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Performance Comparison of Two Real Coefficients and a Complex Linear Equalizer in Shallow Water Situation

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1. Introduction

In underwater acoustic communication, the channel estimate based equalizer is adopted to compensate ISI effect[1)-3)] owing to the reflected signals from surface and bottom. In this study, FFE with LMS algorithm[4)-5)] is applied for BPSK transmission system to cancel out ISI effect. We introduce a BPSK system with two real and a complex coefficient equalizer using Hilbert transform like as Q-channel of QPSK system[6-7)]. The performance of a complex coefficient equalizer is better than two real coefficients one.

2. Concept of Complex Coefficient Linear Equalizer and Simulation Results

Generally, there are two channels – I channel and Q channel – in QPSK mod & demodulation system. The transmitted signal $x(t)$ is demodulated separately to output signal $y_I(t)$ and $y_Q(t)$ using cosine signal or sine signal with same carrier frequency of modulation system, and output signals are converted to 4 states {00, 01, 10, 11} data from each output signal $y_I(t)$ and $y_Q(t)$. When the equalizer is applied to output signal, two types of system are possible. One is to apply two separated real coefficient equalizers on each output signal $y_I(t)$ and $y_Q(t)$. The other is a complex coefficient equalizer on merged output signal $y(t)=y_I(t)+jy_Q(t)$.

Fig. 1 shows a simulation model. The range between the transmitter and the receiver is set to be 10, 20, 50, 100, 200, or 500m. The depth of the transmitter and the receiver set to be 7 m and 20 m are respectively. For the implementation of underwater acoustic communication channel, the image method[8)] is used and channel impulse responses are presented in **Fig. 3**. We assumed that the channel response had 5 impulse signals – direct signal, surface reflected signal, bottom reflected signal, surface-bottom reflected signal, and bottom-surface reflected signal. The sampling frequency and carrier frequency are set to be 160 kHz and 20 kHz respectively. The transmission rate are set to be 100, 200, 500, 1000, 2000, 4000sps. The transmitted image is standard Lena image which consists of 50X50 pixels and 8 bit resolution.

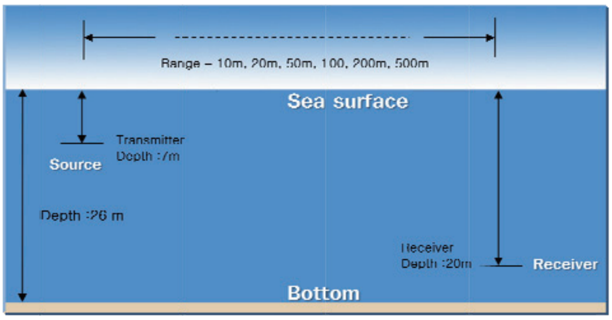

Fig. 1 Simulation model

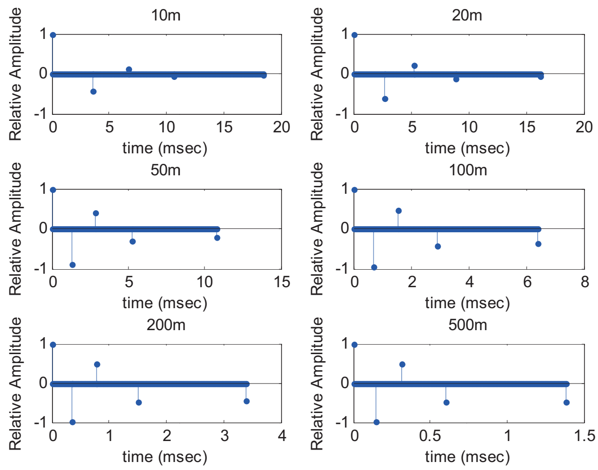

Fig. 2 Channel response according to ranges

In the FFE, $m(n)$, $y(n)$, $z(n)$, $e(n)$ and $\hat{m}(n)$ are assumed binary data in modulation system, channel output, equalizer output, error signal, and decision output respectively. LMS algorithm is used in order to compensate for the ISI. The FFE is consist of a transversal finite impulse response filter with taps to be 30. The filter output, estimation error and tap-weight adaptation are represented as[5)]

$$z(n) = \mathbf{w}^H(n)\mathbf{y}(n) \quad (1)$$
$$e(n) = m(n) - z(n) \quad (2)$$
$$\mathbf{w}(n+1) = \mathbf{w}(n) + \mu\,\mathbf{y}(n)\,e^*(n) \quad (3)$$

Here H, $*$ and μ are Hermitian form, complex conjugate and step size parameter, respectively.

Fig. 3 shows the simulation results of two different equalizers on QPSK system and the error rate to transmission rate and range are shown for different type equalizers. The complex coefficient LMS equalizer is better than the two separated real coefficient LMS equalizer.

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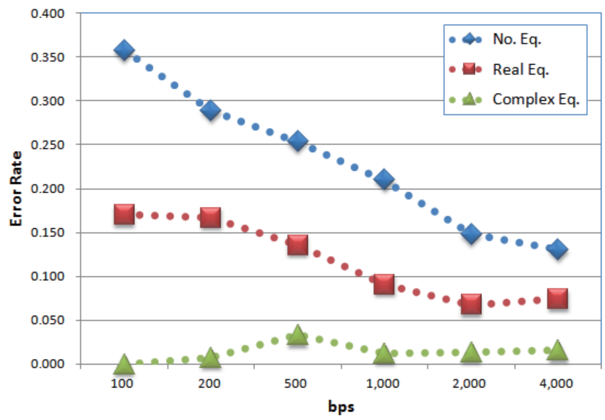


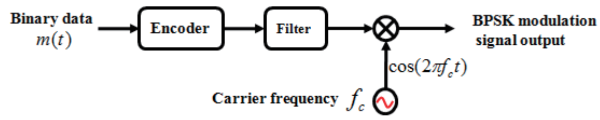
Fig. 3 Results comparison on QPSK system with two different equalizers

This result is applied in BPSK system. BPSK system has same structure like as I-channel of QPSK system and there is two states {0, 1} and has only I-channel. To introduce Q-channel signal, the Hilbert transform is adopted. Hilbert transform is represented as[6)-7)]

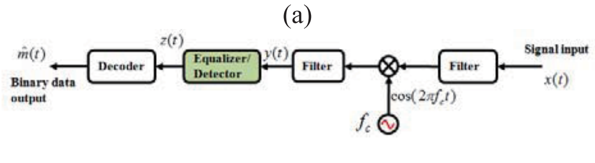
$$H[y(t)] = \int_{-\infty}^{\infty} \frac{y(u)}{\pi(t-u)} du = y_I(t) + jy_Q(t) \quad (4)$$

It is obtained imaginary signal $y_Q(t)$ with a 90° phase shift from original real signal $y_I(t)$. The imaginary part of the binary data in modulation system $m(n)$ is also calculated for estimation error calculation in Eq. (2). BPSK modulation, BPSK demodulation system with a real coefficient equalizer and a complex coefficient equalizer are shown as **Fig. 4**.

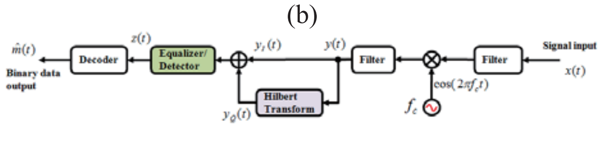
Fig. 5 shows the simulation results of two different equalizers on BPSK system.



(a)



(b)



(c)

Fig. 4 Block diagram of BPSK communication system
(a) BPSK modulation system, (b) BPSK demodulation system with a real coefficient equalizer, (c) BPSK demodulation system with a complex coefficient equalizer

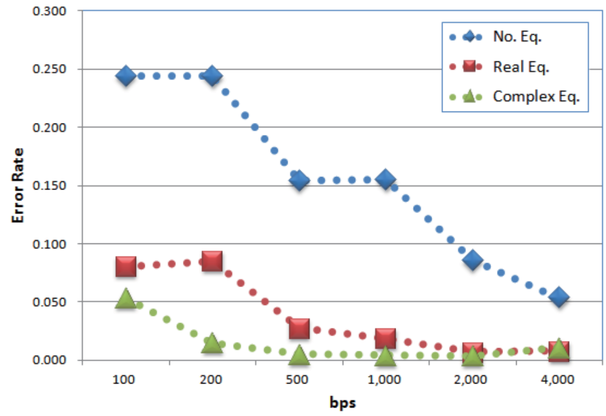


Fig. 5 Results comparison on BPSK system with two different equalizers

3. Conclusions

In this study, FFE with LMS algorithm is applied in QPSK system, and two real coefficients and a complex coefficient equalizers are adopted and compared the results each other. The Hilbert transform is applied in real coefficient BPSK system to get the complex coefficient BPSK system. The performance of a complex coefficient equalizer is also better than two real coefficient one in complex coefficient BPSK system.

Acknowledgment

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