An FPGA Based Design and Implementation of Unambiguous Ranging System Using Golay Sequences

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Abstract

Golay sequences have some properties make it distinctive in the applications and results. However, for this distinction must select the code sequences carefully and accurately. In this paper, an FPGA based, design and implementation for made autocorrelation of pair Golay complementary code sequences after extract all possible formations of 8bit code (192 8-bit pair code), and separate the unduplicated codes(12 at a time) and many (too many) 12 blocks 8-bit combinations with 16 main-to-sidelobe power ratio. There are another propose circuit attached to Tx and Rx which indicated by S1, S2 and S3 for increase the accuracy. Therefore, the Search can be regarded as pioneers of the research application of this technique on the subject and got good results. The Implementation was made by Xilinx-spartan-3A XC3S700AFPGA, with 50 MHz internal clock.

Key words: Radar signal processing, Golay complementary sequences, FPGA-Spartan, nambiguous range.

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1.Introduction:

Radar signal generation and processing techniques are growing ever more advanced. These advances are being driven by the need to improve resolution and reduce spectrum occupancy. The use of Golay sequences is one of these goal tools in many topics which need same purposes.

Where Golay complementary sequences have been used in radar application
to encode Costas frequency hopping continuous waveforms (CW) in order to improve the range (time) sidelobe behavior of received radar signals{1,2}. Even so, he did not mention anything about the selection of the appropriate code without duplication.
While in detection field a method for detecting a point target employing a unitary matrix waveform set formed from Golay complementary sequences was presented by{3}. He took a duplicated in Golay sequences and deals with it by channel Matrix. In ground penetration radar (GPR){4} present a weaker return detection. While {5} test the Golay and PRBS performance using 4096 and 8192 length sequences.
In waveform design, [6] present a systematic way of designing a Doppler resilient sequence of Golay complementary waveforms. While {7}, evaluated the performance of photoacoustic coded excitation (PACE) using Golay Codes. For sidelobe suppression, a proposes to transmit one of the sequences at two offsets, above and below the carrier frequency was presented by {8}. The work in {9, 10, 11,12, 13,and 14 } are contribute in ultrasound medical resolution. Where. in {9}, a determination, of the displacement of an object or a desired region of an object with much-improved resolution a transmitting a pair of Golay complementary sequences. While, {10} present a technique that uses Golay phase encoding, pulse inversion, and amplitude modulation (GPIAM) for microbubble contrast agent imaging. {11} investigates the effect of ultrasound imaging transducer's fractional bandwidth on the gain of the compressed echo signal for different spectral widths of the complementary Golay sequences (CGS). While, acquired images,

using complementary Golay codes, that show the deleterious effects of attenuation on binary codes when processed with a matched filter was presented by {12}. {13} are worked on multimode techniques using Golay complementary sequences are proposed for processing the ultrasonic signal. Where, the improvement of SNR for ultrasound imaging by using Golay code was presented by {14}. Also, In Train wheel detection, in order to compensate the attenuation in wires and the external noise, for sensor, which detects the train wheel, {15} uses a signal codified with Golay complementary sequences. And, in Identification field, {16} present a design of bipolar excitation sequences for identifying linear time-invariant systems in the presence of weak nonlinear distortion by four pairs of Golay complementary sequences.

2. **Golay Code Formulation:**

Golay sequences have some properties that make it distinctive in the applications and results. However, for this distinction the code sequences must be select carefully and accurately. The property of Golay complementary sequences can be expressed mathematically, where a_i and b_i (i = 1,2, . . ., n) are the pair of binary complementary sequences of code length 2^n. The AACFs for the complementary sequences can be expressed as follows {1}:

$$c_j = \sum_{i=1}^{n-j} a_i \, a_{i+j} \qquad (1)$$

and

$$d_j = \sum_{i=1}^{n-j} b_i \, b_{i+j} \qquad (2)$$

The sum of the pair of AACFs can be expressed as;

$$\left.\begin{array}{ll} c_j + d_j = 0 \quad j \neq 0 & \text{for specific unique pair and there relates as in analysis section point 7} \\ c_j + d_j \neq 0 \quad j \neq 0 & \text{for other} \end{array}\right\} \qquad (3)$$

and

$$c_0 + d_0 = 2n \qquad (4)$$

Golay sequences have been used in many applications as stated in review to improve the range sidelobe levels. Golay gave several recursive and one non-recursive methods for generating complementary sequences. The recursive method, used to generate the binary complementary sequences, is based on the following algorithm {1};

$$a_n = [a_{n-1}, b_{n-1}] \quad , \quad b_n = [a_{n-1}, -b_{n-1}] \qquad (5)$$

where the operator [ ] denotes concatenation of sequences, and a_n and b_n represent the complementary binary sequence of length 2^n. If we take the DFT of the above equation, then get {2}

$$|c(k)|^2 + |d(k)|^2 = 2Nc \qquad (6)$$

3. Analysis and Implementation of Unambiguous Range:

There are many features of the Golay code complementary sequences must be investigated in the work, these are;

1. It has coupled complementary code sequences (A and B) with same length.
2. The output when use this code will get from Equations (3) and (4).
3. This output does not produce from unique A and B, But maybe get from code sequences (A) with more than one code sequence (B) and vice versa as indicated in Table (2).
4. Therefore, the selection of A and B will be depended on the applications.
5. Not all formations of selected bits are suitable as Golay code sequences.
6. Other formations which can be suitable as Golay code sequences, which satisfy the Equations (3) and (4) have the output as;
   a. Main loop =2N Side-loop = 0 as in figure(2-a section 1 and 2-b section 5).
   b. Main loop = 2N Side-loop ≠ 0 as in figure(2-a,b other sections).
7. The complementary codes A and B which give sidelobe=0 can get from:

A B, -A B, A^* B, $-A^*$ B, A B^*, -A B^*, A^* B^*, $-A^*$ B^*, A -B, -A -B, A^* -B, $-A^*$ -B, A $-B^*$, -A $-B^*$, A^* $-B^*$, $-A^*$ $-B^*$.

i.e A=6(00000110) then -6↔249;6^*↔96;-6^*↔159: B=53(00110101) then -53↔202;53^*↔172;-53^*↔83 as indicated in table(2). Therefore, only one combination of these 24 pairs codes can use at a time to get the future of Golay code. Because, all of these combinations will gives same results.

Then, after taking the above features in to account, the proposed work are built in four stages and based on eight bit length Golay code's sequences, these are:

The 1st stage involves the extraction of all formations which can be used as Golay 8 bit code sequences (A and B where it are 192 pairs) from all possible formations as in Table (2). Then, Selection of the Golay code sequences such that no common B codes for one A and not even multi A's for one B as in Table (3).

The 2nd stage includes the selection of the suitable number of block codes. This number depends on the range as will be shown in Figure (1) and depends on the design of transmitter and receiver antenna is common or separated. If it is separated, then, the design will be generally based on the whole pulse repetition interval (PRI (T_p) continuous). Even so, if its common, then, the design will be based on less than the whole interval by process time.

The 3rd stage depends on the selection in the previous stage. The synthesis of transmit a wave are composition of the Golay code's sequences on the signal wave and transmitting it. Now, there are two cases;

Case 1: transmitter and receiver separated.

$$R_{un} = \frac{CT_p}{2} \qquad (7)$$

C – wave speed (in free space = speed of light ($3*10^8$ m/sec).

$for\ puse\ duration = 1\mu sec$ and $R_{un} = 300\ Km$

$then\ T_p = 2\ msec$

$$then\ 125\ block\ of\ \ 8\ bit\ Golay\ codes\ sequences\ are\ needed.$$

However, for 8-bit Golay code sequences only 12 non-recurrent block at a time as in Figure (2-a,b) and multi(too many)-possible 12 combination blocks will be with same results.
Therefore, when using 8-bit Golay code sequences with complementary pair codes, the unambiguous range is nearly equal 30 Km.
Case 2: transevier.

$$for\ this\ case\ we\ \ need\ \leq (\frac{125}{2})\ block\ of\ \ 8\ bit\ Golay\ codes\ sequences$$

Therefore, for optimization

$$\frac{R}{c} = \ N_b * \tau * N_B \qquad (8)$$

Where:

R **-** $Range.$
N_b**-** $No. of\ bits.$
τ **-** $Pulse\ duration.$
N_B**-** $No. of\ blocks$**- non-recurrent blocks (one section has a side-lobe = 0 for each correlation process as in Figure(3-a,b))**

with two cases above there are counters which started to count with each code transmitted and stopped with each one received for range calculation.

The fourth stage is the implementation of some blocks from the block diagram in Figure (4), which are related to the subject of the proposed work with its details in same figure, using Xilinx-Spartan-3A XC3S700A FPGA as in Figure(6). The related blocks are;
Block 1: Extraction all possible formations of 8-bit, which can be used as Golay complementary sequences as in Table (2).
Block 2: Selection non-recurrent codes for using in our application unambiguous range as in Table (3).
Block 3: Making an autocorrelation of received (A) complementary of codes.
Block 4: madding an autocorrelation of complementary B of codes after takes from memory which takes it from Block1.

Block 5: Performing Equation (4).

Block 6: Indication the output after check the result of Equation (4) according to the sidelobe states. There are other blocks attached to the main blocks in Figure (4) for accuracy and error detection. These are;

Blocks S1, S2 and S3: Which are to e used where more accuracy is needed. The functions of these blocks are summarized as follows:

Block S1: Add($-A^*$) to the Tx wave stream, then, the Tx wave will be

$[A_0, -A_0^*, A_1, -A_1^*, \ldots\ldots A_7, -A_7^*]$ **instead of** $[A_0, A_1, \ldots\ldots A_7]$.

Block S2: Checking step by the following expressions;

1. **ACR=A XOR $-A^*$ Symmetry**
2. **BC = B XOR $-B^*$ Symmetry**

Block S3: Check the results of the above expression and for more accurate determination of the complementary code according to;

1. **ACR and BC are symmetrical.**
2. **If ACR = $\overline{BC}$ Then A correct and B its complementary Pair code A.**

3. Simulation Results

In Figure (1), the Tx wave contains an eight 8-bit blocks as in Table (1). Furthermore, as in block diagram of Figure (4), after Tx/Rx the autocorrelation has been carried out by adding the Golay pair code sequences according to Equations (3) and (4). Then, the sidelob has been checked, since the main lobe is equal to 2N for all autocorrelation adding. Therefore, Figure(2-a,b) indicate that the sidelobe equal zero for the complementary pair code only, while, the main is 2N always. In Figure(2-a) the complementary code takes place in section 1, while in Figure(2-b) it takes place in section 5. Figure(3-a) represents the whole autocorrelation adding process for received wave (A's) with stored (B's). While figure(3-b) represents the output of adding process when sidelobe checking has been satisfied, where, only complementary code exists. Figure(5), represents the output of the same operation with Xilinx-Spartan-3A XC3S700A FPGA implementation as in Figure(6), with new Tx arrangement. The Tx

arranges are [0 3 7 6 2 5 1 4]. It's clear from the figure the output only for a complementary pair according to sidelobe checking as in Figure(6) with green indicators. The correct output will be obtained when the complementary pairs are conformal. The process time can be reduced using another way (by activation of S's blocks) for checking and determination the complementary.

Table(1)

a-FPGA implementation based on 8-bit 8-block .

seq	A(Dec.)	B(Dec.)
0	6- 00000110	83- 01010011
1	29- 00011101	72- 01001000
2	58- 00111010	111-01101111
3	78- 01001110	130-10000010
4	111-01101111	58- 00111010
5	125-01111101	141-10001101
6	172-10101100	6- 00000110
7	222-11011110	139-10001011

b-The block arrange in Tx/Rx wave

Tx/Rx seq	A(Dec.)
0	6- 00000110
1	78- 01001110
2	222-11011110
3	172-10101100
4	29- 00011101
5	125-01111101
6	58- 00111010
7	111-01101111

5.Conclusions:

In this paper, the design and implementation of a new ranging system based on the Golay complementary sequence code, has been presented. The hardware implementation of the proposed system has been carried out using the FPGA Xilinx-Spartan-3A XC3S700A. In addition, special blocks have been included in the design to enhance the accuracy of the measured ranges. In comparison with the existing ranging techniques, the proposed technique is considered simple, low cost, and accurate. Additional work has to be done to enhance the capabilities of the present system, making use of the features by this technology. As a future work, an effort has be devoted to be include this system additional requirement such as unambiguous Doppler.

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Table (2) Golay Code Sequences formation (8 bit)

A(Dec.)	B(Dec.)	A(Dec.)	B(Dec.)	A(Dec.)	B(Dec.)	A(Dec.)	B(Dec.)	A(Dec.)	B(Dec.)
172	6	144	58	177	125	141	190	202	249
83	6	111	58	114	125	78	190	53	249
53	6	141	65	114	130	9	197		
202	6	177	65	78	130	246	197		
197	9	114	65	141	130	111	197		
58	9	78	65	177	130	144	197		
163	9	18	71	116	132	96	202		
92	9	72	71	46	132	159	202		
184	18	237	71	139	132	249	202		
71	18	183	71	209	132	6	202		
29	18	226	72	132	139	222	209		
226	18	71	72	222	139	33	209		
27	20	184	72	123	139	123	209		
216	20	29	72	33	139	132	209		
39	20	125	78	130	141	39	215		
228	20	190	78	125	141	27	215		
20	27	65	78	65	141	228	215		
215	27	130	78	190	141	216	215		
40	27	249	83	163	144	235	216		
235	27	6	83	197	144	20	216		
72	29	96	83	92	144	215	216		
18	29	159	83	58	144	40	216		
183	29	9	92	172	159	209	222		
237	29	111	92	83	159	46	222		
46	33	246	92	53	159	116	222		
209	33	144	92	202	159	139	222		
139	33	83	96	111	163	18	226		
116	33	172	96	9	163	72	226		
215	39	202	96	144	163	237	226		
235	39	53	96	246	163	183	226		
20	39	197	111	6	172	40	228		
40	39	163	111	249	172	215	228		
27	40	58	111	159	172	235	228		
39	40	92	111	96	172	20	228		
216	40	65	114	190	177	216	235		
228	40	125	114	65	177	27	235		
132	46	190	114	125	177	228	235		
222	46	130	114	130	177	39	235		
123	46	222	116	184	183	29	237		
33	46	33	116	226	183	71	237		
159	53	123	116	71	183	226	237		
96	53	132	116	29	183	184	237		
6	53	46	123	72	184	58	246		
249	53	116	123	18	184	197	246		
246	58	209	123	183	184	92	246		
9	58	139	123	237	184	163	246		
		141	125	177	190	83	249		
		78	125	114	190	172	249		

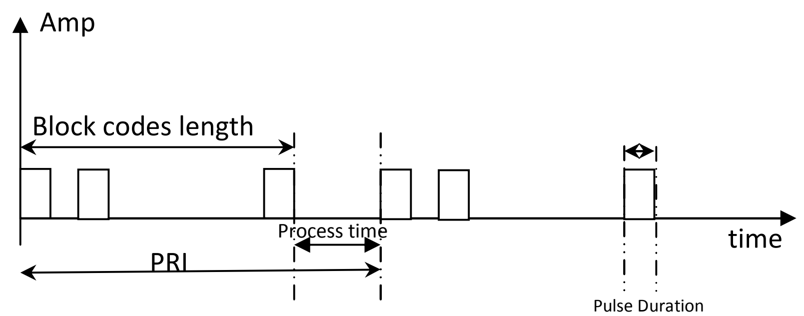
Table(3) 8 bit Goly codes sequences (not repeated in A nor in B)

a

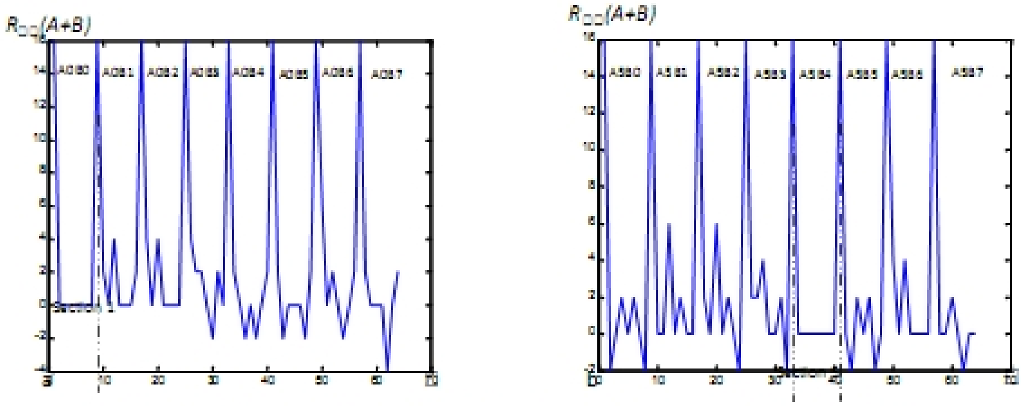
A(Dec.)	B(Dec.)
6	53
9	58
18	29
20	27
27	20
29	18
33	46
46	33
53	6
58	9
65	78
78	65

b

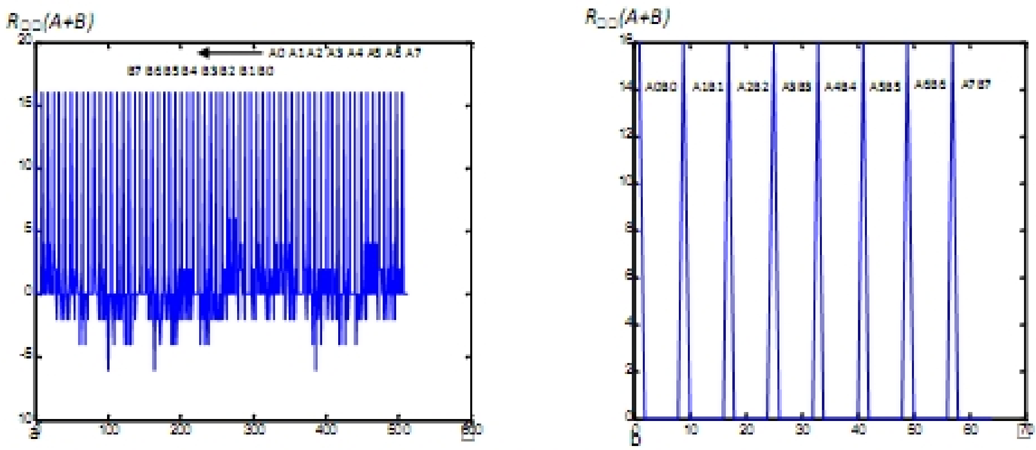
A(Dec.)	B(Dec.)
6	83
9	92
18	71
20	39
27	40
29	72
33	116
46	123
53	96
58	111
65	114
78	125



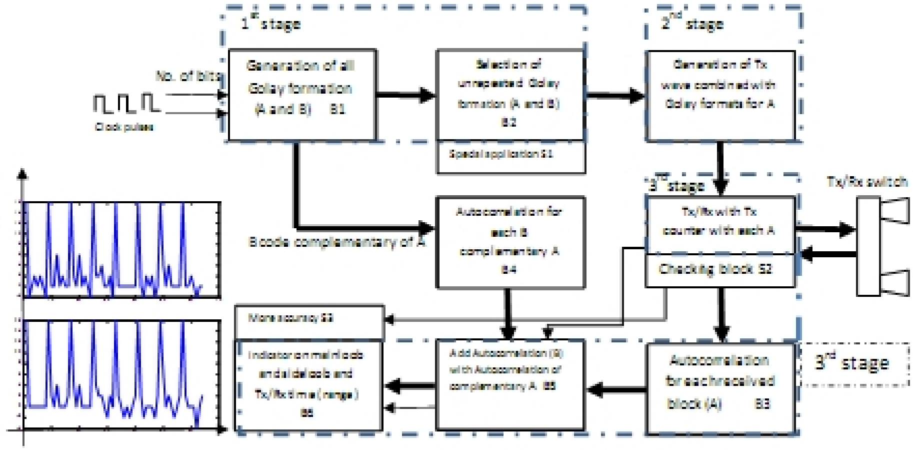
Figure(1). Tx/Rx pulse codes representation



Figure(2). Output of equations (3,4) for complementary and not compatible complementary of Golay code sequences

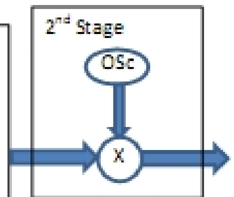


Figure(3). Output of equations (3,4): a) all output for each correlation process b) only sidelobe=0 output



Generation of Golay Code Complementary Sequences Block B1 and B2

```
for i in 0 to 15 loop
   x1(3 downto 0):= CONV_STD_LOGIC_VECTOR(i,4);
   for j in n1+1 to n loop
     x1(j):= bb(j) xor (not x1(n-j));
   end loop;
   xc:=conv(x1,n);
   ac:=conv(a1,n);
   cor(ac,xc,n,pp);
   zc:=0;
   for j in 0 to n loop
     if pp(j)=0 then
       zc:=zc+1;
     end if;
   end loop;
   if zc=n then
     ind:=ind+1;
     bx(ind):=x1;
   end if;
 end loop;
 B1<= bx(1);
 B2<= bx(2);
 B3<= bx(3);
```



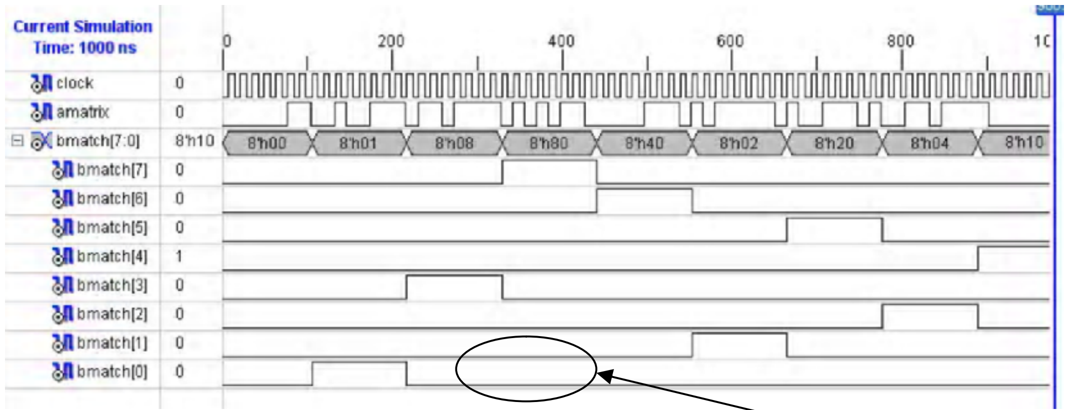
Autocorrelation and Adding of Golay Codes (A&B) block B3 & B5

```
procedure cor (x1,x2:in r;n:in
integer; x3:out r) is
 variable pa,pb:r;
 for j in 0 to n loop
   pa(j):=0;
   pb(j):=0;
   for k in 0 to n-j loop
     pa(j):=pa(j)+x1(k)*x1(k+j);
     pb(j):=pb(j)+x2(k)*x2(k+j);
   end loop;
   x3(j):=pa(j)+pb(j);
 end loop;
```

Indicator of main and sidelobe Block B6

```
variable pa,pb:r;
 for j in 0 to n loop
   pa(j):=0;
   pb(j):=0;
   for k in 1 to n-j loop
     if x3=0.0 then DESIRED;
     else
     x3=UNDESIRED
   end loop;
 end loop;
```

Figure(4). Block digram of the proposed design with its blocks details



Figure(5). Output of the correlation process as built by FPGA

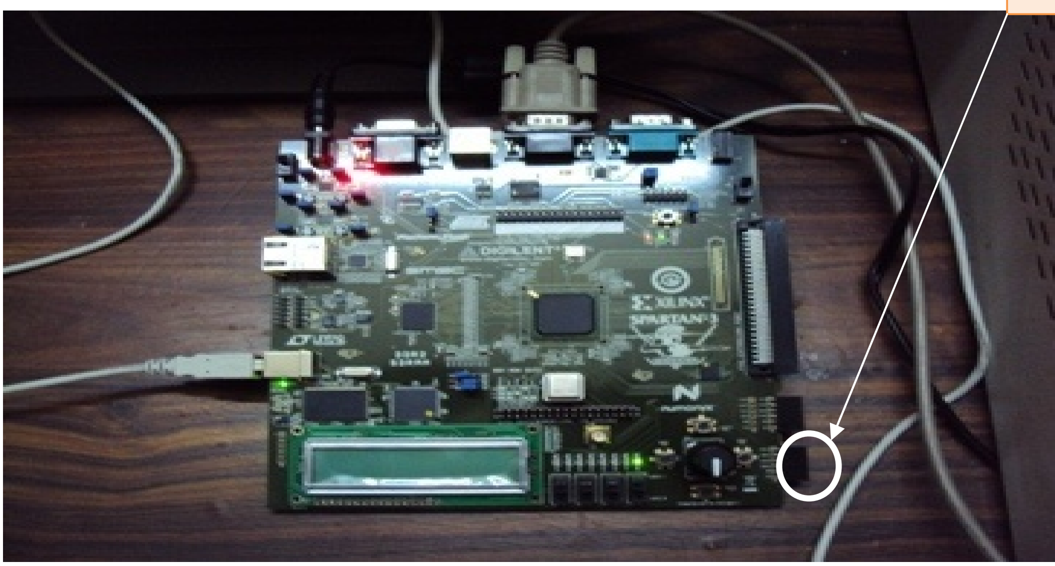


Figure (6). The implementation Circuit

تصميم وتنفيذ نظام مدى غير مشكوك فيه باستخدام متتابعات غولي مبنية بمصفوفة بوابات المجال القابلة للبرمجة موقعيا

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المستخلص

لتسلسل غولي بعض الخصائص التي تجعلها متميزة في مجال التطبيقات والنتائج. لكن لا بد لهذا التمييز من اختيار الرمز المتسلسل بعناية ودقة. في هذه الورقة، واعتمادا على مصفوفة بوابات المجال القابلة للبرمجة موقعيا تم تصميم وتنفيذ عمل العلاقات التبادلية لمتسلسلات غولي الزوجية التكميلية (او التكاملية) بعد استخراج كافة احتمالات تكوين رمز 8 بت (192 رمز ثنائي 8 بت)، وفصل رموز غير المتكررة (12 في وقت واحد) ، وعدد(عدد كبير) من 12 كتلة 8 بت معا مع نسبة 16 التركيز الرئيسي لجمع العلاقات التبادلية إلى التركيز الجانبي لها. هناك دوائر ملحقة مقترحة في جانبي المرسلة والمستلمة والمؤشرة S1, S2 and S3 لزيادة الدقة. يمكن اعتبار البحث من طلائع البحوث بتطبيق هذه التقنية على الموضوع وحصلنا على نتائج جيدة. تم تنفيذ بواسطة Xilinx-spartan-3A XC3S700A FPGA بتردد نبضي داخلي بمقدار 50 ميكا هيرتز.