An UWA OFDM Communication System with Improved Doppler compensation and Initial Synchronization

Shiho Oshiro[1)], Yukiko Muller[1)], Hiromasa Yamada[2)] and Tomohisa Wada[3)]

1) Graduate School of Science and Engineering University of the Ryukyus, Okinawa, Japan
2) OKI Com-Echoes, Shizuoka, Japan
3) Dept. of Engineering, University of the Ryukyus, Okinawa, Japan

***Abstract*—This paper describes an UWA OFDM Communication System with Improved Doppler compensation and Initial Synchronization. We proposed an underwater acoustic OFDM communication system to transmit image or movie data from deep see AUV etc. to surface ship in 2016. By performing experiment in the ocean at depth of 1000m, BER of approximately less than 1E-2 has been successfully obtained using 64QAM without any error compensation. Next, we proposed a new Doppler compensation algorithm of underwater acoustic OFDM communication system in 2020. In this paper, function (CTF) compensation, and the accuracy could be further improved. We simulated previous system and new system. The previous system deteriorated from the initial speed of 3 m/s, but the proposed has stable reception. With CTF compensation can be seen that the slope is improved because the CTF compensation is performed for each an OFDM symbol using the CP signal. Pool experiment was same results as simulation, but it could not support multipath. That will probably need more research in the future.**

Keywords—Underwater, Acoustic Communication, Networking, OFDM, Doppler effect, UWA, CTF

I. INTRODUCTION

In recent years, deep sea exploration has become indispensable due to the development of offshore natural resources such as hydrothermal deposits. To accelerate the creation of seafloor fine topographic maps, deep sea area such as more than 3000 meter must be scanned by Autonomous Underwater Vehicles (AUVs). But every time collect AUVs that scanned seafloor are take a lot of time and reduce a battery. Exploration will be more convenient if high-speed AUVs and motherships can transmit data via underwater acoustic wireless communication. Therefore, it is expected that the High bandwidth of acoustic wireless communication between moving AUVs and motherships as Fig.1. In order to solve this problem, we researched aimed at achieving effective Two steps Doppler compensation Algorithm from moving AUV to AUV/ mothership for OFDM-based UWA communication system based on previous research[1]. But the maximum detectable initial velocity of the AUV was 3m / s[2]. To further improve the accuracy, we proposed two new methods and confirmed the improvement of performance.

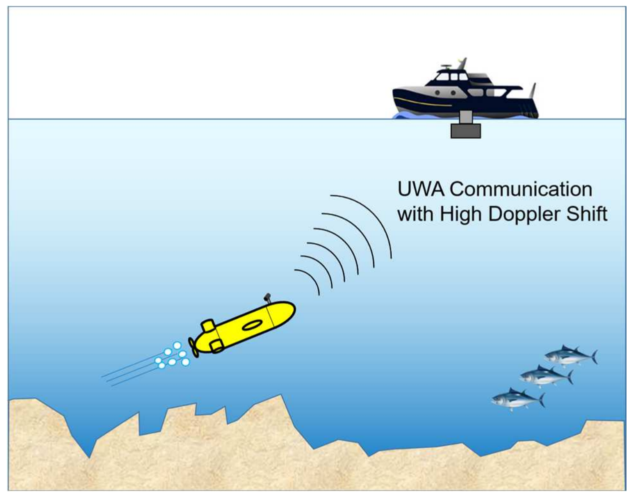


Fig. 1: UWA communication with a high-speed Moving AUV

This paper describes previous research, an UWA OFDM communication system with improved doppler compensation and initial synchronization and pool experiment. The section II describes How to improve doppler effect, work on simulation etc. the detail of previous research. And we propose more improved architecture based on previous research in the section Ⅲ. Pool experiment results are shown in section Ⅳ. Finally, the summary is concluded in section V.

II. PREVIOUS RESEARCH

Fig. 2 shows the Block diagram of typical UWA OFDM Communication system. The upper side is transmitter (TX) while lower side is the receiver (RX). The TX is Conventional OFDM transmitter, but RX has additional Time-Domain doppler compensation potentiality. First, bit information will be mapped using digital modulation schemes like QPSK / 16 QAM /64QAM. Known data is transmitted in the block of pilot insertion. Known pilots contributes to estimating the channel at

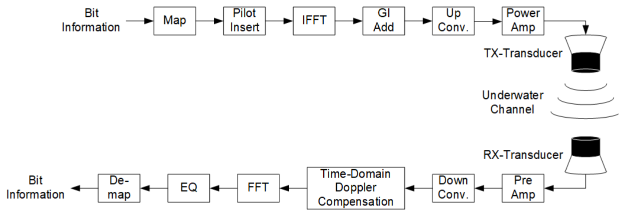


Fig. 2: Typical UWA OFDM Communication system

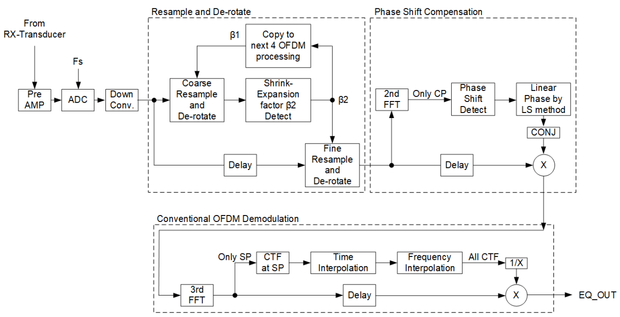


Fig. 3: Previous receiver system block diagram

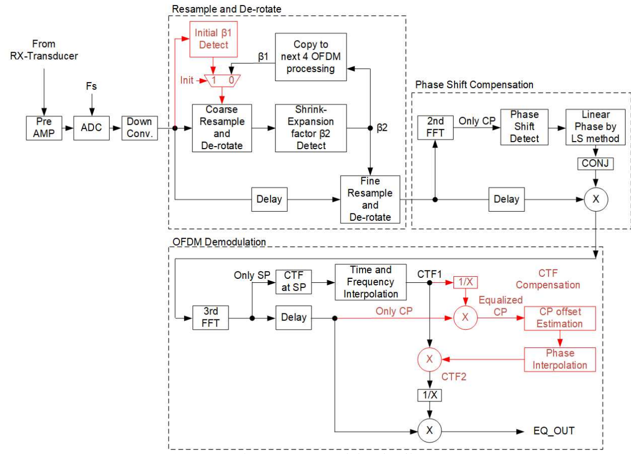
the receiver. Each OFDM symbol is converted to time domain using an inverse Fast Fourier Transform (IFFT) operation. A Guard Interval (GI) is attached at the beginning of each time domain OFDM symbol to overcome the distortion triggered by Inter Symbol Interference (ISI) in the channel. Then the baseband signal is up converted into the center frequency of 20 kHz. Finally, the OFDM passband signal amplified with the power amplifier is emitted from TX transducer into underwater acoustic channel. In the RX side, generally the reverse operations of TX are performed.

The previous receiver system block diagram is shown in Fig. 3. Time-Domain Doppler Compensation part is around upper side by a dotted line. Left side is resample and de-rotate, right side is phase shift compensation. The receiver structure is included an estimation of the GI position (symbol timing), Doppler shift compensation and channel estimation. This diagram already mentioned in previous algorithm [1 - 3]. In our previous proposed algorithm, it has implemented 2 stage Beta (Shrink-expansion) Detection factor, Peak shape cross correlation method and Linear phase error estimation by LS method in Time-Domain doppler compensation block.

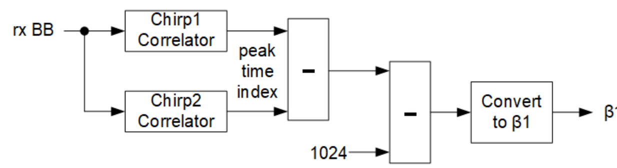
III. Improved Architecture

A. Architecture

From this section, we propose the function (CTF) compensation, and the accuracy could be further improved. Fig. 4 shows Proposed Receiver Block Diagram. (1) is receiver system block diagram. The upper side is this system detects the



(1) Receiver system block diagram



(2) Block diagram of initial beta 1 detector

Fig. 4: Proposed receiver system block diagram with (1) receiver system block diagram and (2) block diagram of initial beta 1 detector

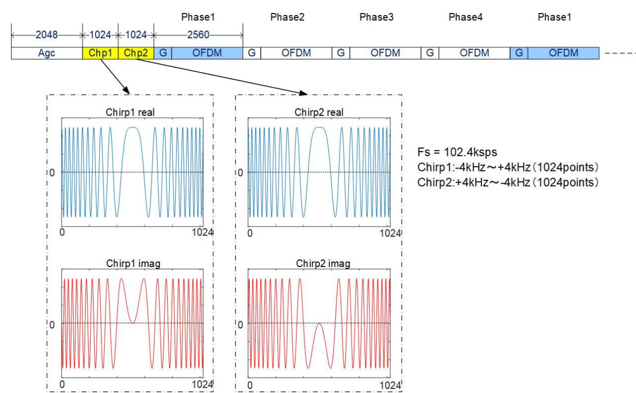


Fig. 5: OFDM time domain signal with prefix

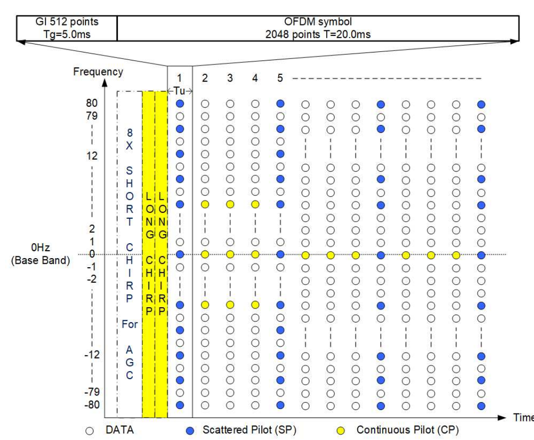


Fig. 6: Time-Frequency structure of OFDM

initial phase shift β1 using a chirp signal. Lower side is CTF-corrected SP signal and 13 phase-corrected CP signals Corrected and added and improved the equalizer. As a result, it be able to confirm that the BER value was reduced, and the performance was improved even when moving at high acceleration. (2) is block diagram of initial beta 1 detector. It shows OFDM Signaling Packets with two Chirp preamble for Initial beta1 detection. This is a method of correcting the Doppler effect by inserting two long chirp signals at the beginning of an OFDM signal, detecting the difference in frequency between the two signals, and applying that value to the initial value of β1. The detail of (2) is shown in Fig. 5. Each chirp signal has a sampling frequency of 102.4ksps. Chirp 1 is -4kHz ~ +4kHz and chirp 2 is +4kHz ~ -4kHz.

The detail of OFDM packet in a time-frequency grid is shown in Fig. 6. The transmission of one OFDM symbol consist of 161 number of subcarriers. Out of which 81 are utilized as Scattered Pilot (SP), 13 as Continuous pilot (CP), while the rest serves as Data. The SP is positioned equally spaced in every 2 subcarriers interval in one OFDM symbol. SP allows the accurate interpolation of channel response simultaneously. CP is positioned equally spaced in every 12 sub-carrier intervals visible with yellow circle. The CP is used to estimate phase shift along time axis for phase compensation.

B. Simulation

Table. 1 shows the signaling system parameters. FFT size is 2048, OFDM symbol length is 20.0 ms (2048 point), GI length is 5.0 ms (512 point), Number of sub-carrier is 161, scattered pilot is 81 every 4 OFDM symbol, Continuous pilot 13 and carrier modulation is QPSK/16QAM/64QAM.

TABLE Ⅰ: SIMULATION PARAMETERS

Parameters	Value
Sampling Frequency Fs	102.4 kHz
Band Width	8 kHz
FFT size	2048
OFDM symbol length T	20.0 ms (2048 point)
Guard Interval length Tg	5.0 ms (512 point)
Sub-carrier spacing	50 Hz
Number of sub-carrier	161
Scattered pilot	81 every 4 OFDM symbol
Continuous pilot	13
Carrier Modulation	QPSK/16QAM/64QAM

it simulated to compare previous system with new system are shown in Fig. 7 to Fig. 10. Modulation is 64QAM, 193 OFDM.

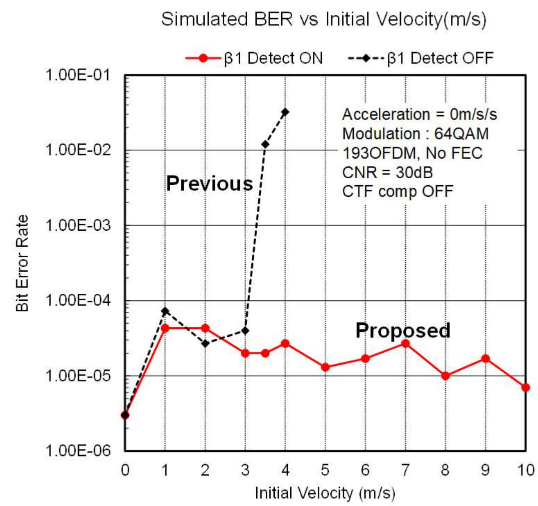


Fig. 7: Simulated BER vs Initial Velocity

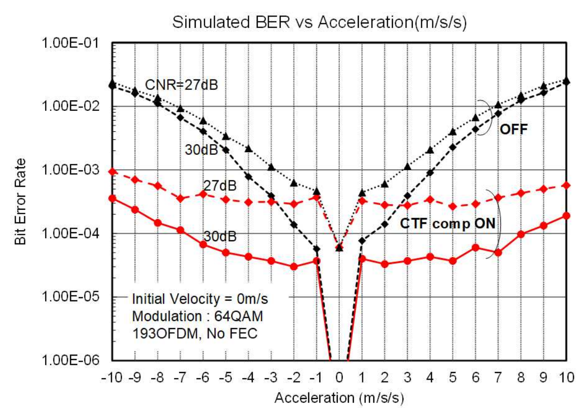


Fig. 8: Simulated BER vs Acceleration(m/s/s)

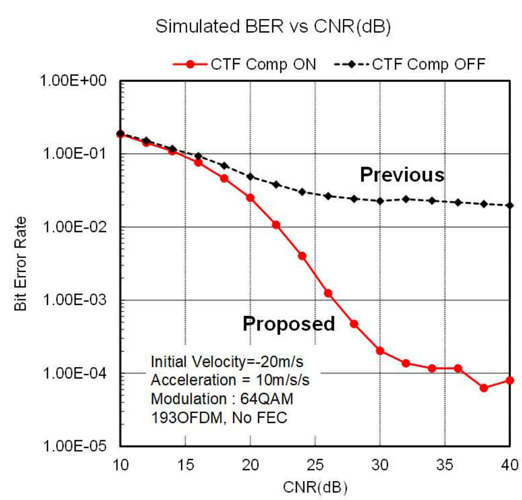


Fig. 9: BER vs Initial Velocity comparison for Initial beta1 detect

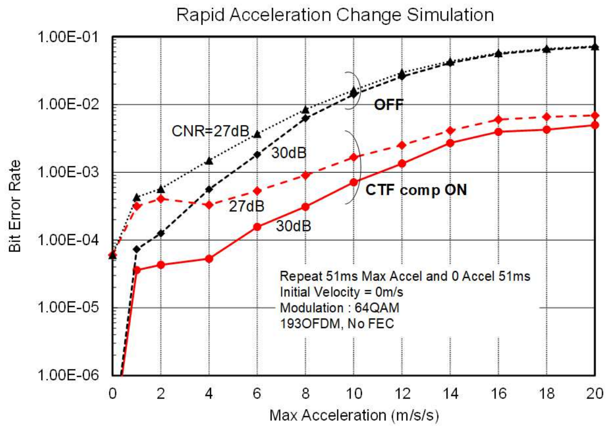
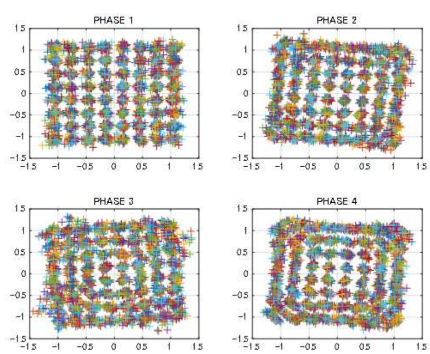
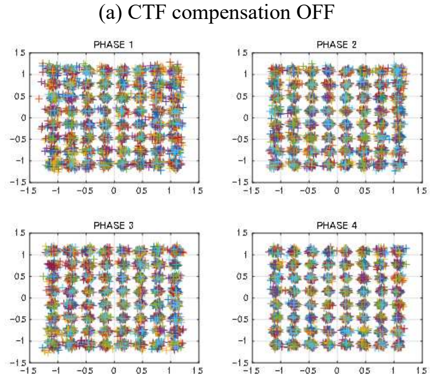


Fig. 10: Rapid Acceleration change simulation.

Previous system is black color, new system is red color. Fig. 7 is Simulated BER vs Initial Velocity. The previous system that turn off the initial beta 1 detector, the black bar is getting worse sharply from the initial speed of 3 m/s, but the red bar proposed has stable reception. Fig. 8 shows simulated BER vs acceleration. For both systems, the BER gets worse as the acceleration increases, and 30dB is better than 27 dB. However, while the previous system deteriorates rapidly, the new system deteriorates slowly. Fig. 9 is simulated BER vs CNR (dB). Raising the CNR of the old system did not improve the BER, but the new system clearly improved from SNR 16 dB.



(a) CTF compensation OFF



(b) CTF compensation ON

Fig. 11: Phase 1 to 4 64QAM constellation map comparison for CTF compensation

Fig. 10 is rapid acceleration change simulation results. The BER inevitably becomes high at the beginning of operation, but the BER of the previous system continues to deteriorate, but the BER of the new system rises gradually. Fig. 11 is a comparison of the 64 QAM constellation maps for phases 1 to 4 for CTF compensation. (a) CTF compensation OFF. Especially phases 2 to 4 are a little rotated. However, CTF compensation ON, we can see that the slope is improved because the CP signal is used to perform the CTF compensation every OFDM symbol.

These simulations show that CTF compensation can improve the Doppler effect. The next chapter introduces the results of experiments performed in the pool.

IV. Pool Experiment

A. EXPERIMENT ENVIRONMENTAL

In August 2022, the experiment were conducted in a non-reflection pool owned by OKI Com-Echoes in Numazu City, Shizuoka, Japan. It shows in Fig. 12. The non-reflection pool does not need to consider the effects of multipath, it is a suitable environment for initial stage performance confirmation experiments. It is used in the stage before conducting ocean experiments.

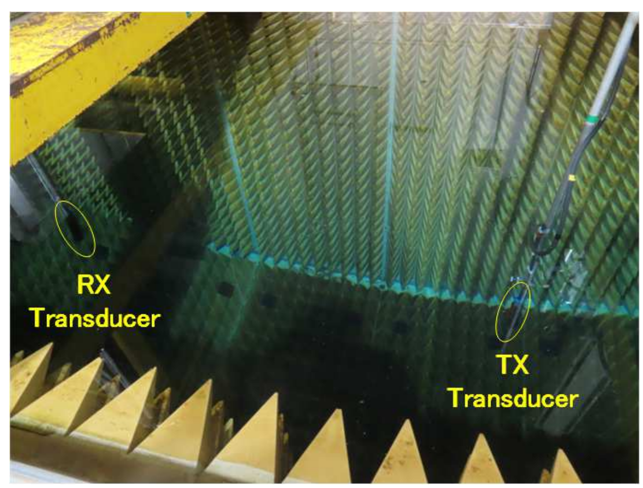


Fig. 12: Experiment in a non-reflection pool owned by OKI Com-Echoes

The detail of experiment environmental is shown in Fig. 13. The non-reflection pool width is 5.0 m, hight is 2.5 m, depth is 2.5 m. Transceivers and receivers are installed up to 1.2m deep in the pool, and it spaced 2.1m apart. The procedure of the experiment is receiver is fixed, and rapid move the transducer. Data recorder is signal processing by MATLAB.

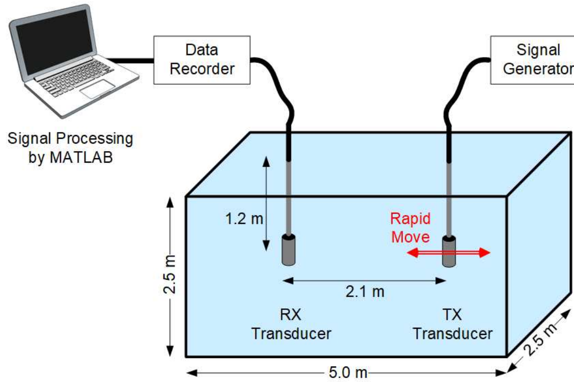
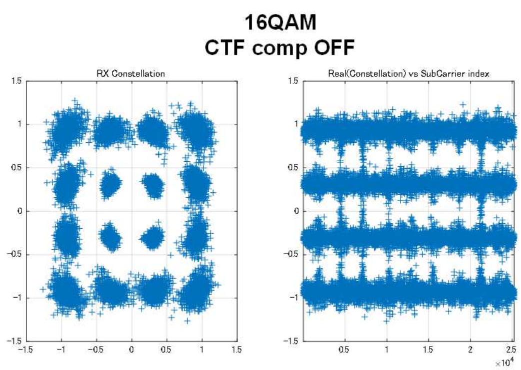


Fig. 13: Experiment setup

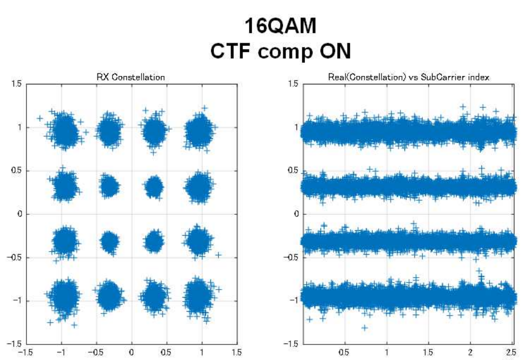
B. EXPERIMENT RESULTS

First, Fig. 14 shows the simulation results for 16QAM. (a) CTF compensation OFF is little noisy, but (b) CTF compensation ON is very clear. Fig. 15 is Real part of constellation and BER of each 4 OFDM block. (a) CTF compensation OFF, BER of 0.0008 shas been detected. In contrast, BER was not detected with CTF compensation.

16QAM does not have a dense constellation of signal points, it seems clear CTF compensation OFF also. but it can know how much improved doppler effect with CTF compensation by 64QAM.

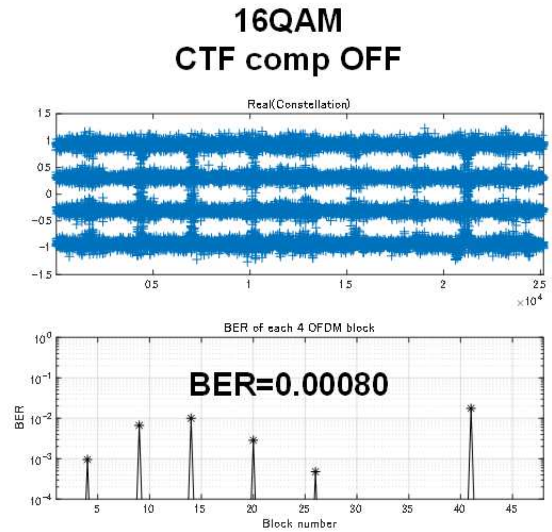


(a) 16QAM, CTF compensation OFF

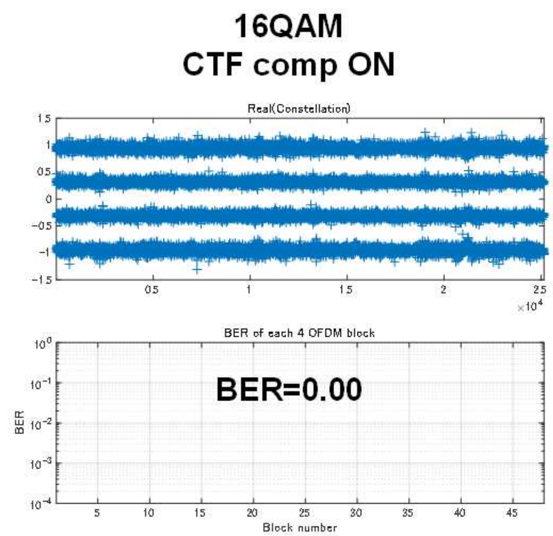


(b) 16QAM, CTF compensation OFF

Fig. 14: 16QAM



(a) 16QAM, CTF compensation OFF

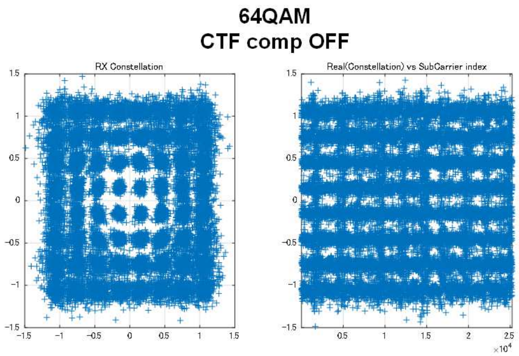


(b) 16QAM, CTF compensation OFF

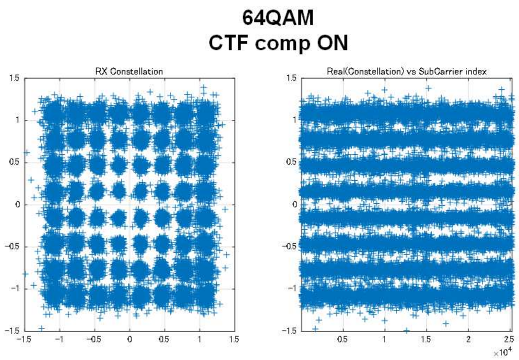
Fig. 15: 16QAM

Next comparison is 64QAM. CTF compensation OFF is very much noisy in Fig. 16. Both results are difficult to find signal points but CTF compensation ON is clear more than CTF compensation OFF. Fig. 17 is Real part of constellation and BER of each 4 OFDM block. (a) CTF compensation OFF is BER of 0.01378 has been detected. (b) CTF compensation OFF is BER of 0.00192 has been detected.

This result shows the effectiveness of CTF compensation. In the future, we plan to make further improvements including the problems found this time, and we plan to ocean experiment in Numazu city, Shizuoka, Japan.



(a) 64QAM, CTF compensation OFF



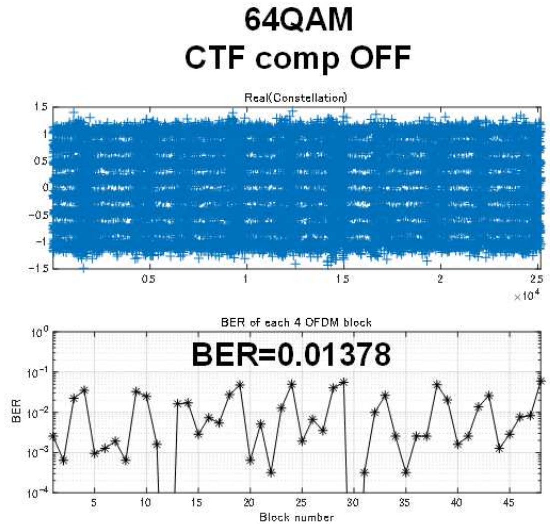
(b) 64QAM, CTF compensation OFF

Fig. 16: 64QAM

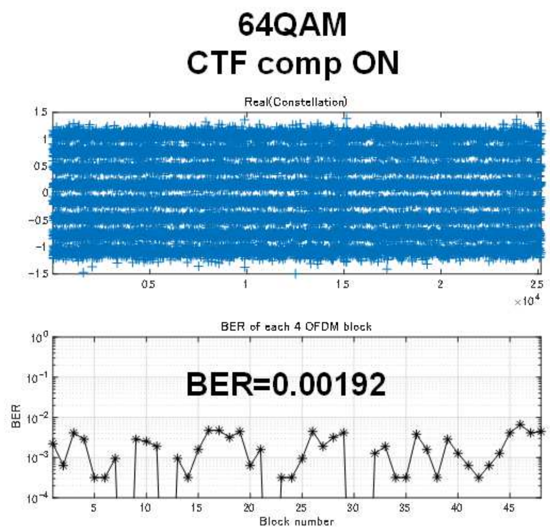
V. CONCLUSION

We proposed a UWA OFDM communication system with improved Doppler compensation and initial synchronization based on previous research. The newly added initial Beta 1 detector was very effective and could be detected cleanly even at 64QAM at the simulation stage. Experiments in a non-reflection pool show that 16QAM can be detected very clear, and even 64QAM with CTF compensation can be detected cleanly, proving that the new system can improve the Doppler effect.

Although the proposed CTF compensation has drastically decreased the number of Bit errors at high transducer acceleration in the pool experiment, we have observed that the effect of CTF compensation has been lowered in multipath channel condition. Remaining future task will be more study for robuster CTF compensation algorithm development.



(a) 64QAM, CTF compensation OFF



(b) 64QAM, CTF compensation OFF

Fig. 17: 64QAM

REFERENCES

[1] Mohammad Ariful Hoq, Shiho Oshiro, and Tomohisa Wada, “Two steps Doppler compensation Algorithm from moving AUV to AUV/Mother Ship for OFDM-based UWA communication system,” IJICSNS International Journal of Computer Science and Network Security, VOL.20, No.12, December 2020.

[2] Tomohisa Wada, Taisaku Suzuki, Hiromasa Yamada, Shigeo Nakagawa; An Underwater Acoustic 64QAM OFDM Communication System with Robust Doppler Compensation, MTS / IEEE OCEANS 2016, Monterey California USA, September 2016.

[3] Takehiko Takahashi, “Realization of effective underwater acoustic communication between Autonomous Underwater Vehicle (AUV) and AUV/mother ship,” Bachelor’s Thesis, 2022

[4] Yusuke Onna,Taisaku Suzuki, Hiromasa Yamada, Shigeo Nakagawa, Tomohisa Wada “A 32 kHz Bandwidth, 8 branch Diversity Underwater Acoustic OFDM Communication System,” MTS / IEEE OCEANS 2018, Kobe JAPAN, May 2018.

[5] Taisaku Suzuki, Hai Minh Tran, and Tomotaka Wada. "An underwater acoustic OFDM communication system with shrimp (impulsive) noise cancelling."Computing, Management and Telecommunications (ComManTel), 2014 International Conference on. IEEE, 2014.