Performance Analysis of CCK- OFDM Over Fading Channel

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Abstract— **The increased use of data communications, improving urban/metropolitan infrastructure, and high mobility user are factors causing signal propagation problems affecting communication service quality. The application of coherent communication system using channel estimation is not sufficient yet to maintain these problems due to its complexity when being applied to high mobility environment. Since non-coherent communication system on the channel does not require carrier recovery, it becomes one of the alternative solutions. DQPSK is one of the non-coherent modulations and Complementary Code Keying use it to map bit stream into phase symbols. In this research each system of CCK and DQPSK were integrated with OFDM. By comparing the BER performance and Eb/No, the results showed that in order to reach BER in 10^{-5}, CCK-OFDM required 15 dB in low mobility environment and 17.5 dB in high mobility environment meanwhile DQPSK-OFDM required 20 dB in low mobility environment and over 30 dB in high mobility environment.**

Keywords—urban/metropolitan; multipath;high mobility; OFDM; CCK; BER; Eb/No

I. INTRODUCTION

The increased use of data communications in urban/metropolitan infrastructure with high mobility may cause some propagation problems. Using channel estimation on receiver could be an ideal solution because it uses channel estimation but the system will be more complex on high mobility environment; therefore, non-coherent modulation is frequently chosen as an option. One of non-coherent modulation is DQPSK but there are still many improvements to be made to improve the performance in terms of BER over Eb/No.

In the previous research, Complementary Code Keying (CCK) which was developed by Intersil and Lucent Technology [2] was restudied in 2003 [4]. In the study, CCK proven to show improvements in indoor measurement.

When CCK was implemented in outdoor and high mobility environment, degradation of signal cannot be overcome. This happened because CCK cannot follow the change of channel and cannot support high data rate transmission.

Therefore CCK was combined with OFDM in this research, and compared it with DQPSK-OFDM to prove its excellence on those environments. Technically, contributions of this research were stated in “Design of The System”.

This paper consists of Introduction, Review of Complementary Code Keying, Design of The System, Measurement of Signal over fading Channel, and Conclusion.

II. REVIEW OF COMPLEMENTARY CODE KEYING

CCK (Complementary Code Keying) uses In-Phase and Quadrature Phase architecture with complex symbol structure [4]. Main compositions of the CCK transmitter block are Complex Code Block and Differential Modulator. Complex Code Block consists of non-coherent modulator DQPSK, the code generator of Binary Complementary Code, Polyphase Complementary Code.

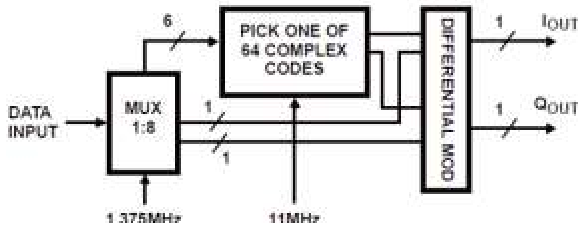


Fig. 1. Transmitter Block Diagram of CCK [6]

Meanwhile, main compositions of CCK receiver block are Match Filter, Codeword Correlator, and Sign Detector.

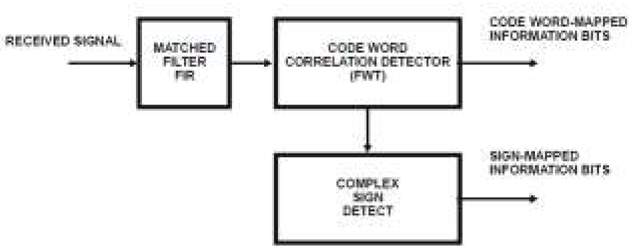
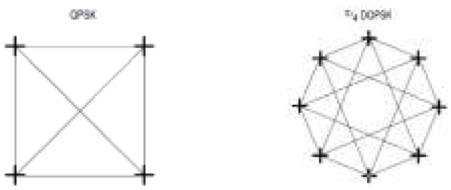


Fig. 2. Receiver Block Diagram of CCK [6]

A. *DQPSK*

DQPSK is one of non-coherent modulation that does not need carrier recovery on the receiver so it is frequently used on the mobile wireless communication [5]. Unlike QPSK that uses per two bits information to create constellation, DQPSK uses initial state from differentiation between the two bits as seen on Fig. 3 below.



(a) (b)

Fig. 3. Constelation of (a) QPSK; (b) π/4 DQPSK [5]

B. *Binary Complementary Code*

Complementary code was used by MJE Golay for infrared multislit spectrometry used in radar and communication [2]. In this case, the codes are used as binary complementary code which its formulas explain below,

$$A_n = A_{n-1}\ B_{n-1} \qquad (1)$$

$$B_n = A_{n-1}\ B'_{n-1} \qquad (2)$$

$$B' = -B \qquad (3)$$

C. *Polyphase Complementary Code*

The polyphase complementary code is used together with the binary complementary codes. The polyphase complementary code uses complex variable which represents four phases, they are {1, -1, j, -j}. These codes are generated based on length of the sequence, N. To create a polyphase complementary code, the $\log_2 N$ subset which is orthogonal with each other is needed to be determined [7].

III. DESIGN OF THE SYSTEM

The CCK modulation has some advantages in handling multipath but the condition getting worst when it is confronted by outdoor condition and high mobility user. Therefore, CCK modulation was combined with OFDM to achieve better performance of BER and Eb/No.

A. *Channel Modelling*

The model of multipath channel use the Jake's model with six paths that are also influenced by AWGN channel depicted by the following structure model on Fig. 4,

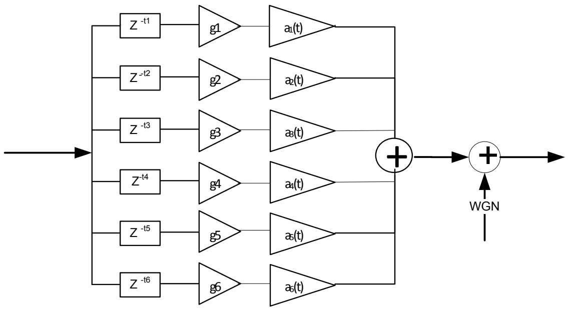


Fig. 4. Model Structure of Multipath Channel with AWGN

Histograms below showed probability density function (PDF) of each channel models with different speed variation. Fig. 5 show that each PDF had Rayleigh distribution which the x-axis represented as probability density and y-axis represented as noise. On these figure, each histogram did not show significant differences because they used the same period of symbol. However, the differences were seen on envelope detection as Fig. 6 show.

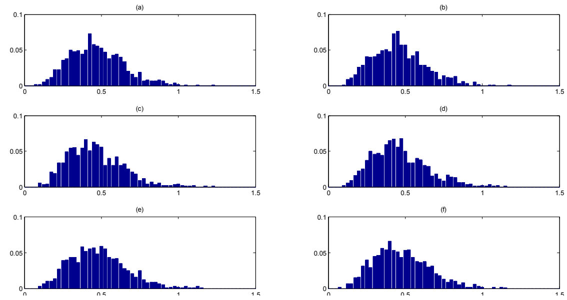


Fig. 5. PDF of Multipath Channel; (a)v=10Km/Hour, (b)v=40Km/Hour, (c)v=80Km/Hour, (d)v=120Km/Hour, (e)v=200Km/Hour, (f)v=300Km/Hour

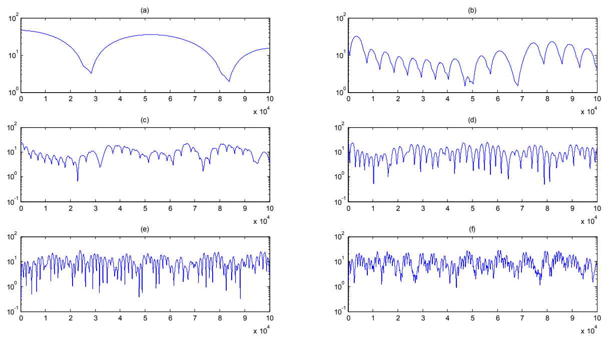


Fig. 6. Envelope of Fading Multipath Channel; (a)v=10Km/Hour, (b)v=40Km/Hour, (c)v=80Km/Hour, (d)v=120Km/Hour, (e)v=200Km/Hour, (f)v=300Km/Hour

B. *Code*

Several codes used in developing the CCK modulation is the binary complementary code and polyphase complementary code which later will generate complex codeword.

- Binary Complementary Code
  According to Golay's rule in equation (1), (2), and (3), the binary complementary code can be explained through the following flowchart in Fig.7,

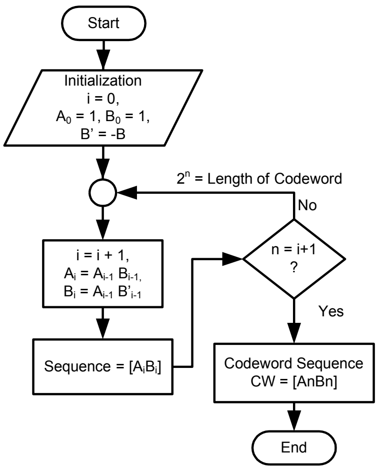


Fig. 7. Processes of Generating Binary Complementary Code

Based on the flowchart above, the following binary complementary code in eight sequence was generated [1 1 1 -1 1 1 -1 1].

- Polyphase Complementary Code
  The length of this polyphase complementary code is adjusted with the length of codeword N. The phases processed in this block were the result of DQPSK modulation (ω_1, ω_2, ω_3 dan ω_4). The amounts of phases that will be generated are as 1+ log2N subset. If the length of the codeword is 8 sequences, then there will be four subsets, they are subset "1", subset "10", subset "1100", and subset "11110000" in one matrix as equation (4) shows and the flowchart below explain,

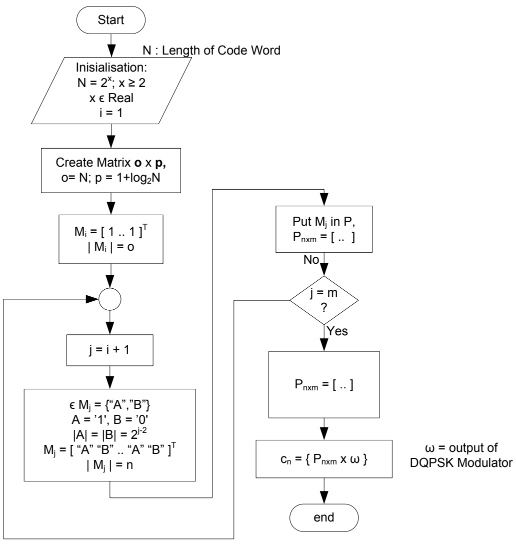


Fig. 8. Processes of Generating Polyphase Complementary Code

$$P_{8x4} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \quad (4)$$

To generate polyphase matrix on equation (5), the matrix created from those subsets on equation (4) was multiplied by $e^{j\theta}$ and φ_i, the result of the DQPSK modulator. The output of this equation was correspondence one to one with the binary complementary code, [1 1 1 -1 1 1 -1 1] as describe on equation (6).

$$M_{polyphase} = e^{j\theta} \times \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} \varphi 1 \\ \varphi 2 \\ \varphi 3 \\ \varphi 4 \end{bmatrix} = e^{j\theta} \times \begin{bmatrix} \varphi 1 + \varphi 2 + \varphi 3 + \varphi 4 \\ \varphi 1 + \varphi 3 + \varphi 4 \\ \varphi 1 + \varphi 2 + \varphi 4 \\ \varphi 1 + \varphi 4 \\ \varphi 1 + \varphi 2 + \varphi 3 \\ \varphi 1 + \varphi 3 \\ \varphi 1 + \varphi 2 \\ \varphi 1 \end{bmatrix} \quad (5)$$

$$c_8 = \begin{Bmatrix} e^{j(\varphi_1+\varphi_2+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_4)}, -e^{j(\varphi_1+\varphi_4)}, \\ e^{j(\varphi_1+\varphi_2+\varphi_3)}, e^{j(\varphi_1+\varphi_3)}, -e^{j(\varphi_1+\varphi_2)}, e^{j(\varphi_1)} \end{Bmatrix} \quad (6)$$

C. Transmitter

The transmitter block as Fig. 9 shows uses binary complementary code and polyphase complementary code to generate complex codeword. The differential modulator normalized the magnitude of the complex codeword, "1" into "1" and "-1" into "0". On the IFFT block, the magnitude and phases of the symbols were transformed by IFFT.

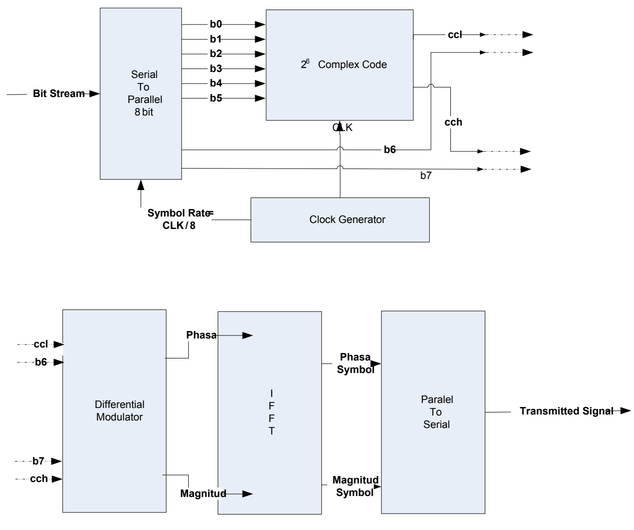


Fig. 9. Transmitter Block Diagram of CCK-OFDM

- Complex Codeword
  From the eight bit of the output of serial to parallel block, there were only six bits that were included in complex codeword. In order to be processed by the DQPSK modulator, the seventh bit (d_6) and the eighth bit (d_7) was set into zero. This made the value of ω_4=0 since the output of the modulator, $\omega = [\omega_1, \omega_2, \omega_3$ and $\omega_4]$.

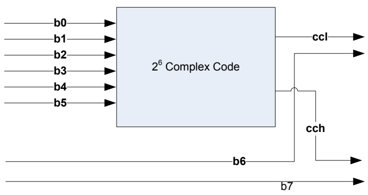


Fig. 10. Block Diagram of Complex Code

When ω_4=0, then the first four symbols (cch) and the next four symbols (ccl) had the same phase values. These phase values eased the receiver to identify the first bit until the sixth bit (d_0–d_5).

$$CW = \{ e^{j(\omega1+\omega2+\omega3)}, e^{j(\omega1+\omega3)}, e^{j(\omega1+\omega2)}, -e^{j(\omega1)}, e^{j(\omega1+\omega2+\omega3)}, e^{j(\omega1+\omega3)}, -e^{j(\omega1+\omega2)}, e^{j(\omega1)} \} \quad (7)$$

$$CW = \{e^{j\theta1}, e^{j\theta2}, e^{j\theta3}, -e^{j\theta4}, e^{j\theta5}, e^{j\theta6}, -e^{j\theta7}, e^{j\theta8} \} \quad (8)$$

- Differential Modulator
  Complex codeword was differentiated between magnitude and phase. Input on the differential modulator was the magnitude of the complex codeword which was adjusted based on binary complementary code. This was later operated by Exclusive-OR by the seventh bit (d_6) and the eighth bit (d_7). Illustration of the process is given by Fig. 11 below,

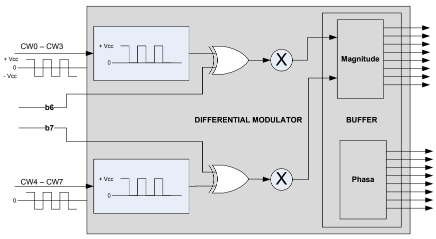


Fig. 11. Block Diagram of Differential Modulator

In this block, every value of the magnitude was normalized, “1” became “1” and “-1” became “0”. This part was done to ease the receiver in identifying the seventh bit (d_6) and the eighth bit (d_7) of each transmitted symbol.

By processing phase and magnitude of the symbol separately, it will prevented the ambiguity of the symbols so occurrence of bit error rate can be minimized.

- IFFT
  Transmission process that uses one subcarrier will exploit a lot of resource and is not durable enough to encounter frequency-selective channels due to user mobility. Therefore, multicarrier techniques using Inverse Fast Fourier Transform is needed. Output from Differential Modulator will be transformed by IFFT as Fig. 12 below describe,

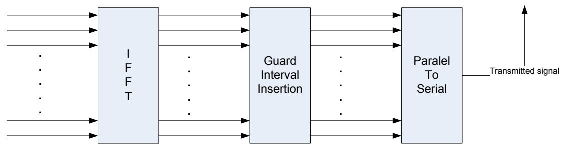


Fig. 12. Block Diagram of IFFT

D. Receiver

Principally, receiver is the opposite of transmitter. However there were some used additional blocks, Filter and Correlator. In this block, Filter was used to reduce noise influence during transmission process and correlator was used to describe phase and magnitude of each symbol.

This receiver block as illustrated on Fig. 13 consisted of Serial to Parallel, FFT, Channel Matched Filter, Codeword Correlator, Complex Detector, and Demapper.

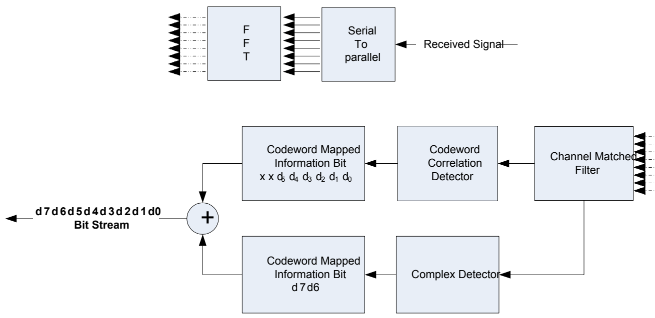


Fig. 13. Receiver Block Diagram of CCK-OFDM

- FFT
  In transmitter, the magnitude and phase were transmitted separately to ease the demapping process of the information bits on receiver.
  In order to process digital signal, the received symbols should be in the range of domain frequency. Thus changing them into time domain using Fast Fourier Transform is needed.

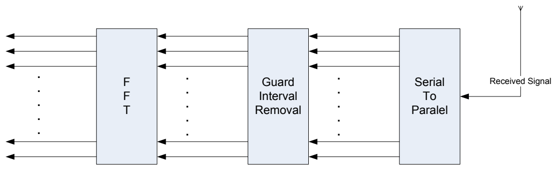


Fig. 14. Block Diagram of FFT

The output signal of the FFT block is cross-correlated by binary complementary code and polyphase complementary code.

- Codeword Correlator
  The symbols that have passed the transmission channel are definitely attenuated. This certainly needs to be normalized by using codeword correlator. The illustration of process is described on Table 1 below,

TABLE 1. EXAMPLE OF PROCESSES IN CODEWORD CORRELATOR

Selected ComplexCode	θ_i	r ∡ θ	Normalized Magnitude
1	0	1 ∡ 0	1
-j	$-\pi/2$	1 ∡ $-\pi/2$	1
-j	$-\pi/2$	1 ∡ $-\pi/2$	1
1	π	-1 ∡ π	0
-1	0	-1 ∡ 0	0
j	$-\pi/2$	-1 ∡ $-\pi/2$	0
-j	$-\pi/2$	1 ∡ $-\pi/2$	1
1	π	-1 ∡ π	0

- Complex Detector
  Complex detector is used to map the information bits that come from the received magnitude and phase symbols. Before it is mapped into information bits, an extraction from the magnitude by the following the pattern of binary complementary code and polyphase (θ_1, θ_2, θ_3, θ_4, θ_5, θ_6, θ_7, θ_8) into phase sequence (ω_1, ω_2, ω_3, ω_4) is needed to be done.

- Demapper
  There are two processes of mapping the symbols into whole information bit sequence; magnitude and phase.
  - Process of demapping from magnitude
    The magnitude that has been previously normalized is later operated by Exclusive-OR with normalized binary complementary code as Table 2 describe. The results are d_7 and d_6.

TABLE 2. EXAMPLE OF PROCESSES IN DEMAPPER FORM MAGNITUDE

Normalized Magnitude	X-OR	Normalized BCK	Demapping		
1	$\oplus$	1	0	0	d_6
1		1	0		
1		1	0		
0		0	0		
0	$\oplus$	1	1	1	d_7
0		1	1		
1		0	1		
0		1	1		

  - Process of demapping from phase
    After the polyphase θ_i is defined into phase ω_i by this process as describe on Table 3. The phase ω_i will be demodulated by DQPSK into bit sequence of 0, 0, d_5, d_4, d_3, d_2, d_1, d_0.

TABLE 3. EXAMPLE OF PROCESSES IN DEMAPPER FROM PHASE

θ_i		$\Sigma\varphi_i$	φ_i			
			φ_1	φ_2	φ_3	φ_4
θ_1	0	$\omega_1+\omega_2+\omega_3+\omega_4$	π	$\pi/2$	$\pi/2$	0
θ_2	$-\pi/2$	$\omega_1+\omega_3+\omega_4$	π	$\pi/2$	$\pi/2$	0
θ_3	$-\pi/2$	$\omega_1+\omega_2+\omega_4$	π	$\pi/2$	$\pi/2$	0
θ_4	π	$\omega_1+\omega_4$	π	$\pi/2$	$\pi/2$	0
θ_5	0	$\omega_1+\omega_2+\omega_3$	π	$\pi/2$	$\pi/2$	0
θ_6	$-\pi/2$	$\omega_1+\omega_3$	π	$\pi/2$	$\pi/2$	0
θ_7	$-\pi/2$	$\omega_1+\omega_2$	π	$\pi/2$	$\pi/2$	0
θ_8	π	ω_1	π	$\pi/2$	$\pi/2$	0

IV. MEASUREMENT OF SIGNAL OVER FADING CHANNEL

After the synthesis process of information bits is successfully completed, the next step is to examine it over fading channels with 20 Km/Hour for low mobility and 100 Km/Hour for high mobility.

The measurement is done on the DQPSK-OFDM and CCK-OFDM by comparing the performance of BER against Eb/No.

Although DQPSK and CCK is a variant of the non-coherent modulation, the performances of both appear different as shown by Fig. 15(a) and 15(b).

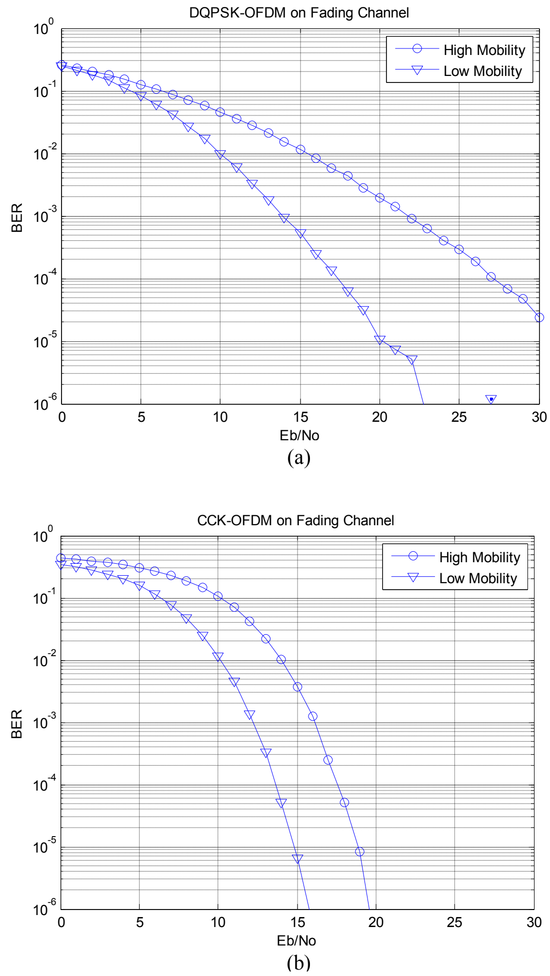


Fig. 15. Testing of BER and Eb/No Performance over Fading Channel: (a) DQPSK-OFDM; (b) CCK-OFDM

According to the measurement above, in order to reach BER 10^{-5}, DQPSK-OFDM required 20 dB in low mobility environment and over 30 dB in high mobility environment. Meanwhile CCK-OFDM required 15 dB in low mobility environment and 17.5 dB in high mobility environment.

The length of computational time needed in each stage on DQPSK-OFDM system was approximately 2.53 ms and CCK-OFDM was approximately 8.02 ms.

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Those mean that CCK-OFDM was better 5 dB in low mobility environment and 12.5 dB in high mobility environment than DQPSK-OFDM did. Although, the length of computational that CCK-OFDM need was over three times longer than DQPSK-OFDM need.

V. CONCLUSION

Non-coherent modulation used in handling the characteristics of multipath channels with the user mobility seems to inadequately result in better performance; thus alternative method to have the better performance is required.

Based on the measurement executed on the channel characteristics, it was shown that the performance of CCK-OFDM measured on BER over Eb/No was better than DQPSK-OFDM, either in the condition of low mobility or high mobility, but this good performance was sacrificing computational time which is about three times longer.

Although the length of computational that CCK-OFDM need was over three times longer than DQPSK-OFDM need, but CCK-OFDM was better 5 dB in low mobility environment and 12.5 dB in high mobility environment than DQPSK-OFDM did.

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