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Review on Patch Antennas for Unmanned Aerial Vehicle Application

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ABSTRACT

The wide-ranging Unmanned Aerial Vehicle (UAV) applications make them one of the Internet of Things promising technologies. The vast potential of monitoring and surveillance for public safety threats using drones is a current issue for researchers. Antennas play an important part in UAV to create reliable communication links. There are different types of antennas that can be used for UAV application depending on antennas size, efficiency, gain, angle of radiation pattern, polarization, etc. This paper mainly focuses on patch antennas for UAV applications. In general, there are two types of patch antenna described which are single patch antenna and array antenna. The review of patch antennas can be a useful guideline to choose or design antenna for UAV applications in the future.

1. Introduction

Nowadays, unmanned aerial vehicles (UAVs) be part of interesting research as the vehicle can fly remotely either by the controller or autonomously. The UAVs have different types of weight and size depending on their applications [1-3]. Another important specification of UAV is their capabilities to fly with maximum altitude, distance, and general operating characteristics. To meet the requirement, the production of the UAV is necessary to have a significant quantity of electronic components such as the antenna [4]. The main function of the antenna is to allow the vehicle to transmit and receive information from other systems. The antenna is required to havehigh gain and high directivity to create reliable link communication [5-6]. Patch antennas are a type of antenna that are able to operate for UAV applications. Patch antennas can be divided into two types, either single patch or array. This chapter outlines the basic principle of the antenna design and evaluation of the antenna performances in terms of antenna size, gain, radiation pattern, andoperating frequency.

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2. Patch Antenna for UAV Application

A microstrip patch antenna is commonly used in various applications. The antenna consists of a variety of shapes of a patch of metal foil with a ground plane on the other side of the substrate board. The characteristic of patch antenna which has a thin planar profile, makes it compatible to integrate it in a UAV. Common microstrip patch antenna shapes are square, rectangular, circular, and elliptical, but any continuous shape is possible. The advantage of using microstrip patch antenna is relatively inexpensive cost to design and produce due to the simple physical geometry. This type of antenna operates at higher frequencies as the wavelength at the operational frequency is directly tied to the size of the antenna. The small size of antenna makes it well suited to use for UAV applications since the presence of an antenna does not affect the balancing of a UAV while flying. Usually, the single patch antenna offers 6-9 dBi for maximum directive gain. To increase the gain, patch array antenna is introduced. Patch array antennas are suitable for UAV applications as they provide much higher gain with little additional cost. The structures of printed microstrip feed make the matching and phase adjust.

2.1 Single Patch Antenna for UAV application

There are various shapes for a single patch antenna which contributes good performance. One of the shapes is a dipole patch antenna. Based on Nosrati *et al.*, [7] a broadband blade dipole antenna with an overall antenna size of 71 cm× 25 cm is proposed as shown in Figure 1 below. The antenna is designed to operate at frequencies of 20-1200 MHz. The shape of the blade provides broad signal coverage while maintaining an aerodynamic shape, thus leading to minimum drag [8-11]. The gain of the antenna is increasing to 5-6 dB while adding slots in the antenna design [12]. The light and small sizeof antenna characteristics enhanced the stability of UAVs to fly.

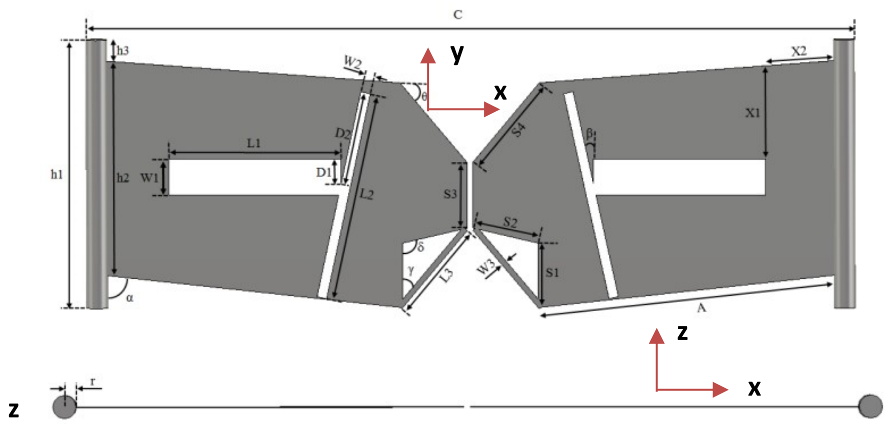


Fig. 1. Blade Dipole Patch Antenna [7]

Next, Trotta *et al.*, [13] offers a bowtie-like printed dipole with an exponential profile etched on two 0.762mm thick Rogers 3035 substrates as shown in Figure 2. The antenna's radiating element consists of two unequal elliptical metallic plates where the size of the element at the bottom is larger comparedto the top. The design fulfils a possible avionic radome aero dynamical constraint while providing wideband operating frequency [14-18]. The compact dimension at operating frequency 0.45 GHz and 0.1 GHz makes the antenna perform well for avionic direction-finding systems.

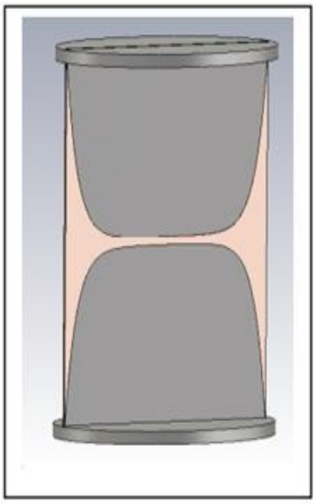


Fig. 2. Bowtie Printed Dipole Antenna [13]

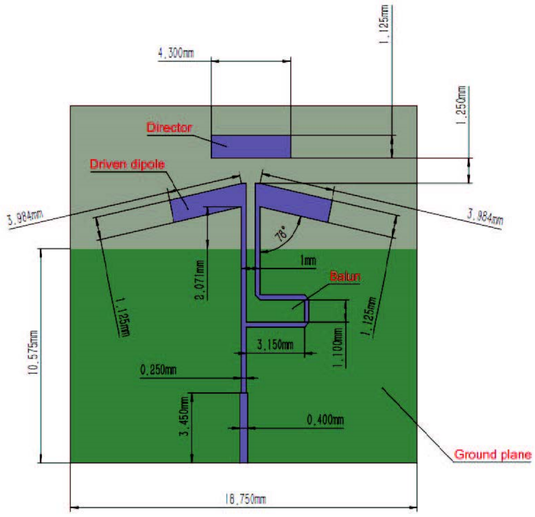


Fig. 3. Quasi- Yagi Patch Antenna [19]

Another single patch antenna for UAV application is presented by Gong *et al.*, [19]. Nevertheless, this type of antenna is used for radar. The antenna consists of dipole antenna, a dielectric slab, and a metallic conducting ground plane as shown in Figure 3. The size of the antennais 17 mm x 18 mm x 0.13 mm. To enhance the bandwidth, the driven dipole of the antenna is rotatedto 12 degrees. The dielectric slab on the ground plane acts as a reflector. The antenna is designed to point to the direction of the transmission, which offers small size and low weight, thus suitable to use as an obstacle avoidance system for unmanned drones, such as quadcopters. This structure of the quasi-Yagi antenna provides better performances [20-21]. Following by Yoon *et al.*, [22] as illustrated in Figure 4, a higher-order mode circular patch antenna is designed with a low-profile characteristic on a UAV fuselage. The antenna is operating at 700 MHz and performs monopole-like radiation characteristics as shown in Figure 5. The monopole like radiation characteristic can be attained by designing antennas using metamaterials and various resonance modes [23-28]. The antenna is designed using TM01 and TM02 conformal annular slots to ensure that the airflow around the aircraft fuselage does not influence the stability of the aircraft [29].

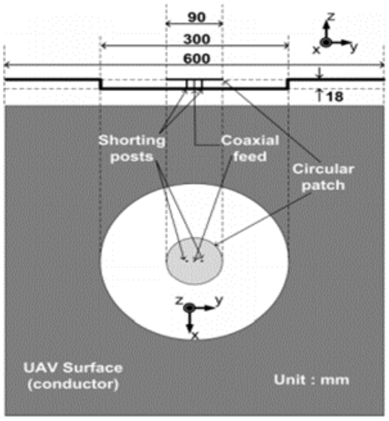


Fig. 4. Conformal Monopole Antenna [22]

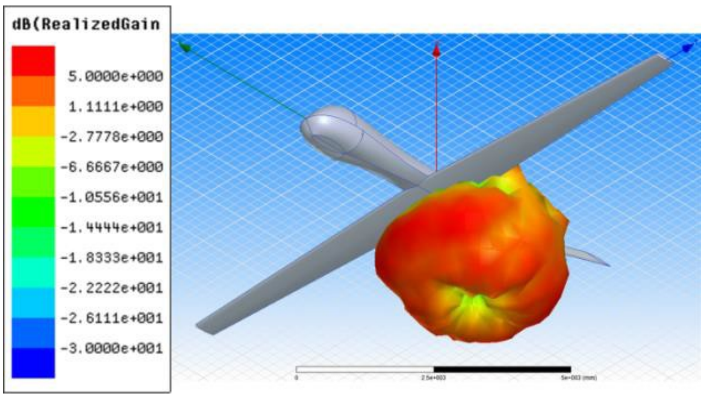


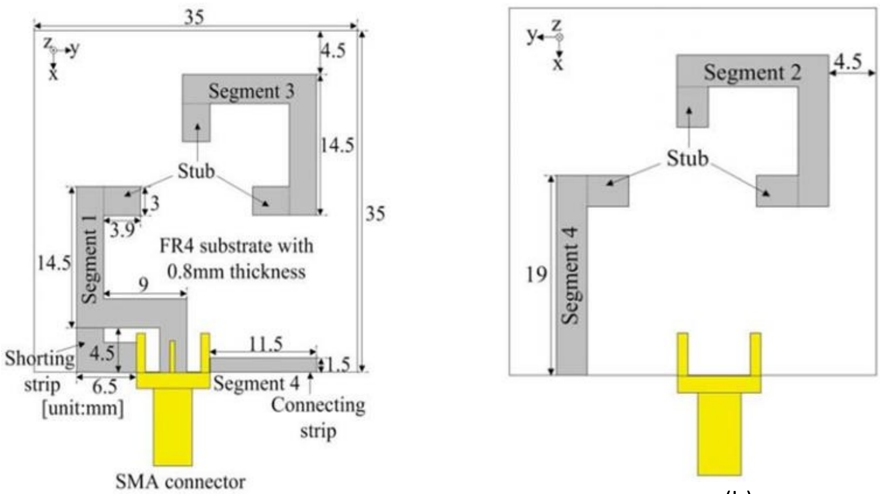
Fig. 5. Antenna radiation pattern on UAV [22]

Thereafter, Patroysky *et al.*, [30] proposed a thin conformal S-band annular slot antenna forUAV application as shown in Figure 6 (a). A conformal antenna is proposed as it fulfils the requirements of low observability or reduced susceptibility to damage [30]. The antenna is operatingat 2300 – 2500 MHz and achieved the value of VSWR: < 2.0:1. The main concept of this antenna is integrating it with carbon fiber reinforced plastics. Figure 6 (b) shows the annular slot antenna design. The maximum mechanical stability has been achieved by molding the antenna into the laminate as shown in Figure 6 (c). The radiation pattern of the antenna is very similar to the quarter-wave monopole antenna which provides high coverage and vertical polarization thus suitable for UAV application.

(a) (b) (c)

Fig. 6. A thin conformal S-band annular slot antenna for UAV application [31]

A printed loop patch antenna has been proposed by Kang and Choi [32]. This project is aimed to have omnidirectional radiation characteristics to enhance the communication efficiency between the ground control system and UAV [33-34]. The antenna is composed of a segmented loop with four segments placed on the FR4 substrate with a dimension of 35 × 35 × 0.8 mm^3 as shown in Figure 8. The capacitive coupling between overlapping segments provides an omnidirectional radiation pattern at 956MHz. The reduced size of the antenna is done by adding stubs and reduction of the number of segments. The addition of shorting strip in the antenna design enhanced the impedance matching of the antenna. The small dimension of the antenna and appropriate antenna performances offer stability to fly high when applied to the UAV.



(a) (b)

Fig. 7. Compact segmented loop antenna (a) Front view (b) Back view [32]

Based on several studies, the flat patch antenna is not suitable for antenna to operate for UWB operating frequency [35-38]. Therefore, the UWB conformal antenna is proposed [39-42]. A single patch antenna for UAV used at ultra-wideband (UWB) frequencies (2.9 GHz to 15.9 GHz) has been designed by Balderas *et al*., [43]. The characteristic of the lower-profile structure with a small dimension of 29mm x 38 mm and UWB frequency operation makes the antenna appropriate to apply at the UAV. Asshown in Figure 9, the antenna is composed of a Y- Y-rounded shape with a parasitic circular element at the center of the structure design. The aerodynamic shape of the antenna makes the problem of drag using flight diminished. Based on their evaluation, the antenna offers the maximum radiation towards the down of the aircraft structure as shown in Figure 9 thus proving that the antenna is very suitable for UAV application.

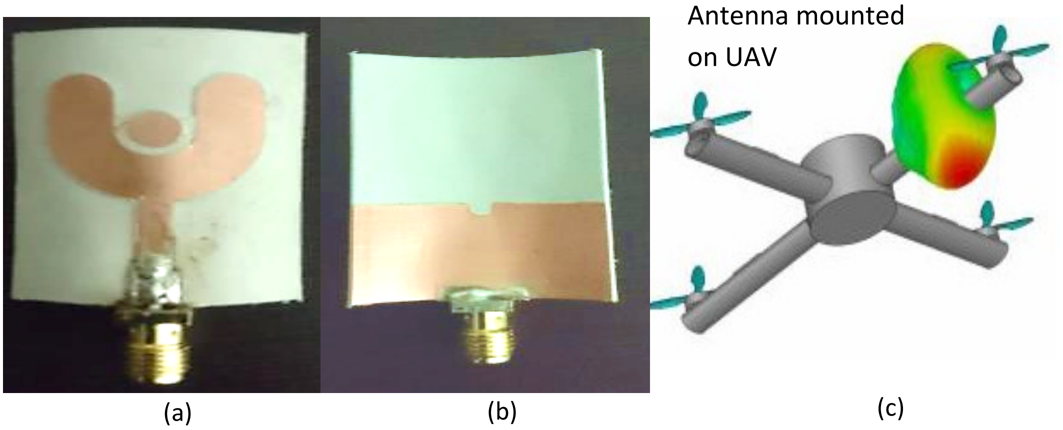
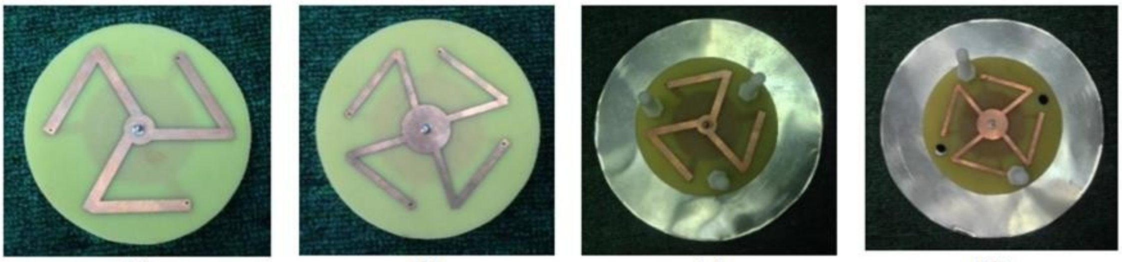


Fig. 8. Low-Profile Conformal UWB Antenna (a) Front view (b) Back view (c) 3-D Radiation Pattern [43]

Based on studies by Sharma *et al*., [44] wideband circular polarization can be achieved by designing a fan blade shaped antenna. Therefore, Safaron *et al*., [45] proposed 3-blade and 4-blade cloverleaf antennas operatingat 2.45 GHz. They did a comparison between antenna design with reflector and without reflector as illustrated in Figure 9. The reflector is added in antenna design to produce a high gain and directionalradiation pattern. The compact of the antenna size offers stability to mount on UAV body. The simulated and measured antenna performances are slightly different due to the inconsistent FR4 material permittivity value. Results show that a 3-blade and 4-blade cloverleaf antenna has a gain of 2.64 dBi and 2.096 dBi, respectively. However, the 3-blade and 4-blade cloverleaf antenna with reflector has a higher gain which is 6.474 dBi and 6.297 dBi respectively. Based on the observation, the antenna with reflector has a higher gain and directional radiation pattern which is more suitablefor UAV application. The antenna is suggested to be mounted underneath the UAV for better coverage between the UAV and ground station.

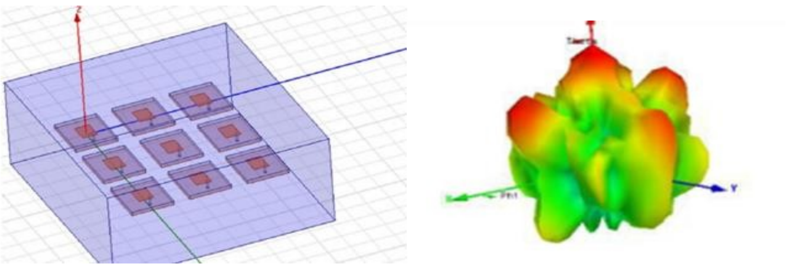


(a) (b) (c) (d)

Fig. 9. Fabricated proposed antennas were (a) 3-blade cloverleaf antenna, (b) 4-blade cloverleaf antenna, (c)3-blade cloverleaf antenna with reflector, and (d) 4-blade cloverleaf antenna with reflector [45]

2.2 Patch Array Antenna for UAV application

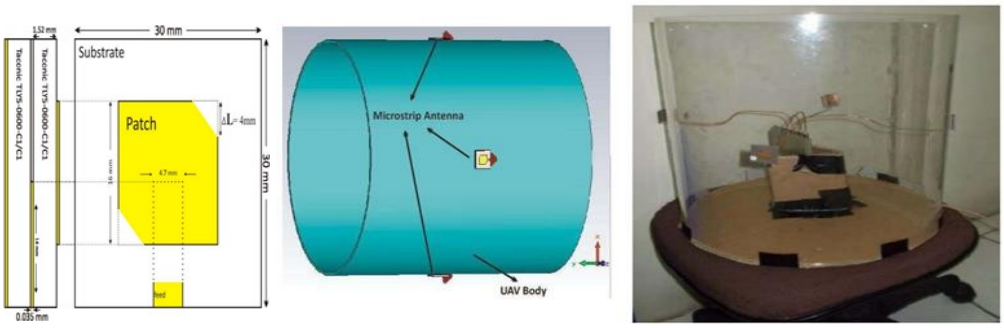
There are several antenna arrays that have been designed for UAV applications. An antenna array means that a set of multiple antennas is connected and works as a single antenna. Usually, the individual antennas which are also known as elements are connected to a single transmitter or receiver by feeding lines thus the power is generated at each element. The electromagnetic waves are radiated by each element hence it combines with each other. Therefore, the antenna enhanced the power radiated, thus providing higher gain and directivity. As a result, the antenna allows the drone to fly high with a reliable connection. There are various shapes and arrangements of array antenna for drone application. Midasala *et al.*, [46] proposed an antenna array with arrangement 3 x 3 of rectangular topology. The number of elements, spacing and feeding current has been optimized to obtain directional radiation pattern andgood cross polarization as shown in Figure 10. The antenna has been composed of FR4 substrate withdielectric constant of 4.4 and operates at frequency 12 GHz to 18 GHz. According to the results, the high gain of 17.29 dB is achieved and the VSWR value is 0.7807. The reasonable performance of the antenna makes the antenna suitable to test on UAV applications.



(a) (b)

Fig. 10. (a) Array antenna arrangement (b) Directional radiation pattern [46]

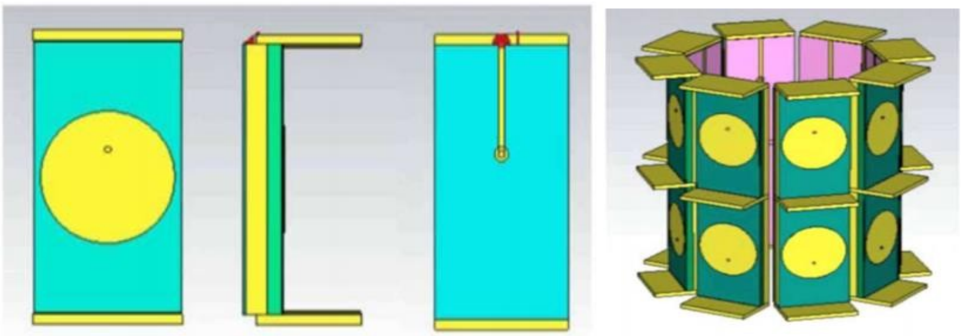
Next, an array antenna for UAV application is proposed by Rahardjo *et al.*, [47]. The paper describes a microstrip antenna array with circular polarization. The conventional rectangular microstrip antennais designed as an antenna element and feed electromagnetically by a microstrip line. There are 1 x 4elements of microstrip antenna array constructed on the surface of the UAV body as shown in Figure 11(b) and (c). As illustrated in Figure 11 (a), the truncation at the corner of the rectangular patchable to produce circular polarization [48-49]. Based on the measurement results, the antenna array can operate at frequency 5.6 GHz with an impedance bandwidth at VSWR < 2 is 720 MHz and gain as 5 dB. The antenna array provides an omnidirectional radiation pattern, thus being able to cover greatercoverage around it hence making it suitable for UAV application. According to the analysis of the results, there is no discrepancy between simulated and experimental results.



(a) (b) (c)

Fig. 11. (a) Rectangular patch antenna (b) Mounted on surface of UAV body (c) Measurement setup [47]

The theoretical of the communication link of antenna for UAV application has been discussed by Porcello [50]. However, it does not implement physically due to the high complexity of the system. A solution to the problem has been suggested by Sun *et al.*, [51]. The antenna designed is constructed with eight elements of the circular array as shown in Figure 12. The antenna array is operating at frequency 5 GHz with a gain > 6 dB. The characteristic of low profile, small size, low cost, and simple geometry isareason for the microstrip patch antenna with vertical polarization is used as the essential radiatingelement. In this project, the antenna module involves two circular arrays for transmission andreception. Each circular array consists of eight elements vertically polarized. The elements are selectively activated depending on the desired direction of the beam. Based on the measurement results, the isolation between transmitter and receiver of the antennas is -40 dB with reflection coefficient below -20 dB, thus proved that circular array antenna provides better air to air links UAV communication systems.



(a) (b)

Fig. 12. (a) The geometry of proposed single element of antenna array (b) Complete structure of antennaarray design [51]

The antenna is placed at the UAV body, which has a cylindrical form [52]. For UAV applications, the antenna is required to be small and lightweight to not give any affection to aerodynamics characteristics [53-54]. In this project by Navarro-Méndez *et al.*, [52] the antenna designed is constructed of a circular array of four elements conforming to the cylindrical shape. Two basic antenna designs have been selected as a radiating element of each array: rectangular microstrip patch antenna and a PIFAantenna as illustrated in Figure 13. According to the measured results, microstrip rectangular patch array antenna design is suitable for large diameter sections while PIFA antenna design is satisfactory for small diameter sections. There is good agreement between simulation and measurement results with omnidirectional. Radiation pattern at operating frequency hence suitable to use it for UAV application.

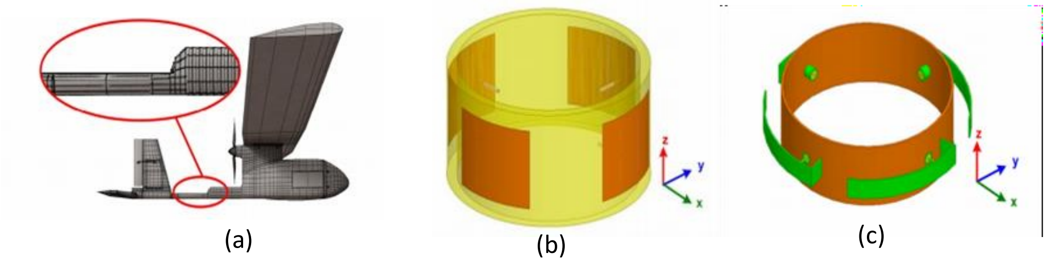


Fig. 13. (a) UAV model for antenna to place (b) Complete rectangular array (c) Complete PIFA array [51]

A compact two patch antenna array design for UAV application is proposed by Chuang *et al*., [55]. The antenna with high gain directivity is an important characteristic while increasing the wireless transmission range. In this project, a compact two patch antenna with operating frequency 2.4 GHz is attached to the top of the remote control facing toward the UAV direction in the setup. The patch of antenna is designed with air cavities to maximize radiation efficiency. Based on Figure 14, thereare three rectangular apertures cut on each patch. The technique is effective while reducing the patch length [56]. The antenna is vertically polarized to the airplane. There is no discrepancy between measured and simulated results of the reflection coefficient. The gain maximum of 9.14 dBi is achieved with total radiation efficiency of 86%.

(a) (b)

Fig. 14. (a) The prototype of antenna design (b) The antenna is attached to the remote control [56]

Table 1 shows several types of antenna designs and their important parameters to be the guideline for designing an antenna for UAV application in the future.

Table 1
Comparisons Of Antenna Design For UAV Application

Type	Operating Frequency	Gain	Saiz	Material	Radiation Pattern	Polarization
Dipole Patch Antenna [7]	20-1200 MHz	5-6 dB	71 cm×25 cm x $1mm^3$	Copper with thickness of 1mm	Omni directional	Linear
Wideband Dipole Patch Antenna [13]	0.5- 0.9GHz	3-4dB	137 x 56 x 159 mm^3	Rogers 3035	Omni directional	Linear
Quasi Yagi Patch Array Antenna [19]	24GHz	8-10dB	17 mm x 18 mm	Rogers RT/Duroid 5880with thickeness 0.127mm	Good End Fire	Linear
High Order Mode Circular Patch Antenna [22]	700 MHz	-	Radius=45mm Height=18mm	Molded to UAV fuselage	Omni directional	Linear
Annular slot antenna [29]	2300 to 2500 MHz	-	5 mm thick andits diameter is about 120 mm	CFRP	Elevation 0 to 45 deg Azimuth 0 to 360 deg	Vertical
Printed Loop Patch Antenna [32]	956 MHz	-	35 × 35 × 0.8 mm^3	FR4	Omni directional	Linear
Low Profile Conformal Patch Antenna [43]	2.9 GHz- 10.1 GHz	2.5-7dB	29 x 39 mm^2	Rogers 5880LZ	Maximum towards down of the aircraft	Linear
Directional Cloverleaf Antenna[45]	2.45 GHz	6.5dB	Radius=80 mm	FR4	Omni directional	Linear
3 x 3 Rectangular Antenna Array[46]	12 to 18 GHz	17.3dB	3cm x 3 cm	FR4	Directional	Linear
Circularly Polarized Microstrip Antenna Array[51]	5.6 GHz	22.2dB	30x 30 x $1.52mm^3$	Talconic TLY5	Omni directional	Circular
Circular Array Antenna [52]	5 GHz	>6dB	58 x 30 x 0.25 mm^3	FR 4	Directional	Vertical
Array Antenna [54]	2.45GHz	9.14dBi	140 x 62 x 10 mm^3	FR 4	Directional	Vertical

3. Conclusions

As conclusion, there are several types of antennas that can be used for UAV application depend on antennas size, efficiency, gain, angle of radiation pattern and polarization. The UAVs havedifferent types of weight and size depending on their applications. A microstrip patch antenna is commonly used in UAV applications as the antenna is low profile, small size, low power consumptionthus makes the UAV capable to fly with maximum altitude, distance, and general operating characteristics. Comparison summary of patch antenna design suitable for UAV application is shownin Table 1. The review of patch antennas can be a useful guideline to choose or design antenna for UAV applications in the future.

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