Light weight dual polarized horn antenna for polarimetry C-band synthetic aperture radar sensor onboard UAV

Agus Hendra Wahyudi[1], Farohaji Kurniawan[1], Bambang Setiadi[2], Agus Wiyono[1], Satria Arief Aditya[1], Wahyu Widada[3], Efendi Dodi Arisandi[4]
[1]Research Center for Aeronautics Technology, National Research and Innovation Agency (BRIN), Bogor, Indonesia
[2]Research Center for Telecommunication, National Research and Innovation Agency (BRIN), Bogor, Indonesia
[3]Research Center for Structural Strength Technology, National Research and Innovation Agency (BRIN), Bogor, Indonesia
[4]Research Center for Rocket Technology, National Research and Innovation Agency (BRIN), Bogor, Indonesia

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ABSTRACT

Unmanned aerial vehicles (UAVs) can collect earth surface information with synthetic aperture radar (SAR) sensors during night, day, and bad weather. However, UAVs have only limited volume and weight for the SAR payload. A very light dual circularly polarized pyramid horn antenna was developed in order to improve sense capability in UAV dual polarimetry SAR images. The pyramid horn was designed and simulated in computer simulation technology (CST) 2022. The horn was capable of producing two circular polarizations right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) alternately using a three stepped septum polarizer and coaxial probe feed on two sides of the waveguide. The results show that the horn antenna was capable of having a wide S11 and S22 bandwidth from 4 GHz to 6.7 GHz. The horn was capable of producing two circular polarizations with an axial ratio below 3 dB from 4.4 GHz to 6.4 GHz. This gain horn antenna was relatively stable in the range of 15 dBiC with a reasonably narrow 3 dB beamwidth of 28° both RHCP and LHCP polarisation in E and H fields respectively.

Corresponding Author:

Agus Hendra Wahyudi
Research Center for Aeronautics Technology, National Research and Innovation Agency (BRIN)
Sukamulya, Rumpin, Bogor, Indonesia
Email: agus111@brin.go.id

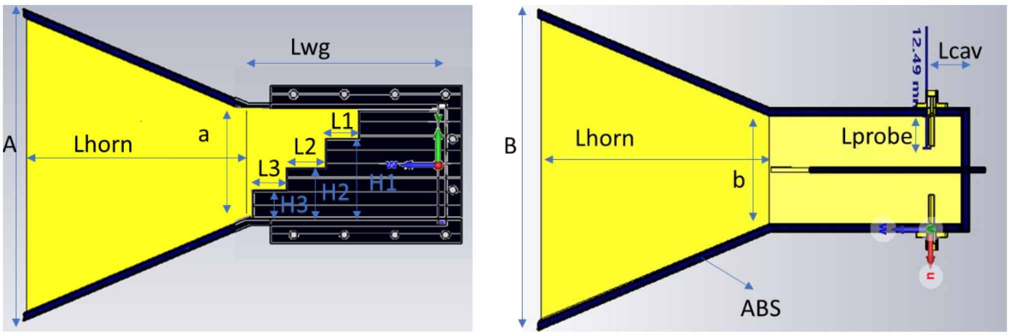
1. INTRODUCTION

UAVs are increasingly in demand by remote sensing users for mapping purposes. One of the active remote sensing sensors in UAVs that can work with various weather, day and night is synthetic aperture radar (SAR) [1]-[4]. In order to improve detection on the SAR application, two types of SAR images that have different polarizations are used (vertical and horizontal or circular to the left and circular to the right) [5]-[7]. Circular polarization has advantages for SARs in UAVs over linear ones. It is more resistant to polarization mismatch interference due to changes in antenna position in the UAV and can provide additional information in the form of inclination angles and improve SAR image detection [5], [8], [9].

However, small UAVs have limited space and weight of SAR payloads that can be used. Therefore, a lightweight SAR sensor antenna is needed and a relatively small size according to the dimensions of the UAV. The antenna must also have high gain and wide enough bandwidth as well as the ability to work in two polarizations left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) to produce SAR images of two different polarizations. A horn antenna is very appropriate for these characteristics because it has a lightweight structure when using 3D printer fabrication methods, large gain, dual polarisation, and wide bandwidth. Microstrip-type antennas are capable of producing circular polarization waves with wide bandwidth but have a small gain for single-element antenna <5 dBi [10]-[12]. Increasing the gain on the microstrip antenna can be done by arranging it in an antenna array [1], [13]. However, this will increase the antenna area and weight, which is very limited for small UAVs. This study aims to investigate the design and use of a 3D-printed dual polarization pyramidal horn antenna in the SAR system that will be used later in small UAVs. The horn performance was adjusted to the existing SAR system, namely the middle frequency at 5.3 GHz and gain 15 dBiC with bandwidth ≥300 MHz, so the resolution was high enough for earth surface mapping applications.

2. RESEARCH METHOD

In designing the horn antenna, a pyramidal horn antenna type with a square waveguide in the C-band (5 GHz to 6 GHz) was used. The method of determining the dimensions of the horn antenna (Lhorn, A, and B see Figures 1(a) and (b)) began with its optimum gain and waveguide dimensions [14]. In order to produce dual polarized circular wave, a stepped septum polarizer was inserted in the middle of the waveguide (see Figures 1(a) and (b)), which functions to change the linear polarization mode TE01 in the rectangular waveguide section to circular polarization in the square waveguide. Circular polarization can be achieved at the desired frequency by adjusting the width and height of stepped on the septum (L and H parameters, see Figure 1(a)) as demonstrated in [15]-[19]. In addition, other methods such as single ridge [20] and double ridge [21] can also produce circular polarization wave. However, ridge polarizer in dual polarized horn antenna may produce poor isolation because there is a coupling between ports. In our dual port antenna, the waveguide was excited with a coaxial probe feed with the dimensions of the probe length and distance to the cavity set so that the resonance was centered on the working frequency of the SAR system (5.3 GHz). The simulation and design were carried out with professional computer simulation technology (CST) 2022 software. Optimal antenna parameters after intensive simulation were obtained values as in Table 1.



(a) (b)

Figure 1. Configuration of dual circularly polarized (CP) pyramidal horn antenna; (a) horn antenna cutout side view and (b) horn antenna cutout top view

Table 1. Optimal values of antenna pyramidal horn dual CP parameters

Parameter symbol	Value (mm)	Parameter symbol	Value (mm)
H1	30.945	a=b	42
H2	19.545	A=B	118
H3	10.755	Lcav	11.784
L1	13.016	Lprobe	12.49
L2	15.405	Lwg	75
L3	13.367	Lhorn	90

The basic material of the horn antenna structure of Figure 1 uses an ABS filament 3D printer which is a polymer that has a dielectric constant of 2.6 and a loss factor of 0.0185 [22]. The horn structure is coated with a conductive paint mixed with silver and copper MG 843AR-340g which has a resistivity of 0.00022 Ω-cm based on the datasheet. The thickness of 0.3 mm of the conductive paint was chosen and it is thicker than the skin depth at the working frequency.

3. RESULTS AND DISCUSSION

The simulation and design were conducted using the professional CST 2022 software. In this section, the results of the numerical simulation are further discussed to analyze the antenna's bandwidth, gain, and radiation patterns. The analysis aims to determine the characteristics of the pyramidal horn dual CP antenna.

3.1. Antenna bandwidth

The antenna's bandwidth criterion was determined by setting the S11 and S22 values to be less than -10 dB. The isolation between ports was evaluated based on the S21 and S12 values. The simulation results, as shown in Figure 2, indicate that the horn antenna exhibited a bandwidth covering the frequency range of 4.55 GHz to 6.67 GHz. In the SAR system's working range for the C-band (5 GHz to 5.6 GHz), the isolation value between ports remained below -20 dB.

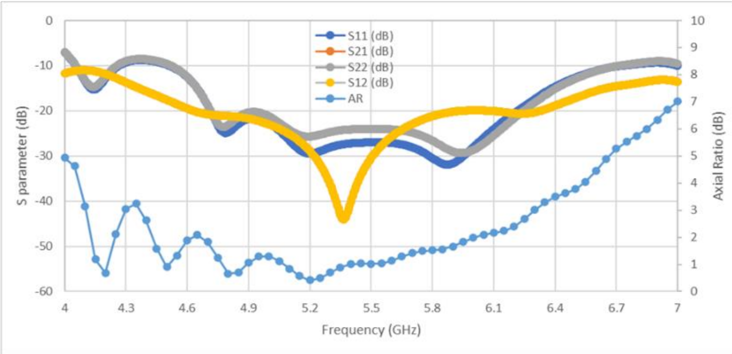


Figure 2. Simulation results S parameter and axial ratio of the horn antenna

The excellent isolation between ports, which was maintained below -20 dB, can be attributed to the presence of a septal wall separating the two ports, preventing undesired coupling between them. The performance of the antenna in the C-band was also supported by the well-functioning S11 and S22 values. This was achieved by adjusting the feeding probe length to correspond to a quarter resonant frequency wavelength. Additionally, the probe-to-cavity distance was set to be approximately a quarter wavelength of the central frequency, which was 5.3 GHz. Apart from the S-parameter values, the bandwidth of an antenna with circular polarization should also meet the criterion of its axial ratio being less than 3 dB. Figure 2 presents the simulation results indicating that the bandwidth for the axial ratio of circular polarization spanned from 4.4 GHz to 6.25 GHz.

3.2. Antenna gain

The simulation result of Figure 3 shows that the gain from the antenna had a fixed tendency of 15 dBiC in the C-band at working frequency range from 5 GHz to 6.7 GHz. The stability of our antenna gain at the working bandwidth of SAR is very advantageous because the amplitude of the chirp signal sent will be the same value. In addition, this stable high gain will be benefit for our UAV power budget since it reduce the needed transmitter power as stated in range radar equation [23], [24].

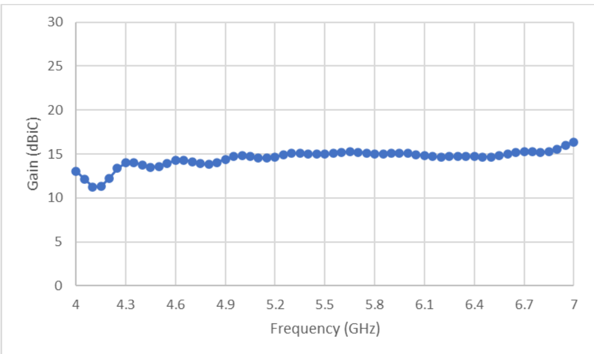


Figure 3. Gain simulated antenna

3.2.1. Radiation patterns

Figure 4 illustrates the radiation pattern of the antenna at frequencies 5 GHz, 5.3 GHz, and 5.8 GHz, specifically in the E and H fields directions. Figures 4(a) and (b) shows radiation pattern at 5 GHz RHCP and LHCP in E and H fields. The gain in broadside were 15 dBiC in both RHCP and LHCP with very low cross-polarization (less than -20 dB). Notably, at 5.3 GHz Figures 4(c) and (d), the antenna achieved a half-power beamwidth (HPBW) of 28° and 28° for the E and H fields, respectively. This indicates that the antenna had a relatively focused radiation pattern, allowing for a narrower coverage angle. Additionally, the cross-polarization at 5.3 GHz was observed to be very low, indicating that the antenna effectively maintains polarization purity. It was also maintaining the same good characteristic in gain, half-power beamwidth and cross-polarisation at 5.6 GHz as shown in Figures 4(e) and (f).

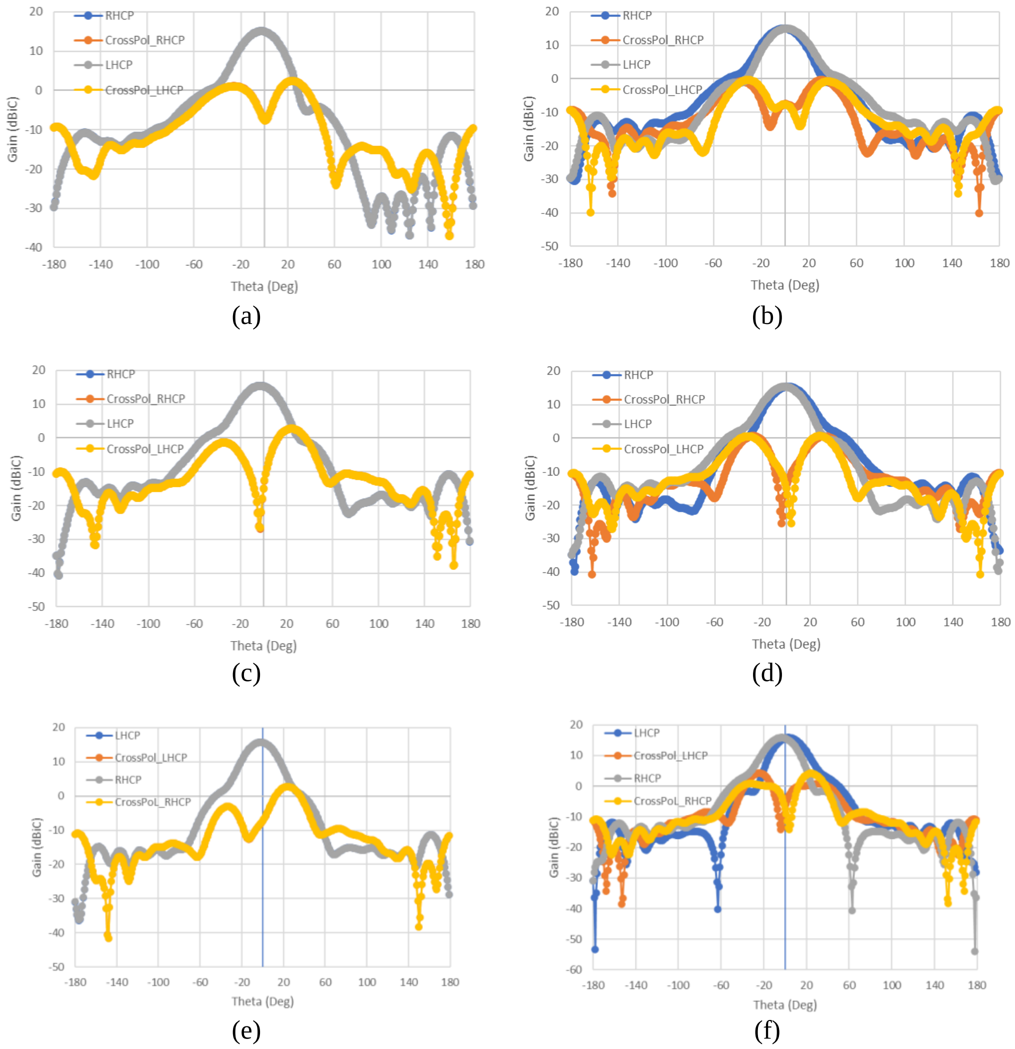


Figure 4. Pyramidal horn antenna radiation pattern at frequencies of: (a) H field 5 GHz, (b) E field 5 GHz, (c) H field 5.3 GHz, (d) E field 5.3 GHz, (e) H field 5.6 GHz, and (f) E field 5.6 GHz

Moreover, the analysis reveals that the antenna exhibited a minimal sidelobe response, with a sidelobe level below -20 dB. This characteristic was highly advantageous, particularly in applications such as SAR systems, where sidelobe reflections can introduce unwanted noise and degrade image quality. The low sidelobe value observed in the radiation pattern ensures that the antenna minimizes sidelobe interference, enhancing the accuracy and clarity of the SAR system's imaging capabilities [25].

For comparison purposes, the performance of this horn antenna was evaluated alongside several C-band CP-SAR sensors, and the results are presented in Table 2. The horn antenna demonstrated a moderate gain of 15 dBiC, making it well-suited for medium-altitude long-endurance (MALE) SAR type UAVs that operate at medium altitudes and possess a smaller aperture field area compared to antenna design [8], [26].

Additionally, the horn antenna featured a significantly wider axial ratio (AR) and S11 bandwidth, resulting in superior SAR resolution when compared to design [8], [26], [27].

Table 2. Comparison of C-band CP-SAR antenna

Antenna type	Gain (dBiC)	Bandwidth S11<-10 dB and AR<3dB	Polarization	Aperture full polarimetry (mm^2)
This study (pyramidal horn)	15	AR: 4.4 GHz to 6.25 GHz, S11: 4.55 GHz to 6.7 GHz	Circular (dual)	118×118×2
Microstrip patch array [8]	22	AR: >400 MHz, S11: 4.9 GHz to 5.75 GHz	Circular (single)	500×300×4
Microstrip patch array [26]	9.74	AR: 100 MHz, S11: 5.2 GHz to 5.6 GHz	Circular (single)	125×65×4
Microstrip patch [27]	7	AR: 250 MHz, S11: 1100 MHz	Circular (single)	65.5×42.4×4
Microstrip patch array [28]	12	S11: 4.47 GHz to 6.47 GHz, AR: 4.6 GHz to 5.86 GHz	Circular (single)	50×50×4

4. CONCLUSION

The designed and simulated antenna using CST 2022 software exhibited impressive capabilities, featuring circular two-way polarization to the right and left with an axial ratio below 3 dB across the frequency range of 4.4 GHz to 6.25 GHz. Additionally, the antenna achieved a medium range gain of 15 dBiC, rendering it highly suitable for deployment in medium UAV distances, particularly in the MALE UAV class. The incorporation of dual polarization in this antenna enabled full polarimetry capability while maintaining a compact aperture area. The utilization of this sensor in UAV applications proved advantageous, as it catered to limited space and weight constraints, enhancing the overall efficiency and practicality of the system.

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BIOGRAPHIES OF AUTHORS

Agus Hendra Wahyudi received a Bachelor's degree in Engineering in Electrical Engineering from Brawijaya University, Indonesia, in 2003, and a Master's degree in Instrumentation Physics from University of Indonesia, in 2010. Received his Ph.D. in Information Science from Chiba University, Japan in 2019. He is currently a young researcher at Research Center for Aeronautics Technology, National Research and Innovation Agency (BRIN), Indonesia. His current research interests include antennas, instrumentation, SAR sensors, and telecommunications. He can be contacted at email: agus111@brin.go.id and agus8hendra@gmail.com.

Farohaji Kurniawan received B.Sc. in Electrical from Gadjah Mada University, Indonesia in 2008 and M.Eng. in Electrical Power Engineering and Electrical Engineering from Tula State University, Russia in 2013. In 2010, he joined the National Institute of Aeronautics and Space (LAPAN), Indonesia at the Aerospace Instrumentation division. In 2013 he joined with aviation division at the Center of Aviation, LAPAN. He received his Ph.D. degree from the Graduate School of Advanced Integration Science, Chiba University, Japan. His field interest includes communication systems, electromagnetics, antennas and propagation, instrumentation and electronics, control, and remote sensing. He can be contacted at email: faro001@brin.go.id.

Bambang Setiadi received B.Sc. in Bandung Institute of Technology, Indonesia in 1999 and M.Eng. in Chiba University, Japan in 2013. He received his Ph.D. degree from the Graduate School of Advanced Integration Science, Chiba University, Japan. His field interest includes SAR signal processing, telecommunication, electromagnetics, antennas and propagation, instrumentation and electronics, control, and remote sensing. He can be contacted at email: bamb043@brin.go.id.

Agus Wiyono received the B.S degree in Physics from the Brawijaya University, Indonesia, and the M.S degree in Electronic Engineering from the University of Indonesia, Indonesia, in 2005 and 2017, respectively. His fields of interest include signal processing, antenna and propagation, instrumentation and control, and FPGA. He can be contacted at email: agus115@brin.go.id.

Satria Arief Aditya received his M.Tr.T in Advance Automation Control Industry from the Politeknik Negeri Jakarta, Indonesia in 2020. He is a Senior Engineer and Leader Baseband Control Unit-SAR Radar MALE Combatan at The National Institute of Aeronautics and Space of Indonesia, LAPAN-BRIN. His research interest includes expert system, signal processing, and automation. He can be contacted at email: satr006@brin.go.id.

Wahyu Widada received his Doctoral degree in Applied Optics and Remote Sensing, Chiba University in 2000. He is a Professor Research in Electronic and Remote Sensing at National Research and Innovation Agency (BRIN), Indonesia. His research interest includes radar, RF electronic, LIDAR, and signal processing. He can be contacted at email: wahy016@brin.go.id.

Effendi Dodi Arisandi completed his Bachelor's degree in Electronic Engineering from Brawijaya Univesity, Malang, Indonesia, in 2003. He then obtained a Master's of Science with major on Physics Science-Mathematics and Natural Science, Indonesia University, Depok, Indonesia, in 2009. For Doctor degree in electrical focus on Pattern Recognition from Beihang University, Bejing, China, in 2014. He is a senior researcher in electronic rocket design at the National Research and Innovation Agency (BRIN) Indonesia and focuses on inertial measurement unit (IMU), control system, and image processing. He can be contacted at email: effe002@brin.go.id.