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Study of FPGA Based OFDM Transmitter and Receiver

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Abstract: *OFDM is a multi-carrier modulation technique with densely spaced sub-carriers that has gained a lot of popularity among the broadband community in the last few years. Orthogonal frequency division multiplexing (OFDM) is an established technique for wireless communication applications. We study the performance of OFDM, including the power spectral density, BER, through intensive MATLAB simulation. In this paper the design and implementation of OFDM system will be illustrated as well as a detailed simulation of the OFDM system using MATLAB-2011 program to study the effect of various design parameters on the system performance. OFDM transceiver will be implemented using FPGA Spartan 3A kit. All modules are designed using VHDL programming language system. VHDL will be used for RTL description and FPGA synthesis tools will be used for performance analysis of the proposed core. Modelsim Xilinx Edition will be used for functional simulation and verification of results. Xilinx ISE will be used for synthesis. The Xilinx's Chip scope tool will be used for verifying the results on Spartan 3E FPGA.*
Index Terms: *Orthogonal Frequency Division Multiplexing (OFDM); Field Programmable Gate Array (FPGA); Inverse Fast Fourier Transform (IFFT); Fast Fourier Transform (FFT).*

I. Introduction

The current communication systems tend to use OFDM systems in order to provide high data rates, minimize inter symbol interference and fading effect. Some examples are Digital Video Broadcasting (DVB), Wireless USB or Wireless Firmware among others While OFDM has become the core of most 4G communication systems as fixed Wi-Fi system (IEEE802.11a standard), mobile Wi-Fi system (IEEE802.11b standard), fixed WiMAX system (IEEE802.16a standard), mobile WiMAX system (IEEE802.16e standard), and Long Term Evolution (LTE) system; it was essential to build this OFDM system on a suitable hard work A technique which allows an arbitrary number of symbol shapes to be distinguishable is orthogonal signaling. Orthogonality describes the degree to which a pair of die rent pulse shapes is independent or unrelated. Functions are orthogonal with respect to each other over the interval a < t < b if,

$\int_a^b \varphi n(t)\varphi m(t)\,dt = 0; n \neq m$ [1]

It are valuable to discuss the mathematical definition of OFDM. This allows us to see how the signal is generated and how the receiver must operate, and it gives us a tool to understand the effects of imperfections in the transmission channel.OFDM transmit a large number of narrowband carriers, closely spaced in the frequency domain. In order to avoid a large number of modulators and filters at the transmitter and complementary filters and demodulators at the receiver, it is desirable to be able to use modern digital signal processing techniques, such as fast Fourier transform (FFT) [2]. Mathematically, each carrier can be described as a complex wave OFDM could be tracked to 1950's but it had become very popular at these days, allowing high speeds at wireless communications [3].

OFDM Model

All The OFDM system was modeled using MATLABTM to allow various parameters of the system to be varied and tested. The aim of doing the simulations was to measure the performance of OFDM under different channel conditions, and to allow for different OFDM configurations to be tested. Four main criteria were used to assess the performance of the OFDM system, which were its tolerance to multipath delay spread, peak power clipping, channel noise and time synchronization errors. The OFDM system was modeled using the Communications Toolbox, Signal Processing Toolbox and Simulink of MATLABTM [2]

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on the modulation scheme (typically QPSK, or QAM) [1]

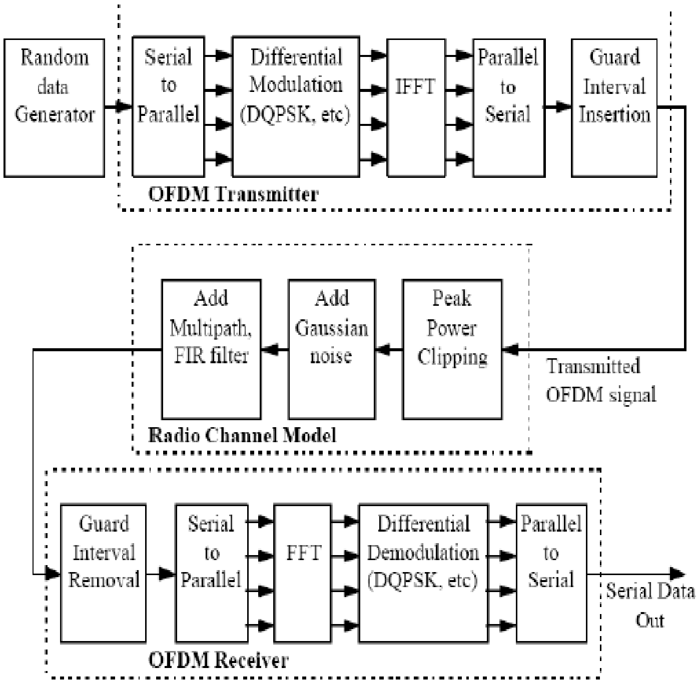


Figure 2.1 the OFDM system

1) Serial to Parallel Conversion:

The input serial data stream is formatted into the word size required for transmission, e.g. 2 bits/word for QPSK, and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission.

2) Modulation of Data:

The data to be transmitted on each carrier is then differentially encoded with previous symbols, and then mapped into a PSK format. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. For example, for QPSK the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

3) Inverse Fourier Transform:

After the required spectrum is worked out, an inverse Fourier transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol.

4) Guard Period:

The guard period used was made up of two sections. Half of the guard period time is a zero amplitude transmission. The other half of the guard period is a cyclic extension of the symbol to be transmitted. This was to allow for symbol timing to be easily recovered by envelope detection. However it was found that it was not required in any of the simulations as the timing could be accurately determined position of the samples. After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM transmission.

5) Channel:

A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath, and peak power clipping to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal. Multipath delay spread is then added by simulating the delay spread using an FIR filter. The length of the FIR filter represents the maximum delay spread, while the coefficient amplitude represents the reflected signal magnitude.

6) Receiver :

The receiver basically does the reverse operation to the transmitter. The guard period is removed. The FFT of each symbol is then performed to find the original transmitted spectrum. The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

7) OFDM generation :

To generate OFDM successfully, the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by first choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on DQPSK. The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

8) Adding a Guard Period to OFDM :

One of the most important properties of OFDM transmissions is its high level of robustness against multipath delay spread. This is a result of the long symbol period used, which minimizes the inter-symbol interference. The level of multipath robustness can be further increased by the addition of a guard period between transmitted symbols. The guard period allows time for multipath signals from the previous symbol to die away before the information from the current symbol is gathered. The most effective guard period to use is a cyclic extension of the symbol. If a mirror in time, of the end of the symbol waveform is put at the start of the symbol as the guard period, this effectively extends the length of the symbol, while maintaining the orthogonality of the waveform. Using this cyclic extended symbol the samples required for performing the FFT (to decode the symbol), can be taken anywhere over the length of the symbol. This provides multipath immunity as well as symbol time synchronization tolerance.

OFDM Transmitters

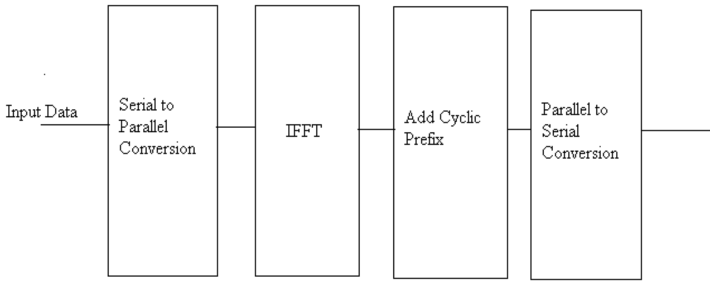


Figure 3.1 OFDM transmitter

The main components of OFDM transmitter are shown in Fig.3.1. The randomizer is used as random bit generator. The first three blocks are used for data coding and interleaving. The coded bits will be mapped by the constellation modulator using Gray codification, this way an + jbn values are obtained in the constellation of the modulator. The serial to parallel converter converts the data bits from the serial form to the parallel form. The Inverse Fast Fourier Transform (IFFT) transforms the signals from the frequency domain to the time domain; an IFFT converts a number of complex data points, of length that is power of 2, into the same number of points but in the time domain. The number of subcarriers determines how many sub-bands the available spectrum is split into The Cyclic Prefix (CP) is a copy of the last N samples from the IFFT, which are placed at the beginning of the OFDM frame to overcome ISI problem. It is important to choose the minimum necessary CP to maximize the efficiency of the system [4]

OFDM Receivers

The main blocks of OFDM receiver are observed in Fig.4.1 the received signal goes through the cyclic prefix removal and a serial-to-parallel converter [2]. After that, the signals are passed through an N-point fast Fourier transform to convert the signal to frequency domain. The output of the FFT is formed from the first M samples of the output. The demodulation can be made by DFT, or better, by FFT, that is it efficient implementation that can be used reducing the time of processing and the used hardware. FFT calculates DFT with a great reduction in the amount of operations, leaving several existent redundancies in the direct calculation of DFT [4].

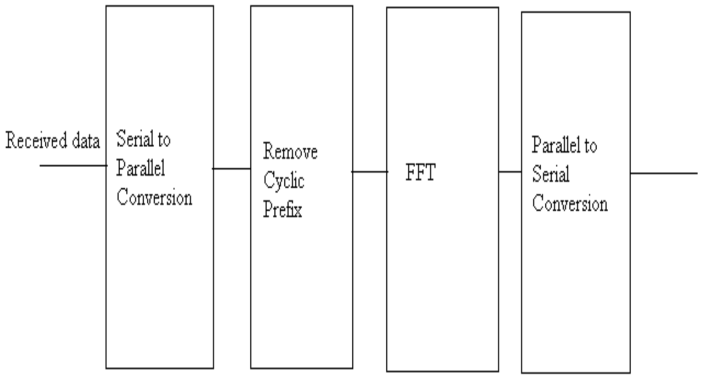


Figure 4.1 OFDM receiver

II. Parameters of An Actual OFDM System

Following are the parameters of Wi-Fi / IEEE 802.11a which is a system based on OFDM:
Data Rates : 6 Mbps to 48 Mbps
Modulation : BPSK, QPSK, 16 QAM and 64 QAM
Coding : Convolution concatenated with Reed Solomon
FFT Size: 64 with 52 sub-carriers uses, 48 for data and 4 pilots.
Subcarrier frequency spacing : 20 MHz divided by 64 carriers or 0.3125 MHz
FFT Period : Also called symbol period, 3.2 µs
Guard Duration : One quarter of symbol time, 0.8 µs
Symbol Time : 4 µs

OFDM Advantages

In general, OFDM systems have the following advantages:
(i) Efficient use of spectrum.;
(ii) Resistant to frequency selective fading;
(iii) Eliminates ISI (Inter-Symbol Interference) and ICI (Inter-Carrier Interference);
(iv) Can recover lost symbols due to the frequency selectivity of channels;
(v) Channel equalization;
(vi) Computationally efficient

OFDM Disadvantages

OFDM systems have the following disadvantages:
(i)High synchronism accuracy;
(ii) Multipath propagation must be avoided in other orthogonality not be affected, and
(iii) Large peak-to-mean power ratio due to the superposition of all subcarrier signals, this can become a distortion problem

Proposed IFFT/FFT Processor

The OFDM transceiver, IFFT/FFT module is a major part. It occupies the major area and power consumption. In this FFT design using a radix-2 Decimation in Frequency (DIF) signal flow graph as shown in Fig. 3 The below signal flow graph is split into 3 processing elements and also have a complex multipliers required. So it is hardware implementation, because some multiplication can be simplified to reduce the chip area

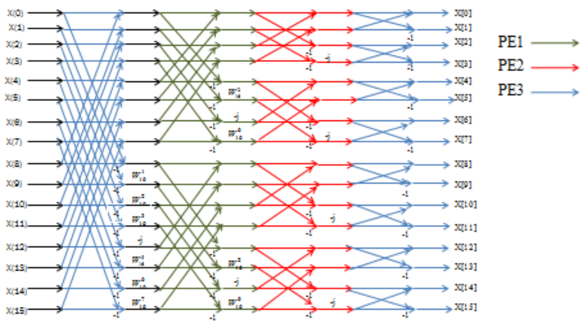


Fig.8.1 Radix-2 DIF FFT signal flow graph of length 16

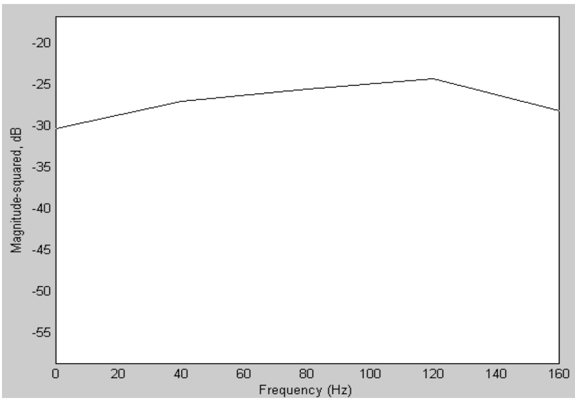
Hardware implementation of FFT/IFFT processor usually employs a Read Only Memory (ROM) to look up the wanted twiddle factor; this ROM is consuming more power and area. In order to eliminate the ROM's to introduce a new complex multiplier circuit it contains a Bit Parallel Multiplier to improve the forgoing issues.
However, the FFT computation to needs to multiply the different twiddle factors in input signal. These twiddle factors to be store in a large size Read Only Memory (ROM). Therefore, to replace this ROM's for area efficient consideration proposed an efficient ROM less FFT/IFFT processor. The complex multipliers ROM's are replaced by add and shift operations. In order to replace the ROM's to reduce the power consumption and area. . In this IFFT/FFT processor are implemented into the OFDM transceiver. This propose OFDM transceiver contain a mapping unit, parallel to serial, serial to parallel converter unit. This proposed design to consume a low area and delay.[8]

III. Simulation Results

The presented OFDM system in the above few subsections will be simulated using MATLAB-2011 on a personal computer of the following specifications:
Intel processor 3.2 GHZ Pentium-four;
2MB cache RAM;
2 GB RAM;
SATA hard disk 250GB. In this part
the simulation of OFDM system using MATLAB Simulink tools will be obtained. The effect of different parameters on the simulation of the OFDM system using MATLAB program is discussed through the following experiments

A Experiment-1

In this experiment, the study of changing FFT/IFFT length with fixed SNR will be discussed. The optimum practical value used for the SNR is 60 dB in the case of using Additive White Gaussian Noise (AWGN) channel. The FFT/IFFT lengths that have been used are 8-points, 16- points, 32-points, 64-points, 128-points, 256-points, 512 points, and 1024 points. This experiment has been applied on OFDM system with 16-QAM. The simulation results for this experiment are shown in the following figures [3]



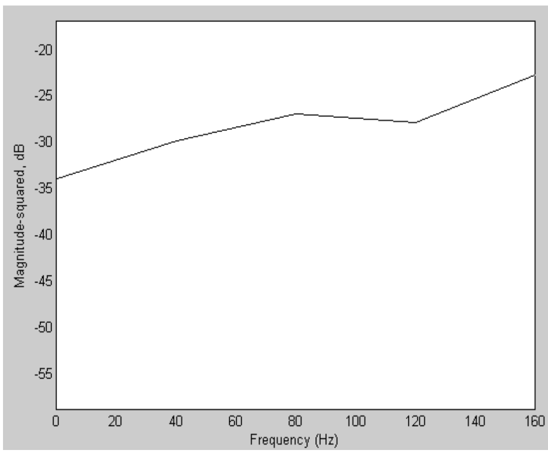
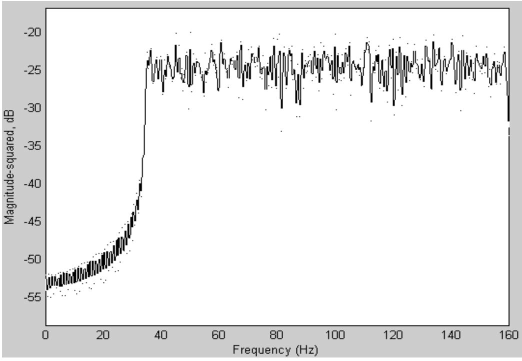


Fig. 9.1.1 OFDM with 16-QAM, 8-points IFFT/FFT with SNR=60 dB



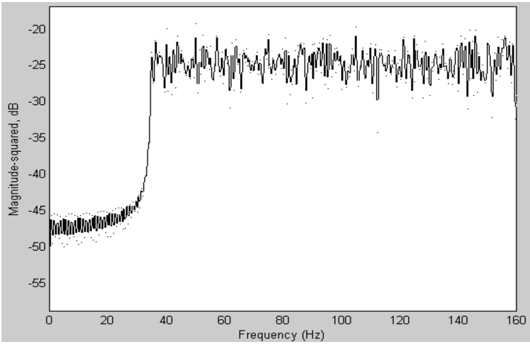


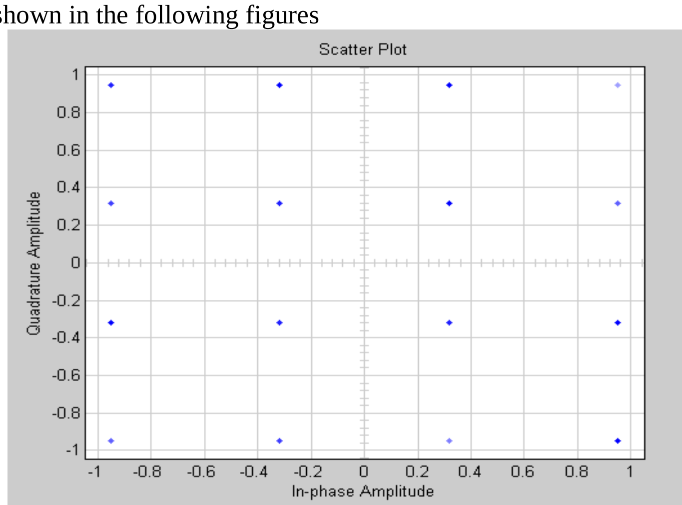
Fig. 9.1.2 OFDM with 16-QAM, 1024-points IFFT/FFT with SNR=60dB

The simulation results for the worst case (8-points FFT) and the best case (1024-points FFT) were presented in the above figures for OFDM with 16-QAM. The result from this experiment is that the more FFT/IFFT length, the more accurate and more practical use of OFDM system; i.e. more subcarriers can be used as shown from the spectra of OFDM signals that are observed in the previous figures [3]

B Experiment-2

In this experiment we discuss the effect of changing of the SNR over the scatter plot for complex digital modulator/demodulator with the same SNR values as in experiment-2. This experiment has been applied on OFDM system with 16-QAM. The simulation results for this experiment are shown in the following figures.

In this experiment the study of changing the SNR with fixed FFT/IFFT length will be discussed. The optimum length used for FFT/IFFT is 1024-points as discussed in experiment-1. The SNR values will be from 10dB to 60dB by step of 1dB. This experiment has been applied on OFDM system with 16-QAM. The simulation results for this experiment are shown in the following figures



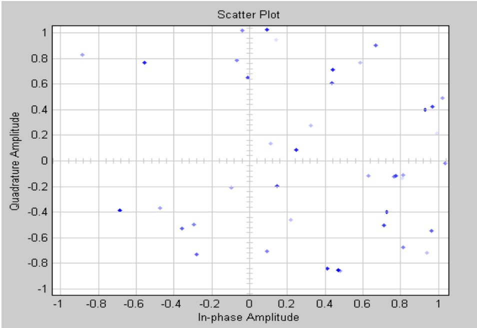


Fig. 9.2.1 OFDM with 16-QAM; scatter plot for modulator/demodulator, SNR=10 dB

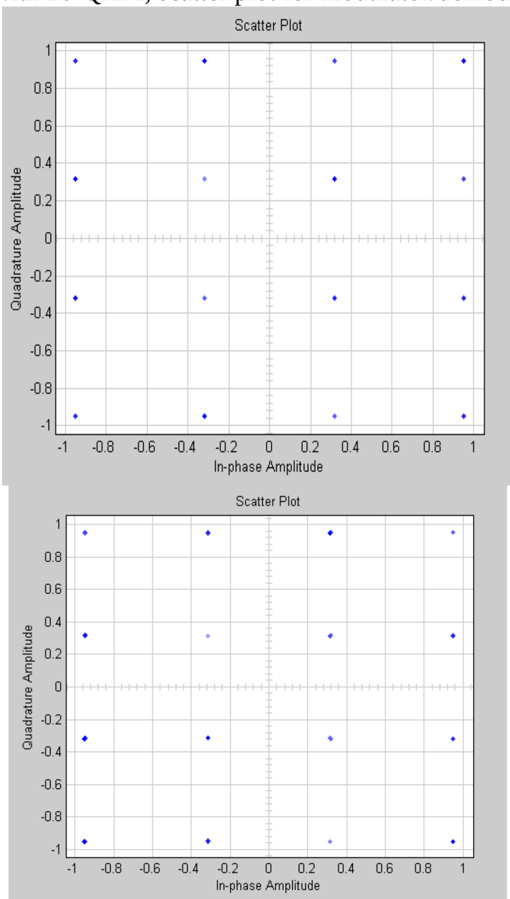


Fig.9.2.2. OFDM with 16-QAM; scatter plot for
Modulator/demodulator SNR=60 dB

From the experimental results of this experiment shown in the previous figures we get that the optimum value for the SNR is 60 dB for minimum scattering in the output of the modulator and demodulator [3]

IV. Conclusion

As discussed in our paper, the simulation results for OFDM system was observed using MATLAB 2011 program. There were two experiments for that; in the first experiment the changing of FFT/IFFT length with fixed SNR was studied, and in the second experiment the effect of the variation of the SNR over the scatter plot at the demodulator was presented. The main results of our experiments were that the optimum FFT/IFFT length was 1024 points and the best value for the SNR was 60dB; and we get that after this value there is no effect of varying the SNR value. After that the VHDL emulation of OFDM system has been observed using FPGAadv7.2 program, then we could implement this system on Xilinx Spartan 3-A kit. 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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