

## UWB MB-OFDM 4-Parallel Radix2 FFT Performance Analysis

Dr. M. J. Mohammed B. M. Ahmad Dr. K. M. Quboa  
Electrical Eng Department, Engineering College, Mosul University

### Abstract

The Ultra Wide-Band Multi Band-Orthogonal Frequency Division Multiplexing (UWB MB-OFDM) system is a low power ( $-41.3$  dBm/MHz); short-range (less than 10 m); high speed (53.3 - 480 Mbps) wireless technology with spectral band width from 3.1 GHz to 10.6 GHz allocated by Federal Communications Commission (FCC) according to IEEE 802.15.3a standard. The UWB spectrum is divided into 14 subbands, each with 528 MHz bandwidth . Each OFDM symbol is transmitted / received a cross each subband using a single 128-point radix2 IFFT/FFT.

In this paper a simulation software is written using Matlab version 10 to evaluate the Bit Error Rate (BER) of the system using the traditional 128-point IFFT/FFT algorithm, and the proposed 4-parallel 32-point radix2 IFFT/FFT algorithm. It has been shown that a time saving is 28.7 % , and that the BER is better off 5dB using the proposed method as compared to traditional method.

### دراسة أداء نظام الطيف الواسع المتعدد الحزم باستخدام أربعة محولات فورير رقمية متوازية

د . محمود جاسم محمد      بشرى محمد أحمد      د . قيدار مجيد قبيع  
قسم الهندسة الكهربائية . كلية الهندسة . جامعة الموصل

### الخلاصة

إن نظام الحزمة العريضة جداً للحزم المتعددة للترددات المقسمة المتعامدة (UWB MB-OFDM) هو ذات قدرة منخفضة ( $-41.3$  dBm/MHz) ; لمسافات البث القصيرة (أقل من 10م) ; ويسرع عالية ( 53.3Mbps - 480 Mbps) يعمل بعرض حزمة من 3.1 GHz إلى 10.6 GHz المحددة من قبل لجنة الاتصالات الاتحادية (FCC) حسب الأنموذج القياسي IEEE 802.15.3a . يُقسم طيف الحزمة UWB إلى 14 حزمة فرعية كل حزمة بعرض 528 MHz . يرسل \ يستلم رمز OFDM عبر كل حزمة فرعية بواسطة كتلة واحدة من محول فورير السريع (IFFT/FFT) ذات الحجم 128.

في هذا البحث تم إجراء محاكاة النظام باستخدام برنامج Matlab النسخة 10 لإيجاد قيم معدل خطأ البت (BER) للنظام التقليدي باستخدام كتلة واحدة من محول فورير السريع بحجم 128 وللنظام المقترح باستخدام أربع كتل متوازية من محول فورير السريع بحجم 32, وتم توضيح إن نسبة الوقت المكتسب هي % 28.7 و BER أفضل بحدود 5dB باستخدام الطريقة المقترحة مقارنة مع الطريقة التقليدية.

## I- Introduction

A substantial change occurred in February 2002 when the U.S. Federal Communications Commission (FCC) issued a Report & Order that authorizes the commercial and unlicensed deployment of UWB in the USA [1]. In 2007, Gueguen et al [2] proposed a new form of the wave transmitted in the system of UWB based on Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM). In 2008, Shin and Lee [3] proposed a four-parallel data-path pipelined 128-point radix-24 MDF FFT/IFFT processor. In 2009, Aripin et al [4] sent video signal using UWB spectrum. In 2010, Ammen et al [5] used wavelet to describe transmitted signal of the type of OFDM and DWT OFDM, and improved the efficiency of the system to send more data by removing the prefix period. In 2011, Gvozdenovic and Eric [6] studied the system UWB MB-OFDM to locate unknown transmitter using Time Difference Of Arrival (TDOA).

The Ultra Wide-Band Multi Band-Orthogonal Frequency Division Multiplexing (UWB MB-OFDM) technology could deliver high data rates from 53.3 Mbps at a distance of 10 m to a data rate of 480 Mbps at a distance less than 2 m. UWB MB-OFDM technology at an Effective Isotropic Radiated Power (EIRP) below  $(-41.3 \text{ dBm/MHz})$  which represents the FCC emission limit for indoor UWB transmission [1].

The transmitter and receiver of a UWB MB-OFDM system is shown in Fig.(1) [7].

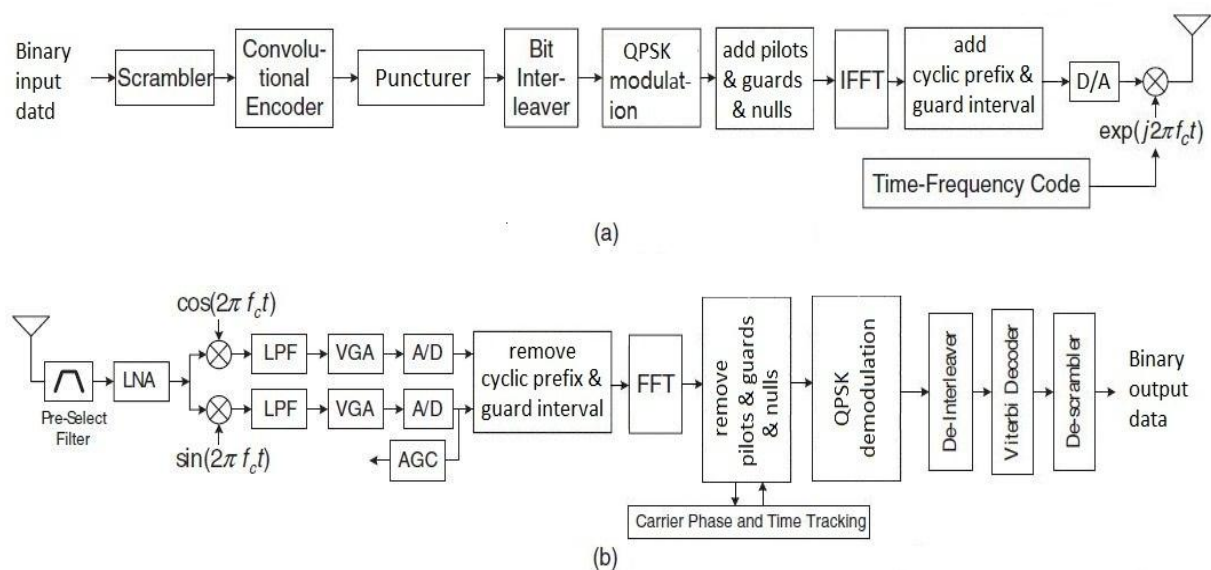


Fig. (1) : The MB-OFDM UWB system (a) transmitter, (b) receiver.

For the transmitter section shown in Fig.(1a), the binary input data stream is scrambled; encoded; punctured; interleaved; and QPSK modulated. The pilots, guards, and nulls are added to support IFFT operation. Next a cyclic prefix (CP) and guard interval (GI) are inserted. This digital binary stream is converted to analogue signal using digital to analogue (D/A) converter and then modulated using Time-Frequency Code (TFC) to create the OFDM symbol to be transmitted .

The spectrum allocated to UWB MB-OFDM is divided into 14 sub bands with 528MHz bandwidth each. Each OFDM symbol, combining a set of 128 narrow band subcarriers, is transmitted using one of the assigned 14 sub bands [8]. The 128 subcarriers are divided into 100 subcarriers for data, 10 subcarriers for guard, 12 subcarriers for pilot and 6 subcarriers for nulls.

In the UWB MB-OFDM system, the following key parameters are important [9]:

- The size of the IFFT which limits the maximum number of possible subcarriers that can be used.
- The number of useful data carrying subcarriers.
- The length of the cyclic prefix (CP) needs to be trade-off to accommodate delay spreads as well as reducing the power wasted in this transmission.

Each OFDM symbol is prepended with a zero-trailing prefix to avoid the Inter Symbol Interference (ISI) and a guard interval to ensure a transition between two consecutive OFDM symbols as given in Table (1) according to IEEE 802.15.3a [7].

Table (1) : The IEEE 802.15.3a key parameters.

Parameter	Value
Number of OFDM subcarriers	128
Number of data subcarriers	100
Number of defined pilot subcarriers	12
Number of guard subcarriers	10
Subcarrier frequency spacing ( $\Delta f$ )	4.125 MHz = ( 528 MHz/128)
$T_{IFFT/FFT}$ : IFFT/FFT period	242.42 ns ( $1/\Delta f$ )
$T_{CP}$ : Cyclic prefix duration	60.61 ns (32/528 MHz)
$T_{GI}$ : Guard interval duration	9.47 ns (5/528 MHz)
$T_{SYM}$ : Symbol duration	312.5 ns ( $T_{FFT} + T_{CP} + T_{GI}$ )

These subcarriers are configured as shown in Fig. (2).

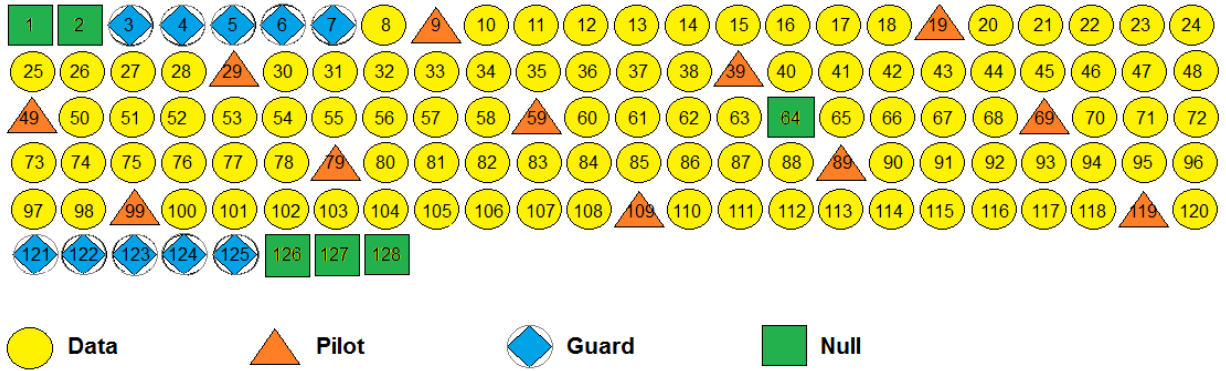


Fig. (2): The UWB MB-OFDM system configuration.

For the receiver section shown in Fig. (1b), the received modulated signal is passed through a preselect filter; amplified with a low-noise amplifier (LNA); down-converted to baseband; demodulated by QPSK demodulation; scaled in amplified by a voltage gain amplifier (VGA); digitized; synchronized demodulated; de-interleaved; decoded by Viterbi decoder, and at last de-scrambled to retain the transmitted binary stream.

## II- The IFFT/FFT Used in UWB MB-OFDM System

The IFFT/FFT is known to be one of the digital base-band modules in an OFDM system which could be of high complexity. As given in Table (1) , a 128 – point IFFT/FFT should finish its job within an OFDM symbol duration of  $T_{SYM} = 312.5$  ns.

The block diagram of OFDM modulation using a single 128 – point IFFT is shown in Fig. (3).

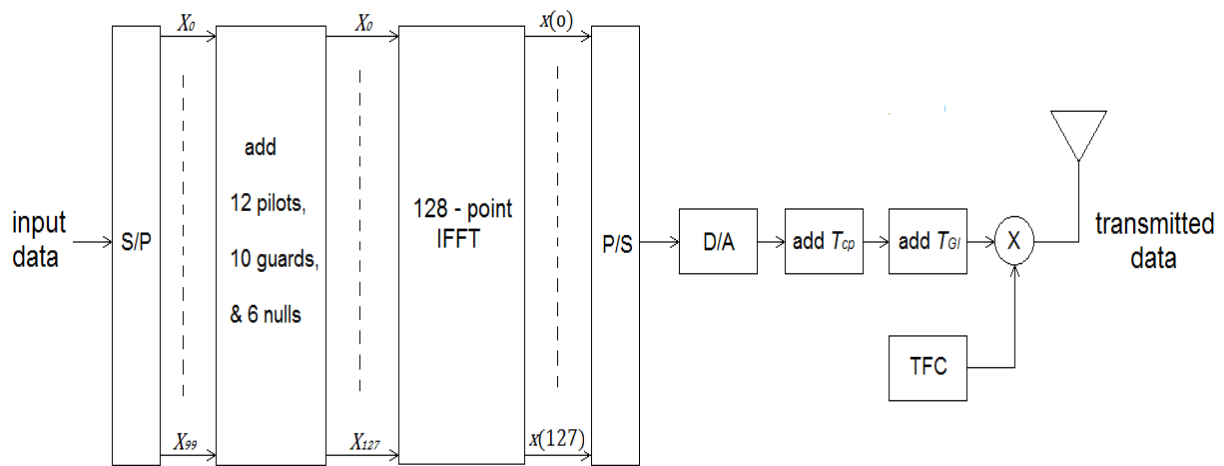


Fig. (3) : The 128-point IFFT in UWB MB-OFDM transmitter section.

The OFDM symbols are interleaved in time and frequency as shown in Fig. (4), with a symbol time of 242.4 ns for each 128-point IFFT in the case of Time – Frequency Code (TFC) { 1 3 2 }.

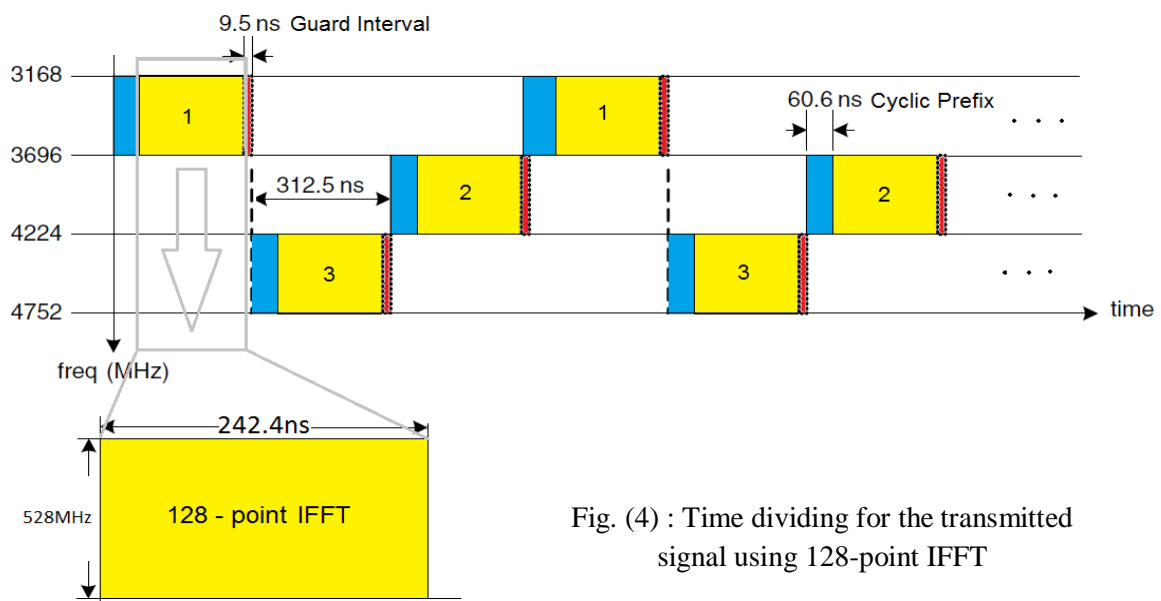


Fig. (4) : Time dividing for the transmitted signal using 128-point IFFT

From theoretical point of view, the output of the IFFT  $x(n)$ , is given by [10]:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi nk/N} \tag{1}$$

where  $N$  is the number of subcarriers ( $N = 128$ ) and  $X_k$  is the modulation input at subcarrier  $k$ . This signal is converted from parallel to serial (P/S) and from digital to analog (D/A), then added in the first of symbol time of cyclic prefix ( $T_{CP}$ ) and in the end of it added time of guard interval ( $T_{GI}$ ). After that the signal up-converted to a specified subband and transmitted according to TFC. The switching is assigned to different users in order to gain frequency diversity while minimizing the multiple access interference.

These symbols, are transmitted over Sahel-Valenzuela (S-V) channel model [11] which are received by the receiver shown in Fig. (1b), using the single 128-point FFT shown in Fig. (5).

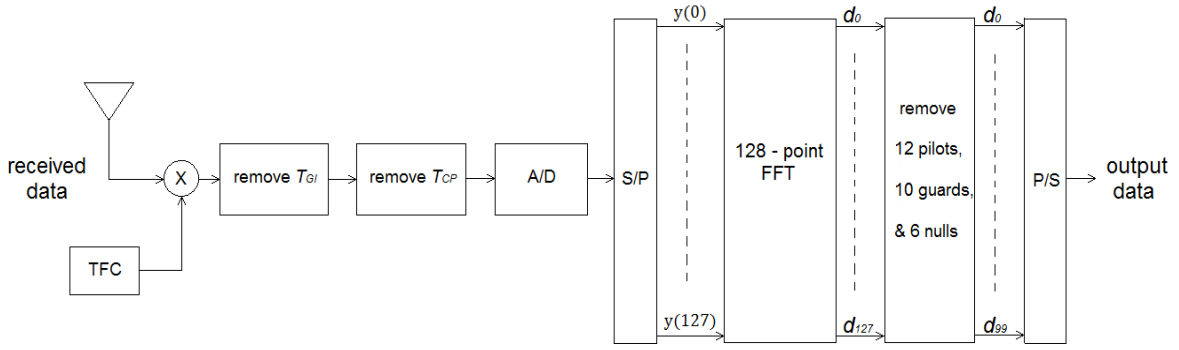


Fig. (5) : The 128 – point FFT in MB-OFDM UWB receiver section.

The received signal,  $y(n)$ , can be expressed by [10]:

$$y(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \sum_{t=0}^{Q-1} h_n(t) e^{-\frac{j2\pi tk}{N}} e^{\frac{j2\pi nk}{N}} + n_n \quad (2)$$

where  $Q$  is the number of multipaths,  $h_n(t)$  is the channel response, and  $n_n$  is the Additive White Gaussian Noise (AWGN).

### III- The Proposed IFFT/FFT Used in UWB MB-OFDM System

The proposed IFFT/FFT algorithm is based on 4-parallel 32-point IFFT/FFT required to keep the parameters assigned in IEEE 802.15.3a standard unchanged. Except the nulls locations are not fixed in this standard. Because 4 units algorithm, the nulls are redistributed as shown in Fig. (6).

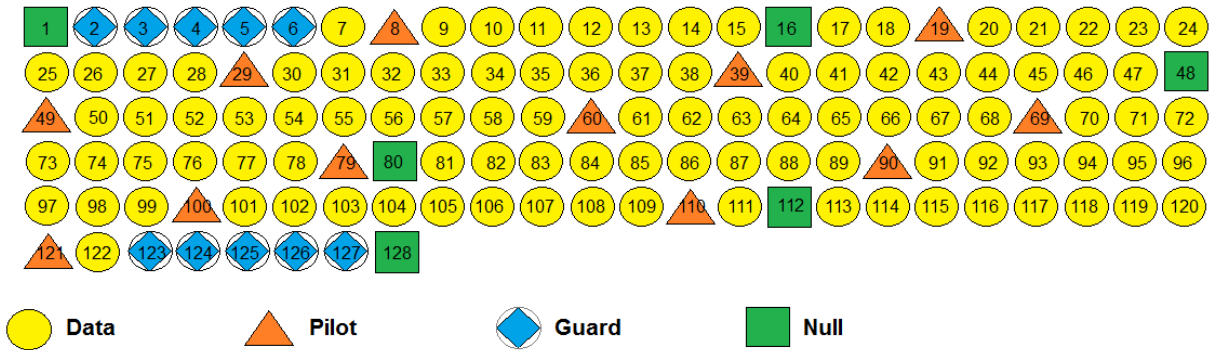


Fig. (6): The proposed configuration using 4-parallel 32-point IFFT.

The block diagram of the proposed 4-parallel 32-point IFFTs is shown in Fig. (7)

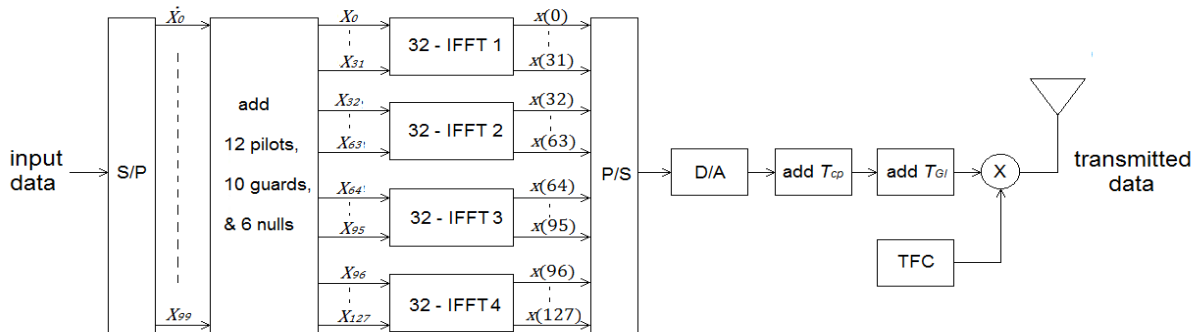


Fig. (7) : The 4-parallel 32-point IFFT in UWB MB-OFDM transmitter section.

For this case, equation (3) is modified for the 4-parallel 32-point IFFT, as follows :

$$x(n) = \frac{1}{\sqrt{32}} \sum_{k=0}^{31} X_k e^{\frac{j2\pi nk}{32}} + \frac{1}{\sqrt{32}} \sum_{k=0}^{31} X_{k+32} e^{\frac{j2\pi nk}{32}} + \frac{1}{\sqrt{32}} \sum_{k=0}^{31} X_{k+64} e^{\frac{j2\pi nk}{32}} + \frac{1}{\sqrt{32}} \sum_{k=0}^{31} X_{k+96} e^{\frac{j2\pi nk}{32}} \quad \text{----- (3)}$$

The block diagram of the receiver using 4-parallel 32-point FFT is shown in Fig. (8).

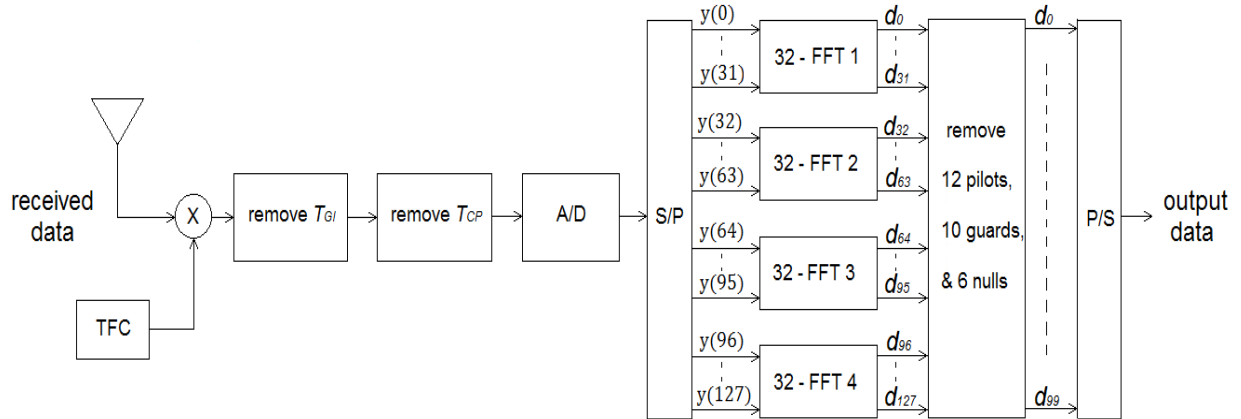


Fig. (8) : The 4-parallel 32-point FFT in MB-OFDM UWB receiver section.

#### IV- Excution Time of IFFT/FFT Algorithm:

It is known that the time of execution of  $T_{IFFT/FFT}$  is proportional to size of IFFT/ FFT ( $N$ ) according to [12]:

$$T_{IFFT/FFT} \propto \left( \frac{N}{2} \log_2 N \right)$$

and according to IEEE 802.15.3a standard , the  $T_{IFFT/FFT}$  for 128-point is fixed to be 242.4 ns, then  $T_{IFFT/FFT}$  for 32-point will be :

$$T_{IFFT/FFT\ 32} = T_{IFFT/FFT\ 128} * \frac{\frac{32}{2} \log_2 32}{\frac{128}{2} \log_2 128} = 43.2 \text{ ns}$$

For the proposed 4-parallel 32-point described in section III , the OFDM symbols are interleaved in time and frequency for TFC code {1 3 2} as shown in Fig. (9).

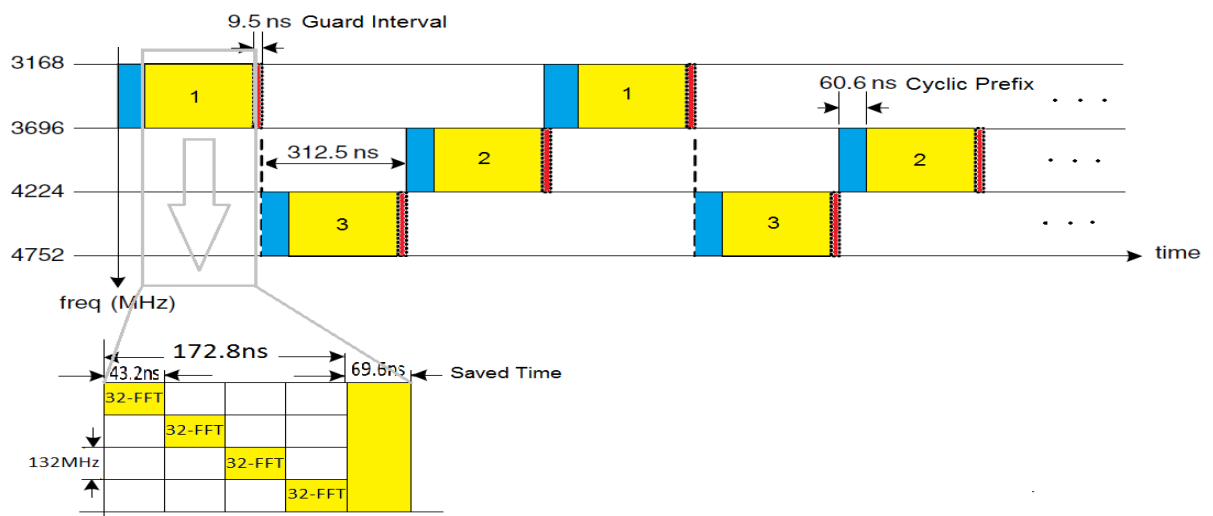


Fig. (9) : Time dividing for the transmitted signal using the proposed algorithm.

From Fig. (9) , it is clear that the 4-parallel 32-point IFFT/FFT will take 172.8 ns (4x43.2 ns) to complete an OFDM symbol compared to 242.4 ns using 128 – point IFFT/FFT . By this proposed method, a time saving of 69.6 ns is obtained which represents 28.7 % of the time allocated for the traditional single 128 – point IFFT/FFT. This saved time could be used in different ways to improve the performance , besides that it reduces the Power Average Ratio (PAR).

**V- IEEE 802.15.3a Channel Model:**

Channel model is based on clustered UWB which is defined by IEEE 802.13a and derived from Saleh-Valenzuela (S-V) model [13] based on measurements. Channel models (CM) are classified into four types CM1 to CM4 for distances in the range up to 10 m, as given in table (2) [10].

Table (2) : Channel characteristics for UWB system [10].

Channel Characteristic	CM1	CM2	CM3	CM4
Mean excess Delay (n sec)	4.9	9.4	13.8	26.8
RMS <sup>1</sup> delay (nsec)	5	8	14	26
Distance(m)	0 – 4	0 - 4	4 – 10	10
LOS <sup>2</sup> / NLOS <sup>3</sup>	LOS	NLOS	NLOS	NLOS

**1. Root Mean Square ; 2. Line-Of-Sight ; 3. Non-Line-Of-Sight**

**VI- UWB MB-OFDM Simulator**

To evaluate the performance of UWB MB-OFDM system using both single 128-point IFFT/ FFT and 4-parallel 32 – point IFFT/ FFT , a software simulator for the system shown in Fig. (2) is written using Matlab version (10). The block diagram of this simulator is shown in Fig. (10).

From Fig. (10) , the generated random input data using Bernouli Random Binary Generator are encoded by convolutional encoder; interleaved six OFDM symbols by symbol interleaver to invest frequency diversity across the subbands and to generate a single symbol to be interleaved by tone interleaver to benefit from the frequency diversity across tone. The interleaved output is modulated using QPSK modulation to produce 100 samples for each OFDM symbol. The serial data are converted to parallel data; add 12 pilots; 10 guards and 6 nulls to complete the 128 samples. These samples are inverse transformed by IFFT ; add cyclic prefix ; appended by guard interval ; converted from parallel to serial and then to analogue signal which is multiplied by TFC to generate the transmitted signal.

The transmitted signal is sent according to (S-V) channel. This channel can be represented by a convolutional process between the channel response , based on four multipath, and the transmitted signal . The noise (AWGN) is added to this signal to represent the received signal .

In the receiver section , the channel effect is removed using channel estimation block which is multiplied by the same TFC; filtered ; digitized and converted to parallel data.The guard interval and cyclic prefix are removed from OFDM symbols ; transformed by FFT ; demodulated ; deinterleaved and decoded using Viterbi decoder. The decoded data are compared with those transmitted to calculate BER using error rate calculation block.

The IFFT & FFT blocks shown in Fig. (10), are simulated using those shown in Figs. (3&5) for the case of single 128-point IFFT/ FFT, and are simulated by those shown in Fig. (11) to simulate the case for 4-parallel 32-point IFFT/ FFT.

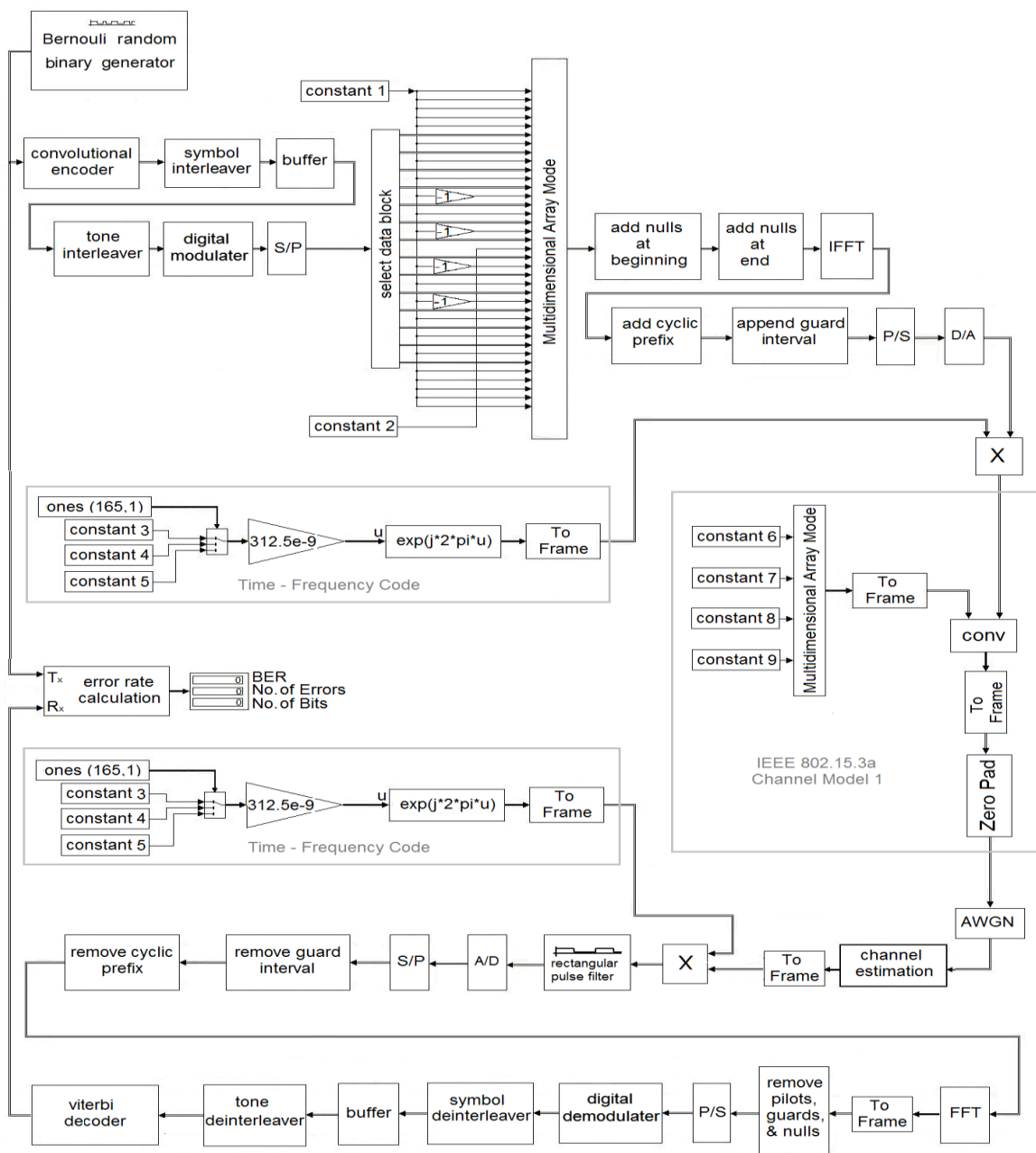


Fig. (10) : Simulator of UWB MB-OFDM system

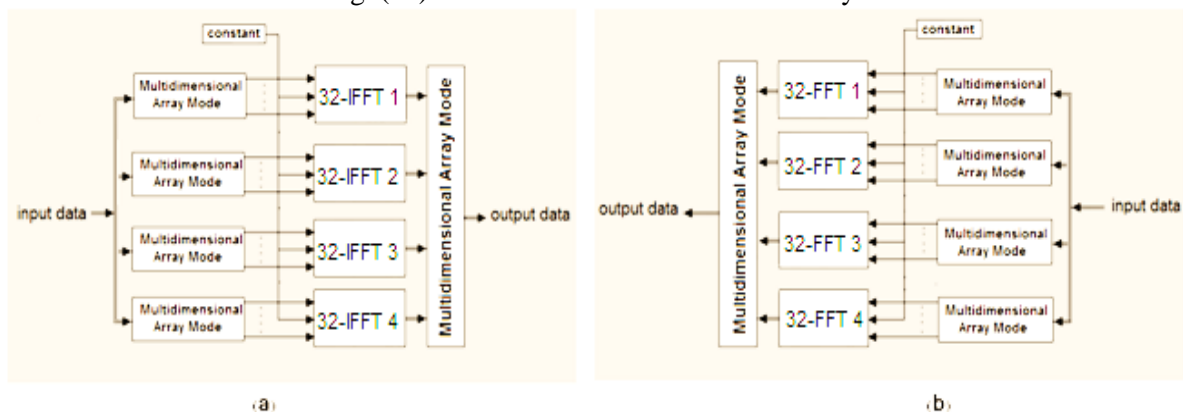


Fig. (11) : Using 4-parallel 32-point in (a) IFFT transmitter section (b) FFT receiver section.



## VII- Simulation Results

The Bit Error Rate (BER) as a function of  $E_b/N_o$  (energy bit  $E_b$  to energy noise  $N_o$ ) is chosen as a measure to evaluate the performance of UWB MB-OFDM system.

The simulation results obtained for 128-point IFFT/FFT shown in Fig. (12) in CM1 for different code rates are compared with those obtained from reference [14] shown in Fig. (13) and reference [15] shown in Fig. (14) for a BER level of  $10^{-4}$  as given in table (3)

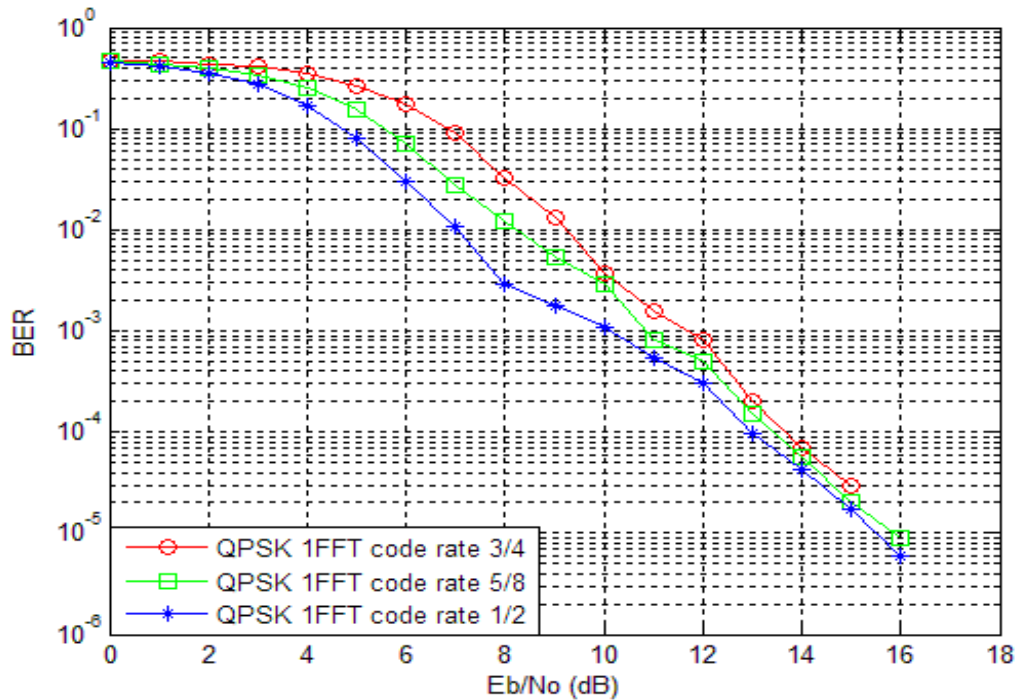


Fig. (12) : Performance of single 128-point FFT in CM1.

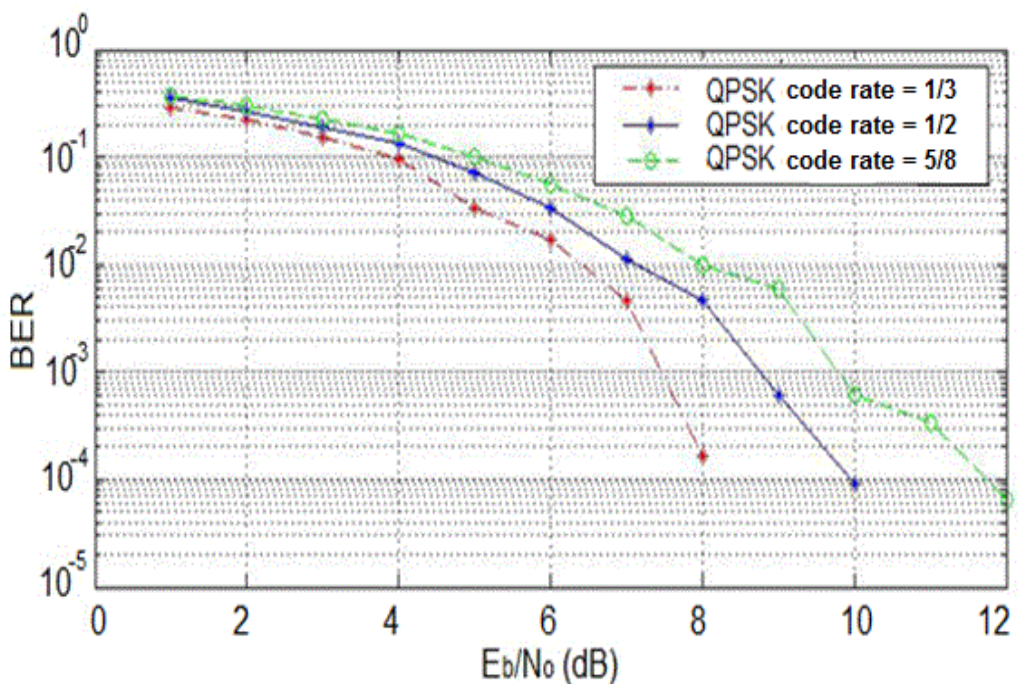


Fig. (13) : Performance of single 128-point FFT in CM1 [14].

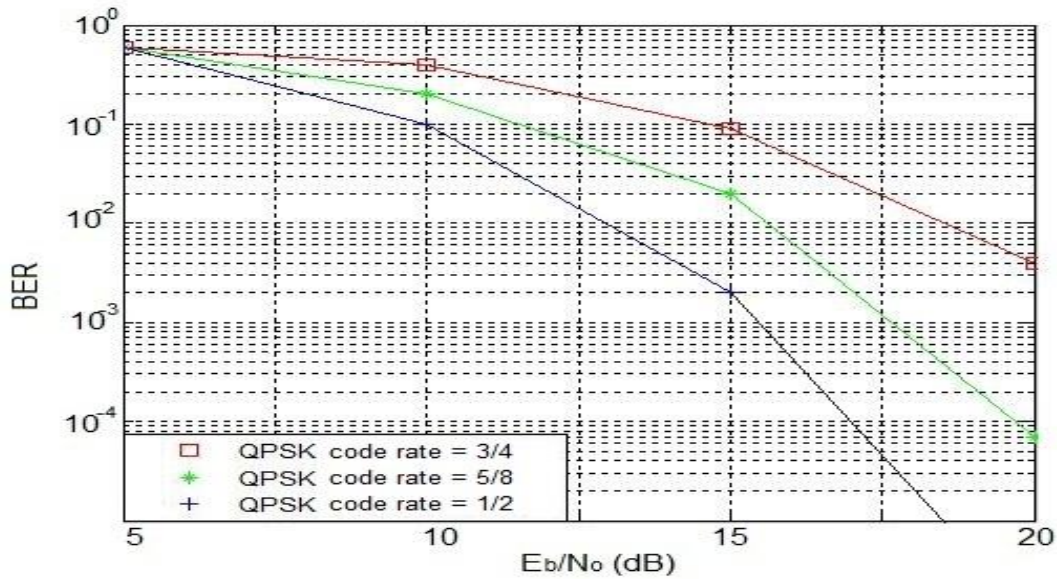


Fig. (14) : Performance of single 128-point FFT in CM1 [15].

Table (3) : BER comparison.

Code Rates	$E_b/N_o$ (dB)		
	Reference [14]	Reference [15]	Proposal Simulator
3/4	—	24.5	13
5/8	11.8	19.5	13.3
1/2	10	17	13.6

From table (3), it is clear that the proposed simulator is working well in between results of references [14&15].

The performance of UWB MB-OFDM system using single 128-point (1FFT) and 4-parallel 32-point (4FFT) in CM1 with a code rate 5/8 are shown in Fig. (15).

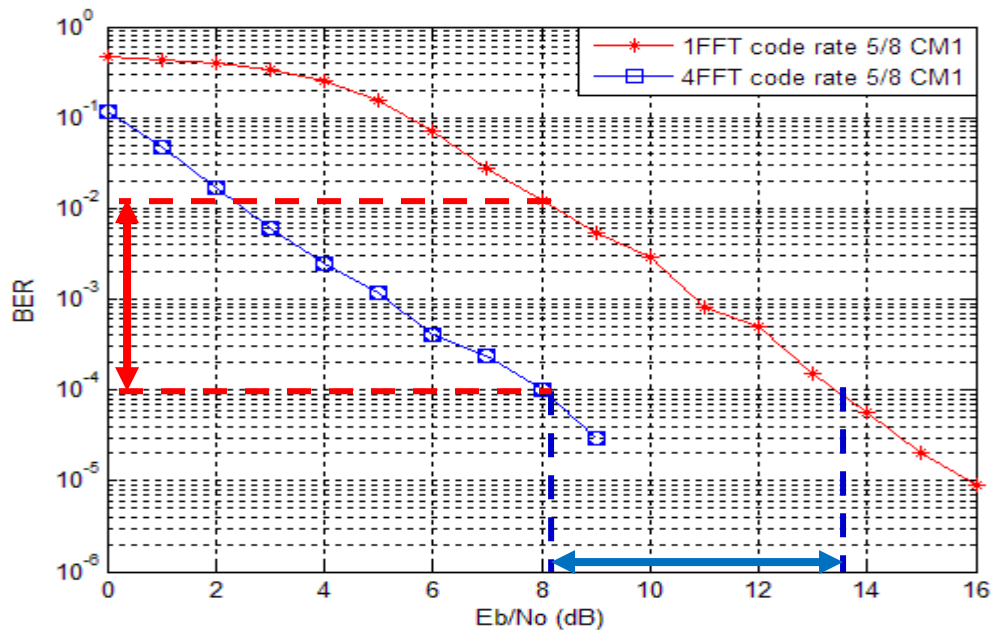


Fig. (15) : Performance at code rate 5/8 of single 128-point FFT and 4-parallel 32-point FFT for CM1.

From Fig. (15) , it is clear that for at a level of  $10^{-4}$  BER, the  $E_b/N_o$  is better off 5dB using the proposed 4-parallel 32-point IFFT/FFT compared to a single 128-point IFFT/FFT and that for the same  $E_b/N_o$ , the BER is almost 100 times better.

The simulation is repeated for 5/8 code rate at different channel models and the results obtained are shown in Fig. (16) for CM2, CM3 and CM4.

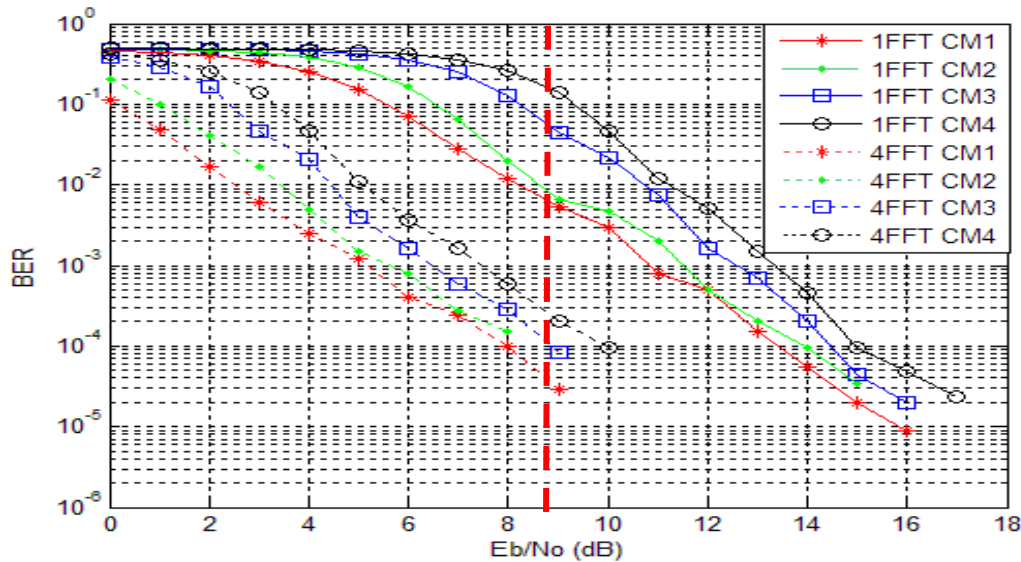


Fig.

(16) : Performance at code rate 5/8 for single 128-point FFT and 4-parallel 32-point FFT in CM1,CM2,CM3 and CM4.

From Fig. (16) , it is clear that the performance of the system using 4-parallel 32-point IFFT / FFT is better than that using single 128-point IFFT / FFT in all channel models. For example , the BER in CM2 is better off by 100 times using 4-parallel 32-point IFFT / FFT than using single 128-point IFFT / FFT.

The effect of coding rates of 1/2 and 3/4 for a fixed channel characteristics CM1 are also investigated and the results are shown in Fig. (17) .

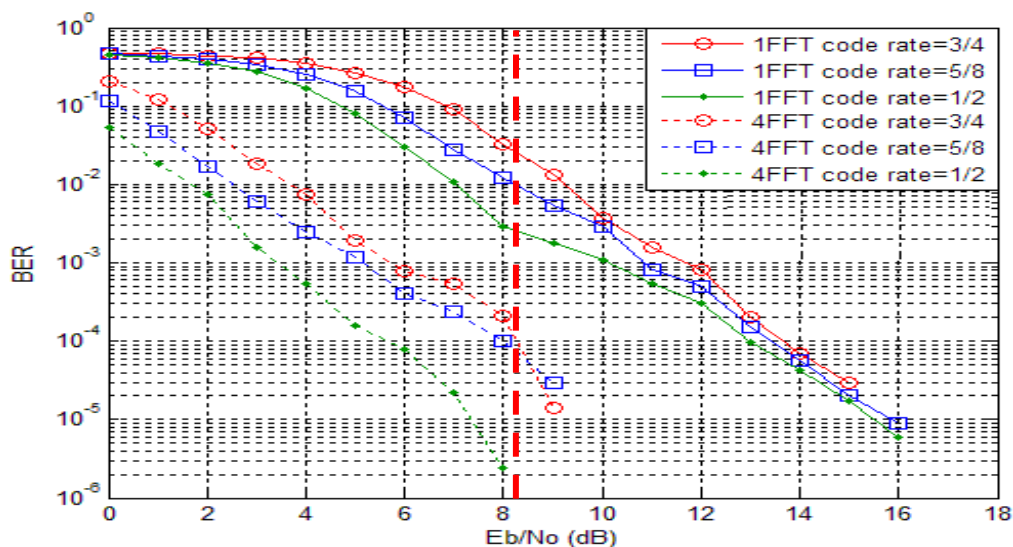


Fig. (17) : Performance of single 128-point FFT and 4-parallel 32-point FFT for code rate 3/4, 5/8 and 1/2 in CM1.

From Fig. (17) , it is clear that the performance of the system using 4-parallel 32-point IFFT / FFT is better than that using single 128-point IFFT / FFT in all code rates, for example , the BER in code rate 3/4 is better off by about 100 times.

### VIII- Conclusion:

In this paper, a Matlab simulation program is written to simulate UWB MB-OFDM system performance. The simulator is used to simulate the traditional 128-point radix-2 IFFT / FFT as well as the proposed 4-parallel 32-point IFFT / FFT radix-2 in UWB MB-OFDM systems. From the results obtained, the following conclusions can be made :

- A time saving of 28.7 % in processing OFDM symbol is obtained when 4-parallel 32-point IFFT/ FFT is used as compared to single 128- point IFFT/ FFT.
- The BER is enhanced using 4-parallel 32-point IFFT/ FFT as compared to single 128-point IFFT/ FFT for code rate 5/8 at different channel models CM1, CM2, CM3 or CM4.
- Even with different code rates , the 4-parallel 32-point IFFT/ FFT are better than that of 128-point IFFT/ FFT.

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