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Parametric Analysis and Design Optimization Investigation of a Single Layer Proximity Fed Array Antenna with Slotted Ground Plane

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Abstract - *A In this paper, a microstrip patch array antenna configuration with a new coupling method is presented. Basic microstrip patch array antenna configuration consisting of a pair of radiating patches coupled in close proximity to a microstrip feed line in the same plane along with a slotted ground plane. By employing directly coupled microstrip patch to the non-radiating edges of the each microstrip patch of the basic configuration, enhancement in bandwidth and gain is achieved with dual band operation. Parametric analyses were performed using CST Microwave Studio simulator to understand effect of various antenna dimension parameters.*

This microstrip patch array provides resonances at two frequencies of 2.468GHz and 3.616GHz. The proposed single layer proximity fed array antenna with slotted ground plane is suitable for WLAN and WiMAX. This array antenna configuration has a measured gain of 9.4 dBi and 6.03dBi respectively with impedance bandwidth of 4.41% and 5.66% respectively across first and second band. The simulated results are in good agreement with the experimental results.

Key Words: microstrip patch array, proximity feed, coupled parasitic patch, parametric analysis, slotted ground plane .

1. INTRODUCTION

Due to rapid development in the field of wireless communication technology the demand for compact and small size antennas are becomes higher. Microstrip patch antennas are well suited for the demand. The microstrip antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. Microstrip patch antennas are extensively used in satellite, wireless and mobile communication applications due to advantages like light weight, conformable to planar and non-planar surfaces, inexpensive to manufacture and mechanically robust when mounted on rigid surfaces. One of the major requirements for modern communication devices is to operate at wider band so that the antenna can support high speed internet, multimedia communication and many other broadband services. However, microstrip patch antennas have inherent limitations on narrow impedance bandwidth and low gain.

To overcome the inherent limitation of narrow impedance bandwidth and low gain of microstrip antenna many techniques have been suggested and investigated. Some of the reported techniques used to enhance impedance bandwidth of microstrip patch antennas are by using stacked parasitic technique [1], microstrip line electromagnetically coupled to antenna [2], and modified shaped patch antenna [3]. Traditionally each antenna operates in a single band, where different antennas are required for various applications. It will cause a limited space and place problem. In order to overcome this problem, multiband antenna can be used, in which a single antenna can operate at many frequency bands. Some of the techniques used to develop dual band microstrip patch antenna are slot loaded patch antenna [4], using fractal geometries in designing patch structure [5] and by using a pair of L slits in the ground [6]. Another important limitation with microstrip patch antenna is its low gain. Several methods are reported to increase the gain of antenna. Array configuration was effectively used for the enhancement of gain in microstrip patch antenna [7]. Some of the other methods used to enhance gain include use of air substrate [8] and resonance method which involves use of a superstrate [9].

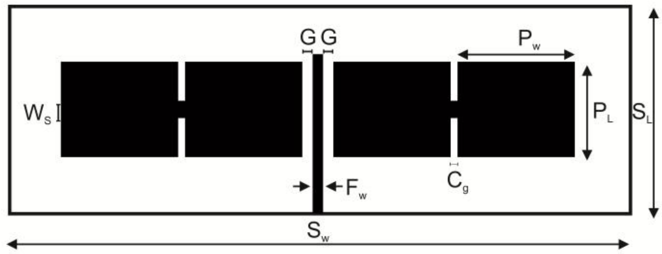
One of the commonly used methods to enhance bandwidth and gain of microstrip patch antenna simultaneously is by using the concept of gap coupled parasitic elements [10]. A novel microstrip patch antenna configuration consists of a pair of square radiating patches coupled in close proximity to a microstrip line in the same side and a coupling arrow shaped slot on the other side is reported in [11]. Generally defected ground structure is implemented in microstrip antenna for various applications like mutual coupling reduction in antenna array, miniaturized antennas, harmonic suppression and cross polar reduction [12]. In the proposed work the microstrip feed line is used to excite the radiating patches through a tapered arrow dumb-bell shaped slot on the ground plane. The defected geometry etched in the ground plane disturbs its current distribution. This distribution affects transmission line characteristics, which causes an increase in effective capacitance and inductance results in coupling more energy to the radiating patches. Recently a number of papers on dual band antennas were reported for WLAN/WiMAX applications which are popular networks to access the internet [13-15]. Although this antenna demonstrates their own merits, they have either limited bandwidth or limited gain. The antenna proposed here can be used for WLAN/ WiMAX application with enhanced bandwidth and better gain.

In this paper a microstrip patch array antenna configurations is presented were additions radiating patches are directly coupled to the non-radiating edges of another radiating element. The basic array antenna configuration that consists of two rectangular radiating patches, which are electromagnetically coupled to the microstrip line in the same plane and a defected ground plane. The feeding technique used in this work is similar to the one reported in [11]. Additional patches are directly coupled to the non-radiating edges to enhance bandwidth and gain, which results in the formation of novel array antenna configuration. The coupling patch elements having the same dimension as that of driven patch are coupled to the non-radiating edges of the driven patch through a narrow strip. With the introduction of two coupling patch elements the proposed novel microstrip array antenna shows dual band characteristics, improved gain and impedance bandwidth is enhanced by a significant level.

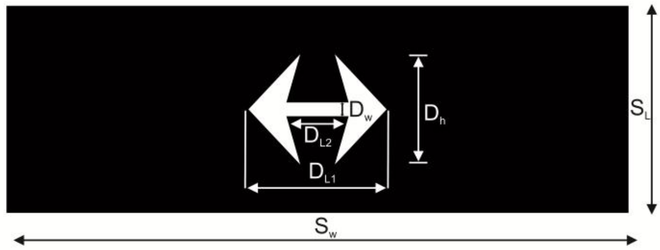
2. ANTENNA CONFIGURATION

The microstrip patch array antennas have been designed and fabricated on FR-4 substrate with ε_r of 4.3, loss tangent of 0.001 with height h of 1.6 mm. In this array configuration a microstrip feed line is centrally placed on the upper side of the substrate. On either sides of the centrally placed feed line, two radiating elements are etched. All four radiating elements have dimensions. To enhance electromagnetic coupling from the feed line to the radiating elements a slot is etched in the ground plane. The spacing between the nearest edges of the patches is kept at λ/12 and the separation between the center points of the patches is 3λ/8. The proximity coupled feed method is used to excite the two radiating patches.

The length and width of each radiating patches are designed for 2.45 GHz operation. The back side of the substrate has a metallic ground plane with a tapered arrow head dumb-bell shaped slot. Second Patch on either sides are directly coupled to the non-radiating edges of the first array elements through a narrow strip. The dimensions of the coupled patch are same as that of the radiating patch. The top view and bottom view of the proposed array antenna is shown in Figure 1. The optimized dimensions of the proposed capacitive coupled microstrip array antenna with pair of radiating patches along with directly coupled patch are given in Table 1. The width of the narrow strip line used to couple radiating and coupled patch is 5mm and the length of the fed line is 45mm. The proposed antenna performance has been studied using CST microwave simulation software. To verify the proposed antenna an experimental prototype was designed fabricated and measured.



(a) top view



(b) bottom view

Fig -1: Geometry of the proposed single layer proximity fed array antenna with slotted ground plane

Table -1: Optimized dimensions of the proposed antenna with coupled parasitic patches.(Units: mm)

S_W	180	P_W	34	G	3.5
S_L	60	P_L	27.6	C_G	1
F_W	3.02	Dw	4	W_S	5
D_{L1}	40	D_{L2}	18	D_h	32

3. PARAMETRIC ANALYSIS

The parametric analysis of the proposed single layer proximity fed array antenna with slotted ground plane is conducted and effects of various antenna parameters on the antenna characteristics are studied. The results and discussion on various parametric studies are provided in this section. The parametric analysis is carried out using CST microwave studio.

3.1 Effect of feed length

Figure 2, plots the antenna return losses characteristics as length of microstrip feed line fL, is varied from 44 mm to 47 mm. It is observed that both the resonances remain almost unaltered. It is also observed that when the fed length increases the return loss of the lower resonant frequency degrades while that of the upper band improves. The bandwidth is found to be stable for the upper band while it decreases in the case of lower band as fed length increases.

From the simulation studies the microstrip feed line length F_L, is chosen as 45 mm.

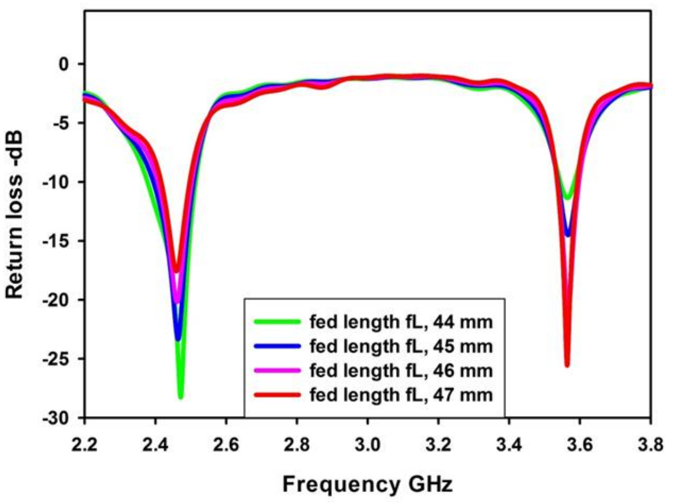


Fig – 2: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various feed length F_L with rest of the parameters as in Table 1.

3.2 Effect of Coupling Gap G

Figure 3, plots the antenna return losses characteristics as G, gap between the microstrip feed line and patch edge is varied from 2 mm to 5 mm. It is observed that in the case of lower resonance a shift towards higher range can be noted with an increase in lower resonant frequency from 2.43GHz to 2.47GHz. It is also observed that when the fed gap becomes 5mm, the return loss of the lower resonant frequency degrades to below -10dB.

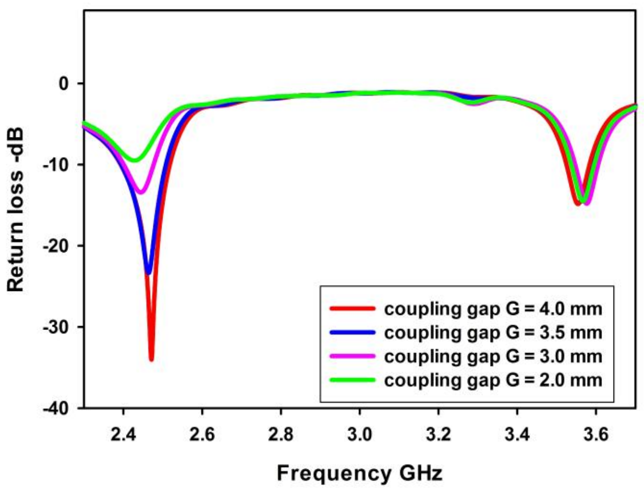


Fig – 3: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various coupling gap G with rest of the parameters as in Table 1.

The bandwidth is found to be decreasing for the lower band from 95MHz to 42 MHz as the gap increases. But the second resonant frequency is observed to be slightly reduce from 3.62 GHz to 3,54 GHz as G is Increased .It is also noted that when the fed gap becomes 4 mm the return loss across the upper resonant frequency degrades to below -10dB level. Bandwidth is almost stable for variations in G. From the simulation studies the value of fed gap G is chosen as 3.5 mm.

3.3 Effect of Patch Length P_L

The effect of patch length P_L over the resonant frequencies is illustrated in the Figure 4. The length of all four radiating patches are varied simultaneously from 26.6mm to 30.6mm and found that the second resonant frequency remains unaltered while the first resonant band is shifted from 2.55 GHz to 2.34 GHz. It is also observed that when the length of the radiating patches becomes 30.6 mm the return loss of the lower resonance degrades to below -10dB. The variations in P_L do not make any changes to upper bandwidth. From the simulation studies the length of parasitic patches P_L, is chosen as 27.6 mm.

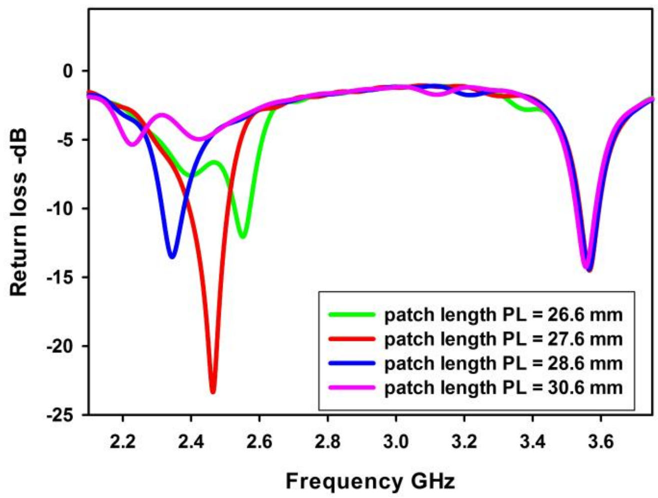


Fig – 4: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various patch length P_L with rest of the parameters as in Table 1.

3.4 Effect of Patch Width Pw

The effect of patch width Pw over the resonant frequencies is illustrated in the Figure 5. The width of the all four radiating patches are varied simultaneously from 33 mm to 37mm and found that the both the resonant frequencies remains unaltered. It is also observed that when the width of the radiating patches increases the return loss of the lower resonance reduces towards -10dB level. The variations in Pw do not make any changes to both lower and upper bandwidths. From the simulation studies the width of all four radiating patches Pw, is chosen as 34 mm.

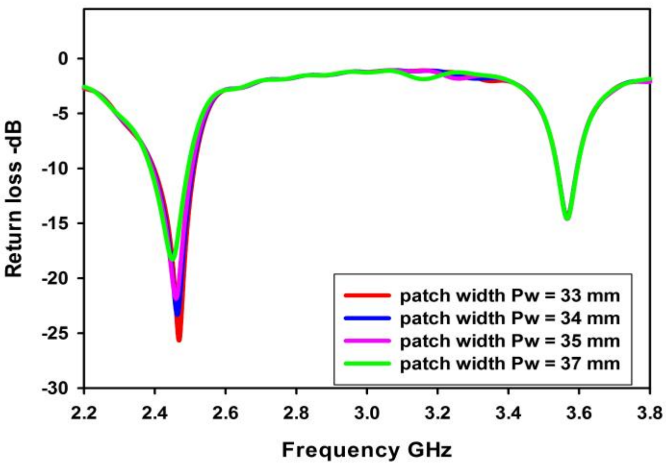


Fig – 5: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various patch width P_W with rest of the parameters as in Table 1.

3.5 Effect of Slot Height D_h

The effect of slot height D_h over the resonant frequencies is illustrated in the Figure 6. The height of the slot etched in the ground plane is varied from 28 mm to 34 mm and found that the lower resonant frequency remains unaltered up to 33mm. It is observed that when D_h, becomes 34 mm the lower resonance band splits in to two closely spaced bands. The bandwidth of the lower resonance increases with D_h. The upper resonance frequency slightly shifts towards lower side as the height of the slot increases. It is also noted that the when the height of the slot becomes 30mm or less the return loss of the upper resonance band degrades and become less than -10dB level.

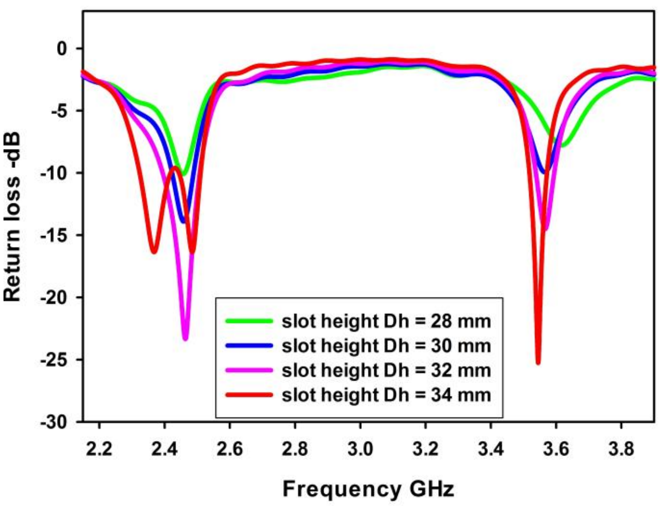


Fig – 6: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various slot height D_h with rest of the parameters as in Table 1.

The variations in D_h do not make any changes to upper bandwidth. From the simulation studies the height of the slot etched in the ground plane D_h, is chosen as 32 mm.

3.6 Effect of Slot Length D_{L1}

The effect of slot length D_{L1} over the resonant frequencies is illustrated in the Figure 7. The length of the slot etched in the ground plane is varied from 36 mm to 42 mm and found that the second resonant frequency remains unaltered while the first resonant frequency slightly shifts towards right side. It is also observed that when the length of the slot becomes 42 mm the return loss of the lower resonant frequency degrades to nearly -10dB along with reduced bandwidth. The variations in D_{L1} do not make any changes to upper bandwidth. From the simulation studies the length of the slot etched in the ground plane D_{L1}, is chosen as 40 mm.

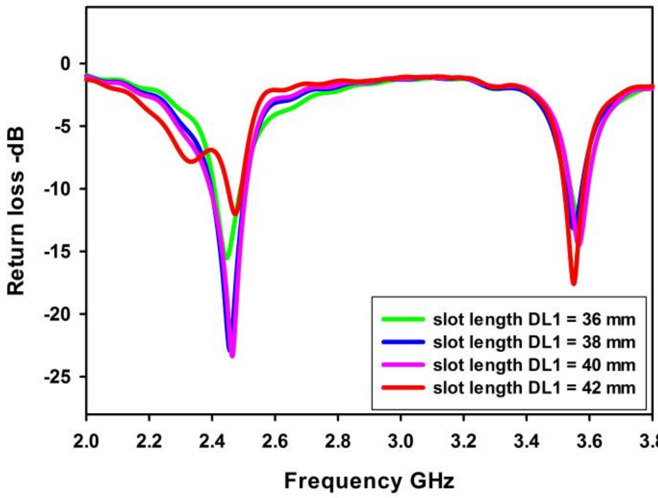
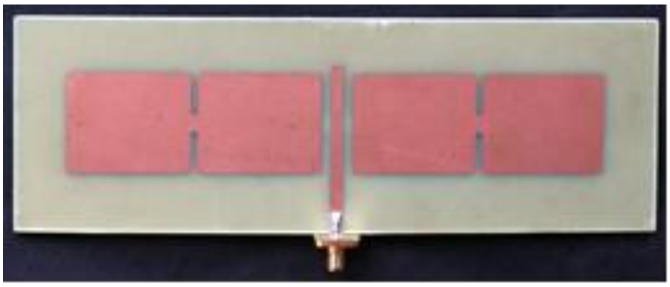


Fig – 7: Simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for various slot length D_{L1} with rest of the parameters as in Table 1.

4. RESULTS AND DISCUSSION

To verify the simulated results prototype of the simulated antenna with optimized dimensions as shown in Table 1 is fabricated and tested. Figure 8, shows the photographs of the fabricated single layer proximity fed array antenna with slotted ground plane. The antenna is etched on a FR 4 substrate having thickness of 1.6mm, loss tangent of 0.001 and with a dielectric constant of 4.3. FR 4 is used because it is very cheap and has excellent mechanical properties. The fabricated microstrip patch array is energized electromagnetically using the commercially available 50Ω SMA coaxial connector. Return loss characteristics, radiation patterns and gain are measured. Experimental verification was carried out using Agilent network analyzer E5071C.



(a) top view

(b) bottom view

Fig -8: Photograph of the fabricated single layer proximity fed array antenna with slotted ground plane. (a) top view and (b) bottom view

4.1 Return Loss Characteristics

Figure 9, shows the measured S_{11}variations with frequency of the proposed single layer proximity fed array antenna with slotted ground plane.

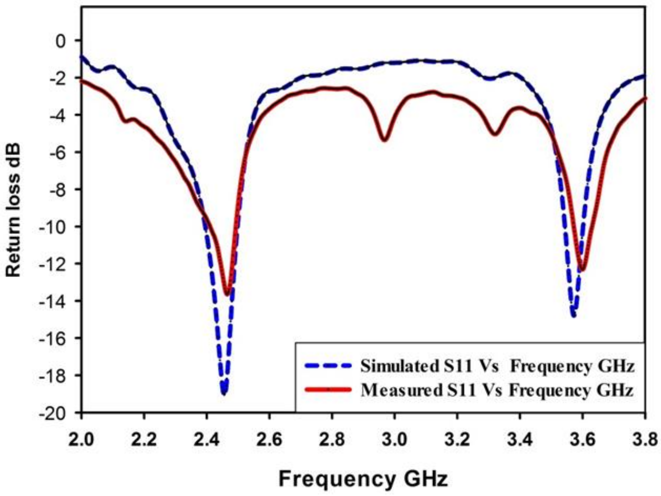
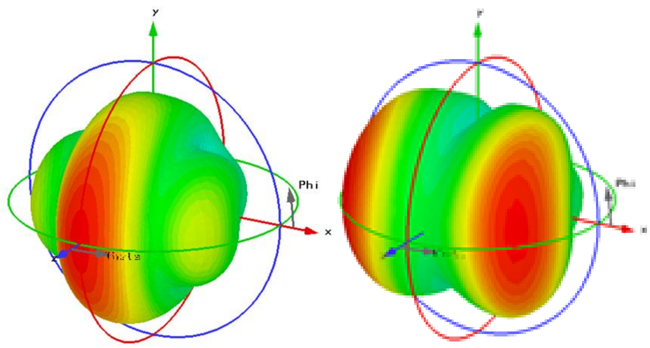


Fig- 9: Measured and simulated return loss characteristics of the proposed single layer proximity fed array antenna with slotted ground plane for dual band applications with dimensions as shown in table 1

The measured -10dB impedance bandwidth of the proposed single layer proximity fed array antenna with slotted ground plane for the lower band is 109MHz (2.408-2517GHz) or 4.41% with peak resonance at 2.468GHz and for the upper band is 208MHz (3.586-3.794GHz) or 5.66% with resonance at 3.676GHz. The simulated band widths are 59.8MHz and 173 MHz respectively across lower and upper operating bands. The operating band of the proposed antenna make it suitable of 2.45 GHz (WLAN) and upper band can be used for 3.5 GHz (WiMAX) applications.

4.2 3 D Radiation Pattern

The simulated three dimensional radiation patters of the proposed single layer proximity fed array antenna with slotted ground plane are depicted in the Figure 10.

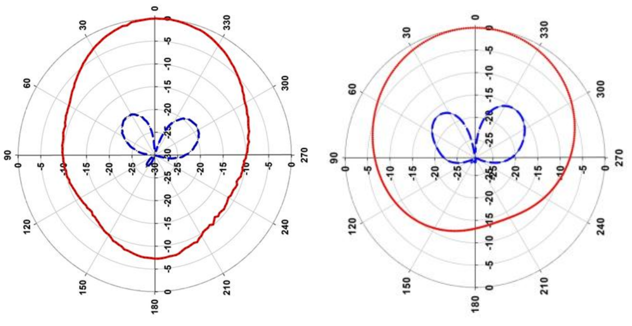


(a) (b)

Fig – 10: Simulated 3D radiation pattern of the proposed single layer proximity fed array antenna with slotted ground plane (with parameters as in Table 1) (a) at 2.459GHz and (b) at 3.593GHz

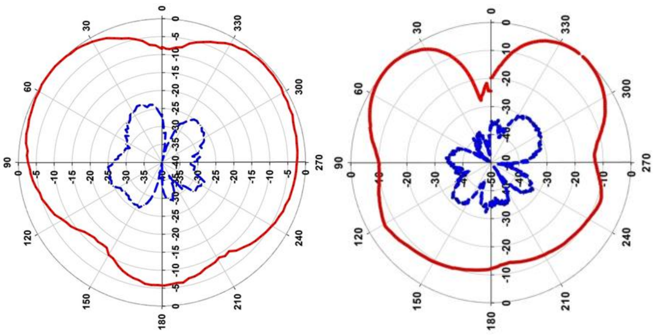
4.3 Measured Radiation Pattern Characteristics

Standard measurement techniques are used to plot the radiation characteristics of the proposed single layer proximity fed array antenna with slotted ground plane. The far field radiation patterns of the dual band microstrip array antenna in the E plane (y-z plane) and H plane (x-z plane) are plotted at the frequencies of 2.468 GHz and 3.676 GHz is shown in Figure 11 and Figure 12 respectively. The radiation pattern data are normalized in order to plot the co-polar and cross polar patterns in one graph. At the lower resonant frequency (2.468 GHz) the maximum power was received by the antenna at the bore sight direction while at the upper resonant frequency (3.676 GHz) the maximum power was received at angle 36^0 with respect to bore sight. The half power beam width [HPBW] of the antenna in the lower resonant frequency is of the order of 113^0 in E plane and 92^0 in H plane respectively. The HPBW of the antenna at the lower resonating frequency is of the order of 91^0 in E plane and 79^0 in H plane respectively. It is also noted that reasonably higher cross polarization level was seen across the second operating frequency. The upper band characteristics will be found useful in non-line of sight applications.



(a) (b)

Fig – 11: Normalized radiation patterns of the antenna at resonant frequency 2.468 GHz (a) E plane (b) H plane (co-polarized, solid line and cross polarized, dashed line).

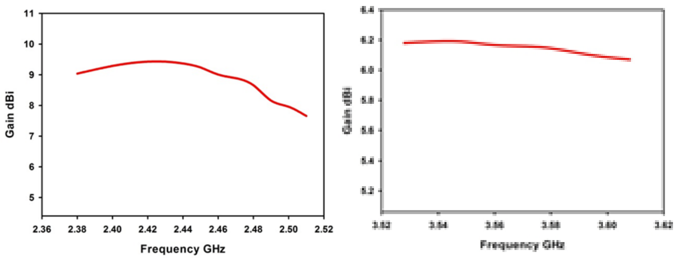


(a) (b)

Fig – 12: Normalized radiation patterns of the antenna at resonant frequency 3,676 GHz (a) E plane (b) H plane (co-polarized, solid line and cross polarized, dashed line).

4.4 Gain Variations Across the Bands

The measured gain of the proposed single layer proximity fed array antenna with slotted ground plane at first resonance frequency is 9.16 dBi and it is comparable with the simulated gain, which is 9.31 dBi. While the simulated and measured gains at the second resonant frequencies are 6.03dbi and 6.16dbi respectively.



(a) (b)

Fig -13: Measured gain with frequency of the proposed single layer proximity fed array antenna with slotted ground plane at (a) first band and (b) second band

Figure 13, depicts measured gain variations across the operating frequency bands. Table 2 shows extracted parameters of the proposed dual band antenna at corresponding resonant frequencies.

Table 2: Extracted parameters of the proposed dual band array antenna with slotted ground plane

Parameters	Frequency at 2.459GHz	Frequency at 3.593GHz
	Values	Values
Electric energy density	0.00133J/m³	0.00134J/m³
Magnetic energy density	0.00319J/m³	0.00256J/m³
H field peak in x direction	43.3357 A/m	41.8739 A/m
H field peak in y direction	25.4782 A/m	23.8752 A/m
H field peak in z direction	77.1463 A/m	72.4792 A/m
E field peak in x direction	5438.42 V/m	5397.49 V/m
E field peak in y direction	9864.27 V/m	9811.34 V/m
E field peak in z direction	9167.28 V/m	9263.67 V/m

5. CONCLUSIONS

A new dual band single layer proximity fed array antenna with slotted ground plane is developed and its operating performances were analyzed. Both simulated and measured results on the array antenna structure demonstrate good results with good impedance matching. Furthermore, the gains at both resonating frequencies are considerably higher with 9.16dBi and 6.03dBi respectively. The results from this research work will contribute a new array configuration towards the use of wireless communication system, especially for WLAN and WiMAX applications

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BIOGRAPHIES

Dr. Jacob Abraham is working as an Associate Professor in the Department of Electronics, Baselios Poulose II Catholicos College [NAAC “A” grade] an aided institution affiliated to Mahatma Gandhi University, Kerala, India. He has more than twenty five years of teaching experience. He obtained his B. Tech in Electronics and Communication Engineering from Mahatma Gandhi University, M. Tech in Optoelectronics from Kerala University and PhD in Microstrip Antennas and Arrays from Mahatma Gandhi University, Kerala, India. He has published around 16 papers in the reputed indexed international journals and more than 25 papers presented in national and international conferences. Besides he has contributed three book chapters also. He also served as editor of the book titled “Recent Developments in Electronics and Communication Engineering” published by IOT Academy. He has also authored a text book on Digital Electronics from Sara Book Publications. He also served as a member board of studies of UG Electronics and as chairman expert committee for PG [Electronics] Syllabus revision of Mahatma Gandhi University. Currently he is a member of Academic Council of Mahatma Gandhi University, Kottayam Kerala. He has successfully completed one minor projects funded by University Grants Commission (UGC). He also served as convener of the UGC sponsored national seminar titled "Modern Trends in Electronic Communication and Signal Processing". His research area includes Microwave Engineering, Printed Antennas, Fractal Antennas, IoT and electric vehicle control and charging. He is life member of ILA and ISCA.