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Design and Implementation of OFDM Transceiver for ISI Reduction using Sinc Filter

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***Abstract* – Orthogonal frequency division multiplexing (OFDM) is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower ratesubcarriers.4G and other wireless systems are currently hot topics of research and development in the communication field. Orthogonal frequency division multiplexing (OFDM) is the most commonly used modulation scheme for high data rate wireless transmission .In this paper, an OFDM Transceiver has been reduced the noise and to increase the throughput for future wireless networks .Here the data rate is increased by implementing a 1024-point parallelized FFT/IFFT Processor. In the modulation scheme sinc Filter is used for Noise Reduction. By this work we may obtain a throughput speed between 2 Gbps and 4Gbps.**

***Index Term* - OFDM, FFT, IFFT, QAM, ISI (Intersymbol Interference).**

1. INTRODUCTION

The principles of OFDM have been in existence for several epochs. OFDM was studied for high-speed modems, digital mobile communications, and high-density recording. One of the systems realized the OFDM techniques for multiplexed QAM using DFT, and by using pilot tone, stabilizing carrier and clock frequency control and implementing trellis coding are also implemented. The OFDM Signals are shown in **Fig. 1.**

The OFDM transmission scheme has Makes efficient use of the spectrum by allowing overlap, By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems. Eliminates ISI and IFI through use of a cyclic prefix. Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel. Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems. In 4G wireless communication systems, bandwidth is a precious commodity, and service providers are continuously met with the challenge of accommodating more users with in a limited allocated bandwidth. Orthogonal frequency division multiplexing (OFDM) is such a technique which provides an efficient means to handle high speed data streams on a multipath fading environment that causes ISI. The required bit rates are achieved due to OFDM multicarrier transmissions. OFDM systems perform better than a single carrier system particularly in frequency selective channels.

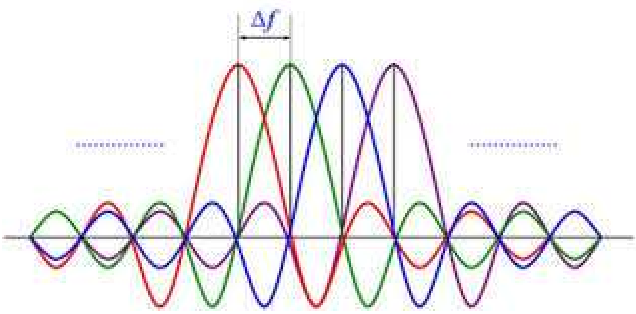


Fig. 1. Spectra of an OFDM sub channel an OFDM signal

It is a multiplexing/multiple access scheme that has many favourable features required for the fourth generation systems. FFT (Fast Fourier Transform)/ (Inverse Fast Fourier Transform) IFFT are the main blocks in OFDM system. They are important in achieving high speed signal processing.FFT helps to transform the signal from time domain to frequency domain where filtering and correlation can be performed with fewer operations. The OFDM hardware implementation has been done either on ASICs, Virtex based FPGA.ASIC based designs suffer from more time to market factor, high cost and provide less flexibility. Moreover, DSP based designs can only support limited data rates due to lack of parallelism and also they have less number of MAC(multiply and accumulate) units.On the other hand, the modern programmable circuits like an FPGA provides parallel processing system, putting the FPGA computing speed at a significant advantage over DSPs .

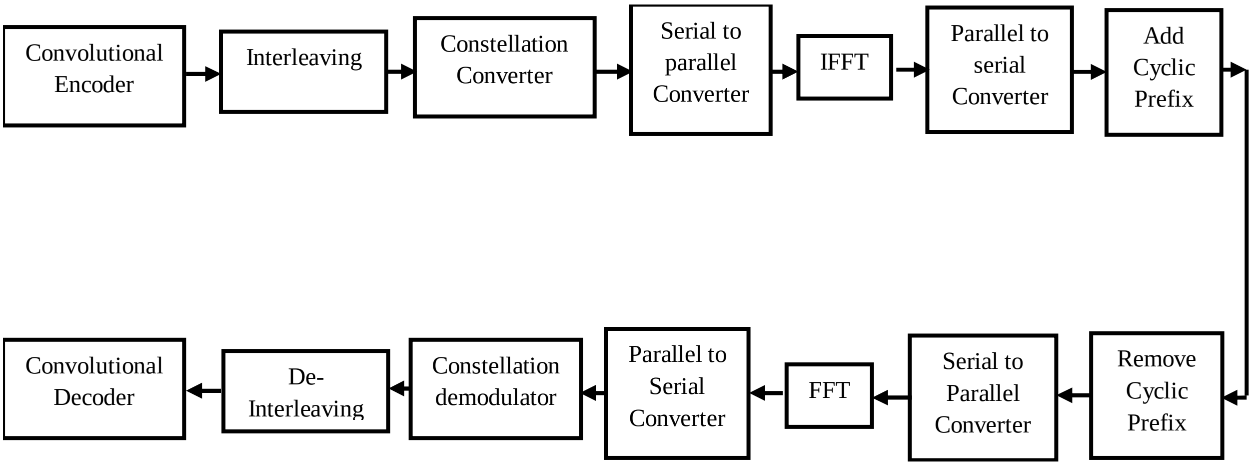


Fig. 2. OFDM Transceiver

This paper presents the implementation of OFDM Transceiver on FPGA to improve speed by utilizing optimal number of Resources in terms of slices, LUTs and multipliers of target FPGA to provide high performance cost effective solution for wireless communication applications.

II. BASICS OF OFDM

The OFDM modulation technique is generated through the use of complex signal processing approaches such as fast Fourier transforms (FFTs) and inverse FFTs in the transmitter and receiver sections of the radio. One of the benefits of OFDM is its strength in fighting the adverse effects of multipath propagation with respect to inter symbol interference in a channel. OFDM is also spectrally efficient because the channels are overlapped and contiguous.OFDM is a combination technique between modulation and multiplexing. Modulation is a mapping of the information on changes in the carrier phase, frequency or amplitude or their combination.

Meanwhile, multiplexing is a method of sharing a bandwidth with other independent data channel. In multiplexing, independent signals from different sources are sharing the channel spectrum. In OFDM, multiplexing is applied to independent signals but these independent signals are a sub-set of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier. By using a DFT, the whole bandwidth will be split into *N* sub channels. The multicarrier transmission technique uses the discrete Fourier transform .As a result, a high data stream will be transformed into *N* low rate streams, which are transmitted over different sub-channels. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The relative amount of dispersion in time caused by multipath delay spread is decreased because the symbol duration increases for lower rate parallel subcarriers.

The other problem to solve is the intersymbol interference, which is eliminated almost completely by introducing a guard time in every OFDM symbol. This means that in the guard time, the OFDM symbol is cyclically extended to avoid intercarrier interference. Mean while a lower rate parallel subcarriers reduces the relative amount of dispersion in time caused by multipath delay spread. Therefore OFDM is an advanced modulation technique which is suitable for high-speed data transmission due to its advantages in dealing with the multipath propagation problem and bandwidth efficiency.

III. OFDM TRANSCEIVER BLOCK DIAGRAM

An OFDM signal is a sum of subcarriers that are individually modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM).The block diagram of an OFDM transceiver is shown in **Fig. 2.**

A. OFDM Transmitter

The main components of OFDM transmitter in Diagram**.** OFDM is invariably used in conjunction with channel coding (forward error correction), and almost always uses frequency and/or time interleaving. Frequency (subcarrier) interleaving increases resistance to frequency-selective channel conditions such as fading. The randomizer is used as random bit generator. The first three blocks are used for data coding and interleaving.An OFDM carrier signal is the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of quadrature amplitude modulation (QAM) or phase-shift keying (PSK). This composite baseband signal is typically used to modulate a main RF carrier.

S(n) is a serial stream of binary digits. By inverse multiplexing, these are first demultiplexed into N parallel streams, and each one mapped to a (possibly complex) symbol stream using some modulation constellation (QAM, PSK, etc.). Note that the constellations may be different, so some streams may carry a higher bit-rate than others.

B. *OFDM Receiver*

The main blocks of OFDM receiver are observed in **Fig. 2.** The received signal goes through the cyclic prefix removal and a serial-to-parallel converter. After that, the signals are passed through an N-point fast Fourier transform to convert the signal to frequency domain.

The receiver picks up the signal r(t), which is then quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency. This also creates signals centered on $2f_c$, so low-pass filters are used to reject these. The baseband signals are then sampled and digitised using analog-to-digital converters (ADCs), and a forward FFT is used to convert back to the frequency domain.This returns N parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then re-combined into a serial stream, $\hat{s}[n]$, which is an estimate of the original binary stream at the transmitter.

IV. FAST FOURIER TRANSFORM

Discrete Fourier transform (DFT) is a very important technique in modern digital signal processing (DSP) and telecommunications, especially for applications in orthogonal frequency demodulation multiplexing (OFDM) systems. Such as IEEE 802.11a/g [1], Worldwide Interoperability for Microwave Access (WiMAX) [2], Long Term Evolution (LTE) [3], and Digital Video Broadcasting-Terrestrial (DVB-T) [4]. However, DFT is computational intensive and has a time complexity of *O*(*N*2). The fast Fourier transform (FFT) was proposed by Cooley and Tukey to efficiently reduce the time complexity to *O*(*N*log 2*N*), where *N* denotes the FFT size.

A. *FFT and IFFT*

The discrete Fourier transform (DFT) X_k of an *N*-point discrete-time signal x_n is defined by,

(1)

Where the twiddle factor , denotes the *N*-point primitive root of unity. However, a straightforward implementation of this algorithm is obviously impractical due to the huge hardware required. Therefore, the fast Fourier transform (FFT) was developed to efficiently speed up its computation time and significantly reduce the hardware cost.

Generally, FFT analyzes an input signal sequence by using a decimation-in-frequency (DIF) or decimation-in-time (DIT) decomposition to construct an efficiently computational signal-flow graph (SFG). Here, our work employs a DIF decomposition because it matches the manipulation manner of single-path delay pipeline facility. An example of radix-2 DIF FFT SFG for *N* = 16 is depicted in **Fig. 3.**

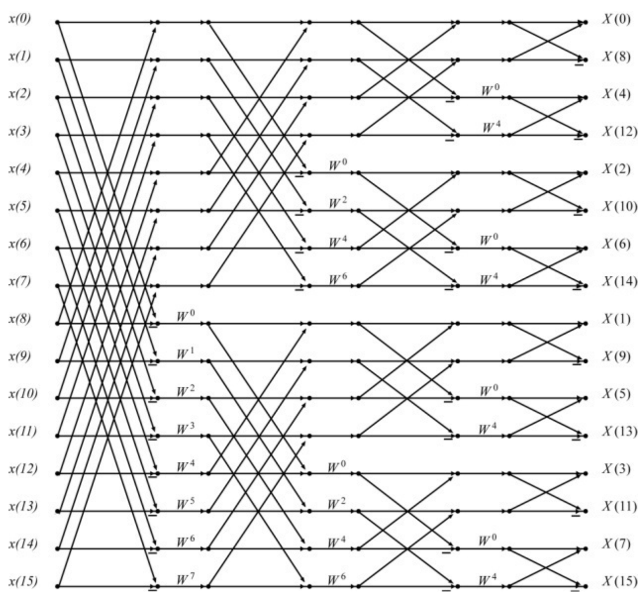


Fig. 3. Radix-2 DIF FFT signal-flow graph of length 16

An example of radix-2 DIT FFT SFG for N = 16 is depicted in **Fig. 4.**

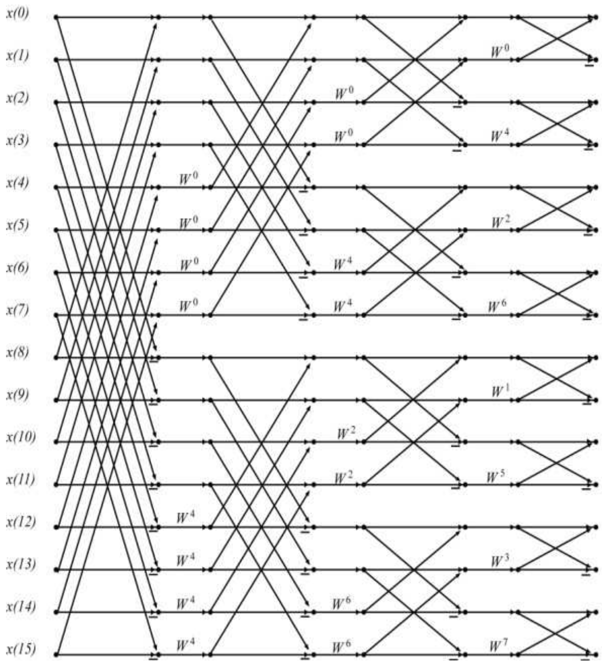


Fig. 4. Radix-2 DIT FFT signal-flow graph of length 16

The inverse discrete Fourier transform (IDFT) of length N is given by,

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k W_N^{-nk}, \qquad 0 \le n \le N-1 \qquad (2)$$

To reuse the same hardware core for reducing the chip area can be rewrite as,

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k^* W_N^{nk}, \qquad 0 \le n \le N-1 \qquad (3)$$

Where the star symbol * denotes a conjugate. This new form can be viewed as a general DFT. In other words, DFT and IDFT can reuse the same hardware core, while IDFT requires some extra computations. These extra computations include conjugating the input data X_k and the outcomes of DFT, as well as dividing the previous output by N.

Obviously, this new reuse version of DFT/IDFT algorithm will also simplify the design effort of an DFT/ IDFT processor and thus reduce the chip area, if both the DFT and IDFT processors are activated alternatively, and not simultaneously.

V. MODULATION METHOD

The modulation scheme in an OFDM system can be selected based on the requirement of power or spectrum efficiency. It is assumed that the majority of readers will be familiar with binary modulation schemes such as binary phase shift keying (BPSK), frequency shift keying (FSK), etc. For those who are not familiar with modulation schemes we give a short non-mathematical explanation of modulation andconstellation diagrams before detailing the history of QAM.

A. Quadrature Amplitude Modulation (QAM)

Quadrature amplitude modulation (QAM) is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (*modulating*) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme.

The two carrier waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components - hence the name of the scheme. The modulated waves are summed, and the resulting waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK), or (in the analog case) of phase modulation (PM) and amplitude modulation.

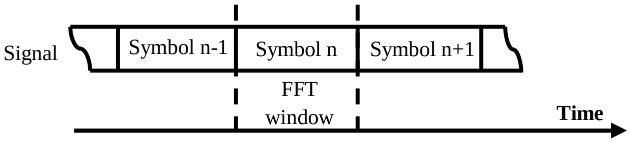
In the digital QAM case, a finite number of at least two phases and at least two amplitudes are used. PSK modulators are often designed using the QAM principle, but are not considered as QAM since the amplitude of the modulated carrier signal is constant.

QAM is used extensively as a modulation scheme for digital telecommunication systems. Arbitrarily high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, limited only by the noise level and linearity of the communications channel.

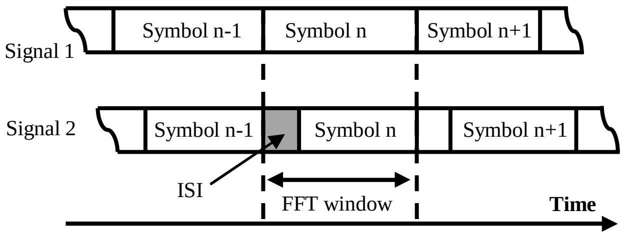
B. ISI (Intersymbol Interference)

In OFDM, the information is carried via a large number of individual carriers in a frequency multiplex. Each carrier transports only a relatively small amount of information, and high data capacities are achieved by using a large number of carriers within frequency multiplex.The signals of ISI is shown in **Fig. 5.**

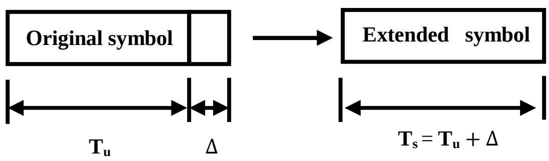
The individual carriers are modulated by means of phase-shift and amplitude-modulation techniques. Each carrier has a fixed phase and amplitude for a certain time duration, during which a small portion of the information is carried. This unit of data is called a symbol,the time it lasts is called the symbol duration. After that time period, the modulation is changed and the next symbol carries the next portion of information.



OFDM symbol duration and FFT window (no guard interval)



Inter-symbol interference with a delayed signal (no guard interval)



Increase of the symbol duration by the guard interval

Fig. 5. ISI (Intersymbol Interference) signals

Modulation and demodulation are accomplished by the use of Inverse Fast Fourier Transformation (IFFT) and Fast Fourier Transformation (FFT) respectively. The symbol duration time is the inverse of the carrier spacing, ensuring orthogonality between the carriers. In general, signals arriving at a receiver by different paths show different time delays which result in **inter-symbol interference (ISI)**, a degradation in reception. An OFDM system with a multipath capability allows for the constructive combination of these signals.

VI. SINC FILTER

In signal processing, a sinc filter is an idealized filter that removes all frequency components above a given cutoff frequency, without affecting lower frequencies, and has linear phase response. The filter's impulse response is a sinc function in the time domain, and its frequency response is a rectangular function.It is an "ideal" low-pass filter in the frequency sense, perfectly passing low frequencies, perfectly cutting high frequencies; and thus may be considered to be a brick-wall filter. Real-time filters can only approximate this ideal, since an ideal sinc filter (aka rectangular filter) is non-causal and has an infinite delay, but it is commonly found in conceptual demonstrations or proofs, such as the sampling theorem and the Whittaker–Shannon interpolation formula.
In mathematical terms, the desired frequency response is the rectangular function.

As the sinc filter has infinite impulse response in both positive and negative time directions, it must be approximated for real-world (non-abstract) applications; a windowed sinc filter is often used instead. Windowing and truncating a sinc filter kernel in order to use it on any practical real world data set destroys its ideal properties.

VII. SIMULATION AND RESULTS

Fig. 6. Shows Filtered Output (10 Frames) for the simulated waveform of 1024 point FFT processor

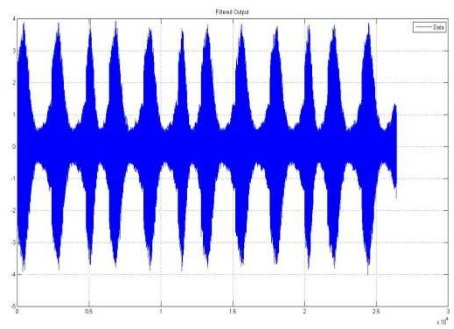


Fig. 6. Output waveform of Fillteredd Output

Fig. 7. Shows the simulated form of Frame Output (10 Frames)

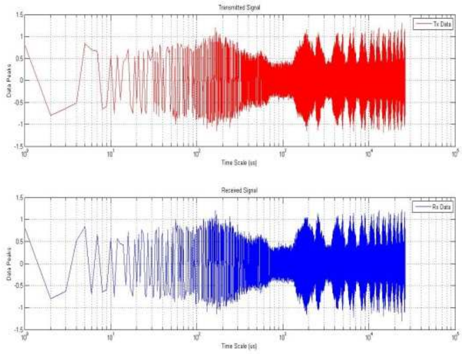


Fig. 7. Output waveform of Frame Output

Fig. 8. Shows the simulated form of Sinc Filter Output

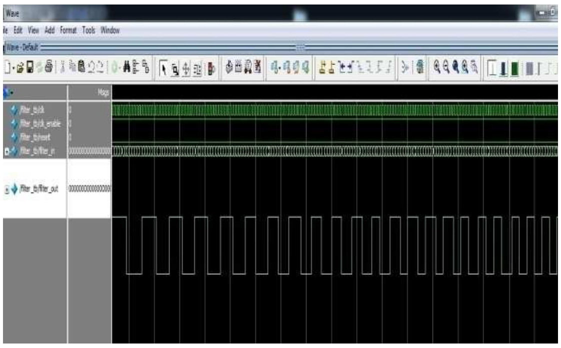


Fig. 8. Output waveform of Sinc Filter Output

Fig. 9. Shows the simulated form of Transceiver Output

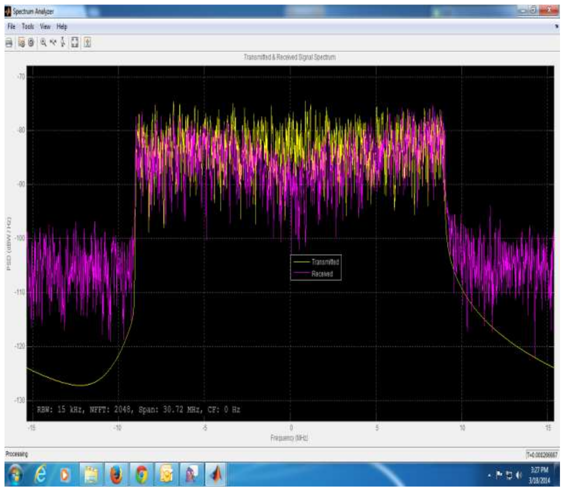


Fig. 9. Output waveform of Transceiver Output

VIII. CONCLUSION

In this work, developed an OFDM transceivers based on the proposed architecture which achieves above 2Gbps. Each models of a transmitter and receiver are implemented and simulated. In the following, we present the performance improvement of our pipelined architecture, in terms of the resource utilization. Verilog code has been generated and simulated using Model sim. The results show that the design has been simulated up to 227.355 MHz and it achieves higher speed and lower area by using Radix-2 parallelized 1024 point FFT/IFFT algorithm using Mat lab. Each FFT stage i.e. radix 2 FFT stage include one radix 2 butterfly computing unit, memory blocks to cache the streaming data, ROM to store FFT twiddle factors, control logic. The memory size of each stage equals the stage number. It is used to reduce the ISI Value using Sinc Filter. This increases its speed and area factor is also taken care of. The occupied area of an FPGA is proportional to number of used multipliers. The proposed design has shown improvement in area factor also in terms of no. of slices and no. of multipliers. Moreover the proposed design has been implemented on multipliers based lower end FPGAs in order to provide cost effective solution for wireless communication applications.

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