Gain Performance Analysis of A Parabolic Reflector Fed with A Rectangular Microstrip Array Antenna

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Abstract—**Satellite communication widely uses antennas with reflectors to achieve high gain for the long-distance signal transmission. This configuration mainly consists of a feeding antenna and a parabolic reflector that should be optimized to obtain the most optimum performance. This paper investigates some factors affecting the antenna performances, especially gain, for a C-band satellite ground station, such as losses contributed by materials, efficiencies, and distance between feeder and reflector. CST Microwaves Studio is used to simulated and investigates the gain performance of the proposed antenna model. The feeder antenna is a 4x4 microstrip array antenna, which has gain and bandwidth of 13.7 dB at frequency 4.148 GHz and 3.794-4.528 GHz, respectively. The parabolic reflector diameter is 2.4 m. The analyzed parameters include gain and directivity generated by theoretical calculations and simulations. Theoretically, the maximum directivity is 39.85 dB. However, the simulated antenna gain is 31.1 dB. This reduced value is coming from the effect of efficiency, material losses, and unexpected radiation pattern from the feeding antenna. The proposed design has successfully increased the gain of 17.4 dB by combining a reflector antenna. This result still has a niche to be further improved by considering the affecting factors.**

Keywords—antenna, parabolic, reflector, microstrip, feed, gain

I. Introduction

Long-distance communications systems, including satellite communication, radar, and remote sensing applications, have widely used antennas with reflectors to reach high gain and the targeted distances. The advantages of an antenna with a reflector are ultra-high gain, low power consumption, low cross-polarization, low voltage standing wave ratio, lightweight by using carbon-fiber material, and low-cost production by using cheap materials [1] [2]. Antenna with a reflector is suitable for transmitting and receiving signals at a ground station of a satellite system. The reflector types are cylindrical, hyperbolic, parabolic, and spherical, as options for matching with a feeder antenna.

The commonly feeding antennas are horn antennas, log-periodic dipole arrays, and spiral antennas [3] [4] [5]. The horn antenna is mostly for point-to-point communication over long distances. Microstrip antennas have also been a candidate as feed antennas because of some offered advantages. They are low profile, easy to feed, easy to make, easy to be combined with other circuit elements, easy to integrate into the system, and easy to produce the desired beam shape and produce a very high gain by arranging it into array [6] [7].

This paper discusses the performances of a microstrip array antenna design as a feeder combined with a parabolic reflector as a receiving antenna for a ground station of a C-band satellite system. The considered microstrip array antenna is a 4x4 microstrip array antenna for C-band satellite applications [8]. By combining the microstrip antenna and a reflector, the analyzed parameters include gain and directivity generated by theoretical calculations and simulations. Some characterized variables are material losses, efficiencies, focal length, and other factors to obtain the most optimum performance. CST Microwaves Studio is used to simulate and examine performances of the proposed antenna model.

II. Theoretical and Investigation Methodology of A Parabolic Antenna Model

A. Feeding Antenna

The considered microstrip array antenna in this paper is a 4x4 microstrip array antenna for C-band satellite applications [8]. The structure of the 4x4 microstrip patch array antenna consists of three layers, as illustrated in Figure 1. The top layer consists of 4x4 rectangular patches for emitting radiation. The middle layer is the microstrip line with a proximity coupling feeding. The bottom layer is the ground plane. The antenna design uses an FR-4 substrate with permittivity (ε_r) and substrate thickness of 4.3 and 1.6 mm, respectively. The total dimension of the antenna is 170 x 170 mm. The characterization results show that the 4x4 microstrip array antenna has gain and bandwidth of 13.7 dB at a frequency of 4.148 GHz and 734 MHz in a range of 3.794-4.528 GHz, respectively. Figure 2 shows the top view of the fabricated 4x4 microstrip array antenna. The patch configuration was obtained after parameterization to get the most optimum design for the desired specification.

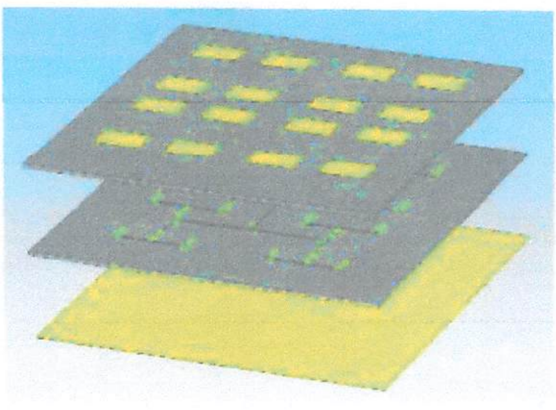

Fig. 1. The structure illustration of the 4x4 microstrip patch array antenna consists of three layers [8]

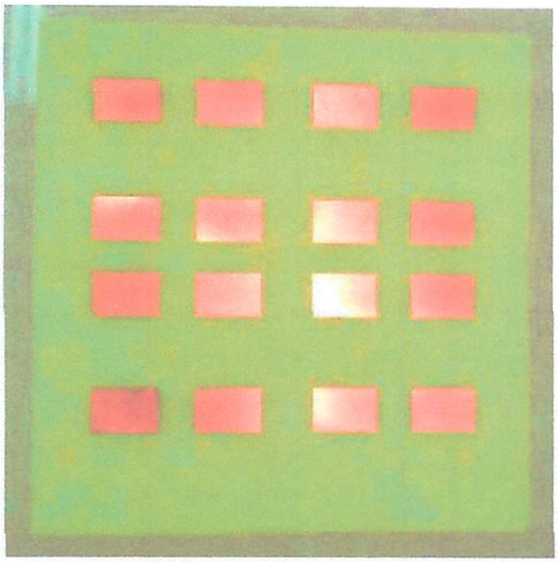

Fig. 2. Top view of the fabricated 4x4 microstrip patch array antenna [8]

B. Gain Improvement by A Parabolic Reflector

A feeder antenna located in front of a parabolic reflector is a common technique to integrate the two main components. The reflector angle, reflector geometry, and feed location relative to the reflector diameter (*f/D* ratio) are critical design conditions. The radiation distribution of the antenna and their projections on the reflector surface plays a vital role in achieving high gain and low cross-polarization ratios. Figure 3 shows a schematic model of a feed antenna located in front of the parabolic reflector. The main design parameters are the diameter of the reflector (D), focal length (F), and the depth of the parabolic (Ho).

Some theoretical approaches of a parabolic antenna considered in this paper are to estimate possibly achieved gain performance from various sources [9] [10]. Equation (1) is to calculate the gain from a parabolic reflector and antenna feed. G, η, and D are the antenna gain, efficiency of a parabolic reflector, and the diameter of a parabolic reflector, respectively. The considered diameter size of the reflector in this research is 2.4 m. This Equation calculates the total maximum gain contributed by the feeder and the reflector. Equations (2) is to estimate the gain from a parabolic reflector. This Equation predicts contributed gain from the use of a reflector without a feeding antenna. Equations (3) is to determine the focal point of a parabola as the location of the antenna feed placement from the deepest point of a parabolic reflector, where F is the focal point, and Ho is the depth of a parabolic reflector.

$$G = \eta \left(\frac{\pi D}{\lambda}\right)^2 \quad (1)$$

$$G = \frac{4\pi D F}{\lambda^2} \quad (2)$$

$$F = \frac{D^2}{16\, Ho} \quad (3)$$

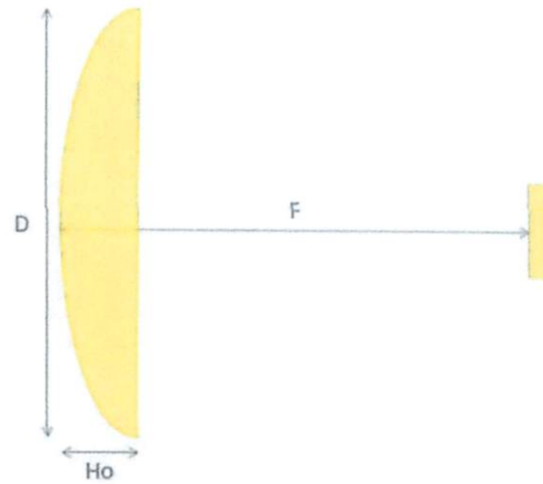

Fig. 3. A schematic model of a feed antenna located in front of the parabolic reflector

III. Simulation of a Microstrip Array Antenna Combined with a Parabolic Reflector

A. The gain of Parabolic Antenna

For calculating from the theoretical approach, it needs information on the feeding antenna performances. This research considers the necessary feeding antenna performance information obtained from previous research [8]. The results of gain, efficiency, and directivity are 13.7 dB, -3.54 dB, and 17.15 dB, respectively. By considering a parabolic reflector with a diameter of 2.4 m and calculation with Equation (1), it can produce 37.35 dB as the most maximum gain that can be achieved theoretically.

Meanwhile, by using equations (2) and (3) to determine the parabolic reflector gain value, the obtained gain is 22.74 dB. This value indicates a gain contribution that can add to the feeding antenna gain. If this value added to the feeding antenna directivity, the achievable maximum directivity is 39.85 dB.

By considering Equation (3), this research conducts a parametric study by characterizing the focal point to obtain the optimum parameter's values. Figure 4 shows the focus length characterization for the considered parabolic antenna model. The gain parameter is changing as the focal point changes. At the focal point of 1088.17 mm, the obtained most optimum gain is 31.1 dB.

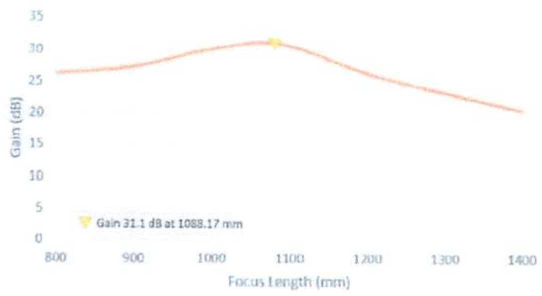

Fig. 4. Gain simulation with focus length characterization

Figure 5 shows the far-field 3D simulation result for the parabolic antenna, which shows a directional radiation pattern with an antenna directivity value of 35.64 dB. The *Ho*, *D*, and *F* are 0.4 m, 2.4 m, and 1088.17 mm, respectively. This obtained gain is lower than the estimated value theoretically, which is 37.35 dB. This condition means some losses occur along with the radiation propagation from the feeding to the reflector and finally to the free space.

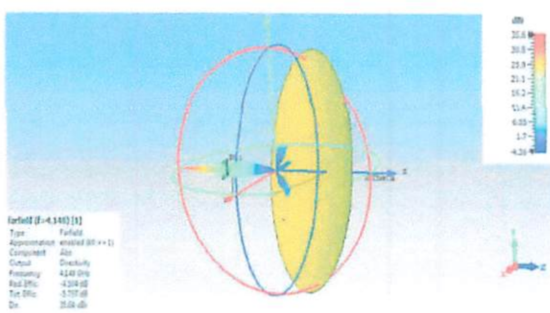

Fig. 5. Far-field 3D Result for the Parabolic Antenna

Table I shows the simulation results in comparison of gain, directivity, and efficiency between the feeding antenna and the combination between feeding antenna and reflector. The gain increases 17.4 dB from 13.7 dB to 31.1 dB. This increase is lower than the estimated by the theoretical, which is about 22.74 dB increase or 5.34 dB lower than expected. This difference can be coming from inefficiency in mismatching, any losses, and radiation efficiency. The efficiency value of -4.54 dB indicates such losses. By including the antenna efficiency, the antenna directivity is 35.64 dB. By considering the theoretical maximum directivity of 39.85 dB, the difference directivity value is 4.21 dB. This difference may be coming from the sidelobe and back lobe of the antenna radiation pattern. At the same time, another factor that might affect is the blocking effect of the signal reflected from the parabolic reflector, which bounces or blocked by the antenna feed. The antenna performances have the potential to be improved by modifying the antenna array design, decrease the sidelobe level value of the feed antenna, and increase the array to 8x8 microstrip array antenna to increase the gain value.

TABLE I. SIMULATION RESULTS COMPARISON OF GAIN, DIRECTIVITY, AND EFFICIENCY BETWEEN THE FEEDING ANTENNA AND THE FEEDING ANTENNA COMBINED WITH THE REFLECTOR

Antenna Parameter	**Simulation Result**	
	Feeding antenna (dB)	***Feeding Antenna and Reflector (dB)***
Gain	13.7	31.1
Radiation Efficiency	-3.45	-4.54
Directivity	17.15	35.64

B. Radiation Pattern

The radiation pattern of the 4x4 microstrip array antenna combined with the 2.4 diameter parabolic reflector produces a directional radiation pattern. Figures 6 and 7 show the antenna radiation pattern at the plane of phi=0° and phi=90° at a frequency of 4.148 GHz. These results are coming from the reflector function to collimate wavefront irradiated from the feeder antenna. This principle is the advantage of a reflector in a parabolic shape. If the feeding antenna located at the proper focal point, the collimating will be in the ideal condition.

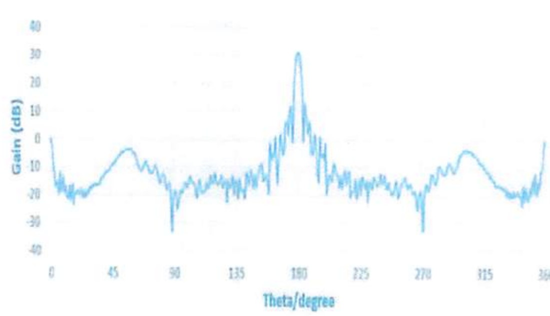

Fig. 6. Radiation pattern at the plane phi=0° at 4.148 GHz

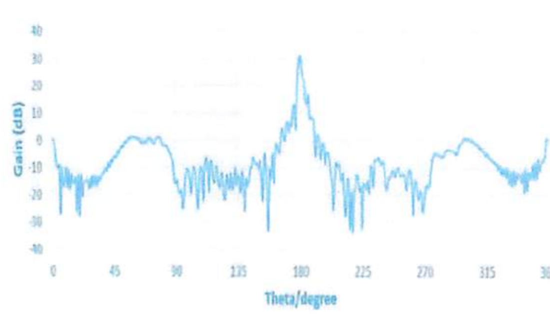

Fig. 7. Radiation pattern at the plane phi=90° at 4.148 GHz

C. Loss Material

Figures 8 shows volume loss in FR-4, as a function of distances between the feeding antenna and the reflector. When the focus length value point to 500 mm, the volume loss in the substrate of FR-4 at 4.148 GHz is 0.232 Watt. The optimum gain (F=1088.17 mm), the loss value for the FR-4 substrate is 0.23821 Watt.

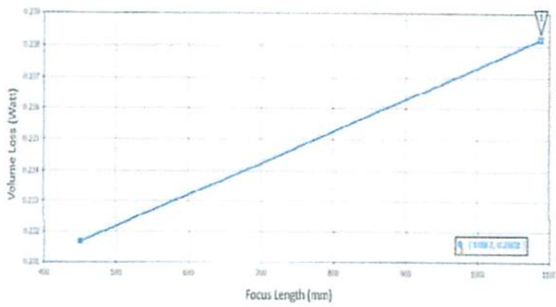

Fig. 8. Volume loss (Watt) in the substrate of FR-4 at 4.148 GHz

Figures 9 shows volume loss in copper, that explains about distances between the feeding antenna and the reflector of parabolic. The material loss in the copper at 4.148 GHz is 0.008 Watt at the focus length value 500 mm. The optimum gain with focus length value 1088.17 mm, the loss value for the copper is 0.0090665 Watt.

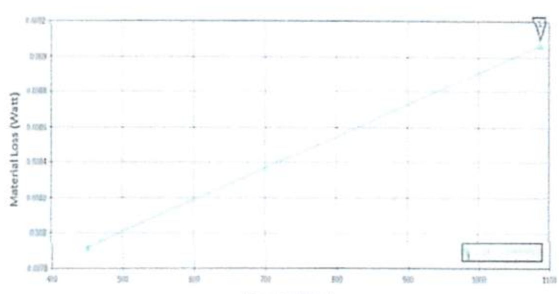

Fig. 9. Material loss (Watt) in the copper at 4.148 GHz

These different values indicate that the material losses are higher in the substrate than in the copper. Therefore, other substrates with low losses or have low loss tangent can be considered to decrease the material loss and will be able to impact the gain improvement.

IV. Conclusions

This paper has investigated some factors that are affecting to obtain the most optimum gain in a parabolic antenna fed with a microstrip array antenna. Those factors are efficiency, focal length, and feeding antenna radiation pattern. By optimizing the feeding antenna placement in a proper focal point, the achievable gain is 31.1 dB. The parabolic antenna efficiency value of -4.54 dB resulting from the simulation shows losses caused by copper and substrate material. For reducing the substrate losses, designing can consider other substrate materials, which has a smaller loss factor. Other strategies for gain improvement is by increasing radiation directivity and reducing sidelobes and back lobes of the feeding antenna radiation. Another factor that possible effect is the blocking effect of the signal reflected from the parabolic reflector, which bounces or is blocked by the antenna feed. Finding a solution to solve those issues in the future will be useful to obtain a high-performance antenna for satellite communications.

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References

[1] E. Cürük, K. Yeğin and C. Özdemir, "A novel ultra-wide band design for feeding structure of Ka Band VSAT parabolic reflector antenna," 2016 21st International Conference on Microwave, Radar and Wireless Communications (MIKON), Krakow, 2016, pp. 1-4.

[2] Y. Asci, E. Curuk, K. Yegın and C. Ozdemir, "Improved splash-plate feed parabolic reflector antenna for Ka-Band VSAT applications," 2016 46th European Microwave Conference (EuMC), London, 2016, pp. 1283-1286.

[3] W. Chaihongsa, K. Nuangwongsa and C. Phongcharoenpanich, "E-plane choke waveguide aperture antenna for front-fed parabolic reflector," 2017 IEEE International Conference on Computational Electromagnetics (ICCEM), Kumamoto, 2017, pp. 190-192.

[4] M. Pehlıvan, K. Yeğın and Y. Aşci, "Design of 1–18 GHz parabolic reflector antenna with LPDA feed," 2016 24th Telecommunications Forum (TELFOR), Belgrade, 2016, pp. 1-3.

[5] A. Mehrabani and L. Shafai, "Compact Rear-Radiating Circularly Polarized Feeds for Front-Fed Reflector Antennas," in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 2449-2452, 2017.

[6] N. H. A. Rahman, M. T. Ali, M. T. Islam and Y. Yamada, "Improvement of contoured beam characteristics of a parabolic reflector antenna by asymmetrically distributed array feed," 2015 IEEE 4th Asia-Pacific Conference on Antennas and Propagation (APCAP), Kuta, 2015, pp. 441-442.

[7] R. Bhattacharjee and K. Debbarma, "Analysis of offset reflector performance fed by 2×2 microstrip antenna array using GO technique," 2018 3rd International Conference on Microwave and Photonics (ICMAP), Dhanbad, 2018, pp. 1-2.

[8] B. P. A. Mahatmanto, C. Apriono, "Rectangular Configuration Microstrip Array Antenna for C-Band Ground Station," 2020 IEEE 27th International Conference on Telecommunications (ICT), Bali, 2020.

[9] Warren. L. Stutzman and Gary. A. Thiele, "Antenna Theory and Design", John Wiley & Sons, 2012.

[10] C. A. Balanis, "Antenna Theory Analysis and Design," John Wiley & Sons, 2016.