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Tx/Rx: Generation and Correlation of a Costas Array FM Code Using FPGA Spatran-3 Technology

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ABSTRACT

This paper describes a real time generation and correlation of Costas array FM code pulse compression using Field Programmable Gate Array (FPGA) for implementation, which provides the flexibility, reconfigure ability and reprogram ability. This implementation contains two parts, the first Part, to generate. Number of frequency sequences, which can use as Costas, where, this part was built in transmitter side. The second part of implementation contains three stages in the receiver side; range determination, correlation and Doppler measurement to the replica of Tx-signal. The tested work was taken for eight digits and two cases of frequency shift (1&2) with an eight time shift for each one. This implementation was built by using VHDL editor for Spartan-3 with IC XC3S200. The clock is 20nsec and can use less than that time.

Keywords: VHDL design, Radar signal processing, Costas code, FPGA, Spartan-3

التوليد والترابط لترميزالتضمين الترددي لمصفوفةكوستاس باستخدام تقنية بوابات المجال المبرمجةموقعيا سبارتن-3

الخلاصة

هذا البحث يوضح التوليدفي الوقت الحقيقي و عمل الترابط (correlation) لترميز التضمين الترددي لمصفوفةكوستاسباستخدام جهاز منطقي قابل للبرمجة (بوابات المجال المبرمجة موقعيا) والذي يحقق مرونة و أعادة البرمجة للتنفيذ(للبناء). هذا البناء يحتوي علىجزئيين، الجزء الأول، توليد المتسلسلات الترددية والتي يمكن استخدامها ككوستس ويكون في جانب المرسلة. الجزء الثاني يحتوي ثلاث مراحل في جانب المستلمة: تحديد المدى وإجراء عملية الترابط وقياس الدوبلر للنسخة المطابقة للإشارة المرسلة.اختبارات العمل تمت على نموذج من ثمان مراتب وحالتين تزحيف بالتردد بقيمة (1و 2) ولكلاالحالتين كان التزحيف بالزمن هو ثمانية وهذا البناء تم باستخدام (VHDL editor for Spartan-3 with IC XC3S200) وبنبضة تشغيل مقدارها (20nsec) ويمكن تقليل زمن هذه النبضة.

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INTRODUCTION

The radar, sonar, communication and computer systems are in an unprecedented progress today. Indeed,communication and computer systems have formed a common space where the quantities of the offered services are growing very fast, which leads to a necessity of extreme optimal using of the connecting channels. This is avery hard technical problem, and can be solved by usingwide-band signal, which has special correlation properties, first of all, the side lobes of the auto-correlation functions of the signals should be as small as possible, because they determine the resolution of multiple copies of a signal, passed to the receiver through different paths[1]. In radar and sonar, signals are used to determine both the distance (range) and velocity (range rate) for the target.The range is proportional to the round-trip delay time (time shift), and the velocity is proportional to the Doppler (frequency shift) of the received signal [2].The signal designer had been continuously putting their efforts to achieve suitable code to satisfy this aim.There are many code techniques can be used.The usage of them depends upon applications and system overall design parameters. TheCostas array FM code is one of the important codes that used to satisfy this task, especially for radar and wireless spread applications.

Related work

In the existing technical literature, many related studies on Costas FM Code have been reported. It's clear from this review the previous work was focused into two main directions, the first one analysis of the Costas code and software implementation because the complexity and difficulties of it. These works are;

Motokov[1] 2009, two modification of a method for synthesis of Costas array was presented.

Huang[3] 2009, he was modified a welch-Costas code family for the spectral-amplitude-coding optical division multiplexing.

Drakakis[4] 2006, he was collected all main mathematical fact about a Costas array, and also, provide the background which needed in simplest terms.

Vellino[5] 1990, A software program is presented to implement a Costas code by prolog, CHIP, and Pascal languages.

Costas[6]1984, A special matrix was present to determine the frequency-time pattern of a uniform pulse train. Then, using this pattern to choice a waveform, a sequence will be produced later called a Costas Code.

COSTAS ARRAY FM CODE

Costas waveforms are a class of pulse compression waveforms, having aspects of both phases coded and stepped frequency pulse for bursts waveforms (multiple pulse).Furthermore, it is similar to a poly phase waveform in that it is a singlewaveforms divided into N (up to 360) sub pulses, with important rule, where, one frequency per time slot, and one-time slot per frequency. Then, each frequency – time slot for which a frequency occurs (a dot as the elements) corresponds to a row column for which no other frequency (dot) occurred [7].Timing diagram of pulse as in figure(1)[8];

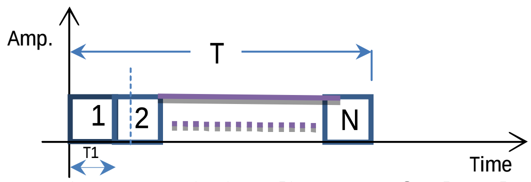

Figure (1) timing diagram of sub pulses

Where, In time domain

$$T_1=T/N \leftrightarrow T=T_1*N \quad (1)$$

T= pulse duration

N= Contiguous sub-pulses

T1= duration of each subpulses.

The N possible frequencices are availaible as defined by;

$$W_i = W_o + i\delta W \quad (2)$$

$$i=1,2,\ldots\ldots N$$

W_o=center of frequency span.

$$\delta W = 2\pi\delta f = 2\pi/T_1 \quad (3)$$

The maximum change in frequency Δf during time T is

$$\Delta f=\Delta W/2\pi = N\,\delta f = N/T_1 \quad (4)$$

Time bandwidth product is

$$\Delta f\ T= (N/T_1)*T_1*N = N^2 \quad (5)$$

The duration of compressed pules is

$$1/\Delta f = T/ N^2 \quad (6)$$

The overall pulses can be viewed as a NxN array of chosen frequencies versus time.A special class of permutation matrices is considered[7]. These matrices may be beneficially used to determine the frequency-time pattern[6], as in figure(2) for N=8.

Time

Frequency

	1	2	3	4	5	6	7	8
1								
2								
3								
4								
5								
6								
7								
8								

the sequence is [5 3 2 7 1 8 4 6]

Figure (2) Hit matrix

The cross-and-auto- ambiguity functions of code are determined by the number of time frequency coincidences for each time and/frequency shift of the code with respect to replica. Furthermore, the Costas technique is used to generate a sequence of frequencies (used in frequency hopping) that produce unambiguous range and Doppler measurement within radar while minimizing the cross talk between frequencies[9].Therefore, using the difference triangle method, ideal sequences were found, according to the equation[10,11].

$$D_{i,j} = a_{i+j} - a_j \qquad i + j \le N \qquad (7)$$

Where:
a_j- Signal sequence.
I,j- row and column.
The coincidence function C(r,s) is defined as the number of coincidences between the original array and itstranslation,where[2,7];

$$C(0,0) = n \qquad (8)$$

$C(r,s) = 0$ if $|r| \ge n$ or if $|s| \ge n$ (9)
$0 \le C(r,s) < n$ except when $r = s = 0$.(10)
Where:
r −shift in column (left-right) –(N-1)≤r≤(N-1)
s −shift in row (up-down) –(N-1) ≤ s≤(N-1)
And this two – dimensional function $C(r,s)$ is called the ambiguity function.

One of the constructions of Costas is a Welch. This construction can use for a number of pulses equal a prime number minus one, as shown;

$i = \alpha^j$(modulo$p$) (11)

Where;
J=0,1,2 …….($p-2$)
i=0,1,2…….($p-1$)
$p = N + 1$

N- number of subpulses.
α - primitive root of p
p - odd prime

Time

Freq.	0	1	2	3	4	5	6	7	8	9
1	●									
2		●								
3									●	
4			●							
5					●					
6										●
7								●		
8				●						
9							●			
10						●				

Frequency time array (N=10,α=2)

Then, the total energy behind these N windows is summed of $C(r,s)$ (double integrals in time and frequency)[7].

PROPOSED IMPLEMENTATION

A hardware/software partitioning methodology for improving performance in a single-chip system composed by Field Programmable Gate Array (FPGA) reconfigurable logic, which is presented, where speedups are achieved by executing critical software parts on the reconfigurable logic[12]. The work in this paper is to reduce the complexity which stated in ref.[1,13] by using (FPGA) technology. The work contains two parts, the first one in the transmitter side before the modulation stage to create a sequence which can use as Costas FM code from all possible sequences for certain length(N=8), and the second part in the receiver side after IF stage for correlate the received signal with replica of transmitted signal after determination the amount of range shifts and before determination the frequency Doppler by its shifts, as in figure(3).

Part one

The first part is to generate and determined the number of sequences, which can be used as Costas code by using equation (7) (difference triangle method), after determine the number of digits which we want(8-digitwere taken in the design), then the number of sequences, which can be used as Costas are 440 from all possible sequences (65536) and (40320) permutation matrices.The VHDL editor with Xilinx XC3s200 spartan-3 program which makes this part shown in figure(4-part-b), and the result of this part shown in figure(5). Where, there are two columns, the first one represent the code which cannot be use as Costas and the second represent the Costas (or the sequences which can work as Costas).

Part two

A second part which represents the process in the receiver side, to determine the accurate range and range-rate from the received signal. This determination of the occurs by determine the shift in time and frequency respectively. As shown in the figure (3) , this part contains two steps, these are;

1. After the pulse signal transmitted (frequency sequence) the counter started, and it stopped when the signal was a return back to the received. Then, from this count can determine the range as;
   Tx Rx time (T_{TR})= number of count * time of counter pulse.
   Range (R) = $CT_{TR}/2$
   Where:
   C-transmitted signal speed (in free space = speed of light).
   T_{TR}- TxRx time.
   R- target range from the observer.
2. When the signal was received with Doppler shift or without (depend on the target motion), then compare it with possible

replica shifted of the transmitted by compression. Then, can determine the amount of the Doppler by find the greatest coincidence with any one of its possible replica (Max. compressor outputi.e max. correlation o/p) as in figure(4-c).

RESULTS

Figures(5,6,7,8 and 9) are the results. Figure(5) represents the result of checking part. Clarify the details of figure(5) are; there are two columns each one represents the results of using the difference triangle methods of a sequence (53281674 and 53271846). The first row represents the timing of clock pulse (20 nsec). The second row represents the sequences which will be checked. The third one represent the result of checking (8hFF means the sequence cannot use as cost as code and 8h11 mean can).The rows from 3^{rd} to 10^{th} represent the result of correlation (each row represents a one-step shift in a frequency and eight-step shift in time). Figure(6 and 7) represents the correlation of four Costas code (13675482 , 12576483, 15387462,and 62813475). The first row is the clock pulse, and the second row represents the value of coincidence without time and frequency shifts (max. coincidence main lobe) the third row represents the number of the sequence in the memory. The rows from 4-10 represent the result of coincidence (each row of them represents an one-step shift in a frequency and eight-step shift in time). Figure (8) same the other but with two steps shift in frequency. Furthermore, figure(9) show the amount of range shifts from the counter and frequency shift after the compressor output.

CONCLUSIONS

From the proposed work two point can be viewed these are;

1. Nearly same time as in reff.[14], but with more flexibility and simple design by use this technology. Moreover, with anability to decrease this time dependence on the application and external peripherals like RAM where this technology can operate with frequency range (25-325 MHz).
2. Reduce the complexities which are stated in reff.[1,13] by use Spartan-3(low cast, small size, ease deal with it, and reprogrammed) technology.

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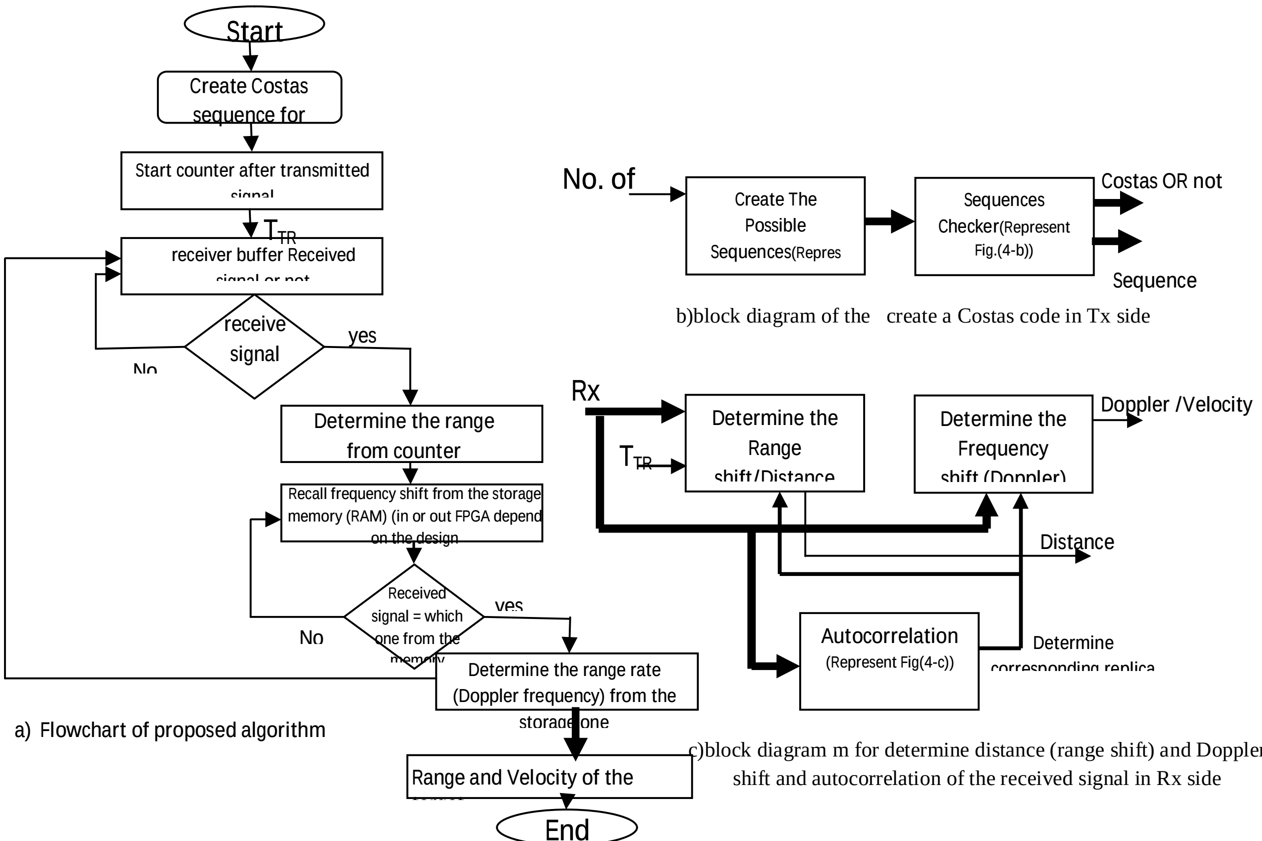

Figure (3) Flowchart and block diagrams of the implementation process

```
libraryIEEE;
useIEEE.STD_LOGIC_1164.ALL;
useIEEE.STD_LOGIC_ARITH.ALL;
useIEEE.STD_LOGIC_UNSIGNED.ALL;
```

```
fori1 in 1 to nloop: for i2 in 1 to nloop: for i3 in 1 to nloop: for i4 in 1 to nloop
fori5 in 1 to nloop: for i6 in 1 to nloop: for i7 in 1 to nloop: for i8 in 1 to nloop
        ifi1/=i2 and i1/=i3 and i1/=i4 and i1/=i5 and i1/=i6 and i1/=i7 and i1/=i8 then
        ifi2/=i3 and i2/=i4 and i2/=i5 and i2/=i6 and i2/=i7 and i2/=i8 then
        ifi3/=i4 and i3/=i5 and i3/=i6 and i3/=i7 and i3/=i8 then
        ifi4/=i5 and i4/=i6 and i4/=i7 and i4/=i8 then
        ifi5/=i6 and i5/=i7 and i5/=i8 then
        ifi6/=i7 and i6/=i8 then
        ifi7/=i8 then
```

Part a

For find all Possible sequences

```
while (ch=0 and k<=n-1) loop
                    foriin 1 to n-k loop
                            y(i):= test(i+k)-test(i);
                    endloop;
                    foriin 1 to n-k-1 loop
                    forl in i+1 to n-k loop
                            ify(i)=y(l) then
                                    ch:=1;
                            endif;
                    endloop;
                    endloop;
                    k:=k+1;
                end loop
```

Part b

for check the sequences as costas

```
foriin 1 to n-1 loop
        w(i)(0):=8;
        forj in 1 to n-1 loop
                match:=0;
                forl in 1 to n-j loop
                        if(x1(l)+i)=x1(l+j) then
                                match:=match+1;
                        endif;
                endloop;
                w(i)(j):=match;
        endloop;
endloop;
```

Part c

correlation

Figure (4) three parts of VHDL Spartan-3 (IC XC3S200 Program.

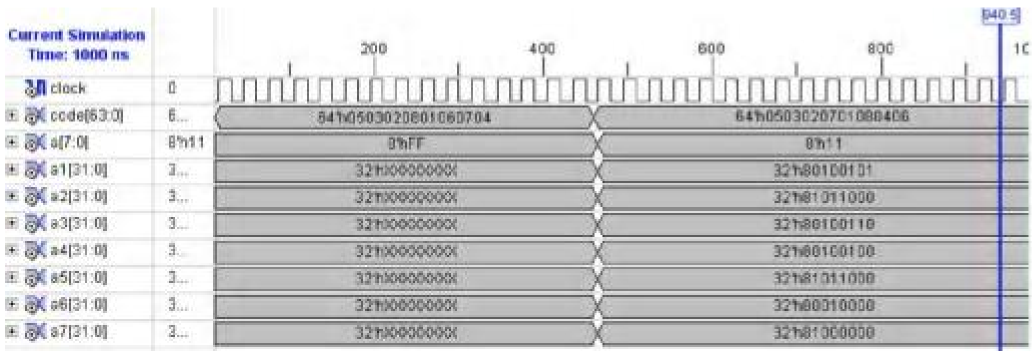

Figure (5) result of unCostasand Costas code.

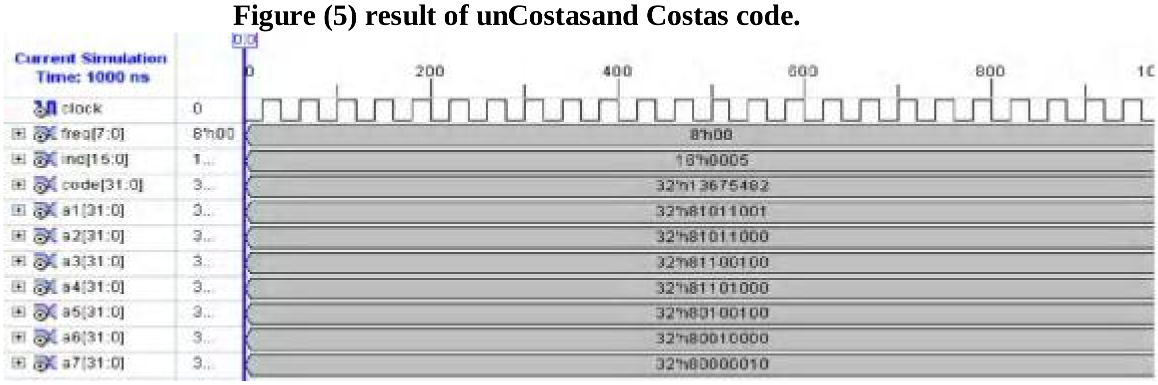

Figure (6) Correlation result of 5th seq. with freq. step shift equal to zero

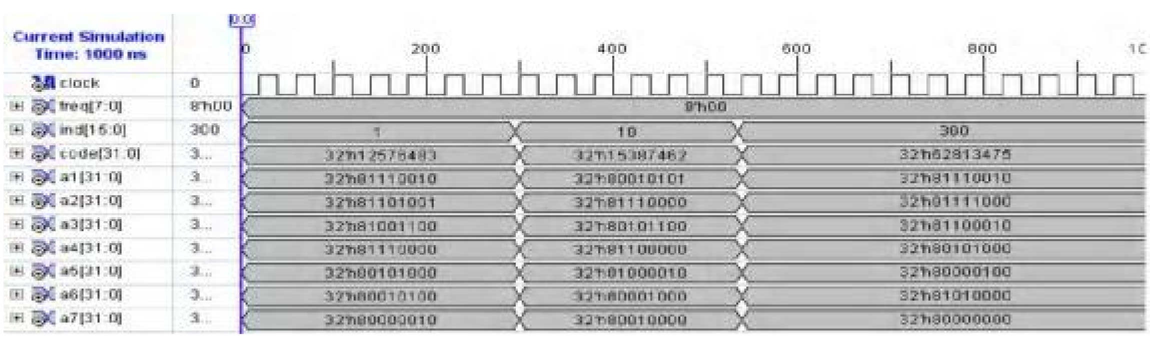

Figure (7) correlation result of 3 Costas seq (1,10 and 200) from memory

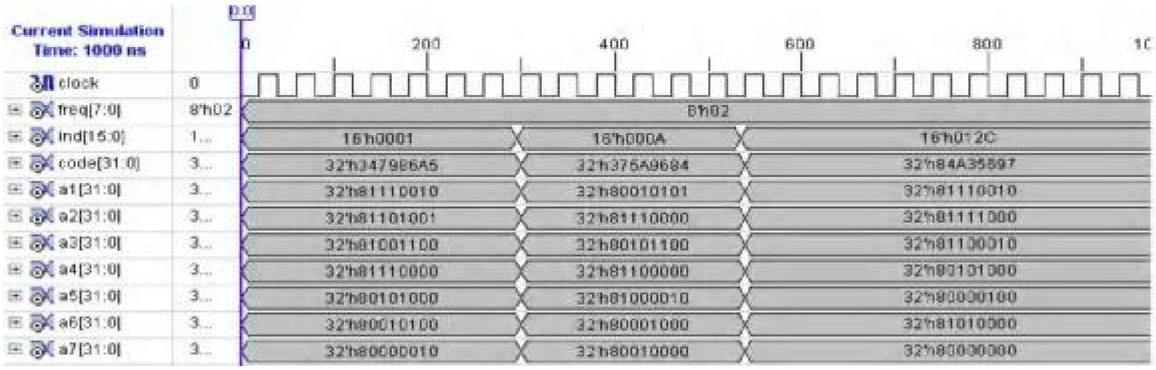

Figure (8) correlation result of 3 Costas seq.(1,10 and 300) from memory with 2 step shift in frequency

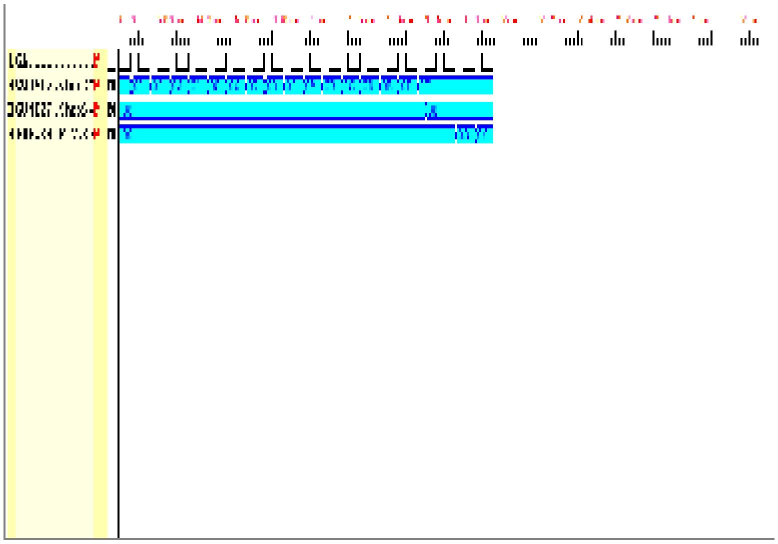

Figure (9) Amount of time and frequency shift