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Real Time End To End System for Underwater Communication

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Abstract **-** Today's technology has begun to improve very fast and communication technology tries to adapt this positive change. Each new innovation of theoretical changes has been trying to be implemented practically. Although it is relatively easier for RF communication to adapt this change since there are many manufactured special ICs for special tasks, it is still a challenging task for underwater communication. It is very difficult to establish a reliable link for underwater communication due to the lack of receiver designs suitable for underwater communication in the literature. Besides, it takes significant amount of time to implement such algorithms on FPGAs with HDL languages. In this paper, several successful telecommunication techniques of both RF and Under Water (UWA) communication are combined to construct a real time operating end to end UWA system. The proposed system is prepared on MATLAB with System Generator blocks. Therefore, it can directly be implemented on Xilinx's FPGAs.

Keywords**:** FPGA, Digital Design, Acoustic Communication, Receiver Design, System Generator**.**

1. Introduction

Electromagnetic waves can only radiate through extremely short distances (a few meters at 10 kHz) at low frequencies and under the water [1]. Optical signals offer high data rates (above MHz) and are best used in the blue-green region (around 500 nm) [1]. However, optical signals cannot propagate beyond 100 meters due to high attenuation problem. Therefore, electromagnetic wireless communication at underwater acoustic communication is considered to be superior to optical communication.

Important modulation schemes such as Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Quadrature Phase Shift Keying (QPSK) [2], Quadrature Amplitude Modulation (QAM) [3], Orthogonal Frequency Division Multiplexing (OFDM) [4]-[5] are evaluated in terms of their suitability for underwater transmission. Unfortunately, underwater acoustic channel is very noisy and it is difficult to estimate the acoustic channel precisely. For this issue, many researches carried out to estimate and model the underwater acoustic channel [5]. Apart from the physical layer, some other researches are focused on the network layer to provide a better underwater communication [6]-[9].

It is strictly necessary to use a FEC (Forward Error Correction) methodology to decrease Bit Error Rate (BER) for underwater communication. Popular FEC methodologies such as Reed Solomon [10] and Polar Codes [11] are implemented for underwater communication systems.

Moreover, some designs in the literature focused on creating a complete receiver system which includes both modulation schemes and forward error correction methodologies. OFDM modulation and Turbo Coding are combined in some studies [12]. They reach 2.8 Kbps to 9 Kbps data rate with 10^{-4} Bit Error Rate. OFDM Modulation is also combined with Polar Coding [11] where 10^{-7} Bit Error Rate is reached at 7 dB SNR.

Although FEC and channel prediction methodologies are implemented on underwater communication systems, there is not yet any end to end real time underwater system implementation in the literature which combines techniques to present a novel system to overcome problems such as multipath. In this paper, we developed a novel end to end real time underwater acoustic communication system.

2. Design and Simulation

The digital design of the system consists of three major parts on the transmitter side. The first part is the Input Sampling Part (ISP). ISP accepts data to the system at pre-determined (adjustable from 40 kHz to 100MHz) frequencies. The second part is the symbol creation part which provides forward error correction encoding and afterwards QPSK modulation is activated for sub-modulation of OFDM. The last stage is the OFDM modulation part.

The Receiver side consists of several subsystems. The first part is the OFDM receiver. Then, the data is extracted and equalized with Zero-Force equalizer. After the equalization, coarse frequency compensation and fine frequency compensation are applied to the received signal. Frequency compensation operations are carried out after the FFT and equalization processes since there are as much as thousands frequency channels before the FFT process. Finally, decoding is performed. Below, the overall diagram of the system is given in Figure 1.

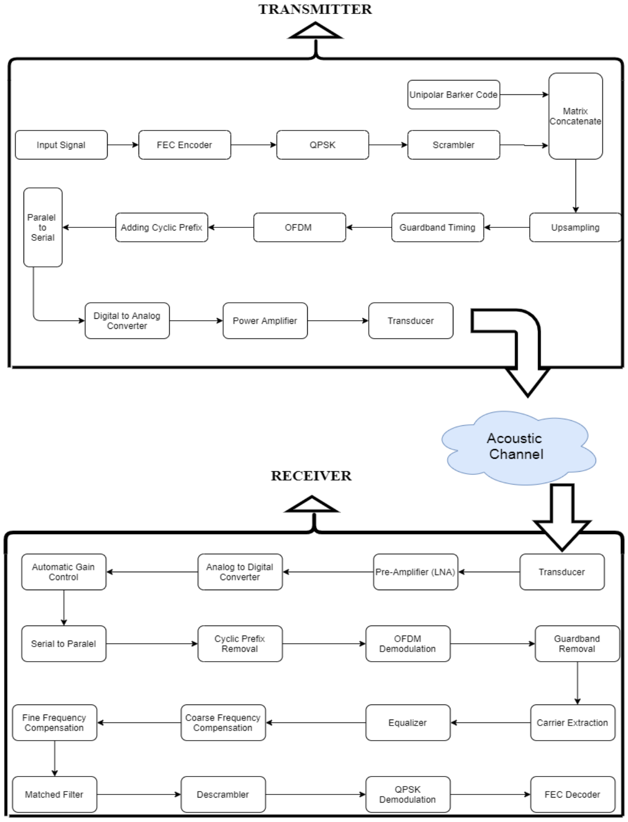

Fig.1 : The Block diagram of the transmitter and receiver

3. Digital Design of the Transmitter

In this paper, several simulations were carried out by using MATLAB software and the system was implemented on Xilinx's FPGA. Therefore, the system is designed by System Generator blocks on MATLAB. The proposed design is suitable to create a valid Axi-Peripheral IP which can be implemented on any Xilinx's FPGA. The design includes only the basic elements such as logic gates, adders and delay elements. Additionally, Black Box block of System Generator is used when necessary. When one writes a code block by using VHDL language, the code block with a few modifications can be used as part of MATLAB simulation with the help of "Black Box" block of System Generator. Therefore, in the digital design of our novel system which may be called Underwater 5G Technology, System Generator blocks were only used to make the system directly applicable to any Xilinx's FPGA [13]. Some blocks in the designed are summarized in the following paragraphs.

3.1 Input Sampling

On the transmitter side, incoming data are sampled with 48 KHz and then the incoming bits are scrambled via a polynomial before sending the bits to the transmitter. The objective of the scrambling is to avoid synchronization problems in the transmission.

3.2 Symbol Creation With QPSK

We understand that QPSK gives better efficiency in a noisy underwater acoustic multipath channel with a high probability [2]-[3], [14]. For this reason, only the QPSK modulation is implemented with System Generator blocks and will be implemented on FPGA as a part of Underwater 5G System. In this paper, Offset QPSK (OQPSK) is decided to be the modulation scheme since it decreases amplitude fluctuations and establishes more stable signals for OFDM modulation. In our design, 3π/4 offset is chosen for OQPSK. MATLAB System Generator Design of the OQPSK is shown in Figure 2.

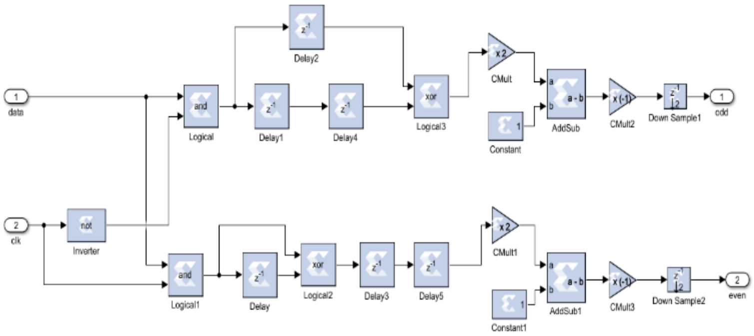

Fig. 2 : System generator design blocks of OQPSK

3.3 Forward Error Correction

The Polar Codes are chosen for the Forward Error Correction (FEC) Methodology. FEC decreases BER significantly. The Polar Codes are also chosen for RF 5G Technology. Research on the performance analysis of the Polar Code implementation for UWA communication is mature and to the best of our knowledge, there is only one research on this issue [15], [11]. In this paper, Polar Codes are chosen to be used for our design to see and contribute to the implementation performance. For the digital design of the FEC, Black Box is used and VHDL code is inserted to the Black Box.

3.4 Barker Codes

To receive a signal especially from a noisy channel, the receiver must know that the incoming signal is not noise and the signal is worth to be decoded. For this purpose, Barker codes are used in the early generation of RF communication with low data rates such as 1-2 Mbps in the 802.11 standard. Barker codes are not preferred to be used in Today's RF technology. However, Barker codes may be useful since UWA works on slow data rates such as 0-100 kbps. Therefore, we decided to use barker codes at the receiver side in this thesis. Autocorrelation function or a match filter can detect barker codes at the receiver side where the beginning of the frame can be detected. After the incoming data is scrambled according to a predetermined polynomial, Barker codes are added at the start of all frames as a preamble. The length of the frames is selected as 384 bits. Each frame includes 384 bits and 26-bit barker code as a preamble is added onto each frame. A match filter checks all the incoming data on the receiver side and if the barker code length is bigger than a threshold value, the frame will be accepted as a valid frame. The use of scrambler and Barker codes are shown in Figure 3.

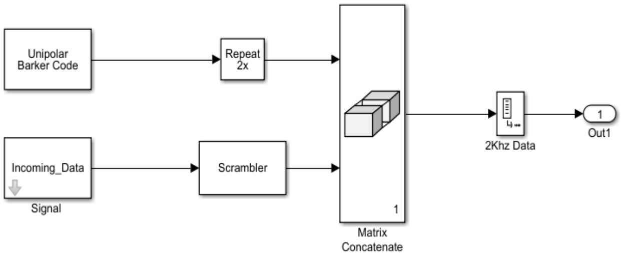

Fig.3 : The use of scrambler and barker codes

3.5 Orthogonal Frequency Division Multiplexing (OFDM) Transmitter

OFDM has recently been used for underwater acoustic communication due to its robust characteristics for channels that require long propagation delay. Cyclic Prefix and Guard Time features of OFDM facilitates robust communication and provides immunity to inter symbol interferences. Since OFDM divides the spectrum into many sub channels with overlapping narrow subbands, symbol duration becomes relatively long compared to the multipath spread of the underwater acoustic channel. As a result, Inter Symbol Interference might be neglected in each subband which simplifies the receiver complexity on the receiver side significantly. This phenomenon motivates researchers to work on OFDM in UWA channels. Therefore, OFDM is a suitable candidate for underwater acoustic communication.

The first stage in the design of OFDM transmitter is the creation of symbols with QPSK modulation and Forward Error Correction. The second stage is the up-sampling application by a factor of 1/12. This process is called Inverse Finite Fourier Transform (IFFT) input packing. The data for which IFFT is performed is packed before the up-sampling process. This OFDM structure is termed as the Inverse Finite Fourier Transform (IFFT) process. IFFT of the baseband symbols creates OFDM symbols. In the previous process, input is packed for the OFDM and it becomes ready for IFFT. However, there is one more additional step for OFDM which is the addition of guard bands to the message signal. This additional step is crucial for underwater 5G technology. Guard bands prevent the Inter Channel Interference (ICI). For the underwater 5G technology, we chose lengths of the guard bands to be 20 ms. We chose this 20 ms with the help of Monte-Carlo simulation methodology. We simulated our system with guard bands and reached least ICI with 20 ms. After the guard bands are created, IFFT of the message signal is performed. Finally, CP is added to the end of the transmitted signal. The whole process is shown in Figure 4. Final part of the OFDM transmitter is the transition to the pass band. There are several options for this process. Base Band to Pass Band process is chosen to be implemented for the underwater 5G technology.

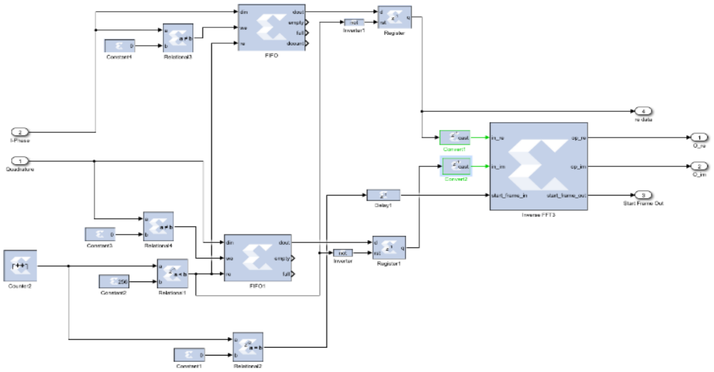

Fig.4 : Implementation of IFFT process

4. Digital Design of the Receiver

There are two main modules which play crucial roles in the design of the receiver. The first module is a well-designed low pass filter to remove the ambient noise. In this paper, the low pass filter is designed by using the Filter Designer and

Analyzer (FDA) module of the System Generator. FDA determines the filter coefficients which are easily adapted to the filter. After trying several implementations, a low pass filter with an excellent performance for underwater 5G technology is designed and implemented. It is chosen in that way to increase spurious free dynamic range. The magnitude response of the filter is shown in Figure 5. The second module is the gain control and the normalization operations module. To treat each data equally, they have to be normalized. In addition, the signal level should be controlled by a gain controller. Then, Cyclic Prefixes must be detached from the incoming signal. A gain control and normalization of OFDM receiver has been carried out in this study successfully.

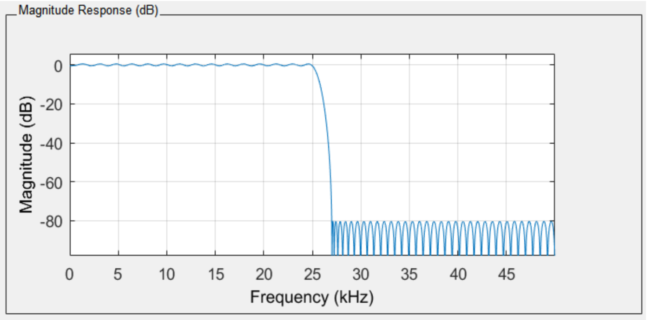

Fig.5 Magnitude response of the low-pass filter

4.1 OFDM Receiver

Once the signals are normalized and filtered, the next thing is to convert OFDM symbols to the QPSK symbols. Each OFDM symbol is carried via a different channel. To create these channels, we used IFFT on the transmitter side to create a frequency bin from these multiple channel streams. On the receiver side, the carriers must be extracted and mentioned frequency bins must be divided into different streams again. For this purpose, we applied FFT to the incoming signal. FFT process extracts the symbols. However, there are residual guard bands which were added on the transmitter side. Location of the guard bands are saved in a memory unit which is a trivial task. Digital Design of the FFT process is shown on Figure 6. A Frame Synchronization Block is also designed. This design helps to detect the valid frame for the remaining part of the receiver.

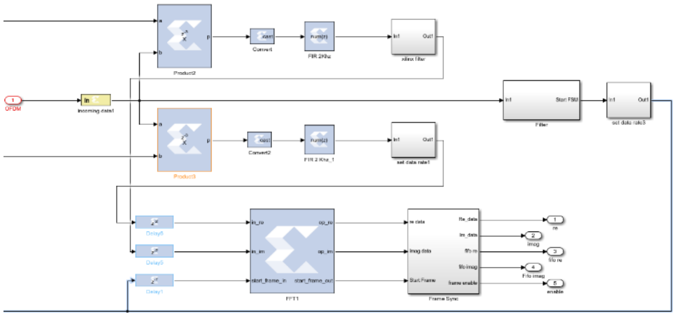

Fig.6 : Implementation of FFT process

Without proper channel equalization, we cannot apply any compensation or decoding algorithms since the signals are corrupted. After the equalization process, the received signal becomes ready to be corrected in terms of phase and frequency offsets. Then, two important blocks are designed. The first one is the Coarse Frequency Compensation which estimates and corrects the phase and frequency offset. The second block is the Fine Frequency Compensation block which corrects residual components of frequency and phase offsets. As it is explained in the transmitter part, Barker Codes are attached to the header of the message signal. Therefore, in the decoding part, we decided a Match Filter which detects the start of the signal.

5. Simulation Results

Digital Design of the blocks shown in Figure 1 are implemented to compose the complete transceiver design. The final stage of the simulation for underwater 5G technology is the performance evaluation part. The Transmitter and the Receiver of the system are connected by an acoustic channel and they are connected to a bit error rate calculation block. The overall design is shown in Figure 7.

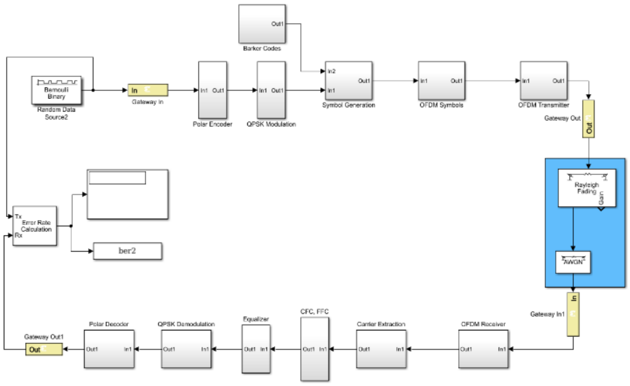

Fig.7 : Simulated overall design

The bit error rates graph for the Underwater 5G Technology for different Polar Code and CP rates are shown in Figure 8. Monte-Carlo methodology is used for the simulation. The other fixed parameters are shown in Table 1.

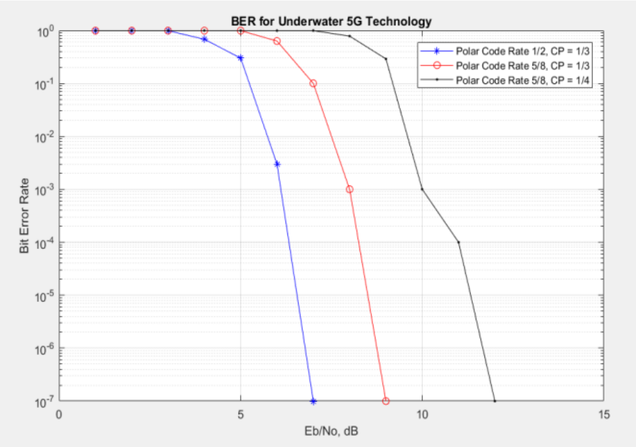

Fig.8 Bit error rate of the proposed underwater 5 G technology

Table 1 : System Parameters

Parameters	Value
Frame length	1024 bits
Cyclic prefix rate 1	1/3 & 1/4
Polar code rate	½ (512 bits) & 5/8 (640 bits)
Modulation type	OFDM
Symbol generation	QPSK
Transmission frequency	20 kHz to 30 kHz
Guard band time	20 ms
Preamble	26 bit barker code
Data rate	30 kbps to 60 kbps

For the comparison, in the literature, UWA communication system which uses Turbo Codes for the FEC methodology has reached 2.8 kbps to 9 kbps with 10^{-4} BER [12], while our proposed Underwater 5G Technology system reaches 30 kbps to 60 kbps with 10^{-5} BER. On the other hand, in the literature, Polar Codes with OFDM is used for UWA Communication systems [11]. Although they don't present an end to end system, they have used OFDM and Polar codes in the physical layer. They have reached 10^{-7} BER while the SNR was 11 dB with a polar code rate of 1/2 [18], while our system can reach this BER with 6 dB SNR with the same polar code rate, which means that our system performs better in a worse SNR environment with a better rating of the polar codes.

6. Conclusion

In this paper, we have presented a complete end-to-end underwater acoustic communication system which operates in real time. Since this system combines the physical layer of 5G technology with known acoustic communication techniques, we called it underwater 5G technology. Underwater 5G Technology aims at maintaining a robust underwater communication link by overcoming the two main obstacles, Scattering and Multipath. For this purpose, a complete digital design is proposed. Designed transmitter and receiver include all the necessary modules for a reliable underwater communication. This communication is called as underwater 5G communication because it imitates all the necessary parts of RF 5G Technology successfully.

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