

## Теория сигналов и систем

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### FRAT-OFDM vs. FFT-OFDM Systems in Fading AWGN Channels

*Digital wireless communication design for high speed data for orthogonal frequency division multiplexing system has been investigated. Fast Fourier transform and finite Radon transform were applied for the investigation. Block diagrams systems with fast Fourier transform and finite Radon transform has been presented. Simulation and comparison (normalized and non-normalized) of fast Fourier transform and finite Radon transform efficiency in orthogonal frequency division multiplexing system was carried out through MATLAB program. The application of finite Radon transform has been shown to provide the gain in the parameter signal to noise ratio from 2 dB to 15 dB. References 5, figures 8, tables 2.*

**Keywords:** Orthogonal Frequency Division Multiplexing (OFDM), Fast Fourier Transform (FFT), Finite Radon Transform (FRAT), Additive White Gaussian Noise (AWGN), Quadrature Amplitude Modulation (QAM), Inverse FFT (IFFT), bit error rate (BER), Signal to Noise Ratio (SNR), fading.

#### Introduction

In this paper, a block diagram of FRAT based on OFDM was designed to decrease Signal to Noise ratio (SNR) and to make comparison between fading channels.

The Study of Finite Radon Transform in Face Recognition was studied by Zhang Yuhua and Wang Xin [1]; proposed implementation of modified FRAT Based OFDM Transceivers was studied by Ali A. Ali and Laith A. Abdul-Rahaim [2], and Design and Simulation of a Proposed Radon Based OFDM Transceiver was studied by Omar M.M. Faraj [3] to proposed FRAT for the first time as a new technique in the implementation of OFDM.

In this paper the 4QAM and 16 QAM modulations were used in small-scale fading channels to improve the increasing gain (dB) in the transmission rate.

#### 1. Small-Scale Fading Channels

Small scale fading occurs due to multipath components in a channel. It consists of two independent mechanisms: the time spreading of the signal, and the time-varying behaviour of the channel. The time-varying behaviour of the channel causes Doppler shift. The Doppler shift is a measure of the spectral broadening of the signal, caused by the relative motion of the receiver with respect to the transmitter. The Doppler shift  $f(d)$  is a function of the speed of the receiver. The Doppler shift in the frequency can be written [4]:

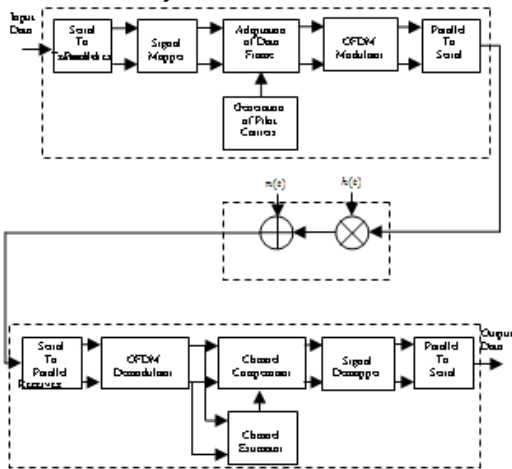
$$f(d) = f \pm \frac{v}{c} \quad (1)$$

Where  $f(d)$  is the change in the frequency of the source seen at the receiver (Doppler frequency),  $f$  is the frequency of the source,  $v$  is the speed difference between the source and transmitter, and  $c$  is the speed of light.

This Doppler shift occurs whether the channel is described as slow fading or fast fading. Thus, in a fast fading channel, the coherence time,  $T_c$ , of the channel is smaller than the symbol duration of the transmitted signal (i.e.  $T_s \gg T_c$ ). In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal,  $s(t)$ , and the symbol period of the signal is much smaller than the coherence time of the channel  $T_s \ll T_c$  [5].

**2. FFT-based OFDM System**

The block diagram of a given system for OFDM is depicted in Fig. 1. First of all, the input serial data stream is formatted into the word size required for transmission, e.g. 2 bit/word for QPSK and 4 bit/word for 16-QAM, and then the format will be shifted into a parallel format. The data is then transmitted in parallel by assigning each word to one sub-carrier in the transmission. After that, the data to be transmitted on each sub-carrier is mapped into one of  $M$ -ary PSK or  $M$ -ary QAM constellation format, as determined (In addition, differential-PSK (DPSK) and differential-QAM (DQAM) are available). This process will convert data to corresponding value of  $M$ -ary constellation which is a complex word, i.e. consists of real and imaginary parts. The training frame (pilot sub-carriers frame) will be inserted and sent prior to information frame. This pilot frame will be used to make channel estimation that is used to compensate the channel effects on the signal. After that, the complex words frame and pilots frame will pass to IFFT to generate an OFDM symbol. Zeros will be inserted in some bins of the IFFT in order to make the transmitted spectrum compact and to reduce the adjacent carrier's interference.



**Fig. 1. Block diagram of OFDM system**

**3. Modified FRAT-Based OFDM System**

The method has been suggested to apply the Optimum Ordering algorithm to a square matrix of any dimension, especially powers of two, i.e. typical sizes of FFT windows. Thus, in a similar manner to several previous theses, we were able to propose an OFDM system that uses this Modified FRAT as a 2D modulator, other than a mapper. The size of its input window will be  $8 \times 8$ , and resulting in an  $8 \times 12$  output matrix, i.e. 96

symbols, thus providing a reduction in the required symbol number for each OFDM packet, compared to 128 symbols for conventional OFDM scheme. This system is illustrated in Fig. 2; it differs from the FFT-based OFDM system in several points:

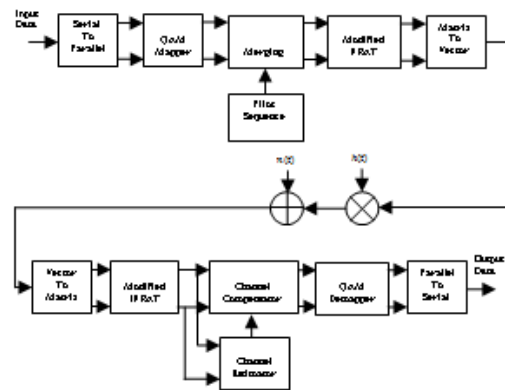
The modulator that replaces FFT is two-dimensional, i.e. modulates a matrix of data rather than a sequence or a vector.

The method by which the pilot carriers are arranged with the data symbols is essentially a merging process, that converts the pilot sequence into a matrix equal in size to the data matrix, then constructs a bigger matrix in which the rows pilot matrix become the odd rows, and of the data matrix the even ones. The resultant matrix becomes the input to the FRAT mapper.

The zero padding happens inside the modulator, in the optimum ordering step, rather than outside it. This will be discussed thoroughly below.

If we return to the Optimum Ordering pattern, given by the equation 2,

$$\begin{bmatrix}
 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 2 & 12 & 11 & 10 & 18 & 9 & 32 & 24 & 16 & 15 & 34 & 13 \\
 3 & 23 & 21 & 19 & 35 & 17 & 0 & 0 & 0 & 0 & 0 & 0 \\
 4 & 26 & 31 & 28 & 52 & 25 & 14 & 54 & 30 & 27 & 36 & 29 \\
 5 & 37 & 33 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
 6 & 48 & 43 & 46 & 22 & 41 & 60 & 20 & 44 & 47 & 38 & 45 \\
 7 & 51 & 53 & 55 & 39 & 49 & 0 & 0 & 0 & 0 & 0 & 0 \\
 8 & 62 & 63 & 64 & 56 & 57 & 24 & 50 & 58 & 59 & 40 & 61
 \end{bmatrix} \tag{2}$$



**Fig. 2. Block diagram of Modified FRAT-based OFDM**

We will notice that the recurring pattern of zeros is in the same locations for several columns (in this case, half of the columns), which is due to two reasons:

The first set of columns contains most of the elements in the given directions, so that when the remaining columns sweep the input matrix in other directions, they will find several used elements in the way, i.e. they intersect with the previous

directions. As the proposed algorithm states, so that the used elements are marked by zero.

As the procedure aims to generate an independent set of projections, each column in the output matrix has the same pattern that exists in the result vector of 1D FFT that is the complex elements in the upper half are copied as conjugates in the lower half. This note is also applied to the columns including patterns of zeros, as the remaining elements from the sweep are re-ordered based on the same principle.

This system was applied for two cases: normalized (the input matrix was divided by its highest value), and non-normalized. The non-normalized case showed better performance than the normalized one. It was found that the power level of the signal can be increased by at least 10 dB. Fig. 3 illustrates the BER performance of the Modified FRAT-OFDM system versus that of the FFT-OFDM, and Fig.4 depicts the frequency spectrum of a modulated packet in each case.

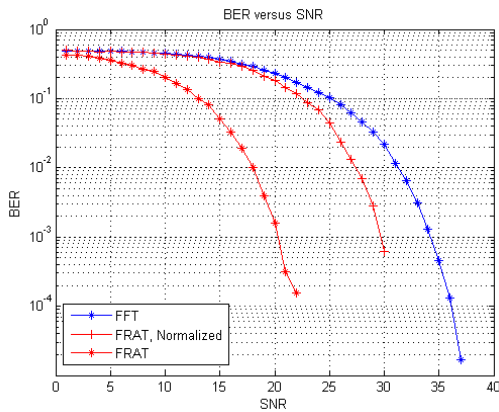
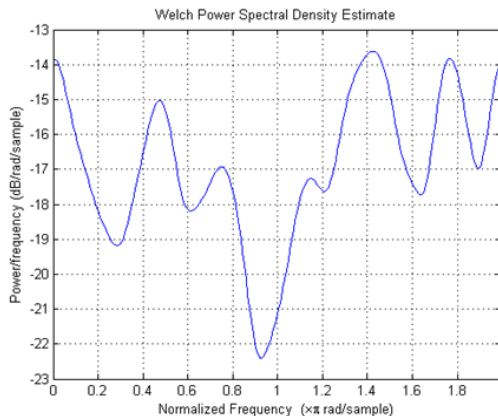
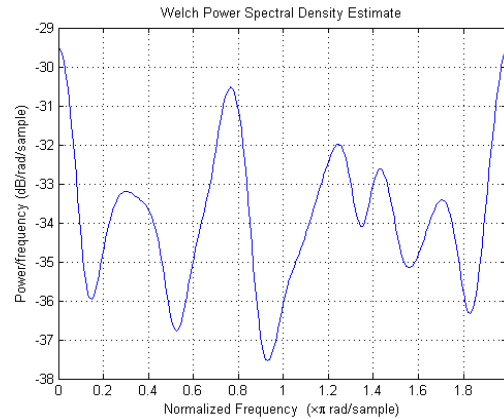


Fig. 3. BER performance of FRAT-OFDM vs. FFT-OFDM in a flat-fading AWGN channel



a)



b)

Fig. 4. Power Spectrum for a FRAT-OFDM modulated packet in the non-normalized case (a) and in the normalized case (b).

#### 4. Simulation and Results

The design of FRAT-based OFDM systems were illustrated and explained in this work. The work gave the simulation results of the proposed systems using MATLAB. The results of both studied systems were taken in three types of channels, and were examined and compared with others. The effects of several parameters of wireless channels on the two systems were investigated. Table 1 shows the parameters of the systems that were used in the simulation.

The performance of the FRAT-OFDM system was illustrated and compared with the FFT-OFDM for the possible two types of channel as well as for two types of modulation, in two cases: normalized and non-normalized. The results obtained for AWGN channel in turn were divided into two cases and demonstrated in details in different cases as presented in table 1.

Table 1. Simulation Parameters

Modulation Type	4-QAM
Number of sub-carriers	64
Size of FRAT input frame	64 8x8
Number of FFT points	64
Channel Model	Flat fading + AWGN Frequency-selective fading + AWGN

**5. Conclusions**

Fig. 5 illustrates the performance of FRAT-OFDM system for 4-QAM modulation in flat-fading AWGN channel. It can be seen that FRAT-OFDM is better than FFT-OFDM, and the gain is about 15 dB for a BER level of  $2 \cdot 10^{-4}$ .

Fig. 6 illustrates the performance of normalized FRAT-OFDM (denoted nFRAT-OFDM) system for 4-QAM modulation in flat-fading AWGN channel. It can be seen that nFRAT-OFDM is better than FFT-OFDM, and the gain is about 6 dB for a BER level of  $10^{-4}$ .

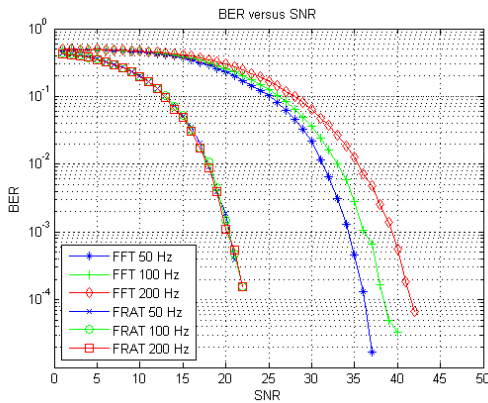
Fig. 7 illustrates the performance of FRAT-OFDM system for 4-QAM modulation in selective-fading AWGN channel. It can be seen that FRAT-OFDM is better than FFT-OFDM with 12 dB of SNR, for a BER level of  $10^{-3}$ .

Fig. 8 illustrates the performance of nFRAT-OFDM system for 4-QAM modulation in flat-fading AWGN channel. It can be seen that nFRAT-OFDM is better than FFT-OFDM, and the gain is about 2 dB for a BER level of  $10^{-3}$ .

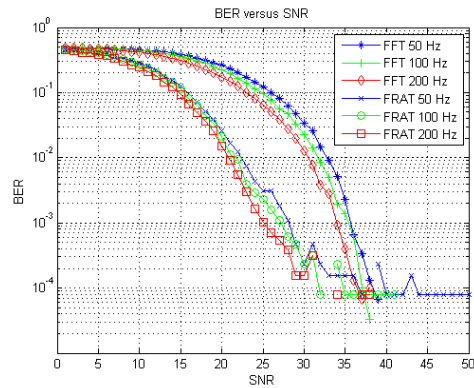
Table 2 summarizes all the obtained results, with respect to the SNR gain and the corresponding BER levels.

**Table 2. The Obtained Results for a Doppler Shift of 50 Hz**

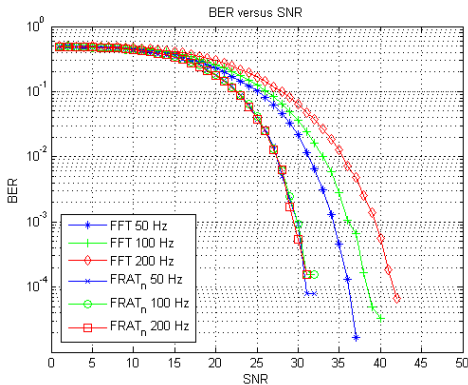
Proposed System	Required SNR		Gain (dB)	BER Level
	FFT-OFDM	Proposed System		
FRAT-OFDM, Flat	36	21	15	$2 \cdot 10^{-4}$
FRAT-OFDM, Selective	35	25	10	$10^{-3}$
FRAT-OFDM, Normalized, Flat	36	31	5	$10^{-4}$
FRAT-OFDM, Normalized, Selective	39	37	2	$10^{-3}$



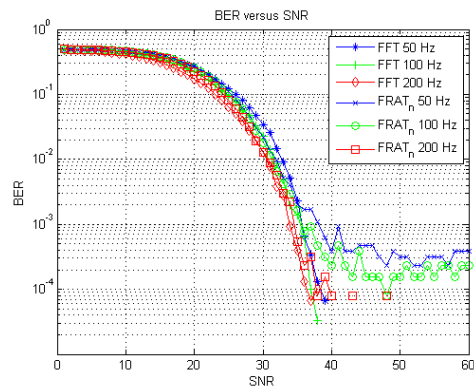
**Fig. 5. BER performance of FRAT-OFDM vs. FFT-OFDM for 4-QAM in a flat-fading AWGN channel**



**Fig. 7. BER performance of FRAT-OFDM vs. FFT-OFDM for 4-QAM in a selective-fading AWGN channel**



**Fig. 6. BER performance of nFRAT-OFDM vs. FFT-OFDM for 4-QAM in a flat-fading AWGN channel**



**Fig. 8. BER performance of nFRAT-OFDM vs. FFT-OFDM for 4-QAM in a selective-fading AWGN channel**

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## Порівняння систем FRAT-OFDM і FFT-OFDM за показником затухання адитивного білого Гаусового шуму в каналах

У статті досліджена розробка системи цифрової бездротової високошвидкісної передачі даних з ортогональним частотним поділом. Для дослідження використані швидке перетворення Фур'є та прикінцеве перетворення Радона. Надані структурні схеми систем із швидким перетворенням Фур'є та прикінцевим перетворенням Радона. За допомогою програми MATLAB проведено математичне моделювання та порівняння (нормоване та ненормоване) ефективності застосування швидкого перетворення Фур'є та прикінцевого перетворення Радона у системі з ортогональним частотним поділом. Доведено, що застосування прикінцевого перетворення Радона забезпечує виграв за параметром "відношення сигнал-шум" від 2 dB до 15 dB. Бібл. 5, рис. 8, табл. 2.

**Ключові слова:** ортогональний частотний поділ (OFDM), швидке перетворення Фур'є (FFT), прикінцеве перетворення Радона (FRAT), адитивний білий гаусів шум (AWGN), квадратурно-амплітудна модуляція (QAM), швидке зворотне перетворення Фур'є (IFFT), частота появи хибних бітів (BER), відношення "сигнал-шум" (SNR), затухання.

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## Сравнение систем FRAT-OFDM и FFT-OFDM по показателю затухания аддитивного белого Гауссова шума в каналах

В статье исследована разработка системы цифровой беспроводной высокоскоростной передачи данных с ортогональным частотным разделением. Для исследования использовались быстрое преобразование Фурье и конечное преобразование Радона. Представлены структурные схемы систем с быстрым преобразованием Фурье и конечным преобразованием Радона. С помощью программы MATLAB проведено математическое моделирование и сравнение (нормированное и ненормированное) эффективности использования быстрого преобразования Фурье и конечного преобразования Радона в системе с ортогональным частотным разделением. Показано, что применение конечного преобразования Радона обеспечивает выигрыш по параметру "отношение сигнал-шум" от 2 dB до 15 dB. Библ. 5, рис.8, табл. 2.

**Ключевые слова:** ортогональное частотное разделение (OFDM), быстрое преобразование Фурье (FFT), конечное преобразование Радона (FRAT), аддитивный белый гауссов шум (AWGN), квадратурно-амплитудная модуляция (QAM), быстрое обратное преобразование Фурье (IFFT), частота появления ошибочных битов (BER), отношение "сигнал-шум" (SNR), затухание.

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