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Digital Acoustic Communication Scheme Suitable for Parametric Loudspeaker

パラメトリックスピーカーに適したデジタル音響通信方式

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1. Introduction

Digital acoustic communication in air plays an important role to establish a wireless link between mobile devices [1]. Existing acoustic communication system tends to broadcast the information using audible sound, resulting in interference to all non-intended receivers. Parametric loudspeakers have a potential to address this problem, since it can create directive low-frequency sound by exploiting nonlinear ultrasound-medium interaction effects, and many useful applications have been proposed such as sound projector for public spaces [2], high-resolution imaging [3], and sensing [4-5]. However, a digital modulation and demodulation technique that is suitable to such nonlinear acoustic channel has not been clarified, to our knowledge.

In this paper, we investigate a digital communication scheme that is suitable for acoustic communication using parametric loudspeaker. Specifically, we design a communication system considering nonlinear acoustic channel, and perform experiments to evaluate the performance of the proposed system.

2. Communication System Considering Nonlinear Acoustic Channel

Figure 1 shows a block diagram of the transmitter and receiver for acoustic communication using parametric loudspeaker. The transmitter reads a message, perform symbol mapping, and perform pulse shaping to obtain pulse signal $a(t)$. Next, the transmitter performs digital modulation on $a(t)$ to obtain modulated signal $b(t)$. Then the transmitter performs amplitude modulation and emits the modulated signal $[1+mb(t)]\sin 2\pi f_2 t$ to the air using the parametric loudspeaker, where m and f_2 are the modulation index ($0<m\leqq 1$) and carrier frequency, respectively. The emit signal is distorted during propagation due to the effect of air nonlinearity, and is received by the receiver as

$$r(t) = \frac{P_1{}^2 A\beta}{16\pi\rho_0 c_0{}^3 z\alpha}\left\{2m\frac{\partial^2}{\partial t^2}b(t) + m^2\frac{\partial^2}{\partial t^2}b^2(t)\right\}, \qquad (1)$$

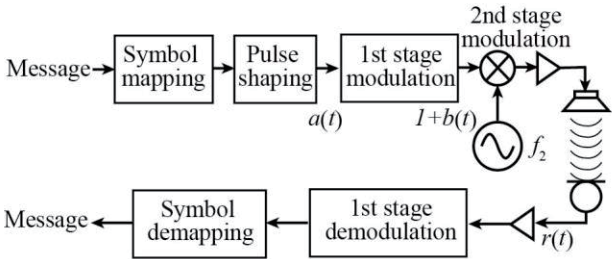

Fig. 1 Block diagram of transmitter and receiver for acoustic communication.

when $P_1 \ll 2\alpha\rho_0 c_0{}^3/\beta\pi f_2$, where P_1, A, β, ρ_0, c_0, z, and α are the sound pressure at the emitter, the radius of the circular piston source which emits the primary wave into the air, the nonlinearity coefficient of the medium, the density of the air, the small signal sound speed, coordinate along the axis of the beam, and dissipation factor corresponding to thermoviscous absorption, respectively. By analyzing Eq. (1), we found that the received signal $r(t)$, whose amplitude and phase are distorted, contains $b(t)$ and second harmonic of $b(t)$. From these findings, the use of frequency shift keying (FSK) would be suitable for acoustic communication using parametric loudspeaker, instead of other modulation techniques such as phase shift keying (PSK).

When we employ FSK as modulation technique, the modulated signal at the transmitter $b(t)$ and the received signal at the receiver $r(t)$ can be expressed as

$$b(t) = \begin{cases} g(\mathrm{t})\cos(2\pi f_0 t), & (S_0 = 0) \\ g(\mathrm{t})\cos(2\pi f_1 t), & (S_0 = 1) \end{cases} \qquad (2)$$

$$g(t) = \begin{cases} 1, & -\frac{T}{2} \leq t \leq \frac{T}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (3)$$

$$r(t) = \frac{P_1{}^2\pi A\beta}{2\rho_0 c_0{}^3 z\alpha}\begin{cases} -mf_0{}^2 g(t)\cos(2\pi f_0 t) - m^2 f_0{}^2 g(t)\cos(4\pi f_0 t), (S_0 = 0) \\ -mf_1{}^2 g(t)\cos(2\pi f_1 t) - m^2 f_1{}^2 g(t)\cos(4\pi f_1 t), (S_0 = 1) \end{cases} \qquad (4)$$

where s and T are message symbol{0,1} and symbol time, respectively. f_0 and f_1 are frequency correspond to symbol of 0 and 1, respectively.

Figure 2(a) shows the power spectrum of the received signal $r(t)$. As shown in the figure, there exist two pairs of signal spectrum that exists on the

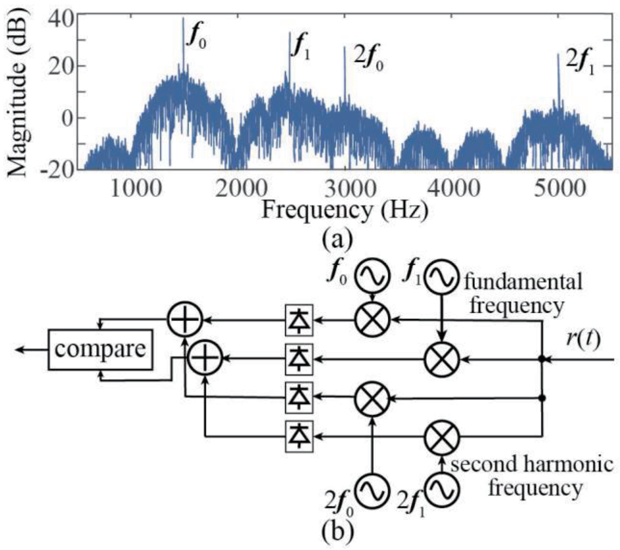

Fig. 2 (a): Power spectrum of the received signal $r(t)$, and (b): PSK receiver with frequency diversity.

fundamental frequency and its second harmonic frequency. Hence the frequency diversity technique [6] can also be utilized in the receiver to improve the communication quality, where the receiver merges the fundamental and second harmonic elements at the demodulation process, as shown in **Figure 2(b)**.

3. Experiment

We evaluate the performance of the digital acoustic communication system using the parametric speaker in experiments **Figure 3** and **Table I** shows the experimental environment and parameters used in the experiment, respectively. As shown in the figure, a parametric speaker consists of 49 ultrasonic emitters (T40-16, Nicera) is connected to the PC with softwawe transmitter via an amplifier (PM390-SE, Denon) and an digital-to-analog converter (USB-6212, National Instruments). The emit sound is recorded by a PCM recorder (DR-05, TASCAM) that is located 3 m away from the speaker, and signal demodulation is performed by a computer with software demodulator. In this experiment, FSK communication is performed using the parameters shown in Table I.

Figure 4 shows the experimental result. The horizontal and vertical axes represent signal-to-noise ratio (SNR) and bit-error rate (BER), respectively. Note that SNR is varied by changing

Table I Parameters used in experiment

Parameters		Values
1st stage modulation	T (ms)	20
	f_0 (Hz)	1,500
	f_1 (Hz)	2,500
	Data rate (bps)	500
2nd stage modulation	Modulation index m	1
	f_2 (Hz)	40,000

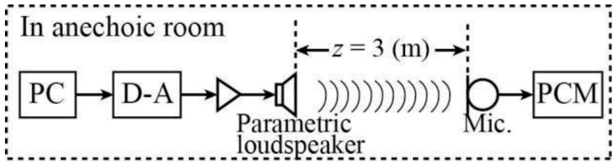

Fig. 3 Experimental environment.

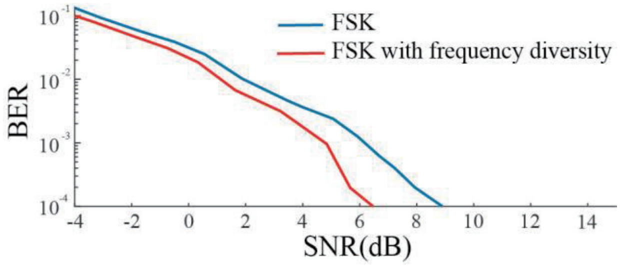

Fig. 4 Relationship between BER and SNR obtained from experiment.

noise level that is added in the software demodulator. From this figure, we found that SNR of 7 dB is necessary to achieve BER of 10^{-3} when we do not employ frequency diversity. On the other hand, the performance of communication system is improved greatly by using frequency diversity – SNR of 5 dB is enough to achieve the same BER. The obtained results suggest that combination FSK and frequency diversity is suitable for digital acoustic communication using parametric loudspeaker.

4. Conclusion

We propose a digital communication scheme that is suitable for acoustic communication using parametric loudspeaker. Specifically, we design a communication system considering nonlinear acoustic channel, and perform experiments to evaluate the performance of the proposed system. We found that SNR of 7 dB is necessary to achieve BER of 10^{-3} when we do not employ frequency diversity. On the other hand, the performance of communication system is improved greatly by using frequency diversity – SNR of 5 dB is enough to achieve the same BER.

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