Development of A 5.4 Ghz C-Band Microstrip SAR Antenna for A Tsunami Detector

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Abstract

A Tsunami is a series of massive oceanic waves resulting from profound tectonic activities in the seabed. The disaster's devastating effect makes fast information delivery during a tsunami crucial in minimizing losses. For this reason, Tsunami warning systems need to be supported by a rapid detection technology. In recent years, radar has been implemented as a tsunami detector due to its sensitivity to oceanic waves. An array antenna using advanced microstrip technology, as the main component of a radar system, can fulfill the requirement for tsunami rapid detection. This paper presents the work that we conducted to develop a tsunami detection antenna using the array approach to improve gain and optimize radiation patterns. We designed a patch antenna with 12 mm in length and 21 mm in width and performed some simulations to obtain the antenna parameters such as gain, bandwidth, and optimal radiation patterns. As the results of our investigation, we determined the resonance frequency to be 5.4 GHz. The study produced a gain of 9.07 dB through simulations on an antenna that resonates at a frequency that meets the antenna work criteria, which include a loss of -26.69 dB, a VSWR of 1.09, and an HPBW (Half Power Beamwith) of 17.3°. Those values indicate that the antenna designed for tsunami detector applications functions correctly.

Keywords: *tsunami, microstrip antenna, array system.*

1. Introduction

A seismic event of significant magnitude can initiate a tsunami. A tsunami is a series of oceanic waves that arise from a tectonic earthquake on the ocean floor, which initiates the tsunami-generating process. An earthquake is an inherent occurrence resulting from the movement of tectonic plates on the Earth's surface (Finn et al. 2019) This seismic event is highly damaging and can consequently initiate a tsunami. A tsunami is a seismic wave that arises from an earthquake, seaquake (Lawson 2007), volcanic eruption (Agustan 2019), or meteor-induced impact in the ocean. Initially, tsunamis remain imperceptible in the deep water, but their rapidly propagating waves will become more prominent when they approach shallower regions.

Radar plays a crucial part in interpreting weather forecast systems, making it a technology that demands high levels of sophistication (Masakazu et al. 2009). Radar or Radio Detection and Ranging is an electromagnetic wave system widely used for airborne objects and motorized vehicle detection, distance measurement, and mapping, in addition to providing meteorological data (Hosking 2016). The radio-frequency radar emits wavelengths ranging from millimeters to meters. Radar works by emitting microwaves toward an object of interest, and the echoes captured from the object are collected and processed. Synthetic Aperture Radar (SAR) provides particular benefits in image processing by detecting ground contours from buildings to lowlands. This is made possible by using microwaves in SAR, which facilitates the identification of the area impacted by the radar signal. SAR is widely implemented on satellites and aircraft, encouraging radar manufacturers to continuously develop antenna designs, shapes, and technology. A microstrip antenna is a type of antenna that is easy to develop and modify (Farohaji et al. 2018) (Yusuf et al 2019). (Mallikarjun et al. 2012).

The C-band is one of the frequency bands commonly used in satellite communication systems (Sheriff et al. 2001). The typical downlink frequency in C-band ranges from 3.7 to 4.2 GHz, while the uplink is 5.925-6.425 GHz. This frequency range is highly compatible with the microstrip antenna designed using CST simulations. The design concept of microstrip array antenna offers benefits since they are small, thin, and lightweight (Balanis 2005). The array antenna consists of multiple microstrip antenna elements arranged in a specific pattern, with a working frequency of 5.4 GHz, and is used as a tsunami detection device.

2. Methodology

The antenna development process in this work was divided into two phases: the design, which is mainly computer-based, and the manufacture. The design process combined the theoretical calculations to provide the preliminary data and the simulation using CST software. During the design phase, simulation using the CST software helped to determine the antenna parameters, such as the patch antenna size and the transmission paths that connect the antenna and a computer or network analyzer. The design process started with a literature review to better understand the background theory behind each antenna component. Then, the patch antenna was designed using CST software, resulting in a rectangular configuration to maximize its performance. The antenna parameters and array configuration were determined following the flowchart in Fig. 2-1.

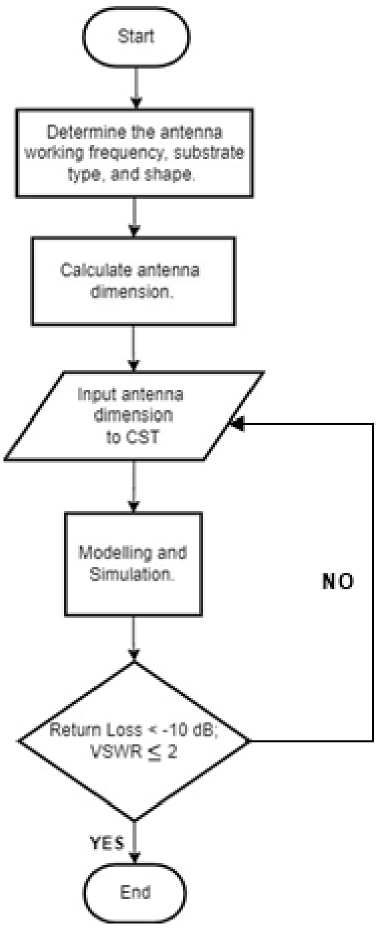

Figure 2-1: The process of designing a single patch antenna.

The first step is constructing a single-band antenna, which operates at 5.4 GHz. As shown in Fig. 2-1, after the working frequency was defined, we selected the type of substrate and the antenna shape and then calculated the antenna dimension. After obtaining the value, we developed a model and conducted CST simulations. The simulation was performed until the return loss was smaller than 10 dB and the VSWR value was less or equal to 2. If those conditions were not fulfilled, the process was repeated by changing the dimension of the patch antenna. Once the return loss and VSWR requirements were satisfied. Once the single-element design parameters were obtained, the design process continued by changing the number of the array antenna to obtain the optimum performance.

The model parameters for a rectangular antenna element are defined in Fig. 2-2. These parameters are the antenna patch width (W) and the length (L), which are then used as a simulation input to construct a single-element antenna.

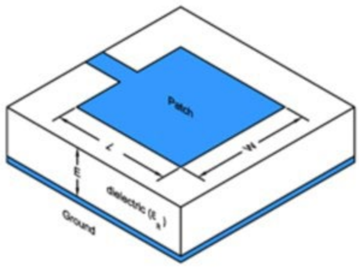

Figure 2-2: Model parameters of a rectangular microstrip antenna element.

The dimensions of a rectangular antenna can be calculated using Eq. (1) – (3) as follows:

$$W = \frac{c}{2f_o\sqrt{\frac{\epsilon_R + 1}{2}}} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_R + 1}{2} + \frac{\varepsilon_R - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right] \quad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_R + 1}{2} + \frac{\varepsilon_R - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right] \quad (3)$$

The design process for multi-element (array) antenna configuration is presented in Fig. 2-3.

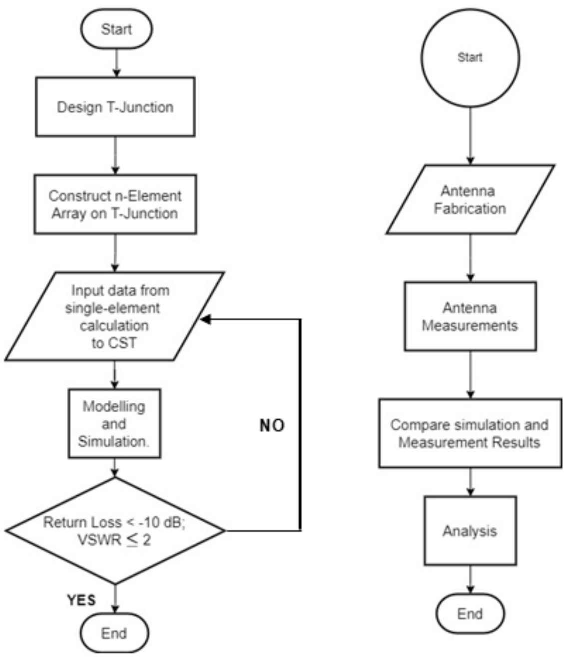

Figure 2-2: The design process of a multi-element antenna array based on a single-square element.

3. Result and Analysis

3.1. Design baseline (Single-elements patch antenna)

The calculated antenna patch width (W) at 5.4 GHz is 16.9 mm, while the length (L) = 16.74 mm. Further calculations on the ground width (Wg) and the ground length (Lg) yield Wg = 27.85 mm and Lg = 24.23 mm. The next step was calculating the supply channel width (Ws) at a frequency of 5.4 GHz, utilized in the preliminary design, leading to Ws = 3.06 mm when the input impedance is 50 Ohm. The design results of the power supply channel indicate that the supply channel's impedance was 50 Ohm and 70.71 Ohm. These values were used to construct the T junction model for the microstrip antenna array, as illustrated in Fig. 3-1. T-junction refers to the shape resembling the letter T. Figure 3-2 displays the 5.4 GHz square patch antenna design results after obtaining all the dimension values.

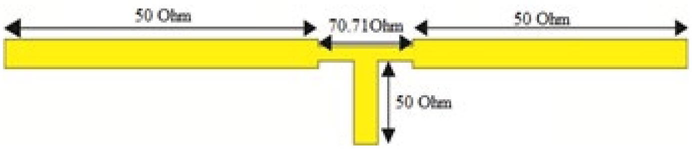

Figure 3-1: T-junction design based on the calculated values.

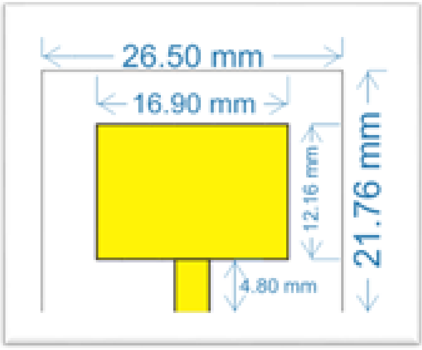

Figure 3-2: Preliminary design of a single square patch antenna element operating at 5.4 GHz.

3.2. Multi-elements array configuration

The antenna performance parameters can be improved by arranging multiple elements in an array to obtain the correct value of the wavelength. The CST software simulation assists in designing the desired antenna by inputting the initial parameter calculation results and the patch width and length calculation results. The result was a rectangular 2, 4, and 8-element patch array shape used as initial references for optimizing the antenna, and the results are presented in Fig 3-3, 3-4, and 3-5.

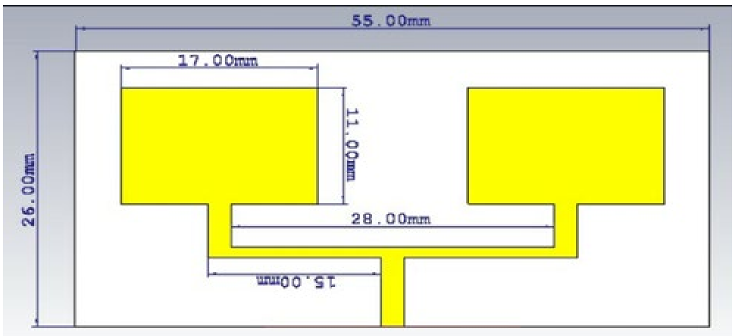

Figure 3-3: The simulation result of the 2-element antenna array configuration.

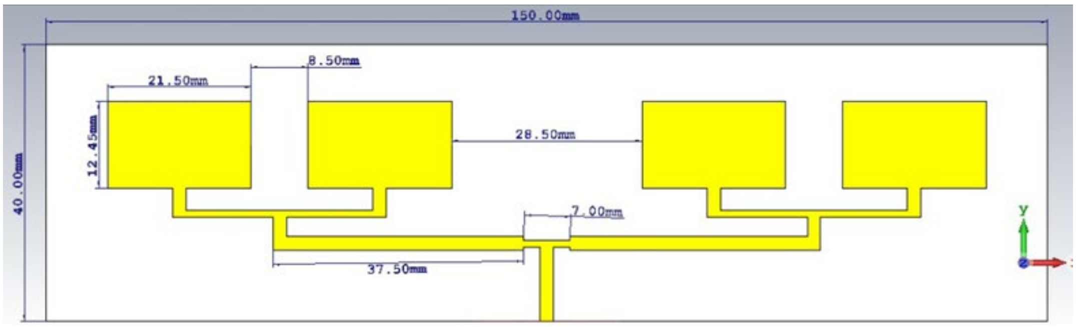

Figure 3-4: The 4-element antenna array configuration simulation result.

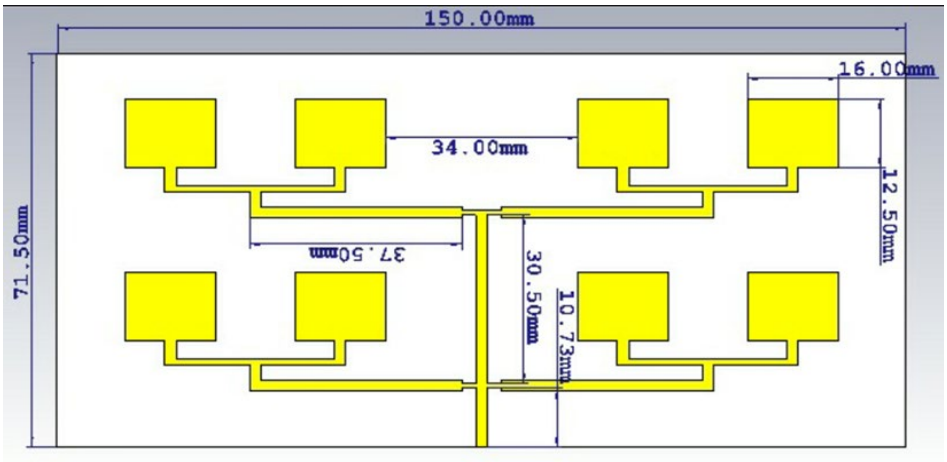

Figure 3-5: The simulation result of the 8-element antenna array configuration

3.2. Antenna performance parameters

As previously explained, the initial procedure in the antenna design is determining the suitable antenna parameter values for a patch consisting of a single element. Following that, optimization is conducted to obtain the optimal return loss value. Currently, random basic element optimization is conducted at a frequency of 5.4 GHz by making adjustments in the patch and the feeder channel dimensions, which are subjected to a tolerance of ± 1 mm. The manifestation of the adaptation resulting from the optimization procedure is illustrated in Table 3-1.

Tabel 3-1: Design Parameters Output of Microstrip Antenna Array.

Microstrip Antenna Array Configuration	**Design Parameters as a Result of Microstrip Antenna Array**		
	VSWR	**Return Loss (dB)**	**Gain (dB)**
Single-Element	1,052	-31,86	3,098
2-Elements	1,525	-13,63	6,283
4-Elements	1,045	-33,15	8,554
8-Elements	1,090	-26.68	9,072

Table 4.1 illustrates the modification of the output parameters of the microstrip antenna design with a centre frequency of 5.4 GHz. The return loss value has fluctuated between a single element and eight elements, as evidenced by this outcome ranging from a single element value of -31.86 dB to a value of -26.68 for the 4-element array.

The return loss value in the 2-element array has decreased compared to the single-element value due to its sole use as a comparison. The return loss value derived from this microstrip antenna design has met the microstrip antenna requirements, as indicated by these results.

Moreover, there is consistency in the VSWR results throughout the range of output parameter values from one element to eight elements, ranging from an initial value of 1.052 to a final value of 1.090. For the 2-element array, the VSWR value remains acceptable as the specified threshold for a microstrip antenna is less than 2. Based on the acquired data, it can be inferred that the VSWR value has achieved conformity with the standardization of microstrip antennas.

The antenna gain ranges from a starting value of 3.098 dB to a maximum value of 9.072 dB. The gain results of the 4-element array satisfy the microstrip antenna requirements for operating at C-band frequencies. However, in order to further enhance the gain, an array consisting of 8 elements is implemented. Employing the array method or expanding the antenna arrangement in the antenna design can significantly impact and amplify the gain characteristics. Based on these characteristics, the 8-element array antenna configuration is expected to satisfy the primary requirements for the radar system in tsunami detection applications.

3.3. Characteristics of the 8-element array microstrip antenna

An array is constructed based on the results of the CST simulation and single-element patch iteration to provide a reliable reference. Subsequently, the calculation and comparison between the simulation results and the parameter calculation can be examined. The performance parameters under analysis are return loss and value at risk (VSWR). First, we start by analyzing the impedance value generated, which is displayable in Figure 8.

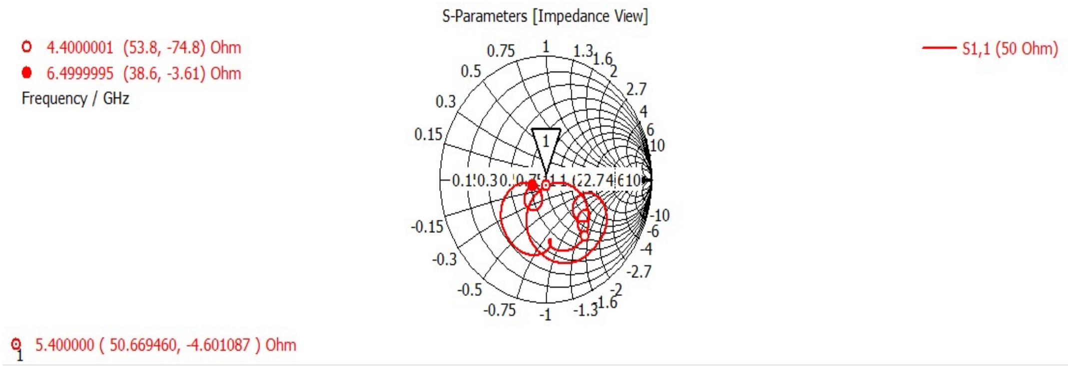

Figure 3-6: Impedance derived from the ultimate configuration of 8-element.

As seen in Fig. 3-6, the impedance value at a frequency of 5.4 is 50.669469-j4.601086 Ω. The return loss form corresponding to the impedance value is shown in Fig. 3-7.

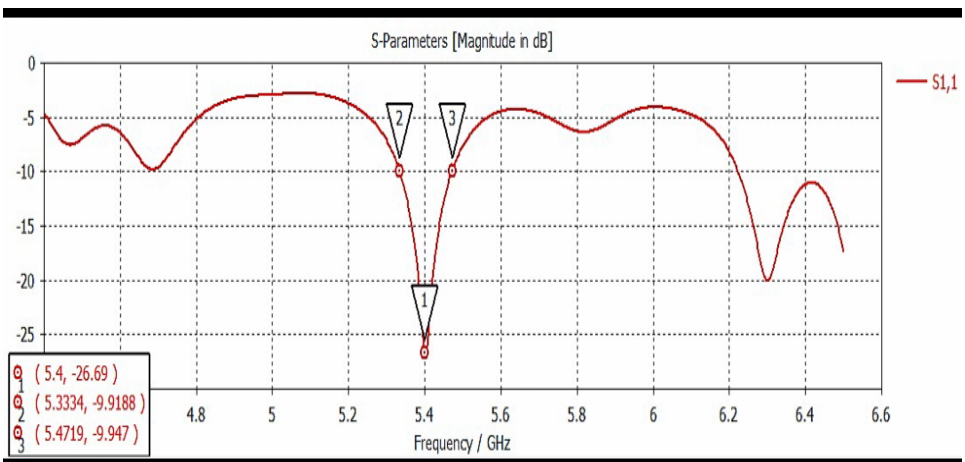

Figure 3-7: The return loss of the 8-element array's final design.

It is evident from Fig. 3-7 that the return loss value is -26.69 dB, which satisfies the required value of the microstrip antenna. The standard value for return loss in microstrip antennas is below -10 dB. Fig. 3-8 displays the corresponding VSWR.

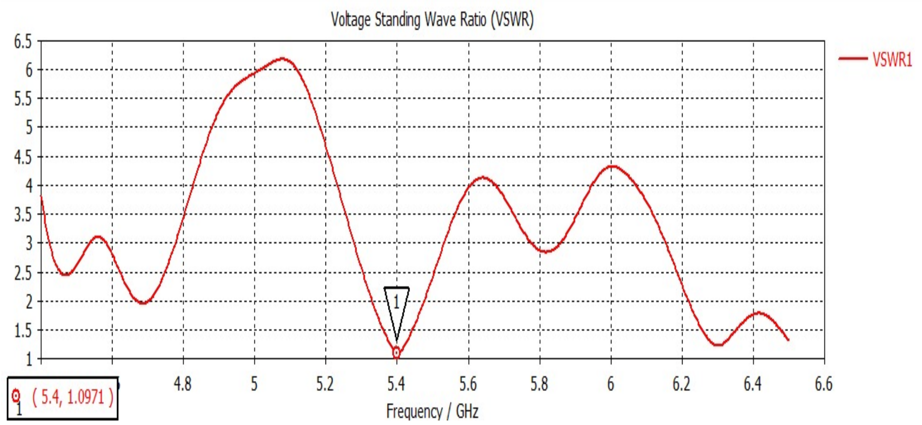

Figure 3-8: VSWR of 8-element array configuration.

According to the simulation results shown in Fig. 3-8, the microstrip antenna operated using CST software achieved a VSWR value of 1.097086 at a frequency of 1.8 GHz, which falls below the operational requirement of <2. Therefore, the designed antenna has fulfilled all its essential operational criteria.

A simulation design with a Return loss value of 26.69 dB, VSWR of 1.097086, and impedance of 50.669469-j4.601086 Ω is included in radar support for tsunami detector applications. Moreover, the design layout utilizing CST software has been finalized, allowing for the fabrication of the antenna and its application in tsunami detection.

Further investigation shows that a transparent radiation pattern directed toward the ocean is required to interpret the tsunami reading indicator. Fig. 3-9 displays the far-field analysis results.

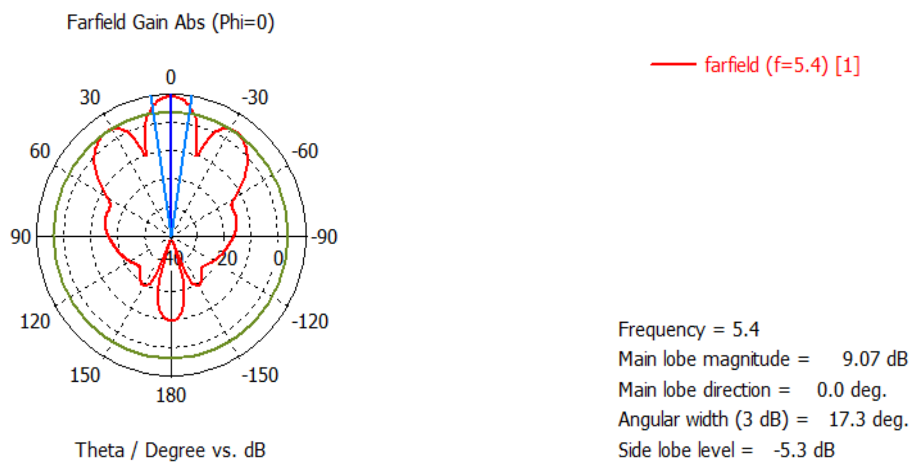

Figure 3-9. Far-field radiation pattern of the 8-element array.

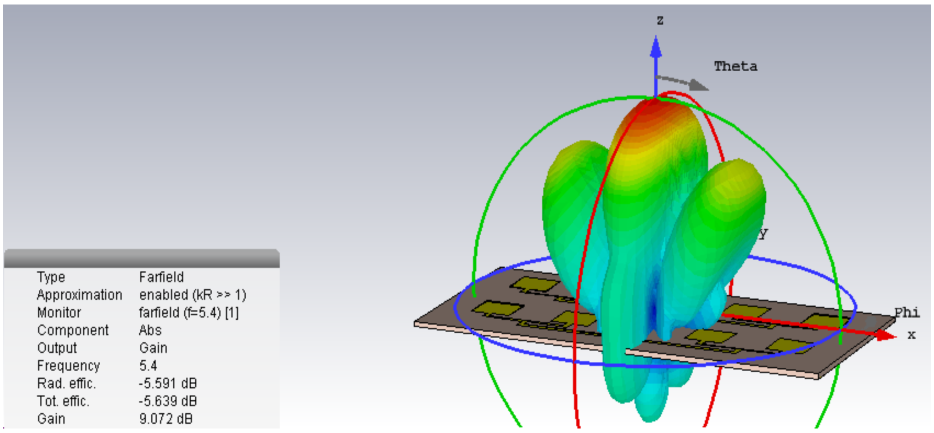

Figure 3-10: Illustration of the 3D gain of the optimal array antenna.

Fig. 3-9 displays the radiation pattern obtained from the simulation results of the 8-element array in polar form. It also presents the support parameters associated with this pattern. A polar plot showing a primary lobe magnitude of 9.072 dB across a half-power beamwidth (HPBW) of 17.3° is shown in Fig 3-9. Figure 3-10 displays the geometric radiation pattern in three dimensions, resulting in a gain of 9.072 dB. Through analysis of the radiation pattern, it is evident that the parameter values mentioned above satisfy the requirements for a microstrip antenna that is prepared for operation.

4. Conclusions

The conclusions below can be derived from constructing a 5.4 GHz (C-Band) microstrip array antenna for this tsunami detector application. The constructed antenna is suitable for use as part of the tsunami detection device due to its performance requirements, VSWR, Return Loss, and gain parameters at a frequency of 5.4 GHz. The antenna was designed using the array method based on the single element with a gain value of 3,098 dB. The antenna gain enhancement was obtained by increasing the number of array elements given by the CST simulation results. The array gain value is increased to 9,072 dB when the final array consists of 8 elements for a half-power beamwidth (HPBW) of 17.3°.

The antenna array configuration with eight elements gives a return loss value of -26.69 dB, which also satisfies the minimum return loss standards. The minimum VSWR requirement for the antenna is less than 2, while the VSWR design results of 1.09 was obtained. The gain achieved, which is 9.702 dB, also exceeds the requirements for the C-Band antenna of 6 dB. The results prove that the design of the C-band microstrip antenna in an 8-element square patch array configuration can be applied for tsunami detection since all the performance parameters meet the criteria for a tsunami detector.

Contributorship Statement

All listed authors contribute equally to the research and manuscript preparation.

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