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W-CDMA 사용자장치 RF 구현을 위한 I/Q 열화성능요구규격 연구

(A Study on Performance Requirement of I/Q Impairments for RF Implementation in W-CDMA User Equipment)

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요 약

본 논문은 QPSK 변조방식을 사용하는 W-CDMA 사용자 설비 시스템에서 진폭 불균형 및 위상 불균형과 같은 RF I/Q 성능열화 요인들에 의한 시스템 성능열화 현상을 다루었다. I/Q 진폭 및 위상 에러에 의한 인접 심볼 간 거리변화를 이용하여 BER 성능 열화를 분석하였고, Matlab 시뮬레이션을 통해 I/Q 진폭 및 위상 에러에 의한 BER 성능열화를 검토하였다. 테스트를 고려하여 구현된 RF 트랜시버와 변복조 측정 장비를 이용하여 성능열화를 에러 벡터 크기 값으로 측정함으로써 하드웨어 구현관점에서 W-CDMA 사용자 설비 시스템의 I/Q 진폭 및 위상 에러에 관한 최소 성능요구 사항 과 성능열화 요인 측정 방법을 제시하였다.

Abstract

This paper deals with performance degradations caused by RF I/Q impairments such as amplitude mismatch and phase mismatch in W-CDMA user equipment which uses QPSK(Quadrature Phase Shift Keying) modulation. The impacts of I/Q impairments on the BER(Bit Error Rate) are analyzed by using the variations of adjacent symbol distance. The BER versus amplitude mismatch and phase mismatch with QPSK constellation is reviewed through Matlab simulation. Performance degradation produced by RF I/Q impairments is measured with the implemented RF transceiver and modulation/demodulation test equipments through EVM(Error Vector Magnitude). The minimum performance requirements of amplitude mismatch and phase mismatch in W-CDMA user equipment are presented from the point of hardware implementation and the test method of the impairments is also included.

Key Words : W-CDMA, I/Q amplitude mismatch, I/Q phase mismatch, EVM, BER, RF transceiver

1. Introduction

In digital communications, modulation signal is often expressed in terms of I and Q.

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This is a rectangular representation of the polar diagram. On a polar diagram, the I axis lies on the zero degree phase reference, and the Q axis is rotated by 90 degrees. Modulation accuracy measurements involve measuring how close either the constellation states or the signal trajectory is relative to a reference signal trajectory[1]. The received signal is demodulated and compared with a reference signal. The difference between the two is the modulation error, it can be expressed in Error Vector Magnitude (EVM).

Figure 1 defines EVM and several related terms. As shown, the error vector is the vector difference between the reference signal and the measured signal.

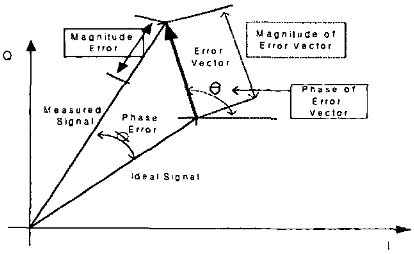

Fig. 1. EVM and related quantities.

By convention, EVM is usually normalized to the utmost symbol magnitude at the symbol times and expressed as a percentage[2] :

EVM = (rms error vector / utmost symbol magnitude) x 100[%]

The magnitude error and phase error between the two vectors provide a way to view unwanted phase and amplitude modulation that may occur in a receiver[3].

In reality, Bit Error Rate (BER) is the best measurement to verify receiver performance, but BER testing is not always possible in the subsystems of a digital radio receiver. Also, BER can indicate a problem exists, but it may not help identify the source of the problem. However, EVM provides a way to quantify the errors in digital demodulation and is sensitive to any signal impairment that affects the magnitude and phase trajectory of a demodulated signal.

EVM may also be normalized to the square root of the average symbol power. In this way, EVM can be related to the signal-to-noise ratio(SNR)[4] :

SNR = -20 log(EVM/100[%])

There has been many papers dealing with performance related to RF transceiver for W-CDMA system[5,6,7]. However, those are largely dependent upon simulation results without considering practical implementation. Thereby it is highly required that the RF performance should be evaluated through the practical test of RF transceiver from the perspective of system development.

In specific, the minimum requirement of I/Q impairment for RF implementation in W-CDMA user equipment has not been defined. Therefore, this paper describes performance degradations caused by RF I/Q impairments such as amplitude mismatch and phase mismatch in W-CDMA user equipment which uses QPSK(Quadrature Phase Shift Keying) modulation. The impacts of I/Q impairments on the BER(Bit Error Rate) are analyzed by using the variations of adjacent symbol distance. The BER versus amplitude mismatch and phase mismatch with QPSK constellation is reviewed through Matlab simulation. Then the performance degradation produced by RF I/Q impairments is measured with the implemented RF transceiver which has practical test-abilities and test equipments through EVM[8]. Specifically, the minimum performance requirements of amplitude mismatch and phase mismatch in W-CDMA user equipment are presented in terms of EVM value. It also gives measurement method to realize parameters which impact the performance degradation.

2. Performance analysis of I/Q Impairment on W-CDMA with QPSK

In general, when a QPSK signal is corrupted by Additive White Gaussian Noise(AWGN), bit error rate is

$$P_b=\frac{1}{2}\left\{1-\left[1-Q\left(\sqrt{\frac{d^2}{2N_0}}\right)\right]^2\right\}$$

$$=Q\left(\sqrt{\frac{d^2}{2N_0}}\right)-\frac{1}{2}Q^2\left(\sqrt{\frac{d^2}{2N_0}}\right) \qquad (1)$$

$$=Q\left(\sqrt{\frac{d^2}{2N_0}}\right)$$

where d is the distance between adjacent symbols, N_0 is the noise power spectral density, and Q(x) is defined as

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{\infty}e^{\frac{-t^2}{2}}dt, x\geq 0$$

$$=\frac{1}{2}erfc\left(\frac{x}{\sqrt{2}}\right) \qquad (2)$$

In the case of coherent QPSK, the distance between adjacent signals is just

$$d=2\sqrt{E_b} \qquad (3)$$

where E_b is the energy per bit. As a result, equation (1) becomes

$$P_b=Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \qquad (4)$$

where E_b/N_o is the ratio of bit energy to noise spectral density. The BER is shown as a function of E_b/N_o as in figure 2.

From the figure 2, an E_b/N_o of 7[dB] is required to achieve a BER of 10^{-3} in W-CDMA System.

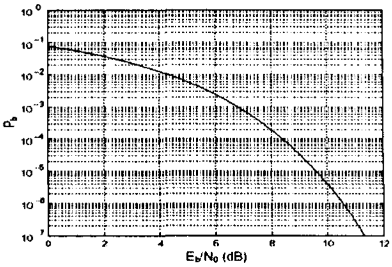

Fig. 2. BER for coherent QPSK

2.1 Gain Mismatch

One of analog impairments which degrade performance in W-CDMA user equipment is gain mismatch along the different signal paths. The received signal is down converted to baseband analog I and Q signal paths. The gain along these two signal paths should be identical, but in practical implementation, it may be different due to circuit mismatch. It can be modeled by the block diagram as illustrated in figure 3.

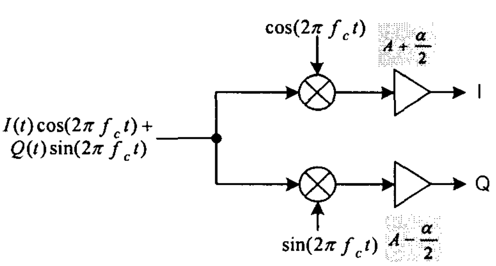

Fig. 3. I/Q gain mismatch in a receiver.

Where A is the average gain and α is the difference in gain along the I and Q signal paths. Thus, with gain mismatch, the output of the I signal path is given by

$$I(t)\frac{A}{2}\left(1+\frac{\alpha}{2A}\right) \qquad (5)$$

while the output of the Q signal path is given by

$$Q(t)\frac{A}{2}\left(1-\frac{\alpha}{2A}\right) \qquad (6)$$

The effect of gain mismatch on a QPSK constellation is illustrated in figure 4. When a QPSK signal with gain mismatch is corrupted by AWGN, the BER can be approximated by averaging the error probabilities for two binary antipodal signals separated by distances dx = $d_o\left(1+\frac{\alpha}{2A}\right)$ and dy $= d_o\left(1-\frac{\alpha}{2A}\right)$:

$$\begin{aligned}P_b&=\frac{1}{2}\left\{Q\left[\left(1+\frac{\alpha}{2A}\right)\sqrt{\frac{d_0^2}{2N_0}}\right]+Q\left[\left(1-\frac{\alpha}{2A}\right)\sqrt{\frac{d_0^2}{2N_0}}\right]\right\}\\&=\frac{1}{2}\left\{Q\left[\left(1+\frac{\alpha}{2A}\right)\sqrt{\frac{2E_b}{N_0}}\right]+Q\left[\left(1-\frac{\alpha}{2A}\right)\sqrt{\frac{2E_b}{N_0}}\right]\right\}\end{aligned} \qquad (7)$$

The error probabilities as a function of E_b/N_o for gain mismatch are plotted in figure 5.

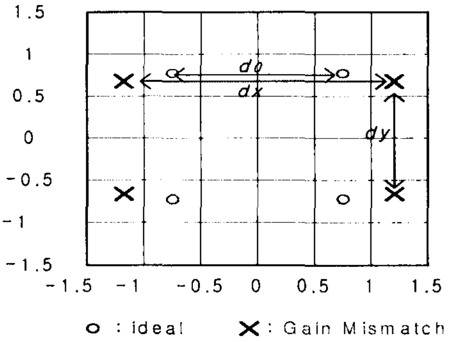

Fig. 4. Effect of gain mismatch on a QPSK constellation

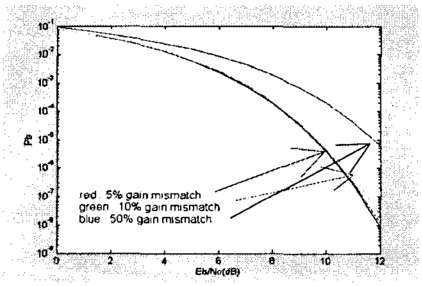

Fig. 5. Probability of error for QPSK with gain mismatch

As seen in figure 5, the BER degradation is minimal for a gain mismatch of 10[%] or less.

2.2 Phase Mismatch

In practical implementation, the phases of the LO signals may deviate from quadrature due to circuit mismatches. Phase mismatch in a receiver can be modeled by the block diagram illustrated as in figure 6, where Φ is the phase deviation from quadrature in the two LO signals.

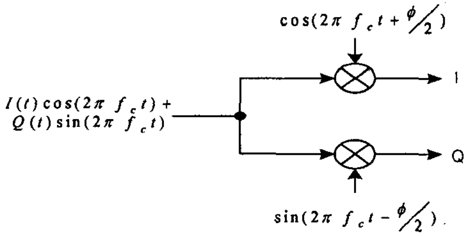

Fig. 6. Phase mismatch in a receiver

Thus, with phase mismatch, the output of the I signal path is given by

$$\frac{1}{2}\left[I(t)\cos\left(\frac{\Phi}{2}\right)-Q(t)\sin\left(\frac{\Phi}{2}\right)\right]=d_x \qquad (8)$$

while the output of the Q signal path is given by

$$\frac{1}{2}\left[Q(t)\cos\left(\frac{\Phi}{2}\right)+I(t)\sin\left(\frac{\Phi}{2}\right)\right]=d_y \qquad (9)$$

The effect of phase mismatch on a QPSK constellation is illustrated in figure 7.

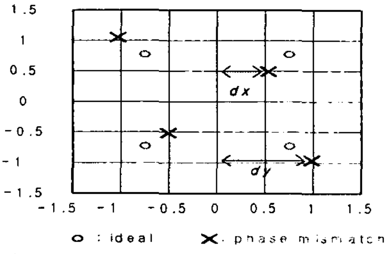

Fig. 7. Effect of phase mismatch on a QPSK constellation

When a signal with phase mismatch is corrupted by AWGN, the probability of error can be approximated by averaging the error probabilities for the symbols in each of the four quadrants of the constellation diagram. Each of the symbols in the first and third quadrants is located at a distance $\frac{d_0}{2}\left[\cos(\frac{\Phi}{2})-\sin(\frac{\Phi}{2})\right]$ from the decision boundaries due to phase mismatch in I signal path(dx). The error probability for these two symbols can be written by

$$P_{b(I,III)} = Q\left[\left(\cos\frac{\Phi}{2}-\sin\frac{\Phi}{2}\right)\sqrt{\frac{d_o^2}{2N_0}}\right] \quad (10)$$

Similarly, each of the symbols in the second and forth quadrants is located at a distance $\frac{d_0}{2}\left[\cos(\frac{\Phi}{2})+\sin(\frac{\Phi}{2})\right]$ from the decision boundaries due to phase mismatch in Q signal path(dy). The error probability for these two symbols is approximately given as

$$P_{b(II,IV)} = Q\left[\left(\cos\frac{\Phi}{2}+\sin\frac{\Phi}{2}\right)\sqrt{\frac{d_o^2}{2N_0}}\right] \quad (11)$$

Consequently, the overall probability of error is approximately

$$P_b = \frac{1}{2}\left\{Q\left[\left(\cos\frac{\Phi}{2}-\sin\frac{\Phi}{2}\right)\sqrt{\frac{2E_b}{N_0}}\right] + Q\left[\left(\cos\frac{\Phi}{2}+\sin\frac{\Phi}{2}\right)\sqrt{\frac{2E_b}{N_0}}\right]\right\} \quad (12)$$

The BER as a function of E_b/N_o for various amounts of phase mismatch is plotted in figure 8. As seen in figure 8, the BER degradation is minimal for a phase mismatch of 5° or less.

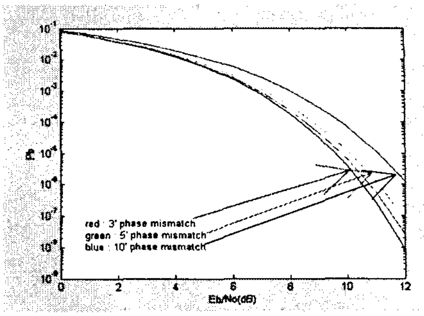

Fig. 8. BER versus phase mismatch

3. Evaluation of Performance degraded by I/Q Impairments in W-CDMA System

The RF transceiver including test-abilities is implemented in order to evaluate the performance degradation caused by I/Q impairments in WCDMA system as in figure 9[9].

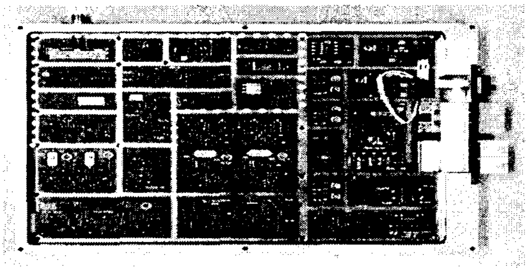

Fig. 9. The implemented RF Transceiver

3.1 EVM measurement of I/Q amplitude error

In order to evaluate the performance degradation of the receiver in W-CDMA user equipment due to I/Q amplitude error, the test set-up is configured as in figure 10. The W-CDMA signal generator is used as a RF signal source. The value of amplitude error is obtained by adjusting the level of I/Q analog baseband signal. The EVM was measured by Tx tester.

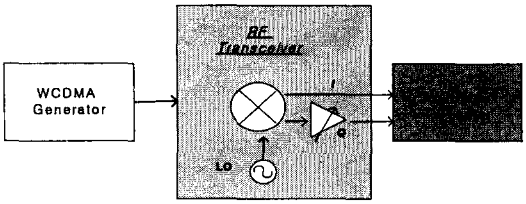

Fig. 10. Test configuration of I/Q amplitude error

The RF single tone of -45[dBm], 2141[MHz], is applied to the receiving front-end of RF transceiver to keep the level of analog baseband I/Q signal equal to -2[dBm]. After balancing the level of analog I/Q signal, the modulated RF signal, 2140 MHz, is applied to the receiving front-end and then measure EVM with Tx tester. The amplitude error value is obtained by adjusting the level of analog baseband Q signal. The test results of EVM versus the value of amplitude error is shown as in figure 11. The minimum performance requirement of I/Q amplitude error is obtained as 0.7[dB] to meet 10[%] EVM defined under simulation result.

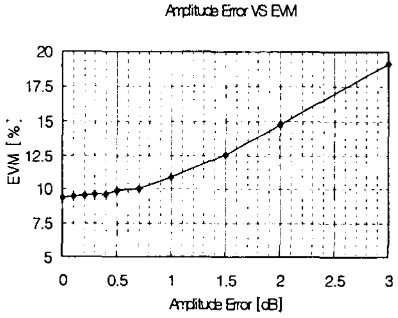

Fig. 11. EVM versus amplitude error

3.2 EVM Measurement of I/Q phase error

For the evaluation of the performance degradation of the implemented direct- conversion RF transceiver due to I/Q phase error, the test set-up is configured as in figure 12. The W-CDMA signal generator is used as a RF signal source. The value of phase error is obtained by adjusting the phase of LO generator. One LO generator is used for I path and another LO generator is used for Q path. The phase of LO generator for Q path is adjusted to produce phase error.

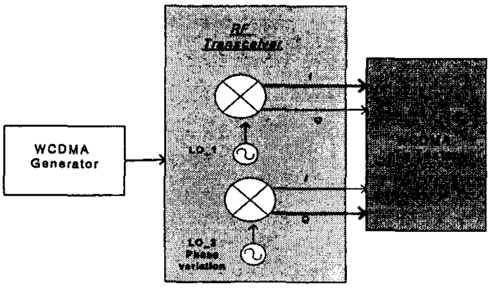

Fig. 12. Test configuration of I/Q phase error

The EVM is measured with Tx tester by adjusting the phase of LO generator for Q path.

The minimum required EVM due to I/Q phase error should be 11[%] below to meet I/Q phase error of 5° or less which was defined from simulation result. The test result is shown in figure 13.

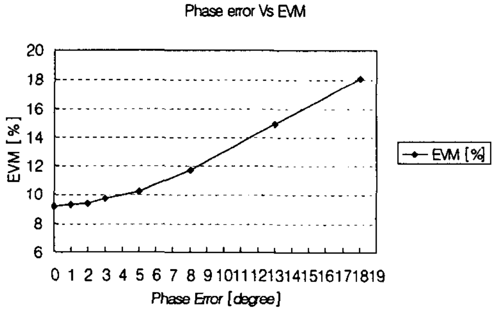

Fig. 13. EVM versus phase error

The test results showed that 10[%] below of I/Q amplitude error and 11[%] below of I/Q phase error were required to meet the minimum performance requirement, an E_b/N_o of 7[dB], in W-CDMA system

4. Conclusion

The performance degradations produced by I/Q impairments such as amplitude mismatch and phase mismatch in W-CDMA user equipment are analyzed by using the variations of adjacent symbol distance. In practical test, I/Q amplitude error of 0.7[dB] max. was obtained to meet I/Q amplitude error of 10[%] below and I/Q phase error of 11[%] below was obtained to meet I/Q phase error of 5° or less.

Specifically, this paper presented the minimum performance requirements of I/Q amplitude mismatch and phase mismatch in W-CDMA user equipment through EVM from the point of hardware implementation. It also gave an easy way to realize how much I/Q impairments were produced in RF transceiver in practical test.

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