Analysis of Tripleband Single Layer Proximity Fed 2x2 Microstrip Patch Array Antenna

Original Scientific Paper

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Abstract *– Microstrip patch antennas that are multiband and downsized are required to suit the high demand of modern wireless applications. To meet this need, a one-of-a-kind triple band array antenna has been proposed. The proposed 2x2 microstrip patch array, which comprises of four hexagon-shaped radiating patches are electromagnetically excited by a centrally positioned microstrip feed line in the same plane along with a slotted ground plane, is investigated. CST Microwave Studio, a powerful 3D electromagnetic analysis programme, was used to design and optimize the array antennas. The 2x2 array antenna was constructed on a FR-4 substrate with a dielectric constant of 4.3, a loss tangent of 0.001, and a height of 1.6mm. To optimize energy coupling from the feed line to the radiating patches, the ground plane has an H-shaped groove cut into it. The suggested 2x2 array antenna's multi-frequency behaviour is shown. Three resonant peaks were detected at 1.891GHz, 2.755GHz, and 3.052GHz. The observed bandwidths for these resonances are 234MHz, 69MHz, and 75MHz, respectively, with measured gains of 7.57dBi, 6.73dBi, and 5.76dBi. The goal of this work is to design, build, and test a single layer proximity fed array antenna. Standard proximity fed array antennas contain two substrate layers; however this array antenna has only one. As a consequence, the impedance matching and alignment are better. Simulated and experimental results showed that the this 2x2 array antenna operates in various important commercial bands, such as L and S bands and the array antenna might be beneficial for a wide range of wireless applications. The proposed antenna has good Impedance, S11, and radiation qualities at resonant frequencies. In this work, the 2x2 array antenna with hexagon-shaped radiating patches was successfully created utilizing the single layer proximity fed antenna concept and gap coupled parasitic patches.*

Keywords*: Triple Band, Single Layer Proximity Fed, 2x2 array, Slotted Ground Plane, Hexagon Shaped Patches*

1. INTRODUCTION

Due to the rapid growth of wireless communication networks and new wireless applications, there is a rising need for miniaturized portable handheld devices. For a portable communication device, the antenna is one of the most critical components. Nowadays, good number of wireless services and devices uses different frequency bands and protocols. To simultaneously cover all of these services, the antennas on portable communication devices should be able to cover many frequency bands at once. Building a multi-band antenna with a small footprint is not only necessary, but also challenging due to the limited space available for antennas in portable devices. Microstrip antennas are appropriate for portable wireless communication devices [1-2] due to benefits such as small weight, cheap cost, and simplicity of production. In contrast, a conventional microstrip antenna has a single resonance frequency and a limited band width [3]. Several ways have been utilized to extend the microstrip antenna's bandwidth [4-6] and enable it to function as a multiband antenna [7-9].

One of the most extensively used methods for enhancing the bandwidth and gain of microstrip patch antennas is to use gap coupled parasitic components. There have been many papers published in the literature on electromagnetically fed gap coupled patch antennas for wireless applications [10-11]. In [12] a triple band proximity fed 2x1 array antenna with defected ground plane is presented. The reported array antenna has two substrate layers and overall thickness of the antenna is 3.2mm. A group of antennas that operate together to transmit and receive radio waves as a single antenna is referred to as an array antenna. As the number of antennas in an array rises, the array's performance improves.

The patch antenna's gain, bandwidth, and emission pattern may be improved using this array antenna configuration [13-15]. Any defect etched in the ground plane of the microstrip array antenna can give rise to increasing effective capacitance and inductance. Slotted ground plane is accomplished by etching a flaw from the ground plane in a basic form. The ground plane faults will disturb the shielded current distribution, resulting in controlled excitation and electromagnetic wave propagation across the substrate layer [16-18]. Using the approaches described above, the proposed 2x2 microstrip array antenna is being constructed.

A single layer proximity fed triple band 2x2 microstrip patch array antenna is described in this paper. Traditional proximity fed patch antennas include two substrate layers. In the current paper a novel design technique is employed to reduce manufacturing complexity. By electromagnetic coupling, a centrally positioned microstrip feedline in the same surface, activates two radiating patches printed on the top surface of the substrate at the same time, as explained in our previous work [19]. In this study, a similar feeding technique is employed to resonate the radiating patches. The array consists of four identically sized radiating components. The lowest two radiating elements are driven patches, whereas the upper two radiating elements are parasitic patches. Parasitic patches are connected to the driven patch through the driven patch's non-radiating edges. Simulation and optimization were performed using CST Microwave Studio. The proposed single layer proximity fed 2x2 microstrip array antenna provides enough gain and impedance bandwidth, as well as triple band capabilities. The array antenna may be utilized for wireless communication equipment and the operating bands are 1.81GHz, 2.707GHz, and 2.962GHz, respectively.

2. ANTENNA GEOMETRY

2.1. SIMULATION BASED ANTENNA EVOLUTION STAGES

The evolution stages of the suggested single layer proximity fed 2x2 microstrip patch array antenna with slotted ground structure is shown in Fig. 1. Initially as illustrated in Fig.1(a), the single layer antenna consists of a hexagonal shaped radiating patch and a microstrip coupling feed line. Both the microstrip patch and feed line are printed on the top surface of the substrate and an H-shaped slot is etched in the ground plane. The microstrip feed line is placed close to the hexagonal shaped radiating patch with a gap G. The hexagon-shaped radiating patch is separated from the microstrip line by a gap G. In this situation, the radio frequency [RF] energy is coupled electromagnetically to the emitting device. The antenna was designed and simulated using CST microwave studio and the findings reveal that it resonates as a single band antenna. From the simulated radiation pattern results, it is observed that the beam maximum of the radiated beam is 37 degree away from the bore sight. In order to correct this pattern behavior, at the next antenna evolution stage another hexagon shaped radiating element is printed on the other side of the microstrip feed line. The new modified antenna design with slotted ground plane is shown in Fig. 1. (b). In this single layer proximity fed 2x1 array antenna configuration, dual band behaviour is seen. The CST Microwave Stimulation tool is used to fine-tune the size of the hexagonal radiating components such that the first band resonates at 1.8GHz. The 2x1 array antenna provides enough bandwidth and gain across both working bands.

The current research looks at the next phase in array antenna development, which aims to enhance the number of functioning bands and bandwidth. In the last evolution stage, two more hexagon-shaped radiating elements with the same dimensions are gap linked with the basic radiating elements, as illustrated in Fig.1. (c). This design is used to create a single layer proximity fed 2x2 microstrip patch array antenna with a slotted ground plane. An H shaped slot cut in the ground plane enhances the coupling to all four radiating patches. The unique features of the proposed single layer proximity fed 2x2 array antenna when compared with reference antenna [12], are triple band bahaviour, small volume, lightweight and improved impedance matching. The slot dimensions in all three antenna configurations have been modified to produce resonance at the desired frequency. A frequency shift or a decrease in impedance bandwidth will arise from a change in any of these design parameters. The length of the feed line is modified in order to improve impedance matching.

2.2 ANTENNA DESIGN PROCEDURE

The key design characteristic of a hexagon shaped radiating patch is its side length s. The equations for side length s, for a hexagonal shaped microstrip patch antenna can be obtained from the resonant frequency equations of the circular shaped microstrip patch antenna as discussed in reference work [12], by equating the respective areas as shown in Fig. 2. A circular patch antenna's basic resonance frequency is determined by

$$fr = \frac{X_{mn}C}{2\pi a_e\sqrt{\varepsilon_r}} \quad (1)$$

Where,

fr = resonant frequency of the patch
X_{mn} = 1.8411 for the dominant mode TM 11
C = velocity of the light in free space
εr = relative permittivity of the substrate
a_e = effective radius of the circular patch and given by

$$a_e = a\{1\text{-}2h/\pi a\varepsilon\,.\ (\ln\pi a/2h + 1.7726)\}^{0.5} \quad (2)$$

In equation (2), 'a' is the actual radius of the circular patch antenna and h is the height of the substrate. By relating the areas of the circular and hexagonal radiating elements as stated in the equation given below, the aforementioned equations may be used to compute the side length *s*, of a hexagonal shaped microstrip patch antenna.

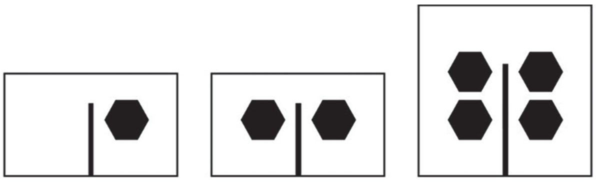


Fig.1. Evolution stages of the proposed single layer proximity fed 2x2 array antenna (a) stage one (b) stage two and (c) stage three

$$\Pi {a_e}^2 = \frac{3\sqrt{3}\, s^2}{2} \quad (3)$$

where'*s*' is the side length of the hexagonal patch.

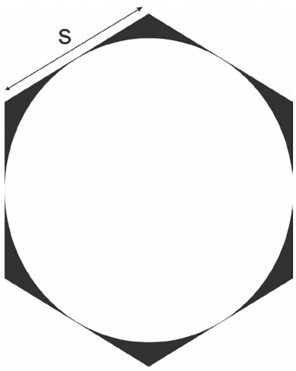


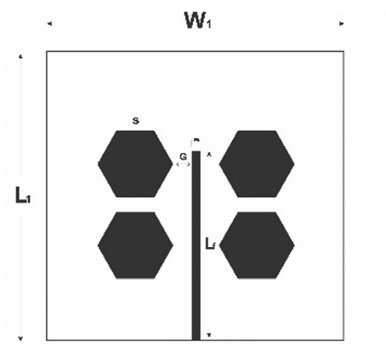
Fig. 2. Formation of a hexagonal shape from a circle

The radiating elements of the proposed array antenna is of hexagonal shape, whose eauation for resonant frequency is obtained using the resonant frequency equation of a circular radiating element by comparing their areas [20]. The resonant frequency of a hexagonal shaped radiating element is,

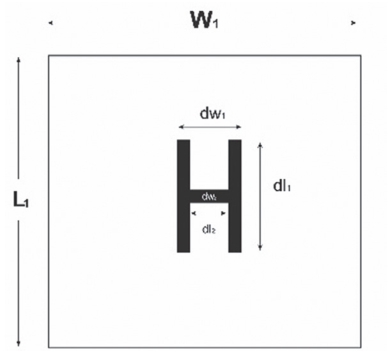
$$fres = \frac{YmnC}{5.714\, ae\sqrt{\varepsilon reff}} \quad (4)$$

Here, Ymn = Y11 (TM11 mode) = 1.841 or Ymn = Y21 = (TM21 mode) = 3.054, ε reff is the effective dielectric constant, C is the veocity of light and ae is the effective radius of the circular patch.

2.3 ANTENNA CONFIGURATION



(a)



(b)

Fig. 3. Geometry of the proposed single layer proximity fed 2x2 array antenna (a) top view and (b) bottom view

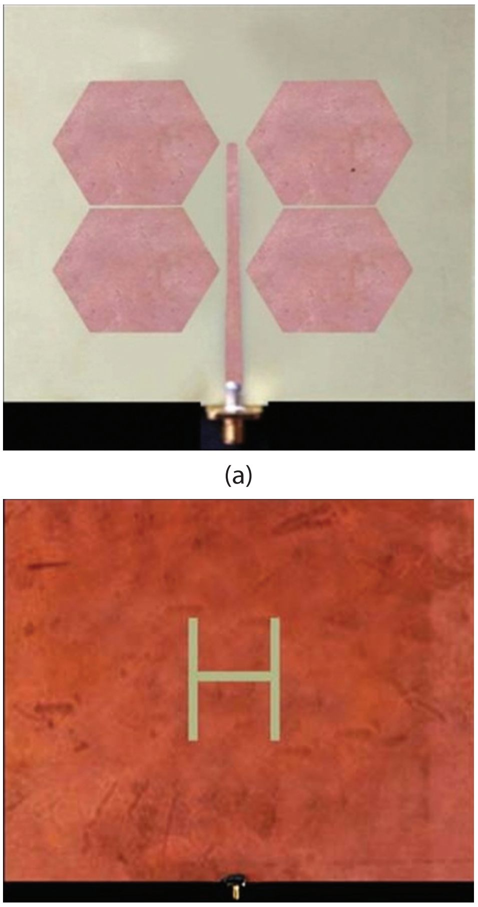
The configuration of the suggested single layer proximity fed 2x2 array antenna with slotted ground plane is shown in Fig.3. A 2x2 array antenna with a dielectric constant of 4.3, with a loss tangent of 0.001, and a height of 1.6mm was designed on a FR-4 substrate. Glass reinforced epoxy laminate sheets, rods, and printed circuit boards are given the grade FR-4. It's a popular and adaptable high-pressurethermoset plastic laminate with excellent strength-to-weight ratios. It's most typically employed as an electrical insulator because of its low water absorption and high mechanical strength. These qualities, together with strong manufacturing capabilities, aided in the selection of thissubstrate for the suggested antenna design. Fig.3 (a) depicts the top view of the suggested single layer proximity fed 2x2 array antenna with slotted ground plane, which consists of four hexgonal shaped radiating patches printed on the top side of the upper substrate with a centrally located microstrip feedline. The distance between the radiating components closest edges and themicrostrip feedline is maintained at λ/12. As illustrated in Fig.3(a), the four hexagon-shaped radiating elements are all activated electromagnatically from the centrally located microstip feed line. Fig. 3(b), shows a metallic ground plane with an H-shaped slot on the rear side of the substrate.

Dimensions of the radiating patches and that of the slot in the proposed array antenna configuration is optimized using CST microwave studio software package, which utilizes the finite integration technique for electromagnetic commutation to operate in three operating bands. Table 1 shows the optimized dimensions of the proposed antenna.

Table 1. Optimized dimensiosns of the proposed 2x2 array antenna (all units in mm).

W1	96	G	3.3	Dl1	23.7
L1	72	Lf	46.4	Dl2	9.6
S	14.6	Wf	4.7	Dw1	30

3. RESULTS AND DISCUSSIONS



(a)

(b)

Fig. 4. Photograph of the fabricated single layer proximityfed 2x2 array antenna (a) top view and (b) bottom view.

The optimal dimensions from the numerically synthesized model as given in Table 1 have been used to fabricate the physical antenna prototype and the performance criteria are measured in a standard anechoic chamber to validate the numerically estimated results. Fig.4 shows the photographs of top and bottom view of the fabricated single layer proximity fed 2x2 array antenna with a slotted ground plane. The antenna is etched on a 1.6mm thick FR 4 substrate with a loss tangent of 0.001 and a dielectric constant of 4.3. Because it is inexpensive and has great mechanical qualities, FR 4 is utilized in this work. Using a commercially available 50Ω SMA coaxial connection, the fabricated microstrip patch array is activated electromagnetically.

The fabricated prototype of the proposed single layer proximity fed 2x2 array antenna is measured for reflection coefficient and gain using vector network analyzer. The measurements are carried out using Agilent E5063A ENA series RF network analyzer, which can be used for testing passive components like antennas up to 18 GHz. The calibration of the network analyzer is performed using short – open – load- through technique. After calibration, the fabricated prototype antenna is connected to analyzer and reflection coefficients are obtained. Broad band standard horn antenna operating between 1GHz and 18 GHz frequencies is used for far field pattern measurements. Both, antenna under test and standard horn antenna are placed inside a fully calibrated anechoic chamber for radiation pattern measurements. The antenna under test or fabricated antenna is placed on a turn table and the attached motor is allowed to rotate the antenna with 100 steps in both principle planes. The chambers are designed to absorb the reflections of electromagnetic radiations and to minimize interfering energy disturbances from external spurious sources.

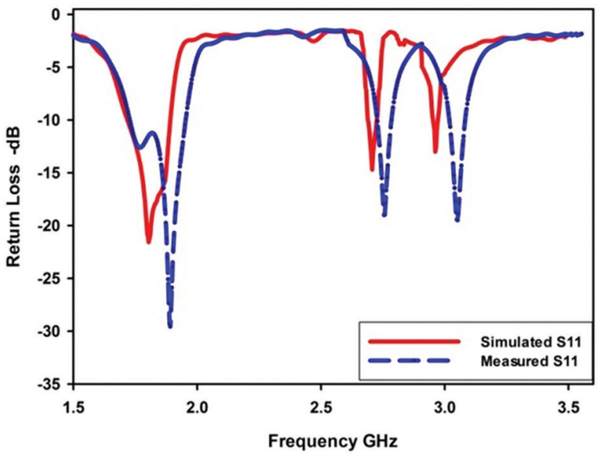


Fig. 5. Simulated and measured return loss characteristics of the proposed single layer proximity fed 2x2 array antenna.

Fig. 5. shows the simulated and measured return loss plot of proposed single layer proximity fed 2x2 array antenna with slotted ground plane for wireless applications. The results can be compared with previous result [12], which shows that the proposed array antenna structure radiates excellent with minimum loss. It is seen from the plot that the proposed array antenna operates for three different frequency bands. The three operating bands achieved during simulation are from 1.717GHz to 1.840GHz, with peak resonance at 1.810GHz; 2.686GHz to 2.731GHz with peak resonance at 2.707GHz and from 2.947GHz to 2.977GHz with peak resonance at 2.962GHz. For the first, second, and third bands, the proposed array antennas simulated bandwidths were 123MHz, 45MHz, and 30MHz, respectively. The measured fundamental resonance of 1.891GHz is observed with an impedance bandwidth of 234MHz (1.723-1.957GHz). The second resonance of 2.755GHz occurs with an impedance bandwidth of 69MHz (2.722 – 2.791GHz). Finally, the third resonance occurs at 3.052GHz with an impedance bandwidth of 75MHz (3.013 – 3.088GHz). Thus, the proposed array antenna is applicable to different wireless communication applications in L and S bands. Changes in inductance are due to manufacturing flaws, connection losses and imperfection in soldering are to be blamed for the minor disparity between the simulated and measured findings.

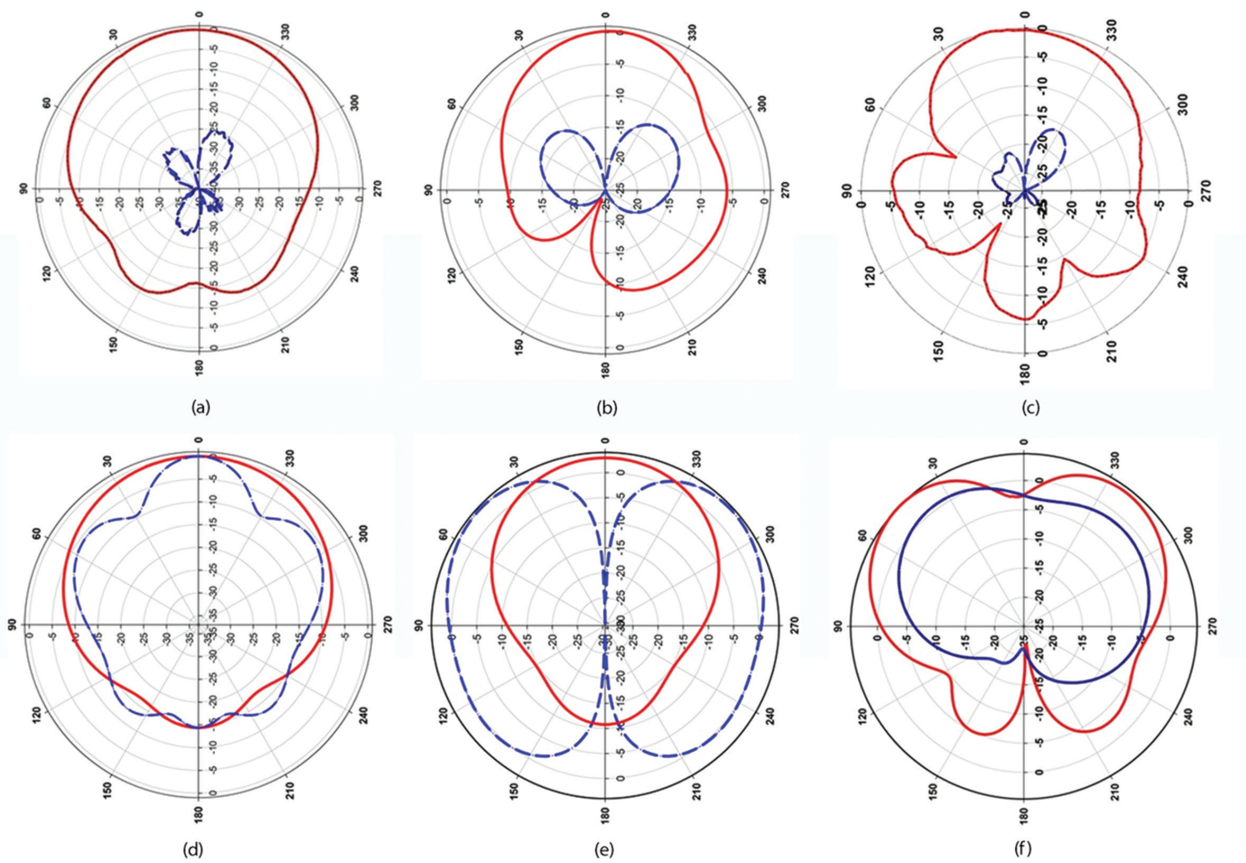


Fig. 6. Measured and normalized radiation patterns of the proposed single layer proximity fed 2x2 array antena at (a) 1.891GHz with Phi=0 (H plane), (b) 1.891GHz with Phi=90 (E plane), (c) 2.755GHz with Phi=0 (H plane), (d) 2.755GHz with Phi=90 (E plane), (e) 3.052GHz with Phi=0 (H plane), (f) 3.052GHz with Phi=90 (E plane)

Fig. 6. shows the observed radiation patterns of the proposed single layer proximity fed 2x2 array antenna in the E (y-z plane) and H (x–z plane) at the resonant frequencies of 1.891GHz, 2.755GHz, and 3.052GHz. Fig.6(a) and 6(b) illustrate the electromagnetic energy distributions of the array antenna in two principal planes at the lower resonant frequency of 1.891GHz. The radiation patterns at this frequency are in the bore sight direction in both planes. In both the E and H planes, the patterns are extremely directed towards the +Z (positive) direction, with modest crosspolarization levels. The antennas HPBW is on the order of 1180 in the E plane and 1050 in the H plane. Fig. 6(c) and 6(d) show the antennas radiation patterns at the second resonant frequency of 2.755GHz . In the H plane, substantial back lobes can be seen. Different established strategies have been employed to diminish the presence of back lobe, and in future study, an appropriate way will be used to reduce back lobe. The antennas half power beam width [HPBW] is in the order of 830 in the E plane and 620 in the H plane. Fig.6(e) and 6(f) illustrate the antennas radiation pattern at the top resonance frequency of 3.052GHz. On both sides, the antenna radiation patterns beam maxima in the H plane are a few degrees distant from bore sight direction. This feature will come handy in non-line of sight applications. The antenna's HPBW is on the order of 810 in the E plane and 690 in the H plane. It should also be noticed that the third operational frequency had a somewhat greater cross polarisation level.

The array antenna realized gain was measured based on the three antenna gain measuremen method [21-22]. The suggested 2x2 array antenna's observed gain at initial resonance frequency is 7.57 dBi, which is close to the simulated gain of 7.31 dBi. At the second and third resonant frequencies, the simulated and observed gains are 6.8dbi and 5.95dbi and 6.73dbi and 5.76dbi, respectively. The observed gain changes over the operational frequency ranges are depicted in Fig.7. The comparison of the proposed work and existing work [12], is discussed in Table 2.

Table 2. Comparison Analysis of the proposed work and existing work.

Frequencies GHz	Reflection Coefficient (dB)		Gain (dBi)	
	Existing Work	Proposed Work	Existing Work	Proposed Work
1.8	-22.56	-28.52	4.8	7.57
2.7	-18.37	-20.87	5.6	6.73
3.0	-19.15	-20.61	5.2	5.76

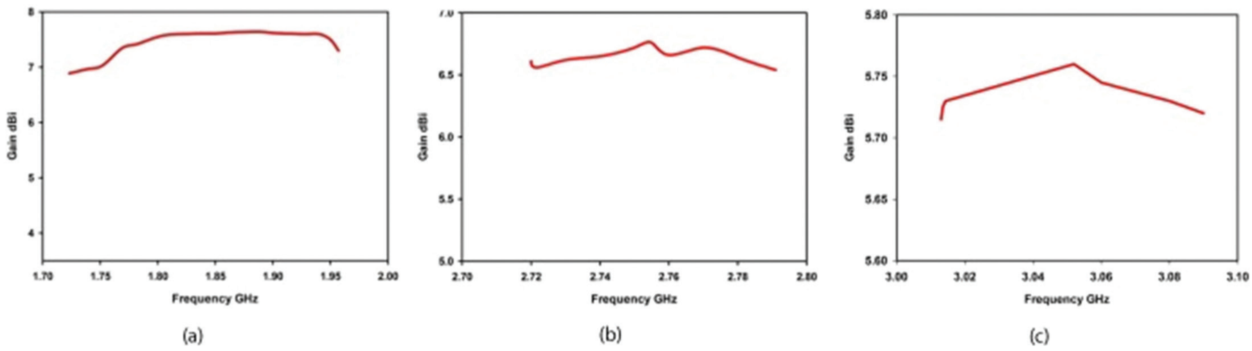


Fig . 7. Measured gain with frequency of the proposed single layer proximity fed 2x2 array antenna at (a) first band (b) second band and (c) third band

Advantages:

1. 2X2 Array Antenna
2. Good Return Loss is Obtained
3. High Gain is Obtained
4. Close aggrement between the measured and simulated results
5. It is used for Wireless Communication

4. CONCLUSION

A single layer proximity fed triple-band 2 x 2 patch array antenna with a slotted ground plane is described in this paper. Radiating array components and a microstrip feed line are printed on the substrate's top surface. Feed line stimulates printed array components electromagnetically. The 2x2 array antenna was designed and simulated with aid of CST studio suite, a high performance 3D electromagnetic analysis software package. The proposed 2x2 array antenna has been built and tested, and the measured and simulated results are very close. The single layer proximity fed array antenna revealed three bands with centre resonant frequencies of 1.891GHz, 2.755GHz, and 3.052GHz, with measured impedance bandwidths of 234MHz, 69MHz, and 75MHz respectively. The far-field radiation patterns of the principal planes (E and H) were measured in a fully equipped anechoic chamber. The gain of the proposed 2x2 array antenna is estimated using a three-antenna technique. The antenna may receive services from a variety of wireless technology networks that operate in both the L and S bands.

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