Collocated Microstrip Antenna Design
Project Report

Course: EE799 : Advanced Antennas

Prof. Jayanta Mukherjee

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Group Number - 3
Group Members:
Avi Yadav 20D070018
Pullabhotla Bhuvana Chandra 200070063
Harshwardhan Kiran Waghchoure 20d070036
Mitali Singal 19d070036
Muskaan Manish Chandra 19d070038
Sarthak Mittal 20D070066
Pavan bodke 200070014
Abhinav ghunawat 200070002
Pratham kapure 200070032
Samriddhi mishra 20D070068

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1 Schematic of the antenna

The following are the specifications of the designed collocated microstrip antenna with the parameter notations as given the research paper [1]

Parameter	Description	Value
ϵ_r	substrate relative permittivity	4.6
W_1	Microstrip square ring outer sidelength	37mm
W_2	Microstrip square ring inner sidelength	24.5mm
W_3	Microstrip square patch sidelength	15mm
W_4	Distance between reference holes on square ring	28mm
Θ_{vias}	Diameter of vias	0.7mm
I_{vias}	Distance between consecutive vias	2mm
d_1	Distance from port3, port4 to its nearest hole reference	4.5mm
d_2	Distance from origin to port1,port2	2.7mm
S	Distance between parallel sides of slots in microstrip square patch	2.5mm
I_m	Length of slot in microstrip square patch	5mm
w_m	Width of slot in microstrip square patch	1mm

Table 1: Specifications of designed collocated antenna

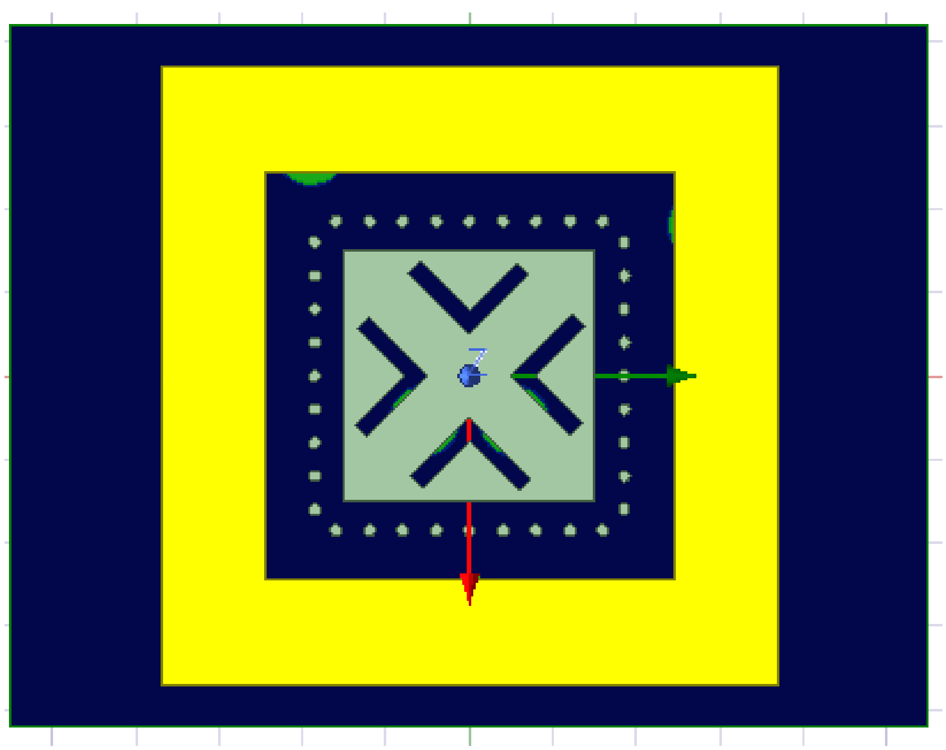

Figure 1: Antenna Schematic Top view

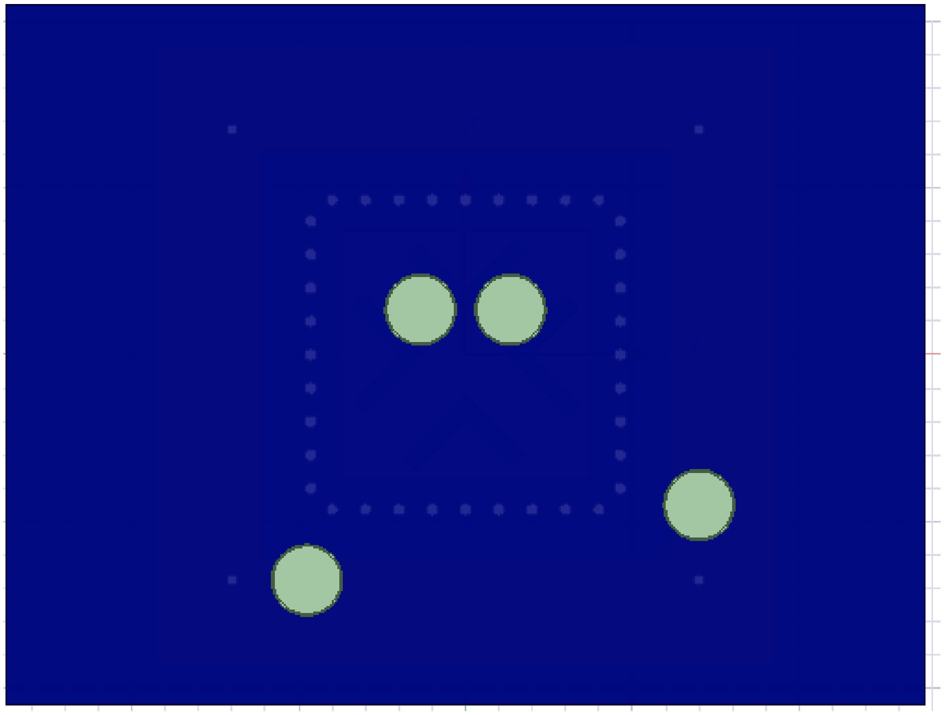

Figure 2: Antenna Schematic Bottom view

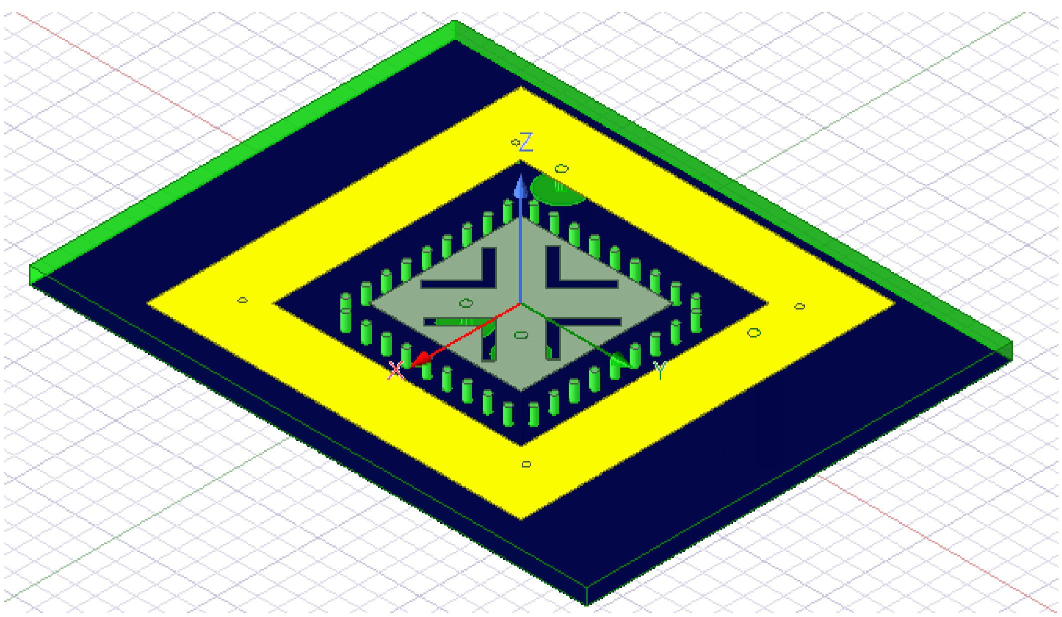

Figure 3: Antenna Schematic Isometric view

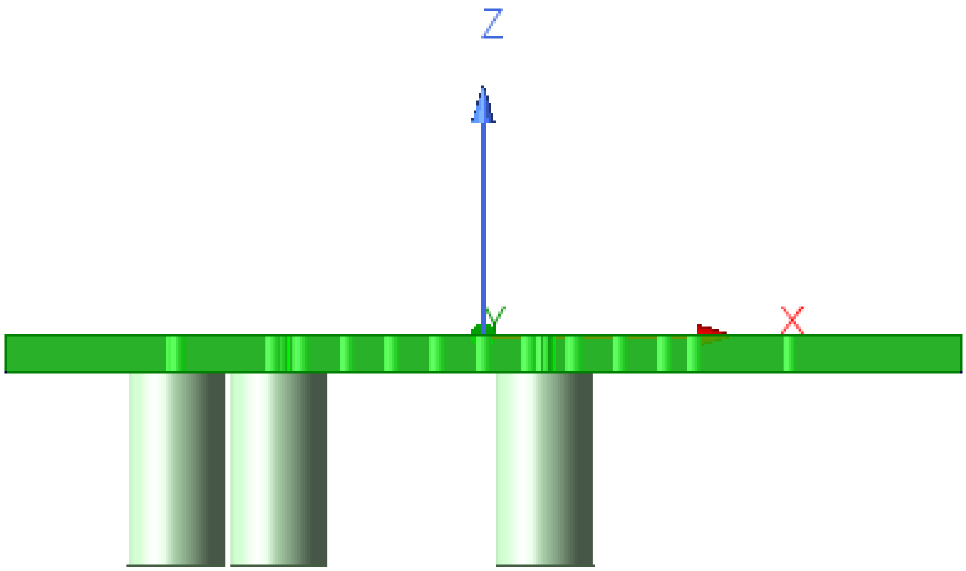

Figure 4: Antenna Schematic Side view along Y-axis

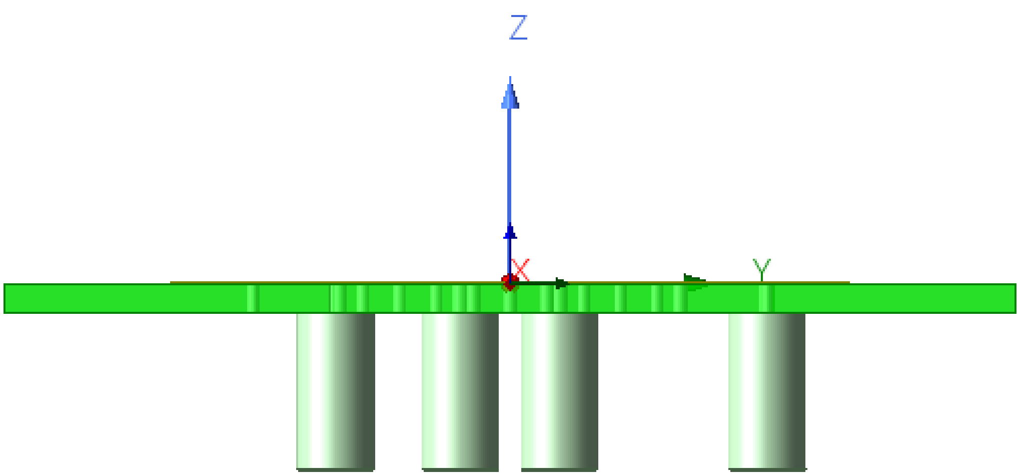

Figure 5: Antenna Schematic Side view along X-axis

2 HFSS Simulation Results

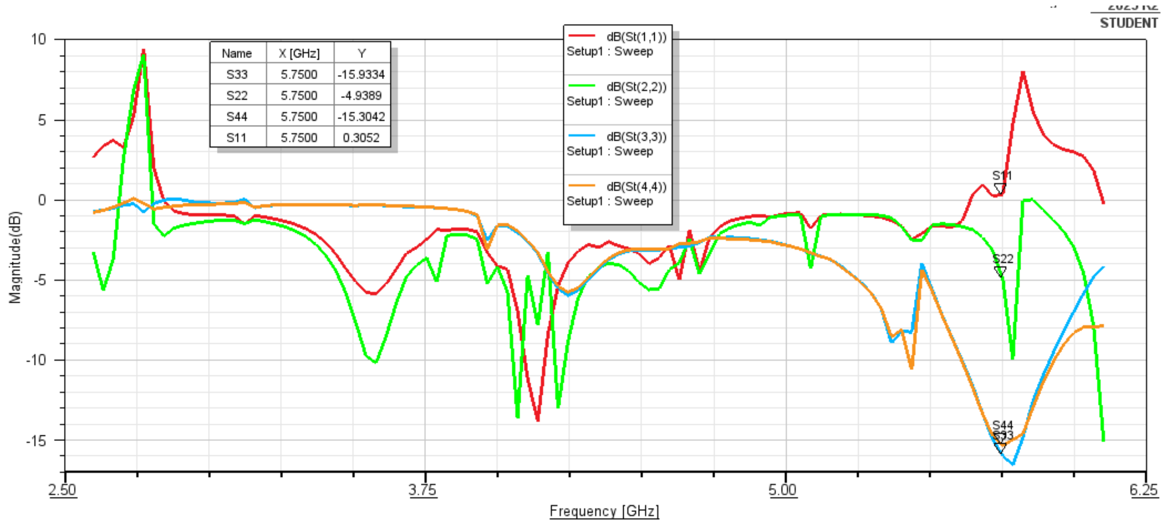

Figure 6: Plot of S11,S22,S33,S44 magnitude in dB

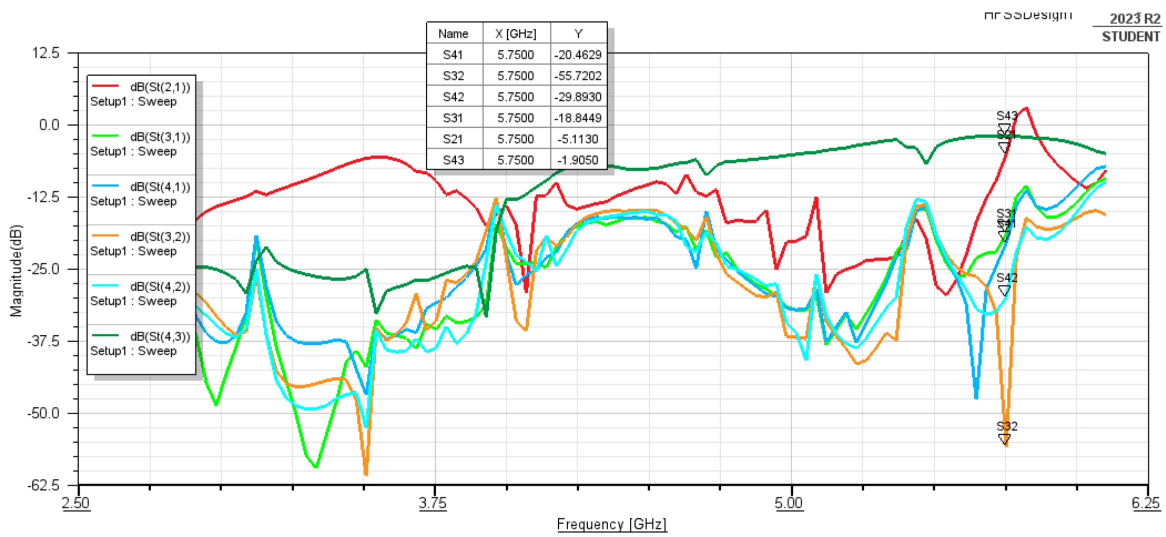

Figure 7: Plot of S21,S31,S41,S32,S43,S42 magnitude in dB

3 Fabricated Antenna design results

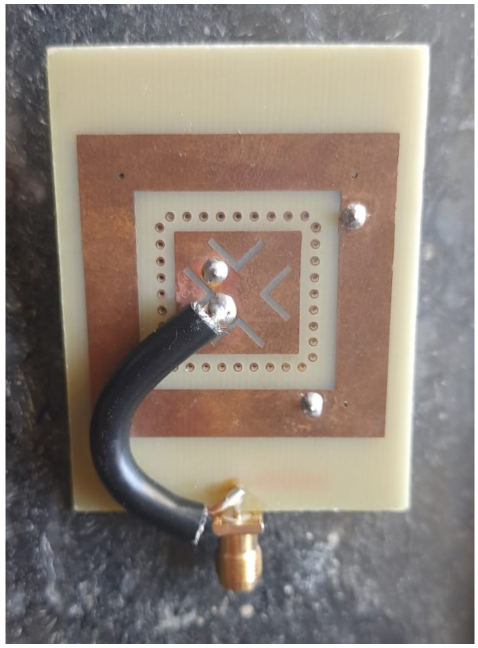

Figure 8: Top view of fabricated antenna

Figure 9: Bottom view of fabricated antenna

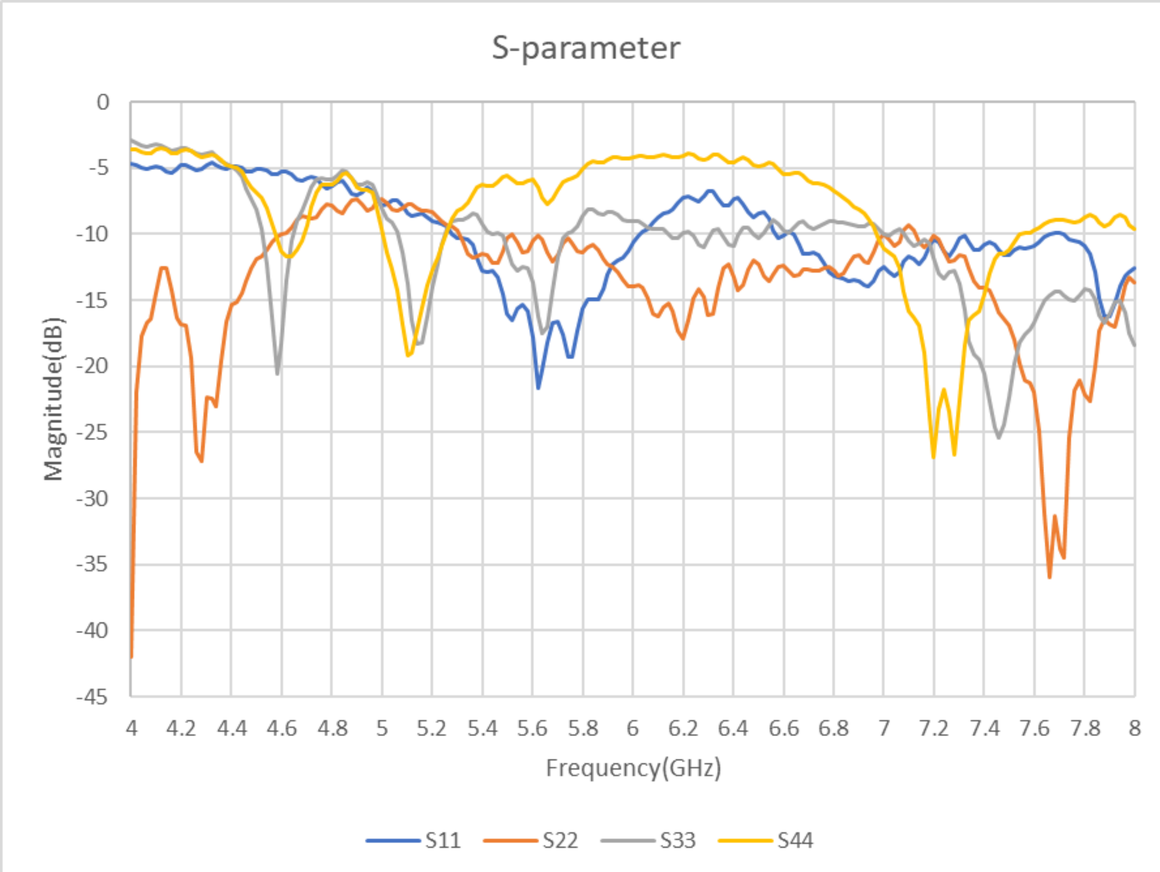

Figure 10: Plot of S11,S22,S33,S44 magnitude in dB

Below are the magnitude(dB) values at 5.75GHz frequency

Parameter	Value(dB)
S11	-19.2
S22	-10.5
S33	-10.2
S44	-5.8

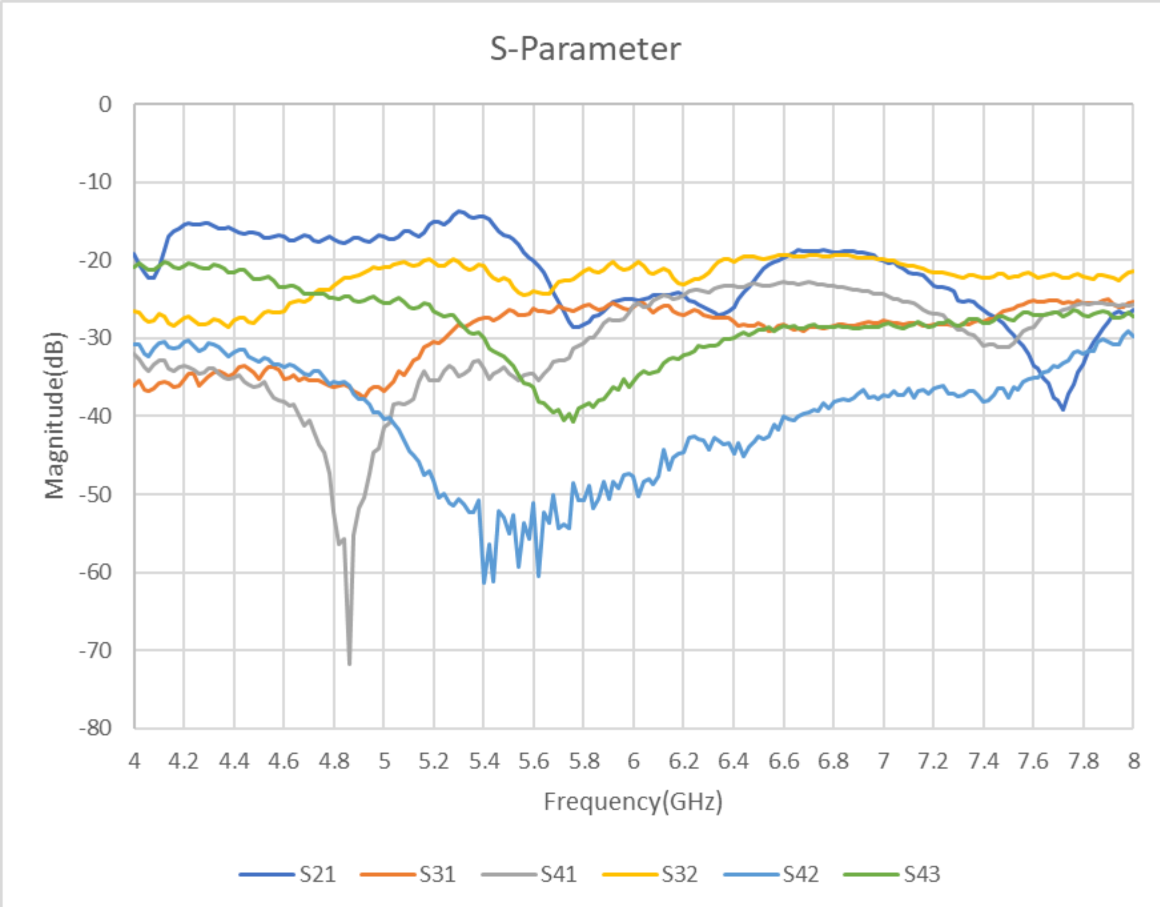

Figure 11: Plot of S21,S31,S41,S32,S43,S42 magnitude in dB

Below are the magnitude(dB) values at 5.75GHz frequency

Parameter	Value(dB)
S21	-28.5
S31	-26.46
S41	-31.3346
S32	-22.506
S42	-48.5839
S43	-40.7612

4 Channel Capacity calculations

Assuming the antenna array is lossless, we can calculate the channel matrix from S-parameters as follows

$$R = I - S^H S$$

where R is the correlation matrix and S is the S-parameter Matrix

Assuming Rayleigh fading, we can get the channel matrix from the correlation matrix by multiplying the square root of the correlation matrix with a complex Gaussian random variable matrix G of zero-mean and unit-variance

$$H = R^{1/2}G$$

The above formulas are derived from [2]. We can calculate the channel matrix of each pair of antennas by taking a 2x2 Gaussian matrix and for a 4x4 MIMO case, we take 4x4 Gaussian matrix , these matrices are randomly generated in MATLAB, and the matrices we used are

G2 = 2×2 complex

	1	2
1	0.0695 + 0.1643i	-0.5191 - 0.2636i
2	0.0293 + 0.3015i	-0.0218 - 0.1672i

Figure 12: 2x2 Complex Gaussian random variable matrix

G4 = 4×4 complex

	1	2	3	4
1	-0.1359 - 0.6703i	-0.7525 + 0.0088i	-1.0650 - 0.7543i	-0.1847 + 0.1290i
2	-0.1938 - 0.5240i	1.1338 - 2.1420i	-0.3144 + 0.6602i	0.3135 - 1.1067i
3	1.0819 - 0.3591i	0.8730 - 0.3232i	-0.1103 + 0.2477i	0.2771 - 0.0598i
4	-0.1761 - 0.2267i	-0.1624 + 0.8785i	0.1952 - 0.0205i	-0.8844 + 1.1342i

Figure 13: 4x4 Complex Gaussian random variable matrix

Next following are the correlation matrix for each pair of transmitter and receiver where in RXY, X,Y represents the port numbers used as transmitter and receiver

R12 = 2×2 complex

	1	2
1	0.9867 + 0.0000i	-0.0071 - 0.0006i
2	-0.0071 + 0.0006i	0.9139 + 0.0000i

Figure 14: 2x2 correlation matrix between port 1,2

R13 = 2×2 complex		
	1	2
1	0.9859 + 0.0000i	-0.0086 + 0.0064i
2	-0.0086 - 0.0064i	0.8942 + 0.0000i

Figure 15: 2x2 correlation matrix between port 1,3

R14 = 2×2 complex		
	1	2
1	0.9873 + 0.0000i	0.0004 + 0.0122i
2	0.0004 - 0.0122i	0.7389 + 0.0000i

Figure 16: 2x2 correlation matrix between port 1,4

R23 = 2×2 complex		
	1	2
1	0.9097 + 0.0000i	-0.0312 + 0.0290i
2	-0.0312 - 0.0290i	0.8908 + 0.0000i

Figure 17: 2x2 correlation matrix between port 2,3

R24 = 2×2 complex		
	1	2
1	0.9153 + 0.0000i	-0.0019 + 0.0009i
2	-0.0019 - 0.0009i	0.7396 + 0.0000i

Figure 18: 2x2 correlation matrix between port 2,4

R34 = 2×2 complex		
	1	2
1	0.8963 + 0.0000i	0.0021 + 0.0018i
2	0.0021 - 0.0018i	0.7395 + 0.0000i

Figure 19: 2x2 correlation matrix between port 3,4

Following is the 4x4 Correlation matrix for MIMO case

R_MIMO = 4×4 complex

	1	2	3	4
1	0.9837 + 0.0000i	-0.0103 + 0.0010i	-0.0097 + 0.0090i	0.0002 + 0.0120i
2	-0.0103 - 0.0010i	0.9083 + 0.0000i	-0.0325 + 0.0303i	-0.0029 + 0.0003i
3	-0.0097 - 0.0090i	-0.0325 - 0.0303i	0.8885 + 0.0000i	0.0009 + 0.0010i
4	0.0002 - 0.0120i	-0.0029 - 0.0003i	0.0009 - 0.0010i	0.7388 + 0.0000i

Figure 20: 4x4 correlation matrix

Now after calculating correlation matrix, we get channel capacity matrix from the relation that is mentioned above and following are the Channel capacity matrices

H12 = 2×2 complex

	1	2
1	0.0947 + 0.1618i	-0.5299 - 0.2606i
2	0.0143 + 0.2947i	-0.0004 - 0.2047i

Figure 21: 2x2 channel capacity matrix between port1,2

H13 = 2×2 complex

	1	2
1	0.0404 + 0.1758i	-0.4997 - 0.2693i
2	0.0461 + 0.2836i	-0.0634 - 0.1157i

Figure 22: 2x2 channel capacity matrix between port1,3

H14 = 2×2 complex

	1	2
1	0.0482 + 0.1894i	-0.5047 - 0.2769i
2	0.0433 + 0.2668i	-0.0802 - 0.1246i

Figure 23: 2x2 channel capacity matrix between port1,4

H23 = 2×2 complex	1	2
1	0.0106 + 0.1851i	-0.4647 - 0.2682i
2	0.0644 + 0.2836i	-0.1104 - 0.0779i

Figure 24: 2x2 channel capacity matrix between port2,3

H24 = 2×2 complex	1	2
1	0.0533 + 0.1617i	-0.4894 - 0.2549i
2	0.0333 + 0.2579i	-0.0360 - 0.1232i

Figure 25: 2x2 channel capacity matrix between port2,4

H34 = 2×2 complex	1	2
1	0.0617 + 0.1711i	-0.4895 - 0.2583i
2	0.0317 + 0.2662i	-0.0494 - 0.1473i

Figure 26: 2x2 channel capacity matrix between port3,4

Now following is the channel capacity matrix for a MIMO case

H_MIMO = 4×4 complex	1	2	3	4
1	0.0049 - 0.6179i	-0.5318 + 0.2488i	-1.1394 - 0.7647i	-0.2070 + 0.2017i
2	-0.0879 - 0.3149i	1.1603 - 1.8248i	-0.4372 + 0.7417i	0.2801 - 1.0301i
3	0.8222 - 0.3649i	0.4413 - 0.5838i	-0.1170 + 0.4305i	0.0273 - 0.1526i
4	-0.2108 - 0.2562i	-0.2851 + 0.7217i	0.0617 + 0.0345i	-0.8150 + 0.9726i

Figure 27: 4x4 channel capacity matrix for MIMO

After calculating the capacity matrices, we can calculate the channel capacity in each case from the equation

$$C = log_2 \left(\left| I_{N_r} + \frac{\rho_r}{N_t} H H^H \right| \right)$$

where N_t is number of transmitter antennas, N_r is number of receiver antennas, and ρ_r is SNR at the receiver

Now, assuming an SNR of 15dB, which is minimum for a goog communication, we find the channel capacities of each channel pairs and also MIMO channel capacity

Channel	Capacity(bits per tx)
C12	3.7468
C13	3.6336
C14	3.5540
C23	3.4975
C24	3.4398
C34	3.4643
MIMO Channel	12.2454

Table 4: Channel capacity values for different channels

References

[1] J. Sarrazin, Y. Mahe, S. Avrillon, and S. Toutain, "Collocated microstrip antennas for mimo systems with a low mutual coupling using mode confinement," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 2, pp. 589–592, 2010.

[2] N. Honma, K. Murata, H. Sato, K. Ogawa, and Y. Tsunekawa, "Channel capacity evaluation of mimo antenna based on eigenvalues of s-parameter," *IEICE Trans. Commun.*, vol. 99-B, pp. 95–103, 2016.