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Modified circular patch antenna with key shape slot for wireless communication systems

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***Abstract*- The paper presents the design aspects and radiation performance of a compact broadband single-feed circular patch antenna with key shaped slot for modern wireless communication systems. The two measured resonant frequencies of proposed antenna lie in the lower and upper bands adopted by IEEE 802.16 for Wi-Max communication systems. This dual band operation is achieved by introducing an offset circular ring slot near the periphery of conventional circular patch while broadband performance from proposed structure is achieved by attaching a narrow slit with this ring slot. The reflection coefficient (S_{11}), VSWR, input impedance and pattern measurements are carried out to verify the outcome of simulation analysis. The simulated radiation patterns drawn at four resonance frequencies in the frequency range where broadband response is achieved are almost identical in shape. The direction of maximum radiations is normal to the patch geometry. The gain of antenna is low but presents variation of <1dBi within desired frequency range.**

***Index Terms*- Broadband operation, dual band, Microstrip patch antenna, radiation properties**

I. INTRODUCTION

Microstrip antennas have attracted much interest in modern communication systems, due to their inherent properties including small size, light weight, low cost on mass production, low profile and easy integration with other circuit components [1-2]. However their capability to operate at a single frequency, narrow bandwidth and low gain in comparison to other microwave antennas restricts their practical applications [3-5]. Modern mobile and wireless communication systems demand compact size broad band and dual / multi frequency antennas hence possibility to apply these antennas for modern communication systems is reinvestigated by applying modifications in patch geometries [6]. Wong et al. [7] obtained a compact circular microstrip antenna with a patch size less than 10% of the conventional circular patch antenna by using a shorting pin along with meandering of circular patch. Hsu and Wong [8] designed a circular patch antenna on a thick air substrate with a pair of wide slits having impedance bandwidth greater than 25% and a peak antenna gain about 8.3 dBi. Krishna et al. [9] reported the improved bandwidth design of a compact dual band slot loaded circular microstrip antenna with a superstrate for application in major wireless communication bands. Bao and Ammann [10] proposed the design of a compact circularly polarized wideband circular patch antenna embedded in a narrow annular-ring which uses an unequal cross-slotted ground plane. Recently Azenui and Yang [11] proposed a transmission line fed crescent patch antenna for wide band applications with displaced center of circular region from center of outer ellipse. Recently, Garima et al. [12] reported the radiation performance of an off centered circular ring slot antenna. This dual band antenna has two resonance frequencies in the lower and upper frequency bands allocated by IEEE 802.16 working group for Wi-Max applications. The bandwidth of this antenna in both frequency bands is low hence this antenna is modified in this communication to further improve its bandwidth and other radiation parameters.

II. MODIFICATIONS IN ANTENNA STRUCTURE & ITS MEASURED RESULTS

A conventional circular patch antenna with patch

radius 1.62 cm designed on Glass epoxy FR-4 substrate with relative permittivity ε_r = 4.4, substrate height h = 0.159 cm and loss tangent = 0.025 resonates at frequencies 2.52GHz and 5.12GHz as shown in Fig.1. The first resonance frequency corresponds to the dominant TM_{11} mode while the second resonance frequency corresponds to TM_{02} mode. The bandwidth presented by antenna at each of these frequencies is narrow (1-2%) and gain has low value (~1.5dBi). These values suggest that antenna in its present form is not much suitable for modern communication systems.

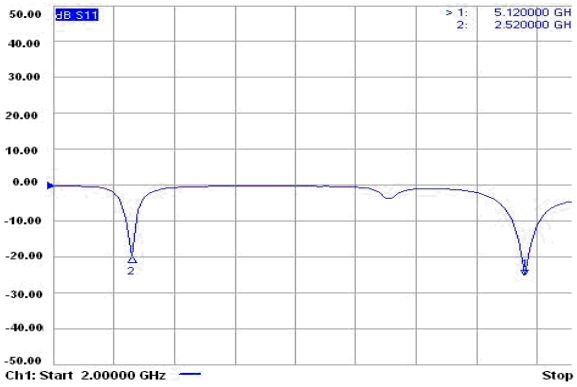
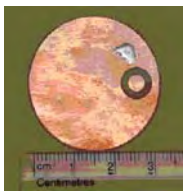
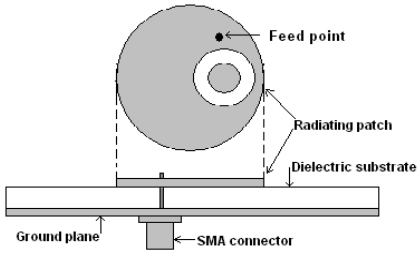


Fig. 1. Measured reflection coefficient (S_{11}) of conventional circular patch antenna with frequency



"(a)"



"(b)"

Fig. 2. (a) Designed off centered circular ring slot antenna (b) Feed arrangement

We therefore modified this circular patch geometry by applying an off centered ring slot with inner and outer radius 2mm and 4mm respectively and center of ring slot located 1.05 cm away from the center of outer circular patch as shown in designed antenna in Fig. 2(a). The outer patch is excited through an inset feed SMA connector as shown in Fig. 2(b) with 50 ohm feed line. The inner circular patch is thus gap coupled with the outer patch. The measured reflection coefficient (S_{11}) results shown in Fig. 3 suggest that antenna is presenting good matching with feed network at two resonance frequencies namely f_1 = 2.47GHz and f_2 = 5.83GHz which lie respectively in the lower and upper bands allocated for Wi-Max systems. Antenna is still presenting poor bandwidth at both frequencies (3.45% in upper band and 3.03% in lower band).

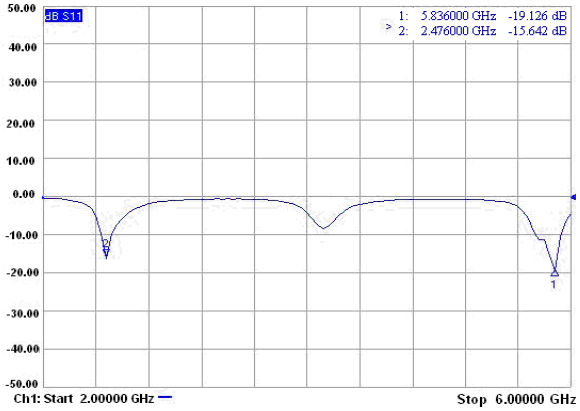


Fig. 3. Measured reflection coefficient (S_{11}) of off centered circular ring slot antenna with frequency

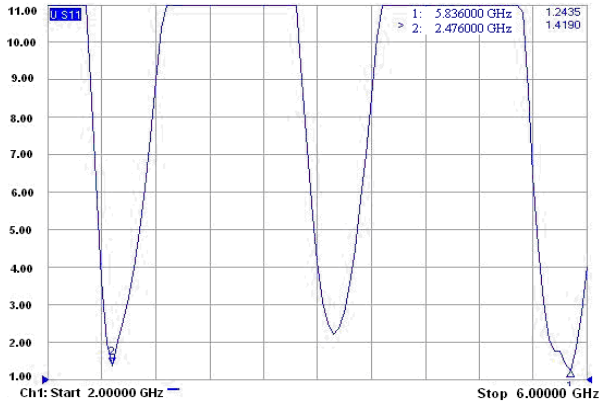


Fig. 4. Measured VSWR of off centered circular ring slot antenna with frequency

The measured VSWR of antenna, as shown in Fig. 4, at the two resonance frequencies 2.47GHz and 5.83GHz are 1.42 and 1.24 respectively which are better than maximum desired (2:1) value. The variation in measured input impedance of antenna as a function of frequency is shown in Fig. 5 which indicates that the input impedance of antenna is close to 50 ohm impedance of the feed line.

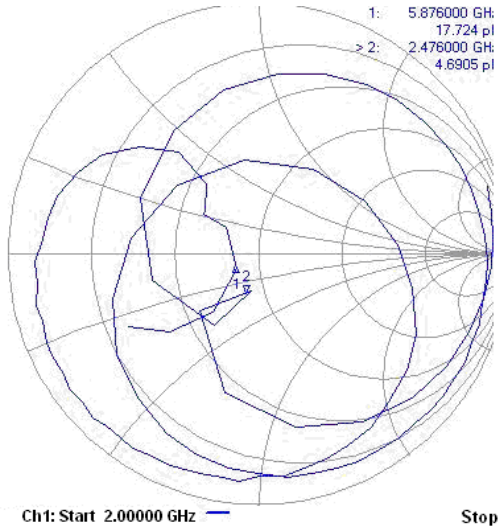


Fig. 5. Measured input impedance of off centered circular ring slot antenna with frequency

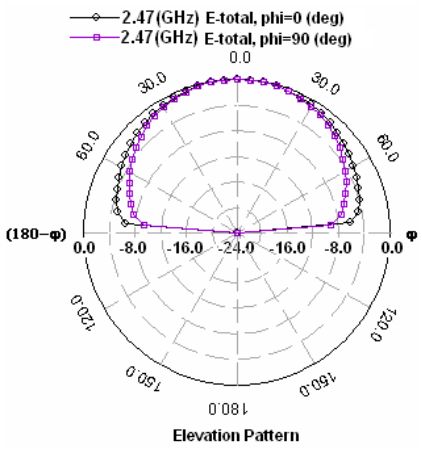
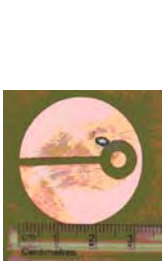


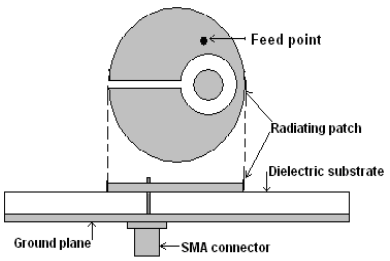
Fig. 6. Simulated radiation pattern of off centered circular ring slot antenna at frequency 2.47GHz

The representative simulated radiation patterns of this antenna at frequency 2.47GHz is shown in Fig. 6 which suggest that the direction of maximum radiations is normal to patch geometry and patterns are more or less symmetric in nature. The 3dB beam width of both E and H plane patterns are almost equal. The results suggest that with the introduction of an offset circular ring slot near the periphery of conventional circular patch, dual band operation is achieved but the impedance bandwidth needs further improvement. We therefore modified this antenna further and results of this modified antenna are presented in the next section.

III. CIRCULAR PATCH WITH OFF CENTERED KEY SHAPED SLOT

Considering the latest trends of modern communication systems in which broadband multi frequency antennas with higher performance are preferred, we further modified previously reported antenna by applying a narrow slit attached with circular ring slot as shown in Fig. 7(a) and named it modified circular patch antenna with key shape slot (CPAKSS). The structure is re-optimized to attain further improved performance. The optimum performance from antenna is achieved when the center of ring slot (outer radius 5mm and inner radius 2mm) is 10 mm away from the center of outer circle and thickness of applied slit is 2mm. The feed arrangement is shown in Fig. 7(b). The simulated and measured reflection coefficient (S_{11}) variations for the proposed patch geometry with feed location (x = 5.7 mm, y = 3.9 mm) are shown in Figs. 8(a) and 8(b) respectively.





"(a)" "(b)"

Fig. 7. (a) Designed off centered key slot circular ring slot antenna (b) Feed arrangement

The simulation results of proposed antenna shown in Fig. 8(a) reveals that antenna has three resonance frequencies namely 2.581 GHz (VSWR 1.32), 3.150GHz (VSWR 1.45) and 5.20 GHz (VSWR 1.20) where imaginary part of input impedance is close to zero. Out of these three resonance frequencies, the first frequency lies in the lower band while last frequency lies in upper band allocated for Wi-Max systems by IEEE 802.16 working group. The second resonance frequency 3.15GHz is marginally away from the allocated median band. In upper band another resonance frequency at 4.765 GHz is also realized where VSWR presented by antenna is 1.53. The two S_{11} curves corresponding to frequencies 4.765GHz and 5.20GHz are partly overlapped over each other to present improved impedance bandwidth of the order 13.06% in the upper band which is around six times higher than that of a simple circular patch antenna operating under similar conditions.

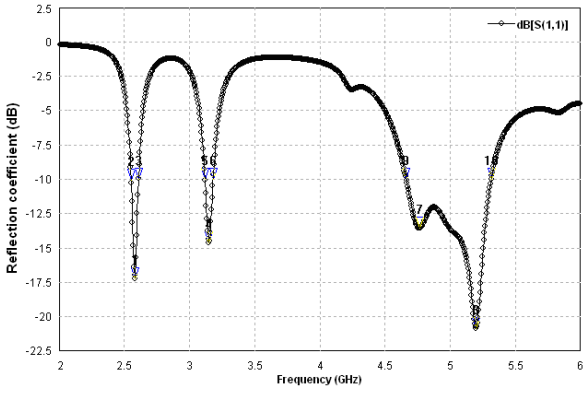


Fig. 8(a). Simulated reflection coefficient (S_{11}) of proposed CPAKSS antenna with frequency

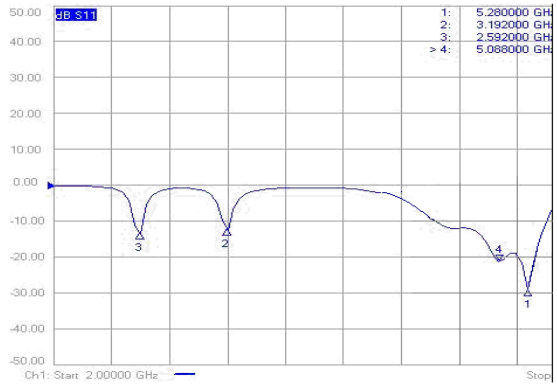


Fig. 8(b). Measured reflection coefficient (S_{11}) of proposed CPAKSS antenna with frequency

The measured resonance frequencies of this antenna are 2.592GHz, 3.192GHz, 5.088GHz and 5.280GHz which are in close agreement with the simulated resonance frequencies. The measured impedance bandwidth is 765MHz or 15.25% with respect to the central frequency. The measured VSWR of antenna at all the resonance frequencies are lower than 2:1 value and measured real part of input impedance of antenna at 5.28GHz is close to 50ohm with imaginary part close to zero. At other frequencies, fair matching between antenna and feed line may be realized.

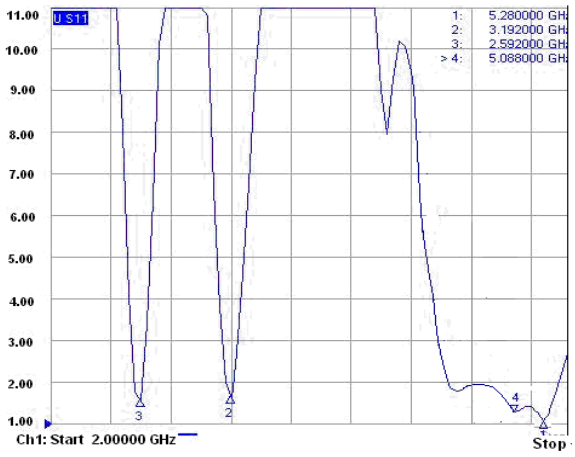


Fig. 9. Measured VSWR of proposed CPAKSS antenna with frequency

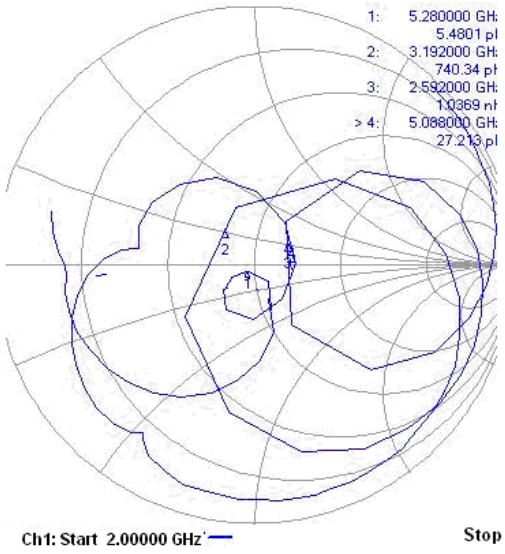


Fig. 10. Measured input impedance of CPAKSS geometry with frequency

The two dimensional simulated E and H plane radiation patterns of proposed antenna at two extreme frequencies of the input impedance bandwidth 4.66 GHz and 5.32GHz where broadband response is obtained are shown in Figs. 11 and 12 respectively. The E-plane radiation patterns in both figures are more or less identical in shape and indicate that antenna radiates maximum energy normal to the patch geometry. The 3dB beam width of patterns in both figures is almost same. The measured E and H plane radiation patterns of this antenna at frequency 5.28GHz are shown in Fig. 13. These patterns suggest that the direction of maximum radiations is directed normal to patch geometry and H plane patterns are little more directive (3dB beam width 59°) than E plane patterns (3dB beam width 67°).

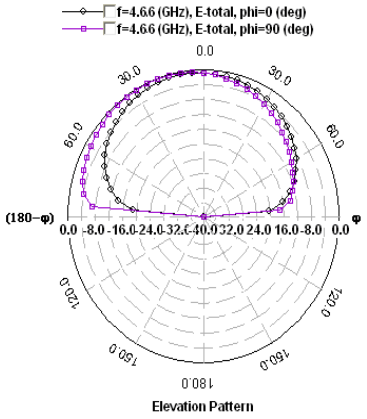


Fig. 11. Simulated E and H plane patterns of antenna at frequency 4.66 GHz

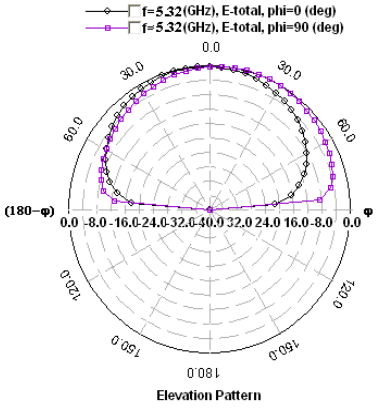


Fig. 12. Simulated E and H plane patterns of antenna at frequency 5.32GHz

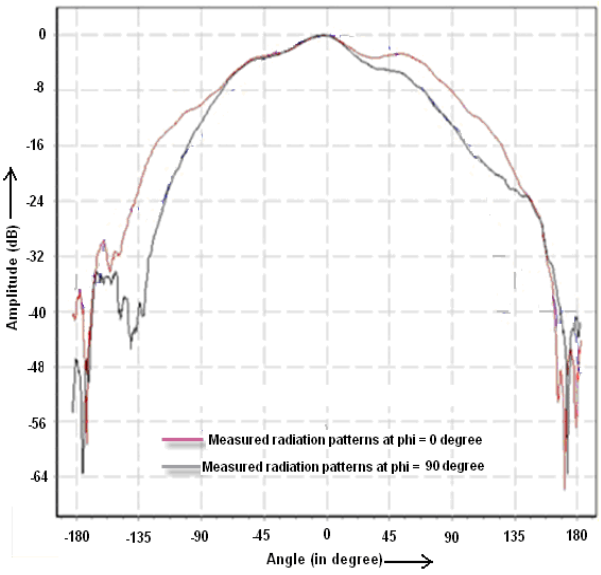


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Fig. 13. Measured E and H plane radiation patterns of the antenna at frequency 5.28GHz

IV. DISCUSSION AND CONCLUSIONS

The off centered circular ring surrounding circular patch geometry reported earlier [12] is further modified in this paper and named it modified circular patch antenna with key shape slot CPAKSS. This modified antenna is simulated and later designed on glass epoxy FR-4 substrate and its performance is investigated in free space. The measured results suggests that modified antenna resonates at three frequencies with improved measured bandwidth (15.25%), which is almost seven times higher than that of a simple circular patch antenna operating under similar conditions. Beside this, antenna is useful for dual band operation i.e. for lower (2.4 - 2.64 GHz) and upper (5.15 – 5.85 GHz) bands adopted by IEEE 802.16 working group for Wi-Max communication systems. The gain and efficiency of antenna are low but with the application of better substrate material, these limitations may be overcome.

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