Chapter

Bi-Ellipse Microstripline Antenna Array Varians

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Abstract

The objectives of this research include obtaining and verifying the impedance formula of the designed *bi-ellipse* microstrip antenna and correlating the results obtained through simulation and experimentation. The research also aims to obtain the structure and dimensions that provide optimal characteristics of the designed *bi-ellipse* microstrip antenna and produce a prototype at S, C and X-Band frequencies. This research produced the structure and dimensions of a *bi-ellipse* microstrip antenna that provide optimal characteristics of antenna. The characteristics results of the antenna parameters in this research include a 8x2 array, with a bandwidth value of around 100.0 MHz obtained at a working frequency of 7.09GHz (7.04 GHz - 7.14 GHz), with a reflection coefficient value of 0.02, Voltage Standing Wave Ratio (VSWR) of 1.06, return loss of −30.00 dB and a gain of 7.30 dB. For the 8x4 array, a bandwidth value of approximately 210.0 MHz is obtained at a working frequency range of 2.85GHz, which ranges from 2.74GHz - 2.95GHz, with a reflection coefficient value of 0.04, Voltage Standing Wave Ratio (VSWR) of 1.09, return loss of −27.06 dB and a gain of 8.19 dB. The results presented above fulfill the indicators of good antenna characteristics parameters applicable to radar communication systems.

Keywords: Microstrip Antenna, Array, *Bi-Ellipse*, Impedance Formula, Radar

1. Introduction

Electromagnetic field theory is essential in designing and analyzing the shape and size of the antenna. In general, the electromagnetic fields generated depend on the distance of the source access and terrain. The further course of electromagnetic fields affects the spread process from the transmitter to the receiver, weakening the signals. Therefore, the required antenna design with specific dimensions, such as a high gain value and significant directivity with return loss is minimal. Various studies have been conducted on microstrip antenna. In this research, a new type of antenna is design with an nxn array bi-ellipse microstrip. This is an antenna type microstrip with various characteristics, including a thin cross-section, lightweight mass, simple to make, and can be easily integrated with Microwave Integrated Circuits (MICs) made in multifrequency.

In this research, the nxn array bi-ellipse microstrip antenna is developed in multiband frequency for satellite communication. The optimization of the width feeding stripline is meant to enhance the performance of the antenna. The proposed nxn array bi-ellipse microstrip antenna operates in multiband frequency. It targets the multiband frequency, reflection coefficient less than 1, Voltage Standing Wave Ratio (VSWR) less than 2, and gain more than 5 dB.

Numerous studies have been conducted on a wide variety of designs and shapes of microstrip antenna by providing slots, patches, and adding several arrays. The use of a slot can increase bandwidth. This is because smaller widths increase the bandwidth, number of arrays, and antenna gain [1–3]. According to previous studies, the antenna's array is used to direct radiated power toward a desired angular sector. The number, geometrical arrangement, relative amplitudes, and phases of the array element depend on the angular pattern that needs to be achieved.

Other research used a flexible, compact antenna array operating at a frequency of 3.2-13GHz, which covers the standard Ultra-Wide Band (UWB). The design aimed to integrate Multiple Input Multiple Output (MIMO) based flexible electronics for Internet of Things (IoT) applications. The proposed antenna is printed on a single side of a 50.8 μm Kapton Polyimide substrate, which consists of two half-elliptical shaped radiating elements fed by two Coplanar Waveguide (CPW) structures. The simulated and measured results showed that the proposed antenna array achieves a broad impedance bandwidth with reasonable isolation performance of S_{12} < -23 dB [4]. Furthermore, it exhibits a low susceptibility to performance degradation due to the effect of bending. The system's isolation performance, along with its flexible and thin profile, suggests that the proposed antenna is suitable for integration within the flexible Internet of Things (IoT) and wireless systems. The research conducted by indicates good performance in antenna design. However, the application is limited to the wireless communication system. A related study on a novel S-band right-handed circularly polarized (RHCP) slot antenna for supporting the communication system of GAIA II/LAPAN-Chibasat was conducted [5, 6]. This satellite implemented the L-band Circularly Polarized Synthetic Aperture Radar (CP-SAR) sensor, with an X-band antenna employed for mission data downlink and S-band antenna for the command and telemetry. The S-band antenna is printed on the substrate with a relative permittivity of 2.17 and a thickness of 1.6 mm. A crescent-shaped slot is placed on the ground plane to strengthen the radiation on the edge of the feed-line. Furthermore, a parasitic strip rectangular-shaped is added on the ground plane to enhance the antenna. The truncation technique is employed to increase the axial bandwidth ratio (ARBW) and the gain [4, 7, 8]. The total dimension of the antenna is 170 mm × 170 mm. This research's weakness is the bandwidth produced, which is less than 3 dB and return loss below −10 dB. Also, the substrate used in designing the antenna is challenging to determine. The research shows the design and development of an X-band microstrip patch planar array antenna with high gain and low sidelobes. The radiating patches are fed using a thin, grounded substrate microstrip distribution network with a common geometry. All the 512 array elements are fed using a direct feeding technique by utilizing a thin copper wire soldered at the patch and feed network ends. The array operates in the 10.1-10.5GHz frequency band with a 2:1 VSWR. Furthermore, the high gains were above 30.5dBi with sidelobe levels better than -23 dB in both planes. The antenna application was found in the medium-range radar systems operating at X-band frequency [9, 10]. This research also acts as references used to increase the gain of the antenna and other applications designed within the radar band frequency range. The bi-ellipse microstrip antenna array variants are designed to optimize antenna characteristics capable of supporting the radar application system.

2. Theories

2.1 Microstrip antenna

Microstrip antennas are electrically thin, lightweight, comfortable, low cost, easily fabricated and can be connected to Microwave Integrated Circuits (MICs) at various frequencies [11]. There are various types of microstrip antenna designs on the taper section. There is a rectangular, circular, triangle shape according to the empirical analysis of antenna design. The design of the antennas varies with the single side and the double side. This study designed bi-ellipse microstripline antenna with 8x2 and 8x4 array, to produce greater gain so that it could be more optimally applied to radar communication systems.

2.2 Array factor

Microstrip antennas arranged in Array are not only useful for widening bandwidth but also have an impact on the radiation pattern produced. The radiation pattern in the Antenna is generally written with the equation:

$R\ (\theta, \varnothing)$ with i element in the position of $r_i = (x_i, y_i, Z_i)$

The relationship with the wave emitted from the antenna array (Y) with the multiplier of complex numbers (w_i) in the function (θ, ∅), is obtained:

$$Y = R\ (\theta, \varnothing) w_1 e^{-j\ k.r_1} + R\ (\theta, \varnothing) w_2 e^{-j\ k.r_2} +\ \ldots R(\theta, \varnothing) w_N e^{-j\ k\ r_N}$$

With k is the wave vector in the incoming wave.

Next can be written:

$$Y = R\ (\theta, \varnothing) \sum_{i=1}^{N} w_i e^{-j\ k.r_i}$$

$$Y = (\theta, \varnothing)\ AF$$

$$; AF = \sum_{i=1}^{N} w_i e^{-j\ k.r_i}$$

AF = Array Factor (as an Antenna position function) [11].

2.3 Antenna design and optimization

In principle, the microstrip antenna has a characteristic narrow bandwidth. It has several advantages, including a thin, small, light in weight, and can be applied to the Microwave Integrated Circuit (MICs). The bandwidth can be widened using the array technique or by a panel system [11–16]. The panel systems (engineering array) involve strengthening (gain) of an antenna. In contrast, the rationing array technique is commonly used microstrip line. Graphically, microstrip antenna design is shown in **Figure 1**.

2.3.1 Empirical analysis and design

Figure 2 shows the microstrip antenna design dimensions.

The following **Table 1** is a dimension parameter of the antenna design:

Antenna arrangement with a transmission line. In the transmission line length l equivalent circuit is described as follows (**Figure 3**):

The first calculation involves finding the total electricity permittivity (ε_{rtot}) using the capacitor equation as follows.

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{\varepsilon_o\,\varepsilon_{rtot}\,A/d\,tot} = \frac{1}{\varepsilon_o\,\varepsilon_{r_1}\,A_1/d_1} + \frac{1}{\varepsilon_o\,\varepsilon_{r_2}\,A_2/d_2} \tag{1}$$

where ε_{r1} is ε_r for air ($\varepsilon_{r1} = 1$), ε_{r2} is ε_r for substrate (ε_r FR_4 = 4.3), d_1 the thickness of the substrate and d_2 distance of substrate to the reflector, with d tot, is $d_1 + d_2$ [12].

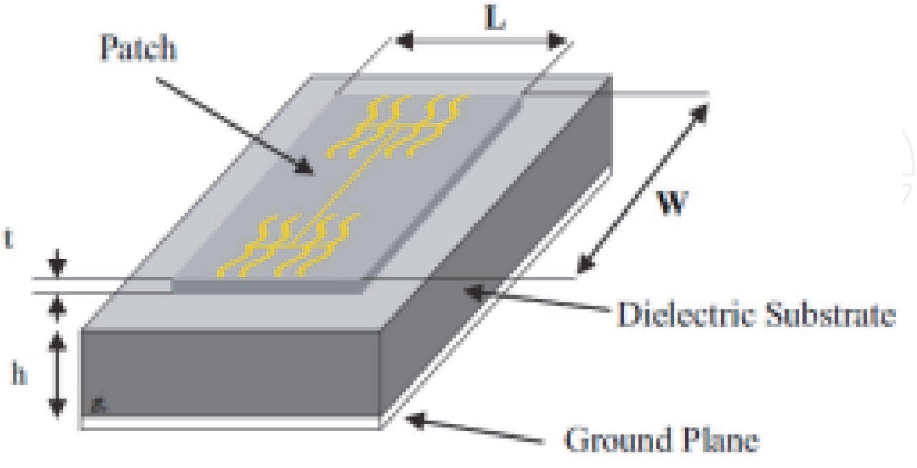


Figure 1.
Microstrip antenna design.

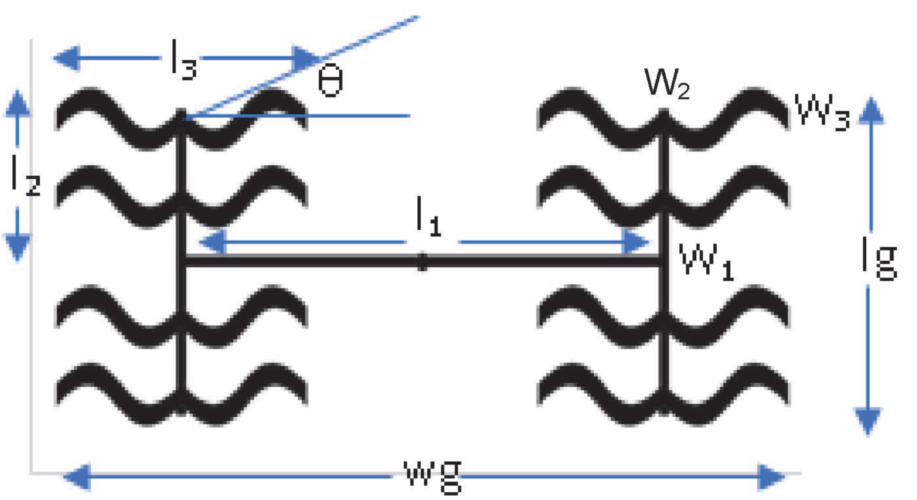


Figure 2.
The bi-ellipse microstrip antenna design dimensions.

Parameters	Dimension	Description
Wg	100	Width
Lg	50	Length
l_1	30 mm	Length of feeding stripline
$l_2 = l_3$	15 mm	Length of curve stripline
$w_1 = w_2$	1 mm	Width of stripline
w_3	2 mm	Width of curve stripline
θ	30°	Gradient in curve line

Table 1.
Dimension parameter of the Bi-ellipse Microstripline Array antenna design.

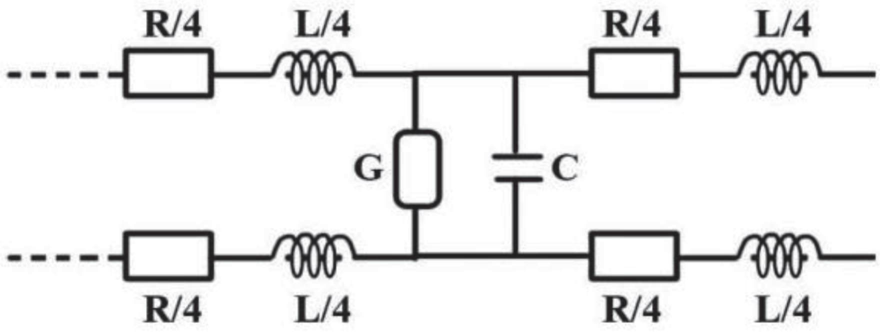


Figure 3.
Equivalent circuits in transmission lines [12].

A capacitor equation is used in this empirical analysis because, in principle, this is a device that stores electrical energy in an electric field. The capacitor made of two parallel conducting plates separated by a dielectric that is a parallel plate capacitor. When a battery is connected across the capacitor, one plate gets attached to the positive end and another to the negative. The potential of the battery is then applied across that capacitor. In this case, plate one is in positive potency with respect to plate two. At steady-state conditions, the current tries to flow from the battery through the capacitor from its positive to the negative plate unsuccessfully. This is because of the two separation of these plates with an insulating material. This is in line with the microstrip work principal in specific dielectric substrates.

To calculate the effective permittivity electricity (ε_{eff}), the following equation is used:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 10\frac{h}{w}\right)^{-0.555} \tag{2}$$

Where ε_r is the same with εr_{tot}, h is d_{tot}, and w is the width for patch and strip line side [11, 12].

Permittivity is a material property that affects the Coulomb force between two points charges.

The following equation is used to determine the maximum dimension in the patch side (w_1):

$$\mathrm{f} = \frac{2\mathrm{c}}{3\mathrm{w}\sqrt{\varepsilon_r}}$$

$$w_1 = \frac{2\mathrm{c}}{3\sqrt{\varepsilon_r}\,\mathrm{f}} \tag{3}$$

where c is lightspeed in air, ε_r is electricity permittivity, and f is frequency [12].

To calculate the effective width strip line side ($w_{2,3}$), the following formula is used.

$$\mathrm{W}_{2,3} = \frac{1}{2\mathrm{f}\sqrt{\mu_0 . Z_o}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{4}$$

Where f is frequency, μo is permeability constant, and Zo is characteristic impedance [12].

Permeability is derived from a magnetic field's production by an electric current or charge and all other formulas for the magnetic field produced in a vacuum.

The calculation wavelength of the substrate (λg), uses the following equation:

$$\lambda g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} \tag{5}$$

From the analysis above formula (1)–(5), the parameters for antenna fabrication can be fixed [11–13].

2.3.2 Simulation

The simulations were created using Finite different Time Domain (FDTD) method. The selection method of fabrication was essential to optimize the results, which reflect the optimal parameters generated as characteristic of the designed antenna. The numerical analysis of nxn array double bi-ellipse microstrip antenna design involves Preparation, Reader Review, Determination of the substrate and the dimensions of the antenna, and analyzing the empirical formula antenna design numerically, characterizing outcome parameters microstrip antenna through data analysis and calculations. Fabrication is carried out using the FR_4 material substrate with a UV photoresist laminate technique.

2.3.3 Fabrication

Bi-Ellipse microstripline array varians antenna prototype was fabricated by UV photoresist laminate. In our work, the antenna prototypes are fabricated on Flame Retardant 4 (FR_4) material with 4.3 dielectric constant. The first step in the fabrication process is to generate the photo mask artwork by printing on stabline or rubylith negative film of the desired geometry on butter sheet. Using the precision cutting blade of a manually operated co-ordino graph the opaque layer of the stabiline or rubylith film is cut to the proper geometry and can be removed to produce either a positive or negative film representation of the antenna sketches. The design dimensions and tolerances are verified on a cordax measuring instrument using optical scanning. Enlarged artwork should be photo reduced using a high precession camera to produce high resolution negative, which is later used for exposing the photo resist. The photographic negative must be now held in very close contact with the polyethylene cover sheet of the applied photo resist using a vacuum frame copy board or other technique, to assure the fine line resolution required. With exposure to proper wavelength of light, polymerization of the

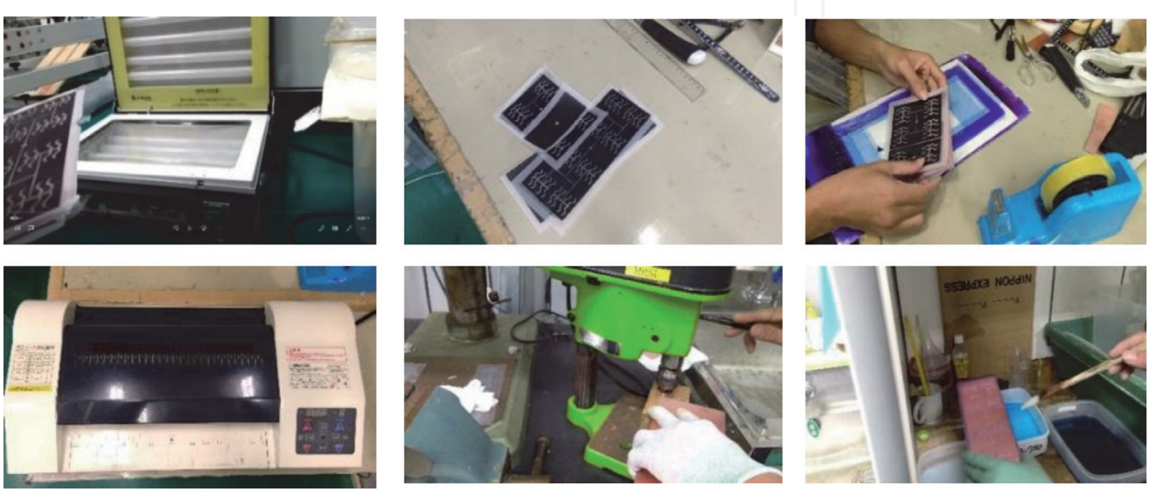
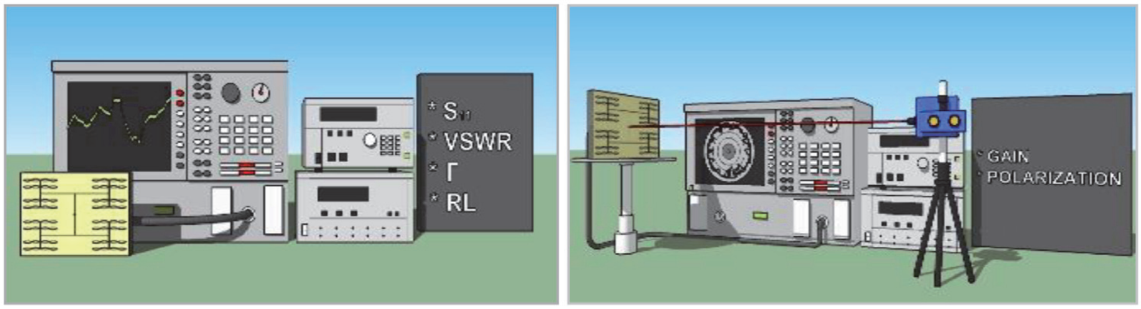
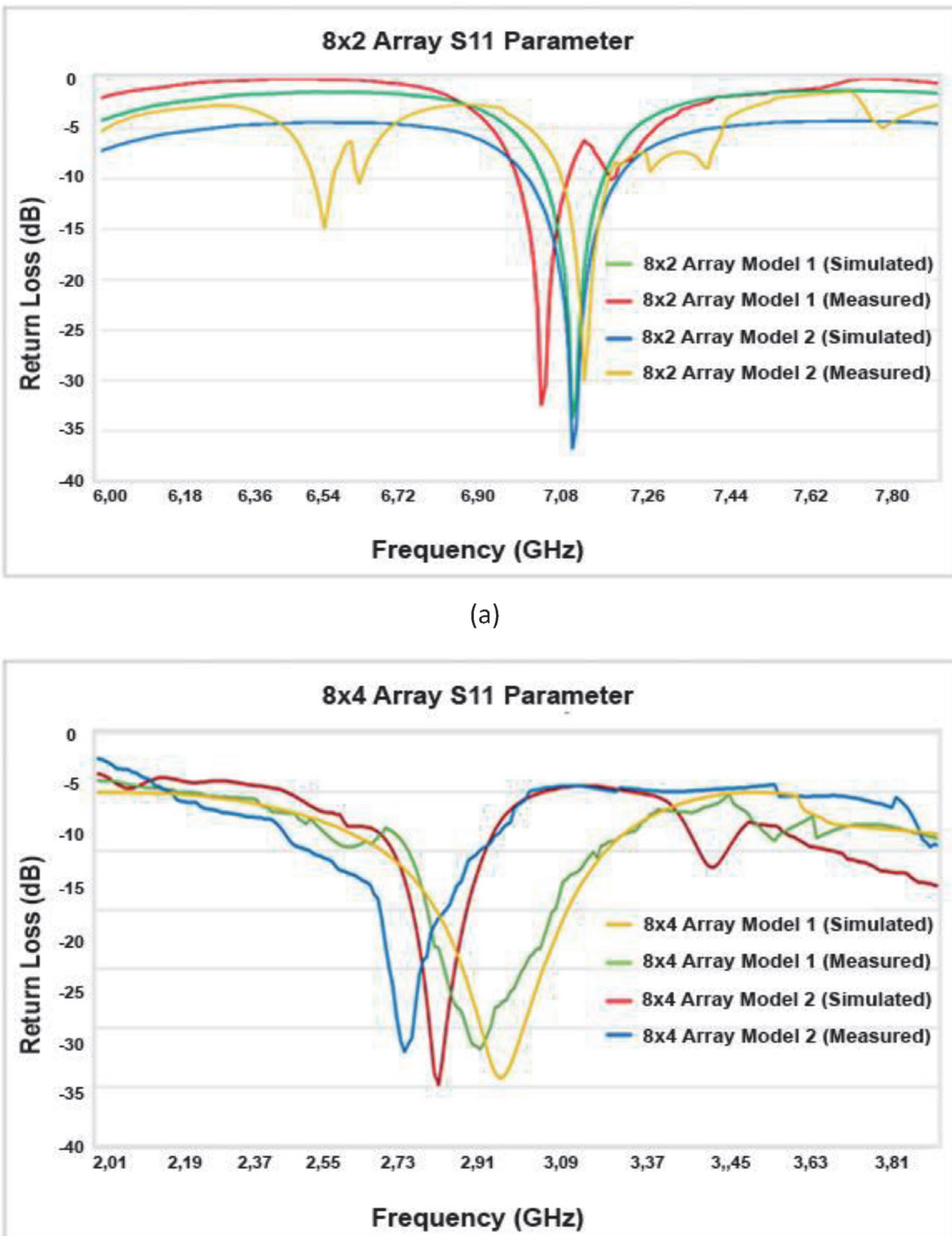


Figure 4.
Fabrication process.



(a) (b)

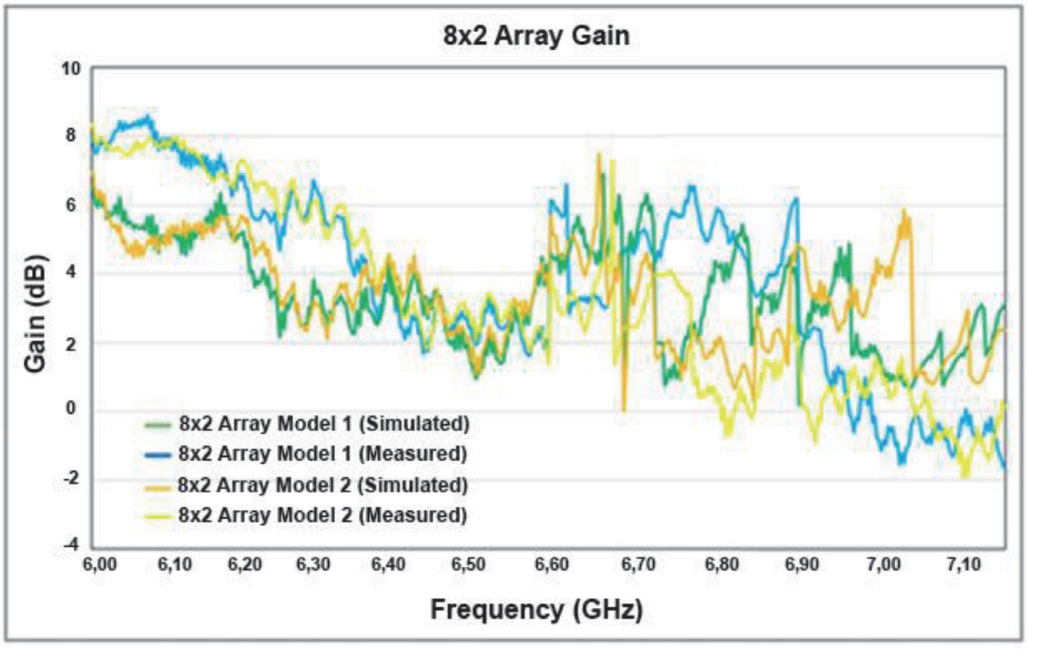
Figure 5.
Measuring process in the laboratory using (a) network analyzer and (b) in the chamber.



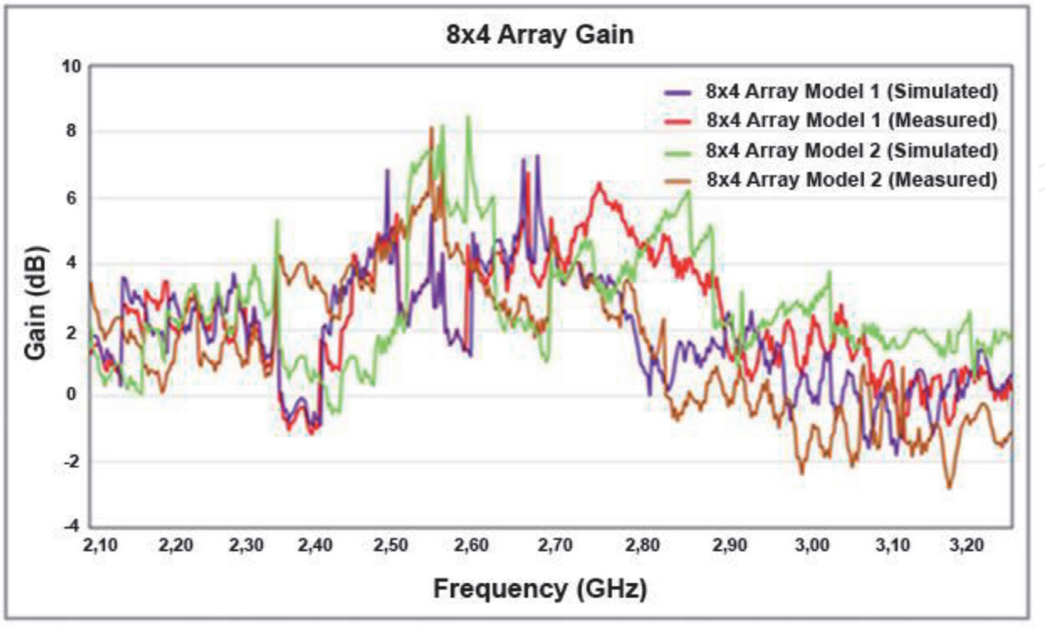
(b)

Figure 6.
(a) S_{11} parameter graph of the simulation and measurement results in the 8x2 array variant of bi-ellipse *microstrip antenna, (b) S_{11} parameter graph of the simulation and measurement result in the 8x4 array variant of* bi-ellipse *microstrip antenna.*

exposed photo resist occurs making it insoluble in the developer solution. Now, it is then coated with a negative photo resist and exposed to UV-radiation and it is immersed in developer solution up to two minutes through the mask. The exposed photo resist hardens and those in the unexposed areas are washed off using a developer. The unwanted copper portions are now removed using Ferric Chloride ($FeCl_3$) solution. $FeCl_3$ dissolves the copper coating on the laminate except which is underneath the hardened photo resist layer after few minutes. Finally, the laminate is then washed with water and cleaned in acetone solution to remove the hardened negative photo resist. The fabrication process has shown in the following **Figure 4**.



(a)



(b)

Figure 7.
(a) Gain graph of the simulation and measurement results in the 8x2 array variant of bi-ellipse *microstrip antenna. (b) Gain graph of the simulation and measurement results in the 8x4 array variant of* bi-ellipse *microstrip antenna.*

3. Result and discussion

The data of the antenna design is obtained using a network analyzer in the chamber. To compare the simulation results, the antenna is measured using Network Analyzer. This is meant to determine the antenna design characteristics, including S_{11} Parameter, Bandwidth, VSWR, coefficient reflection, and return loss. The chamber in the laboratory is used to determine the gain and polarization pattern. An experimental schematic diagram in the laboratory is shown in **Figure 5**.

The **Figures 6** and **7** show the comparison between simulation and measurement results of the antenna S_{11}-parameters and gain for 2x2 and 2x4 array models, respectively.

In the simulation, 8x2 array *bi-ellipse* microstrip antenna “model 1” work in 7.12 GHz frequency with a bandwidth range of approximately 90.0 MHz (7.07GHz-7.16GHz). The simulation result shows that the antenna works well within the design frequency range. This shows that it is effective in the bandwidth and antenna performance and can be applied in communication, especially in the C-Band frequency range. The simulation shown in the S_{11} parameter has a reflection coefficient 0.02, VSWR 1.04, return loss −33.75 dB, and 6.90 dB gain. In measurement, 8x2 array *bi-ellipse* microstrip antenna “model 1” works in 7.04 GHz frequency with bandwidth range of approximately 60.0 MHz (7.01GHz-7.07GHz), reflection coefficient 0.02, VSWR 1.05, return loss −32.43 dB and 6.61 dB Gain. The simulation 8x2 array *bi-ellipse* microstrip antenna “model 2” works in 7.11 GHz frequency with a bandwidth range of approximately 110.0 MHz (7.06GHz-7.17GHz). The simulation shown in the S_{11} parameter includes a reflection coefficient 0.01, VSWR 1.03, return loss −36.74 dB, and 7.49 dB Gain. In measurement 8x2, array *bi-ellipse* microstrip antenna “model 2” works in 7.14 GHz frequency with bandwidth range approximately of 60.0 MHz (7.11GHz-7.17GHz), reflection coefficient 0.03, VSWR 1.06, return loss −30.00 dB and 7.30 dB Gain.

Parameters	fc (GHz)	RL (dB)	VSWR	Γ	Gain (dB)
8x2 array bi-ellipse microstrip antenna					
Model 1					
Simulated	7.12	−33.75	1.04	0.02	6.90
Measured	7.04	−32.43	1.05	0.02	6.61
Model 2					
Simulated	7.11	−36.74	1.03	0.01	7.49
Measured	7.14	−30.00	1.06	0.03	7.30
8x4 array bi-ellipse microstrip antenna					
Model 1					
Simulated	2.97	−29.23	1.07	0.03	7.28
Measured	2.95	−27.01	1.09	0.04	6.75
Model 2					
Simulated	2.82	−29.83	1.07	0.03	8.46
Measured	2.74	−27.06	1.09	0.04	8.19

Table 2.
The comparison between simulated and measured of nxn array bi-ellipse microstrip antenna.

In the simulation, an 8x4 array *bi-ellipse* microstrip antenna "model 1" works in 2.97 GHz frequency with a bandwidth range of approximately 300.0 MHz (2.82GHz-3.12GHz). The simulation result shows that the antenna works well

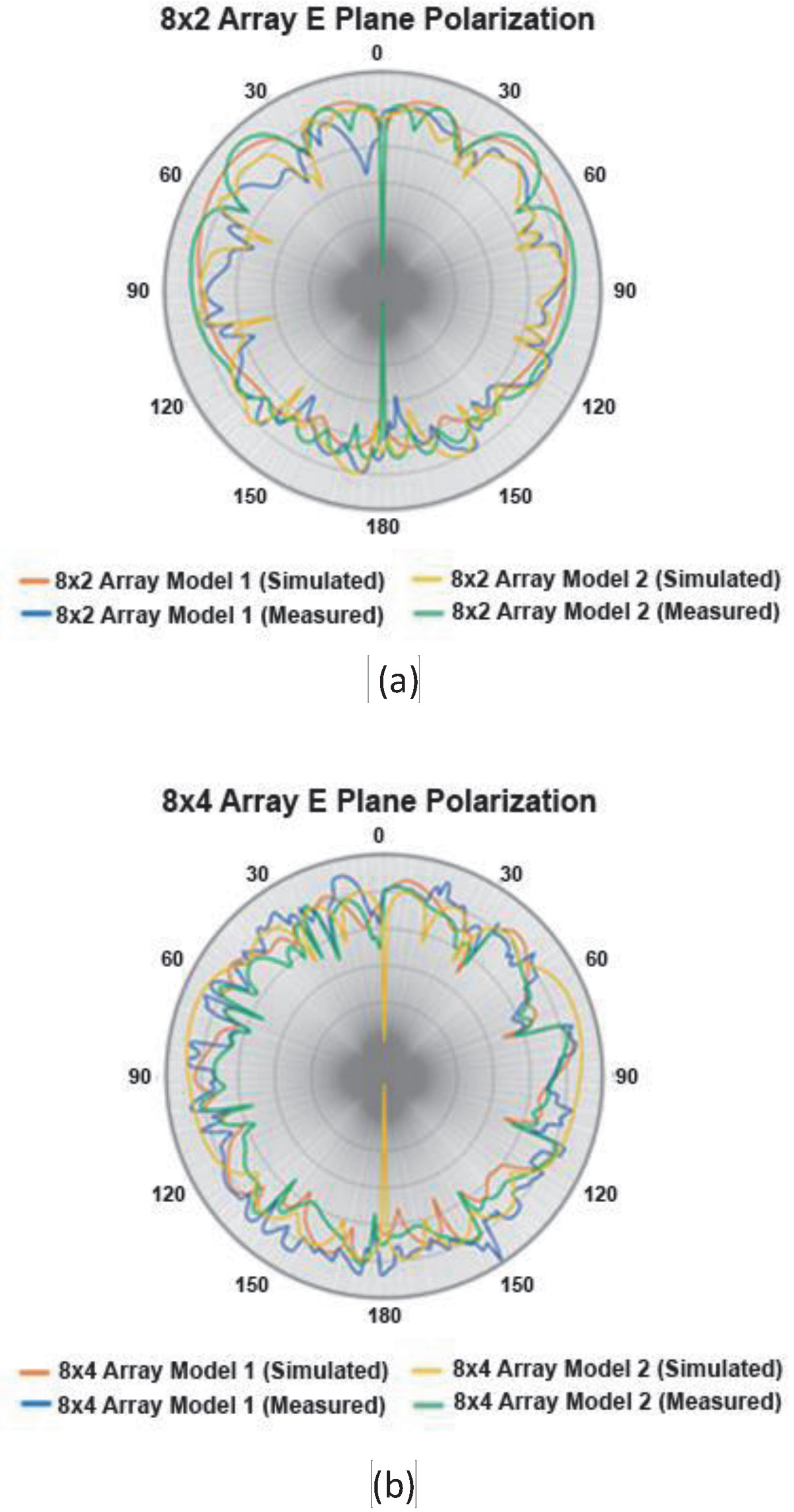


Figure 8.
(a). The E plane polarization of the 8x2 array bi-ellipse microstrip antenna. (b). The E plane polarization of the 8x4 array bi-ellipse *microstrip antenna.*

within the design frequency range. This indicates that the 8x4 array *bi-ellipse* microstrip antenna “model 1” is effective in bandwidth and antenna performance. Therefore, it can be applied in communication, especially in the S-Band frequency range. The simulation shown in the S_{11} parameter includes a reflection coefficient 0.03, VSWR 1.07, return loss −29.23 dB, and 7.28 dB Gain. In measurement, 8x4 array *bi-ellipse* microstrip antenna “model 1” works in 2.95 GHz frequency with bandwidth range of approximately 280.0 MHz (2.81GHz-3.09GHz), reflection coefficient 0.04, VSWR 1.09, return loss −27.01 dB and 6.75 dB Gain. In the simulation, 8x4 array *bi-ellipse* microstrip antenna “model 2” work in 2.82 GHz frequency with a bandwidth range approximately 120.0 MHz (2.76GHz-2.88GHz). The simulation shown in the S_{11} parameter includes a reflection coefficient 0.03, VSWR 1.07, return loss −29.83 dB, and 8.46 dB Gain. In the measurement, 8x4 array *bi-ellipse* microstrip antenna “model 2” works in 2.74 GHz frequency with bandwidth range approximately 150.0 MHz (2.68GHz-2.83GHz), reflection coefficient 0.04, VSWR 1.09, return loss −27.06 dB and 8.19 dB Gain.

The following **Table 2** summarizes the results of the proposed antenna.

The polarization and radiation pattern in the nxn array double bi-ellipse microstrip antenna design is linear and omnidirectional radiation pattern. The performance-based on polarization is presented in **Figure 8**.

This research indicates that the *bi-ellipse* microstrip antenna designed has several characteristics, including reflection coefficient < 1, voltage standing wave ratio ≤ 2, and return loss > -15 dB. Gain >5 dB, axial ratio, and radiation pattern are good indicator parameters that can be applied in satellite communications, especially in radar applications.

4. Conclusions

This study aims to design a bi-ellipse Microstripline Antenna Array consisting of more optimal characteristics parameters. The empirical formula and numeric analysis were optimally applied to the satellite communication system in relation to the antenna’s characteristics. The analysis result showed that a 8x2 array bi-ellipse microstripline antenna parameter obtained, comprises of 1.06 VSWR, 0.02 Reflection Coefficient, and − 30.00 dB Return Loss. Also, a 8x4 array, consists of 1.09 VSWR, 0.04 Reflection Coefficient, and − 27.06 dB Return Loss. These two simulations and measurement are compared to design a *bi-ellipse* Microstripline Antenna Array with more optimal characteristics parameters that are fabricated and applied to obtain a better satellite communication system.

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Conflict of interest

“The authors declare no conflict of interest.”

Appendices and Nomenclature

R	Barriers [ohm]
β	Betha [−]
C	Capacitance [Farad]
Fc	Center of frequency [Hz]
Z_o	Characteristic impedance [ohm]
G	Conductance [$kg^{-1}m^{-2}s^3A^2$]
ε_{eff}	Effective permittivity [−]
E	Efficiency [%]
ω	Frequency [Hz]
Ω	Impedance [ohm]
L	Inductance [$kgm^2s^{-2}A^{-2}$]
Z_{in}	Input impedance [ohm]
~	Infinite [−]
L	Length [m]
Z_l	Load impedance [ohm]
μ_o	Permeability [−]
Γ	Reflection coefficient [−]
εr	Relative permittivity [−]
RL	Return loss [dB]
S_{11}	Return loss parameter [dB]
θ	Tetha, Gradient [°]
VSWR	Voltage Standing Wave Ratio [−]
λ	Wavelength [m]
λ_o	Wavelength in the air [m]
λ_g	Wavelength in the substrate [m]
W	Wide [m]
H	Width of the substrate [m]
T	Width patch [m]

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