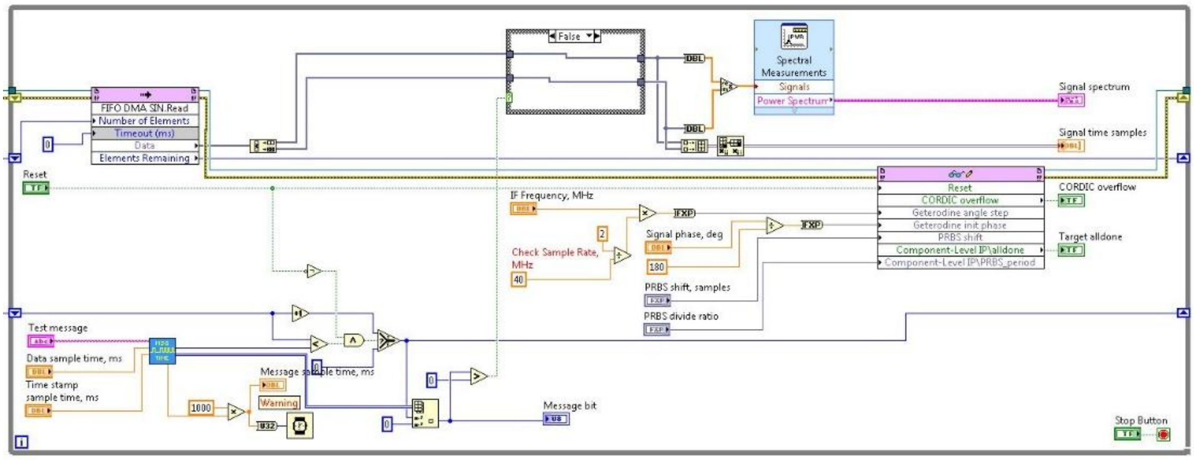

Figure 3. LabVIEW VI block diagram of formation of pseudosatellite navigation signal

The digital code of the modulating sequence of the navigation signal is converted into an analog signal DAC. Phase and quadrature components of the analog signal from the DAC output are filtered by a low-pass filter (LPF) and arrive at the output of the generator of the arbitrary waveform signal. Thus, the output of NI PXIe-5450 formed modulating sequence corresponding to the structure of the navigation signal (Figure 4).

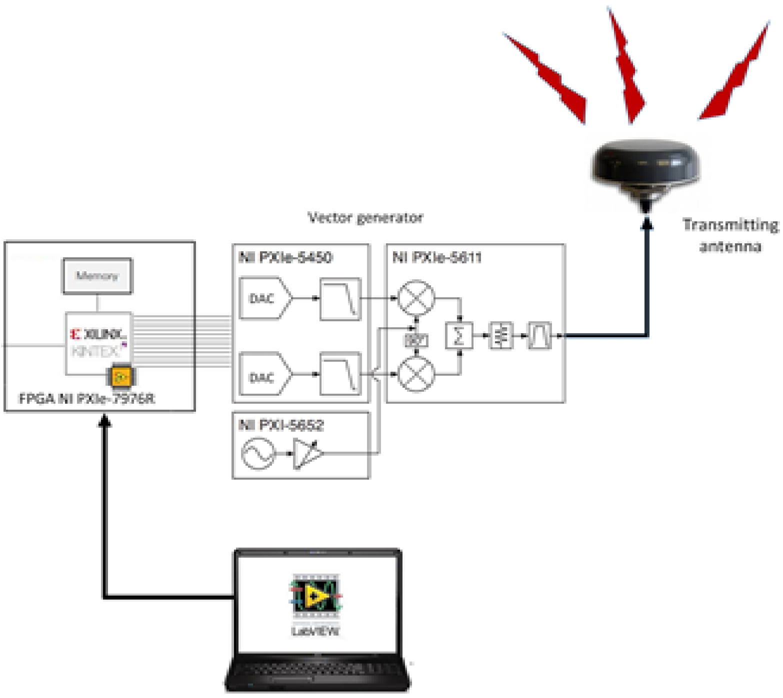

Figure 4. Functional scheme of pseudosatellite model

The dual-channel generator of various in-phase quadrature signals with built-in 512 MB memory is characterized by a 16-bit resolution and a sampling rate of up to 400 megamond/second per channel; the frequency band of the analog signal output is 145 MHz [9]. The transmission rate of continuous data stream is more than 600 MB/s from the main station, the phase noise density is less than minus 146 dBs/Hz, the average noise density is minus 160 dBm/Hz, the inter-channel phase skew is 25 picoseconds, the unevenness is ± 0.15 dB for band 120 MHz. All these characteristics ensure high purity of the spectrum of the emitted navigation signals of the PS.

The vector signal generator NI PXIe-5673 uses direct signal transfer from the main band to the radio frequency range. The inputs of the vector modulator NI PXIe-5611 receive in-phase and quadrature components of modulating sequence navigation signal and a continuous RF signal on the carrier frequency from the high-frequency generator NI PXI-5652.

To solve the problem of navigational provision of consumers, similar to the Global Navigational Satellite System (GNSS) GLONASS, the time scales of the PS must be synchronized, and signals of all PS must be coherent. Therefore, the peculiarity of formation of a highly stable coherent navigation signal PS is the synchronization of all functional units of the vector generator by a highly stable reference signal from a GNSS receiver with a frequency of 10 MHz.

In order to reduce the error associated with the multipath propagation of navigation signals, in conditions of a complex terrain, it is advisable to use directional antennas with the directional pattern of a special shape as the transmitting antennas to create the required navigation field [10].

The basis for the formation of the digital code of the modulating sequence is a field-programmable gate array (FPGA). There are several basic FPGA architectures, each of which has the advantage of either speed of operation or simplicity of implementation. The development of computational architectures working at frequencies of 100–200 MHz requires pipelining calculations. Despite the fact that the pipeline architecture has large overheads for equalizing the delays of the computational blocks, its use is justified when processing and converting signals for solving navigational tasks.

The NI PXIe-7976R module is made in PXI Express format in FPGA KINTEX-7, which provides the best price / performance / watt ratio among 28nm FPGA, offering high density DSP blocks, low-cost chassis and support for widely used interfaces such as PCI Express Gen3 and 10 Gbit Ethernet [9]. FPGA KINTEX-7 in the tasks of digital signal processing provides maximum flexibility, speeding the design of a wide range of applications for the study of short-range navigation systems. The process of formation of the pseudo-random sequence of the navigation signal with the modulation of operational information is to create quadrature components. The law of time variation of the quadrature components corresponds to the polynomial of the code sequence and the digital information transmitted navigation signal. Using the CORDIC processor, which is identical to the pipeline processor, in terms of hardware resources, and operates in a rotating mode, at the same time allows the quadrature components of the pseudorandom sequence of navigation signal I (t) and Q (t) to be obtained immediately [10]. The CORDIC processor operates according to the expressions:

$$\begin{aligned} x^{(i+1)} &= x^{(i)} - d_i y^{(i)} 2^{-i}, \\ y^{(i+1)} &= y^{(i)} + d_i x^{(i)} 2^{-i}, \\ z^{(i+1)} &= z^{(i)} - d_i \tan^{-1} 2^{-i} \end{aligned} \qquad (1)$$

where x=cos (z), y = sin (z), z – target angle, $d \in \{-1, 1\}$.
To accelerate calculations, the intermediate values of $\tan^{-1}2^{-i}$ are calculated in advance and stored in registers. At each iteration, the sign of the intermediate value of the angle is checked, and then the increment of the angle at the next iteration of the conveyor is selected.

The pipeline implementation allows calculating values of I (t) and Q (t) in one clock cycle, and is capable of operating at a frequency of more than 100 MHz.

The flexible programming architecture of LabVIEW allows one to program in the FPGA the necessary ensemble of the pseudo-random sequence of navigation signals and then automatically compile the VI LabVIEW code into VHDL to implement the FPGA logic (Figure 5).

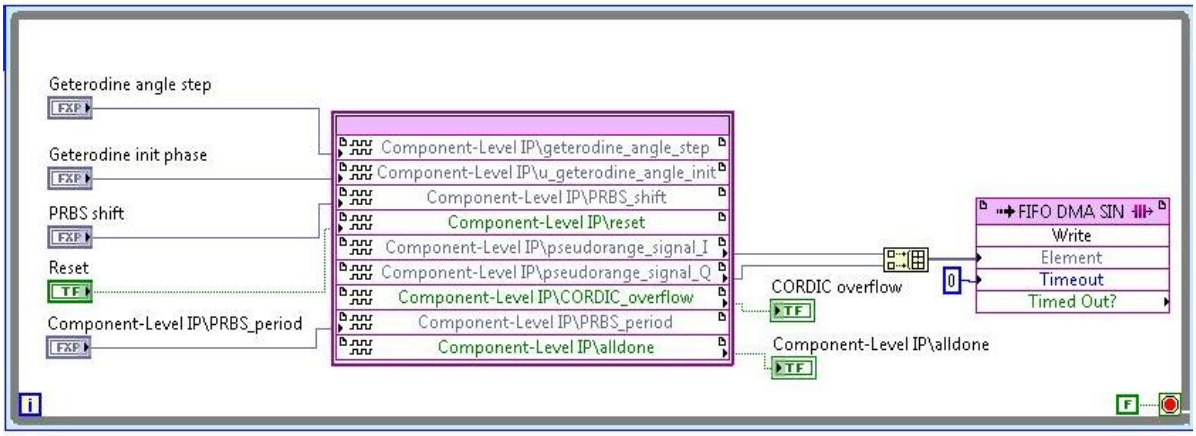

Figure 5. IP compilation unit in VHDL programming language

4. Conclusion

Thus, the developed software and hardware complex allows generating code PDSs based on various polynomials and transmitting, in accordance with the developed format, operational information of the base station's navigation message with the required quality (Fig 6).

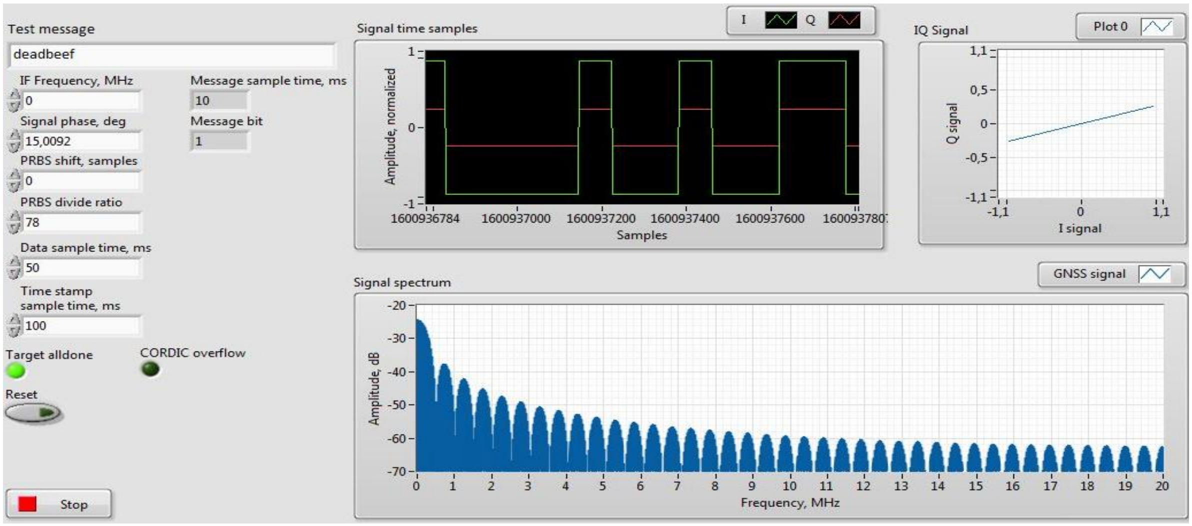

Figure 6. LabVIEW front panel control and monitoring of navigation signal parameters

It is possible to do research on the autocorrelation properties of the PDS and the cross-correlation properties of various code sequences. The created hardware and software complex based on the hardware platform National Instruments provides simulation of the navigation field, the ability to analyze the generated navigation signals, and with the help of LabView programming environment it is possible to implement flexible control of the components of the short-range navigation system based on pseudosatellites and in general to conduct studies on the creation of the radio navigation field.

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