Design of OFDM Based Acoustic Communication System using FPGA

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ABSTRACT

This paper describes an Underwater Acoustic Communication system for establishing communication between monitoring station and the underwater device. In underwater communication, signal degradation caused by strong multi-path, extremely high ISI, Doppler spread etc are avoided by using an OFDM multi carrier modulation scheme and it is used to obtain high data rates with the utilization of an effective bandwidth. The FPGA is chosen to implement the OFDM based communication system due to its reconfigurability. The functionality is implemented and tested in FPGA.

Keywords: *ISI, OFDM, QPSK, IFFT, FPGA*

[1] INTRODUCTION

The need for underwater wireless communication [2] exists in a broad range of applications, such as sensor-based, disaster prevention, and assisted navigation, speech transmission between divers, collection of scientific data recorded at ocean-bottom stations. Wireless underwater communication can be established by the transmission of acoustic waves. Underwater communication requires high-speed data rates over a relatively long distance, in terms of kilometres, in a shallow water environment.

In Orthogonal Frequency-Division Multiplexing (OFDM) [1], large numbers of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as Quadrature Phase-Shift Keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

The primary advantage of OFDM over single-carrier modulation schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without using complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate Inter Symbol Interference (ISI). OFDM is robust to Inter Symbol Interference (ISI), Inter Carrier Interference (ICI), and Doppler Effect as far as orthogonality among each subcarrier is preserved. The reconfigurable nature, short time to market has made system designers to choose an FPGA (Field Programmable Gate Array) to implement OFDM based communication system [9].

2. UNDER WATER ACOUSTIC COMMUNICATION

Underwater acoustic communication [2] is a rapidly growing field of research and engineering. The Electromagnetic (EM) waves in an underwater environment are subject to high attenuation and can travel only for short distances. The Electromagnetic waves that propagate through underwater are the extra low frequency ones (30Hz-300Hz). They require very large antennas and high transmission power. The acoustic signals can propagate easily in the underwater compared to Electromagnetic waves. The best suitable signal which is used for transmission in underwater sea environment is acoustic signal. Hence, acoustic transmission is the best possible option for underwater communication. However, with the sparse nature of the water, communication in underwater is predominantly a tedious task. Several modulation techniques has evolved to withstand the channel characteristics of the water and to attain a less noisy communication.

3. TYPE OF MODULATION TECHNIQUE USED

The Acoustic communication system gets affected mainly due to multipath propagation, attenuation, Doppler spread, Inter Symbol Interference, Inter Carrier Interference and ambient noise. In order to overcome all the drawbacks of underwater channel, we can choose an OFDM. The OFDM is a multi-carrier modulation technique with high data rates, high bandwidth efficiency. In OFDM, the entire channel is divided into narrowband flat fading sub channels, therefore it is more resistant to frequency selective fading, in which a single stream of data is divided into several sub-carriers with which the high data stream is converted into low data stream. This results in longer symbol durations and thus better integration intervals. OFDM [1], [4] can achieve efficient spectrum utilization, flexible subcarrier allocation and adaptable subcarrier modulation and it is computationally efficient by using FFT/IFFT technique.

Each subcarrier is modulated using Quadrature Phase Shift Keying (QPSK) technique. These subcarriers are chosen such that they are orthogonal to each other. Therefore, there is no need to have non-overlapping subcarrier channels to eliminate the Inter carrier Interference (ICI).

4. OFDM BASED COMMUNICATION SYSTEM USING FFT/IFFT

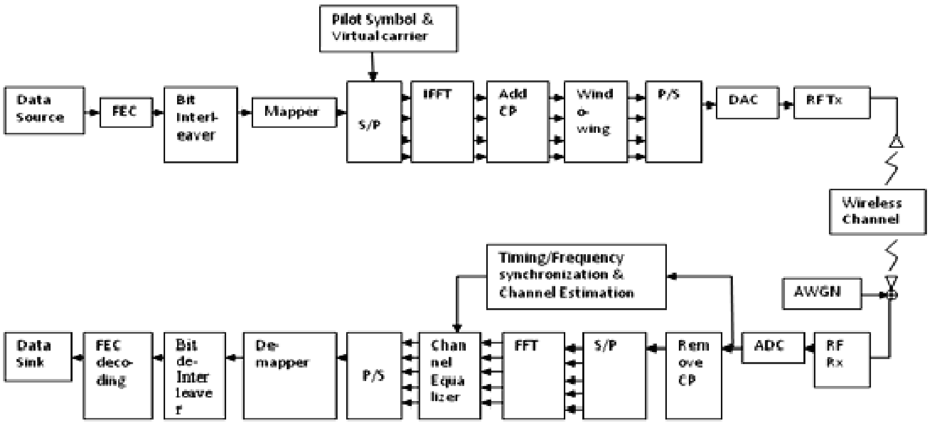

Fig.1. OFDM Based Communication System

The block diagram of the OFDM [1] is shown in above fig 1.In this, the binary information is first given to the data source and is mapped according to the modulation chosen in the 'Mapper', which is QPSK (Quadrature Phase Shift Keying) here. The serial-to-parallel (S/P) converter subdivides this sequence into blocks of symbols, which is then modulates the sub-carriers. The FFT/IFFT is a highly efficient procedure for computing DFT/IDFT (Forward/Inverse Discrete Fourier Transform) and reduces the computational time required to compute DFT/IDFT, improves the performance then yields the time-domain signal x(n) with the following equation as :

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X_k' \, e^{\frac{j2\pi nk}{N}}, \qquad n = 0,1 \dots N-1. \qquad \textbf{(1)}$$

Then the successive blocks in time domain are formed and are appended serially in succession by the Parallel-to-Serial (P/S) block. The Digital-to-Analog (D/A) converter block gives the information signal 'x(t)' to be transmitted. Depending on the level of performance improvement needed by the end user, suitably powerful channel coding schemes can be applied. The (Parallel-to-Serial) converter converts parallel bits stream into serial bit stream. The QPSK modulator then chooses between the two symbols. The OFDM modulated waveform is appended with a synchronizing pulse, which is a chirp signal and is transmitted. At the receiver, the primary task is to achieve timing synchronization. This is done by matched filtering the received waveform with the frame synchronization pulse.

Once the timing synchronization is achieved, the received waveform is divided into symbols and is applied to OFDM demodulator with adaptive equalizer to estimate symbols transmitted. This decoded message can be suitable for command, control and monitoring the activities of underwater data acquisition devices.

5. DESIGN OF FFT/IFFT USING FFT/IFFT IP CORE

With the integration of DSP (Digital Signal Processor) and FPGA [5], the implementation of an OFDM based underwater acoustic communication is achieved to attain high data rates. The efficiency of such a communication system is dependent on the architecture of FFT/IFFT we choose. Here Radix-2 Lite Burst I/O architecture was chosen for the implementation of both FFT and IFFT using FFT/IFFT V8.0 IP core [11]. It uses a time-multiplexed approach to butterfly and uses a shared adder/subtractor, thereby reducing resources at the expense of an additional delay per butterfly calculations. The transform size (N) chosen here is 1024.

The 'tvalid' signal is related to the "master" and 'tready' signal is related to the "slave", the data is transferred only when these two signals are 'High'.The signal 's_axis_config_tdata' carries the information of transform size , cyclic prefix length, forward or inverse FFT and scaling factor length. Here in this signal, if we consider fwd/inv as '1' then it performs FFT and if it is '0' then it performs IFFT.

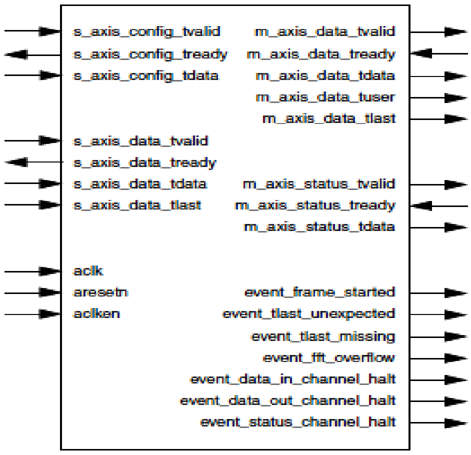

Fig.2. FFT/IFFT V8.0 IP CORE

5.1 Transmitter Design

OFDM transmitter maps the message bits into a sequence of symbols and these symbols will be subsequently converted into N parallel streams. Each of N symbols from serial-to-parallel (S/P) conversion is carried out by the different subcarriers.

5.2 OFDM Parameter Selection

The main parameters of the transmitter [11] are namely,
(a) Sampling Frequency, Fs
(b) Number of FFT and IFFT points, N
(c) The length of the cyclic prefix, as a fraction of the symbol duration
(d) The modulation scheme of the individual sub-carriers.
The selection of the parameters is as follows:
(a)The minimum sampling frequency needs to be about 2.56 times (or at-least 2 times) the value of maximum frequency content of the signal.
(b) The length N, of the FFT or IFFT needs to be a power of 2, for utilization of the Radix-2 algorithm.
(c) The symbol duration needs to be more than 30 msec in order to overcome the effects of multi-path and the ISI.
(d) The modulation scheme used among the sub-carriers is QPSK. The sub-carrier spacing needs to be more than the maximum deviation due to Doppler shift. Higher sub-carrier spacing results in lesser Inter-Carrier-Interference (ICI) due to minor drifts in sampling rate.

Table 1. Proposed OFDM Parameters.

Sampling Frequency	48000Hz
FFT and IFFT length	1024
Guard Time / Cyclic Prefix	32 bits
Sub-Carriers Modulation	QPSK
Symbol Duration (Without Cyclic Prefix)	32msec
Symbol Duration (With Cyclic Prefix)	34msec
Number of Carriers Used	43
Carrier Spacing	47Hz
Frequency Band of Usage	15984.375 to 18000 Hz

5.3 Receiver Design

In any Communication system, receiver design is predominantly important and is required to take utmost care to recover the original transmitted signal with less distortion. This depends upon the optimum algorithms used in the receiver design. In the OFDM based Acoustic Communication System [3], Synchronization and Channel Estimation plays a major role. Symbol timing synchronization must be performed to detect the starting point of each OFDM symbol, which facilitates obtaining the exact samples.

In the experimental setup, the analog output signal from the DSK6713 [10] will be fed to a power amplifier, the output of which will be given to the transducers. At the other end, another transducer will pick up the signal from the water medium and the signal will be fed to the mike input of DSK6713 through a pre-amplifier.

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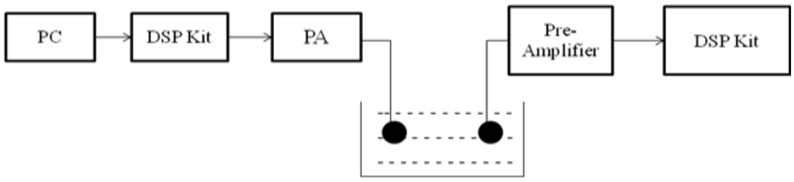

Fig.3. OFDM Based Acoustic Communication System Using DSK 6713

7. IFFT SIMULATION RESULTS

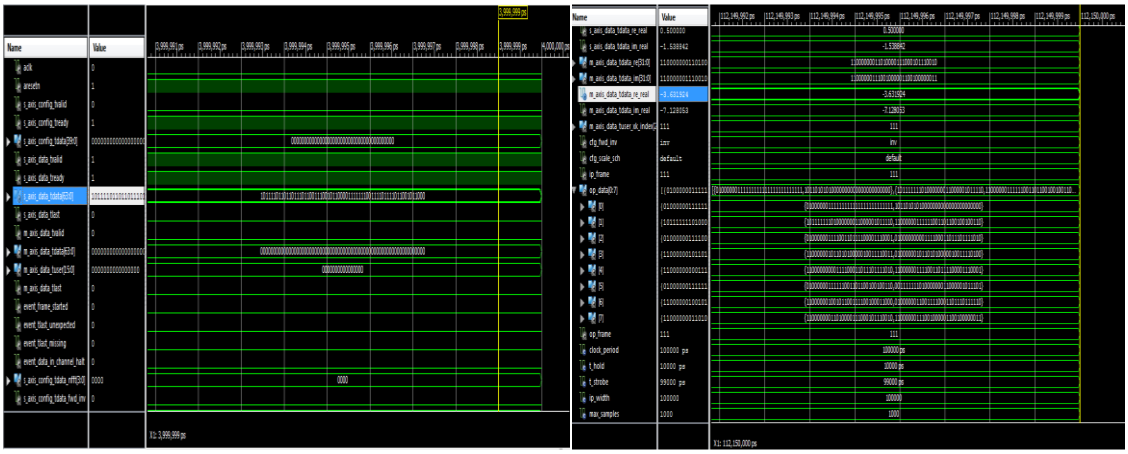

Fig.4. IFFT Simulation Results

CONCLUSION

In this paper, an Inverse Fast Fourier Transform (IFFT) using an existing Intellectual Property (IP) Core FFT/IFFFT V8.0 [11] in Xilinx 14.4 has been implemented for underwater acoustic communication system.

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