IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 45-49

High Performance Fbmc/Oqam System for Next Generation Multicarrier Wireless Communication

[1]R.Priyadharshini, [2]A.Savitha, [3]Ms.T.Rathi,
[1,2]UG Students, [3]Assitatnt Professor, Department Of ECEApollo Engineering College, Poonamalle.

Abstract : *In This Paper We Propose Cyclic Prefix Less Filter-Bank Multi-Carrier With Offset Quadrature Amplitude Modulation (FBMC/OQAM) System Over OFDM For Next Generation Wireless Standards. We Proved That Overall Throughput Metrics Of OFDM System In Fact Largely Limits By Delay Insertion And Also Depends On Many Parameters And Even With Multistage Pipelining Data Rate Can't Be Extended Up To 5G Requirements. Therefore, The Availability Of Efficient Hardware Implementations With Maximum Operating Frequency Becomes Of High Interest. In This Work, Pipelined Hardware With Maximized Parallel Processing Architecture Is Used At The Transmitter Which Capable Of Supporting Several Filter Lengths With Low Complexity And Its Efficiency Is Compared With OFDM Implementations. For A Functional Verification Extensive Test Bench Simulation Is Carry Out And Proposed Architecture Complexity Analyzes In Terms Of Multipliers Used And Memory Resources With Respect To A Typical OFDM Transmitter. Finally Through Hardware Synthesis, Its Complexity Gap And High Throughput Performance Rate Over Multi Carrier OFDM System Is Proved In Hardware Implementation Perspectives.*

Keywords *- OFDM, Quadrature Amplitude Modulation, Filter Bank, Bit Error Rate , Signal Detector Etc.*

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) Is A Multicarrier Transmission Technique, Which Divides The Available Spectrum Into Many Carriers, Each One Being Modulated By A Low Rate Data Stream. OFDM Is Similar To FDMA In That The Multiple User Access Is Achieved By Subdividing The Available Bandwidth Into Multiple Channels, Which Are Then Allocated To Users. However, OFDM Uses The Spectrum Much More Efficiently By Spacing The Channels Much Closer Together. This Is Achieved By Making All The Carriers Orthogonal To One Another, Preventing Interference Between The Closely Spaced Carriers

OFDM Can Be Viewed As A Collection Of Transmission Techniques. When This Technique Is Applied In Wireless Environment, It Is Referred To As OFDM. In The Wired Environment, Such As Asymmetric Digital Subscriber Lines (ADSL), It Is Referred To As Discrete Multi Tone (DMT). In OFDM, Each Carrier Is Orthogonal To All Other Carriers. However, This Condition Is Not Always Maintained In DMT [1]. OFDM Is An Optimal Version Of Multi Carrier Transmission Schemes. OFDM Started In The Mid 60's, Chang Proposed A Method To Synthesize Band Limited Signals For Multi Channel Transmission [2]. The Idea Is To Transmit Signals Simultaneously Through A Linear Band Limited Channel Without Inter Channel (ICI) And Inter Symbol Interference (ISI) .

A General Set Of Orthogonal Waveforms Is Given By

$$\psi_k(t) = \begin{cases} \dfrac{1}{\sqrt{T_s}} e^{j2\pi f_k t} & t \in [0, T_s] \\ 0 & otherwise \end{cases}$$

F K Is The Frequency Of The Kth Sub-Carrier, With K=0,1,…..Nc-1.

Subcarrier Allocation

Instead Of Transmitting The Data Symbols Serially, The Multi-Carrier Transmitter Partitions The Data Into Blocks Of Nc Data Symbols That Are Transmitted In Parallel By Modulating The Nc Carriers. The Symbol Duration For A Modulated Carrier Is Ts=1/ W.

The Multi-Carrier Signal Can Be Written As A Set Of Modulated Carriers As.

$$s(t) = \sum_{k=0}^{N_c-1} x_k \psi_k(t) \tag{1}$$

Xk Is The Data Symbol Modulating The Kth Sub-Carrier.

Ψk (T) Is The Modulation Waveform At The Kth Sub-Carrier.
S(T) Is The Multi-Carrier Modulated Signal.

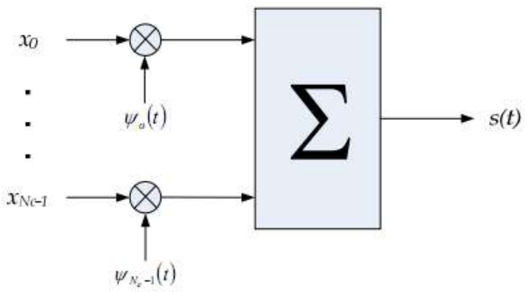


Fig. 1. Multi-Carrier Modulation

- A Number Of Steps Can Be Taken When Designing A Multi-Carrier System To Mitigate The Effects Of Fading.
- In Time Domain, The Data Symbol Duration Can Be Made Much Longer Than The Maximum Excess Delay Of The Channel. This Can Be Done Either By Choosing Max Ts >>Tmax .
- In Frequency Domain, The Bandwidth Of The Sub-Carriers Can Be Made Small Compared To The Coherence Bandwidth Of The Channel Bcoh >>W/Nc. The Sub-Bands Then Experience Flat- Fading, Which Reduces The Equalization To A Single Complex Multiplication Per Carrier.

II. FBMC SYSTEM MODEL

In OFDM, Information Bits To Be Transmitted Are First Modulated To Generate Complex In-Phase I And Quadrature Q Components Cn(M). A Maximum Of M QAM Symbols Are Modulated, Corresponding To The Number Of Active Sub-Carriers Of OFDM. Then, An IFFT Of Length M (IFFTM) Is Computed And A Block Of M Complex Samples Is Generated In Time Domain. Unused Sub-Carriers Are Padded To Zero At The Input Of The IFFT. The Baseband OFDM Modulation In Discrete Time Domain Can Be Written As:

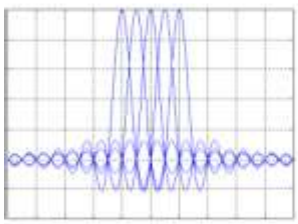


Fig 2: Spectra Of An OFDM Signal.

2.1 Architecture Modifications

A Cyclic Prefix (CP) Is Inserted At The Beginning Of A Block (OFDM Symbol) To Avoid Inter-Symbol Interference Caused By The Delay Spread Of A Multipath Channel At A Noticeable Cost In Spectral Efficiency. A Typical Sota Hardware Architecture Is Presented In Fig. 1. The First Unit Of The Proposed OFDM Modulator Architecture Is The QAM Mapper Which Is Typically Implemented Through A Look-Up Table (LUT), Supporting Up To 64-QAM, As Specified In The Long Term Evolution (LTE) Standard. The R22 SDF Architecture [4] Was Chosen For The IFFT Block Thanks To Its Low Complexity, Its Minimum Memory Requirement And Its Pipelined Structure. The Devised Architecture For The IFFT Uses The Decimation In Frequency (DIF) Decomposition Which Results In Output Samples In Bit Reversal Order [5].

2.2 Mapping Model

FMBC Defines Two Constellation Mapping Schemes: QPSK And QAM Modulations. The QPSK Spreads Data Into Several Subcarriers And The QAM Requires Data Reordering. The Spreading And Reordering Processes Involve Non-Trivial Amount Of Buffer Storages And Also Latency.

Conventionally Those Processes Are Done As Separate Phases: Interleaving First And Then Spreading Or Reordering. But, We Can Unify The Spreading And The (Inverse)-Reordering With The (De)Interleaving Process. With The Proposed Interleaver Architecture, We Can Perform The Spreading Before The Interleaving

Process By Fully Utilizing Array Cells Of Our Interleaver.

The DCM (Inverse)-Reordering Pattern Can Be Combined Into The (De)Interleaving Process So That The Reordering Is Done In Parallel With The Interleaving Process.

The Word Orthogonal Indicates That There Is A Precise Mathematical Relationship Between The Frequencies Of The Carriers In The System. In A Normal Frequency-Division Multiplex System, Many Carriers Are Spaced Apart In Such A Way That The Signals Can Be Received Using Conventional Filters And Demodulators.

2.3 Signal Interference

In OFDM Tranceivers, Guard Bands Are Introduced Between The Different Carriers And In The Frequency Domain, Which Results In A Lowering Of Spectrum Efficiency. It Is Possible, However, To Arrange The Carriers In An FBMC Signal So That The Sidebands Of The Individual Carriers Overlap And The Signals Are Still Received Without Adjacent Carrier Interference. To Do This, The Carriers Must Be Mathematically Orthogonal.

They Used Guard Space Between Symbols To Combat ICI And ISI Problem. This System Did Not Obtain Perfect Orthogonality Between Sub Carriers Over A Dispersive Channel. It Was Peled And Ruiz Who Introduced Cyclic Prefix (CP) That Solves The Orthogonality Issue [5]. They Filled The Guard Space With A Cyclic Extension Of The OFDM Symbol. It Is Assumed The CP Is Longer Than Impulse Response Of The Channel.

2.4 Cyclic Prefix As Filter Bank

Inter Symbolic-Interference (ISI) Is Induced In A Signal When It Passes Through A Frequency-Selective Channel. In OFDM Systems, It Causes The Loss Of Orthogonality Of The Sub-Carriers, Resulting In Inter-Carrier Interference (ICI). The Concept Of Cyclic Prefix (CP) Was Introduced As Filter Banks To Combat This Problem In FBMC System. In FBMC System Each Symbol Is Pre-Occupied With Unique Filter Coefficients To The Transmitted Symbol As An Alternative To CP Insertion As Shown In Figure 3, And Removed Before Demodulation.

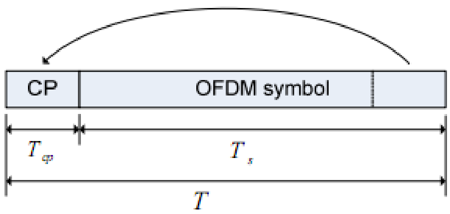


Fig. 3:Cyclic Prefix

FBMC Transmission Scheme Advantages

- Makes Efficient Use Of The Spectrum By Allowing Overlap.
- By Dividing The Channel Into Narrowband Flat Fading Sub-Channels, Though Is More Sensitive To Frequency Selective Fading Than OFDM Systems It Offers Significant Throughput Gain.
- Eliminates Inter Symbol Interference (ISI) Through Use Of A Filter Banks.
- 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 OFDM Systems.
- It Is Possible To Use Hardware Optimized FFT With Reasonable Complexity, FMBC Is Computationally Efficient By Using FFT Techniques To Implement The Modulation And Demodulation Functions.

2.5 Orthogonality Between Sub-Carriers.

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 The Modulation Scheme (Typically Differential BPSK, QPSK, Or QAM). 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.

III. FFT IMPLEMENTATION

The N-Point DFT Is Formulated As

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{nk}, k = 0,1,\ldots N-1 \tag{1}$$

Where The Twiddle Factors Is Defined As $W_N^{nk} = e^{-\frac{2\pi nk}{N}}$ .Then Denotes The Time Index And The K Denotes The Frequency Index. The Radix 2k Algorithm Can Be Derived By Integrating Twiddle Factor Decomposition Through A Divide And Conquer Approach.

Radix -22 Algorithm

Consider The First Two Steps Of Decomposition In Radix-2 DIF FFT Together.Applying A 3-Dimensional Linear Index Map As Follows $n = \frac{N}{2}n_1 + \frac{N}{4}n_2 + n_3\{n_1, n_2 = 0,1 n_3 = 0 \sim \frac{N}{4} - 1\}$ (2)

$$k = k_1 + 2k_2 + 4k_3\{k_1, k_2 = 0,1 k_3 = 0 \sim \frac{N}{4} - 1\}$$

IV. EXPERIMENTAL RESULT ANALYSIS

Here We Compare The Performance Of The Proposed FBMC Over Using Single Compound OFDM As A Benchmark Schemes To Explore The Throughout Rate With The Complexity Reduction Schemes Described As Shown In Table 2. We Extended This Analyzes Using MATLAB Generated Binary Values For Hardware Implementation To Proved Its Implications In Wireless Applications. The Hardware FPGA Synthesis Was Carried Without Using Any Degree Of EDA Driven Optimization Since The Objective Of This Work Is To Prove The Performance Of The Aforementioned Designs, Using Architectural Level Modifications To Analyze The Highest Achievable Complexity Reduction And Frequency.

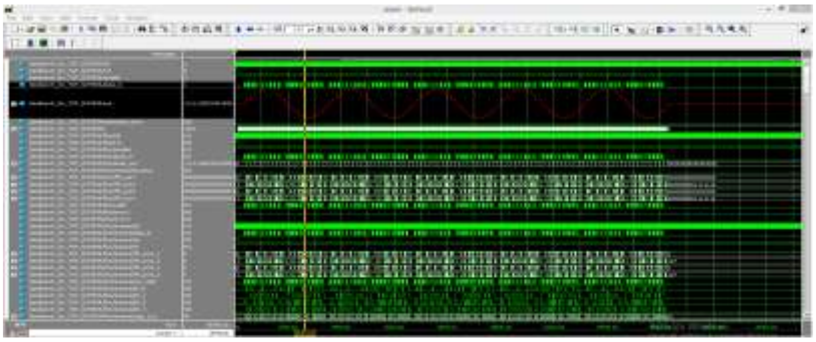
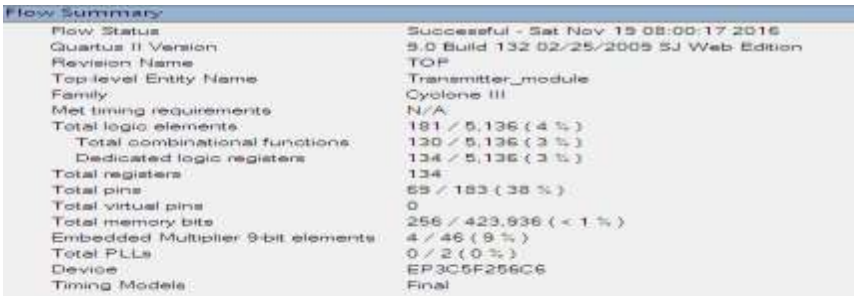


Fig. 4: FBMC Functional Verification

Nc -Point Inverse Fourier Transform (IFFT) Is Performed On Zero-Padded Xk To Generate Time-Domain Vector X(N) Cyclic Prefix Of Ncp Is Then Pre- Appended To X(N) Forming Xg(N) Vector Of Nc+Ncp Symbols. After Receiving The Data Equalization Is Applied Using A Pilot-Based Channel Estimation Method, And The Pilot Symbols Are Removed From The Equalized Signal. The Equalized Data Then Undergoes A P/S Conversion And Demodulation, Creating Estimates Of The Transmitted Binary Data.



Flow Summary	
Flow Status	Successful - Sat Nov 15 08:00:17 2016
Quartus II Version	5.0 Build 132 02/25/2005 SJ Web Edition
Revision Name	TOP
Top-level Entity Name	Transmitter_module
Family	Cyclone III
Met timing requirements	N/A
Total logic elements	181 / 5,136 (4 %)
Total combinational functions	130 / 5,136 (3 %)
Dedicated logic registers	134 / 5,136 (3 %)
Total registers	134
Total pins	65 / 183 (38 %)
Total virtual pins	0
Total memory bits	256 / 423,936 (< 1 %)
Embedded Multiplier 9-bit elements	4 / 46 (9 %)
Total PLLs	0 / 2 (0 %)
Device	EP3C5F256C6
Timing Models	Final

Fig. 5: Synthesized Report

In This Paper We Have Used Parallel FFT For OFDM With Maximum Spectral Efficiency. The Performance Of These Methods Was Simulated On MODELSIM, And Successfully Synthesized Using QUARTUS II EDA Tools. Finally We Proved That The Proposed System Is Implementable In FPGA Devices.

Table 1. Trade Off Analyzes Of OFDM Vs FBMC With QUARTUS II Hardware Synthesis Using CYCLONE III Family

Transmission model	AREA	Fmax report
OFDM	160	98.05 MHz
FBMC	181	216.92 MHz

Table 2. FFT Hardware Complexity Reduction Report

FFT model	AREA(LE's)	Fmax
4 MUL	8	77.69 MHz
3 MUL	6	60.48 MHz
SHIFT/ADD	0	79.65 MHz

V. CONCLUSION

In This Paper, Offset Modulation Combined FMBC Pipelined FFT Architecture Has Been Proposed For OFDM-Based WPAN Applications. Highly Parallelized FBMC/OQAM Transmitter Is Designed And Its Complexity And Performance Gap Over OFDM Is Well Proved Using FPGA Synthesis. Analytical FPGA Synthesis Results Of The Proposed Cyclic Prefix Less FBMC Transmitter Shows Significant Throughput Enhancement Over OFDM Methods. In This Paper We Carried Out FFT With Combined FBMC Pipelined FFT Architecture. To Reduce The Complexity Further Multiplier Less Shift Based Accumulation Will Be Proposed. In Order To Reduce Overall Latency Of Accumulation Prefix Based Arithmetic Computation Will Be Added.

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