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Design of Ultra Wide-Band Bowtie Antenna for GPR Applications

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Abstract

Ground Penetrating Radar (GPR) is one technology that utilizes a radar system to determine the location of objects that are below the surface of the ground. In its current development, GPR uses an Ultra Wide-Band (UWB) radar system that works at frequencies between 10 MHz to 10 GHz [1]. The use of UWB radar systems are to get high resolution values which affect the level of accuracy in detecting objects. In general, in the implementation of the UWB radar system for GPR technology, antenna types such as bow-tie antennas, TEM Horn antennas, tapered slot antennas, spiral antennas, and vivaldi antennas are used [2] . The characteristic of antenna needed in GPR system must have wide bandwidth to examine the resolution of image. In this report, a bowtie antenna is investigated GPR applications. The bowtie antenna is used because this type of antenna has a smaller size and lightweight. The bowtie antenna design was carried out using RT-Duroid 5880 dielectric substrate with dielectric constant (εr) at 2.2 and thickness (h) at 1.57 mm to get the low profile antenna dimensions. The bowtie antenna is operated in the range from 1,6 to 2,6 GHz for a VSWR $\leq$2.

Keywords: Bowtie Antenna, Ground Penetrating Radar (GPR), Ultra Wide-Band, Low-Profile Antenna, RT Duroid 5880.

1. Introduction

At this time, there are many technologies that utilize radar systems. One implementation is Ground Penetrating Radar (GPR). Ground Penetrating Radar (GPR) is one of radar types technology which is used to detect the buried target into the ground with high resolution and shallow dept penetration. However, a problem that often occurs is the difficulty of finding an accurate location of objects under the ground because of the thickness of the soil. Thus, GPR requires a high resolution value to overcome these problems. GPR uses an Ultra Wide-Band (UWB) radar system that works at frequencies between 10 MHz to 10 GHz [1]. The use of UWB radar systems aims to get high resolution values. High resolution values affect the level of accuracy in detecting objects. Antenna characteristic which is needed in GPR system is an antenna with a wide bandwidth and has a narrow pulse width. Thus, UWB antennas are used to meet the needs of the GPR system. The condition of a UWB antenna is that it must have a bandwidth that is greater or equal to 25% of its center frequency [3].

In general, as an implementation of the UWB radar system for GPR technology, antenna types such as bow-tie antennas, TEM Horn antennas, tapered slot antennas, spiral antennas, and vivaldi antennas are used [2]. However, types of antennas such as TEM horn antennas and Vivaldi antennas have larger sizes and heavier masses compared to bowtie antennas which have smaller sizes and lightweight. Therefore, in this study a bowtie antenna is proposed because this type of antenna has a smaller size and lightweight. The bowtie antenna design was carried out using RT-Duroid 5880 dielectric substrate with dielectric constant (εr) 2.2 and thickness (h) 1.57 mm to get the low profile antenna dimensions. The bowtie antenna is operated in the range from 1,6 to 2,6 GHz for a VSWR $\leq$2.

2. Literature Study

2.1 Ground Penetrating Radar

Ground Penetrating Radar (GPR) or commonly referred as Surface Penetrating Radar (SPR) is a technology of the radar which is used to detect the buried target into the ground without having to dig it by utilizing radio waves that operate at frequency between MHz to GHz. In general, GPR is widely used in various fields of work such as the field of environment for estimating soil properties, identifikation of soil mineral content, and measuring soil depth; archeology to study historic sites; civil engineering for borehole inspection, analysis of bridge deck conditions, strength of buildings and concrete bones, and detecting the presence of cables; military field for detecting mines buried in the ground [1], [4], [5]. GPR performance and its ability to detect an object are influenced by several factors. These factors such as bandwidth for the level of resolution produced, the frequency of work for its application and late-time ringing that affect the received signal [6], [7].

2.2 Ultra-Wide Band (UWB)

According to the Federal Communication Commission (FCC), UWB is a technique that has a fractional-bandwidth (FBW) value that can be defined in the equation (1) [3] as follow:

$$Fractional\ Bandwidth\ (FBW) = \frac{2\,(FH-FL)}{(FL-FH)} \geq 25\% \quad (1)$$

Where FH is the highest frequency and FL is the lowest frequency. At the transmitter, UWB must have a greater fractional bandwidth or value equal to 0.25 or 25%. In addition, the impedance relative bandwidth (percent of bandwidth) can also be determined by using the equation (2), (3), (4) [3]:

$$Range\ Frequency\ (\Delta f) = FH - FL \quad (2)$$

$$Frequency\ Center\ (fc) = \left(\frac{FH-FL}{2}\right) \quad (3)$$

$$Bandwidth_{(\%)} = \left(\frac{\Delta f}{fc}\right) \times 100\% \quad (4)$$

Where Δf is the range of frequencies used and fc is the middle frequency.

3. **System Design**

3.1 Determination of Specification

The specifications for antennas in the GPR system are expected as shown in Table 1.

Table 5: Specification of bowtie antenna for GPR system.

Parameter	Value
Operated Frequency	1,6 – 2,6 GHz
Bandwidth	*Ultra-Wide Band*
Return Loss	$\leq -10\ dB$
VSWR	≤ 2
Ringing Level	$\leq -30\ dB$
Radiation Pattern	*Unidirectional*
	Conductor : Copper ($t = 0{,}035\ mm$)
	Substrate : RT Duroid 5880 ($\varepsilon_r = 2{,}2\ ; h = 1{,}57\ mm$)

3.2 Determination of Antenna Design

The antenna is designed following the standard of microstrip antenna with a curve-shaped bowtie patch. To this antenna design a parasitic element is added to the side of the feedline. The addition of this parasitic element aims to widen the bandwidth of the bowtie antenna [8]. A dielectric substrate material is used for the antenna based on the RT-Duroid 5880 which has a dielectric constant (εr) of 2.2 and a thickness (h) of 1.57 mm. This antenna works at a frequency of 1.6 - 2.6 GHz for GPR system applications. The dimensions of the curve bowtie patch are obtained from the equation (5) [9] as follow:

$$y\ (x) = s.\,e^{rx} \quad (5)$$

Where $y(x)$ is the length of the side of the bowtie arm, s is the gap width on the patch and r is the diameter of the curve. For the dimensions of the antenna substrate, an equation can be used from (6) and (7) as follow:

$$W_s \geq 6h + 2TL \quad (6)$$

$$L_s \geq 3h + TL + L_f \quad (7)$$

Where Ls is the length of the substrate, Ws is the width of the substrate, c is the speed of light, TL is length of the side of the bowtie arm and Lf is length of feedline. So from the results of calculations using equation (5), (6) and (7), the antenna dimensions are shown in Table 2 and the antenna design is shown in Figure 1.

Table 2: Dimension of bowtie antenna.

Parameter	Dimension (mm)	Note
Ls	50	Length of substrate
Ws	80	Width of substrate
Lf	37	Length of feedline
Wf	5,5	Width of feedline
TL	38	Length of the side of the bowtie arm
g	1	Gap between feedline
Lc	10	Length of parasitic element

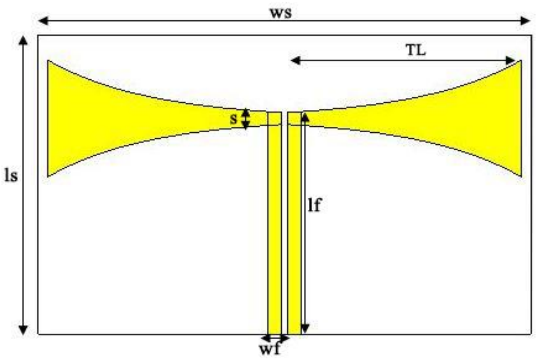

Fig. 1: Bowtie microstrip antenna without parasitic element.

4. Result and Analysis

Based on the antenna dimensions that have been designed through equations (5), (6) and (7), the bowtie antenna initiation will be carried out into the simulation software. The return loss value from the simulation results can be seen in Figure 2.

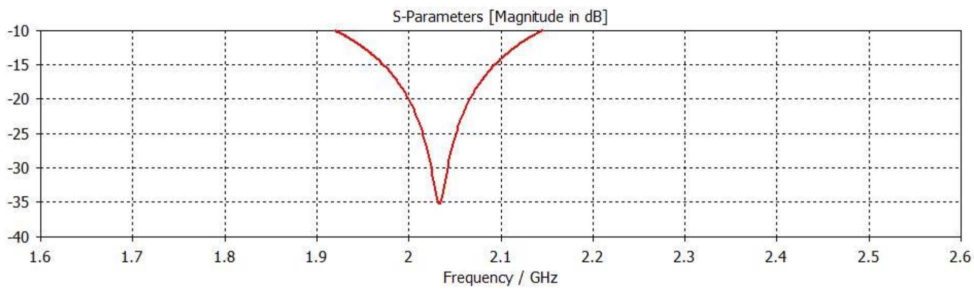

Fig. 2: Simulation of return loss graph of bowtie antenna without parasitic element simulation.

Return loss is the ratio of the power reflected back to the antenna with the power transmitted by the antenna. In Figure 2, it can be seen that the return loss value obtained in the simulation results is -14,15 dB at frequency 2,1 GHz. Then, the obtained bandwidth is at 226,1 MHz. However, the results of the optimization have not reached the minimum bandwidth expected because the resulting bandwidth did not reach the UWB category. So, the parasitic elements were added to the bowtie antenna in order to widen the antenna bandwidth which can be seen in Figure 3.

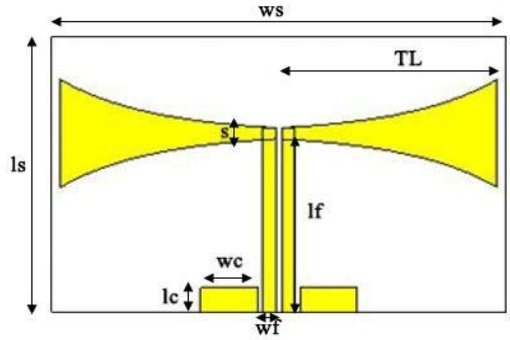

Fig. 3: Bowtie antenna with the addition of parasitic element.

The dimensions of the bowtie antenna with the addition of parasitic elements are shown in Table 3.

Table 3: Dimensions of bowtie antenna with parasitic elements.

Parameter	Dimension (mm)	Note
Ls	50	Length of substrate
Ws	80	Width of substrate
Lf	37	Length of feedline
Wf	5,5	Width of feedline
TL	38	Length of the side of the bowtie arm
g	1	Gap between feedline
Lc	10	Length of parasitic element
Wc	20	Width of parasitic element
gc	0,5	Gap between feedline and parasitic element

Based on the bowtie antenna initiation with addition of parasitic elements, the return loss value from the simulation results can be seen in Figure 4.

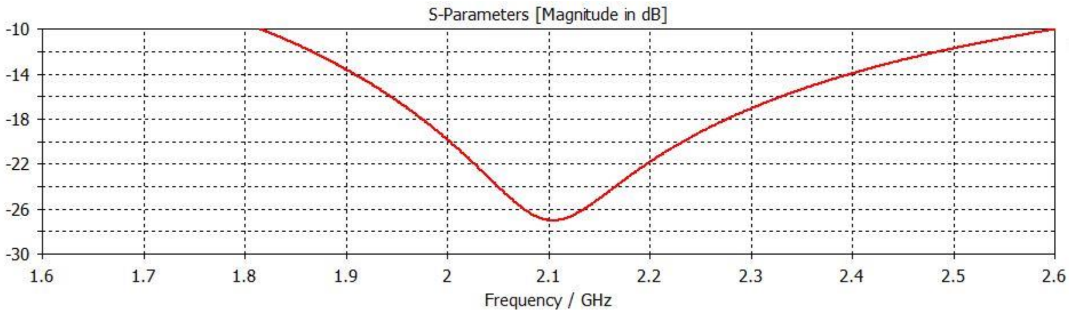

Fig. 4: Return loss graph of bowtie antenna simulation results.

In Figure 4, it can be seen that the return loss value obtained in the simulation results is -27,025 dB. Then, the obtained bandwidth is at 785 MHz from the frequency range in 1,815 – 2,6 GHz. This result clearly can meet with the UWB criteria because the fractional bandwidth value is more than the middle frequency.

Whereas VSWR is the ratio between the maximum voltage and the minimum voltage on a standing wave caused by the reflection of the wave between the transmission line and the antenna. The VSWR value for the simulation results on the bowtie curve antenna is 1,09 dB. While the radiation pattern is the antenna's radiating direction in radiating power in a certain direction. The radiation pattern is measured by azimuth direction and elevation. The depiction of the radiation pattern as an antenna beam intensity as a function of the spherical coordinate parameters (θ, φ).

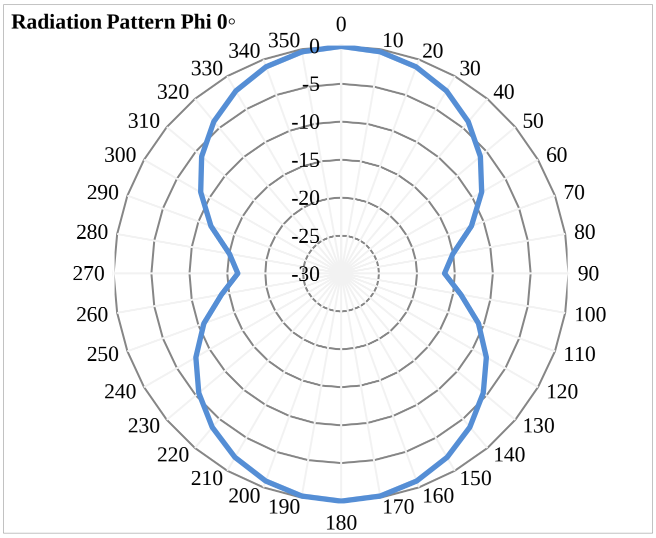

Fig. 5: Horizontal radiation pattern (azimuth, θ = 0 °)

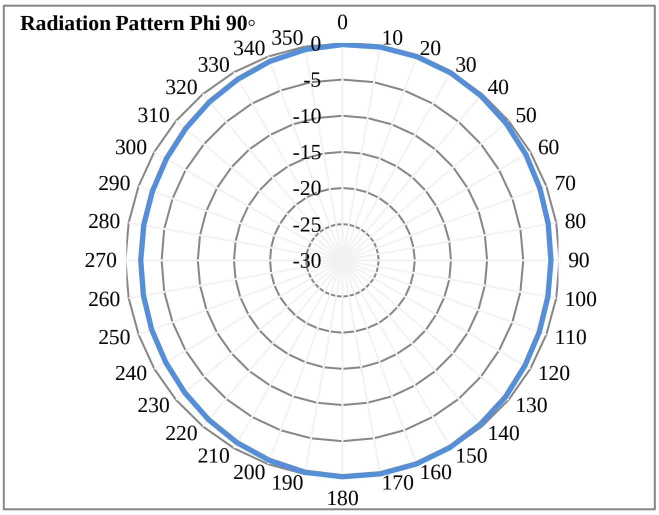

Fig. 6: Vertical direction radiation pattern (elevation, θ = 90 °)

Based on Figure 5, the simulation results on the radiation pattern in the horizontal direction have a maximum transmit power at an angle of 0º and 180º. Thus, the position of the antenna in transferring maximum power can be done at that angle in the direction of azimuth. While the radiation pattern with vertical direction as in Figure 6 shows that the antenna has a maximum power beam at all beam angles with respect to its vertical direction. Thus, the position of the antenna can be placed in all angles of elevation direction.

While the ringing level value obtained from the simulation results is -32,35 dB with a pulse width of 6 ns. Thus, the maximum limit of the ringing level meets the criteria of the GPR system specification. Moreover, the effect of adding parasitic elements on bowtie antenna is shown in Table 4.

***Table 4: Bowtie antenna comparison without parasitic elements and with parasitic elements*.**

Parameter	Bowtie antenna without parasitic elements	Bowtie antenna with the addition of parasitic elements
Return Loss (dB)	-14,15	-27,025
VSWR	1,48	1,09
Bandwidth (MHz)	226,1	785
Ringing Level (dB)	-30,84	-32,35

5. Conclusion

In this study a bowtie antenna was designed as an antenna on the GPR system. The antenna is designed using the RT-Duroid 5880 substrate material with the addition of the parasitic element method which aims to increase the bandwidth of the antenna. Based on the simulation results, the bowtie antenna with parasitic elements has a bandwidth of 785 MHz which means the fractional bandwidth value is greater than 25%, ringing level of -32,35 dB, return loss of -27,025 dB and VSWR 1,09 for transmit power efficiency. The antenna has a radiation pattern in the bidirectional form where the maximum transmit power is at an angle of 0º and 180º in the azhimut direction and at each angle in the elevation direction. Thus, the results of the design of the bowtie antenna indicate that the bowtie antenna has met the criteria of the GPR antenna system.

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