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High Performance FBMC/OQAM System for Next Generation Multicarrier Wireless Communication

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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 to OFDM is proved in implementation perspectives.

KEYWORDS: Fast Fourier Transform(FFT),cyclic prefix(CP), orthogonal Frequency Division Multiplexing (OFDM).

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]. Though OFDM is an optimal version of multi carrier transmission schemes recent research shows that Filter-Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC/OQAM) is considered as potential alternative and complexity can also be reduced by almost a factor of two at the transmitter side. The idea is develop similar architecture choices are for both OFDM and FBMC as the common blocks with the transmitter to transmit signals simultaneously through a linear band limited channel without inter channel (ICI) and inter symbol interference (ISI) .

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A general set of orthogonal waveforms is given by

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

f_k is the frequency of the kth sub-carrier, with k=0,1,…..Nc-1.

MULTI-CARRIER MODULATION

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.

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

X_k is the data symbol modulating the kth k sub-carrier.
ψ_k (t) is the modulation waveform at the kth sub-carrier.
S(t) is the multi-carrier modulated signal.

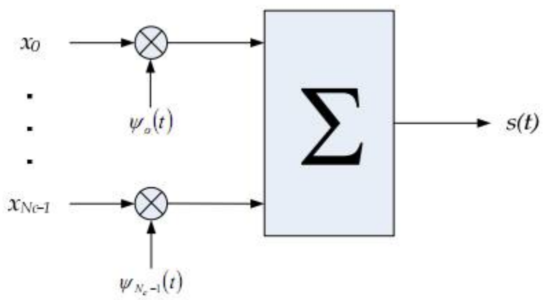

Fig 1. Multi-carrier modulation

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 >>τ_{max} .
- In frequency domain, the bandwidth of the sub-carriers can be made small compared to the coherence bandwidth of the channel B_{coh} >>W/Nc. The sub-bands then experience flat- fading, which reduces the equalization to a single complex multiplication per carrier.

II. FBMC SYSTEM MODEL

FBMC is of great interest by researchers and research laboratories all over the world. It has already been accepted for the next generation 5G air interface wireless local area network standards and Mobile Multimedia Access Communication (MMAC) Systems. Also, it is expected to be used for wireless broadband multimedia communications. This new standards specify bit rates from 10Gbps to 20Gbps. FBMC can be seen as either a modulation technique or a multiplexing technique. One of the main reasons to use FBMC is to increase the throughput rate using CP less

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transmission or using parallel processing task. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers will be affected. Error correction coding can then e used to correct for the few erroneous subcarriers. The word orthogonal indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system.

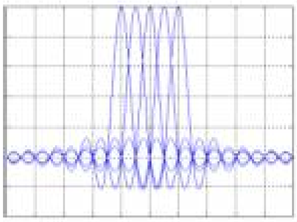

Fig 2. Spectra of an OFDM signal.

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. In such receivers, 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.

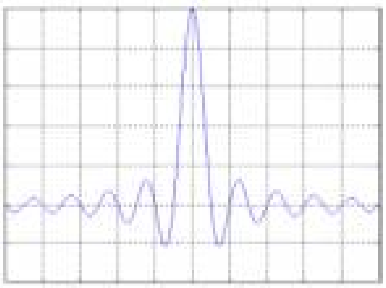

Fig 3.Spectra of an OFDM sub-channel

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.

A. SIGNAL INTERFERENCE

In OFDM transceivers, 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 OFDM 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. 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.

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B. CYCLIC PREFIX USING POLY PHASE NETWORK

Inter symbolic-interference (ISI) induced through multipath propagation signal when it passes through a frequency-selective channel causes the loss of orthogonality of the sub-carriers, resulting in inter-carrier interference (ICI). In general the concept of cyclic prefix (CP) was introduced to combat this problem [14]. In FBMC/OQAM modulator the PPN filter methodology is incorporated as follows:

$2(q-1)$ single port RAM of size $M/2 \times QIFFT$, where QIFFT is the length of the output of IFFT (real or imaginary part).

$2q$ real multipliers: q taps per PPN, each tap having only 2 multipliers since the filter coefficients are real valued.

$2(q-1)$ real adders: 2 for each tap (complex adders), except for the last one. It is possible to reduce the number of adders by adopting a tree-like organization

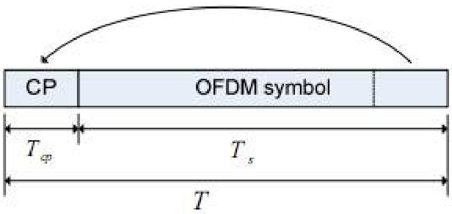

Fig 4.Cyclic prefix

C. FBMC TRANSMISSION SCHEME ADVANTAGES

- Makes efficient use of the spectrum by allowing overlap.
- By dividing the channel into narrowband flat fading sub-channels, FBMC is more resistant to frequency selective fading than single carrier systems are.
- Eliminates Inter Symbol Interference (ISI) 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.
- It is possible to use maximum likelihood decoding with reasonable complexity, OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.

D. ORTHOGONALITY BETWEEN SUB-CARRIERS.

To generate FBMC 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.

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III. RADIX -2^k ALGORITHM

The N-point DFT is formulated as

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

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 2^k algorithm can be derived by integrating twiddle factor decomposition through a divide and conquer approach.

A. RADIX -2^2 ALGORITHM

Consider the first two steps of decomposition in radix-2 DIF FFT together.Applying a 3-dimensional linear index map as follows $n=\frac{N}{2}n_1+\frac{N}{4}n_2+n_3\{n_1,n_2=0,1n_3=0\sim\frac{N}{4}-1\}$ (2)

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

The DFT has the form of

$$X(k_1+2k_2+4k_3)=\sum_{n_3=0}^{\frac{N}{4}-1}\sum_{n_2=0}^{1}\sum_{n_1=0}^{1}x(\frac{N}{2}n_1+\frac{N}{4}n_2+n_3)W_N^{nk}$$

$$=\sum_{n_3=0}^{\frac{N}{4}-1}\sum_{n_2=0}^{1}\{B_{\frac{N}{2}}^{k_1}(\frac{N}{4}n_2+n_3)\}W_N^{(\frac{N}{4}n_2+n_3)(k_1+2k_2+4k_3)} \quad (3)$$

where the first butterfly structure has the form of

$$B_{\frac{N}{2}}^{k_1}(\frac{N}{4}n_2+n_3)=x(\frac{N}{4}n_2+n_3)+(-1)^{k_1}x(\frac{N}{4}n_2+n_3+\frac{N}{2}) \quad (4)$$

Decomposing the composite twiddle factor,it can be expressed in Eq.(5).

$$W_N^{(\frac{N}{4}n_2+n_3)(k_1+2k_2+4k_3)}=(-j)^{n_2(k_1+2k_2)}W_N^{n_3(k_1+2k_2)}W_{N/4}^{n_3k_3} \quad (5)$$

Substituting the Eq.(5) into Eq.(3) and expanding the summation with regard to index n_2 ,we have a set of 4 DFTsof length $N/4$.

$$X(k_1+2k_2+4k_3)=\sum_{n_3=0}^{\frac{N}{4}-1}[H_{N/4}^{k_1k_2}(n_3)W_N^{n_3(k_1+2k_2)}]W_{N/4}^{n_3k_3} \quad (6)$$

where a secondary butterfly structure $H_{N/4}^{k_1k_2}(n_3)$ is expressed as

$$H_{N/4}^{k_1k_2}(n_3)=B_{\frac{N}{2}}^{k_1}(n_3)+(-1)^{k_2}(-j)^{k_1}B_{\frac{N}{2}}^{k_1}(n_3+\frac{N}{4}) \quad (7)$$

After these two columns, full multiplications are used to apply the decomposed twiddle factor $W_N^{n_3(k_1+2k_2)}$ in Eq.(6).Applying this cascade decomposition recursively to the remaining DFTs of length $N/4$ in Eq.(6), the complete radix -2^2 FFT algorithm is obtained. Equation (7) represents the first two columns of butterflies with only trivial multiplication of (-j) which can be implemented using only real-imaginary swapping and sign inversion.

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The radix-2^2 algorithm is characterized according to the merit that it has the same multiplicative complexity and as the radix-4 algorithm, but still retains simple structures of the radix-2 butterfly.

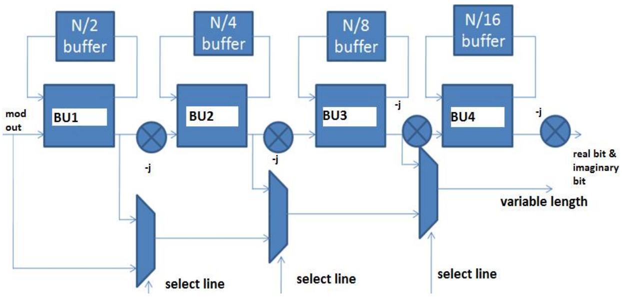

Fig 5. FFT radix-2^2 architecture

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.

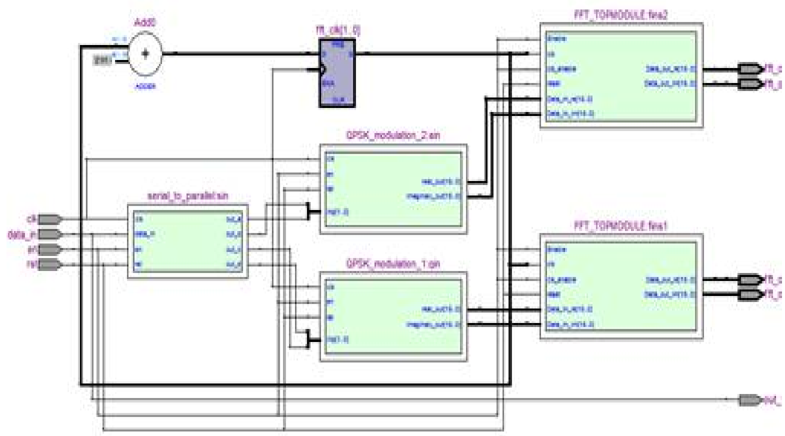

Fig 8. Synthesized report

IV. RESULT ANALYSIS

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

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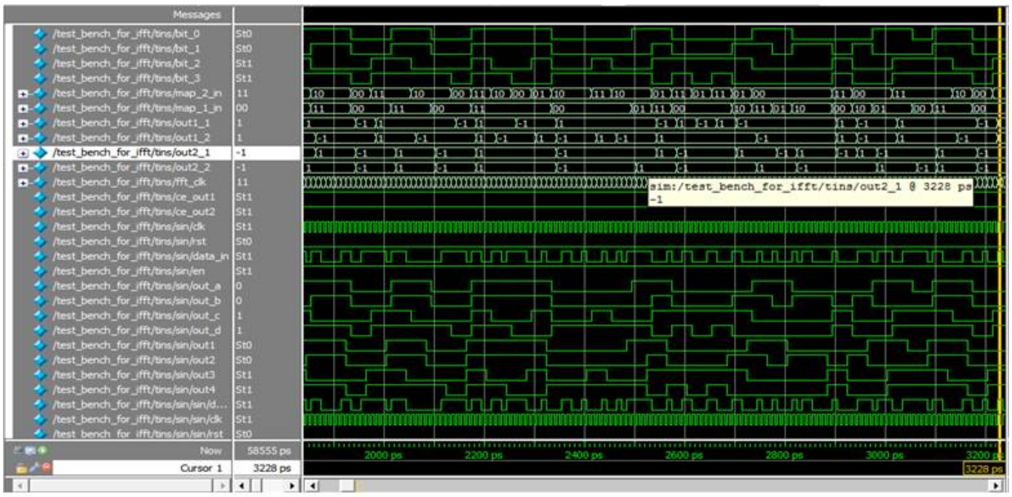

Fig 7. Simulated output.

COMPARISON TABLE OF QUARTUS II SYNTHESIS REPORT IN ALTERA CYCLONE FAMILY FPGA'S.

TYPE	Multiplier Used	AREA	SPEED
4 MUL BASED	8	453	131.94 MHz
3 MUL BASED	6	459	129.1 MHz
PROPOSED	4	291	137.91 MHz

V.CONCLUSION

In this paper, a radix -2^k algorithm and 8 point combined SDC-SDF pipelined FFT architecture radix -2^k FFT architecture have been proposed for FBMC-based WPAN applications. The number of complex multipliers and twiddle factor LUTs are reduced using pre-shuffling units in the radix -2^k algorithm. The proposed radix -2^k FFT processor is extended into accurate FFT architecture for the 8-point SDC-SDF FFT processors. The proposed architecture has potential applications in high-rate FBMC-based WPAN systems.

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BIOGRAPHY

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