Design and Realization of Two Array Triangle Patch of Microstrip Antenna With Gold Plat at Frequency 2400-2450 MHz For Hexagonal Nanosatellite

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Abstract**—**Ministry of Education and Culture developed a nano-sized satellite technology, or so-called nanosatellite, to design Indonesia inter-University Satellite-1 (IiNUSAT-1) as a learning tool of space engineering, for the universities in Indonesia. These nano satellites orbiting in Low Earth Orbit trajectory (LEO). This satellite has a primary function for data communication. On the space segment subsystems are RSPL (Remote Sensing Payload) as an image sensor payload following the transmitter system (antenna) that can be used for sensing applications earth's surface.

Based on the above conditions, this research was made of two arrays of microstrip antenna with a triangular patch. This antenna works on S-band frequency, on 2400-2450 MHz with VSWR $\leq$ 1.7. To meet a good data transmit ability, the antenna has been designed with gain above 6 dBi, with the transmitting range of 700 km. On the surface of the patch antenna, will be given a gold plating to extend the life of the antenna from corrosion.

From the measurement results, obtained values of VSWR is 1.150 at center frequency in 2.425 GHz for the antenna with the gold plat. *Gain* obtained from the measurements is 6.120 dBi. This antenna has a transmit pattern of unidirectional and polarized elliptical, circular approach.

Keywords—nano satellite; arrays of microstrip antennas; triangular patch; s-band; gain 6 dBi

I. BACKGROUND

Technology of Satellite communication is developing. Furthermore, research in this area has also been done in universities in the world that focusing to create an effective and efficient technology at a low cost. One of that technology is nano-sized satellite or usual called nanosatellite. Starting from these interests, the consortium INSPIRE (Indonesian nanosatellite Platform Initiative for Research and Education) under DP2M DIKTI Ministry of Education develop Indonesia inter-University Satellite-1 (IiNUSAT-1) [1]. Sub system in the satellite is Remote Sensing Payload (RSPL) as image payload sensor combine with transmitter that is used for earth surface sense application.

This nanosatellite put on Low Earth Orbit (LEO). Most part of satellite transmits electromagnetic wave with circular polarization for maximum propagation. Other characteristic is unidirectional radiation pattern with wide beamwidth. Furthermore, appropriate with link budget, system need gain above 6 dBi, light and small antenna structure.

Antenna that matches with above specification is arrays of microstrip antennas. Software that used in this research is CST 2010[8].

Purpose of this research is designing double arrays of microstrips antennas with two patch triangle that operate on S-band frequency (2400-2450 MHz). Furthermore, this research use also circular polarization on transmitter for RSPL application in IiNUSAT-1.

II. BASIC THEORY

A. Nano Satellites

Nano satellite is an artificial satellite that using small component, whit weight about 10-15 kg. This nano-sized satellite will orbit on a trajectory of Low Earth Orbit (LEO) with a distance of 700 km above the earth's surface.

B. Antenna[5]

The antenna is a device that connects between the guided waves with a wave of free space and conversely.

There are six parameters of antenna that used in this research. The parameter are radiation pattern, polarization,

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VSWR (Voltage Standing Wave Ratio), return loss, gain, and bandwidth.

C. *Form of Radiated Triangle Elements*[7]

This form has the advantage compared to a rectangular form, which is widely required by a triangular form to produce the same radiation characteristics smaller than required by a rectangular form. This is particularly advantageous in the fabrication of the antenna.

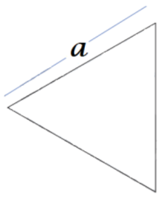


Figure 1 Plane of Triangle Patch

The resonant of frequency can be found using the following formula:

$$f_r = \frac{ck_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2+mn+n^2} \quad (1)$$

Where c is the wave propagation velocity of light, a is the long side of the triangle, and m, n, l is a number that is not zero and satisfy the conditions:

$$m+n+l = 0 \quad (2)$$

Equation (2) applies if the triangle radiated element surrounded by a perfect magnetic wall. If the radiated element is surrounded by an unperfect wall magnet, then a value is replaced with the a_e value which is effective value of the long side of the triangle.

For TM_{10} mode resonant frequency (f) is defined as follows:

$$f_{10} = \frac{2c}{3a\sqrt{\varepsilon_r}} \quad (3)$$

$$a = \frac{2c}{3f_{10}\sqrt{\varepsilon_r}} \quad (4)$$

The effective length can be obtained by the equation:

$$a_e = a - h(\varepsilon_r)^{-0.5} \quad (5)$$

For the vacuum wave length values obtained with the formula:

$$\lambda = \frac{c}{f} \quad (6)$$

D. *Rationing Antenna Techniques*

In the present research, the authors chose microstrip line technique. In this technique, rationing is done by connecting the line suppliying with patches, where patches and rationing line using the same materials. But it did not happen as expected matching impedance and will appear unwanted radiation from the feeder.

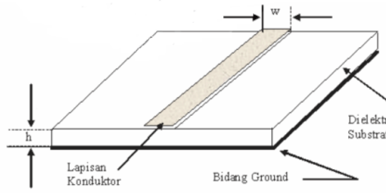


Figure 2 Techniques of Microstrip Line Rationing

Microstrip line transmission consists of two conductors, a strip (feed line) with width w and the ground plane, the two separated by a substrate with high permittivity ε_r h as shown in figure 2. Strip width (w) and high substrate (h) will affect the characteristic impedance Z_o.

The value of w can be searched using the following formula.

$$w = \frac{2h}{\pi}\left\{ B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\} \quad (7)$$

Where, h = 1.6 mm (values fabrication) = thickness of substrate and π = 3.14.

$$B = \frac{60\pi^2}{Zo\sqrt{\varepsilon_r}} \quad (8)$$

E. *Antenna Array*

The antenna array is an array of multiple antennas are identical. Total field of the antenna array is determined by the vector sum of the field radiated by a single element.

There are several kinds of antenna array configurations, including: linear, planar, and circular.

- Terms Measurement
  Measuring an ideal antenna is done in a room freely without reflection or an echo chamber (Anechoic Chamber). Antenna measurements performed in the far field antenna, it is intended that the antenna is not affected by the terrain of the surrounding objects. Distance measurement between the transmitter antenna to the receiver is:

$$R > 2\frac{D^2}{\lambda} \quad (9)$$

  Where D is the length of the largest dimension of the antenna.

III. Design and Implementation System

A. *Preface*

In the process of designing a microstrip antenna the first thing to do is determining the operating frequency of the antenna itself, which is at 2400-2450 MHz. After the frequency is obtained, the next step is to determine what substrate to use in the radiating element.

- Design Stage
  The design process of this microstrip antenna is done by the experimental method, the stages of manufacture are determination of specifications, design with CST software, and manufacturing based on simulation model. There are some supporting stages which is as follows, modeled in a flowchart.
- Design Specification
  This following antenna that will be made is a single rectangular patch microstrip antenna with specification as follows.
  - Working Frequency : 2400- 2450 MHz

- Impedance : 50 Ω
- VSWR : ≤ 1,7
- Radiation Pattern : *Unidirectional*
- Polarization : Circulare
- Gain : ≥ 6 dBi
- Connector : SMA *Female*

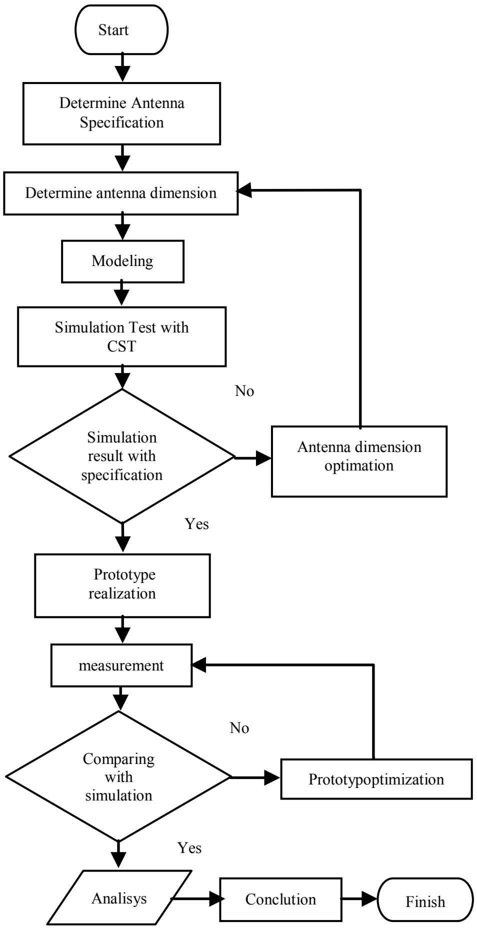


Figure 3. Design Flowchart

- Substrate Determination

There is an important parameter in choosing the substrate that will be used which is the thickness and tangent loss (tan δ) of substrate dielectric. It was choosen FR-4 Substrate with a low dielectric constant to get a small dimension antenna

B. Design of Antenna Construction

- Spesification of One Patch Element Antenna

To determine the length side of triangle can be done with electromagnetic transver copel mode of TM_{10}. Patch side length of tringle (a) can be calculated:

$$a = \frac{2c}{3f_{10}\sqrt{\varepsilon_r}} = \frac{2x3x10^8}{3x2.425x10^9\sqrt{4.4}} = 39.318 \text{ mm}$$

Determine the effective side length of triangle:

$$a_e = a - h(\varepsilon_r)^{-0.5} = 39.318\text{-}1.6(4.4)^{-0.5} = 38.555 \text{ mm}$$

- Specification of Two Antenna Patch Elements

Specification of two antenna patch element which oftenly called antenna array. Every patch element connected to the line with the length of λ/2. To connect it with 50 Ω supply so it is used T-Junction and the line from patch to supply using the line as λ/4 transmission to match it. As ilustrates below.

Figure 4. Feedline Antena Array

- Feed Line Width

$$B = \frac{60\pi^2}{Zo\sqrt{\varepsilon_r}} = \frac{60(3.14)^2}{50\sqrt{4.4}} = 5.640 \ ; \pi = 3.14$$

$$W = \frac{2h}{\pi}\{ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}]\} \ ; h = 1.6$$

$$= \frac{2(1.6)}{3.14}\{ 5.640 - 1 - \ln(2(5.640) - 1) + \frac{4.4-1}{2(4.4)}[\ln((5.640) - 1) + 0.39 - \frac{0.61}{4.4}]\}$$

$$= 3.057 \text{ mm}$$

C. Antenna Simulation

- Antenna Design on CST 2010 Software

The first step to do is designing the antenna geometric shape base on the calculation to the simulator.

Table I Optimization of Antenna Dimension on CST 2010 Simulator

No	Length of *Feedline* (mm)	Width of *Feedline* (mm)	Length of Triangle side (mm)	VSWR for 2.425 GHz	VSWR for 2.4 GHz and 2.45 GHz
1.	30.928	3.057	39.318	2.626	2.230 and 3.470
2.	23.195	3.057	39.318	6.760	5.533 and 7.518
3.	30.928	3.000	39.318	2.627	2.229 and 3.471
4.	30.928	3.000	38.439	1.980	2.456 and 1.941
5.	30.928	3.000	36.961	5.480	6.828 and 4.232
6.	15.500	3.000	37.677	1.515	1.635 and 2.426
7.	15.500	3.000	37.490	1.287	1.800 and 1.770

Through several optimization steps, both the feed line length, feed line width, and the length of triangle patch side, at the end it is obtained the feed line length = 15.500 mm, feed line width = 3.000 mm, and the length of triangle patch side = 37.490 mm.

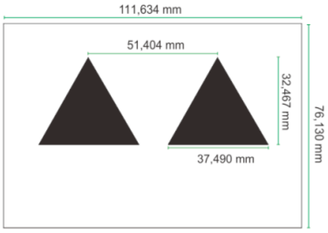


Figure 5.a. Antenna Dimension

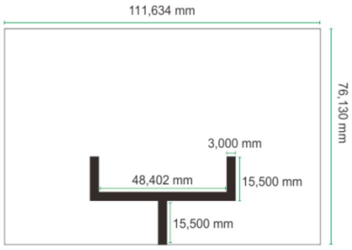


Figure 5.b. Antenna Feedline Dimension

D. *Simulation Result*

- VSWR and Bandwidth

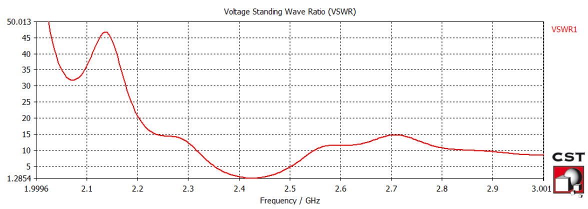


Figure 6. Graphic of VSWR at Frequency of 2-3 GHz

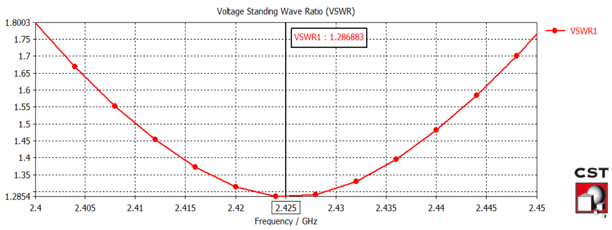


Figure 7. Graphic of VSWR at Frequency of 2.4-2.45 GHz

Simulation result shows that the design bandwidth (2400 MHz-2450 MHz) is reached at VSWR ≤ 1.85.

- Impedance

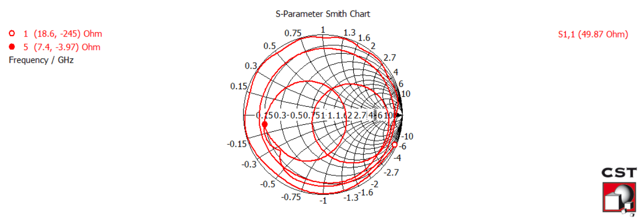


Figure 8. Graphic of Impedance.

- Gain/radiation pattern

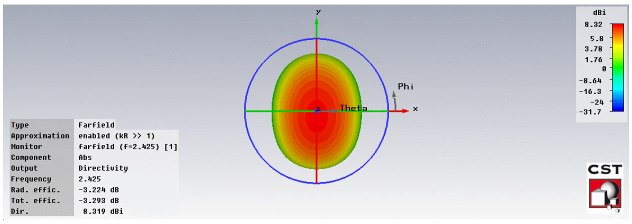


Figure 9. Graphic of Gain

From the picture above, it is shown that antenna gain from the simulation result is 8.319 dBi.

IV. SYSTEM TESTING AND ANALYSIS

A. *Preliminary*

The related measurement parameters including antenna return loss (S_{11} parameter), VSWR, input impedance, radiation pattern, polarization, and gain. Measurement parameters is done in Electronics and Telecommunication Research Center (PPET) - Indonesian Institute of Sciences (LIPI), Bandung.

B. *VSWR, Return Loss, and Impedance Measurements*

- Measurement results of VSWR, Return Loss and Impedance

1. VSWR

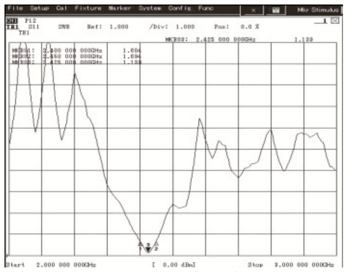
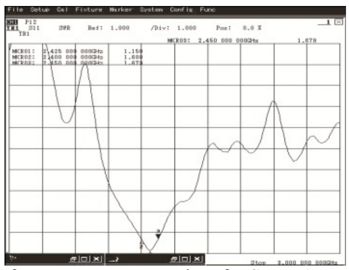


Figure 10. Graphic of Measurement Results of VSWR Antenna Without Gold Plat



2. Figure 11. Grafic of Measurement Results of VSWR Antenna With Gold Plat

Table II. VSWR Measurement Results

Type of Antenna in the frequency 2.425 GHz	VSWR
Antenna without gold plat	1.139
Antenna with gold plat	1.150

The measurement results indicate that the gold plating method for antenna radiator element, deos not really affect the VSWR value. It was obtained for both antenna VSWR values $\leq$ 1.7. For antennas without gold plat

VSWR values obtained for 1.139, while for antenna with Gold plat VSWR values obtained for 1.150.

3. Impedance

Impedance values measured at the center frequency of 2.425 GHz for the antenna without the gold plat is 46.322 + j5,.528 Ω, while gold plated antenna is 43.667 - j1.500 Ω.

4. Return Loss

At 4.425 GHz frequency, for the antenna without a gold plat, the value of the return loss of -23.456 dB, while for the antenna with a gold plat, the value of the return loss of -23.084 dB. From the results of these measurements, indicate that the antenna without the gold plat has a return loss of better than an antenna with a gold plat.

- Analysis of Measurement Results on VSWR, Return Loss and Impedance

  In the VSWR measurement, as shown in Figure 10 and Figure 11 it can be seen that at 2.4-4.45 GHz frequencies have VSWR ≤ 1.7, and at 3.35 GHz frequency has a value for the antenna VSWR = 1.139 without gold plat to the antenna VSWR = 1.150 with gold plat. From the results obtained, it is in compliance with expected initial specification, which is working on 2.4-4.45 GHz frequencies and has a VSWR ≤ 1.7.

  In Figure 10 and Figure 10 it can be seen that at a frequency of 2.425 GHz measured impedance value is 46.322 + j5, 528 Ω for the antenna without the gold plat, while the antenna is gilded 43.667 - j1, 500 Ω. If the impedance is obtained exactly 50 Ω VSWR it will be very small, about the size of 1.00, which means very little reflection occurs, in other words □ = 0, then Ztransmission-line = Zantenna. So to have a frequency VSWR values close to 1, would have measured impedance value will be close to 50 Ω for the transmission line, in this case gauge coaxial cable impedance is 50 Ω.

  From the above comparison, we know that the overall value of VSWR, return loss, and antenna impedance measurement results without the gold plat does not change significantly compared to the antenna with a gold plat.

C. *Measurement of Radiation Pattern*

- Antenna Radiation Pattern Measurement Results

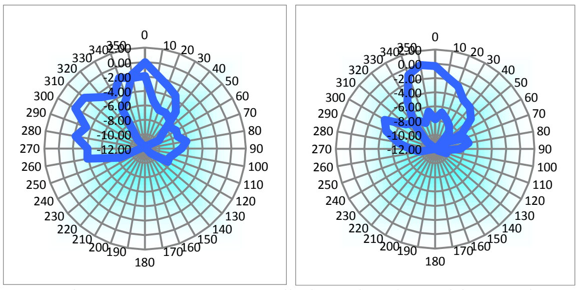


Figure 12 Chart Pattern Antenna Radiation Direction Without Azimut gold plat (left) and Antenna with gold plat (right)

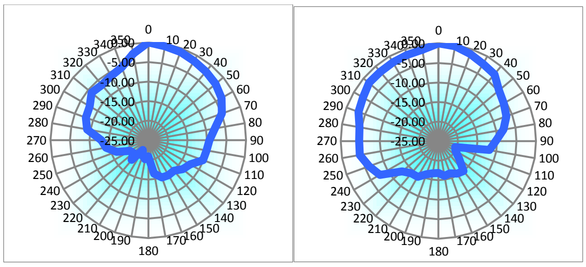


Figure 13. Graphic Radiation Pattern Antenna Elevation Direction Without Gold Plat (left) and Antenna with gold plat (right)

- Radiation Pattern Analysis of Measurement Results

  From the results of measurements of the radiation pattern can be seen both in azimuth and elevation. Results are happening already approaching pre-determined specifications. The radiation pattern in question is unidirectional.

D. *Polarization Measurement*

- Polarization Measurement Results

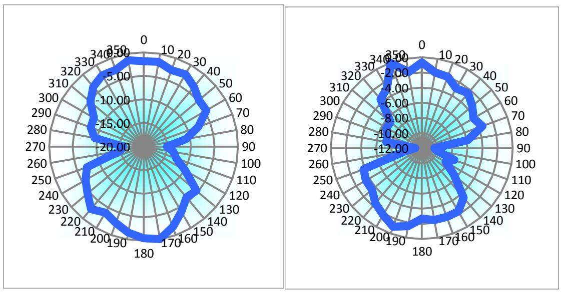


Figure 14. Graphic of Antenna Polarization Measurement Without Gold Plate (left) and Antenna with Gold Plate (right)

- Polarization Analysis of Measurement Results

  From the measurement results, for the antenna without the gold plat obtained maximum received power is on the angle of 170^0 and minimum received power is on the angle of 270^0.

Maximum received power=
= -22.09 dBm = 78.614 x 10-6 Watt
Minimum received power=
= -37.75 dBm `= 12.957 x 10-6 Watt

Antenna without the gold plate has a value of axial ratio of 2.457, which means the antenna has an elliptical polarization close to circular polarization.

As for the antenna that has been given a gold player, obtained the maximum received power is on the angle of 340^0 and minimum received power is on the angle of 270^0.

Maximum received power
= -23.17 dBm = 69.422 x 10-6 Watt
Minimum received power
= -35.15 dBm `= 17.478 x 10-6 Watt

Antenna with a gold plat has a value of axial ratio of 2, which means that the antenna has an elliptical polarization close to circular polarization.

E. Gain Measurement

- Gain Measurement Results

Table IV. Gain Measurement Results

Measurement	Antena					
	AUT (Antenna Without Gold Plating)		AUT (Antenna With Gold Plating)		Reference	
	(-dBm)	(dB)	(-dBm)	(dBm)	(dB)	(dBm)
1	23.56	-23.56	23.84	-23.84	18.00	-18.00
2	22.07	-22.07	24.01	-24.01	17.83	-17.83
3	23.30	-23.30	24.00	-24.00	17.80	-17.80
4	22.78	-22.78	23.98	-23.98	17.75	-17.75
5	23.91	-23.91	23.53	-23.53	18.06	-18.06
6	23.11	-23.11	23.97	-23.97	18.02	-18.02
7	22.82	-22.82	23.65	-23.65	18.01	-18.01
8	22.74	-22.74	23.30	-23.30	17.84	-17.84
9	22.92	-22.92	24.06	-24.06	17.76	-17.76
10	23.11	-23.11	23.77	-23.77	18.25	-18.25
Average	23.032	-23.032	23.811	-23.811	17.93	- .932

- Analysis of Gain Measurement Results

The gain can be determined using the following formula:

G_{AUT} without gold plating(dBi) = P_{AUT} (dBm) – P_{REF} (dBm) + 12 dBi
= -23.032 - (-17.931) +12 DBi
= 6.899 dBi

G_{AUT} with gold plating(dBi) = P_{AUT} (dBm) – P_{REF} (dBm) + 12 dBi
= -23.811 - (-17.931) +12 DBi
= 6.120 dBi

F. Comparison of Simulation Results with Measurement Results

Table V. Comparison of Simulation Results with Measurement Results

Parameter	Initial Spesification	Antenna Without Gold Plating Result Measurement	Antenna Without Gold Plating Result Measurement
VSWR at frequency 2.425 GHz	1.287	1.139	1.150
VSWR at frequency 2.4 GHz and 2.45 GHz	1.800 and 1.770	1.684 and 1.694	1.680 and 1.679
Impedance	50 Ω	46.322+j5.528 Ω	43.667- j1.500 Ω
Gain	≥ 6 dBi	6.899 dBi	6.120 dBi
Radiation Pattern	*unidirectional*	*unidirectional*	*unidirectional*
Polarization	circular	Ellipse with AR = 2.457	Ellipse with AR = 2

V. CONCLUSION

The conclusion we can have from the whole designing process and implementation are:

- To make this antenna micro strip design, we have to be concern on the design specification, choosing substrate, appropriate antenna dimension calculation, and skill of using simulation software.
- The performance for this design is quite good, VSWR value is 1,139 in frequency of 2.425 Mhz and gain 6.899 dBi.
- Micro strip antenna without gold plate has better VSWR than the one with the gold plate.

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