

DESIGN OF OPTIMAL FILTER BANK FOR MULTICARRIER MODULATION SYSTEMS

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Abstract -Spectral efficiency is the key factor for the development of future wireless communications. Recently, filter bank multicarrier (FBMC) modulations have attracted a lot of attention due to capability to efficiently cope with frequency selective channels. Much of the attention in the present literature emphasizes on the use of conventional orthogonal frequency division multiplexing (OFDM). However, the OFDM system sacrifices data transmission rate because of the insertion of cyclic prefix (CP). To remedy the problem of the OFDM systems, filter bank multicarrier modulation has attracted increasing attention recently. In this paper, the challenges associated with the OFDM system are addressed. OFDM system transmits redundancy in terms of Cyclic Prefix (CP), which decreases the spectral efficiency of the system and also, transmit and receive filters in OFDM system suffer from poor frequency response because of the use of rectangular window function. Hence in order to increase the data rate in OFDM system, a non-rectangular window based prototype filters are proposed for the transmitter and receiver end, which eliminates the use of CP in OFDM system. The performance of OFDM system with the suggested filter bank based multicarrier systems is compared in terms of bit error rate (BER).

Keywords: OFDM, filter bank multicarrier, Transmultiplexer, Nyquist condition

I. INTRODUCTION

Recently, a worldwide convergence has occurred for the use of OFDM as an emerging technology for high data rates. In particular, many wireless standards (Wi-max, IEEE 802.11a, LTE, DVB) have adopted the OFDM technology as a mean to increase dramatically future wireless communications. OFDM is a particular form of multi-carrier transmission and is suited for frequency selective channels and high data rates. Due to multipath fading over wireless communication, the consecutive OFDM symbols overlap at the receiver and gives rise to ISI and ICI. To minimize the ISI, it uses cyclic prefix (CP) of appropriate length to transform the time invariant multipath channel into a frequency non-selective channel. But CP is a redundancy, which decrease the spectral efficiency of the system. To solve this problem in OFDM system, filter bank multicarrier (FBMC) modulation has attracted increasing attention recently. Compared with the conventional OFDM system, the FBMC system provides higher useful data rate because FBMC does not require the CP.

OFDM is nothing but a specific case of transmultiplexer where the rectangular pulse is taken as the prototype filter in analysis and synthesis filter banks. But because of rectangular window for prototype filter, the transmit and receive filters suffer from poor frequency responses. The stopband attenuation of these filters is only 13 dB. In many wireless communications applications it is desirable to have transmitters which have small out of band energy. The required ideal bandwidth efficiency can be achieved by using non-rectangular windows for pulse shaping in such a manner that the cascade of

transmit and receive filters meets the Nyquist criterion.

For the prototype filter design, it is often required that the stopband energy of the filter be minimized, while on the other hand, the nearly perfect reconstruction (NPR) condition be satisfied.

II. OFDM SYSTEM

To generate the OFDM successfully the orthogonality principle between the carriers must be maintained. For this reason, OFDM is generated by first choosing the spectrum required, based on the input data, and modulation scheme used. In digital communications, information is expressed in the form of bits. The term symbol refers to a collection, in various sizes, of bits. OFDM data are generated by taking symbols in the spectral space using M-PSK, QAM, etc, and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). Since Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead. Once the OFDM data are modulated to time signal, all carriers transmit in parallel to fully occupy the available frequency bandwidth. During modulation, OFDM symbols are typically divided into frames, so that the data will be modulated frame by frame in order for the received signal be in synchronize with the receiver. Long symbol periods diminish the probability of having inter-symbol interference, but could not eliminate it. To make ISI nearly eliminated, a cyclic extension (or cyclic prefix) is added to each symbol period. An exact copy of a fraction of the cycle, typically 25% of the cycle, taken from the end is added to the front. This allows the demodulator to capture the symbol period with an uncertainty of up

to the length of a cyclic extension and still obtain the correct information for the entire symbol period.

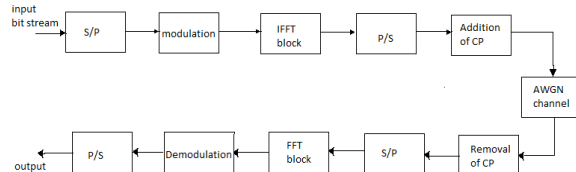


Fig1: OFDM block diagram

III. TRANSMULTIPLEXER SYSTEM

Figure 2 below shows the complete transmultiplexer structure. A transmultiplexer (TMUX) is a multi-input, multi-output, multirate structure which is exactly opposite to that of M channel QMF bank. Basically it is a TDM-FDM-TDM converter. In the TMUX system shown in Fig. 2, the M input signals x_i , $i = 0, 1, \dots, M-1$ are first upsampled by M . The obtained signals are then passed through the filters $F_i(z)$, $i = 0, 1, \dots, M-1$ and summed to form signal $y(n)$, which is fed to the channel. At the receiver end, y is filtered by $H_k(z)$, $k = 0, 1, \dots, M-1$ and subsampled by M to form the reconstructed signals, \hat{x}_i , $i = 0, 1, \dots, M-1$.

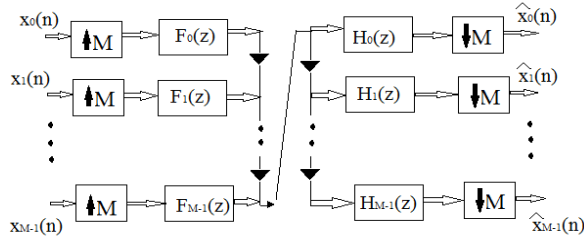


Fig 2. The complete transmultiplexer structure

A. Input-Output Relations for Transmultiplexers

By using the polyphase identity we see that each branch in the figure is in reality an LTI system. We can therefore express

$$\hat{X}_k(z) = \sum_{m=0}^{M-1} S_{km}(z) X_m(z), \quad 0 \leq k \leq M-1 \quad (1)$$

Where $S_{km}(z)$ is the 0^{th} polyphase component of $H_k(z)F_m(z)$.

By defining,

$$x(n) = [x_0(n) \dots x_{M-1}(n)]^T \quad (2)$$

$$\hat{X}(n) = [\hat{x}_0(n) \dots \hat{x}_{M-1}(n)]^T$$

We can express (1) more compactly as

$$\hat{X}(z) = S(z) X(z) \quad (3)$$

So the transmultiplexer is an LTI system with transfer matrix $S(z)$. The system is free from cross talk if and only if $S(z)$ is diagonal. Under this condition, each

reconstructed TDM signal is related to the original signal $x_k(n)$ according to

$$\hat{X}_k(z) = S_{kk}(z) X_k(z) \quad (4)$$

The transfer functions $S_{kk}(z)$ represent the distortion that remain after cross talk elimination. If $S_{kk}(z)$ is allpass for all k , there is no amplitude distortion; if $S_{kk}(z)$ has linear phase, there is no phase distortion. Finally, a perfect reconstruction (PR) transmultiplexer is one for which

$$S_{kk}(z) = c_k z^{-n_k}, \quad \text{for all } k \quad (5)$$

For some nonzero c_k and integer n_k , The TDM signals are then recovered without error, that is, $\hat{x}(n) = c_k x_k(n - n_k)$.

B. Study Based on Polyphase Matrices

The use of polyphase decomposition adds further insight into the operation of the transmultiplexer. We can redraw the analysis and synthesis banks in terms of the polyphase matrices $E(z)$ and $R(z)$. The resulting equivalent transmultiplexer circuit is shown in fig 2a, which simplifies to fig 2b after invoking the noble identities.

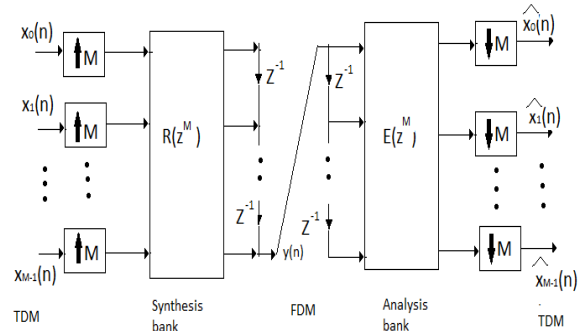


Fig.2a Equivalent structure for the transmultiplexer in terms of polyphase matrices

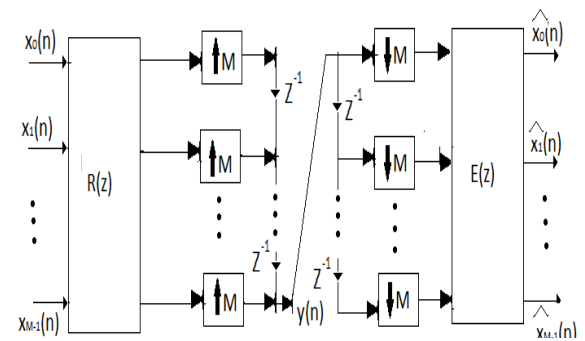


Fig.2b Rearrangement using the noble identities

IV. PROPOSED SYSTEM

We consider the TMUX systems with the prototype filters $F_0(z)$ resp. $H_0(z)$ such that their cascade satisfies Nyquist property. We have adopted the algorithm presented in [12]. But the system is not desirable in terms of computational complexity, so

we use DFT filter bank and polyphase structures to reduce the complexity

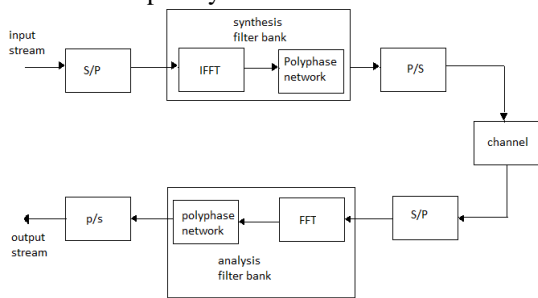


Figure 3 Block diagram of proposed FBMC

When the number of channels is small, typically less than 20, the complexity is dominated by the filter bank. Since in filter bank based multicarrier systems the basic symbol waveform is a Nyquist pulse overlapping with the previous and next symbol, so the orthogonality of subchannels is easily lost. Though the arbitrary scaling of the amplitudes does not affect the orthogonality, but the nonlinear phase response of channel does. One possible approach to eliminate the effects of nonlinear phase response is to use the oversampled filter banks. Fig. 4 presents the model of such system. Here N signals are transmitted and each of them is upsampled by a factor of M such that $M \geq N$.

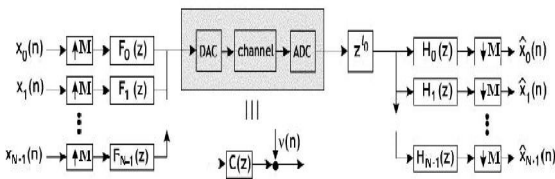


Fig. 4 Filter bank transceiver

V. DISCUSSION ON SIMULATION RESULTS

Filter bank based multicarrier system vs. OFDM

This part deals with the TMUX system, which uses the filters satisfying Nyquist condition as the prototype filters at the transmitter and receiver end. Because of better stopband attenuation of the non-rectangular window prototype filters than the ones with rectangular window, the proposed system outperforms the OFDM system. Figure 5 give the idea of the stop-band attenuation of the eight filters designed by employing the idea given in [12].

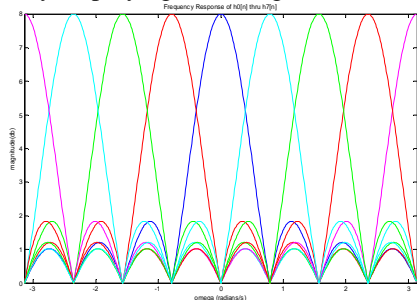


Fig. 5 Stop band attenuation of the filters designed by employing the idea given in [12]

The comparisons of the performance of OFDM system and that of filter bank based multicarrier system are presented in Fig. 6

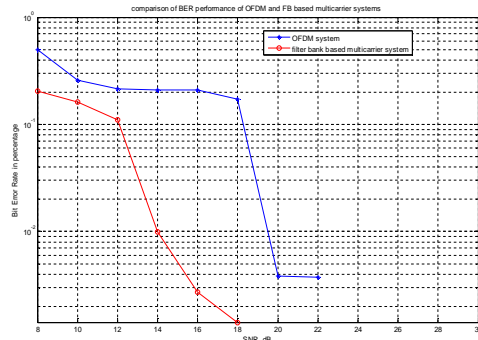


Fig. 6 The comparison of the performance of OFDM system and filter bank based multicarrier system

CONCLUSION

In this paper, we design the bandwidth efficient system by employing the non-rectangular window based prototype filters instead the rectangular window based ones of the OFDM system. We also compare the performance of OFDM system and the suggested filter based multicarrier system in terms of BER versus SNR. It is also observed that the proposed filter bank based multicarrier system outperforms the normal OFDM system.

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