Hardware Implementation of OFDM system on TMS320C6713 and verifying the results by using DIP Switches and LEDs

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ABSTRACT

In this paper, the real-time implementation of OFDM system is carried out in MATLAB Simulink by using 16-QAM modulation with AWGN channel. We model the concept with blocks from Simulink’s large collection of prewritten blocksets. Basically, a block diagram that models the complete OFDM system is built using Simulink. To operate on DSK C6713 we use the C6x Target and Real Time Workshop (RTW) to generate (or build) ANSI C code intended for the TI C6713 DSK. The C6x Target will then automatically take the generated ANSI C code and uses the TI CCS v3.1 tools to compile specific machine code and finally loads the targeted machine code to the TI C6713 DSK hardware.

The performance of the implemented OFDM system can be viewed in real time using DIP switches and LEDs on the DSK C6713 for different values of the SNR of the AWGN channel.

Keywords: MATLAB, Simulink, Digital Signal Processing, Real-Time Workshop (RTW), RTDX.

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is commonly used for high data rate wireless communications due to its inherent error robustness in a multipath environment and has been chosen for several next generation broadband wireless local area network (WLAN) standards like IEEE802.11a, IEEE802.11g, and European HIPERLAN/2, and terrestrial digital audio broadcasting (DAB) and digital video broadcasting (DVB-T) [1]-[4].

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier transmission technique that divides the available spectrum into subcarriers [5]. The subcarriers are closely spaced and are modulated with low data rates. They are orthogonal to one another at a frequency spacing, $f_s = 1/T_s$, equivalent to the reciprocal of the symbol time, $T_s$, such that $f_s = 1/T_s$ or its multiple. Moreover, low data rate transmission across orthogonal carriers allows overcoming Inter-Symbol Interference (ISI) and reflections due to multipath. In multipath environments, ISI causes spreading of energy between OFDM symbols resulting in transient changes in amplitude and phase of subcarriers at start of a symbol [6]. These amplitude and phase changes occur at the new value required for the next data symbol. This is a disadvantage as an OFDM symbol needs to remain constant during transmission as subcarriers need to remain orthogonal to one another. If this is not the case, the subcarriers’ spectral shape will not be a proper sinc function $\text{sinc}(x) = \sin(x)/x$ wave. A remedy to remove ISI is to use Cyclic Prefix (CP) [7] as a guard interval as a repetition of a symbol’s end. In this way, a CP also allows linear convolution of a frequency selective multipath channel to be modeled as circular convolution, which in turn may be transformed to frequency domain. This allows for frequency domain operations such as channel estimation and equalization. However, due to a rapidly varying channel, an OFDM symbol will not always remain constant, resulting in loss of orthogonality due to frequency offset and will cause sub-channel leakage, Inter-Carrier Interference (ICI).

2. Real-Time Implementation of OFDM system

Real-time DSP has now become an important technique because of the fast-growing demands in consumer, communication and high-end multimedia products that utilize DSP technologies. There has been a strong motivation for engineers to work in real-time DSP algorithms, implementations, and applications to meet the increased challenges from industry.
In this paper, we highlight how to effectively use both MATLAB [8]-[9] and Simulink [10] for developing an OFDM system including transmitter, receiver and AWGN channel. Several important MATLAB toolboxes, tools, and Simulink blocksets include Signal Processing Toolbox [11], Signal Processing Tool, Fixed-Point Blockset [12], and Signal Processing Blocksets are being used. Simulink and its blocksets are being used to demonstrate DSP concepts and its applications. This “Simulink-first, MATLAB-second” process provides a systematic approach of understanding the DSP principles and real-time implementations.

The implementation of real-time OFDM system requires Simulink to simulate and verifying each phase, a DSP environment for FFT/IFFT implementation by writing its algorithms in C/C++ programming language is required. This process is exhaustive and takes more time so we have introduced the simulation and implementation of the system through Simulink, which is a graphical programming language. By utilizing this environment the designer can dedicated most of the time in developing and enhancing the algorithm and less time on the coding.

The implementation process is done through utilizing the Real Time Workshop (RTW) and the Target Support Package software introduced by MATLAB. The OFDM system has been build as a separate Simulink model and verified on the Code Composer Studio (CCS3.3) C6713 Device Functional Simulator from Texas Instruments. The system has been emulated on the C6713DSP starter kit. The complete OFDM system has been simulated in a complete Simulink environment, which is ready to be downloaded on a DSP processor by just one click.

3. OFDM SYSTEM MODEL

In conventional OFDM systems, whole system bandwidth is divided into many orthogonal sub-carriers with narrow bandwidth, and data blocks are transmitted independently on the subcarriers. In the discrete time domain, an OFDM signal \( x_n \) of \( N \) subcarriers can be expressed as

\[
x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j 2\pi kn/N}, \quad 0 \leq n \leq N-1
\]

Where \( X_k \), \( k = 0, 1, 2, \ldots, N-1 \), are input symbols modulated by BPSK, QPSK or QAM and \( n \) is the discrete time index. OFDM is a multicarrier modulation technique which splits high-rate data streams into a number of lower data rate streams that are transmitted simultaneously over a number of subcarriers. Because the symbol duration increases for the lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Inter symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. Moreover, OFDM provides greater immunity to multi-path fading and impulse noise, and reduces the complexity of equalizers, while efficient hardware implementation can be realized using Fast Fourier Transform (FFT) techniques.

4. 16-LEVEL QAM SIMULINK MODEL OF A COMPLETE OFDM SYSTEM

The OFDM model has been developed in Simulink using 16-level QAM. The blocks included in this model are RTDX (Real Time Data Exchange) input channel, Integer to Bit Converter, Bit to integer Converter, General 16 level QAM modulation, Selecting rows and obtaining complex conjugate, IFFT (Inverse Fast Fourier Transform), Addition of cyclic prefix, Removal of cyclic prefix, FFT (Fast Fourier Transform), Frame status conversion, Remove zero padding, Remove pilot insertion, Select rows and obtain conjugate, General 16 level QAM de-modulation, Integer to bit converter, Bit to integer converter and RTDX (output channel).
5. SYSTEM SPECIFICATIONS

The 16-point Quadrature Amplitude Modulation (16-QAM) OFDM system has been implemented in Simulink using look-up tables. Mapping four data bits onto one complex-valued symbol along with Gray coding was implemented making adjacent symbols differ in only one bit. Incoming data bit stream is mapped to a complex number representing subcarriers amplitude and phase. Furthermore, a 128-point Fast Fourier Transform (FFT) and Inverse FFT was implemented.

DSP Board Details:
- TMS320C6713 DSP - 225 MHz, floating point, 256 Kb internal RAM/Cache.
- CPLD - Programmable "glue" logic.
- External SDRAM – 16 Megabytes, 32-bit Interface.
- External Flash - 512Kbytes, 8-bit interface (256Kb usable).
- AIC23 - Stereo, 8 KHz –96KHz sample rate, 16 to 32 bit samples, jacks, microphone, line-in, line-out and speaker.
- 4 User LEDS - Writable through CPLD.
- 4 User DIP Switches – Readable through CPLD.
- 3 Configuration Switches – Selects Power, Configuration and boot modes.
- Daughter card Expansion Interface- allows user to enhance functionality with add-on daughter card.

6. Hardware Implementation

The OFDM system has been implemented in DSK starter kit from Spectrum Digital which uses the Texas Instrument’s TMS320C6713DSP processor. The C6713 brings the highest level of performance in the C6000 DSP platform of floating-point DSPs. At the initial clock rate of 225 MHz, the C6713 can process information at a rate of 1.35 giga-floating-point operations per second (GFLOPS) which is adequate for implementing complex algorithms. The DSP kit includes an AIC23 codec that includes 2 ADCs and DACs. The DSP kits will be used to process signals at baseband. Simulink model is transformed to a DSP implementable model using Real Time Workshop (RTW) and C6x , the following steps are executed:

1. Prepare a Simulink model and test run to check its proper working by simulating it and obtain desired results.
2. Connect the DSP kit and run Diagnostics to check the proper functioning of each unit of the DSP kit.
3. Open Code Composer Studio (CCS) to connect the DSK C6713 kit.
4. Now, open: MATLAB→Simulink model and set the target blocks depending upon the DSP kit configuration.

5. Open: Simulation→Configuration parameters→Solver and initialize, initial and final time as 0.0 and 1.0 and type as fixed step and solver as discrete.

6. Now go to RTW and select the system target file as ccslink_ert.tlc which generates the C language code automatically.

7. Go to Link for CCS option and set the following parameters:
   i. Handle name: cc
   ii. Stack size: 8192
   iii. Build action: Build

8. Save the model and go to RTW and click generate code.

9. The signal flow will finally build the model and generate the ANSI C code by creating a project automatically in Code Composer Studio.

7. RESULTS

The MATLAB links with CCS and starts the compilation. Simulink interfaces with CCS and generates automatically ANSI C code. The C6x Target then automatically take the generated ANSI C code and uses the TI CCS v3.1 tools to compile specific machine code and finally loads the targeted machine code to the TI C6713 DSK hardware. After the loading of the machine code to the hardware, validation of the OFDM system is carried out using DIP switches and LEDs for different signal to noise ratios of the signal.

When the signal to noise ratio of the AWGN channel is low i.e. SNR = 5 dB, as shown in figure 1.

![Figure 1 Simulink model of OFDM system for SNR=5 dB.](image)

It is found that all the LEDs are flickering and does not respond to the input given by DIP switches as shown in figure 2.
When the signal to noise ratio of the AWGN channel is above 30 dB, as shown in figure 3.

![Simulink model of OFDM system for SNR=50dB.](image)

**Figure 3** Simulink model of OFDM system for SNR=50dB.

It is observed that the LEDs are not glowing initially. But when we apply the input through DIP switch the corresponding LED glows. As shown in figure 4, DIP switches 1 and 4 are pressed to give the input.
We can see that the LEDs 1 and 4 are glowing. This indicates that the Real Time Implementation is successful. Similarly we can try other inputs also.

8. Conclusion

In this paper we introduced the simulation and implementation of a complete OFDM SYSTEM on a DSP through a graphical programming language, which is Simulink. Using a graphical environment in both the simulation and implementation stages makes the designer’s mind dedicated most of the time in developing and enhancing the algorithm and less time on the coding. Moreover using a graphical programming language makes the algorithm very clear and can be easily modified and debugged.

References