Rectangular Configuration Microstrip Array Antenna for C-Band Ground Station

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***Abstract*—Data communication between satellites and earth stations requires reliable high gain antennas. The array technique of a microstrip antenna offers advantages, such as low profile, easy to make, easy to feed, easy to be combined with other microstrip circuit elements, easy to integrate into the system, and especially increasing gain. This paper proposes a microstrip array antenna consisting of a 4x4 rectangular patch radiating element with a microstrip line feeding technique designed with quarter-wavelength transformer impedance matching. Designing and parameterization are conducted with CST Microwave Studio. The antenna is designed and fabricated on double layers of FR-4 Epoxy substrates where the thickness and dielectric constant are 1.6 mm and 4.3, respectively. The antenna dimension is 170 x 170 mm. The proposed antenna design has a good agreement between simulation and measurement. It can work from within the frequency range of 4.054-4.614 GHz with a bandwidth of 560 MHz. The 4x4 Microstrip Rectangular Patch Array Antenna has an overall 14.03 dB gain antenna. The proposed antenna meets the frequency requirements for C-band satellite applications.**

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

I. Introduction

As an archipelago country consisting of more than 17,000 islands, the use of satellites is crucial for Indonesia to connect and communicate all regions effectively. It takes a lot of parameters to develop a satellite communication system that must tackle many environmental factors. One of those is the high intensity of rainfall. C-band satellite channel is quite reliable in the face of weather conditions to cope with high rainfall conditions [1].

Antennas are the primary devices in wireless communication systems, including a satellite system. Antenna radiation performances will directly affect communication quality. Among various types of antennas, recently, microstrip antennas play a significant role in wireless communication systems [2] [3] [4]. A microstrip antenna offers advantages, such as low profile, easy to make, easy to feed, easy to be combined with other microstrip circuit elements, and easy to integrate into the system. The basic structure of a microstrip antenna has three layers. The top, middle, and bottom layers are patches, a dielectric substrate, and a ground plane, respectively. The material used for the top and bottom layers is metal, usually copper. This antenna is more compact and lightweight when compared to the other antennas. Various techniques can be applied to improve antenna performance, such as an array technique. By applying the array configuration technique, microstrip antenna offers high gain radiation performance that is necessary for satellite communication systems.

A feeding technique is also crucial in antenna design. It affects adequate power delivered from an electronic circuit system to the antenna and determine bandwidth. In a microstrip antenna, the proximity coupling feeding technique can provide wide bandwidth and low false radiation [5] [6] [7]. Also, there is flexibility in choosing feedline geometry. This feature is useful in selecting the desired resonating frequency and for impedance matching.

A patch design and its array arrangement in a microstrip antenna will produce specific radiation characteristics [8] [9] [10]. A single element antenna has a broad radiation pattern and less directivity. An improvement by applying array configuration can increase directivity and decrease beamwidth. This array can overcome obstacles such as the high attenuation level suffered by atmospheric conditions and low capacity to penetrate the structure that makes it necessary to provide high gain [11] [12] [13].

This paper proposes a microstrip patch antenna array in a rectangular configuration with a proximity-coupling technique for ground station antenna of C-band satellite communication systems to operate at a central frequency of 4.148 GHz with an input impedance of 50 Ω using a double layers dielectric substrate of FR4 epoxy. Substrate permittivity (ε_r) and thickness are 4.3 and 1.6 mm, respectively. A parallel feed connects array elements with a distance of 0.5 λ between elements in horizontal and vertical directions. A transmission line design based on the quarter-wavelength transformer impedance matching feed all patch elements. The parameters considered for discussion and analysis are return loss, bandwidth frequency, radiation pattern and antenna gain.

II. Antenna Design

A. Design of Single Element Microstrip Antenna

This research conducts design and parameterization with CST Microwave Studio. After obtaining an optimum antenna design, the next step is fabricating the optimum design into a prototype antenna. Then, the prototype is measured to validate the simulated parameters.

This research considers the substrate of FR-4 epoxy with a dielectric constant (ε_r) of 4.3, dielectric substrate thickness of 1.6 mm, and copper thickness of 0.035 mm. Figure 1 shows the

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structure of a single element microstrip patch antenna. The antenna dimension derivation is coming from the microstrip antenna design formula for a single rectangular element intended for the determined resonant frequency, which is 4.148 GHz in this case. The patch width (*W*) is 15.78 mm. The patch length (*L*) is 14.51 mm. The substrate width is 31.56 mm. The substrate length is 29.02 mm. The substrate thickness (*h*) is 1.6 mm. The conductor thickness (*t*) is 0.035 mm. The microstrip line width (*Wf*) is 3.68 mm. The length of the microstrip line (*Lf*) is 11.55 mm. These values are simulated and characterized to reach the most optimum parameter's value. The feeding system of this microstrip antenna is the proximity-coupling technique. The advantages of the proximity-coupling are easy to model, large bandwidth, and low spurious radiation.

Figure 2 shows the proximity-coupled feed technique. The microstrip line is in between patch and ground. This condition indicates consideration of the use of two substrate layers in the latter fabrication process.

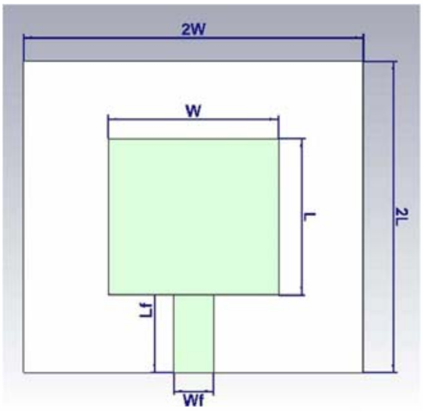

Fig. 1. The top view structure of a patch of single element microstrip antenna

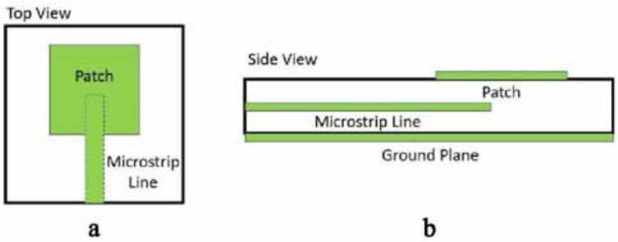

Fig. 2. Illustration of proximity coupling feed from (a) top view, and (b) side view

B. Design of 4x4 Microstrip Patch Array Antenna

Microstrip patch array antenna will improve the performances of a single element microstrip antenna in terms of bandwidth and directivity. This paper considers a 4x4 microstrip patch array antenna. The feeding input impedance is 50 Ω, which the value of an SMA coaxial connector impedance. The connector penetrates from the bottom of the ground plane. It shares the power from the middle point of the proximity coupling feed. Those feeding lines based on quarter wavelength transmission lines matching technique to connect 100 Ω feeding lines. The quarter wavelength transmission lines is a practical technique used for impedance matching purposes. The feeder network plays an essential role due to impedance matching from the source to the load when the design of the array antenna.

Figure 3 shows the top, mid, and bottom layers of the 4x4 microstrip patch array antenna. The antenna consists of three layers, and the total dimension of the antenna is 170 x 170 mm. The patch on top layer implemented as the radiator is the one widely used configuration for the microstrip antenna. The patch width (*W*) and patch length (*L*) will define the antenna working frequency. The mid-layer of the 4x4 microstrip array antenna consists of a microstrip line configuration. The 4x4 rectangular patches configuration purpose is to increase the antenna gain. The proximity coupling feed and coaxial feed is the chosen transmission line network to feed all patches. A quarter wavelength transformer of 70.7 Ω is applied to match the 100 Ω impedance line to the 50 Ω impedance line coming from a coaxial cable. The ground plane covers the bottom layer of the 4x4 microstrip array antenna.

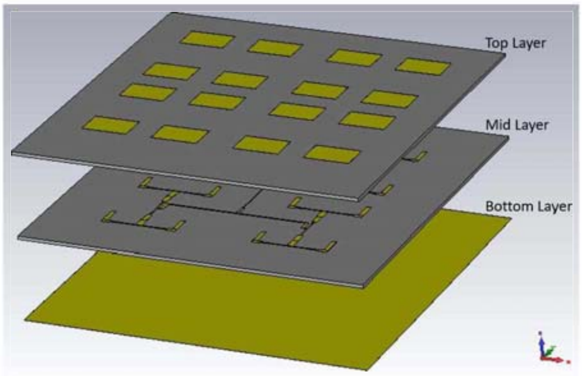

Fig. 3. Top, mid, and bottom layers of the proposed 4x4 microstrip patch array Antenna

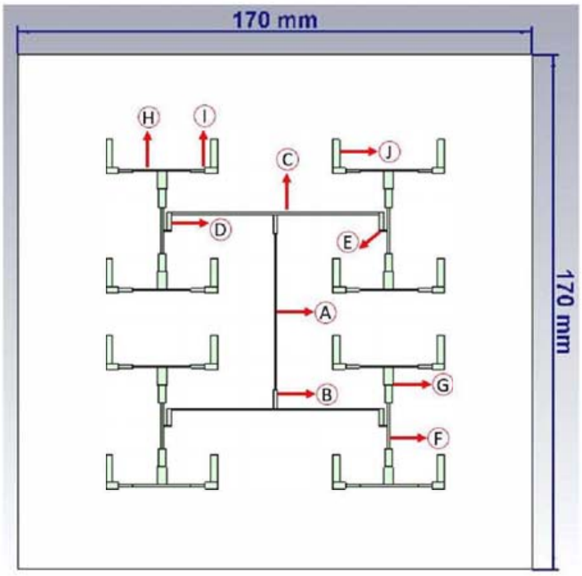

Fig. 4. Microstrip line configuration for feeding of the 4x4 radiating patch array elements

Figure 4 shows the 4x4 microstrip line design and variables to feed the 4x4 radiating patch array elements. This research conducts the parametric study of those variables to obtain the most optimum parameters' values. After conducting the parameterization, Table 1 is a list of dimensions of the variables of an obtained optimum design performance.

TABLE 1. SIZES OF OPTIMUM VALUES OF TRANSMISSION LINE VARIABLES

Variables	Dimension (mm)
WA	0.285
LA	51.611
WB	1.383
LB	6.257
WC	0.614
LC	68.136
WD	1.543
LD	5.706
WE	0.443
LE	2.975
WF	0.659
LF	15.271
WG	2.535
LG	5.945
WH	0.467
LH	19.158
WI	0.968
LI	4.689
WJ	2.75
LJ	9.353

III. RESULTS AND DISCUSSION

A. Antenna fabrication

After getting the most optimum design result of return loss and a high gain from the simulation software, then the next step is the antenna fabrication process. Figures 5, 6, and 7 show the top, the mid-layer, and the bottom layer of the fabricated 4x4 microstrip patch array antenna, respectively. Return loss in a range frequency of 2 to 6 GHz is measured by using Network Analyzer Rohde & Schwarz ZVL. Gain measurement is carried out in a range frequency of 2 to 6 GHz using Network Analyzer Hewlett Packard 8753E and reference antenna use Schwarzbeck BBHA 9120. Radiation patterns measurement is carried out in the anechoic chamber at frequency 4.148 GHz by using Network Analyzer Hewlett Packard 8753E 32kHz-6GHz.

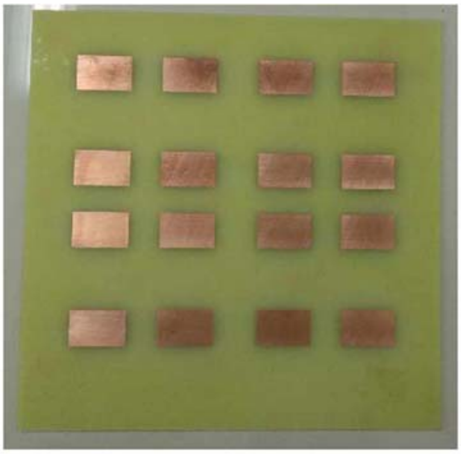

Fig. 5. The top layer of fabricated 4x4 microstrip patch array antenna

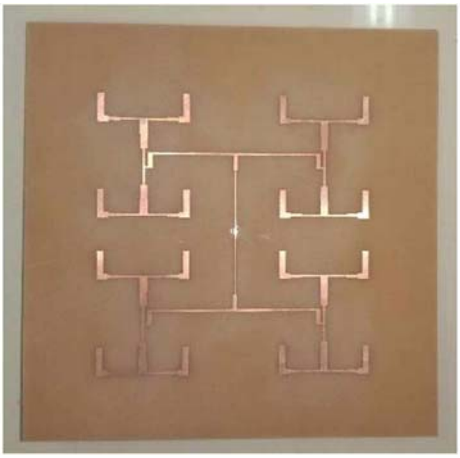

Fig. 6. The mid-layer of fabricated 4x4 microstrip patch array antenna

Fig. 7. The bottom layer of fabricated 4x4 microstrip patch array antenna

B. Return Loss Measurement

Figure 8 shows a return loss comparison between simulation and measurement. From the simulation result, the return-loss graph shows the bandwidth is 734 MHz in a range of 3.794-4.528 GHz. The measurement result shows that the fabricated antenna design can work from in a frequency range of 4.054-4.614 GHz with a bandwidth of 560 MHz. From the measurement results compared to the simulation results, it shows that there are shifting frequencies. There is a probability inaccuracy of the fabricated antenna, which is not precise, like the designed antenna, especially when combining the two substrates. The characteristics of FR4 substrate material in the fabricated antenna are possibly not the same characteristics due to possibly a gap occurs in between the two combining substrates. Poor soldering of the connector between the ground plane and the microstrip line can provide another loss contribution. Although there is a different working frequency between the fabricated antenna and the designed antenna, the bandwidth characteristic is remaining a good agreement on both simulation and fabrication results.

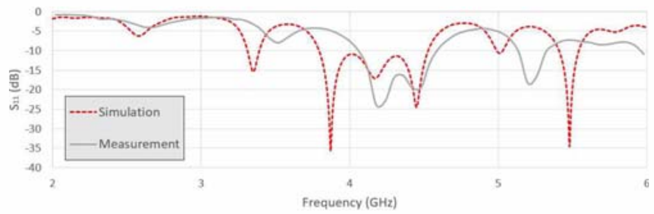

Fig. 8. Return loss (S_{11}) comparison between simulation and measurement

C. Gain Measurement

Figures 9 shows the gain comparison between simulation and measurement. The obtained maximum gain for simulation results at 4.148 GHz is 13.7 dB. The fabricated antenna has an overall 14.03 dB of the gain antenna. The gain comparison also shows a good agreement with little differences. There is an improvement gain of the antenna between simulation results compared with the measurement result of the 4x4 microstrip patch array antenna.

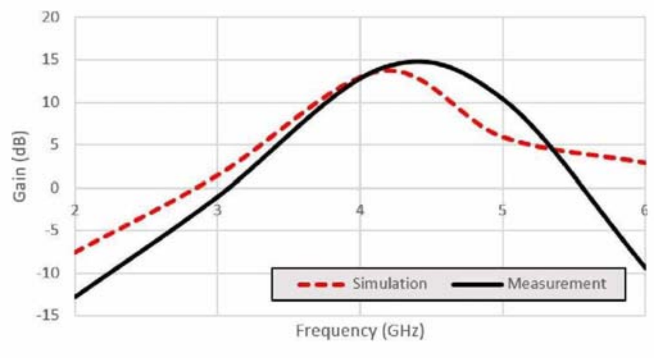

Fig. 9. Antenna gain comparison between simulation and measurement

D. Radiation Pattern Measurement

Figures 10 and 11 show the comparison between simulation and measurement of radiation pattern at frequency 4.148 GHz for E-plane and H-plane, respectively. From the simulation and measurement results, the radiation pattern indicates a directional pattern affected by the array configuration. The radiation pattern from measurement shows almost similar results compared with the simulation result.

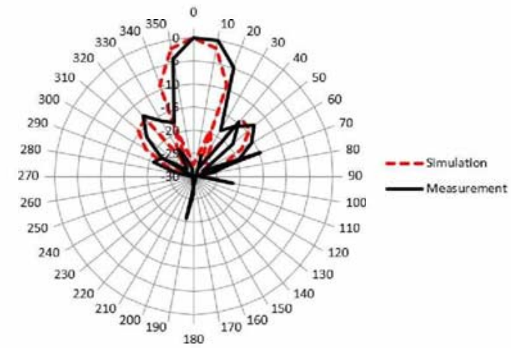

Fig. 10. E-plane Radiation Pattern (dB) of 4x4 Microstrip Patch Array Antenna at 4.148 GHz

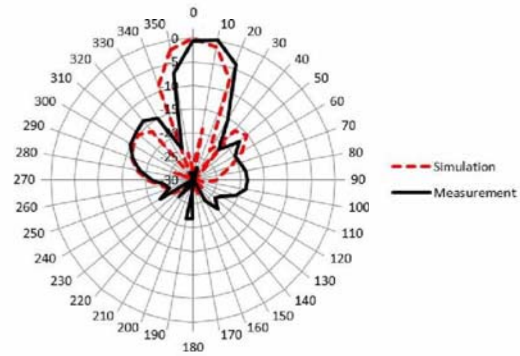

Fig. 11. H-plane Radiation Pattern (dB) of 4x4 Microstrip Patch Array Antenna at 4.148 GHz

IV. Conclusions

This paper has discussed design, fabrication, and simulation of the proposed 4x4 microstrip patch array antenna using proximity coupling feeding network to reach necessary performances for a C-band ground station satellite system. The antenna prototype resonant frequency is in a range of 4.054-4.614 GHz with a working bandwidth of 560 MHz. The 4x4 microstrip patch array antenna has also obtained a gain value of 14.03 dB at frequency 4.148 GHz. These results indicate that the proposed antenna is potentially for more development for the ground station antenna of the C-band satellite system.

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