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Design of a Dual-Polarization Dual-Wideband Planar Antenna

A'isya Nur Aulia Yusuf, and Fitri Yuli Zulkifli

***Abstract*—Wireless communication is a fundamental requirement because of its low cost, high flexibility and convenience, continuing improvements in speed and connectivity, and accessibility in remote areas. One example is very small aperture terminal (VSAT) communication. A VSAT is a two-way satellite ground station operating at C-band and Ku-band frequencies, with linear and circular polarization in the C band and linear polarization in the Ku band. For the data transmitted by a satellite to be utilized by a user, the antenna on the user side must have dual-wideband and dual-polarization characteristics. In this study, a dual-polarization planar dual-wideband antenna with dimensions of 30 x 39 x 1.52 mm^3 was designed using a dual-port approach. The introduction of a slot and perturbation on the patch side results in the dual-wideband characteristics of the antenna. The introduction of slots into the antenna ground results in circular polarization. The proposed antenna has resonant frequencies of 3 - 15 GHz on port 1 and 3.31 – 7.79 GHz and 9.05 – 15 GHz on port 2, with circular polarization characteristics on port 1 and linear polarization characteristics on port 2. On port 1, the gains at frequencies of 4.2 GHz is 3.93 dB, while on port 2, the gains at frequencies of 3.9 GHz is 0.51 dB.**

***Keywords*— planar antenna; dual wideband; dual polarization**

I. Introduction

WITH the development of communication technology, wireless communication has become a fundamental requirement. This is because wireless communication offers many advantages, including lower costs, higher flexibility and convenience, continuing improvements in speed and connectivity, and accessibility in remote areas. Satellite communication technology is an example of wireless communication technology that is currently developing quite rapidly because it can enable users to connect with other users who are very far away and can even reach remote locations that are difficult to access with other communication technologies, such as cellular systems or terrestrial telephony. One type of satellite communication that is continuing to yield important developments at present is very small aperture terminal (VSAT) communication.

A VSAT is a two-way satellite ground station with a dish antenna of less than 3.8 meters in size. One example of a VSAT antenna that has been industrially produced [1] operates at C-band and Ku-band frequencies with two kinds of polarization (linear and circular) in the C band and linear polarization in the Ku band. This antenna receives data at frequencies of 3.625 - 4.2 GHz and 10.95 - 12.75 GHz in the C and Ku bands, respectively. Meanwhile, for transmitting data, the antenna works at frequencies of 5.85 - 6.425 GHz and 13.75 - 14.5 GHz in the C and Ku bands, respectively. For the data transmitted by a satellite to be utilized properly by users of a communication system, a user-side antenna that is capable of working in the VSAT antenna frequency ranges as specified above with dual-band and dual-polarization characteristics is needed. In this study, a planar antenna is used for this purpose. This design was chosen because planar antennas have the advantages of being low in profile, configurable in terms of the resonant and polarization frequencies, and easy to manufacture.

Several studies on planar antennas with more than one operating frequency and polarization have been previously conducted. Long [2] designed antennas for satellite communication and navigation systems in the L1 and L2 frequency ranges (1565 - 1626 MHz), with both left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP). RHCP and LHCP characteristics were obtained by using two isolated ports, while an increase in bandwidth was achieved by using parasitic patches. Mouffok [3] designed a dual-band antenna with polarization diversity operating at frequencies of 700 - 862 MHz and 2.5 - 2.69 GHz for multiple-input multiple-output (MIMO) Long Term Evolution (LTE) applications. In that study, polarization diversity was obtained through the orthogonal positioning of the designed antenna radiating elements. Xu et al. [4] developed an antenna design with 4 substrate layers for C-band and Ku-band operation. In this antenna, a tuning stub is attached to the feedline for expanded bandwidth and impedance matching, and a crossed dipole antenna is used for dual-polarization operation. The proposed antenna has vertical and horizontal polarization capabilities for both operating frequencies. Zhang [5] designed a dual-band antenna with linear and circular polarization. This antenna uses a meander slot for dual-band characteristics and a metallic via for achieving circular polarization. Circular polarization was obtained at a frequency of 2.45 GHz, while linear polarization was obtained at a frequency of 3.89 GHz. Osman [6] proposed an antenna design with a circular patch shape. On the x-axis and y-axis, the edges of the circle are each assigned 2 slots 90 degrees from each other, and in each slot, a switch is provided to achieve reconfigurable polarization characteristics. Depending on the active switch, the antenna will exhibit linear polarization, RHCP or LHCP. The antenna operates at frequencies of 2.4 - 2.6 GHz for circular polarization and 3.288 - 2.498 GHz for linear polarization. Lee [7] presented an antenna design with a complementary split-ring resonator

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A'isya Nur Aulia Yusuf and Fitri Yuli Zulkifli are with Universitas Indonesia (e-mail: aisya.nur@gmail.com, yuli@eng.ui.ac.id).

(CSRR). A PIN diode is placed in the outer slot of the CSRR. Circular polarization characteristics are obtained by turning the diode on and off. If the diode is on, the antenna polarization becomes RHCP, while if the diode is in the off state, the antenna polarization becomes linear. Raton [8] designed a patch antenna with configurable polarization. Polarization configurability is achieved by adjusting eight PIN diodes embedded in the antenna supply network. With this PIN diode arrangement, the antenna can provide linear polarization and RHCP. Although the designs of [7] and [8] are able to provide configurable polarization, the proposed antenna structures are quite complex, with large antenna dimensions. As an alternative to a CSRR, configurable polarization can also be achieved through adjustment of the states of a dual in-line package (DIP) switch and diode, as in the study by Chen et al. [9]. Antennas fitted with DIP switches and diodes can produce vertical and horizontal linear polarizations as well as RHCP and LHCP. Singh [10] proposed a double-layer multiband circularly polarized patch antenna that employed the slotted patch fed with proximity coupled feed having defected ground plane (DGS). The antenna has a bandwidth of 12.98%, 4.7%, 4.69%, and 5.39% at frequencies of 11.15 GHz, 4.17 GHz, 4.87 GHz, and 1.98 GHz, respectively. The proposed antenna also has 3 dB axial ratio bandwidth (ARBW) from frequency 10.289 – 11.285 GHz. Srivastava [11] introduced a dual-band integrated wideband multi resonating patch antenna operating at frequencies of 5.35 – 5.9 GHz and 13.35 – 15.35 GHz with simulated maximum gain of 3.6 dB and 6 dB, respectively. The antenna is fed by coaxial probe feed and uses rectangular patch with circular and linear slot to increase the number of resonant frequencies. According to the results, the antenna encompasses the C-, X- and Ku- band of electromagnetic spectrum.

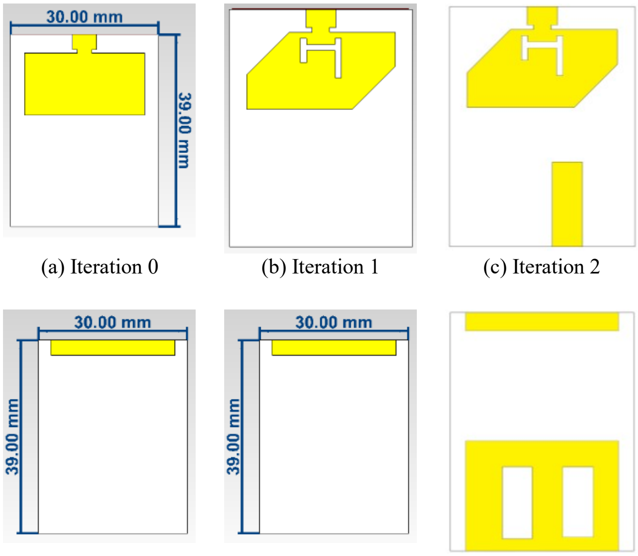
No previous research has proposed a planar antenna design with operating frequencies in the C band (3.625 - 4.2 GHz and 5.85 - 6.425 GHz) and Ku band (10.95 - 12.75 GHz and 13.75 - 14.5 GHz), with linear and circular polarization capabilities in the C band and linear polarization in the Ku band. Therefore, the current research focuses on the design of a planar dual-band dual-polarization antenna operating at C-band and Ku-band frequencies, with linear and circular polarization in the C band and linear polarization in the Ku band.

II. Antenna Design Method

The antenna is designed using a Taconic TLY-5 substrate with a substrate thickness of 1.52 mm and a relative permittivity of 2.2. In this study, a planar antenna with two ports is proposed. One port is intended for operation with linear polarization, while the other port is intended for operation with circular polarization.

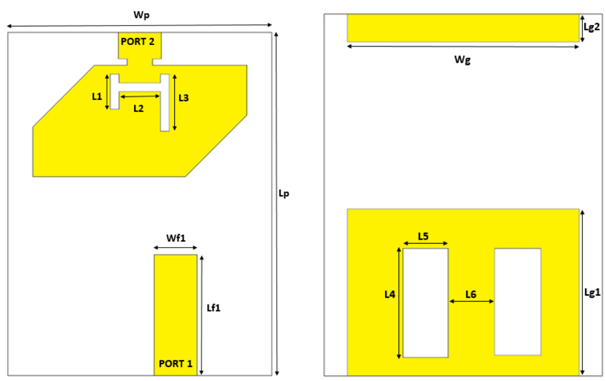
The antenna design process is carried out through several iterations. In iteration 0, the antenna is designed to have a rectangular patch with a stepped feed line (Fig. 1a), while the ground is a rectangular partial ground (Fig. 1d). In iteration 1 (Fig. 1b) pertubations were made on both sides of the existing diagonal patch, and slots were added to the patch. In addition to create circular polarization, pertubation is also used to widen the bandwidth at high frequencies. This is because when pertubated, there is a cutting of the patch so that there is a reduction in the patch area. While the slot serves to reduce the patch area so that the bandwidth at high frequencies is more optimal. The iteration 1 simulation results show that this port has fulfilled the resonant frequency in both C-band and Ku-band, and has linear polarization. Further iterations are needed to design antennas that operate at the same resonant frequency but have circular polarization in the C-band receiver and transmitter frequency ranges.

In iteration 2, the dual-port method is used to apply two types of polarization in the same frequency range because it is easy to fabricate and quite flexible when applied in real situations. The patch section is in the form of a vertical rectangular feedline (Figure 1c) and the ground section is partially designed with a rectangular shape that is given 2 vertical rectangular slots (Figure 1f). This method is carried out with the aim of achieving circular polarization in the C-band frequency range and having a wide resonant frequency and covering the specified frequency specifications. The simulation result of each iteration is shown in Table I.



(a) Iteration 0 (b) Iteration 1 (c) Iteration 2
(d) Iteration 0 (e) Iteration 1 (f) Iteration 2
Fig. 1. Iteration of patch (top) and ground (bottom) antenna designs

The proposed antenna design and dimensions are shown in Fig. 2 and Table II.



(a) (b)
Fig. 2. Design of the proposed antenna: (a) patch; (b) ground

TABLE I
SIMULATION RESULT OF EACH ITERATION

Simulation Result	Iteration 0	Iteration 1	Iteration 2
Frequency (GHz)	2.89 – 6.63	2.82 – 6.6 and 10.81 – 16	2.92 – 16 (port 1); 2.7 – 6.7 and 10.49 – 16 (port 2)
AR Bandwidth (GHz)	-	-	3.9 – 4.2 and 5.3 – 7.2 (port1)

TABLE II
DIMENSION OF THE PROPOSED ANTENNA DESIGN

Dimension	Value (mm)
Wp	30
Lp	39
Wf1	4.88
Lf1	13.75
L1	4
L2	4.7
L3	6.5
L4	11.75
L5	4.88
L6	5
Lg1	18
Lg2	3
Wg	25

III. SIMULATION AND MEASUREMENT RESULTS

With the antenna design shown in Fig. 2, the resulting axial ratio (AR) values can be seen in Fig. 3.

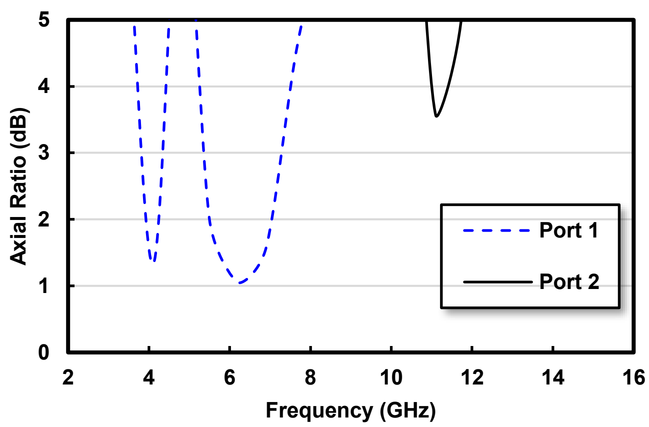


Fig. 3. Simulation results for the AR

As seen from Fig. 3, the proposed antenna design exhibits circular polarization with an AR value of ≤ 3 on port 1 (blue) at frequencies of 3.9 - 4.2 GHz and 5.3 - 7.2 GHz, whereas port 2 (black) does not have an AR of ≤ 3 throughout the entire frequency range. Thus, it can be determined that port 1 exhibits circular polarization in part of the C-band receiver frequency range and at all C-band transmitter frequencies, while port 2 exhibits linear polarization across the C-band and Ku-band frequencies. The aim of the next simulation is to determine the gain achieved by the antenna design proposed in this study. Table III shows the gain values for both ports at the center frequency of each specified frequency range.

TABLE III
SIMULATION RESULTS FOR ANTENNA GAIN

Frequency (GHz)	Gain of port 1 (dB)	Gain of port 2 (dB)
3.9	3.982	-0.131
6.13	5.112	1.128
11.8	6.026	4.117
14.12	6.764	4.837

According to the simulation results, at the center frequency of the C-band receiver range, 3.9 GHz, ports 1 and 2 have gains of 3.982 dB and -0.131 dB, respectively; at the center frequency of the C-band transmitter range, 6.13 GHz, ports 1 and 2 have gains of 5.112 dB and 1.128 dB, respectively; at the center frequency of the Ku-band receiver range, 11.8 GHz, ports 1 and 2 have gains of 6.026 dB and 4.117 dB, respectively; and at the center frequency of the Ku-band transmitter range, 14.12 GHz, ports 1 and 2 have gains of 6.764 dB and 4.837 dB, respectively. The simulation results for the gains on port 1 are all positive, and in accordance with gain theory, the greater the operating frequency is, the greater the gain. However, the port 2 gain values in the C-band frequency range tend to be low and even negative. This is probably due to the high isolation (more than -20 dB) between the two ports in that frequency range. The aim of the next simulation is to determine the efficiency achieved by the antenna design proposed in this study. The total antenna efficiency graph is shown in Fig. 4.

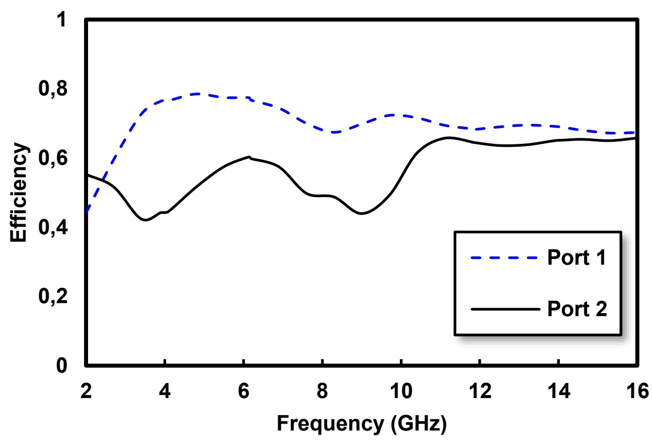


Fig. 4. Simulation results for antenna efficiency

The efficiency values vary over the antenna's resonant frequency range. The highest efficiency on port 1 is observed at a frequency of 4.79 GHz, with a value of 0.78 (approximately 78%), whereas on port 2, the highest efficiency is observed at a frequency of 11.1 GHz, with a value of 0.65 (approximately 65%). The efficiency in the C-band frequency tends to be significantly higher on port 1 than port 2, possibly because the isolation between the two ports at C-band frequencies is quite high (more than -20 dB) and because in the antenna design, the ground for port 1 is close to the patch for port 2 and therefore affects the antenna radiation at port 2.

The designed antenna was fabricated using a Taconic TLY-5 substrate with a substrate thickness of 1.52 mm, a patch thickness of 0.035 mm, and substrate dimensions of 30 mm x 39 mm. The antenna has two connector ports; on the patch side, port 1 has a rectangular feed line and is located at the bottom of the antenna, while port 2 has a rectangular patch with a slot and a perturbation introduced by cutting away two corners of the patch to create two diagonal sides and is located at the top of the antenna. The ground layer for port 1 is a rectangle measuring 25 mm x 28 mm, into which two vertical rectangular slots are cut, while ground port 2 is rectangular with dimensions of 25 mm x 3 mm. The fabricated antenna is shown in Fig. 5.

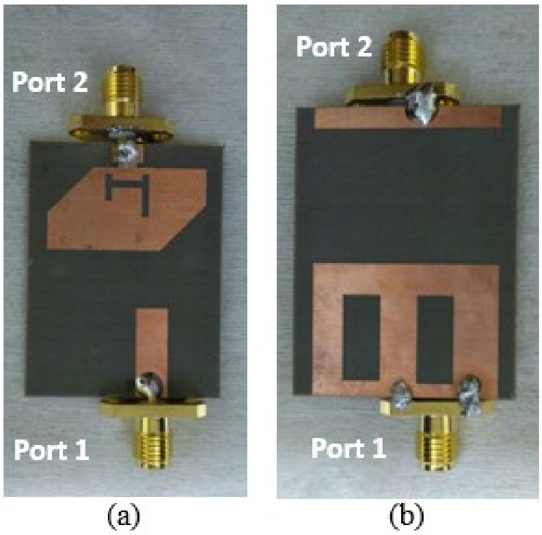


Fig. 5. Antenna fabrication results: (a) patch; (b) ground

Return loss measurement was performed for each port by connecting the antenna to port 1 of a network analyzer. A comparison of the measured and simulated return losses for port 1 is shown in Fig. 6.

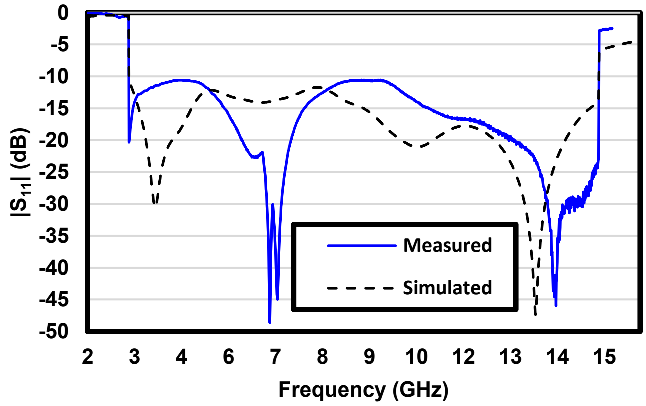


Fig. 6. Simulated and measured return losses at port 1

From the plot of the measurement results, it can be seen that the return loss is approximately -10 dB at frequencies of 3 – 15 GHz. These frequency specifications indicate that the measured antenna can operate at C-band and Ku-band frequencies. The simulation results indicate that the antenna also have a return loss value below -10 dB at frequencies of 3 – 15 GHz. Thus, the antenna simulation and measurement results show ultrawideband characteristics with a bandwidth of more than 10 GHz. Meanwhile, a comparison of the measured and simulated return losses for port 2 is shown in Fig. 7.

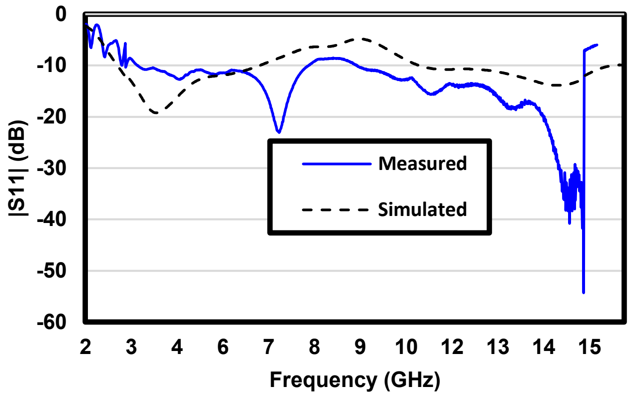


Fig. 7. Simulated and measured return losses at port 2

As seen from the plot of the port 2 measurement results, the return loss is approximately -10 dB at frequencies of 3.31 – 7.79 GHz and 9.05 – 15 GHz. These frequency specifications indicate that the measured antenna can operate at C-band and Ku-band frequencies. The simulation results indicate that the antenna should have dual-wideband characteristics with a return loss value below -10 dB at frequencies of 2.7 - 6.5 GHz and 10.67 - 13.5 GHz. Similar to the simulation results, the measurement results also show dual-band characteristics; however, the operating frequencies are shifted. This shift may be caused by several factors, such as a level of port matching that is not exactly equivalent to 50 ohms, the placement of the connector, or nonoptimality of the calibration process at high frequencies. A comparison of the measured and simulated port isolation results is shown in Fig. 8.

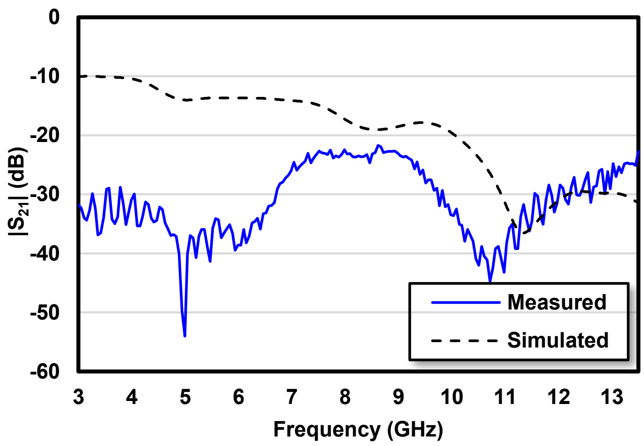


Fig. 8. Simulated and measured return losses for port isolation

An isolation value of -20 dB is used as the threshold to determine the performance of the fabricated antenna. As seen from the plot of the measurement results, the isolation is below -20 dB at frequencies of 3 - 13.5 GHz. This indicates that ports 1 and 2 of the fabricated antenna do not affect each other throughout the measured frequency range. The simulation results indicate that the antenna should have an isolation value below -20 dB only over a frequency range of 10.1 - 13.5 GHz, corresponding to good isolation at Ku-band frequencies. This is probably because the antenna design for port 2 has a smaller ground than that for port 1, thus allowing the isolation between the ports to be below -20 dB. The difference between the measured and simulated results is attributed to nonoptimality in the connector installation and calibration processes, causing the measured values to deviate from the simulated values.

Radiation pattern and gain measurements for port 1 were carried out at frequencies of 4.2 GHz. The results of measurements and simulations of the E- and H-plane fields at 4.2 GHz are shown in Fig. 9.

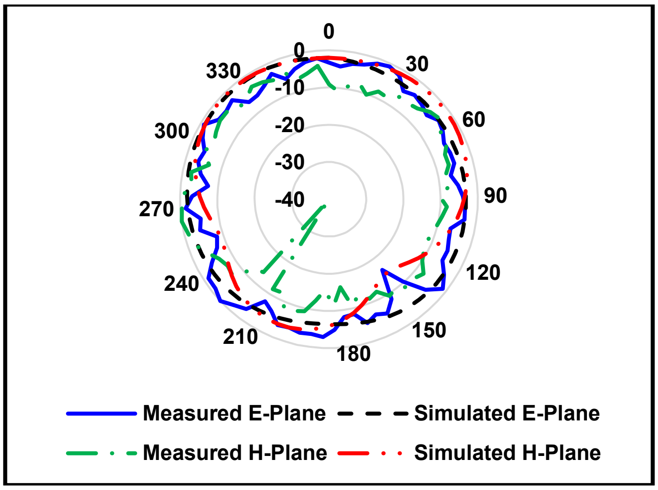


Fig. 9. Simulated and measured E-plane and H-plane fields for port 1 at 4.2 GHz

The radiation pattern for phi = 0 at a frequency of 4.2 GHz tends to spread out in all directions and is approximately circular, although not perfectly. The same is seen for phi = 90, where the antenna also radiates in all directions. From the simulation and measurement results, it can be seen that on port 1, the antenna has a characteristic omnidirectional radiation pattern at a frequency of 4.2 GHz.

The radiation pattern and gain at port 2 were measured at frequencies of 3.9 GHz. The results of measurements and simulations of the E- and H-plane fields at a frequency of 3.9 GHz are shown in Fig. 10.

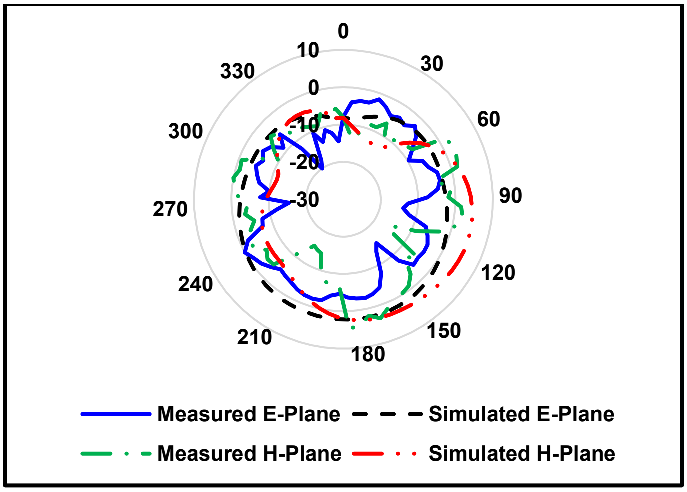


Fig. 10. Simulated and measured E-plane and H-plane fields for port 2 at 3.9 GHz

The radiation patterns measured at a frequency of 3.9 GHz with values of both phi = 0 and phi = 90 indicate that the antenna radiates in all directions with an almost circular shape. From these measurements, it can be seen that on port 2, the antenna has a characteristic omnidirectional radiation pattern at 3.9 GHz.

In this study, the circular polarization characteristics at port 1 were observed from the highest gain values generated in each polarization test for the E- and H-plane fields. In the RHCP test, the highest gain produced by port 1 at a frequency of 4.2 GHz was 3.93 dB. These values are not much different from the simulation results, where at frequencies of 4.2 GHz, the resulting gain values are 4.06 dB. From the test results, it can be seen that on port 1, the antenna has circular polarization characteristics (RHCP) consistent with the simulation results. By contrast, on port 2, no testing was conducted to determine the polarization characteristics. Instead, testing on port 2 was carried out to determine the highest gain value generated at the center frequency of each frequency range. At frequencies of 3.9 GHz, the maximum measured gain values were 0.51 dB. These values are not much different from the simulation results, where at these three frequency points, the resulting gain values are 0.4 dB.

Conclusion

Based on the reported results of antenna design, fabrication, and measurement, it can be concluded that according to simulations, the proposed antenna design has resonant frequencies of 2.92 - 16 GHz on port 1 and 2.7 - 6.7 GHz and 10.49 - 16 GHz on port 2. The simulations show that the proposed antenna has circular polarization characteristics on port 1 and linear polarization characteristics on port 2. In measurements, the proposed antenna design was found to have resonant frequencies of 3.75 - 4.68 GHz and 5.6 - 9.3 GHz on port 1 and 3.13 - 5.72 GHz and 10.41 - 12.29 GHz on port 2. Judging by the measured polarization gains, the antenna has circular polarization characteristics (RHCP) on port 1. On port 1, the gains at frequencies of 4.2 GHz and 6.2 GHz were measured to be 3.4 dB and 4.5 dB, respectively, while simulations indicate values of 4.06 dB and 5.15 dB, respectively. On port 2, the gains at frequencies of 3.9 GHz, 6.13 GHz, and 11.8 GHz were measured to be 2.12 dB, 2.52 dB, and 6.13 dB, respectively, while simulations indicate values of 0.4 dB, 1.21 dB, and 4.17 dB, respectively. Compared to previous studies, the proposed antenna design has the advantages of smaller dimensions (30 mm x 39 mm x 1.52 mm) and a more compact and simpler design (using only 1 substrate layer), making it easier to fabricate.

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