

Implementation of SISO-OFDM Transmission using MATLAB on DSP Processor

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Abstract: The design and deployment of a real-time simplex wireless SISO-OFDM transmission setup on 5GHz employing on TMS320C6713 DSP Starter Kits (DSKs) as the baseband transmitter and receiver is proposed. The baseband system level design is done using Matlab/Simulink and the deployment on the TMS320C6713 DSKs is performed by means of IDE link via automatic code generation directly from Simulink blocks, offering a flexible way from system level design and simulation to actual implementation and verification. Orthogonal Frequency Division Multiplexing (OFDM) technology has been adopted by a variety of standards. This technology was chosen due to its robustness at high data rates in a frequency selective multipath channel. In orthogonal frequency-division multiplexing (OFDM), multiple user symbols are transmitted simultaneously over orthogonal subcarriers which form an OFDM symbol. Compared to other modulation methods, OFDM symbols have a relatively long time duration, whereas each subcarrier has a narrow bandwidth. The bandwidth of each subcarrier is small enough to assume a flat (non selective) fading in a moderately frequency-selective system. These subcarriers have overlap in time and frequency domains, nonetheless, the signal waveforms are designed to be orthogonal, due to a cyclic extension of each OFDM symbol in the time domain. A practical implementation involves the inverse fast Fourier transform (IFFT) at the transmitter and the fast Fourier transform (FFT) at the receiver. The narrowband nature of subcarriers makes the signal robust against frequency selectivity caused by a multipath delay spread. However, OFDM is relatively sensitive to its dual, namely, time selectivity, which is due to rapid time variations. Time variations corrupt the orthogonality of the OFDM subcarrier waveforms so that inter carrier interference (ICI) occurs. Orthogonal frequency division multiplexing (OFDM) techniques has widely been considered to be a very promising strategy to enhance data rate, capacity, and quality for broadband wireless systems.

Keywords: SISO-OFDM, MATLAB, Simulink ,Code Composer Studio(CCS), DSP Processor, FFT,IDFT.

I. INTRODUCTION

The rapid growths in telecommunication market in the last decades are in need of new techniques that can provide high data rates. Wireless communications has seen enormous growth in the past few years. Wideband wireless OFDM communication systems are much popular because of their high spectral efficiency and the capability of OFDM to transmit high data rates over Broadband radio channels with frequency selective fading. Such systems are also popular due to the inherent error robustness in a multipath environment and hence 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).OFDM is a special case of multicarrier data transmission technique in which a single data stream is transmitted over multiple subcarriers of narrow bands. The subcarriers are closely spaced and are modulated with low data rates. These subcarriers are orthogonal to each other. Due to rapid increase in the transistor density, it is better to keep the functionality completely in a programmable Digital Signal Processor (DSP) which allows for much faster changes and upgrades. OFDM needs to compute several hundred or thousand points of Fast Fourier Transforms (FFT)

within a few tens of microseconds in order to achieve high speed data transmission in narrow bands. Initially TMS320C5402 DSP Starter Kit (DSK5402) was used as the combination of C and Assembly programming languages. After that the main programming language was assembly. Since the assembly programming is very difficult, ready to use assembly code segments are required. So instead of working on C or Assembly languages, it is better to work with Matlab and Simulink. First, the use of Simulink enables the creation of models from the Simulink's large collection of pre-written block-sets and then the C code is generated with the help of Real Time Workshop and Embedded Target for TI C6000 DSP. Here, both Matlab and Simulink are effectively used to develop an OFDM system including transmitter and receiver. The complete OFDM system is simulated in the Simulink environment, which can then be downloaded on to a DSP processor. OFDM is leading the engineers into a new era of digital transmission and is becoming the chosen modulation technique worldwide.

II. IMPLEMENTATION

Here, the signal processing is description that is we will begin with a concept of what should be programmed. The next step is to model the concept with blocks from Simulink's large collection of prewritten block sets. Basically, a block

diagram that models the concept is built using Simulink. If a specific block required is not included in Simulink's block sets, we may choose to write the own blocks from scratch using Matlab. The Simulink uses a block based approach to algorithm design and implementation. At this point the design is still not designed to operate on any specifically hardware. To do that, we are using the C6x Target and Real Time Workshop 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 from the SIMULINK block diagram. In the next step, the TI CCS tools such as the compiler, assembler and a linker are used to compile the specific machine code and load the targeted machine code to the TI C6713 DSK hardware. The experienced designer may choose to directly write the ANSI C code instead of building the SIMULINK model. The Code Composer Studio communicates with the DSP board through an USB host interface. The real time processed data can then be finally observed using an oscilloscope.

III. OFDM SYSTEM USING DSP PRINCIPLES

OFDM is a special case of multicarrier data transmission technique in which a single data stream is transmitted over multiple subcarriers of narrow bands. The subcarriers are closely spaced and are modulated with low data rates. They are made orthogonal to one another by appropriately choosing the frequency spacing between them. The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other. The block diagram of an OFDM system is shown in fig.1. The random data generator generates a bit stream. This data stream is processed using the 16-QAM modulator to map the data into complex signals. These symbols are passed to an IFFT block to perform the IFFT operation and the time domain signals are obtained. The time domain modulated OFDM symbol from IFFT block is converted back to a serial stream and a guard interval in the form of cyclic prefix is added to each OFDM symbol. This data is now passed through an AWGN channel. The reverse operation is done at the receiver to obtain the original data back. That is, the cyclic prefix is removed and processed in the FFT block and finally passed through demodulator for data recovery.

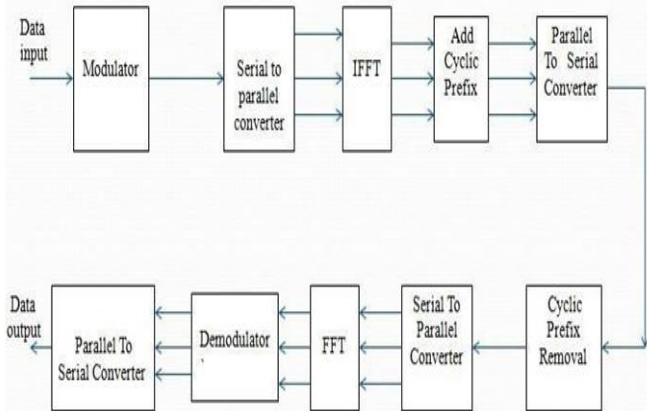


Fig.1. Block diagram of OFDM system.

A. Modulation

In the modulation technique, the signal wave is transformed in order to send it over the communication channel to minimize the effect of noise. This is done so that the received data can be demodulated to give back the original data. In an OFDM system, the high data rate information is divided into small packets of data which are placed orthogonal to each other. This is achieved by modulating the data by a desirable modulation technique such as Quadrature Amplitude Modulation.

B. Communication Channel

This is an AWGN channel through which the data is transferred. The noise present in this channel affects the signal and causes distortion in its data content.

C. Demodulation

Demodulation is the technique by which the original data is recovered from the modulated signal which is received at the receiver end. Here, the received data is first passed through a low pass filter and the Guard Interval is removed. After the data is converted back to parallel stream, the FFT operation is performed. A demodulator is used to get back the original signal. By considering the un modulated signal data and the data at the receiving end, the bit error rate and the signal to noise ratio is calculated. This is achieved by de modulating the data by a desirable modulation technique such as Quadrature de amplitude modulation.

IV. OFDM SIMULATION

The OFDM model has been developed in Simulink using 16- level QAM as shown in Fig.2. The blocks included in this model are random integer generator, Integer to Bit Converter, Bit to Integer Converter, general 16 level QAM modulator, selecting rows and obtaining complex conjugate, IFFT(Inverse Fast Fourier Transform), FFT (Fast Fourier Transform frame status Conversion general 16 Level De-Modulator And a time scope to observe the simulation results.

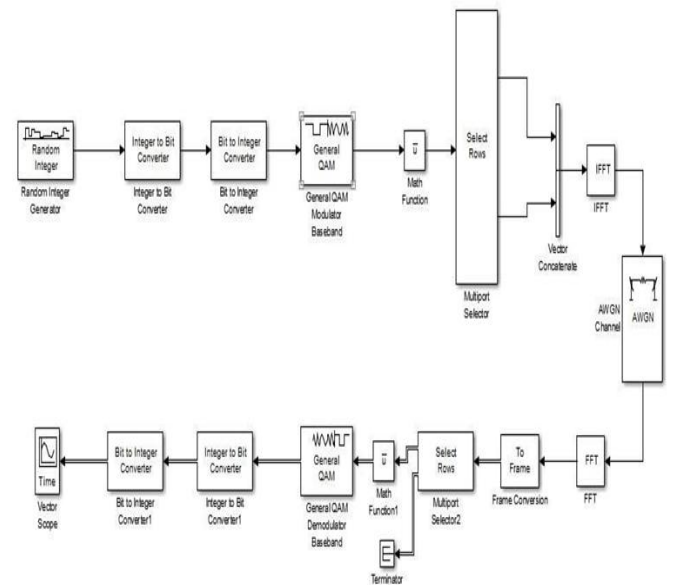


Fig.2. Simulink model of a complete OFDM system.

Implementation of SISO-OFDM Transmission using MATLAB on DSP Processor

V. DIGITAL SIGNAL PROCESSING

DSP is one of the fastest growing fields of technology and computer science in the world. In today's world almost everyone uses DSPs in their everyday life but, unlike PC users, almost no one knows that he/she is using DSPs. DSPs are special purpose microprocessors used in all kind of electronic products, from mobile phones, modems and CD players to the automotive industry; medical imaging systems to the electronic battlefield and from dish washers to satellites. There are many reasons why we process these analog signals in the digital world. Traditional signal processing was achieved by using analogue components such as resistors, capacitors and inductors. However, the inherent tolerance associated with these components, temperature and voltage changes and mechanical vibrations can dramatically affect the effectiveness of analogue circuitry. On the other hand, DSP is inherently stable, reliable and repeatable. With DSP it is easy to change, correct or update applications. Additionally, DSP reduces noise susceptibility, chip count, development time, cost and power consumption.

A. TMS320C6713 DSP Description

The TMS320C67 DSPs (including the TMS320C6713 device) compose the floating point DSP generation in the TMS320C6000 DSP platform. The TMS320C6713 (C6713) device is based on the high-performance, Very Long Instruction Word (VLIW) architecture developed by Texas Instruments, making this DSP an excellent choice for multichannel and multifunction applications. The features of the C6713, 225 MHz device delivering up to 1800 MIPS. This DSP generation is designed for applications that require high precision accuracy. The C6713 is based on the TMS320C6000 DSP platform designed to fit the needs of high-performing high-precision applications such as pro-audio, medical and diagnostic.

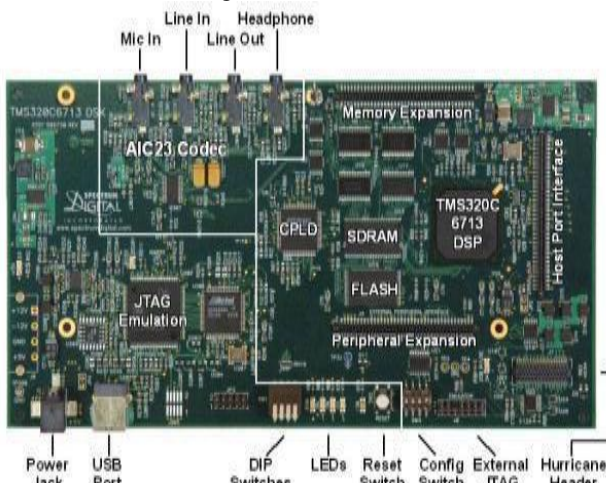


Fig.3. TMS320C6713 board architecture.

Other hardware features of the C6713 board include:

- Embedded JTAG support via USB.
- High-quality 24-bit stereo codec.
- Four 3.5mm audio jacks for microphone, line in, speaker and line out.

- 512K words of Flash and 8 MB SDRAM.
- Expansion port connector for plug-in modules.
- On-board standard IEEE JTAG interface.
- +5V universal power supply.

The DSP environment used in this paper is the C6713. Fig.3 shows the architecture of the C6713.

B. DSP Implementation

In the past, the small systems implemented on DSP by writing its algorithm by C/C++ or assembly, using a text programming languages in writing, but long and complicated algorithms makes the process exhaustive and difficult to debug, modify, and learn. The following sections describe the simulation and implementation of OFDM transceiver with on a DSP platform through a graphical programming language, which is SIMULINK. This makes every part in the system architecture very clear and easier to understand, follow, modify and debug.

VI. DSP SOFTWARE IMPLEMENTATION

In, the C6713 board, like a personal computer, needs to load software to establish its behaviour and function. This software's can be designed in a variety of approaches. The designer will begin with a concept of what they want to program. The next step is to model the concept with blocks from Simulink's large collection of pre written block sets. Basically, a block diagram that models the concept is built using Simulink as shown in Fig.4. If a specific block required is not included in Simulink's block sets, the designer may choose to write their own blocks from scratch using MATLAB. At this point the design is still not designed to operate on any specified hardware. To do that, the designer uses the C6x Target and RTW to generate (or build) ANSI C code intended for the C6713. The C6x Target will then automatically take the generated ANSI C code and uses the Code Composer Studio (CCS) tools to compile specific machine code and finally loads the targeted machine code to the C6713 hardware. For the experienced designer, they may choose to directly write the ANSI C code.

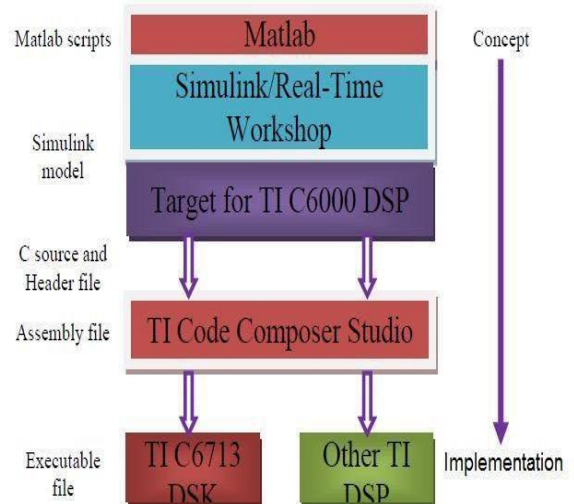


Fig.4. Software design flow.

A. Simulation Model

OFDM transmitter with variable symbol timing and carrier frequency error is designed. The model implements a 64 carrier OFDM waveform with a 16 point cyclic prefix. The OFDM symbol has 16 pilots, and uses 4 Quadrature Amplitude (QAM) for the 48 remaining data streams. Once the implementation of the model in SIMULINK is achieved, and already tested that it works properly, the next step is targeting the model on the DSP board. In this paper, the implementation of the model on a TMS320C6713 DSP board from Texas Instrument is carried out. Having the implementation of the model in Simulink and after testing that this is working properly, the next step is targeting the model on the DSP board. For accomplishing this assignment, the following tools have been used:

- Code Composer Studio v 3.1
- Embedded Target for TI c6000 DSP

B. The Code Composer Studio

CCS is the necessary software support tools, which provides an integrated development environment (IDE), bringing together the C compiler, assembler, linker, debugger, and so on. It has graphical capabilities and supports real-time debugging. It provides an easy-to-use software tool to build and debug programs. The C compiler compiles a C source program to produce an assembly source file. The assembler assembles the source file to produce a machine language object file, combines object files and object libraries as input to produce an executable file by the linker with extension ".out". This executable file can be loaded and run directly on the C6713 processor.

C. Real-Time Data Exchange

DSP programs can be transfer data between the DSP device and a host computer without affecting the DSP application using RTDX. There are components on the DSP device (target) and the host computer that allow this communication to happen. Real-Time Data Exchange (RTDX) provides real-time, continuous visibility into the way target applications operate in the real world. RTDX allows system developers to transfer data between target devices and a host without interfering with the target application. Key statistics and performance can be monitored in real time. Through the Joint Team Action Group (JTAG), communication with on-chip emulation support occurs to control and monitor program execution. The C6713 DSK board includes a JTAG interface through the USB port.

D. Target for c6000 DSP

Embedded Target for the TMS320C6000 DSP Platform integrates Simulink® and MATLAB®with Texas Instruments eXpressDSP™ tools. The software collection lets you develop and validate digital signal processing designs from concept through code. The Embedded Target for C6000 DSP consists of the C6000 target that automates rapid prototyping on your C6000 hardware targets. The target uses C code generated by Real-Time Workshop® and your development tools to build an executable file for your targeted

processor. The Real-Time Workshop build process loads the targeted machine code to your board and runs the executable file on the digital signal processor. Using the Embedded Target for C6000 DSP and Real-Time Workshop, you can create executable code for the following boards:

- C6416 DSP from Texas Instruments
- C6701 Evaluation Module from Texas Instruments
- C6711 DSP from Texas Instruments
- C6713 DSP from Texas Instruments (board used in this paper work)
- TMDX326040. A daughter card for the C6711 DSK

VII. DEPLOYMENT AND EXPERIMENTAL DEMONSTRATION

The Simulink models for the transmitter and receiver are hierarchically organized into subsystems. That is, processes such as modulation, synchronization, estimation, sampling clock offset estimation etc., are organized into discrete modules. Hence, a clear intuitive link between theory and practice is illustrated. As mentioned, implementation is done at the TMS320C6713 DSK, through automatic code generation from these Simulink modules. The TMS320C6713 DSK board revision C, serves as a hardware reference design for the TMS320C6713 Digital Signal Processor (DSP) . The DSP is a 32 bit floating-point processor operating at 225MHz. The board has 8MB of synchronous DRAM and 512KB of non-volatile Flash memory. The board ships with an embedded AIC23 stereo codec with sampling frequencies up to 96 KHz. In this work, we use a sampling frequency of 48 KHz. The first 10 subcarriers(1875Hz) are set to null (unused) due to codec, mixer and amplifier bandwidths. Technical specifications are shown in Table 1. Also, to reduce the Codec’s frame rate, blocks symbols are transmitted/received and then un-buffered so as processing to be performed over single transmission symbols.

TABLE I: DSP Parameters

Parameter	Value
Sampling frequency (Fs)	48KHz
FFT/IFFT	256
Subcarrier spacing	$F_s/256 = 187.5\text{Hz}$
Subcarrier Modulation	M-DPQSK ($M= 4, 16,$)
DMT symbol duration	6.7 msec (320 samples)
Cyclic prefix (CP)	1.3msec (64 samples)
Bit rate	Tunable (<i>in the order of Kbps</i>)
Baseband Bandwidth	33,75KHz (2*80 subcarriers)
Carrier frequency	5GHz

VIII. SIMULATION AND DSP BOARD RESULTS

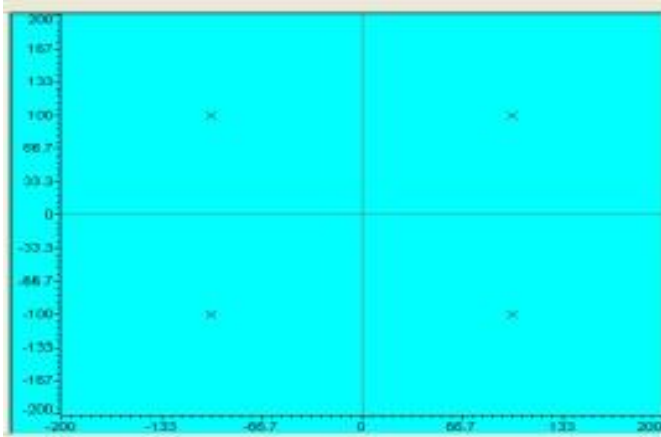
The simulation and DSP results are taken for CFO=0 Hz, 20 Hz, 100 Hz, 300 Hz, 500 Hz, while STO = 0 sample, 1 sample, 4 samples and SNR=10 dB. Then the Bit Error Rate (BER) and Mean Square Error (MSE) are plotted against SNR.

Implementation of SISO-OFDM Transmission using MATLAB on DSP Processor

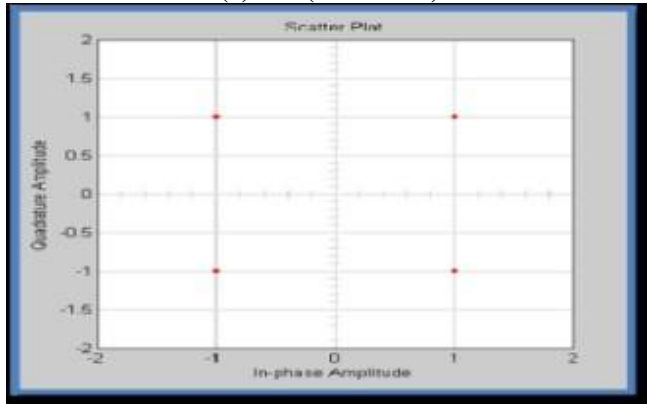
A. Symbol Timing Offset and Carrier Frequency Offset Effect

These are some of simulation and DSP cases results as shown in Figs.5 to 13.

Case 1: There is no timing and frequency error $CFO = 0$, $STO = 0$, Channel = No Noise



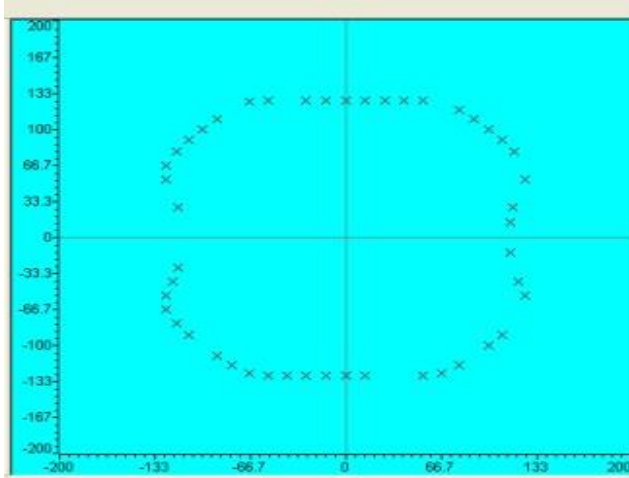
(a) Data (MATLAB)



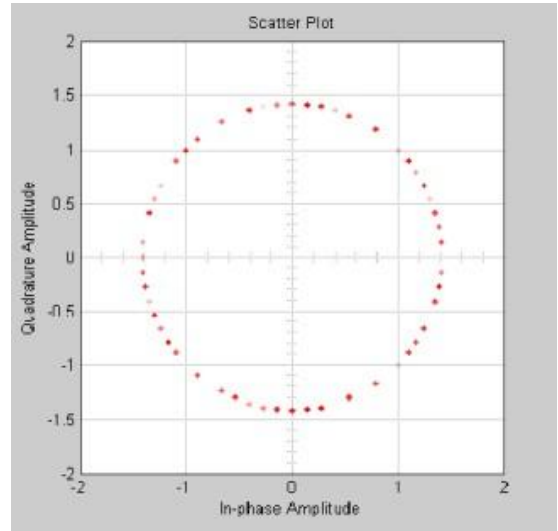
(b) Data (C6713)

Fig.5. MATLAB and DSP data Constellation provided $CFO = 0$, $STO = 0$ and No Noise.

Case 2: In this case $STO = 1$ sample, $CFO = 0$ and Channel = No Noise.



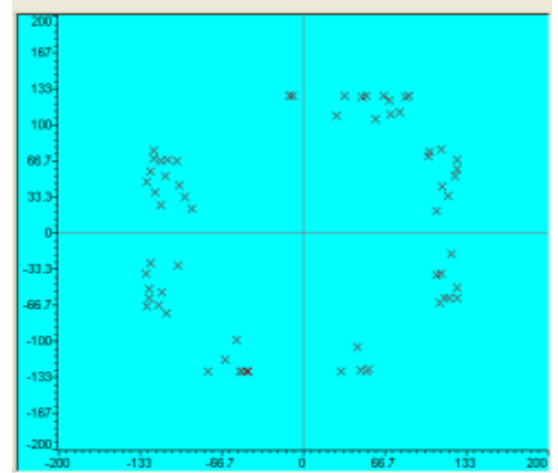
(a) Data (MATLAB)



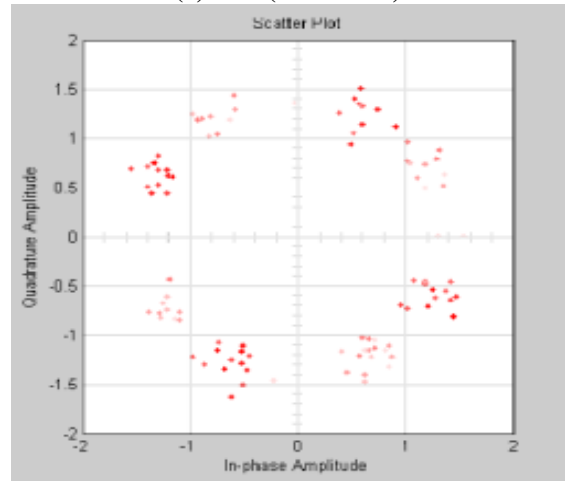
(b) Data (C6713)

Fig.6. MATLAB and DSP data Constellation provided $CFO = 0$, $STO = 1$ sample and No Noise.

Case 3: In this case $STO = 0$, $CFO = 100$ Hz, and Channel = No Noise.



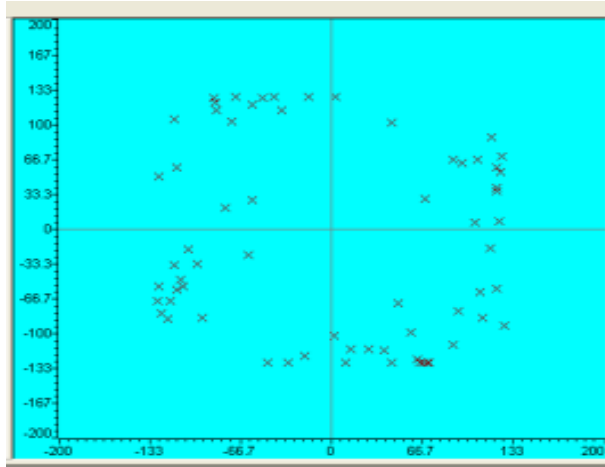
(a) Data (MATLAB)



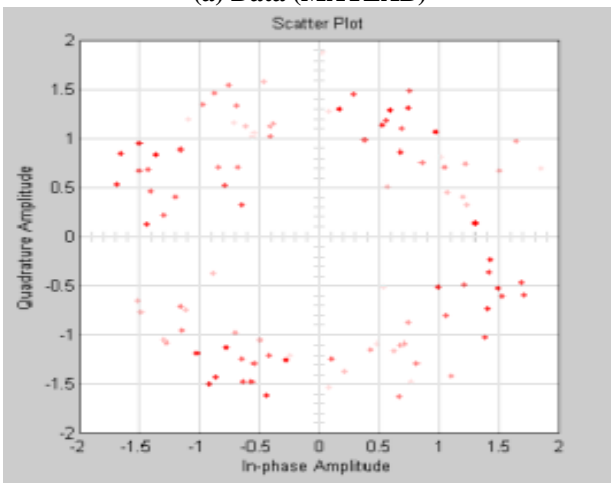
(b) Data (C6713)

Fig.7. MATLAB and DSP data Constellation provided $CFO = 20$ Hz, $STO = 0$ and Channel = No Noise.

Case4: In this case STO=0, CFO=100Hz and Channel =AWGN SNR = 10.



(a) Data (MATLAB)



(b) Data (C6713)

Fig.8.MATLAB and DSP data Constellation provided CFO = 100 Hz, STO = 0 and Channel = AWGN SNR = 10.

After simulate the model on different values of STO and CFO and use Monte Carlo Simulink, plot the Bit Error Rate and SNR relation for these different values.

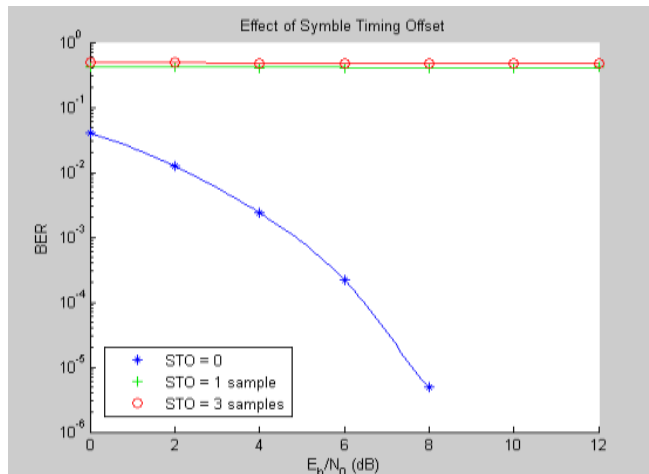


Fig.9. Illustrates the Effect of Symbol Timing Offset.

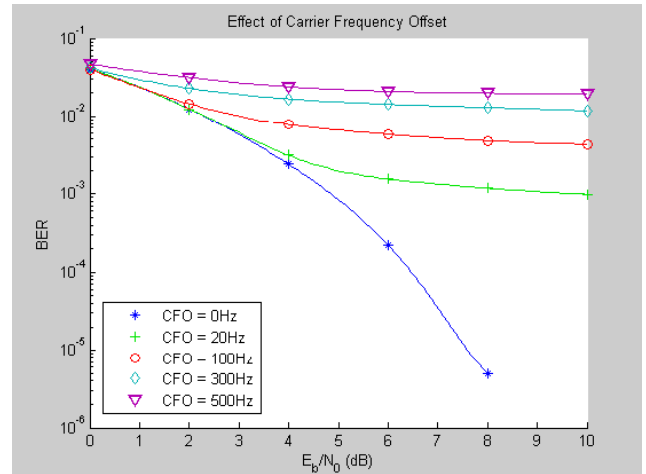


Fig.10. Illustrates the Effect of Carrier Frequency Offset.

From MATLAB results, the Mean Square Error with respect to SNR for different values of STO and CFO had been plotted after record the input data and the output data, calculate the mean square error for these results. Fig.11 and Fig.12 illustrate the effect of timing and frequency offsets.

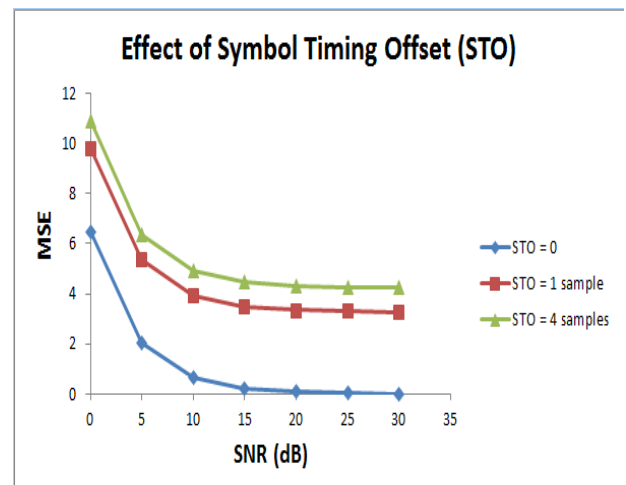


Fig.11. Illustrates the Effect of Symbol Timing Offset.

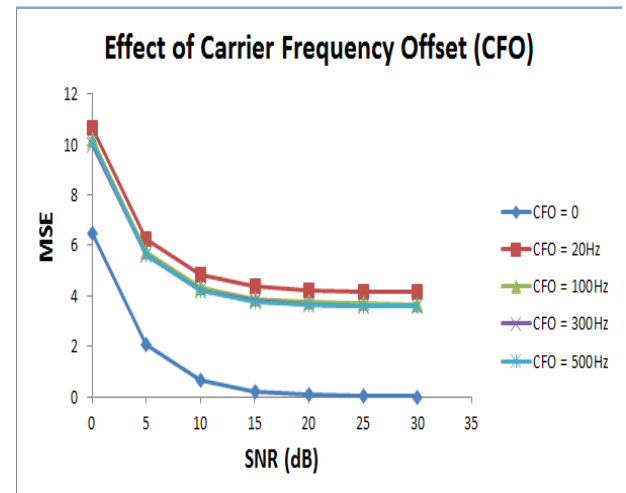


Fig.12. Illustrates the Effect of Carrier Frequency Offset.

Implementation of SISO-OFDM Transmission using MATLAB on DSP Processor



Fig.13. Code Composer Studio and hardware set up with DSK 6713.

IX. CONCLUSION

Real time broadcast-like SISO-OFDM wireless transmission on 5GHz employing TMS320C6713 DSP boards was demonstrated. Baseband design was based on Simulink and deployment was done on the C6713 DSP's via automatic code generation. Experimental measurements confirmed the system's specifications and typical results verified its functionality and showed its potential for demonstrating contemporary wireless communication concepts to students. Thus the purpose of this simulator has achieved. It makes the study of OFDM processing very easy.

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