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Design of 2 ×4 Alamouti Transceiver Using FPGA

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***Abstract* -In this paper, the concept of Alamouti's transmit diversity technique in MIMO system is implemented based on Hardware Description Language (HDL), using Xilinx Field Programmable Gate Array (FPGA) .The proposed design based on Alamouti's transmit diversity scheme which is a space-time block code (STBC) with two transmit antennas and four receive antennas. The implementation demonstrates the space-time code in a baseband system. The encoding and decoding algorithms are implemented using VHDL, where the Virtex2P is used to complete the receiver part design theoretically. Finally the design MIMO systems are implemented successfully.**

Keywords: MIMO System, STBC, Alamouti's scheme, FPGA, VHDL.

I. INTRODUCTION

Traditional wireless communication systems with one transmit and one receive antenna are denoted as Single Input Single Output (SISO) systems, whereas systems with one transmit and multiple receive antennas are denoted as Single Input Multiple Output (SIMO) systems, and systems with multiple transmit and one receive antenna are called Multiple Input Single Output (MISO) systems [1, 2,3]

Multiple Input Multiple Output (MIMO) systems in wireless communications refer to any wireless communication system where at both sides of the communication path more than one antenna is used. MIMO technology, has rapidly gained in popularity over the past decade due to its powerful performance-enhancing capabilities. It has been widely accepted as a promising technology to increase the transmission rate and the strength of the received signal, with no additional increase in bandwidth or transmission power, as compared with traditional Single-Input Single-Output (SISO) systems [1, 2, 4, 5].

MIMO systems constructively explore multi-path propagation using different transmission paths to the receiver. These paths can be exploited to provide redundancy of transmitted data, thus improving the reliability of transmission (diversity gain) or increasing the number of simultaneously transmitted data streams and increasing the data rate of the system (multiplexing gain). The multiple spatial signatures can also be used for combating interference in the system (interferences reduction) [6]. Multiple-input multiple-output (MIMO) communications system provides many benefits like array gain, diversity gain, coding gain, and improved capacity as compared to the single-input single-output systems(SISO) [7].

SPACE–TIME coding for multiple transmit antennas has attracted considerable attention due to its potential capacity increase, see, for example. Due to a large number of codewords for a reasonable rate space–time code, its decoding complexity may be prohibitively high. Alamouti [8] recently proposed an orthogonal space–time (OST) code design for two transmit antennas such that the decoding is fast, i.e., symbol-bysymbol decoding, and has the full diversity. This idea has been extended to a general number of transmit antennas by Tarokh, Jafarkani, and Calderbank [9], and further generalized in [10]. The key reason for the fast decoding of OST codes is the orthogonality that enables maximum-likelihood (ML) decoding of multiple symbols to be reduced into ML decoding of individual symbols.

II. MIMO SYSTEM WITH TWO TRANSMIT AND FOUR RECEIVE ANTENNAS

Fading is one of the major problems in wireless communication systems which limits the link performance. One efficient way to reduce the severe attenuations in fading channels is to make use of transmit antenna diversity. Since it does not increase the transmission bandwidth and its cost is paid at the base station by increasing the number of transmit antennas, transmit antenna diversity is extensively studied in recent years. Space-Time Block Code (STBC) is the compromising approach when performance versus complexity trade-off is considered. Orthogonal Space-Time Block Codes (OSTBC), beside their diversity advantage, provide decoding simplicity since transmitted symbols are separately decoded by means of linear processing [11]. Alamouti's scheme for two transmit antennas is the unique orthogonal space-time block code for complex channel symbols, providing both full diversity and full rate where two symbols are transmitted in each coding step. There may be applications where a higher order of diversity is needed and multiple receive antennas at the remote units are feasible. In such cases, it is possible to provide a diversity order of 2M with two transmit and M receive antennas as shown in Fig.1. [8].

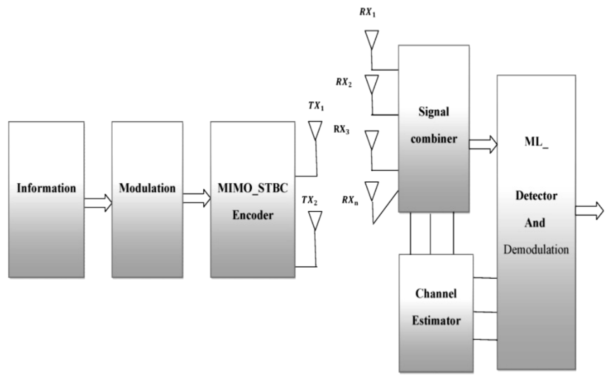


Fig.1. Simple MIMO system model

Multiple-input-multiple-output (MIMO) communication systems use multiple antennas at both the transmitter and the receiver .Under rich multipath environments with independent multipath fading between each transmit and receive antenna pair, MIMO wireless communications systems achieve significant capacity gains over conventional single antenna systems by exploiting the plurality of modes present in the matrix channel within the same time frequency slot .Moreover MIMO systems offer significant diversity advantage over traditional wireless communication systems by exploiting both transmit and receive diversity by employing various space-time coding schemes. These have led to MIMO being regarded as one of the most promising emerging wireless technologies. MIMO system considers with *M* transmit and *N* receive antennas. The transmitted signal bandwidth is narrow enough, so its frequency response can be considered as flat. The noise at the receiver is described by an $N\times1$ column matrix, denoted by n [12].

III. ALAMOUTI SYSTEM WITH TWO TRANSMIT AND TWO RECEIVE ANTENNAS

Alamouti schemes can be written in simple matrix form. For instance for 2 by 2 system, received signal at time interval t_1 and t_2 can be expressed in equation (1) [12, 13].

$$\begin{pmatrix} r_1 & r_2 \\ r_3 & r_4 \end{pmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_3 & h_4 \end{bmatrix} \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} + \begin{bmatrix} n_1 & n_2 \\ n_3 & n_4 \end{bmatrix} \quad (1)$$

The encoder takes two modulated symbols s_1 and s_2 at a time. The transmit matrix S is given by equation (1)

$$S = \begin{pmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{pmatrix}$$

Where *s** *is* complex conjugate of *s*. During the first transmission period , two signals s_1 and s_2 are transmitted simultaneously from the first and second antennas ,respectively. In the second transmission period, signal $-s_2^*$ is transmitted from first antenna and signal s_1^* from second antenna as shown in TABLE.1.

TABLE.1. the Encoding And Transmission Sequence For Alamouti STBC Scheme

	Tx_1	Tx_2
T	s_1	s_2
t + T	$-s_2^*$	s_1^*

It is clear that the encoding process is done in both space and time domain. 'For the combiner following simple matrix form represented by equation (2) can be written [12, 13,14,15].

$$\begin{pmatrix} \hat{s}_1 \\ \hat{s}_2 \end{pmatrix} = \begin{pmatrix} h_1^* & h_2 & h_3^* & h_4 \\ h_2^* & -h_1 & h_4^* & -h_3 \end{pmatrix} \times \begin{pmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \end{pmatrix} \quad (2)$$

Then by applying maximum likelihood detector s_1 and $s_2$can be estimated. In the similar way for 2 by 4 system as shown in Fig.2.

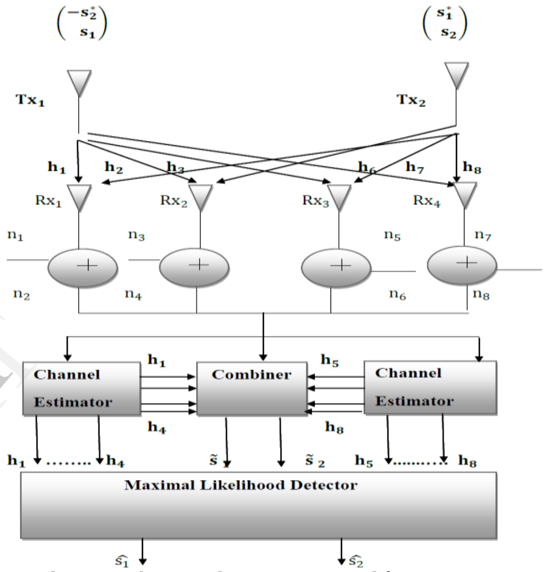


Fig.2. Alamouti scheme with two transmit and four receive antennas.

The following matrix form in equation (3) for the received signal in time interval t_1 and t_2 can be written [12].

$$\begin{pmatrix} r_1 & r_2 \\ r_3 & r_4 \\ r_5 & r_6 \\ r_7 & r_8 \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_3 & h_4 \\ h_5 & h_6 \\ h_7 & h_8 \end{pmatrix} \times \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} + \begin{pmatrix} n_1 & n_2 \\ n_3 & n_4 \\ n_5 & n_6 \\ n_7 & n_8 \end{pmatrix}$$

(3)

For the combiner, following simple matrix form in equation (4) can be defined [12].

$$\begin{pmatrix} \hat{s}_1 \\ \hat{s}_2 \end{pmatrix} = \begin{pmatrix} h_1^* & h_2 & h_3^* & h_4 & h_5^* & h_6 & h_7^* & h_8 \\ h_2^* & -h_1 & h_4^* & -h_3 & h_6^* & -h_5 & h_8^* & -h_7 \end{pmatrix} \times \begin{pmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \\ r_5 \\ r_6^* \\ r_7 \\ r_8^* \end{pmatrix} \quad (4)$$

In the similar way for 2 transmitted antennas and M received antennas system matrix form in equation (5) represented the received signal in time interval t_1 and t_2 [12].

$$\begin{bmatrix} r_1 & r_2 \\ r_3 & r_4 \\ r_5 & r_6 \\ r_7 & r_8 \\ \vdots & \vdots \\ r(2m-1) & r(2m-2) \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_3 & h_4 \\ h_5 & h_6 \\ h_7 & h_8 \\ \vdots & \vdots \\ h(2m-1) & h(2m-2) \end{bmatrix} \times \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \begin{bmatrix} n_1 & n_2 \\ n_3 & n_4 \\ n_5 & n_6 \\ n_7 & n_8 \\ \vdots & \vdots \\ n(2m-1) & n(2m-2) \end{bmatrix} \quad (5)$$

For the combiner for 2 by M antenna configuration, following simple matrix form in equation (6) can be written [12].

$$\begin{pmatrix} \hat{s}_1 \\ \hat{s}_2 \end{pmatrix} = \begin{pmatrix} h1^* & h2 & h3^* & h4 & \cdots & h(2m-1)^* & h(2m-2) \\ h2^* & -h1 & h4^* & -h3 & \cdots & h(2m-2)^* & -h(2m-1) \end{pmatrix} \times \begin{pmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \\ r_5 \\ r_6^* \\ r_7 \\ r_8^* \\ r(2m-1) \\ r(2m-2)^* \end{pmatrix} \quad (6)$$

And finally in the same way symbols s_1 and s_2 can be detected using maximum likelihood detector.The characteristics of this scheme is given by [14]:

- No feedback from receiver to transmitter is required for CSI to obtain full transmit diversity.
- No bandwidth expansion (as redundancy is applied in space across multiple antennas, not in time or frequency).
- Low complexity decoders.
- Identical performance as MRC if the total radiated power is doubled from that used in MRC. This is because, if the transmit power is kept constant, this scheme suffers a 3-dB penalty in performance, since the transmit power is divided in half across two transmit antennas.
- No need for complete redesign of existing systems to incorporate this diversity scheme. Hence, it is very popular as a candidate for improving link quality based on dual transmit antenna techniques, without any drastic system modifications.

IV. DESIGN OF MIMO SYSTEM USING FPGA

A. *MIMO TRANSMITTER*

Fig.3. shows the block diagram of the Alamouti transmitter. It consists of three sub-blocks. Which are the serial-to-parallel converter, BPSK or QPSK modulator and Alamouti encoder. The input data is a composition of serial binary bits which are fed into the Alamouti transmitter design.

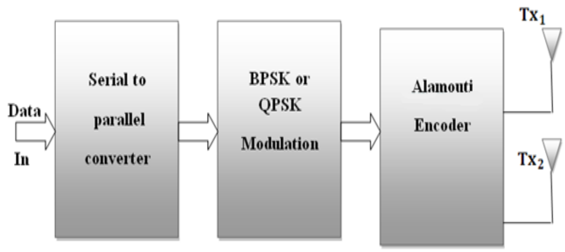


Fig.3. Block Diagram of Alamouti Transmitter

The Alamouti transmitter design, manipulates these binary bits in such a manner that it follows the Alamouti's transmit diversity technique to produce outputs at two transmit antennas. At this point, take note that there is an assumption that the fading and inputs are constant for the duration of the encoding process. Alamouti transmitter scheme can be represented as shown in Fig.4. and Fig.5. shows internal circuit of Alamouti transmitter.

When serial input data (00)	T	t + T
Tx1	(80)Hex	(80)Hex
Tx2	(80)Hex	(80)Hex
When serial input (01)	T	t + T
Tx1	(80)Hex	(81)Hex
Tx2	(7F)Hex	(80)Hex
When serial input (10)	T	t + T
Tx1	(7F)Hex	(80)Hex
Tx2	(80)Hex	(7F)Hex
When serial input (11)	T	t + T
Tx1	(7F)Hex	(81)Hex
Tx2	(7F)Hex	(7F)Hex

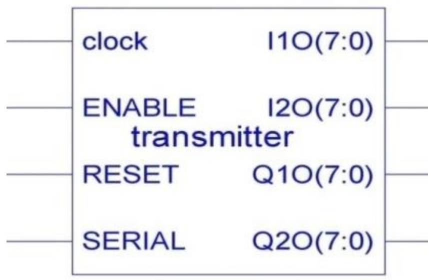


Fig.4. Alamouti transmitter

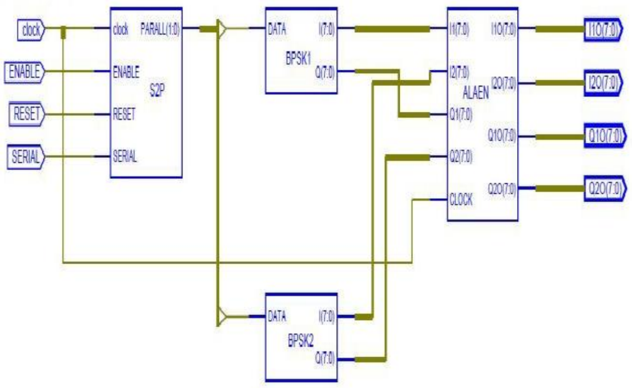


Fig.5. Internal circuit of alamouti transmitter

the output of transmitter is illustrated in TABLE.2. where time simulation waveforms is shown in Fig.6. which have the imaginary part equal to (0), in the case of BPSK ,while for QPSK it have another values.

TABLE.2.The Output Data of Alamouti Transmitter

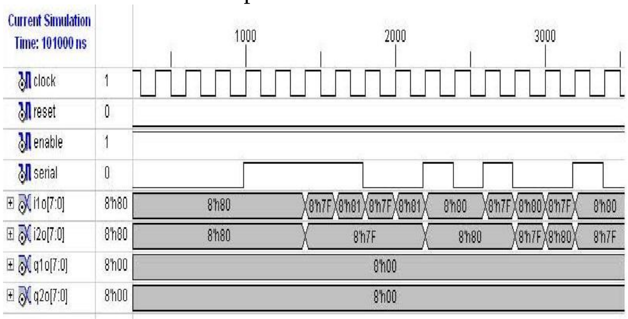


Fig.6. Time simulation waveforms of alamouti transmitter

B. MIMO RECEIVER

Alamouti receiver system shown in Fig.7.has many circuits which are used in MIMO system with two receiver antennas like equalizer, modulation and parallel to serial converter. So, these circuits will not explain and just Alamouti decoder circuit will be discussed.

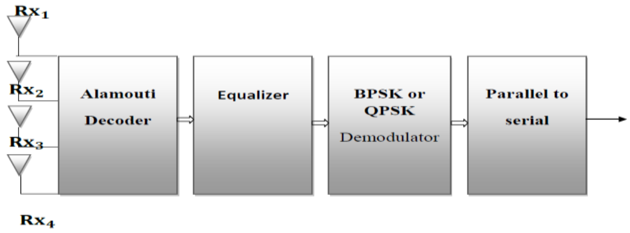


Fig.7. Alamouti Receiver System With Four Anntena

Alamouti transmit diversity technique has applied in the Alamouti decoder which has an addition and subtraction functions involved. This operation of addition and subtraction are performed by the combiner control and Add/Subtract circuits respectively according to Equation (3) and (4). The equations (5) and (6) are converted into VHDL and synthesized. The design consists of four multiplier functional units, and four associated add/subtract units with registers to accumulate the totals. Also, There is a control logic, implemented as a state machine, to multiplex inputs through the various functional units, and control whether the add/subtract units add or subtract (these control lines are not shown in the diagram), the Alamouti decoder scheme is shown in Fig.8.

The design is a multi-cycle implementation, it takes multiple clock cycles to compute the results. The multipliers take one clock cycle to calculate a product, and the add/subtract units take one clock cycle. Therefore, the two output symbol (real and imaginary parts) are produced every 16 clock cycles.

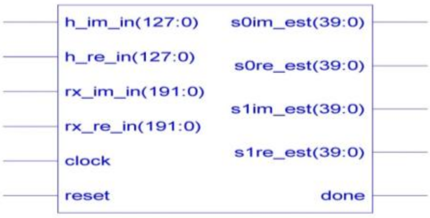


Fig.8. ALAMOUTI DECODER WITH FOUR RECEIVER ANTENNA

C. CHANNEL MODEL

Channel modeling in MIMO system with four receiver differes from MIMO receiver with two receiver, since the number of antenna increases which increases the number of received data . Channel module has many real and imaginary parts for noise, so the Additive White Gaussian noise (AWGN) can be substituted to the channel module after taking from MATLAB and converted to binary number.

Alamouti transmitter and Alamouti receiver are connected together by channel module to get complete transmission system as shown in Fig.9.

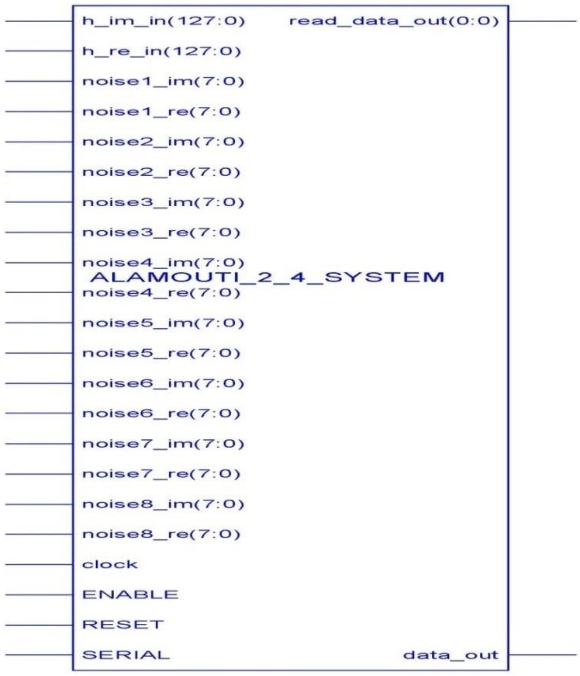
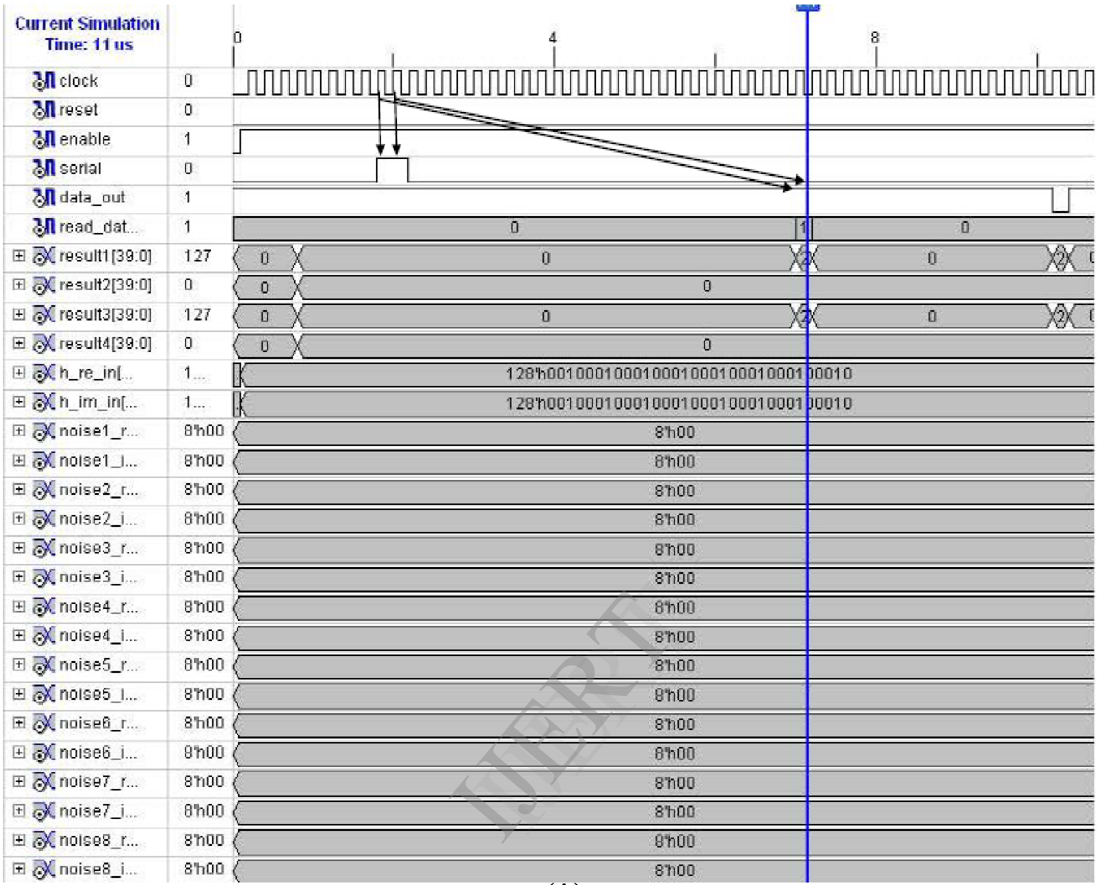


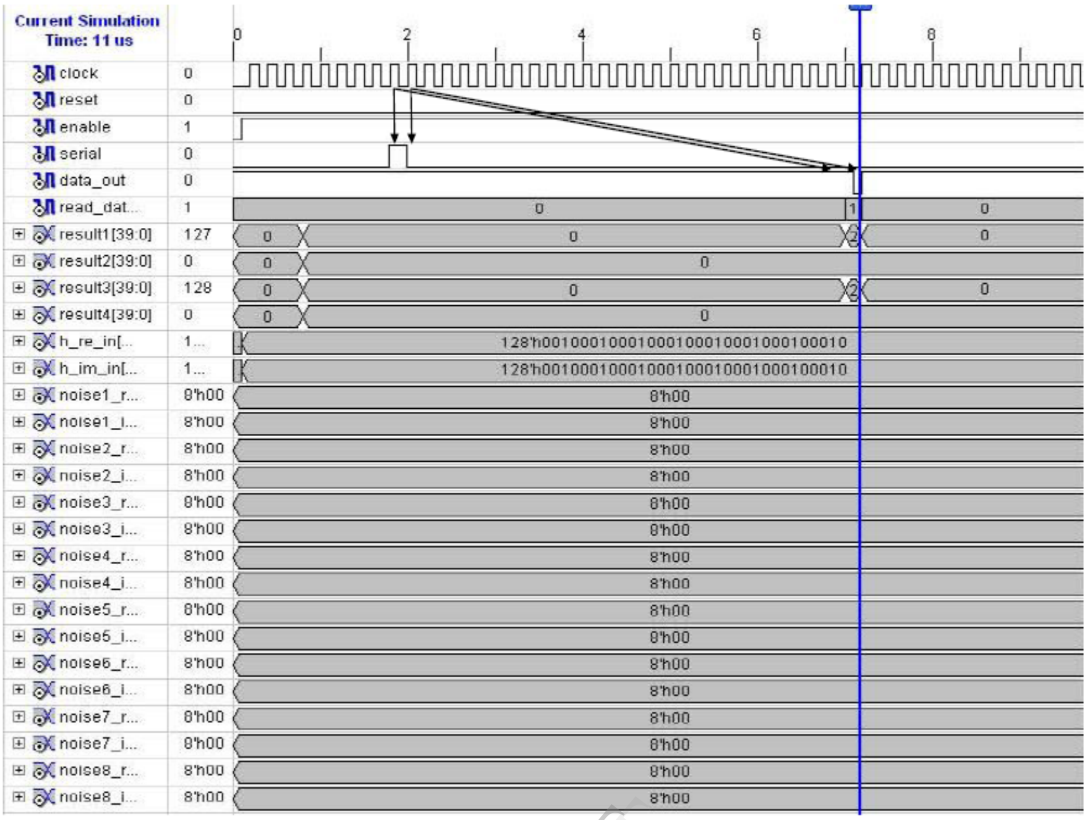
Fig.9. Mimo (Alamouti) System With Two Transmitter And Four Receiver Anntenas

Finally, for the design implementation test, the input signal is fed into the Alamouti transmitter module and the output is monitored at the designed Alamouti receiver module. The output waveform results of transmission is shown in

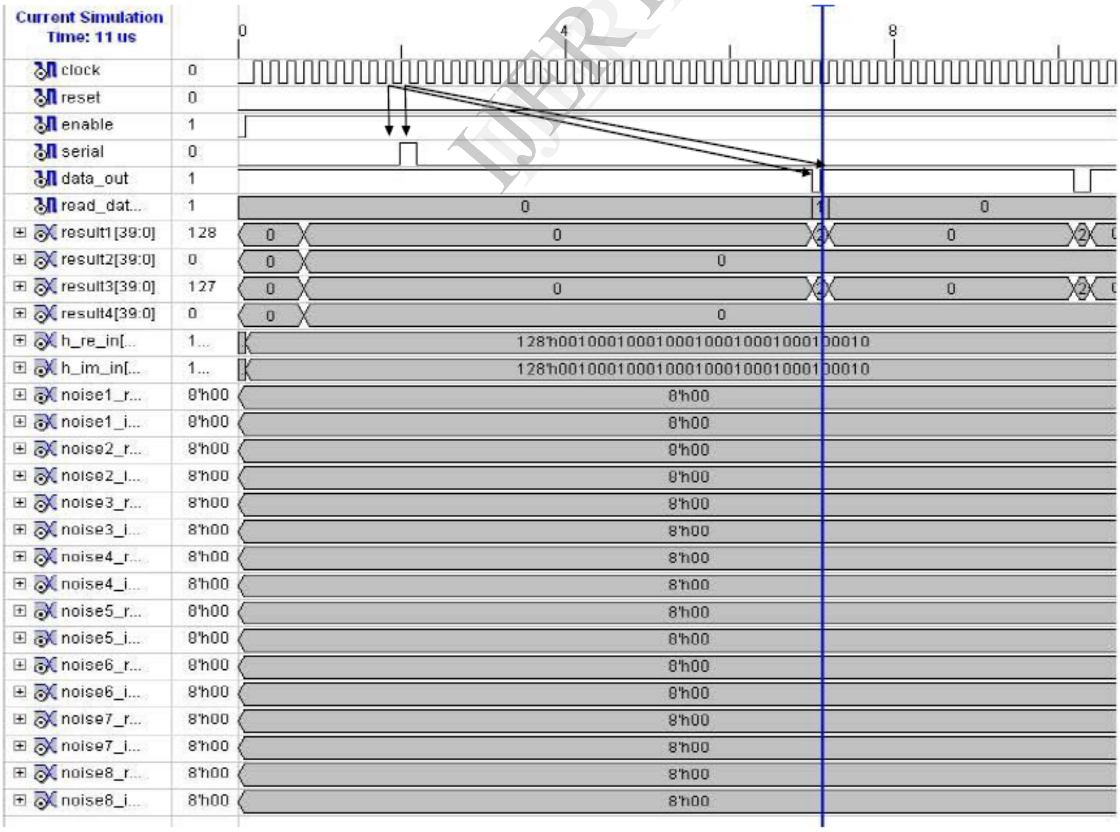
Fig.10. and Fig.11. Assume that there is no noise and interference presented at the channel (ideal channel) at one state, then taking the results of mobile radio channel of MIMO system which programming in MATLAB and converted to a binary number which is substituted in channel module with no noise. Output data can found when read data_out is logic '1'. The input clock is twice than output clock so when read data-out logic '1' the interval is made for two data bits.



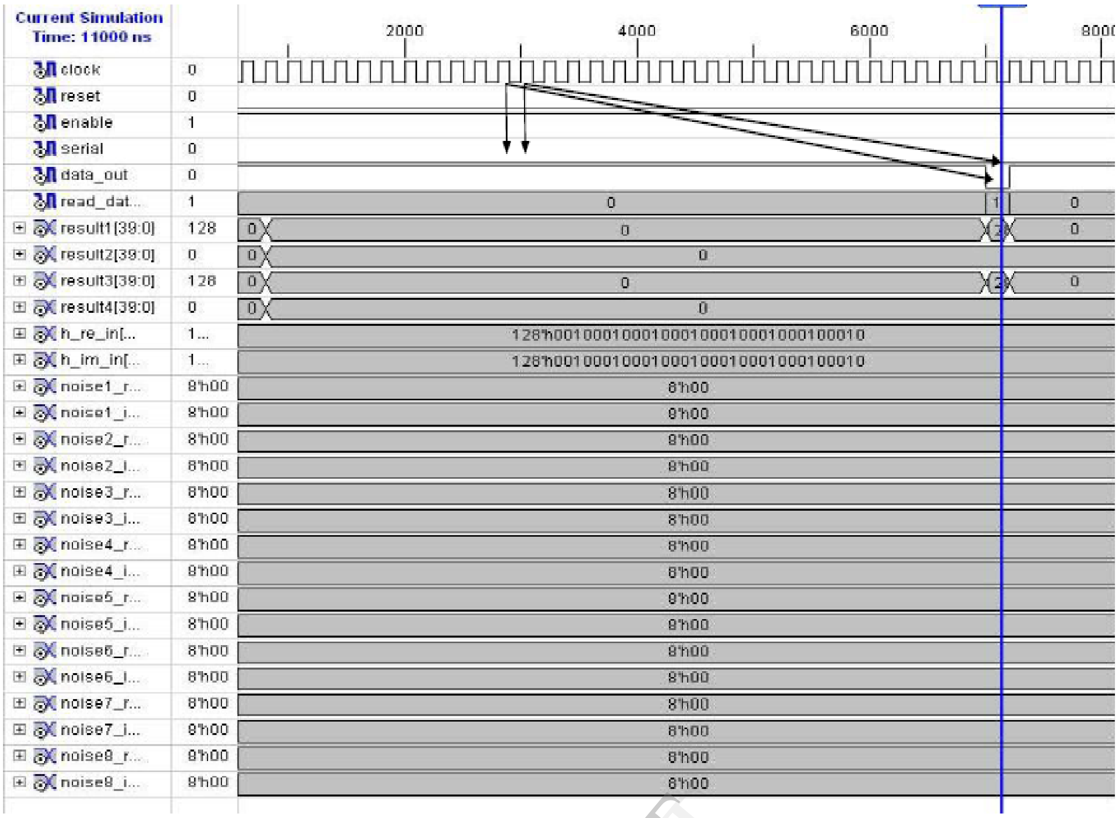
(A)


Current Simulation Time: 11 us
clock
reset
enable
serial
data_out
read_dat...
result1[39:0]
result2[39:0]
result3[39:0]
result4[39:0]
h_re_in[...
h_im_in[...
noise1_r...
noise1_i...
noise2_r...
noise2_i...
noise3_r...
noise3_i...
noise4_r...
noise4_i...
noise5_r...
noise5_i...
noise6_r...
noise6_i...
noise7_r...
noise7_i...
noise8_r...
noise8_i...
128'h00100010001000100010001000100010
8'h00

(B)

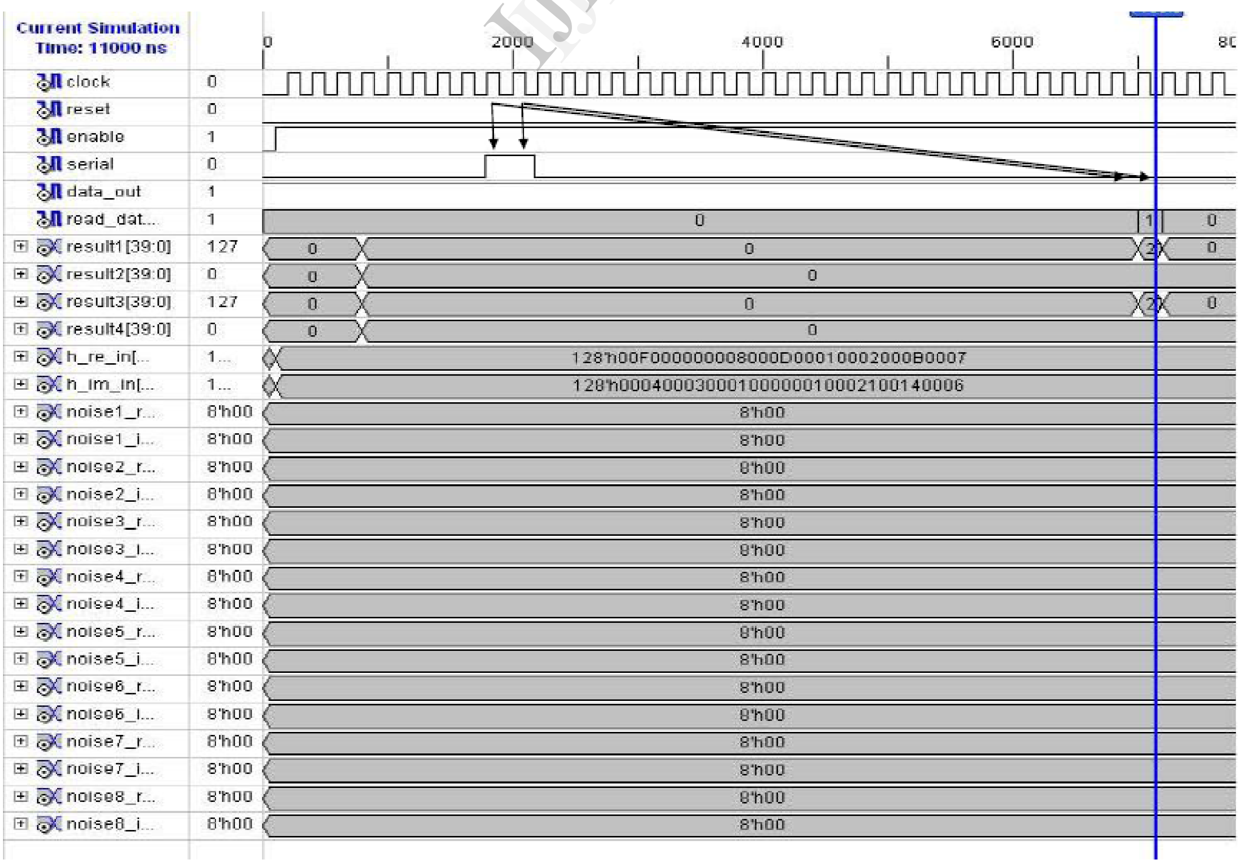

Current Simulation Time: 11 us
clock
reset
enable
serial
data_out
read_dat...
result1[39:0]
result2[39:0]
result3[39:0]
result4[39:0]
h_re_in[...
h_im_in[...
noise1_r...
noise1_i...
noise2_r...
noise2_i...
noise3_r...
noise3_i...
noise4_r...
noise4_i...
noise5_r...
noise5_i...
noise6_r...
noise6_i...
noise7_r...
noise7_i...
noise8_r...
noise8_i...
128'h00100010001000100010001000100010
8'h00

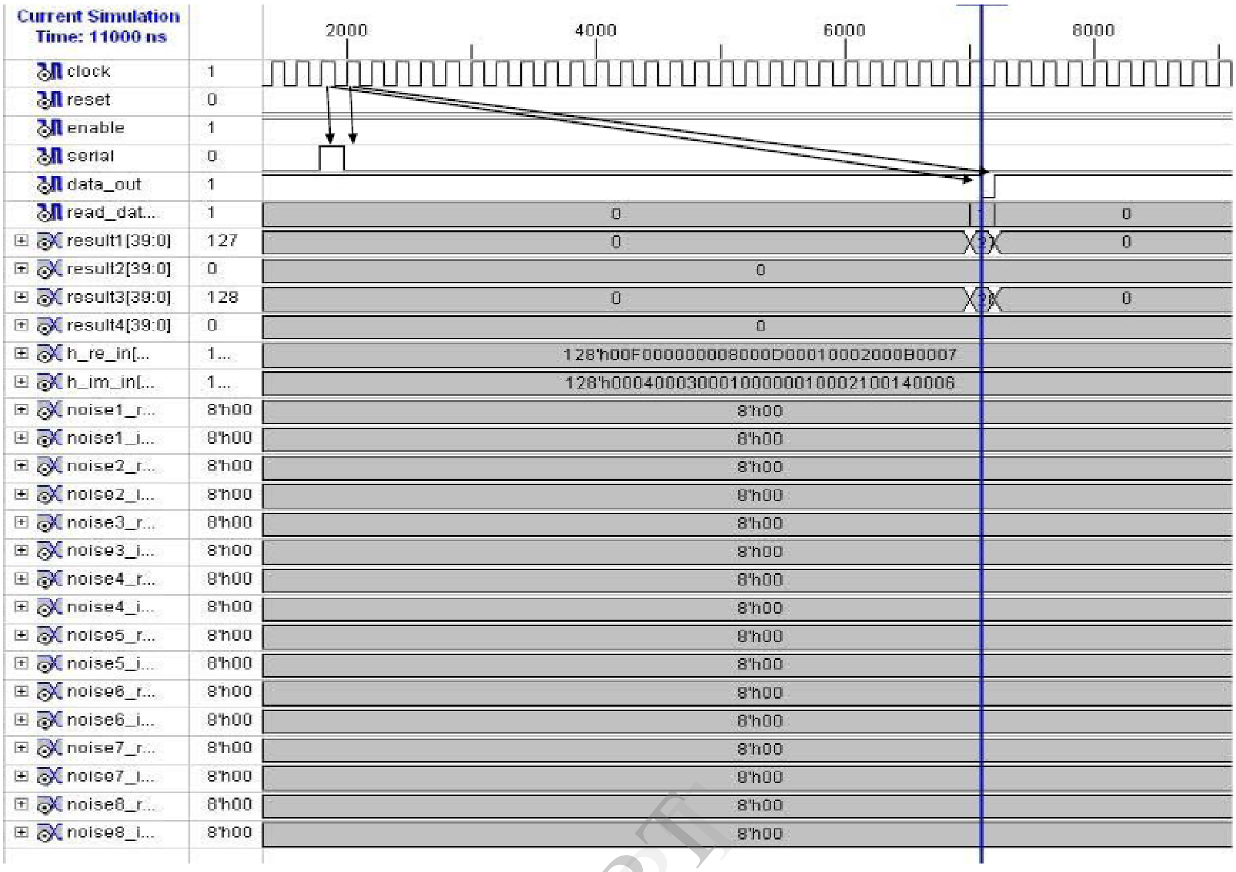
(C)



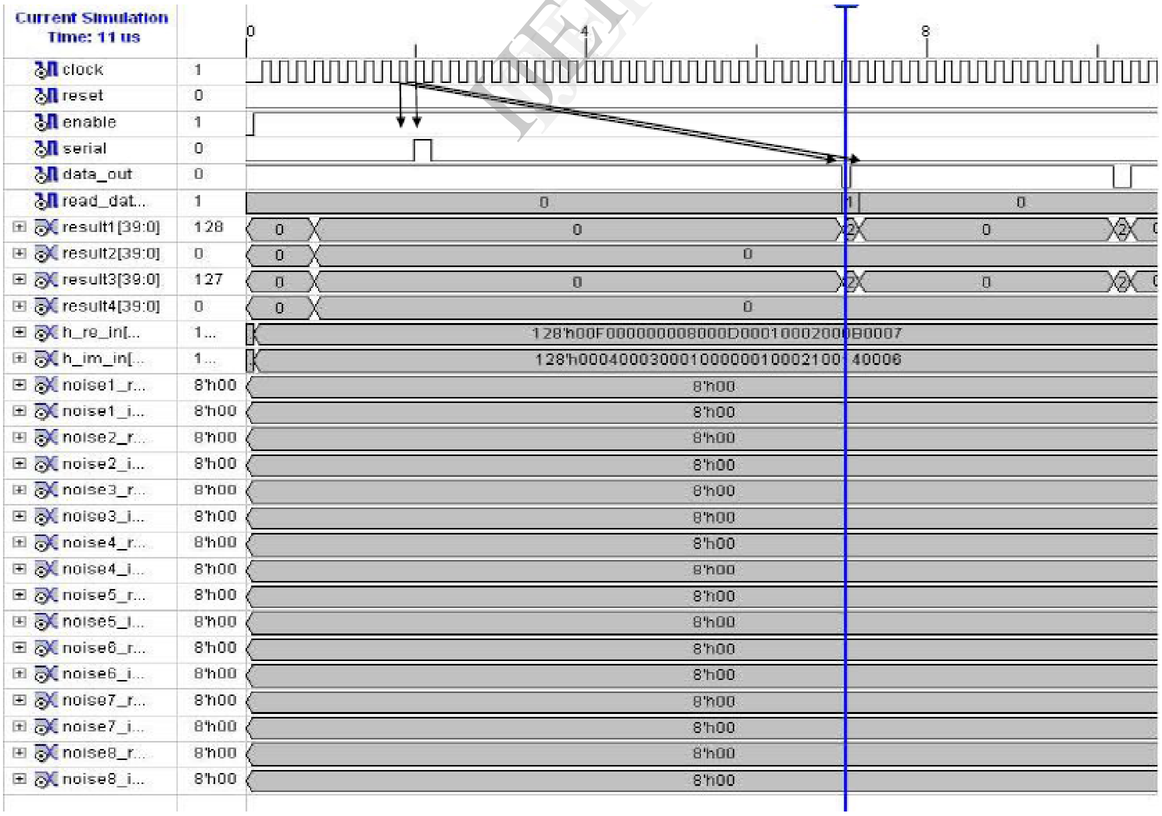
(D)

Fig.10. Output waveform of Alamouti system in ideal channel
(A) At serial input (11) (B) At serial input (10)
(C) At serial input (01) (D) At serial input (00)

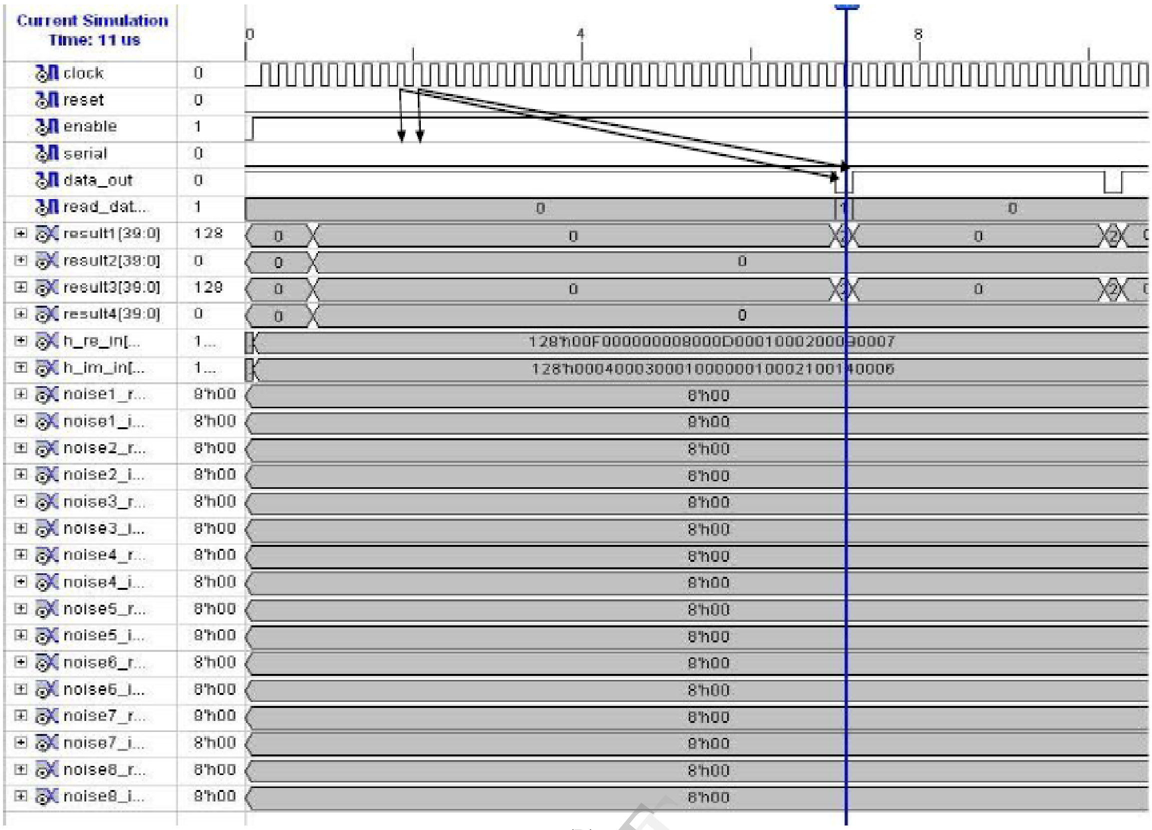



Current Simulation Time: 11000 ns
2000
4000
6000
8000
clock 1
reset 0
enable 1
serial 0
data_out 1
read_dat... 1
result1[39:0] 127
result2[39:0] 0
result3[39:0] 128
result4[39:0] 0
h_re_in[... 1...
h_im_in[... 1...
128'h00F000000008000D00010002000B0007
128'h00040003000100000010002100140006
noise1_r... 8'h00
noise1_i... 8'h00
noise2_r... 8'h00
noise2_i... 8'h00
noise3_r... 8'h00
noise3_i... 8'h00
noise4_r... 8'h00
noise4_i... 8'h00
noise5_r... 8'h00
noise5_i... 8'h00
noise6_r... 8'h00
noise6_i... 8'h00
noise7_r... 8'h00
noise7_i... 8'h00
noise8_r... 8'h00
noise8_i... 8'h00

(B)


Current Simulation Time: 11 us
0
4
8
clock 1
reset 0
enable 1
serial 0
data_out 0
read_dat... 1
result1[39:0] 128
result2[39:0] 0
result3[39:0] 127
result4[39:0] 0
h_re_in[... 1...
h_im_in[... 1...
noise1_r... 8'h00
noise1_i... 8'h00
noise2_r... 8'h00
noise2_i... 8'h00
noise3_r... 8'h00
noise3_i... 8'h00
noise4_r... 8'h00
noise4_i... 8'h00
noise5_r... 8'h00
noise5_i... 8'h00
noise6_r... 8'h00
noise6_i... 8'h00
noise7_r... 8'h00
noise7_i... 8'h00
noise8_r... 8'h00
noise8_i... 8'h00

(C)



(D)

Fig.11. Output waveform of Alamouti system in MIMO channel with no noise
(A) At serial input (11) (B) At serial input (10)
(C) At serial input (01) (D) At serial input (00)

Virtex2P is used in system design, since the design is too large to be implemented with Spartan 3A/3AN. The design summary of MIMO system with two transmitted and four received antenna is shown in TABLE.3. which explains the number of logic utilization in the design.

TABLE.3. Summary of Mimo System (Alamouti) With Two Transmitted And Four Received Antenna

Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slices	6997	13696	51%
Number of Slice Flip Flops	2426	27392	8%
Number of 4 input LUTs	13142	27392	47%
Number of bonded IOBs	390	644	60%
Number of GCLKs	1	16	6%

The hardware design poses some unique challenges. Considerations such as how implemented matrix in VHDL, how implemented perfect equalizer in VHDL, how many clock cycles a given operation takes, or whether an operation can be completed in parallel with another, rarely matter at earlier stages in the process. However, details like these are critically important when implementing hardware. All designs of the system have been implemented in VHDL except for the channel estimator and maximum likelihood detector as the transmission was not performed over real wireless channels. The implemented components have been tested to verify correctness of operation and functionality. Alamouti's transmit diversity scheme is a space-time block code with support for two transmit antennas and an arbitrary number of receive antennas. The objective of this work is to present an FPGA (Xilinx) design of a wireless communication system based on Alamouti's transmit diversity technique using two transmit antennas and an arbitrary number of receive antennas. The design is implemented on Xilinx FPGA boards using the Spartan 3A3/3AN and virtex2P tool and Xilinx ISE software.

V. CONCLUSIONS

MIMO system based on Alamouti's space-time code is designed and implemented successfully .The main conclusions obtained from this work can be summarized as follows:

- The proposed system with two transmitter and four receiver antennas are coded and verified using VHDL successfully.
- The inclusion of an Alamouti encoder in a transmitter design does not significantly increase its complexity.
- The implementation of an Alamouti receiver is somewhat more challenging. These challenges are due to the constraints in implementing it on the FPGA, using many circuits each one have many internal circuits like decoder which contains add/ subtract and control circuits, and equalizer circuit which have division and addition circuits.

- This implementation is a part of an ongoing effort to develop an FPGA based multiple antenna wireless communications system, when used for getting high data rates and spectral efficiency. This design can be extended into different ways. First , it can be generalized to support multiple receive antennas using the decoding algorithm. It could be extended to support more than two transmit antennas using the generalization of Alamouti's code. Therefore, this work is proved that it is a quite feasible to design and implement an Alamouti code using commercially available FPGAs. This puts the possibility of further testing and research into MIMO systems.
- The proposed design requires FPGA kit with high capacity like Virtex family for implementation.
- Space–time codes have a simple architecture and can be implemented using FPGA.

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