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Inter-Symbol Interference with Impulse Response and its Effect for Acoustic Communication
音響通信におけるインパルス応答の影響とシンボル間干渉

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1. Introduction

The inter-symbol interference (ISI) is one of the problems that need to be overcome for wireless digital communications. Therefore, to minimize an ISI effect is the objective in the design of the wireless digital communication system. Among numerous researches about acoustic digital communications[1-5)], there are preceding studies about the quantitative evaluation of the ISI, and the communication method to overcome the ISI due to multipath environment. While the quantitative evaluation of the ISI and methods to overcome the ISI due to multipath environment for the acoustic digital communication have been well investigated, the ISI due to band-limiting of channels is not really investigated. In the acoustic digital communication, the channel band-limiting is caused mainly due to an impulse response duration of transducers, because many acoustic communication systems use transducers in the mechanical resonance state to achieve a high electroacoustic conversion efficiency. Evaluating the ISI effect owing to the band-limiting of channels quantitatively can contribute actively to the acoustic digital communications, when the ISI effect of the impulse response duration of transducers is dominant rather than that of multipath environment, like short range communications.

This study is aimed to investigate the ISI effect due to an impulse response duration of transducers for the acoustic digital communication. Specifically, we investigated signal-to-noise ratio (SNR) characteristics by measuring bit-error-rate (BER) for all digital bit patterns, and clarified the relationships among the digital bit pattern, the ISI effect, and a communication quality.

2. Experimental environments and conditions

2.1 Performance evaluation system

Figure 1 shows a performance evaluation system for the acoustic communication. This system consists of a personal computer (PC), digital to analog and analog to digital converters (DAC, ADC), a speaker amplifier, a transmitter, a receiver, a microphone amplifier, and a sound propagation path. The transmitter is a piezoelectric vibrator whose resonant frequency is designed to be 40 kHz, and the receiver is an omnidirectional wideband capacitor microphone. The transmission signal is created and modulated by LabVIEW in the PC. The transmitted signal from the transmitter propagates the channel and is received by the receiver, then white Gaussian noise is added to the received signal and demodulated by LabVIEW in the PC.

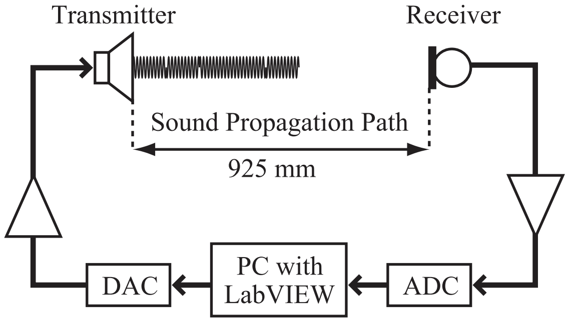

Fig. 1 Block diagram of a performance evaluation system for acoustic communication system.

2.2 Experimental condition

We evaluated the relationships among the digital bit pattern, the ISI effect, and a communication quality experimentally by using a performance evaluation system as shown in Fig. 1. **Table I** shows the parameters which is used for this experiment. The transmit data length is 6 bits. We modulate all 64 bit patterns from '000000' to '111111' by bi-phase shift keying (BPSK). The carrier frequency is 40.25 kHz which is equal to the measured resonance frequency of the transmitter. The symbol time is 120 μs and the sampling frequency is 1.5 MHz. We adopt a roll-off cosine filter to the modulated signal whose roll-off rate is 0.5 in order to limit the signal bandwidth.

Table I: Parameters which is used for experiment.

Transmit data length	6 bits
Modulation	BPSK
Carrier frequency	40.25 kHz
Symbol time	120 μs
Sampling frequency	1.5 MHz
Roll-off rate	0.5

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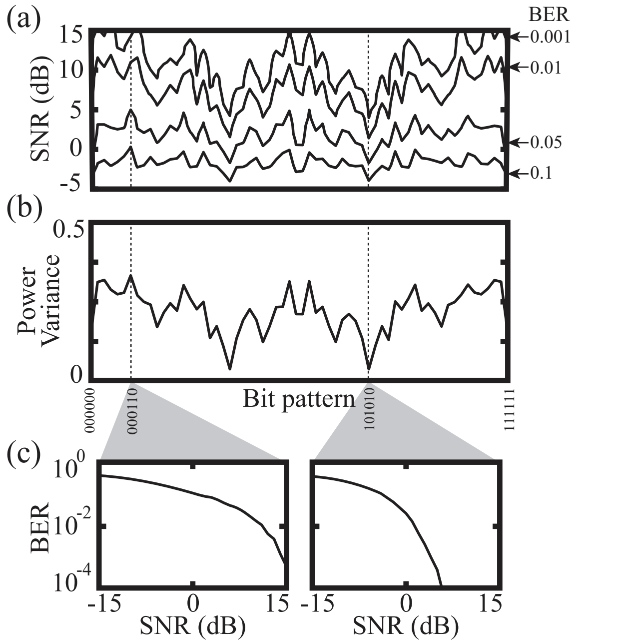

Fig. 2 Obtained results; (a) Contour line of BER in each bit pattern. (b) Variance in each bit pattern. (c) BERs when bit pattern is '000110' and '101010'.

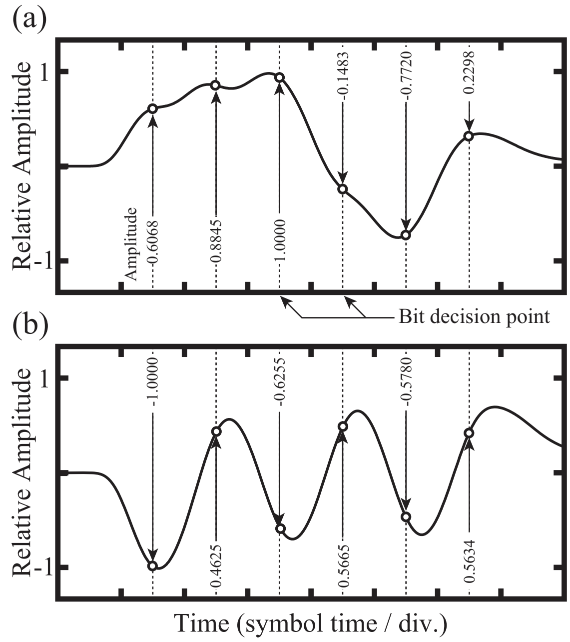

Fig. 3 BPSK demodulated signals;
(a) Demodulated signal when bit pattern is '000110'.
(b) Demodulated signal when bit pattern is '101010'.

3. Experimental results

We measured BER of each bit pattern by changing SNR from -15 dB to 15 dB every 1 dB for 10,000 times. The obtained results are shown in **Fig. 2**. Figure 2(a) shows the contour line of the BER in each bit pattern and the SNR. Figure 2(b) shows the power variance in each received symbol pattern. Figure 2(c) shows the BERs when the bit pattern is '000110' and '101010' in which the worst and the best SNR characteristics is achieved in this experiment. From Fig. 2(a), there are distributions of BERs. Moreover, a relationship between the SNR characteristic and the power distribution of bits can be confirmed in Fig. 2(a) and Fig. 2(b). There is a correlation between the SNR characteristic and the variance of the received symbol power. As the power varies in each bit, the SNR characteristic worsens. This distribution of BERs and the bit power variance are expected due to the ISI effect. In Fig. 2(a) and Fig. 2(b), the worst SNR characteristics and the maximum bit power variance is achieved when a bit pattern is `000110' and the best SNR characteristics and the minimum bit power variance is achieved when a bit pattern is `101010'. Figure 2(c) shows the BERs of '000110' and '101010'. In Fig. 2(c), BER of 10^{-3} is achieved at 14 dB in the bit pattern '000110', while the same BER is achieved at 4 dB in the bit pattern '101010'. **Figures 3(a) and 3(b)** shows the BPSK demodulated signals when bit pattern is '000110', and '101010', respectively. There are amplitude distributions due to the ISI. But the amplitude distribution due to the ISI in Fig. 3(b) seems to be improved, compared to Fig. 3(a). It is expected that the transmit digital data bit pattern should change frequently, because the ISI interferes with subsequent symbols and it worsened the SNR characteristics.

4. Conclusions

We evaluated the ISI effect by measuring SNR characteristics for all digital bit patterns. The obtained results suggest that there is a correlation between the SNR characteristic and the variance of the received symbol power. Moreover, it is expected that the transmit digital data bit pattern should change frequently to avoid the ISI effect due to an impulse response of the transducer. For example, the Manchester code is expected to be suitable for acoustic digital communications, when the ISI effect of impulse response duration of transducers is dominant rather than multipath environment, like short-range communications.

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