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PAPR analysis in UFMC system using companding technique for wireless communications

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Abstract: The Universal Filtered Multi Carrier (UFMC) system is a promising alternative waveform for both orthogonal frequency division multiplexing and filter bank multi-carrier systems due to its high spectral efficiency. However, UFMC undergoes with high peak-to-average power ratio (PAPR), which affects the efficiency of the power amplifier. Companding techniques are simple and proficient to reduce the PAPR of UFMC signals. In this paper, we use a companding technique, which is non-linear companding transform technique in UFMC system, which reduces PAPR of UFMC signals without changing the average power of the companded signal, is proposed. The proposed method offers flexibility in selecting companding parameters to achieve optimal performance in terms of PAPR, average power level, and bit error rate (BER). The proposed method confirms that the companding technique offers better PAPR reduction and BER characteristics when compared to the original UFMC signal and clipping technique. The BER of the proposed companding technique is assessed for higher order modulations and it presents better PAPR characteristics when compared to the original signal. UFMC system is implemented and comparative analysis are carried out in terms of M-ary QAM modulation scheme, side lobe attenuations of the Dolph-chebyshev filter and Bit Error Rate (BER) over different fading channels.

Keywords: UFMC, PAPR, BER, QAM, Companding, Dolph-Chebyshev Filter

1. Introduction

OFDM is a multi-carrier modulation scheme in which the data into small portions and use a number of parallel orthogonal subcarriers to transmit the data. Orthogonal Frequency Division Multiplexing or OFDM is a modulation scheme that has become popular in recent wireless and telecommunications standards. The major drawback with OFDM it has less spectrum efficiency. It has less efficiency because it uses some of the available band for cyclic prefix. Cyclic prefix adds the guard period in between the data bits to reduce inter-symbol interference as shown in the figure below. Due to overlap of side lobe of the adjacent sub band leads to inter-symbol interference. The Inter-symbol interference occurs in the receiver section. In the wireless channel there is a multipath fading and the transmitted signal will be delayed at receiver. The delay in time domain leads to the interference of the signals in the frequency domain and that leads to inter-symbol interfere. In OFDM the orthogonality of the carriers may be lost and that leads to inter carrier interference (ICI). The cyclic prefix also helps in retaining the orthogonality of the carriers and thereby reduces ICI.The BER of OFDM is also high. The use of Orthogonal Frequency Division Multiplexing (OFDM) in the context of 4G is considered unsuitable for 5G because of various challenges, such as problems with synchronization, inadequate spectral efficiency, and a more Peak to Average Power Ratio (PAPR). As a result, new waveforms have been developed and studied as potential replacements for 5G implementation.

UFMC is a multi-carrier transmission technique and its underlying principle is based on Frequency Division Multiplexing (FDM). In FDM the input data stream is subdivided into a large number of sub bands with narrow bandwidth. The single carrier transmission system uses a single carrier signal for the entire bandwidth, whereas in a multi carrier transmission available bandwidth is made into few sub bands and uses multiple sub carriers and hence, the data rates will be increased in multi carrier systems. In the UFMC scheme, the available bandwidth is partitioned into several sub-bands that are allocated to multiple subcarriers. Generally, the input signal and the carrier signal are given to the product modulators and that generates the modulated signal. But the implementation of these product modulators is very complex. So instead of using a large number of product modulators i.e. (one product modulator for one sub band) we use a single block that does the same operation like product modulators and thereby reduces the amount of hardware at both receiver and transmitter. Both in OFDM and FBMC the modulated signal is filtered at once and for that it requires filter of larger length. Whereas in UFMC each sub band will have a separate filter and as a result requires a filter of smaller length when compared with OFDM and FBMC. Since the filtering operation is performed on a set of contiguous subcarriers within each subband as a result, it lowers the out of band side lobe levels and thereby decreases the Inter symbol interference and also the Inter carrier interference to a large extent when compared with OFDM.

Advantages of UFMC are

i. there is no requirement of using cyclic prefix in UFMC so it is highly efficient in utilizing the available bandwidth.
ii. In UFMC each sub band is filtered by using a separate filter. The filter attenuates the out of band radiation levels of side lobes of carriers in each sub band.
iii. filter of smaller length should be required when compared to FBMC and also it results in out of band radiations.

Disadvantages of UFMC are

i. In the receiver section, FFT block of larger size is required and designing such larger block is very complex.
ii. If the available bandwidth is divided into narrow bands in such case there may less interference between the sub bands.

2. QAM (Quadrature Amplitude Modulation)

In QAM the amplitude and the phase of carrier signal are varied w. r. t the input data bits. In this modulation scheme, the I and Q components are represented by two carriers that are 90° out of phase with each other. Since there is both amplitude and phase variation the carrier signal is given by

$$X_c(t) = A_c\, cos(2\pi f_c t + \theta) = a \times I + b \times Q$$
$$I = A\, cos(2\pi f_c t) \quad \text{and} \quad Q = A\, sin(2\pi f_c t)$$

where $x_c(t)$ denotes the Carrier signal, A_c denotes Amplitude of carrier signal, f_c denotes the frequency of the carrier signal and M denotes the order of QAM.

$$a, b \in \{A \times (2I + 1)\} \quad \text{and} \quad 0 \leq i \leq \frac{\sqrt{M}}{2} - 1$$

2.1 16 QAM

For 16 QAM the value of M = 16. So, the number of bits per symbol is given by

$$k = log_2 M = log_2 16 = 4$$

The carrier signal is given by

$$X_c(t) = a \times I + b \times Q$$
$$a, b \in \{A \times (2I + 1)\} \quad \text{and} \quad 0 \leq i \leq \frac{\sqrt{M}}{2} - 1$$
$$a, b \in \{A, -A, 3A, -3A\}$$

The values of a and b are (A, A), (A, -A), (-A, A), (-A, -A), (A, 3A), (A, -3A), (-A, 3A), (-A, -3A), (3A, A), (3A, -A), (-3A, A), (-3A, -A), (3A, 3A), (3A, -3A), (-3A, 3A), (-3A, -3A)

If A=1 then the values of a, b are (1, 1), (1, -1), (-1, 1), (-1, -1), (1, 3), (1, -3), (-1, 3), (-1, -3), (3, 1), (3, -1), (-3, 1), (-3, -1), (3, 3), (3, -3), (-3, 3), (-3, -3)

The values of $x_c(t)$ are (I + Q), (I - Q), (- I + Q), (- I - Q), (I + 3Q), (I -3Q), (- I + 3Q), (-I -3Q), (3I + Q), (3I - Q), (-3I+ Q), (- 3I- Q), (3I + 3Q), (3I - 3Q), (-3I + 3Q), (- 3I - 3Q)

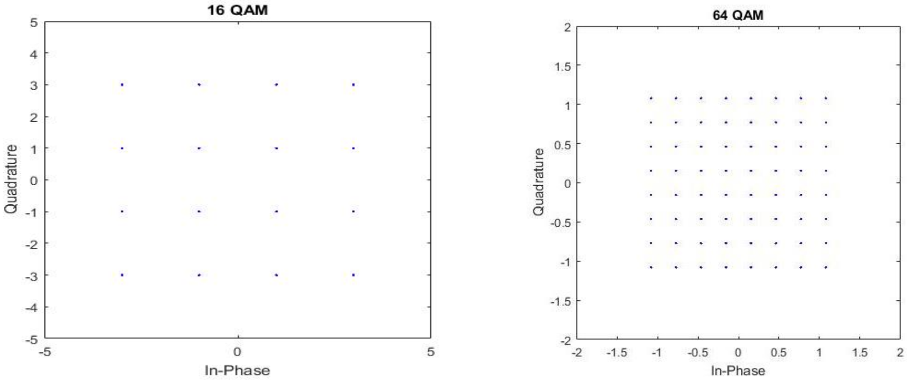


Fig 1:16 QAM and 64 QAM Constellation diagrams

2.2 64 QAM

For 16 QAM the value of M = 16. So, the number of bits per symbol is given by

$$k = log_2 M = log_2 16 = 4$$

The carrier signal is given by

$$X_c(t) = a \times I + b \times Q$$
$$a, b \in \{A \times (2I + 1)\} \text{ and } 0 \leq i \leq \frac{\sqrt{M}}{2} - 1$$
$$a, b \in \{A, -A, 3A, -3A, 5A, -5A, 7A, -7A\}$$

There will total 64 combinations in which the values of a, b are chosen. Then finally $x_c(t)$ will have 64 values. In 64 QAM, there are 64 symbols and each symbol consists of 6 bits. All these symbols are aligned in the form's a square in the constellation Diagram so the constellation is also referred as Square Constellation.

3. Companding

Companding is a technique that involves expanding small signals in the transmitter section and compressing them at the receiver side. The main objective of this technique is to amplify small signals while reducing the impact of noise. Generally, the companding procedure is employed at the sender's end after receiving the output from the IFFT block. There are two commonly known kinds of companders: µ-law and A-law companders.

i. µ−law companding

u-law companding, also known as µ-law, is a non-linear compression technique that is used primarily in North America and Japan. It uses a logarithmic function reduce input signal's dynamic range through compression. In u-law companding, the input signal is first amplified and then divided into segments of different sizes, based on the amplitude of the signal. The segments with lower amplitudes are compressed more than the segments with higher amplitudes. This results in a smaller dynamic range and a higher signal-to-noise ratio.

$$y(x) = W\frac{\log(1 + \mu\frac{|x|}{w})}{\log(1 + \mu)}\text{sgn}(x)$$

ii. A-law companding

A-law companding, on the other hand, is a non-linear compression technique that is used primarily in Europe and other parts of the world. It uses a piecewise linear function reduce input signal's dynamic range through compression. In A-law companding, the input signal is divided into segments of different sizes, based on the amplitude of the signal. The segments with lower amplitudes are compressed more than the segments with higher amplitudes, but the compression is more uniform across the different segments compared to u-law companding.

$$F(x) = sgn(x)\begin{cases} \frac{A|x|}{1 + \ln(A)}, & |x| < \frac{1}{A} \\ \frac{1 + \ln(A|x|)}{1 + \ln(A)}, & \frac{1}{A} \leq |x| \leq 1 \end{cases}$$

4. UFMC system model

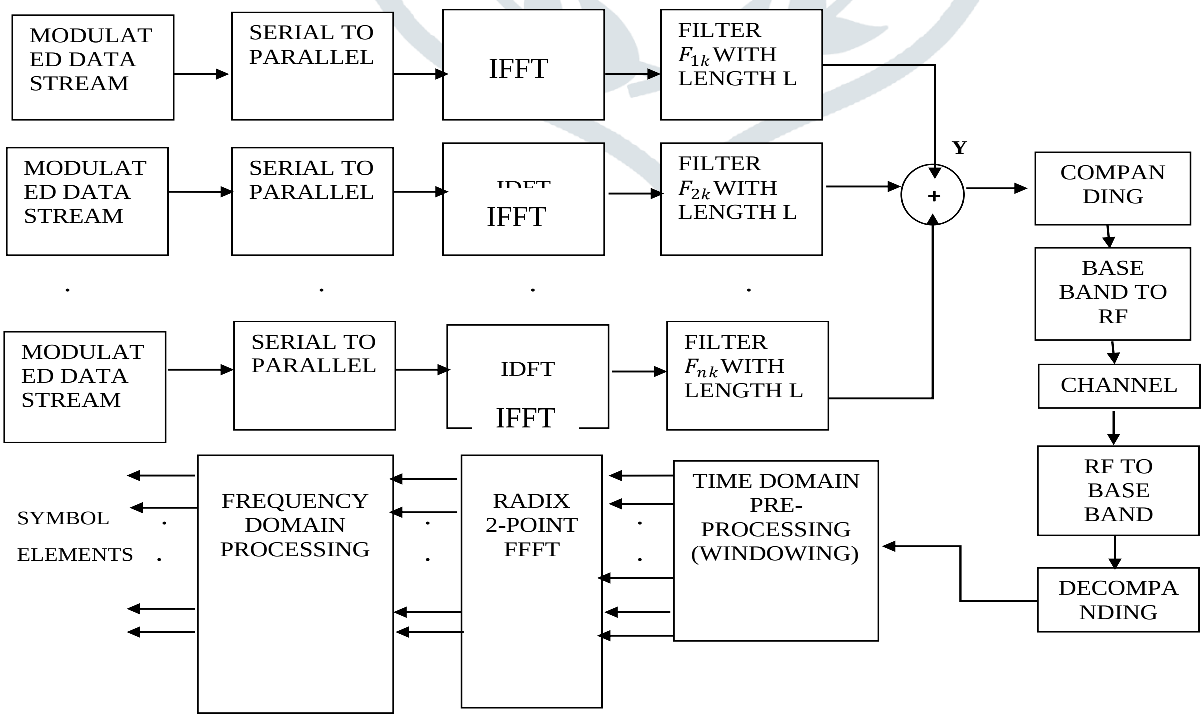


Fig 2: UFMC Block Diagram

The system model of UFMC represented in Fig 1. The entire bandwidth is splitted into B sub-bands. UFMC system model allocates N subcarriers across B sub-bands. Overall count of subcarriers is N.

4.1 UFMC Transmitter Section

4.1.1 symbol mapping

The input data may be in either in Binary or in gray format. The input data will be mapped using different mapping techniques. Some of them are Phase Shift Keying (PSK), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature amplitude modulation (QAM) and Amplitude Phase Shift Keying (APSK). Based on the type and order of the mapping scheme required number of bits are mapped together to form a single symbol. For example, in QPSK, generally two bits in the input data are mapped together and form one symbol, whereas in BPSK one bit is mapped into one symbol.

4.1.2 serial to parallel converters:

This block converts the serial data into parallel data. For example, if QPSK is used, then two symbols are combined together to form one symbol. So, two consecutive bits are combined and converted into parallel data using this converter.

4.1.3 IFFT Block:

To obtain the modulated signal the message signal should be multiplied with the carrier signal so to perform multiplication operation product modulators are used. In a multi carrier system large number of carriers is used. To multiply each carrier with the input signal it requires plenty of product modulators but it is difficult to design that many product modulators. So, an N-point IFFT is used as a substitute for designing too many product modulators. The IFFT block also converts the signal from the frequency domain to time domain. To transform the frequency domain signal into the time domain, Inverse Discrete Fourier Transformation (IDFT) of N-point operation is carried out for each sub-band i. The data symbols are modulated in the designated subcarrier positions for sub-band i, while zeros are inserted in the unallocated subcarrier positions in the frequency domain to facilitate the IDFT. As a result, the output signal after IDFT is N.

4.1.4 Filter:

To convert the modulated signal into the time domain, an IFFT block is utilized. The resulting output is then fed into a Dolph-Chebyshev filter with a value of L length. This filter reduces the levels of out-of-band radiation and side lobes of carriers in each sub-band. However, it also eliminates the orthogonality between subcarriers. In OFDM, a rectangular filter is utilized which results in high side lobe levels due to poor centering in both the time and frequency domains. To address this issue, the output signal x_i is filtered using a FIR filter f_i with the length of L .Therefore, the output signal of subband i is given by

$$y_i(k)=x_i * f_i = \sum_{l=0}^{L-1}(f_i(l)x_i(k-l)) \quad \text{where } k=0,1,\ldots\ldots\ldots,N+L-1$$

As a result of the linear convolution between x_i and f_i, the symbol length becomes N+L-1.The aim of incorporating a Finite Impulse Response (FIR) filter for each subband is to minimize out-of-band radiation. The rectangular symbol shape in Orthogonal Frequency Division Multiplexing (OFDM) is not adequately localized in either time or frequency, resulting in the Fourier transformation of the rectangular symbol shape, also known as the sinc function, has a high level of spectral side lobes. In cases where errors with synchronization disrupt the orthogonality among subcarriers, the excessive out-of-band radiation can spread to adjacent subbands. UFMC's block-wise filtering strategy can significantly minimize out-of-band radiation designing the FIR filter appropriately. Filters of Dolph-Chebyshev kind are well-suited for this objective due to their capacity to be characterized by attenuation in sidelobes, which decreases the highest level of out-of-band radiation. Consequently, this study utilizes Dolph-Chebyshev filters, as demonstrated in Fig. 2, which displays a filter Dolph-Chebyshev kind in both the time and frequency domains using typical parameters (filter length of FIR is 80, attenuation in side-lobe is 60 dB).

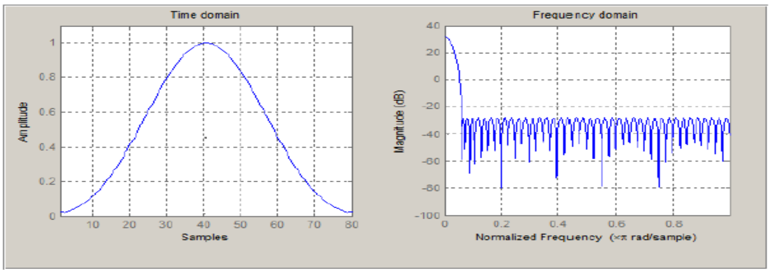


Fig 3: A filter using the Dolph-Chebyshev method has been designed with a length of 80 dB and is capable of attenuating side-lobes by 60 dB.

To demonstrate the reduction in out-of-band radiation that can be achieved with the implementation of UFMC involved the utilization of filtering techniques to achieve its benefits. A comparison of waveforms between OFDM and UFMC was carried out using the Dolph-Chebyshev filter in a single subband, as demonstrated in the accompanying figure. The results showed that UFMC greatly reduces out-of-band radiation, making it a superior system to OFDM. As a result, devices and users with less stringent synchronization requirements, such as those with timing and frequency misalignments, create interference much low for better synchronized users in UFMC.

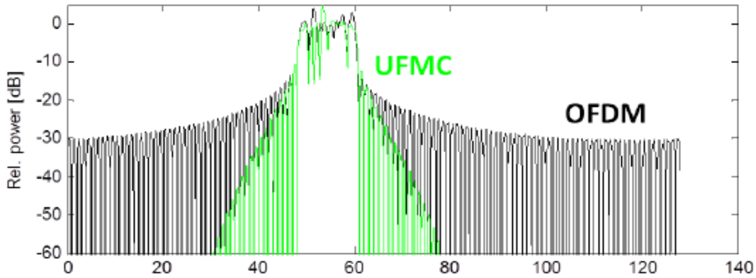


Fig 4: One sub band's OFDM and UFMC waveforms.

Once all sub-bands are filtered, their signals are transmitted and combined. The signal which is transmitted y_U is

$$y_U(k) = \sum_{i=1}^{B} y_i(k)$$

4.2 UFMC receiver section:

Once the signal r_U goes through a channel wireless mode, which is characterized by the Channel Impulse Response (CIR) h(k), its resulting form can be described as follows:

$$r_U(k) = h(k) * y_U(k) = h(k) * \left(\sum_{i=1}^{B} x_i * f_i\right) + w(k)$$

For achieving analog to digital converter operation, the Time Domain Preprocessing is used.But the pre-processing of time-domain windowing has two effects. Firstly, In the frequency domain, the window function convolves and creates self-interference. In addition, relaxed synchronization can attenuate out-of-band radiation from neighbouring devices or users based on the allocated frequency.

Once the windowing pre-processing is completed, the time-domain signal that is received undergoes a transformation into the frequency domain through the use of the FFT block. In order to accommodate the length of the UFMC symbol, which is N+L-1, additional zeros are added to enable the execution of a 2N-point FFT.

Thus, the relevant signal in frequency domain Y_U is

$$Y_U(k) = \frac{1}{\sqrt{N}} \sum_{l=0}^{N+L-2} r_U(l) e^{-j2\pi lk/2N} \quad \text{where } k=0,1,\ldots\ldots,2N-1$$

It is important to note that for detection, instead of using only N samples like in OFDM, all N+L-1 samples are employed. This is applicable when the channel either has a single-tap or the interference of ISI and ICI is insignificant. As a result, the frequency-domain signal is affected. Y_U can be expressed as:

$$Y_U(k) = H(k) \sum_{i=1}^{B} X_i(k) F_i(k) + W_U(k)$$

where X_i(k) and F_i(k) are 2N-point FFT of $x_i$and f_i respectively.

The output of the FFT block will contain twice the number of frequency samples needed. For frequency-domain equalization per subcarrier, every second sample is discarded from the FFT block's output. Then, the output is multiplied by the equalizing vector that accounts for the phase variations due to the filter and channel. The resulting output is converted to serial data, demodulated, and the message signal is extracted.

5. Fading channels

Fading refers to the gradual reduction in the intensity of a signal, caused by multipath propagation or shadowing (when a large structure or hill obstructs the primary signal path). The rate at which the channel modifies the signal's magnitude and phase, as well as the coherence bandwidth (which determines the maximum frequency range over which two signal frequencies are likely to experience amplitude fading), are both used to classify fading. If the delay constraint of a channel exceeds its coherence time, it results in slow fading.

Large-scale propagation models forecast the average signal strength, while small-scale propagation models forecast the rapid fluctuations. Different models are employed based on the number of NLOS components and the LOS component. Additive White Gaussian Noise (AWGN) represents communication in open space, where only a powerful LOS component exists. In most practical situations, one or more NLOS components are present. The Rician distribution models a LOS component and multiple NLOS components. The K-factor of the Rician distribution determines the strength of the LOS component relative to the NLOS components, where a high K-factor results in AWGN, and for K = 0, the fading has a Rayleigh distribution, indicating no LOS. The following section outlines some important fading models.

5.1 Rayleigh Fading

The fundamental principle of Rayleigh fading assumes that a multipath signal received is comprised of numerous reflected waves with phase and quadrature amplitudes that are independently and identically distributed. This model is applicable in scenarios such as mobile systems where there is no direct line-of-sight path between the transmitter and receiver antennas, tropospheric and ionospheric signal propagation, dense urban areas, or ship-to-ship radio connections. The Rayleigh probability density function is used in this model.

$$P(x)=\frac{x}{\alpha^2}\exp(\frac{-x^2}{2\sigma^2}) , x\geq 0$$

It is possible to observe the probability density function (pdf) of the channel impulse response, which is modeled using the Rayleigh fading model.This is advantageous in simulating scenarios where there is no significant signal component, as it models worst-case conditions.

5.2 Ricean Fading

Ricean fading is applicable in cases where there is a dominant LOS signal. This technology can be used in various environments, including micro-cellular urban and suburban land mobile.
The Rician probability density function is given by

$$P(x)=\frac{x}{\alpha^2}\exp(\frac{-(x^2+\beta^2)}{2\alpha^2})I_0\left(\frac{x\beta}{\alpha^2}\right)$$

The distribution has two parameters, α and β, where α represents the shape and β represents the scale. If α is set to 0, the distribution becomes a Rayleigh distribution. In the context of a Ricean fading channel, the distribution is characterized by two parameters: K and Ω. K is determined by the ratio of power in the direct path to the power in the scattered path, with K = α^2/(2β^2), and Ω represents the power in the direct path and acts as a scaling factor for the distribution.

6.PAPR and BER

6.1 Peak to Average Power Ratio (PAPR)

The Peak-to-Average Power Ratio (PAPR) is a metric that expresses the ratio of the highest power level of a signal sample to its average power value. This measure indicates the correlation between the maximum power of a symbol transmitted and its average power level. This is applicable in situations when multiple subcarriers attain the maximum value simultaneously, the output envelope increases, resulting in a peak in the output. These peaks accumulate during transmission, resulting in a high peak value that is much larger than the sample's average value.

$$PAPR = \frac{\max\{|x[n]|\}^2}{E\{|x[n]|\}^2}$$

A high saturation region caused by the PAPR level prompts the power amplifier to function, leading to a rise in errors and out-of-band radiation (OOB).To handle PAPR, a high-resolution quantizer is required for the analog-to-digital converter, increasing the complexity and power demands at the receiver front-end. PAPR reduction is essential in multicarrier techniques to attain high power efficiency.

6.2 BER(Bit Error Rate)

In communication, when the signal travels from transmitter to receiver it requires a media i.e channel. So while transmission some sort of unwanted signal (noise) combines with the transmitting signal and change the properties of original signal and produces errors. In data transmission when the received bit and corresponding transmitted bit are unequal then errors will occur. If signal contains sequence of bits of length N and n_e denotes the number of error bits then BER is given by

$$BER = \lim_{N\to\infty}\left(\frac{n_e}{N}\right)$$

6. Results

The current status of UFMC appears to be a suitable modulation technique for high performance wireless communications. The system is implemented in matlab with the following simulation parameters as shown in the Table 7.1

Table 7.1:Simulation Parameters and Specifications

Simulation Parameters	Specifications
System	UFMC
Filter type	Dolph-chebyshev fir filter with length 43
Modulation	4QAM,16QAM,64QAM,256QAM
Side lobe attenuation	5dB-40dB
Size of fft	512

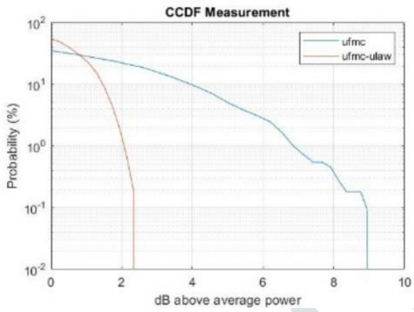
Size of sub band	20
Sub band offset	156
SNR	0dB-15dB
No.of sub bands	10
Channel	Rayleigh and Ricean fading for k=1 and k=10

7.1 PAPR values of UFMC system with AWGN:

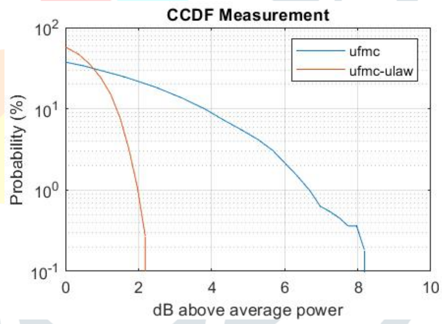
Modulation	OFDM	UFMC	UFMC-Mu Law
4 QAM	8.4175	9.04	2.4265
16 QAM	8.8378	8.2379	2.2374
64 QAM	9.6728	8.6229	2.3385
256 QAM	7.2899	8.0416	2.1703

Table 7.2: PAPR Values of UFMC System with AWGN For Different QAM Values

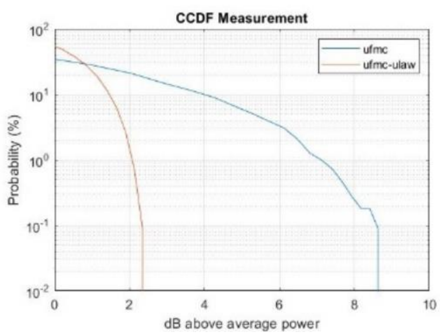
From the above table, the PAPR values shows that there is a decrease in PAPR values of UFMC after applying mu-law companding and before applying it. mu-law companding technique, which is nonlinear companding transform technique in UFMC system, which decreases the UFMC signals PAPR while keeping the companded signal average power unchanged. Above results depicts that there is a reduction in the PAPR values after applying mu law companding technique.



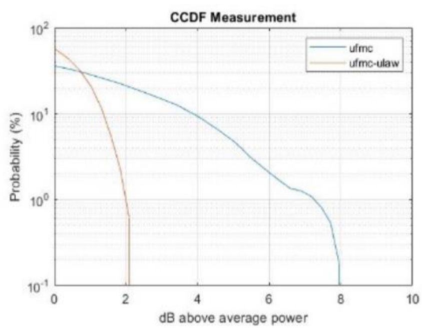
(a)



(b)



(c)



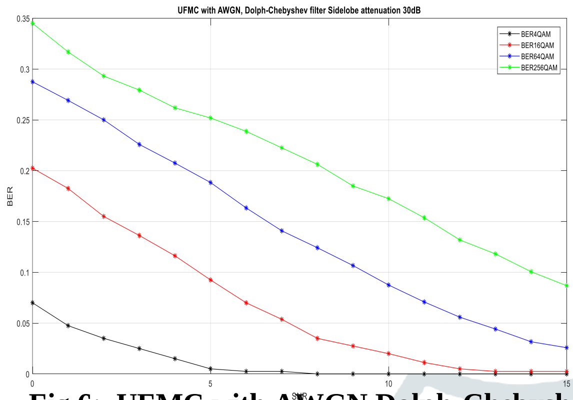
(d)

Fig 5: PAPR Values of UFMC System with AWGN For Different QAM Values (a)2QAM (b)4QAM (c)6QAM (d)8QAM

The complementary cumulative distribution function (CCDF) is a statistical representation of a signal's time-domain waveform that captures its power characteristics. It is plotted as a graph with signal power statistics on the y-axis and average signal power on the x-axis. The CCDF curve shows how long the signal remains at or above a certain power level at each point, with power level expressed in decibels (dB) relative to the average signal power level. The CCDF graphs above demonstrate the reduction in peak-to-average power ratio (PAPR) values for the UFMC system after applying mu-law companding for various Quadrature Amplitude Modulation (QAM) levels.

7.2 BER Vs SNR Graphs of UFMC System With AWGN

The Bit Error Rate (BER) of UFMC is evaluated by implementing various QAM modulation schemes with a fixed number of subcarriers (10) and Dolph-Chebyshev filters with attenuation side lobe ranging from 5dB to 40dB. The channel is assumed to be an Additive White Gaussian Noise channel with mean value of zero and unity variance



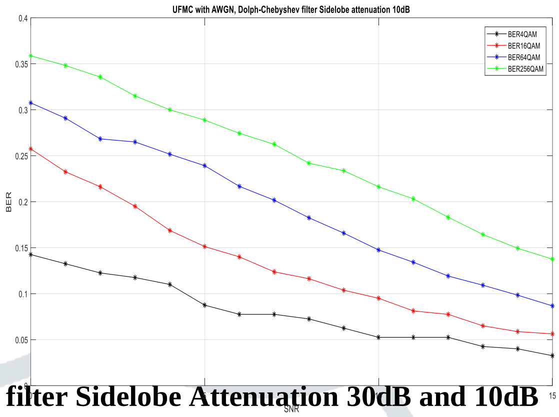


Fig 6: UFMC with AWGN,Dolph-Chebyshev filter Sidelobe Attenuation 30dB and 10dB

In the above figure 5,The implementation of various QAM modulation schemes on UFMC is evaluated in terms of bit error rate (BER) using 10 subcarriers and Dolph-Chebyshev filter with attenuation in side lobe of 10dB and 30dB. The channel is modeled as an Additive White Gaussian Noise channel with zero mean and unity variance. Results indicate that increasing the signal-to-noise ratio (SNR) from 0dB to 15dB reduces BER. A comparative analysis is conducted to evaluate the impact of different modulation schemes, side lobe attenuation, and BER over Rayleigh and Ricean fading channels.

7.3 BER VALUES OF UFMC SYSTEM OVER RAYLEIGH FADING CHANNEL

UFMC signals are carried out in Ricean fading channel with zero mean and unity variance of Additive White Gaussian Noise to understand the effects of flat fading channel.

Table 7.3:Side Lobe Attenuation=5dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.195	0.40875	0.4175	0.42812
5	0.1075	0.36	0.40833	0.41
10	0.0825	0.335	0.39583	0.41
15	0.045	0.32625	0.38333	0.402

Table 7.4:Side Lobe Attenuation=10dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.1925	0.3125	0.3625	0.40187
5	0.135	0.26625	0.33	0.38875
10	0.1075	0.23125	0.3175	0.36875
15	0.08	0.21375	0.29667	0.355

Filtered OFDM is a specific case of UFMC, where the entire bandwidth is filtered. In UFMC, a Dolph-Chebyshev filter is employed with sidelobe attenuation values of 5dB, 10dB, and 20dB, while the channel is estimated as a Rayleigh fading channel. The bit error rate (BER) is evaluated for M-ary QAM systems under different signal-to-noise ratio (SNR) values ranging from 0 to 15 dB. Results demonstrate that increasing the sidelobe attenuation reduces the BER for all M-ary QAM modulation schemes, as depicted in the above tables. (7.3-7.4).

7.4 BER VALUES OF UFMC SYSTEM OVER RICEAN FADING CHANNEL

Table 7.5 :K=1 And Side Lobe Attenuation=5dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.175	0.23	0.3241	0.3718
5	0.1	0.1425	0.2433	0.2993

10	0.0575	0.09	0.1516	0.2175
15	0.045	0.0575	0.1	0.1525

Table 7.6:K=1 And Side Lobe Attenuation=10dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.15	0.2175	0.3175	0.37
5	0.095	0.1512	0.2275	0.2968
10	0.55	0.085	0.1541	0.2218
15	0.032	0.055	0.0925	0.145

Table 7.7:K=10 And Side Lobe Attenuation=5dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.175	0.23	0.3241	0.3718
5	0.1	0.1425	0.2433	0.2993
10	0.0575	0.09	0.1516	0.2175
15	0.045	0.0575	0.1	0.1525

Table 7.8:K=10 And Side Lobe Attenuation=10dB

SNR(dB)	4QAM	16QAM	64QAM	256QAM
0	0.175	0.2175	0.3175	0.37
5	0.1	0.1512	0.2275	0.2968
10	0.0575	0.085	0.1541	0.2218
15	0.045	0.055	0.0925	0.145

The same scheme is applied on Ricean fading channel with Rice factor k=1 and k=10 as shown in the tables(7.5-7.8). It is observed that with increase in SNR,Rice factor and sidelobe attenuation in the Dolph-chebyshev filter, BER is reducing in UFMC system in Ricean fading and AWGN.

7. Conclusion

In this project, the peak-to-average power ratio (PAPR) of UFMC is evaluated using different QAM modulation schemes with 10 subcarriers and a Dolph-Chebyshev filter with attenuation in sidelobe of 5dB and 10dB. The channel is modeled as an Additive White Gaussian Noise channel with zero mean and unity variance. The PAPR value of UFMC is estimated before and after applying mu-law companding technique, which results in a reduction in PAPR. Additionally, the bit error rate (BER) is evaluated for M-ary QAM systems under different SNR values ranging from 0dB to 15dB. UFMC is viewed as a generalization of filtered OFDM, where the entire bandwidth is filtered. A comparative analysis is conducted to evaluate the impact of different modulation schemes, sidelobe attenuation, and BER over Rayleigh and Ricean fading channels. For Rayleigh fading, the BER is estimated for M-ary QAM systems with SNR values ranging from 0 to 15 dB, and increasing the sidelobe attenuation reduces the BER for all M-ary QAM modulation schemes under Rayleigh fading and AWGN. The same scheme is applied to Ricean fading channels with Rice factor values of k=1 and k=10. Results indicate that increasing the SNR, Rice factor, and sidelobe attenuation in the Dolph-Chebyshev filter reduces the BER in the UFMC system under Ricean fading and AWGN.

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