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Design and Realization of Directional Biquad and Omnidirectional Biquad Antennas as First-Person View (FPV) Receiver Antennas

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ABSTRACT

UAV is an unmanned aerial vehicle controlled remotely by a pilot or automatically by pre-programmed instructions. UAVs are equipped with First Person View (FPV) technology, which facilitates user monitoring. FPV monitoring can be done using with goggles and a monitor screen. The monitor screens available in the market typically use dipole antennas as their default antennas. However, the drawback of the default monitor screen antenna is its limited range, typically only reaching up to 200-300 meters. This research focuses on the design and implementation of biquad antennas for FPV receivers in UAV systems operating at a frequency of 5.8 GHz. The aim is to create antennas with a larger reception range from the transmitter compared to the default FPV monitor screen antenna. Simulation results from CST Studio show that the Biquad Directional antenna has a VSWR value of 1.508, a return loss of -13.867 dB, and a gain of 3.416 dBi. On the other hand, the Biquad Omnidirectional antenna with 4 lobes has a VSWR value of 1.7065, a return loss of -11.666 dB, and a gain of 1.973 dBi. Meanwhile, the Biquad Omnidirectional antenna with 6 lobes has a VSWR value of 1.226, a return loss of -19.863 dB, and a gain of 1.865 dBi. In practical testing on the FPV monitor screen, all three types of antennas were successfully realized and able to capture real-time images from the UAV transmitter. The maximum distances achieved are 634 meters for the Biquad Directional antenna, 352 meters for the Biquad Omnidirectional 4 lobes antenna, and 545 meters for the Biquad Omnidirectional 6 lobes antenna.

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1. INTRODUCTION

An Unmanned Aerial Vehicle or UAV is a pilotless flying machine controlled remotely by a pilot or automatically through pre-programmed software [1]. UAVs have various applications, including long-range reconnaissance, surveillance, military use, cargo transport, as well as capturing images for mapping and entertainment purposes. UAVs are equipped with First Person View (FPV) technology, which facilitates user monitoring.

First Person View (FPV) involves Remote Control (RC) operation of UAVs that allows the pilot to see what the UAV sees, simulating the experience of piloting the UAV itself. The remotely operated vehicle is controlled from a first-person perspective through an onboard camera, and the video feed is wirelessly transmitted to FPV Video Goggles or displayed in real-time on a video monitor. To enable FPV functionality, a wireless transmission channel is required to connect the UAV to the Ground Station, typically using a 5.8 GHz frequency. Most commercially available FPV monitor screens come with default dipole antennas. These default antennas have a limited range of only 200-300 meters. Due to the restricted coverage area of these antennas, FPV operations are often suboptimal, leading to several disadvantages for users. Therefore, a 5.8 GHz frequency antenna has been designed to enhance FPV range, which will be installed on the FPV receiver monitor screen.

The designed antenna consists of both omnidirectional radiation patterns, capable of capturing signals from all directions, and directional radiation patterns, focusing the signal towards a specific direction. Both types of antennas will utilize the Biquad model, which involves an antenna with two equal sides resembling a square. The goal of designing and realizing these two antennas is to significantly extend and broaden the FPV range from the transmitter located on the UAV to the receiver screen monitor, achieving improved performance compared to the default FPV antenna.

Several relevant studies that have been conducted serve as the foundation or support for this research. Studies by Syaiful Rahmat, Agil Setiawan, and Fakhrana Dhaifina contribute to the background of this study. In a study conducted by Syaiful Rahmat in 2016 titled "Perancangan dan Realisasi Antena Mikrostrip Biquad

Ganda Untuk Antena Penerima FPV" the focus was on designing and implementing a dual biquad microstrip antenna as a receiver antenna for a UAV system at the ground station side. The research results indicated a unidirectional radiation pattern of the dual biquad microstrip antenna with a VSWR value of 1.192 and a return loss of -21.124 at a frequency of 5.8 GHz. The achieved gain measurement was 7.7 dBi [1].

A study by Agil Setiawan in 2015 with the title " Perancangan Dan Realisasi Antena Cloverleaf Dan Antena Helix Sebagai Antena FPV (First Person View) Pada Quadcopter" focused on the design of Cloverleaf and Helix antennas installed on a quadcopter. This study revealed that both the Cloverleaf and Helix antennas exhibited omnidirectional radiation patterns. The VSWR value for the Cloverleaf antenna was 1.433, while the VSWR value for the Helix antenna was 1.389. Distance measurement results showed an achieved range of 500 meters at a height of 40 meters [2].

In 2017, Fakhrana Dhaifina conducted a study titled "Perancangan Dan Realisasi Antena Biquad Yagi Dan Antena Biquad Omnidirectional Sebagai Repeater Pasif Untuk Meningkatkan Daya Terima Sinyal WCDMA" This research aimed to design, realize, and test passive repeaters for enhancing WCDMA radio signal reception in an indoor rural environment. The outdoor antenna, a 10-element biquad Yagi antenna, operated at a frequency of 2.02 GHz, had a gain of 8.09 dBi, a VSWR of 1.182, and a unidirectional radiation pattern. The indoor antenna, a biquad omnidirectional antenna, also operated at 2.02 GHz, with a gain of 1.39 dBi, a VSWR of 1.301, and an omnidirectional radiation pattern [3].

In comparison to the aforementioned studies, the difference in this research lies in the variation of the applied biquad antennas and their intended use, which is to be installed as FPV receiver antennas. In this study, it is anticipated that the designed and implemented antennas will yield an extended communication range between the transmitter and the FPV receiver.

2. RESEARCH METODOLOGY

The stages or research methods that will be used in this study are as follows:

- Literature Study Method

Literature study is a method of collecting research data from sources such as books, the internet, articles, and others that will assist the writer in compiling the research report.

- Experimental Method

The experimental method involves designing, simulating, creating, and testing antennas that have been developed with the goal of antenna specification design.

- Antenna Design

This design produces a representation of an antenna that is suitable for addressing the problem of the range of FPV (First Person View) video transmission that will be developed and implemented.

There are several stages in antenna design, including determining the operating frequency of the antenna, specifying the antenna's characteristics, selecting the materials or substances used, as well as determining the antenna's dimensions. Based on the design results, it will then be designed and simulated using CST Studio Suite 2019 software. If the antenna does not meet the expected specifications, an antenna optimization process is carried out.

- Antenna Realization

After the simulation and optimization processes, the mathematically calculated antenna will be implemented on the FPV receiver, in the form of an LCD monitor, for field testing to determine the distance value that can be received by the receiver antenna from the FPV transmitter located on the drone.

- Data Analysis

This stage will result in the processing of data and facts that are relevant to the research question. As for the research flow, it is presented in the flowchart diagram of the research shown below.

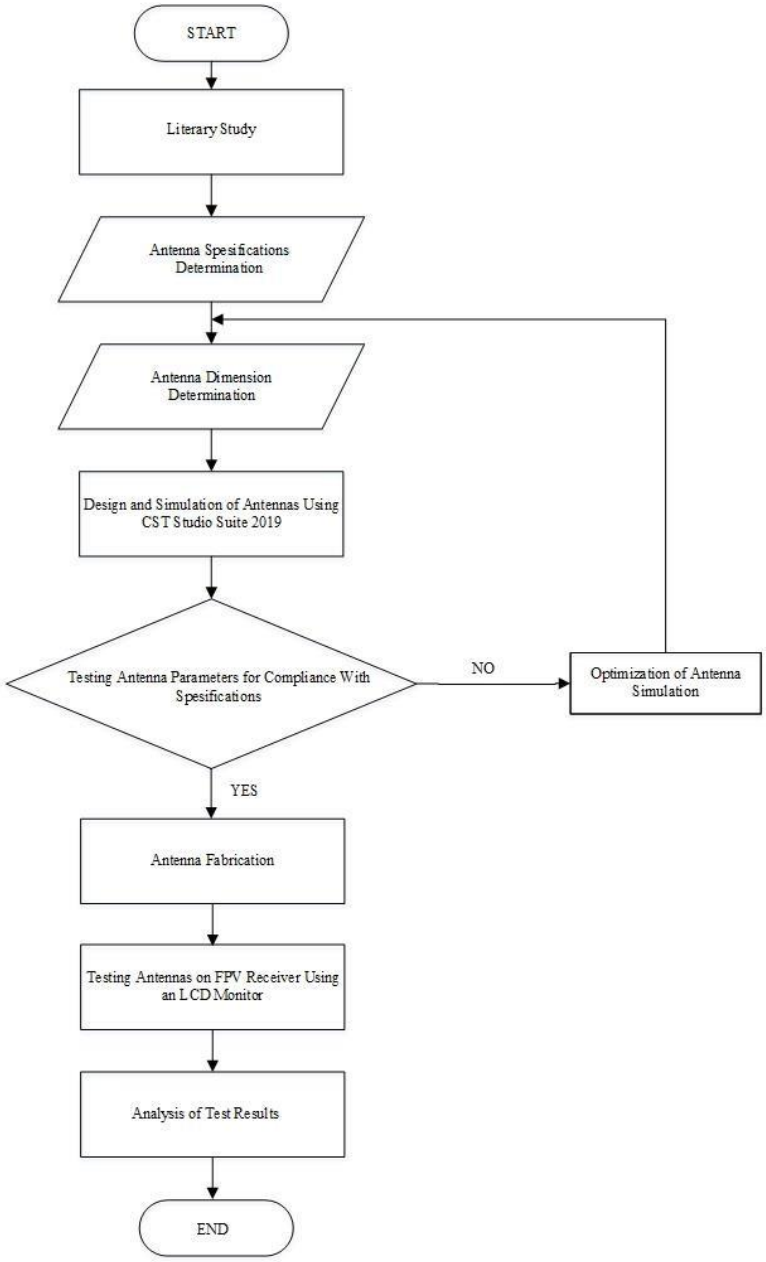

Figure 1. Research flowchart

2.1. Antenna Specifications

The designed antennas are the biquad directional antenna and the biquad omnidirectional antenna. The material used in creating the antennas is copper wire, and for the reflector on the biquad directional antenna, a double-layer FR-4 board is used.

The specifications of the antennas to be constructed are as follows:

- Operating Frequency : 5.8 GHz
- VSWR : ≤ 2
- Return Loss : $\leq$-9.54 dB
- Gain Biquad Directional : $\geq$ 2.5 dBi
- Gain Biquad Omnidirectional : $\geq$ 1.5 dBi

2.2. Antenna Dimensions

Before proceeding with the antenna design phase, mathematical calculations are carried out first to determine the antenna's dimensional size. The calculations for the antenna dimensions are as follows:

2.2.1. Finding the wavelength (λ)

The wavelength can be found with the following formula:

$$\lambda = \frac{c}{f} \quad (1)$$

Where λ is wavelength, *c* is the speed of light, and *f* is frequency used. This antenna will use a frequency of 5.8 GHz so the wavelength according equation (1) are follow:

$$\lambda = \frac{c}{f} = \frac{3x10^8 \text{ m/s}}{5.8x10^9 \text{ Hz}} = 5.17 \text{ cm} = 51.7 \text{ mm}$$

2.2.2. Length of each side (*dx*)

The length of each side of the antenna is one-quarter of the wavelength.

$$dx = \frac{1}{4}\lambda \quad (2)$$

So, if the wavelength is 51.7 mm, then the value of *dx* or the length of each side is as follows:

$$dx = \frac{1}{4}\lambda = \frac{1}{4}(51.7 \text{ mm}) = 12.925 \text{ mm}$$

2.2.3. Air gap between the antenna and the reflector (*a*)

The separation distance between the antenna and the reflector, or air gap (*a*), has a value of 1/8 of the antenna length.

$$a = \frac{1}{8}\lambda \quad (3)$$

$$a = \frac{1}{8}\lambda = \frac{1}{8}(5.17 \text{ cm}) = 0.64625 \text{ cm} = 6.46 \text{ mm}$$

2.2.4. Reflector Width (W_{ref}) dan Reflector Length (L_{ref})

The antenna reflector is in the shape of a square with the reflector width being half of the wavelength and the reflector length having the same value as the wavelength.

$$W_{ref} = \frac{\lambda}{2} \quad (4)$$

$$W_{ref} = \frac{\lambda}{2} = \frac{5.17\text{cm}}{2} = 2.585 \text{ cm} = 25.85 \text{ mm}$$

$$L_{ref} = \lambda \quad (5)$$

$$L_{ref} = \lambda = 5.17 \text{ cm} = 51.7 \text{ mm}$$

3. RESULTS AND DISCUSSION

3.1. The Results Of The Antenna Simulation

The antenna simulation is conducted using CST Studio Suite 2019 software with three variations of biquad antennas: directional biquad, omnidirectional biquad 4 lobes, and omnidirectional biquad 6 lobes. The dimensions are based on mathematical calculations and employ copper wire with a diameter of 0.6 mm.

From the antenna simulations in CST Studio Suite 2019 software, the following antenna parameters are obtained.

Table 1. Antenna parameter values

Types of Antennas	Antenna Parameter		
	VSWR	Return Loss	Gain
Directional Biquad	2.075	-9.128	3.039 dBi
Omndirectional Biquad 4 Lobes	1.864	-10.408	1.907 dBi
Omnidirectional Biquad 6 Lobes	2.127	-8.862 dB	1.934 dBi

In the simulation, the designed biquad directional and omnidirectional 6 lobes antennas do not meet the antenna design specifications, so it is necessary to optimize the antenna by changing the length of each side of the antenna.

3.2. Antenna Optimization Results

3.2.1. Directional Biquad Antenna

The first optimization performed is by changing the length value of each side of the antenna or dx as many as six antenna variations, namely 13,239 mm, 13,146 mm, 13,082 mm, 13,039 mm, 12,788 mm, and 12,675 mm while other dimensions such as reflector length, reflector width, air gap, wire diameter are fixed. The optimization results obtained parameter values as shown in the following table.

Table 2. VSWR, return loss, and gain value of 0.6 mm diameter antenna

Length Of Each Side / *dx* (mm)	VSWR	Return Loss (dB)	Gain (dBi)
12.675	2.009	-9.489	2.954
12.788	2.039	-9.319	2.959
12.925	2.075	-9.128	3.039
13.039	2.106	-8.967	3.088
13.082	2.119	-8.903	3.107
13.146	2.136	-8.82	3.101
13.239	2.164	-8.686	3.159

From the optimization performed, the values of VSWR and return loss did not meet the antenna design specifications. The VSWR value increases as the length of *dx* is added. VSWR is used to evaluate how efficient an antenna is and whether it is matching or not. A high VSWR value indicates a mismatch between the antenna impedance and the transmission line impedance. A high VSWR value implies that the power reflected back to the source is also significant.

VSWR is closely related to return loss, as both parameters are used to evaluate the compatibility of antenna with the transmission line. Return loss is used to determine how much power is lost. A high return loss value indicates a good match between the antenna and the transmission line. In the simulation of the directional biquad antenna, when the length of the antenna sides is small, the resulting return loss in this model is high.

The next antenna parameter is *gain*. Gain at a longer *dx* side length has a greater value compared to when *dx* is short. Therefore, the longer the biquad directional antenna side length, the higher the achieved gain.

Since the antenna with a wire diameter of 0.6 mm did not meet the expected antenna design specifications, optimization was carried out by changing the copper wire diameter to 1.2 mm with seven variations of *dx* sizes.

Table 3. VSWR, return loss, and gain values for the 1.2 mm diameter antenna

Length Of Each Side / *dx* (mm)	VSWR	Return Loss (dB)	Gain (dBi)
12.675	1.55	-13.322	3.321
12.788	1.53	-13.567	3.381
12.925	1.508	-13.867	3.416
13.039	1.489	-14.129	3.462
13.082	1.482	-14.235	3.477
13.146	1.472	-14.381	3.532
13.239	1.165	-22.334	3.569

The simulation indicates that a copper wire diameter of 1.2 mm yields antenna parameter values—VSWR, return loss, and gain—that meet the design specifications: VSWR $\leq$ 2, return loss $\leq$ -9.54 dB, and gain $\geq$ 2.5 dBi. In the simulation results, a good VSWR value is obtained, adhering to the specifications. In contrast to the 0.6 mm diameter, with a 1.2 mm diameter, the VSWR value decreases as the side length or *dx* becomes longer. Similarly, the return loss value increases as the *dx* length grows.

3.2.2. Omnidirectional Biquad 4 Lobes Antenna

In the initial simulation of the biquad directional 4 lobe antenna using dimensions calculated through mathematical calculations, the antenna parameter values met the design specifications. To understand the impact of changing *dx* on the antenna parameters in the omnidirectional 4 lobes model, six different sizes were designed by altering the *dx* values.

Table 4. VSWR, return loss and gain values of omnidirectional biquad 4 lobe antenna with 0.6 mm diameter

Length Of Each Side / *dx* (mm)	VSWR	Return Loss (dB)	Gain (dBi)
12.675	1.8273	-10.674	1.994
12.788	1.8365	-10.606	2.05
13.039	1.8505	-10.505	1.992
13.082	1.8559	-10.467	1.974
13.146	1.8613	-10.428	2.013
13.239	1.8641	-10.409	1.991

In terms of VSWR and return loss values for this model, the results indicate that as the size of each side or *dx* increases, the resulting VSWR value becomes larger, and the return loss value becomes smaller. However, the gain value is not influenced by changes in the length of each side of the antenna. From this simulation, it is evident that the biquad omnidirectional 4 lobes antenna with a copper wire diameter of 0.6 mm has parameter values that already comply with the antenna design specifications.

Furthermore, the biquad omnidirectional 4 lobes antenna was simulated using a wire diameter of 1.2 mm to understand its impact on antenna parameters, as shown in the following table:

Table 5. VSWR, return loss, and gain values for the 1.2 mm diameter omnidirectional biquad 4 lobe antenna

Length Of Each Side / dx (mm)	VSWR	Return Loss (dB)	Gain (dBi)
13.239	1.7363	-11.402	1.935
13.146	1.7268	-11.48	1.934
13.082	1.7217	-11.529	1.97
13.039	1.7189	-11.555	1.925
12.925	1.7065	-11.666	1.973
12.788	1.6936	-11.784	1.926
12.675	1.6852	-11.863	1.958

When designing the omnidirectional 4 lobes antenna using a wire diameter of 1.2 mm, the simulation results show parameter values that adhere to the design specifications and provide better results than when using a wire diameter of 0.6 mm.

3.2.3. Omnidirectional Biquad 6 Lobes Antenna

In the initial step, optimization was carried out by altering the length of each side of the antenna (*dx*) with six variations while still using a copper wire diameter of 0.6 mm. The simulation results for this step can be seen in the following table:

Table 6. VSWR, return loss, and gain values for the 0.6 mm diameter omnidirectional biquad 6 lobes antenna

Length Of Each Side / *dx* (mm)	VSWR	Return Loss (dB)	Gain (dBi)
13.239	2.1608	-8.701	1.933
13.146	2.1494	-8.755	1.936
13.082	2.1392	-8.805	1.972
13.039	2.1335	-8.832	1.945
12.788	2.0963	-9.019	1.977
12.675	2.0822	-9.091	1.946

The results indicate that the VSWR and return loss values do not meet the antenna design specifications, where the simulated VSWR value is greater than 2, and the simulated return loss value is larger than -9.54 dB.

As the antenna has not met the design specifications, it was further optimized by changing the copper wire diameter to 1.2 mm, while keeping the *dx* value constant at 12.925 mm. The VSWR value when using a 1.2 mm copper wire diameter yields a good value of 1.226. Additionally, the simulated return loss value is -19.863 dB, and the gain value is 1.865 dBi. These antenna parameter values align with the expected antenna design specifications.

To understand the impact of changing *dx* on the omnidirectional biquad 6 lobes antenna parameters, six antennas with different *dx* sizes were designed using 1.2 mm diameter copper material. The *dx* values and the results of the simulations are presented in the following table:

Table 7. VSWR, return loss, and gain values for the 1.2 mm diameter omnidirectional biquad 6 lobe antenna

Length Of Each Side / *dx* (mm)	VSWR	Return Loss (dB)	Gain (dBi)
13.239	1.2462	-19.204	1.826
13.146	1.2415	-19.53	1.831
13.082	1.2398	-19.407	1.83
13.039	1.2372	-19.492	1.82
12.788	1.2282	-19.793	1.875
12.675	1.2245	-19.921	1.867

In Table 7, the simulation results in terms of antenna parameters obtain good values in accordance with the expected antenna specifications.

From the various optimizations carried out, the optimized results using antenna dimensions based on mathematical calculations and a copper wire diameter of 1.2 mm yielded the following parameter values:

Table 8. Antenna simulation results after optimization

Antenna Types	Antenna Parameter Values (After Optimization)		
	VSWR	Return Loss	Gain
Directional Biquad	1.508	-13.867	3.416 dBi
Omndiirectional Biquad 4 Lobes	1.706	-11.666	1.973 dBi
Omnirectional Biquad 6 Lobes	1.226	-19.863 dB	1.865 dBi

The antennas that have been optimized are then fabricated for implementation on the FPV receiver, specifically the monitor screen.

3.3. Realization of the Antennas on the FPV Monitor

The antenna that has been installed on the monitor screen successfully displays real-time images. Here is the form of the antenna realization on the FPV receiver.

Figure 2. Directional biquad antenna on the monitor screen

Figure 3. omnidirectional biquad 4 lobes antenna on the monitor screen

Figure 4. Omnidirectional biquad 6 lobes antenna on the monitor screen

In this research, the FPV receiver utilizes a monitor screen. During field testing, the default antenna managed to achieve a distance of 280 meters for real-time image transmission.

Following the default antenna's distance testing, the next round of testing was conducted by replacing the default antenna with a directional biquad antenna on the monitor screen. The directional biquad antenna attached to the monitor was then tested to determine its maximum distance capability for displaying images. The results showed that the farthest range this antenna achieved was 634 meters. After the drone moved away from the monitor at a distance of 640 meters, the monitor could no longer display real-time images, becoming filled with noise. The advantage of this antenna lies in its long-range capability, although it has a unidirectional radiation pattern.

Subsequently, the next distance testing was conducted using the omnidirectional biquad 4 lobes antenna. The results demonstrated that this antenna could transmit images to the transmitter up to a distance of 352 meters. Its radiation pattern covers all directions, but it is limited in terms of long-range transmission due to its radiation pattern.

For the final distance testing, the omnidirectional biquad 6 lobes antenna was used. This antenna managed to transmit images up to a distance of 545 meters, displaying real-time images with slight noise. The performance of the biquad 6 lobe antenna was great compared to the biquad 4 lobes antenna, attributed to the impact of the number and arrangement of antenna components.

Among the three realized antenna types, the directional biquad antenna achieved the farthest distance of 634 meters because this antenna has unidirectional radiation pattern that is able to focus its signal reception in certain direction.

4. CONCLUSION

The designed antennas is directional biquad antenna, 4 lobes and 6 lobes omnidirectional with simulation using CST Studio Suite 2019 software. The designed biquad directional antenna, simulated using a 1.2 mm diameter copper wire and dimensions of 12.925 mm for each side, 51.7 mm for reflector length, 25.85 mm for reflector width, and an air gap of 6.46 mm, was able to operate at a frequency of 5.8 GHz. The CST Studio simulation resulted in a VSWR value of 1.508, return loss of -13.867 dB, and a gain of 3.416 dBi.

The designed omnidirectional biquad 4 lobes antenna, simulated using a 1.2 mm diameter copper wire and dimensions of 12.925 mm for each side, resulted in a VSWR value of 1.7065, return loss of -11.666 dB, and a gain of 1.973 dBi. And the designed biquad omnidirectional 6 lobe antenna, simulated using a 1.2 mm diameter copper wire and dimensions of 12.925 mm for each side, resulted in a VSWR value of 1.226, return loss of -19.863 dB, and a gain of 1.865 dBi.

In the simulations, the length of each side (dx) of the biquad antenna affected VSWR and return loss values. Increasing dx led to higher VSWR and lower return loss if the length used was not compatible with the working frequency.

The directional biquad, omnidirectional biquad 4 lobes, and omnidirectional biquad 6 lobes antennas that were fabricated and realized on the FPV monitor screen were capable of capturing real-time images from the transmitter at sequential distances of 634 meters, 352 meters, and 545 meters.

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