Universal ranging code generator of GLONASS and GPS open navigation signals

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***Abstract*—Satellite navigation systems are used to determine the position and synchronization of users of these systems. Each system includes a satellite constellation in orbit, broadcasting navigation information and signals.**

By estimating the travel time of signals from different satellites to receiver, the user's location can be calculate. Signals include ranging codes to measure propagation delay.

Navigation systems such as GPS and GLONASS include about 30 satellites. Each satellite transmits up to 10 different signals. And each signal has its own ranging code.

In this paper, the universal ranging code generator of open navigation signals is presented. This structure allows the generation of ranging codes for about 75% of all open GLONASS and NAVSTAR GPS navigation signals. Ranging codes generation methods for the existing GNSSs are considered. Initialization parameters to configure the universal generator are also found. In addition, we received different types of navigation signals using the FPGA-based receiver that includes the universal ranging code generator module. As a result, correlation functions of different signals are obtained.

***Index Terms*—Global navigation satellite system, GLONASS, GPS, code generator, ranging code, pseudo-random sequence**

I. Introduction

One of the core functions performed by the navigation receiver is to measure the delay of the received signal. In GNSS the signal is modulated by a pseudorandom sequence to increase the accuracy of the delay measurement. These sequences are known as the ranging (or primary) codes. Such signals are used not only for GNSS, but also for local navigation systems [1].

Navigation systems are gradually expanding, for instance, new types of navigation signals are introduced. Often different types of pseudorandom sequences are used for signals of different types as ranging codes. These codes are described in the ICD for each signal. However, the variety of ranging code generators complicates the development of navigation receivers and reduces the flexibility of configuration. Let's consider in more detail the generators of ranging codes for GLONASS and GPS navigation signals, which are given in the ICD.

II. Types of ranging code generators used in GNSS signals

Signals of the GLONASS and GPS systems can be divided into three groups according to the type of ranging code generators are used:

- generation via linear-feedback shift register (LFSR).
- using pseudo-random memory code sequences.
- generation of ranging codes with using hash functions.

The third group includes closed signals such as M-code. The signals of the second group include for example the GPS L1C signal which uses Weil codes [2]. Different combinations of shift registers are used to generate the ranging codes of the first group. This type of generators is the most numerous about 87% of all open signals using this method of generating sequences. Let's consider the structure of such generators more closely.

The simple structure of the PRN code generator is used to generate the ranging code for signal GLONASS L1OF. This structure consists of a single 9-bit linear-feedback shift register (LFSR) (see fig. 1). Feedback taps are 5th and 9th. The output m-sequence with period $L = 2^9 - 1 = 511$ characters is taken from tap 7. The initial state is "1" in each bit of the register [3].

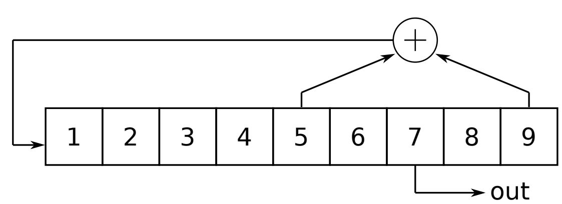

Fig. 1. Structural scheme Gln L1OF ranging code generator

There are two types of the ranging codes which obtained as the modulo-2 sum of two M-sequences – Gold codes and Kasami codes.

The ranging code of the signal GPS C/A this is an example of the Gold code. The generator consists of two LFSR of the same length. In this case 10-bit registers are used, G1 and G2 (see fig. 2). The output sequence is generate by the modulo-2 addition of two sub-sequences, from G1 and G2 registers. Feedback taps are given by polynomials $G1(X) = 1 + X^3 + X^{10}$ and $G2(X) = 1 + X^2 + X^3 + X^6 + X^8 + X^9 + X^{10}$. Output tap of G1 register is – 10th. Output taps of G2 register depend on PRN numbers and are given in the ICD [4], thereby generating a set of different C/A-codes for CDMA.

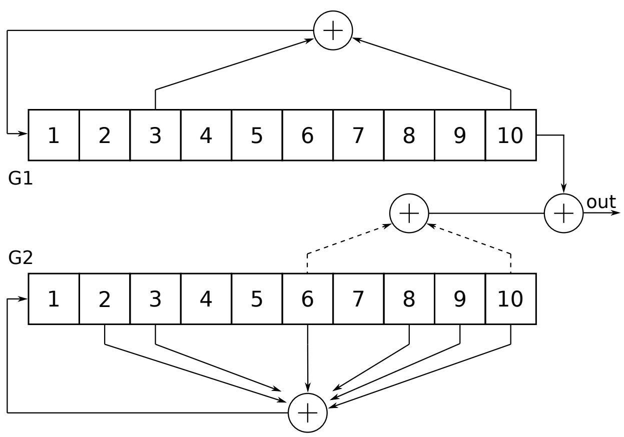

Fig. 2. Structural scheme GPS C/A ranging code generator

The ranging code of the GPS L2C signal is the truncated M-sequence. The initial state of the register is set at the end of each epoch. The code generator in the ICD [4] is given in the Galois configuration (see fig. 3), while most generators are in the Fibonacci configuration. Galois configuration is alternate structure that allows generate the same output stream as a conventional LFSR, but offset in time. Thus, the generator can be converted to a Fibonacci configuration. To do this, we need to find the correct phase of the M-sequence. This means that it is necessary to find the correct initial state of the shift register. Hence, we managed to get the generator in the 27-bit LFSR form (see fig. 4). Feedback taps of this register are given by polynomial $X = 1 + X^3 + X^4 + X^5 + X^6 + X^9 + X^{11} + X^{13} + X^{16} + X^{19} + X^{21} + X^{24} + X^{27}$. The output sequence is taken from the last digit of the register.

The GLONASS L1OC signal pilot component is an example of using Kasami codes as the ranging sequences. These codes generated as the modulo-2 sum of two sequences from two registers [5], 12-bit and 6-bit (the length of one of them is twice as short). Kasami codes are also used in the GLONASS L2OCp signal.

As shown above the LFSR-generators have different structures. They use different feedback taps, different output taps, different initial states. Registers of different bit sizes are used. However all generators have a lot in common. We analyzed all the recommended structures of ranging code generators presented in the ICD for each signal. And we present the structure of the universal generator, which allows generates ranging codes for about 75% of open GLONASS and NAVSTAR GPS navigation signals.

III. Structure of the Universal Ranging Code Generator

Universal ranging code generator (see fig. 5) consists of two 14-bit linear feedback shift registers SR_1 and SR_2. Reset to the initial state occurs at the beginning of each epoch. The initial states of the shift registers are in the corresponding registers CODE_STATE_1 and CODE_STATE_2. The bitmask in the registers CODE_BITMASK_1 CODE_BITMASK_2 sets the feedback taps. The bitmasks in the registers CODE_OUT_BITMASK_1 and CODE_OUT_BITMASK_2 defines output taps. At each cycle of operation, one character of the ranging code is generated. Controlling the frequency of clock pulses to the generator allows controlling the rate of bit generation.

To save resources used by the structure of the universal ranging code generator, two modes of operation are used:

1) two separate 14-bit registers
2) two registers are combined into one and form a 28-bit shift register

The shift registers SR_1 and SR_2 are combined by the flag – ”cons”. At the beginning of work registers are initialized by initial states. Further, the operation of the generator depends on the selected mode.

In the first mode structure of PRN code generator consist of two m-sequence generators with different

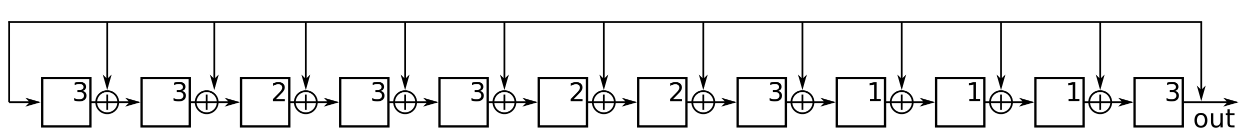

Fig. 3. Structural scheme GPS L2C ranging code generator in Galois configuration

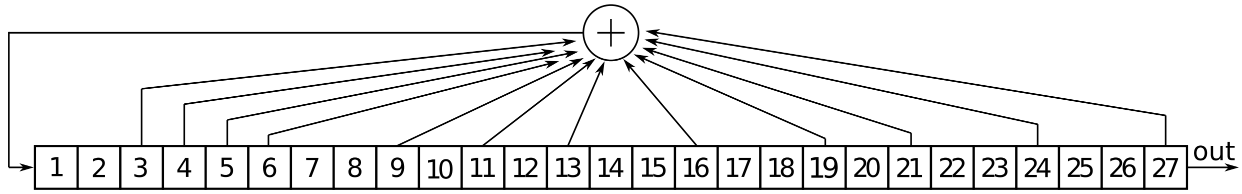

Fig. 4. Structural scheme GPS L2C ranging code generator in Fibonacci configuration

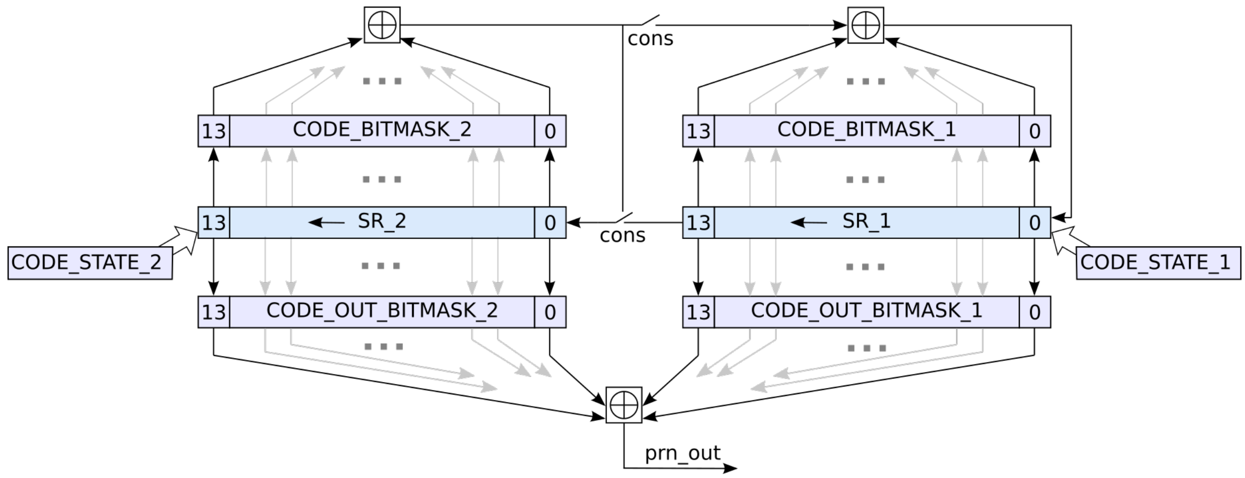

Fig. 5. Structural scheme of the universal code generator

initial states and different feedback taps. At each step, the bits defined by the registers CODE_BITMASK_1 and CODE_BITMASK_2, are summed modulo 2. Further, registers SR_1 and SR_2 are shifted to the left. The calculated bits are written to the lower digits of the corresponding shift registers.

In the second mode, two shift registers are combined into one. Thus we get one 28-bit shift register. This structure allows the generation ranging code of signals that require a 27-bit register.

Shift registers SR_1 and SR_2 are shifted to the left during each operation cycle. Bits defined by the bitmasks in registers CODE_BITMASK_1 and CODE_BITMASK_2 are modulo-2 summed. The calculated bit is written to the least significant bit SR_1. And the most significant bit of SR_1 is written to the least significant bit of SR_2.

In each mode the output sequence is formed by modulo-2 sum of bits defined by the bitmasks in registers CODE_OUT_BITMASK_1 and CODE_OUT_BITMASK_2.

IV. The initialization parameters of the universal ranging code generator

The setting of the universal generator is carried out by writing the control words corresponding to different signals to the registers.

Tables I-II show the initializing parameters of the universal generator for different GNSS signals. All control words can be divided into two groups. The first three words: bitmask1, bitmask2, out bitmask1 depend only on the type of signal, while: out bitmask2, code state1, code state2 depend on the signal type and the number of PRN sequence (i.e., the number of satellite).

For control words that depend on the number of PRN sequence, the cumulative mask is shown in the table. This mask allows identify which bits are used to generate codes for all PRN code numbers. The row ”Summary” shows all bits used for generation all signal types of each system and all PRN code numbers.

As shown in tables I-II, registers bitmask1, bitmask2 and out bitmask1 accepts only 7 different states. Thus, the initialization of these registers can be presented as a 3-bit word. This replacement can reduce the resource consumption in the implementation of the universal generator in a ASIC.

TABLE I

THE INITIALIZATION PARAMETERS – GLONASS

Signal	***bitmask1***	***bitmask2***	***out bitmask1***	***out bitmask2***	***code state1***	***code state2***
LxOF	00000100010000	–	00000001000000	–	00000111111111	–
L1OCd	00001001000000	00001101000100	00001000000000	00001000000000	00000001001100	{00001111110000}
L1OCp	00110010100000	00000000100001	00100000000000	00000000100000	00101000110000	{00000000111111}
L2OCp	11000010001000	00000001100000	10000000000000	00000001000000	00011100101100	{00000001111111}
L3OCd	11000010001000	00000001100000	10000000000000	00000001000000	00011100101100	{00000001111110}
L3OCp	11000010001000	00000001100000	10000000000000	00000001000000	00011100101100	{00000001111110}
Summary	11111111111000	00001101100101	10101001000000	00001001100000	00111111111111	{00001111111111}

TABLE II

THE INITIALIZATION PARAMETERS – GPS

Signal	***bitmask1***	***bitmask2***	***out bitmask1***	***out bitmask2***	***code state1***	***code state2***
C/A	00001000000100	00001110100110	00001000000000	{00001111111111}	00001111111111	00001111111111
L2C CM	01001001010010	01010100111100	01000000000000	00000000000000	{01111111111111}	{11111111111111}
L2C CL	01001001010010	01010100111100	01000000000000	00000000000000	{01111111111111}	{11111111111111}
L5 I	01101100000000	01100011101101	01000000000000	01000000000000	01111111111111	{01111111111111}
L5 Q	01101100000000	01100011101101	01000000000000	01000000000000	01111111111111	{01111111111111}
Summary	01101101010110	01111111111111	01001000000000	{01001111111111}	{01111111111111}	{11111111111111}

V. CORRELATION FUNCTIONS OF THE GNSS SIGNALS

To verify the correctness generation of sequences, we conducted experiments to receive different types of navigation signals with different types of ranging codes. The universal ranging code generator was implemented as the SystemVerilog module as part of the navigation receiver software. The stand (see fig. 6) consisting of the FPGA-based navigation receiver Clonicus based on SoC Zynq-7030 developed by the Navigation Systems Laboratory, the imitator and the PC was used to conduct the experiments.

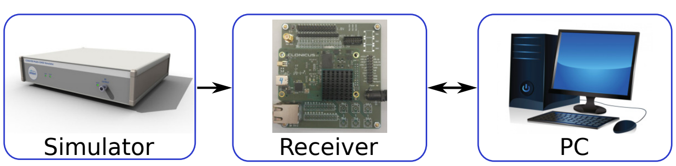

Fig. 6. Structural scheme of the stand

To exchange data with the receiver, a binary information exchange protocol is used. This protocol supports the transmission of 1-ms correlation sums of a selected channel to a PC. Correlation functions of envelopes of different signals were produced from these data. The figures 7-8 show the results for GLONASS L1OCd and L2OCp, respectively.

The form of correlation functions corresponded to the estimated one. It confirmed the correct generation of ranging codes.

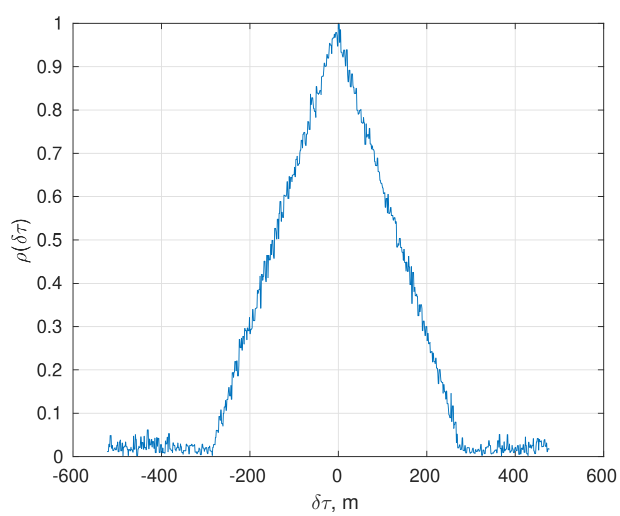

Fig. 7. Correlation function of the GLONASS L1OCd signal

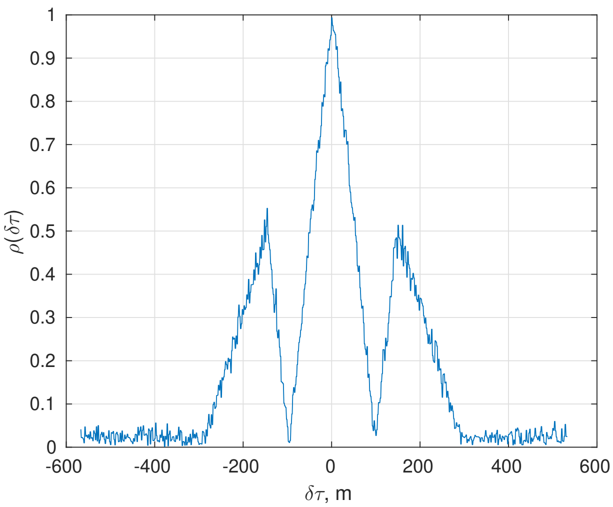

Fig. 8. Correlation function of the GLONASS L2OCp signal

VI. Versatility of the Universal Ranging Code Generator

The structure of the universal generator allows to generate ranging codes for the majority of navigation signals which use LFSR based PRN code generators, but, nevertheless, not all. This structure does not allow the generation of GPS P-code. Table III shows the total number of signal types in each system, as well as the number supported by the proposed generator.

TABLE III
Open signals covered by the universal PRN code generator

Signal	*Open signals*	*Signals with LFSR-based generator*	*Possible to generate*	*Unable to generate*
GLONASS	7	7	7	0
GPS	9	7	5	4
Summary	16	14	12	4

As shown in table, the universal generator supports 75% of the types of open signals of these systems.

VII. Conclusion

Analysis of the structures of the PRN code generators GLONASS and GPS navigation signals allowed to find commonality in different generators and to find the universal generator structure. The generator allows forming sequences for Gln L1OF, Gln L2OF, Gln L1OCd, Gln L1OCp, Gln L2OCp, Gln L3OCd, Gln L3OCp, GPS C/A, GPS L2 CM, GPS L2 CL, GPS L5 I, GPS L5Q signals, i.e., more than 70% of open signals. The initializing parameters for configuring the universal generator for the various types of codes are given. Recommendations for further optimization of the universal generator are formulated.

A series of experiments to receive signals with different types of ranging codes enabled us to check the correctness of the generated codes. As a result, estimated correlation functions were obtained.

Acknowledgment

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