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## **A NEW METHOD TO IMPROVE THE SPEED AND POWER CONSUMPTION OF THE DIGITAL RECEIVER USING EIGHT POINT FFT COMPUTATIONS IN OFDM RECEIVER SYSTEMS**

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### **ABSTRACT**

It is offered a new approach in this article to implement of Orthogonal Frequency Division Multiplexing receiver part according to Fast Fourier Transform. This approach greatly reduces computations and complexity and increases the speed of computations, so that the number of computations in OFDM receiver part is reduced to 2 multiplication operations and 26 addition operations. The proposed approach increases the speed of receiving data and the speed of FPGA processor and decreases power consumption and circuit size greatly. Offered approach is compared with existing approaches and its characteristics are affirmed with using of implementation and synthesis.

**Keywords:** *Orthogonal Frequency Division Multiplexing, Fast Fourier Transform, FPGA*

### **INTRODUCTION**

It can be used of parallel data transmitting approaches in order to achieve high bit rate data transmitting and receiving of wireless systems.

One of techniques to transmit high-frequency data is multiplexing approach that enables us to transfer data parallelly and simultaneously, Orthogonal Frequency Division Multiplexing technique (OFDM) can be mentioned as one of multiplexing approach.

In this approach, data are mounted on several multiple orthogonal carriers and then they can be sent parallelly, Fourier can make these carriers.

The main motivation of using OFDM is resistance of this system in multipath channels (multiple releases). Since the bit rate of every sub-carrier reduces in compare to the rate of main bit so the time period of symbol increases, meanwhile the time period of the interference signal is constant. So the inter symbol interference (ISI) has reduced and as a result system efficiency will improve in multipath channels (figure 1).

OFDM is a kind of baseband modulation and it must use one of DPSK, QPSK, nQAM (n= 16, 64, 128,...) approaches to transmit it. Unlike other multi-carrier systems, carriers are perpendicular on each other in OFDM technique and so the carriers orthogonality cause that different carriers can be separated from each other in receiver although they are overlapping in the frequency domain.

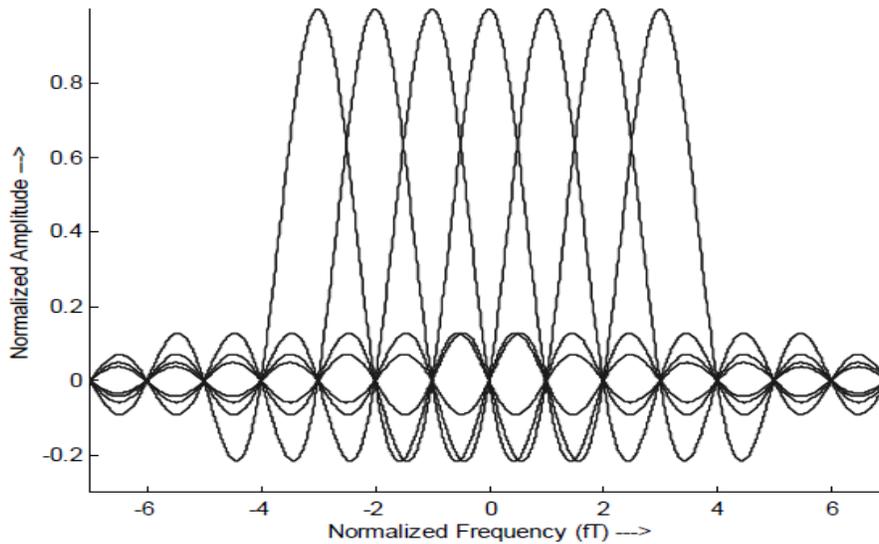
Some of its applications are as follows:

OFDM applied instances:

- 1- Telecommunication.
- 2- Television and radio.
- 3- All digital transmitter and receiver systems.
- 4- OFDM constitutes the base of DAB (digital radio transmitters).
- 5- OFDM constitutes the base of DVB and HDTV.
- 6- OFDM is under investigation to use in 4G wireless systems.
- 7- It applies on high bandwidth data communication on Mobile radio channels such as HDSL up to 1.6Mbps, ADSL up to 6Mbps and also VDSL to 100Mbps.

This article includes 7 sections. It is offered a review of past works in the second section, operating principles of receiver system with the use of fast Fourier transform and FFT structure in the third section, suggestive approach in the fourth section, comparison and output results of synthesis in the fifth and sixth sections and conclusion in the seventh section.

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**Figure 1: Sub-carrier in OFDM spectrum**

### A Review of Past Works

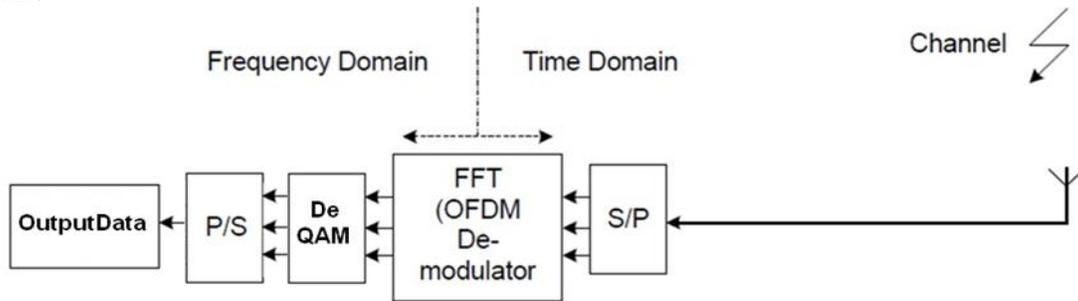
In the 1960s, OFDM technique has been used in several high frequency military systems such as KINEPLEX, ANDEF and KATHRYN (Mosier and Clabaugh, 1958; Porter, 1968; Zimmerman and Kirsch, 1967). In 1971, Mr. Weinstein and Ebert applied the idea of using Discrete Fourier Transform (DFT) in parallel data transmission systems as a part of modulation and de-modulation process (implementing OFDM) which created a major change in reducing the complexity of system (Weinstein and Ebert, 1971). Another important step was taken by Peled and Ruiz in 1980, they suggested to use the suffix of iterate or iterate expansion to solve carriers orthogonal problem (Peled and Ruiz, 1980). In 2005 Mr Chang considerably reduced the computation number of Fast Fourier Transform (FFT) and also inverted Fast Fourier Transform (IFFT). In his performed works about FFT, the number of addition and multiplication operations was reduced to 30 and 16, respectively. It was also reduced the number of addition operations, multiplication operations and the number division operations to 24, 16 and 14, respectively, for IFFT (Chang, 2005). In 2009, OFDM receiver was synthesized with 512 points FFT algorithm on the basis of Radix-2, increasing the frequency up to 100MHz has been the purpose of designing. The computational complexity of this design has not been optimized desirably and prior designs are synthesized on the chips with a more powerful processor which has led the increasing of the frequency (Eldin *et al.*, 2009). In 2009, an approach was implemented with the using of correlation between input data bits and also with using of FFT/IFFT on the basis of Radix-2 and Radix-4 so that the hamming distance between input data encodes four bits data and then it decodes them at the receiver. In this work, the speed of transmitting/ receiving has increased but the encoding/ decoding has computational complexity (Rajeswari and Satish, 2009). In 2010, the FFT algorithm was implemented on the basis of Radix-2 on FPGA processor as the processing core algorithm and operating frequency was limited up to 1000MHz. the speed of receiving data were increased up to 16 bits and because of FFT implementation on the core, it was noted to operating frequency but it has much processing load for processor (Xiu-fang and Zhen-long, 2010). In 2012, an approach was proposed to increase the efficiency of sixteen-points FFT/ IFFT, to reduce power consumption and increase efficiency in wireless broadband communication systems that are based on OFDM (WiMax) and to reduce the computation time for communication systems that are based on the IEEE802.16 standard. In this approach, the number of sixteen-points FFT multiplication computations on the basis of 2Radix pattern was reduced from 24 real multiplications to 20 real multiplications on the basis of 4Radix pattern. This approach only reduces multiplication computations due to complexity of multiplications and no innovation takes place to reduce adding computations, and also it was held a lot of rotation coefficients in the memory because of

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calculation of 16, 64 and 128 points FFT whereas W phase rotation could factorize similar coefficients (for example  $W_4^0 = W_8^0$ ) after simplification of these coefficients (Arioua and Belkouch, 2012).

**OFDM Receiver System**

Received signals can be separated from each other with the using of modulated carriers correlation techniques through a communication channel (wireless antenna) in OFDM receiver system due to being orthogonal. For doing this, at first received serial data were converted to parallel data by convertor block of serial to parallel and after that these data were employed as FFT input and then the output of this were employed as the input of DeQAM demodulation (the opposite of mapping action) in order to modulated signals were separated from each other and finally it can be exploited from serial data in the receiver system by convertor block of parallel to serial. OFDM receiver block diagram of Figure 2 shows above statements.



**Figure 2: OFDM receiver system diagram block**

One of the main reasons of using OFDM is related to high resistance property which is shown in front of special frequency fading or narrowband interference. A small attenuation or interference can interrupt all communication in a single carrier system, but only a small percentage of the carriers will be affected in a multi-carrier system. These small numbers of error carriers can also be corrected by encoding approaches of error correction. OFDM is extremely using the bandwidth. This technique has been used in the all wired and wireless communication standards. One of the major disadvantages of parallel transmitter systems like OFDM is the complexity of realization and implementation of system, since a lot of similar demodulator block are necessary for modulation, and this similar demodulator set in OFDM receiver can be implemented by discrete Fourier transform (Weinstein and Ebert, 1971). Doing the modulation process by using discrete Fourier transform makes the system production and implementation to becommodious but its computation volume is great and complicate, this factor is time consuming and also increases power consumption and decreases the productivity of hardware as well as lacks the proper efficiency in high frequencies with high transmitting rate.

**Fast Fourier Transform**

To receive data in receiver system it is used of Fast Fourier transform FFT instead of discrete Fourier Transform due to great and complicated computation volume; for this reason it is proposed to decrease and optimize the computational complexity of Fourier transform to reduce computational volume in addition to increase data receiving frequency, as well as to reduce power consumption and consumed memory.

**Discrete Fourier Transform**

FFT operates on finite sequences. Wave forms which are analog in nature should be sampled at discrete points before FFT algorithm can be used. The sampling operation is done periodically (periodic) in discrete Fourier transform (DFT) on the signal in the time domain. DFT equation is according to equation (1) (Douglas, 2006; Porter, 1968).

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-\frac{j2\pi nk}{N}} \tag{1}$$

X(k) shows DFT frequency output in kth of spectrum point which is from 0 to N-1. The N amount shows the sampling points numbers in the DFT data frame. The x(n) amount shows nth of time sampling and n

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is also from 0 to N-1. In the total equation, x(n) can be real or complex. DFT equation can be rewritten as equation (2) (Champagne and Labeau, 2004).

$$(k) = \left[ \sum_{n=0}^{N-1} x(n) W_N^{nk} \right] \tag{2}$$

The amount of phase rotation coefficient of  $W_N^{nk}$  is determined through equation (3) (Douglas, 2006).

$$W_N^{nk} = e^{-j2\pi nk/N} \tag{3}$$

These functions are written based on sine and cosine and are in polar form (Vladimir and Rama, 2010). Investigation of first equation shows that calculation of every points of DFT calculation needs below calculations:

The complex multiplication is (N-1) and complex addition is (N-1). If you want to calculate N points in the DFT you will need the N (N-1) complex multiplications and the N (N-1) addition multiplications so if the number of N increases the number of multiplications and additions will increase and consequently it will be needed more and more complex calculations. With the using of the symmetry and periodicity of phase rotation coefficient, the sine and cosine basis functions will be according to Equation (4) (Douglas, 2006).

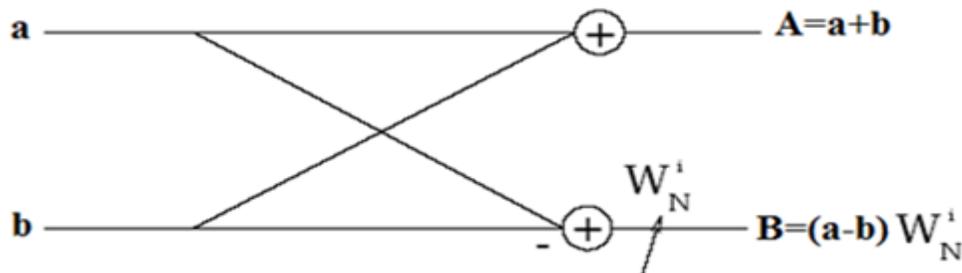
$$W_N^{r+\frac{N}{2}} = -W_N^r, W_N^{r+N} = +W_N^r \tag{4}$$

**FFT Algorithm**

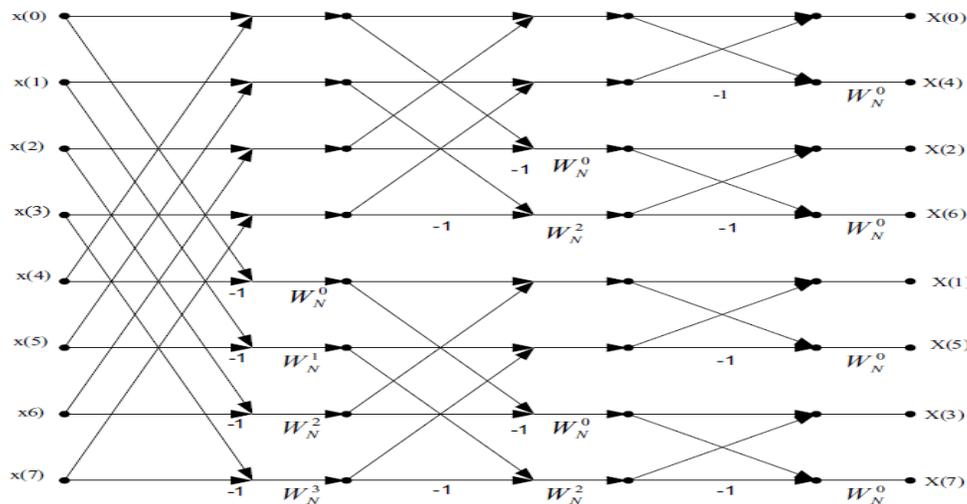
There are two approaches for implementation and accomplishment the FFT algorithm; 1- structural approach 2- direct calculation approach. Since there are 8 points in the direct approach it will be needed 56 complex additions and 56 complex multiplications or in the other word it is needed N(N-1) complex addition operations and N(N-1) complex multiplication operations for N points (Oppenheim, 1999).

**Eight Points FFT Structural Approach**

Structural approach is implemented by using of butterfly calculations like figure (3).



**Figure 3: Single butterfly flowchart in FFT**



**Figure 4: Eight points FFT butterfly flowchart**

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FFT butterfly computations are done in three stages for N= 8. In the first stage, input data are received directly, their even and odd samples are processed separately and the output of the first stage is employed as the input of the second stage. The second stage calculations are done and this process is repeated at the final stage i.e. the third stage. Even output are grouped together and are added pairly, other inputs are multiplied with their own special phase rotation coefficient (W) and every inputs undergoes butterfly operation. Some of these outputs should be multiplied with W again. The outputs of stage two are employed at stage three and in the third stage the butterfly computations are repeated. Because of the calculations for the phase rotation coefficient at each stage, the complexity of the output equations will be increased as the number of stages increases.

For implementation of such a structure and with due attention to the repetition of Ws, It is better to calculate all Ws according to figure (4) firstly and then use them. (5) and (6) equations show changing the polar coordinates in to trigonometry equations and the calculation formula of phase rotation coefficient, respectively (Mosier and Clabaugh, 1958).

$$e^{j\theta} = \cos \theta + j. \sin \theta \tag{5}$$

$$W_N^n = e^{\frac{-j2\pi n}{N}} = \cos\left(\frac{-2\pi n}{N}\right) + j. \sin\left(\frac{-2\pi n}{N}\right) \tag{6}$$

With due attention to (5) and (6) equations, table (1) shows the calculations result of phase rotation coefficients for implementation of FFT structure.

**Table 1: The symmetry characteristics of  $W_8^n$**

$W_8^n$	N
+1	0
+0.7071 – 0.7071j	1
-j	2
-0.7071j – 0.7071	3
-1	4
+ 0.7071j – 0.7071	5
+j	6
+ 0.7071j	7

**Proposed Approach**

The output or frequency points are grouped in the DIF algorithm. DFT (1) can be divided in to two halves i.e. evens and odds (Douglas, 2006; Mosier and Clabaugh, 1958).

$$X(k) = \left[ \sum_{n=0}^{\frac{N}{2}-1} x(n) W_N^{kn} + \sum_{n=\frac{N}{2}}^{N-1} x(n) W_N^{kn} \right] \tag{7}$$

Equation (8) is the simpler form of changing the DFT equation:

$$X(k) = \left[ \sum_{n=0}^{\frac{N}{2}-1} x(n) W_N^{kn} + \sum_{n=0}^{\frac{N}{2}-1} x\left(n + \frac{N}{2}\right) W_N^{k\left(n + \frac{N}{2}\right)} \right] \tag{8}$$

Equation (9) is another form of changing the DFT equation:

$$X(k) = \left[ \sum_{n=0}^{\frac{N}{2}-1} x(n) W_N^{kn} + W_N^{k\frac{N}{2}} \sum_{n=0}^{\frac{N}{2}-1} x\left(n + \frac{N}{2}\right) W_N^{kn} \right] \tag{9}$$

Equation (10) shows the changing of DFT equation in to Fast Fourier form.

$$X(k) = \sum_{n=0}^{\frac{N}{2}-1} [x(n) + (-1)^k . x\left(n + \frac{N}{2}\right)] W_N^{kn} \tag{10}$$

Now consider k separately as even and odd. (even) k= 2r and (odd) k= 2r+1.

Equation (11) shows the calculation of even points of Fourier series.

$$X(2r) = \sum_{n=0}^{\frac{N}{2}-1} [x(n) + x\left(n + \frac{N}{2}\right)] W_N^{2nr} \tag{11}$$

Equation (12) shows the calculation of odd points of Fourier series.

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$$X(2r + 1) = \sum_{n=0}^{\frac{N}{2}-1} [x(n) + x(n + \frac{N}{2})] W_N^{(2r+1)n} \tag{12}$$

With due attention to  $W_N^{2nr} = W_N^{nr}$  and  $W_N^{(2r+1)n} = W_N^{nr} \cdot W_N^n$ , it can be written the equation (13) and

(14) simpler:

$$X(2r) = \sum_{n=0}^{\frac{N}{2}-1} [x(n) + x(n + \frac{N}{2})] W_{N/2}^{nr} \tag{13}$$

$$X(2r + 1) = \sum_{n=0}^{\frac{N}{2}-1} [x(n) + x(n + \frac{N}{2})] W_{N/2}^{nr} \cdot W_N^n \tag{14}$$

Two above equations as DFT, it is considered N/2 points. DFT, it can be divided N/2 points again until just two points remain in every DFT. This algorithm is called FFT (DIF) because outputs are divided to smaller elements to create this algorithm.

The calculation time of FFT algorithm is faster than DFT algorithm, since the number of addition and multiplication operations in FFT is less than in DFT. It has been used of eight points Fast Fourier Transform (FFT) for implementation of OFDM receiver. In equation (15), it has been shown total equation of FFT to calculate x(0), x(1), x(2), x(3) points (FFT final output amount) for eight point (N=8) in frequency domain.

$$x(m) = \left[ \sum_{n=0}^{\frac{N}{2}-1} X(2n) W_{\frac{N}{2}}^{nm} + W_N^m \sum_{n=0}^{\frac{N}{2}-1} X(2n + 1) W_{\frac{N}{2}}^{nm} \right] \tag{15}$$

Calculation of x(0) for m= 0:

$$x(0) = [X(0) + X(2) + X(4) + X(6) + [X(1) + X(3) + X(5) + X(7)]]$$

We put their phase amount instead of Xs:

$$x(0) = [\text{Re}X(0) + \text{Re}X(2) + \text{Re}X(4) + \text{Re}X(6) + [\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) + \text{Re}X(7)]]$$

Calculation of x(1) for m= 1:

$$x(1) = [X(0) - X(4) - [-X(1) + X(3) + X(5) - X(7)] \times 0.7071 - [X(2) - X(6) - [-X(1) - X(3) + X(5) + X(7)] \times 0.7071] \times j]$$

We put their phase amounts instead of Xs:

$$x(1) = [\text{Re}X(0) - \text{Re}X(4) - [-\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) - \text{Re}X(7)] \times 0.7071 [-\text{Im}X(2) - \text{Im}X(6)] + [-\text{Im}X(1) - \text{Im}X(3) + \text{Im}X(5) + \text{Im}X(7)] \times 0.7071]$$

Calculation of x(2) for m= 2:

$$x(2) = [X(0) - X(2) + X(4) - X(6) - [X(1) - X(3) + X(5) - X(7)] \times j]$$

$$x(2) = [\text{Re}X(0) - \text{Re}X(2) + \text{Re}X(4) - \text{Re}X(6) - [-\text{Im}X(1) + \text{Im}X(3) - \text{Im}X(5) + \text{Im}X(7)]]$$

Calculation of x(3) for m= 3:

$$x(3) = [X(0) - X(4) + [-X(1) + X(3) + X(5) - X(7)] \times 0.7071 + [X(2) - X(6) + [-X(1) - X(3) + X(5) + X(7)] \times 0.7071] \times j]$$

$$x(3) = [\text{Re}X(0) - \text{Re}X(4) + [-\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) - \text{Re}X(7)] \times 0.7071 + [-\text{Im}X(2) - \text{Im}X(6)] - [-\text{Im}X(1) - \text{Im}X(3) + \text{Im}X(5) + \text{Im}X(7)] \times 0.7071]$$

In equation (16), it has been shown total equation of FFT to calculate x(4), x(5), x(6), x(7) points (FFT final output amount) for eight point (N=8) in frequency domain (Mosier and Clabaugh, 1958).

$$x(m + \frac{N}{2}) = \left[ \sum_{n=0}^{\frac{N}{2}-1} X(2n) W_{\frac{N}{2}}^{nm} - W_N^m \sum_{n=0}^{\frac{N}{2}-1} X(2n + 1) W_{\frac{N}{2}}^{nm} \right] \tag{16}$$

Calculation of x(4) for m= 0:

$$x(4) = [X(0) + X(2) + X(4) + X(6) - [X(1) + X(3) + X(5) + X(7)]]$$

We put their phase amounts instead of Xs:

$$x(4) = [\text{Re}X(0) + \text{Re}X(2) + \text{Re}X(4) + \text{Re}X(6) - [\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) + \text{Re}X(7)]]$$

Calculation of x(5) for m= 1:

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$$x(5) = [X(0) - X(4) + [-X(1) + X(3) + X(5) - X(7)] \times 0.7071 - [X(2) - X(6) + [-X(1) - X(3) + X(5) + X(7)] \times 0.7071] \times j ]$$

We put their phase amounts instead of Xs:

$$x(5) = [ \text{Re}X(0) - \text{Re}X(4) + [-\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) - \text{Re}X(7)] \times 0.7071 - [ -(\text{Im}X(2) - \text{Im}X(6)) - [-\text{Im}X(1) - \text{Im}X(3) + \text{Im}X(5) + \text{Im}X(7)] \times 0.7071 ] ]$$

Calculation of x(6) for m= 2:

$$x(6) = [X(0) - X(2) + X(4) - X(6) + [X(1) - X(3) + X(5) - X(7)] \times j ]$$

$$x(6) = [ \text{Re}X(0) - \text{Re}X(2) + \text{Re}X(4) - \text{Re}X(6) + [-\text{Im}X(1) + \text{Im}X(3) - \text{Im}X(5) + \text{Im}X(7)] ]$$

Calculation of x(7) for m= 3:

$$x(7) = [X(0) - X(4) - X(1) + X(3) + X(5) - X(7)] \times 0.7071 + [X(2) - X(6) - X(1) - X(3) + X(5) + X(7)] \times 0.7071 \times j$$

$$x(7) = [ \text{Re}X(0) - \text{Re}X(4) - [-\text{Re}X(1) + \text{Re}X(3) + \text{Re}X(5) - \text{Re}X(7)] \times 0.7071 + [ -(\text{Im}X(2) - \text{Im}X(6)) + [-\text{Im}X(1) - \text{Im}X(3) + \text{Im}X(5) + \text{Im}X(7)] \times 0.7071 ] ]$$

When we pay attention in to calculated relations of x(1), x(5) and x(3), x(7), we can see that there are some common calculative factors between these four points, includes:

$$\text{Re04} = \text{Re}X(0) - \text{Re}X(4)$$

$$\text{Re17} = \text{Re}X(1) + \text{Re}X(7)$$

$$\text{Re35} = \text{Re}X(3) + \text{Re}X(5)$$

$$\text{Re} = [ -\text{Re17} + \text{Re35} ] * 0.7071$$

$$\text{Im26} = - ( \text{Im}X(2) - \text{Im}X(6) )$$

$$\text{Im17} = - \text{Im}X(1) + \text{Im}X(7)$$

$$\text{Im35} = - \text{Im}X(3) + \text{Im}X(5)$$

$$\text{Im} = [ \text{Im17} + \text{Im35} ] * 0.7071$$

$$\text{RP} = \text{Re04} + \text{Re} \quad \text{IP} = \text{Im26} + \text{Im}$$

$$\text{RM} = \text{Re04} - \text{Re} \quad \text{IM} = \text{Im26} - \text{Im}$$

Equation (17) shows the final result of x(1), x(5) and x(3), x(7) points of designing FFT equations:

$$x(1) = [ \text{Re04} - \text{Re} - [ \text{Im26} + \text{Im} ] ] \quad \text{briefly we will have } \rightarrow x(1) = [ \text{RM} - \text{IP} ]$$

$$x(5) = [ \text{Re04} + \text{Re} - [ \text{Im26} - \text{Im} ] ] \quad x(5) = [ \text{RP} - \text{IM} ] \quad (17)$$

When we pay attention in to calculated relations of x(0), x(4) and x(2), x(6), we can see that there are some common calculative factors between these four relations, includes:

$$\text{Re1735} = \text{Re17} + \text{Re35}$$

$$\text{Im1735} = \text{Im17} - \text{Im35}$$

$$\text{E} = \text{Re}X(0) + \text{Re}X(4)$$

$$\text{D} = \text{Re}X(2) + \text{Re}X(6)$$

$$\text{Re0246} = \text{E} + \text{D}$$

$$\text{ED} = \text{E} - \text{D} \quad (18)$$

Equations (18) shows the final result of x(0), x(4) and x(2), x(6) points of designing FFT equations:

$$x(0) = [ \text{Re0246} + \text{Re1735} ]$$

$$x(4) = [ \text{Re0246} - \text{Re1735} ]$$

$$x(2) = [ \text{ED} - \text{Im1735} ]$$

$$x(6) = [ \text{ED} + \text{Im1735} ] \quad (19)$$

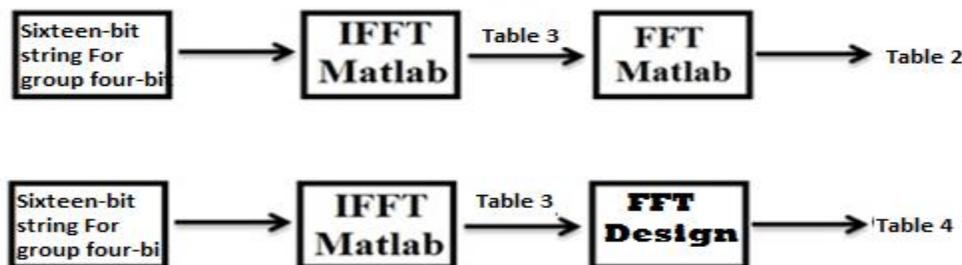
According to presented relations, it is needed 16 addition operations and 2 multiplication operations to calculate x(1).....x(7) points.

**Comparison between Designing FFT Output Results with Matlab Software**

It has been used of Quartus II Version 11 synthesize software to do the optimized FFT designing and it has been compared the FFT designing synthesized output results with Matlab simulator results. To ensure about the correctness of the provided synthesis operation, we one time give IFFT command output of

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Matlab software (Table 3) to FFT input command of Matlab software and consequently the results of table 2 can be obtained, it means FFT command input of Matlab software = FFT command output of Matlab software, and we will also design IFFT command output results of Matlab software for FFT input and then the results of table (4) is achieved. The performance accuracy of the proposed design can be proven by comparing achieved results of IFFT command input (Table 2) with achieved results of proposed approach (Table 4).



**Figure 5: Evaluation method of designed FFT**

According to figure (5), it is separated two sixteen-bits strings as four-bits categories to do this comparison and it is calculated its decimal equivalent (real numbers) with IFFT command by Matlab simulator software, the results of these calculations that are as complex numbers were employed in the proposed design FFT, after these data being employed in the proposed structure we will compare the obtained actual data with applied data in the Matlab software IFFT, it shows the same results and this similarity confirms the correctness of the proposed design.

inputData1: 1000110101110010 → A.0010 B.0111 C.1101 D.1000  
 inputData2: 1101011100101000 → A.1000 B.0010 C.0111 D.1101

**Table 2: Input data with the command of Matlab software IFFT**

	Modulation	Input data 1	Modulation	Input data 2
0	-12		+12	
1	+12		-12	
2	-4		-12	
3	+4		+12	
4	+4		-4	
5	-4		+4	
6	+12		+4	
7	-12		-4	

**Table 3: IFFT command output of MATLAB software**

	First output (for the first input)	Second output (for the second input)
X0	0	0
X1	-2+2i	2-2i
X2	-2+2i	2-2i
X3	-2+4.8284i	4.8284+2i
X4	0	0
X5	-2-4.8284i	4.8284-2i
X6	-2-2i	2+2i
X7	-2-0.8284i	-0.8284+2i

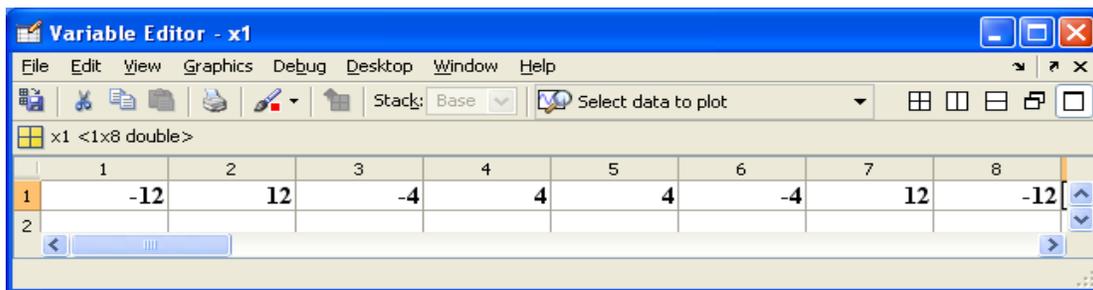
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**Table 4: The designed FFT module output for receiving outputs of IFFT command of MATLAB software**

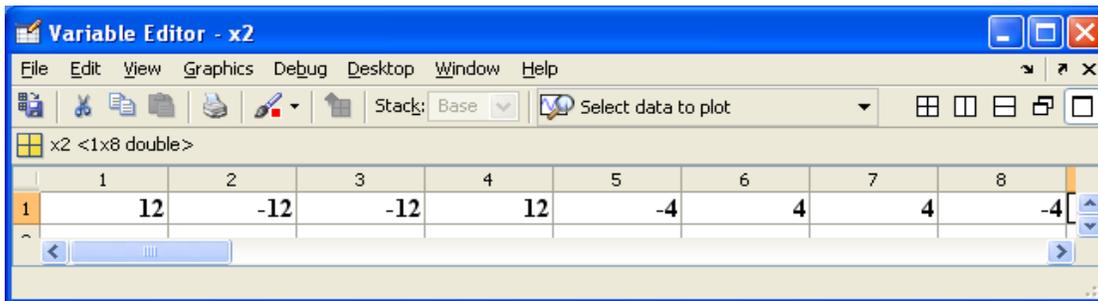
	The first Output of FFT	The second Output of FFT
xx0	-12	12
xx1	12	-12
xx2	-4	-12
xx3	4	12
xx4	4	-4
xx5	-4	4
xx6	12	4
xx7	-12	-4

**Synthesized Results of Proposed Design**

In the (6) and (7) figures, we give the x1 and x2 input data to IFFT command of Matlab software to calculate IFFT of those points.

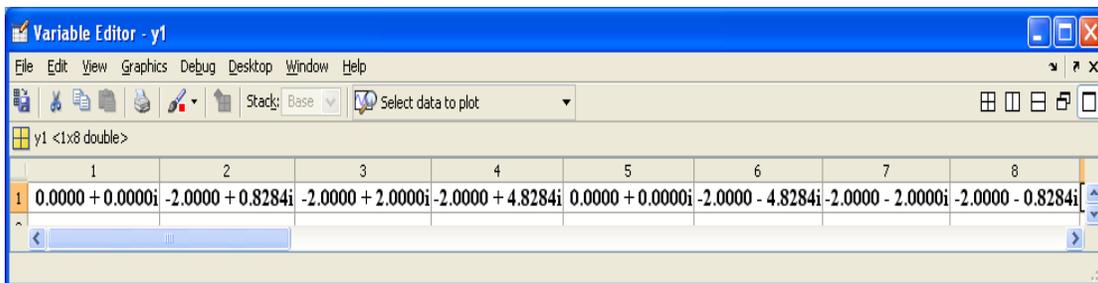


**Figure 6: The first input data to IFFT command in the MATLAB software**

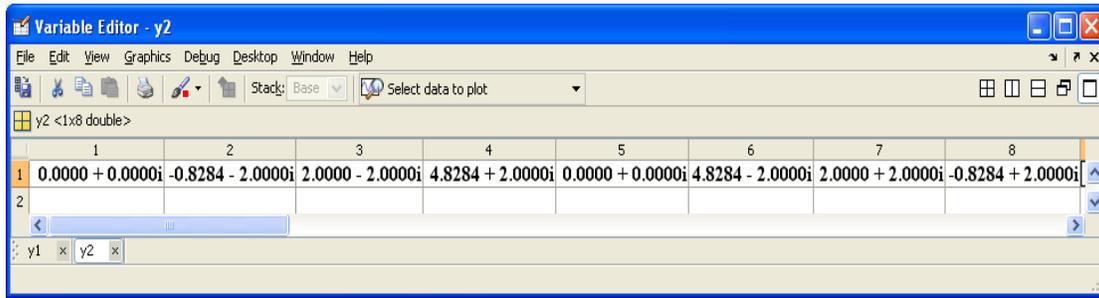


**Figure 7: The second input data to IFFT command in the MATLAB software**

In the (8) and (9) figures, it can be seen the IFFT command output of Matlab software for receiving x1 and x2 input data.

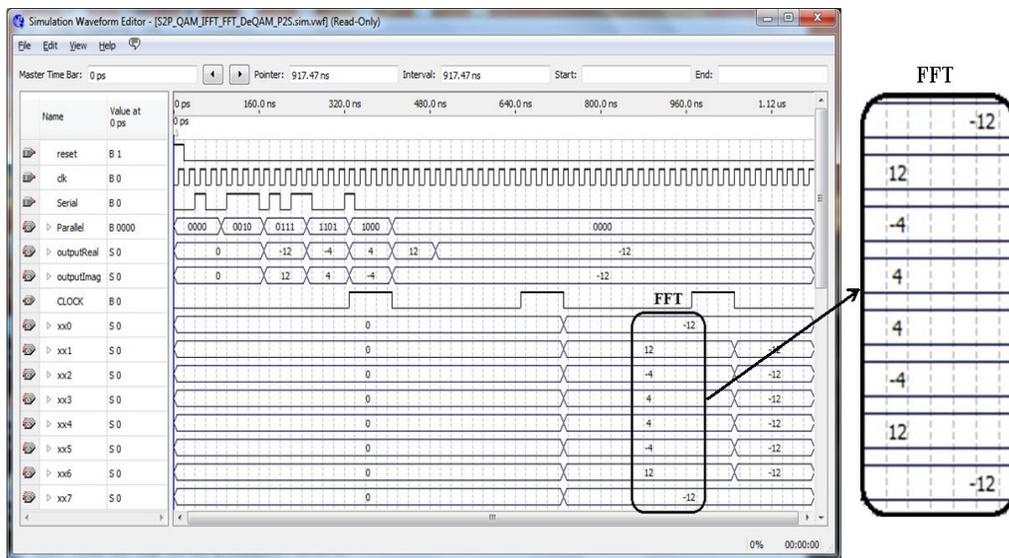


**Figure 8: IFFT command output of MATLAB software (for receiving the first input)**

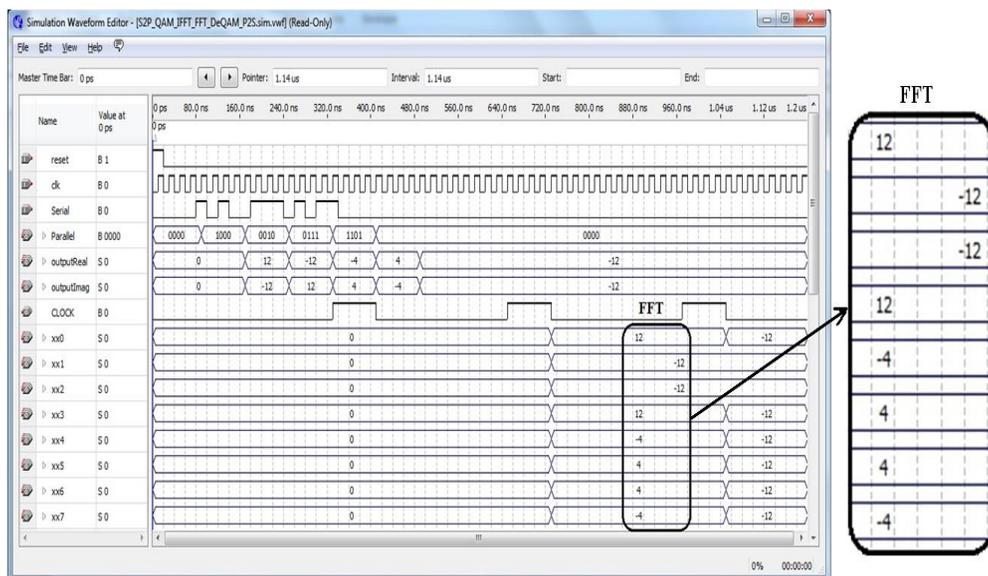


**Figure 9: IFFT command output of MATLAB software (for receiving the second input)**

In the figure (10), it can be seen the proposed approach output for the receiving the first 16-bits strains and these results is shown in the left column of table (4).



**Figure 10: The module output of design FFT for the first input data**



**Figure 11: The module output of design FFT for the second input data**

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In the figure (11), it can be seen the proposed approach output for the receiving the second 16-bits strains and these results is shown in the right column of table (4).

**Comparison and Conclusion**

In this article, the numbers of computational operations has been compared on the basis of the proposed approach and done works as well as direct approach (DFT). Consequently, the total number of required addition operations has been reduced from 30 from to 26 and the number of required multiplying operations has been reduced from 16 to 2. Meantime, most of the proposed approaches has been often performed separately to reduce multiplication computations or reduce addition computations, but it has not presented any approaches to reduce addition and multiplication operations simultaneously. Due to computational repetition of phase rotation coefficient in FFT structural process, factorization operation of these coefficients was performed in the proposed approach which it causes to reduce used memory. Briefly, it can be said that reducing the computational operations, reducing used memory and using of factorization to simplify FFT relations cause to reduce the circuit complexity and on the other hand so reducing the complexity causes chip heat loss thus power consumption will reduce, and when the complexity and power consumption have been reduced so it would be possible to increase the operating frequency. In table (5), the proposed design characteristic is clearly evident from the comparison of the ultimate numbers of computational operations which are used in the eight-points FFT algorithm of OFDM receiver, previous works and the direct approach.

**Table 5: Comparison of needed computational operation numbers in FFT algorithm of OFDM receiver**

Points number (N)	Direct approach		Done algorithms		Proposed approach	
	Complex multiplication	Complex addition	multiplication	addition	multiplication	addition
8	32	72	16	30	2	26

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