A Low-Cost GPS Satellite Signal Baseband System Using FPGA Prototyping

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ABSTRACT

The Global Positioning System (GPS) has been widely used in life, such as automobile, airplane and mobile phone. To verify the received function of GPS receiver, we design a simplified four-channel GPS Digital Satellite Signal (GPS-DSS) baseband system using a low-cost FPGA prototyping which includes design of C/A code generator, navigation messages processing and Bipolar-Phase Shift Keying (BPSK) baseband modulation. Experimental results shown that our proposed baseband system only used 10 percent of slices in Xilinx Xc2s50e FPGA resource.

1: INTRODUCTION

The *Global Positioning System* (GPS) was used in military application in early time. The GPS has been used in civil industries recently. The GPS application in civil industry are more than in military application, such as navigation for vehicles, airplanes, transport ships and building measurement and so on. The GPS has already become mainstreams for navigated of the accessory. The GPS may be indispensable application for mobile telecommunication of 3G in the future, such as hand-held electronic product.

The GPS signal position precision will be affected by external environments such as urban canyons and valleys. The testing signal for GPS receiver can be generated by a GPS *Digital Satellite Signal* (GPS-DSS) baseband system. Therefore, developing a GPS-DSS baseband system is very useful for testing the position correction of GPS electronic product in this state. Moreover, only a few companies research about GPS signal simulator at present includes Chroma, Spirent, Rohde-Schwarz, IFR and Agilen. These companies mainly develop single channel GPS signal simulator. Because the testing instrument of multi-channel GPS signal simulator is expensive. Therefore, developing a low-cost and flexible four-channel GPS Digital Satellite Signal baseband system is very urgent. Therefore, we propose a simplified four-channel GPS-DSS baseband system for testing the position capability of the GPS receiver.

The rest of this paper is organized as follows. In Section 2, we discuss related work of GPS systems. The proposed four-channel GPS-DSS baseband system architecture will be described in Section 3. In Section 4, we discuss experimental results. Finally, we conclude this paper in Section 5.

2: RELATED WORK

The GPS navigation system was widely applied in our life. A lot of mobile devices have embedded the GPS function. The GPS system can mainly be divided into three parts [1] which are space segment, control segment and user segment. However, the service of GPS system has includes *Standard Positioning Service* (SPS) and *Precise Positioning Service* (PPS). But PPS was used by Ministry of National Defense of U.S.A., and does not open to the civil industries. The satellite transmitted the format of navigation message and the mixed method of navigation message with *Coarse/Acquisition* (C/A) code is described as follows.

The precision of SPS was described in [2]. The GPS satellite signal will be interfered by the atmosphere during the process of signal conveying. Therefore, the receiver receiving unhealthy satellite signal will reduce the precision of positioning definitely. In addition, the C/A code added *Selective Availability* (SA) effect, so the question of precision positioning always perplex researcher in early time.

The drawback of GPS positioning system may be obstructed by buildings or foliage which detail is described in [3] and [4]. *Pseudolites* (PL) are simulation factual satellite launchers that are another auxiliary technology for GPS positioning. Generally receiving four satellite signals can position for GPS receiver, but the GPS receiver is easy to be blocked by the influences of external factor, such as building. So the PL can help to position for GPS receiver. Hence satellite signal combines with the extra PL signal that will improve precision of the positioning.

The dual-band pseudo-satellite launcher [5] includes the $L1$ carrier (1575.42 MHz) and the $L2$ carrier (1227.60 MHz), respectively. The $L1$ carrier is used for code modulation in the military or civil. The $L2$ carrier is used for the code modulation only in the military. The research uses digital logic and *Radio-Frequency* (RF) circuits to generate pseudo-satellites signal, where the digital logic circuit major in order to produce of code

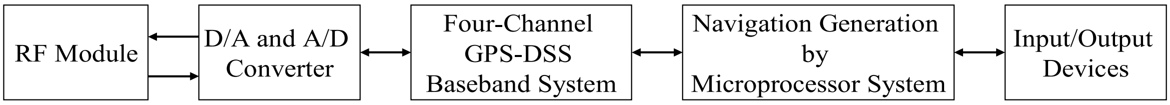


Fig. 1. Four-channel GPS-DSS simulator architecture

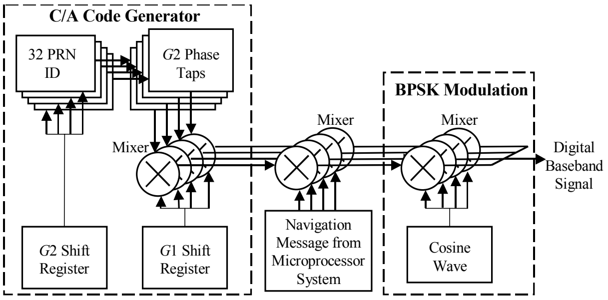


Fig. 2. Simplified four-channel GPS-DSS baseband system

and control *Phase-Locked-Loop* (PLL) and RF circuitmajor use microwave passive components to implement. The multi-channel GPS simulator using traditional approach to design and implement was proposed in [6]. The [6] is purposed to generate different satellite baseband signal to estimate position correctness of the GPS receiver. Hence, if the system wants to set up four-channel then the system cost will be expensive. In our goal is to design a low-cost system. Therefore, we propose a new architecture of GPS-DSS baseband system which can satisfy the cost demand for GPS measure instrument.

3: SYSTEM ARCHITECTURE OF FOUR-CHANNEL GPS SATELLITE SIGNAL BASEBAND SYSTEM

A four-channel GPS-DSS simulator architecture consists of GPD-DSS baseband systems, microprocessor system, input/output devices, A/D and D/A converter and RF module which are shown in Fig. 1. The GPS-DSS baseband systems are adoption *Time Division Multiple* (TDM). The navigation message of GPS-DSS simulator is generated by microprocessor system. The function of GPS-DSS baseband system is to generate C/A code, mix navigation message with C/A code and module by *Biphase-Shift Keying* (BPSK) and implement using FPGA. The modulated navigation signal will be transmitted by RF modulation on $L1$ carrier. The GPS receiver will receive the pseudo GPS satellite signal for function testing and verification.

The simplified four-channel GPS-DSS baseband system for GPS-DSS simulator is shown in Fig. 2. The simplified four-channel GPS-DSS baseband system consists of C/A *Code Generator*, *Navigation Message*, BPSK *modulation* and *mixer*. We reduce the FPGA resource usage in the four-channel GPS-DSS baseband system using IP reuse concept, as $G1$ shift register, $G2$ shift register and cosine wave generation circuit. Traditionally, the four-channel GPS-DSS baseband system needs four C/A code generators and four BPSK modulations. In this paper, we reduce the *Direct Digital Synthesis* (DDS) in the BPSK modulation and the shift registers in the C/A code generator, as shown in Fig. 2. The FPGA resources and cost of the simplified four-channel GPS-DSS baseband system are less than [6].

```
Procedure SVID     /* main procedure*/
begin
   setting the number of SV and navigation message;
   for 1 to n          /* n is amount of satellite*/
   begin
      decode the number of SV;
      C/A code generation();
      Mix navigation message with C/A code;
      BPSK modulation();
   end for;
end procedure;      /*end of main*/
------------------------------------------------------------
Procedure C/A code generation
begin
   setting reset is 1, let all registers are1;
   reset equal 0 is start;
   combine the outputs of G1 shift register and G2 shift
   register;
   generate C/A code;
end procedure;                    /*end of generation*/
------------------------------------------------------------
Procedure BPSK modulation
begin
   if (message=1)
      output=cos;
   else
      output=-cos;
   end if;
end procedure;                    /*end of modulation*/
```

Fig. 3. The algorithm of simplified four-channel GPS-DSS baseband system

Navigation messages in GPS-DSS baseband system include ephemeris data of satellites, track information etc. We mainly focus on the design of C/A code generator, mixer and BPSK modulation. The navigation massages generates from microprocessor system, but we do not discuss it in this paper.

The algorithm of simplified four-channel GPS-DSS baseband system is shown in Fig. 3 and describe as follows. In Procedure SVID, the main procedure process the setting of *Satellite Vehicle* (SV) number, mixing C/A code and navigation message include two procedure called as C/A code generation() and BPSK modulation(). The signal of mixed C/A code and navigation message will be modulated using BPSK. The C/A code generator, mixer and BPSK modulation will be described in the following subsection. Finally, we use hardware description language, Verilog, to implement our proposed simplified four-channel GPS-DSS baseband system.

Table 1. C/A code assignments

SV PRN ID	G2 Phase Taps	First 10 chips	SV PRN ID	G2 Phase Taps	First 10 chips
1	2 & 6	1101000000	17	1 & 4	1001101110
2	3 & 7	1110010000	18	2 & 5	1100110111
3	4 & 8	1111001000	19	3 & 6	1110011011
4	5 & 9	1111100100	20	4 & 7	1111001101
5	1 & 9	1001011011	21	5 & 8	1111100110
6	2 & 10	1100101101	22	6 & 9	1111110011
7	1 & 8	1001011001	23	1 & 3	1000110011
8	2 & 9	1100101100	24	4 & 6	1111000110
9	3 & 10	1110010110	25	5 & 7	1111100011
10	2 & 3	1101000100	26	6 & 8	1111110001
11	3 & 4	1110100010	27	6 & 9	1111111000
12	5 & 6	1111101000	28	8 & 10	1111111100
13	6 & 7	1111110100	29	1 & 6	1001010111
14	7 & 8	1111111010	30	2 & 7	1100101011
15	8 & 9	1111111101	31	3 & 8	1110010101
16	9 & 10	1111111110	32	4 & 9	1111001010

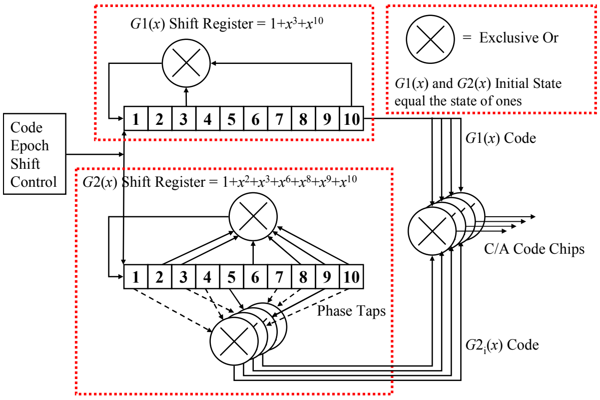


Fig. 4. Four-channel C/A code generator

3.1: COARSE/ACQUISTION CODE GENERATOR

Each satellite transmits a satellite signal that consists of a set of navigation message and a set of independent C/A code which works at 50 bps and 1.023MHz, respectively. Moreover, C/A code is one kind of them of *Pseudo Random Noise* (PRN) code. Each satellite has a regular PRN code. Therefore, receivers can recognize different satellites utilizing PRN code. The C/A code generator structure is shown in Fig. 4. The C/A code chips pattern is the exclusive-or (XOR) of two 1023-bit patterns, $G1(x)$ code and $G2_i(x)$ code. The $G1(x)$ and $G2(x)$ sequences are generated by ten stages shift register which are shown in the following equations (1) and (2) as referred to the shift register input. The $G2_i(x)$ patterns are achieved by combining the output of two stages of the $G2(x)$ shift register by exclusive-or. Because each satellite had the same $G1(x)$ and $G2(x)$ sequences, hence only one set of $G1(x)$ and $G2(x)$ sequences are need in the four-channel GPS-DSS baseband system.

$$G1(x) = 1 + x^3 + x^{10} \tag{1}$$

$$G2(x) = 1 + x^2 + x^3 + x^6 + x^8 + x^9 + x^{10} \tag{2}$$

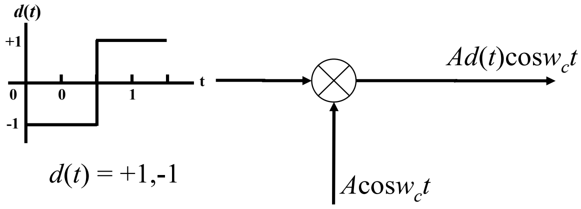


Fig. 5: BPSK modulator structure

Thirty-two SV PRN ID are generated by Table 1. Table 1 contains tabulation of the $G2(x)$ shift register phase taps, corresponding SV PRN ID and first ten of C/A code. For example, executing the exclusion-or both phase taps 5 and 9 are transmitted data of PRN ID 4 which is presented by full lines in Fig. 4.

The $G2_i(x)$ code phase selection generate 32 satellites PRN code according to $G2(x)$ phase taps in Table 1. The four exclusive-or are used to choose four satellites PRN code among a set of 32 satellites in $G2(x)$ shift register. The C/A codes are generated by the exclusive-or of $G2_i(x)$ code and $G1(x)$ code, where $G2_i(x)$ code are selection satellite 4, 9, 14 and 17 PRN ID, respectively. The GPS satellite signal is generated by the exclusive-or C/A code and navigation message, where the navigation message is generated by microprocessor system.

3.2: BPSK MODULATION

The GPS space vehicles (SVs) transmit two carrier frequencies call $L1$, the primary frequency, and $L2$, the secondary frequency. The carrier frequencies are modulated by spread spectrum codes with a unique PRN sequence associated with each SV and by the navigation data message. The civil application only uses the signal of $L1$. However, $L1$ signal must mix $L1$ carrier, C/A code and navigation message. The BPSK modulation is shown in Fig. 5. The input of BPSK modulator is from the exclusive-or output of C/A code and navigation message. The output of BPSK modulator can generate a modulation signal for exclusive-or the C/A code and navigation message. When input of BPSK modulator is high ($d(t) = +1$) then output is normal-phase cosine wave. When input of BPSK modulator is low ($d(t) = -1$) then output is reversed-phase cosine wave. In Fig. 5, the w_c represents signal carrier frequency namely $L1$ frequency, but the carrier frequency is established 1.023 MHz in this work. We use Xilinx System Generator V7.1 to generate Verilog code for cosine wave function.

3.3: TEST PLATFORM

The test platform architecture with spectrum analyzer for our proposed simplified four-channel GPS-DSS baseband system is shown in Fig. 6. The outputs of simplified four-channel GPS-DSS system are GPS satellite baseband signals which are connected to logic analyzer and Rohde & Schwarz SMIQ. The logic analyzer is to measure the accuracy of satellite signal. However, the GPS satellite baseband signal will be modulated on the frequency of $L1$ carrier by Rohde & Schwarz SMIQ and then transmits to spectrum analyzer and observe the result.

To verify verification the transmission function in our proposed system, we replace spectrum analyzer, and in Fig. 6 by GPS receiver and GPS testing software which architecture is shown in Fig. 7. After the GPS satellite baseband signals are modulated on the frequency of $L1$ carrier by Rohde & Schwarz SMIQ, the GPS satellite baseband signals will be transmitted to GPS receiver. Finally, the check of the receiver's accuracy is received the GPS satellite signal by GPS testing software.

4: EXPERIMENTAL RESULTS

The simulation of simplified four-channel GPS-DSS baseband system will be simulated by *ModelSim SE* 5.7g. The C/A code generator simulation is setting at the satellite 32, as shown in Fig. 8(a) and 8(b). We compare the difference the results of C/A code between beginning as Fig. 8(a) and running after 1ms as Fig. 8(b). The results in Fig. 8(a) and 8(b) are the same as in the first 10 chips in Table 1. The C/A code each period is 1ms. Finally, SV 4, SV 9, SV 14 and SV 17 are generated in the four-channel GPS-DSS baseband system and the output signals are shown in Fig. 9.

We use Xilinx Xc2s50e FPGA to implement our proposed simplified four-channel GPS-DSS baseband system. The system testing architectures are shown as Fig. 6 and Fig. 7, and they both choose the SV 21 to test and verify the system function. We use spectrum analyzer to measure the output modulation signal in our proposed simplified four-channel GPS-DSS baseband system and the test platform shown in Fig. 6. To easily to check the result, we show the one channel modulation signal measured result in Fig. 10.

To verify our proposed system working properly, we use GPS receiver and GPS testing software to receive the output RF signals from our proposed four-channel GPS-DSS baseband system and RF transmitter, Rohde & Schwarz SMIQ which testing platform shown in Fig. 7. The testing results are shown in Fig. 11 and the SV 21

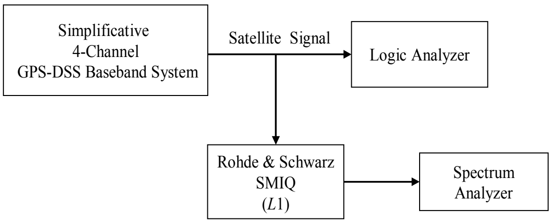


Fig. 6. Test platform architecture with spectrum analyzer

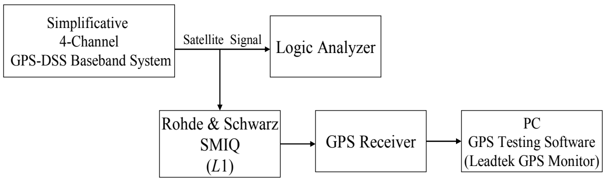


Fig. 7. Test platform architecture with GPS receiver and testing software

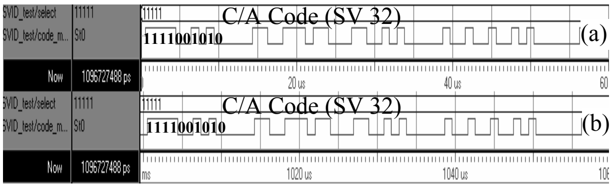


Fig. 8. Verification the signal of C/A code (a) at the beginning (b) after 1ms

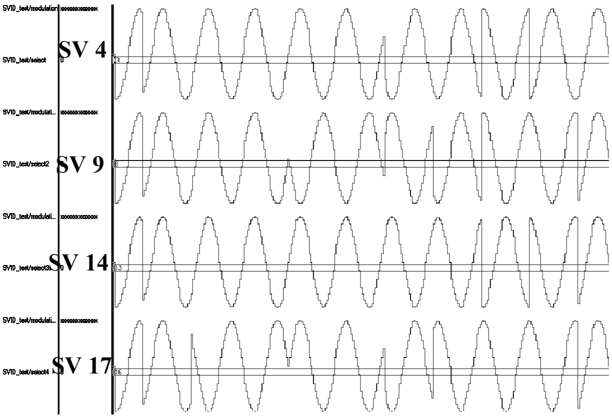


Fig. 9. The output modulation signals of simplified four-channel GPS-DSS baseband system

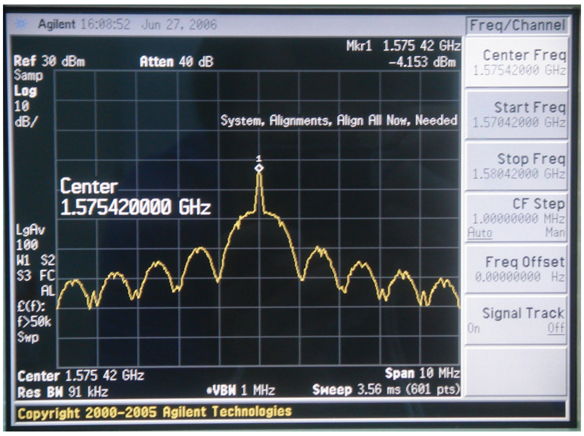
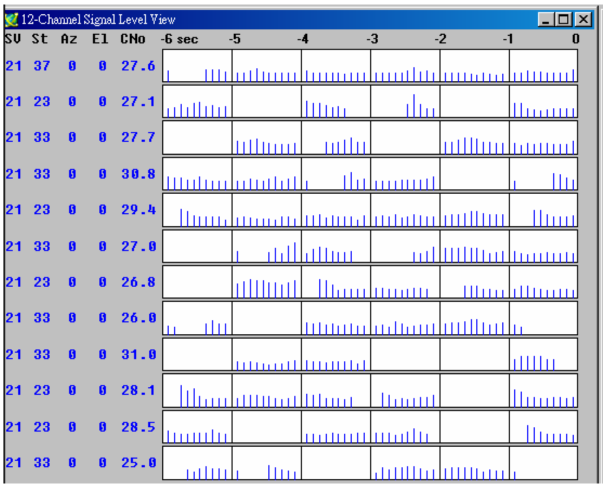


Fig. 10. The one channel modulation signal for simplified four-channel GPS-DSS baseband system on *L*1 carrier with spectrum analyzer



SV	St	Az	El	CNo
21	37	0	0	27.6
21	23	0	0	27.1
21	33	0	0	27.7
21	33	0	0	30.8
21	23	0	0	29.4
21	33	0	0	27.0
21	23	0	0	26.8
21	33	0	0	26.0
21	33	0	0	31.0
21	23	0	0	28.1
21	23	0	0	28.5
21	33	0	0	25.0

Fig. 11. The satellite receives state on the SV 21 by GPS testing software

Table 2. Resource used in Xilinx Xc2s50e for GPS-DSS baseband system

	Proposed			[6]		
Items	Total	Usage	Used Rate	Total	Usage	Used Rate
Slices	768	83	10%	768	165	21%
Flip Flops	1536	83	5%	1536	111	7%
4-input LUTs	1536	152	9%	1536	299	19%
Bonded IOBs	146	83	56%	146	137	93%
GCLKs	4	2	50%	4	2	50%

signals are correctly received in this experiment. For comparison the implementation results for GPS-DSS baseband system, we implement our proposed and [6] architectures. The experimental results are shown in Table 2. From Table 2, the used FPGA slices, Flip-Flops and LUTs in our proposed architecture are reduced than the related architecture [6]. Specially, our proposed architecture only uses 10 percent of slices in the Xilinx Xc2s50e.

5: CONCLUSIONS

The GPS Digital Satellite Signal (GPS-DSS) simulator is used to generate satellite signals to verify the function of GPS receiver. The satellite signals are processed and generated by GPS-DSS baseband system. A low-cost simplified four-channel GPS-DSS baseband system is proposed and which includes design of the C/A code generation, navigation messages processing and BPSK modulation used by FPGA system. Furthermore, the simplified GPS-DSS baseband system allows user to rapidly estimate position correctness of the GPS receiver. In this work, we have reduced FPGA slices usage by using IP reuse concept. Experimental results show that our proposed system only uses 10 percent of slices in a low-cost Xilinx Xc2s50e FPGA resource.

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