A BER Performance of Analysis and Comparison for Ultra-Narrowband Digital Radio System

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Abstract

In this paper, we evaluate the performance of the digital modulation schemes described in the APCO Project 25 FDMA specifications which can be used for applying the ultra-narrowband technology to the current domestic simple two-way radio systems, and discuss difficulties in the DSP implementation of the systems. We analyze the effect on the systems' BER performance of receiver non-matched filter and frequency-offset between the transmitter and receiver oscillators. And we present a frequency offset compensation method for improving the system performance.

The results of performance analysis showed that the CQPSK of APCO Project 25 using non-matched filter degraded the BER by 0.5~1.0 dB comparing with PI/4 DQPSK using matched filter. In the event of 2 % frequency offset, about 1 dB performance loss was produced at the BER of 10^{-3}. With the frequency-offset compensation method implemented in the systems using phase recovery scheme of PSK synchronization detection, the performance degradation of about 1.0 dB was occurred at the BER of 10^{-3} for 10 % of frequency offset. The proposed method can be used for the improvement of system performance.

Key words : Ultra-Narrowband Modulation, CQPSK, DQPSK, Frequency Offset Compensation.

Ⅰ. Introduction

Recently, the increase of spectrum demand in LMR (Land Mobile Radio) System using frequencies of VHF and UHF has been requiring how to increase the spectrum reuse efficiency. For an alternative plans, changing from wide-band channel to narrow-band channel(25 kHz ⇒ 12.5 kHz ⇒ 6.25 kHz) and using multiple access technology which can increase 4~5 times of frequency reuse efficiency in comparison with current 25 kHz channel FM scheme have been reviewed. In other way, the FDMA and TDMA have been under consideration in order for users to use the limited frequency band and the limited transmission capacity without interference. Therefore the existing analog FM and SSB schemes have been changing into digital scheme such as Project 25 and TETRA(refer to Fig. 1).

Up to now, seven digital LMR systems with high frequency reuse efficiency have been proposed by ITU-R Study Group 8. There are three schemes for FDMA such as Project 25, TETRAPOL and EDACS (Enhanced Digital Access Communication System) Aegis. As a TDMA scheme, TETRA(Terrestrial Trucked Radio), IDRA(Integrated Digital Radio), and DIMRS (Digital Integrated Mobile Radio System) are included. There is also Geotek's FHMA scheme as a hybrid scheme. Among these schemes, the Project 25 of FDMA scheme and three TDMA scheme meet ultra-narrowband(6.25 kHz below) standard[1]. Specially, APCO(Association of Public-Safety Communications

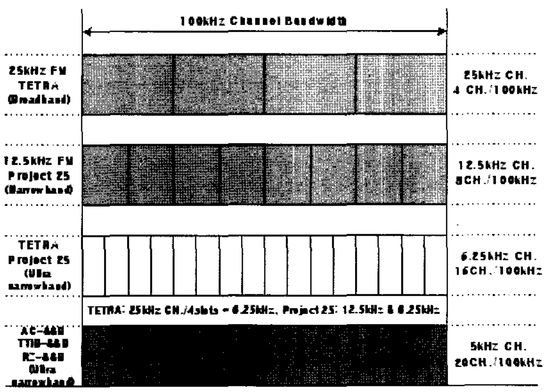

Fig. 1. The comparison of spectrum reuse efficiency for LMR.

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Officials) Project 25 of U.S.A. and TETRA of Europe have been developing into wireless multimedia services which includes not only the existing voice service but also high quality image service, data service, and remote medical service through the opened system standard processing.

For instance, APCO dealing with public safety in the field of police and fire station has been changing the ANSI standard known as Project 25 to a new standard through cooperation with TIA. The FDMA scheme at phase I and also the both FDMA and TDMA at phase II has been considered[2]. Some of the systems were commercialized(12.5 kHz bandwidth) and some of them are under commercialization(6.25 kHz bandwidth). In Europe, most of systems were developed already. Therefore 325 systems in 55 nations have already been completed and are in service now. In domestic case, narrow-band processing is under going for several frequencies of UHF band(335.4~470 MHz) and VHF band(138~174 MHz). However, there is lack of the technology standard of 6.25 kHz ultra-narrow band.

As an alternative scheme to increase the frequency reuse efficiency, this paper described digital modulation performance adopted by APCO Project 25 FDMA standard[3] which is available to ultra-narrowband technology of the current domestic two-way simple radio systems. For the practical verification, the impact of frequency offset on system BER performance was evaluated by the use of commercial DSP module and then a frequency offset compensation method is proposed to improve the system performance.

Ⅱ. Ultra-Narrowband Digital Modulation Scheme

Digital modulation scheme for channel bandwidth of 12.5 kHz and 6.25 kHz is defined in APCO Project 25 FDMA standard. In case of the C4FM(Compatible 4-Level Frequency Modulation) modulation scheme, a non-linear power amplifier of high power efficiency can be used due to the constant amplitude of carrier. However, the channel spacing of 12.5 kHz should be used as the bandwidth increases. In case of CQPSK (Compatible Quadrature Phase Shift Keying) modulation scheme, the amplitude and phase are changed at the same time. Thereby channel spacing of 6.25 kHz is available to high frequency efficiency. However, high linearity of power amplifier is required. CQPSK modulator transforms the input data into in-phase component and quadrature-phase component by 2 bits as in Fig. 2.

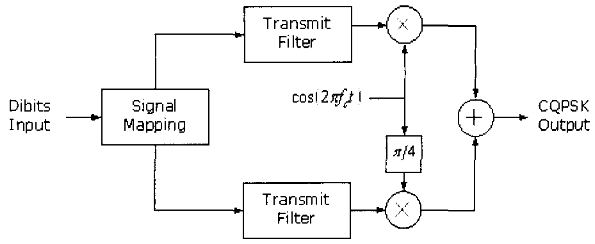

Fig. 2. CQPSK modulator block diagram.

Each component passes raised cosine filter with 0.2 roll-off factor and then CQPSK output signal is generated through quadrature modulation processing. The carrier phase rotates $+3\pi/4$, $+\pi/4$, $-\pi/4$, and $-3\pi/4$ over the input data of 01, 00, 10, and 11 during a symbol period. The result is the same as $\pi/4$ shift DQPSK modulation scheme[4]. The pulse shaping is adapted to receive C4FM signal and CQPSK signal in CQPSK modulation scheme, which is different from $\pi/4$ shift DQPSK using matched filter.

The Project 25 standard chooses a combined receiving structure composed of frequency modulation detector, integrator and dump to receive analog FM, C4FM and CQPSK signal feasibly as in Fig. 3.

In case of receiving $\pi/4$ shift DQPSK signal, the matched filter should be implemented before frequency detector with IF filter. However, it is difficult to implement the IF filter with matched filtering characteristics. Therefore it is realized by putting pulse shaping filter in transmitter and band pass filter in receiver, which is called CQPSK using non-matched filtering scheme in Project 25 standard.

2-1 CQPSK Performance Degradation Due to the use of Non-Matched Filter

Project 25 CQPSK modulation scheme causes more performance degradation than $\pi/4$ shift DQPSK modulation scheme due to the use of non-matched filter. When using raised cosine pulse with α roll-off factor as a transmitting filter and brick wall filter as a receiving filter in CQPSK, the SNR is described as in eq. (1). On the other hand, the SNR in using matched

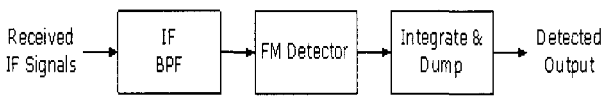

Fig. 3. Receiver structure using frequency detector, integrate and dump.

filter is $2E_b/N_0$[5],[6].

$$SNR = \frac{2E_b}{(1-\alpha/4)(1+\alpha)N_0} \tag{1}$$

The performance degradation of CQPSK using non-matched filtering in comparison with modulation scheme using matched filtering is represented in eq. (2)

$$L = 10\log_{10}(1-\alpha/4)(1+\alpha)\ \text{(dB)} \tag{2}$$

By using eq. (2), the performance degradation of CQPSK versus the variation of roll-off factor is depicted in Fig. 4. Since Project 25 CQPSK uses α =0.2, 0.57 dB of performance loss is occurred comparing with modulation scheme using matched filter.

Ⅲ. Performance Analysis using Computer Simulation

Computer simulation was carried out under AWGN channel. FIR filter for CQPSK and matched filter for $\pi/4$ shift DQPSK were selected as a receiving filter. It is assumed that the capture of ideal symbol timing is possible for BER analysis.

3-1 The Impact of Non-Matched Filter

Raised cosine pulse with 0.2 α and 160 taps as a transmitter filter was used. A receiver filter was designed through Parks-McClellan FIR filter design method[7]. Baseband difference detection for signal detection and integrate & dump for frequency detection were combined[8].

The BER performance analysis under AWGN channel between CQPSK using non-matched filter and $\pi/4$ shift DQPSK using matched filter is shown in Fig. 5. In $\pi/4$ shift DQPSK, square-root raised cosine pulse

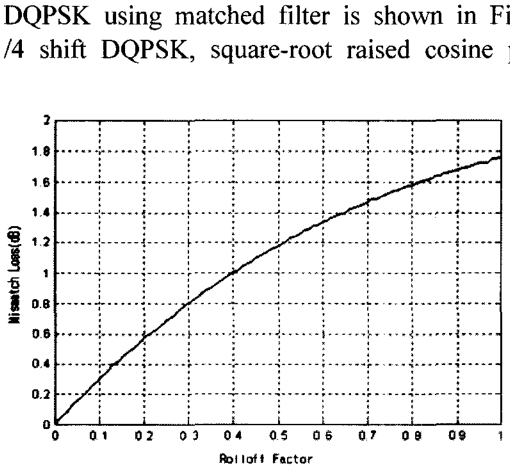

Fig. 4. Performance degradation of CQPSK versus the variation of roll-off factor.

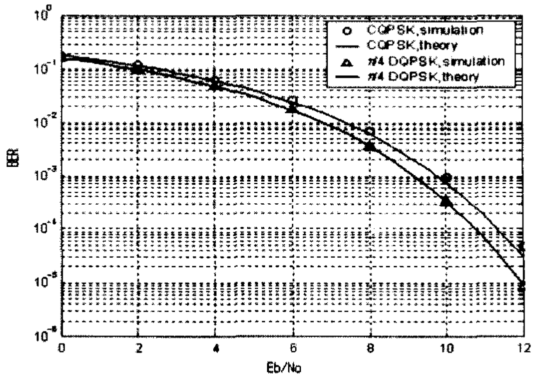

Fig. 5. BER comparison between CQPSK and $\pi/4$ shift DQPSK.

with 160 taps was used as matched filter. Other factors are equal to the case of CQPSK. The simulation showed that a further performance degradation was occurred comparing with the theoretical value in eq. (2). This result was caused by the different bandwidth between the designed filter and ideal filter.

3-2 Impact of Frequency Offset

LO plays very important role for frequency translation in digital modulation and demodulation. The frequency of LO can be changed easily due to the variations of temperature, voltage, road and surroundings. Frequency offset between transmitter LO and receiver LO is one of main factors causing performance degradation. The impact of frequency offset on the performance depends on the bandwidth of a modulation signal. When a signal bandwidth is small, even a small frequency offset can generate a quite amount of performance degradation by increasing frequency spectrum deviation comparing with the signal bandwidth.

Phase difference between symbols in one symbol period is one of $+3\pi/4$, $+\pi/4$, $-\pi/4$ and $-3\pi/4$ for CQPSK and $\pi/4$ shift DQPSK. When the phase difference varies with $\pm\pi/4$ and above from the existing value, in other words, when the frequency offset exceeds ± 12.5 % of transmission rate, BER is degraded rapidly. The impact of frequency offset on BER performance for CQPSK is shown in Fig. 6. The impact of frequency offset on BER performance for $\pi/4$ shift DQPSK is shown in Fig. 7. The frequency offset is normalized with respect to symbol rate and the base-band detection method is used for signal detection. 2 % of frequency offset degrades 1 dB of performance at BER = 10^{-3}.

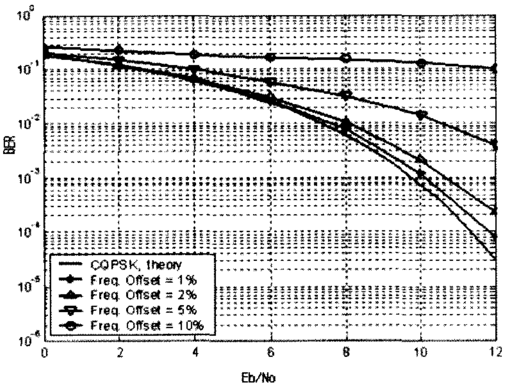

Fig. 6. The impact of frequency offset on BER performance for CQPSK.

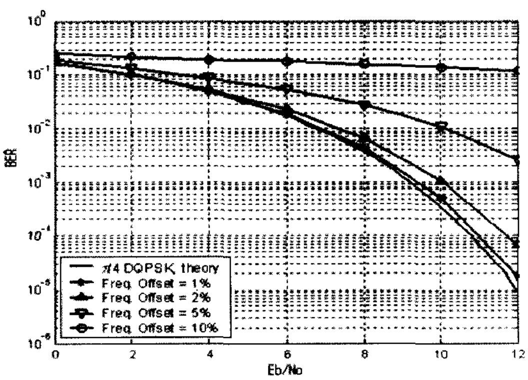

Fig. 7. The impact of frequency offset on BER performance for $\pi/4$ shift DQPSK.

3-3 Frequency Offset Compensation

The amount of frequency offset depends on accuracy and stability of LO. At least 5 ppm of LO is required for LMR in general[9]. When LO with very high stability is required, temperature compensation circuit is necessary.

The proposed frequency offset compensation method is shown in Fig. 8. The frequency compensation in

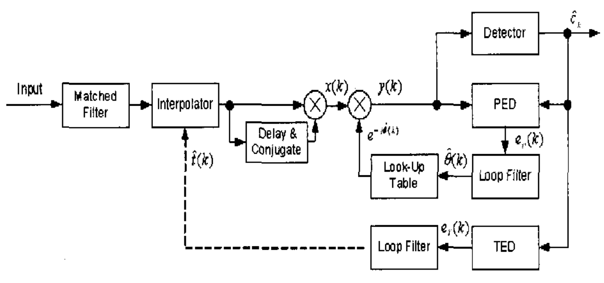

Fig. 8. Receiver structure including frequency offset compensation.

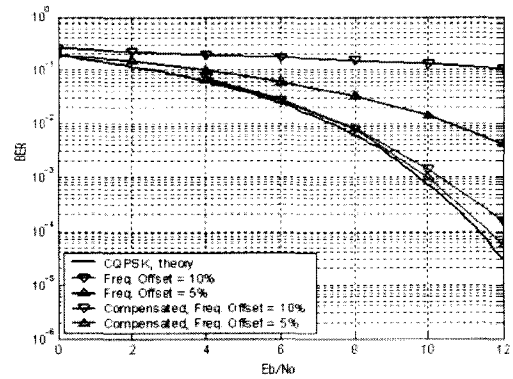

Fig. 9. BER performance versus frequency offset compensation for CQPSK.

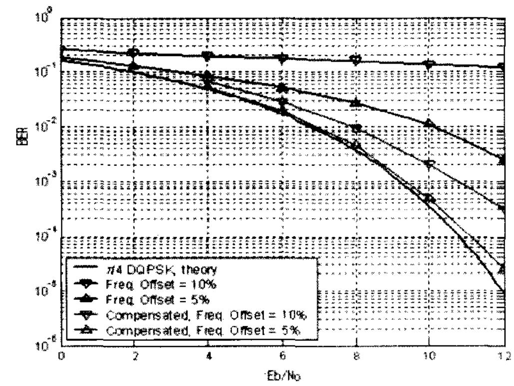

Fig. 10. BER performance versus frequency offset compensation for $\pi/4$ shift DQPSK.

DPSK difference detection is the same method as carrier phase recovery in PSK synchronization detection. Phase error between difference detection and decision is obtained as in eq. (3)[10].

$$e_P(k) = \mathrm{Im}\left\{\hat{c}_k^* x(k) e^{-j\hat{\theta}(k)}\right\} \tag{3}$$

Im(·) is imaginary part and (·)* is conjugate complex. The output of phase error detector produces phase error of $\hat{\theta}(k)$ through loop filter.

$$\hat{\theta}(k+1) = \hat{\theta}(k) + \gamma e_P(k) \tag{4}$$

Here γ is step size parameter in phase error detection process. The solution of $e_P{}^{-j\hat{\theta}(k)}$ is acquired by using the detected phase error and look-up table and then the phase of difference detection signal is compensated using feedback structure.

BER performance versus frequency offset compensation for CQPSK is depicted in Fig. 9. BER performance versus frequency offset compensation for $\pi/4$

shift DQPSK is depicted in Fig. 10. The normalized loop bandwidth of symbol timing recovery and frequency offset compensation feedback system was settled as 0.001. When frequency offset compensation is working and frequency offset is 10 %, 0.5 dB of performance loss for CQPSK and 1.0~1.5 dB of performance loss for $\pi/4$ shift DQPSK were produced.

Ⅳ. Implementation of Modulation Scheme using DSP

The modulation/demodulation scheme was implemented in TMS320VC5510 DSK board of Spectrum Digital by using C language to analyze CQPSK implementation issue[11]. The whole test configuration was set up as in Fig. 11 and the signal transmitting process is described in Fig. 12.

LDU(Logical link Data Unit) frame described in Project 25 standard for the voice transmission is generated with random data and then is transformed into I/Q signal in transmitting path. One LDU frame is composed of 864 symbols including 24 frame synchronization symbols. Interpolation method was used in implementing raised cosine filter for transmitting pulse shaping to save calculation time. One symbol period is represented with 10 samples for each I, Q component. Since sampling rate is defined as 48,000 sample/sec, the symbol rate becomes 4,800 symbol/sec. The

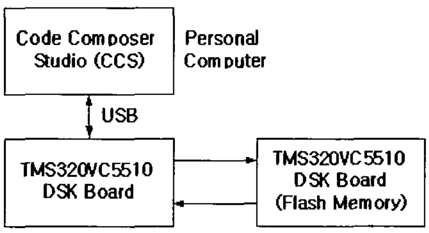

Fig. 11. Test configuration of modulation/demodulation using DSP board.

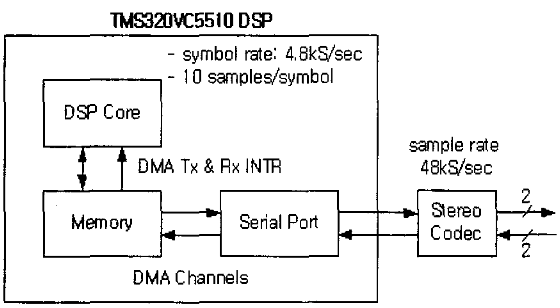

Fig. 12. Signal transmitting process in DSP board.

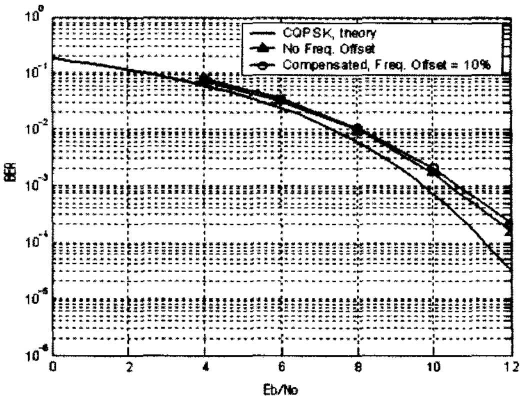

Fig. 13. BER performance of CQPSK implemented with DSP by using frequency offset compensation.

samples are moved to transmitting buffer through DMA(Direct Memory Access) Tx interrupt routine and then are transferred to transmitting resister in serial port through DMA channel, finally are transferred to codec.

In receiving path, the samples received at serial port through codec are transferred to receiving buffer through DMA. Each 10 sample of I and Q component is moved from receiving buffer to other place of memory through DMA Rx interrupt routine and then is processed in demodulation program. After the received samples are passed through filtering, symbol timing recovery, frequency offset compensation algorithm, and difference detection, original symbol is detected. The data is retrieved after detecting the starting time of frame through frame synchronization detection using correlation. The BER is calculated by comparing the data with original transmitting symbol.

Feedback symbol timing recovery algorithm using Gardner timing error detector was implemented for symbol timing recovery[12]. Phase compensation of feedback difference detected signal was implemented for frequency offset compensation. CQPSK BER performance was described in Fig. 13. The loop bandwidth of symbol timing recovery feedback system is 0.001 and loop bandwidth of frequency offset compensation system is 0.005. The loop bandwidth of frequency offset compensation system did not affect BER performance, relatively. When frequency offset is 10 %, 1.0 dB of performance degradation comparing with theoretical value was produced at BER=10^{-3}.

Ⅴ. Conclusions

This paper presents the influence of non-matched filter and frequency offset on the performance of APCO Project 25 FDMA modulation scheme. This modulation scheme can be applied to the current domestic simple two-way radio that uses ultra-narrowband.

When non-matched filter is applied instead of matched filter, the SNR performance decreases by 0.5~1.0 dB. The 2 % frequency offset causes about 1 dB Eb/No performance degradation at 10^{-3} BER. Proposed frequency offset compensation scheme makes the performance of overall system less sensitive to frequency offset. At 10 % frequency offset, the performance with compensation scheme is almost same as the performance at 2 % frequency offset without it. This scheme can be applied to digital simple two-way radio system.

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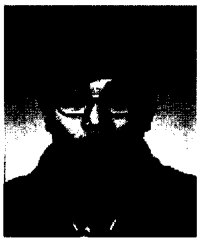

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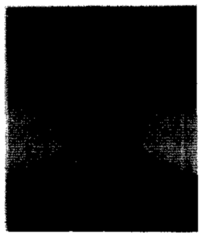

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