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Antennas for Search and Rescue Using Electromagnetically Coupled Patch and Bow-Tie Structures Based on PDMS

[1]Idris H. Smaili, [2]*Hidayath Mirza, [3]Rais Ahmad Sheikh, [4]Nishat Sultana, [5]Eman Harb, [6]Haja Banu Shaikh

[1,2,3]Department of Electrical and Electronic Engineering, College of Engineering and Computer Science, Jazan University, P.O. Box114, Jazan 45142, Saudi Arabia
[4,5]Department of Business Administration, Applied College, Jazan University, Jazan 45142, Kingdom of Saudi Arabia
[6]Department of Computer, Applied College, Jazan University, Jazan 45142, Kingdom of Saudi Arabia

***Abstract* - This research aims to develop low-profile rectangular electromagnetically coupled patch and bow-tie antennas using a polymer substrate, specifically designed for search and rescue missions. The antennas are fabricated on a polydimethylsiloxane (PDMS) substrate known for its durability, flexibility, water resistance, and suitability for demanding environments. The search and rescue application requires antennas with longer electrical lengths due to the lower operating frequency of 406 MHz, resulting in larger physical dimensions. To address this, an Electromagnetically Coupling-based antenna approach is employed to ensure a compact form factor. Simulation results demonstrate that both antennas operate at a central frequency of 406 MHz, with the Rectangular Electromagnetically Coupled Patch Antenna exhibiting a bandwidth of 11.93 MHz and the Bow-Tie Antenna showcasing a wider bandwidth of 300 MHz. The fractional bandwidths for the two antennas, expressed with a -10 dB reference level, are found to be 2.93% and 66.66% respectively.**

Keywords: wearable antennas, flexible antennas, compact antennas, search and rescue, Cospas-Sarsat.

I. INTRODUCTION

COSPAS, short for Cosmicheskaya Systyema Poiska Aariynyich Sudov, and SARSAT, an abbreviation for Search & Rescue Satellite technology assisted Tracking System, constitute a satellite-based radiolocation system that operates globally to provide assistance in search and rescue operations for individuals facing distress in aviation, maritime, and terrestrial environments. SARSAT was jointly developed by France, Canada, and the United States. COSPAS-SARSAT, an intergovernmental network established in 1979 by Canada, France, the United States, and the Soviet Union, involves the collaboration of 45 nations. The purpose of the COSPAS-SARSAT system is to transmit Search and Rescue (SAR) data, including emergency location information, to the authorized authorities of the 45 nations that have ratified the agreement. This data transmission facilitates efficient coordination and execution of search and rescue missions. Currently, the program operates with a total of 62 operational satellites[1].

Numerous scholars have made noteworthy contributions to this subject matter through publications focused on the development of antennas tailored specifically for this particular purpose. These research studies have diligently addressed the imperative requirement of ensuring the robustness of antennas in challenging environmental conditions by employing durable materials. The investigation presented in the following examines the performance of two distinct designs of meandering dipole antennas operating at a frequency of 406 MHz [2]. Two textile materials are under consideration, one exhibiting conductivity while the other lacks electrical conductivity. The conductive textile material possesses an electrically measured loss tangent (tan) of 0.044 and a permittivity (ε_r) of 1.44. Its thickness measures three millimeters. The second fabric variant, referred to as a shielding blanket, incorporates conductive elements into its design for the suggested antennas. The shielding layer is measured to have a thickness of 0.17 millimeters and exhibits a conductivity of 1.18 x $10^5$5 S/m. The antenna in question demonstrates a fractional bandwidth of 10.05%. Its proposed dimensions are 200 millimeters by 75 millimeters by mm^3, equivalently expressed as $0.271\lambda_0 \times 0.102\lambda_0 \times 0.0041\lambda_0$. References [3] and [4] provide details about a patch-type antenna operating at a frequency of 406 MHz. The antenna employs a low-loss foam material as its substrate, and the conductive components are fabricated using an inkjet-printing technique. At the tuned frequency of 406 MHz, the antenna's dimensions are 283 millimeters by 65 millimeters by 17.5 mm ($0.383\lambda_0\times 0.088\lambda_0\times0.024\lambda_0$). To evaluate its performance, the antenna was positioned perpendicular to a human body model, with the separation distance systematically varied from 0 to 200 millimeters. Additionally, the impact of water on the antenna's return loss was investigated by varying the distance between the water and the antenna from 0 to 120 millimeters. This allowed the researchers to examine the influence of water on the return loss characteristics. A unique system that may be worn on a life vest was presented by researchers in a recent study[5]. In a recent study, researchers introduced a novel system designed to be worn on a life vest [5]. This system comprises two attachable antennas, where one antenna is coupled to the floating elements on the chest, while the other antenna is coupled to the floating elements on the neck. As life jackets commonly feature buoyant components on the chest and neck, these areas were chosen for antenna attachment to fulfill their intended functions. Both antennas under investigation in this study are meandering dipole antennas, folded and utilizing a Rohacell substrate. Their resonant peak is achieved at a frequency of 406 MHz. At this frequency, the antenna dimensions measure 300 millimeters by 150 millimeters by one millimeter $(0.406\lambda_0 \times 0.203\lambda_0 \times 0.0014\lambda_0)$. The proposed antenna exhibits a fractional bandwidth of 4%. Experimental results showed a simulated gain of 7 dB when the antenna was situated on the chest; however, this value decreased to 1 dB when the antenna was positioned on the head [6].

II. ANTENNA DESIGN

2.1 Materials

During the course of this investigation, the antenna configuration incorporates two distinct materials. One of these materials, LessEMF Inc. ShieldIt Super™, is a conductive textile employed in the development of the antenna's conductive components, specifically the radiator and the ground plane. This particular textile was manufactured by LessEMF Inc. It possesses a thickness of 0.17 mm and exhibits an electrical conductivity of 1.18 x 10^5 S/m. In contrast, the polydimethylsiloxane (PDMS) substrate utilized in this study has a permittivity (ε_r) value of 2.7, a loss tangent (tanδ) value of 0.02, and a thickness of 3 mm. ShieldIt Super and PDMS have previously found applications in the field of satellite communications antennas and polarizing converter surfaces [7]–[9].

2.2 Rectangular electromagnetically coupled patch antenna (RECP)

Patch antennas are widely utilized due to their compact form, lightweight nature, and compatibility with Monolithic Microwave Integrated Circuits (MMICs), making them advantageous for various applications [10], [11]. However, a key limitation of patch antennas is their inherent constraint in bandwidth, primarily influenced by the resonance characteristics of the patch structure.

In modern times, communication systems such as GPS, vehicular networks, and WLAN demand compact and cost-effective antennas. Consequently, planar technology has emerged as a valuable and often necessary solution to meet these requirements. Compared to typical single-layer patch antennas, EM-coupled patch antennas exhibit superior impedance bandwidth. To enhance the bandwidth, various techniques can be employed, including adjusting patch height, reducing relative permittivity, utilizing stacked patches, incorporating coplanar parasitic subarrays, integrating shorting pins, or introducing slots.

The EM-coupled patch antenna configuration consists of a patch element positioned on top of a two-dielectric structure, with a feed line extending underneath the patch between the two substrates. These components are electromagnetically interconnected. The bandwidth enhancement is achieved by placing the patch element on a thicker combined substrate. Conversely, mitigation of spurious radiation is accomplished by positioning the feed line closer to the ground plane [12], [13], as illustrated in Fig. 1 (a), (b), (c), and (d). Fig. 1 (a) and (b) depict the front view and side view of the antenna design, while Fig. 1 (c) and (d) present the same antenna design using CST Microwave Studio. Table 1 provides the dimensions of the antenna parameters used for design and simulation.

The feed line, located on the lower substrate, is a microstrip line extending beneath the patch. This arrangement enables the feed to be in close proximity to the ground plane, thereby minimizing undesired radiation from the feed network. Matching the feed is achieved by appropriately overlapping the line and patch.

2.3 Procedure for Working

The rectangular patch antenna is commonly utilized as a microstrip antenna in various applications. Typically, it operates in close proximity to its resonance frequency to achieve a real-valued input impedance. The presence of fringing fields causes the effective length of the patch to increase. As a result, the length of a half-wave patch is often shorter than half a wavelength in the dielectric medium.

By employing two substrates, the feed can be positioned closer to the ground plane, effectively minimizing undesired radiation from the feed network. This configuration allows for a substantial combined thickness of substrate material between the patch and the ground plane. The increased overall thickness of the composite substrate enables a wider range of impedance frequencies compared to a patch with only one substrate. The antenna design presented here is intended for Search and Rescue applications at a frequency of 406 MHz. The antenna exhibits a -10dB fractional bandwidth of 2.93%, spanning from 400 MHz to 411.93 MHz, with a bandwidth of 11.93 MHz.

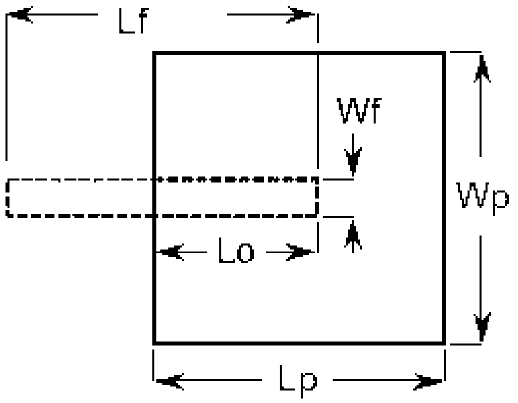


Figure 1(a): Top View of Rectangular electromagnetically coupled patch antenna (RECP)

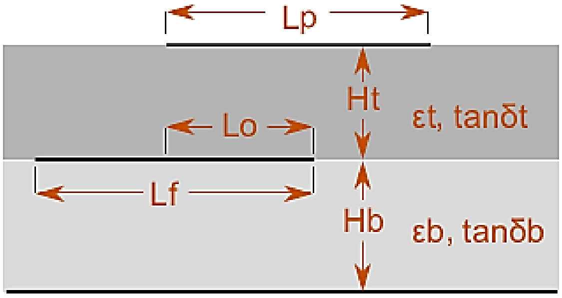
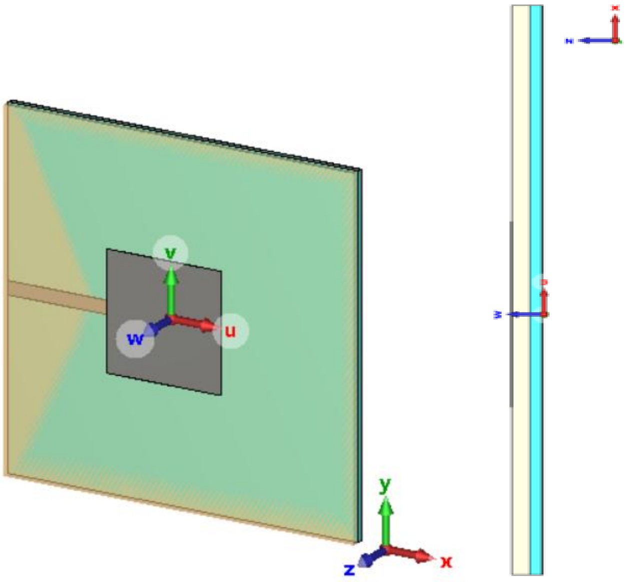


Figure 1(b): Side View of Rectangular electromagnetically coupled patch antenna (RECP)



(c) **(d)**

Figure 1(c): Front View and, (d): Side view of Rectangular electromagnetically coupled patch antenna (RECP) in CST

Table 1: Description of parameters used for designing the antenna

Parameter	Value (mm)	Parameter	Value (mm)
f_0	406 MHz	H_t	13.33
L_p	200.32	L_f	287.72
W_p	200.32	W_f	23.30
L_o	104.64	ε_b	2.7
H_b	9.51	ε_t	2.7

2.4 Antenna Topology of a Bow-tie antenna

Modified dipole configurations are commonly employed to achieve broad frequency coverage while maintaining a simple antenna design. The bow-tie antenna, considered a straightforward variant of the dipole antenna, exhibits satisfactory wide-band performance despite its inherent simplicity [14].

The bow-tie antenna has gained significant popularity due to its efficient operation across a wide range of frequencies, from UHF to the millimeter wave spectrum. It has also been successfully utilized in various array configurations. The antenna's performance is relatively insensitive to minor parameter fluctuations, enhancing its durability in the presence of manufacturing tolerances. However, while the bow-tie antenna offers satisfactory wide-band performance, it does not possess the characteristics of a high-performance antenna. More complex designs may be required for demanding applications.

For pulse radiation applications, such as ground penetrating radar (GPR), the resistively loaded bow-tie antenna has been identified as a viable option [15], [16]. The construction of the bow-tie antenna is straightforward, and it exhibits a high level of durability. However, at lower frequencies, the antenna's size can become excessively large, limiting its practicality. Bow-tie antennas are often implemented with the assistance of a dielectric substrate or fabricated using suspended metal cut-outs. To preserve antenna performance, it is preferable to use thin substrates with low permittivity.

Bow-tie antennas exhibit moderate gain and a wide range of operating frequencies. The primary factor restricting the performance bandwidth is pattern performance. For applications that do not require high complexity, a 3:1 operating bandwidth can be achieved. While a wider range of frequencies may exhibit favorable impedance characteristics, the primary beam of the antenna experiences unpredictable shifts at higher frequencies. The impedance characteristics also degrade when thicker substrates with higher permittivity are employed.

Figure 2(a) and Figure 2(b) depict the front and side views of the antenna design, while Figure 2(c) and Figure 2(d) illustrate the design in CST Microwave Studio. Table 2 provides a description of the parameters used in designing the antenna.

The design guidelines for the bow-tie antenna are outlined as follows:

- To improve the impedance match, it is recommended to decrease the thickness and permittivity of the substrate.
- To achieve a higher operating frequency, it is advised to decrease the length of the arms.
- Conversely, to increase the operating frequency, it is recommended to increase the length of the arms.
- In order to enhance the antenna's gain, it is advisable to reduce both the substrate thickness and permittivity.

The Bow-Tie antenna is now introduced for its application in Search and Rescue scenarios, specifically at a frequency of 406 MHz. The antenna under consideration exhibits a fractional bandwidth of -10 dB, spanning 66.66% from 300 MHz to 600 MHz, with a bandwidth of 300 MHz.

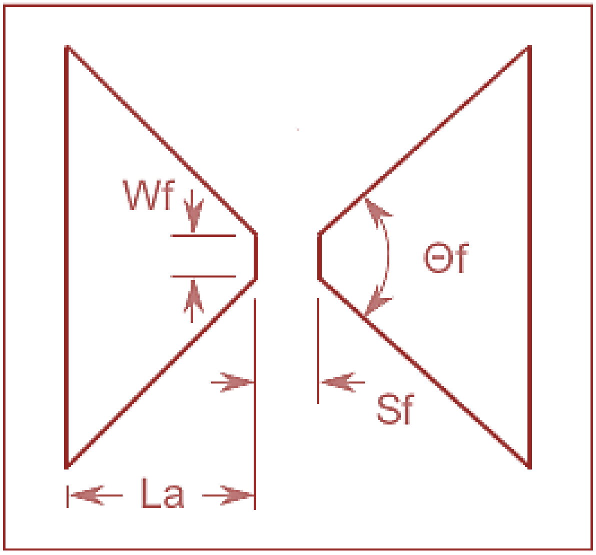


Figure 2(a): Front view of bow-tie antenna

Figure 2(b): Side view of bow-tie antenna

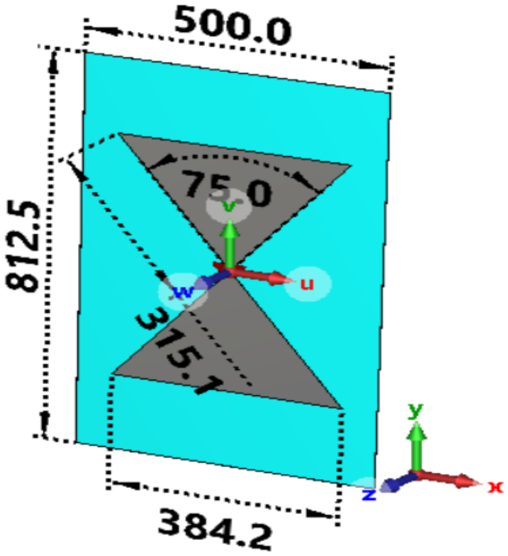


Figure 2(c): Simulated front view of the antenna in CST

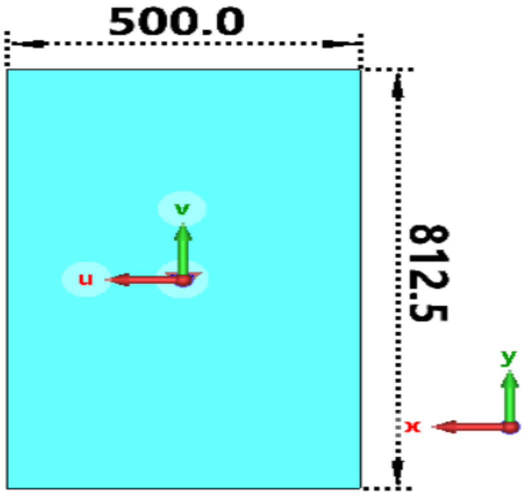


Figure 2(d): Simulated back view of the antenna in CST

Table 2: Description of parameters used for designing the bow-tie antenna

Parameter	Value (mm)	Parameter	Value (mm)
ε_r	2.70	S_f	0.50
L_a	250.00	θ_f	75°
W_f	0.50	H_s	0.30

III. RESULTS AND DISCUSSIONS

The reflection coefficient results for two different antennas, namely the RECP antenna and the bow-tie antenna, are depicted in Figure 3(a) and Figure 3(b), respectively. Both antennas demonstrate resonance at a frequency of 406 MHz, indicating optimal impedance matching for the intended frequency. The bow-tie antenna exhibits a wider bandwidth of

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67.4 MHz, whereas the RECP antenna has a bandwidth of 40.5 MHz. This observation underscores the ability of both antennas to effectively cover a range of frequencies around 406 MHz.

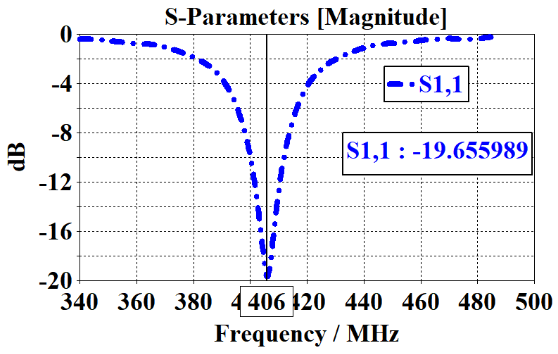


Figure 3(a): -10 dB reflection coefficient RECP antenna

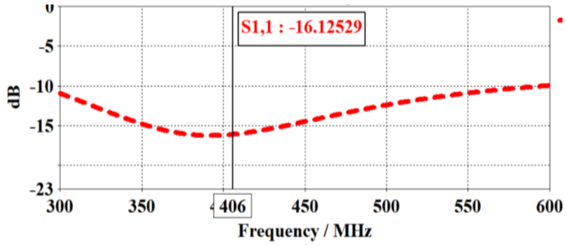


Figure 3(b): -10 dB reflection coefficient Bow-Tie antenna

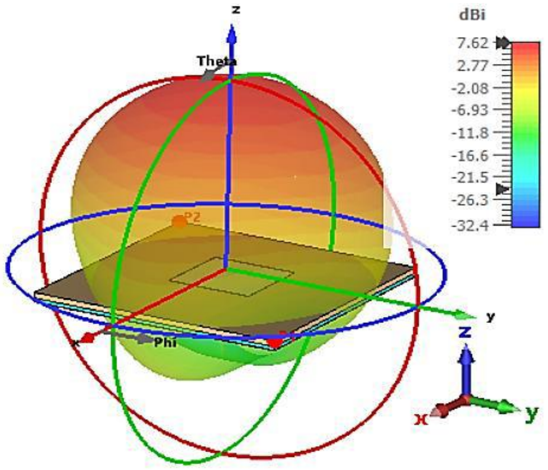


Figure 4(a): 3D radiation pattern with antenna in the center for RECP antenna

Both the RECP antenna and the bow-tie antenna exhibit three-dimensional (3D) gain radiation patterns, as illustrated in Figure 4(a) and Figure 4(b), respectively, along with their respective antenna structures. In both cases, the maximum gain is observed in the z-direction, which is advantageous considering the antennas will be positioned on beacons and oriented towards the sky. This characteristic is of utmost importance as it enables effective signal transmission to satellites. It is crucial to avoid any nulls at 0° or in the z-direction, as this would hinder signal transmission to the satellite. The realized gains achieved by both the RECP antenna and the bow-tie antenna surpass the recommended values for radiation patterns [17].

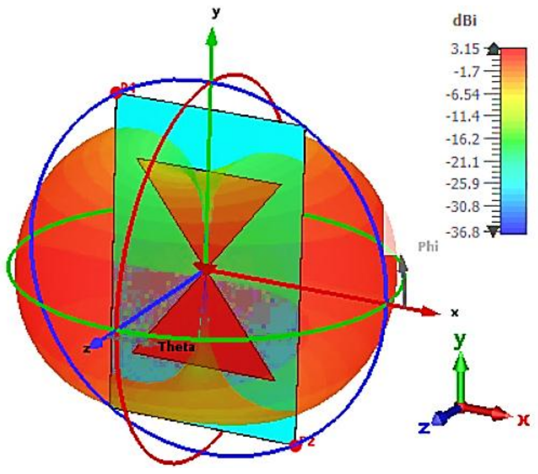
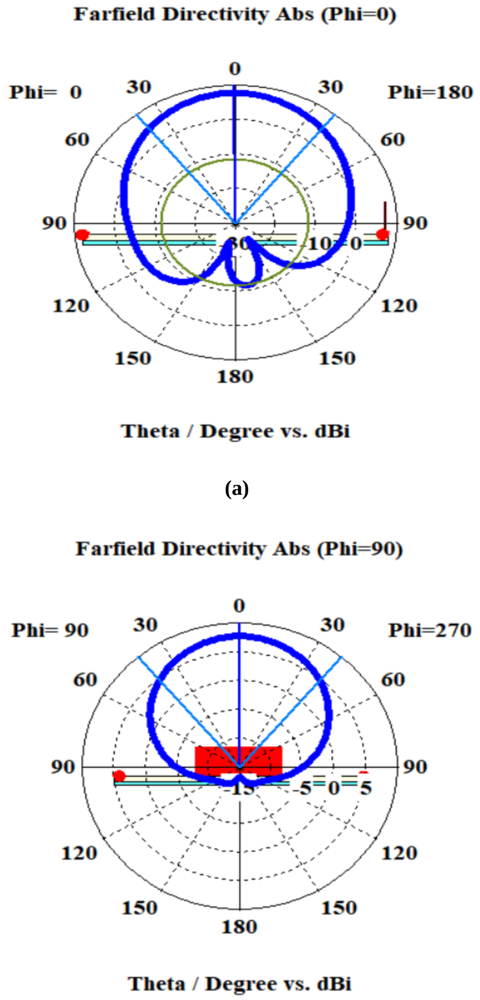


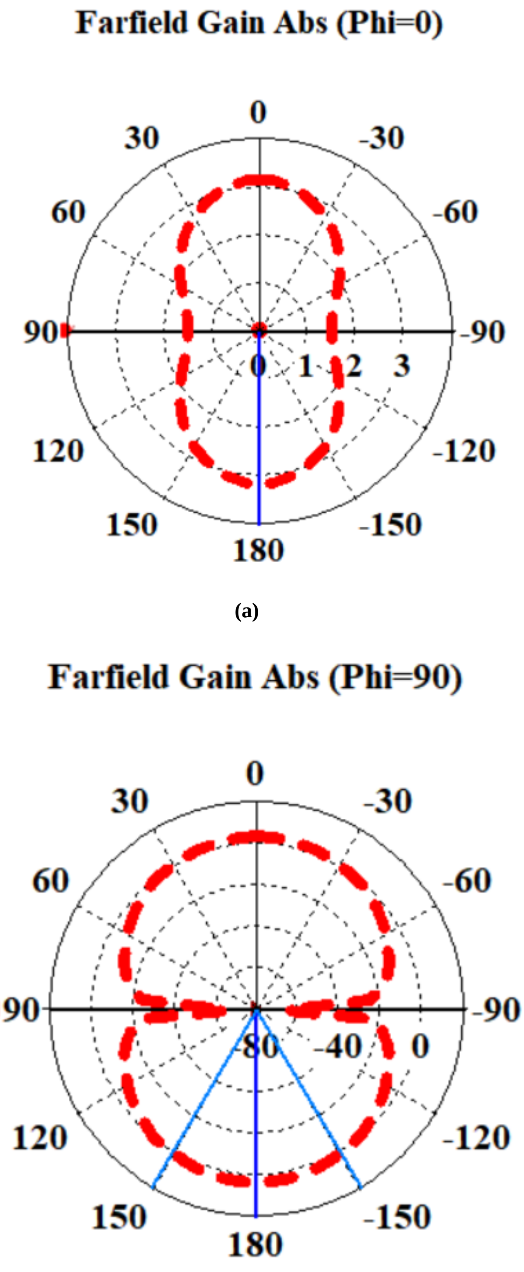
Figure 4(b): 3D radiation pattern with antenna in the center for bow-tie antenna



(a)

(b)

Figures 5(a), 5(b) demonstrate the magnitude of directivity depicted as radiation patterns for different angular values (φ) of 0° and 90°. Notably, the antenna exhibits no nulls at 0°



(b)

Figure 6: Simulated Gain radiation patterns of the bow-tie antenna in free space: (a) E_{φ} (φ =0°), and (b) E_{φ} (φ=90°)

In the case of the bow-tie antenna, it exhibits a pattern that is largely omni-directional inside the horizontal plane when operating at frequencies that are close to the minimum frequency (fmin=300MHz). When positioned in the broadside direction, the antenna is able to obtain the highest possible gain. The pattern, on the other hand, undergoes a dramatic decline as the frequency rises above twice the minimum frequency, which is 600 MHz. The radiation patterns that are displayed in Figure 6(a) and 6(b) demonstrate the typical behavior of a bow-tie structure when it is in an environment that is free of obstructions. The flare angle of this structure is 75 degrees or more.

IV. CONCLUSION

The goal of the current research is to create a novel and adaptable COSPAS-SARSAT beacon antenna. The antenna is designed to be used in COSPAS-SARSAT Mission Control Centers and operates at a frequency of 406 MHz.

Two antennas have been presented, each fulfilling separate fundamental objectives. The first objective is to achieve optimal impedance matching at 406 MHz, while the second objective is to attain maximum gain at a 0-degree angle. These two functions are independent of each other. In terms of construction, the conducting element of the antenna is composed of Shield It Super, while the substrate is made of PDMS. The entire structure is designed to be flexible from the ground up, offering flexibility as a key feature. During the analysis of the two antennas, it was observed that the simulated -10 dB fractional bandwidth under planar conditions was 2.93% for the RECP antenna and 66.66% for the meander line antenna, respectively.

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