EE-442 Wireless Receiver: Algorithms and Architectures

OFDM Project

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1. Introduction

This report aims to show the concept and composition of the OFDM (Orthogonal Frequency Division Multiplexing) system that our team designed and results that our system generated in the OFDM project.

In the project, we design and implement an OFDM system for acoustic transmission. OFDM is a type of method for digital modulation and adopted for many real-life applications such as Wi-Fi and TV broadcasting. In OFDM, a wideband channel is converted into multiple narrowband channels and the transmitted signals from each subcarrier has overlapping spectra to maximize system's spectrum efficiency. Since each subcarrier signal is orthogonal, they do not cause intersymbol interference (ISI). OFDM brings us to utilize all the available bandwidth. Since multiple signals are send at the same time, we can insert guard interval between OFDM symbols to prevent ISI between the symbols occurred by multipath fading without lowering data rates. Another advantage that we obtain when adopting OFDM is simplicity of the system to estimate channel. This is thanks to the Fourier Transform. By using cyclic prefix as guard intervals, we can estimate channel for each subcarrier by dividing received symbols transformed into frequency domain by sent symbols.

Typical issues we need to deal with when using OFDM system are:

- High PAPR (Peak to Average Power Ratio) in the system
- Weakness to frequency offset and doppler shift.

Especially, the latter problem causes frequency misalignment and spoils received symbols completely.

In our OFDM system, a function of phase tracking and periodical update of channel estimation by periodically inserted training symbols increases the system's robustness. Even if some changes in channels (e.g. a speaker or a microphone is moved or obstacles is set between the devices) occurs, our system updates channel estimation after closest training symbols and prevents misalignment of symbols which come after.

2. OFDM System Composition

Block diagram in Figure 2.1 shows the composition of our OFDM system. The bits generator, transmitter, receiver, and image regenerator are implemented with Matlab. Each component in the system is explained in details in the following subsections. Audio functions in Matlab are used to facilitate the audio I/O. In the test of our OFDM system, supplied Logitech speakers and Valleman microphone are used for outputting and inputting audio signals respectively (Figure 2.2).

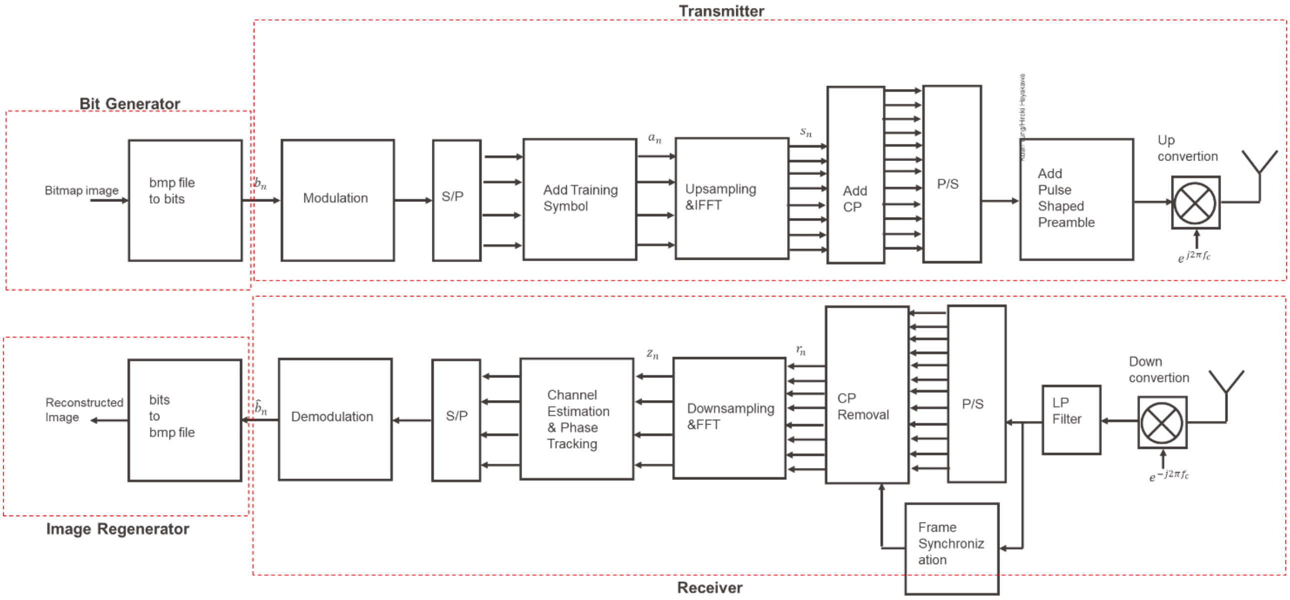


Figure 2.1: OFDM System

Figure 2.2: Logitech Speaker and Valleman Microphone

2.1. Image to Bits Conversion

In this project, a bitmap image with size of 256×256 is converted to a bitstream through following processing steps and transmitted over channel after being altered into OFDM symbols. The reconstructed image helps us visually understand the effects of channel and the cause of errors in our system.

2.1.1. Decimal to Binary Conversion

The size of image data is 256×256 and each entry of the data has values in decimal numbers. The decimal numbers are converted into binary value with de2bi() function in Matlab. The converted binary sequence is pseudo randomized via XOR operation with a known random sequence generated by LFSR, and the binary sequence can be restored with the same XOR operation.

2.1.2. Random Padding

The QPSK symbols which are created from the converted binary values (= bits) are not necessarily multiples of the number of subcarriers in the OFDM systems. Random binary values are added to the tail of the bits so that the bitstream can have the length of multiple of the OFDM subcarriers.

2.2. Transmitter

In this section, the transmitter functions are explained.

2.2.1. Modulation

In the transmitter, the generated bits, firstly, are mapped into QPSK constellation and then converted into N parallel streams where N is the number of the OFDM subcarriers.

2.2.2. Training Symbol Generation and Its Insertion

Pseudo randomized binary sequence with the same length as the number of the subcarriers is generated via LFSR operator and it is mapped into BPSK constellation. The BPSK symbols are parallelized and we use it as a training symbol. The training symbol is inserted before beginning and every 41 OFDM symbols. This insertion frequency of the training symbols is determined with the observation of the channel.

2.2.3. OS_IFFT

After training symbols insertion, IDFT operation is performed on the parallel symbols to convert them into the time domain. Both up-sampling operation and parallel to series conversion are also performed in the function.

2.2.4. Cyclic Prefix Insertion

In our system, the last samples of each OFDM symbol in time domain are copied and inserted before the OFDM symbol. This is called cyclic prefix in general. We decided to choose 500 samples as the length of cyclic prefix through the observation of the impulse response for the channel.

2.2.5. Preamble Generation and Its Insertion

Preamble is inserted at the head of OFDM symbols. As well as the training symbols, the preamble is generated via LSFR and BPSK constellation. The length of the Preamble is 100 in our system. The preamble is scaled so that its maximum power has the same value of the one of the OFDM symbols. Then, upsampling with sampling frequency of 48 kHz and pulse shaping with a root raised cosine filter is performed. As for pulse shaping, we choose 21 taps for filter length.

2.2.6. Upconversion

We choose 8 kHz for carrier frequency. Generated symbols in time domain through former process is upconverted with the carrier frequency.

2.3. Receiver

In this part, the receiver functions are explained.

2.3.1. Down Conversion

Reverse process of Upconversion.

2.3.2. Low Pass Filtering

We adopt a simple lowpass filter to equalize frequency domain of original symbols and received symbols.

2.3.3. Frame Synchronization

Matched filtering with root raised cosign filter is performed on all the received symbols, and then the position of preamble is detected by seeking the value of denominator over set threshold. After frame synchronization, filtered symbols are discarded.

2.3.4. Cyclic Prefix Removal

Considering index information obtained via frame synchronization, cyclic prefixes are removed from received symbols.

2.3.5. OS FFT

Reverse process of OS IFFT.

2.3.6. Channel Estimation and Phase Estimation

Cyclic prefix makes it possible to estimate channel of each subcarrier by simply dividing received training symbols by original training symbols. We calculate both magnitude and phase angle of estimated channel.

2.3.7. Phase Tracking

The phases of received training symbols are estimated by calculating channel phase. We adopt a Viterbi-Viterbi algorithm to track the phase of following OFDM symbols.

2.3.8. Demodulation

Reverse process of Modulation.

2.4. Image Regenerator

Reverse process of Bits generator.

3. Results and Discussion

In this part, we show the result generated from our systems.

3.1. Task 1

In task 1, we are asked to verify that our system work well in good channel conditions. To keep the over sampling factor an integer, we choose 300 for the number of subcarriers. Other key configurations are summarized as follows.

- f_sampling: 48,000 Hz
- f_carrier: 8,000 Hz
- number of subcarriers: 300
- Length of cyclic prefix: 150

We transmitted the training symbol and one data symbol (Random Bits, not image data) and the obtained BER for a received symbol was zero. Following figure indicates that changes in phase between the training symbol and the first symbol are negligible.

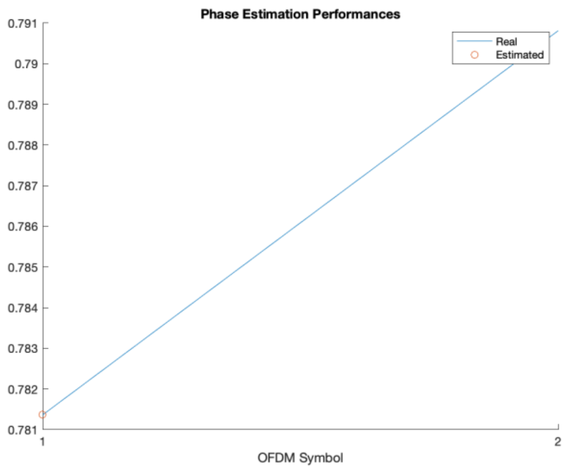


Fig3.1: Phase Change

3.2. Task 3

In task 3, we investigate how many symbols can be transmitted before needs for phase tracking generates. To check if we need to implement the phase tracking function in our OFDM system, we perform this task prior to task 2. Configurations for task 3 are same as task 1. We transmit series of OFDM symbols generated from random bits and record obtained BERs (Fig 3.2). The result indicates that we can transmit up to around 60 symbols without phase tracking. To send image data, the length of OFDM symbols are longer than 60; therefore the function to track phase is required in our system. Fig 3.3 shows phase changes over time in the channel for the subcarrier with the highest frequency and the performance of the phase tracking function in our systems. By implementing the function, BER for 70 OFDM symbols are improved (0.33 → 0.0032).

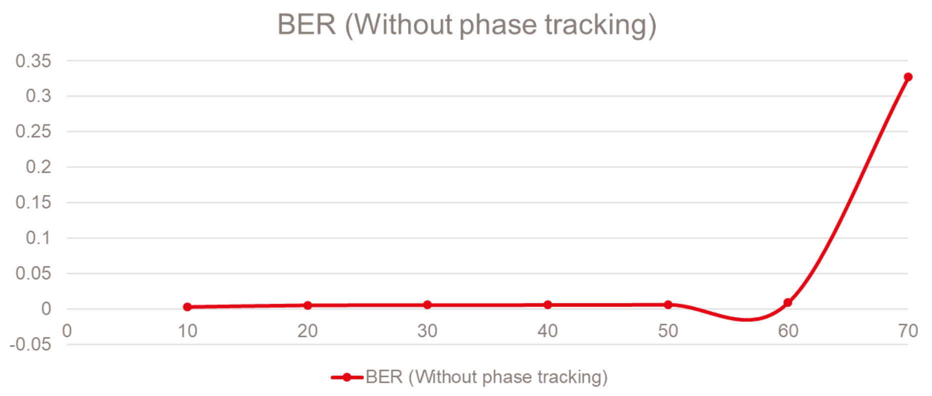
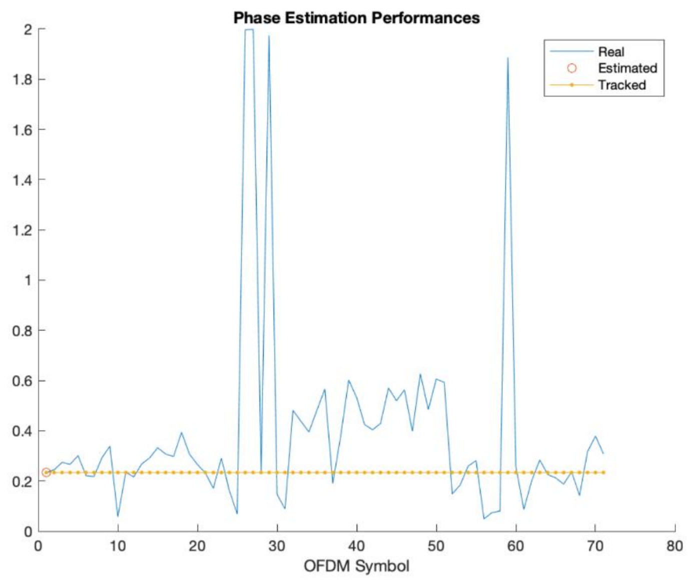


Fig3.2: Obtained BER



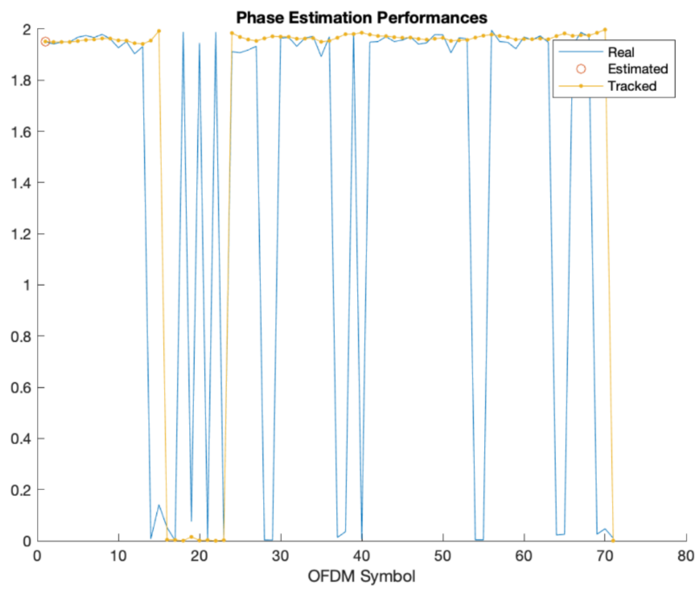


Fig3.3: Phase Tracking Behavior (L: Without Tracking, R: With Tracking)

3.3. Task 2

In this task, we transmit image of Freddie Mercury in Fig 3.7 and investigate the spectrum of our channel. The key configurations for this task are as follows. We increase the number of subcarriers to 1,600 aiming to improve data rate. However, in order to avoid the risk of the frequency misalignment, our selection for the number of subcarriers is not that big. Training symbols are inserted before every 41 OFDM symbols in addition to the one in front of the first symbol. We choose half the OFDM symbol length for the length of the cyclic prefix in the beginning and update it after observing estimation of delay spread.

- f_sampling: 48,000 Hz
- f_carrier: 8,000 Hz
- number of subcarriers: 1,600
- Length of cyclic prefix (CP): 800 / 300

The delay spread is computed by perform an inverse FFT to the spectrum of our channel over frequency (see in Fig 3.5). As we can see in the figure, the effect of delay continues for approx. 0-15ms and 185-200ms. In 30ms, the system transmits about 240 symbols. Thus we change the length of cyclic prefix to 300, which results in increase of system efficiency (66.7% for CP of length 800 → 84.2% for CP of length 300). Fig 3.6 shows changes in spectrum of 1st, 401st, 801st, and 1201st subcarriers. The magnitude is normalized by being divided by the maximum value of the selected subcarriers. We can find that each subcarrier shows different trend. As a whole, either magnitude or phase do not fluctuate so much over time; however, some subcarriers indicate relatively big changes in both magnitude and phases after 3,000ms. Images in Fig 3.7 are reconstructed ones through our OFDM systems. The left figure is for the case with CP length of 800 and the right one is for the case with CP length of 300. The calculated BER for each case are 0.00049733 and 0.00030488 respectively and we suppose the reason why CP with the shorter length shows better results is relevant to the length of whole transmitted symbols. Thanks to the shorter CP, the case with CP length of CP 300 has shorter length of symbols, which is less affected by changes in channels such as phase shifts and frequency shifts.

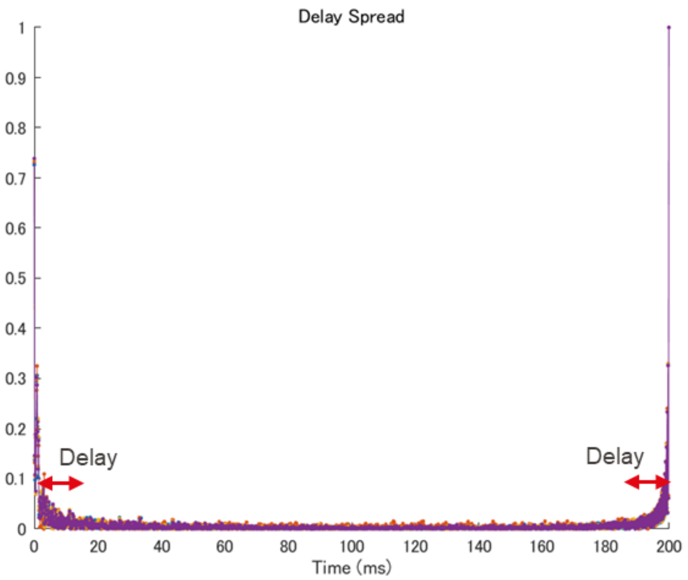


Fig3.5: Delay Spread

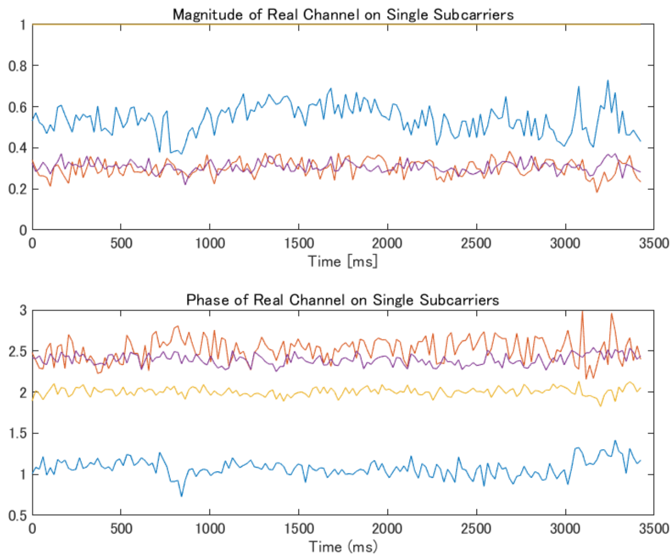


Fig 3.6: Changes in Spectrum over Time

Fig 3.7: Original and Reconstructed Images (L: Original, C: CP 800, R: CP 300)

3.4. Task 2 with built-in speaker and microphone in a laptop

Since in the previous section the spectrum of our channel over frequency is not saved correctly and supplied Logitech speakers and Valleman microphone have already been returned, we again perform the task 2 with a built-in speaker and microphone on a laptop. Key configuration is as follows. Due to the changes in devices used in the experiment, we update the length of CP. Fig 3.8 shows newly calculated delay spread for our channels and the delay continues for about 50ms, which corresponds to 400 symbols. Thus, we choose, in this section, 400 for the length of CP and now the system efficiency is 80 %. The channel spectrums over frequency are indicated in Fig 3.9. Channel is estimated at every training symbol. Every estimated channel shows the same trend in the magnitude. Large fluctuations in the magnitude occur at middle or high frequencies. As for the changes in phases, each estimated channel indicates continuous down trend over frequency and steep decline is observed at points with lower frequency. The trend of spectrum over time, as well as the results in the previous section, shows different ways of fluctuation between subcarriers (see in Figure 3.10). Due to the gap in the specification of used devices, the experiment in this section shows worse results (see the noisy reconstructed figures in Fig 3.11). The obtained BERs for the case with CP length of 800 and the case with CP length of 400 are 0.035941 and 0.012995 respectively.

- f_sampling: 48,000 Hz
- f_carrier: 8,000 Hz
- number of subcarriers: 1,600
- Length of cyclic prefix: 800 / 400

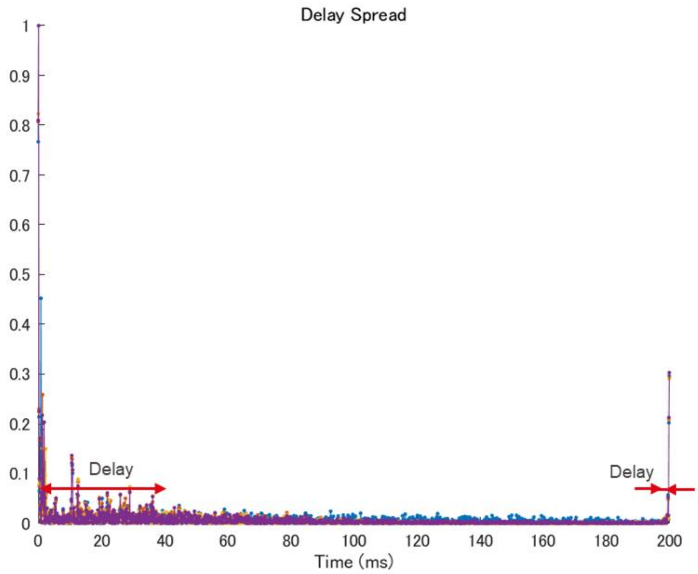


Fig 3.8: Delay Spread with Built in Speaker and Microphone on a laptop

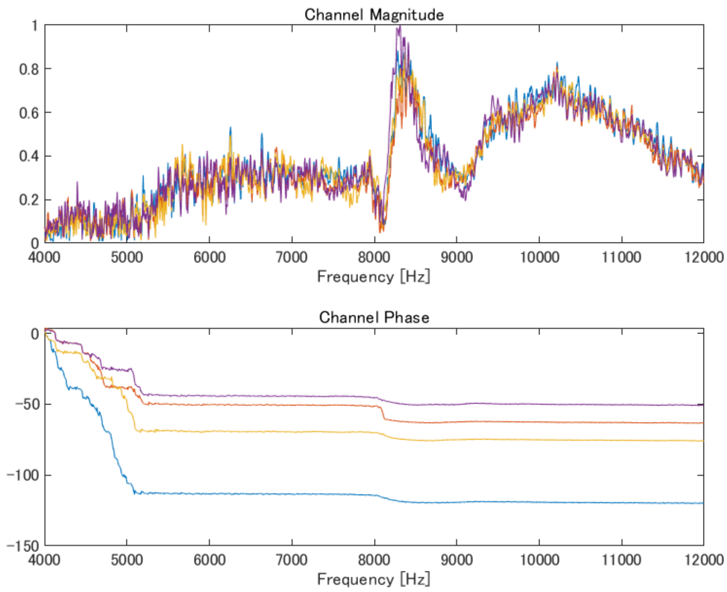


Fig 3.9: Channel Spectrum over Frequency

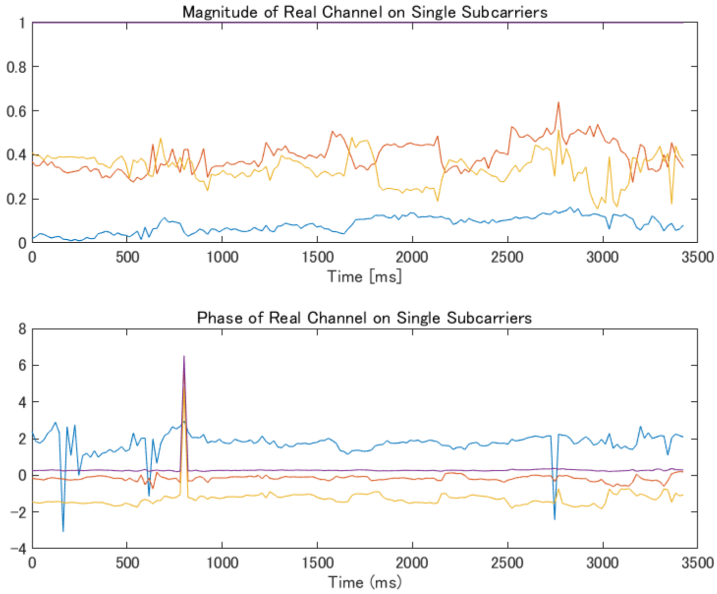


Fig 3.10: Channel Spectrum over Time

Fig 3.11: Reconstructed Figures (L: CP length of 800, R: CP length of 400)

4. Conclusion

In the project, we designed and implemented an acoustic OFDM transmission system. Our system is equipped with the function of phase tracking and periodical update of channel estimation, and has robustness to changes in channels. Through the Task 1-3, we verified our system regenerates transmitted data bits correctly and copes well with phase changes in channels.