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Microstrip Antenna with Slotted Rectangular Truncated Corner Patch for ADS-B Receiver on Cubesat

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ABSTRACT

Automatic dependent surveillance-broadcast (ADS-B) is an advanced technology for air traffic monitoring. Using frequency of 1090 MHz, ADS-B transponder transmit aircraft identity, altitude, speed, position, and other information periodically to ground station. Nanosatellite Laboratory of Telkom University develops Tel-USat 2, a CubeSat with ADS-B signal receiver as the mission in purpose to expand the scope of its signal reception. This paper presents a rectangular truncated corner microstrip antenna for ADS-B receiver on a nanosatellite with center frequency of 1.090 MHz, Voltage Standing Wave Ratio (VSWR) = 1,15 with bandwidth of 11,5 MHz in the frequency range of 1.086 – 1.097,5 MHz, unidirectional radiation pattern, circular polarization with axial ratio = 2,89 dB, antenna gain = 4,22 dBi and able to receive ADS-B signals from aircraft with furthest detected distances of 320,17 Km.

Key words : ADS-B, Cubesat, Microstrip Antenna, Rectangular Patch, Truncated Corner.

1. INTRODUCTION

One effort to improve service quality and safety in aviation is the use of ADS-B technology for air traffic monitoring. However, ground based ADS-B signal receiver system has limited coverage area especially in a place where terrestrial communication could not reach such as on the ocean. ADS-B signal reception technology on satellites has begun to be developed in purpose to expand the signal reception coverage area. One example of the satellite is Cubesat, a type of satellite which orbits at LEO (400 - 650 Km) and has a standard unit size of U, each U has a shape of cube with a volume approximately 10×10×10 cm3 [1].

Nanosatellite Laboratory of Telkom University is developing Tel-USat 2, a Cubesat with ADS-B signal receiver as the mission. Using Rasberry Pi and ADS-B receiver modules [2] as well as a microstrip circular patch antenna with a gain of 1.02 dBi, these payload able detect aircraft with the farthest detected distance of 189 Km on testing [3].Development on the side of the antenna using rectangular truncated corner patch is purposed to improve the performance of the ADS-B signal reception system on Tel-USat 2. Based on previous research [4],[5], it has been proven that microstrip antennas with rectangular patch produce higher gain than circular patch, while truncated corner technique is used to obtain circular polarization, slot also applied on patch in purpose to reduce the size of the patch so that the antenna could fit with CubeSat structure.

2. DESIGN CONCEPT

2.1 Automatic Dependent Surveillance-Broadcast

Aircraft that equipped with ADS-B Out transmits its information consist of the position, altitude, speed, and other parameters periodically every 0.5 seconds to the ADS-B receiver on ground station. The received data used by air traffic control (ATC) as source of information for aircraft traffic monitoring. ADS-B has advantages in the form of high-precision flight observations and wider earth surface coverage compared to conventional radar. The maximum range that can be covered by ADS-B as far as 200 Nautical Mile (370 Km). In Indonesia, the application of ADS-B uses the 1090ES mode with the frequency used at 1090 MHz [6].
Transmitter responder or commonly called a transponder is a transmitter from an aircraft that communicates with the ground station. The ADS-B Out transponder used on the aircraft must meet the specifications as in Table 1,

Table 1: ADS-B Out Transponder Specification [7].

Parameters	Value
Center Frequency	1090 MHz
Minimum Power Transmit	51 dBm
Maximum Power Transmitt	57 dBm

2.2 Space Based ADS-B Communication Link

Using Cubesat as ADS-B signal receivers provide the advantage of wider coverage areas, especially in areas that are difficult to reach by terrestrial communication such as the sea, forests, and mountains. Tel-USat 2 is a Cubesat with size of 3U and one of its mission is to receive ADS-B signal. The ADS-B communication link on Tel-USat 2 shown in Figure 1. Signal from the airplane transmitted and received by the satellite, the received signal forwarded to ADS-B ground station receiver to be processed as information for air traffic monitoring,

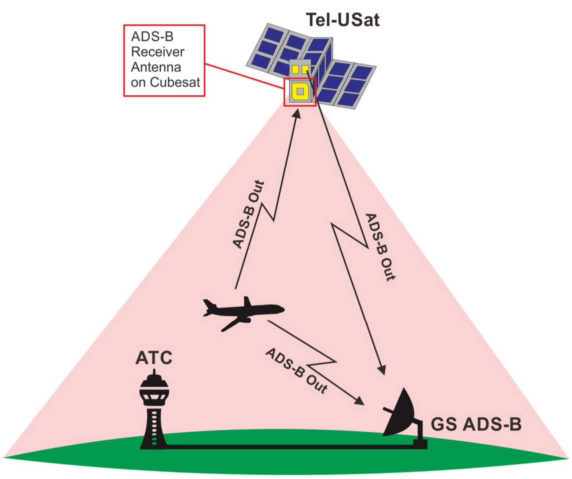

Figure 1: Tel-USat ADS-B Communication Link.

The link budget is an important parameter that needs to be taken into account to ensure the communication systems (especially satellite communications) have enough link so that the data that is sent can be received in the destination well. In this section, link budget used to calculate the value of antenna gain that needed for the communication using equation (1) and (2) with orbit height of 500 Km, min. transmitted power of 125 W (51 dBm), and receiver sensitivity of -97.5 dBm,

$$P_{RX} = P_{TX} - L_{TX} + G_{TX} - L_{P} - FSPL + G_{RX} - L_{RX}, \quad (1)$$

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2. \quad (2)$$

As the result of the calculation, with   = receiver sensitivity,   as power transmit from aircraft,   as cable loss from transmitter (assumed 1 dB), as transmitter antenna gain from aircraft (assumed 1 dBi), loss polarization (assumed 3 dB), FSPL as free space path loss that obtained using (2), as cable loss from receiver (assumed 1 dB). The receiver antenna gain target that obtained is = 2.67 dBi (rounded to 3 dBi).

2.3 Truncated Square Patch Microstrip Antenna

Microstrip antenna are popular for use in a variety of applications. It have some advantages such as lightweight, small and an adjustable shape. Nowadays many research about methods and modifications on microstrip antenna in order to improve its performance [8-10].
Microstrip has many types based on the shape of the patch, including circles, rectangles, rings, hexagons, and various other shapes. Rectangular patches are one of the most commonly used types of microstrip antennas. The dimension of rectangular patch limited by its length (L) and width (W) of the patch. The dimensions of the rectangular microstrip are shown in Figure 2,

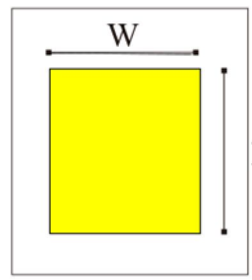

Figure 2: Rectangular Microstrip Antenna.

To get the dimensions of the rectangular patch, equation (3-6) can be used,

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}}, \quad (3)$$

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - 2\Delta L, \quad (4)$$

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff} + 0.3) \times \left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258) \times \left(\frac{W}{h} + 0.8\right)}, \quad (5)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}, \quad (6)$$

with W as patch width, f_r as center frequency, μ_0 for vacuum permeability ($1{,}257 \times 10^{-6}\ H/m$), ε_0 for vacuum permittivity ($8{,}85 \times 10^{-12}\ F/m$), ε_r for substrate dielectric constant, L for patch length, and ΔL as the extension of the edge of the patch, ε_{reff} as effective dielectric constant and h as substrate thickness [11]. An electromagnetic wave that passes through the ionosphere will experience the phenomenon of the Faraday effect, the rotation of the polarization plane of radio waves [12], therefore on the receiving side of the ADS-B signal on a satellite, a circularly polarized antenna is needed to minimize polarization mismatch. Both rectangular and circular microstrip patches without any modification, generally produce linear polarization. However, circular polarization obtained by several techniques, one of them is by truncated corner as shown in Figure 3 [13],

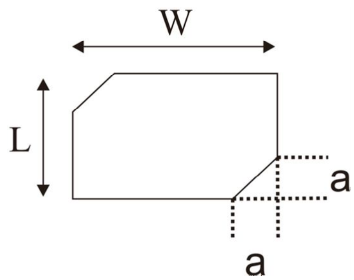

Figure 3: Truncated Square Patch.

To calculate the length of the truncated side, equations 7-9 can be used,

$$Q_0 = \frac{c\sqrt{\varepsilon_r}}{4 f_0 h}, \quad (7)$$

$$\frac{\Delta s}{s} = \frac{1}{2Q_0}, \quad (8)$$

$$a = L\sqrt{\frac{\Delta s}{s}}, \quad (9)$$

Q_0 is the unloaded quality factor, c is the speed of light (3×10^8 m/s), f_0 as center frequency, $\frac{\Delta s}{s}$ as truncation ratio and a as truncation length [14].

2.4 Slotted Patch

Slotted patch used to minimize the size of patch antenna [15]. Table 2 show the effect of slot size to the resonant frequency with patch length and width of 79.5 mm and 80 mm,

Table 2: Effect of Slot Size and Resonant Frequency.

Slot Length/Width (mm)	Resonant Frequency (MHz)
5	1212.5
8.5	1206.5
12.1	1194.5
15.7	1175
19.3	1151
22.8	1122.5
26.4	**1090**

2.5 Proximity Couple

The proximity couple method shown by Figure 4 is a feeding method where the feed line and the patch antenna do not directly contact each other physically. This technique uses two substrates, with the patch at the very top of the substrate, the feed line position between the two substrates and the ground plane at the very bottom. This technique is widely used to reduce the feed line radiation effect on the patch antenna and increase the bandwidth of the antenna [11],

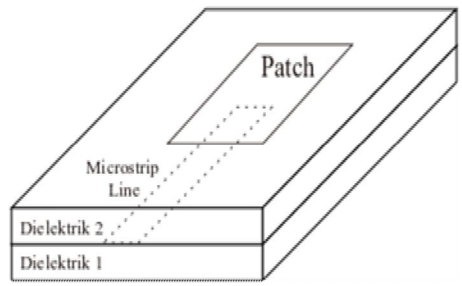

Figure 4: Proximity Couple Feed.

3. ANTENNA DESIGN

The designed antenna use Rogers RT/Duroid 5880 which has a dielectric constant of 2.2 as the substrate, in purpose to increase the gain. The size of the antenna is limited by the CubeSat standard size with total antenna size of 98×98×3.5 mm^3.

3.1 Antenna Specification

The antenna needs to meet up the specifications in Table 3 to support the mission of the ADS-B signal receiver on the TEL-USat 2,

Table 3: Antenna Specification.

Frequency	1090 MHz
Radiation Pattern	Unidirectional
Polarization	Right Hand Circularly Polarized (RHCP)
Bandwidth	2.6 MHz ± 25 KHz
VSWR	< 2
Gain	3 dBi

The ADS-B 1090ES Mode works at a frequency of 1090 MHz, for applications in satellites, antennas are designed to have a unidirectional radiation pattern with the main beam direction facing the surface of the earth. The minimum bandwidth is 2.6 MHz with + 25 KHz as a prediction for Doppler effect [16], VSWR < 2 and Gain 3 dBi based on link budget calculations.

3.2 Antenna Design

To fit up with the CubeSat structure, the microstrip antenna dimension should not more than 10×10 mm^2 area and thickness < 6.5 mm. From the calculation and optimization, obtained the size of antenna as shown on Table 4 and the design shown on Figure 5 and 6,

Table 4: Antenna Dimension,

Parameters	Value (mm)	Description
Wg	98	Ground plane Width
Lg	98	Ground plane Length
Wp	80	Patch Width
Lp	79.5	Patch Length
a	6.1	Truncation Length
s	26.4	Slot Length and Width
Wf	2.61	Feed Line Width
Ts	1.575	Substrate Thickness
Lf	40	Feed Line Length

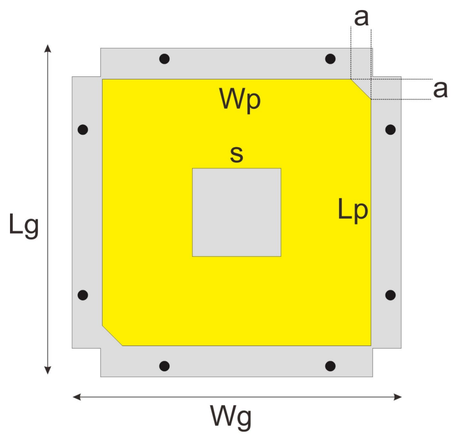

Figure 5: Designed Microstrip Front View,

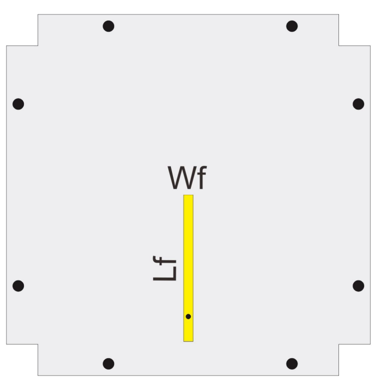

Figure 6: Feeding Method of Designed Microstrip.

4. EVALUATION AND ANALYSIS

The fabricated microstip antenna shown on Figure 7 and 8. The fabricated antenna measured and compared with the simulation result, then analyzed and evaluated. Parameters that analyzed are VSWR, bandwidth, gain, radiation pattern, axial ratio and polarization. ADS-B signal receiving test applied as well to get the value of farthest distance of detected aircraft,

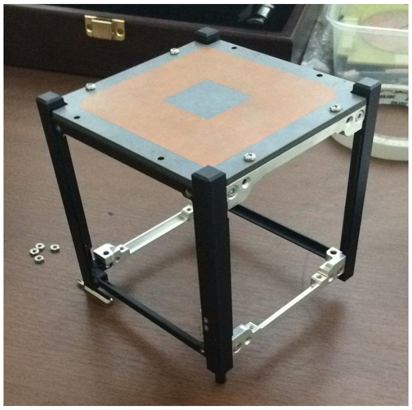

Figure 7: Microstrip Antenna on Cubesat Structure,

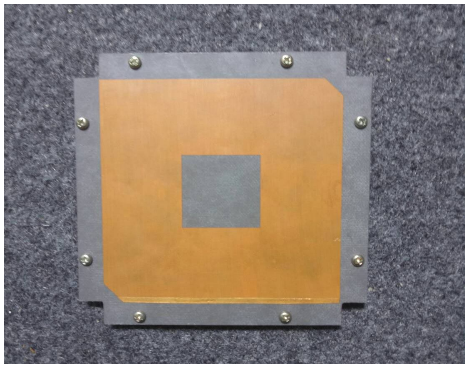

Figure 8: Microstrip Antenna Front View.

4.1 VSWR and Bandwidth

As shows on Figure 9 is a VSWR comparison between simulation and measurement. The red line shows the simulation VSWR with a value of 1.217, while the measurement obtained a VSWR value of 1.15 shown by a blue dashed line. From Table 5, as we can see, with the VSWR reference below 2, the bandwidth obtained is 17.2 MHz for simulations and 14.9 MHz for the realization.

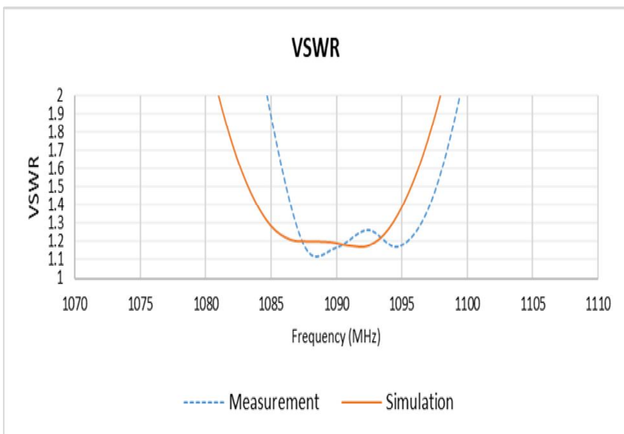

Figure 9: Antenna VSWR Comparison,

Table 5 - Antenna VSWR and Bandwidth.

Parameters	Simulation	Measurement
Bandwidth	17.2 MHz	14.9 MHz
VSWR	1.217	1.15

4.2 Gain and Radiation Pattern

Based on the link budget calculation, an antenna with gain of 3 dBi is required. In simulations, an antenna with a gain of 5.73 dBi obtained. After gain measurement using link budget method, obtained 4.22 dBi as the gain of the fabricated antenna that can be seen in Table 6,

Table 6: Antenna Gain and Beamwidth.

Parameter	Simulation	Measurement
Gain	5.73 dBi	4.22 dBi
Beamwidth Azimuth (-3dB)	90°	63°
Beamwidth Elevation (-3dB)	90.7°	65°

The unidirectional radiation pattern obtained from the results of simulations and measurements shown in Figures 10 and 11,

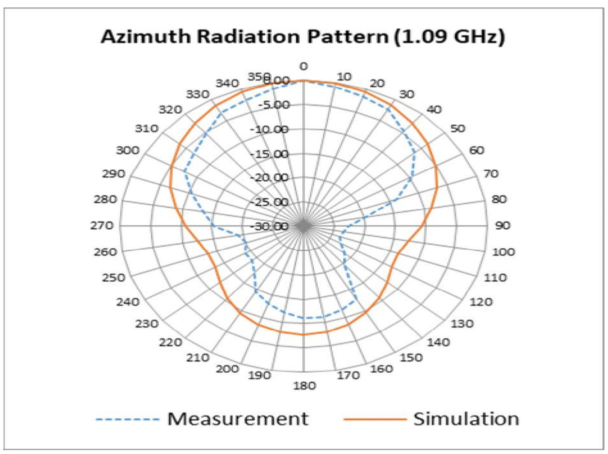

Figure 10: Azimuth Radiation Pattern,

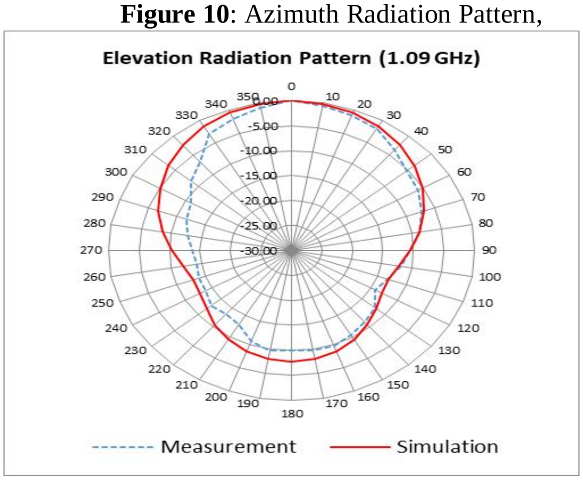

Figure 11: Elevation Radiation Pattern.

4.3 Polarization

The polarization measurements shown in table 7 obtained by comparing the orthogonal components of E-field. The axial ratio value obtained is 1.17 dB from the simulation and 2.89 dB from the measurement. It shows that the antenna polarization is circular with an axial ratio below 3 dB,

Table 7: Antenna Polarization.

Parameter	Simulation	Measurement
Axial Ratio (dB)	1.17	2.89

4.4 Aircraft Detection Test

Aircraft detection test was done using ADS-B receiver payload prototype on Tel-USat 2 and took place at Ararkula Building 4th floor (-6.976161 S, 107.629729 E) and Tokong Nanas Building 10th floor (-6.972630 S, 107.629382 E), Telkom University. Aircraft detection data shown in Table 8 and 9. The farthest aircraft that was detected successfully is 320.17 Km,

Table 8: Aircraft Tracking Data from Ararkula Building,

ICAO address	Flight	Alt *(feet)*	Spd (knots)	Lat	Long	Distance
8a028e	GIA430	24675	413	-6.285	107.406	80.73
8a021e	GIA617	24525	421	-6.214	108.132	101.29
8a0516	BTK6263	17200	338	-6.075	107.804	102.04
8a01cc	LNI694	15825	372	-6.348	106.981	100.06
8a07a0	AWQ659	37000	467	-5.649	107.134	157.42
8a02f1	LNI866	19050	305	-6.213	106.715	131.94
8a03ac	CTV333	22925	427	-6.115	108.02	105.01
75006f	XAX216	35000	497	-7.442	109.303	198.59

Table 9: Aircraft Tracking Data from Tokong Nanas Building.

ICAO addres	Flight	Alt *(feet)*	Spd (knots)	Lat.	Long.	Distance
8a020e	GIA150	25175	407	-5.427	106.172	235.57
8a03db	BTK6500	34475	463	-6.587	108.837	140.06
8a0419	AWQ7516	33200	467	-6.632	108.895	144.78
8a04a4	CTV980	28000	447	-4.818	105.709	320.17
86cf5a	ANA836	9375	276	-5.979	106.608	157.93
8a0246	GIA562	26850	402	-5.724	107.266	144.54
8a05c4	CTV880	23975	424	-5.518	106.089	234.85
8a03bb	GIA282	15725	313	-5.829	106.893	150.98
8a04ce	BTK6200	19950	412	-5.891	107.123	132.66
8a021b	GIA580	15400	350	-5.915	106.852	145.64
8a0366	LNI710	14800	371	-6.008	106.772	143.11
8a03c5	GIA611	31900	441	-6.206	108.63	139.58
8a074c	CTV940	20025	415	-5.575	106.096	229.95

4.5 Overall Antenna Analysis

Overall antenna analysis is done by comparing the main parameters such as VSWR, bandwidth, gain, radiation pattern and polarization from the specification, previous research, simulation results and measurement. The comparison can be seen in the Table 10,

Table 10 : Overall Antenna Analysis.

Parameters	Specification	Previous Research	Simulation	Measurement
Frequency Range (MHz)	1088.67-1091 .33 MHz	700 – 1200 MHz	1081.1 – 1098.3 MHz	1084.6 - 1099.5 MHz
Bandwidth	2.6 MHz ± 25 kHz	500 MHz	17.2 MHz	14.9 MHz
Radiation Pattern	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Axial Ratio	AR ≤ 3 dB	0.5 dB	1.17 dB	2.89 dB
VSWR	≤ 2	1.99	1.217	1.15
Gain	3 dBi	1.02 dBi	5.73 dBi	4.22 dBi

There are bit differences between simulation result and measurement, that caused by the lack of fabrication and environment factor on measurement. However, both simulation and measurement have fulfil all the specification. There is gain improvement by 3.2 dB from the previous research that only have 1.02 dBi of gain.

5. CONCLUSION

The designed microstrip antenna work on frequency range of 1084.6 - 1099.5 MHz with VSWR = 1.15 on frequency of 1090 MHz. The truncated corner method on rectangular patch gave improvement on axial ratio, so that can be obtained AR = 2.89 dB. Rectangular slot on the patch applied to reduce the size of the patch with the final size of patch is 79.5 × 80 mm2 and total antenna size is 98×98 mm2. Using Rogers RT/Duroid 5880 substrate with dielectric constant of 2.2, the obtained gain is 4.22 dBi and able to detect aircraft with farthest detected distance of 320.17 Km in detection test that take place on Ararkula Building 4th floor and Tokong Nanas Building 10th floor, Telkom University.

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