Design and Optimization of a Bowtie Antenna for Ground Penetrating Radar (GPR) System

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The location of underground objects can be determined by using Ground Penetrating Radar (GPR) system. The GPR operates in both MHz and GHz frequency band ranges and it uses ultra-wideband (UWB) radar systems. These systems are used to obtain high-resolution values for the accurate detection of objects. Typically, UWB radar systems for GPR technology are implemented using different types of antennas such as TEM horn antennas, cone slot antennas, helical antennas, bow-tie antennas, and Vivaldi antennas. The antenna characteristics required by ground penetrating radar systems must have a large bandwidth to check image resolution. This article describes the design method and theoretical conception of a bow-tie antenna that is developed for GPR applications. The dimensional parameters of the antenna are varied and their effects are judged in order to analyze its influence on return loss and operating bandwidth. The prescribed antenna is designed on a low-cost FR-4 substrate of 520 mm × 240 mm dimensions. Bow-tie antennas have been extensively studied and used to transmit and receive electromagnetic waves. The advantages of using this form are high radiation efficiency, thin profile, ease of manufacture and low manufacturing cost. Bow-tie antennas have been researched and developed as special-purpose electromagnetic wave receivers or transmitters. We have studied the dimensions of the antenna in the frequency range from 0.1 GHz to 3 GHz, using the electromagnetic simulation tool in the frequency domain CST.

Keywords: Ground Penetrating Radar (GPR), Bowtie Antenna, BF, CST.

1. INTRODUCTION

GPR is a high-resolution method for imaging the surface and subsurface. It is based on EM wave propagation within the frequency range of 10 MHz – 10 GHz. The GPR consists of two antennas, one emits electromagnetic waves which functions as transmitting antenna and the other as receiving one or both of them at the same time [1-2]. Transmitting antennas generate electromagnetic waves and scatter the waves onto objects buried in the ground or behind walls. The wave speed corresponds to the dielectric constant of the medium. When a wave hits an object, part of the wave is reflected by the object and the receiving antenna captures that part of the wave. The working schematic of the GPR system is shown in Fig. 1 [2].
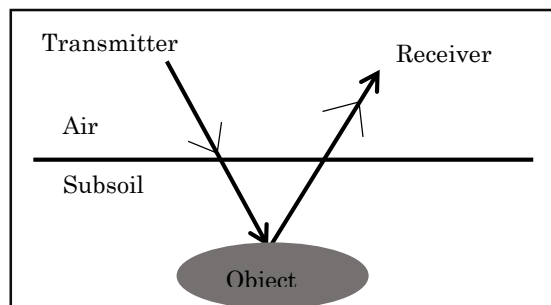

Fig. 1 – General working principle of GPR.

Different types of antennas such as horn antennas, loop antennas, and microstrip antennas, but a lot of research has been done on printed bowtie antennas to improve their broadband characteristics, that's why we are chose in our work to improve the bowtie antenna characteristics [3]. Bow-tie antennas are the preferred antenna type for most researchers when performing GPR measurements [4]. This can be explained in particular by its linear polarization characteristics, its low directivity, its relatively limited bandwidth and its ease of manufacture [3-5]. That's why we are chosen in our work to improve the bowtie antenna characteristics. This work develops a bow-tie antenna for GPR applications. This antenna consisting of a single piece of metal with two horns and a feeder wire attached to it. It is used in many applications such as Ground Penetrating Radar and is widely used. An extensive research studies have been carried out demonstrating different antenna design techniques for GPR applications [6-8].

This article presents the design of a bow-tie antenna for intended GPR applications. The influence of the geometrical parameters of the antenna is studied, three parameters of a T-BA will optimize, length, width and the distance between two antenna triangles, to know their influence on the resonant frequency and the working bandwidth is analyzed. The antenna studies are built on an inexpensive FR-4 substrate measuring

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520 mm × 240 mm. We checked the antenna dimensions in the frequency range from 0.1 GHz to 3 GHz using the CST frequency domain electromagnetic simulation tool.

Antenna efficiency is also an important part of the system. Better antenna efficiency depends on continuous optimization. The physical characteristics of the antenna.

2. GEOMETRY OF ANTENNA

The prescribed design has been implemented on a 1.6 mm thick FR-4 substrate. The substrate's dimensions are designated as length, $L = 520$ mm, and width, $W = 240$ mm. The antenna is fed with a 300-ohm SMA connector. The optimized dimensions are indicated in Fig. 2 as $L_T = 188.8$ mm, $L_m = 136$ mm, $W_T = 192$ mm, $W_m = 10.4$ mm, $S = 46.4$ mm, $G = 3$ mm. The simulation results are showing in Fig. 3.
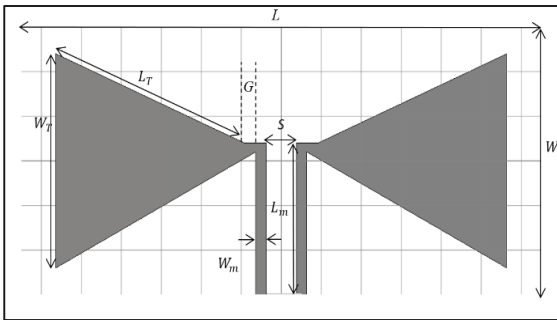
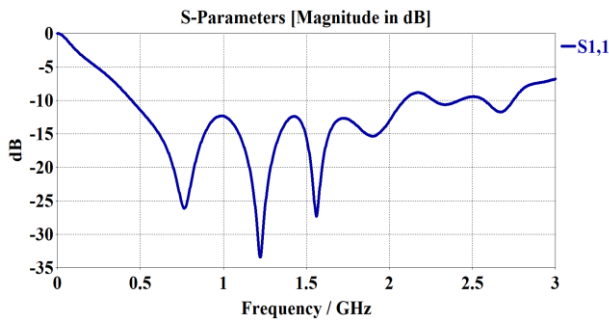**Fig. 2** – Bowtie antenna geometry

Fig. 3 – S_{11} vs. frequency characteristics

3. RESULTS AND DISCUSSION

The proposed bow-tie antenna has been studied, simulated and optimized by CST Microwave Studio, taking all major design parameters into consideration. This section discusses and explains the effects of length variations, width variations and also analyze the dimensional changes in the distance between two antenna triangles on the resonance behavior (S_{11} parameter, Bandwidth, resonant frequency etc) [5].

3.1 Length Variations

In this phase of geometrical investigations, we are interested in improving the reflection coefficient of the proposed antenna. In order to achieve this goal, we have optimized the length of the antenna, starting with the variation with a value of $L_T = 160$ mm. The values of length parameter are varied with a decreasing step

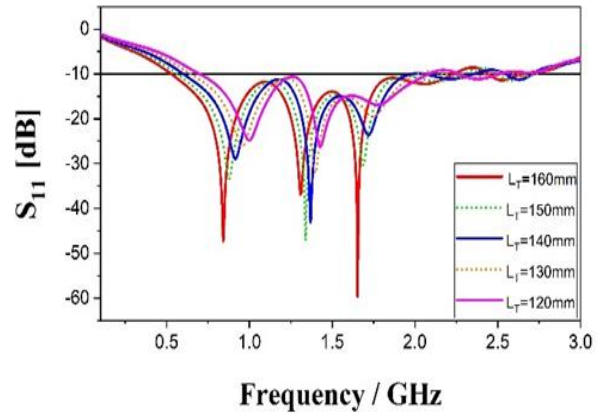of 10 mm and taken up to a value of $L_T = 120$ mm. The results are presented in Fig. 4.

Fig. 4 – S_{11} graphs of simulated antenna (variations of length).

Initially, the analysis has been started with $L_T = 120$ mm, the S_{11} value for this case is noticed as – 26 dB at the frequency 1.426 GHz. The bandwidth is obtained from the frequency range 0.708 GHz to 2.035 GHz. For a value of $L_T = 130$ mm, we can see that the S_{11} value for this antenna is – 32 dB at 1.398 GHz along with a frequency range coverage from 0.652 GHz to 2.0 GHz resulting in a bandwidth of 1.347 GHz. Then for the value of $L_T = 140$ mm, the antenna functions at 1.368 GHz with a reflection coefficient of – 42 dB. The entire bandwidth is attained from 0.608 GHz to 1.935 GHz. The prescribed design with $L_T = 150$ mm provides 1.351 GHz bandwidth from the frequency range 0.572 GHz to 1.923 GHz. The antenna shows a S_{11} (dB) of – 47 dB at 1.340 GHz in this design case. Finally, with $L_T = 160$ mm, the reflection coefficient value obtained for this antenna is – 60 dB at the frequency of 1.654 GHz. The total bandwidth achieved is 1.324 GHz from 0.534 GHz to 1.858 GHz.

Then the value proposed for the length is $L_T = 160$ mm.

3.2 Width Variation

In this section the variations of width, WT of the antenna are performed to justify its effect on the antenna's characteristics (mainly operating bandwidth) and to select its optimal value based on analysis. The width values are varied in accordance of 20 mm step size from 110 mm to 190 mm. Fig. 5 shows the result of the simulation.
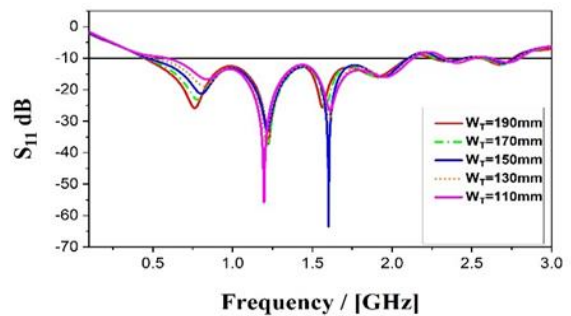

Fig. 5 – S_{11} graphs of simulated antenna (variation of width).

For a dimension of $W_T = 110$ mm, the reflection coefficient value achieved by this antenna at 1.196 GHz frequency is -55 dB. The bandwidth is found as 1.3518 GHz from the frequency range of 0.609 GHz to 2.127 GHz. Next, the width is tuned to $W_T = 130$ mm. The observations are S_{11} of -37 dB at 1.209 GHz, IBW of 1.589 GHz and frequency band coverage from 0.519 GHz to 2.108 GHz. Again, when WT is varied and fixed to 150 mm, this antenna has a return loss of 63 dB at 1.602 GHz. It operates with a bandwidth of 1.591 GHz from 0.499 GHz to 2.09 GHz. Further, for $W_T = 170$ mm, our analysis shows that this antenna's return loss is 36 dB at 1.225 GHz. The bandwidth attained for $W_T = 170$ mm is 1.63 GHz (0.467 GHz to 2.097 GHz). Finally, when WT equals 190 mm, the antenna resonates at 1.224 GHz with a S_{11} of -37 dB. For this case, the antenna obtains maximum bandwidth of 1.639 GHz and covers a frequency spectrum from 0.455 GHz to 2.094 GHz. Then the value proposed for the width is $W_T = 150$ mm.

3.3 Distance Between the Two Antenna Triangles

In this section, we have discussed the optimization of the distance (S) between the two antenna triangles through parametric variations. The distance or gap parameter is varied with a uniform step size of 10 mm from $S = 16.4$ mm to $S = 56.4$ mm. The results obtained after analysis are presented in Fig. 6.
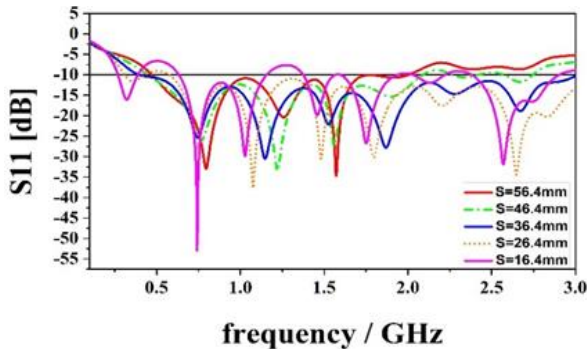

Fig. 6 – S_{11} graphs of simulated antenna (variations of distance between the two antenna triangles).

In the first step of the execution of analysis, the distance between patch triangles (S) is set to 16.4 mm and with this, the antenna resonates at 0.741 GHz with a return loss 52.7 dB. Then the obtained bandwidth is 0.517 GHz from the frequency range 0.635 GHz to 1.152 GHz. For a value of $S = 26.4$ mm, we can see that the return loss value for this antenna is 37.7 dB at 1.074 GHz and it covers the frequency range 0.583 GHz to 3 GHz, resulting in a bandwidth of 2.417 GHz. The antenna results in a bandwidth of 2.573 GHz covering a wide frequency spectrum of 0.427 to 3 GHz and resonates at 1.150 GHz with a return loss of 30.4 dB for

$S = 36.4$ mm. After that, for $S = 46.4$ mm, the bandwidth is reported as 1.625 GHz (0.455 – 2.080 GHz) and a maximum return loss of 33.4 dB is attained at 1.222 GHz. Then, for $S = 56.4$ mm, the return loss value obtained for this antenna is 34.6 dB at the frequency 1.265 GHz and the bandwidth obtained is 1.324 GHz from the frequency range 0.477 GHz – 1.742 GHz. Then the value proposed for the distance (S) between the two antenna triangles is $S = 16.4$ mm.

3.4 Gain & Radiation Efficiency

It can be observed that the proposed antenna has a peak gain of 5.54 dB at 1.55 GHz and the minimum radiation efficiency is more than 94 % for full working band.
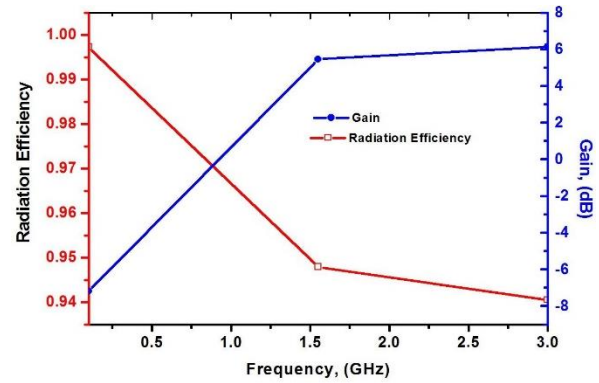

Fig. 7 – Gain and Efficiency vs frequency of proposed bowtie antenna

4. CONCLUSION

An antenna is the most crucial component of a ground penetrating radar (GPR) system. Better outcomes for GPR applications will be produced by system advancements in antenna designing methods. In this presented article, a bow-tie antenna design is prescribed for the GPR system. The structure is constructed using FR4 substrate material. The width, the distance between the two antenna triangles and the length of the antenna are all optimized to determine which of these three parameters has the greater impact on the antenna. Based on the simulation results, it is noted that the antenna length and width have an influential effect in characteristics parameters by contributing to the notable variations in the levels of reflection coefficients in between -26 dB and -60 dB for the optimization of length, and between -36.7 dB to -66.5 dB for optimization of widths. The results obtained with the variation of distance between antenna triangulars show that this parameter has an effect on the bandwidth of antenna and also on reflection coefficient. So, the distance between the two antenna triangles has a major effect on the antenna than the variations in width and length.

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Розробка та оптимізація антени-метелика для георадарної системи

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Місцезнаходження підземних об'єктів можна визначити за допомогою системи георадара. Георадар працює в діапазоні частот МГц і ГГц і використовує ультраширокосмугові (UWB) радарні системи. Ці системи використовуються для отримання значень високої роздільної здатності для точного виявлення об'єктів. Як правило, радіолокаційні системи UWB для технології георадару реалізуються з використанням різних типів антен, таких як рупорні антени TEM, конусні щілинні антени, спіральні антени, антени-метелик і антени Вівальді. Характеристики антени для георадарних систем повинні мати велику смугу пропускання для перевірки роздільної здатності зображення. У цій статті описано метод проектування та теоретичну концепцію антени-метелика, розробленої для георадара. Розмірні параметри антени змінюються, і їх вплив оцінюється, щоб проаналізувати її вплив на зворотні втрати та робочу смугу пропускання. Зазначена антена розроблена на недорогій підкладці FR-4 розмірами 520 мм × 240 мм. Антени-метелик були широко вивчені та використані для передачі та прийому електромагнітних хвиль. Перевагами використання цієї форми є висока ефективність випромінювання, тонкий профіль, проста конструкція та низька вартість виготовлення. Антени-метелик були досліджені та розроблені як приймачі і передавачі електромагнітних хвиль спеціального призначення. Нами розроблена і досліджена антена для діапазона частот від 0,1 до 3 ГГц, використовуючи інструмент електромагнітного моделювання в частотній області CST.

Ключові слова: Георадар (GPR), Антена-метелик, BF, CST.