A Small Ultra-Wideband Unidirectional Microstrip Antenna for Through-Wall Radar Application

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***Abstract*— A portable through-wall radar needs a small size broadband antenna with a unidirectional radiation pattern. The antenna that meets these requirements is microstrip antenna. This paper explains an Ultra-Wideband (UWB) microstrip antenna that has been designed and manufactured for through-wall radar application. The design and simulation of the antenna were carried out with 3D electromagnetic simulator. The substrate material of the antenna was FR-4 with a dielectric constant of 4.3 and a thickness of 1.6 mm. The simulation results showed that the antenna had a 4.8 GHz of bandwidth ranging from 4.2 to 9 GHz, with a return loss less than -10 dB. The antenna dimension using FR-4 substrate is smaller than using Duroid 5880 with a dielectric constant 2.2. Additionally, the measurement results showed that the antenna had a 5 GHz of bandwidth ranging from 3.8 to 8.8 GHz, with a return loss less than -10 dB.**

***Index Terms*—microstrip antenna, ultra-wideband, unidirectional, through-wall radar, FR-4.**

I. INTRODUCTION

Ultra-wideband (UWB) through-wall radar has been the concern of the academics and the industry stake-holders for its role in the security system, fire rescue, collapse building, and things pertaining to natural disasters such as earthquake or thunder storm [1]. Compared to traditional radar, UWB radar has many advantages such as high resolution, resistance to multipath phenomenon, extremely low power emission and low power consumption [2]. In addition, one of the important components in the UWB through-wall radar is the antenna.

There are some requirements that should be met for the antenna of UWB through-wall radar application, namely the very wide bandwidth with the unidirectional radiation pattern and the compact size [2]. One of the antennas that meet the requirements is microstrip antenna. It has some advantages such as, a simple and light body, adjustable radiation pattern, relatively easy manufacturing process, and low materials cost. Moreover, for the aim of this study, this microstrip antenna needs to have the frequency range which fits the UWB through-wall radar.

The technology of ultra-wideband (UWB) is the short-length communication with a very wide bandwidth. According to the Federal Communications Commission (FCC), the appropriate UWB frequency for the commercial tool is within the range of 3.1 – 10.6 GHz [3]. Additionally, in 2007, the Office for Communication (OfCom) determined the standard for the UWB radar, which is at the frequency range of 4.2 – 8.5 GHz [4].

Most of the UWB microstrip antenna has omnidirectional radiation pattern because it uses the monopole antenna [5-7]. To have a unidirectional radiation pattern, the reflector is planted on the monopole antenna [2, 8]. In addition, another kind of UWB antenna is the Vivaldi antenna, which has a unidirectional radiation pattern. However, it is not fit for the application of portable through-wall radar since it will increase the thickness of the radar itself.

Previous research [3] that used the UWB antenna for through-wall radar application, with Duroid 5880 substrate material, showed that the antenna fulfilled the standard of OfCom. Nevertheless, because the Duroid 5880 substrate material is quite expensive, this study is aimed at manufacturing the same kind of antenna [3] with lower material cost and obtained widely, which is the FR-4. The UWB microstrip antenna resulted in this study is expected to be able to be used for through-wall radar application at a lower cost; thus, it fulfills the requirements mentioned above.

II. THE ANTENNA DESIGN AND SIMULATION

The manufacturing of the UWB antenna was started by designing similar antenna as previous study in [2] but with different substrate material as shown in Figure 1. In the previous study, the material used for substrate was Duroid 5880 with 2.2 and 1.575 mm of dielectric constant and thickness respectively. Meanwhile, in this study, the substrate used was FR-4 with 4.3 and 1.60 of dielectric constant and thickness respectively.

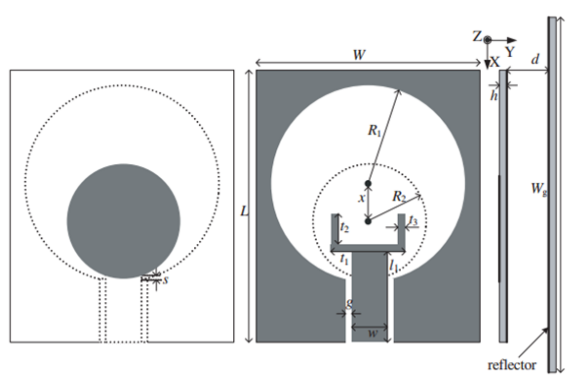

Figure 1: Antenna dimension [2]

By using different substrate material, the dimension of the antenna would also be different. One of the influencing factors in determining the antenna frequency is the circle dimension slot. Equation (1) and (2) were used to determine R_1 and R_2 dimension [7].

$$R_1 \approx \frac{c}{4f_1\sqrt{\frac{1+\varepsilon_r}{2}}} \times \frac{2}{\pi} \tag{1}$$

$$R_2 \approx \frac{R_1}{2} \tag{2}$$

where: R_1 = back patch radius
R_2 = front patch radius
f_1 = the lowest frequency (4.2 GHz)
c = light velocity (3 x 10^8 m/s)
ε_r = dielectric constant (4.3 for FR4)

Furthermore, the iteration process was done for several times until the optimal result was achieved and the specifications were fulfilled. The graph showing the iteration result for the parameter R_2 can be observed in Figure 2.

Figure 2 shows that the optimal dimension for R_2 is 6 mm. The final results of the other antenna dimensions are displayed in Table 1. In addition, it can be seen from the table that the other antenna dimensions in this study were smaller than they were in the previous study [2].

Table 1
The comparison of UWB antenna dimension

Dimension	Substrate Materials	
	Duroid 5880	FR-4
W	30 mm	24 mm
L	34 mm	28 mm
R_1	13.7 mm	10.8 mm
R_2	7.5 mm	6 mm
x	5.3 mm	2.5 mm
w	3.6 mm	2.7 mm
g	0.2 mm	0.9 mm
s	1.0 mm	2.5 mm
l_1	9.5 mm	8 mm
t_1	7.5 mm	5.6 mm
t_2	4.0 mm	2.6 mm
t_3	0.4 mm	0.4 mm
d	16 mm	10 mm
Reflector Dimension	50 x 50 mm	36 x 24 mm

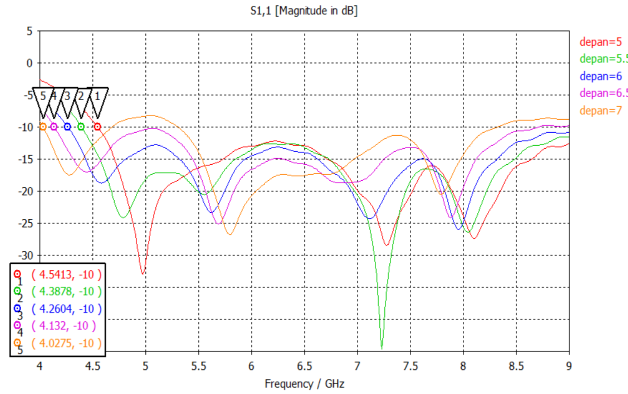

Figure 2: Parameter sweep for parameter R_2

The simulation results, based on the dimensions in Table 1 for the return loss and gain are displayed in Figure 3 and 4 respectively. Meanwhile, the radiation pattern can be observed in Figure 5 through Figure 7.

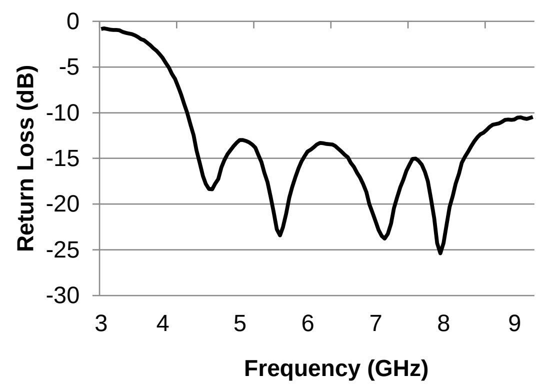

Figure 3: Simulation result of return loss antena

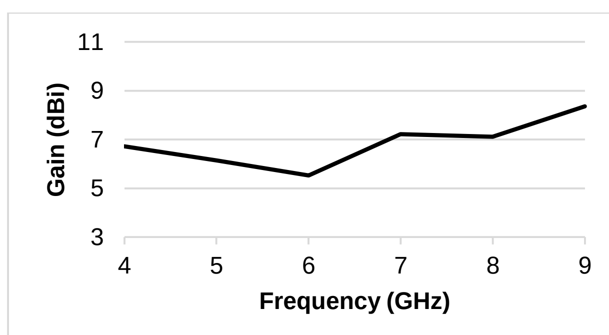

Figure 4: Simulation result of gain antena

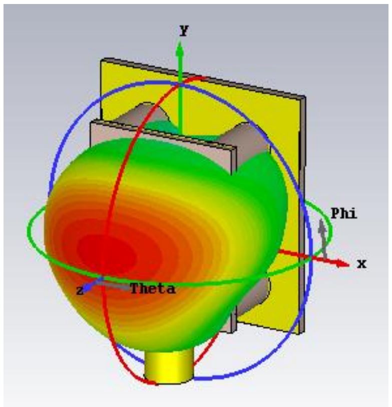

Figure 5: 3D simulation result of the antenna radiation pattern in the frequency 6.5 GHz

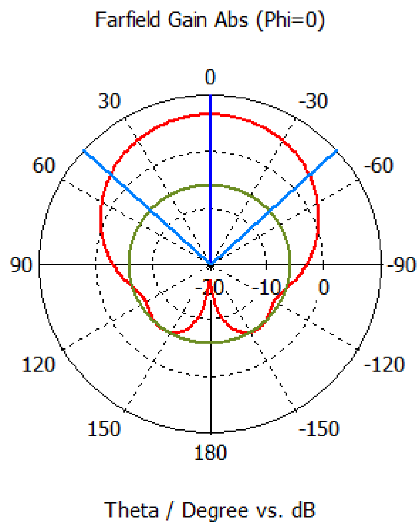

Figure 6: Simulation result of the antenna radiation pattern of H-plane in the frequency 6.5 GHz

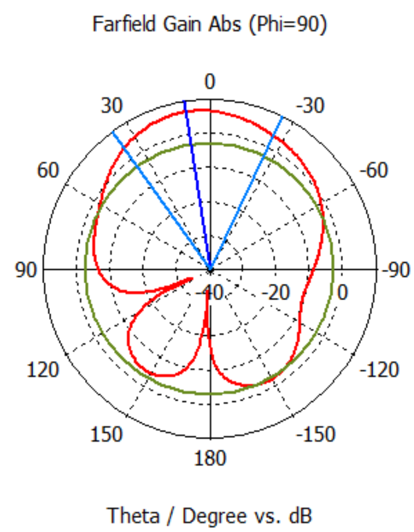

Figure 7: Simulation result of the antenna radiation pattern of E-plane in the frequency 6.5 GHz

From Figure 3, it is shown that the bandwidth of the antenna has fulfilled the specifications, in which the frequency ranges from 4.2 – 8.5 GHz for the return loss of less than -10 dB. Additionally, based on Figure 4, the antenna has gained about 6 – 8 dBi in the same frequency range. Meanwhile, from Figure 5 until 7, it can be seen that the antenna has unidirectional radiation pattern.

III. The Manufactured and Measurement Results

The manufactured result of the UWB microstrip antenna, after being added with the SMA connector and the spacer is displayed in Figure 8. The manufactured antenna is similar to the design in the simulation. Nevertheless, due to the relatively small current dimension, there were some differences, especially the lack of neatness in the material cutting at the back patch and the front patch.

Figure 8: Manufactured result of UWB microstrip antenna

The next step is measuring the antenna parameters. The measurement is done to verify whether the manufactured antenna has the same characteristics with the simulation results yielded previously. The measured antenna parameters were return loss, gain, and radiation pattern. The measurement of the return loss is shown in Figure 9 and the measurement results of the gain and the radiation pattern are displayed in Figure 10 and 11 respectively.

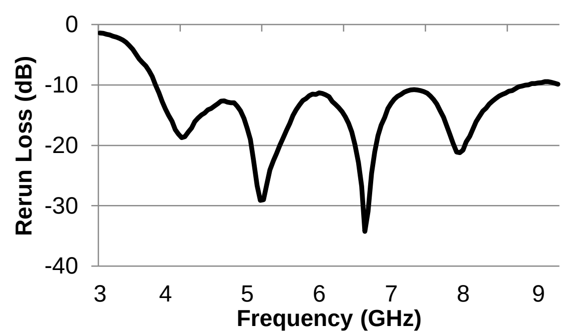

Figure 9: Measurement result of antenna return loss

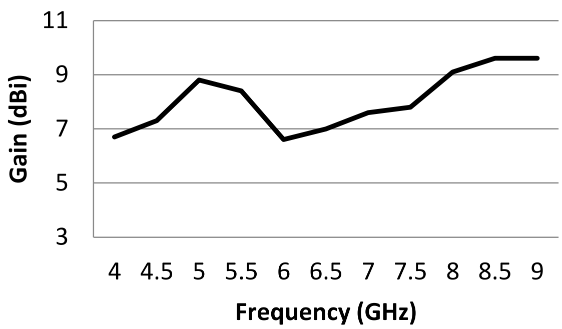

Figure 10: Measurement result of antenna gain

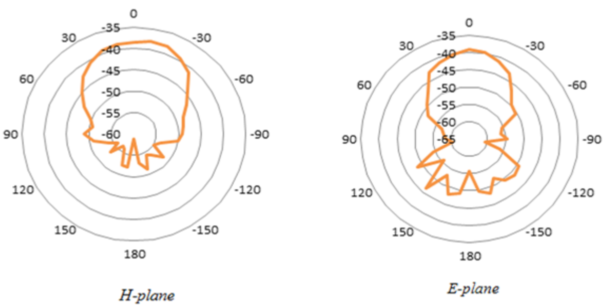

Figure 11: Measurement result of radiation pattern

IV. Results and Discussion

The results of this study showed that the measurement results of the antenna are close to the simulation results, and they worked at the parameters that are required as the UWB antenna for through-wall radar application. In addition, Figure 12 shows the comparison of the return loss (S11) between the simulation result and the measurement result.

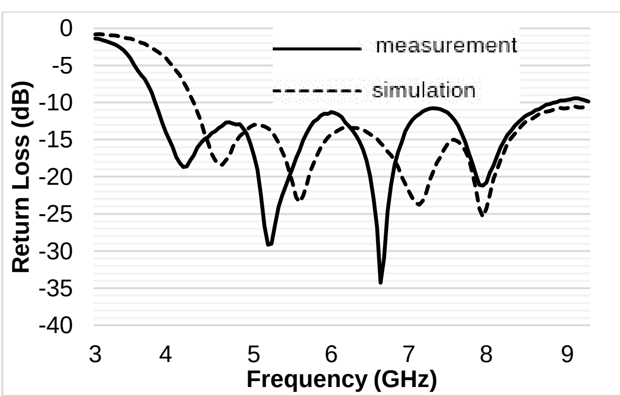

Figure 12: Comparison of the return loss between the simulation and the measurement result

Based on the comparison between the measurement and simulation result as shown in Figure 12, it can be seen that there is a shift at the low operating frequency of the antenna. The lowest values of operating frequency are 4.2 GHz for the simulation result and 3.8 Ghz for the measurement results respectively. Meanwhile, the upper frequency of the simulation and measurement results are 9 GHz simulation and 8.8 GHz for measurement respectively. Additionally, the antenna bandwidth resulted in the measurement is 5 GHz. However, beyond the result, the antenna actually has fulfilled and even exceeded the parameters for the UWB antenna of a radar based on the determination from OfCom (Office of Communications), that is within the frequency range of 4.2 – 8.5 GHz.

Based on Figure 10, it can be seen that the gain of the antenna resulted in measurement is within the range of 7-9 dBi. It is rather different compared to the gain of the simulation result, which is within the range of 6 – 8 dBi, as displayed in Figure 4. The measurement result of the antenna radiation pattern for the H-plane and E-plane shown in Figure 11 indicates that the antenna has a unidirectional radiation pattern, which is a slight different from the simulation results as shown in Figure 6 and Figure 7.

V. Conclusion

In this study, a UWB microstrip antenna has been designed and manufactured using FR-4 substrate material with 4.3 and 1.6 mm of the dielectric constant and thickness respectively. Moreover, it has the frequency range from 3.8 to 8.8 GHz with a return loss less than -10 dB. The antenna gain is around 7 – 9 dBi with a unidirectional radiation pattern. Based on the small dimensional manufactured antenna, it can be concluded that such antenna can be used for the through-wall radar application which fits to the OfCom recommendation. For future research, we can add a metamaterial to improve the gain and/or bandwidth of the antenna.

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