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Compact Rectangular Microstrip Patch Yagi-Uda Antenna for 5.75 GHz Amateur Radio Applications

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Abstract:

This paper presents the design and performance analysis of a compact rectangular microstrip patch Yagi-Uda antenna for amateur radio (HAM) applications operating at 5.75 GHz in the ultra-high frequency (UHF) band. The proposed antenna is fabricated on the RT/Duroid 5880 substrate with a dielectric constant of 2.2, thickness of 1.575 mm and loss tangent of 0.0009 with low dielectric losses and high radiation efficiency. The antenna design consists of a driven element, a reflector and five directors. Simulation is carried out using CST Microwave Studio and the optimized antenna shows a return loss of -62.24 dB, VSWR near to unity (1), a gain of 8.39 dBi, a beamwidth of 59.7° and an efficiency of 89.62% at the resonant frequency of 5.75 GHz. The antenna offers a bandwidth of 200 MHz (5.65-5.85 GHz) with stable radiation characteristics, making it highly suitable for compact HAM radio transceivers and UHF communication systems.

Keywords — **Amateur Radio, Gain, Microstrip Patch Yagi-Uda Antenna, RT Duroid 5880**

I. INTRODUCTION

Amateur radio, commonly known as HAM radio, enables licensed users to establish wireless communication without relying on commercial networks or the internet. It serves as a medium for experimentation, education and emergency communication. HAM operators use various frequency bands, including the high-frequency (HF), very-high-frequency (VHF), and UHF ranges, for local and long-distance communication. In India, amateur radio has been effectively utilized during natural disasters such as floods, cyclones and earthquakes, providing a reliable backup communication network when conventional systems fail [1-2].

Antennas are a key component of any amateur radio system. The Yagi–Uda antenna is widely used in these applications due to its directional radiation pattern and moderate gain. However, traditional Yagi antennas require significant physical space, making them less suitable for users living in compact environments such as apartments. To address this limitation, microstrip technology offers a low-profile and lightweight alternative design while maintaining acceptable performance [3-4].

Microstrip patch antennas are planar structures that can be easily integrated into modern communication systems. They consist of a conducting patch on one side of a dielectric substrate and a ground plane on the other. Although a single patch antenna provides broadside radiation with limited gain, combining it with parasitic elements such as a reflector and directors allows the formation of a microstrip-based Yagi-Uda configuration, which improves forward gain [5].

Research on compact and high-gain microstrip Yagi-Uda antennas has evolved significantly in recent years to meet the demands of modern communication and amateur radio systems. A recent study by R. Singh et al. [6] introduced a broadside Yagi-Uda antenna with an enhanced gain structure for millimeter-wave 5G applications. Their dual-layer metal configuration achieved a compact 12.5×20 mm² footprint with improved radiation efficiency. Similarly, J. Zhang et al. [7] developed a flexible, screen-printed 1×4 quasi-Yagi-Uda array on a transparent substrate for 5G systems, highlighting the adaptability of Yagi geometries for conformal and printed technologies.

Focusing on sub-6 GHz and IoT applications, A. Khan and M. Rahman [8] proposed a multilayer Yagi-Uda-based microstrip antenna exhibiting a gain of 10.9 dBi with a 27 % bandwidth, proving the relevance of Yagi principles in compact, low-profile systems. The theoretical foundation for gain and efficiency limitations was strengthened by S. Johansson and K. Lee [9], who established analytical bounds for microstrip patch antennas, explaining the importance of design trade-offs between miniaturization and radiation performance.

Further innovation was observed in the work of N. Patel et al. [10], who enhanced the performance of a 5.2 GHz microstrip antenna using composite dielectric substrates and multiple superstrates, achieving higher efficiency and bandwidth-techniques that could be adapted to 5.75 GHz designs. Complementing this, M. Ibrahim et al. [11] designed a compact quasi-Yagi microstrip patch antenna offering wide bandwidth and high gain suitable for ultra-wideband (UWB) systems, thereby showing the importance of director-reflector elements for bandwidth increment.

T. Roberts in [12] provided an overview of recent innovations in microstrip patch antennas, identifying the fusion of Yagi–Uda and patch designs as a promising avenue for biomedical and wireless systems. Likewise, P. Sharma [13] conducted a detailed literature review on Yagi-Uda antennas, examining their history and explaining why they are still important for modern compact devices. For practical applications near the 5.75 GHz band, D. Mehta et al. [14] designed efficient microstrip antennas operating at 5.8 GHz for intelligent transportation systems.

Nowadays most of the people in cities are staying in apartments where the space is limited. These microstrip antennas can be a good fit for HAMs operators residing in these apartments as they don't take as much space as a traditional Yagi Antenna takes.

The proposed work focuses on the design of a compact and high-performance microstrip Yagi-Uda antenna optimized for 5.75 GHz amateur radio applications, unlike previous studies that mainly targeted WLAN or 5G bands. The antenna achieves excellent performance within a 65×120 mm^2 geometry using a single RT/Duroid 5880 substrate ($\varepsilon r=2.2$, $\tan(\delta)=0.0009$) and five directors, ensuring low loss and simple fabrication. The simulated results show a gain of 8.39 dBi, return loss of -62.24 dB, VSWR near to unity and efficiency of 89.62 %, outperforming many reported planar Yagi-Uda designs. This design effectively bridges the gap between traditional bulky Yagi antennas and modern microstrip technology, offering a compact, efficient, and practical solution for urban HAM operators with limited installation space.

The remaining structure of the paper is as follows. Section-II explains the design of microstrip antenna. The design of the microstrip patch Yagi-Uda antenna is explained in section-III. In Section-IV the simulation results of the antenna are analysed. Section-V address the conclusion of the proposed work.

II. RECTANGULAR MICROSTRIP PATCH ANTENNA

The Fig. 1 shows the basic structure of the rectangular microstrip patch antenna. This antenna is mainly composed of a radiating patch, dielectric substrate, microstrip feedline and ground plane. A thin metal patch is placed over the substrate and bottom of the substrate is covered by ground plate. When feeding is given to the patch through feed line, antenna radiates.

HAM radio operates on HF, VHF and UHF range. The proposed microstrip antenna is designed to operate at 5.75 GHz. To achieve maximum electromagnetic radiation in the desired direction, one need to choose a substrate having low loss of tangent (δ) [15]. Therefore RT/Duroid 5880 has been selected as the substrate with a dielectric constant of 2.2, a thickness of 1.575 mm and a loss of tangent of 0.0009.

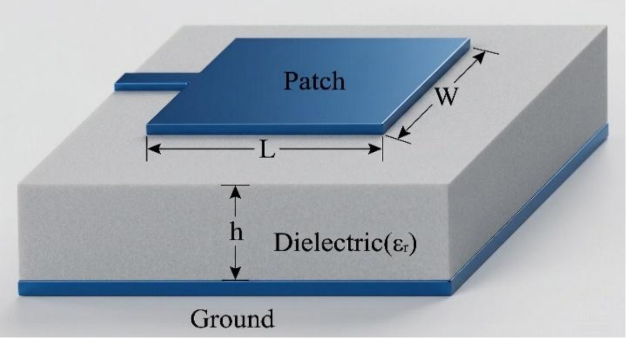

Fig. 1 Structure of Microstrip Patch Antenna [5]

For feeding, microstrip inset feed technique is used as it provides good impedance matching. The design equations for the rectangular microstrip patch antenna are as follows [15-18]:

1. Wavelength of an Antenna

$$\lambda = \frac{c}{\mathrm{f_r}}$$

2. Width of the Patch

$$W = \frac{c}{2\mathrm{f_r}}\sqrt{\frac{2}{\epsilon_r + 1}}$$

3. Length of the Patch

$$L = L_{eff} - 2\Delta L$$

4. Resonant Frequency of Antenna

$$f_r = \frac{c}{2 * (L + 2\Delta L) * \sqrt{\epsilon_{reff}}}$$

5. The effective dielectric constant

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} + [1 + 12\frac{h}{w}]^{-1/2}$$

6. Effective length

$$L_{eff} = \frac{C}{2f_r\sqrt{\epsilon_{reff}}}$$

7. Extension in Patch length

$$\frac{\Delta l}{h} = 0.412\frac{(\epsilon_{reff+0.3})(\frac{w}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)}$$

8. Characteristic Impedance

$$Z_o = \frac{87}{\sqrt{\epsilon_r + 1.41}}\, X \ln\left(\frac{5.98h}{0.8w + t}\right)$$

III. DESIGN OF MICROSTRIP PATCH YAGI-UDA ANTENNA

Every communication device/system requires transmitting and receiving antennas to pass the message, audio or video signals. HAM radio transmits or receives these signals using a directional antenna called Yagi-Uda. Yagi-Uda antenna finds its application in HF, VHF and UHF range [19]. This antenna design is having mainly three elements a reflector, a driven element and the directors [20-21].

After designing microstrip patch antenna, the Yagi-Uda antenna is designed. The patch of the microstrip antenna acts as the driven element of Yagi antenna. Reflector and directors are added around the patch to increase the gain of the single driven element by several decibels in one direction. Driven element is directly connected to feeding line (transmission line) which energizes the antenna.

Reflector and directors are parasitic/non-driven elements; they receive energy through mutual induction with a driven element or another parasitic element. Usually, the width of the reflector is 5 % or more longer than the driven element and the width of the director is 5 % or less longer than the driven element. The spacing between the reflector and driven element or director and driven element or between the directors can affect the performance of the antenna.

The Fig. 2 shows the proposed microstrip patch Yagi-Uda antenna design. As shown, 50Ω microstrip inset line feeding is directly given to driven element. The material used for directors, reflector, driven element, microstrip feed line and ground plane is copper with 5.8×10^7 S/m conductivity. RT Duroid 5880 material is used as substrate [22]. The dimensions of the optimized microstrip patch Yagi-Uda antenna are shown in Table-I.

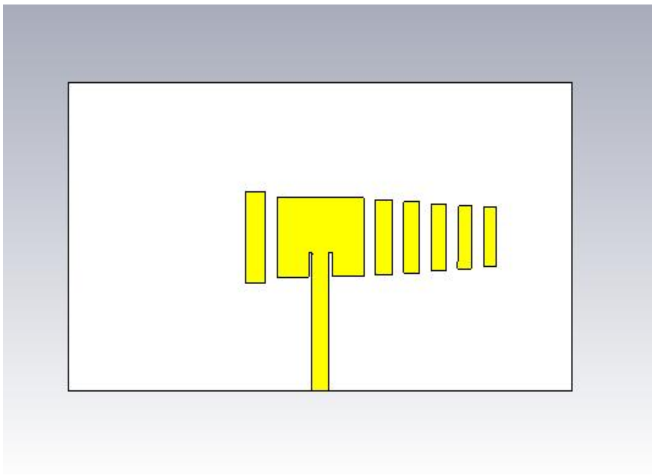

Fig. 2 Two-dimensional model of designed microstrip patch Yagi-Uda antenna

TABLE I
DIMENSIONS OF THE PROPOSED ANTENNA

Sl. No.	Parameters	Dimensions
1	Operating Frequency	5.75GHz
2	Dielectric Constant	2.2
3	Substrate Thickness	1.575mm
4	Loss Tangent	0.0009
5	Patch Width	16.67mm
6	Patch Length	20.62mm
7	Substrate Width	65mm
8	Substrate Length	120mm
9	Feed Line Width	19.02mm
10	Feed Line Length	29.255mm

IV. SIMULATION RESULTS

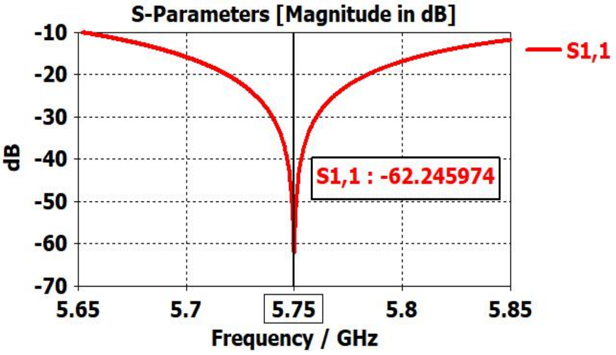

Fig. 3 Return Loss of the Antenna

The proposed microstrip patch Yagi-Uda antenna is designed using CST Microwave Studio software. Fig. 3 shows the return loss of the proposed antenna. It can be observed that S11 is below -10 dB for overall frequency range. -62.24 dB of return loss is achieved at 5.75 GHz. It is observed from the Fig. 4, the obtained Voltage Standing Wave Ratio (VSWR) is less than 2 for overall bandwidth and at center frequency VSWR value is 1.

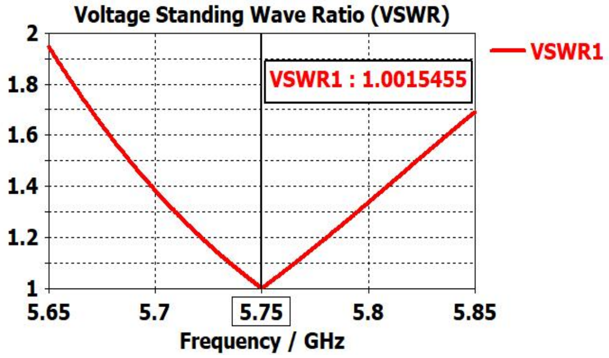

Fig. 4 VSWR of the Antenna

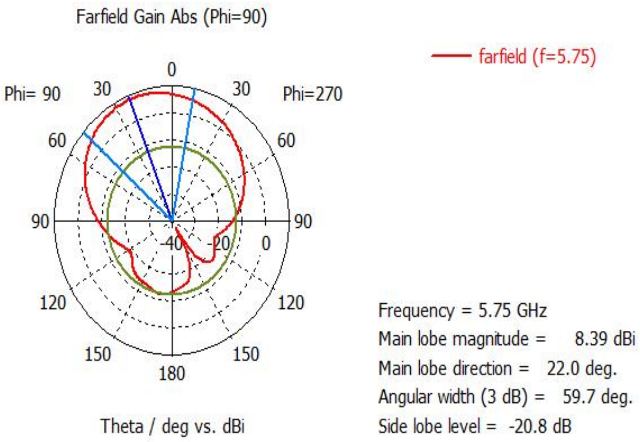

Fig. 5 Gain Pattern of the Antenna

Fig. 5 shows the gain pattern at 5.75GHz. 8.39dBi is the gain achieved with 5 directors. -20.8dB of front to back ratio (F/B ratio) is achieved. As shown 59.7˚of Beamwidth is achieved.

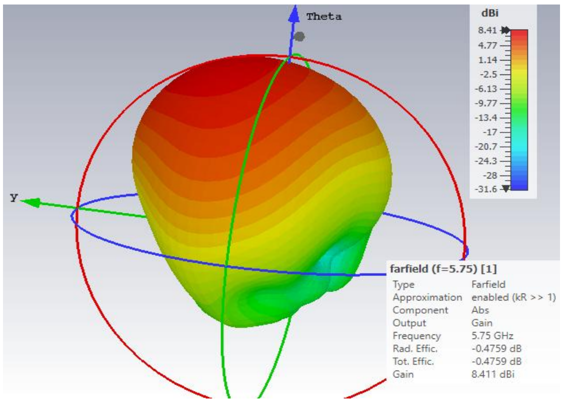

Fig. 6 Radiation pattern of the Antenna

Fig. 6 shows the radiation pattern of the antenna at centre frequency. The Fig. 7 shows the total efficiency achieved and that is 89.62%. The below Table II shows the simulation results of the designed antenna. As shown in below table, the gain of the antenna increased as the number of director increases.

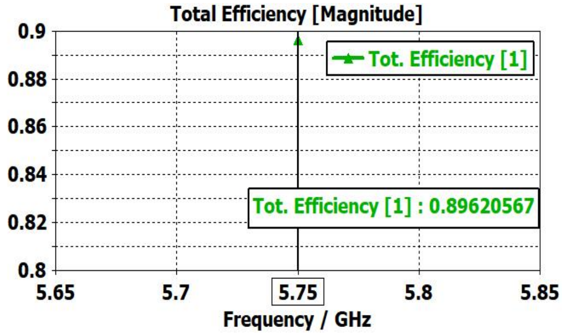

Fig. 7 Efficiency graph of the Antenna

TABLE III
SIMULATION RESULTS OF THE DESIGNED ANTENNA

Antenna Type	No. of Directors	f_r	S11 (dB)	VSWR	Gain (dBi)
Rectangular Microstrip Patch Yagi-Uda Antenna	1	5.75 GHz	-20.53	1.2	7.46
	2		-27.73	1.08	7.90
	3		-55.01	1	8.24
	4		-53.18	1	8.30
	5		-62.24	1	8.39

V. CONCLUSION

A compact 65x120mm^2 of microstrip patch Yagi-Uda antenna is designed at 5.75GHz for amateur radio applications. The RT/Duroid 5880 substrate is used with a dielectric constant of 2.2 and height of 1.575mm. The proposed antenna contains a driven element, 5 directors and a reflector. Only five directors used in this design. Because when 6th director was designed, due to the impedance mismatch, the gain value started decreasing. An electromagnetic solver software called CST Microwave Studio is used to study the performance of the simulated results. The designed antenna produced a gain of 8.39 dBi, Directivity of 8.86 dBi, Return Loss of -62.24 dB, VSWR of 1.001 and beamwidth of 59.7° at center frequency. 200 MHz (5.65 GHz to 5.85 GHz) of Bandwidth is covered. The side lobe level is -20.8 dB and achieved efficiency is 89.62%.

The future work will be fabricating and testing of the proposed antenna. Also, the comparison between the simulated and fabricated work for further improvement.

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