CHAPTER 6

HADAMARD COMBINED WITH COMPANDING TRANSFORM FOR PAPR REDUCTION

6.1 INTRODUCTION

The effective way to minimize the Peak-to-Average Power Ratio (PAPR) of OFDM signals is the utilization of Hadamard and Companding transform. This transform reduce the PAPR without restrictions on system parameters such as number of subcarriers, frame format and constellation type (Park et al 2000). In this chapter first, SLM technique using hadamard transform was proposed ,then for further reduction of PAPR a new method suggest that µ law companding transform is applied to all the branches after taking IFFT in the OFDM transmitter section. Simulation results are discussed by comparing PAPR of OFDM system using hadamard transform and using new method.

6.1.1 Hadamard and PAPR

The technique of Hadamard Transform is based upon the relationship between correlation property of OFDM input sequence and PAPR probability. The average power of the input sequence represents the peak value of the autocorrelation. Hence the peak value of autocorrelation depends on the input sequence provided that number of sub carriers remains unchanged. The utilization of Hadamard transforms is to reduce the peak powers of the OFDM systems.
6.1.2 Companding Transform and PAPR

Companding is the process of compressing amplitude signal at the transmitter and expanding them at a receiver. In µ law compander the signals with lower amplitudes are amplified with greater gain (Osamu Takyu et al., 2006). In OFDM systems the occurrence of subcarriers having very large peak amplitudes is less frequent, while most of the subcarriers have low peak amplitudes. Because of less frequent high amplitude subcarriers, the average power is low, resulting in High PAPR. The high PAPR can be reduced if one of the following is possible either decrease in the peak amplitudes of the subcarriers or an increase in the average power of the transmitted OFDM signal. If a OFDM signal is passed through a µ law compander which is designed to cover the range of all amplitudes encountered (Yasir Rahmatallah et al 2011), the subcarrier with highest peak amplitude will remain relatively unaltered if near to the higher levels where all other subcarriers with low peak amplitudes will be amplified with varying but larger gains .Thus the peak power remains relatively unaltered while the average power of the signal is increased due to the µ law companding process .As a result there is a potential reduction in PAPR. Companding the subcarriers using µ law can be described by the equation

\[
y = x_{\text{peak}} \frac{\ln \left(1 + \mu \frac{|x|}{x_{\text{peak}}} \right)}{\ln \left(1 + \mu \right)} \text{sgn}(x)
\]

(6.1)

Where \( x \) is the instantaneous input signal, \( y \) is the companded output signal, \( x_{\text{peak}} \) is the maximum input /output signal and \( \text{sgn} \) is the signum function The PAPR formula for the companded OFDM is given by

\[
PAPR_{\text{comp}} = \max \left[ \frac{N \ln(1 + \mu [P_{\text{peak}}]^{0.5})}{\sum_{n=1}^{N} \ln(1 + \mu [P_{n}(t)]^{0.5})} \right]
\]

(6.2)
Where \( P_n(t) \) is the normalized instantaneous power i.e. \( \frac{1}{X_{\text{Peak}}} \) of the \( n^{\text{th}} \) sub carrier and the \( P_{\text{peak}} \) is the normalized peak power from the compander. The maximum PAPR for the companded OFDM transmission occurs for the situation when the data of the each sub carrier is the same. In such a situation, the IFFT of the data results in a peak power at one IFFT point and zero power at all other points. Therefore the maximum PAPR is given by

\[
P_{\text{PAPR\,comp\,max}} = \max \left[ \frac{N\ln(1 + m[P_{\text{peak}}^{0.5}])}{\ln(1 + m[P_{\text{peak}}^{0.5}])} \right] = N \tag{6.3}
\]

When the PAPR of both general OFDM and companded OFDM signal is identical, indicating that companding does not reduce PAPR for this situation. In our technique we are giving a random inputs for that the above equation is very effective in reducing the PAPR. The above equation helps in validating the formulation of PAPR of companded OFDM by showing that the maximum PAPR is the same as the maximum theoretical value of OFDM given by \( N \) or \( 10 \log_{10}(N) \) in dB.

6.2 SLM TECHNIQUE WITH HADAMARD TRANSFORM

![Figure 6.1 Block diagram of the SLM technique with Hadamard Transform](image)
The block diagram of the SLM transmitter with hadamard transform is shown in the Figure 6.1. The sequence of data bits are mapped to constellation points by PSK to produce the sequence symbols $X_0, X_1, X_2, \ldots, X_{N-1}$. Then these symbols are divided into block of length ‘N’, where ‘N’ denotes the number of sub carriers. Then each inputs $X=[X_0, X_1, X_2, \ldots, X_{N-1}]$ is multiplied by Hadamard matrix and each output block is multiplied by ‘M’ different phase sequence $e^{j\phi_i}b_i$, where $i = 1, 2, \ldots, M$. Note that the parameter $\phi_i$ which depends on the constellation at the transmitter does not affect the PAPR. For the first branch $b_1$ is the unit vector. The element of phase sequence of the other branch are (i.e. $b_2, b_3, \ldots, b_m$). After computing the IFFT of the each branch there are ‘M’ different OFDM signals with the same information. PAPR reduction is achieved by multiplying independent phase sequences to the original data and determining the PAPR of each phase sequence/data combination. The combination with the lowest PAPR is transmitted (Boon Kien Khoo et al., 2007).

### 6.3 NEW SLM TECHNIQUE

![Block diagram of the new SLM technique using companding transform](image)

**Figure 6.2** Block diagram of the new SLM technique using companding transform
Figure 6.2 represents the new SLM technique. In this technique companding transform is applied for all the branches after taking IFFT. The companding transform is based on two algorithms one is µ-law algorithm and the second one is A-Law algorithm. In the new technique we are applying µ-law algorithm. This transformation essentially changes the probability distribution of the amplitude of OFDM signal and achieves the PAPR reduction by both enlarging the small amplitudes and compressing large signals. The power is adaptively allocated for each sub-carrier according to the distribution in each block. The companding scheme shows better performance than the clipping technique. However, the average signal power increases after the compression and the compressed signal still exhibit non-uniform distributions. Commanding is highly used in speech processing where high peaks occur infrequently. OFDM signal also exhibit similar characteristic where high peaks occur infrequently. Companding technique improves the quantization resolution of small signals at the price of the reduction of the resolution of large signals, since small signals occur more frequently than large ones. Due to companding, the quantization error for large signals is significantly large which degrades the BER performance of the system. So the companding technique improves the PAPR in expense of BER performance of the system.

6.3.1 Algorithm

1. Start the program.

2. Get the number of bits in a block as input as m.

3. Generate random of ‘1’ s and ‘0’ s as array which is taken as the message signal.

4. Modulate the input signal in PSK modulation.
5. Generate hadamard matrix order.

6. Multiply modulated signal with every rows of hadamard matrix.

7. Multiply different phase constants for different paths.

**CASE 1**

8. Take IFFT for every paths and add cyclic prefix.

9. Calculate the PAPR for each path.

10. Select the path which has minimum PAPR.

**CASE 2**

11. Take companding transform for every path.

12. Take IFFT for every path and add cyclic prefix.

13. Calculate the PAPR for each path.

14. Select the path which has minimum PAPR.

15. Choose the threshold value.

16. Plot the CCDF graph

18. Compare the result of

   i) Hadamard transform

   ii) Hadamard with Companding transform.
6.3.2 Flow Chart for the New SLM Technique

![Flow Chart for the New SLM Technique]

Figure 6.3 Flow chart of new SLM technique

6.4 SIMULATION AND RESULTS

In this work the simulation was carried out by using MATLAB software. Randomly generated input is uniformly distributed. The work is carried out for the CCDF of different ‘N’ values from 32 to 512 using PSK modulation scheme. The companding factor $\mu$ selected in this study is ‘3’. For all the ‘N’ values the OFDM signals achieve good performance in PAPR reduction using new SLM technique than the hadamard transform. Simulation of PAPR values using CCDF plot is shown from Figure 6.4 to Figure 6.8.
Figure 6.4 CCDF Plot of PAPR values for PSK modulation (N=32)

Figure 6.5 CCDF Plot of PAPR values for PSK modulation (N=64)
Figure 6.6 CCDF Plot of PAPR values for PSK modulation (N=128)

Figure 6.7 CCDF Plot of PAPR values for PSK modulation (N=256)
Figure 6.8 CCDF Plot of PAPR values for PSK modulation (N=512)

The PAPR comparison table and the simulation parameters are shown in Table 6.1 and 6.2.

Table 6.1 PAPR comparison with different ‘N’ value for PSK Modulation

<table>
<thead>
<tr>
<th>No. of Sub carriers N</th>
<th>PAPR of OFDM system by using hadamard transform (in dB)</th>
<th>PAPR of OFDM system using new method (in dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>64</td>
<td>6.6</td>
<td>5.7</td>
</tr>
<tr>
<td>128</td>
<td>9.1</td>
<td>9</td>
</tr>
<tr>
<td>256</td>
<td>11.6</td>
<td>11.5</td>
</tr>
<tr>
<td>512</td>
<td>14.1</td>
<td>13.9</td>
</tr>
</tbody>
</table>
Table 6.2 Simulation parameter considered in this study

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Type / Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation Type</td>
<td>PSK</td>
</tr>
<tr>
<td>Number of Subcarriers used for PAPR reduction</td>
<td>8, 16, 32, ……, 1024</td>
</tr>
<tr>
<td>Hadamard Matrix order</td>
<td>$H_0, H_1, H_2, H_3, ……, H_n$</td>
</tr>
<tr>
<td>Type of new Scheme used for Reduction</td>
<td>$\mu$-law Companding method</td>
</tr>
<tr>
<td>Type of Plot used for Reduction</td>
<td>CCDF</td>
</tr>
</tbody>
</table>

Figure 6.9 Bar chart analysis of PAPR values using Hadamard Transform
Figure 6.10 Bar chart analysis of PAPR values using Hadamard Transform with companding Transform

Figure 6.11 Bar chart analysis of PAPR values (Hadamard Transform vs Hadamard with companding)
From the comparison table and Bar chart analysis it is noted that for all the ‘N’ values the new technique achieves a good PAPR reduction. For PSK mapping with N=32, the PAPR difference between hadamard transform and new technique is 0.1 dB, there is a 0.9 dB difference for N=64 from hadamard to new method. For higher order subcarriers there is an average of 0.1 dB reduction attained. This improvement in the systems performance have been maintained even when different combination of modulation scheme and number of subcarriers were used. This new technique is efficient, signal independent, distortionless, it does not require any complex optimization and reduces the complexity of the system.

6.5 SUMMARY

From this study it was observed that the hadamard with companding transform shows a good peak reduction performance than by applying only hadamard transform. For all the subcarriers the new SLM technique performs a good role in PAPR reduction.