Generation of Binary Sequences of Length 10230 Bits Having Better Odd and Even Correlation with Large Linear Complexity for Use in Global Navigation Satellites Systems (GNSS) Applications

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ABSTRACT

Binary sequences used in Global Navigation Satellites Systems (GNSS) are found to be easily decoded due to less linear complexity. The correlation properties are extremely important while selecting the sequences for GNSS Applications. Linear Feedback Shift Register (LFSR) based Sequences are being used in GNSS Systems such as Global Positioning System (GPS) L2 CM (L2 frequency band Civil Moderate) Signal. Due to the short cycling of LFSR these sequences result in poor correlation properties. In this work the properties of binary sequences used in the state of the art GPS L2CM Navigation signal is explored. The odd and even correlation properties of GPS L2CM sequences are presented in detail. These sequences are analyzed for their Linear Complexity property. A method is proposed for generation of 10230 bit length binary sequences. A new set of binary sequences with set size of 47 sequences are generated using chaotic real sequences. The generated sequences are analyzed for odd correlation, even correlation and linear complexity properties. The proposed binary sequences are found to have better correlation and excellent linear complexity properties as compared to GPS L2 CM Sequences, which make them suitable for use in GNSS Applications.

1. INTRODUCTION

Binary sequences play vital role in Global Navigation Satellites Systems (GNSS) Systems. GNSS Systems such as Global Positioning System (GPS) by US, European GNSS (GALILEO), Russians Global Navigation Satellite System (GLONASS), Indian Regional Navigation Satellite System (IRNSS) by India, Quasi Zenith Satellite System (QZSS) by Japan and Chinese BeiDou Navigation Satellite System (BEIDOU/COMPASS) use binary sequences for various types of services provided by each GNSS system. User receiver at ground identifies a unique service from a GNSS System using these binary sequences.

GPS system is widely used for location services across the world. Towards enhancing the capabilities of GPS system, a new GPS signal namely GPS L2 band Civil Moderate (GPS L2 CM) signal having binary sequences of length 10230 bits was added in L2 frequency. This signal provides one order better accuracy than the existing GPS C/A (Coarse Acquisition) signal having binary sequences of length 1023 bits.

Binary spreading sequences provide secure and reliable transmission for GNSS Systems. Binary sequences derived from Linear Feedback Shift Register (LFSR) are the commonly used Pseudo Random Binary Sequences in spread spectrum applications [1]. For GNSS Systems, the property of spreading sequence length plays an important role. It is always

designed such that the spreading sequence length should be an integer multiple of chip rate. However binary sequences generated using conventional methods such as Gold Codes, which are based on LFSR are restricted to code length (2^N-1) for 'N' stages. The GPS L2 CM sequences are generated using N = 27 stage LFSR. The length of the binary sequence of 27 stage LFSR is 134217727 bits. However to meet the sequence length constraints these binary sequences are short cycled/reset to 10230 bits in state-of-the art GPS Navigation System. The process of short cycling results in poor correlation properties of the truncated sequences [1]. The desirable properties to be considered in the design of the binary sequences for GNSS Systems are described in the literature [1-5]. However in the existing literature, the detailed analysis of the properties namely odd correlation and linear complexity of the new civilian signal GPS L2 CM sequences are not done.

The security of the GNSS Systems depends on the linear complexity property of the binary spreading sequences. It is observed from the literature that due to the low linear complexity property binary sequences used in BeiDou System were decoded by Gao et al. [6]. Also similar instance of decoding Galileo In Orbit Validation Element-A (GIOVE-A) codes, was done by Psiaki et al. [7]. Design of binary sequences with high linear complexity is being attempted by many researchers [8-11].

Binary sequences used for GNSS Applications are expected to perform well in real world environment such as multipath, interference etc. Whenever there is a flip in a bit in the navigation sequence or the bit in the secondary code sequence is observed within the integration period of the binary spreading sequence, it is difficult to acquire the signal and this depends on the odd correlation properties of the spreading sequence [12-14].

In this work a method is proposed to derive binary sequences with good even correlation, odd correlation and linear complexity properties. Proposed binary sequences are of length 10230 bits and are derived from chaotic real valued sequences.

The paper is organized as follows. Correlation and linear complexity properties are defined in the Section 2. Section 3 provides correlation and linear complexity properties of GPS L2 CM sequences in detail. In Section 4, proposed method of generating chaotic binary sequence is discussed. The correlation and linear complexity properties of the proposed binary sequences are provided in Section 5. Section 6 concludes the work.

2. CORRELATION AND LINEAR COMPLEXITY PROPERTIES

In this section the correlation and linear complexity properties are defined.

2.1 Correlation property

Considering two binary sequences x and y of length N bits the aperiodic correlation is defined [15] and is given by,

$$C_{x,y}(l) = \begin{cases} \sum_{j=0}^{N-1-l} x_j y_{j+l}^*, & 0 \le l \le N-1 \\ \sum_{j=0}^{N-1+l} x_{j-l} y_j^*, & 1-N \le l \le 0 \\ 0, & |l| \ge N. \end{cases} \quad (1)$$

Here l denotes the shift of one sequence say y relative to the other sequence x.

Even Cross Correlation (even CCR) property between two sequences x and y is provided [15] by,

$$\theta_{x,y}(l) = C_{x,y}(l) + C_{x,y}(l-N) \quad (2)$$

Even Auto Correlation (even ACR) property for a single sequence say, sequence x or sequence y is defined [15] as,

$$\theta_{x,x}(l) = C_{x,x}(l) + C_{x,x}(l-N) \quad (3)$$

Odd Cross Correlation (odd CCR) property between two sequences x and y is provided [15] by,

$$\hat{\theta}_{x,y}(l) = C_{x,y}(l) - C_{x,y}(l-N) \quad (4)$$

Odd Auto Correlation (odd ACR) property for a single sequence say, sequence x or sequence y is defined [15] as

$$\hat{\theta}_{x,x}(l) = C_{x,x}(l) - C_{x,x}(l-N) \quad (5)$$

The importance of properties of even correlation is well understood in the literature for GNSS systems. Any improvement in the correlation is an added advantage for GNSS system.

Especially the odd correlation plays an important role in GNSS systems when there is a flip in the bit of the binary sequence, due to the presence of multipath or interference and that leads to difficulty in acquiring and tracking the satellite signals.

2.2 Linear complexity property

Linear complexity [16] for a binary sequence represents the length of shortest LFSR required to generate the same binary sequence. Berlekamp – Massey algorithm [16] is commonly used for computation of Linear complexity.

Linear complexity property plays vital role in advanced applications of GNSS systems such as security of driverless cars, Unmanned Arial Vehicles (UAV), Internet of Things (IoT) etc.

Next section provides the correlation property and linear complexity property of 10230 bit GPS L2 CM binary sequences.

3. CORRELATION AND LINEAR COMPLEXITY PROPERTIES OF GPS L2 CM SEQUENCES

GPS L2 CM sequences of length 10230 bits are generated using the method provided in the GPS Interface Control Document (ICD) [17] and the correlation and linear complexity properties are analyzed.

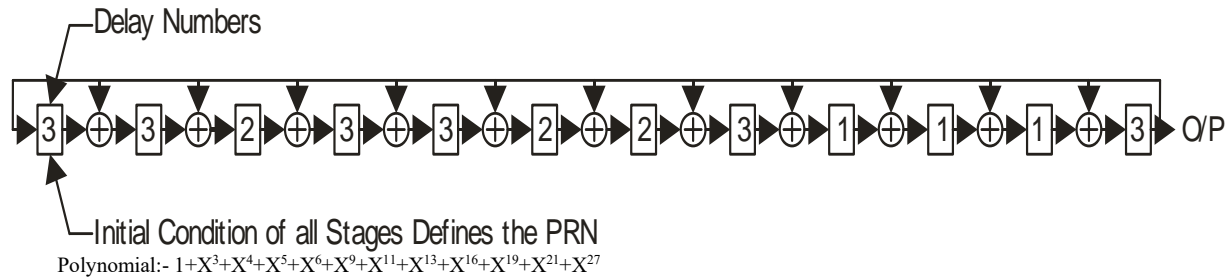### 3.1 Generation of GPS L2 CM sequences

The GPS L2 CM code is a new civilian signal which has improved navigation accuracy which repeats for every 20 ms and are LFSR based codes reset after 10230 bits having chip rate of is 511.5 Kbps.

These codes are being transmitted from block II series replenishment satellites (IIR-M), block II series follow on satellites (IIF) and also subsequent blocks of GPS Satellites. Block diagram of the GPS L2 CM signal generator is shown in Figure 1. The L2 CM sequences are obtained by short cycling the LFSR for every count of 10230 chips by resetting with a specified initial state. The polynomial used to generate the L2 CM signal is 1112225171 (octal) of degree 27. The 27 bit LFSR provides sequences of length $(2^{27}-1)$ which is equal to 134217727 bits out of which 134207497 bits are discarded to get the required 10230 bit sequences. A set of 37 binary sequences of length 10230 bits are generated from the method given in Figure 1 by selecting different initial values for LFSR and all the 37 sequences are short cycled to 10230 bits. The initial values to generate the 37 sequences are given in Table 1.

LFSR based sequences are most commonly used binary sequences for GNSS. However for GNSS Signals, it is desirable to have binary sequences period to be multiple of on-board fundamental frequency (10.23 MHz) i.e. multiple of 1023. Considering 10th multiple of 1023 bits which is equal to 10230 bits and is the required binary sequence length of GPS L2 CM sequences. However it is not possible to generate

10230 bit period, binary sequences using LFSR. Hence the sequences from LFSR are truncated/short cycled to 10230 bits.

All the 37 GPS L2 CM sequences of length 10230 bits are generated using MATLAB.

Polynomial:- $1+X^3+X^4+X^5+X^6+X^9+X^{11}+X^{13}+X^{16}+X^{19}+X^{21}+X^{27}$

Figure 1. GPS L2 CM Binary Sequence generator

Table 1. Initial values of 27 stage LFSR for 37 GPS L2 CM sequences

S V ID	GPS PRN No	Initial Shift register Stage(Octal)	End Shift register Stage(Octal)
1	1	742417664	552566002
2	2	756014035	034445034
3	3	002747144	723443711
4	4	066265724	511222013
5	5	601403471	463055213
6	6	703232733	667044524
7	7	124510070	652322653
8	8	617316361	505703344
9	9	047541621	520302775
10	10	733031046	244205506
11	11	713512145	236174002
12	12	024437606	654305531
13	13	021264003	435070571
14	14	230655351	630431251
15	15	001314400	234043417
16	16	222021506	535540745
17	17	540264026	043056734
18	18	205521705	731304103
19	19	064022144	412120105
20	20	120161274	365636111
21	21	044023533	143324657
22	22	724744327	110766462
23	23	045743577	602405203
24	24	741201660	177735650
25	25	700274134	630177560
26	26	010247261	653467107
27	27	713433445	406576630
28	28	737324162	221777100
29	29	311627434	773266673
30	30	710452007	100010710
31	31	722462133	431037132
32	32	050172213	624127475
33	*	500653703	154624012
34	*	755077436	275636742
35	*	136717361	644341556
36	*	756675453	514260662
37	*	435506112	133501670

3.2 Even and odd ACR properties of GPS L2 CM sequences

Investigation is carried out for even and odd ACR properties. The results of maximum off peak even ACR and maximum off peak odd ACR values are tabulated in Table 2. The off peak even and odd ACR values are found to be multiple valued because of truncation. From Table 2, it is found that maximum even ACR for the set of 37 sequences is -26.90 dB and the
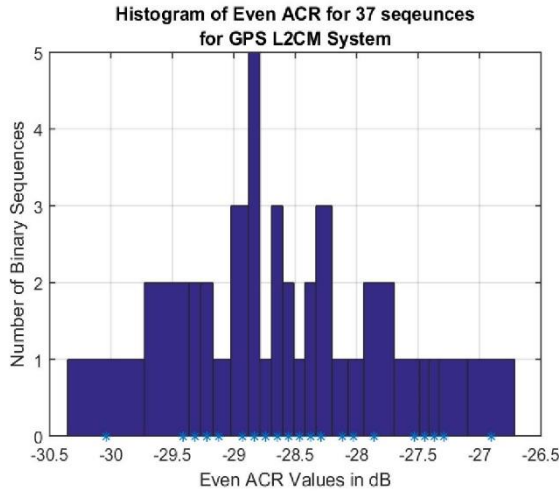
maximum odd ACR is found to be -27.24 dB. The histogram of off peak even ACR and the off peak odd ACR is shown in Figure 2 and Figure 3 respectively. In Figure 2, it is found that only for 5 sequences out of 37 sequences are having off peak even ACR value of -29.2 dB. In Figure 3, it is found that only for 4 sequences out of 37 sequences are having off peak odd ACR value of -28.5 dB.

**Table 2.** Off peak maximum even ACR and odd ACR for 37 GPS L2 CM sequences

GPS L2 CM Sequence Number	Off Peak Maximum even ACR Value	Off Peak Maximum odd ACR Value
1	-28.833	-27.408
2	-28.928	-28.602
3	-28.928	-28.070
4	-28.833	-27.569
5	-28.466	-29.120
6	-30.040	-27.774
7	-29.120	-28.787
8	-29.217	-29.267
9	-28.648	-28.694
10	-28.740	-28.975
11	-29.416	-29.071
12	-28.833	-29.120
13	-28.556	-28.511
14	-28.288	-28.833
15	-28.027	-29.366
16	-26.905	-28.928
17	-28.113	-29.169
18	-27.858	-27.942
19	-29.416	-29.416
20	-28.648	-28.648
21	-28.288	-27.368
22	-28.376	-28.556
23	-28.556	-28.740
24	-28.928	-29.071
25	-28.288	-27.691
26	-28.833	-28.556
27	-28.648	-27.250
28	-28.376	-28.787
29	-28.833	-28.511
30	-27.448	-28.511
31	-27.289	-29.267
32	-29.316	-27.488
33	-27.858	-28.694
34	-27.368	-28.975
35	-29.217	-28.511
36	-27.528	-28.156
37	-29.316	-28.070

Figure 2. Histogram of maximum off peak even ACR for 37 GPS L2 CM sequences
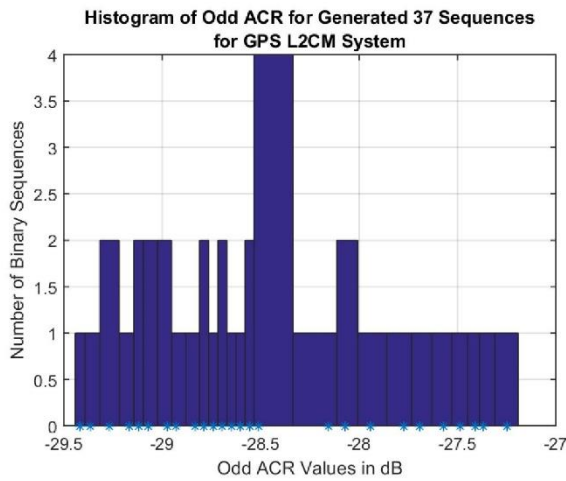
**Figure 3.** Histogram of maximum off peak odd ACR for 37 GPS L2 CM sequences

3.3 Even and odd CCR properties of GPS L2 CM sequences

Investigation is also carried out for even and odd CCR properties. The histogram of results of all 666 combinations of pairwise maximum even CCR values and pairwise maximum odd even CCR values are plotted in Figure 4 and Figure 5 respectively. From Figure 4 and Figure 5, the even and odd CCR values are found to be multiple valued because of truncation. Also in Figure 4, it is found that the maximum pairwise even CCR value is -25.39 dB and the occurrences of pairwise even CCR values are found to be populated near -28.5 dB. In Figure 5, it is found that the maximum pairwise odd CCR value is -26.32 dB and the occurrences of pairwise odd CCR values are found to be populated near -28.5 dB.

From the correlation results following observations are made

- The odd correlation and even correlation functions of the GPS L2 CM sequences are multiple valued due to truncation of LFSR sequences.
- The GPS L2 CM Binary sequences are found to have better odd correlation performance. The odd ACR and odd CCR values are found to be better than the even ACR and even CCR values by 0.34 dB and 0.93 dB respectively. It is to be noted that the GPS L1 C/A PRN

code designed during the first generation of GPS is found to have better even correlation properties when compared to odd correlation properties [18].
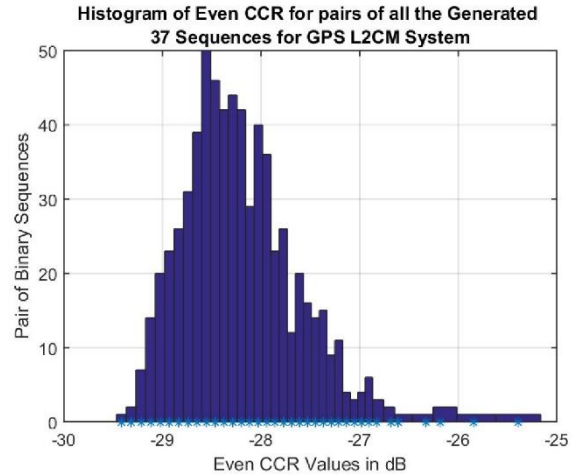
Figure 4. Histogram of pairwise maximum even CCR of all 666 combinations for 37 GPS L2 CM sequences
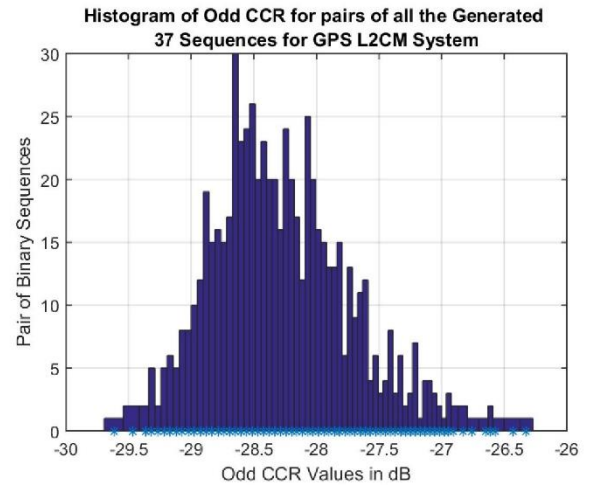
Figure 5. Histogram of pairwise maximum odd CCR of all 666 combinations for 37 GPS L2 CM sequences

3.4 Linear Complexity properties of GPS L2 CM sequences

Linear complexity (LC) values are computed for all 37 sequences using Berlekamp – Massey algorithm [16] and it is found to be 27. In the next section a method is proposed to generate binary sequences having better properties than GPS L2 CM sequences.

4. PROPOSED METHOD OF GENRATING CHAOTIC BINARY SEQUENCE

Proposed method [18] for deriving binary sequences from chaotic sequences is shown in Figure 6.
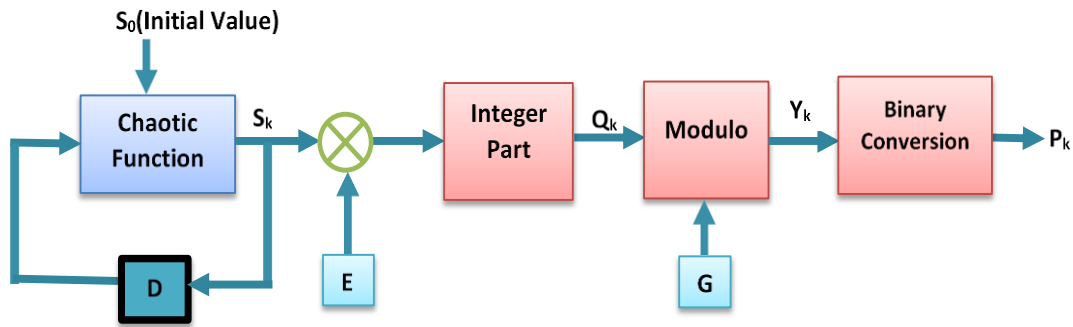
Due to its simplicity Logistic map is the commonly used chaotic map [19-21]. This work considered chaotic sequences generated by Logistic Map defined by the equation [21]

$$S_{k+1} = BS_k (1 - S_k) \tag{6}$$

S_k is real valued chaotic output with bound $0<S_k<1$, B is bifurcation factor. The bifurcation factor is in the range $3.57< B < 4$ and will always ensure that the output from this system is chaotic in nature.

In the proposed method the real valued chaotic sequences are converted to binary sequences governed by the following equation [18]

$$Y_k = \lfloor (S_k) * E \rfloor mod(G) \qquad (7)$$

Using Eq. (6), iteratively real valued infinite sequence $\{S_k\}$, $k = 0,1,2, ...,$ is generated. Each real valued sequence S_k is multiplied by a large integer E and modulo operation is performed over another integer G by selecting G and E as $G < E$. As shown in Figure 6, the integer part Q_k is considered and fraction is rejected. Resulting integer Y_k is mapped to binary directly to obtain output sequence Pk.

The binary sequences generated using the proposed method are investigated for correlation and linear complexity properties in the next section.

Figure 6. Proposed method for generation of binary sequences using chaotic function for GNSS applications

5. CORRELATION AND LINEAR COMPLEXITY PROPERTIES OF THE PROPOSED BINARY SEQUENCES

A set of 100 binary sequences of length 10230 bits were generated from the proposed method by selecting the initial values randomly and setting integer G=4, B = 3.99 and E=32767. MATLAB simulations are performed to obtain 47 binary sequences from the proposed method and the initial values of all the 47 binary sequences are listed in Table 3.

Table 3. Initial values for generation of proposed binary sequences

Binary Seqeunce Number	Initial Value
1	0.656560157622049
2	0.379428069773115
3	0.956473170430473
4	0.837323305625539
5	0.186769582443968
6	0.917937385063156
7	0.449003245887149
8	0.317813959862539
9	0.210370839512595
10	0.421562177994972
11	0.115709453804408
12	0.313397650853574
13	0.452906953664362
14	0.707796016680767
15	0.354081569750622
16	0.500947441246977
17	0.353750830722854
18	0.563401008883089
19	0.656157553061328
20	0.326484624595631
21	0.682479882613947
22	0.248820030659104
23	0.677767695635484
24	0.365907196587940
25	0.479347941435340
26	0.576065641236740
27	0.216510493002707
28	0.929057543334895
29	0.832411734145950
30	0.651115097100317
31	0.682275215512988
32	0.435351966932894
33	0.148961992745456
34	0.305386520123207
35	0.682400839938918
36	0.685798293358962
37	0.547081326731316
38	0.903628961195317
39	0.784678357417467
40	0.790692597585520
41	0.974153022080358
42	0.725750333188450
43	0.686225815491298
44	0.735791042001489
45	0.892298117955924
46	0.656560157622049
47	0.379428069773115

5.1 Even and odd ACR properties of proposed sequences

Investigation is carried out for even and odd ACR properties. The results of maximum off peak even ACR and maximum off peak odd ACR values are tabulated in Table 4. From Table 4, it is found that maximum even ACR for the set of 47 sequences is -29.02 dB and the maximum odd ACR is found to be -27.28 dB. The histogram of off peak even ACR and the off peak odd ACR is shown in Figure 7 and Figure 8 respectively. From the Figure 7, it is found that 32 sequences out of 47 sequences are having off peak maximum even ACR in the range -29 dB to -

29.2 dB. From the Figure 8, it is found that more than 9 sequences out of 47 sequences are having off peak odd ACR value better than -28.5 dB.

Table 4. Off peak maximum even ACR value and off peak maximum odd ACR value of the proposed binary seqeunces

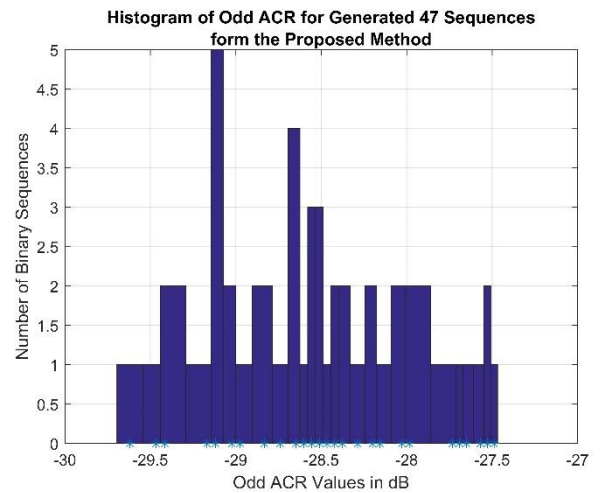| Proposed Binary Sequence Number	Off Peak Maximum even ACR Value	Off Peak Maximum odd ACR Value
1	-29.217	-27.650
2	-29.023	-29.120
3	-29.416	-29.169
4	-29.120	-27.733
5	-29.723	-29.120
6	-29.120	-28.421
7	-29.416	-28.648
8	-29.517	-28.740
9	-29.023	-27.984
10	-29.416	-28.648
11	-29.023	-28.556
12	-29.619	-27.691
13	-29.217	-28.833
14	-29.120	-28.421
15	-29.120	-29.023
16	-29.723	-29.416
17	-29.120	-29.619
18	-29.023	-28.648
19	-29.217	-27.528
20	-29.316	-28.200
21	-29.217	-28.975
22	-29.023	-29.023
23	-29.120	-28.648
24	-29.316	-29.416
25	-29.517	-28.027
26	-29.120	-28.833
27	-29.316	-28.376
28	-29.217	-29.466
29	-29.316	-28.027
30	-29.217	-28.466
31	-29.023	-27.488
32	-29.120	-28.376
33	-29.120	-29.120
34	-29.619	-28.556
35	-29.217	-28.602
36	-29.023	-28.288
37	-29.217	-28.511
38	-29.416	-29.120
39	-29.120	-28.200
40	-29.023	-29.120
41	-29.023	-27.528
42	-29.217	-28.511
43	-29.023	-27.984
44	-29.316	-28.556
45	-29.933	-27.569
46	-29.120	-28.156
47	-29.217	-28.511

5.2 Even and odd CCR properties of proposed sequences

Investigation is carried out for even and odd CCR properties. The histogram of results of all 1081 combinations of pairwise maximum even CCR values and pairwise maximum odd even CCR values are plotted in Figure 9 and Figure 10 respectively. From the Figure 9, it is found that the maximum pairwise even CCR value is -26.01 dB and the occurrences of pairwise even CCR values are found to be populated near -28.5 dB. From Figure 9, it is found that the maximum pairwise odd CCR

value is -26.32 dB and the occurrences of pairwise odd CCR values are found to be populated near -28.5 dB.
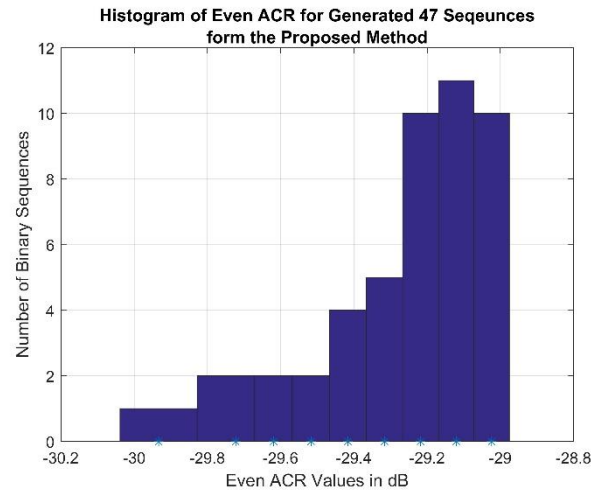
Figure 7. Histogram of maximum off peak even ACR for 47 proposed binary sequences

Figure 8. Histogram of maximum off peak odd ACR for 47 proposed binary sequences

The histogram results of all 1081 combinations of pairwise maximum even CCR and pairwise maximum odd CCR for a set of proposed 47 binary sequences are as shown in Figure 9 and Figure 10 respectively. From the histogram it is observed that for a set of 47 binary sequences of length 10230 bits, the maximum pairwise even cross correlation is -26.01 dB and maximum pairwise odd cross correlation is found to be -26.32 dB.

Table 5 provides comparison of the correlation properties of the proposed sequences and GPS L2 CM sequences.

Table 5. Comparison of Correlation properties of proposed sequences and GPS L2 CM sequences

Sl No	Property	GPS L2 CM sequences	Proposed Sequences
1	Even ACR	-29.02 dB	-26.90 dB
2	Odd ACR	-27.48 dB	-27.24 dB
3	Even CCR	-26.21 dB	-25.39 dB
4	Odd CCR	-26.32 dB	-26.32 dB

From the Table 5 following observations are made
- Proposed binary sequences outperform the GPS L2 CM sequences in maximum off peak even ACR by 2.12 dB.
- Proposed set of binary sequences are found to have better even CCR by 0.82 dB as compared to the GPS L2 CM sequences.
- Proposed set of binary sequences are found to be having better maximum off peak odd ACR by 0.24 dB.
- Odd CCR property is same for both the binary sequences.
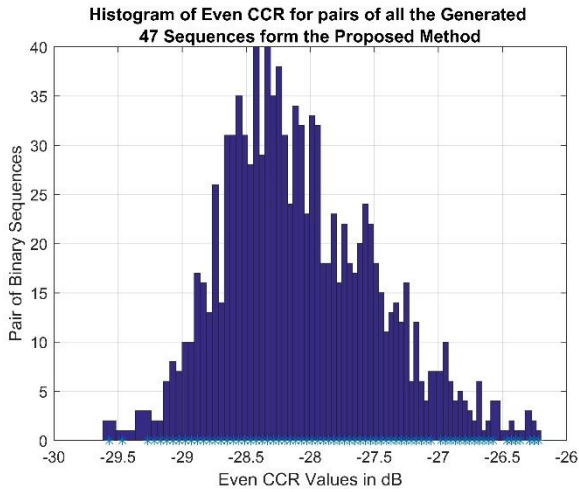
Figure 9. Histogram of pairwise maximum even CCR of all 1081 combinations for 47 proposed binary sequences
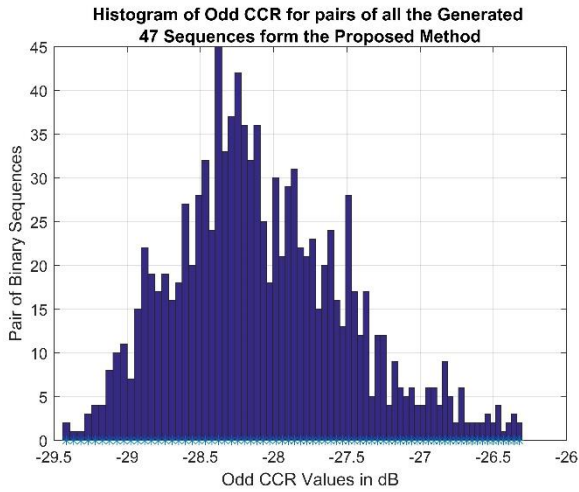
Figure 10. Histogram of pairwise maximum odd CCR of all 1081 combinations for 47 proposed binary sequences

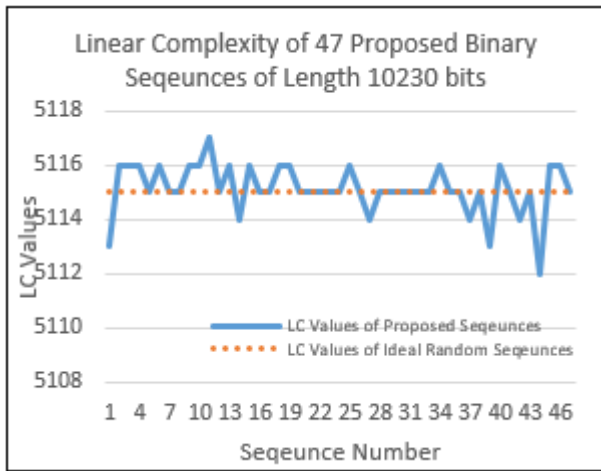### 5.3 Linear Complexity properties of proposed sequences

The Linear complexity (LC) property profile of the generated 47 binary sequences of length 10230 bits are computed using Berleykamp- Massey Algorithm [16]. In Table 6, the values of LC for all the 47 proposed binary sequences along with their initial values are tabulated. It is found from Table 4 that the linear complexity for 10230 bits binary sequences proposed is 5115 ± 3. Security of the proposed sequences is excellent as compared to GPS L2 CM sequences.

The Linear complexity profile for proposed binary sequences is as shown in Figure 11. The dotted line represents the expected linear complexity value of 5115 for ideal random

sequences of length 10230 bits. The continuous line represents the Linear Complexity of the Proposed 47 binary sequences. From the Figure 11 it is observed that the proposed binary sequences possess the near ideal linear complexity property.

Table 6. Initial values for generation of proposed binary sequences and linear complexity property of proposed binary sequences

Binary Seqeunce Number	Initial Value S_0	LC value of generated sequence
1	0.656560157622049	5113
2	0.379428069773115	5116
3	0.956473170430473	5116
4	0.837323305625539	5116
5	0.186769582443968	5115
6	0.917937385063156	5116
7	0.449003245887149	5115
8	0.317813959862539	5115
9	0.210370839512595	5116
10	0.421562177994972	5116
11	0.115709453804408	5117
12	0.313397650853574	5115
13	0.452906953664362	5116
14	0.707796016680767	5114
15	0.354081569750622	5116
16	0.500947441246977	5115
17	0.353750830722854	5115
18	0.563401008883089	5116
19	0.656157553061328	5116
20	0.326484624595631	5115
21	0.682479882613947	5115
22	0.248820030659104	5115
23	0.677767695635484	5115
24	0.365907196587940	5115
25	0.479347941435340	5116
26	0.576065641236740	5115
27	0.216510493002707	5114
28	0.929057543334895	5115
29	0.832411734145950	5115
30	0.651115097100317	5115
31	0.682275215512988	5115
32	0.435351966932894	5115
33	0.148961992745456	5115
34	0.305386520123207	5116
35	0.682400839938918	5115
36	0.685798293358962	5115
37	0.547081326731316	5114
38	0.903628961195317	5115
39	0.784678357417467	5113
40	0.790692597585520	5116
41	0.974153022080358	5115
42	0.725750333188450	5114
43	0.686225815491298	5115
44	0.735791042001489	5112
45	0.892298117955924	5116
46	0.656560157622049	5116
47	0.379428069773115	5115

Figure 11. Linear Complexity profile of proposed set of 47 binary sequences of length 10230 bits in comparison of ideal random sequences Linear Complexity (LC) profile

6. CONCLUSION

In this work, a set of 37 GPS L2 CM binary sequences are generated. The odd correlation, even correlation and the linear complexity properties are analyzed for GPS L2 CM binary sequences. It is observed that the GPS L2 CM Sequences are obtained by truncating very long LFSR sequence and hence the correlation properties are degraded due to truncation. It is also found that the maximum off peak even ACR value is -26.90 dB, maximum of peak odd ACR value is -27.24 dB, maximum pairwise even CCR value is -25.39 dB, maximum pairwise odd CCR value is found to be -26.32 dB and LC value is 27.

A method is also proposed to generate binary sequences of length 10230 bits. A set of 47 binary sequences of length 10230 bits are generated. The generated binary sequences are analyzed for odd correlation, even correlation and linear complexity properties. For the set of 47 sequences of length 10230 bits it is found that maximum off peak even ACR value is -29.02 dB, maximum off peak odd ACR value is -27.24 dB, maximum pairwise even CCR value is -26.02 dB, maximum pairwise odd CCR value is found to be -26.32 dB and the LC is found to be 5115 $\pm$3.

It is found that the proposed sequences as compared to GPS L2 CM binary sequences are better in having maximum off peak even ACR of 2.12 dB greater, pairwise maximum even CCR of 0.82 dB grater, maximum off peak odd ACR by 0.24 dB higher value. The generated sequences are found to have large LC of 5115 $\pm$3 as compared to LC of 27 for GPS L2 CM binary sequences and hence provides excellent inherent security.

Due to the better correlation properties and large linear complexity the proposed sequences are suitable for use in secure GNSS Applications.

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NOMENCLATURE

S_k	real valued chaotic output. This is a dimension less quantity
B	bifurcation factor for chaotic logistic map. This is a dimensionless quantity
E	large positive integer, dimensionless quantity
G	positive integer, dimensionless quantity
Y_k	integer valued output from the chotic generator. This is a dimension less quantity

Subscripts

k	k^{th} symbol output from the proposed sequence generator
x	binary sequence x
y	binary sequence y