e-ISSN: 2477-7986

Journal of Measurements, Electronics, Communications, and Systems *(Vol.08 No.2 Pg.29-35, December 2021)*

PARAMETRIC STUDY OF NATURAL DIELECTRIC MATERIALS THICKNESS IN WAVEGUIDE ANTENNA MODE TE_{10} COASTAL RADAR 3 GHz ANTENNA

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Manuscript received August 11, 2021; revised November 5, 2021; accepted December 23, 2021

Abstract

Manufacturing process was important in the development of antenna technology in order to obtain the antenna optimal performance. One of the approaches to increase the antenna performance was to use a natural dielectric material. In this research, a waveguide antenna was designed by inserting a natural dielectric material, an FR-4-Epoxy (ε = 4,3 in the simulator) into a waveguide with a width of 72 mm, a height of 34 mm, and a length of 50 mm. The properties of the TE_{10} mode waveguide antenna were modified by slightly varying the position of the dielectric material and adding an initial thickness of 1.6 mm. The excitation of the waveguide was configured using TE_{10} mode. The Observed paramters in this research are S_{11} (return loss) and radiation parameters (gain and directivity). On the simulation shows that the best performance of the waveguide antenna was obtained when the dielectric position is 2 mm from the connector and thickness 3,2 mm. The simulation also generates the parameter S_{11} of -22,8 dB with gain and directivity was 5,77 and 1,799 respectively at a frequency 3 of GHz while from measurement the frequency was shifted at 3,15 GHz with S_{11} -23,05 dB. The result of this research shows that the addition of dielectric material to the waveguide antenna as a resonator will affect the antenna parameters this is due to the nature of the dielectric material which has a special permittivity value that changes the nature of the medium of wave propagation propagating on the antenna. From the observations in the simulation stage, the closer the position of the material to the connector and the thicker the material, the better the return loss, even though it slightly shifts the working frequency of the antenna from the initial frequency.

Keywords: *Antenna; Frequency; Natural Dielectric Material;* TE_{10}*mode; Waveguide*

DOI: 10.25124/jmecs.v8i2.4068

1. Introduction

Radar (Radio Detection and Ranging) is a device that serves for detection, measure, and map objects by electromagnetic (EM) waves [1]-[3]. EM waves can propagate on various media. A common example in observing wave propagation characteristics is to use a waveguide medium [4]-[6]. In waveguide, the EM waves become more directional [7]-[8]. The waveguide is designed using metal (generally aluminum) with a certain dimensional cavity filled with air [9]. The waveguide can be modified related to the parameters of the electric field, the magnetic field, and the distribution of power that propagates in the waveguide by modifying the wave propagation medium in the waveguide [10]. One of them is using a dielectric material to create dielectric degradation which causes the decreasing of the internal electric field inside the material [11]-[12].

Research on the properties of dielectric materials is closely related to their ability to store and release electrical and magnetic energy. Dielectric properties are very important to explain some phenomena in the field of electronics especially in telecommunications [13]. Previous studies on the antenna designed proposed the dielectric antenna resonator using parameter anisotropic material [14], dielectric antenna resonator in millimeter wave frequency [15] and dielectric material for high power antennas [16]. Previous works show that the dielectric materials can be used to modify the working frequency and can be implemented in microwave applications.

This research implemented an antenna using a TE_{10} waveguide mode that inserts the dielectric material as a resonator. This research was conducted with the aim of designing an antenna with high directivity and a minimum gain of 2 dBi and adequate return loss to be applied to 3 GHz S-Band coastal radar antenna. As for voltage standing Wave Ratio (VSWR), it has been previously tested from existing antennas that have been designed and fabricated and during the experiment this parameter did not change so significantly that it did not become a major concern in the observations (VSWR obtained was in the range of 1.3 - 1.31). The research was carried out by designing a rectangular waveguide and simulating the antenna parameters. After that, the dielectric materials were inserted into the waveguide and its effect on the antenna parameters is compared with the initial parameter. The antenna is then fabricated and the real parameters were measured and compared to the simulation results. The parameter that has been observed with simulation method in this research was the reflection loss and radiation pattern for extracting the information of the value from gain and directivity parameters.

2. Experimental Method

The rectangular waveguide was designed in several steps. The first step, a rectangular waveguide with Mode TE_{10} is designed using WR 284 waveguide. The next step was inserting FR-4 Epoxy dielectric ($\varepsilon = 4.3$ in the simulator with an initial thickness of 1.6 mm). Then simulation tests were conducted to find the expected parameters ($S_{11} < -10$ dB and gain> 2 dBi). This research also conducted to observe the impact of dieletric material to the directivity parameters. The simulation method is carried out by shifting the dielectric position toward the connector with 2 mm, 15 mm, and 24 mm distances. Furthermore, the dielectric thickness is varied by 1.6 mm, 3.2 mm, and 4.8 mm size.

2.1 Pre-Simulation Configuration

The research flow chart is presented in Fig. 1. The research process is carried out starting from determining the dimensions of the waveguide size, designeding TE_{10} rectangular waveguide, inserting an FR-4 dielectric material at a predetermined position and the specified size. Dielectric material insertion is done to change the initial parameters of the waveguide antenna without changing the dimensions of the original physical size to get the desired antenna parameters. From the several simulations that have been carried out, the best results are taken according to the requirements of the desired parameter criteria. The designed of the waveguide is done by using WR 284 waveguide specifications with the initial working frequency range at 2.6 to 3.95 GHz. Determining the value of height and width of waveguide can be calculated using Eq. (1).

$$f_{c0} = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \qquad (1)$$

f_{c0} is the cut-off frequency and m and n are the modes of the TE. Parameters a and b are the width and height of the waveguide. If TE_{10} mode then $m = 1$ and $n = 0$. Figure 2.2 shows the initial of the waveguide using the WR 284 designed in the CST Studio Suite.

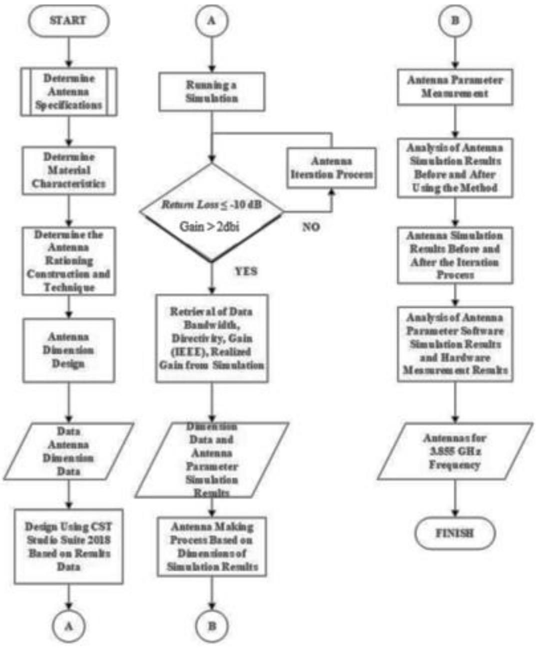

Fig. 1 The flow chart of the research

The initial design of the waveguide antenna using TE_{10} mode feeding and PEC is installed at the end of the waveguide can be seen from Fig. 2 In the initial design shown from Fig. 2, the waveguide with a length X width X height was 50 x 72 x 34 mm^3 and the width of the inner and outer sides of the waveguide is 2 mm. The installation is equipped by SMA connectors with 0.62 mm copper connector dimensions.

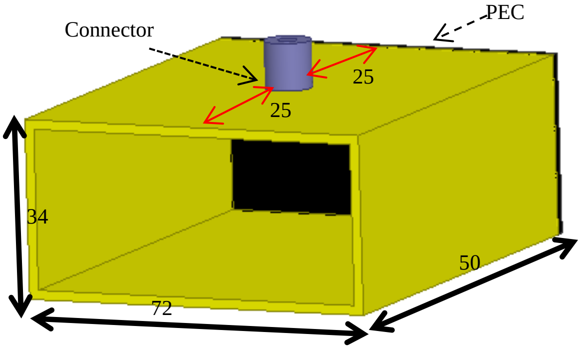

Fig Initial designed of TE_{10} mode rectangular waveguide with PEC at the edge of waveguide (units in mm)

The second layer is a 2.3 mm radius glass and the outer layer (jacket) uses a copper material with 2.4 mm radius. The length of the copper in the waveguide is 17 mm (half of the height of the waveguide). The position of the connector is in the middle of the waveguide (the distance from each side of the tip of the waveguide is 25 mm)

In Fig. 2 the rectangular waveguide is given a connector at the center of upper side of the waveguide following the configuration of TE_{10} mode. The connector used is the SMA female connector. The designed and size of the connector in the CST Studio Suite simulation must be adjusted to the female SMA connector to avoid the frequency difference between the simulation and the real device. The TE_{10} Mode rationing process on the connector is specified to obtain the highest electric field vector intensity. The point of excitation on the connector is carried out on a layer of Polytetrafluoroethylene (PTFE) glass material. The direction of excitation is taken from the outer wall of the glass material towards the inside of the glass material.

In Fig. 3 rectangular waveguide that has been installed with a SMA connector, so that the excitation moved from the cover to the connector in the glass layer.

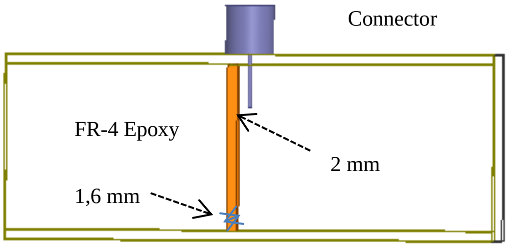

Fig. 3 Waveguide initial designed with inserted FR-4 Epoxy material

The figure 2.3 shown the design of a waveguide antenna with an FR-4 dielectric material inserted with a distance of 2 mm from the connector. Then during the simulation test, the distance changes from 2 mm, 15 mm, and 24 mm with the aim of observing the effect of changing the distance between the material and the connector on the resulting antenna parameters. In addition to changing the distance, observations were also made based on the effect of changes in the thickness of the material with an initial thickness of 1.6 mm and then changed to 3.2 mm and 4.8 mm. In Figure 2.3 the dielectric uses an FR-4 type with a thickness of 1.6 mm and a permittivity value of 4.3. The distance between the connector and the dielectric is 2 mm.

3. Result and Discussion

The simulation stage is carried out by changing the distance between the connectors with an FR-4 Material (thickness = 1.6 mm) by changing the distance from 2 mm, 15 mm, and 24 mm respectively. The best distance results are then used in the next simulation stage, namely observing the effect of changes in material thickness with scenarios of changing material thickness from 1.6 mm to 3.2 mm and 4.8 mm. The simulation results for the S_{11} parameters are shown in Figure 3.1.

In Fig. 4 the desired working parameters are obtained at frequency 3 GHz with a value of S_{11} -23.22 dB. From the simulation results, the larger the distance between the dielectric material from the connector results in an insignificant change in the S_{11} parameter, but this method shifts the frequency from 2.975 GHz to 2.9 GHz (about 0.075 GHz lower).

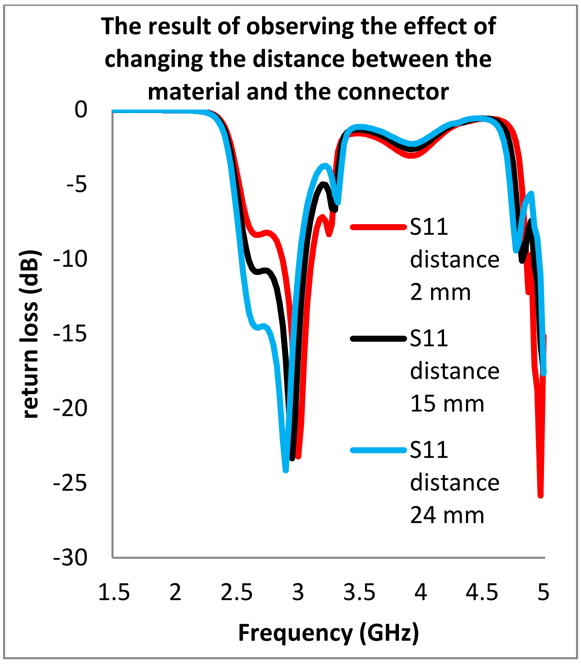

Fig. 4 The effect of the distance between the material and the connector

Next is the simulation result of Radiation pattern with distance 2 mm, 15 mm, and 24 mm respectively from Fig. 5–7 This part of experiment was to observe the main lobe angle (directivity) and its magnitude (gain).

In Fig. 4, the main lobe angle is 87.0 deg with magnitude of 5.48 dBi. In Fig. 5 the main lobe angle is 98.0 deg with magnitude of 1.61 dBi respectively. Lastly in Fig. 6, the main lobe angle is 98.0 deg with magnitude of 1.64 dBi respectively. By changing the distance between the material and the connector results in an increase in the intensity of the electric field. This is consistent with the higher attenuation value of the reflection when the distance from the material to the connector becomes smaller. This cause the magnitude of main lobe increased each time the distance larger also the main lobe angle.

Next experiment was observed by changing the thickness of the material to the parameters S_{11}, gain and antenna directivity. In this test, the distance between the connector and material is 2 mm because this distance produces an antenna with a working frequency as needed, namely 3 GHz. The simulation result by changing the thickness of the material can be seen from the following Fig. 7

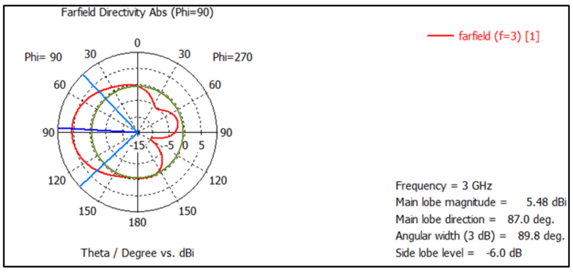

Fig. 5 Radiation pattern of distance between material and connector was 2 mm (3D) Plotting result

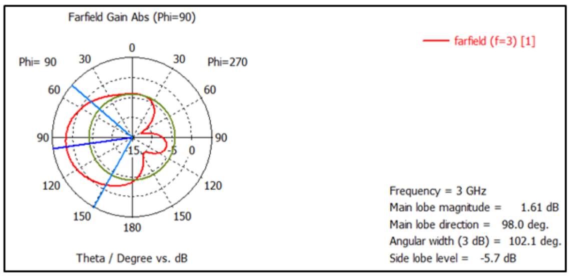

Fig. 6 Radiation pattern of distance between material and connector was 15 mm (3D) Plotting result

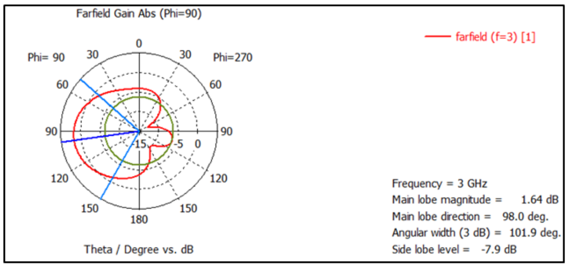

Fig. 7 Radiation pattern of distance between material and connector was 24 mm (3D) Plotting result

In Fig. 8 the desired working parameters are obtained at frequency 3 GHz with a value of S_{11} -22.8 dB with thickness 3,2 mm. F From the observations, the thicker the material, the higher the S_{11} value (close to 10 dB). In addition, changes in the thickness of the material that are getting bigger also cause a shift in the working frequency of the antenna to be lower which is from 1.5 GHz (from thickness 1.6 mm to 4.8 mm) Next is the simulation result of Radiation pattern with thickness 3,2 mm and 4,8 mm respectively from figure 3.6 – 3.7.

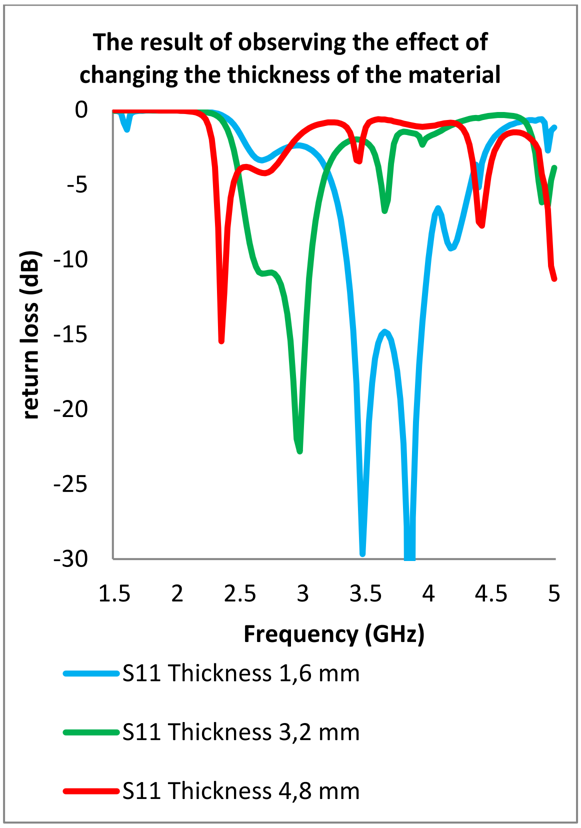

Fig.8 observation resulted from the effect of changing thickness of the material

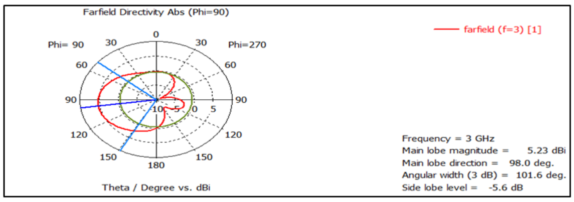

Fig.6 Radiation pattern of material thickness of 3,2 mm (3D) Plotting result

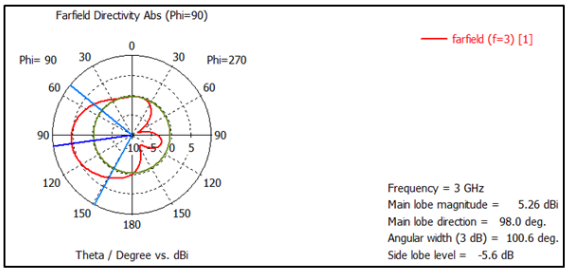

Fig.7 Radiation pattern of material thickness of 4,8 mm (3D) Plotting result

In Fig.6, , the main lobe angle is 98.0 deg with magnitude of 5.23 dBi respectively. In Figure 3.7, , the main lobe angle is 87.0 deg with magnitude of 5.26 dBi respectively. Based from the simulation results of changes in material thickness there is a slight increase in gain when the material gets thicker although the angle of the main lobe does not change.

Fig. 7 an FR-4 Dielectric Material with thickness 1,6 mm (left), 3,2 mm (center), and 4,8 mm (right)

Fig. 7 are FR-4 materials with various thicknesses used during the simulation shown from Fig.8. As for the S_{11} parameter from measurement results using Vector Network Analyzer (VNA) compared with simulation result can be seen from Fig. 8

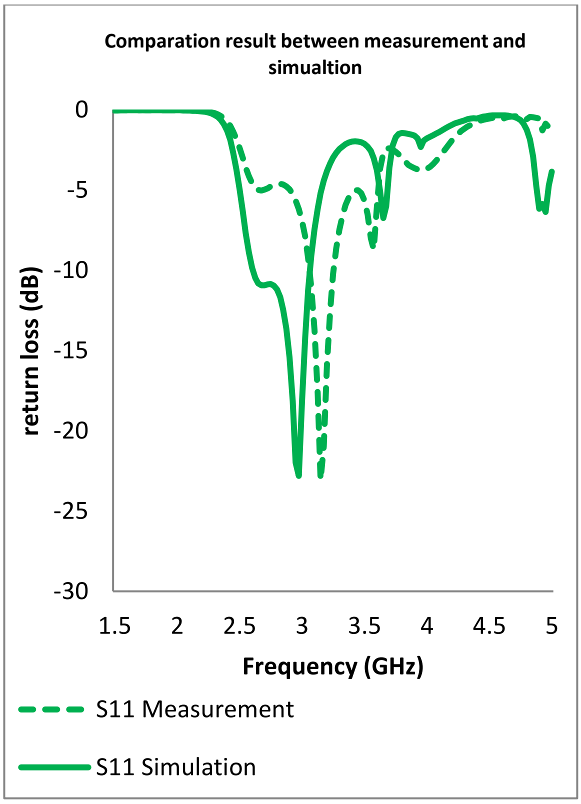

Fig. 8 Result from measurement compared to the simulation

Measurements were made by realizing the antenna using a rectangular wave ridge with a length of 50 mm, a width of 72 mm, and a height of 34 mm. The position of the material is placed with a distance of 24 mm and 3.2 mm thick. This designed was chosen to be realized because the simulation results of this designed are the closest to the desired results. In the measurement of the S_{11} parameter, a difference of 1.1 dB is obtained and the frequency shifts up to 3.15 GHz. This is analyzed due to the dimensional dissimilarity of the fabricated antennas with simulations, causing differences. In addition, the influence of less than ideal environmental conditions at the time of measurement causes interference that changes the S_{11} parameter from the measurement results

4. Conclusion

From the simulation results, the closest to the desired specification is an antenna with a material spaced from the connector of 2 mm and a thickness of 3.2 mm. as for the results of changes in distance where when the distance of the connector is further away from the material, the return loss becomes smaller. This is due to the effect of the greater coupling so that the value of the electric field intensity also increases. In the observation, changes in thickness have no significant effect on changes in the return loss value, but the experiment is quite significant in shifting the frequency so that it is not a good method in finding good antenna parameters because it can shift the working frequency not according to needs. for the gain and directivity parameters, there is no significant change in both the distance and thickness changes

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