High Gain 4x4 Microstrip Rectangular Patch Array Antenna for C-Band Satellite Applications

B. Pratiknyo Adi Mahatmanto
Department of Electrical Engineering,
Faculty of Engineering
Universitas Indonesia
Depok, West Java, Indonesia
b.pratiknyo@ui.ac.id

Catur Apriono
Department of Electrical Engineering,
Faculty of Engineering
Universitas Indonesia
Depok, West Java, Indonesia
catur@eng.ui.ac.id

***Abstract*—C-band satellite receiving antenna requires a high gain to reach the long-distance wireless transmission between ground station and satellite. Among various antenna types, the advantages of microstrip antennas are low profile, easy to fabricate, easy to feed, easy to incorporate with other microstrip circuit elements and integrate into systems, and easy to use in an array to increase the directivity. This paper proposes a microstrip array antenna consist of a 4x4 rectangular-shaped patch radiating element with a microstrip line feeding technique using a quarter-wavelength transformer impedance matching. The array antenna technique has the purpose of obtaining high gain and achieving greater directivities. This research considers an FR-4 Epoxy substrate in which the thickness and dielectric constant are 1.6 mm and 4.3, respectively, to deploy the antenna structure. The antenna design is simulated and parameterized by using CST Microwave Studio to obtain the most optimum performance. The result shows that the 4x4 microstrip rectangular patch array antenna has an overall gain of 13.7 dB, and from the return-loss graph shows, the working bandwidth is 734 MHz ranges from 3.794-4.528 GHz. These results indicate that the proposed antenna design is suitable and promising for C-band satellite applications.**

Keywords*—*C-band, microstrip, rectangular patch, array antenna, gain, return loss, bandwidth

I. Introduction

For such a large area country of Indonesia consists of more than 17.000 islands spread from Sabang to Merauke, this condition forces the archipelago country to utilize space by using satellites to be able to communicate between islands effectively. Satellite systems offer a wide area coverage by utilizing the altitude of the satellite. However, there are a lot of issues and challenges in developing a satellite system for communication and other purposes. In designing the point of view, it takes many parameters that must meet the parameters expected to communicate using satellite lines with many factors. High rainfall rate is one of the determining factors. Compared with other types of satellites, communications satellites that work on C-band channels are fairly reliable in the face of weather conditions to cope with high rainfall conditions [1] [2]. The development of this satellite type will be useful for such a country that has to deal with high rain intensity.

Among the components to develop a satellite system, the antenna is an important component for satellite communications as part of a transmitter and receiver for transmitting and capturing electromagnetic wave radiation. For a satellite application, the system requires a high-gain antenna to provide a communication link between the satellite and the ground station to provide high power radiation intensity and convey signals in that long-distance wireless transmission. The type of microstrip antenna has characteristics that match the satellite communication [3] [4] [5]. The advantages of microstrip antennas are slimmer, simple to fabricate, convenient to feed, easy to incorporate with another microstrip circuit, and it can easily integrate into the systems. It can combine to an array configuration to upgrade the directivity [6].

The microstrip array antenna technique with single or multiple feeds is necessary to get high gain and to achieve greater directivities, which is important in a satellite system [7] [8] [9]. The type of feeding method, which is usually connecting microstrip patch element antenna to ports that connect to another transmission line, is proximity-coupled feed or electromagnetically-coupled feed [10] [11]. The advantages of this feeding method are possible in the planar feeding, less line radiation compared to microstrip feed because the line is closer to the ground plane, and allows for higher bandwidth because no probe inductance so the substrate can be thicker.

This paper proposes a design of microstrip antenna for C-band satellite applications with a rectangular-shaped patch radiating element modified into rectangular array antenna configuration up to 4x4 elements to obtain high gain. The frequency work of the C-band antenna from a range of 3.794-4.528 GHz, with its expected bandwidth of 734 MHz and linear polarization. This research considers the dielectric substrate of FR-4 epoxy material. 4x4 Microstrip rectangular patch array antenna feed uses proximity coupled feed technique to increase the gain and bandwidth values of the antenna design.

II. Antenna Design

In a microstrip antenna design, the dielectric component affects the dimension of the patch element. From (1) and (2) show the analytical dimension of patch width (W) and length (L) depend on the speed of light (c), expected resonant frequency (fr), substrate dielectric constant (ε_r), effective relative permittivity (ε_{reff}), vacuum permittivity (ε_0), and vacuum permeability (μ_0). Table 1 shows the detail of the substrates material and conductor material considered in this paper. The substrate types, the dielectric constant (ε_r), the substrate thickness, and the copper thickness are FR-4 substrate, 4.3, 1.6 mm, and 0.035 mm, respectively. After determining the resonance frequency (fr) and substrate dielectric constant (ε_r), using (1) and (2), the next step is to find the initial estimate of the width and length of the rectangular patch. The obtained calculated width and length are the initial information to design a single element patch of microstrip antenna. A parametric study will be the next step to obtain the most optimum performance by using CST Microwave Studio software.

TABLE I. DIELECTRIC SUBSTRATE PARAMETER

Parameter	Dimension
Dielectric substrate	FR-4
Dielectric constant	4.3
Substrate thickness	1.6 mm
Copper thickness	0.035 mm

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\,\Delta L \tag{2}$$

A. *Microstrip Antenna for Single Element*

Fig. 1 shows the structure of a single element microstrip patch antenna. From (1) and (2), the patch width (W) and length (L) are 15.78 mm and 14.51 mm, respectively. The width and length of the FR-4 substrate are 31.56 mm and 29.02 mm, respectively. The length of the microstrip line (Lf) is 11.55 mm. These estimated values are simulated and characterized to achieve the most optimum parameters.

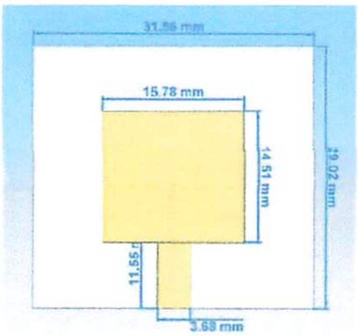
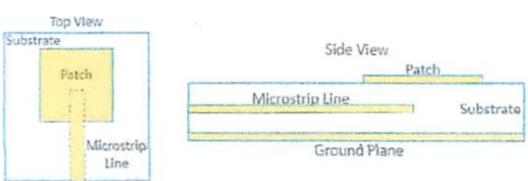


Fig. 1. Front view of single element microstrip patch antenna

The feeding system for the single element microstrip antenna is the proximity-coupling technique. The advantages of the proximity-coupling are simple to model, wide bandwidth, and low spurious radiation. Fig. 2 shows the Proximity-coupled Feed technique from the top view and side view. A microstrip line feeding is inside the dielectric substrate and between patch and ground plane.



a b

Fig. 2. Proximity-coupled feed technique (a) top view, and (b) side view

B. *1x2 Microstrip Array Antenna*

From a single element to array configuration is the next step to improve gain performance. Fig. 3 shows the antenna array designed with two rectangular patches arranged in a 1x2 array configuration. The feeding technique is the quarter wavelength matching network to keep matching between the feeding system and the patch elements. After parameterization to enhance the gain, the effective separation between patches is 0.525 of wavelength. The overall antenna dimension is 70 x 50 mm.

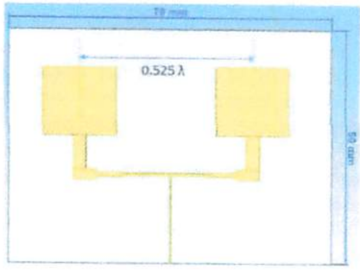


Fig. 3. Top view of 1x2 microstrip array antenna

C. *2x2 Microstrip Array Antenna*

Fig. 4 shows the 2x2 microstrip array antenna designed with four rectangular patches elements arranged in a 2x2 configuration. The improvement in a rectangular configuration is to obtain gain improvement and also beamwidth reduction in both planes of E-plane and H-plane. The effective separation between patches is 0.512 λ. The 2x2 overall antenna dimension, including the dielectric substrate, is 100 x 100 mm.

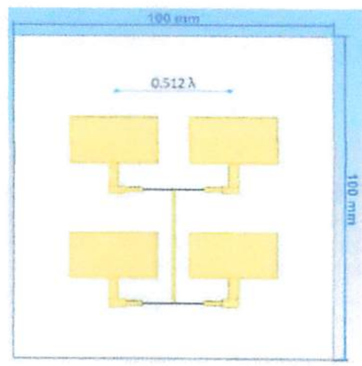


Fig. 4. Top view of 2x2 microstrip array antenna

D. *4x4 Microstrip Array Antenna*

Fig. 5 shows the top layer of array improvement into a 4x4 patch array configuration. Fig. 6 shows the matching network for those patch elements. This design shows the power distribution system for every patch element of the microstrip antenna uses the proximity-coupled feeding technique to improve the antenna robustness due to the enlarging size. The array antenna feeding connector is SMA coaxial type

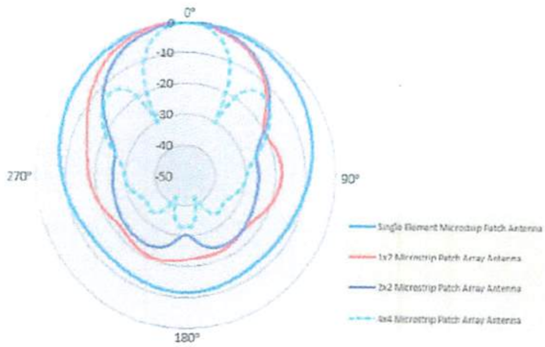


Fig. 9. E-Plane radiation pattern at frequency 4.148 GHz

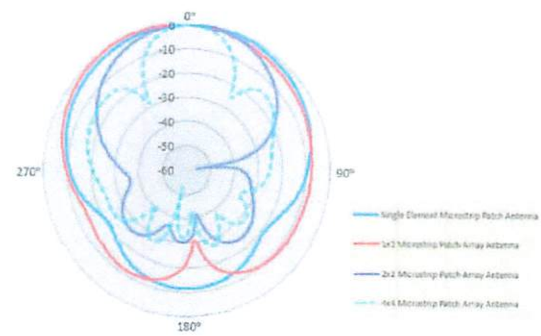


Fig. 10. H-plane radiation pattern at frequency 4.148 GHz

C. Gain

Fig. 11 and Fig. 12 show the simulation result of antenna gain comparison and far-field 3D of the 4x4 antenna, respectively. The maximum gain obtained for 4.148 GHz for single element microstrip patch antenna is 4.94 dB. The antenna gain for a 1x2 microstrip array antenna is 6.55 dB. The antenna gain value for the 2x2 microstrip array antenna is 9.6 dB. The antenna gain for 4x4 Microstrip Array Antenna is 13.7 dB. There is an improvement gain between single element microstrip antenna, 1x2, 2x2, and 4x4 Microstrip Array Antenna. Fig. 12 shows the Farfield 3D Result for 4x4 Microstrip Patch Array Antenna, and the radiation pattern shows the directional pattern.

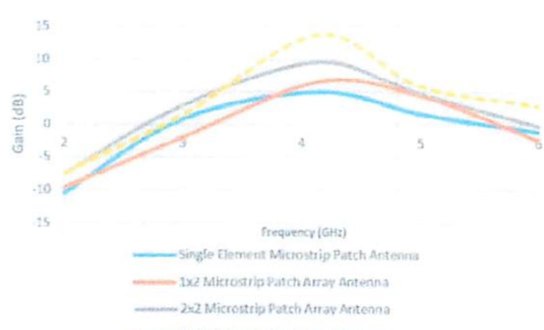


Fig. 11. Antenna Gain for a single element, 1x2, 2x2, and 4x2 microstrip patch array antenna

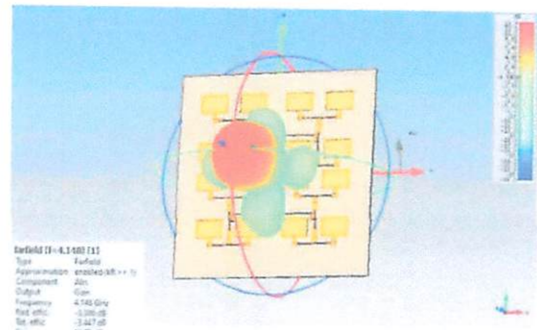


Fig. 12. Far-field 3D result for 4x4 microstrip array antenna

Radiation efficiency for a 4x4 microstrip array antenna in this design is -3.386 dB, influenced by the loss of material and loss of metal. Loss material obtained from the substrate material, in this case, is coming from the FR-4 material. Loss metal influenced by microstrip patch and microstrip line made by copper.

D. Polarization

Fig. 13 shows the axial ratio of the 4x4 microstrip array antenna. The value of the axial ratio from 3 GHz until 5 GHz indicates that the 4x4 microstrip array antenna produces linear polarization because the axial ratio value is more than 10 dB, which is 40 dB from 3 GHz until 5 GHz. Fig. 14 shows polarization for 4x4 microstrip array antenna from the top view and side view.

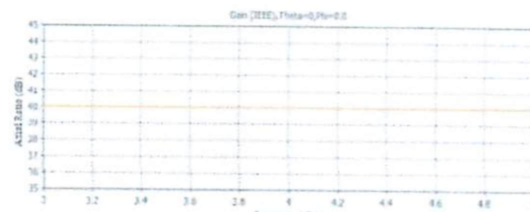


Fig. 13. Axial Ratio for 4x4 microstrip array antenna

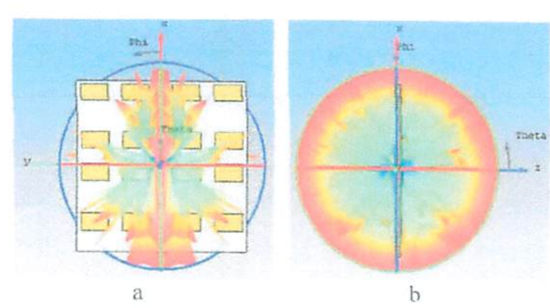


Fig. 14. Polarization for 4x4 microstrip array antenna (a) top view, and (b) side view

TABLE II. PARAMETERS RESULT IN COMPARISON

Antenna	Bandwidth Frequency	Gain (4.148 GHz)	E-plane	H-Plane
Single element	3.797-4.205 GHz	4.94 dB	96.6°	96°
1 x 2	3.734-4.385 GHz	6.55 dB	51.5°	81.5°
2 x 2	4.066-4.152 GHz	9.6 dB	46.9°	50.7°
4 x 4	3.794-4.528 GHz	13.7 dB	24.5°	25.4°

Table II shows comparison results of the most optimum design in each configuration in terms of frequency bandwidth, antenna gain, E-plane radiation pattern, H-plane radiation pattern for microstrip antenna for single element, 1x2, 2x2, and 4x4 microstrip array antenna. It shows the performances become better as the number of elements increases, especially in the gain parameter. For the rectangular configuration of 2x2 and 4x4, it shows that the beamwidth is becoming close between E-plane and H-plane. The results showed that the rectangular array technique had succeeded in improving the gain and balancing the beam bandwidth.

IV. CONCLUSIONS

The design of high gain 4x4 microstrip rectangular patch array antenna on FR-4 substrate with dielectric constant (ε_r) of 4.3 and thickness of 1.6 mm for the C-band satellite have been calculated, simulated, and parameterized for the expected C-band satellite applications. Microstrip array antennas perform better than single microstrip antennas in terms of bandwidth and gain. The characterization result shows that the 4x4 microstrip array antenna has an antenna gain of 13.7 dB at 4.148 GHz, while the working bandwidth is 734 MHz ranges from 3.794-4.528 GHz. The simulation results between single element microstrip antenna, microstrip array antenna 1x2, 2x2, and 4x4 show that the array method can improve antenna performance in terms of increasing gain and increasing the frequency of operational bandwidth. These results indicate that the proposed array design antenna can contribute as an antenna for C-band satellite applications.

ACKNOWLEDGMENT

Ministry of Research and Technology / National Agency for Research and Innovation supports this research through Penelitian Tesis Magister (PTM) Grant, the year 2020, contact number: NKB-501/UN2.RST/HKP.05.00/2020.

REFERENCES

[1] R. Ritronnasak, T. Charoenpru and L. Waranon, "Integration and Installation of The Low Cost C-band Receiving System for Himawari-8 Satellite," *2018 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Chiang Rai, Thailand, 2018, pp. 732-735.

[2] H. Sun, F. Zhang and C. Jia, "Research on Key Technologies of C/Ku Dual-Band Satellite Communication," *2019 International Conference on Robots & Intelligent System (ICRIS)*, Haikou, China, 2019, pp. 149-151.

[3] T. Reynalda, A. Munir and E. Bharata. (2011). Characterization of 4×4 High Gain Microstrip Array Antenna for 3.3GHz WiMAX Application. 10.1109/TSSA.2011.6095437.

[4] R. M. Hashmi and K. P. Esselle, "Planar high-gain antennas for direct broadcast satellite reception," *2016 IEEE 2nd Australian Microwave Symposium (AMS)*, Adelaide, SA, 2016, pp. 17-18.

[5] P. M. Dhenge, P. S. Ashtankar and S. M. Kharad, "Design and development of C-Band planer antenna for satellite communication using HFSS," *2016 International Conference on Communication and Signal Processing (ICCSP)*, Melmaruvathur, 2016, pp. 0055-0057.

[6] D. Chatterjee and A. K. Kundu, "Performance analysis and comparative study of microstrip patch antenna using aperture coupled and proximity coupled feeding methodology," *2017 International Conference on Computer, Communication and Signal Processing (ICCCSP)*, Chennai, 2017, pp. 1-7.

[7] C. Kumar, V. S. Puram, V. S. Kumar and D. Venkataramana, "Design Consideration of High Gain Microstrip Antenna Arrays for Telemetry Tracking and Command System of Geostationary Satellites," *2018 IEEE Indian Conference on Antennas and Propagation (InCAP)*, Hyderabad, India, 2018, pp. 1-3.

[8] C. Kumar, B. S. Reddy, B. P. Kumar, V. S. Kumar and V. V. Srinivasan, "Novel high gain dual band single aperture array with large cross-polarized isolation at Ku-band for the TT&C system of a geostationary satellite," *2017 IEEE International Conference on Antenna Innovations & Modern Technologies for Ground, Aircraft and Satellite Applications (iAIM)*, Bangalore, 2017, pp. 1-5.

[9] E. García-Marín, J. L. Masa-Campos and P. Sánchez-Olivares, "4 x 4 stacked patch array with siw and microstrip corporate feeding network for ku-band," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, 2016, pp. 1-4.

[10] A. S. S. Mariyanto, M. Irfan, S. Ariessaputra and O. M. C. Mustiko, "Design and realization of microstrip antenna for GPS application using proximity coupled techniques," *2017 11th International Conference on Telecommunication Systems Services and Applications (TSSA)*, Lombok, 2017, pp. 1-4.

[11] R. Widiandari and A. Munir, "Proximity Coupled X-Band Patch Antenna Array With Dual Polarization," *2016 International Electronics Symposium (IES)*, Denpasar, 2016, pp. 165-168.