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Design and Analysis of Different Bow-Tie Configurations for Submarines

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ABSTRACT: Antenna design is generally specified by the length which should be equal to half-wavelength at the frequency of interest. This creates difficulty in designing antennas for very low and high frequencies. Along with it, Communication with submarines through conventional means of communication is difficult as the signals attenuate at high frequencies when they travel through good electrical conductors like salt water. This paper attempts to design different bow-tie antennas specified solely by the angle for under water communication in submarines in the frequency range of 200 - 400 MHz with a bandwidth of 200 MHz. The proposed antennas are printed above FR4 substrate which is cost effective and has zero water absorption. The antenna is fed by coaxial cable that makes matching easier. Advantages of the proposed antennas are wide bandwidth, directional radiation pattern, low cross polarization, low profile and minimum fabrication complexity. The results showed that the antennas possess minimum reflection coefficient (< - 8 dB) and high gain (> 2) within the specified frequency band. The models are designed and analysed using CST software.

KEYWORDS: bow-tie antenna; reflection coefficient; gain; flare angle

I. INTRODUCTION

The parameters like bandwidth, efficiency and gain can be provided by wideband antennas within the limited volume. The most important feature of wideband is that they can simultaneously access intermediate frequencies within a frequency band. Bow-tie is such type of wideband antenna which is solely defined by its flare angle. Flare angle, α helps to achieve impedance matching. It can also be varied with width, gap and height of the bow-tie. For longer bow-tie arm or larger angles, the current flows through longer path to the gap, so the effective length of the antenna is increased, leading to longer wavelength, which corresponds to lower frequency. A wider impedance bandwidth can be achieved by adding a pair of parasitic patches or with curving edges for a bow-tie slot or introducing slots configurations inside the bow-tie arms.

The main application of this antenna is in submarines. Submarines communicate with the outside world by raising an antenna above the sea level or antennas within the depth of sea. To communicate with submerged submarines several antennas such as VLF and ELF antennas are used. VLF radio waves can penetrate seawater up to a depth of 8 – 10 m whereas ELF waves can penetrate seawater to depths of 100 meters. Submarines use frequencies in the HF, VHF and UHF ranges to carry information by raising antenna above the surface of the water. HF antennas are used when the submarine operating far away from the shore and VHF/UHF antennas are used when it is within the line-of-sight distance. Submarines would be operating deep inside the water most of the time but at predefined time schedule, they would ascend up to the periscopic depth and raise their antenna above the surface of water in order to communicate with the outer world. But it could endanger the submarine to its detection by the enemy radars or airborne observers.

As the antenna impedance is different when the antenna is in air or water, an appropriate matching circuit is used to attain the impedance matching. But antennas utilising a matching circuit may suffer from complete signal loss if any changes in temperature and salinity occur in the water due to the high dielectric property of water. Thus choose broadband underwater antenna that can accommodate the changes in such a heavy dielectric medium. Within dipoles, one of the simplest types of antenna is the bow-tie that potentially has the correct properties to be used as an underwater antenna.

The main purpose of the proposed antenna is to provide i) Minimum reflection coefficient and ii) maximizing gain within the frequency band in order to obtain maximum power transfer.

II. RELATED WORK

In [1] Low Frequency multiband slotted bow-tie antenna is proposed for stroke detection. Magnetic Resonance Imaging (MRI) and Computed Tomography (CT scan) which are used to detect stroke suffer from problems such as high costs as well as harmful side effects as a result of ionization. As an alternative technique, the antenna can be operated directly on or near to the skin without any damage to the body. Due to the increasing signal attenuation in human tissues with the higher frequency, low frequencies are required for stroke detection. The result from simulation shows that this technique provides a high potential for medical diagnostics due to low system complexity, low cost and non-ionizing characteristics of microwave signals. In [2] authors used the adaptive nature of bow-tie antenna that can be achieved by changing the flare angles according to the variation in the antenna elevation and soil type. This helps to minimize the reflections at the input terminal of antenna which leads to maximum energy that result in maximum radiation by the antenna. The variation in the flare angle is possible by short-circuiting the feed gaps with the help of PIN diodes. This antenna type is mainly used in the application of Ground Penetrating Radar surveys where the distance between the antenna and the ground varies due to non-flatness of the ground surface and/or the operator's movement. In [3], three types of novel bow-tie antennas with round corners are presented including quadrate, rounded-edge and triangular shapes. When quadrate bow-tie antenna with round corners is compared with quadrate bow-tie antenna, it shows that former has smaller area than the latter. This results in better return loss due to the round corners with radius R_1. Due to the existence of round corners, the return loss and stability of radiation patterns are improved simultaneously by changing the current distribution on radiation surface of triangular BTA. In [4], author presents various means of radio communication to send messages to submarine at various depths of under water. Conventional means of radio communication cannot receive signals at the depths as the higher frequencies get attenuated very sharply in sea water. Two main bands used for means of communication in under water are VLF and ELF band. In VLF band, signals can penetrate up to 8 - 10 m of depth. ELF is another band which can communicate with submarine up to 100 m depth but data rate is very low. HF and VHF/UHF frequency bands are used as means of communication with submarines when they are at the surface of the sea. This is made possible by raising antenna above the surface of water. The proposed multiband antenna in [5] is a rectangular patch with a slot bowtie on it and printed on a Teflon substrate. This paper discusses the idea of introducing circular and hexagonal slots configurations inside the bowtie arms, leading to double resonances in the 2 and 3 GHz bands besides the resonance in the 5 GHz band.

III. ANTENNA DESIGN

Different configurations of bowtie antennas discussing in the paper are simple bowtie, rounded bowtie, slotted bowtie and wired bowtie antenna. All the four antennas are fabricated above FR4 substrate which is cost-effective in nature with a dielectric constant of 4.4. They are fed by coaxial cable which have advantages like easy to couple, fabricate, wider bandwidth and less spurious radiation. Parameters were optimized using CST software.

Simple bowtie antenna shown in Fig.1 consists of bi-triangular sheet of metal which is specified by the angle between them. The specifications are designed to work in the frequency range of 200 - 400 MHz. Arm_length is defined as the half length of the bow-tie which takes 289.82mm value for simple bow-tie. Flare angle is 60˚ which is defined as the angle within the metal sheet. The thickness of the substrate is 3.175mm. The substrate dimension is 94.1 x 57.96 cm^2. Advantages of simple bow-tie are broadband characteristics, high gain, attractive radiation pattern, low cross polarisation, low profile and minimum fabrication complexity.

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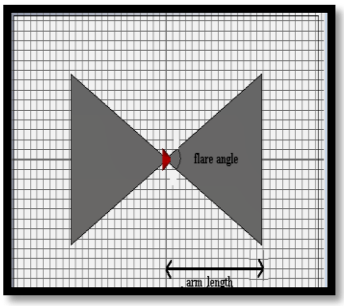

Fig.1. Simple Bow-Tie Antenna

A bow-tie antenna with curved edges called as rounded edge bow-tie antenna as shown in Fig.2 which can widen the bandwidth of the simple bow-tie. The arm_length is extended to 365.60mm in case of rounded bowtie with flare angle equals 87˚. The substrate dimension is 91.4 x 91.4 cm^2 with substrate thickness of 3.2 mm. The better return loss, flatter input impedance and more stable radiation patterns are the advantages. It is used extensively in many domains such as pulse-exciting antennas, ground-penetrating radar etc.

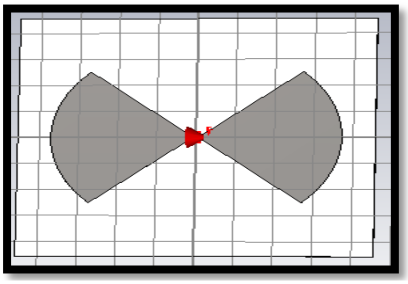

Fig.2. Rounded Edge Bow-Tie

Rounded edge bow-tie with slots as shown in Fig.3 can widen the bandwidth that ranges from 17 % to 40 %. The specifications of the slotted antenna are same as that of the rounded edge. The only difference is that it includes a slot of dimension 14.4 cm x 8.3 cm x 8.3 cm. By proper selection of the slot parameters, the antenna can achieve wide bandwidth. Slotted bow-tie antenna can be used in aircraft radar, X-band, UWB applications etc.

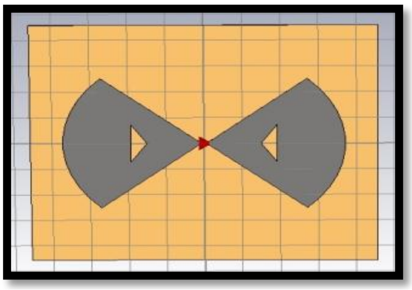

Fig.3.Slotted Rounded Edge

An array of thin wire dipoles having a common feed point at the vertex is termed to be wired bow-tie antenna shown in Fig.4. A wire bow-tie antenna can be optimized to provide minimal reflection at its terminal and maximal transmitted field strength. All the dipoles are printed on FR4 substrate with a dielectric constant of 4.4 and thickness of the substrate is 3.2 mm. The substrate dimension of the wide band antenna is 91.4 x 91.4 cm^2. The adaptive form of this design allows a fast and convenient way for controlling the bow-tie flare angle required in a real GPR survey depending on soil type.

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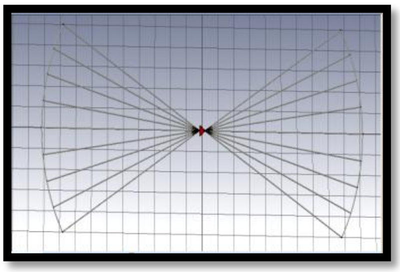

Fig.4.Wired Bow-Tie Antenna

IV. SIMULATION RESULTS

All the results are simulated using CST (Computer Simulation Technology) software. Reflection coefficient and gain are the two important parameters used to confirm whether the parameters of the designed antenna are suitable for submarine applications. Reflection coefficient determines the frequency band in which minimum power will be reflected towards source and maximum power will be radiated. Gain gives the power transmitted in the direction of peak radiation to that of an isotropic source. An antenna having gain > 2 dB can give better directivity and efficiency.

In simple bow-tie antenna, the reflection coefficient is < -10 dB which results in 89 – 90 % of the power radiation for the whole band. Fig.5 shows that the frequency band ranges from 233.65 MHz to 412.08 MHz. The corresponding bandwidth for the antenna is 178.43 MHz which is lesser than the required result, 200 MHz.

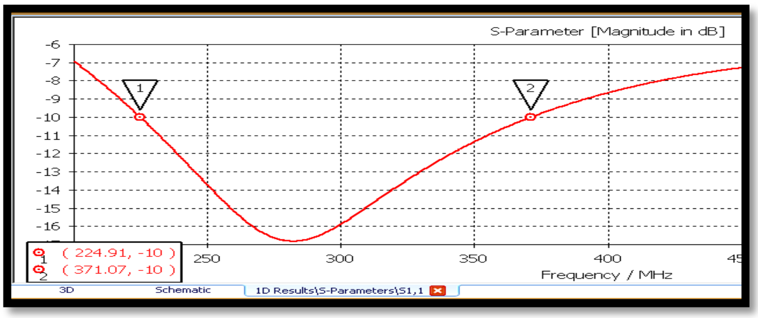

Fig.5. Reflection coefficient of Simple Bow-Tie Antenna

In terms of gain, it is clear from the Fig.6 that the gain is greater than 2 in all the three frequencies such that it can give better radiation. Result shows that maximum gain attained by Simple Bow-Tie is 3.464 dB at 400 MHz.

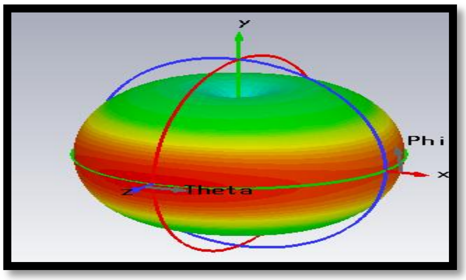

Fig.6. Gain of Simple Bow-Tie Antenna

By curving the edges, the performance of the simple bow-tie antenna can be improved. Rounded edge bow-tie is not sensitive to small parameter variations. Fig.7 shows that by curving the edges of the bow-tie, the lower frequency gets shifted to left results in broader bandwidth with 89.34 % power transfer.

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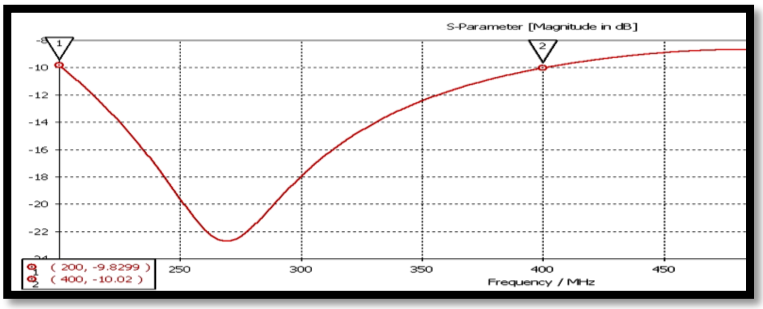

Fig.7. Reflection coefficient of Rounded Edge Bow-Tie Antenna

Rounded edge bow-tie antenna obtains a maximum gain of 3.588 dB which is greater than the simple bow-tie antenna at central frequency, 400 MHz as shown in Fig.8.

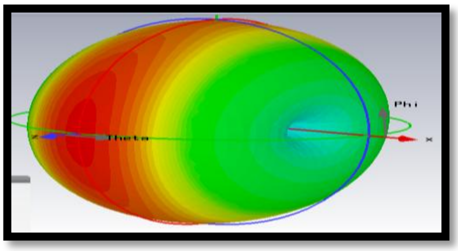

Fig.8.Gain of Rounded Edge Bow-Tie Antenna

Slotted bow-tie antennas provide wider bandwidth depends on the position of the slots in the arms. Fig.9 shows the antenna can radiate 89.52 % of the power with reflection coefficient < -9.5 dB which satisfies the condition (< -8 dB).

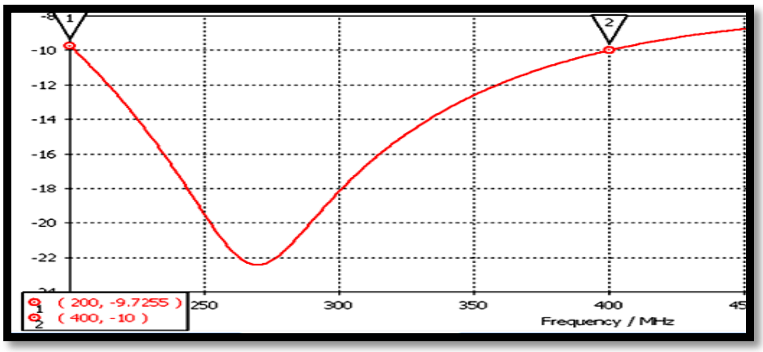

Fig.9. Reflection coefficient of Slotted Edge Bow-Tie Antenna

Fig.10 illustrates that it give maximum gain of 3.762 dB at the central frequency of 400 MHz which is greater as compared to rounded and simple bow-tie antenna.

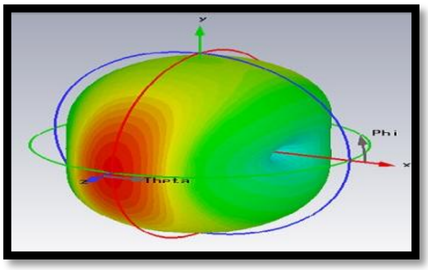

Fig.10.Gain of Slotted Edge Bow-Tie Antenna

Wired bow-tie is a type of 3D structure practical antenna which provides lesser reflection coefficient and higher gain compared to other bow-tie antenna. Fig.11 shows that frequency band covers reflection coefficient less than -8.47 dB.

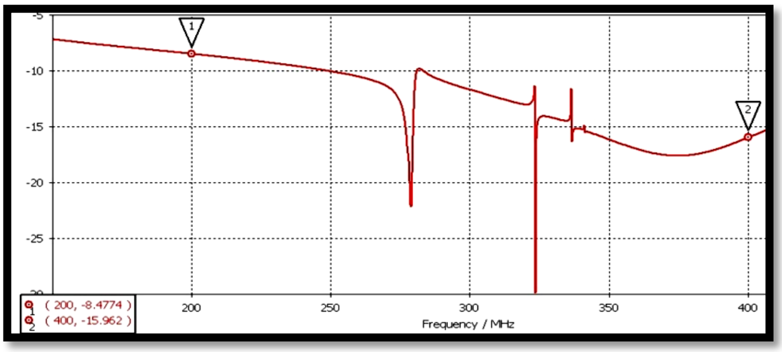

Fig.11. Reflection coefficient of Wired Bow-Tie Antenna

Fig.12 indicates that out of all the other configurations of bow-tie, wired bow-tie is having maximum gain at the central frequency.

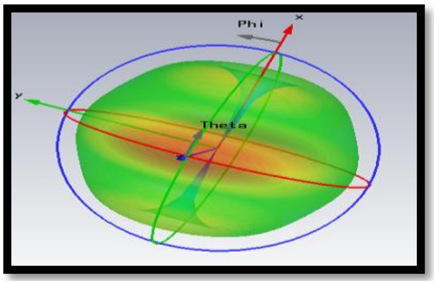

Fig.12.Gain of Wired Bow-Tie Antenna

Wired bow-tie antenna design attains a maximum gain of 4.407 dB at 400 MHz which is greater in magnitude as compared to other structures like simple, rounded and slotted bow-tie antennas. Thus this antenna can be used in practical applications with maximum output power. Another important factor of this antenna is that the performance can be varied with the help of flare angles. There is a possibility of matching the bow-tie antenna to the feed line by varying its flare angle either electronically or mechanically with the help of PIN diodes which results in better performance.

V. CONCLUSION AND FUTURE WORK

Broadband bow-tie antennas are designed and simulated by CST software for the frequency band from 200-400 MHz. Simple bow-tie is designed to acquire the desired frequency band. But the simulation result shows that it can only give bandwidth up to 179 MHz with a maximum gain of 3.464 dB at the central frequency of 400 MHz. Thus designed a rounded edge bow-tie for widening the bandwidth. This design helps to achieve bandwidth of 200 MHz with a maximum gain of 3.588 dB at 400 MHz. A slotted bow-tie antenna is proposed for improving the bandwidth for the required application. Slots in the arms help to achieve approximately 200 MHz bandwidth with a gain of 3.762 dB at the central frequency. A wired bow-tie is simulated to obtain a 3D structure for practical application which covers the frequency band with 86% power transfer and obtain high gain of 4.407 dB. Compared to the above antennas, wired bow-tie can easily match the input impedance with the help of flare angles to achieve maximum power transfer.

There are many techniques from which one can obtain more bandwidth, less mismatch, high gain and maximum radiation can be obtained. Adaptive bow-tie is the one which can adapt its input impedance depends on the variation in the flare angles which in turn maximizes the power transfer. Another technique makes use of fractal geometry, which gives rise to fractal antennas to attain higher bandwidth and antenna gain with in a smaller volume. Different types of

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balun shape are utilized to reduce discontinuity in power flow and enhancement for return loss at the resonant frequencies. This helps in maximum power transfer and good radiation pattern.

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BIOGRAPHY

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