# PAPR of ofdm using 4-qam and 16-qam

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Abstract – Orthogonal Frequency Division Multiplexing (OFDM) is one of modulation technique that has an ability to deal with multipath fading. However in the time domain, this modulation technique produces a large Peak-to-Average Power Ratio. This large PAPR value has an effect to the hardware performance, especially in the amplifier’s efficiency. This paper simulates the PAPR value on 4-QAM and 16-QAM. The PAPR phenomenon is studied using Matlab Software that compared with the analytical method. As the conclusion, for the same sub channel number, 16-QAM gives the higher PAPR value than 4-QAM. In addition, the more sub channel is used, the higher PAPR value will be.

Keywords: OFDM, PAPR, 4-QAM, 16-QAM.

Abstrak – Orthogonal Frequency Division Multiplexing (OFDM) merupakan salah satu teknik modulasi yang mampu menghadapi pudaran lintasan jamak. Namun demikian, modulasi ini menghasilkan nila Peak-to-Average Power Ratio yang tinggi pada domain waktu. Nilai PAPR yang tinggi ini berpengaruh pada unjuk kerja perangkat keras, khususnya pada efisiensi penguat (amplifier). Penelitian ini mensimulasikan nilai-nilai PAPR, berturut-turut pada modulasi 4-QAM dan 16-QAM. Fenomena PAPR tersebut disimulasikan menggunakan perangkat lunak Matlab. Hasil simulasi tadi, kemudian, di bandingkan dengan hasil perhitungan secara analitis. Simulasi menunjukkan bahwa 4-QAM menghasilkan nilai PAPR yang lebih tinggi daripada modulasi 16-QAM, untuk jumlah sub kanal yang sama. Selain itu, disimpulkan pula bahwa semakin banyak sub kanal yang digunakan, semakin tinggi pula nilai PAPR yang terjadi.

Kata kunci: OFDM, PAPR, 4-QAM, 16-QAM.

## Introduction

Today, the data communications are more various. Each communication needs a high data rate and an efficient bandwidth use. For the air media, this higher data rates should be balanced with the system ability to cope with multipath fading. This need can be fulfill with the existence of Orthogonal Frequency Division Multiplexing (OFDM) technique [Deng, 2005]. OFDM can handle multipath fading and use a bandwidth efficiently. OFDM is efficient in bandwidth use because its signal is orthogonal (see Figure 1(a)).

In OFDM technique, a bandwidth is divided into some channel, each is called sub-channel. Each sub-channel is independent each other and has one-carrier. In the time domain, OFDM signals are a superposition of its sub channels. Typically, each sub channel uses QAM modulation. The superposition of these sub channels makes the occurrence of PAPR phenomenon in the OFDM. The PAPR phenomenon is not applicable for the receiver amplifier [Lawrey, 1999]. OFDM signals have a strong relation with the chosen modulation mode. This paper will see how the 4-QAM and 16-QAM modulation mode affect the PAPR value. In addition, it will include the effect of the sub channels in producing PAPR value.

## OFDM

Research about OFDM is begun in 1950, when the idea of using parallel data transmission is took place. The idea wants to combine the parallel data transmission and FDM (Frequency Division Multiplexing) to transmit information signal. This idea, then, became a concept in 1960. In January 1970, United State got the patent of this concept [Nee, 2000].

Parallel data transmission divides the bandwidth into some small bandwidth, which is called sub channels. Each sub channels contain one carrier. FDM concept use one bandwidth for some information channels in the same time. This FDM concept is, then, adopted and used together with the parallel data transmission. The combination of these concepts is known as multi-modulation or conventional FDM. The difference between conventional FDM and OFDM can be seen in Figure 1.



Figure 1(a). Conventional FDM, (b) OFDM

A sub channel in an OFDM channel can be described in the equation 1, like below:

|  |  |
| --- | --- |
| *, 0≤ t ≤ T* | (1) |

The variable *x* is the symbol bits, and *f* is the frequency of each sub channel. Furthermore, the multi-carrier OFDM signal, which is shown by Figure 1(b), has a mathematical description as in equation 2 [Han, 2004].

|  |  |
| --- | --- |
| *, 0≤ t ≤ T* | (2) |

The variable *N* is the number of symbols, *Xn* is the symbol bits (*n* = 0, 1, ..., *N*-1), and *fn* is the frequency of each sub channel. To obtain the orthogonal relationship, *fn* should be equals to *n*×Δ*f*, which is equal to *n* divided by *T*. The variable *T* refers to the symbol duration. The real part of the equation 2 can be written as equation 3 [Matiæ, 1998].

|  |  |
| --- | --- |
|  *, 0≤ t ≤ T* | (3) |

The value of *an* and *bn* depend on the modulation used. Table 1 shows the value of *an* and *bn* for modulation BPSK, QPSK, and 16-QAM.

**Tabel 1** The value of *an*, dan *bn*

|  |  |  |  |
| --- | --- | --- | --- |
|  | BPSK | QPSK | 16QAM |
| *an* | ± 1 | ± 1 | ± 1, ± 3 |
| *bn* | 0 | ± 1 | ± 1, ± 3 |

In the receiver, OFDM signal can be obtained using FFT, which is shown in the equation 4 [Matlab, 2007]

|  |  |
| --- | --- |
| *, 0≤ t ≤ T* | (4) |

## PAPR on OFDM

### PAPR Mathematical Description

An OFDM signal, in a time domain, consists of the superposition of a number of individual sub-carrier. It means the more sub channel we have, the higher amplitude we get. The ratio of the signal’s peak power and its average power is called PAPR (Peak-to-Average Power Ratio), which is defined in the equation (5) [Deng, 2005].

|  |  |
| --- | --- |
|  | (4) |

The peak power is obtained from the square of maximum amplitude (see equation 5) [Deng, 2005].

|  |  |
| --- | --- |
|  | (5) |

The average power is found from the probability of the occurrence of one OFDM symbol (see equation 6).

|  |  |
| --- | --- |
|  | (6) |

### Hardware Problem

A higher PAPR value becomes a problem in the hardware side. A signal with a higher PAPR needs a very linear receiver amplifier. It means the power gain should work below its saturation point. However, it will need a receiver that consumes a lot of power [Jantunen, 2004]. Moreover, a power gain that work around its saturation point will occur a signal distortion and out of band radiation.

One technique to solve this hardware limitation is by cutting its peak to the maximum value that the hardware can handle. Nevertheless, the peak cutting will make a new problem, which is the signals distortion. A harmonics component will arise in the frequency domain. In this case, the data bit that is received by the receiver can be wrong reading. Table 2 shows the PAPR value that can be considered in cutting OFDM peak power [Baxley, 2004].

Table 2. PAPR (dB) towards the cutting level

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *N* | *64* | *128* | *256* | *512* | *1024* |
| *p* = 10 -2 | 9,97 | 10,3 | 10,6 | 10,8 | 11,1 |
| *p* = 10 -3 | 10,9 | 11,2 | 11,4 | 11,6 | 11,8 |
| *p* = 10 -4 | 11,7 | 11,9 | 12,1 | 12,3 | 12,5 |
| *p* = 10 -5 | 12,3 | 12,5 | 12,7 | 12,8 | 13,0 |
| *p* = 10 -6 | 12,9 | 13,1 | 13,2 | 13,4 | 13,5 |

## Simulation Design

The schema that used in this simulation can be shown in Figure 2. From this figure, it can be seen that the serial data bits that become the program input is divided into *n*-bit so it gives the parallel data output. Then, this parallel data bits is mapped according to its modulation mode. This simulation will used 4-QAM and 16-QAM modulation mode. After each bits is mapped, the IFFT process is then begin. The output of this IFFT is the OFDM signals. From this OFDM signal, we can obtain the peak power and average power. Finally, the PAPR of OFDM is calculated by dividing the peak power from its average power.



Figure 2. Diagram Block of the Simulation

## Hasil dan Pembahasan

To know the 4-QAM and 16-QAM effect on the PAPR, this research simulates the problem using Matlab.

### 4-QAM Modulation

Analytically, for one sub channel, the peak power occurs when the data 11 arise (see Figure 3). In this modulation mode, the PAPR result can be obtained as below:

* Peak Power = = = 2 V
* Average Power = = = = 1 V
* *PAPR* = = 2

From the simulation result, the peak power has the same result as the analytical calculation, which is 2V. The average power is about 1.00012V. It results the PAPR value of 1.99976. Compared with the analytical result, this result has an error around 0.12%. This error happens because of the round-off error. Figure 3 shows the simulation result for the data 11.



Figure 3. Simulation result for the data 11.

For one channel OFDM, the average PAPR value is almost same for data 00, 01, 10, and 11. However, the results of more than two channels are increasing, as shown in Table 3.

Table 3. The Maximum PAPR value for *N* channels

|  |  |
| --- | --- |
| *N*-sub channels | PAPR |
| 2 | 3.76 |
| 5 | 8.93 |
| 10 | 17.50 |
| 15 | 26.06 |
| 20 | 34.62 |
| 30 | 51.73 |
| 50 | 85.96 |
| 100 | 171.48 |
| 1000 | 1636.61 |

### 16-QAM Modulation

The next analysis is given to the 16-QAM modulation mode. For one sub-channel, the peak power occurs when the data bit equals to 1111. Analytically, the PAPR can be calculated as below.

Peak Power =, with *A* is the maximum value.

=

= = 

= 18

Average Power = 

= 

= = = 5

*PAPR* =  = 3,6

This analytical result is then compared with the simulation using Matlab. From the simulation result (see Figure 4), the PAPR value equals to 1.99976. Nearly the same for the 4-QAM, its peak power equals to the analytical value, which is 2V. The average power is 18V and the average power is 9.0011V. The PAPR value is obtained by dividing 18V with 9.0011V that equals to 1.99975. Figure 4 shows the simulation result of 16-QAM when the data is 1111.

The average PAPR of 16 bit sequences (one channel only) results almost the same value that is 2V. Moreover, the PAPR of OFDM for two or more can be seen in Table 4. From this table, it can be concluded that the more channel used, the more PAPR value we get. In other words, the additions numbers of the channels make the PAPR value increasing.



Figure 4. Simulation result for one channel 16-QAM for data 1111.

Table 3. The Maximum PAPR value for *N* channels 16-QAM

|  |  |
| --- | --- |
| *N*-sub channels | PAPR |
| 2 | 6.766 |
| 5 | 16.074 |
| 10 | 31.502 |
| 15 | 46.913 |
| 20 | 62.320 |
| 30 | 93.128 |
| 50 | 154.73 |
| 100 | 308.73 |
| 1000 | 2946.16 |

## Conclusions.

From the simulation and the analytical result, we can obtain some conclusion. The conclusion is based on two comparisons. The first conclusion is based on the comparison of PAPR value for different modulation mode in a channel. Furthermore, the second conclusion is based on the comparison of the PAPR value for one modulation mode for more than one channel.

1. For the same number of sub channels, 4-QAM modulation gives the lower PAPR value than the 16-QAM.
2. For the same modulation mode, more sub channels will gives more PAPR addition value.
3. If 4-QAM has an average signal 1 W, then 16-QAM will produce PAPR value five times bigger.

## Future Research.

These results of 4-QAM and 16-QAM should be continued with the results from 64-QAM modulation mode to obtain a stronger conclusion.

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