Design and Performance Analysis of MIMO Patch Antenna Using CST Microwave Studio

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Anil Kumar Sahu
Bharat Institute of Engineering and Technology

Neeraj Kumar Misra
Vellore Institute of Technology (VIT) -AP University, Amaravati, India

Chapter 37
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Anil Kumar Sahu, Neeraj Kumar Misra, K. Mounika, and Prakash Chandra Sharma

Abstract Multiple-inputs and multiple-outputs (MIMO) referring to the fact that it is a wireless technology, which is used to transfer more data at the same time between transmitter and receiver to increase data rate and minimize errors. Basically, this concept is a type of technology for wireless networks that allows access points or wireless routers to have multiple antenna. In this paper, the basic patch antenna using coaxial probe feed and basic patch antenna using a microstrip line feed, which is fed by a microstrip line, were designed by using resonant frequencies of 2.45 GHz which is used for applications like industrial, scientific, and medical (ISM) band. The main objective of this paper to implement 2×2 multiple-input multiple-output (MIMO) system and also to design four mutually orthogonal MIMO patch antennas with a single substrate, which are fed by four microstrip lines using the same resonant frequency of 2.45 GHz which is also applicable to the WLAN. All antenna parameters such as VSWR, insertion loss, return loss, and correlation coefficient are calculated. The characteristics of the proposed antennas are simulated using CST Microwave Studio 2018 software.

37.1 Introduction

The number of wireless handheld devices are increasing tremendously. Antennas have been becoming a useful technology and most used topic in wireless communication systems in the past decades, so it is critical to design broadband and high-gain antennas to cover a wide frequency range, and for that purpose, various developments are discussed in this book. In an incredible number of microwave applications, a highly directive antenna with a fundamental beam checked to a certain angle is used to transmit the electromagnetic waves. Here, antennas are used in both transmitters

A. K. Sahu · N. K. Misra (✉) · K. Mounika
Department of Electronics and Communication Engineering, Bharat Institute of Engineering and Technology, Hyderabad 501510, India

P. C. Sharma
School of Computing and Information Technology, Manipal University, Jaipur, India

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and receivers. It plays a vital and significant role in the field of mobile and wireless communications (medical applications, radars, satellites, ground-penetrating radar, aviation, etc.). Predominately, when we talk about the antenna radiation pattern which are divided into three main categories such as isotropic antenna, omnidirectional antenna, and directional antenna. Each kind of antenna is acceptable in its own properties. Antenna technology is rapidly changing, in fact the demand is increasing significantly. We can say antennas are the pillar and practically everything in the wireless communication without which the word might have not reached at this time of technology [1]. Generally, we design antenna for 50 Ω input impedance. So, the antenna impedance has to be matched using a matching network and that has to be a lossless matching network. Lossless matching networks consist of indicators, capacitors may be transmission lines or coaxial lines, but in general, not resistance. Patch antenna array is desiged, and furthermore investigated their focal points and detriments relying on the outcomes. Antenna parameters, for example, radiation pattern, antenna gain, directivity, and power acquired are considered in this paper. These patch antennas are utilized as basic, and patch antennas are used for the biggest and most requesting applications. Circular polarizations, feed line flexibility, frequency agility, dual frequency operation, broadband width, dual characteristics, and beam scanning can be effectively obtained from these patch antennas. The dielectric resonators (DRs) are studied for low losses and high radiation efficiency [2]. An antenna which comprises of a resonant rectangular parallelepiped dielectric on top of a ground plane is portrayed. A microstrip antenna offers various techniques to enhance bandwidth for wideband applications, and a microstrip patch antenna is one of the most promising antennas these days, because the structure itself is so simple [3].

Multiple-inputs and multiple-outputs (MIMO) antennas acquire a large amount of data transfer which are suitable for 4G and 5G mobile communication systems requiring high quality and speed [4]. For the implementation point of view, it is difficult to fit multiple elements on a handheld terminal, and designing of space between the terminals is also challenging [5, 6].

Below the dielectric material, there is a ground plane on the bottom side and that is shown in the Fig. 37.1. Microstrip patch antennas are easily designed where terminals

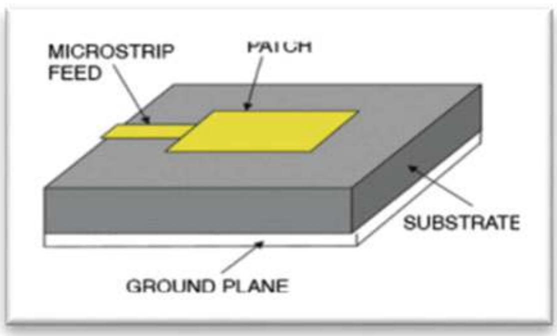


Fig. 37.1 Basic diagram of microstrip patch antenna

having small-size, lightweight, flexible, low-cost and that are ease to construct using a fabrication technique of conventional microstrip [7, 8]. Because of these advantages of microstrip patch antennas, we have numerous applications such as telemetry and communication, GPS system, naval communications, and furthermore used in the areas of RFID (radio frequency identification) [9–11].

37.2 Methodology

While designing a microstrip patch antenna, the impedance matching should be accurate, and for designing antennas, feeding techniques have been used and the radiation patterns of antennas have been computed by Computer Simulation Technology (CST) Microwave Studio software. The microstrip patch antenna arrays are very important to increase directivity, gain, and also to manage radiation patterns. Basically, the microstrip antennas are divided into two categories of feeding methods, where first category is contacting type and the second category is non-contacting type. Contacting type feeding method denotes microstrip transmission lines are directly connected to the patch antennas, and the input impedance is determined by the positioning of transmission lines with respect to the patch. Whereas, in case of second category non-contacting type feeding method, power is transferred from microstrip transmission lines to the patch through electromagnetic fields. Here, in this non-contacting type feeding, the possibilities of connecting line feed is more but construction is difficult. In the first category, there are two methods, one is line feed microstrip antenna (microstrip line feed) and the other is probe feed microstrip antenna (coaxial probe feed). In the second category, there are two methods which are even more popular, one is aperture-coupled microstrip (aperture-coupled feed) and the other is a proximity feed microstrip (proximity-coupled feed). In this paper, we are discussing about the first category feeding methods. In microstrip line feed, microstrip patch has been fed by transmission line which is smaller in width and the patch is fixed on dielectric material. In fact, this type of feed is very popular, especially for arrays, where we have n number of elements and we need to connect all those n elements. Most of the time a microstrip line is used for that purpose.

37.3 Results and Discussion

37.3.1 Design of Basic Patch Antenna with Coaxial Probe Feed

For designing the rectangular patch antenna, it is essential to identify the length and width of the patch. As we discussed in the introduction of microstrip patch antenna, the radiation occurs due to fringing effect. Fringing field occurs when we have two

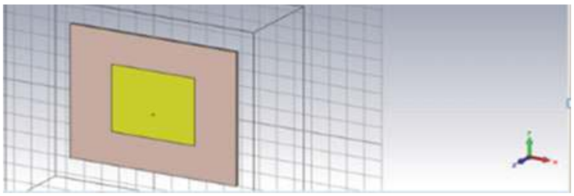
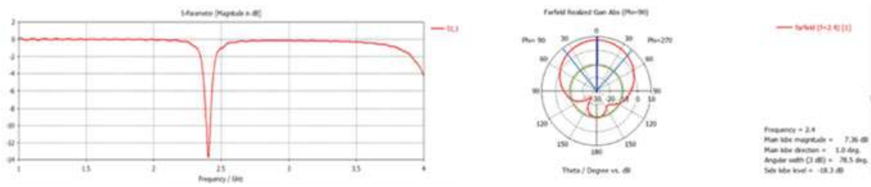


Fig. 37.2 3D view of simple rectangular patch antenna using coaxial feed



(a) (b)

Fig. 37.3 Simple rectangular patch antenna **a** S_{11} parameter, **b** far-field polar plot

parallel plates, it actually increases the effective capacitance. In coaxial probe feed method, the feed line can be sited at any preferred position into the rectangular patch antenna. Figure 37.2 presents the 3D view of the rectangular patch antenna. Using similer software, we can get the simulation results of patch antennas with different applications in 2D pattern. But in this design, we can see the 3D simulation, pattern results using Computer Simulation Technology (CST) Microwave Studio suite 2018, and simulation results are shown in Fig. 37.3a and b. For designing rectangular patch antenna with coaxial feed, we just use PCB and coaxial field needs to be optimized. Design specifications: dimensions of substrate: 38.6 × 52.8 sq mm, substrate dielectric constant: 10.2, dimensions of patch: 19.3 × 26.4 sq mm, thickness of substrate: 1.6 mm, radius of circular feed: 1.85 mm, length of circular feed: 7.75 mm.

37.3.2 Design of Rectangular Patch Antenna with Microstrip Line Feed

In the microstrip line feed method, the microstrip transmission line is joined to the patch antenna. The two sides of the patch are radiated and the other two sides are not radiated which causes cross polarization correct only. So, an increase in width of the dielectric substrate leads to increase in microstrip transmission feed, which acts as spurious feed radiation. When the width of the substrate increases, the feed line also increases. Figure 37.4 presents the 3D view of the simple rectangular patch antenna. The equivalent circuit of microstrip line feed is same as coaxial probe feed which shows the width of feed line is contributed to the inductance, and remaining antenna

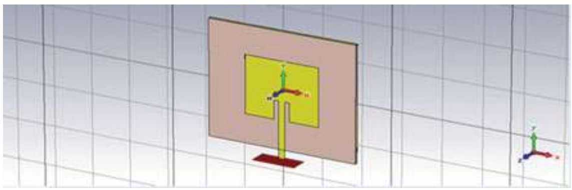
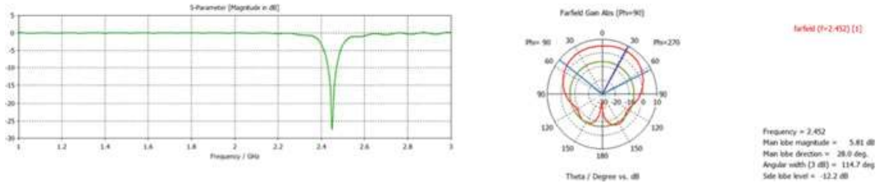


Fig. 37.4. 3D view of simple rectangular patch antenna using microstrip line feed



(a) **(b)**

Fig. 37.5 Simple rectangular patch antenna **a** S_{11} parameter, **b** far-field polar plot

is represented as an RLC tank circuit. Figure 37.4a and b shows the simulation result for S_{11} and far field polar plot, respectively. Design specifications: dimensions of substrate: 115.2 × 88.88 sq.mm, thickness of substrate: 1.5 mm, dimensions of patches: 28.80 × 22.22 sq.mm, thickness of patches: 0.02 mm, substrate dielectric constant: 10.2.

37.3.3 Orthogonal MIMO Array Design and Analysis

In this MIMO array design, the two antennas are perpendicular to each other, so we used polarization diversity to achieve orthogonal polarization. By considering the orthogonal method, the first antenna is perpendicular to second antenna which means antennas shifted to 90° in angle. Figure 37.6 represents the 3D view of MIMO. For these two antennas, there should be 18.75 mm minimum distance between the antennas. The antennas with a symmetric form are fixed on a dielectric substrate with $ER = 4.3$, where the range of the dielectric substrate is $2.2 < ER < 12$. The two independent antennas with two port systems are shown in CST Microwave Studio

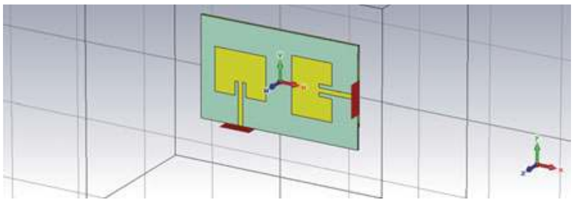


Fig. 37.6 3D view of MIMO array of two antennas

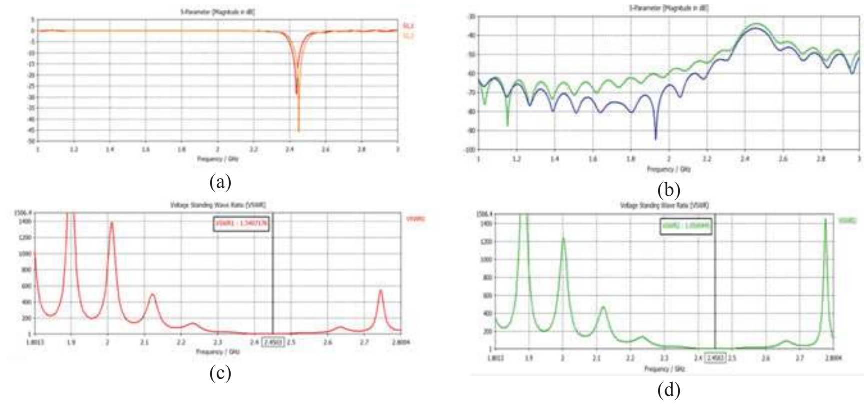


Fig. 37.7 Plot for **a** S_{11} and S_{22} parameters, **b** S_{12} and S_{21} parameters. **c** VSWR plot at port 1, **d** VSWR plot at port 2

simulation software with the simulation results. Figure 37.7 presents the plot for S-parameters and VSWR. Design specifications are considered as: dimensions of substrate: 75 × 57.8 sq. mm, thickness of substrate: 1.6 mm, dielectric constant of substrate: 4.3, dimensions of patch: 37.5 × 28.9 sq, width of microstrip fed: 3.1 mm, length of microstrip fed: 28 mm.

37.3.4 Design of 2 × 2 MIMO System

In this 2 × 2 MIMO antenna, we take two identical antenna elements, where the antenna elements will talk to each other. It is because the radiation field of the first antenna will influence the radiation field of second antenna and vice versa. This is known as mutual coupling. While designing any MIMO antenna system, we should suppress this mutual coupling as minimum as possible. Figure 37.8 presents the 3D view of 2 × 2 MIMO design. Mutual coupling is quantized by s_{21} parameter which is actually the transmission parameter which is identical to s_{12} because it is the reciprocal system. So, it doesn't matter whether to quantify in terms of s_{12} or s_{21} on both are actually equal. In practical minor system, good mutual coupling level

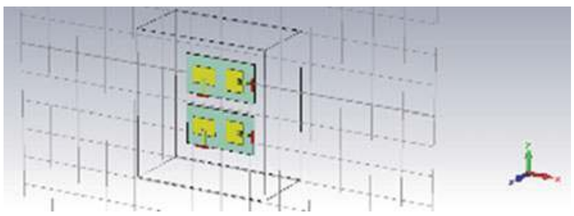


Fig. 37.8 3D view of 2 × 2 MIMO system with four ports

should be below 20 dB. In CST Microwave Studio, we placed four-port system, and there should be 30 mm distance between the antennas and the distance must be more than far field distance. Figure 37.9 presents the plot for S-parameters and VSWR. The channel matrix coefficient is able to compute by noticing the values of S_{31}, S_{32}, $S_{41,}$ and S_{42} from the simulation plot as shown in Fig. 37.10. The far field polar plot is presented in Fig. 37.11. Specifications are considered as the thickness of substrate: 1.6 mm, dielectric constant of substrate: 4.3, dimensions of patch: 37.5

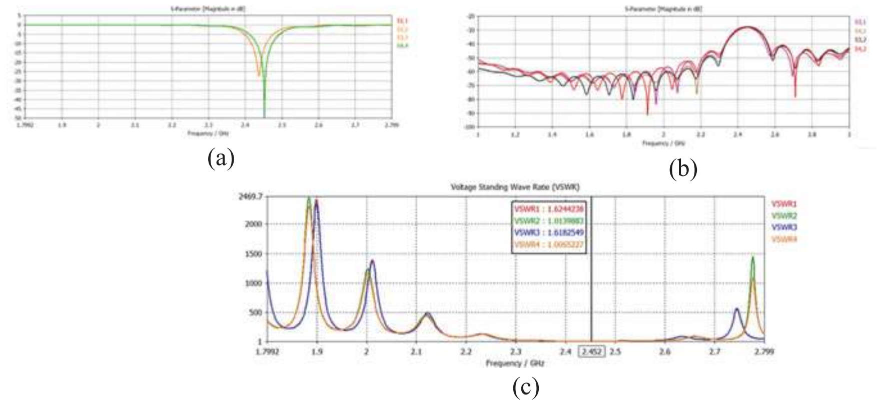


Fig. 37.9 **a** Plot of S_{11}, S_{22}, S_{33}, and S_{44} parameter, **b** Plot of S_{31}, S_{41}. S_{32}, and S_{42} parameters, **c** VSWR plots at port 1, 2, 3, 4

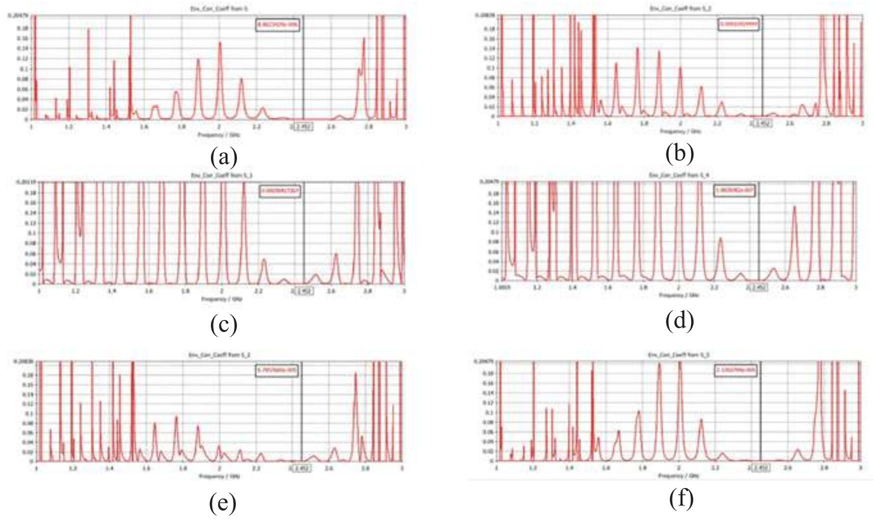


Fig. 37.10 Correlation coefficient between **a** port 1 and 2, **b** port 1 and 3, **c** port 1 and 4, **d** port 2 and 3, **e** port 2 and 4, **f** port 3 and 4

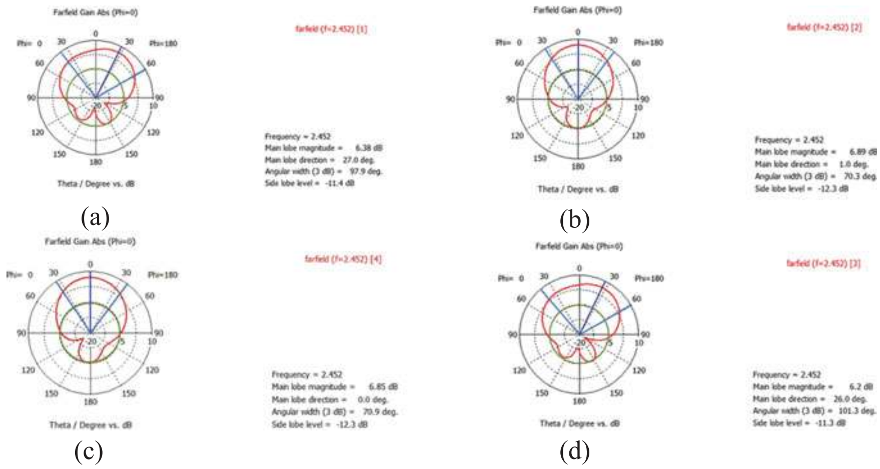


Fig. 37.11 Far-field polar plot **a** Port 1, **b** Port 2, **c** Port 3, **d** Port 4

× 28.9 sq.mm, width of microstrip fed: 3.1 mm, length of microstrip fed: 28 mm. Figures 37.13 and 37.14 show the correlation coefficient and far filed polar plot, respectively.

37.3.5 Four Mutually Orthogonal Patch Antenna Design

In this design, we consider four independent identical antennas which are perpendicular to each other to attain orthogonal polarization. Here, we have an antenna configuration which means four transmits at the base station (BS) side and four receives at the user equipment (UE) side. We can also say that the interface resources are more efficiently used and translate into capacity enhancements all over the network not only close to the base station but also all over the network. There should be 18.75 mm distance between the antennas in the array which indicates the value of height is 0.15 λ wavelength. Here for the design of antennas, the same dimensions are considered as the above design. The antennas with a symmetric form are fixed on a dielectric substrate with ER = 4.3 with return loss less than −10 dB. Figure 37.12 presents the

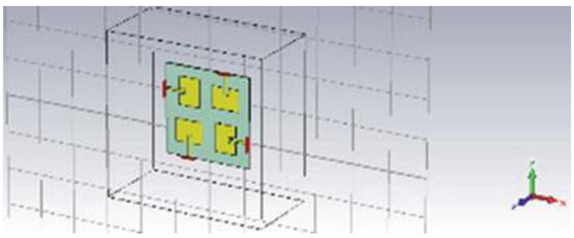


Fig. 37.12 3D view of orthogonal MIMO patch antenna

orthogonal MIMO design. The four independent antennas with four port systems are shown in CST Microwave Studio simulation software with the simulation results. Figure 37.13 presents the plot for the correlation coefficient.

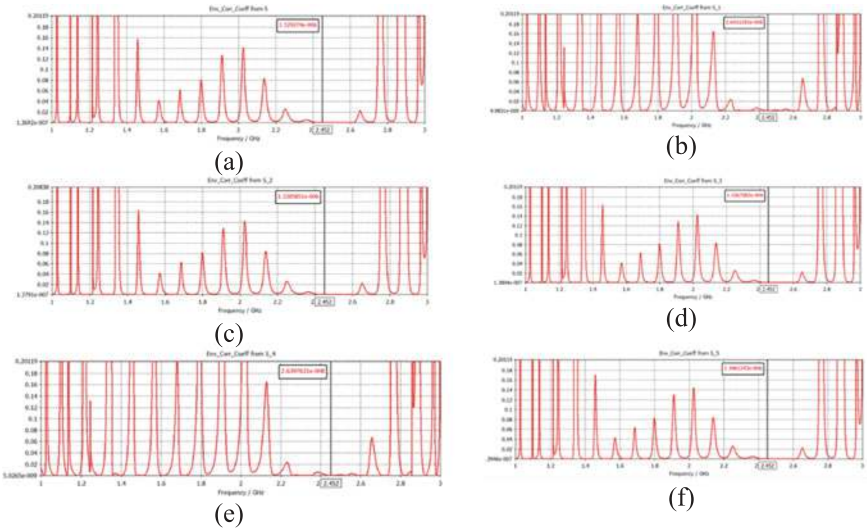


Fig. 37.13 Correlation coefficient between **a** Port 1 and 2, **b** Port 1 and 3, **c** Port 1 and 4, **d** Port 2 and 3, **e** Port 2 and 4, **f** Port 3 and 4

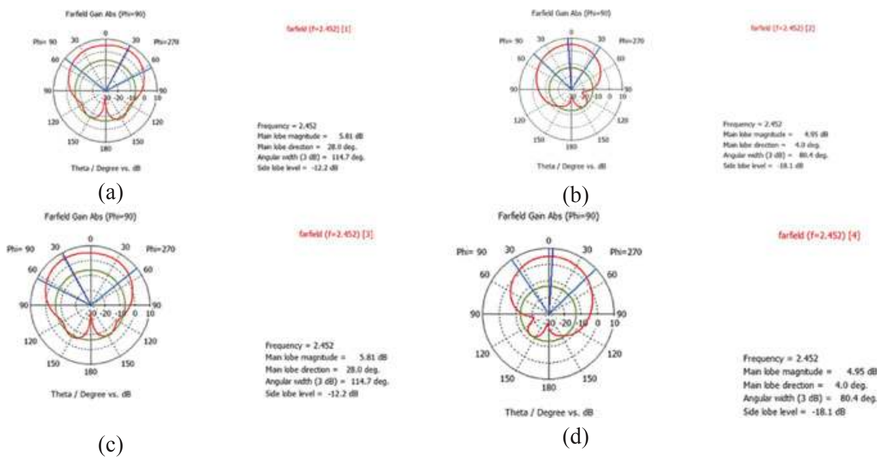


Fig. 37.14 Far-field polar plot at **a** Port 1, **b** Port 2, **c** Port 3, **d** Port 4

37.4 Simulation Results

From above results, we can observe that correlation coefficient between different ports is very less (<< 1) which represents good isolation between them. Whereas, good isolation represents the high efficiency of the antennas. We can observe that return loss and insertion loss are specified in all antennas as S-parameters $S11$, $S22$, $S33$, and S44 <-10 dB using the resonant frequency of 2.45 GHz ISM band. Here, power transmission efficiency is measured by voltage standing wave ratio (VSWR), and we can observe that VSWR1 $=$ 1.29, VSWR2 $=$ 1.07, VSWR3 $=$ 1.29, VSWR4 $=$ 1.07 using the resonant frequency of the 2.45 GHz ISM band frequency, where the values of VSWR are less than 2 indicates the matching conditions are improved.

37.5 Conclusion

We have studied basic introduction of antenna theory and analyzed basic microstrip patch antenna, and the MIMO system is worked on 2.45 GHz resonant frequency using Computer Simulation Technology (CST) Microwave Studio software. Several design techniques are discussed in detail with examples, and the fundamental properties of different antenna types. We found that the antennas in the MIMO systems are working freely with one another by examining different boundaries of the MIMO array, which is a vital prerequisite for MIMO antenna design. The outcomes from the above designs are encouraging and we used FR-4 substrate as dielectric material. We have analyzed various parameters of 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.

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