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Implementation of Orthogonal Frequency Division Multiplexing

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Abstract:
The demand of wireless communications is increased in high speed, high security applications like missile communication, satellite communication etc. The communication with these features can be achieved by using different carrier modulation techniques like single carrier, multi carrier modulation etc. The multi carrier modulation with orthogonality of carriers provides high speed communication. This process is called Orthogonal Frequency Division Multiplexing (OFDM).The high speed and band width utilization can be achieved by using OFDM. The high security communication can be achieved by using coders and spreaders with different random generator sequences with the help of Spread Spectrum techniques and it is used for high speed and high secured communication system. The OFDM technique consists of a back to back connected transmitter and receiver with 8-point FFT/IFFT and QPSK modulation. This technique is designed by using Verilog HDL with Xilinx ISE Design suite 12.4 version tool.

***Keywords:* OFDM, IFFT, FFT, QPSK**

I.INTRODUCTION

The secured and high speed data wireless data networks are the order of the day in missile communication. Future systems may demand a data communication up to 10 Mbps or more. Communicating at high transmission rates over the harsh wireless environment, however, creates many difficult and challenging problems. The requirement of high RF bandwidth and implementation difficulties discourages the development of such system.

The demand for high-speed and high security wireless communications services has grown tremendously. Today, Third Generation (3G) cellular wireless services have become very popular in many countries over the world although their deployment has been slower at the beginning. The 3G standard was created by the International Telecommunication Union (ITU) and is called IMT-2000 in order to harmonize worldwide existing 3G systems to provide global roaming. A 3G system must allow simultaneous use of speech and data services, and provide peak data rates of at least several hundred of kbps, and up to several Mbps according to the original releases of the 3G interfaces:

A Fourth Generation (4G) system is expected to provide many high-speed data services such as Internet Protocol (IP) telephony, ultra-broadband Internet access, gaming services and streamed multimedia. Recently, pre-4G technologies such as mobile Worldwide Interoperability for Microwave Access (WiMAX) and first-release Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) technologies have been available on the market. These technologies are based on the advantages of OFDM technology which offers high-speed data transmission and robustness to multipath fading without having to provide powerful channel equalization. A number of the World's operators and vendors are already committed to LTE deployments and developments, making LTE the market leader in the upcoming evolution to 4G wireless communication systems. The OFDM is a multi carrier technique. Multi carrier modulation technique has more advantages compared to single carrier modulation technique. The difference between the single carrier modulation technique and multi carrier modulation technique are explained below.

1.1 Single-Carrier Vs Multi-Carrier Modulation

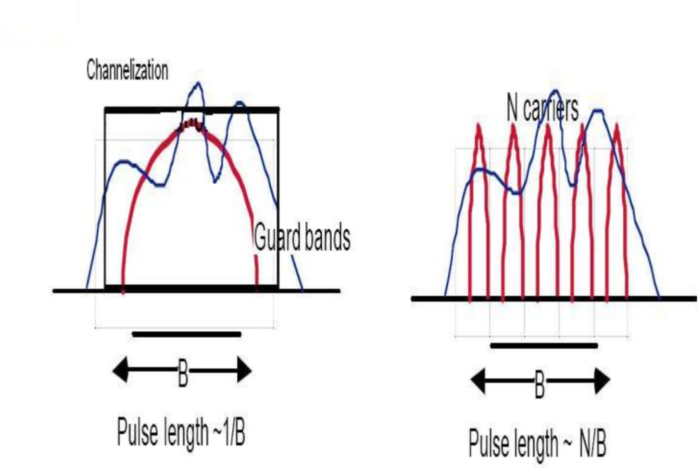

Fig 1: Single Carrier Vs Multi Carrier

II ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

The Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation scheme that transmits data over a number of orthogonal subcarriers. A conventional transmission uses only a single carrier modulated with all the data to be sent. OFDM breaks the data to be sent into small chunks, allocating each sub-data stream to a sub-carrier and the data is sent in parallel orthogonal sub-carriers.

OFDM is actually a special case of Frequency Division Multiplexing (FDM). In general, for FDM, there is no special relationship between the carrier frequencies, f1, f2 and f3. For OFDM on the other hand, there must be a strict relation between the frequency of the sub-carriers, i.e. fn = f1 + nΔf where Δf =1/TU and TU is the symbol time. These subcarriers have different frequencies which are orthogonal to each other. Each sub channel requires a longer symbol period. Therefore OFDM systems can overcome the Inter Symbol Interference (ISI). As a consequence, the OFDM systems can result in lower bit error rates and higher data rates than conventional communication systems. The difference between the Frequency Division Multiplexing (FDM) and Orthogonal Frequency Division Multiplexing is shown in Figure.

Splitting the channel into narrowband channels enables significant simplification of equalizer design in multipath environments. Flexible bandwidths are enabled through scalable number of sub-carriers.

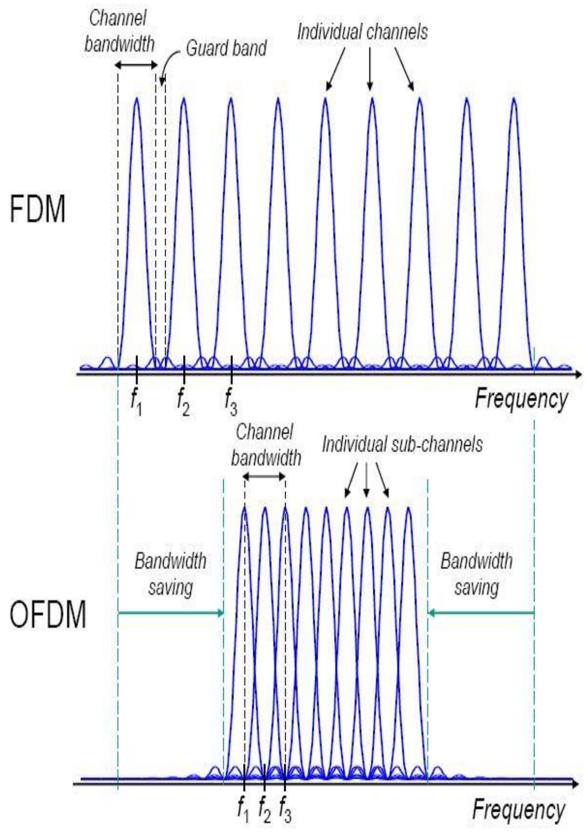

Fig 2: FDM Vs OFDM

2.1 Orthogonality between the subcarriers:

The essential property of the OFDM signal is the orthogonality between the subcarriers. Orthogonal means “perpendicular”, or at “right angle”. Two functions, $X_q(t)$ and $X_k(t)$, are orthogonal over an interval [a, b] if the inner product between them is zero for all q and k, except for the case that $q = k$, i.e. when $X_q(t)$ and $X_k(t)$ are the same function. Mathematically this can be written as:

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$$\langle x_q, x_k \rangle = \int_a^{b_U} x_q(t) \cdot x_k(t) dt = \begin{cases} 1, & k = q \\ 0, & k \neq q \end{cases}$$

The orthogonality allows simultaneous transmission on a lot of sub carriers in a tight frequency space without interference from each other. In essence this is similar to CDMA, where codes are used to make data sequence independent (also orthogonal) which allows many independent users to transmit in same space successfully. In this all the frequencies are harmonic to one frequency. In this case these carriers are orthogonal to each other, when added together; they do not interfere with each other.

The complexity of OFDM system can be reduced by applying the Discrete Fourier Transform (DFT) to generate the orthogonal subcarriers waveforms. In this model, baseband signals are modulated by the Inverse DFT (IDFT) in the transmitter and then demodulated by DFT in the receiver. Therefore, all the subcarriers are overlapped with others in the frequency domain, while the DFT modulation still assures their orthogonality. Moreover, the windowing technique is used to attack the Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI) problems.

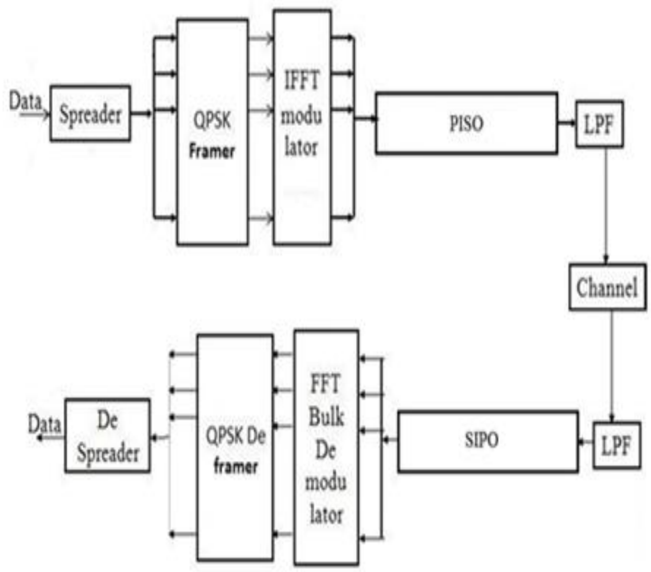

Fig 3: Block diagram of OFDM

2.2 Spreader:

The Spreader can be implemented by using the Linear Feedback Shift Register (LFSR). The generator polynomial governs all the characteristics of generator. The feedback generator uses only the output bit to add several stages of shift register. This is desirable for high speed hardware implementation as well as software implementation. The m stage linear feedback shift register is shown in Figure

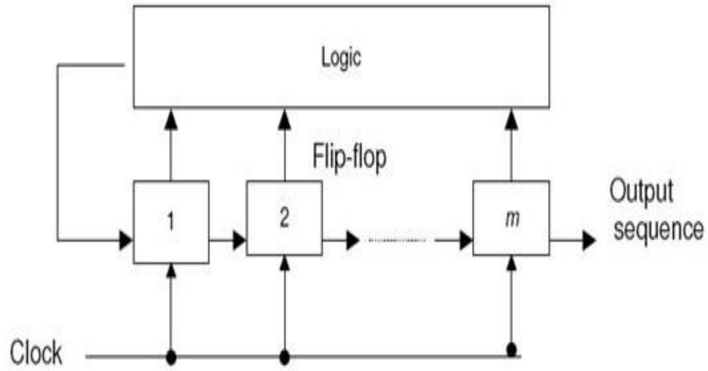

Fig 4: m stage linear feedback shift register

It consists of a shift register made up of m flip flops and a logic circuit. The flip flops in the shift registers are regulated by a single timing clock. The binary sequences are shifted through the shift registers and output of the various stages are logically combined and feedback as the input to first stage. The initial contents of flip flops determine the contents of memory. The generated PN sequence is mainly generated by three factors that are length m of the shift register, initial state of flip flops and feedback logic.

The number of possible states of the shift register is at most 2^m for an m flip flop. So the generated PN sequence must be periodic with a period at most 2^m. When the feedback logic consists of Exclusive-OR gates, the shift register is called linear and in such a case, the zero state is not permitted. Therefore the period of PN sequence produced by a linear m-stage shift register cannot exceed 2^m-1. When a sequence of period 2^m-1 is generated, it is called Maximal Length (ML) sequence.

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2.3 QPSK framer:

Information such as sound (audio), images (video) and digital data can be transmitted from one point to other using radio waves. This is done by modulating an RF signal carrier with the information to be transmitted. The Modulation is variation of one or more properties of RF signal to represent the information being transmitted.

The different types of modulation techniques to be used are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK) etc. Amplitude Shift Keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. Frequency Shift Keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. Phase Shift Keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). The difference between ASK, FSK and PSK are shown in Figure 5

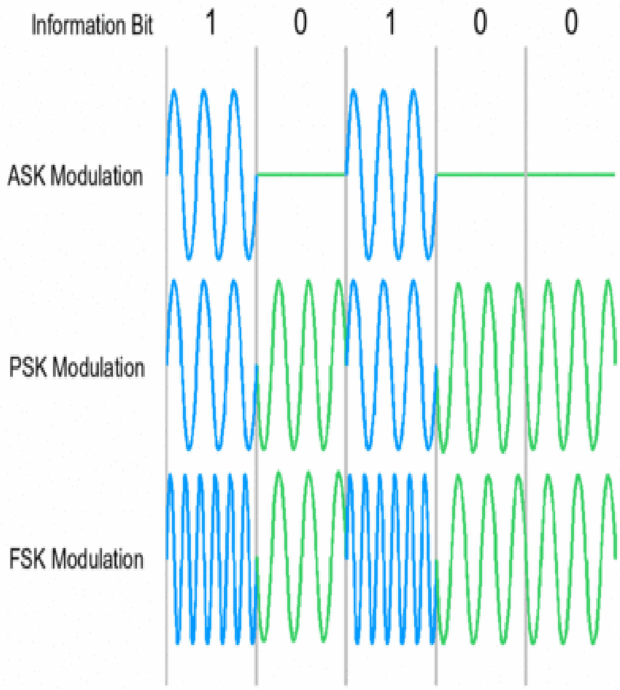

Fig 5: Difference between the ASK, FSK and PSK modulation techniques

2.4 QPSK Modulation:

The Quadrature Phase Shift Keying (QPSK) is the digital modulation technique. The Quadrature Phase Shift Keying (QPSK) is a form of Phase Shift Keying in which two bits are modulated at once, selecting one of four possible carrier phase shifts (0, Π/2, Π, and 3Π/2). The Quadrature Phase Shift Keying (QPSK) is effectively two independent BPSK systems (I and Q), and therefore exhibits same performance but twice bandwidth efficiency.

QPSK perform by changing the phase of the In-phase (I) carrier from 0° to 180° and the Quadrature-phase (Q) carrier between 90° and 270°. This is used to indicate the four states of a 2-bit binary code. Each state of these carriers is referred to as a Symbol.

Quadrature Phase-shift Keying (QPSK) is a widely used method of transferring digital data by changing or modulating the phase of a carrier signal. In QPSK digital data is represented by 4 points around a circle which correspond to 4 phases of the carrier signal. These points are called symbols. The constellation diagram of QPSK modulation technique is shown in Figure 6

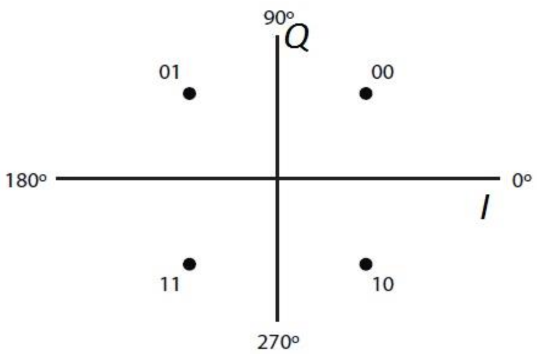

Fig 6: Constellation diagram of QPSK modulation technique

The binary data modulates each phase, producing four unique sine signals shifted by 45° from one another. The two phases are added together to produce the final signal. Each unique pair of bits generates a carrier with different phase. This is shown in Table

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Table 1: Carrier phase shift for each pair of bits represented

Bit pairs	Phase(degrees)
00	0
01	90
10	180
11	270

2.5 IFFT Modulator:

To reduce the complexity, Inverse Fast Fourier Transform (IFFT) technique is used in transmitter. The IFFT is used to convert from frequency domain to time domain. IFFT is an algorithm that is useful for speeding up the computation.

When applied in time domain, the algorithm is referred to as a Decimation-In-Time (DIT) FFT. The Decimation refers to significant reduction in the number of calculations performed on time domain data.

The Fast Fourier Transform (FFT) is an algorithm that efficiently computes the Discrete Fourier Transform (DFT). The DFT of a sequence {x(n)} of length N by a complex valued sequence {X(K)}

$$X(K) = \sum_{n=0}^{N-1} x(n)e^\wedge(-\frac{j2\pi nk}{N}) \quad , 0 \le k \le N\text{-}1.$$

Let W_N be the complex-valued phase factor, which is an N th root of unity expressed by

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

Hence X (K) becomes

$$X(K) = \sum_{n=0}^{N-1} x(n)\, W_N^{-nk} \quad , 0 \le k \le N\text{-}1.$$

Similarly Inverse Discrete Fourier Transform (IDFT) become

$$X(n) = 1/N \sum_{k=0}^{N-1} X(K) W_N^{nk} \quad , 0 \le n \le N\text{-}1.$$

The Decimation In frequency Fast Fourier Transform (DIF-FFT) decomposes the DFT by recursively splitting the sequence elements X (K) in the frequency domain into sets of smaller and smaller subsequences.

2.6 DIF-IFFT construction rules:

- The given sequence of length $N=2^M$, where m is the integer
- The numbers of stages in DIF-FFT algorithm are $\log_2^{N.}$
- The numbers of complex multiplications are $N/2 \log_2^{N.}$
- The numbers of complex additions are $N \log_2^{N.}$
- The exponent of the twiddle factor as a function of stage index(m) is given as
- $K = \frac{Nt}{2^\wedge(M-m+1)}$, where t=0,1,2………..2^{M-m}-1.
- The output is in bit reversal form.

The butterfly diagram of 8-point DIT-FFT is shown in Figure

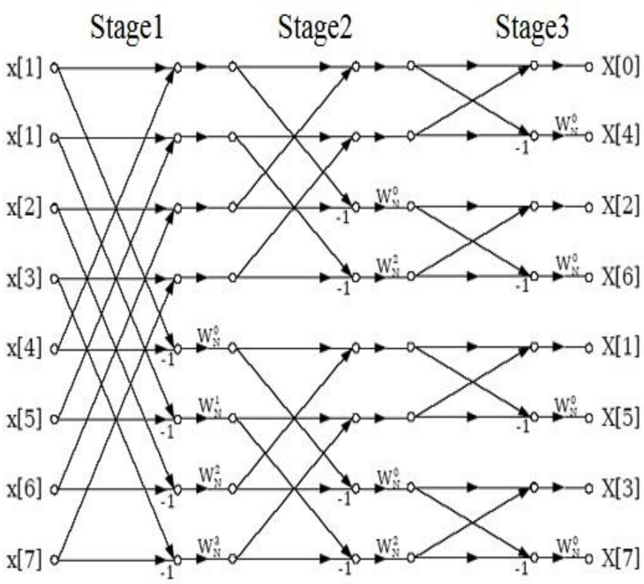

Fig 7: Butterfly diagram of 8-point DITFFT

2.6 Parallel in Serial out (PISO):

The parallel in serial out block converts the parallel data in to serial data in each clock pulse. The output of

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the Inverse Fast Fourier transform (IFFT) consists of 8 real and 8 imaginary parts. So the parallel data is converted into serially in 16 clock cycles. This can be shown in Figure

SR7	SI7	SR6	SI6	SR5	SI5	SR4	SI4	SR3	SI3	SR2	SI2	SR1	SI1	SR0	SI0

Fig 8: Output of parallel in serial out in each clock pulse

To eliminate ISI in OFDM a guard time is inserted with duration longer than the multipath channel maximum delay. Moreover, to eliminate ICI in OFDM the guard time is cyclically extended. Note that in a multipath channel an appropriate guard time avoids ISI but not ICI, unless it is cyclically extended. The cyclically extension of an OFDM symbol is shown in Figure 2.19. Here the cyclic prefix to be added is the least significant bits (LSB) of the OFDM frame are added to the most significant bits (MSB).

Fig 9: Cyclically extended OFDM frame

The cyclic prefix to be added is at most ¼ th of the OFDM frame. It may be noted that is the serial data of real and imaginary numbers are actually time domain signals when converted from digital to analog. And the frequencies that they represent are orthogonal to each other. The orthogonality of sub-channels is key point for higher capacity of the OFDM because it allows overlapping of sidebands. Overlapping results in 50% increase in capacity of the wireless channel. The guard delay between two OFDM symbols must maintain this orthogonality. The Cyclic Prefix is copied from tail portion of the OFDM symbol and added to the beginning of next OFDM symbol in such a way that orthogonality of the sub-channels is maintained. This combined data of the OFDM symbol and cyclic prefix constitutes the full OFDM symbol in time domain to be converted into analog signal I and Q which will be transmitted after multiplying the I and Q separately with sine and cosine of the IF signal and added together to form base band signal. The base band signal is RF modulated and given to RF front end.

2.7 Serial in Parallel out (SIPO):

The Serial in Parallel out (SIPO) is used to convert serial data into parallel data. In the receiver after RF front end analog to digital conversion is done separately for I and Q channels and the cyclic prefix is removed. The serial data is converted into parallel eight streams representing the same time domain signal as transmitted by the IFFT.

III FFT Demodulator:

To reduce the complexity Fast Fourier Transform (FFT) technique is used in receiver. The FFT is used to convert from time domain to frequency domain. The FFT is an algorithm that is useful for speeding up the computation.

When applied in time domain, the algorithm is referred to as decimation-in-time (DIT) FFT. Decimation refers to significant reduction in number of calculations performed on time domain data.

The Fast Fourier Transform (FFT) is an algorithm that efficiently computes the Discrete Fourier Transform (DFT). The DFT of a sequence {x (n)} of length N by a complex valued sequence {X (K)}

$$X(K) = \sum_{n=0}^{N-1} x(n)e\hat{}(-\frac{j2\pi nk}{N}) \quad , \text{Where } 0\leq k \leq N-1.$$

Let W_N be the complex-valued phase factor, which is an N th root of unity expressed by

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

Hence X(K) becomes

$$X(K) = \sum_{n=0}^{N-1} x(n)\, W_N^{-nk} \quad , 0\leq k \leq N-1.$$

Similarly Inverse Discrete Fourier Transform (IDFT) become

$$X(n) = 1/N \sum_{k=0}^{N-1} X(K) W_N^{nk} \quad , 0\leq n \leq N-1.$$

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The Decimation In frequency Fast Fourier Transform (DIF-FFT) decomposes the DFT by recursively splitting the sequence elements X (K) in the frequency domain into sets of smaller and smaller subsequences.

3.1 DIT-FFT construction rules:

- The given sequence of length $N=2^M$, where m is integer
- The input is in bit reversal form.
- The numbers of stages in DIT-FFT algorithm are $\log_2^{N.}$
- The numbers of complex multiplications are N/2 $\log_2^{N.}$
- The numbers of complex additions are N $\log_2^{N.}$
- The exponent of the twiddle factor as a function of stage index(m) is given as
- $K = \frac{Nt}{2\text{^}m}$, where t=0, 1, 2…………2^{m-1}-1.

The butterfly diagram of 8-point DIT-FFT is shown in Figure

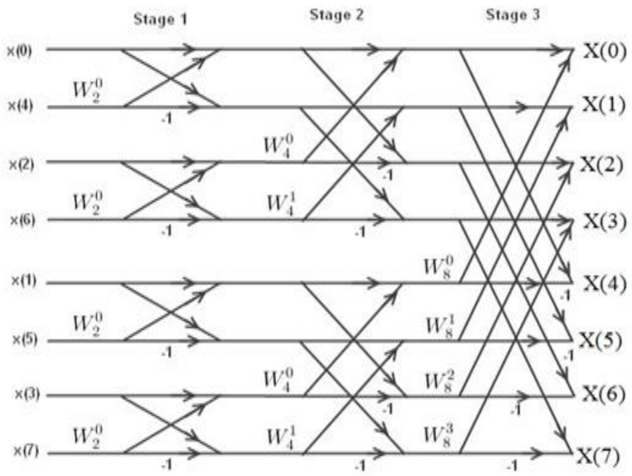

Fig 10: Butterfly diagram of 8-point FFT

3.1.1 QPSK Deframer:

The parallel data bits are taken two bits together and converted from I, Q to the data bit pattern. The parallel data is converted into serial data. This operation is exactly reverse to QPSK framer.

3.2 Despreader:

The serial data is again Exclusive-OR with the PN pattern and resulting in original data bit pattern.

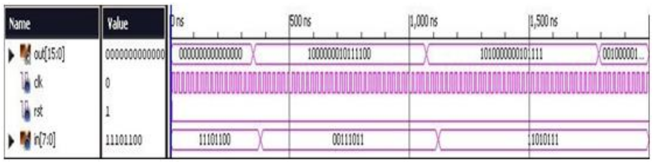

Fig 11: Simulation results of Spreader

Fig 12: Simulation results of QPSK Framer

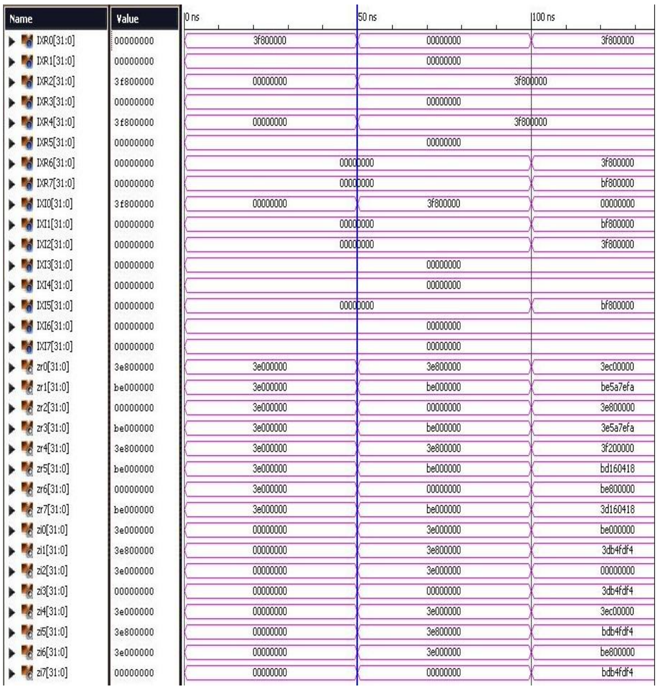

Fig 13: Simulation results of IFT

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Fig 14: Simulation results of PISO

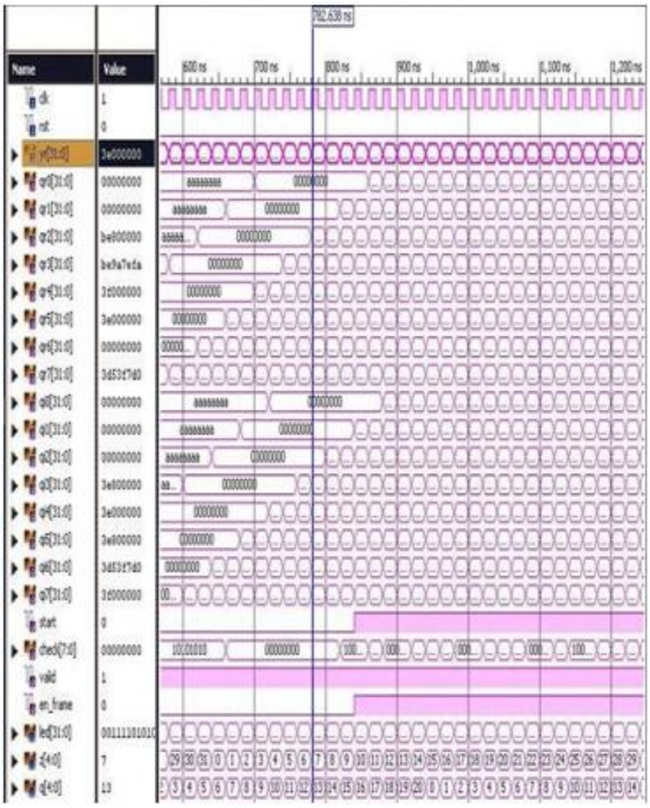

Fig15: Simulation results of SIPO

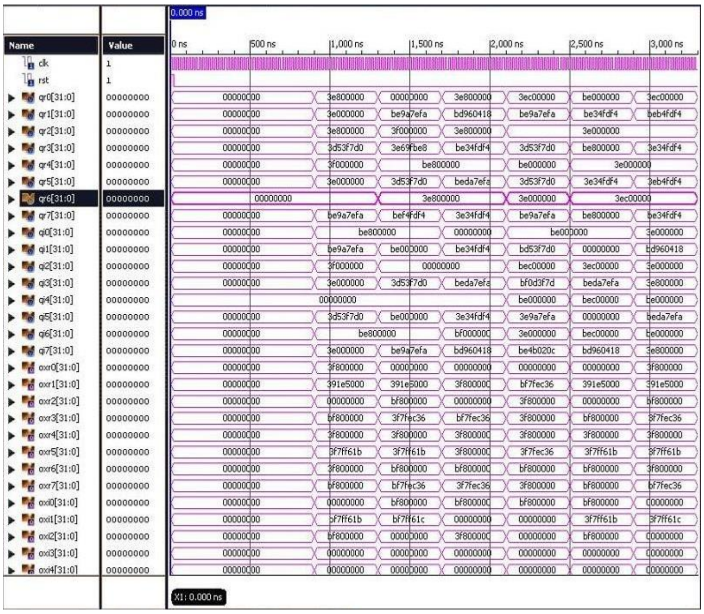

Fig 16: Simulation results of FFT

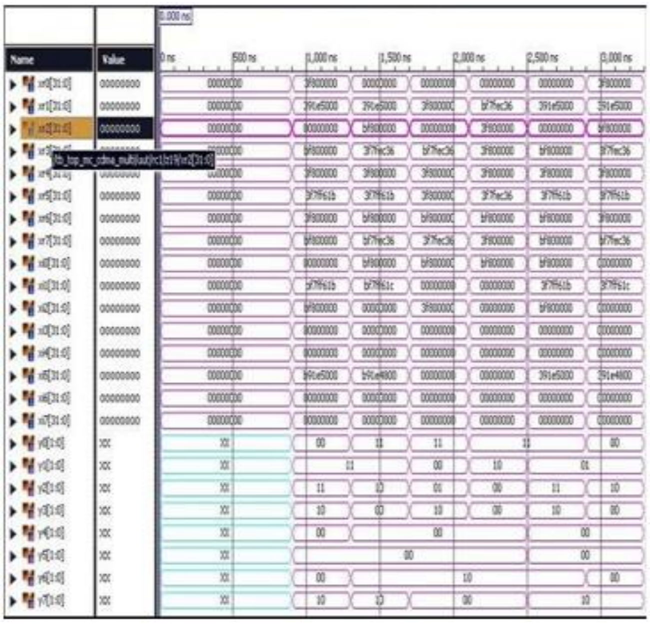

Fig 17: simulation results of QPSK Deframer

Fig 18: simulation results of Despreader

IV. CONCLUSION AND FUTURE WORK

The objective is the implementing the core processing blocks of an Orthogonal Frequency Division Multiplexing (OFDM) system, namely the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT). The Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (FFT) have been chosen to implement the design instead of the Discrete Fourier Transform and Inverse Discrete Fourier Transform because they offer better speed with less computational time. These methods requires the odd and even samples inputs are process separately before they are combine to give the final output. The result of the computation is in integer bits which might comprises of real and imaginary components. The decimal value of the output if greater than 0.5 is approximated to 1 and vice versa. The design implementation is done using VHDL coding. Direct mathematical method is adopted because it is an efficient and optimized method instead of the structural implementation which is based on butterfly operation.

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