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REVIEW OF ANTENNAS USED IN FPV/WLAN APPLICATIONS

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Abstract: An Unmanned Aerial Vehicle (UAV) commonly known as a drone or an Unmanned Aircraft System (UAS) is an aircraft without a human pilot aboard. UAV requires links to be established for communications such as telemetry (Video telemetry- First Person View (FPV)), telecommand (GPS) and flight command (RF Control). Antennas are an essential part of remote control of UAVs. The antennas used in UAVs must have small form factor, should not affect the UAV aerodynamic characteristics and at the same time, improve the power management efficiency by providing high gain and directional radiation pattern. The most common frequencies used for FPV video transmission are 900 MHz, 1.3, 2.4, and 5.8 GHz. The image resolution of FPVs is affected by the penetration depth of waves and hence the highest ISM band frequency of 5.8 GHz is preferred for FPV transmission systems. In a broad sense, antennas that were designed for 5.8GHz fall under either a linear polarizing (LP) antenna or a circular polarizing (CP) antenna. LP antennas are constituted mainly by structures like normal dipole, monopole, blade dipole and also disposable structures like inkjet-printed Yagi antennas. The family of circularly polarized antenna can be classified as derivative from LP antennas and Dielectric resonator antenna (DRA) structures. The former one includes structures like stacked loop antennas, cloverleaf antennas etc., while the latter one provides a vast degree of designing freedom and parametric advantages that are held by DRA over conventional antenna structures. Omnidirectional circularly polarized (CP) antennas have received more attention compared with linear polarized (LP) antennas due to several key advantages such as reducing the Faraday rotation effect, suppressing multipath reflection and eliminating the receiver-transmitter synchronizing problem. CP permits a maximum degree of freedom of choice in antenna position. This paper gives an extensive review of antennas and modern flight controlling techniques that are used in FPV based UAV applications. Both linear and circular polarized antennas as well as the scanning technique that are used in finding field patterns for UAV platforms are reviewed.

Keywords: Antenna, Beam steering methods, circularly polarized antennas, Dipole antennas, First Person View, ISM band, linearly polarized antennas, Monopole antennas, Precision format flying, Scanning sequences, Unmanned Aerial Vehicle

1. INTRODUCTION

In the present-day communication scenario, the wireless domain dominates over all other means of communication. Wireless transmission is directly linked with antennas which lead to the extremes in antenna designing to find application-specific ideal antennas. Wireless communication falls under the frequency spectrum of 9 KHz - 300 GHz range, in which, mm (millimetre) wave range is above 300MHz, in which most UAV antennas operate. As a counterpart of basic wired communication, IEEE has designed protocols for wireless communication also, namely 802.11 standards, which is a part of LAN protocols (802) [1]. Using this standard, vehicle to device communication is possible and usually it is done by 802.11p protocol. 802.11p is one of 12 subdivisions of 802.11protocols in which features like AM, CSMA-CA, and TDMA with communication rates of 1 Gbps are found. This protocol provide license for communication at the frequencies of 900Mhz, 1.2, 2.4, 5.9 and 60 GHz.[2]

In the subsections following, a general introduction of UAV and FPV technology that is in use is given. The different types of antennas and polarizations are also introduced.

— Unmanned Aerial Vehicles

An Unmanned Aerial Vehicle (UAV) is a small aircraft without a human pilot on board. UAV systems mainly consist of three crucial elements which are, UAV itself, a ground-based controller for aircraft and a sustainable communication link between the aircraft and ground-based controller (GBC). Almost all communication that is done by the ground-based controller to UAV is through a wireless channel. There are sensors embedded in UAV from which data collection from the surrounding is possible and these collected data are transferred from UAV to GBC through radio links. In primitive versions of UAV, a narrowband uplink and downlink are provided with an optional link for the analog video feed from UAV to GBC for flight controlling instructions. At present, UAV uses 802.11p structure protocols for communication in the digital domain.[3] Using the aforementioned protocols, communication is possible from GBC to UAV and by signalling the on-board sensors and actuators, the vehicle can be steered.

There are many varieties of UAVs in terms of the structure but for this paper, the four motor (quadcopter) UAV system (Figure 1.1 [2]) based works are reviewed due to its popularity. In this type of UAV, there are mainly 3 digital communication links that is to be established between the UAV and GBC, which are telemetry, tele-command, and payload communications links. All of these links are designed following 802.11p. Telecommand and payload communication links are directed from GBC to UAV while the direction of communication is inverted for the telemetry link.[4]. Information that is collected by the UAV system includes high-resolution video feed, GPS sampling signals, etc which can act as telemetry data with the finest data sampling.[4].

Figure 1. 1 Quadcopter UAV system

— First Pearson View

This is a modern method by which UAVs are flown by the remotely acceded controller as shown in Figure 1.2 and Figure 1.3. [5] This takes advantage of video/image recording done on the UAV system which is directed back to the GBC which can be accessed by devices like Google VR glasses for piloting. The pilot who is controlling the aircraft from ground level will be experiencing a first-person view of the image in front of him. The communication links that needed to be established between the GBC and UAV falls under RC video transmission with channel frequency of 900.1200,2400 and 5800 GHz.[6] As per the tests conducted from previous experiments [7], lower range frequency provides better penetration depth and range. There are some major concerns like portability issues and the rate of data transmission etc. The current generation of FPVs are using a 5.8GHz frequency channel for data transmission [3].

Due to the inclusion in ISM bandwidth, the spectrum licensing problem is avoided. As per the findings in [7], a major problem that appeared is the over usage of channel bandwidth and a multipath effect with data interference which will be prohibiting UAV from operating in the desired frequency. As a remedy for this, numerous research and development are undergoing in antenna designing communities to find an ideal solution.[6].

Figure 1. 2 FPV used in UAV system

Figure 1. 3 FPV viewfinder in (1.2) enlarged

— Antennas

Antennas are a major component of wireless communication. These devices can be defined as the interface between radio waves propagating through space and electric current moving in metal conductors used in transmitter or receiver. UAV based FPV use radio control mechanism and hence an appropriate antenna is required to carry out the communication [8]. According to the studies conducted in [8] and [1], there are some major restrictions in antenna designing for FPV based UAV applications. Even then, there are numerous types of antennas designed and tested to find the perfect fit for the specified application.[7].

≡ Classification of antenna

Many parameters are being used for the classification of antennas. As presented in [2], a mainly used parameter is the polarization. Polarization is a property of the antenna which specifies the outgoing nature of field lines. There are mainly Linearly Polarized Antennas (L.P) and Circularly Polarized Antennas (C.P) both of which can be used in FPV applications. In linear polarization shown in Figure 1.4,[8] the field lines will be inline or in one direction and hence the name linear polarization. Circular polarization as shown in Figure 1.5 [9]displays time-varying nature in the direction of field lines. Considering a full wavelength of the sinusoidal signal being fed to the circularly polarized antenna, the outgoing field lines would have rotated 360^0 within the time the signal has passed through the antenna.

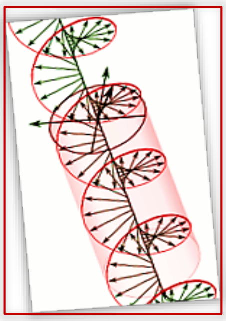

Figure 1. 4. Linear Polarization

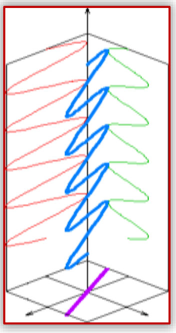

Figure 1. 5. Circular polarization

The measurement of Axial Ratio (AR) specifies the type of polarization an antenna constitutes. AR is defined as $20\log\left(\frac{E_y}{E_x}\right)$, and is the numerical measurement of the antenna's polarization nature. From the conclusions in [6], it is noted that the antennas having a value of axial ratio less than 6dB are circular polarization antennas and those with axial ratio value greater than 24dB are linear polarized antennas. This paper categorises different polarizing profiled radiating antenna for FPV application based on these criteria. Additional to this, there are supplementary methods for providing needed polarization, which is antenna steering methods and precision format flying, all of which will assist to establish the omnidirectional nature of antenna.

≡ Antennas parameters for UAV

As per the observation and inference in [10], some restrictions not allow placing the antenna with large gain and powerful transceiver on the small vehicle. The first restriction results from the size and weight of the antenna. Exemplary weight of small UAV is about five kilogram and the wingspan is about 1-2 meters. By increasing antenna weight and size the possibility of mounting heavy payload decreases [11]. The second restriction is the impossibility to mount turntable or scanning antenna array [4]. These facts bring to the necessity for developing special antennas. Some specific points to be followed for designing an antenna which is suitable for mounting on the UAV system for FPV applications can be listed [12]. These are:

☐ Omnidirectional antenna radiation pattern
☐ 2.4 GHz or 5.8GHz operating frequency
☐ VSWR < 2
☐ A shortwave *antenna*
☐ Short-circuited with the ground plane
☐ Small size (Maximum of 1.5 m wingspan)

It is necessary to use short wave antenna; otherwise, the influence of near objects will be increased because of strong reactive current in the near-field region. The antenna must be short-circuited for protecting from electrostatic discharge (ESD)[10]. Considering parametric restriction, [4] suggests that power losses through propagation for a distance of 1500 meter from GBC to be 74-100 dB and for the maximum distance of 3000 meters, it should be limited to 120 dB. It means that the minimum of antenna gain should occur beneath the vehicle and the maximum must be directed along broadside direction.[13].

The following sections of this paper are organised as follows. Chapter II emphasizes the antennas used in the UAV application and a classification based on the polarization profile is given. A general study of each of these antennas based on their radiation parameters including AR, Gain, Operational bandwidth, etc. is also done. The above listed parameters are then tabulated in Chapter III for comparison of antenna used in UAVs, which is succeeded by the conclusion and future scope of antenna technology for UAV in Chapter 4.

ANTENNAS FOR FPV

From the studies reported in [7], it is clear that there is the need for a specific antenna design to be followed for FPV enabled UAV application. The characteristics like small body weight and size, omnidirectional pattern, operating frequency within ISM, V2V bandwidth, etc., are the main restrictions in [8]. As per [14], the antenna's polarization nature show that both LP and CP antennas can be used in FPV based UAV application. This review paper is based on the works conducted on different types of antennas and three different types of UAV control techniques for finding the effective configuration of the antenna in FPV applications. The flight pattern control and flight formation methods are also included in this paper [15][16][14]. The following subsections explain linear and circular polarization natures of antennas. Table 1 shows different types of antennas and their polarization nature.

Table 1. Different types of antennas and polarization

Linear polarization	Circular Polarization
Simple dipole antenna	Micro strip antenna array
Monopole antenna	Planar quasi isotropic antenna
Bladed dipole antenna	
Disposable antenna	Multi petal antenna
Clover leaf antenna	3-D folded antenna

— Linearly Polarized Antenna

It is evident from the work of [12] that LP antennas can be used in UAV based FPV applications. Linearly polarized antenna refers to the one-dimensional nature of outgoing field lines. The LP antenna is associated with single plane omnidirectional characteristics of radiation. The directional nature of field lines can either fall in vertical or horizontal nature but will not appear together to form a planar pattern.

≡ Dipole antenna

A dipole antenna is used as a linearly polarized antenna for UAV based FPV application in [17]. The dipole antenna will be producing a radiation pattern closely resembling the radiation pattern of the elementary dipole. In [18], a simple dipole antenna is being constructed with two identically similar dimension conducting wires flared at 90^0. The transmitter and receiver nodes are connected using SMA port and feeding is provided through the coaxial feeding structure. As per the findings in [19], the length of the dipole is related to the frequency of operation. The best approximation is found in [20], which is taking ½ wavelength dipole as default. The length of the dipole can be found as $L = \frac{n\lambda}{2}$.

As per the results of the flight experiment reported in [21], it is clear that the best attainable gain in the frequency of 5.8 GHz using a $1.25\,\lambda$ dipole is 5.2dB as shown in Figure 2.1.[21] The radiation pattern in Figure 2.2 [19] is largely concentrated on the vertical plane.

Figure 2. 1 Dipole antenna structure

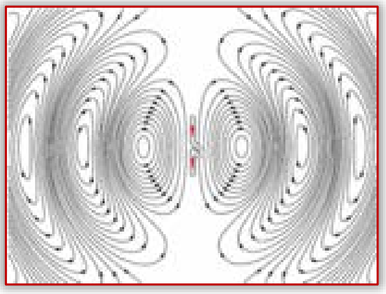

Figure 2.2. Dipole antenna radiation pattern

Its omnidirectional radiation characteristics is limited to a single axis. There are some works including [22], where dipole antenna parameters are tried to be enhanced by introducing a reflector and director element and hence forming a YAGI structure. The YAGI structure is a perfect example of driven array formation using simple dipole. Even though it increases the gain and directivity, there is no improvement in the natural radiation pattern.

— Monopole antenna

According to the results of the work in [23], it is clear that monopole antennas can act as a viable alternative to dipole antenna for UAV applications. Half-cut dipole resembles a monopole structure, which is a straight metal rode shaped conductor feeding signals through one of its ends. From the works in [24], it is clear that monopole antennas shown in Figure 7 [23]are driven using the coaxial feeding technique which results in a similar kind of pattern when comparing to dipole antennas. Like the dipole antenna, the dimensions will be a deciding factor in fixing operational frequencies. Often the chosen length of the antenna is $= \frac{\lambda}{4}$.

Like the case of the dipole antenna, monopole antenna shows similar traits in radiation nature, which can also be observed in Figure 2.4.[18] In the case of monopole antennas, radiation is in all angles of the azimuthal direction which will form a single plane omnidirectional radiation pattern much like the radiation pattern of a dipole antenna. As per the studies in [18], it is found that at high-frequency applications monopole antenna can use a metal body as the ground plane for radiation. In the case of UAV structures, the gigahertz range of frequency enabled the designer to take the liberty of making the chassis of UAV as the ground plane for monopole antenna. Using a monopole antenna, a test drive of UAV suggests that the optimized antenna gain reported at 5.8 GHz is 5.19dB with input impedance of 36.8 Ohms [23].

Figure 2.3. Monopole antenna structure

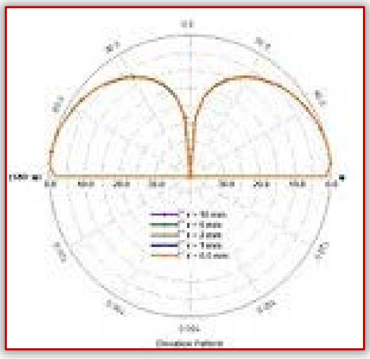

Figure 2.4. Monopole antenna radiation pattern

≡ Bladed dipole antenna

As an improvement from the traditional shape of dipole and monopole antenna, a bladed dipole antenna is introduced in [17]. The work concentrated on the planar structure of the antenna by introducing a metal sheet. Another attempt succeeded in improvising the structure of dipole by integrating metal sheet [25]. In addition to the design constraints of UAV, there is an additional factor of aerodynamic nature to be considered in these modifications. By creating a wing-shaped structure from the metal sheet, a remedy for the aforementioned problem is reported in [8]. This makes blade antennas the most promising candidate for airborne applications. In close inspection, the structural aspect of a bladed dipole antenna can be described as the lining of two monopoles with an oblique edge, connected by spread metal sheets. This configuration makes the antenna size large with ground plane covering almost all of its dimensions. For a working bandwidth under 450MHz, it is found that the peak antenna gain is 15dB. Figure 2.5[25] shows the bladed dipole antenna which is having a close resemblance to ordinary dipole structure in Figure 2.1 [24][22].

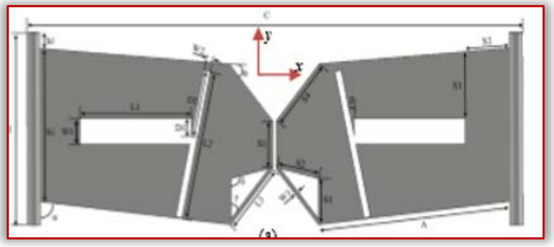

Figure 2.5. The bladed dipole antenna structure

It can be provided with coaxial feeding and also be fed through a simple micro strip line feeding technique due to the planar nature. The use of broadband impedance transformer in the setup in [23] is for impedance matching which helps for the reduction of VSWR rating of the antenna structure. While observing the radiation patterns of a bladed dipole antenna it is noted that there is much improvement in terms of reduction of blind spots and increase in range (two times) when compared with a simple dipole antenna. The two-dimensional radiation pattern is shown in Figure 2.6.[17].

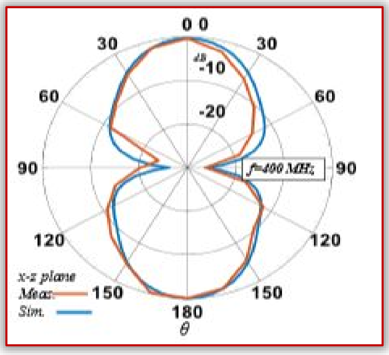

Figure 2.6. Bladed dipole antenna radiation pattern

≡ Disposable antenna

In is suggested that the antennas for UAV structure has to be made from rigid substrates [26]. But, most of the rigid substrates will have to be omitted when considering the criteria like reusability and recyclability. The work on the disposable drone is currently attracting significant research interest [27]. These types of UAVs are made from inexpensive and degradable materials such as paper or cellulose-based elements. This type of antenna designing is considered as cheapest in bulk production. The antenna fabrication is done by an inkjet printing method. In this, the UAV substrate is being coated with conducting materials like silver nanoparticles which will work as an antenna. Inkjet printing helps in increasing the portability where the antenna can be printed anywhere on the drone's body [28]. Antennas were designed to operate in the range of 2.4GHz and 5.8GHz which is suitable for effective drone control.

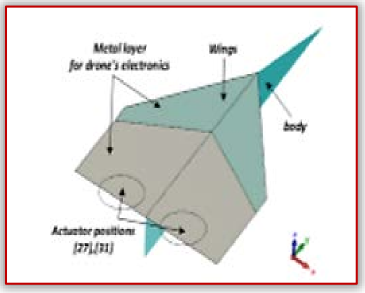

Figure 2. 7. Disposable antenna structure

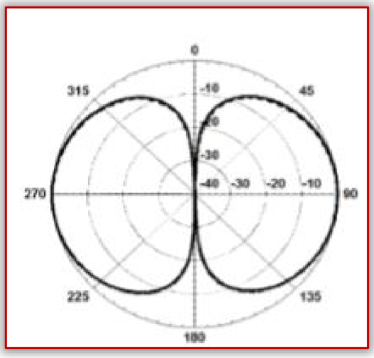

Figure 2.8. The disposable antenna radiation pattern

Figure 2.7[27] explains the structure of disposable antenna with the monopole structure, and it can also be called a modified disposable monopole antenna [24]. The radiation pattern of disposable antenna structure as in Figure 2.7 shows large coverage over radiation plane as shown in Figure 2.8[20]. The disposable antenna can inherit varieties of radiation patterns including directional, bidirectional and omnidirectional, depending on the shape of antenna that is printed on the UAV. The antenna referred for FPV application in [25] has a measurable gain of 2.75dB, with 200MHz BW at 5.8GHz.

≡ Cloverleaf antenna

According to [29], multiple antenna integration structures like cloverleaf antennas can be derived from the simple micro strip patch antenna. The antenna in the concerned work in [26], has a four-petal structure with a length of $1.25\,\lambda$. Figure 2.9 [30] shows the structures of the cloverleaf antenna with 4 petal system. Due to the close relationship with micro strip patch antenna, it is likely to inherit qualities like compactness, adaptive nature with various feeding techniques, low profile structure, inexpensive martial fabrication and ease of mounting into a structure. Different structures can be found related to works in [30] with various arm lengths and the number of the loops (petal) [29]. The arm length is selected as per the frequency of operation while the number of loops depends upon the desired bandwidth of the antenna. The test piloted version of the cloverleaf antenna consists of a centre feed with a coaxial feeding excited through an SMA port. This results in maximum gain of 2.1dB at 5.8GHz with a narrow bandwidth of 100MHz. The directional characteristic shown in Figure 2.10[29] suggests that it is suited for UAV application with omnidirectional radiation characteristics.

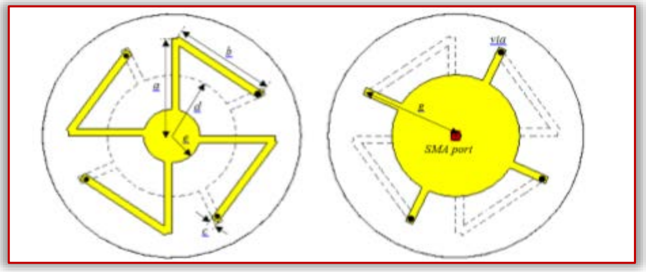

Figure 2. 9. Cloverleaf antenna structure

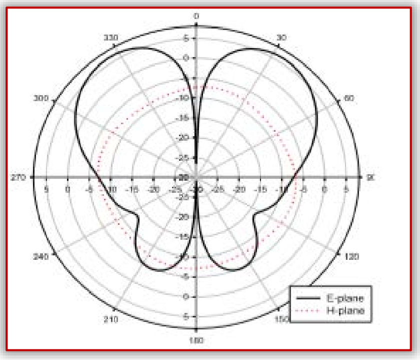

Figure 2. 10 Cloverleaf antenna radiation pattern

The linearly polarized antenna provides high gain and directivity, but there are drawbacks needed to be addressed when considering the finding in [31], which mentions major defects while using an L.P antenna in FPV applications. The findings can be listed as

- The degree of freedom flying is limited.
- There may be an appearance of multiple blind spots.

- Output gain will have a narrow bandwidth.
- Planar polarization creates multi-pathing effects.
- Possibilities of cross-polarization will be large.
- High altitude UAV will suffer from the Faraday Rotation effect.
- The use of extensive conductor contacts creates low radiation efficiency.
- In the case of printed antennas, structures will be fragile and durability will be low.

These are the problems that are faced due to the usage of a linearly polarized antenna. The use of a directional beam will create a limited space of flying and this will lead to the creation of regularly occurring blind spots. The linear polarization may lead to the reception of reflecting signal which makes data interference and cause multipath effect. In the case of high flying UAV, there can be an atmospheric effect of Faraday rotation which will change the polarization nature of radiation by an offset, which will lead to package missing in data transfer as well as cross-polarization in data projection. Even with all of its drawbacks, LP antenna stay well respected among UAV community.

As per the pre-processing data capture techniques in [2], the integration of scanning strategies can be done with L.P antenna, so that it can overcome drawbacks. These scan strategies for FPV applications are explained in next section.

Scan Strategies

The modification of flight patterns through which improvement of efficient UAV based FPV application is possible is explored in [16] . According to [32], scan strategies can be followed by L.P antenna-based UAV to improve effectiveness in their FPV application. More complex flight pattern was developed such that information even from the curved as well as the planar surface can be extracted with ease [16]. This is a milestone in L.P antenna designing for the FPV application. Pilots were able to collect data with multiple scans and combine them in temporal fashion such that a two-dimensional representation of AUT pattern is obtained. These types of data processing can be found in GPS units in which points of trajectory are determined using multiple scanning iteration. In short, flight patterns that are developed in [14] are designed for UAV which uses linear polarization antenna for communication. Using these scanning strategies, data gathering from LP antennas becomes a real possibility. According to the spatial distribution of flight patterns scanning strategies are being divided into three, which are discussed in the following subsections.

Cartesian raster scan

The Cartesian raster scan as shown in Figure 2.11 [32] consists of several rectilinear parallel flight paths formed at a constant height and with a constant UAV orientation. The UAV orientation can be parallel or perpendicular to the flight pattern segments. This will be providing two orthogonal field components. However, during the test flight of UAV, it is noted that flight pattern requires a large amount of power consumption and flight time because of the many turns the craft has to perform to reduce the average speed [14]. This Cartesian raster scan has already been using in the far-field measurement of the antenna array. To map specific details of radiation patterns such as the distribution of the main beam, this type of scanning has proven useful. With minor upgrading of antennas, it is seen that the Cartesian raster scan can also be implemented in near-field scanning as well.

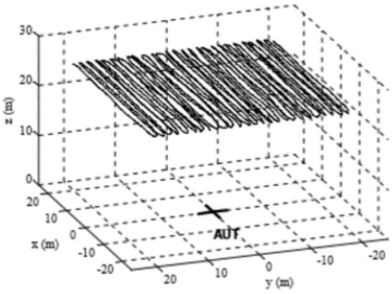

Figure 2. 11. Cartesian raster scan

Radial raster

The second flying pattern that is mentioned in [16] and shown in Figure 2.12 [16] is radial raster scanning. It can be developed on a planar surface and with curved segments as well. It consists of several rectilinear constant height paths having a radial direction to the vertical axis. The yaw angle which is defined as the angle between the fragments to be scanned is kept constant throughout the scanning procedure. It is noteworthy that the inclusion of a circular circumference for scanning can introduce the effect of components like θ(azimuth angle), and ϕ(elevation angle) in UAV flight. In a test flight, it was noted that additional post-processing is still required to obtain the two components of the AUT pattern from the measured data [16]. The flight efficiency, in terms of covered area vs. time, is higher than the Cartesian raster. However, the sampling density is higher close to the centre and reduces as the radius is increased. This feature will lead to both a constant path loss and minimum flight duration. It should be noted that the azimuthal sampling density is more uniform to the radial raster.

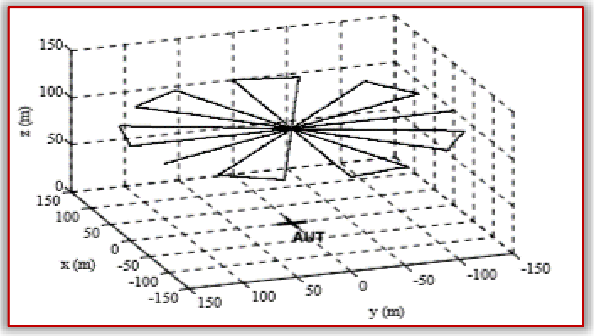

Figure 2. 12. Radial raster scan

Azimuthal 3D raster

The drawbacks of the previous two scanning techniques has led to the development of this Azimuthal 3-d raster scanning shown in Figure 17[16]. In this, several circular concentric paths of scanning is performed at different heights, maintaining a constant distance between the UAV flight path. Moreover, the flight envelope is of three-dimensional axis, with a single circular path having a constant height, with a high flight accuracy. UAV orientation (yaw) should be set as parallel (perpendicular) to the flight direction (speed vector) to detect either the φ or θ. It should be noted that the UAV horizontal orientation continuously varies within a single circular path also. This behaviour cannot be implemented straightforward with some pilot platforms. Subsequent post-processing will be required to obtain the AUT pattern [14].

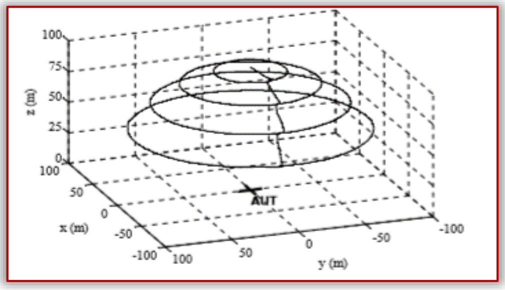

Figure 2. 13. Azimuthal raster scan

— Circularly Polarized Antenna

As per [33], CP antenna performance dominate over LP antenna performance. The previously investigated antennas have noticeable drawbacks due to the linear polarizing nature of radiation. The main advantage of circular polarization is the avoidance of problems related to the plane of polarization. When the signal is being fed to the antenna, plane of polarization will start to rotate with time. When the signal is being fed, the plane of polarization would have rotated a complete 360 degree by the time taken for a full wavelength signal to pass through the antenna. Various types of antennas can be observed that possess circular polarization nature. In most of the cases, the circular polarization is obtained from the combinations of linearly polarized antennas. LP antennas are being arranged together so that their combined radiation patterns will fill the void nulls that are being left by individual radiation patterns.

≡ Planar quasi-isotropic antenna

According to [8], perfect radiation pattern for remote control applications is isotropic. As per [34], an antenna is designed to emit a quasi-isotropic radiation pattern as shown in Figure 2.15 [34]. The antenna that is displayed in Figure 2.14 [34] is the result of the integration of slot structures in monopole antennas. The monopole antenna is being designed for emitting a vertical omnidirectional radiation pattern. Due to the stacked structure, there are limited number of feeding techniques applicable. It is found that best results are being obtained under the Grounded Coplanar-Waveguide (GCPW) feeding technology for monopole antenna [35]. The vertical radiation pattern is the result of the monopole created due to the vertical shorting of circular patch structure. According to the duality principle, a horizontal magnetic current source is found to be equal to an electric source in the vertical direction, and in this way the radiation pattern is created in the vertical direction. But there are nulls present directed in the z-direction of the vertical monopole radiation pattern. To compensate these nulls, slots are inserted in the ground plane of GCPW. The slotted loops that are created play an important role in masking the nulls created from vertical monopole. For increasing the field strength, additional patches are introduced with rectangular shape in the ground plane, which will compensate nulls that are occurring in z-direction. With the test flight conducted at 5.8 GHz for the measurement of antenna parameters and radiation measurements, the input impedance is viewed as 50 ohms with output gain peaks at 12dB for a 500MHz working bandwidth [32].

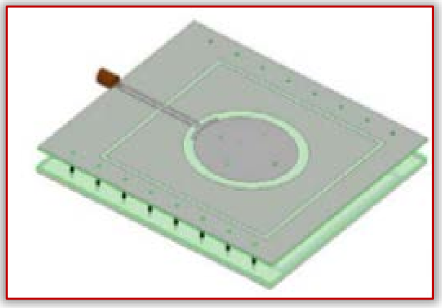

Figure 2. 14. Planar quasi-isotropic antenna structure

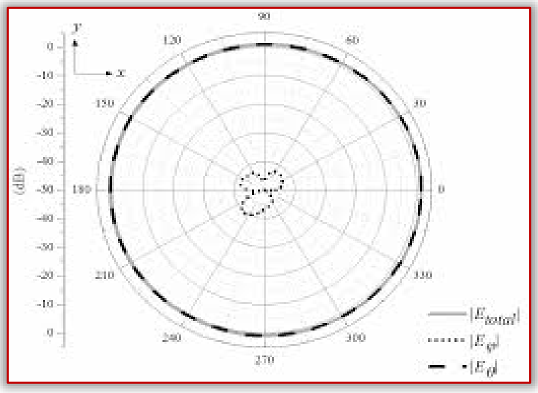

Figure 2. 15. Planar quasi- isotropic antenna radiation pattern

≡ 3-D Folded Loop antenna

As per [20], the simplest wire antenna - a dipole - does not provide the desired performance. This is clear from the inappropriate coverage pattern and unwanted coupling to electronic devices in aircraft. Improvements to this dipole is made in [36], where two dipoles separated by λ/4 produces a cardioid shaped pattern, and its null can be used to negate the effects of coupling with airplane electronics, thus addressing most of the requirements. Then the challenges of embedding the dipoles into the wing shape with 15mm height without losing efficiency and the lack of coverage in the downwards direction remain unanswered. In finding a solution to this problem, in [37], the design of a structure with a loop antenna is presented.

When considering a natural substitution for a dipole antenna it is best to choose a loop antenna over others [37]. This loop antenna is better suited for wing structures, unlike other alternative loop antennas. There is an additional possibility with which loop antenna can again be folded into the rectangular structure without changing the radiation pattern, but unfortunately over usage of loop antenna can cause a mutual coupling between the loop structures. To face the problem of making a loop antenna even smaller, one has two methods that can be followed:

- Reducing the size of the loop and placing it on the dielectric substrate, but this will result in the reduction of radiation efficiency.
- To fold the loop even further to make it electrically small and fit it in the surface of dielectric material.

Designers in [32] opted to go for the second option by miniaturization of loop antennas as shown in Figure 2.16 [36], which will result in a portable small size antenna having the efficiency of the full-scaled antenna. The input impedance measured is 50 ohms with gain value 5.2dB for a BW of 200MHz for FPV application specific frequency and the radiation pattern is as shown in Figure 2.17 [36].

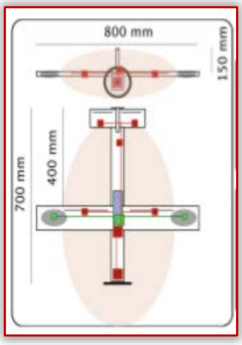

Figure 2. 16. 3-D folded loop antenna structure

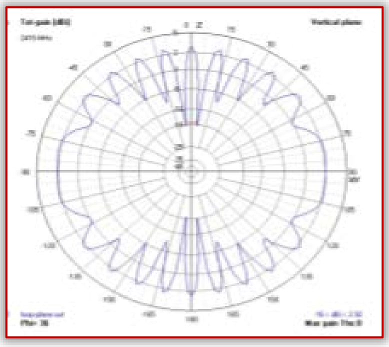

Figure 2. 17. 3-D folded loop antenna radiation pattern

≡ Multi-petal antenna

Taking the baseline model from [26] , [38] came up with a 3-D configuration of the omnidirectional CP antenna. It looks like petals of a flower. The overall structure consists of N identical loops. Each loop is being rotated along the polar axis with a constant angle offset called pitch angle. Radial arm projecting outward from the centre axis will be measuring 0.25λ. In between two loops, there is an angle difference called the rotational angle. The circumference of a single loop will be one full wavelength λ and the feeding current can have constant amplitude and varying phase throughout the surface of the loops. The tilted loops of this antenna will be having the same phase and excitation point. The circular polarization is obtained by keeping amplitude same and maintaining a phase difference of 90^0. The circular polarization is shown in Figure 2.18[38]. Considering the current and its phase at the initial feeding point, there is the division into three with first and third petals covering the radiation lobes through the x-y plane, and the perpendicular loop referring to segment no 2 covering nulls in the z-direction by which a complete omnidirectional radiation pattern is observed as shown in Figure 2.19 [38]. With axial ratio below 3dB and input impedance of 70 ohms, the gain measured is 1.3dB for 500 MHz of working bandwidth for this antenna under the FPV application.

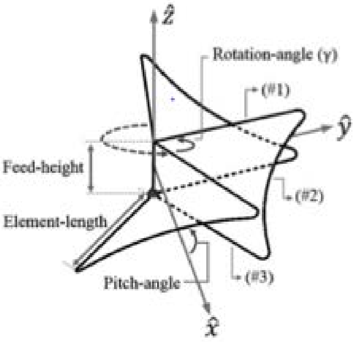

Figure 2. 18. The multi petal antenna structure

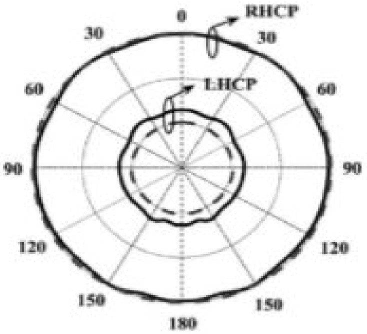

Figure 2. 19. Multi petal antenna structure radiation pattern

≡ Microstrip antenna array

An array antenna in 5.8 GHz frequency band is designed in [31]. This being derived from the single elemental micro strip patch antenna, the properties like lightweight, small size and easiness of mounting are applicable to this structure as well. The designing of the antenna arrays showed in Figure 2.20[31] is done by placing 12 circularly polarized patches on 1.6mm thick substrate, which is made of FR4 epoxy and the substrate is sharing ground plane with feeding network.

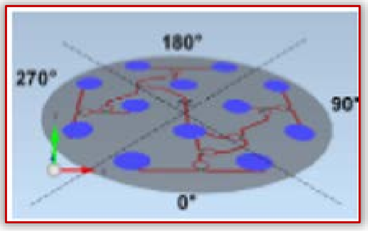

Figure 2. 20 Micro strip antenna array

Each of the patches has their feeding points, and as per the placing of the elements in the array, the orthogonal field components are being generated. The total antenna structure is divided into 4 sectors. In every sector, there is a network of 3 patches with a single feeding element where the feeding signal will be offset by an angle of 90^0. With this patch rotational strategy, the axial ratio is reduced. The power divider circuit which is used in the array element excitation is similar to that found in SMDs. The signal with amplitude and phase obtained from the power divider circuit will allow a good compromise between the maximum gain, beam width, and side lobe levels. The test flight report shows that with the input impedance of 70 Ohms and an axial ratio below 6dB, the antenna shows a gain of 1.2dB for a bandwidth of 200MHz with radiation pattern as in Figure 2.21[20] .

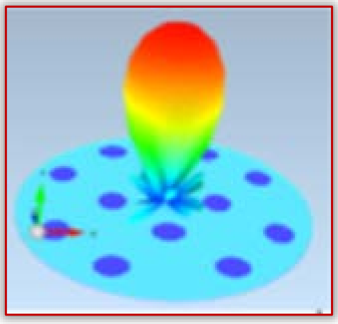

Figure 2. 21. Micro strip antenna array radiation pattern

— Miscellaneous

In the previous sections, the methods that depend upon LP antennas to form CP antennas are explained. The conversion of linear polarization to circular polarization can also be done by using methods like applying a polarizer or implementing precision format flying etc. It is also possible to manipulate the collective outcome of the radiation profile of the antennas to get the desired pattern. Two widely used methods are visited in the next section.

≡ Beam steering antenna

According to [1], the 5.8 GHz ISM band is preferred for FPV transmission systems. However, the 5.8 GHz ISM band is more sensitive to multipath interference than other frequencies. As shown in [39], beam steering properties are used to reduce multipath interference and enhance FPV video link performance. Multipath interference can be remedied by steering the beam in the direction of the pilot and reducing radiation to other directions. The phased array configuration of the antenna is a beam steering method but there is complication regarding the phase offsetting and current divider circuit designing for the array with large number of elements [8]. In [40], including microwave components to modify a beam-steering antenna with three reconfigurable parasitic elements for drone FPV applications is presented. A cylindrical rode structured monopole antenna is placed at the centre of the equilateral triangle structure that is formed by parasitic walls is shown in Figure 2.22 [40].

The excitation of parasitic walls is done using electromagnetic coupling with the driven monopole antenna. There is an embedded PIN diode in the walls to control the electromagnetic coupling which act as a switching device. The monopole antenna is fed with a coaxial feeding line which will result in an omnidirectional radiation pattern in a vertical direction. When PIN diode is in the on-state, the parasitic walls will be transparent and hence the field lines of monopole antenna can pass through this transparent wall.

Switching the PIN diode is configured such that triggering will be one by one. At any given time only one of the 3 pin diodes will be active and the other two will be in off mode. This is accomplished by trigger pulses to control the PIN diodes, and beam steering is possible such that the parasitic wall can direct the main lobe of the monopole antenna to any angle as shown in Figure 2.23 [40].

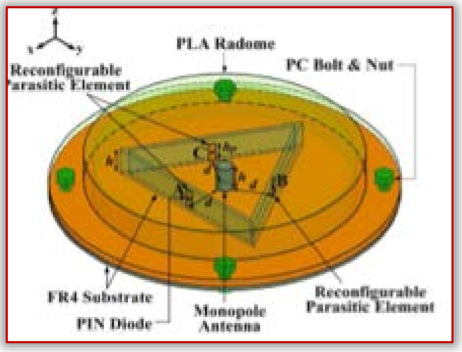

Figure 2. 22. Beam steering using PIN diode

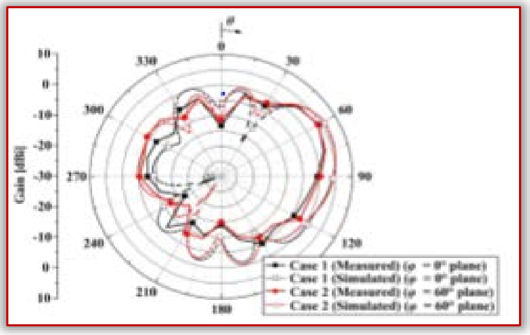

Figure 2.23. Radiation pattern

≡ Precision Formation Flying

As per [11], the way to optimized communication is by utilizing antenna arrays. However, equipping UAVs with antenna arrays is impractical. This is because the antenna arrays need a lot of space and energy. A possible solution to this problem is to make the antenna array by clustering of UAV networks [41]. In this situation, the UAVs would first share the information to be transmitted among each other and then perform data aggregation, compression, and additional processing such as feature extraction to condense the data as much as possible. Following the additional processing, the UAVs would fly in a specialized 3-d formation giving rise to good array performance and then transmit together, by synchronizing their electromagnetic parameters to focus their limited power in the direction of the intended receiver. Not only does this have the advantage of combining their transmitted power, but it also improves the situation further by sending much of this power in the direction of the receiver, causing less wastage[40].

The property of antenna systems, called directivity, is the primary reason for the formation of the antenna array. The UAVs formation of flights could be modelled by using a chosen geometric shape such as a linear array, a planar array, and a 3-dimensional array. Linear and planar antenna arrays are the basic formation. However, the UAVs formation flight can maintain any geometric shape in space; ie. UAVs can take advantage of a 3D antenna array considering optimal positions for UAVs formation flight to have maximum performance in terms of directivity and enlarging the range of operation. Communications at a long-range for UAVs can be improved by considering optimal positions for UAVs in a

3D non-uniform array (as flight formation group) [41]. This is shown in Figure 2.24[42].

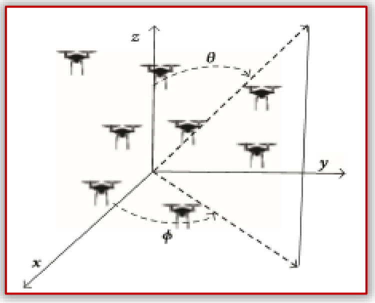

Figure 2. 24 Precision formation flight of UAV

The aforementioned designing and methods of CP antenna tracking are intended to overcome the difficulties that is put forward by LP antennas, but some drawbacks are detected during the analysis of CP antenna such as [21]

- Low Gain.
- Lesser range than LP.
- Low directivity.
- In array, the inclusion of more elements will cause a reduce of aerodynamics.
- Even the formation of a multi petal antenna requires high complex designing.
- Beam steering requires add on MW components.
- In co-ordinate flight, it is comparably costlier when considering the usage of a single UAV.

All of these drawbacks will be the motivation of the present-day research on developing an optimized antenna for FPV application.

COMPARISON OF ANTENNAS

Antennas are classified based on characteristics of physical setup as well as the radiation measurements. As explained in previous sections, there are mainly 2 types of polarization profiled antennas namely LP and CP antennas. As a subdivision, the LP antenna contains dipole, monopole, cloverleaf, disposable and bladed dipole antennas. Apart from the linear polarization, as a common trend, all of these LP antennas constitute a narrow bandwidth with moderate directivity and gain out values.

The polarization being linear, the axial ratio value will be greater than 9dB. These linearly polarized antennae will be the core elements in designing circularly polarized antennas. As can be found in the previous sections, large portion of circularly polarized antennas are being derived from the linearly polarized antennas or flight steering methods, where the radiating element present at that structure reassembles a linearly polarized (monopole antenna) antenna element.

In the construction of the CP antenna, the nulls that were created by the single LP antenna element were masked by using another LP antenna placing at specific spatial orientation. All of the CP antenna designed follows similar values of low axial ratio, low gain, moderate directivity, and wide bandwidth. For numerical analysis, a comparison is given in Table 2.

Table 2. Comparison of antennas

	Dipole	Monopole	Blade dipole	Disposable
Polarization	Linear	Linear	Linear	Linear
Bandwidth	<200MHz	<200MHz	<400MHz	<200MHz
Peak Gain	5.2dB	5.19dB	15dB	2.75dB
Directional	1-d	1-d	1-d	1-d
Axial ratio	>9dB	>9dB	>6dB	>9dB
Resistance	50 Ohms	36.8 Ohms	50 Ohms	50 Ohms
Efficiency	Low	Low	Low	Low
Aerodynamic	Moderate	Moderate	High	High
Fabrication	Metal rode/wires	Metal rode/wires	Metal wire & sheets	Paper and Inkjet
Durability	Moderate	Moderate	Fragile	Very Fragile

	Clover leaf	Microstrip array	Planar quasi	Multi petal	3-D Folded
Polarization	Linear	Circular	Circular	Circular	Circular
Bandwidth	<100MHz	<200MHz	<500MHz	<500MHz	<200MHz
Peak Gain	2.1dB	1.2dB	12dB	1.29dB	5.2dB
Directional	1-d	2-d	2-d	2-d	2-d
Axial ratio	>6dB	<3dB	<3dB	<3dB	<3dB
Resistance	50 Ohms	70 Ohms	50 Ohms	70 Ohms	50 Ohms
Efficiency	Low	Low	Low	High	Low
Aerodynamic	Less	Less	Moderate	Moderate	Moderate
Fabrication	Microstrip Lines	Microstrip Lines	Metal sheet with slots	Metal wires	Metal sheets folded
Durability	Moderate	Moderate	Fragile	Strong	Moderate

CONCLUSION AND FUTURE TRENDS

5.8GHz frequency is used for FPV application, which suffer severely from multipath interference. The development of a linearly polarized antenna is being hindered by the multipath effect, cross-polarization, narrow bandwidth, Faraday rotation effect and a low radiation efficiency due to extensive usage of conductive materials. As a remedy to these drawbacks, CP antennas were designed but they lack appropriate gain and directivity and their range will be limited. Even though there are some flight controlling methods and beam steering methods to establish circular polarization in the UAV network, all of these methods lack portability and exceeds the financial budget of the user. All of these inferences point towards the need for an optimal design of the FPV application enabled antenna. A few options for future research are

- As for now the most efficient way of antenna installing for a UAV is by using polarization or beam steering multiplexing. The multiplexing systems use more than one linear antenna which will require accurate spatial arrangement and well-designed power divider circuit for antenna excitation. Due to the use of multiple antennae the effective bandwidth will be high when comparing to a single circularly polarized antenna. For obtaining an ideal antenna for UAV application there is a need of obtaining a perfectly shaped circularly polarized antenna with wide bandwidth.
- For obtaining wide bandwidth, modified feed structure like GCPW feed can be used and also similar structures which is adaptive to circular polarization and result in lower Axial Ratio value may be used.

— Dielectric resonator antenna (DRA) involvement is rather remained silent for FPV application. But the flexible nature of DRA makes it a perfect candidate for future works. The polarization profile of DRA structures can be easily controlled by using feeding techniques, which makes it a futuristic option for UAV antennas. Due to the verities of substrates that can be found as a DRA material give antenna designer more option to work with. DRA normally have wide bandwidth, a moderate gain, and a large impedance matching range. DRA structure often gets credited for its adaptability and by using this future works can be planned with the integration of different antenna structures with DRA materials.

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