# Enhanced Concert in Multi-Carrier Wireless System using Rajan Transform

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***Abstract* -- Orthogonal frequency division multiplexing is a scheme of encoding digital information on numerous carrier frequencies. The orthogonality permits an proficient modulator and demodulator realization by means of FFT algorithm resting on receiver side, and inverse FFT resting on sender side. A substitute technique for orthogonal transmission and reception of data using Rajan Transform and Inverse Rajan Transform has been proposed in this paper. The performance of both systems are compared by measuring BER and from simulation results it is observed that the performance of the system gets improved by using Rajan Transform and Inverse Rajan Transform instead of IFFT and FFT.**

***Index Terms -- Orthogonal frequency division multiplexing, FFT, IFFT, Rajan Transform, Inverse Rajan Transform.***

## I. INTRODUCTION

An Orthogonal Frequency Division Multiplexing (OFDM) system is a multiple sub-carrier communication system in which the data is processed simultaneously in a parallel fashion on many narrowly spaced, orthogonal sub-carriers. Inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) in a widely used OFDM system are used in multiplexing the signals at the transmitting end and decoding the signal at the receiver end respectively. In order to reduce the Inter symbol interference, cyclic prefix (CP) is added before the signal is transmitted. This is done so that the delay spread of the channel shall be increased longer than the impulse response of the channel. However the channels' spectral containment will be reduced due to the CP.

An alternative way of orthogonal transmission and reception can be done using Rajan and Inverse Rajan transforms. This method does not require CP, and hence the spectral containment is healthier. The Rajan and Inverse Rajan Transforms also perform encryption and decryption of data stream respectively, along with the transformation process.

The main aim of this paper is to simulate and study orthogonal transmission and reception of data using Rajan Transform which can also be used in applications where conventional FFT based OFDM is generally employed. There are six sections in this paper : section II enlighten conventional FFT-OFDM, section III portray Rajan transform, section IV illustrate Inverse Rajan Transform, section V explicate orthogonal transmission and reception of data using Rajan Transform, section VI show the comparative studies of conventional OFDM and orthogonal transmission and reception of data using Rajan Transform, section VII make clear to conclusion.

## II. FFT BASED OFDM

The OFDM communication system is shown in Fig.1. The data generator generates a binary data stream in a random manner ($d_k$). The generated data is BPSK modulated ($X_m$) and this serial data stream is then converted to N-parallel bit streams using a serial-to-parallel converter, where N is the number of sub-carriers used. Now IFFT operation is performed on each of this parallel streams. The output ($X_t$) will be in discrete time domain .

$$X_t(n) = \frac{1}{\sqrt{N}} \exp \sum_{i=0}^{N-1} X_m(i) \exp(j2\pi \frac{n}{N} i) \quad (1)$$

Where $X_t(n)$ is in discrete time domain and $X_m(i)$ is in discrete frequency domain.

To reduce ISI, Cyclic prefix (CP) is added and the digital stream of data is converted to analog data using DAC before transmission. Now the data is transmitted over the channel. In the receiving section, ADC is used to get back the digital stream. The cyclix prefix is now removed. The FFT operation is performed after the serial data is converted to parallel stream. After the FFT operation, the parallel stream is converted to serial data. This serial data is BPSK demodulated. The output($Y_m$) of the FFT which will be in frequency domain .

$$Y_m(i) = \sum_{n=0}^{N-1} Y_t(n) \exp(-j2\pi \frac{n}{N} i) \quad (2)$$

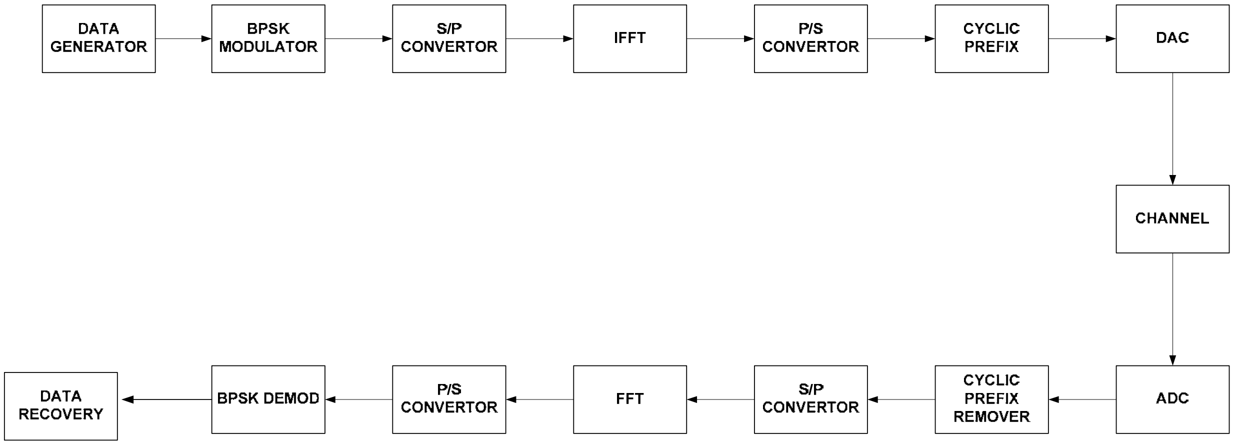


Fig:1. Block Illustration of FFT-Based OFDM

## III. RAJAN TRANSFORM

Rajan Transform (RT) is basically a fast algorithm which is based on, but different from Decimation-In-Frequency (DIF) Fast Fourier Transform algorithm. Consider a number sequence x(n) of length N, and a power of 2, initially it is divided into two halves each consisting of (N/2) points so that it satisfies

$$a(j) = x(i)+x(i+(N/2)) \; ; \; 0 \leq j \leq N/2 \; ; \; 0 \leq i \leq N/2 \qquad (3)$$
$$b(j) = |x(i) - x(i-N/2)| \; ; \; 0 \leq j \leq N/2 \; ; \; (N/2) \leq i \leq N \qquad (4)$$

Now, this (N/2)-point segment is further divided into equal halves and so on, until further division is not possible. Hence, $\log_2 N$ gives the total number of stages. RT is pertinent to any number of sequences and is represented as X (k), for the sequence of length $N=2^k$. The output of RT is of the form X(t)E(r). Here the E(r) represents the encryption keys which are in the form of 0’s and 1’s. These keys are denoted within the brackets. The butterfly diagram of RT is shown in Fig.2.

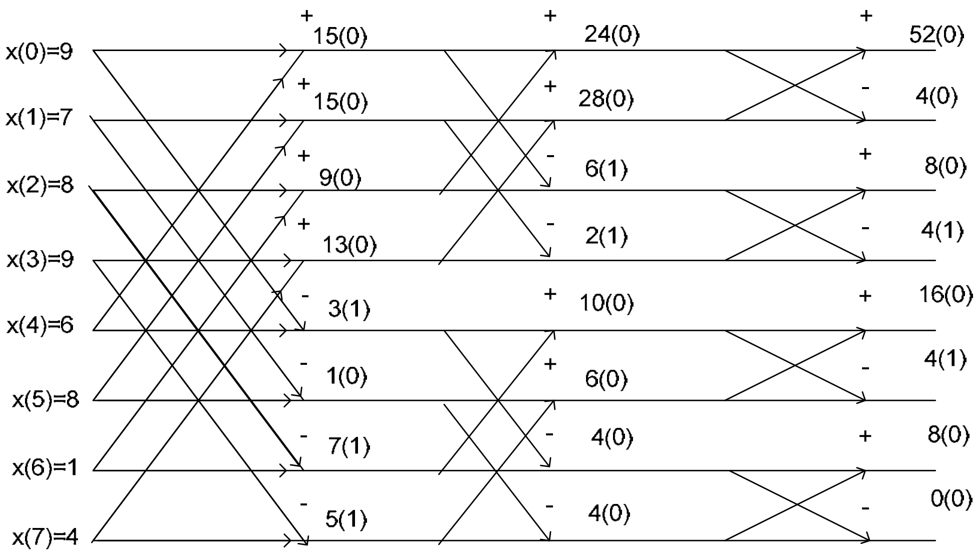


Fig:2. Illustration of Rajan Transform

Consider a sequence x(n) = 9,7,8,9,6,8,1,4. The butterfly diagram for this transform along with the encryption key (number 0 or 1 inside the brackets) .From the diagram it can be seen that E(r) is a padding of three sequences $E_1(r)$ = 0,0,0,0,1,0,1,1, $E_2(r)$ = 0, 0, 1,1, 0, 0, 0,1 and $E_3(r)$= 0, 0, 0, 1, 0, 1, 0, 0. That is, E(r) = $E_1(r)E_2(r)E_3(r)$. The encryption keys are generated based on X(k) at the end of each stage. If X(k) is positive, 0 is generated and when X (k) is negative, 1 is generated. Now, the sequence X(k)E(r) = 52,4,8,4,16,4,8,0, 0, 0, 0,0, 1, 0, 1,1, 0, 0, 1,1,0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0 is the RT of the input sequence x(n).

## IV. INVERSE RAJAN TRANSFORM

Recovery of the signal x(n) can be done by Inverse Rajan Transform (IRT). The basic necessities for the IRT computation are the RT coefficients along with the encryption keys generated in the forward RT process. The computation of IRT is carried out as follows. Initially the input sequence is separated into segments consisting of two points so that either

$$a(2j+1) = (X(2k)+X(2k+1))/2 \quad (5)$$
$$a(2j) = \max (X(2k), X(2k+1))-a(2j+1) \quad (6)$$

if $E_1(2r)= 0$ and $E_1(2r+1) = 0$; $0 \leq j < N$; $0 \leq k \leq N$; $0 \leq r \leq N$

or

$$a(2j) = (X(2k)+X(2k+1))/2 \quad (7)$$
$$a(2j+1) = \max (X(2k), X(2k+1) - a(2j) \quad (8)$$

if $E_1(2r) = 1$ or $E_1(2r+1) = 1$; $0 \leq j \leq N$; $0 \leq k \leq N$; $0 \leq r \leq N$.

The result of this process is a 4-point output which is further processed as stated above until further divisions are not possible. The butterfly diagram of Inverse Rajan Transform is illustrated below in Fig.3.

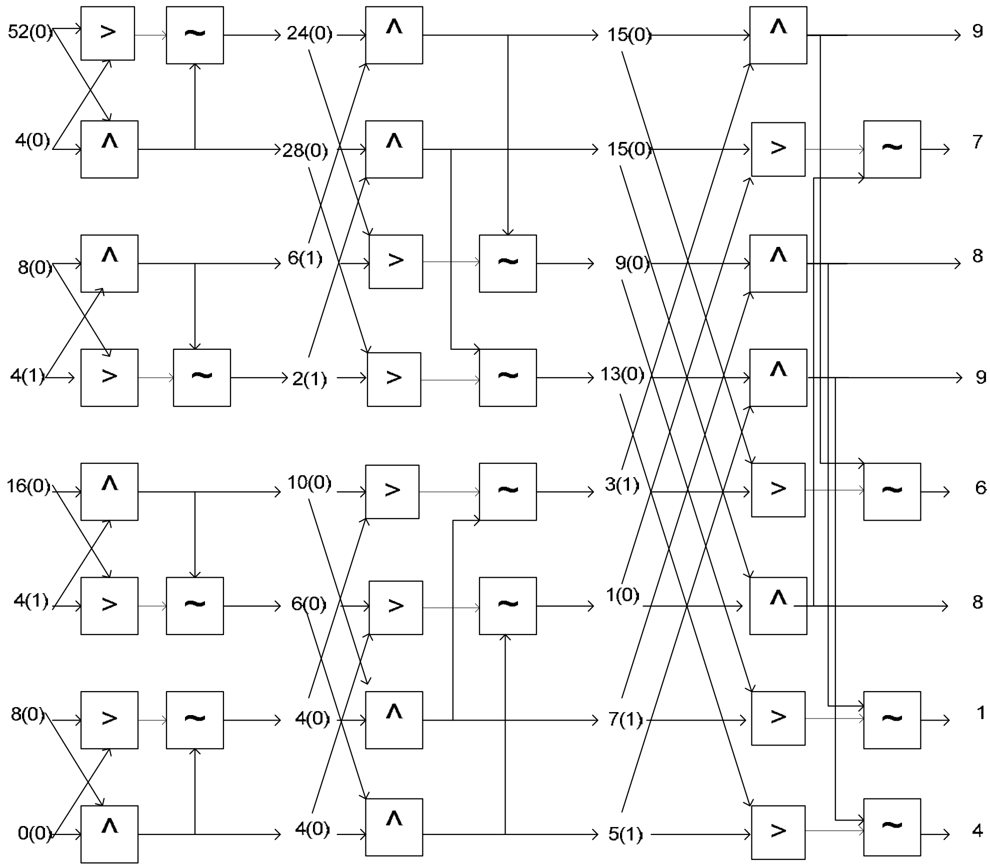


Fig:3. Illustration of Inverse Rajan Transform

In the above diagram, the following operators ^, >, ~, represent average, maximum and difference of the two numbers respectively. Here the encryption keys play a major role in positioning the resultant values in order to continue the process. The input to the IRT is the sequence along with the encryption keys. Consider the input as X(k)E(r) = 52,4,8,4,16,4,8,0, 0, 0, 0,0, 1, 0, 1,1, 0, 0, 1,1,0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0. Now, the output of the IRT is observed to be x(n) =9,7,8,9,6,8,1,4

## V. PROPOSED METHOD

The data generator generates a binary data stream in a random manner ($d_k$). The generated data is BPSK modulated ($X_m$) and this serial data stream is then converted to N-parallel bit streams using a serial-to-parallel converter, where N is the number of sub-carriers used. Now RAJAN TRANSFORM is performed on each of this parallel streams. The output ($X_t$) is then converted to serial bit stream and this digital stream is converted to analog data using DAC. This data is transmitted through the channel.

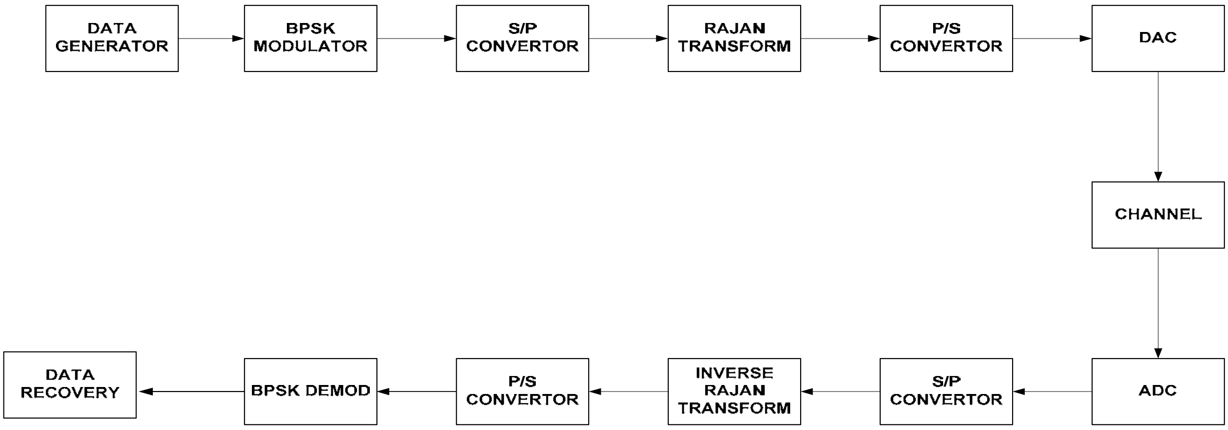


Fig:4. Block Illustration of Rajan Transform

In the receiving section, the reverse operation of transmission section takes place. The input from the channel is converted from analog to digital stream using ADC. This digital stream is converted to parallel data and is fed as an input to the INVERSE RAJAN TRANSFORM block.The output of this block is again converted to serial data and BPSK demodulated.

## VI. COMPARISON OF FFT-OFDM AND ORTHOGONAL TRANSMISSION AND RECEPTION OF DATA USING RAJAN TRANSFORM.

Comparison studies are based on computational complexity and bit error rate (BER) of FFT-OFDM and Rajan Transform technique.

Computational complexity of Rajan transform was found to be lesser than FFT. This is because no of complex number additions of FFT is $N\log_2 N$ but for Rajan transform it is $\log_2 N$. Table.1.validate the above said statement.

Table.1. Calculation of Computational complexity of FFT and Rajan transform

| Bits/symbol | N | FFT $N\log_2 N$ | RAJAN TRANSFORM $\log_2 N$ |
|---|---|---|---|
| 1 | 2 | 2 | 1 |
| 2 | 4 | 8 | 2 |
| 3 | 8 | 24 | 3 |
| 4 | 16 | 64 | 4 |
| 5 | 32 | 160 | 5 |
| 6 | 64 | 384 | 6 |
| 7 | 128 | 896 | 7 |
| 8 | 256 | 2048 | 8 |
| 9 | 512 | 4608 | 9 |
| 10 | 1024 | 10240 | 10 |

Observations based on simulation for two channel FFT-OFDM and Rajan Transform was shown in Fig.5 and Fig.6.

The BER was found to be 0.5625 and 0.3125 for FFT-OFDM and Rajan Transform. The BER decreases with increase in channels.

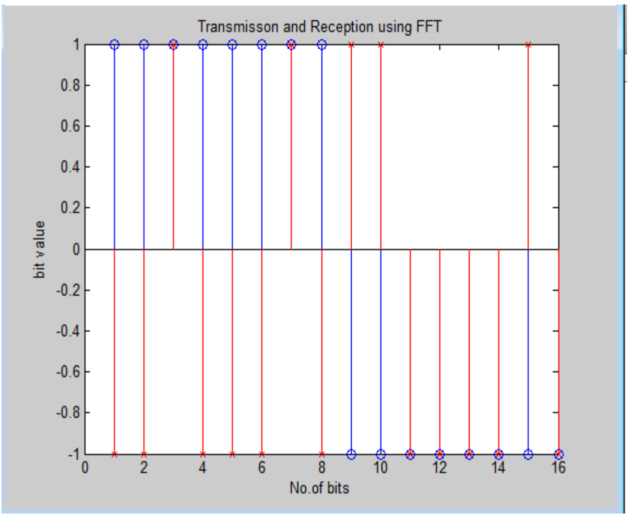


Fig.5.Simulation Results of FFT based OFDM.

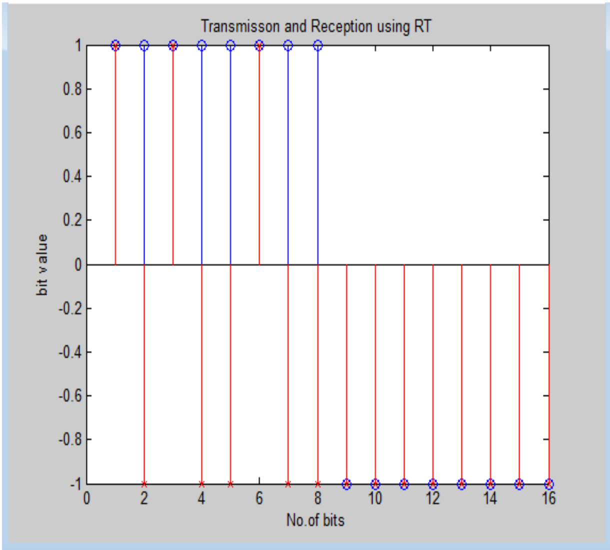


Fig.5.Simulation Results of Rajan Transform.

## VII. CONCLUSION

Thus the computational complexity and Performance of FFT based OFDM and Orthogonal transmission and reception of data was compared using Bit Error Rate.From the comparison it is observed that Orthogonal transmission and reception of data results in improved performance than FFT based OFDM.

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