一、緒論

OFDM 為多重載波調變技術，具有均勻分隔之子載波和重疊頻譜的特性，可有效對抗因多重徑衰退(Multi-path Fading)所產生之頻率選擇性衰退通道(Frequency Selective Fading Channel)。此外，子載波(Sub-carriers)彼此之間正交的特性可以更有效率的使用頻寬，並可利用 CP(Cyclic Prefix)有效消除符元干擾，以上的優點讓正交分頻多工被廣泛的使用在許多通訊系統中。例如數位廣播(Digital Audio Broadcasting，DAB)、「微波存取全球互通系統」(Worldwide Interoperability for Microwave Access；WiMAX)及「第三代行動通訊夥伴計畫之長期演進技術」(3rd Generation Partnership Project, Long Term Evolution: 3GPP LTE)。

但 OFDM 技術仍有幾項缺點需要去克服，當多個子載波訊號同相位相加時，產生較高的訊號峰均值功率比(Peak to Average Power Ratio，PAPR)，造成傳送過程中，訊號經過放大器時之非線性區放大產生非線性失真，因而造成傳送訊號帶內錯誤率上升、帶外干擾增加。所以如何降低 OFDM 訊號的 PAPR 一直是很重要的課題。

正交多頻分工(OFDM)為多載波系統是將多個子載波在同一符元時間內疊加，當多個子載波訊號同相位相加時，合成的載波瞬時功率就會遠大於訊號的平均功率，而導致較大的峰值與平均功率比(Peak to Average Power Ratio;PAPR)，同時由於高的峰值對均值功率比會使信號進入放大器時，讓工作點超出放大器的線性工作區造成信號非線性失真，解決這個問題的方法是增加放大器線性工作區，但也因此造成發射機製造成本的增加[1][2]，而且過高峰值對均值功率比是偶發性，所以只為了偶發性所產生的過高峰值對均值功率比而增加放大器線性工作區，會使放大器的效率降低也不符合成本。

在實際 OFDM 系統中，Pilot 子載波用來做通道估測，為了改善 Precoding[3] 方法在插入 Pilot 子載波時，降低 PAPR 的效果比未插入 Pilot 子載波還要少，所以嘗試加入其他方法來改善這個問題。而 Precoding 應用在固定式 WiMAX[4] 下(子載波 192 個)，以文獻上最初的定義(10%)需要 20 個子載波，這對於帶外功率的會提高不少，所以也嘗試調整 Precoding 方法中額外使用的子載波數目來搭配，並模擬出 PAPR 和帶外頻譜功率散溢的改善結果，為本篇文的研究動機。

二、OFDM 系統及 PAPR 簡介

2.1 正交分頻多工

傳統單載波傳輸技術是以單一子載波傳送所有資，在無線傳輸過程中易受多徑干擾使訊號無法有效正確接收；而多載波傳輸技術將資分別放在多個子載波上並列傳輸，每個子載波只傳送部分資。傳統多載波傳輸技術將頻帶分割成多個沒有互相重疊的子載波(Sub-channel)，雖可抵抗多重徑干擾造成的延遲擴散(Delay Spread)，但是對頻帶的使用效率而言，非常沒有效率，費了許多頻寬作為保護使用。為了能更有效利用頻寬，能將頻域上的子載波互相重疊放置，可有效率的使用頻寬。重疊部分可能會互相干擾，避免干擾的方法為讓載波彼此之間成正交，即為 OFDM

OFDM 系統隨著演算法和數位訊號處理 (DSP) 的技術的成熟更精進，以快速富立葉轉換(FFT)、快速富立葉逆轉換(IFFT)的運算，使得多載波的 OFDM 系統能夠成功實現，也因此讓這技術為在各類系統上廣泛的被選用[1][2]。

正交分頻多工(Orthogonal Frequency Division Multiplexing；OFDM)近來成為熱門的話題，例如在無線區域網 (Wireless Local Network；WLAN)上目前常用之四種標準採用正交分頻多工技術(IEEE 802.11a/b/g/n)。目前寬頻網上被廣泛使用的非對稱數位用戶迴 (Asymmetric Digital Subscriber Line；ADSL)，

加上歐洲新的數位視頻訊號廣播標準(Digital Video Broadcasting；DVB)和高畫質電視標準(High Definition Television；HDTV)。而當前熱門的微波存取全球互通系統(Worldwide Interoperability for Microwave Access；WiMAX)及第 3 代行動通訊組織(Third Generation Partnership Project;3GPP)提出之長期演進技術 (Long Term Evolution;LTE)也是應用此技術[1][2]。

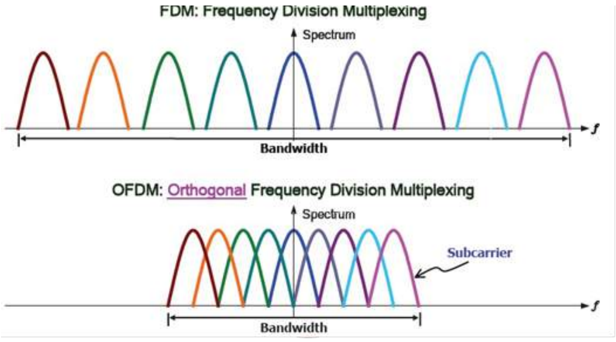


圖 2.1 FDM、OFDM 調變技術頻寬上使用的比較

2.2正交分頻多工系統架構

OFDM 系統的信號是先將欲傳輸的資串流映射(Mapping)成，映射方式有 BPSK、QPSK、16QAM、64QAM 等，將此信號由串列(Serial)信號轉為並列(Parallel)信號傳輸，再經過反快速傅立葉轉換(Inverse Fast Fourier Transform，IFFT)轉換成 OFDM 信號之後再將信號轉回串列信號，為了提高信號的抗符碼干擾(Inter Symbol Interference，ISI)，在串列信號後加入保護區間(Guard Interval，GI)，經過通道後，在接收端先移除保護區間，將串列信號轉成並列信號，之後並列信號經過快速傅立葉轉換(Fast Fourier Transform，FFT)，再將並列信號轉成串列信號，最後把信號做反映射(Demapping)，得到原始傳送的資。

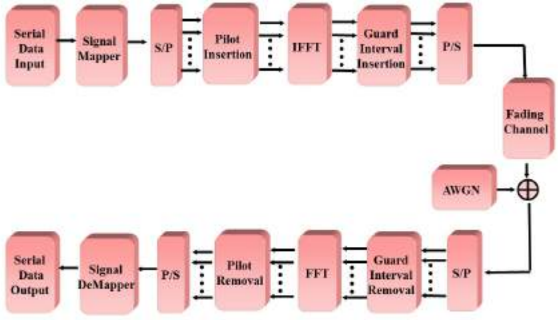


圖 2.2 OFDM 基頻方塊圖

子載波之間彼此符合正交(Orthogonal)的特性，每一個子載波的零交點 (Zero Crossing)必為其它子載波的主瓣之最高點。子載波主瓣的中心點之值不會被其它子載波影響，所以這些子載波可互相重疊，不產生載波

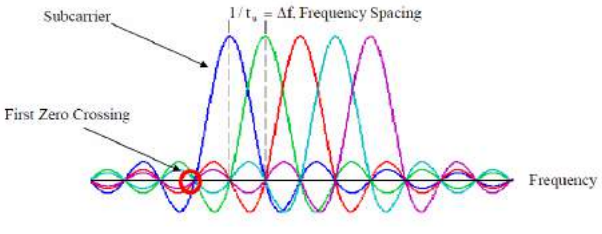


圖 2.3　五個彼此正交的子載波

2.3 OFDM 系統中 PAPR 所造成的影響

2.3.1 PAPR 定義

OFDM 訊號與單載波訊號相比有較高的「峰值對均值比」(Peak-to-Average Ratio；PAR)，這又可稱為「峰均值功率比」(Peak-to-Average Power Ratio；PAPR)，因為多載波訊號是多個窄頻訊號的總和，當這些窄頻訊號在同一相位時，會造成瞬間非常大的峰值，即某些時間點上線性相加的總和是非常大的，某些時間點上則不會，所以訊號的峰值與平均值相比會非常大 [1][2]。以圖 2.4 為例，分別為 1 倍頻率的子載波，2 倍頻率子載波，3 倍頻率子載波，4 倍頻率子載波，每個子載波的最大振幅均為 1，我們可以看到峰值隨著子載波的增加而變大，如圖 2.5。

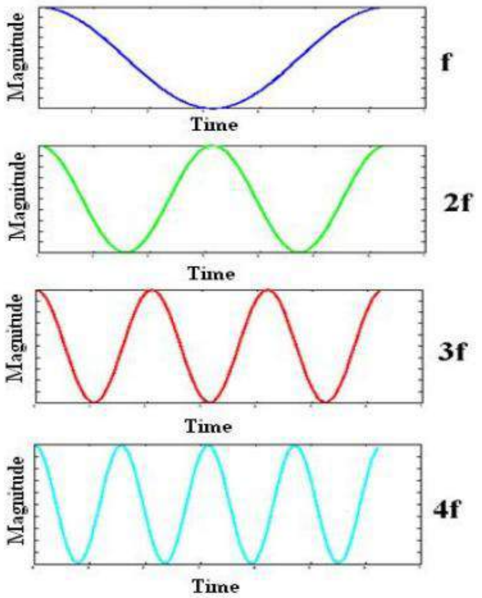


圖 2.4　分別為 1 至 4 倍頻率之子載波的波形圖

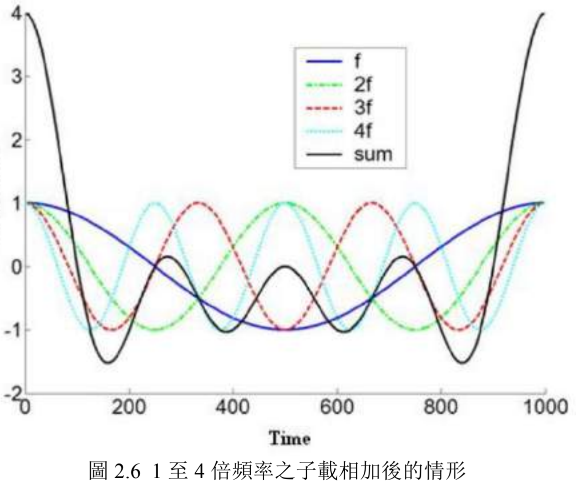


圖 2.6 1 至 4 倍頻率之子載相加後的情形

問題 一：增加類比轉數位(A/D)和數位轉類比(D/A)的複雜度，因為信號的變動範圍是與PAPR比成比例，訊號的範圍越大，會使量化雜訊越大，造成解析度變差，使用高效能的DAC與ADC的轉換器會增加系統複雜度還有成本。

問題二：降低射頻功率放大器的效能，PAPR高代表功率變化之範圍相對較大，發射機功率放大器的動態特性範圍就要夠大，以免造成非線性失真，但也因此造成發射機製造成本的增加。

三、降低峰值對均值功率比之研究

3.1 透過截波法降低 PAPR

截波法是降低 PAPR 最簡單且最直接的方法，一個信號的峰值振幅將被限制住，波峰裁減可以看成是對 OFDM 信號乘上一個方型視窗函數 (Rectangular Window)A，當振幅大小小於 A，振幅不會被改變，但是當振幅大小大於 A 時，方型視窗函數就會限制信號將振幅改變成 A，意思就是使信號縮小，如公式(3.1):

$$x_n = \begin{cases} x_n & |x_n| \le A \\ Ae^{j\arg} & |x_n| > A \end{cases} \quad (3.1)$$

截波率(Clipping Ratio，CR)定義為(3.2)式：

$$CR = \frac{A}{\sqrt{P_{av}}} \quad (3.2)$$

截波率是門檻值 A 與截波前信號均方根值之比值。

3.2 透過編碼方法降低 PAPR

傳統所謂的編碼法只加入錯誤更正碼(Error Correcting Code，ECC)，如區塊碼(Block Code)與迴旋編碼(Convolution Code)，這種編碼法使接收端接收信號時得以更正因系統非線性現象造成的接收錯誤。而這裡是討以編碼法降低峰均值功率比，一般是以 Reed-Muller 編碼法來產生格雷互補序列(Golay Complementary Sequence)為基礎。與其它降低峰均值功率比的方法比較起來，編碼法降低峰均值功率比的幅度算是不錯的，不過編碼法的缺點在於傳送端和接收端需要很大的表以作查詢，由於過程太過複雜，在現實環境上使用不甚方，而且 OFDM 系統的子載波數目增加，將會找不到這麼多組的格雷互補序列，所以這方法只適合使用於低載波數的 OFDM 系統。

3.3 符元重組(Symbol Scrambling)

多樣訊號表示的方法，多訊號表示法是產生多組相同的資訊但是不同波形的信號，從中挑選 PAPR 最小的信號做傳送，產生多組不同波型的信號須要增加IFFT 個數來計算每一組的 PAPR，所以會增加系統的運算複雜度，且需要在欲傳輸的信號中加入消息位元(Side Information)讓接收端可以解調回原始信號。

3.4改變星狀圖點形狀狀(Constellation shaping)的方法

星狀圖點形狀改變(Constellation shaping)是一種有效的降低 OFDM 系統中 PAPR 的技術[1][4]，序列資

峰值不會出現 在同一個時刻上，接收端也可以透過反矩陣即可恢復原始資 。此方法適用於 任意的子載波數及任意的調變方法的多載波系統，降低實現的複雜度[1][4]

四、系統模擬與探討

4.1 模擬參數

本篇研究之模擬是根據固定式 WiMAX 參數為背景，以 QPSK，16QAM、 64QAM 調變下，有 192 個資 子載波(Data subcarrier)、8 個導航子載波(Pilot subcarrier)、左邊有 28 個零子載波(Null subcarrier)、右邊有 27 個零子載波，如
圖 4.1 所示。

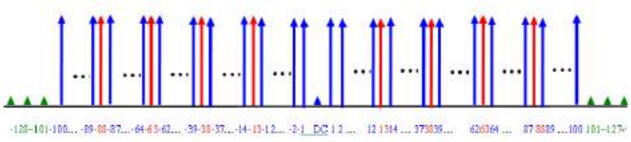


圖 4.1 固定式WiMAX子載波分配

4.2 預先編碼矩陣方法模擬

預先編碼矩陣(Precoding)方法[3][4]，是利用降低星狀圖點間序列的相關 性特性降低 PAPR。其原理為將經過調變後之星座圖乘上 Procoding 矩陣將星 座圖資 加以擾亂。在 OFDM 系統中，發射端流程裡，將調變後的資 經由「串列訊號轉換成並列訊號」與「快速富立葉逆轉換」兩程序之間乘上 Precoding 矩陣。如圖 4.2 所示。

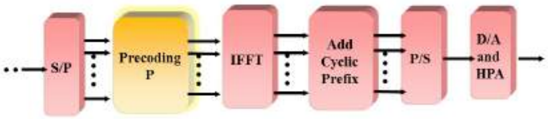
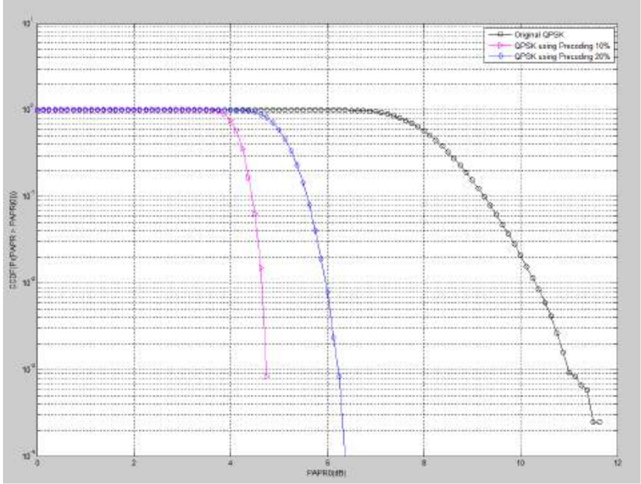


圖 4.2 發射端 Precoding 矩陣轉換之架構圖

因為 Precoding 需要用到額外的子載波， 以文獻所定義的一個參數 β=(L-N)/N=Np/N 來當作模擬基準，其中 N 是原始系統使用子載波的個數，Np 需額外用道子載波的個數，L=N+Np。

根據圖 4.2 發射端 Precoding 矩陣轉換之架構下，在未插入 Pilot 狀況下擬出的結果如圖 4.3。



與原始 訊號之CCDF比較圖

但是考慮到實際應用的環境使用時，必須考慮插入 Pilot 子載波的影響， 因此文獻所提的模擬架構應該修正為插入 Pilot 的架構圖，如圖 4.4 所示。根據 此架構，重新模擬結果比較如圖 4.5 所示，模擬結果顯示在插入 Pilot 後，原先 被 Precoding 矩陣而降低 PAPR 的效果已經不再這麼明顯。由此可得知插入 Pilot 子載波後，因其插入為固定的位置，所以對 PAPR 產生不同的影響，所以對星 座圖資 相關性有很強的改變作用。

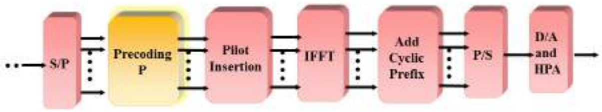


圖4.4 發射端Precoding 矩陣轉換考量Pilot子載波之OFDM架構圖

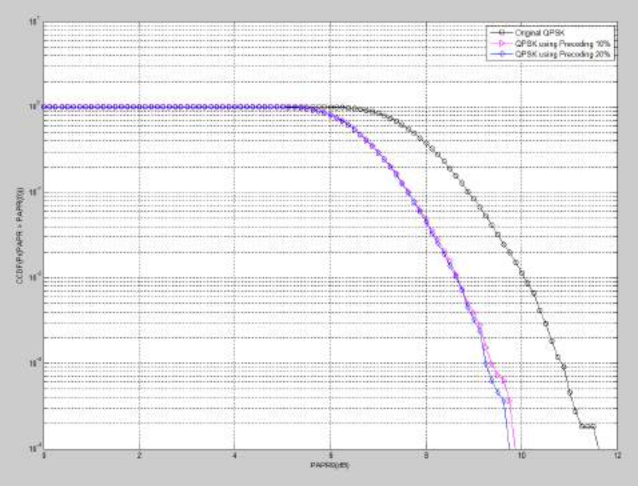


圖4.5加入Pilot子載波後，利用不同Precoding矩陣與原始訊號之CCDF比較圖

4.3 非線性壓縮擴展方法及模擬

最先發展的非線性壓縮擴展方法為 μ-law 方法[5][6]，其最初用來語音壓 縮技術，在話音通信中，因放大器的線性限制，在發送時對語音音量域進行壓 縮，在接送時又擴展其音量域的一種方法。μ-law 方法主要觀念為在 OFDM 系 統中，在時域上將較大信號壓縮或保持不變，將較小的信號加以放大，取得降 低 PAPR 的效果。非線性壓縮擴展方法也是訊號失真的方法的其中之一，而 μ-law 特性曲線如圖 4.6 所示。由此特性曲線顯示 μ 值越大信號動態範圍越大 壓縮及放大比例越大。

圖 4.7 所示 μ-law 方法在發射端在由頻域經 IFFT 轉成時域信號後再經過 μ-law 進行時域信號的壓縮擴，再將信號由數位轉為類比經由天線傳送，接收 端將信號接收後經類比轉為數位後經過解壓縮的過程，再經串列轉並列將接收 的類比時域上的資 經 FFT 轉換成頻域上數位的資 。

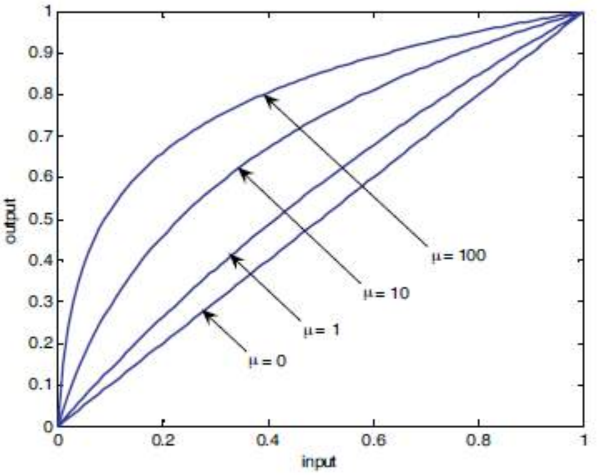


圖 4.6μ-law特性曲線

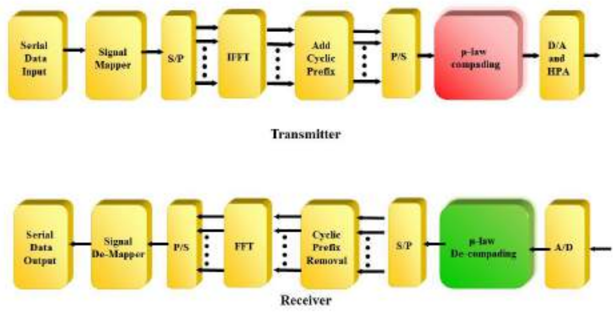


圖 4.7μ-law之OFDM傳送及接收端架構圖

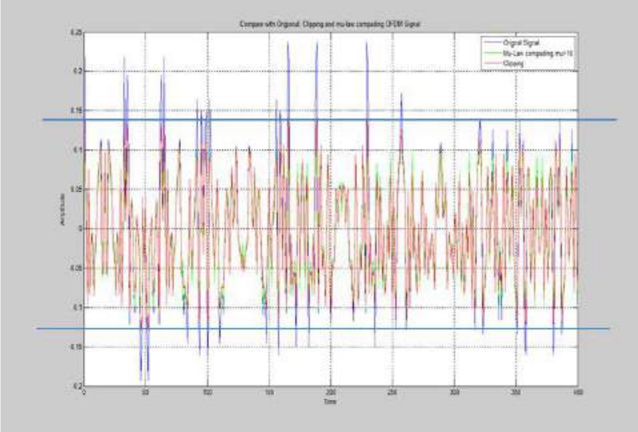


圖 4.8 時域信號經過μ-law及clipping方法的結果

根據圖 4.8 所示時域信號經過 μ-law 壓縮擴展方法在時域上會盡量將較 小的信號放大，將較大之信號壓縮在限定的範圍(clipping threshold)內或保持不 變，此限定範圍(clipping threshold)可依照系統功率飽和點設計，在此架構下， 模擬出的 PAPR 結果如圖 4.9。由此結果顯示 μ 值設定越大時域信號改變的動 態範圍越大，所得到降低 PAPR 效果越好。但由於此技術也為訊號失真的方法 之一，所以在頻譜上會因非線性失真在頻域上會產生高頻震盪造成帶外頻譜功 率散溢的問題，如圖 4.10。

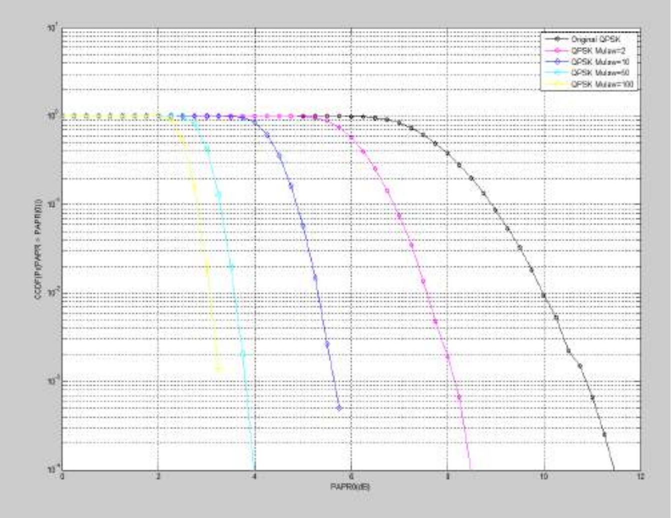


圖 4.9 利用不同 μ 值設定(μ=2，10、50、100)之壓縮擴展方法與原始訊號之 CCDF 比較圖

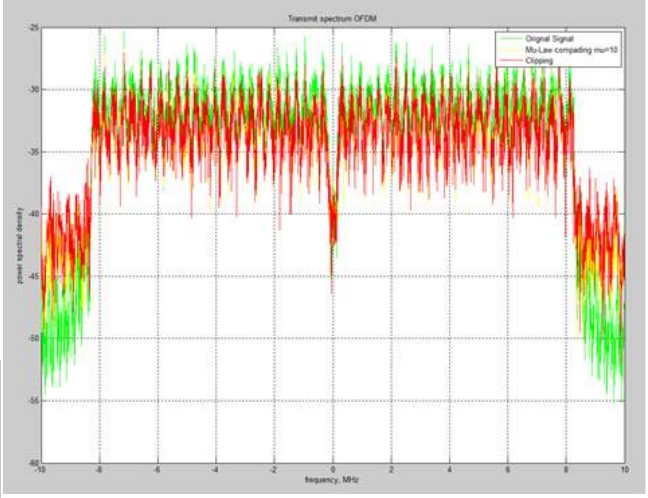


圖 4.10 原始 OFDM 信號頻譜與透過 Clipping 、μ-law(μ=10)壓縮擴展方法比較圖

4.4 結合 Precoding 與 μ-law 方法降低 PAPR

由於 Precoding 之方法在插入 Pilot 子載波後降低 PAPR 沒有顯著改善之 問題，所以結合 μ-law 方法進行修正改善，圖 4.11 為結合 Precoding 與 μ-law 兩種方法之 OFDM 系統架構圖，圖 4.12 為結合 Precoding 與 μ-law 兩種方法之 PAPR 模擬結果。模擬結果在 Precoding 方法插入 Pilot 子載波後，經過 μ-law 方法於時域上進行信號之壓縮擴展對 PAPR 有明顯的改善, 在調整 μ 值大小 (μ=2、μ=5、μ=10、μ=50、μ=100)控制參數後，顯示 μ 值越大 PAPR 改善程度 越佳。

由圖 4.14 結合 Precoding 與 μ-law 兩種 PAPR 降低方法頻譜模擬結果顯示，但由於 μ-law 方法的加入造成帶外頻寬散溢的問題，隨者 μ 值越大帶外頻 寬散溢也越明顯。如圖 4.13 所示。

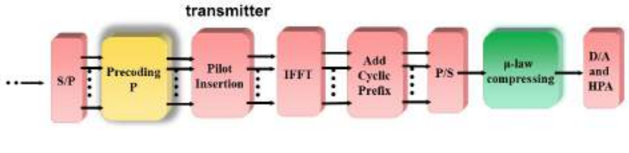


圖 4.11 結合Precoding與μ-law方法之OFDM系統架構圖

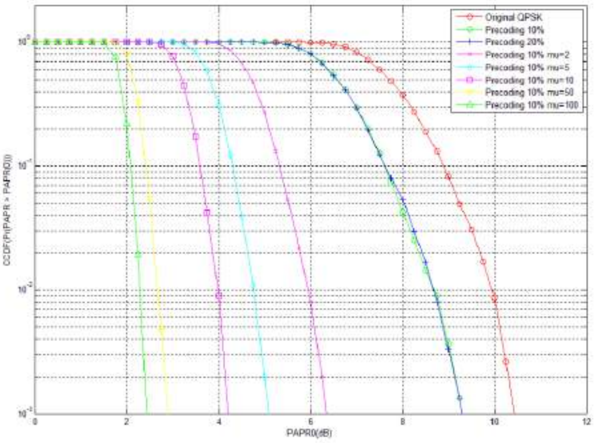


圖 4.12 Procoding方法加入Pilot子載波再利用不同μ值設定之壓縮擴展方法與原始訊號之CCDF比較圖

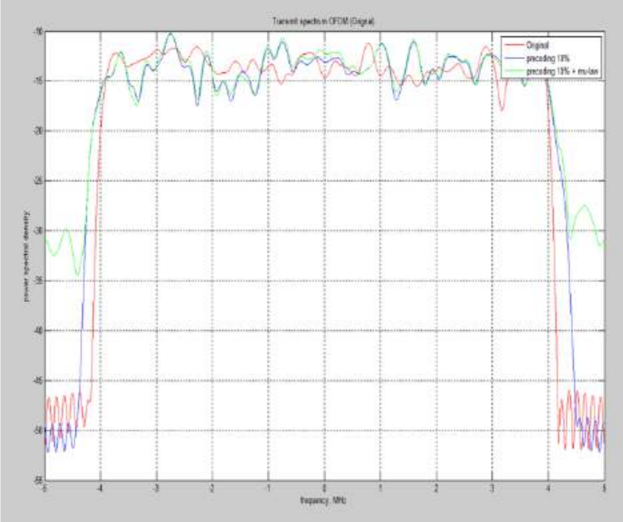


圖 4.13採用Procoding with 10%結合μ-law壓縮擴展方法頻譜比較圖

4.5結合 Precoding 及 μ-law 動態壓縮擴展方法之改善

由於 μ-law 方法的加入造成帶外頻寬散溢的問題，其主要造成之原因為在頻譜上會因非線性失真的關係在頻域上會產生高頻震盪造成帶帶外功率頻譜的散溢問題(out of band)，因此修正及調整減少需要進行 μ-law 方法的時域信號百分比。調整方法為時域上超過每個 OFDM symbol 中最大值的才進行 μ-law compading 動態壓縮擴展。

圖 4.14 為結合 Precoding with 10%與調整 μ-law compading 動態壓縮擴展 50~90% 之 PAPR 結果，圖 4.15 為其頻譜比較圖。圖 4.18 至 4.19 為超過每個 OFDM symbol 最大值的 70%及 90%方進行 μ-law compading 動態壓縮擴展之PAPR 與頻譜圖。模擬結果顯示超過每個 OFDM symbol 最大值的 50%~70%方進行 μ-law compading 動態壓縮擴展之條件，因較多的的資可進行壓縮所以可得到較好的 PAPR，但帶外頻譜散溢問題較嚴重。再觀察超過每個 OFDM symbol 最大值的 80%及 90%方進行 μ-law compading 動態壓縮擴展之條件， PAPR 亦有改善，但改善程度與 50%~70%時的 PAPR 相比較少但帶外頻譜散溢問題改善程度卻較佳。上述結果可知，壓縮比例越少，相對降低 PAPR 越少，而超過每個 OFDM symbol 最大

PAPR 改善程度不分上下，但帶外頻譜散溢問題會有較明顯的改善。

上述結果比對後顯示，調整在每個 OFDM symbol 中最大值的 90%才進行

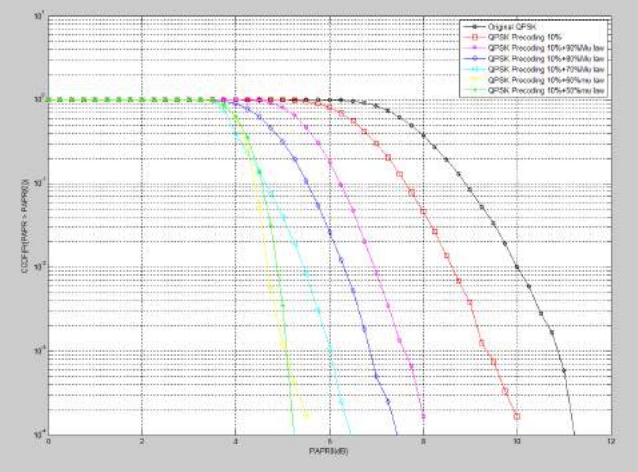


圖 4.14結合Precoding 10%與調整至超過每個OFDM symbol中最大值的50%~90%才進行動態壓縮擴展方法與原始訊號之PAPR CCDF比較圖

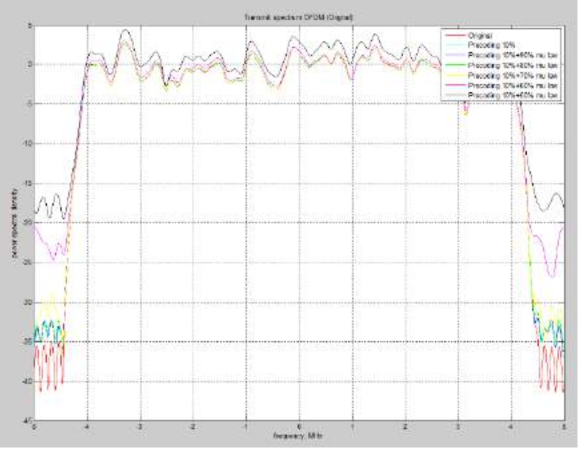


圖 4.15結合Precoding 10%與調整至超過每個symbol中最大值的50%~90%才進行動態壓縮擴展方法與原始訊號之頻譜比較圖

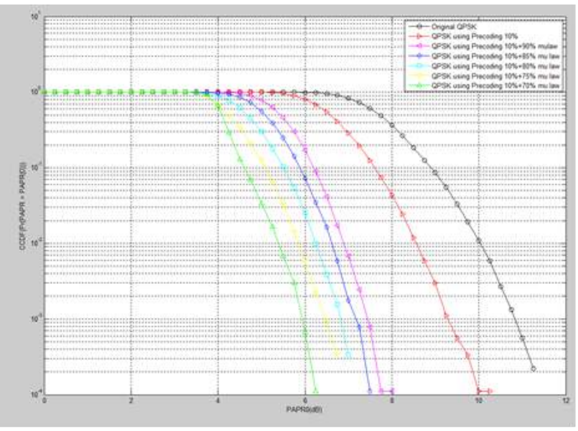


圖 4.16結合Precoding 10%與調整至超過每個symbol中最大值的70%~90%才進行動態壓縮擴展方法與原始訊號之PAPR CCDF比較圖

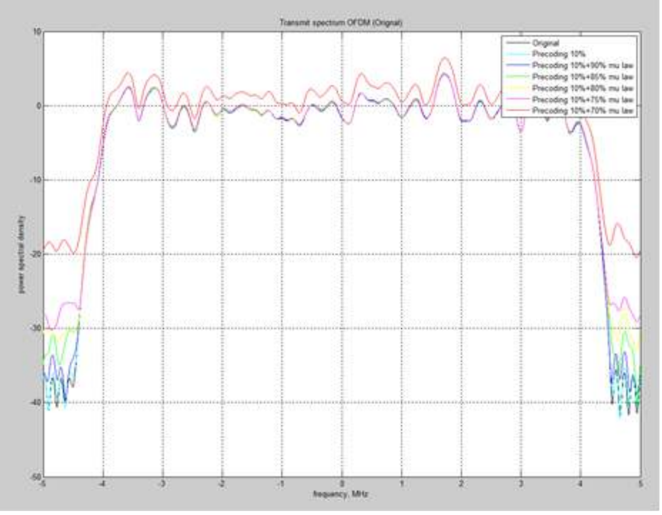


圖 4.17結合Precoding 10%與調整至超過每個symbol中最大值的70%~90%才進 行動態壓縮擴展方法與原始訊號之頻譜比較圖

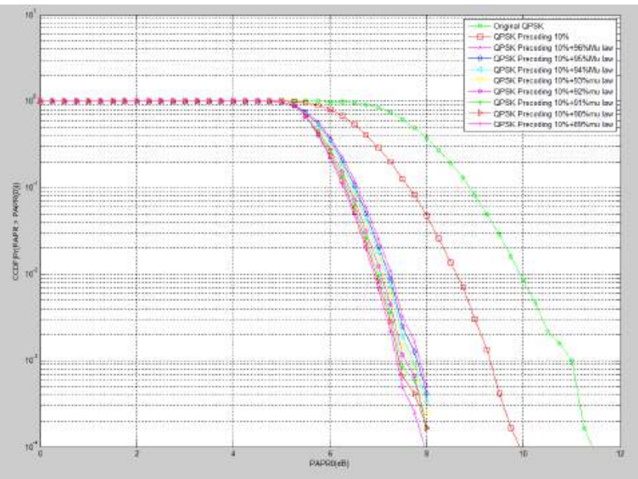


圖 4.18結合Precoding 10%與調整至超過每個symbol中最大值的89%~96%

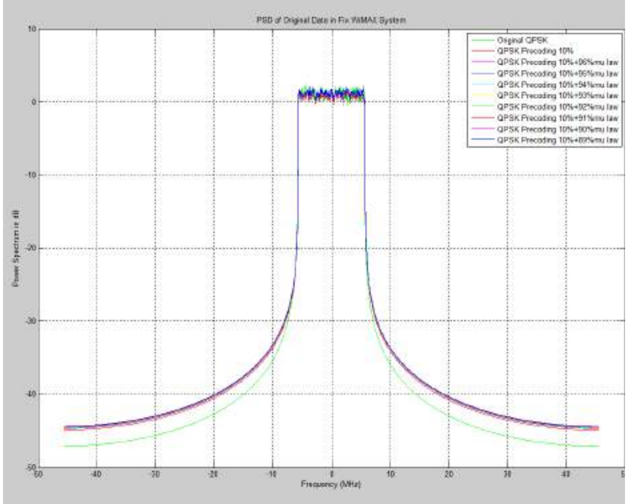


圖 4.19 結合 Precoding 10%，在 QPSK 調變下調整至超過每個symbol 中最大值 的 89%~96%才進行動態壓縮擴展方法之頻譜比較圖

4.6結合 Precoding with 1%~5%與 μ-law 動態壓縮擴展之修正

此篇 文提出一種新的方法，是調整預先編碼(Precoding)法的子載波使用 的數量不同與 μ-law

子載波）、Precoding with 3%(增加 6 個子載波）、Precoding with 4%(增加 8 個子載波）、Precoding with 5%(增加 10 個子載波)圖 4.20 為結合 Precoding with 1%~5%與 μ-law 動態壓縮擴展方法之 OFDM 系統架構圖。

將上述方法結合，所畫出如圖 4.21 和圖 4.22。模擬結果中，可挑選出 Precoding with 1%結合 μ-law compading 動態壓縮擴展 92%可在頻譜圖中得到 最佳的帶外功率表現。

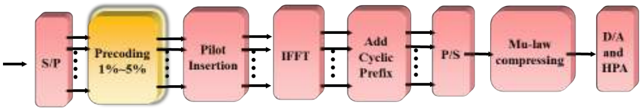


圖 4.20 結合Precoding with 1%~5%與μ-law方法之OFDM系統架構圖

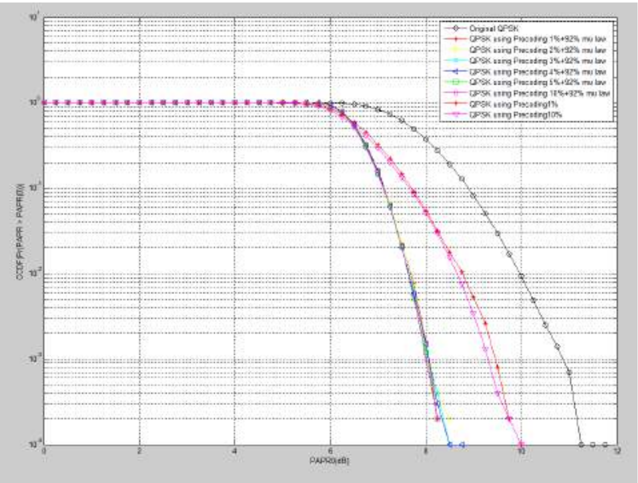


圖 4.21結合 Precoding with 1%~5%與μ-law 92%動態壓縮擴展方法在 QPSK

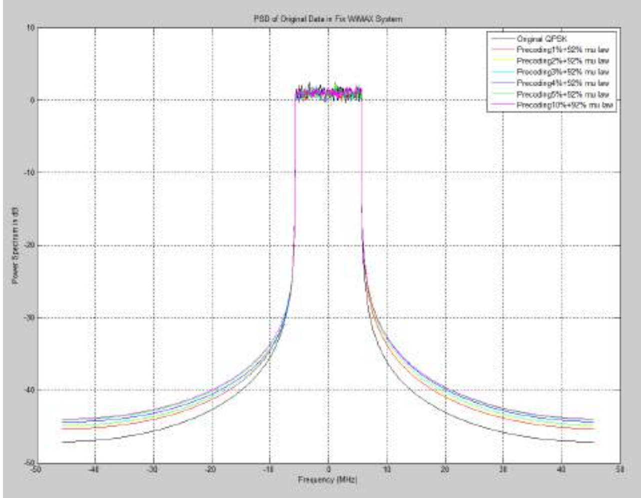


圖 4.22 結合 Precoding with 1%~5%與μ-law 92%動態壓縮擴展之頻譜比較圖(a)

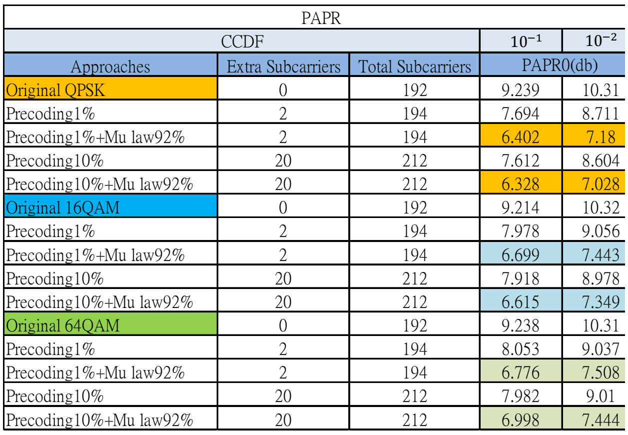
使用 QPSK 調變(b)20MHz~30MHz 放大

4.7結合 Precoding with 1%、Precoding with 10%與 μ-law 92%動態 壓縮擴展方法之模擬結果

綜合以上之比較，挑選出中間值 μ-law 92%動態壓縮擴展方法與 Precoding with 1%及 Precoding with 10%分別結合，以此兩種方式搭配不同
調變(QPSK、16QAM、64QAM)做比較。將模擬結果之PAPR CCDF 彙整於表 4.1，頻 譜圖彙整於表 4.2。模擬

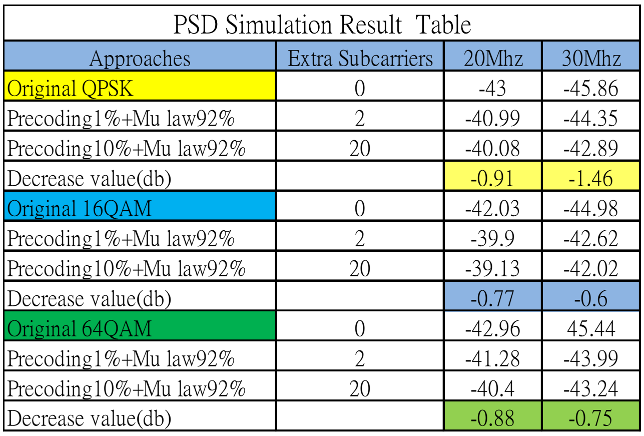
情形可以得到最佳的改善。

表 4.1 結合 Precoding with 1%、Precoding with 10%與 μ-law 92%動態壓縮擴展方法之 PAPR CCDF 比較表



PAPR				
CCDF			10^{-1}	10^{-2}
Approaches	Extra Subcarriers	Total Subcarriers	PAPR0(db)	
Original QPSK	0	192	9.239	10.31
Precoding1%	2	194	7.694	8.711
Precoding1%+Mu law92%	2	194	6.402	7.18
Precoding10%	20	212	7.612	8.604
Precoding10%+Mu law92%	20	212	6.328	7.028
Original 16QAM	0	192	9.214	10.32
Precoding1%	2	194	7.978	9.056
Precoding1%+Mu law92%	2	194	6.699	7.443
Precoding10%	20	212	7.918	8.978
Precoding10%+Mu law92%	20	212	6.615	7.349
Original 64QAM	0	192	9.238	10.31
Precoding1%	2	194	8.053	9.037
Precoding1%+Mu law92%	2	194	6.776	7.508
Precoding10%	20	212	7.982	9.01
Precoding10%+Mu law92%	20	212	6.998	7.444

表 4.2 結合 Precoding with 1%、Precoding with 10%與 μ-law 92%動態壓縮擴展之頻譜比較表



PSD Simulation Result Table			
Approaches	Extra Subcarriers	20Mhz	30Mhz
Original QPSK	0	-43	-45.86
Precoding1%+Mu law92%	2	-40.99	-44.35
Precoding10%+Mu law92%	20	-40.08	-42.89
Decrease value(db)		-0.91	-1.46
Original 16QAM	0	-42.03	-44.98
Precoding1%+Mu law92%	2	-39.9	-42.62
Precoding10%+Mu law92%	20	-39.13	-42.02
Decrease value(db)		-0.77	-0.6
Original 64QAM	0	-42.96	45.44
Precoding1%+Mu law92%	2	-41.28	-43.99
Precoding10%+Mu law92%	20	-40.4	-43.24
Decrease value(db)		-0.88	-0.75

五、結論

本篇文引用結合 μ-law compading 及 Precoding 方法，利用 μ-law compading 方法解決 Precoding 在插入 Pilot 子載波後 PAPR 狀況沒有明顯改善問題。為解決此結合方法造成的帶外頻譜功率散溢問題，調配輸出信號進行
μ-law compading 的比例，調整方法為超過每個 symbol 中最大值的固定比例才進行 μ-law 動態壓縮擴展，減少壓縮的比例，模擬結果顯示超過每個 symbol 最大值的 90%方進行 μ-law 動態壓縮擴展之條件可得到更佳的帶外頻譜功率散溢與 PAPR 之間的平衡。
本篇文再提出，將 Precoding with 10%(增加 20 個零子載波)調整至 Precoding with 1%(增加 2 個零子載波)、Precoding with 2%(增加 4 個零子載波)、Precoding with 3%(增加 6 個零子載波)、Precoding with 4%(增加 8 個零子載波)、Precoding with 5%(增加 10 個零子載波)，與 μ-law 動態壓縮擴展結合，模擬結果顯示 Precoding with 1%結合 μ-law 動態壓縮擴展對於帶外功率改善有更顯著的效果。綜合上述結果，結合 Precoding with 1%加上 92%動態壓縮擴展與結合 Precoding with 10%加上 92% μ-law 動態壓縮擴展做比較，模擬結果顯示 Precoding with 1%加上 92% 動態壓縮擴展對於帶外功率改善，會得到最佳的表現。

I. Introduction

The OFDM is a multi-carrier modulation technique characterized by evenly separated subcarriers and overlapped spectrums; thus, OFDM can effectively cope with the issue of Frequency Selective Fading Channel derived from Multi-Path Fading. Furthermore, advantages such as the more effective utilization of the bandwidth by subcarriers characterized by orthogonality between each other and the effectiveness of CP (Cyclic Prefix) eliminating inter-symbol interference make the OFDM widely used in many communications systems like the Digital Audio Broadcasting (DAB), WiMAX (Worldwide Interoperability for Microwave Access) and the 3GPP LTE (3rd Generation Partnership Project, Long Term Evolution). But, the OFDM technique still has some defects that need to be conquered. When multiple same-phase subcarrier signals are added, a higher PAPR (Peak to Average Power Ratio) is produced, and the higher PAPR (Peak to Average Power Ratio) will generate Nonlinear Distortion when signals pass through the nonlinear area of the amplifier during the process of transmission, which causes increased error rates among the in-band signals and increased out-of-band interference. Therefore, how to reduce the PAPR in OFDM signals has been a very important issue.

The OFDM is a multicarrier system that overlaps multiple subcarriers within the same symbol time. When multiple same-phase subcarrier signals are added, the synthetic instantaneous carrier power will greatly exceed the average power of the signals and cause larger peak values and larger PAPR (Peak to Average Power Ratio). Meanwhile, the ratio of high peak values to the average power makes the working point exceed the linear working area of the amplifier and cause nonlinear distortion of signals when signals enter the amplifier. Ot solve this problem, we need to increase the amplifier linear working area, but this also increases the costs of transmitters [1][2], and the ratio of ultra-high peak values to the average power is incidental. So, if we only want to deal with the incidental ratio of ultra-high peak values to the average power by increasing the amplifier linear working area, the efficiency of the amplifier will only decline and the costs will only go higher.

In the realistic OFDM system, pilot subcarriers are used for Channel Estimation. In order to improve the Precoding [3] method, when pilot subcarriers are inserted, the effect of lowering the PAPR is much less than that before the pilot subcarriers are inserted. So, we need to try some other methods to solve or at least ameliorate this problem. When Precoding is applied to the fixed WiMAX [4] (with 192 subcarriers), by the original definition in relevant literature (10%), 20 subcarriers will be needed, and this will improve pretty much of out-of-band power. So, we also try to adjust the number of additional subcarriers used in the Precoding Matrix method, simulate the PAPR, and make improvements to the problems of diffusion and effusion in the out-of-band frequency power. This study is motivated in hope of making improvements or finding solutions to the problems and issues as stated above.

II. The OFDM system and The introduction of the PAPR

2.1 OFDM (Orthogonal Frequency Division Multiplexing)

The traditional single-carrier transmission technique uses single subcarriers to transmit all data. During the

And the OFDM technique put the data over the multiple subcarriers for Parallel Transmission. Every subcarrier only transmits part of the data. The traditional OFDM technique divided the band into multiple non-overlapped subcarriers (Sub-channel). Although this method can resist Delay Spread caused by Multipath Interference, inefficiency in use of the frequency band very often occurs and this phenomenon wastes so much of the bandwidth in order to offer protection. In order to more efficiently use the bandwidth, if we can overlap subcarriers in frequency domain, we efficiently use the bandwidth. The overlapped part may cause interference. To avoid interference, we need to create orthogonality between carriers, and this is what we call as the OFDM technique in this study. From Fig. 2.1, we can see that the OFDM system saves nearly half of the bandwidth.

The maturation of algorithms and the DSP (Digital Signal Processing) technique, plus the calculation or computation of the FFT (Fast Fourier transform) and IFFT (inverse fast Fourier transform) and the OFDM system, make it more easily for the OFDM system with multi-carriers to be realized. And thus, this technique is widely adopted over various types of systems [1][2].

Recently, the OFDM (Orthogonal Frequency Division Multiplexing) has become a popular topic. For example, nowadays, four standards commonly used in the WLAN (Wireless Local Network) adopts the OFDM (Orthogonal Frequency Division Multiplexing) technique (IEEE 802.11a/b/g/n) for the ADSL (Asymmetric Digital Subscriber Line) commonly used over the Broadband Networks.

Meanwhile, the technique is applied to the new DVB (Digital Video Broadcasting) and the HDTV (High Definition Television) in Europe. Other applications like the WiMAX (Worldwide Interoperability for Microwave Access) and the LTE (Long Term Evolution) proposed in the 3GPP (Third Generation Partnership Project) also make use of the technique [1][2].

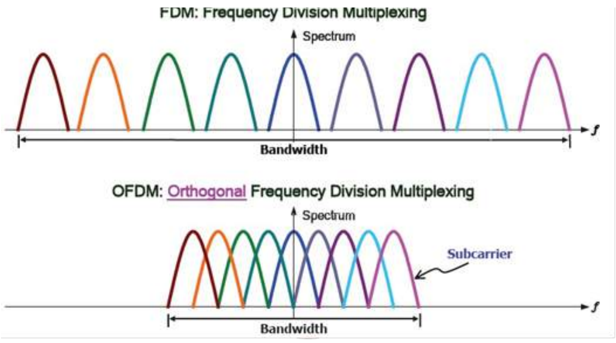


Fig. 2.1 Comparisons of using the FDM technique and the OFDM modulation technique over the bandwidth

2.2 The Framework of the OFDM (Orthogonal Frequency Division Multiplexing) System

Signals of the OFDM system first transmits Data Stream Mapping (Mapping)成????? in advance. (這句話有很大問題…有點不知所云，請查看原文，是否漏寫東西進去呢?????)… And then, the selected mapping methods that transform serial signals into parallel signals include BPSK, QPSK, 16QAM, and the 64QAM. Parallel signals, which go through the IFFT (Inverse Fast Fourier Transform) and the OFDM, are then switched back to tandem signals. In order to the enhance the ISI (Inter Symbol Interference) of signals, the GI (Guard Interval) is added behind the tandem signals. After the tandem signals pass through the channels, the receiving terminal will first remove the Guard Interval, and transform tandem signals themselves into tandem signals. At last, demapping is done to the tandem signals, and originally transmitted data are finally obtained.

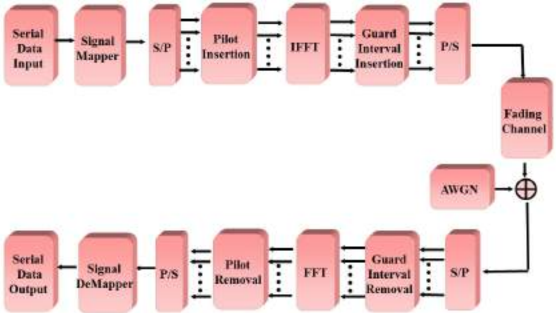


Fig. 2.2 The block diagram of the OFDM baseband

Orthogonality between subcarriers is discerned, and the zero crossing of every subcarrier will surely appear at the peak-point of the main lobe among other subcarriers. The central point of the main lobe among subcarriers will not be influenced by other subcarriers. So, these subcarriers can be overlapped. The ICI (Inter Carrier Interference) will not generate interference problems between signal carriers, and will save the channel bandwidth occupied by the ICI, as shown in Fig. 2.3.

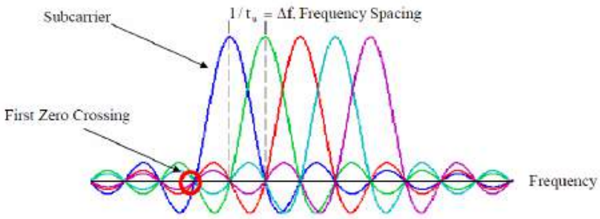


Fig. 2.3 5 subcarriers orthogonal to each other

2.3 Influences as a result of the PAPR in the OFDM system

2.3.1 The definition of the PAPR

The PAR (Peak-to-Average Ratio) is higher as we make comparisons between the OFDM signals and single carrier signals, and we call the higher PAR as the PAPR (Peak-to-Average Power Ratio). As multi-carrier signals symbolize multiple narrowband signals, the Narrowband Signals will appear in the same phase, and this will cause very large instantaneous peak values. In other words, at some point of time, the sum of linear additions is very large, but at some point of time, the sum of linear additions is not. So, compared to average values, the peak values of signals are very large [1][2]. Using Fig. 2.4 as an example, among subcarriers of the 1-fold frequency, subcarriers of the 2-fold frequency, subcarriers of the 3-fold frequency, and subcarriers of 4-fold frequency, the maximum amplitude of every subcarrier is equal to 1. And we can see that the peak values grow big with the increase of subcarriers, as shown in Fig. 2.5.

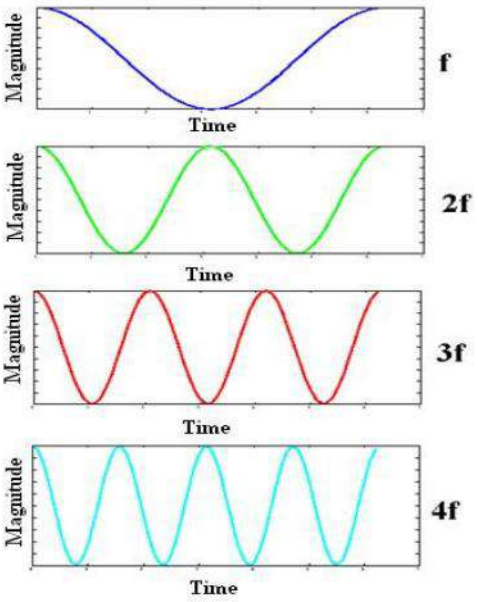


Fig. 2.4 Waveforms of Subcarriers of the 1-fold Frequency, the 2-fold Frequency, the 3-fold Frequency, and the 4-fold Frequency

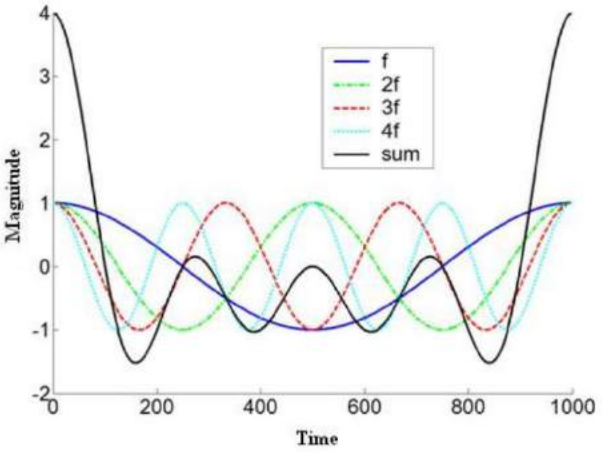


Fig. 2.6 Additions of Subcarriers of the 1-fold Frequency, the 2-fold Frequency, the 3-fold Frequency, and the 4-fold Frequency

2.3.2 Problems derived from the High Peak-to-Average Power Ratio

Problem I: The complexity of Analog to Digital (A/D) and Digital to Analog (D/A) goes up because changes in signals are in proportion to the PAPR. The wider range of signals will make the quantization noise bigger, and the resolution will vary as well. Converters using high-effect DAC and ADC will increase the complexity of the systems and costs.

Problem II: Reduction of the radio frequency and power efficiency of the amplifier. The PAPR (high) shows that when the range of change in power is relatively large, the larger dynamic range of the transmitter power (amplifier) is needed for fear of nonlinear distortion, but it also increases the costs generated by transmitters.

III. A study on Reduction of the Ratio of Peak Values to Average Values

3.1 Reduction of the PAPR using the Carrier Waves

Use of Carrier Waves can lower the PAPR in the simplest and most direct way. The peak amplitude of a signal will be limited, and peak clipping can be considered as OFDM times A (which is a parameter representing the Rectangular Window). When the amplitude is smaller than A, the amplitude will not be changed, but when the amplitude is larger than A, the abridged, as shown in Formula (3.1):

$$x_n = \begin{cases} x_n & |x_n| \le A \\ Ae^{j\arg} & |x_n| > A \end{cases} \quad (3.1)$$

The rate of Carrier Waves (Clipping Ratio, CR) is defined as in Formula (3.2):

$$CR = \frac{A}{\sqrt{P_{av}}} \quad (3.2)$$

The Rate of Carrier Waves is the threshold value A, and the ratio of signals before carrier waves to root mean square values.

3.2 Reduction of the PAPR via the Encoding Method

Traditionally, the so-called encoding method only has the ECC (Error Correcting Code) such as the Block Code and the Convolution Code. This type of encoding method makes it easier for the receiving terminal to correct input errors caused by nonlinearity when signals are received. Here, we are talking about using encoding methods to lower the ratio of the PAPR to Power Consumption. Generally, we use the Reed-Muller encoding method to generate the Golay Complementary Sequence. Compared with other methods of lowering the ratio of the PAPR to Power Consumption, the encoding method that lowers the ratio of the Peak Value to Power Consumption appears to be a pretty good method. But, the disadvantages of the encoding method consist in the transmitter, and the receiving terminal will require a very large table for inquires. As the process is overly complicated, it is unrealistic to put the process into practice. Plus, if the number of subcarriers is increased in the OFDM system, we will never find so many of the Golay complementary sequences. Thus, this method can only be applied to the OFDM system with low wave numbers.

3.3 Recombination of Symbols (Symbol Scrambling)

The method of describing diversified signals… The MSR (Multiple Signal Representation) can signals with different waveforms and multiple sets of the same information. But the smallest signals in the PAPR are chosen from transmission purposes. If we need to generate signals with different waveforms, we need to increase the number of the IFFT to calculate the PAPR in each group. So, we will increase the computational complexity of the system, and we will need add the Side Information into the signals that need to be transmitted. Then, we add the Side Information to make the receiving terminal demodulated into original signals.

3.4 Method of Changing Constellation Shaping

Change in Constellation Shaping is a type of method or technique that can effectively lower PAPR in the OFDM SYSTEM [1][4]. After using modulation and the serial-to-parallel converter for sequence data, every subcarrier over the spectrums times a certain special matrix makes every subcarrier pass through the IFFT, but peak values over the time domain will not appear at the same time, and the receiving terminal can also recover the original data with the inverse matrix. This method can be applied to any number of subcarriers and a multicarrier system with any modulation methods to lower the realization complexity [1][4].

4.1 Parameters for Simulations

Simulations in this study is based on fixed WiMAX parameters. Under the modulation of QPSK, 16QAM, and 64QAM, there are 192 data subcarriers and 8 pilot subcarriers, with 28 null subcarriers on the left and 27 null subcarriers on the right, as shown in Fig. 4.1.

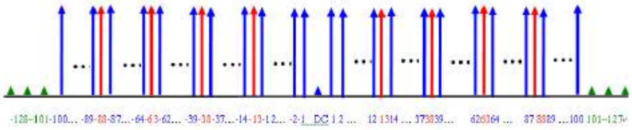


Fig. 4.1 Distribution of Fixed WiMAX Subcarriers

4.2 Simulation of the Precoding Matrix Method

The Precoding Matrix Method [3][4] lowers the PAPR by lowering the relevance of the Stars on the Main Sequence, the principle of which is for the constellation diagram after modulation times the precoding matrix to disrupt the information on constellation diagram. In the OFDM SYSTEM, over the Transmitter End, the data after modulation will then go through two processes of “Serial-to-Parallel” and “Inverse Fast Fourier Transform (IFFT)” and multiplies the Precoding matrix, as shown in Fig. 4.2.

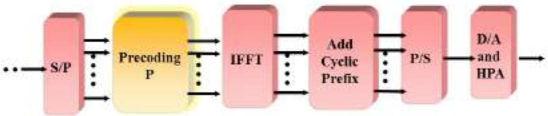


Fig. 4.2 Architecture of Precoding Matrix Transformation over the Transmitter End

As precoding requires additional subcarriers, β=(L-N)/N=Np/N, the parameter defined in the literature, is taken as Simulated Datum, where N represents the number of subcarriers in the original system, Np represents the number of subcarriers as additionally required, and L equals N+Np.

According to Fig. 4.2, under the framework of the Precoding Matrix method over the Transmitter End, the results as simulated without pilot insertion are as shown in Fig. 4.3.

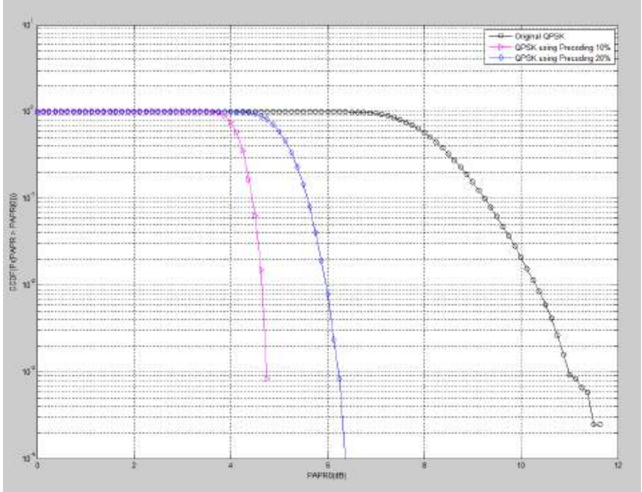


Fig. 4.3 With N=192 subcarriers (where pilot subcarriers are not inserted), we use different original signals in the CCDF Comparison Chart with the

environment, we must consider the effect of inserting pilot subcarriers. So, the Simulation Architecture proposed in the literature should be modified into the Architecture of Pilot Insertion, as shown in Fig. 4.4. According to the architecture, comparisons of simulation results are as shown in Fig. 4.5. and the simulation results show that after Pilot Insertion, the effect of the Precoding Matrix method lowering the PAPR is no longer significant. Thus, after we insert pilot subcarriers in fixed positions, we see different effects on the PAPR, and so the relevance of the constellation information plays a very strong role in sparkling changes.

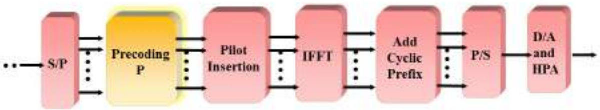


Fig. 4.4 The OFDM architecture over the Transmitter End - Conversion of the Precoding Matrix method in consideration of pilot subcarriers

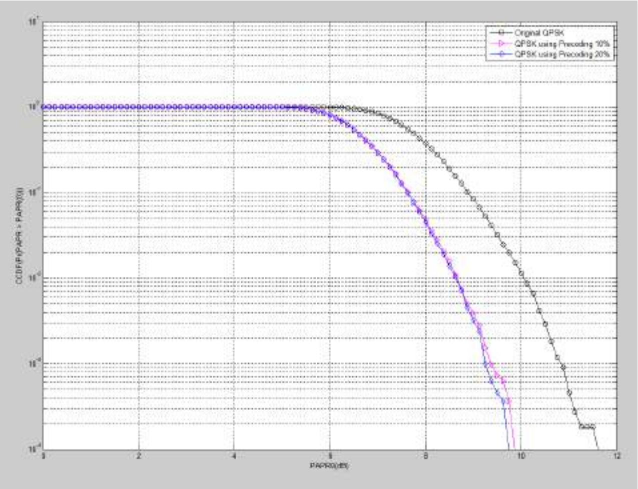


Fig. 4.5 After we add pilot subcarriers, we will use a different Precoding Matrix to make comparisons between original data of the CCDF.

4.3 Nonlinear Companding Method and Simulation

The Nonlinear Companding Method is the first developed method using μ-law [5][6], and the preliminary purpose is to make Speech Compression. During voice communications, owing to the linear restrictions over the amplifier, the Nonlinear Companding Method can also be used for compression of the domain of voice volume at the time of transmission, and the extension of the volume field at the time of transfer. The primary concept of using μ-law is to keep larger and constant signal compression in the OFDM system, and magnify smaller signals to obtain lower effects of the PAPR. Meanwhile, the Nonlinear Companding Method is also one of the methods of signal distortion, and the characteristic curves using μ-law are as shown in Fig. 4.6. Here in this figure, characteristic curves show that the larger the μ value, the larger the signal dynamic range, and the larger the proportion of compression and scale-up.

As shown in Fig. 4.7, μ-law is used over the Transmitter End. IFFT is used over the frequency domain and is turned into time domain signals, which in turn goes through μ-law for compression/expansion of time domain signals. The time domain signals after compression/expansion then go through Digital-to-Analog and they are later transmitted via antennas. The receiving terminal then puts the time domain signals after compression/expansion through Analog-to-Digital after signal reception, and decompression at a later stage of course. Then, after reception of the time domain signals undergoing decompression, those signals will pass through FFT and be transformed into digital information over the frequency domain.

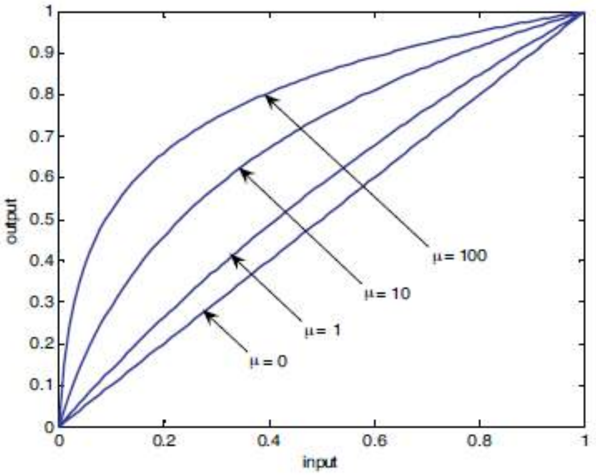


Fig. 4.6 characteristic curves using μ-law

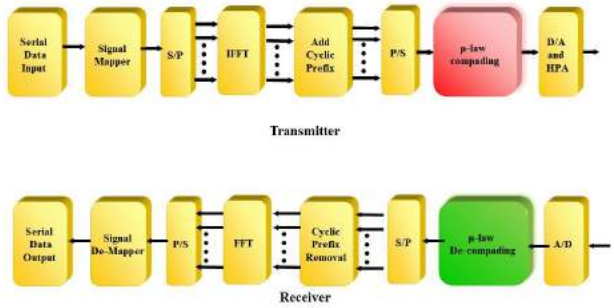


Fig. 4.7 The architecture of OFDM transmission and the receiving terminal using μ-law as a method

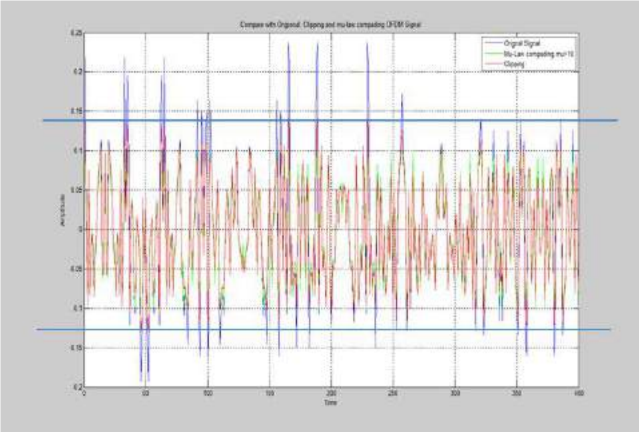


Fig. 4.8 The results of the proportion of clipping with signals over the time domain using μ-law

According to Fig. 4.8, time domain signals that go through μ-law for compression/expansion will magnify smaller signals as much as possible in the time domain, large-scale signals are restricted to a defined conclusion (clipping threshold) or they can remain constant. The clipping threshold may be designed based on the Power Saturation Point of the System. Under the architecture, the results of PAPR as simulated are as shown in Fig. 4.9. The results of PAPR indicate that the larger the μ value, the larger the dynamic range of the changes in signals over the time domain, and the better the effects of PAPR obtained. But, as the technique is also one of the nonlinear distortion over the frequency spectrum, and the problem of the out-of-band power spectrum can thus occur, as shown in Fig. 4.10.

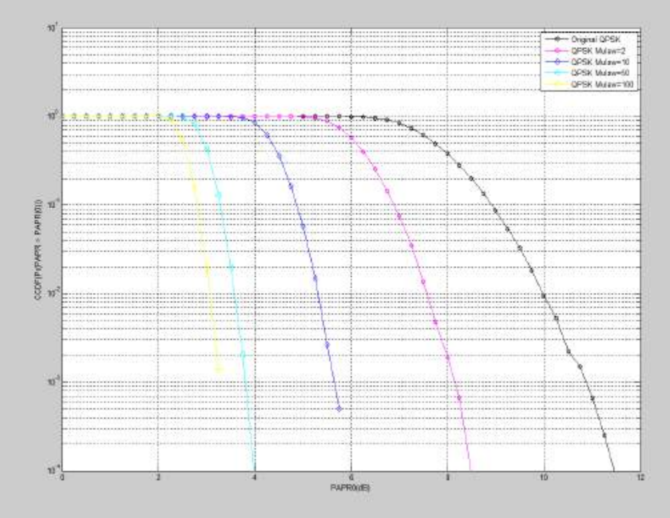


Fig. 4.9 using different values of μ (μ=2, 10, 50, 100) for dynamic compression/extension to make comparisons between original data of the CCDF.

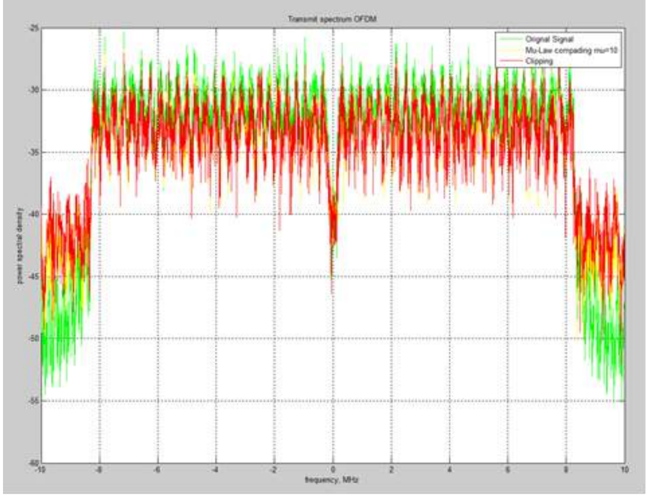


Fig. 4.10 Original OFDM Signal Spectrum, and using Clipping and μ-law (μ=10) for compression/expansion methods

4.4 Combining Precoding and μ-law to lower the PAPR

The Precoding Matrix Method, after insertion of Pilot subcarriers, may lower the PAPR with obvious problems that need to be improved. So, we need to combine μ-law to make improvements. Fig. 4.11 shows the OFDM SYSTEM architecture for combination of the Precoding Matrix method and the μ-law. Fig. 4.12 combines the Precoding Matrix method and μ-law to obtain the simulation results at PAPR. After insertion of pilot subcarriers, the simulation results based on the Precoding Matrix Method will go through μ-law over the time domain for compression/expansion of signals, and this will certainly make improvements to the PAPR. After adjusting the control parameters and the values of μ (μ=2, μ=5, μ=10, μ=50 and μ=100), the larger the values of μ, the more the improvements discerned in PAPR.

Fig. 4.14 combines the Precoding Matrix method and μ-law and shows the simulation results of Power Reduction at PAPR. But owing to the fact that μ-law can cause the problem of out-of-band bandwidth diffusion and effusion, the larger the values of μ, the more obvious the diffusion and effusion of the bandwidth, as shown in Fig. 4.13.

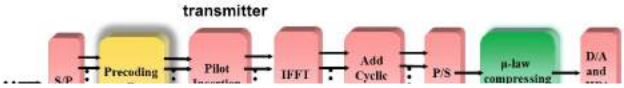


Fig. 4.11 Combining Precoding and μ-law under the OFDM system architecture

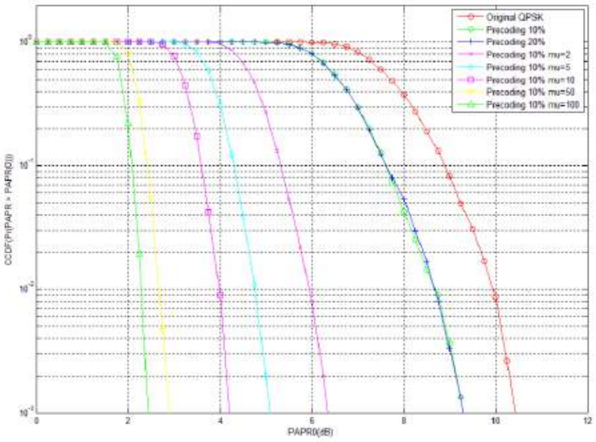


Fig. 4.12 The Precoding Matrix method in consideration of pilot subcarriers. Then we use different μ values for compression/expansion methods and make comparisons between original data of the CCDF.

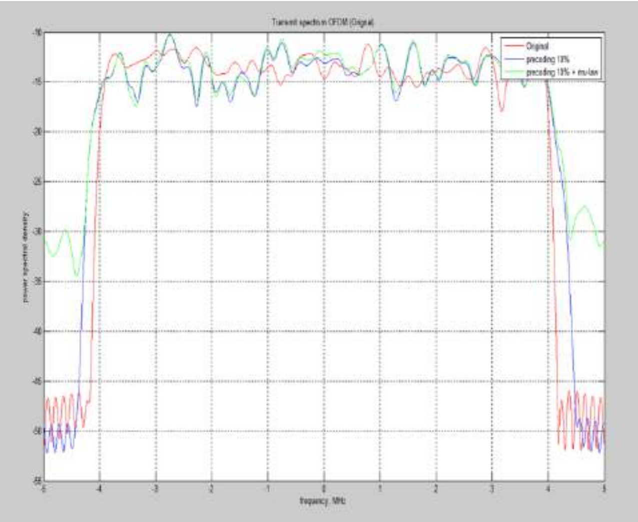


Fig. 4.13 Adopting Precoding with 10% and μ-law for the Nonlinear Companding Method and the making of the spectrum comparison chart

4.5 Combining Precoding and μ-law for Improvement of Dynamic Compression/Extension

The addition of μ-law can cause the problem of out-of-band bandwidth. The major cause is that nonlinear distortion over the frequency spectrum can cause high-frequency oscillations and vibrations over the frequency domain and diffusion/effusion of out-of-band power in the frequency domain. Thus, the correction and adjustment help reduce the percentage of time domain signals required when μ-law is used. The adjustment method requires that only the maximum value in every OFDM symbol over the time domain will be picked for dynamic compression/expansion based on μ-law Companding.

Fig. 4.14 combines Precoding with 10% and adjusts μ-law Companding for dynamic compression/expansion at 50~90% PAPR. Fig. 4.15 shows the spectrum comparison chart. Fig. 4.18 and Fig. 4.19 shows that μ-law companding will be adopted only when 70% and 90% of the maximum value is exceeded in every OFDM symbol for dynamic compression/expansion of the PAPR and spectrogram. The simulation results show that μ-law companding will be adopted only when 50%~70% of the maximum value is exceeded in every OFDM symbol for dynamic the problem of out-of-band spectrum diffusion/effusion only becomes more serious. Then back again, we already observe that only when 80% and 90% of the maximum value in every OFDM symbol is exceeded will the μ-law companding for dynamic compression/expansion be adopted. The PAPR will also be improved, but compared to the situation where only when 50%~70% of the maximum value is exceeded in every OFDM symbol for dynamic compression/expansion of the PAPR and spectrogram will μ-law companding be adopted, but much is improved in out-of-band spectrum diffusion/effusion. The results show that the lower of the compression ratio, the less the relative reduction in PAPR. Only when more than 80% of the maximum value in every OFDM symbol is exceeded can μ-law companding be used for dynamic compression/expansion. There will be no difference in improvement to the PAPR, but there will be more obvious improvement to the issue of out-of-band spectrum diffusion/effusion.

After making comparisons, the above-mentioned results show that only when 90% of the maximum value in each OFDM symbol can μ-law companding be used for dynamic compression/expansion.

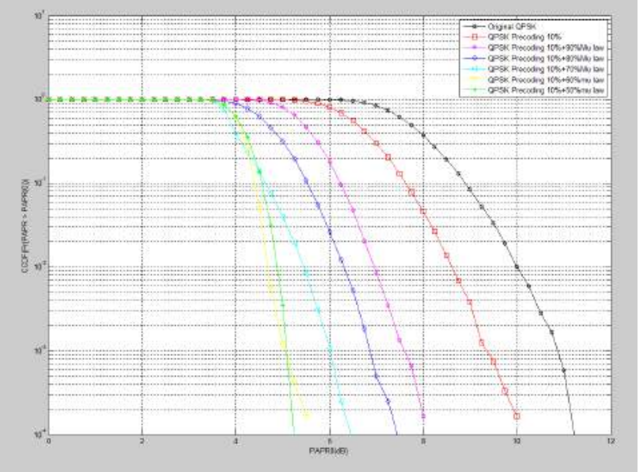


Fig. 4.14 Making adjustments to Precoding 10% until 50%~90% of the maximum value in each OFDM symbol is achieved for dynamic compression/extension to make comparisons between original data of the PAPR CCDF.

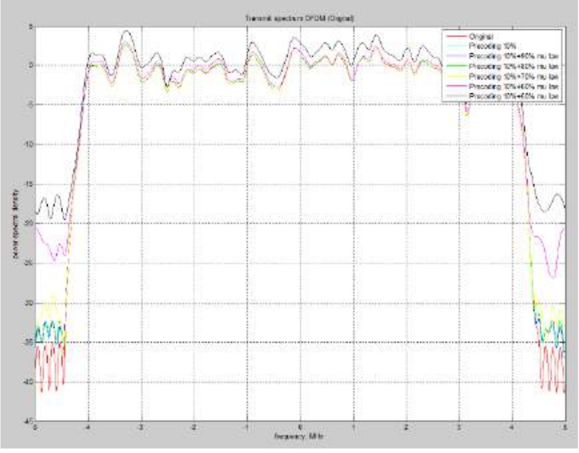


Fig. 4.15 Combining Precoding 10% and making adjustments to Precoding 10% until 50%~90% of the maximum value in each symbol is achieved for dynamic compression/extension to make comparisons between original data of the PAPR CCDF.

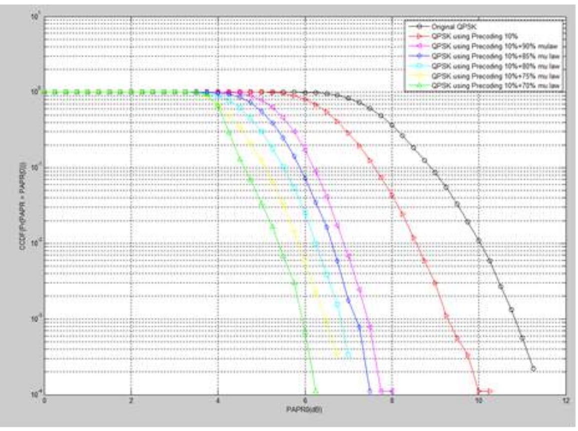


Fig. 4.16 Combining Precoding 10% and making adjustments to Precoding 10% until 70%~90% of the maximum value in each symbol is achieved for dynamic compression/extension to make comparisons between original data of the CCDF.

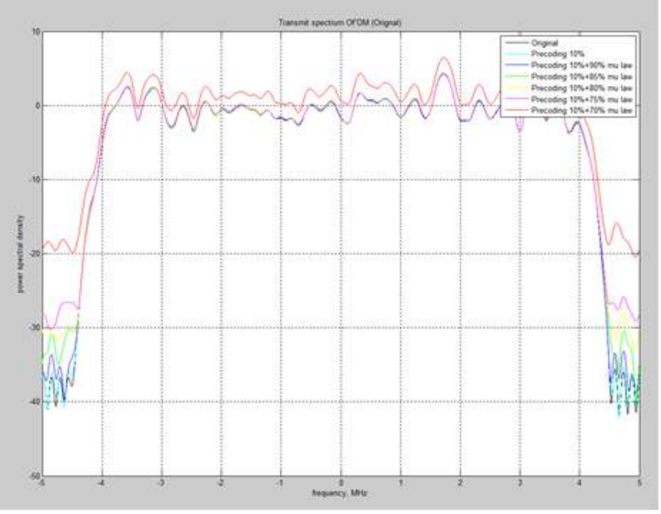


Fig. 4.17 Combining Precoding 10% and making adjustments to Precoding 10% until 70%~90% of the maximum value in each symbol is achieved for dynamic compression/extension and the making of the spectrum comparison chart.

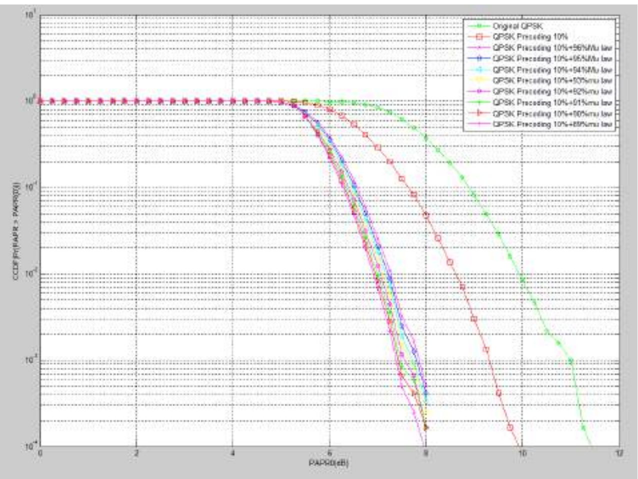


Fig. 4.18 Combining Precoding 10% and making adjustments to Precoding 10% until 89%~96% of the maximum value in each symbol is achieved.

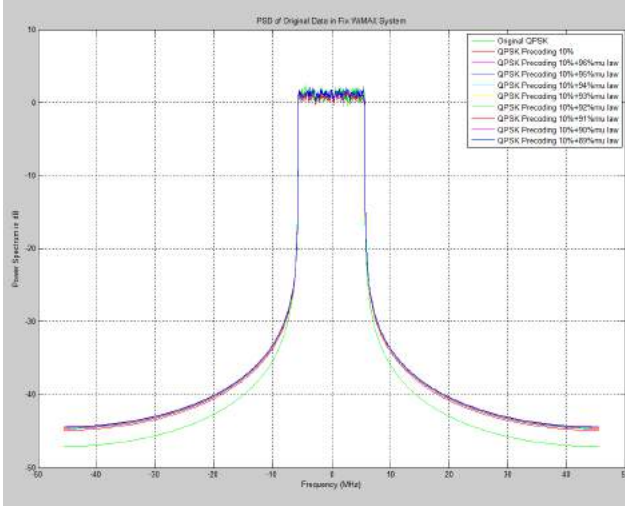


Fig. 4.19 Combining Precoding 10%. Under QPSK modulation, 89%~96% of the maximum value in each symbol is achieved for dynamic compression/extension and the making of the spectrum comparison chart.

4.6 Combining Precoding 1%~5% and μ-law for correction of Dynamic Compression/Extension

This thesis proposes a new type of method to adjust the different number of subcarriers used in the Precoding Matrix Method and μ-law companding compression/expansion 92%. Adjustment is made, so that you can see Precoding with 1% (2 subcarriers added), Precoding with 2% (4 subcarriers added), Precoding with 3% (6 subcarriers added), Precoding with 4% (8 subcarriers added), and Precoding with 5% (10 subcarriers added). Fig. 4.20 combines Precoding with 1%~5% and μ-law dynamic compression/expansion in the OFDM SYSTEM architecture.

The combined use of the aforementioned methods is shown in Fig. 4.21 and Fig. 4.22. Among the simulation results, we can pick Precoding with 1% in combination with μ-law companding for dynamic compression/expansion. 92% (of what? 92% Precoding?) the optimal out-of-band power performance can be obtained in the spectrogram.

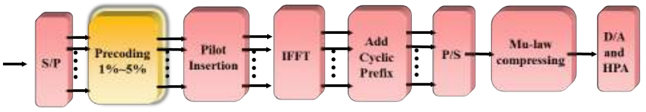


Fig. 4.20 Architecture of the OFDM system combining Precoding with 1%~5% and μ-law

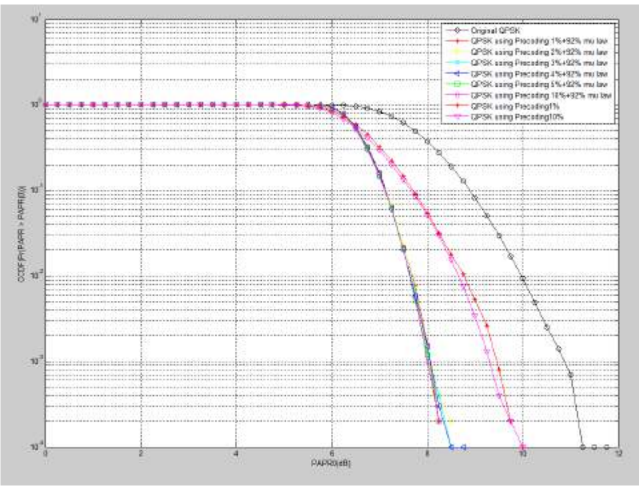


Fig. 4.21 Combining Precoding with 1%~5% and μ-law 92% for

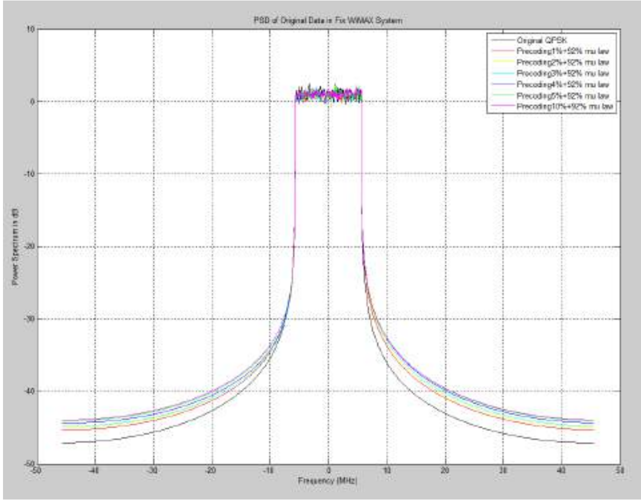


Fig. 4.22 Comparing Precoding with 1%~5% and μ-law with 92% for dynamic compression/extension over the frequency spectrums (a) Using QPSK modulation and (b) 20MHz~30MHz for amplification

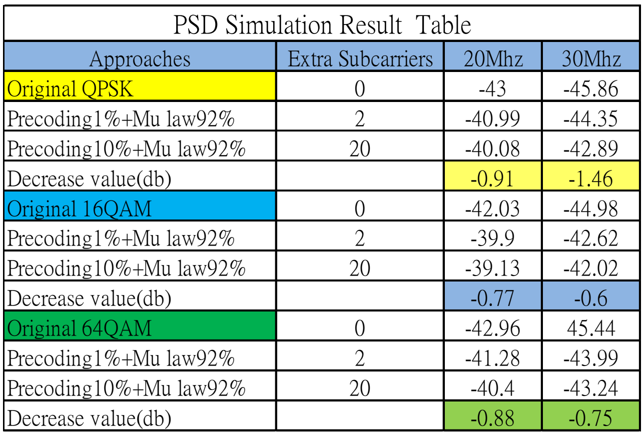
4.7 Simulation Results of combining Precoding with 1%, Precoding with 10% and μ-law 92% for dynamic compression/extension

Based on the above-stated comparisons, intermediate value is picked using μ-law 92% for dynamic compression/expansion. Precoding with 1% and Precoding with 10% in combination with different types of modulation techniques (QPSK, 16QAM, and 64QAM) are juxtaposed for comparisons. PAPR CCDF based on simulation results is compiled in Table 4.1, and the spectrogram is organized in Table 4.2. Simulation results show little difference between Precoding with 1% and Precoding with 10% over the performance of PAPR CCDF, but optimal improvement can be obtained over the spectrogram to tackle the issue of out-of-band spectrum power diffusion/effusion.

Table 4.1 Combining Precoding with 1%, Precoding with 10% and μ-law 92% to make the table of PAPR CCDF comparisons for Dynamic Compression/Extension

PAPR				
CCDF			10^{-1}	10^{-2}
Approaches	Extra Subcarriers	Total Subcarriers	PAPR0(db)	
Original QPSK	0	192	9.239	10.31
Precoding1%	2	194	7.694	8.711
Precoding1%+Mu law92%	2	194	6.402	7.18
Precoding10%	20	212	7.612	8.604
Precoding10%+Mu law92%	20	212	6.328	7.028
Original 16QAM	0	192	9.214	10.32
Precoding1%	2	194	7.978	9.056
Precoding1%+Mu law92%	2	194	6.699	7.443
Precoding10%	20	212	7.918	8.978
Precoding10%+Mu law92%	20	212	6.615	7.349
Original 64QAM	0	192	9.238	10.31
Precoding1%	2	194	8.053	9.037
Precoding1%+Mu law92%	2	194	6.776	7.508
Precoding10%	20	212	7.982	9.01
Precoding10%+Mu law92%	20	212	6.998	7.444

Table 4.2 Combining precoding with 1%, precoding with 10% and μ-law 92% to make comparisons of spectrums for Dynamic Compression/Extension



PSD Simulation Result Table

Approaches	Extra Subcarriers	20Mhz	30Mhz
Original QPSK	0	-43	-45.86
Precoding1%+Mu law92%	2	-40.99	-44.35
Precoding10%+Mu law92%	20	-40.08	-42.89
Decrease value(db)		-0.91	-1.46
Original 16QAM	0	-42.03	-44.98
Precoding1%+Mu law92%	2	-39.9	-42.62
Precoding10%+Mu law92%	20	-39.13	-42.02
Decrease value(db)		-0.77	-0.6
Original 64QAM	0	-42.96	45.44
Precoding1%+Mu law92%	2	-41.28	-43.99
Precoding10%+Mu law92%	20	-40.4	-43.24
Decrease value(db)		-0.88	-0.75

V. Conclusion

In this thesis, we make reference to μ-law companding and the Precoding method. And we use μ-law companding to solve the Precoding method. After insertion of pilot subcarriers, there is no obvious improvement to the PAPR. In order to deal with the problem of out-of-band spectrum power diffusion/effusion caused by the bonding method, a certain proportion of μ-law companding is used for allocation of the output signals. Adjustment is made so that only when a fixed proportion of the maximum value is exceeded in every OFDM symbol for dynamic compression/expansion of the PAPR and spectrogram can the μ-law dynamic compression/expansion be adopted, and that shall reduce the proportion of compression and decompression. Simulation results show that only when 90% of the maximum value in every symbol is exceeded in every OFDM symbol for adoption of μ-law dynamic compression/expansion can we obtain the best balance between out-of-band frequency power diffusion/effusion and the PAPR.

The thesis further proposes that adjustment of Precoding with 10% (20 null subcarriers added) to Precoding with 1% (2 null subcarriers added), Precoding with 2% (4 null subcarriers), Precoding with 3% (6 null subcarriers added), Precoding with 4% (8 null subcarriers added), and Precoding with 5% (10 null subcarriers added), all of which can be combined with μ-law dynamic compression/expansion. The simulation results show that Precoding with 1% in combination with μ-law dynamic compression/expansion may improve the out-of-band power to a more significant degree. In summary, we can combine Precoding with 1% with 92% for dynamic compression/expansion and we can combine Precoding with 10% plus 92% using μ-law dynamic compression/expansion. Simulation results show that Precoding with 1% in combination with 92% dynamic compression/expansion can make improvements to the out-of-band power spectrum and obtain the optimal performance.