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# Design and Implementation of COFDM Transceiver using TMS320C6713

[1]Sura Mohammed and [2]A.E. Abdelkareem
[1]Department of Information and Communication Engineering,
[2]Department of of Networks Engineering, AL-Nahrain University, Baghdad, Iraq

**Abstract:** In this study, the design and implementation of Coded Orthogonal Frequency Division Multiplexing (COFDM) system is presented. The design of COFDM system-level is done by using MATLAB/Simulink while the implementation is based on TMS320C6713 DSK from Texas Instruments Inc. The collaboration of MATLAB Integrated Development Environment (IDE) and Code Composer Studio (CCS) are adopted. The real time implementation is one of the most difficult issue of OFDM implementation The problem of real time implementation is the memory consumption and the processing time. The other problem is synchronization of OFDM receiver. Time and frequency synchronization to distinguish the begin of the OFDM symbol. The transceiver performance is evaluated based on Real-Time Data Exchange (RTDX) with Additive White Gaussian Noise (AWGN) channel with using channel estimation method. In addition, the designed system is investigated with the convolutional encoder of 1/2 Punctured-6/7 code rate with block interleaving. The data rate 9.6 kB/sec, processing time 4 msec and the bit error rate performance for SNR $10^{-1}$ = 2 dB and $10^{-4}$ = 12 dB.

**Key words:** COFDM, MATLAB Simulink, DSP, CCS, AWGN, block interleave, convolutional code

## INTRODUCTION

In the recent decade, a fast growth in communications demands a new technology that can provide high data rates (Van Nee and Prasad, 2000). Many communications systems have been deployed with increasing data rates such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and mobile services (Terry and Heiskala, 2002). The main reason for increasing attention on OFDM technique is its ability to provide high-speed transmissions with low-complexity data rates. The OFDM has the ability to overcome the Inter-Symbol Interference (ISI) signals effectively through selective radio channels (Van Nee and Prasad, 2000; Terry and Heiskala, 2002). The main idea of Orthogonal Frequency Division Multiplexing (OFDM) is separating fast rate data stream into slower parallel one in order to increase the symbol duration and eliminate ISI as possible (Engels, 2002). OFDM is a special case of both multicarrier modulation scheme and multiplexing technique (Han *et al.*, 2009).

In OFDM, the data stream modulates a set of orthogonal carriers (one carrier does not interfere with the other) and the whole group is sent to the channel (frequency division multiplex). Usually, the data stream consists of appropriate in-phase and quadrature values based on QAM constellations (Pikasis *et al.*, 2012;

The objective of this study is to design and implementation a Coded Orthogonal Frequency Division Multiplexing (COFDM) and executed it by using Simulink with TMS320C6713. The MATLAB has the capabilities of converting the Simulink block into C Code for the C6000 DSP family. In Simulink, the transmitter, receive systems and the channel are designed and built in MATLAB Simulink. the AWGN channel has been used. The code will be loaded from the computer to the TMS320C6713 processor by the use of embedded JTAG.

**Literature review:** Yan *et al.* (2012) studied the implement OFDM underwater acoustic modems receiver. With two different data rate is 3.2kB/sec for Single Input Single Output (SISO) and 6.4 kB/sec for and Multi Input Multi Output (MIMO). The goal of this receiver is to accelerate the coding speed, processing time must be less than the OFDM symbol time. With non-binary Low-Density Parity-Check (LDPC) coding increase the error gain by 2 dB but increase the processing time to 50 msec for SISO and 101 msec for MIMO. The main parameter in the design of the transmitter is Zero Padding (ZP) the sampling frequency is 48 kHz and the bandwidth of the signal 6 kHz the carrier frequency 12 kHz. The OFDM block consist of the preamble and the data, the preamble consist of two symbol which use for frame detection and synchronization. The number of subcarrier in the preamble 512 subcarrier, the preamble has duration

**Corresponding Author:** Sura Mohammed, Department of Information and Communication Engineering, AL-Nahrain University, Baghdad, Iraq

time of 221.9 msec in the data the OFDM symbol consist of 1024 subcarrier and duration time 170.7 msec.

By Abdulsattar and Jebur (2014), frequency and timing synchronization of OFDM using Simulink relying on the position of the appraised start of OFDM symbol using four cases of timing offset 1st case is exact point in this case the OFDM symbol recovered without interference 2nd case little early symbol estimated after the finish of the (slacked) channel response; the symbol is not overlapped and without ISI 3rd case too early symbol estimated to the finish the channel response of the past OFDM symbol avoid ISI and ICI occur 4th case is little late of the prediction of symbol arrival the FFT will be for current symbol and the next symbol.

By Varsha and Jagadeesh (2015) half-duplex OFDM using MATLAB Simulink, TMS320C6713 processor and CCS. using the 16 QAM mapper to map the data. The symbol pass through AWGN channel then remove CP and pass the signal to FFT and 16-QAM de -mapper to retrieve the symbol.

By Fukuda and Abrao (2016) channel samples and OFDM demodulator were actualized completely in the DSP TMS320C6678 platform. A 256-QAM OFDM BER execution is contrasted and hypothetical esteems. In addition, the memory measure isn't requesting, expending not very many assets 4 times DSP clock cycles needed to demodulate the signal. The implementation is done using CCS and BIOS Multicore Software Development Kit (MCSDK), the noise was generated inside the platform via. Box Muller transform, the user can calculate the clock of the DSP using two methods the first one is profiler tool and the second is calling the function itoll provided by the header c6x h. It sends image as a data to the target kit it modulated and convert to OFDM symbol; the symbol undergoes to fading channel and the additive thermal noise were included at the recipient input, at that point the OFDM images were demodulated and sent back to the PC where the first information were contrasted with the recuperated information pointing with decide the normal BER.

By Kiran and Rao (2016), SISO_OFDM system setup on 5 GHz using QAM modulation technique and AWGN channel causes distortion in the data sampling frequency 48 kHz and FFT/IFFT 256 with subcarrier spacing 187.5 Hz with cyclic prefix 64 sample.

## MATERIALS AND METHODS

**System model:** The structure of the proposed system is shown in Fig. 1. OFDM system transmitter model consists of five stages. First stage, the bit's stream is generated using the random data generator. Second stage, the stream is encoded using punctured convolutional encoder. Third stage, the stream modulated using the 16-QAM baseband modulation to map the data into complex signals. Forth stage is adding pilot sequence. Finally, the 5th stages a time domain signals are obtained by process by using Inverse Fast Fourier Transformer IFFT block, the pilot sequence inserted to the streams is added to each OFDM symbol. This data is now passed across an AWGN channel.

The data after the encoder and interleaver passed to base band QAM modulator $\{x_{i, n}\}$. The output of the modulator is a complex data sample donated as $\{d_{k,n}\}$. The

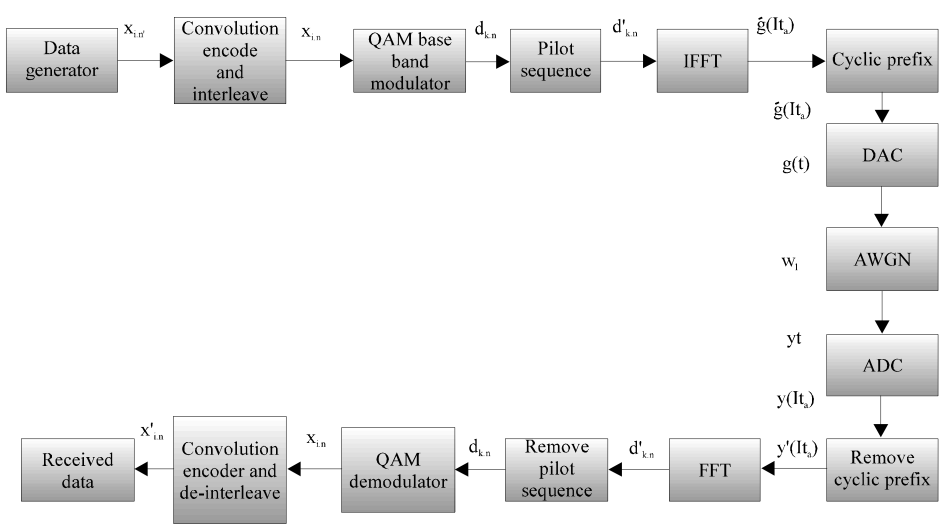


Fig. 1: Suggested OFDM Model

pilot sequence inserted to the sample donated as $\{d'_{kn}\}$, next the sample $\{d'_{kn}\}$ modulated using IFFT. The transmitted signal after IFFT is Eq. 1:

$$g'(lt_a) = \sum_{n=-L}^{+L} d_{kn} S'(lt_a - KT) e^{jnw_s lt_a} \quad (1)$$

Assuming $s'(lt_a\text{-}KT)$ and replacing:

$$e^{jnw_s\, lta} = e^{j2\pi \frac{nl}{N_{FFT}}}$$

To obtain Eq. 2:

$$g'(lt_a) = S_0 \sum_{n=-L}^{+L} d_{k.n} e^{j2\pi \frac{nl}{N_{FFT}}} \quad (2)$$

The overall symbol duration will be donated as Eq. 3:

$$T_{sym} = T_s + T_{cp} \quad (3)$$

Where:

$T_s$ = Duration of OFDM symbol

$T_{cp}$ = Duration of the cyclic prefix

The received signal which received is shown in Eq. 4. To obtain the main data back the opposite process is carried out at the receiver which consists of the first step is to synchronize which done by CP correlation method, then removing. The original OFDM symbol is extracted and processed by using FFT. The channel estimation was depending on pilot sequence. Finally, the output of FFT passes through demodulator in order to recover the main data. The parameter for implementation the system is shown in Table 1 (Eq. 4):

$$y(t) = g(t) + w_1 \quad (4)$$

Where:

y(t) = Received signal

g(t) = Transmitted signal

$w_1$ = Additive noise

**System implementation**

**OFDM Model:** The suggested model is show in Fig. 2. The data is generated using Bernoulli Binary Generator block in Simulink library with 144 samples per frame. After the data generation, 192 samples per frame are obtained using convolutional encoder. The encoder uses the punctured convolutional encoder with code rate 6/7, constraint length 7 using the polynomial {133, 171} and the Euclidean distance would be 3 (Yan *et al*., 2012). The stream passes through interleaver matrix the stream data elements read row by row and sends from the matrix contents to the output column by column. Now 48 samples was modulation using 16 QAM modulator baseband block.

Table 1: COFDM design parameter

| Parameter | Value |
|---|---|
| Total number of transmitted bit/Bit | $10^8$ |
| Sampling frequency/kHz | 32 |
| Sample per frame | 144 |
| FFT/IFFT (N-point) | 64 |
| Subcarrier spacing/Hz | 500 |
| Cyclic prefix | 16 |
| Modulation | 16-QAM |
| Data rate | Tunable |
| Maximum bandwidth/Hz | 16000 |
| Symbol period /msec | 5 |

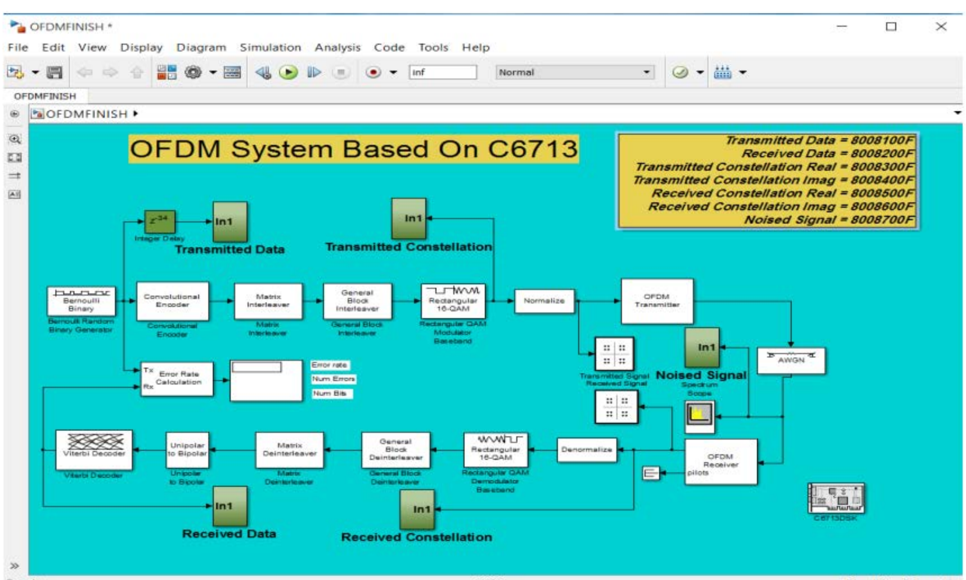


Fig. 2: Block interleaved COFDM system design through AWGN channel

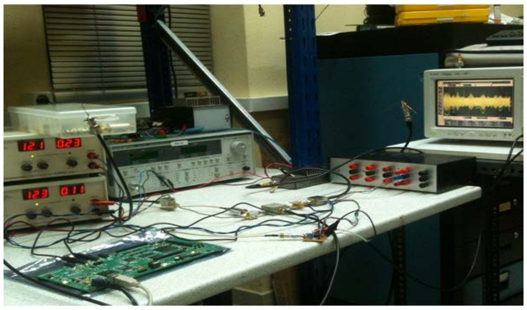

Fig. 3: Real time implementation

After modulating, the pilot sequence inserted to the streams and zero padding inserted in order to prepare the signal dimension to perform (IFFT) to change the signal from frequency space to time-space.

When IFFT process is completed, the cyclic prefix will be added. In this model a 25% cyclic prefix will be used to overcome the ISI, inter carrier interference ICI and multipath impacts besides being used in the synchronization process. The cyclic prefix expansion will be finished by replicating the last piece of the signal and blending it at the beginning. The signal transmitted over the AWGN channel with adding the time and frequency errors.

At the receiver, the first stage is the timing and frequency synchronization using cyclic prefix properties to find time and frequency offset then remove the CP. After synchronization the data passes to (FFT) then remove the zero padding. The pilot sequence would be passing to the channel estimator and terminated using terminator. The useful information will be renormalizing and demodulated by using baseband demodulator. After demodulating the stream would be de-interleave and decoded using the Viterbi decoder.

The previous explanation show how the system will be work by using MATLAB Simulink. For real time implement OFDM system is considered based on TMS320C6713 DSK as shown in Fig. 3, the procedure will be described as follow.

The sub-block used to show the transmitted signal, first the signal multiplied by gain 30 then converts the data into 8-bit signed integer and wrote to the memory of the Kit which store it at location 0×8008100 f. The capacity of the buffer is 144 this buffer store data type of 8 bit signed integer.

To get the constellation of the transmitted data on the board first separate the real and imaginary. Multiplied each part (real and imaginary) by gain 30. Then, convert it to 8 bit signed integer and store it in the buffer of size 512 and write to the memory of the kit at location 0×8008300 f for the real part and for the imaginary part at location 0×8008400 f.

The signal with noise, first separate the real and imaginary then square the real and imaginary then add them and take the square root of them. Multiply the result by gain 100 and convert it to 8 bit signed integer to store it in buffer size 512 byte at location 0×8008700f.

The sub-block used to show the received signal; first, the signal multiplied by gain 30 then, converts the data into 8-bit signed integer and wrote to the memory of the kit which stores it at location 0×8008200f. The capacity of the buffer is 144 this buffer store data type of 8-bit signed integer.

To get the constellation of the received data on the board first separate the real and imaginary. Multiplied each part (real and imaginary) by gain 30. Then, convert it to 8 bit signed integer and store it in the buffer of size 512 and write to the memory of the kit at location 0×8008500f for the real part and for the imaginary part at location 0×8008600f.

**Channel estimation:** The pilot sequence which inserted in OFDM symbol is used for channel estimation. The estimation is performed per frame basis. Let $P_{tx}$ (k) be the complex QAM value that modulates the subcarrier of index k due to channel effects. And if $P_{rx}$ (k) at the receiver after FFT to obtain the frequency domain, H (k) for every individual subcarrier is calculated using the following relation applies Eq. 5:

$$H(k) = \frac{P_{rx}(k)}{P_{tx}(k)} \quad (5)$$

Where:

H (k) = The transfer function of the channel
$P_{tx}$ (k) = A priori known and registered to the receiver

This estimate of H(k) is then used to calculate the correct QAM values for data symbols using the following formula Eq. 6:

$$S_{tx_{corrected}}(k) = \frac{1}{H(k)} S_{rx}(k) \quad (6)$$

where, $S_{rx}$(k) and $S_{tx}$ corrected (k) is the QAM value (kth subcarrier) before and after channel estimation respective.

## RESULTS AND DISCUSSION

The simulation result of block interleaved COFDM system is taken for CFO = 0 Hz while STO = 0 sample and SNR = 15 dB. The spectrum of the suggested block interleaved COFDM with $T_s$ of 1/32000 sec using 4 pilots and 12 zero padding signals is shown in Fig. 4. Transmitter constellation of the system is shown in Fig. 5. Figure 6 shows the signal power for all transmitted frame

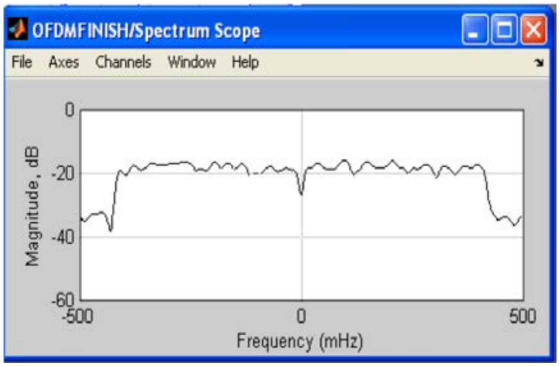


Fig. 4: Spectrum of the received signal of block interleave COFDM system

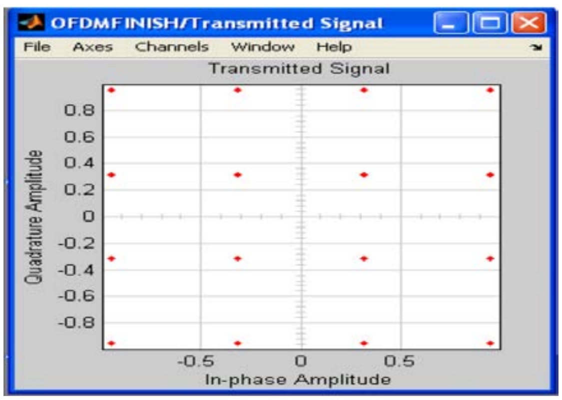


Fig. 5: Constellation of transmitted signal using 16 QAM of block interleave COFDM system

it shows that the power stabilizes at 10 dB. The received constellation of the COFDM system is shown in Fig. 7. The constellation takes 52 bits for each OFDM symbol. Figure 7 shows that the mapped symbol seems more accurate than (Misra *et al*., 2009; Fukuda and Abrao, 2016; Kiran and Rao, 2016) because of the use of interleaving and convolutional coding but the drawback is increasing in complexity of the system.

The performance over indoor channel without any Doppler shift is shown in Fig. 8; the Bit Error Rate BER is plotted against SNR which compares with theoretical BER for coding OFDM system. The Fig. 8 showed that the difference between the theoretical coded system and the suggested system is 1 dB. Table 2 shows that the performance of the suggested system approaches from the performance of the theoretical system.

**LAB results:** The real-time results of the transmitted and received COFDM are shown in the following figures. Figure 9 show the transmitted and received data. It shows the matching between the transmitted and the received data. Figure 10 shows the constellation of the transmitted signal on the platform. Figure 11 shows the constellation of the received signal. The accurate mapping is obtained using interleaving and convolutional coding as appear in Fig. 11. Finally, the signal adding noise is shown in Fig. 12.

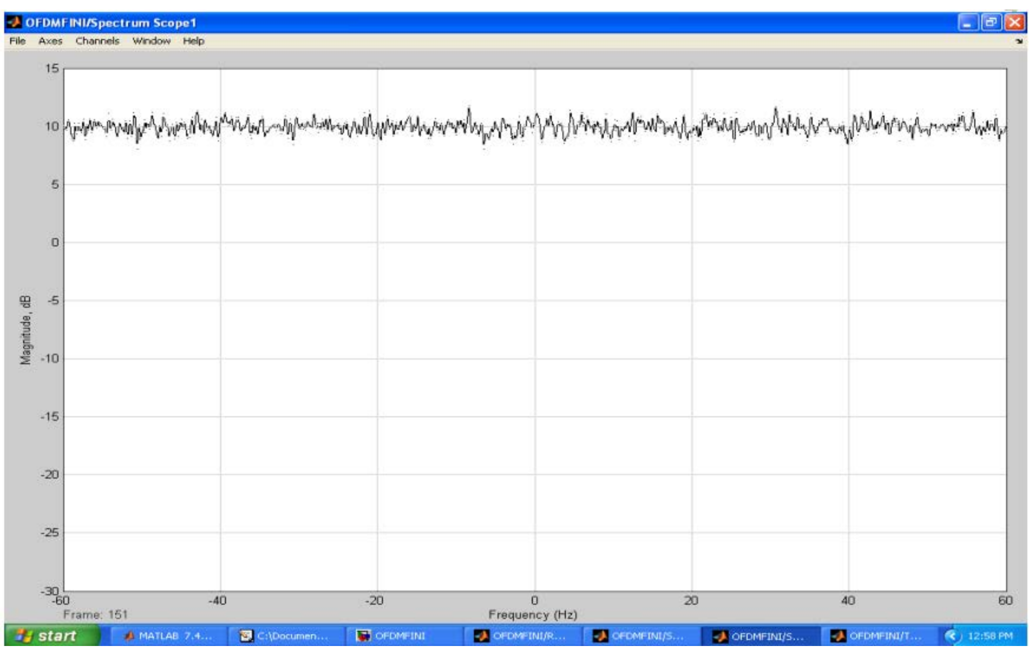


Fig. 6: Power for all transmitted frame over AWGN channel

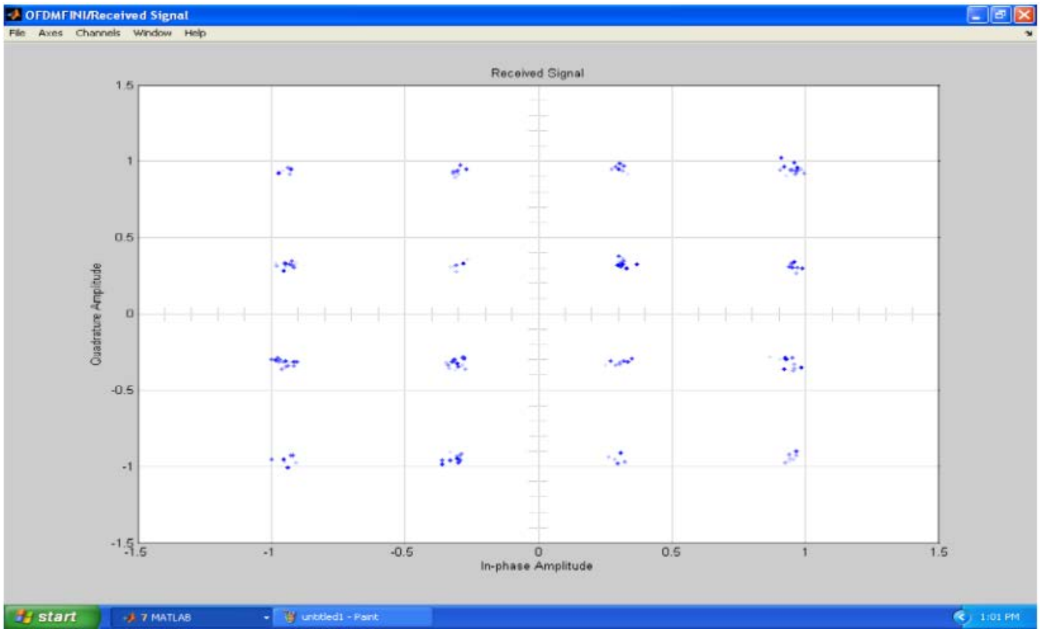


Fig. 7: Constellation of received signal using 16QAM of block interleave COFDM system

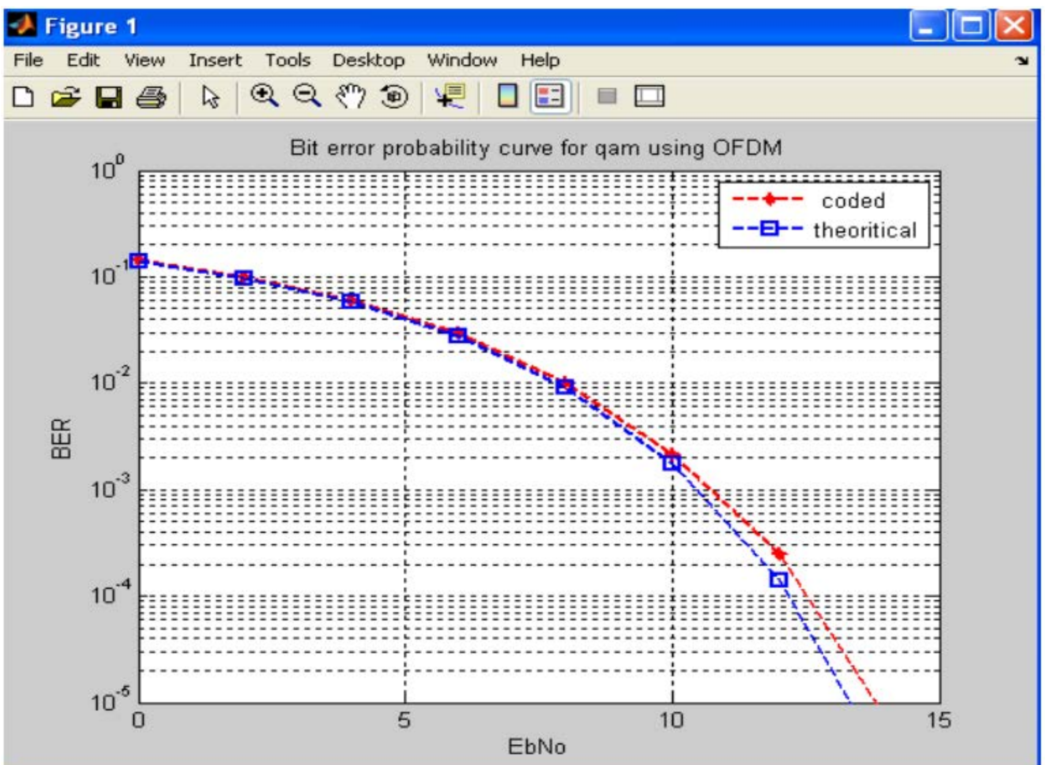


Fig. 8: Comparison of BER for encoded system between the theoritical and the designed system

Table 2: Result comparison

| System | Values | | | | |
|---|---|---|---|---|---|
| COFDM system | 2 dB ($10^{-1}$) | 8 dB ($10^{-2}$) | 10 dB ($10^{-3}$) | 12 dB ($10^{-4}$) | 14 dB ($10^{-5}$) |

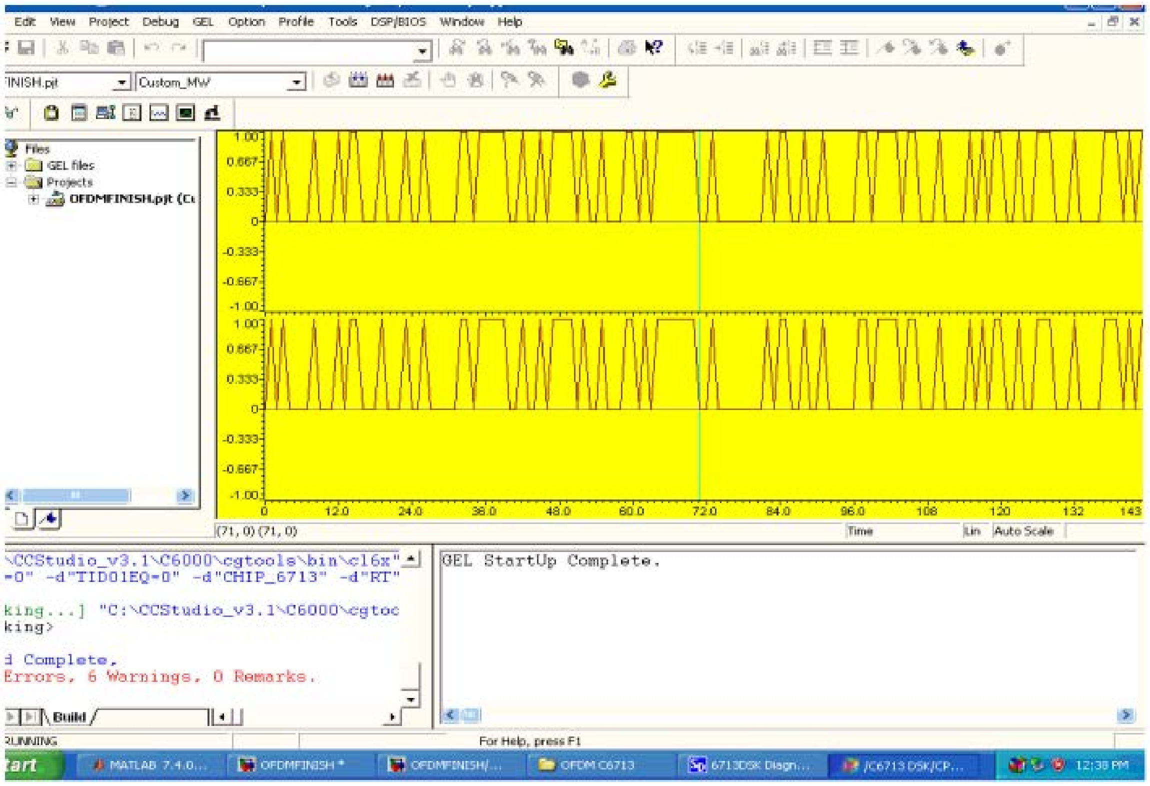


Fig. 9: The transmitted signal versus received of 15 dB COFDM

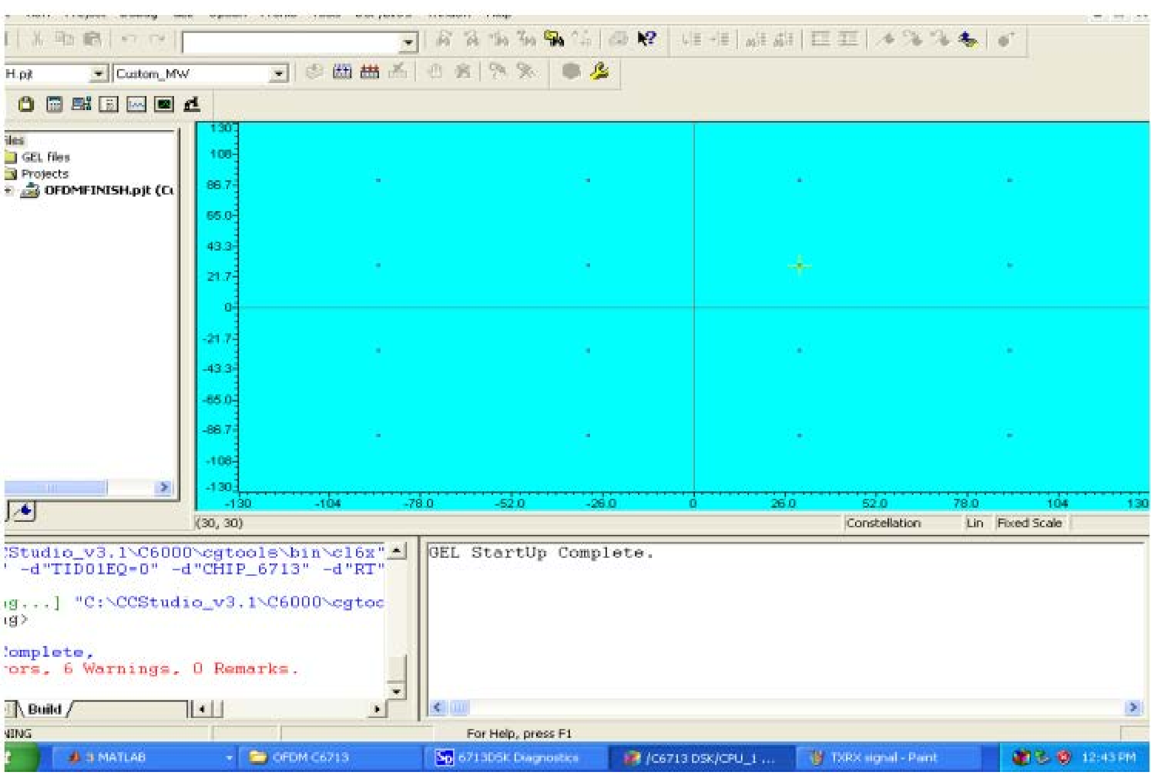


Fig. 10: The constellation of transmitted signal of 15 dB COFDM

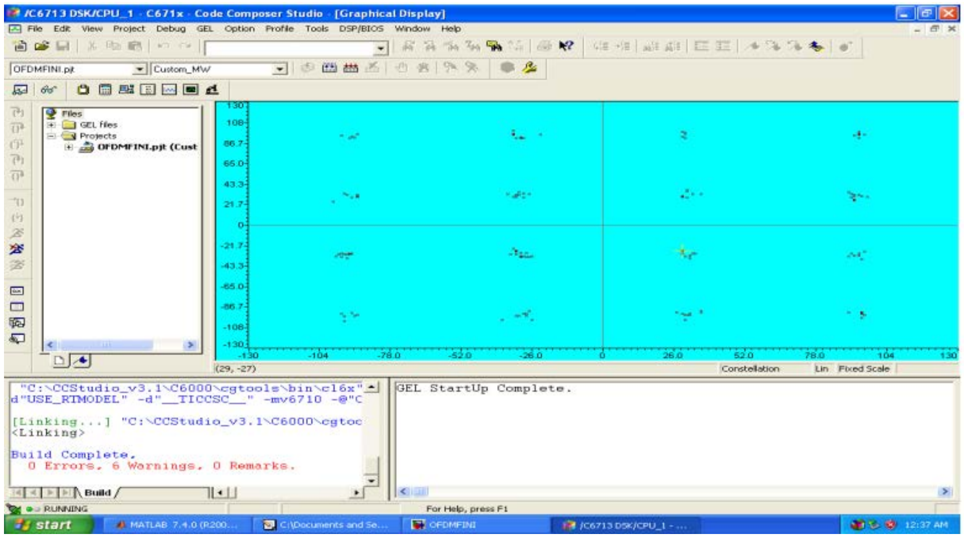


Fig. 11: The constellation of the received signal of 15 dB COFDM

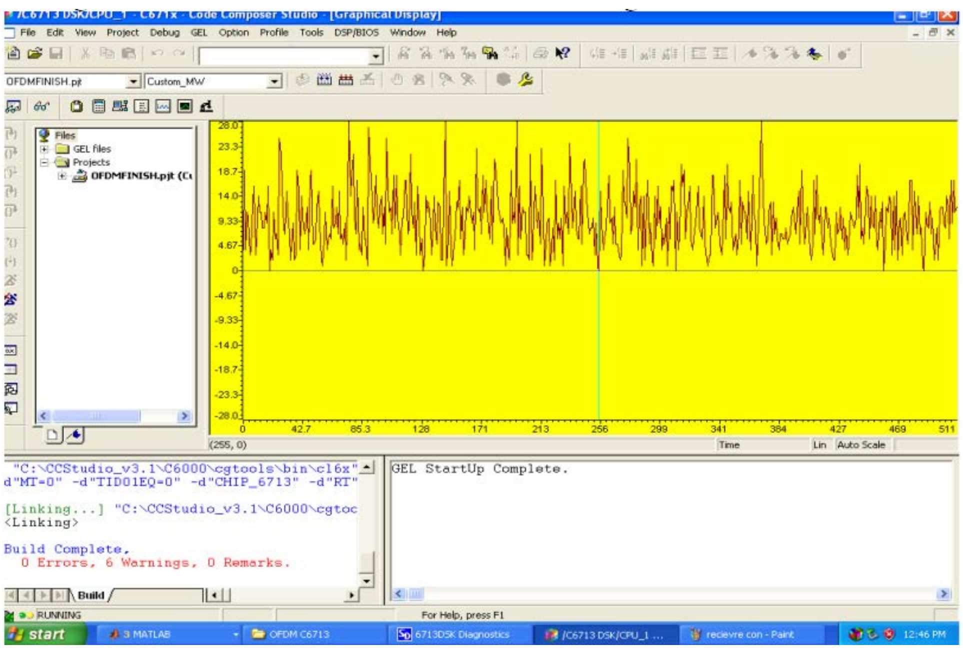


Fig. 12: The transmitted signal after passed through AWGN channel store at the memory of the platform for block interleaved COFDM

## CONCLUSION

Real-time implementation of COFDM transceiver can be achieved in two methods. The first is method is implemented by write the transmitter and receiver in CCS directly using C language and using the library of the TMS320C6713 DSK. This method needs two TMS320C6713 DSK, one for transmitter and other for receiver. The communication between them using wireless channel this will need to design RF unit. This method is a complex approach because of the effect of the channel impact. But this approach 100% real time implementation.

The second method using MATLAB Simulink IDE, code composer studio for TMS320C6713. IDE allows automatic code generation directly from Simulink blocks, offering a flexible way to transform from system level design and simulation to actual implementation and verification. The device interface converts the baseband signal from the host computer to a DSP processor. The implementation of COFDM in this method is simple because of the use of facilitates of Simulink.

In this study, we use the second method. In the system designing the signal passed through AWGN. Where the signal is encoded using convolutional encoder (1/2) punctured into (6/7) code rate we use this code rate to simplify Viterbi decoder in the receiver. Block interleaving and 4 pilot signal used to distinguish OFDM symbol, 16 QAM baseband modulator and 64sub carrier's and 16 cyclic prefix, so that, the total number of OFDM symbol is 80 sub carriers.

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