A Triple Band Arc-Shaped Slot Patch Antenna for UAV GPS/Wi-Fi Applications

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***Abstract* - In this paper, a triple band capacitive-fed circular patch antenna with arc-shaped slots is proposed for 1.575 GHz GPS and Wi-Fi 2.4/5.2 GHz communications on unmanned aerial vehicle (UAV) appliactions. In order to enhance the impedance bandwidth of the antenna, a double-layered geometry is applied in this design with a circular feeding disk placed between two layers. The antenna covers 2380 - 2508 MHz and 5100 - 6030 MHz for full support of the Wi-Fi communication between UAV and ground base station. The foam-Duroid stacked geometry can further enhance the bandwidths for both GPS and Wi-Fi bands when compared to purely Duroid form. The simulation and measurement results are reported in this paper.**

I. INTRODUCTION

Modern Unmanned Aerial Vehicles (UAV) usually carries a large number of surveillance sensors and communication modules for information gathering and surveillance purposes [1]. It requires extensive communications and data transferring between the sensors, such as GPS receiver and accelerometer, and the Ground Base Station (GBS) [2]. Therefore, antenna systems integrated on the UAV device are critical to establish reliable radio communication links. For this application, patch antenna becomes a good candidate due to its simple geometry, low profile and inexpensive cost. In [3], a directional triple band planar antenna is proposed for WLAN/WiMax access point applications. The triple-band planar antenna consists of a top-loaded dipole for the 2.4 GHz band, two shorter pairs of dipoles are for the 3.5 GHz and 5 GHz bands. In [4], the antenna operates at 1.6 GHz and 2.05-2.29 GHz. Modifying the subtending angle of the arc-shaped slot allows tuning of the frequency bands and the band spacing ratio. In [5], a triple band H-shaped slot antenna fed by microstrip coupling is proposed, exciting a monopole mode, a slot mode, and their higher-order modes, to cover GPS (1.575 GHz) and Wi-Fi (2.4-2.485 GHz and 5.15-5.85 GHz), respectively. In [6-8], different antennas have been report to realize tri-band (WLAN/WiMax). They were developed for user terminals, such as mobile handsets or laptop computers with omnidirectional and low radiation gain. However, the antenna for UAV application needs wide bandwidth and high gain. In this paper, a tri-band patch antenna design with a capacitive feeding disk and double-layer stacked substrates is presented. It can be mounted on the side of UAV. With using the capacitive feeding disc and stacked substrate, the impedance bandwidths at both frequencies are much improved. It has wider bandwidth than the antenna in [3] and higher gain than the antenna in [5] to fully support the UAV GPS and Wi-Fi communications.

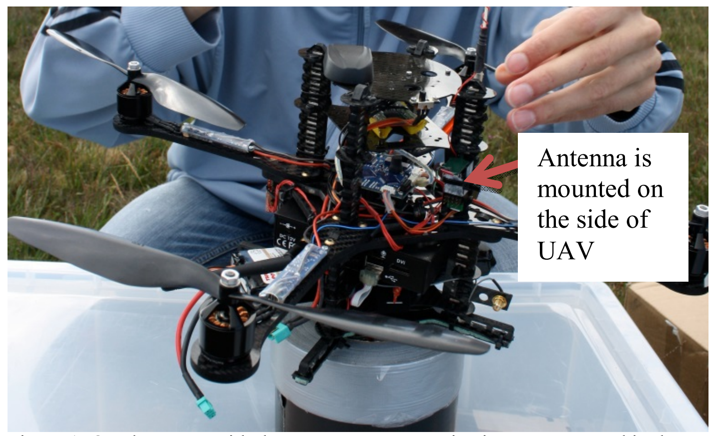


Figure 1. Quadrocopter with three antenna communication systems used in the project

II. ANTENNA CONFIGURATION

Figure 1 illustrates the UAV with the proposed patch antenna will be mounted on. Three separate communication systems are applied on the UAV – GPS, Wi-Fi 2.4/5.2GHz and a remote control unit operates at 2.4GHz. Therefore, the antenna needs supporting a triple band operation. Several antenna types have been attempted, including spiral antenna, monopole antenna and patch antenna. Amongst these antenna types, patch antenna is least susceptible to the rest of UAV device because of its full ground plane. The ground plane shields most RF interferences and demonstrates stable and efficient communication links. Figure 2 shows the configuration of the patch antenna. It is composed of a circular patch, a circular feeding disk stacked between two substrate layers and a square ground plane of 50×50 mm. The bottom substrate is a 7mm-thick polystyrene foam. The copper feeding disc with impedance matching of each resonance can be adjust-

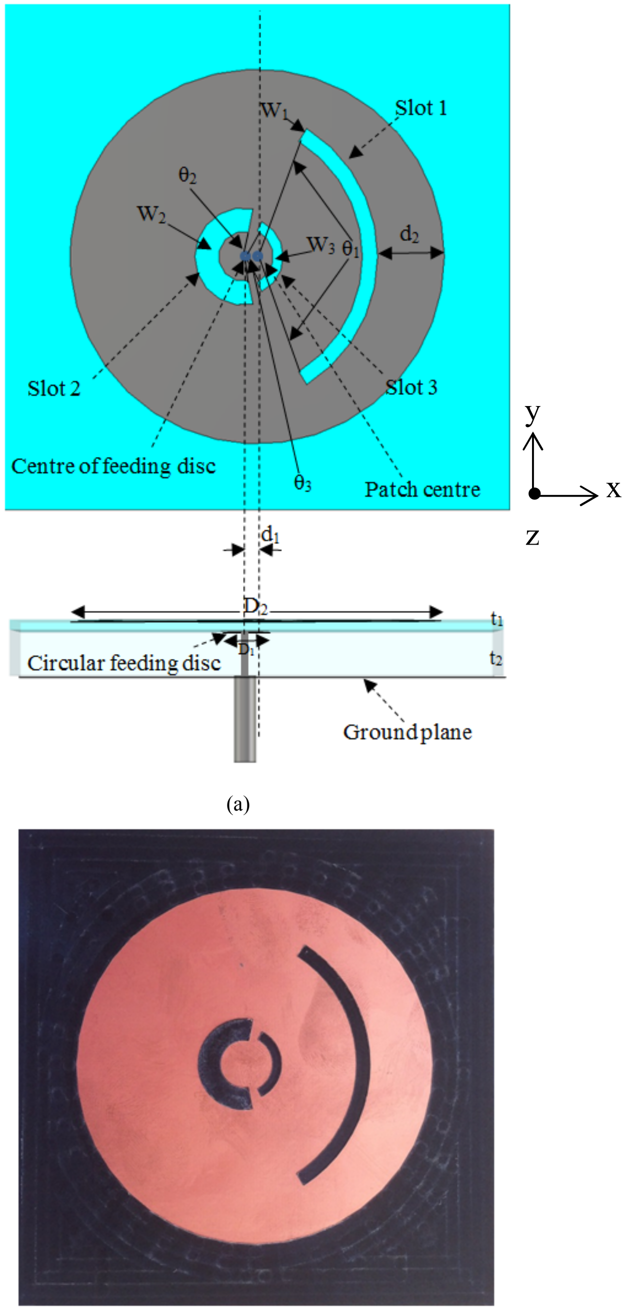


Figure 2. Geometry and the fabricated prototype of the proposed antenna

ed. The diameter D_1 = 10 mm is placed on the top of the foam. The top substrate layer stacked on the polystyrene foam is a single sided Rogers Duroid 5880 laminate with the thickness of 1.575 mm. The relative permittivity (ε_r) of the laminate is 2.2. Dimensions of both substrate layers are 50x50mm, with same sized ground plane on the back of the form. The circular feeding disk between these two substrate layers is connected to the center conductor of a coaxial cable, which is located at the distance of d_1 = 2.4mm with respect to the center of the circular patch, whose diameter is D_2 = 74.4 mm.

Figure 2 (b) shows a photo of the fabricated antenna prototype. In order to excite three resonances for the antenna, three arc-shaped slots are embedded on the circular patch, named Slot 1, 2, 3 in Figure2. By controlling the slot width, the

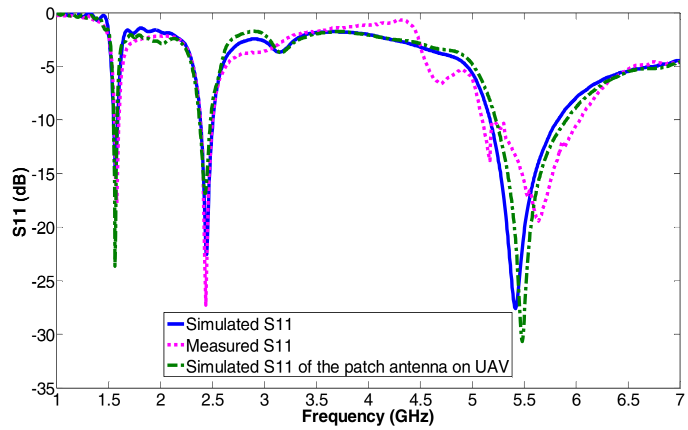


Figure 3. Measured S11 in free space against simulated S11 in free space and on UAV

optimized slot widths in this design are 3mm, 4.7mm, and 2mm, respectively. Slot 1 is located at the centre of the circular patch and subtended by an angle θ_1 = 127.5° with distance d_2 = 13.3 mm to the edge of the patch, while Slot 2 and Slot 3 are centered with respect to the feeding disc centre and subtended by angle θ_2 = 205° and θ_3 = 122°. The radius (from the inner edge to the centre of the feeding disc) of Slot 2 and Slot3 are 5.65 mm and 4.83 mm, respectively.

III. SIMULATION AND MEASUREMENT RESULT

A. Simulated and Measured S11

With the increase in bandwidth by applying the capacitive feeding disk, the antenna can cover 2380 to 2508 MHz and 5100 to 6030 MHz for fully support of the Wi-Fi communication between UAV and GBS. The foam-Duroid stacked geometry further enhances the bandwidths compared to that with only single-layered Duroid substrate.

Figure 3 shows the simulated and measured S11 of the proposed patch antenna. As presented, the antenna operates at 1.575 GHz with 45 MHz bandwidth, 2.45 GHz with 128 MHz bandwidth and 5.2 GHz with 930 MHz bandwidth, which is sufficient for both GPS and dual-band Wi-Fi operations. The simulation and measurement results show good agreement. At 5.2 GHz, the measured bandwidth is better than the simulated. In addition, the effect on the antenna performance from UAV shown in Figure 1 is considered in the investigation. Figure 3 shows the comparison of S11 for the antenna in free space and mounted on the UAV. It can be seen that when the antenna is fixed on UAV, at 5.2 GHz band the S11 is slightly offset to higher frequency. There is no noticeable frequency shift at the other bands due to the full sized antenna ground plane. Therefore, it effectively solves the problem when using monopole antenna for Wi-Fi communication.

B. Impedance matching analysis

Figure 4 shows real part in Z-parameters of the antenna with slot 3 and antenna without slot 3. At 5.2 GHz band, the real part is higher than that when the slot 3 is removed. Figure 4 also shows imaginary part in Z-parameters of the antenna with slot 3 and antenna without slot 3. It can be seen the inductance of the antenna with slot 3 is higher at 5.1 GHz than that of the antenna without slot 3. At 5.5 GHz, the inductance of the antenna with slot 3 is lower than that of the antenna without slot 3. So the slot 3 gives wider impedance match for the antenna.

C. *Surface current distributions*

Figure 5 shows current distributions on the patch at 1.575, 2.4 and 5.2 GHz. For the case of surface current shown in Figure 5 (a), the resonant mode is perturbed TM_{11} mode, it can be observed that the excited current distribution is very similar to that of the TM_{11} mode of the case without the slot. With the presence of the slot, the fundamental mode TM_{11} of the circular mode has been slightly perturbed because the slot is located close to the patch boundary, where the excited patch surface current for the TM_{11} mode had a minimum value. In Figure 5 (b), the second resonant mode excited in the present design is the perturbed TM_{01} mode. In Figure 5 (c), it can be seen the surface current is mostly concentered around slot 2 and 3. In this mode, the slot is radiating rather than the patch radiating.

D. *Simulated radiation patterns*

Simulated radiation patterns of antenna standalone and on the UAV in two principle planes (E-plane and H-plane) are plotted in Figure 6 and Figure 7 at 1.575, 2.45 and 5.5 GHz. It can be seen in Figure 6 that the cross-polarization across E-plane is very low. It has symmetrical co- polarization pattern and cross-polarization pattern across H-plane. In Figure 6 (c) the main lobe of co-polarization across E-plane is offset 20° due to the affect ion of Slot 2 and Slot 3.

In Figure 7, cross-polarization across E-plane is much higher than that in Figure6. As the antenna is mounted on the UAV, the radiation pattern is affected by the presence of the UAV. Same reason causes the unsymmetrical co and cross-polarization across H-plane. The main lobe and 3 dB beam width is similar with Figure 6 (c).

IV. CONCLUSION

The performance of a circular patch antenna with a capacitive feeding disk and arc-shaped slots is reported. Adding the slots and modifying their dimensions provide a tri-frequency band antenna operating at GPS 1.575 GHz and Wi-Fi 2.4/5.2 GHz. The antenna can be mounted on the side of an UAV to support its communication systems. In order to minimize interferences from the rest of the UAV structure, patch antenna becomes a good candidate to offer an independent working environment due to its full-sized ground plane. The bandwidth of the proposed antenna, benefiting from the capacitive feeding and the stacked substrates, has achieved 45 MHz at GPS band, 128 MHz at 2.4 GHz band and 930 MHz at 5.2 GHz, giving the antenna gain of 7.23 dB at 1.575 GHz, 8.34 dB at 2.45 GHz and 9.28 dB at 5.5 GHz, respectively. The radiation pattern will be measured and presented in presentation.

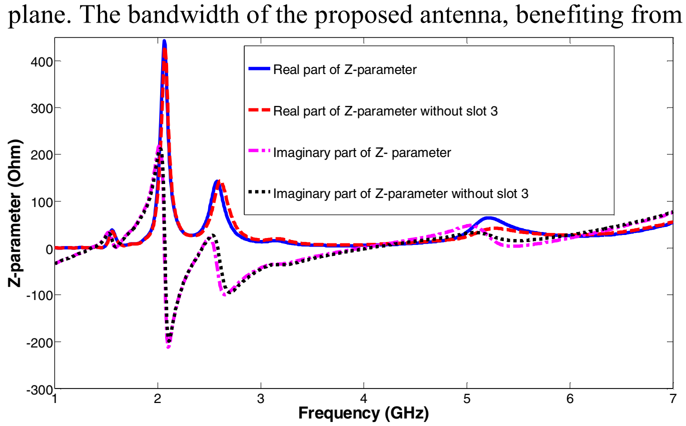
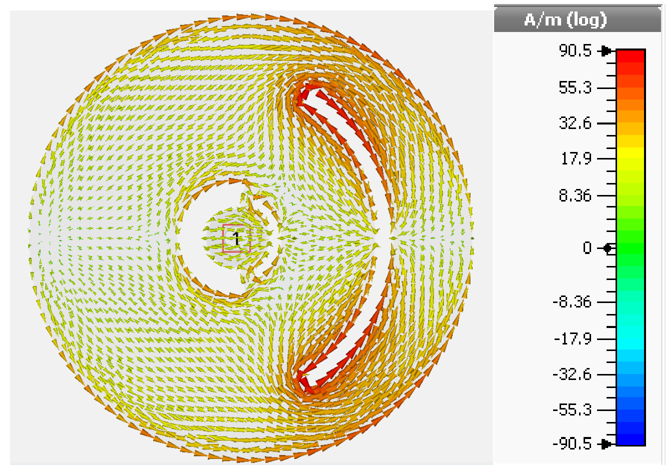
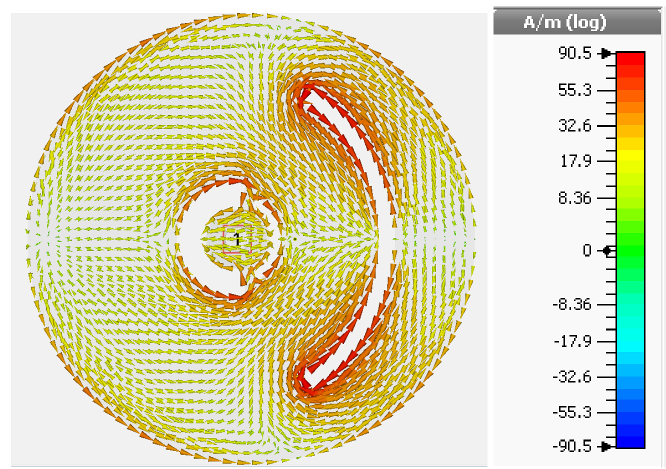


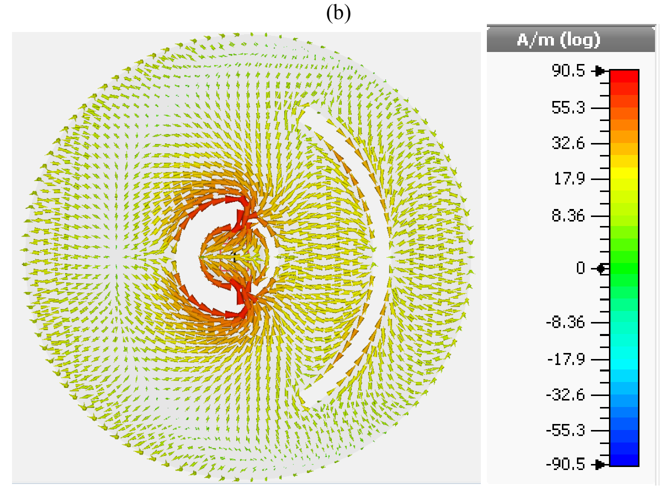
Figure 4. Comparied Z-parameters between the antenna and antenna without slot 3



(a)



(b)



(c)

Figure 5. Simulated surface current distribution of frequency (a) f_1 = 1.575 GHz (b) f_2 = 2.4 GHz and (c) f_3 = 5.5 GHz

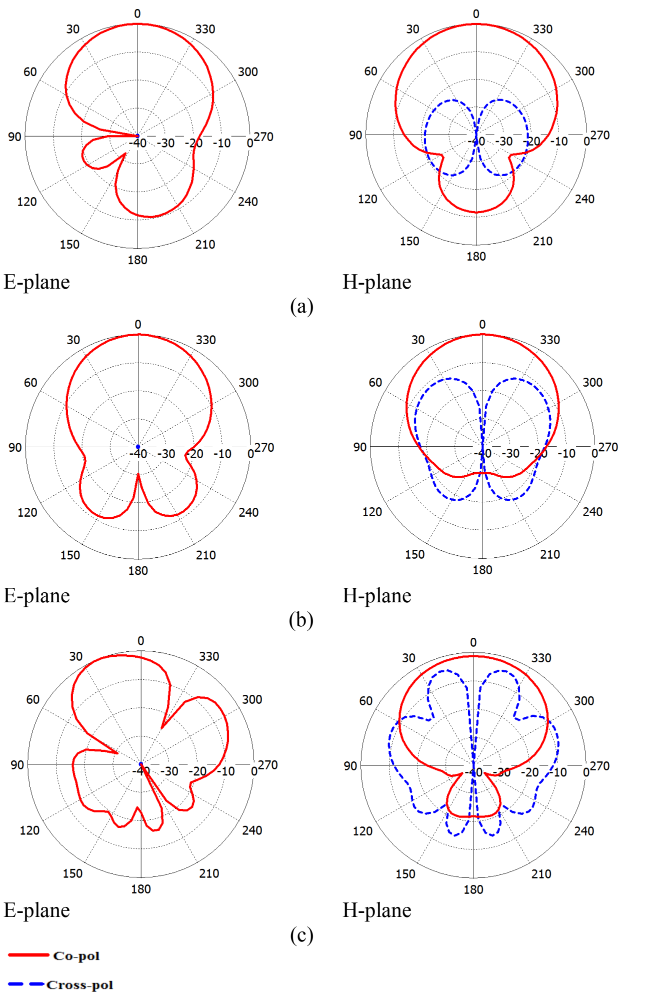
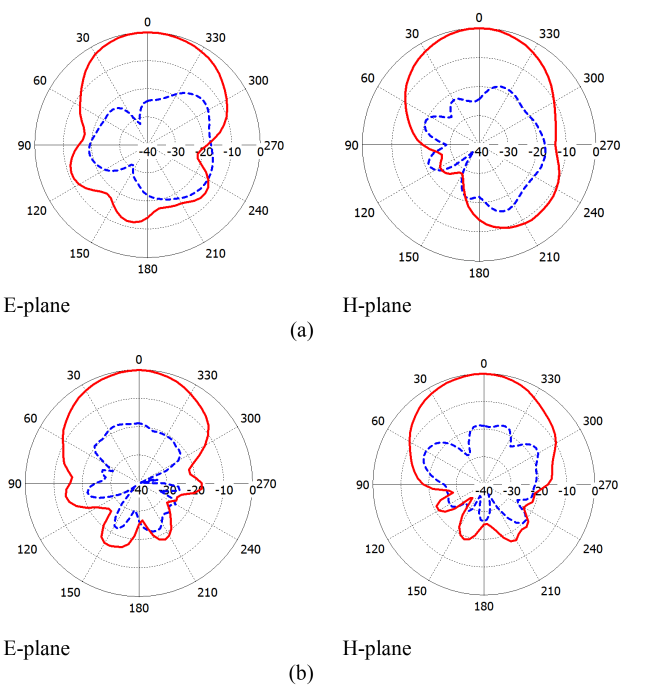


Figure 6. Simulated radiation pattern for the antenna (a) f_1= 1.575 GHz, (b) f_2 = 2.45 GHz, (c) f_3 = 5.5 GHz



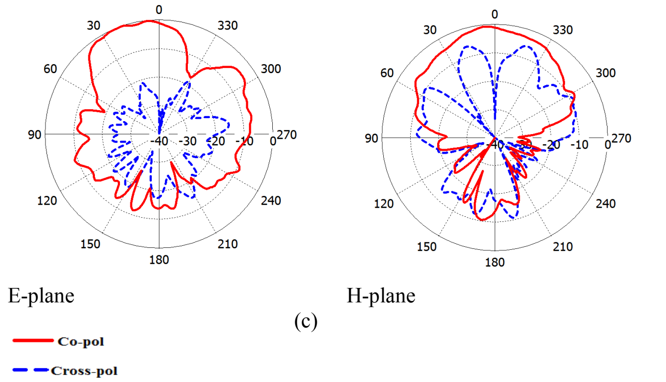


Figure 7. Simulated radiation pattern for the antenna on UAV (a) f_1= 1.575 GHz, (b) f_2 = 2.45 GHz, (c) f_3 = 5.5 GHz

V. ACKNOWLEDGEMENT

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