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COMPACT DUAL BAND SLOT LOADED CIRCULAR MICROSTRIP ANTENNA WITH A SUPERSTRATE

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Abstract—Design of a compact dual frequency microstrip antenna is presented. The structure consists of a slotted circular patch with a dielectric superstrate. The superstrate, not only acts as a radome, but improves the bandwidth and lowers the resonant frequency also. The proposed design provides an overall size reduction of about 60% compared to an unslotted patch along with good efficiency, gain and bandwidth. The polarization planes at the two resonances are orthogonal and can be simultaneously excited using a coaxial feed. Parametric study of this configuration showed that the frequency ratio of the two resonances can be varied from 1.17 to 1.7 enabling its applications in the major wireless communication bands like AWS, DECT, PHS, Wi.Bro, ISM, and DMB. Design equations are also deduced for the proposed antenna and validated.

1. INTRODUCTION

Microstrip antennas offers many attractive features such as low profile, light weight, easy fabrication, integrability with microwave and millimeter-wave integrated circuits, and conformability to curved surfaces [1]. Modern communication systems such as those for satellite link (GPS, Vehicular, etc.), for mobile communication and for wireless local area networks (WLANs), often require compact antennas to satisfy the severe constraints on physical dimensions of the portable equipments. In addition to compactness, operation at two or more discrete frequency bands is also a desired feature. Such a design can avoid the use of multiple antennas, like for instance, by integrating receiving and transmitting functions in to the same communication system or the same antenna operating in the GSM 1800 MHz and WLAN 2.4 GHz application bands.

Several compact dual band microstrip antenna designs have been reported over the years. A simple technique for achieving this has been to load the radiating patch with a slot, which when appropriately designed can not only lower the fundamental resonant frequency of the antenna but also lead to a dual/wide band operation. It is the meandering of the excited surface current paths in the radiating patch of the antenna that lowers its resonant frequency. The meandering of the surface current paths can be achieved by loading several meandering slits at the non radiating edges of a rectangular patch [2–4] or at the boundary of a circular patch [5] or by loading slots inside the radiating patch [6–11]. The dual frequency operation is achieved when the slots perturb the fundamental resonant frequency of the patch exciting a new resonance mode. The resonance frequency of the new mode can be either lower [12, 13] or higher [14] than the original dominant mode with either the same [12] or orthogonal polarization [15] and is strongly dependent on the slot dimensions.

In this paper, a single probe-fed circular patch antenna loaded with a sector slot along with a superstrate and having dual band operation is presented. The lower resonance of the antenna is by virtue of the increase in the current path on the patch due to the slot while the higher resonance is similar to that of an un-slotted circular patch of same size. The coordinates of the probe feed is suitably chosen for maximum impedance matching at both the resonances. A superstrate when employed not only protects the antenna from environmental hazards but lowers its resonance frequency further while improving the gain and bandwidth [16–20]. The present design has a coaxially fed conducting patch with air/foam as substrate and FR4 dielectric as radome. In this case, as copper cannot be deposited on air/foam, the patch was fabricated on FR4, inverted and supported by nylon spacers. The radiation characteristics at its two resonant frequencies are similar to that of a conventional circular patch antenna except the polarizations. The orthogonal polarizations can be simultaneously excited using a coaxial feed. The dual frequencies can be tuned by changing the dimensions of the slot. The simulation studies on the antenna have been carried out using IE3D^{TM} [21]. Design equations for the proposed antenna are also presented.

2. ANTENNA DESIGN

The prototype of the proposed antenna is given in Fig. 1. It has a sector-slotted circular patch, sandwiched between a substrate of

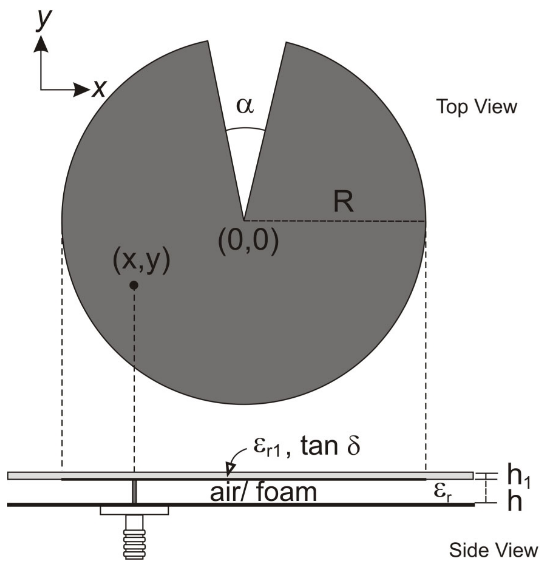

Figure 1. Geometry of the microstrip-fed sector slotted circular patch antenna with a radome.

permittivity ε_r and thickness h and a superstrate of permittivity of ε_{r1} and thickness h_1. The size of the ground plate and superstrate is $100 \times 100\,\text{mm}^2$. The effects of a sector slot and superstrate on a circular patch antenna is studied from antennas of different dimensions as tabulated in Tables 1 and 2. Antenna 1 is a simple probe-fed circular patch antenna on FR4 substrate which operates at 2.65 GHz. When a sector-slot is etched on the circular patch (antenna 2), dual resonances are observed at 1.94 GHz and 2.7 GHz, but with low radiation efficiency and narrow bandwidth at the lower resonance. The radiation efficiency(η) can be improved as in antenna 3, to 77% and 98% at 1.93 GHz and 2.66 GHz respectively, when air is used as the substrate; h is increased to 5mm and radius of the patch, R, to 30 mm, to get the same resonances.

A superstrate loaded dual band sector slotted circular patch antenna (antenna 4) is the proposed design. It can be observed that the superstrate reduces the resonance frequencies slightly and improves the impedance bandwidth. The superstrate also provides mechanical strength to the design as well as provides protection against environmental hazards even though there is a slight reduction in efficiency and gain due to the lossy FR4 superstrate ($\tan\delta = 0.02$). The results (Table 2) indicate resonances at 1.7 GHz and 2.4 GHz with bandwidths (ΔBW) of 5.1% and 3.9%. Hence, a reduction in size with an improved bandwidth is achieved at the lower resonance of the proposed design compared to an un-slotted patch, with no superstrate (antenna 5). Also, compared to an un-slotted circular patch on a thin FR4 substrate (antenna 6), a significant improvement in bandwidth, efficiency and gain is obtained for the present design at the cost of a slight increase in size.

To get an insight into the working of this sector-slotted circular patch antenna, the simulated current distribution on the patch at its resonant frequencies are shown in Fig. 2, where the darker areas represent higher intensity. It can be observed from the figure that the higher resonance is similar to that of an un-slotted circular patch antenna while the lower resonance is the result of the lengthening of the current path along the perimeter of the patch due to the presence of the sector slot. The two resonances are found to be with orthogonal polarizations.

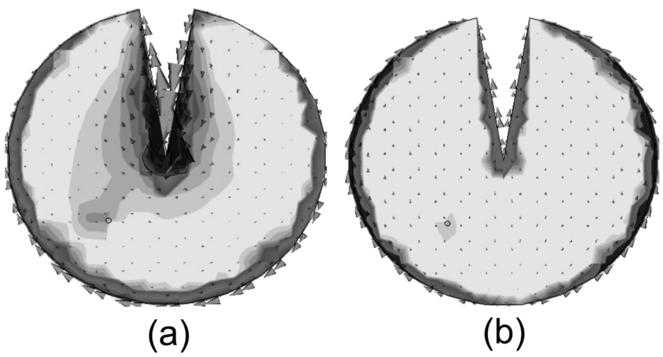

Figure 2. Current distribution on patch at (a) 1.72 GHz and (b) 2.4 GHz.

The dual resonance frequencies of the proposed design can be deduced by replacing the sector-slotted circular patch by two equivalent circular patches of circumferences C_1 and C_2. The circumference of C_1 is the total perimeter of the circular patch with sector slot and its corresponding resonance frequency would be f_{r1}, the lower resonance frequency of the proposed design. Similarly the circumference of C_2 is the length of the major arc of the sector-slotted circular patch and its resonant frequency would be f_{r2}, the second resonance of the proposed design. The resonance frequency, f_r, of a circular patch with air as substrate (ε_r=1, h) and a thin superstrate (ε_{r1}, h_1) is approximated from [22] as

$$f_{ri} = \frac{1.841c}{P_e\sqrt{\varepsilon_{reff}}} \tag{1}$$

where c is the speed of light, ε_{reff} is the effective permittivity approximated to that of a two layered patch antenna as

$$\varepsilon_{reff} = \frac{\varepsilon_r \varepsilon_{r1}(h + h_1)}{\varepsilon_r h_1 + \varepsilon_{r1} h} \tag{2}$$

P_e is the effective circumference of the equivalent circular patches C_1 or C_2.

$$P_e = P_i\{1 + \frac{2h}{\pi R \varepsilon_{re}}(ln\frac{\pi R}{2h} + 1.7726)\}^{\frac{1}{2}} \tag{3}$$

where

$$i = \begin{cases} 1, & P_1 = Circumference\ of\ C_1 = R(2\pi - \alpha) + 2R \\ 2, & P_2 = Circumference\ of\ C_2 = R(2\pi - \alpha) \end{cases} \tag{4}$$

R is the radius and α is the slot angle of the proposed antenna. The resonant frequencies calculated using the above equation are compared with the measured results in Table 2.

Table 1. Antenna parameters.

Antenna	R (mm)	ε_r	h (mm)	ε_{r1}	h_1 (mm)	*feed* coordinate	α (deg)
1	15.5	4.4	1.6	-	0	(4,5)	0
2	15.5	4.4	1.6	-	0	(6,6)	20
3	30	1	5	-	0	(11,13)	20
4	30	1	5	4.4	1.6	(11,13)	20
5	48	1	5	-	0	(21,0)	0
6	24	4.4	1.6	-	0	(7,8)	0
7	30	1	5	4.4	1.6	(11,13)	0

The influence of the slot parameters on the dual frequencies is studied by varying the slot angles, and slot vertex positions. The variation of two resonant frequencies, f_{r1} and f_{r2}, with slot angle is plotted in Fig. 3(a). When α is increased from 10° to 90°, f_{r1} and f_{r2} increases from 1.69 GHz to 1.86 GHz and 2.37 GHz to 2.81 GHz. This can be attributed to the fact that on increasing the slot angle, the perimeter of the antenna or in other words the length of the current path decreases which in turn increases resonant frequencies. Thus by varying the slot angle α, ratio of the two resonances can be changed from 1.402 to 1.51.

Table 2. Comparison of antenna properties.

Antenna	*Simulated*					*Calculated*
	f_{r1} (GHz)	ΔBW (%)	η_1 (%)	dir_1 (dB$_\mathrm{i}$)	$gain_1$ (dB$_\mathrm{i}$)	f_{r1} (GHz)
1	-	-	-	-	-	-
2	1.94	1.54	10.5	6.1	-3.7	2.07
3	1.93	1.8	77	8.8	7.6	1.94
4	1.7	5.1	62	8.7	6.6	1.8
5	1.7	4.1	98	9.8	9.65	1.61
6	1.7	2.3	30	6.3	1.04	1.7
7	-	-	-	-	-	-
Antenna	*Simulated*					*Calculated*
	f_{r2} (GHz)	ΔBW (%)	η_2 (%)	dir_2 (dB$_\mathrm{i}$)	$gain_2$ (dB$_\mathrm{i}$)	f_{r2} (GHz)
1	2.65	2.5	39	6.4	2.2	2.62
2	2.7	2.3	40	6.4	2.45	2.77
3	2.66	4.1	98	9.7	9.5	2.6
4	2.4	3.9	93	9.6	9.2	2.4
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	2.4	6.2	93	9.7	9.4	2.3

The distance of the vertex of the slot from the center also affects the resonant frequency. As can be seen in Fig. 3(b), there is a marked shift in the first resonance fr1 from 2.05 to 1.42 GHz while the change in f_{r2} is insignificant, leading to a dual band frequency ratio variation from 1.17 to 1.7. Here also, it is clear that the lower resonance f_{r1} is caused by the presence of the slot and higher resonance f_{r2} is due to the circular patch. The calculated resonant frequencies are observed to be comparable with the measured values especially for small slot angles, α.

On varying either or both the angular dimension and the vertex of the sector slot, the lower resonance can be varied in the range 1.42–1.86 GHz while the higher from 2.37–2.81 GHz with more than 3.5% bandwidth at both the resonances making the proposed design selectively cover the AWS† (1710–1755 GHz), DECT‡ (1880–

† Advanced Wireless Services

‡ Digital Enhanced Cordless Telecommunications

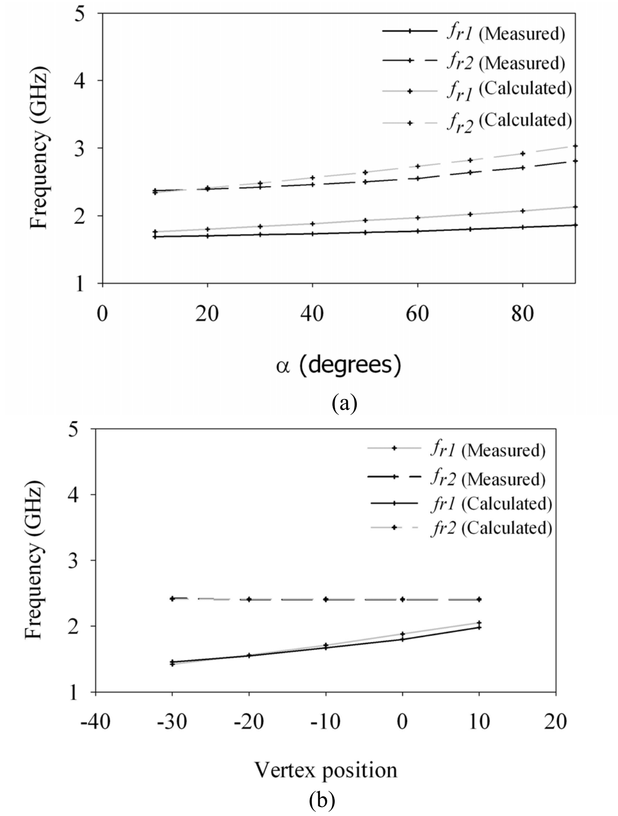

Figure 3. Variation of resonance frequencies of the proposed antenna (a) with slot angle α and (b) with vertex position.

1900 MHz), PHS[§] (1905–1920 MHz), Wi Bro[‖] (2300–2390 MHz), ISM[¶] (2400–2485 MHz), DMB[+] (2605–2655 MHz) frequency bands.

3. RESULTS

The proposed probe-fed sector slotted circular patch antenna protected by a radome (antenna 4), designed for 1.7 GHz/2.4 GHz operation was fabricated and its return loss and radiation patterns are measured using HP 8510C network analyser.

§ Personal Handy Phone Systems
‖ Wireless Broadband
¶ Industrial, Scientific and Medical
\+ Digital Multimedia Broadcasting

The simulated and measured return loss of the proposed antenna, along with that of an unslotted patch, are shown in Figure 4. The unslotted circular patch antenna resonates almost at the same frequency as the higher resonance f_{r2} of the proposed antenna for small slot angles, α.

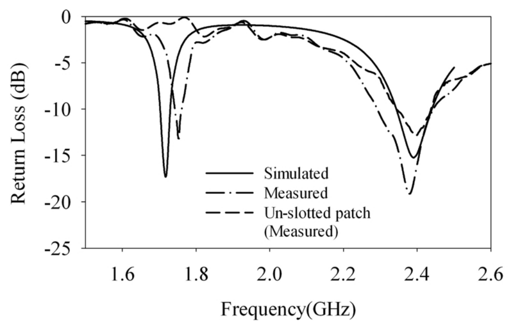

Figure 4. Measured and simulated return loss of the proposed design (antenna 4).

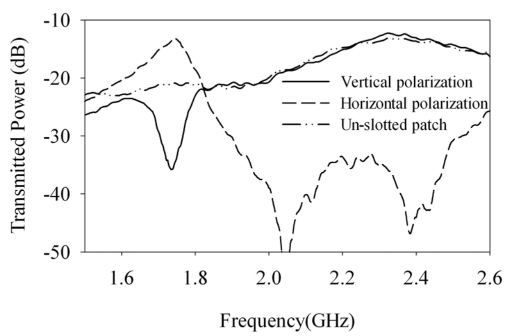

Figure 5. S_{21} from the proposed antenna along vertical & horizontal polarizations and from an un-slotted circular patch of the same size.

The transmission characteristics (S_{21}) of the proposed antenna and an un-slotted circular patch antenna of same radius are shown in Figure 5. The S_{21} measurements using a linearly polarized horn antenna indicated that the two resonances are orthogonally polarised. The gain of the proposed antenna at the second resonance are comparable with that of the un-slotted circular patch antenna of the same radius (antenna 7) while the gain at the first resonance is slightly lower. These results are comparable with the results in Table 2.

The polarization of this configuration is along the x-axis at f_{r1} and along y axis at f_{r2}. The E-plane and H-plane radiation patterns are plotted at both resonance frequencies and shown in Figure 6. The radiation patterns are in broadside direction with better cross polar level at f_{r2}.

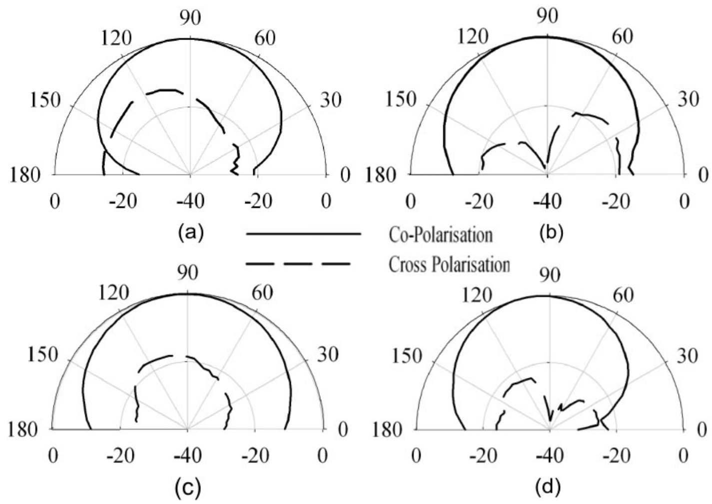

Figure 6. H-plane and E-plane radiation patterns of the proposed antenna (a & b) at 1.75 GHz and (c & d) at 2.39 GHz.

4. CONCLUSION

A compact coaxially fed sector-slotted circular patch antenna with a superstrate for dual-frequency operation has been designed and experimentally verified. A simple sector slot on the circular patch leads to dual resonances with the first being lower than the fundamental resonance of the un-slotted circular patch. A dielectric superstrate is employed as a radome which in addition to protection, lowers the resonance frequency further and improves the bandwidth. Hence the proposed dual band antenna is simple in design and has improved efficiency, gain and bandwidth at the cost of a slight increase in size compared to a conventional circular patch on a thin substrate. But when compared to an unslotted circular patch with air as substrate, as in the proposed design, it has an advantage of 61% reduction in size along with dual frequency operation and protection from environmental hazards and mechanical strength due to the radome. The antenna radiates in the broadside direction with orthogonal polarisations at the two resonances. Design equations are presented to predict the resonant frequencies of the proposed design. Parametric analysis revealed that resonances of the antenna can be changed by varying the slot parameters so that dual frequency ratio can be tuned from 1.17 to 1.7 suitably covering major wireless communication bands like AWS, DECT, PHS, Wi.Bro, ISM and DMB.

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