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Tunable and Dual Band Slot Loaded Hexagonal Microstrip Antenna for Wireless Communications

Sumit B. Bhapkar [1], Prof. P. R. Badadapure[2]
[1, 2] Department of Electronics & Telecommunication
JSPM's Imperial College of Engineering & Research,
Wagholi, Pune, India,
[1]sumitb23@gmail.com, [2]badadapurep@gmail.com

ABSTRACT

This article describes the design of single layer dual frequency microstrip antenna for IEEE 802.11b/Bluetooth and WiMAX applications. The new configuration of the antenna is achieved by using open hexagonal ring slot placed at the boundary of the hexagonal patch. The proposed dual frequency antenna exhibits two adjacent resonant modes with the same plane of polarization, radiation characteristics, and impedance characteristics and these modes are excited at frequencies near the fundamental mode TM_{11} of the hexagonal patch without a slot. Compared with the conventional hexagonal patch, the proposed antenna can achieve a large amount of size reduction. It has also been observed that by controlling the width of slot and distance R_1, the two frequencies f_1 and f_2 can have frequency ratio (f_2/f_1) in the range between 1.28 and 1.44. The antenna is simulated and analyzed using Ansoft HFSS.

Key words: dual frequency, microstrip antenna(MSA), open hexagonal ring slot, frequency ratio, resonant frequencies.

1. INTRODUCTION

The miniaturization of the microstrip antenna (MSA) is essential for portable devices and based on this many researchers concentrated on the design of compact MSA. Besides that MSA offers benefits such as light weight, small volume, and ease of integration with Monolithic Microwave Integrated Circuits (MMIC) but narrow bandwidth is the major limitation of the MSA and many bandwidth enhancement techniques reported in [1].

Recently Dual frequency patch antennas have drawn lots of attention in the mobile and wireless communications. The dual frequency antennas are tunable both or one of the two frequencies and two resonant modes for two frequencies exhibit similar radiation characteristics. When two frequencies are significantly spaced, the dual band operation obtained. The dual frequency antenna uses single radiating element for achieving dual band performance and different techniques reported in [2], and many applications require dual frequency operation such as synthetic aperture radars (SAR), RFID system, satellite links etc. Dual frequency operation with a pair of slots at radiating edges, with the frequency ratio of 1.6 to 2.0 or stepped slots at non-radiating edges with frequency ratio 1.23 to 1.63 recently shown in [3, 4], the two modes generated has the similar plane of polarization and broadside radiation characteristics. In [5] authors presented dual-frequency patch antenna with the frequency ratio of 1.28–1.42 and the slot provide reactive loading and obtained using by placing open rectangular ring close to the boundary of the rectangular patch. A circular MSA with an offset open ring slot for dual-frequency operation with two resonant modes with similar radiation characteristics presented [6]. Jui-Han Lu presented slot loaded equilateral triangular MSA [7], in this dual frequency operation achieved by loading two pairs of slots in the triangular patch, one is placed at the side edges of patch and other is placed at the bottom side and by protruding a narrow slot out of the slots close to sides edged, a broadband operation achieved using single probe feed. Using the pair of slots in equilateral triangular MSA dual frequency operation achieved [8], in this two resonant modes are perturbed TM_{10} and TM_{20} of a triangular patch of similar radiation characteristics and polarization. By using the notch in rectangular patch [9], shorting pin with a slot in rectangular patch [10], dual frequency operation achieved. Gap coupled MSA for dual and triple frequency operation investigated in [11].

Use of the stacked configuration antenna for compact differential dual frequency operation obtained [12], compared to conventional stacked dual frequency, the dimensions of the proposed antenna reduced effectively. New configuration introduced in [13] for high-frequency ratio suitable for satellite applications, in which combination of circle notched rectangular patch and circular patch used to achieve dual-frequency operation with two distinct bands, and similar radiation characteristics reported. Dual band circularly polarized antenna using parasitic circular patch reported [14]. In [15] stub loaded circular MSA investigated, in this circular MSA loaded along its feed axis with one or two subs, dual frequency operation achieved when the length of the stub is comparable to the quarter wavelength. RMSA for Bluetooth and WiMAX applications presented in [16], dual band operation is achieved through the slot loading technique.

In this article slot loaded hexagonal MSA for IEEE 802.11b/Bluetooth and WiMAX applications, the operation is realized by embedding open hexagonal ring slot along the boundary of the hexagonal patch and exhibits the similar plane of polarization and broadside radiation characteristics. By using variations in the width and distance R_1, on each -10 dB impedance bandwidth is reported and the antenna is tuned in a suitable range. The proposed antenna is optimized using HFSS based on Finite Element Method (FEM) software [17] followed by experimental verifications.

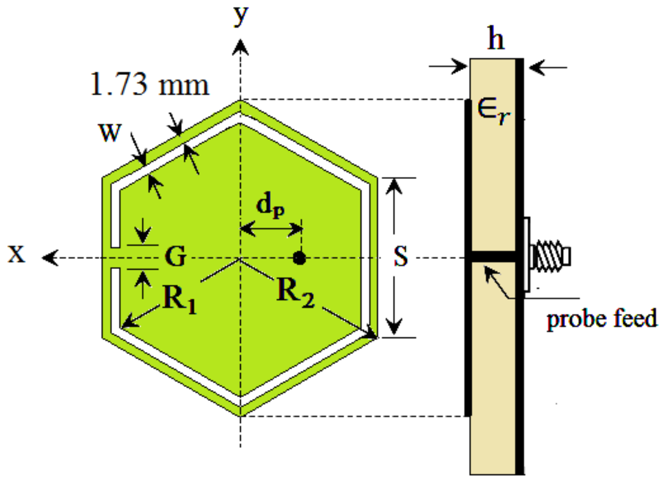

Figure 1: Schematic of the proposed dual frequency hexagonal microstrip antenna with open hexagonal ring slot.

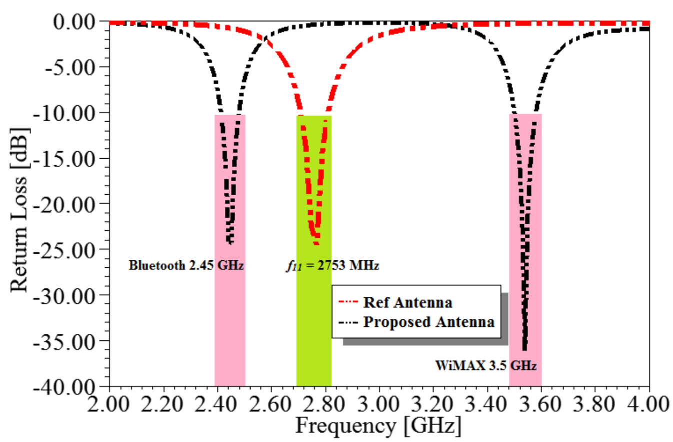

Figure 2: The simulated return loss of the reference antenna and proposed dual frequency MSA shown in Figure 1.

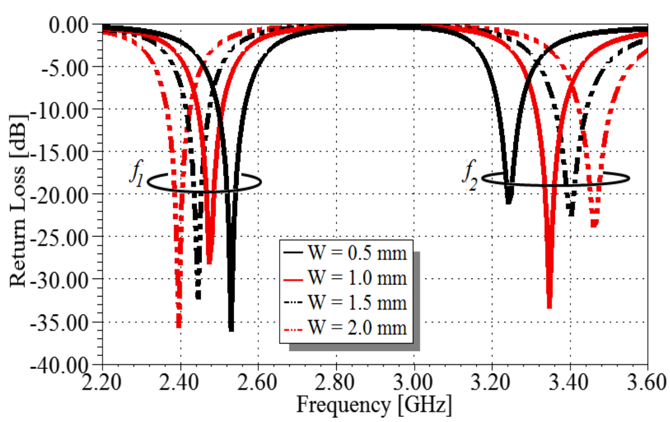

Figure 3: Return loss against the frequency of the proposed dual frequency antenna shown in Figure 1 with various widths (W) of the open hexagonal ring slot; $\in_r$= 4.4, h = 1.6 mm, R_1 = 14 mm, R_2 = 15 mm + W, G = 2 mm, and ground plane size = 55×55 mm^2.

2. DESIGN GEOMETRY

For the design of hexagonal patch, it is needed to understand the design of circular patch since these antennas are closely related to each other [2]. The fundamental resonance frequency of the circular patch for dominant mode TM_{11} is given by [1]. Initially, hexagonal MSA without slot has a side length of S and is printed on a low-cost FR-4 epoxy dielectric material having height h=1.6 mm, tan∂=0.02 and dielectric constant $\in_r$=4.4.

The geometry of the proposed compact dual frequency hexagonal antenna with an open hexagonal ring slot shown in Figure1. An open hexagonal ring slot of width W is implanted close to the edges with a distance of 1.73 mm away from the edges of the hexagonal patch. The overall size of the ground plane found to be 40×40 mm^2. The side length S is found to be 16 mm at fundamental frequency f_r = 2753 MHz The optimum width of slot W is found to be 1 mm. The gap spacing G between two open-ended hexagonal ring slot took to be very small and it is kept at 2 mm with R_1= 13 mm, and R_2 = 16 mm.

For the proposed antenna, the portion of the patch enclosed by the open hexagonal ring slot assumed to be distance R_1, and the relation found from the proposed antenna geometry is $R_2 = R_1$ +W+1mm. Thus, for the proposed antenna there exist two hexagonal patches of different distance R_1 and R_2. A single coaxial probe used to feed antenna of available SMA connector and it is found that by choosing suitable feed location d_p away from the center of the hexagonal patch shown in Figure 1. Two new resonant frequencies f_1 and f_2 are generated of the fundamental mode TM_{11} of the simple hexagonal patch without slot and generated frequencies have a similar plane of polarization and radiation characteristics with good impedance matching.

3. RESULTS AND DISCUSSION

Initially, simple hexagonal patch without slot is designed using f_r = 2.7 GHz and optimized feed location found to be 6.0 mm from the center of the hexagonal patch shown in Figure 1. According to the antenna design described above, based on Ansoft HFSS, many numerical simulations of the open hexagonal ring slot MSA have been performed.

It is observed that for a simple hexagonal patch of distance R_2 = 16 mm, designed at the fundamental frequency is f_{11} = 2753 MHz (mode TM_{11}). In the vicinity of 2753 MHz, for the proposed antenna (open hexagonal ring slot) two new resonant frequencies lower f_1 = 2450 MHz and higher f_2 = 3500 MHz, rather than single mode TM_{11} of the fundamental frequency of the simple hexagonal patch without slot are excited as shown in Figure 2. For the lower mode of frequency f_1 is less than 2753 MHz, while the higher mode of frequency f_2 is greater than 2753 MHz. From the HFSS simulation results the two modes generated are associated with TM_{11}, these two modes have a similar plane of polarization and radiation characteristics.

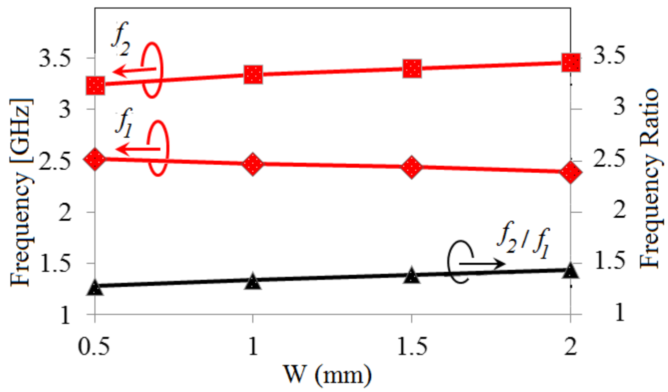

Figure 4: Resonant frequencies f_1 and f_2 and frequency f_2/f_1 against width (W) of the hexagonal patch enclosed by the open hexagonal ring slot for the antenna studied in Figure 2.

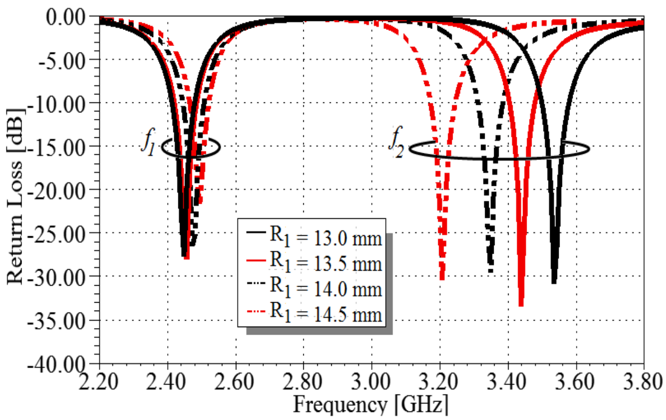

Figure 5: Return loss against the frequency of the proposed dual frequency antenna shown in Figure 1 with various R_1 of the open hexagonal ring slot; ϵ_r= 4.4, h = 1.6 mm, R_2 = 15 mm + W, G = 2 mm, W = 1 mm and ground plane size = 55×55 mm^2.

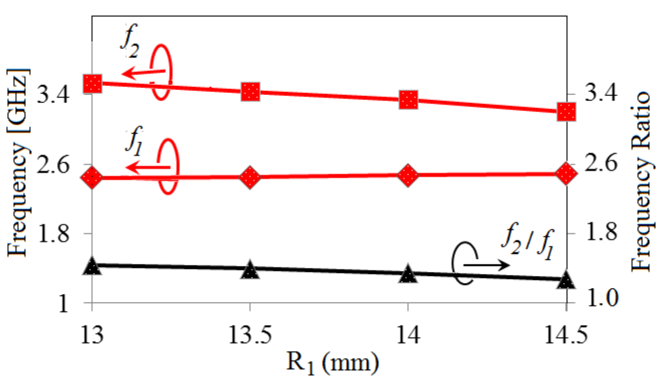

Figure 6: Resonant frequencies f_1 and f_2 and frequency ratio f_2/f_1 against R_1 of the hexagonal patch enclosed by the open hexagonal ring slot for the antenna studied in Figure2.

According to these results, Figure 3 shows the two new resonant frequencies of f_1 and f_2 against the various widths W. In the computation, other parameters of the proposed antenna are fixed as ϵ_r = 4.4, h=1.6 mm, G = 2 mm, S = 16 mm, R_1 = 14 mm. It is observed that with increase in width of slot from 0.5 mm to 2.0 mm, the lower frequency f_1 is decreased from 2529 MHz to 2395 MHz while the higher frequency f_2 is increased from 3242 MHz to 3465 MHz and the corresponding impedance bandwidths for different widths W with Voltage Standing Wave Ratio (VSWR) 2:1 described in Table I. Thus by observing the effect of width of the open hexagonal ring slot on the frequencies f_1 and f_2, the present design exhibits tunable behavior for both the frequencies and frequency ratio of the two frequencies (f_2/f_1) increases from 1.28 to 1.44 as shown in Figure 4 (see Table I).

Table 1: Results of the Proposed Dual Frequency Antenna with Various Width W of the Hexagonal Patches Enclosed By the Open Hexagonal Ring Slots; $\epsilon_r = 4.4, h = 1.6\,mm, R_1 = 14\,mm,\ R_2 = 15\,mm + W, G = 2\,mm$ and Ground Plane Size = 55×55 mm^2.

Slot Width (mm)	d_p (mm)	f_1, BW (MHz, %)	f_2, BW (MHz, %)	f_2/f_1
0.5	6.0	2529, 2.8	3242, 2.0	1.28
1.0	6.3	2473, 2.7	3343, 2.3	1.34
1.5	6.5	2243, 2.6	3400, 2.4	1.39
2.0	6.2	2395, 2.7	3465, 2.5	1.44

Figure 5 depicts the calculated results of the return loss at frequencies for different distances R_1. For this other parameters have been fixed to ϵ_r = 4.4, h=1.6 mm, G = 2 mm, S = 16 mm, W = 1.0 mm. It has been observed that with the increase in R_1 from 13 mm to 14.5 mm, lower frequency f_1 is fixed while higher f_2 is decreased from 3536 MHz to 3206 MHz as shown in Figure 6. Thus by observing the effect of R_1 on the performance of the proposed antenna, frequency f_1 is fixed and f_2 is tunable hence frequency ratio of the two frequencies (f_2/f_1) decrease from 1.44 to 1.28 as depicted in Figure 6.

It is found that for the proposed antenna shown in Figure 1, in the vicinity of fundamental frequency 2.7 GHz, two new resonant frequencies f_1 and f_2 are excited having the similar plane of polarization and broadside radiation characteristics with cross polarization, beneath -10 dB in x–z plane and y–z plane observed and shown in Figure 7. The gain for the two operating frequencies is also about the same and it is about 3.23 dBi and 73% radiation efficiency obtained. The proposed antenna is designed and simulated using Ansoft HFSS.

As there are many parameters for the proposed antenna by properly tuning these parameters, good impedance matching can be obtained at both the frequencies. Figure 8 shows impedance characteristics of the proposed antenna shown in Figure 1 for two different frequencies f_1 = 2450 MHz (IEEE 802.11b/Bluetooth) and f_2 = 3500 MHz (WiMAX) with good impedance matching.

4. CONCLUSION

A new design of the single layer single feed open hexagonal ring slot for dual frequency operation has been presented and studied. By varying the parameters of the proposed antenna such as width W and distance R_1, the frequency ratio of the two frequencies is tuned in the range ~ 1.28 to 1.44. The frequency ratio of the antenna varies linearly with width W of the slot while it depends inversely on distance R_1. The two resonant frequencies exhibit the similar plane of polarization and broadside radiation characteristics with good impedance matching. The proposed dual frequency antenna is suitable for IEEE 802.11b/Bluetooth (2.45 GHz) and WiMAX (3.5 GHz) wireless applications.

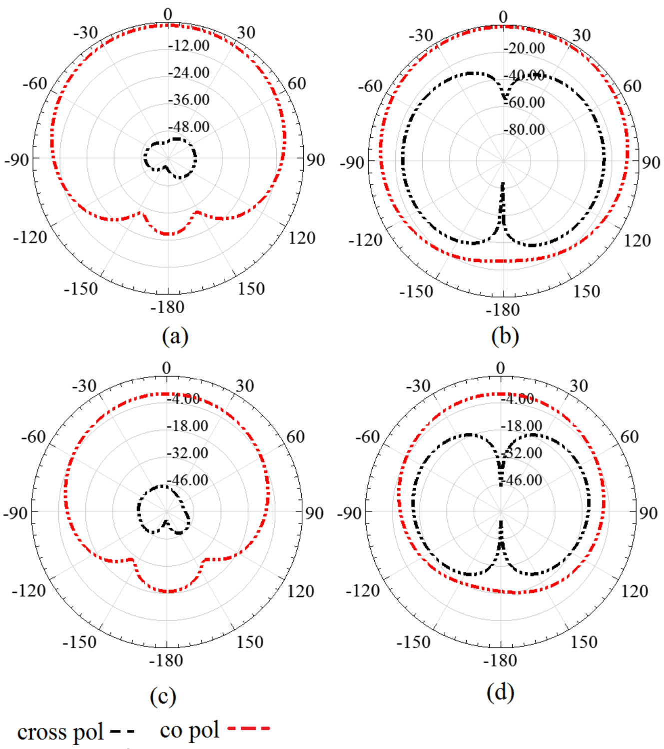

Figure 7: Radiation characteristics of the antenna shown in Figure 1 at f = 2450 MHz (a) *E*-plane (*x*–*z* plane) and (b) *H*-plane (*y*–*z* plane), at f = 3500 MHz (c) *E*-plane (*x*–*z* plane) and (d) *H*-plane (*y*–*z* plane).

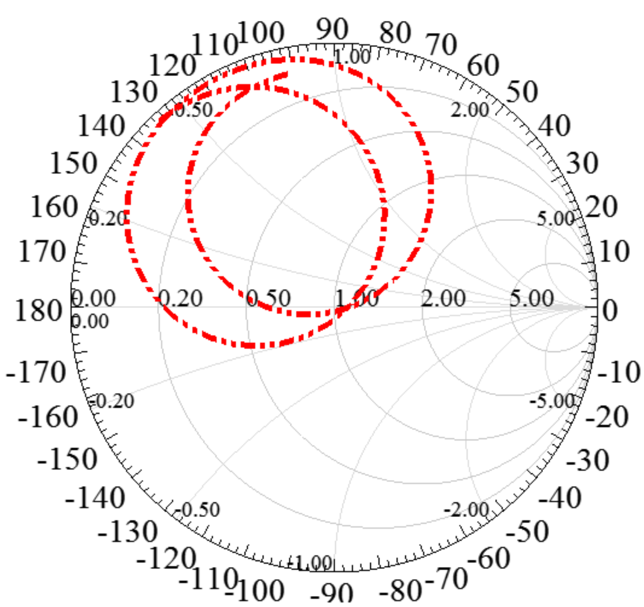

Figure 8: Impedance characteristics of the proposed antenna shown in Figure 1.

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