Design and Comparison Analysis of Multiple Antenna Systems for 2.4 GHz ISM Band Frequency using Microstrip Antennas

Harshal Nigam
Electronics Engineering Department
University College of Engineering
Rajasthan Technical University, Kota, India

Mithilesh Kumar
Electronics Engineering Department
University College of Engineering
Rajasthan Technical University, Kota, India

ABSTRACT
In, this paper, compact antenna have been designed and implemented in a SISO system and multiple antenna systems including 1X2 SIMO, 2X1 MISO and 2X2 MIMO systems respectively. 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. The antennas are designed on CST Microwave studio simulation software with return loss less than -10dB, the MIMO system is designed using polarization diversity of the individual antennas which yields better result in terms of return loss (S_{11} and S_{22}) and mutual coupling (S_{12} and S_{21}).Furthermore, a capacity analysis of the above systems is done on MATLAB software. Multiple-Input Multiple-Output (MIMO) systems offer highest capacity to wireless systems compared to the others. The system is designed for an operation frequency of 2.4 GHz with MIMO system that offers an increased data rate.

Keywords
Double-sided Printed, Industrial Scientific and Medical (ISM), Multiple Input Multiple Output (MIMO), Multiple Input Single Output (MISO), Single Input Multiple Output (SIMO), Single Input Single Output (SISO)

1. INTRODUCTION
Multiple input multiple output (MIMO) systems were described in the mid-to-late 1990s by Gerard Foschini and others, [1] the diversity and signal processing employed with MIMO transforms a point-to-point single channel into multiple parallel or matrix channels, hence multiplying the capacity. A traditional communications link, which we call a single-input-single-output (SISO) channel, has one transmitter and one receiver, but instead of a single transmitter and a single receiver we can use several of each. The SISO channel then becomes a multiple-input-multiple-output, or a MIMO channel. Multi channel types include: SIMO: Single-Input Multiple-Output is a degenerate case when the transmitter has a single antenna. MISO: Multiple-Input Single-Output is a degenerate case when the receiver has a single antenna MIMO: Multiple-Input Multiple-Output is a case in which both the ends have multiple numbers of antennas. Fig 1 shows the details of each of the above systems as in [2]. The industrial, scientific and medical (ISM) are reserved internationally for the use of radio frequency (RF), the 2.4 GHz ISM band is used for many applications like for Wi-Fi family of standards (802.11 a,b,g,n..), cordless phones, wireless medical telemetry equipments and Bluetooth short range wireless applications [3]

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 incorporating the polarization diversity of the two antennas to minimize the correlation between the multiple signals as in [4], efforts [5–8] have been contributed to the reduction of mutual coupling between antennas, to achieve compactness in MIMO systems, the use of pattern diversity as in [9,10], multimode diversity as in [11], and polarization diversity techniques as in [12] in conjunction with space diversity are discussed in the literature. The orthogonality of two distinct polarizations constructs independent and uncorrelated signals on each antenna and thus leads to potentially a full-rank MIMO channel and a full rank MIMO channel which obviously gives improved channel capacity. Further, we have designed 2X1 MISO and 1X2 SIMO systems using these antennas.

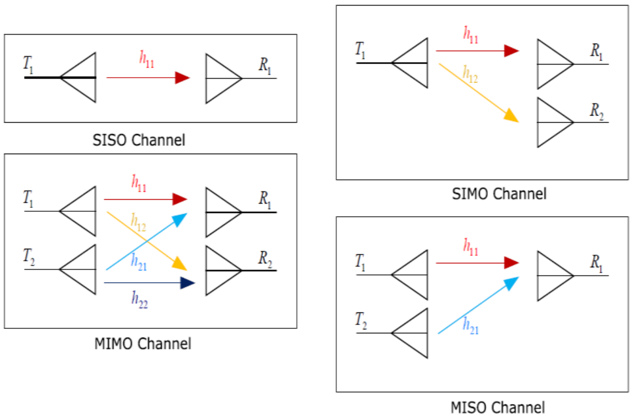


Fig 1: Multi channel types

These systems are simulated on CST Microwave studio and finally a capacity comparison of all these systems is done. This paper is organized as follows. In Section 2, the design methodology and structure of a basic single antenna is described along with the simulation results. Section 3 incorporates the use of above antenna to design a simple SISO system along with simulation results. Section 4 shows the design of MIMO array which is further analyzed for different parameters. In Section 5 the above antennas are used in a 2X2 MIMO system, polarization diversity is applied to the above MIMO antennas and simulated results are analyzed further. In Section 6, 2X1 MISO and 1X2 SIMO systems are designed using the basic antenna. Section 7 shows the capacity analysis of the above designed systems on MATLAB software using the results from CST and finally section 8 concludes the analysis of the paper.

2. BASIC ANTENNA DESIGN ANALYSIS

The antenna is designed on a substrate printed on both sides. The top and bottom patches printed on the substrate are the radiating structure and the ground plane, on one side is the patch and other side is a ground plane. The geometry of the given antenna is illustrated in Fig 2. It is fabricated on a 76.8 X 57.8 mm^2 FR-4 substrate with a dielectric constant of 4.3 and a substrate thickness of 1.6 mm. The back view is shown in Fig 3.The top patch of the substrate has dimension of 39.4 X 28.9 mm^2 which is fed by a strip line having a width of 3.1 mm. The bottom patch of substrate is just a ground plane. The proposed antenna has been simulated by CST Microwave studio. The simulation results of the antenna are shown in Fig 4, from the simulated graph it is observed that for frequency of 2.4 GHz, S_{11}<-10dB showing good matching conditions.

3. SISO SYSTEM DESIGN ANALYSIS

The above antenna will be used for the design of Single Input Single Output (SISO) system having the same single antenna on transmitting and receiving sides. Here, the system design is easy, there is no problem of mutual coupling as in MIMO system so no diversity techniques are used here. As seen in the Fig 5 the two port SISO system having single antenna on both the sides with a separation of 50 mm between both the antennas which is greater than the far field distance The simulation curves for the two port system are shown combined as S_{11}, S_{22}, S_{21} and S_{12} in Fig 6, from the curves it can be seen that both the transmitting and receiving ends are working on the 2.4 GHz ISM band frequency (by observing S_{11} and S_{22}). The channel matrix for the system can be calculated by observing S_{21} from the plots, at a frequency of 2.4 GHz, this will be the coefficient of the channel matrix, as it simply denotes the ratio of received and transmitted voltages, which is the channel matrix coefficient as given by (1)

$$H = S21 \tag{1}$$

This is the channel matrix for SISO system which will be further used for capacity calculation.

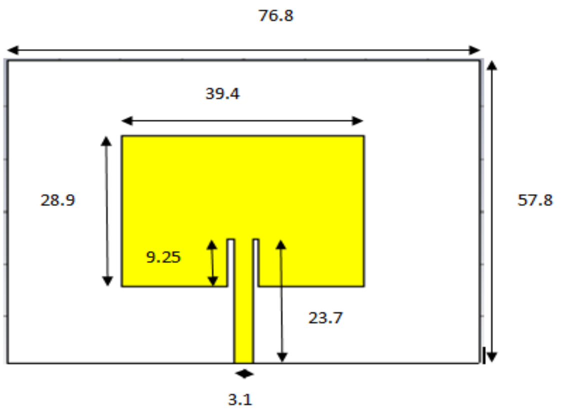


Fig 2: Antenna geometry with dimensions in mm (front view)

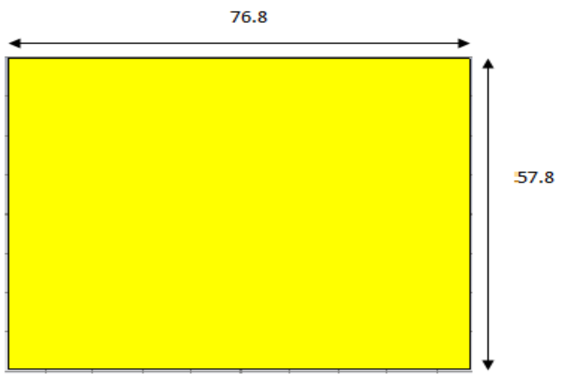


Fig 3: Antenna geometry with dimensions in mm (back view)

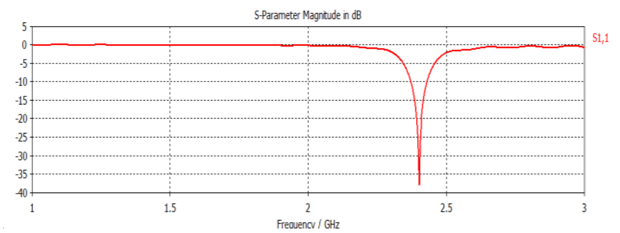


Fig 4: Return loss for the antenna

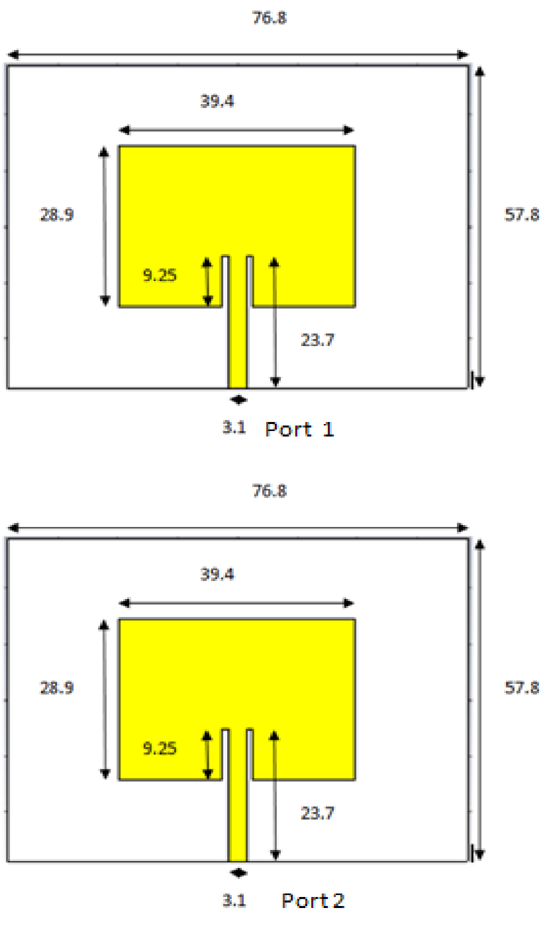


Fig 5: Two port SISO system

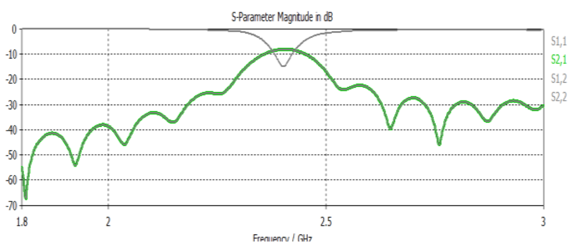


Fig 6: Simulated result for two port SISO system

4. MIMO ARRAY DESIGN AND ANALYSIS

The MIMO array is designed using polarization diversity of the individual antennas, to achieve orthogonal polarization one antenna is rotated to 90^0 with respect to its adjacent element as shown in the Fig 7.The separation between the antennas is 5.75 mm which is 0.046 λ which is also very less leading to a compact array. The antennas in the array have the same dimensions as mentioned in Section 2. The antennas are mounted on a substrate symmetrically with εr = 4.3, which in turn is mounted on a ground plane. The above two port system is simulated on CST Microwave Studio simulation software.

The simulation plots for the array are shown in Fig 8. We can observe that S_{11}<-10 dB for the 2.4 GHz ISM band frequency and also S_{22}<-10 dB for this frequency. Thus, both antennas are meeting the specified requirement of return loss also we can see the S_{12} and S_{21} plots for the two port system, we can observe that both S_{12} and S_{21}<-15 dB for the 2.4 GHz ISM band frequency, thus the two antennas are nearly independent of each other and value of mutual coupling between the two antennas is very low. We also calculate the correlation coefficient and diversity gain for the two antenna array.

Correlation coefficient formula using S parameters is given as in (2)

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

It comes out to be 0.000027. This is good because coefficient correlation should be < 0.1 for MIMO antenna. Diversity gain is the increase in signal to noise ratio due to the diversity scheme which is given by the formula in (3)

$$DG = 10 * \sqrt{1 - (0.99 * \rho)^2} \quad (3)$$

It comes out to be 9.9 dB, which shows an acceptable gain in terms of diversity.

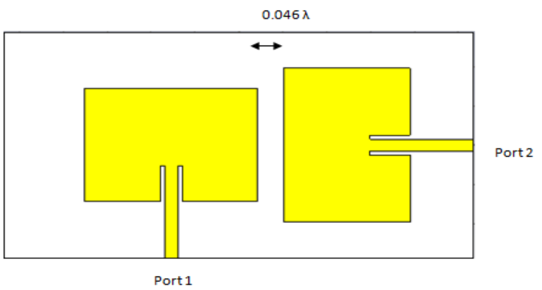
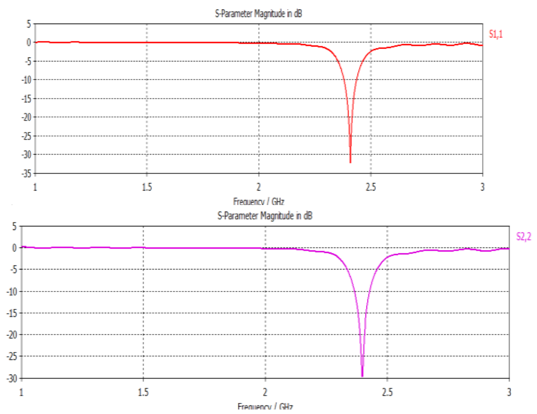


Fig 7: MIMO array of two antennas



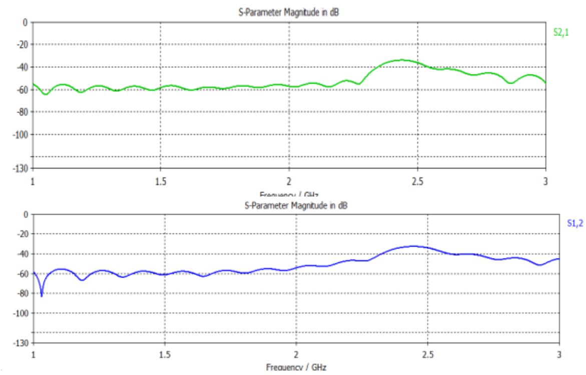


Fig 8: Simulated results for 2 port MIMO array

5. DESIGN OF 2x2 MIMO SYSTEM

We have designed the MIMO array, now for the 2X2 MIMO system this array will be used both on transmitting and receiving end forming a communication system, we can see antennas with ports numbered 1 and 2 for transmitting side and ports 3 and 4 for the receiving side as in Fig 9. The distance between transmitting and receiving sides is taken to be 50 mm which is greater than the far field distance of the antennas, this is the same distance that we used for SISO system design. The four port system is simulated on CST Microwave Studio and the channel matrix for the system can be calculated by observing $S_{31,}$ $S_{32,}$ S_{41} S_{42} from the simulation plot of the four port system as in Fig 10, at a frequency of 2.4 GHz, these will be the coefficients of the channel matrix, as the S parameters simply denote the ratio of received and transmitted voltages, these ratios denote channel matrix coefficient.

The channel matrix for the 2X2 system as in (4)

$$H = \begin{matrix} S31 & S32 \\ S41 & S42 \end{matrix} \quad (4)$$

This channel matrix will be further used for capacity analysis of this system.

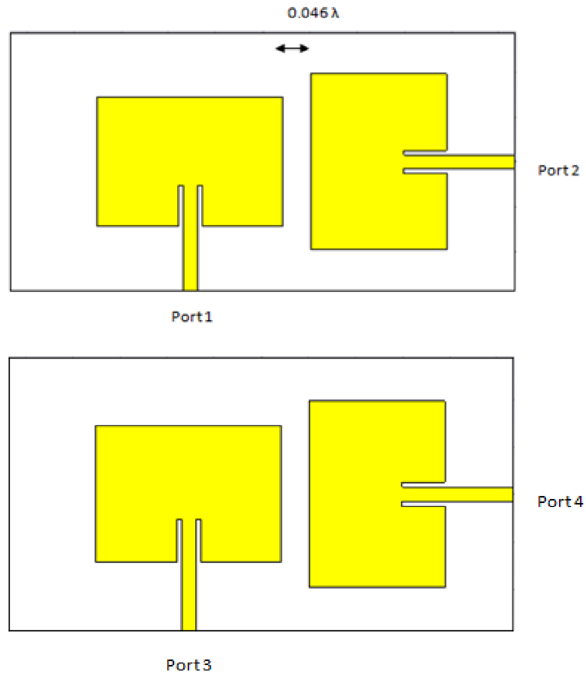


Fig 9: 2X2 MIMO system with four ports

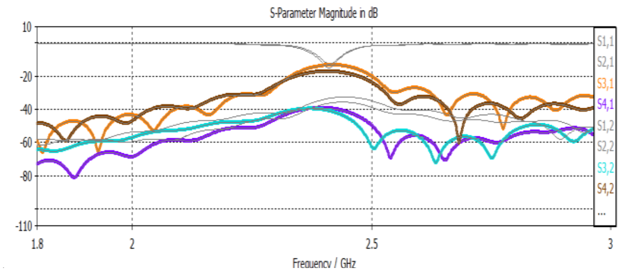


Fig 10: Simulation result for the 2X2 MIMO system

6. SIMO AND MISO SYSTEM DESIGN

In, the previous sections we have designed the SISO and MIMO systems. SIMO systems have single antenna on the transmitting end and two antennas on the receiving end, respectively. Similarly, MISO systems have two antennas on the transmitting end and single antenna on the receiving end, respectively, to implement these two systems, the single antenna is placed facing the center point of the distance between the two antennas on other side, means it is kept at equal distances from the two antennas facing it. These, three port systems are simulated on CST microwave studio. Considering, the MISO case first, we can see the design of the system as in Fig 11 with ports numbered 1 and 2 for the transmitting end and port 3 for the receiving end respectively. The distance between the two antenna systems is kept same as taken in previous sections. The simulated S parameter results for this system is as shown in Fig 12, we can observe that antennas in the array are working independently of each other by observing S_{11} and S_{22} and also that receiving end is also working on same frequency as transmitting side. The channel matrix of the system can be obtained as in (5).

$$H = \begin{bmatrix} S31 & S32 \end{bmatrix} \quad (5)$$

This matrix will be used for further analysis of the system.

In the same way, SIMO system is also designed having single antenna on transmitting end and multiple antennas on receiving end. The 3 port system is shown in Fig 13 with the same distance between the two ends as taken previously. The simulated results are as shown in Fig 14. The channel matrix for the system is as in (6)

$$H = \begin{bmatrix} S31 \\ S41 \end{bmatrix} \quad (6)$$

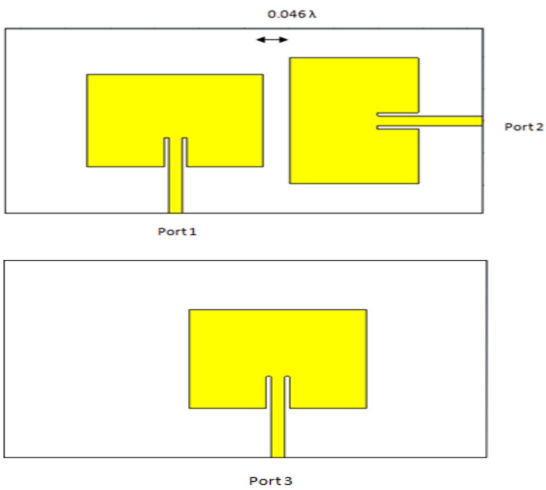


Fig 11: Three port MISO system

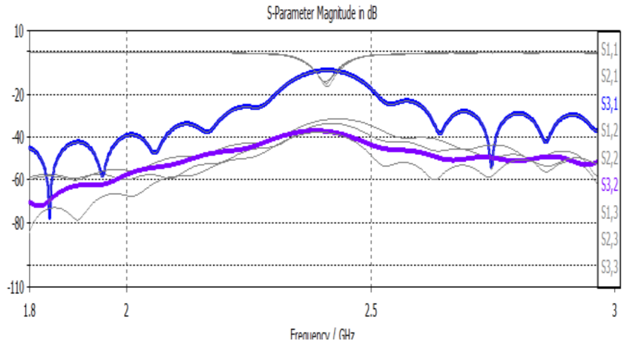


Fig 12: Simulated result for MISO system

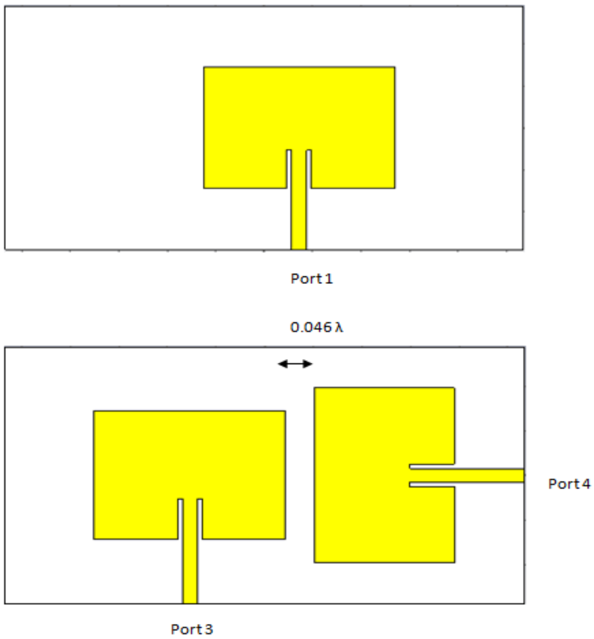


Fig 13: Three port SIMO system

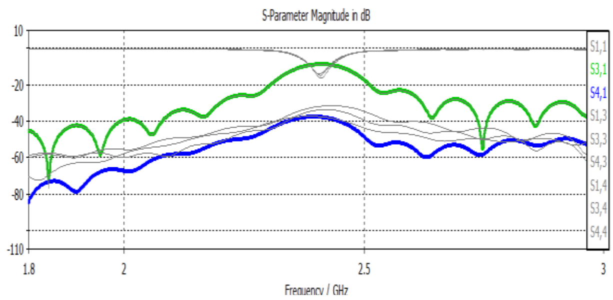


Fig 14: Simulated result for SIMO system

7. CAPACITY ANALYSIS OF ABOVE SYSTEMS

Channel capacity is the maximum information rate that can be transmitted and received with arbitrarily low probability of error at the receiver. It can be expressed in bps/Hz for a unit bandwidth. Compared to a conventional single antenna system, the channel capacity of a multiple antenna system with NT transmit and NR receive antennas can be increased by the factor of min (NT, NR) without using additional transmit power or spectral bandwidth. In this section we will compare the capacity of above systems using the channel matrix for each.

7.1 Capacity of SISO System

According to Shannon capacity of wireless channels, given a single channel corrupted by an additive white Gaussian noise at a level of SNR, the capacity is given as data rate per channel use as in (7)

$$C = \log 2(1 + SNR) \quad \text{bps/Hz} \tag{7}$$

where C is the Shannon limits on channel capacity, SNR is signal-to-noise ratio, in the practical case the capacity is given as in (8)

$$C = log2(1 + SNR\ IHI^2) \tag{8}$$

where H is the 1x1 channel matrix which we will be using from our design of SISO system as in section 3.

7.2 Capacity of SIMO and MISO Systems

For the SIMO system, we have N antennas at receiver and only one at transmitter. The same amplitude signals are added coherently and noise is added incoherently to produce an overall increase in SNR compared to SISO case. The capacity is given as in (9)

$$C = log2 \det\ [I + SNR * H'H] \tag{9}$$

Where I is the identity matrix of order n given by min (M, N), here M=1 which is the number of transmitting antennas and N=2 that is the number of receiving antennas and H is the channel matrix for the SIMO system.

For the MISO system, we have M antennas at transmitter and only one at receiver. The capacity in this case is given as in (10)

$$C = log2 \det \left[I + \frac{SNR}{M} HH'\right] \tag{10}$$

Where H is the channel matrix for the MISO system as designed above and other parameters remaining same as above with M=2 and N=1.

7.3 Capacity of MIMO System

For the MIMO system, we have M antennas at transmitter and N antennas at receiver. The signals received on multiple antennas at the receiver are added coherently also there is an incoherent addition of noise so there is increase in signal to noise ratio which is greater than the SIMO and MISO case. For a MIMO system the capacity is given as in (11)

$$C = log2 \det \left[I + \frac{SNR}{M} H'H\right] \tag{11}$$

where H is the combined channel matrix for the 2X2 system as obtained from section 4. With other parameters remaining the same as above cases with M=2 and N=2.Thus, we calculate the channel capacity for both cases as shown in Fig 15.

7.4 Capacity Enhancement

We can see from Fig 15 that there is a capacity enhancement of the MIMO system over the other three systems, this is because MIMO system creates different paths and so number of bits sent per second will be increased and also it can be seen that as number of receiving antennas increase capacity increase as the capacity of SIMO system is more than that for MISO case.

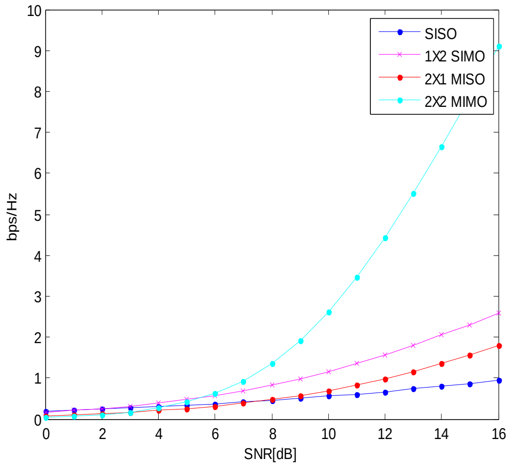


Fig 15: Capacity comparison of above systems

8. CONCLUSION

A new methodology has been defined by designing practical systems and a capacity enhancement of the 2X2 MIMO system over the other system is shown along with the design considerations. The system is operating on 2.4 GHz ISM band frequency using practical antennas designed on CST Microwave studio. We have analyzed the MIMO array and found that the antennas in the MIMO system are operating independently of each other which is a necessary requirement for MIMO system design. The performance analysis of the different multiple antenna systems along with SISO systems is done by using the channel matrix from CST instead of using a random channel matrix. We can see that Multiple-Input Multiple-Output (MIMO) systems offer high capacity to wireless systems and the capacity increases as long as the number of receiving antennas is greater than or equal to the number of transmitting antennas. MIMO systems offer an increased capacity but this requires a complex design and problems associated with mutual coupling need to be taken care of otherwise they create huge interference, also the cost for designing the system is high.

9. REFERENCES

[1] G. Foschini, M. Ganns**.** 1998. On limits of wireless communications in a fading environment when using multiple antennas,Wireless Personal Comminications pp. 311-335.

[2] G.J.Foschini.1996. Layered space-time architecture for wireless communication in a fading environment when using multi element antennas. BLTJ, Autumn

[3] International Telecommunication Union. 19 October 2009. 1.15. industrial, scientific and medical (ISM) applications (of radio frequency energy): Operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications.

[4] Emami-Forooshani,S. Noghanian. 2010. Semi-deterministic channel model for MIMO systems Part-II: results. IET microwaves, antennas & propagation, Vol.4 pp 26-34.

[5] Ganatsos,T.,K. Siakavara, and J. N. Sahalos. 2007 Neural network based design of EBG surfaces for effective polarization diversity of wireless communications antenna systems. PIERS Online, Vol. 3, No. 8, 1165–1169.

[6] Ren,W. 2008. Compact dual-band slot antenna for 2.4/5 GHz WLAN applications. Progress In Electromagnetics Research B, Vol. 8,319–327.

[7] Khaleghi,A. 2006. Diversity techniques with parallel dipole antennas: radiation pattern analysis. Progress In Electromagnetics Research PIER 64,23–42.

[8] Tu,T.-C.,C.-M. Li,and C.-C. Chiu, 2005. The performance of polarization diversity schemes in outdoor micro cells. Progress In Electromagnetics Research, PIER 55,175–188.

[9] Matilde Sanchez-Fernandez, Eva Rajo-Iglesias, Oscar Quevedo-Teruel, M. Luz Pablo-Gonzalez. 2008 Spectral Efficiency in MIMO Systems Using Space and Pattern Diversities Under Compactness Constraints. IEEE T 1637-1645.

[10] Mukherjee and Hyuck M. Kwon. 2007. Compact Multi-user Wideband MIMO System Using Multiple-Mode Microstrip Antennas. Proceedings of Vehicular Technology Conference Spring 2007. pp 584-588.

[11] Waldschmidt, C. Kuhnert, S. Schulteis, and W. Wiesbeck,. 2003. Compact MIMO-Arrays Based on Polarization-Diversity. Proceedings of IEEE Antennas and Propagation. Symp. Vol.2, pp. 499-502.

[12] M. A. Jensen, J. W. Wallace. 2004. A review of antennas and propagation for MIMO wireless communications. IEEE Trans. Antennas Propagation., Vol. 52, pp. 2810-2824.