Time Synchronizing Signal by GPS Satellites

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Abstract: -In many industrial and trading activities such as navigation, mapping, power distribution, telecommunication, weather station, digital radio, industrial control systems and research centers,… one of the main exchanged information which has been transferred between different parts is time tag, indicats the precise time of action taking place. Synchronization between these tags is the main portion of these systems. With transmitting the time synchronizer signal in determined timing intervals to all of these sections by one common reference, synchronization will be done. This common reference could be accessed by GPS Satellites. In this approach GPS satellite, timing signals, Golden Code, methods of coding and decoding of GPS satellite signals will be introdused. Synchronizing time with precise time calculation on GPS receivers, system simulation in MATLAB from GPS satellite transmitter to receiver and implementing the receiver hardware will be discussed.

Key-Words: - PRN Code, QPSK, Synchronization, Spread Spectrum, Almanac, Ephemeris, C/A & P(Y) code

1 Introduction

A Global Positioning System[1] or Navigation Satellite System consists of more than 24 SVs[2], rotate in middle earth circuit and transmit signals to GPS receivers for determing the precise time, position, speed and direction of movement. The synchronizing time transmitted by GPS will be used as worldwide common reference for the important activities needs the precise time.

For calculating the time synchronization, at least 4 satellites shall be used. Each satellite transmits its own navigation message with distinct spread spectrum codes: the Coarse / Acquisition (C/A) or PRN code. Minimal Cross Correlation, minimum noise and interferers to other PRN codes and high autocorrelation of each PRN code allows all satellites to transmit the signals at the same frequency.Using PRN code the GPS receivers determine the time delay between GPS satellite and receiver. In section 2 method of transmitting and receiving signals, two different carriers L1, L2, types of transmitted information such as Almanac, Ephemeris and timing code information (C/A and P code), QPSK modulation will be verified. PRN Code Generation (C/A & P(Y)) will be introduced in section 3. In section 4 calculation of precise time and location by at least 4 satellites and C/A code will be discussed. Algorithm for calculating the precise time with four GPS satellites and computer simulation in MATLAB comprising the PRN code generator, time delay, QPSK modulator, White Gaussian noise, QPSK demodulator and find delay part for calculating the time delay between GPS transmitter to receiver will be discussed in section 5. The proposed diagram for implementing the GPS receiver and C/A code generation hardware are shown in section 6.

2 Method of Transmitting and Receiving Information

Two different carrier signals have been used in GPS satellites for transmitting information: **L1** with 1575.42 MHZ frequency (2x77x10.23 MHz) for transmitting the Navigation Message, C/A and P Code, **L2** with 1227.60 MHZ (2x60x10.23MHz) for transmitting P-Code and the new code named L2C for estimating the ionospheric delay using modeling parameters. These codes are broadcasted to the receivers in navigation message. In General, GPS satellites transmit three types of information

Almanac:

Almanac data is course orbital parameters. Each SV broadcasts Almanac data for all SVs. This Almanac data is not very precise and is considered valid for up to several months. Almanac data consists of healthy or faulty, current time and date. This information is essential for precise position calculation.

From the almanac data GPS receiver identifies the satellites that are likely to be received from the actual position. Receiver limits its search to these previously defined satellites and hence this accelerates the position determination.

[1] GPS
[2] Space Vehicle

Ephemeris:
Ephemeris data is very precise orbital and clock correction for each SV and is necessary for precise positioning. Each SV broadcasts only its own Ephemeris data. This data is valid for about 30 minutes. The Ephemeris data is broadcasted by each SV every 30 seconds.

Timing Information:

C/A Code:
The Coarse / Acquisition code or C/A is a 1,023 bit long pseudorandom code. It is broadcastd at 1.023 MHz frequency and modulates the L1 signal in phase for generating the widespread spectrum. C/A code is repeatd every millisecond. Each satellite sends a distinct C/A code, which allows it to be uniquely identified.

P-code:
Usually reserved for military applications.
The P-code is a similar code to C/A. It is broadcastd at 10.23 MHz and it repeats only once a week. In normal operation, the so-called "anti-spoofing mode", the P code is first encrypted into the Y-code, or P(Y), which can only be decrypted by units with a valid decryption key. P code modulates L1 and L2 carriers in phase. Navigation Message modulates L1 and C/A codes. 50 bytes/sec Navigation message Data is combined with both the C/A code and P(Y) code prior to modulation with the L1 carrier. This combination uses the XOR process. Since C/A code XOR Data and P(Y) code XOR Data is synchronous operation, the bit transition rate can not exceed the chipping rate of the PRN codes.
The L2 frequency can be modulated by either P(Y) code XOR Data or C/A code XOR Data or with P(Y) code alone as selected by the control segment. P(Y) code and C/A codes are never present simultaneously on L2, as is the case with L1.
In general, P(Y) code XOR Data is the one selected by the control segment. Navigation message Data gives information about the satellite's orbits, their clock corrections and other system status. The P(Y)-code XOR Data is modulated in-phase quadrature[3] with the C/A-code XOR Data.

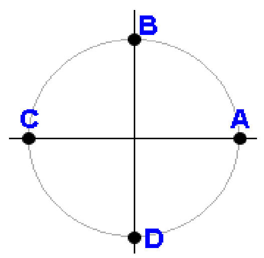


Fig. 1. QPSK modulation with four 90 degree phase region (A, B, C, D)

[3] Quadra Phase Shift Keying

The term "quadrature" implies that there are four possible phases (4-PSK) which the carrier can have at a given time, as shown in figure 1, the four phases are labelled {A,B,C,D} corresponding to one of {0,90,180,270} degrees.

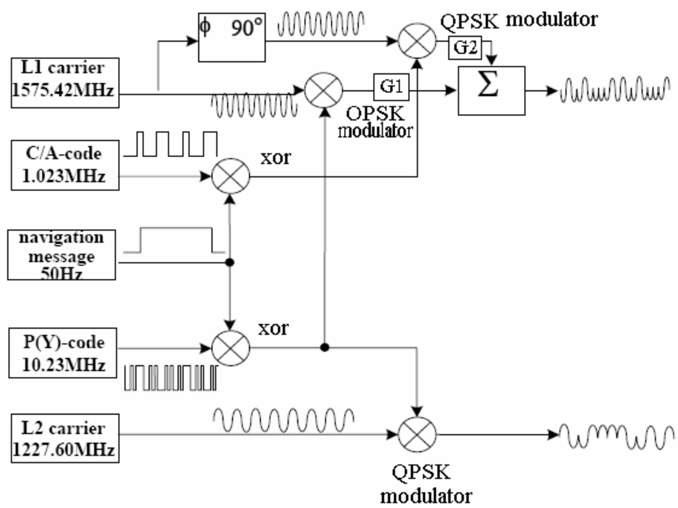


Fig. 2. C/A code and navigation message are mixed and modulates with L1 carrier in QPSK modulator making the GPS satellite signal

3 PRN Code Generation (C/A & P(Y))

GPS satellites broadcast the PRN codes modulated with the other GPS information such as orbital (ephemeris) and clock parameters (see Fig 3). By combining the PRN code with the 50 Hz data, the result signal is spread out over a broad part of the spectrum. (Spread Spectrum).

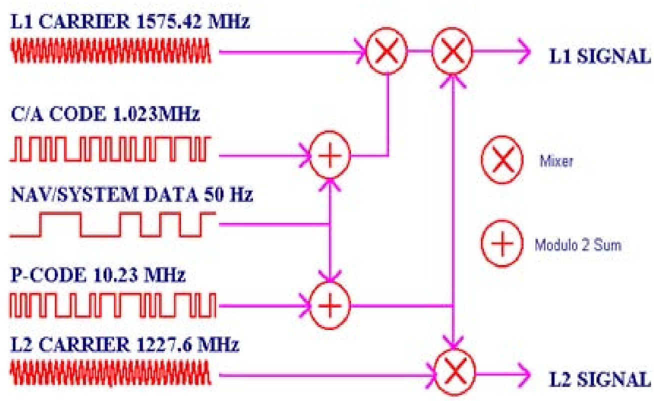


Fig. 3. PRN code modulation with the other GPS data

The result is so that the signal power is very low, even beneath the noise floor. In other words: it is very hard to distinguish the signal from noise.

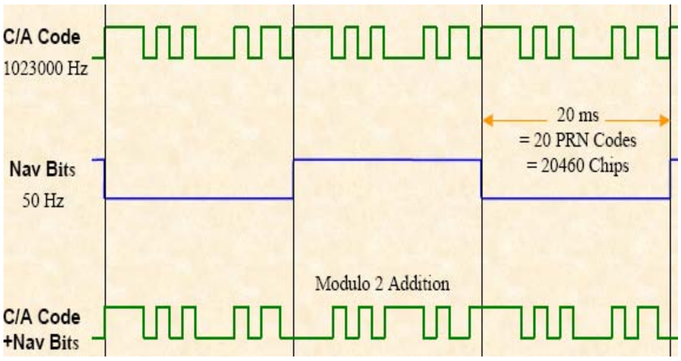


Fig. 4. C/A code and navigation message and combination of them with XOR (module 2 adding)

In the receiver, the PRN Code and GPS data have to be separated. This is done by again mixing the received signal from GPS satellite with a locally generated PRN Code by GPS receiver. This code must be the same as PRN Code which has been generated in the satellite. As these two codes are not synchron with each other and the equal parts of the code should be mixed with each other, so the code generated in the receiver must be shifted in time until the two codes be exactly synchron with each other. In this case the receiver 'locks' (full correlats) and these two codes can block each other out. This method is called despreading. Every satellite has its own unique PRN-code so that the GPS receiver can distinguish the signals from various satellites. GPS receivers are able to generate 32 PRN-codes.
At a time the GPS receiver is started up it couldn't recognize which GPS signal is from which satellite. So receiver make itself to be lock with the 32 known PRN codes one by one. If one code locks then the information of one satellite can be decoded. This information also contains data.
The main reason for using PRN codes in the GPS system is that the PRN code enlarges the unambiguous measurement range. After 1023 bits the code is repeated. In this case the GPS receiver is aware it is 'looking' at the right code and not at its predecessor or successor. Looking at the wrong code gives a navigation error of 300 km (corresponding to the code length of 1 millisecond).

Pseudo Random Noise[4] Codes have random noise characteristics but are precisely defined.
In the other word PRN code is a sequence of zeros and ones (a long series of bits 0's and 1's), each zero or one referred to as a “chip” because they carry no data and doesn't seem to be a regular pattern in the bits. But actually it has regular arrangement. It is Selectd from a set of Golden Codes.

[4] PRN

The codes-patterns repeat after the 1023rd bit. For the 1023 bit pattern 10 shifting registers and some digital adders are needed. In general with n shifting registers a series of 2n -1 bits can be generated. For n = 10 this will become 1024 (= 2^{10}) - 1 = 1023 bits. The codes are generated with a speed of 1.023 MHz (or 1023000 bits per second).
Gold codes use 2 generator polynomials for generating PRN code .
Two “10-bit generator polynomials”(G1 and G2):
G1 = 1 + x3 + x10
G2 = 1 + x2 + x3 + x6 + x8 + x9 + x10
Figure 5 illustrates the two 10-bits for each of two polynomials G1 and G2. At first step 10 initial bits for each polynomial containing the coefficient of each nominal have been considered then the first step bits shift to the right and substitute the left bit with output of XOR of bits (in G1: bits 3 and 10 and in G2: bits 2, 3, 6, 8, 10) C/A cod generates by XOR the first bit of G1 with the XOR result from two bits of G2 that called phase tap. In the following figure tap 3 & 8 has been used for making PRN31.
Selecting two bits (Phase Taps) from G2 polynomial has individually done for each SV according to the following schedule. In this way different C/A codes with unique composition will be prepared for each of the GPS satellites.

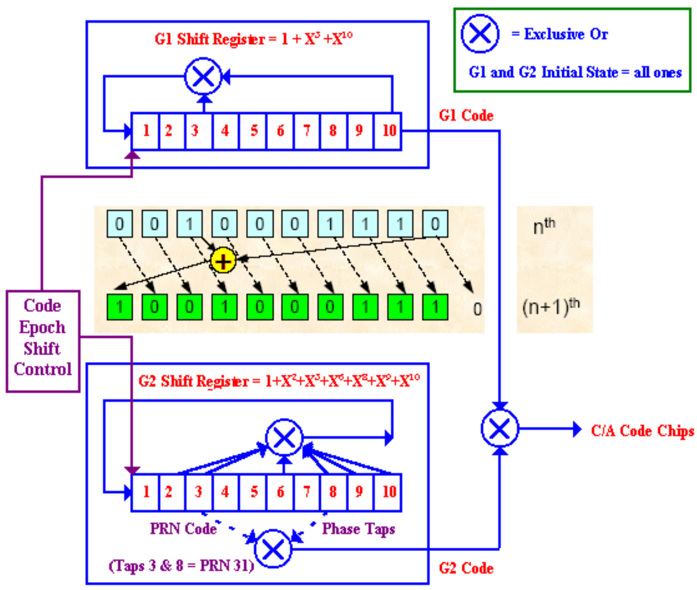


Fig. 5. C/ A generate by two 10 bits generator polynomials

These PRN codes characterized with minimal Cross Correlation to other PRN codes, noise and interferers, high autocorrelation value only at a phase shift of zero which allows all satellites signals to be transmited at the same frequency. Three types of Golden codes have been used by GPS: C/A, P and Y

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. 6. G2 phase taps for 37 GPS satellites for generating C/A codes

4 Calculating Position And Time

Distance between GPS receiver and satellite is calculated by multiplying the travel time of GPS radio signal and velocity which is equal to the speed of light (186,000 miles per second), Distance = Velocity * Time. By calculating the distance between a receiver and one GPS satellite it will be supposed that receiver is located on the surface of sphere centered on the satellite. The radius of sphere is equal to the distance between satellite and receiver. By calculating the distances of receiver from second satellite, the location of GPS to be supposed not only on the first sphere but also on the surface of the second sphere. In the other word the location will be on the circle located at the intersection of two spheres. By calculating the distance of receiver from third satellite the position of receiver will be at one of the two points of intersection between surfaces of three spheres.

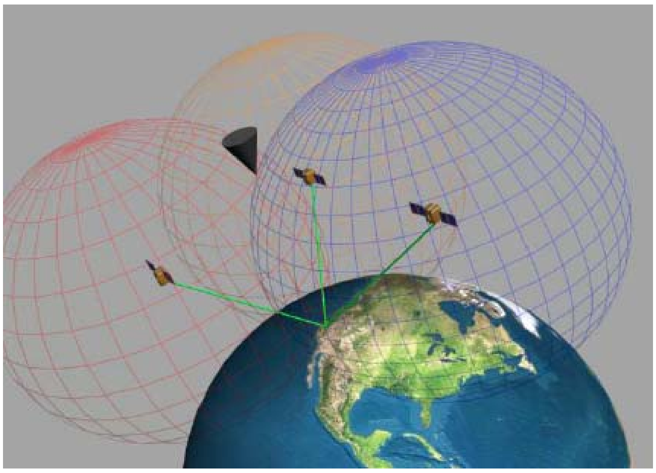


Fig. 7. The accurate location is calculated from distance measurements to at least three GPS satellites

By calculating the distance from forth satellite and intersect the forth sphere with two mentioned points, the precise time and position could be determined.

Each GPS satellite uses multiple atomic clocks for contributing very precise time data of GPS signals. GPS receivers decode these signals and effectively synchronized themselves to the GPS atomic clocks. With this opportunity, users in all around the world can determine the time to within 100 billionths of a second, without the cost of owning and operating atomic clocks.
Each satellite transmits its own navigation message with distinct spread spectrum codes: the Coarse / Acquisition (C/A) code, which is a 1,023 chip pseudo-random (PRN) code at 1.023 million chips/sec. Each satellite has its own C/A code so it can be uniquely identified and received separately from the other satellites transmitting on the same frequency. By supposing a precise time for receiver, a receiver and transmitter send the PRN code simultaneously which are equal. To determining delay, receiver compares the bits sequence received from the satellite with an internally generated C/A code and then calculates delay and distance from GPS Satellite. But as the clock of receiver is not synchron with GPS satellite, the offset (error in calculation of time delay and distance) will be recognized which in turn causes the offset errors in radiuses of four GPS satellites.

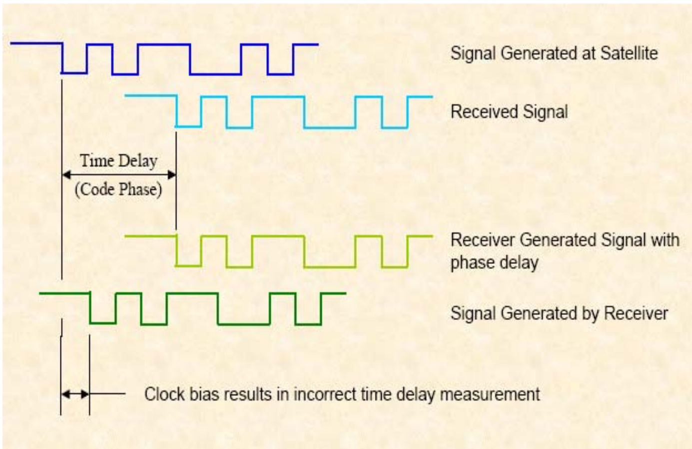


Fig. 8. Receiver clock is not synchron with GPS receiver, which causes the offset error.

GPS receiver changes the offset error in positive and negative direction to lead the four spheres to intersect in one point. In this case the precise time, synchron with GPS atomic clock and real position has been determined.
By comparing the rising and trailing edges of the bit transitions, modern electronics can measure signal offset to within approximately 10 nanoseconds for the C/A code. Since GPS signals propagate at the speed of light,

this represents an error of about 3 meters. This is the minimum error possible using only the GPS C/A signal.

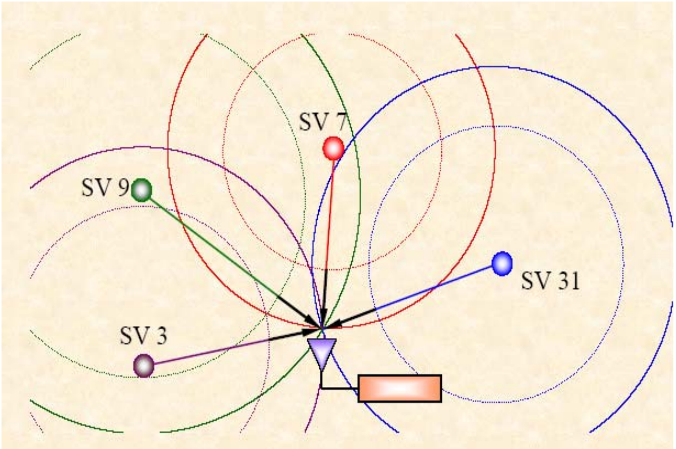


Fig. 9. Bolded spheres indicate the real position and colorless spheres indicate the position which receiver suppose it has. Precise time can be calculated when four spheres intersect in one point.

5 Computer Simulation

Figure 10 illustrates the algorithm of system from GPS satellite transmitter to receiver for precise time calculation. In the first step four PRN codes have been generatd for each of four satellites in GPS satellite transmitter

By these time delayes, distances between receiver and GPS satellites (radiuses of four sphere centered on GPS receiver) are determined.

By considering the offset error, algorithm will be repeated until the intersection of the four spheres in one point taking place.

This point is the real position of receiver. The precise time could be calculated in this case.

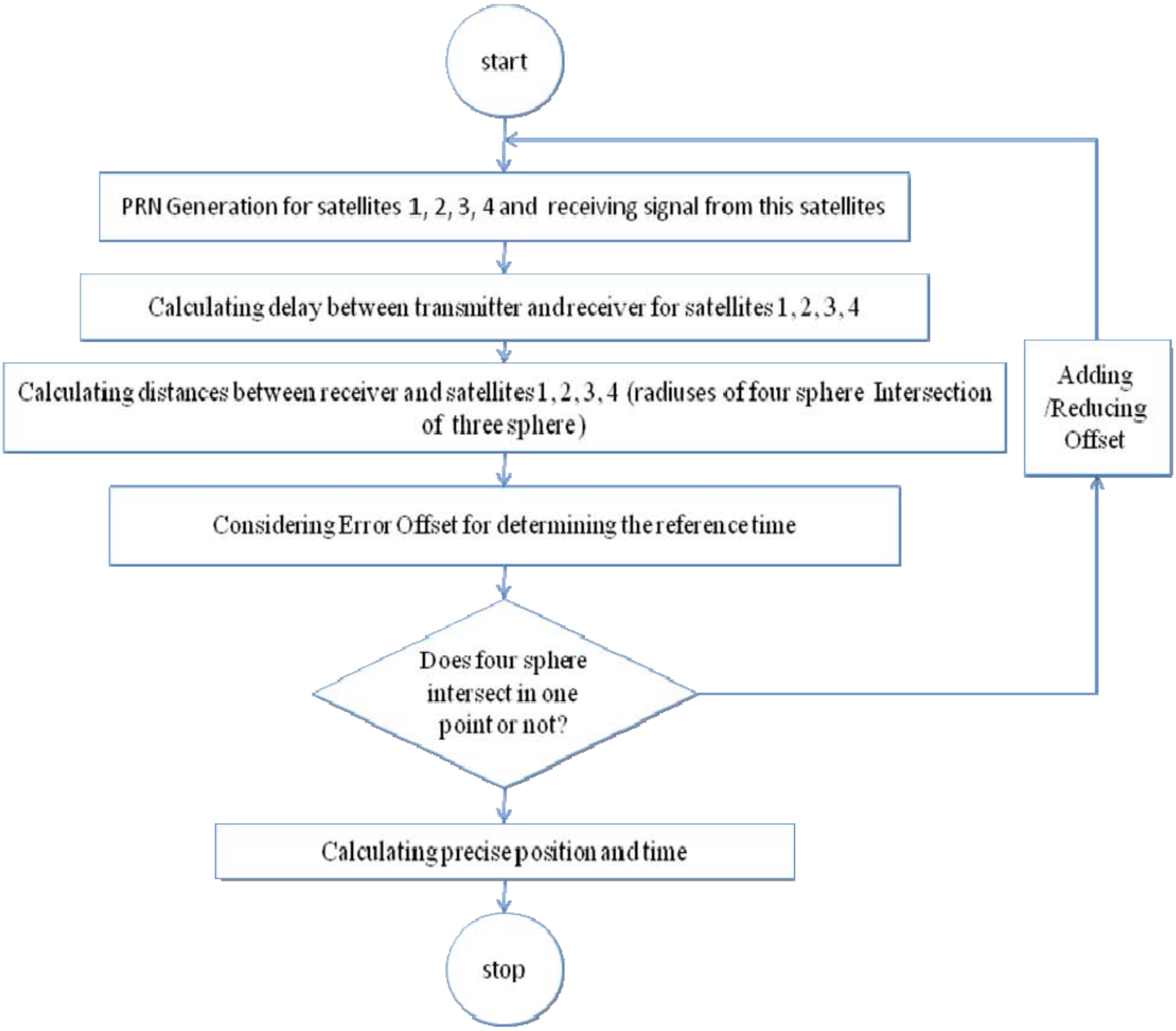


Fig. 10. Algorithm of system for determining the precise time from GPS satellite transmitter to receiver

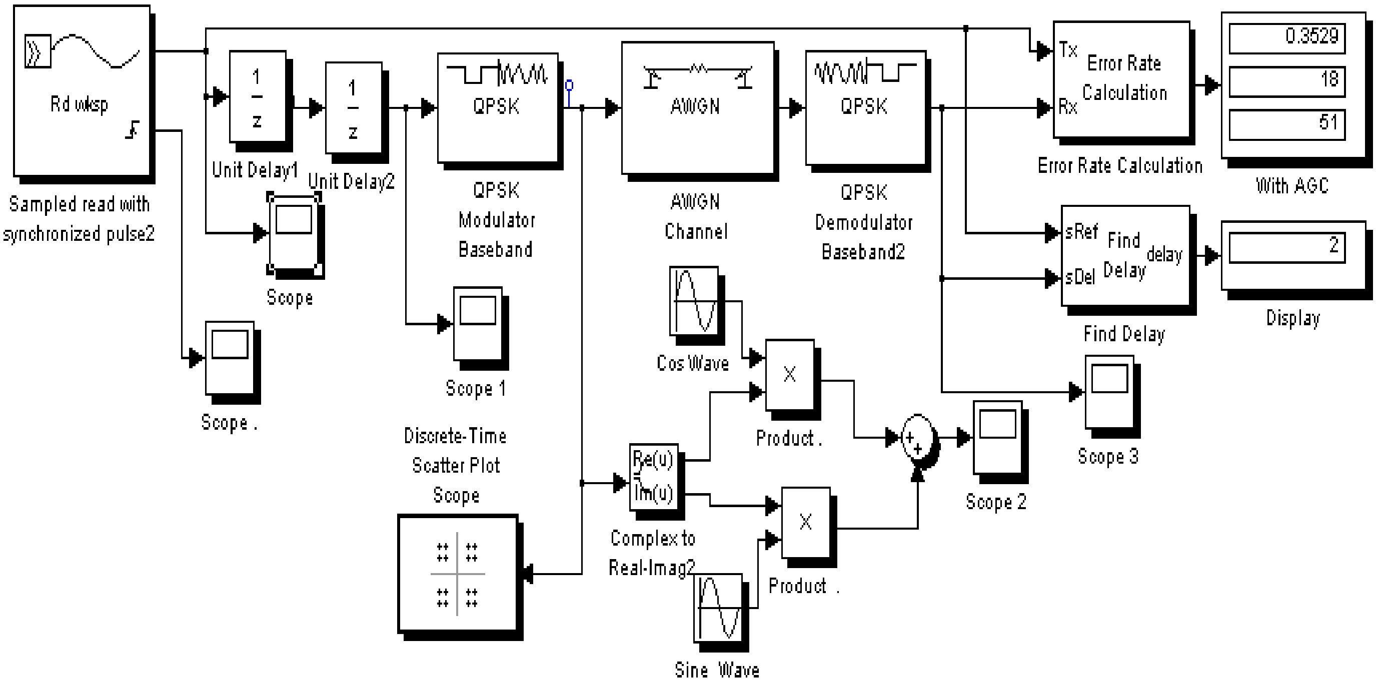


Fig. 11. System implementation from GPS satellite transmitter to GPS receiver by MATLAB Simulink

Figure 11 demonstrates the implementation of algorithm in figure 10 from GPS satellite PRN code generator in GPS transmitter to receiver by MATLAB Simulink toolbox for calculating the delay time between one GPS satellite and receiver.
Different parts of the system shown on figure 11 from the left side are as follows:

-Sampled read with synchronized pulse2:
This part generates the Pseudo Random Noise (PRN) code with 1023 HZ frequency.

-Unit delay1 and Unit delay 2 :
These parts are for simulating the time delay for broadcasting the signal from GPS transmitter to receiver, causes by distance between GPS satellite and receiver,

-Modulator QPSK band Base:
In this part the PRN code is modulated by QPSK phase modulation in satellite transmitter.

-Channel AWGN :
The Gaussian White Noise for considering the noise between GPS transmitter and receiver is simulated by this part

-QPSK Demodulator Baseband2:
The Quadra Phase Shift demodulator which demodulates the signal in GPS receiver to obtain the PRN code in receiver.

-Error Rate Calculation:
Error Rate calculates the signal difference (error) between PRN code generated in GPS transmitter with the PRN code demodulates in receiver. Delay and noise between transmitter and receiver causes the error between these two signals.

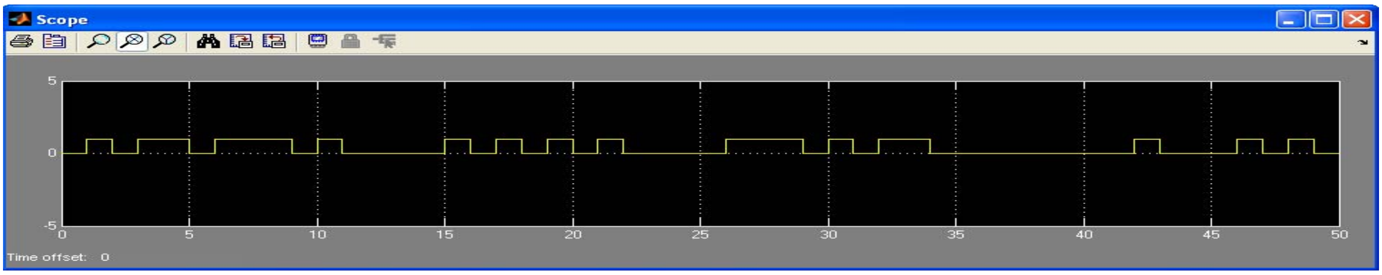
-Find Delay:
The time delay between PRN code in GPS transmitter and receiver signal is calculatd by this part.

-Display:
This part demonstrats the delay calculated by Find Delay part representing the time delay in transmitting signal from GPS satellite transmitter to receiver.

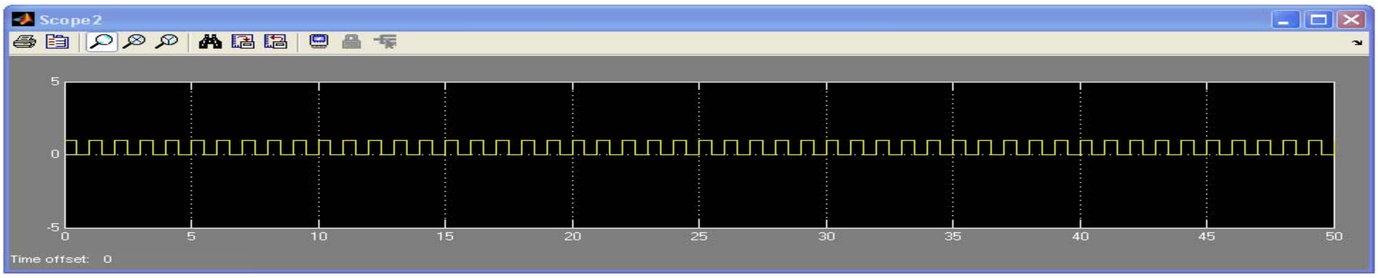
In this simulation two delay units are considered for simulating the delay between GPS receiver and transmitter.
After simulation the Find Delay part determines the delay equal to sum of two delay units.

The above simulation has been repeated from transmitter to receiver for four satellites for determining four delays and four distances. The precise time will be determined by calculating the intersection point of four spheres centered at each satellite and apply the error offset (by changing radiuses of spheres till intersection the surfaces of them in one point).

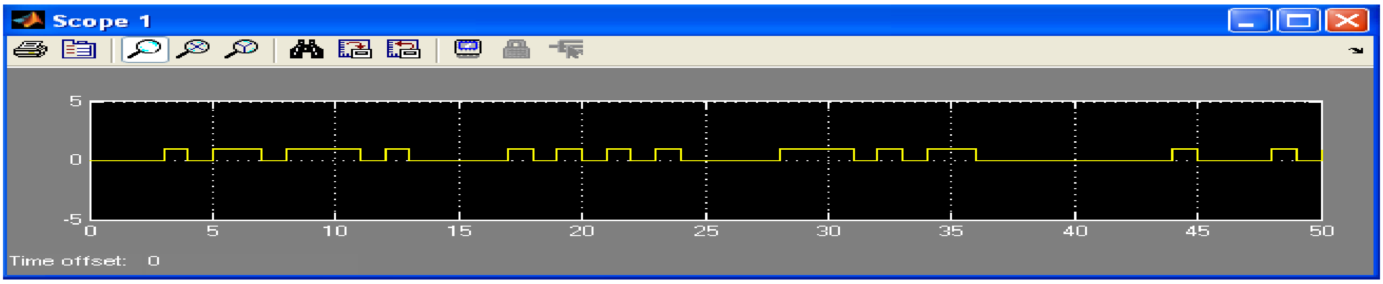
The result of four sphere intersection in one point has been drawn in AutoCAD (see figure g).



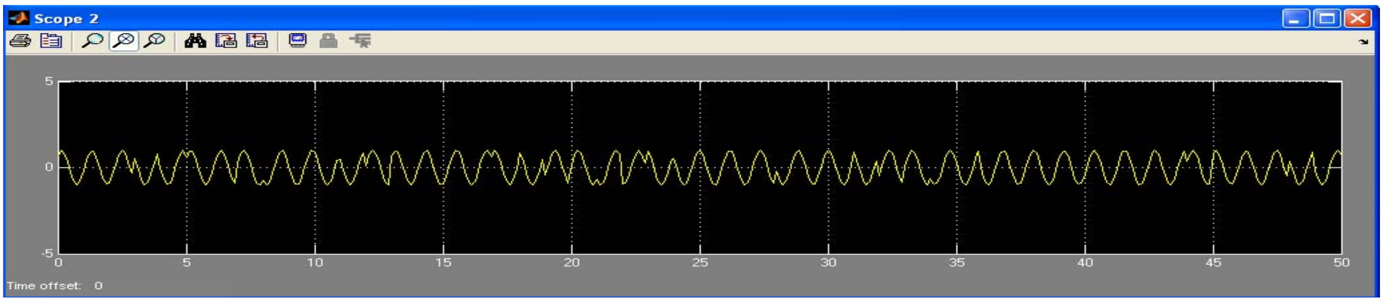
(a)



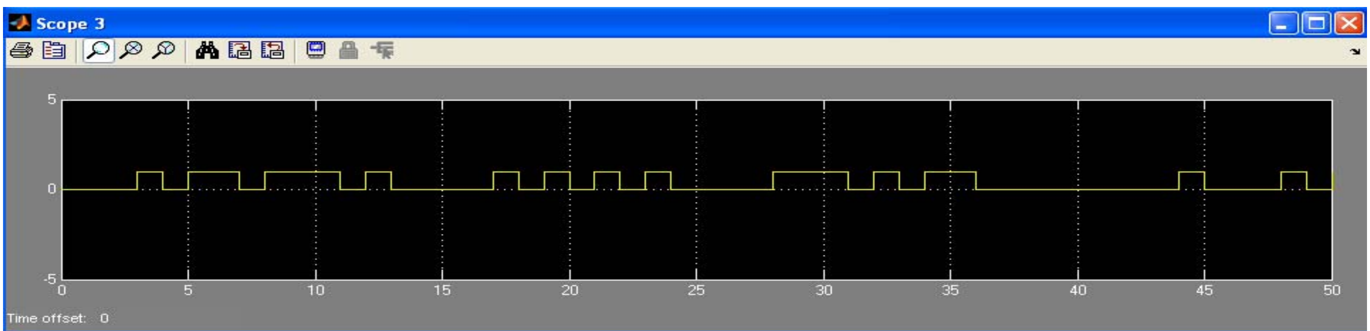
(b)



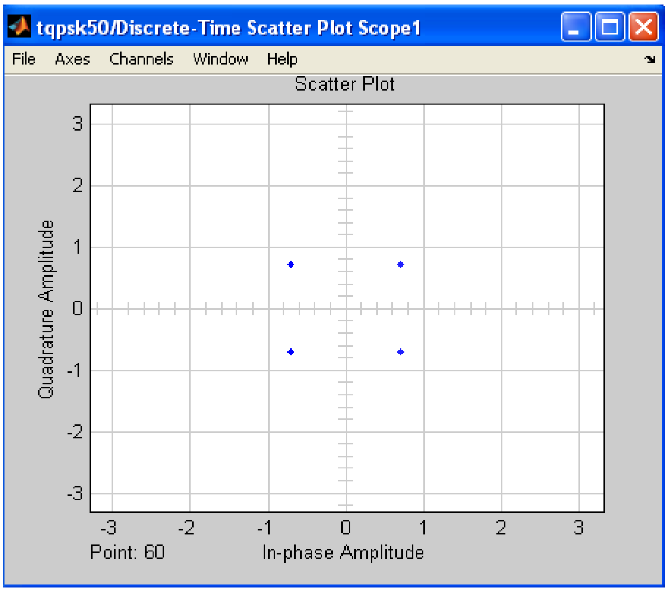
(c)



(d)



(e)



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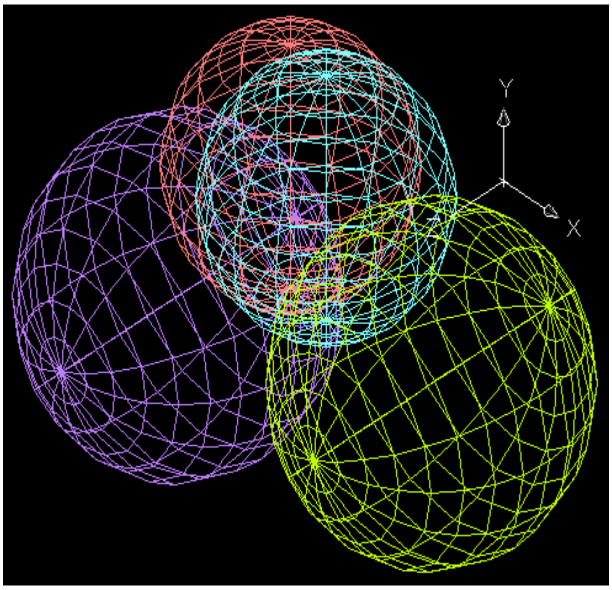
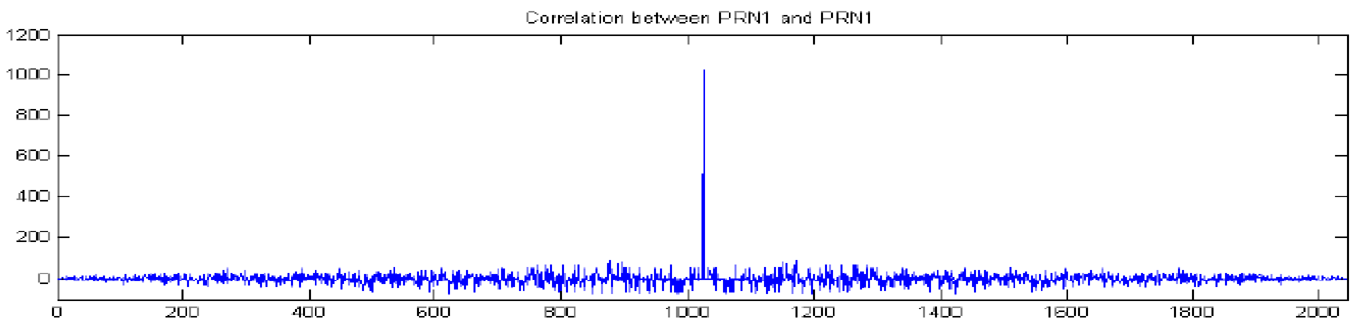


(g)



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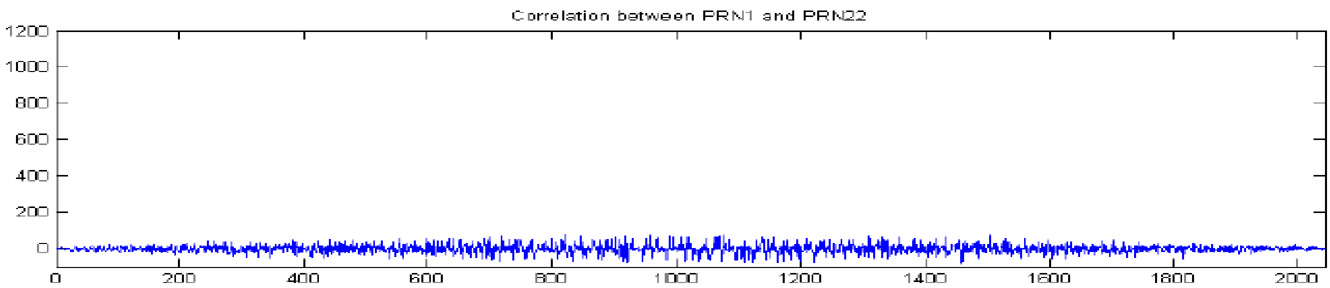

(i)

Fig. 12. (a) PRN code in transmitter. (b) Clock signal
(c) PRN code in receiver,
(d) transmitted signal after QPSK modulator.
(e) Received signal after QPSK demodulator. (f) Constellation Diagram.
(g) Intersection of four sphere in one point in AutoCAD.
(h) Correlation between PRN1 and PRN1.
(i) Correlation between PRN1 and PRN22

Figure (12-a) and (12-c) show the PRN code GPS on transmitter and receiver which are equal but not synchron with each other. The find delay unit shift the signal in receiver until these two signals being locked (full correlated) with each other. In this case the compensated delay is equal to time delay take place for broadcasting signals from GPS transmitter to receiver.

6 Implementation

Based on the simulation , the following diagrams could be applied for implementing the GPS transmitter and receiver. QPSK demodulation has been done on the CPU.

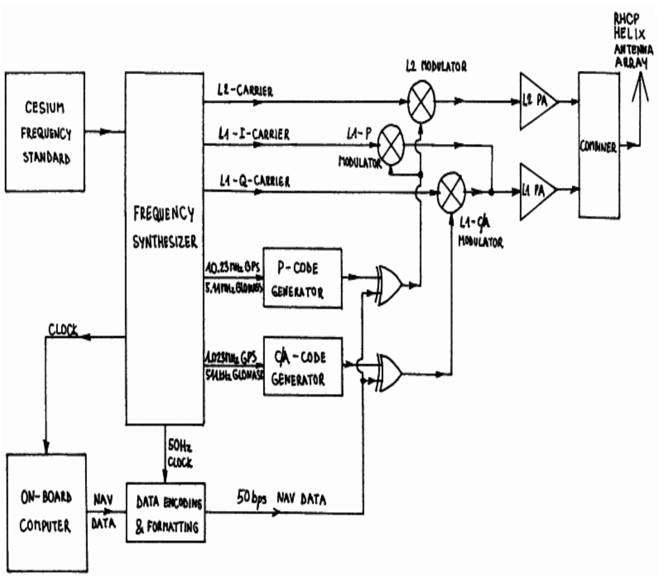

Fig. 13. GPS transmitter hardware implementation diagram

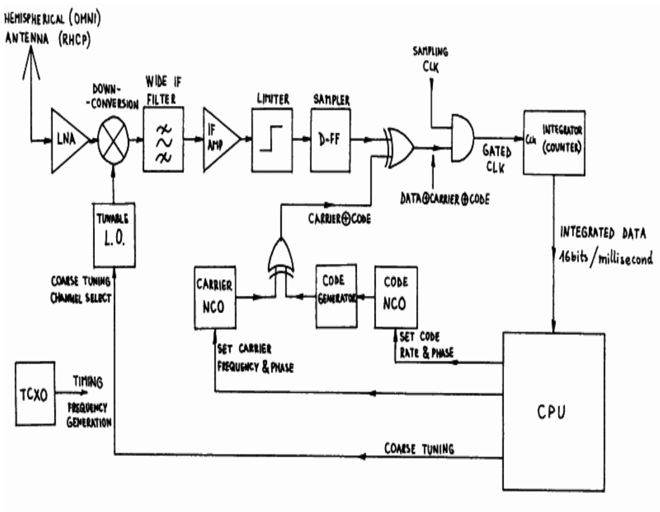

Fig. 14. GPS receiver hardware implementation diagram

Following diagram could be applied for implementing the C/A code generation unit. As it is shown, the 10 bit shift register is used for each two 10-bit generator polynomials which have been described in section 3.

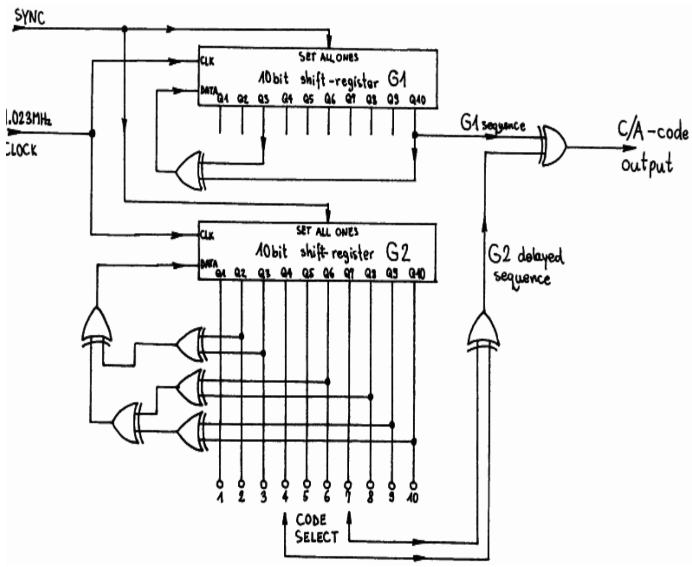

Fig.15. C/A code generation unit, hardware implementation diagram

7 Conclusion

In this paper the time synchronization signal produced by GPS satellites has been introduced and simulatd from transmitter to receiver. QPSK modulation and PRN code generator has been done in MATLAB. Implementing Algorithm for C/A code generation has been shown too. QPSK modulator with double information transition decreases the power consumption of system. So the QPSK modulation proposed for low power transition system. Using PRN code for data modulation with wide spread spectrum and noisy manner makes it difficult to be detected in case of un authorized users and detectors so that the information will be very confidential and safe in this case. This specification can be developed and proposed for very important and credential information transition.
Based on simulation the block diagrams of GPS receiver for hardware implementation has been proposed.

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References:

[1] J. Ashjaee, "On precision of GPS C/A code," IEEE Aerospace and Electronic
[2] The United States Naval Observatory (USNO), http://tycho.usno.navy.mil/gpscurr.html.
[3] Misra, P., and Enge, P., Global Positioning System Signals, Measurements, and Performance. Ganga-Jamuna Press, 2001.
[4] Binary Phase Shift Keying Version 2.13: Jun3,20075:10pmGMT-5 BY Don Johnson
[5] A Low- Cost GPS Satellite Signal Baseband System Using FPGA Prototyping by Trong-Yen Lee, Che-Cheng Hu, Yung-Lin Hsu, China-Chun Tsai and Shue Hsiao
[6] Mosavi, M. R., 2004. A wavelet based neural network for DGPS corrections prediction. WSEAS Transaction on Systems, 3(10), pp. 3070-3075.
[7] Misra, P., and Enge, P., Global Positioning System Signals, Measurements, and Performance. Ganga-Jamuna Press, 2001.
[8] Zarlink Semiconductor, GPS 12-Channel Correlator, GP2021, DS4077, Issue 3.2, April, 2001.
[9] Wayne A. Scales, Chapter 14, Fundamental GPS Signal Techniques, course materials for Fundamental Global Positioning System GPS Theory and Design, Fall 2002.
[10] Parkinson, Bradford, and Spilker, Jr., James. Global Positioning System: Theory and Applications. Vol. I.
[11] F. Scuglik, Time Synchronization Possibilities in Wireless networks for Embedded Systems, WSEAS transactions on communications, 2005, vol 4; ISSU 11, pages 1215-1218
[12] Global Positioning System Over View, http:/www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
[13] GUO-SHING HUANG, Time Synchronization and Frequency Stabilizing Using GPS Carrier Phase with Extension Controller, WSEAS transactions on electronics July 14, 2007