June 29-July 4, 2008
www.acoustics08-paris.org

An experiment for signal identification of the MIMO communication by sonic waves

Daisuke Hayashi, Yasukazu Maeda, Toru Itakura and Hideo Shibayama

Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, 135-8548 Tokyo, Japan
m107077@sic.shibaura-it.ac.jp

Recently, the communication method by MIMO works in a field of the wireless communication. We do research on application to the MIMO system in an acoustic field by sonic wave. As the transmission method, we use the space division multiplexing (SDM) that is the method for the purpose of the improvement of the transmission rate that accepted the number of the transmission elements by sending plural signals at the same time. It is important to identify each signal from several different signals that are transmitted at the same frequency band. And, we study method for detecting each signal. This paper describes influence of the signal detection for the different conditions of the multi-path propagation.

1 Introduction

At the space that can't use electric wave (e.g. underwater and underground, and a small space), when we want to communicate that the information such as a picture or the control signal by wireless, we use a sonic wave. But at the sonic wave communication, transmission rate is limited because it uses low frequency.

Now we are studying MIMO communication by sonic wave for the improvement of the transmission rate.

MIMO is a method that is recently studied hard in the communication system which used the electric wave such as the wireless LAN, and it communicates by plural transmission and receiver elements (Multiple Input Multiple Output), and it is a communication method for the improvement of the transmission rate that accepted the number of the elements (Space Division Multiplexing-SDM).

When we communicate at the same frequency and the same time by plural transmission and receiver elements, it is an important problem to identify each signal from several different signals that are transmitted.

In addition, this method has a characteristic that it is a better condition to have much multi-path which was avoided by the conventional communication.

Therefore in this paper, we measured an impulse response (channel response) in different propagation environment, and we inspected the state that performed MIMO communication in the environment by simulation.

We describe how the identification characteristic of the signal changes by a propagation environmental difference, when we adopted this method in an acoustic field by sonic wave.

This paper consists of them as follows.

At first, in Chapter 2, we show the summary of the MIMO method, and an outline about the Zero-Forcing algorithm that we adopted this time. And we explain the receiver correlation to become the index to evaluate propagation environment, and we speak a reason that much multi-path condition is a better propagation environment at this method.

In Chapter 3, we explain the contents of the experiment, and propagation environment that we measured this time. In Chapter 4, we show the results and consideration. Chapter 5 is a conclusion.

2 MIMO System Summary

2.1 MIMO System Summary

We show the summary of the 2x2 MIMO system (speaker: 2, microphone: 2) in Fig.1. An independent signal is transmitted by the same frequency from each speaker, and through propagation path (channel); it is received by each microphone. Assume that the transmitted signals from each speaker are s_1 (t) and s_2 (t), signal m_1 (t) and m_2 (t) received by each microphone are expressed by the Eq. (1), where the h_{mn} (m=1, 2 n=1, 2) is a channel response between the speaker n and the microphone m. The n_1 (t) and n_2 (t) are noises that are independent respectively. And, Symbol * expresses the convolution operator.

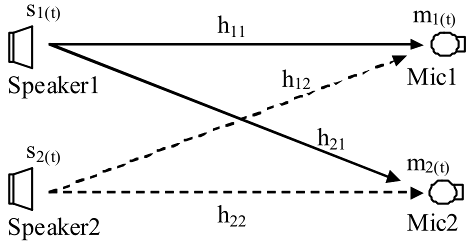


Fig.1 MIMO System Summary

$$\begin{bmatrix} m_1(t) \\ m_2(t) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} * \begin{bmatrix} s_1(t) \\ s_2(t) \end{bmatrix} + \begin{bmatrix} n_1(t) \\ n_2(t) \end{bmatrix}. \quad (1)$$

2.2 Zero-Forcing(ZF)

From Eq.(1), if we can estimate a channel response beforehand, we can distinguish the original information that has been transmitted. In this paper, we adopted simplest algorithm called Zero-Forcing (ZF) as technique of the signal identification.

In ZF, we calculate a weight matrix expressed in the following Eq.(2) by a channel response matrix H that we acquired by training signal.

$$W^T = (H^E * H)^{-1} * H^E, \quad (2)$$

where T is transpose matrix, and E is conjugate transpose matrix.

We distinguish an original signal by convolution the weight matrix of the Eq.(2) in the receiver signal.

$$s_o(t) = W^T * m(t). \quad (3)$$

Estimating the weight matrix under the condition of low S/N ratio, this algorithm has a fault that an identification characteristic extremely deteriorates. However, we think that judgment is possible enough by this method if this experiment that paid its attention to a difference of the propagation environment by the arrival situation of the multi-path.

2.3 Receiver Correlation

In the MIMO system that is represented by Eq.(2), this method distinguishes the signal by weight matrix that uses channel matrix. From this point, when the correlation of each channel response is high, the identification of the signal becomes difficult.

For example, let each response of h_{11} - h_{22} be 1. That is,

$$H = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \qquad (4)$$

Each signal received by two microphones is expressed from Eq. (1) as follow.

$$\begin{aligned} m_1(t) &= s_1(t) + s_2(t) + n_1(t), \\ m_2(t) &= s_1(t) + s_2(t) + n_2(t). \end{aligned} \qquad (5)$$

Therefore, being similar can expect only the reduction effect of the noise then even if there are plural receiving elements.

This is a reason said to that there had better be a lot of multi-path in MIMO. When a signal transmitted by each speaker is received each through the different path by each microphone, correlation falls down, and the identification degree of the signal improves.

On this accounts, we calculate receiver correlation to show in the Eq.(6) as an evaluation method of the channels in each propagation environment.

$$\rho_{ij} = \frac{\sum_{f=1}^{F} \sum_{k=1}^{K'} h_{ik}^{*}(f) h_{jk}(f)}{\sqrt{\sum_{f=1}^{F} \sum_{k=1}^{K'} |h_{ik}(f)|^2} \sqrt{\sum_{f=1}^{F} \sum_{k=1}^{K'} |h_{jk}(f)|^2}} \qquad (6)$$

This value becomes the complex number, but it is the absolute value that influences a characteristic, and if the value is lower that propagation path is easily identified.

3 Experiment Contents

3.1 Summary

By the experiment, we carried out for five different propagation environments and measured a channel response in each environment. On this occasion, we set up the 2x2 MIMO communications that are constructed by two speaker and two microphones. Frequency of carrier wave is 1.9 kHz. The distance between the speakers and the microphones is 9cm that become the half wave length.
In measuring the channel response, transmitted some TSP signals that are in 0.02-10 kHz frequency band, from the speaker. And acoustic signal received by the microphone is quantized by an A/D convert with sampling frequency 20 kHz.

Using the channel responses obtained by the experiment, we evaluate the propagation environment. And, we simulated the environmental conditions that communicated by the QPSK signal which is made on a PC.

3.2 Propagation Environment

Figures 2-6 show the experimental setup of the propagation environment. For the first experiment condition (AEC), we select that the influence condition for the multi-path is little. In Fig.2, the speakers (S_1, S_2) and microphones (M_1, M_2) in an anechoic room whose size is 1.8 m (H) x 1.8m (W) x 1.6m (D).

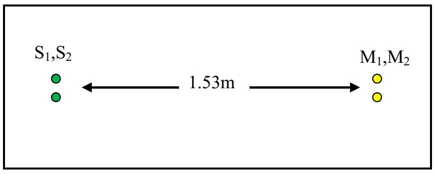


Fig.2 AEC (multi-path: little)

For the second experiment condition (AwR), the multi-path in a propagation environment is generated by a metal board reflector whose size is 1.0m (H) x 0.6m (W) (thickness: 3mm).

Figure 3 shows the experimental setup in the anechoic room.

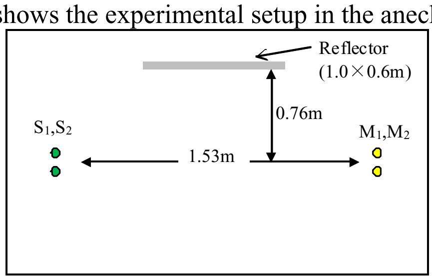


Fig.3 AwR (multi-path: more than one)

For the third experiment condition (ROOM), we measured in an ordinary room without acoustic material. Figure 4 shows the measuring setup. Reflected waves are generated on the rigid walls in the room. And, multi-path is in the propagation path between the transmitters and the receivers.

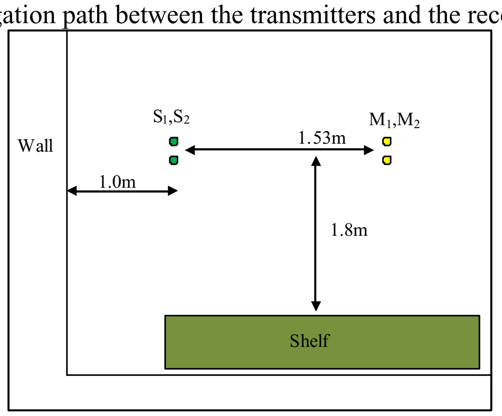


Fig.4 ROOM (multi-path: much)

For the fourth experiment condition (RwR), we measured again in the ordinary room shown in Fig.4 under a different measuring condition for the third experiment condition.

In the experiments, the direct waves from the speakers are not received in transmission waves measured by the microphones. Figure 5 shows the fourth experiment setup. No direct wave by use of the reflector board shown in Fig. 3.

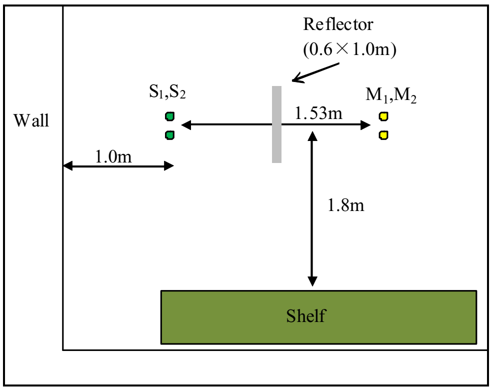


Fig. 5 RwR (multi-path: much, no direct wave)

Finally (PIPE), in Fig.6, we changed some environment and measured a channel response in a pipe of a diameter of 20cm. In this case, there is much multi-path with short delay.

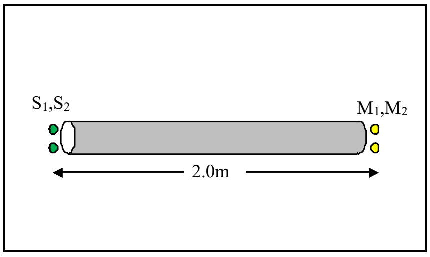


Fig. 6 PIPE (multi-path: much, short delay)

4 Result and Consideration

4.1 Receiver Correlation

Figure 7 shows the calculated results of the receiver correlation by Eq.(6) for each environment mentioned above. The symbol O represents the correlation coefficient at 1.9 kHz.

The correlation coefficient calculated under five different transmission conditions is shown in Table 1. Under the AEC, the correlative coefficient is highest. And, under the RwR, the value is the lowest value.

In ROOM, we expressed environment with much multi-path, but became a high correlative coefficient in comparison with AwR and PIPE which have the reflector that the level of the reflection wave is large.

Table 1 Transmission condition and correlation coefficient

Transmission condition	Correlation coefficient
AEC	0.92
AwR	0.55
ROOM	0.8
RwR	0.42
PIPE	0.52

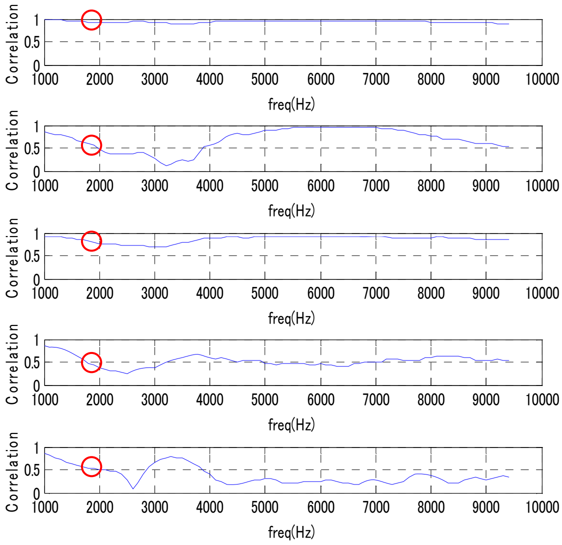


Fig. 7 Receiver Correlation

4.2 Communication Simulation

Next, we simulated it about the state that communicated in the propagation environment that we measured. In the simulation, to express a communicating state, we convoluted the QPSK signal which was made on a PC, and each channel response that was measured.

The QPSK signal is symbol rate 250sps (500bps) at carrier wave frequency 1.9 kHz. In addition, in all environments, Eb/No are 10 dB, and we do not take the error correcting.

At first we show constellation in AEC and AwR in Fig.8. The upper sections in a figure are constellation in the M_1 before performing signal identification by ZF, and the lower sections are the result that we distinguished by ZF by the data.

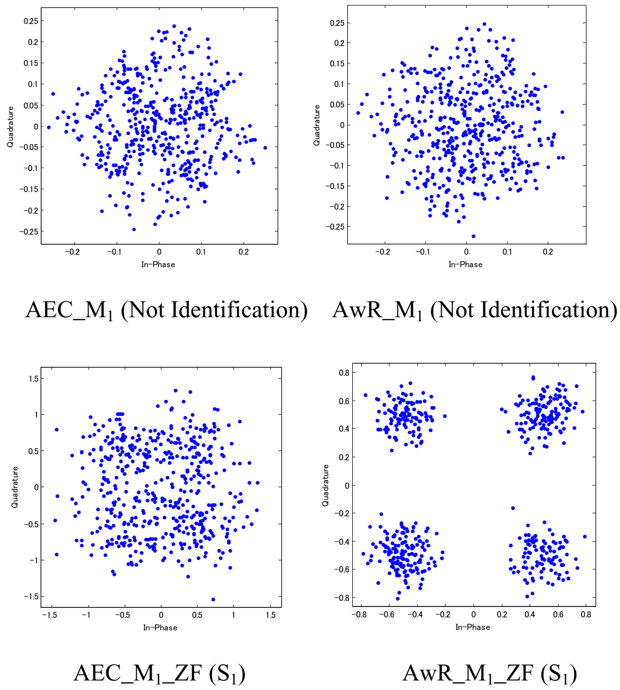


Fig.8 Constellation AEC, AwR

In this figure, we see that the identification of the signal is more difficult in AEC which has little multi-path, and that identification is easy in AwR which has multi-path more than at least one.

In Fig.9, we show the channel responses in both environments.

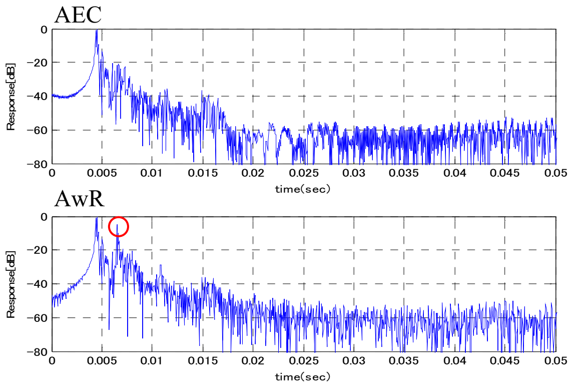
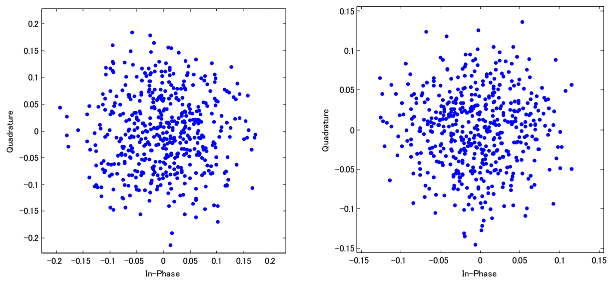


Fig.9 Channel Response AEC, AwR (S_1-M_1)

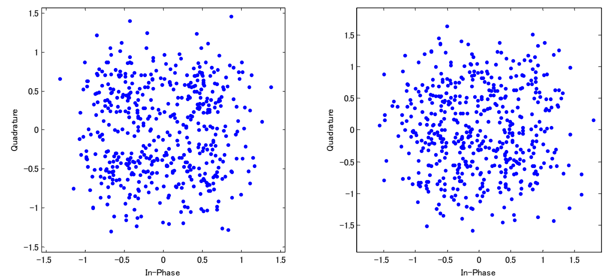
But this adopts a channel response between M_1 and S_1, and the amplitude does normalization at the level of the direct wave.

In the figure of AwR, because the main reflection wave is only one, in the case of 2x2 MIMO, we see that identification is enabled if there is at least one reflection wave.

Next, we show constellations of ROOM and RwR in Fig.10.



ROOM_M_1 (Not Identification) RwR_M_1 (Not Identification)



ROOM_M_1_ZF (S_1) RwR_M_1_ZF (S_1)

Fig.10 Constellation ROOM, RwR

At ROOM and RwR, although there is plural multi-path and the correlative coefficient is lower than AEC, an identification result is not good.

This is thought the ISI (Inter-Symbol Interference) by the influences of the delay wave.

In Fig.11, we show the both environment's transfer functions that are neighborhood of carrier wave frequency (BW=1 kHz).

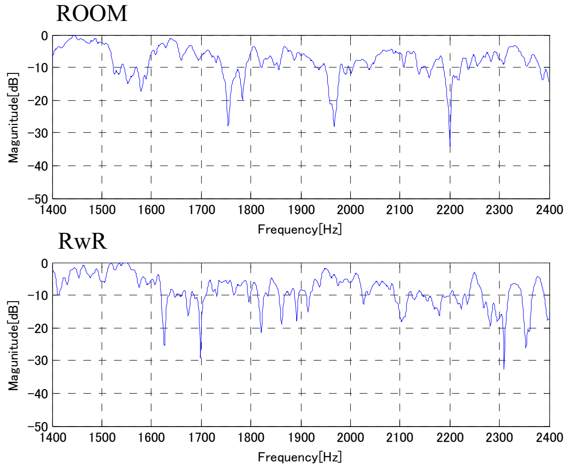
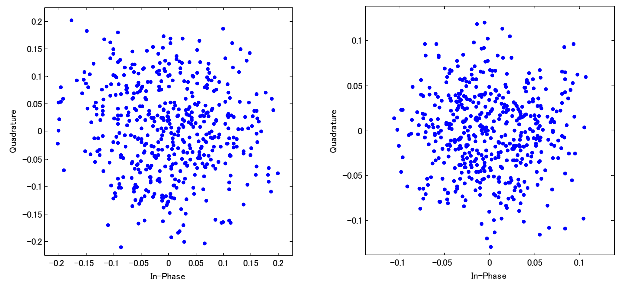


Fig.11 Transfer Function ROOM, RwR (S_1-M_1)

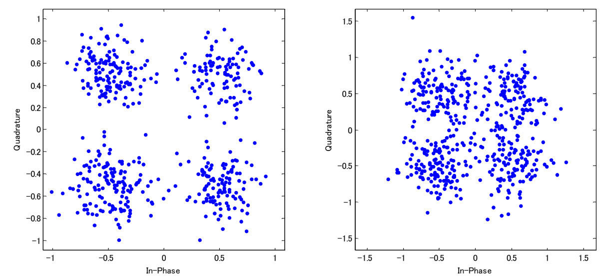
But this adopts a transfer function between M1 and S1, and the amplitude does normalization with the maximum in a band.

In this figure, we see that ISI occurs, because frequency selectivity fading produces even transmission rate of the 250sps degree.

Than this, we show the result in Fig.12, when we lowered transmission rate to 50sps in ROOM and RwR.



ROOM_M_1 (Not Identification) RwR_M_1 (Not Identification)

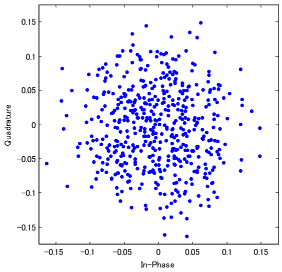


ROOM_M_1_ZF (S_1) RwR_M_1_ZF (S_1)

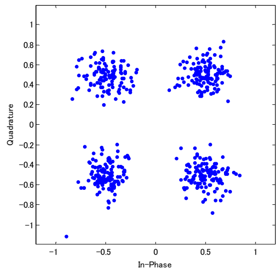
Fig.12 Constellation_50sps ROOM, RwR

Influence of selectivity fading decreases in ROOM, and an identification characteristic improves, however, in RwR which we cannot reduce influence to of selectivity fading, although some improvement is seen, it followed that the identification was difficult.

Finally, in Fig.13, we show constellation in PIPE.



PIPE_M$_1$ (Not Identification)



PIPE_M$_1$_ZF (S$_1$)

Fig.13 Constellation PIPE

PIPE has much delay wave like ROOM and RwR, and it takes low correlation coefficient, but a lot of the delay time of the delay wave is short in comparison with the direct wave. This transfer function is shown in Fig.14.

Therefore the ISI did not occur, and a good identification characteristic was provided. However, if we give more transmission rate, it is easily expected that ISI occurs under influence of frequency selectivity fading.

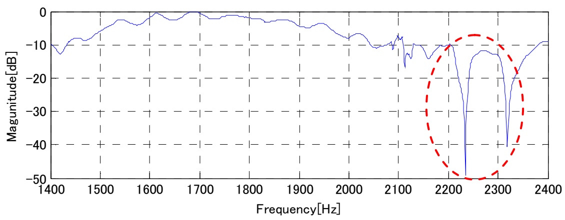


Fig.14 Transfer Function PIPE (S$_1$-M$_1$)

5 Conclusion

For realization of the MIMO communication by sonic wave, we studied the signal identification in various environments.

As a result, at first we see that the MIMO communication by sonic wave is possible, and that the environment that has plural multi-path takes good identification characteristic. In the case of 2x2 MIMO, if there was a main reflection wave more than one, identification was possible.

However, when we think about more general applications, we cannot ignore influence of ISI by the delay wave. In the acoustic field, we can expect suitable environment for MIMO that has much multi-path and low correlation coefficient. However, in this environment, if we are aimed to the improvement of the transmission rate, the ISI will be the problem that we cannot avoid.

The influence by the delay wave can decrease if we use equalization algorithm such as the MLD (Maximum Likelihood Detection), and if we can perform equivalence of value definitely, it is known that the communication capacity improves more depending on a correlative value.

We will study on the base of this equivalent equalization algorithm for the realization of the sonic MIMO communication in future.