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FPGA Based Design & Implementation of Alamouti MIMO Encoder for Wireless Transmitter

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Abstract- This paper address the Design and implementation of Alamouti Transmit Diversity Scheme using FPGA for Multi-Input-Multi-Output (MIMO) wireless communication transmitter.

The task of the FPGA based MIMO Encoder is to process two digital signals (S1 & S1) having real(q) and Imaginary (i) parts, are being transmitted using two transmitting antennas by employing Alamouti transmitting scheme in VHDL.

The FPGA devices of the Xilinx family are used to report the results. The performance is checked for optimized device resource utilization, data link for two symbol period. The role of MIMO Encoder/transmitter to handle the traffic of multiuser though multiple channels, to ensure the quality signals at the receiver even in failure of any channel.

Keywords – FPGA, MIMO Encoder, Transmitter, MIMO Decoder, Receiver, antenna, Signal to Noise Ratio (SNR), OFDM.

I. INTRODUCTION

Wireless communication is divided into mobile communications and fixed wireless communications. Each type of communication has huge demand according to customers need in the market. The demand of wireless communication is constantly growing and need the tether less connectivity[2]. The users of the wireless communication demands for higher data rates, good voice quality and higher network capacity restricted due to limited availability of radio frequency spectrum, Bandwidth, Channel Capacity, physical areas and transmission problems caused by various factors like fading and multipath distortion[1].

To improve the performance of fading channels, diversity techniques are used. In diversity technique, communication channel is supplied with multiple Transmitting and Receiving antennas. The signal is transmitted and received through multiple paths. As a result, the probability that all replicas of signals will fade simultaneously is reduced considerably. So Diversity techniques are used to overcome the fading problem and to improve the performance of the radio channel without increasing the transmitted power or bandwidth and improves the SNR.

Among the various diversity techniques spatial diversity is best suitable for the wireless communication. Multi-input-multi-output (MIMO) wireless communication uses spatial diversity techniques.

Alamouti suggested new transmit diversity techniques to provide the same diversity order as that of Maximum Ration Combining (MRC) by using two transmit antenna and one receive antenna[4].

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Transmit diversity is more cost effective than receive diversity for base station, to improve the reception quality of all the remote units under the base station.

Thus by employing Alamouti's scheme for multiple transmit and receive antenna the diversity can be achieved to improve the performance of radio wireless communication channel [4]. The algorithm is developed for Alamouti scheme considering 2 Transmit and 2 Receive Antenna (Known as MIMO system of 2x2 size) which has been design and implemented using FPGA. The performance of the system is observed for various parameter like Data link, Physical resources utilization. The operation of the system has been realize thorough simulation results.

This paper is organized as follows. Section II as overview of MIMO System, Section III described the channel capacity and its improvement on employing MIMO system, Section IV described the an overview of Almouti's space time encoder as MIMO transmitter, Section V shows the steps to develop algorithm, design and implementation using FPGA with RTL view, simulation results. Section VI shows tool used for design and implementation and Section VII discusses about the results and conclusion.

II. MIMO SYSTEM

One possible way to improve the reliability of wireless communications is to employ diversity. Diversity is the technique of transmitting the same information across multiple channels to achieve higher reliability. Even if one particular channel is unusable the information may still be recovered from the redundant transmission over the other channels. Therefore the overall reliability of the communications system is improved, at the cost of transmitting redundant information. MIMO systems are able to achieve impressive improvements in reliability and capacity by exploiting the diversity offered by the multiple channels between the transmit and receive antennas.

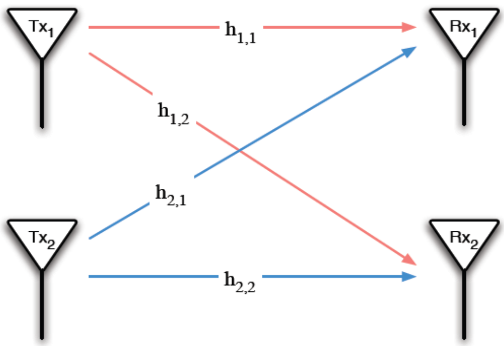


Fig.1- Communication Channel in 2x2 MIMO Systems

Diversity Coding- techniques are used when there is no channel knowledge at the transmitter. In diversity methods a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas using certain principles of full or near orthogonal coding. Diversity exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beam forming or array gain from diversity coding. Spatial multiplexing can also be combined with pre-coding when the channel is known at the transmitter or combined with diversity coding when decoding reliability is in trade-off

In the 2×2 system in Figure 7 there is the potential for both transmit and receive diversity. Receive diversity is when the same information is received by different antennas. For instance the information sent from Tx1 is transmitted across channels h1,1 and h1,2, and received by both Rx1 and Rx2. Transmit diversity is when the same information is sent from multiple transmit antennas. One possible way to achieve this is to code across multiple symbols periods. For instance, at time t antenna Tx1 could transmit the symbol s then at time t+1 antenna Tx2 would transmit the same symbol s. The Alamouti scheme uses a method similar to this to obtain transmit diversity.

III. CHANNEL OF WIRELESS COMMUNICATION SYSTEMS

A. Capacity of Wireless Communication Channel

According to Shannon theory, the capacity of a channel for error free transmission of information is given by $C = B \log_2 (1 + SNR)$

Where *B* is transmission bandwidth, and *SNR* is the signal to noise ratio of the channel. This equation gives the absolute maximum capacity of the channel (in bits/second). The channel capacity can be increased by increasing the bandwidth used in transmission, or to increase in SNR. Multi-Antenna systems use a rather novel approach to increase the overall capacity of a wireless communications system by using more channels. Each of the individual transmission channels is still limited according to above Equation. However the overall capacity of the system is now the sum of the capacities of the individual channels[3].

B. Modeling the Wireless Communication Channel

Under assumptions that the channel is flat-fading‖ channel, the complicated transmission environment can be mathematically represented by using complex numbers to represent the magnitude and phase change of the transmission channel. The in-phase component is the real part of the complex representation, and the quadrature component is the imaginary part.

For a SISO system this model can reduce the entire transmission environment to a single complex number. The system can then be represented using Equation (1),

$$y = h\,x + e \qquad \text{----------(1)}$$

Where **h** is the complex number representing the channel, **x** is the input signal, **e** is a complex number modeling the thermal noise at the receiver.

Similarly MIMO systems can be modeled with Equation (2). The variables have the same meaning as for the SISO case, however instead of the scalar complex numbers in Equation (1), the variables are matrices of complex numbers.

$$Y = HX + E \qquad \text{--------------------(2)}$$

IV. OVERVIEW OF ALAMOUTI SPACE TIME ENCODER

MIMO uses space time coding described by an Alamouti code. The Alamouti Code is belonging to a class of Space-Time Block Codes (STBC). The Space-Time refers to coding across space & time. Coding across space by using multiple transmit and receive antennas, and across time by using multiple symbol periods[5]. Like normal block codes, the Alamouti code operates on blocks of input bits, however rather than having 1 dimensional code vectors it has 2 dimensional code matrices. STBCs can be described by a code matrix, which defines what is to be sent from the transmit antennas during transmission of a block.

The code matrix is of dimension **Nt × tb,** where Nt is the number of transmit antennas and tb is the number of symbol periods used to transmit a block. So the rows of the matrix represent the transmit antennas, and the columns are the time (symbol) periods. The code matrix for the Alamouti code is given in Equation (1). The symbols are first copied straight through to the output arrays unmodified. Then the symbols are swapped over to the opposite transmit antenna and complex conjugated, also one symbol is negated.

$$X = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \qquad \text{------------(1)}$$

The code belongs to a special subclass of STBCs known as Orthogonal Space Time Block Codes (OSTBC). The code matrices of OSTBCs satisfy the following constraint.

$$XX^H = \sum_{n=1}^{n_s} |s_n|^2 \cdot (\alpha I) \qquad \text{------------(2)}$$

where $\mathbf{n_s}$ is the number of symbols, **Sn** is the nth complex symbol, $\boldsymbol{\alpha}$ is an arbitrary constant and $(\cdot)^H$ denotes the Hermitian conjugate given as $X^H = (X^*)^T$.

There are a number of properties that make OSTBCs particularly interesting. Foremost is that Maximum Likelihood (ML) detection of different symbols is decoupled. In the case of the Alamouti code this means that the two symbols which are coded together can be detected independently at the receiver. In other words the same techniques used to detect symbols one at a time in a SISO scheme can be used in the Alamouti scheme as well.

V. IMPLEMENTATION OF ALAMOUTI MIMO ENCODER

A. Operational Details :

The Inputs signals from the various users are first applied to BPSK/QAM/QPSK modulator, took an 16-bit char input and produced two arrays, representing the real(q) and imaginary (i) parts of the symbols for the applied user inputs.

The Alamouti encoder takes the two arrays output by the BPSK modulator or any other type of modulator like QAM, QPSK as input and produces two 2-dimensional arrays as output. These arrays represent the real(q) and imaginary (i) parts of the symbols that are sent to the Radio Frequency (RF) “front-ends” on each of the transmit antennas. It loops through the input arrays operating on pairs of symbols at a time.

Here, I directly consider the real and imaginary signals for One symbol without using BPSK or other modulators. So q1,i1 and q2,i2 as real, imaginary part of two Symbols (signals) S1 and S2 respectively.

The Alamouti encoder contains sequential logic and thus requires some control logic, and a clock signal. The encoder has four 16 bit inputs for the real and imaginary parts of the two symbols S1 & S2 being encoded. The inputs are not registered, and are assumed to be held constant for the duration of the encoding process (2 clock cycles).There are also four 16 bit outputs for the real and imaginary parts of the encoded symbols.

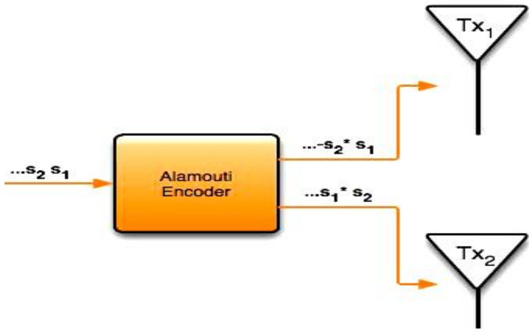


Figure-2 shows the operational diagram of Alamouti MIMO encoder for two transmitting antennas. In line with Equation

Figure-2-. Operational diagram of Alamouti MIMO Encoder st

copied straight through to the output arrays unmodified. Then the symbols are swapped over to the opposite transmit antenna and complex conjugated, also one symbol is negated. Complex conjugation is achieved by simply negating the imaginary part of the input before placing it into the output. Also the complex conjugation and extra negation operations are combined into a single step for the relevant symbol by negating the real part instead of the imaginary.

It is designed to operate at the same clock speed as the data rate of the system, so one clock cycle is assumed to be one symbol period. Since it takes two clock cycles to encode two symbols the modulator must maintain a state to indicate if it is currently in the first or second time period. This state is implemented as a single bit signal that is toggled for each clock cycle.

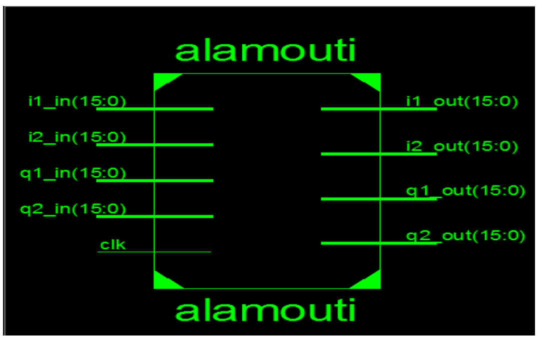
These outputs are further may be feed to the OFDM and Physical layers and then to the RF module of 2.4GHz Transceiver (Maxim MAX2822) or other. These chips are compatible with the physical layer of the IEEE 802.11b standard for wireless networking.

B. Algorithms :

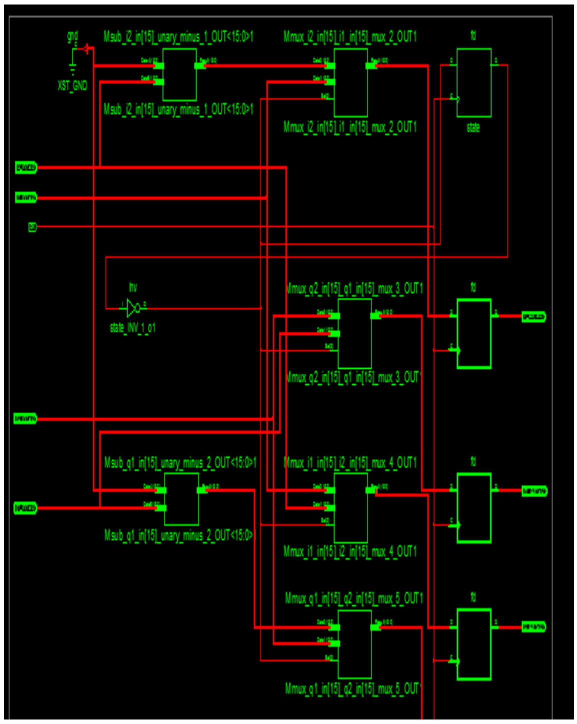
- Apply Two 16 bit random data input as real (q1) and Imaginary(i1) for symbols S1. Similarly for symbol S2.
- For First time **t**, sent the symbol S1 by transmitting antenna TX1 and symbol S2 by transmitting antenna TX2.
- For Next time **(t+1)**, swap the symbol such that (-S2*) by TX1 and (S1*) by transmitting antenna TX2.
- Maintain and assign the state S for every transition.
- Repeat the above sequence for next set of data.

C. Implementation Results:

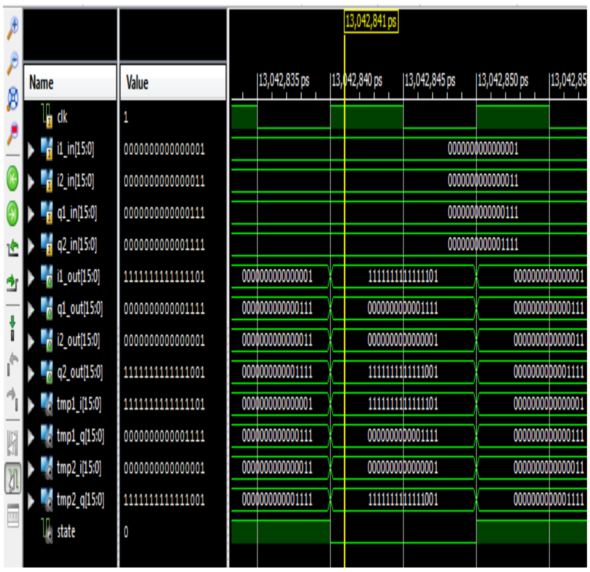
❖ **Alamouti Encoder-RTL View-Top Level**



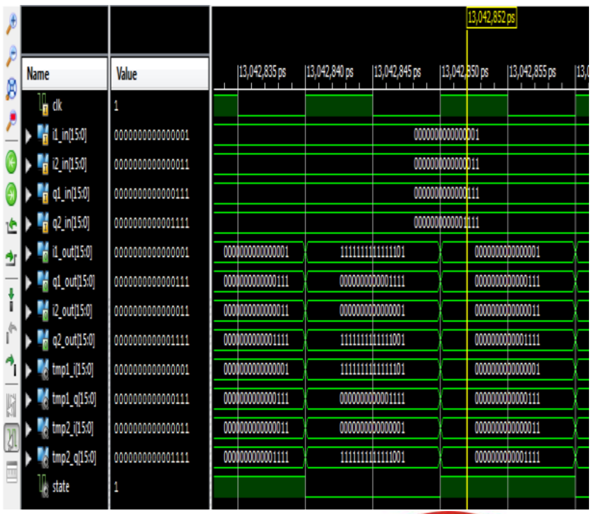
❖ **Alamouti Encoder-RTL View -Block Level schematic**



❖ **Alamouti Encoder- Simulation Result-1 (State =0)**



Alamouti Encoder- Simulation Result-2 (State =1)



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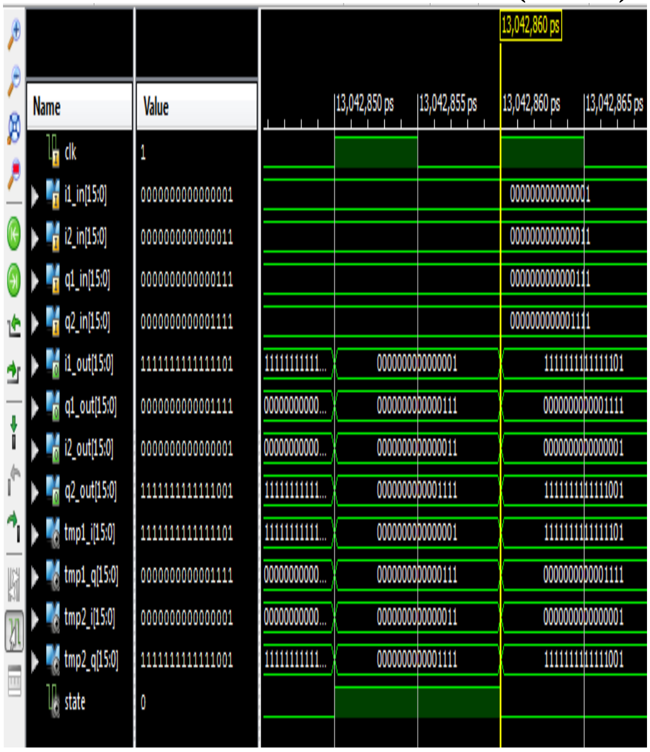
- **Alamouti Encoder- Simulation Result-3 (State =0)**



- **Device Utilization Summary :**

Slice Logic Utilization	Used	% Utilization
Number of Slice Registers	65	1
Number used as Flip Flops	65	1
Number of Slice LUTs	97	1
Number used as logic	97	1
Number of occupied slices	34	1
Number of fully used LUT-FF pairs	65	67
Number of slice register sites lost to control set restrictions	7	1
Number of bonded IOBs	129	21
Number of BUFG/BUFGCTRLs	1	3

VI. TOOLS & IMPLEMENTATION

Tools Xilinx and Model Sim are used for design and implementation. The complete design may be downloaded to available FPGA devices and can establish 3G/4G Wireless link, Suggested RF module is of 2.4GHz transceiver (MaximMAX2822). These chips are compatible with the physical layer of the IEEE 802.11b standard for wireless networking.

VII. CONCLUSIONS

We have presented the design methodology used in the implementation of a Alamouti MIMO Encoder for wireless transmitter which can be used for a 3G/ 4G radio system/ wireless network. The architecture of the system has been optimized to comply with the throughput requirements while reducing implementation area.

The transmitting TWO symbols, four 16 bit inputs as real and imaginary part of symbols are mapped to satisfy the algorithm. These data inputs are transmitted in time slots by two antennas. The simulation results shows the I/P Data applied and sequence of transmission. This module will be the basic element for MIMO transmitter system may be further equipped with OFDM, Physical layers and

For Two Users with four 16 bit inputs for real and imaginary part, the total device resources utilization is approximately 10% of target device xc6vlx130t-2ff1156,

RF Combining network to enhance reliability of the MIMO system.

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