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Design and Performance Analysis of MIMO-DSSS System for 2.4 GHz ISM Band Wi-Fi Applications Using Microstrip Antennas

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ABSTRACT: *In this paper, compact antenna has been designed and implemented in a 2X2 Multiple-Input Multiple-Output (MIMO) system. The antennas are compact double-sided printed microstrip patch antennas and fed by a microstrip line designed for a frequency of 2.4 GHz used for industrial, scientific and medical (ISM) band applications. Polarization diversity of the two antennas is used to construct independent and uncorrelated signals on each antenna. The antennas are designed on CST Microwave studio simulation software with return loss less than -10dB, and the two antennas are combined as a single system forming a MIMO array of two antennas, Further, using the results from CST, MIMO-DSSS system has been implemented and a performance analysis of this system is done on MATLAB software. The performance of this system is studied using BPSK modulation and finally bit error rate is obtained. The paper details the implementation of the digital communication system along with the simulated and measured results. The system is designed for 802.11n Wi-Fi family of standards that has an operation frequency of 2.4 GHz but with MIMO system that offers an increased data rate.*

KEYWORDS : *Direct sequence spread spectrum (DSSS), Multiple-Input Multiple-Output (MIMO) system, industrial scientific and medical (ISM)*

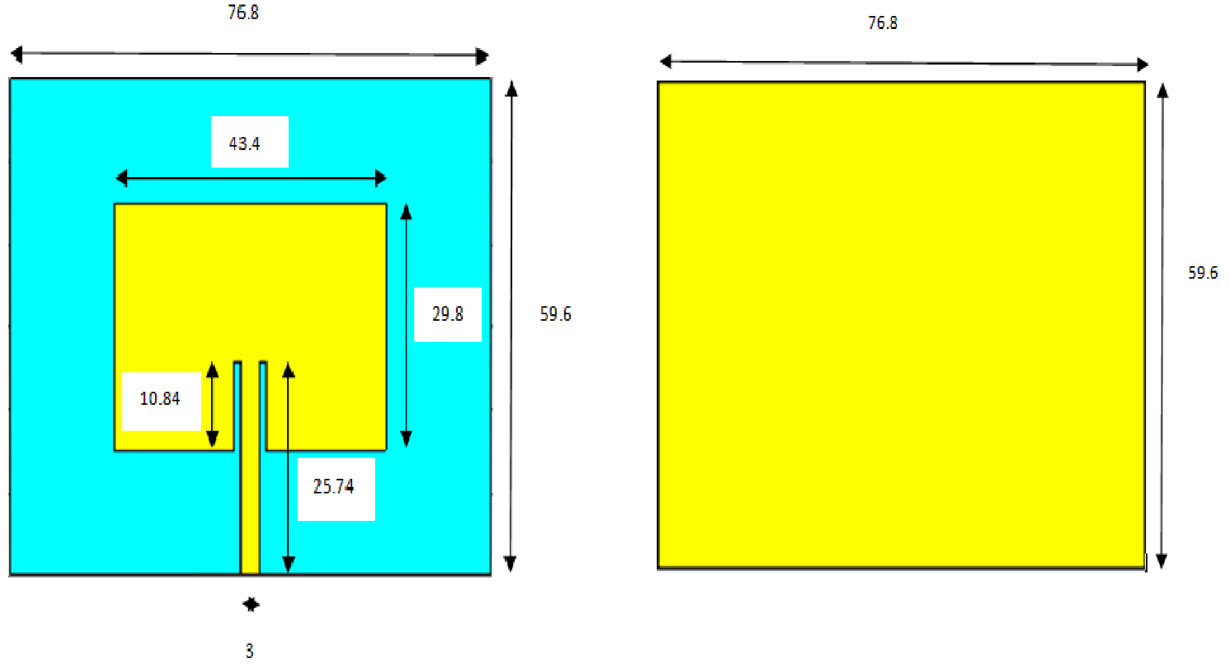
I. INTRODUCTION

Wireless Communications are evolving from pure telephony systems to multimedia platforms offering a variety of services. Future wireless systems should be flexible to match different constraints concerning data rate, delay, reliability and quality-of-service. Multiple input multiple output (MIMO) system multiplies the data rate throughput achievable in wireless communication [1], it optimizes the use of the transmission spectrum and power [2,3] by using MIMO, additional paths can be used to increase the capacity of a link [4]. The 2.4 GHz industrial, scientific and medical (ISM) band is largely license exempt band also the regulation is minimum and there is free access. It is used for many applications like cordless phones, wireless medical telemetry equipments and for Wi-Fi family of standards (802.11 a,b,g,n) which are the most widely known network bearer standards. The 802.11n standard was defined in October 2009, is becoming widely adopted. It uses 2.4 GHz or 5.8 GHz ISM band frequency, it is interoperable with 802.11b and uses 802.11g-like modulation, but with MIMO. There have been many reported work on antenna design at 2.4 GHz ISM band frequency as in[5][6].The MIMO array design of antennas has been reported for a frequency of 2.4 GHz, apart from this polarization diversity [7] antennas have also been designed, all these designs were implemented with a goal to achieve independent antenna arrays where the signals on the two antennas are uncorrelated and independent of each other, efforts [8–10] have been contributed to the reduction of mutual coupling between antennas.In this paper, a simple and compact planar antenna is designed that shows acceptable return loss for 2.4 GHz ISM band frequency. This antenna is further used in the design of a 2X2 MIMO system.

The basic aim of MIMO antenna design is to minimize the correlation between the multiple signals as in [11],to achieve compactness in MIMO systems, the use of pattern diversity as in [12,13], multimode diversity as in [14], and polarization diversity techniques as in [15] in conjunction with space diversity are discussed in the literature. In the present design, the orthogonal polarization concept is applied to the proposed multi slot patch antenna yielding better results in terms of return loss and mutual coupling. This MIMO system is further used to design a communication system using DSSS technique where encoding is done using BPSK modulation. The system is further analyzed for its performance analysis. The paper is organized as follows, Section II details the single antenna design analysis, and this antenna is further used in Section III to form a MIMO array. In Section IV the two antenna array is fed equally by a directional coupler. Section V details the design a compact 2X2 MIMO system. Section VI details the coding implementation of MIMO-DSSS system using the results from above sections and finally Section VII concludes the analysis of paper.

II. SINGLE ANTENNA DESIGN ANALYSIS

The antenna is designed on a substrate which is printed on both sides, on one side is the patch and other side is a ground plane. The patch is fed by a micro strip feed line. The geometry of the given antenna is illustrated in Figure 1. It is fabricated on a 76.8 X 59.6 mm^2 substrate with a dielectric constant of 4.1 and a substrate thickness of 1.5 mm. The top patch of the substrate has dimension of 43.4 X 29.8 mm^2 which is fed by a strip line having a width of 3 mm. The bottom patch of substrate is just a ground plane. The proposed antenna has been simulated by CST Microwave studio.



(a) (b)

Figure 1. Geometry of the antenna with dimensions in mm (a) Top view (b) Bottom view

The simulation results of the antenna are shown in Figure 2, from the simulated graph it is observed that for frequency of 2.4 GHz, S_{11}<-10dB showing a significant return loss.

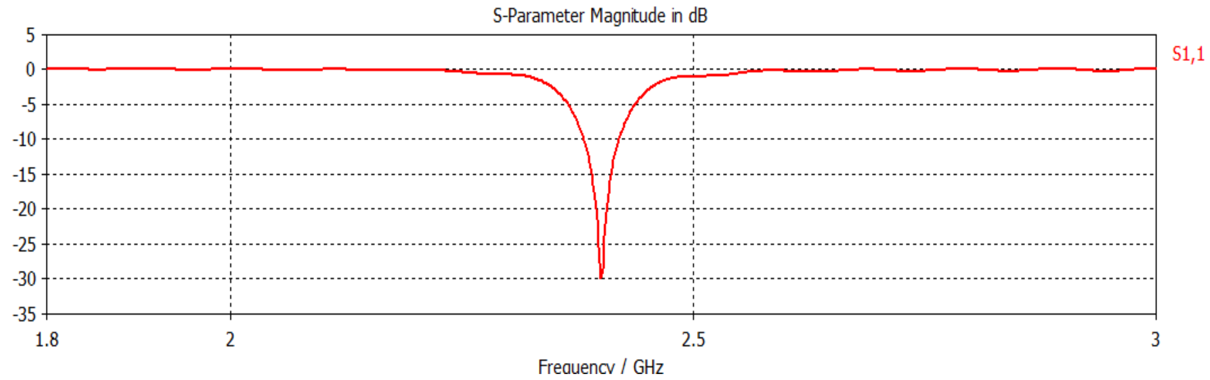


Figure 2. Simulated result of the single antenna

III. MIMO ARRAY DESIGN

The main criteria for MIMO system design is mutual coupling, which can be reduced by increasing the distance between the elements of the antennas. We can achieve less mutual coupling by diversity concept since miniaturization is the main task in the upcoming wireless devices, the mutual coupling can be mitigated more with the use of polarization diversity. In the design of our system to achieve orthogonal polarization, one antenna is rotated to 90^0 with respect to its adjacent element as shown in the Figure 3.The separation between the antennas is 7.12 mm which is 0.057 λ. The antennas in the array have the same dimensions as mentioned in Section II. The antennas are mounted on a substrate symmetrically with $\varepsilon r = 4.1$, which in turn is mounted on a ground plane.

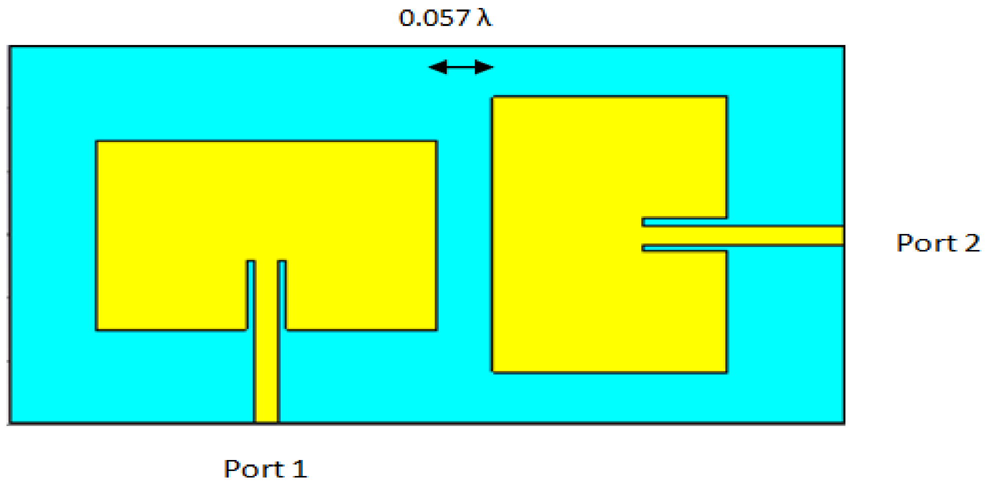
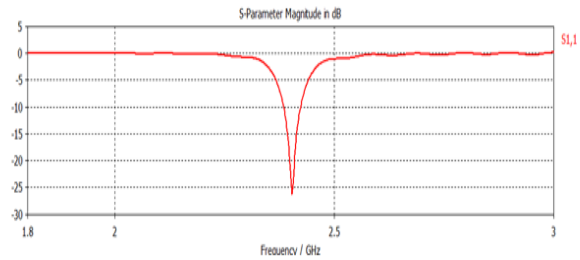
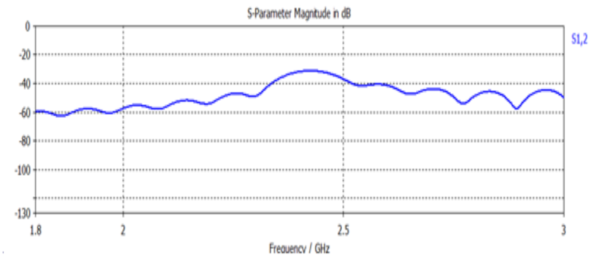


Figure 3. MIMO antenna array having two ports

The above two port system is simulated on CST Microwave Studio simulation software. We can see from the simulated results of Figure 4 that the two antennas are working independently of each other as seen from the S_{11} and S_{22} plots for the two antennas that both are working on the 2.4 GHz ISM band with a significant return loss, also the mutual coupling S_{12} and S_{21} between the two antennas is very low at this frequency.



(a)



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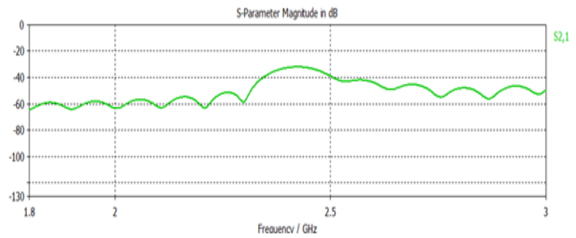
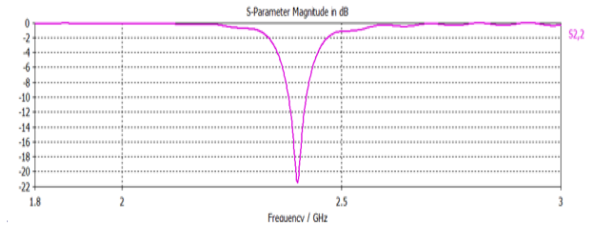


(c)



(d)

Figure 4. Plots for simulation of MIMO antenna array (a) S_{11} (b) S_{12} (c) S_{21} (d) S_{22}

We have also calculated the correlation coefficient and diversity gain for this two antenna array. The correlation coefficient is given by the formula as in (1)

$$\rho = \frac{\left|S11^{*}S12 + S21^{*}S22\right|^{2}}{(1 - |S11|^{2} - |S21|^{2})(1 - |S22|^{2} - |S12|^{2})} \qquad (1)$$

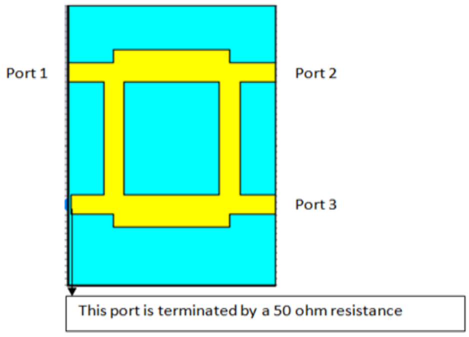
Using the values of S- parameters from the plots of Figure 4 at the 2.4 GHz frequency, the correlation coefficient comes out to be 0.001.The diversity gain is also calculated which is given by the formula as in (2)

$$DG = 10 * \sqrt{1 - (0.99 * \rho)^{2}} \qquad (2)$$

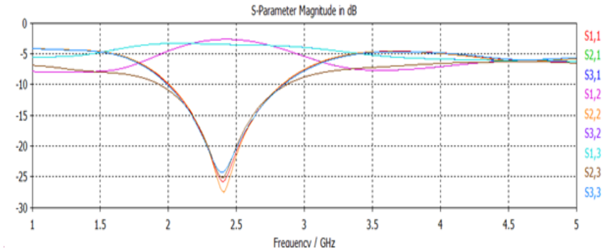
Diversity gain comes out to be 9.9 dB. The values of correlation coefficient and diversity are in accordance that the antennas are working independently of each other and increase in signal to noise ratio due to diversity scheme is also significant respectively.

IV. FEEDING THE MIMO ARRAY

The MIMO array designed above has two antennas showing polarization diversity and are independent of each other, for a practical MIMO system there are two antennas on the transmitter side and two on the receiver side respectively separated by the same distance, also the two antennas should be fed equally with same phase Thus, in our case we will be using a directional coupler to feed the above two antennas respectively.A 3 dB directional coupler with four ports having design frequency of 2.4 GHz is designed, input is given from one port of the coupler, which is evenly divided between other two ports with a 900 phase shift between the outputs, also very little output is received at the isolated port. The isolated port is terminated by a matched load of 50 ohms. The coupler is as shown in Figure 5 along with the simulated results. The ratio of voltages between the output voltages at port 2 and port 3 with respect to the input port (port 1) is given by S_{21} and S_{31} respectively. This ratio will be utilized further in the channel matrix calculations.



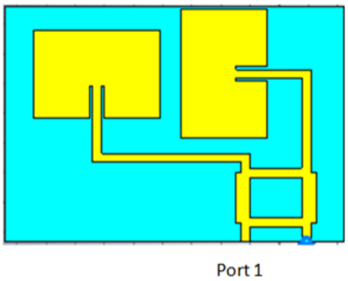
(a)



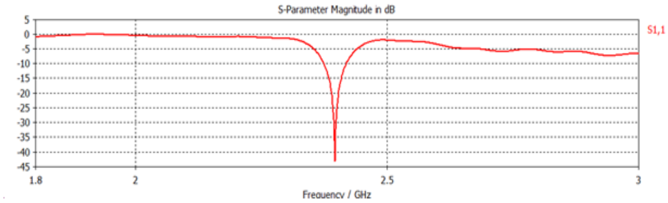
(b)

Figure 5. 3-dB directional coupler (a) Coupler design (b) Simulated result

To feed the two antennas with this coupler the feed lines from the output ports of coupler to the antennas are of different lengths such that the final input to the antennas is in phase. The antenna is as shown in Figure 6 along with the simulated result, we can see that S_{11}<-10dB showing a significant return loss.



(a)



(b)

Figure 6. Compact MIMO antenna (a) antenna design (b) simulated result

The fabrication of the antenna was carried using the antenna substrate with dielectric constant of 4.1 and height 1.5 mm with microstrip line feed impedance of 50 ohms and ports of width 2.18mm. The testing of the fabricated design was done on vector network analyzer Rohde & Schwartz ZVB20 and calibrated using SOLT method. The photograph of the fabricated antenna is shown in Figure 7 along with the compared measured and simulated results in Figure 8 with the VNA screen output of measured results. We can see that there is a small difference in the two result which may be due to some measurement error or defects in hardware implementation.

V. 2X2 MIMO SYSTEM DESIGN

The two antenna system is fabricated as one system with a single port as discussed above, now the same antenna is fabricated again and the two antennas are kept separated with each other by a distance greater than the field distance taken to be 100 mm here and for this two port system S_{21} is measured. The design of the system having two ports is as shown in Figure 9 showing software design and practical design arrangement .The two antennas were first separated in the CST software environment and then in an actual scenario. Thus, we get two S parameters result for the software simulation and actual measurements respectively.

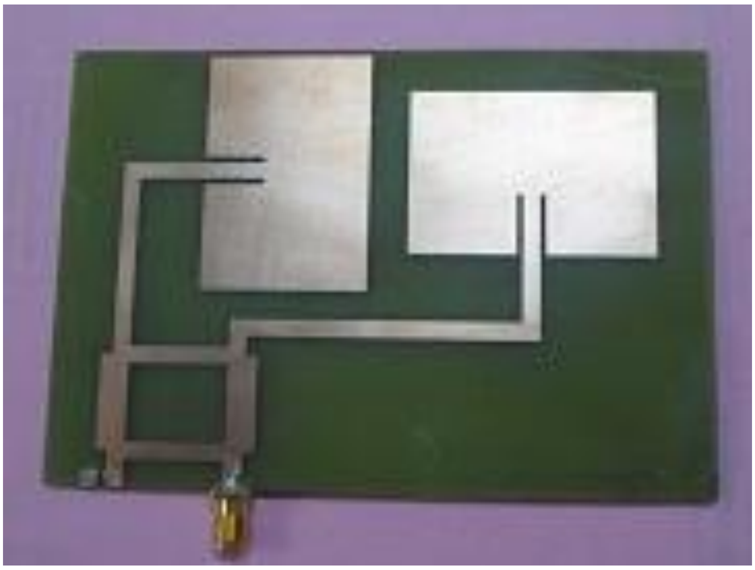
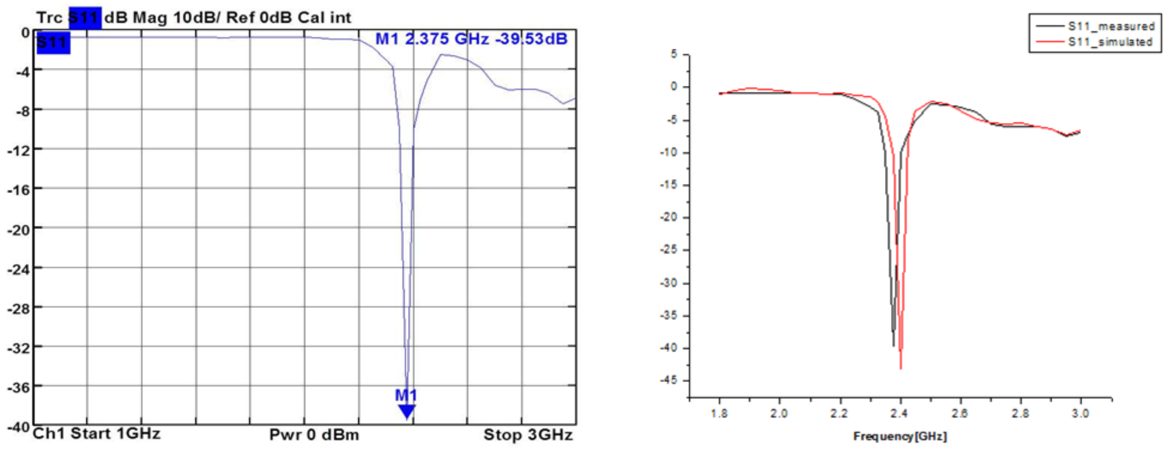


Figure 7. Photograph of fabricated antenna

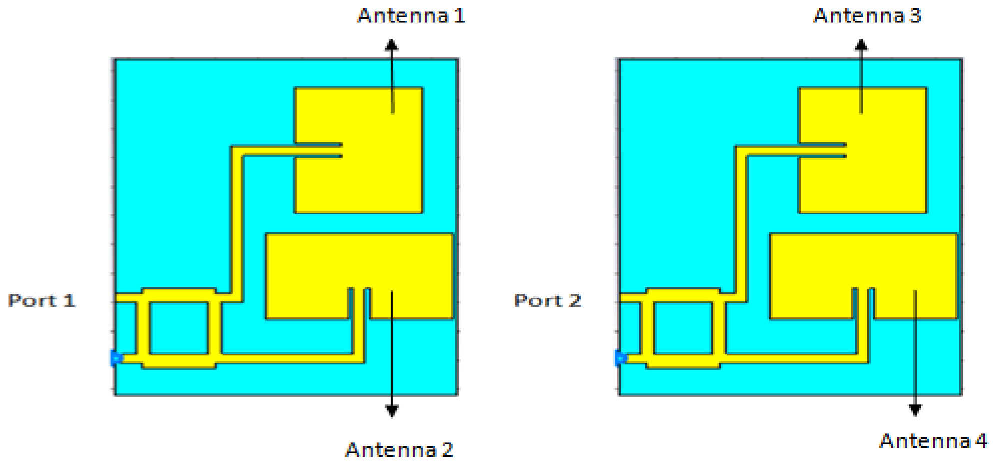


(a) **(b)**

Figure 8. (a) VNA Screen Output (b) Compared measured and simulated results

which are shown compared in Figure 10. In the MIMO system of Figure 9 having four antennas number from 1-4. The channel matrix for the system will be given by (3) where V_{31}, V_{32}, V_{41} and V_{42} denote the ratio of voltages between antennas 3 and 1, 3 and 2, 4 and 1 and 4 and 2 respectively. Now, from the simulated S-parameter results of the coupler we know the ratio of voltages between different ports of the coupler, and from the simulated result of the 2 port MIMO system as in Figure 10 we know the ratio of voltages at port 1 and port 2 of the MIMO system of Figure 9. Using, these two ratios we can calculate V_{31}, V_{32}, V_{41} and V_{42} respectively thus we can obtain the channel matrix of the 2x2 system from (3).

$$H = \begin{matrix} V31 & V32 \\ V41 & V42 \end{matrix} \qquad (3)$$



(a)

(b)

Figure 9. 2 port MIMO system (a) Software design (b) Practical Design

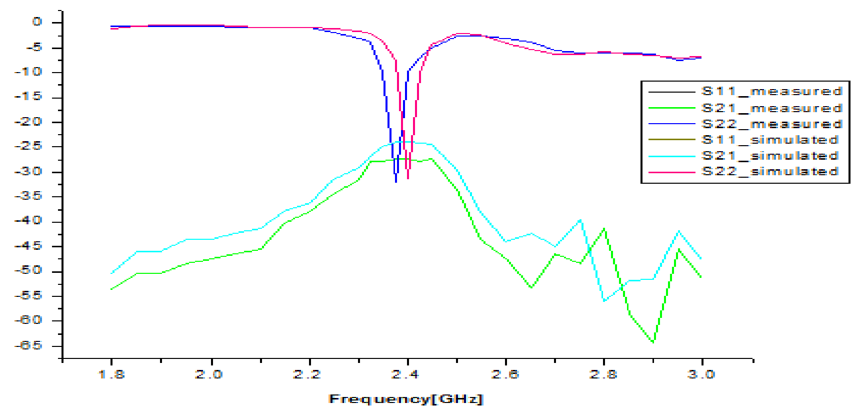


Figure 10. Comparison results for simulated and measured for 2X2 MIMO System

VI. MIMO-DSSS SYSTEM

DSSS is a technique where a signal is spread in a wider bandwidth using a spreading code. Here, the digital signal stream is combined with the spreading sequence bit stream using exclusive-OR. We incorporate coherent binary phase shift keying into the transmitter and receiver sections. The block diagram is as shown in Figure 11.We first generate random bits which are input to the system, then the incoming data stream is converted to a polar NRZ waveform b(t) as shown in Figure 12 as the original bit sequence. The bit interval Tb for the bit sequence is taken to be 18 ns. Now, this data sequence is followed by two stages of modulation. The first one is where this data sequence is multiplied with a spreading code that is the pseudorandom bit sequence c(t) as shown in Figure 12. The chip rate for this sequence Tc is taken to be 1ns. The multiplied output sequence b(t)*c(t) is as shown in Figure 12. This output sequence is then subjected to binary PSK modulator. The frequency of carrier used for BPSK modulation is 2.4 GHz. The transmitted signal is direct sequence spread binary phase shift keyed (DS-BPSK) signal as shown in Figure 12. The signal is then de-multiplexed into two separate streams and each stream is transmitted from an independent antenna. The channel matrix obtained from CST for a 2X2 system as obtained in previous section is used in coding the output from the 2X2 system with random noise added. This output is then followed by a BPSK demodulator using the same carrier as in the transmitting side and after this the sequence is multiplied by the pseudorandom code which is also the same as used at the transmitting side. The integration is carried out for the bit interval $0 \leq t \leq Tb$ providing a sample value and finally a decision is made at the receiver by doing a threshold detection. The output bits are compared to the input bits to evaluate the bit error rate (BER) at different signal to noise ratio. The channel matrix of the 2X2 system is taken both for software simulation and practical measurement and we get two plots for BER versus signal to noise ratio as shown in Figure 13. We can see that as the signal to noise ratio increase BER decreases and also for the measured system the BER is more as compared to the simulated one.

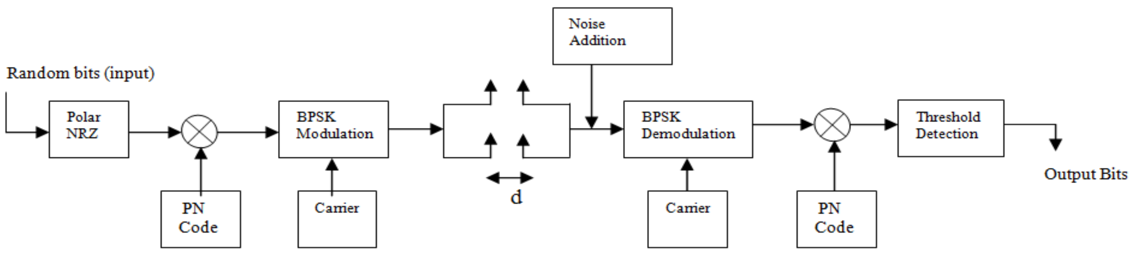


Figure 11. Block diagram for MIMO-DSSS system

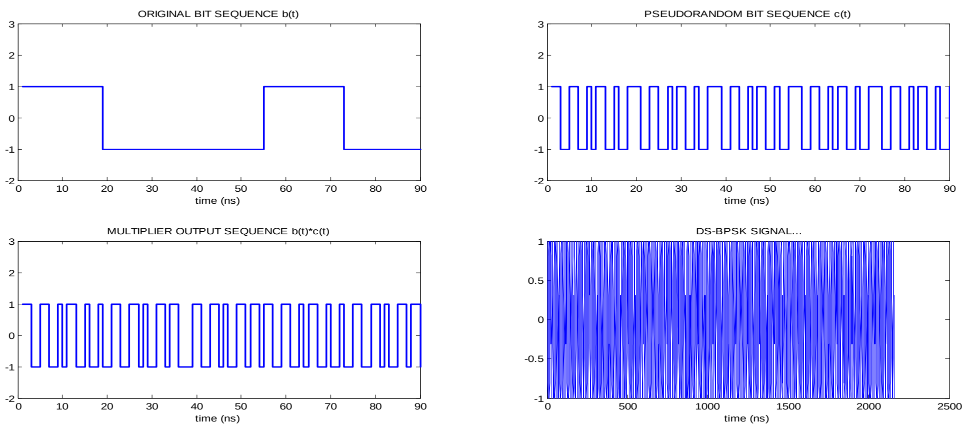
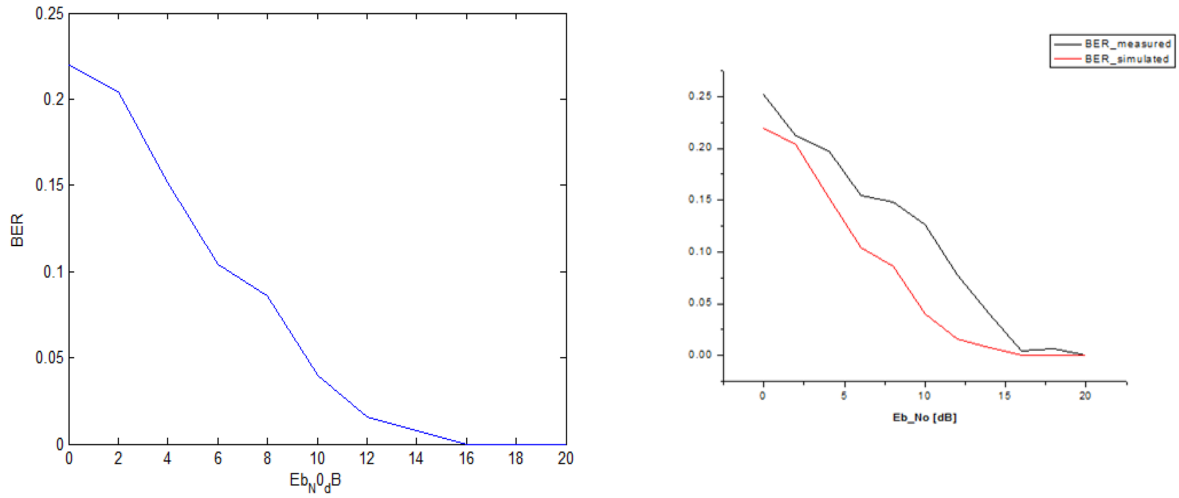


Figure 12. Waveforms for the digital communication system



(a) **(b)**

Figure 13. BER vs SNR (dB) (a) Simulated result (b) Compared result

VII. CONCLUSION

A new methodology has been defined to estimate the performance analysis of a 2X2 MIMO-DSSS system operating on 2.4 GHz ISM band frequency using practical antennas designed on CST Microwave studio, the two antennas in the array are working independently of each other and are fed with equally with same phase signals. The channel matrix from CST has been used for further coding DSSS-MIMO system instead of using a random channel matrix. The BER versus SNR curves are shown for the system, as expected the bit error rate decrease by increasing signal to noise ratio and also it can be seen that the measured BER values are coming higher than the simulated one. The system can be used for IEEE 802.11n Wi-Fi family of standards that uses 2.4 GHz ISM band frequency along with MIMO system using DSSS modulation technique.

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