Nano World Journal

https://doi.org/10.17756/nwj.2024-s1-011

Research Article Open Access

Flexible Search and Rescue Antennas Using Rectangular Electromagnetically Coupled Patch Using Fe_3O_4 Nanoparticles and Bow-tie Antennas Based on Pure PDMS Substrate

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Received: January 03, 2024
Accepted: March 06, 2024
Published: March 11, 2024

Citation: Mirza H and Sultana N. 2024. Flexible Search and Rescue Antennas Using Rectangular Electromagnetically Coupled Patch Using Fe_3O_4 Nanoparticles and Bow-tie Antennas Based on Pure PDMS Substrate. *NanoWorld J* 10(S1): S57-S62.

Published by United Scientific Group

Abstract

The primary objective of this research is to develop low-profile rectangular electromagnetically coupled patch (RECP) and bow-tie antennas utilizing a polymer substrate. This technology was specifically designed to cater to the requirements of search and rescue missions. The antennas being discussed in this context are the RECP and bow-tie antennas, which have been specifically constructed on a substrate made of polydimethylsiloxane (PDMS). PDMS is selected due to its advantageous characteristics, including its durability, flexibility, water resistance, and appropriateness for deployment in demanding environmental circumstances. The operation of the search and rescue application requires the use of antennas with a longer electrical length due to the lower frequency of 406 MHz consequently, these antennas demonstrate a propensity towards larger physical dimensions. The problem can be resolved by employing an electromagnetically coupling-based antenna, hence guaranteeing a compact form factor. The findings from the simulations indicated that the antenna functioned at a central frequency of 406 MHz, with a bandwidth of 11.93 MHz for the RECP antenna and 300 MHz for the bow-tie antenna. The bandwidths observed for the two antennas were found to be 2.93% and 66.66% when expressed as a fractional bandwidth percentage with a -10 dB reference level. Furthermore, the construction of a low-profile RECP has been implemented by incorporating iron oxide (Fe_3O_4) nanoparticles in conjunction with a pure PDMS substrate. The selection of this antenna was based on its narrow bandwidth for the reflection coefficient. The incorporation of a magneto dielectric substrate into the existing substrate has resulted in a significant improvement in the antenna's characteristics, particularly the -10dB fractional bandwidth, which has increased from 2.93% to 13.38%. To the authors' knowledge it is the first time a magneto dielectric surface has been used in search and rescue antenna.

Keywords

Wearable antennas, Flexible antennas, Compact antennas, Search and rescue, COSPAS- SARSAT, Iron oxide nanoparticles

Introduction

COSPAS, an abbreviation for Cosmicheskaya Systyema Poiska Aariynyich Sudov, and SARSAT, a shortened form of Search and Rescue Satellite technology assisted Tracking System, are fundamental constituents of a satellite-based radiolocation system that operates through global collaboration. The purpose of this system is to offer support in search and rescue missions for those who are in a state of difficulty, encompassing aviators, seafarers, and land passengers. SARSAT was developed simultaneously by France, Canada, and the United States. COSPAS-SARSAT is an intergovernmental network of emergency rescue satellites designed to fulfil a humanitarian objective. The collaborative endeavor, which was commenced in 1979 by Canada, France, the United States, and the Soviet Union, included the involvement of 45 nations. The COSPAS-SARSAT system enables the transmission of search and rescue data, encompassing emergency location information, to the relevant authorities of the 45 nations that have ratified the agreement. The transmission of data facilitates efficient coordination and execution of search and rescue endeavors. Currently, the program consists of a collective of 62 operational satellites [1].

Quite a few academics have made significant contributions to this topic by publishing research that are concentrated on the development of antennas that are specifically suited for this one purpose. These studies have considered the critical necessity of ensuring the durability of the antennas under demanding environmental circumstances by employing a variety of long-lasting materials. This requirement has been given due consideration. An investigation of the presentation of two different designs for meandering dipole antennas that can work at a frequency of 406 MHz can be found [2]. There are two potential textile materials, one of which is conductive while the other does not conduct electricity. The first textile material has a loss tangent (tanδ) of 0.044 and a permittivity (ε_r) of 1.44 when measured electrically. It is three millimeters in thickness. The second type of fabric, which is referred to as a shield, is a blanket. Conductive elements are incorporated into the design of the antennas that have been suggested. The layer is measured to have a thickness of 0.17 millimeters, and its conductivity is found to be 1.18 x 10^5 S/m. It has been determined that the antenna in question has a fractional bandwidth of 10.05%. The proposed antenna has dimensions of 200 millimeters by 75 millimeters by mm^3, which can also be written as $0.271\lambda_0$ x $0.102\lambda_0$ x $0.0041\lambda_0$. The reference [3] provides information on an antenna that is of the patch type and that operates at a frequency of 406 MHz. As the substrate, it makes use of a low-loss foam material, and the conductive components are made via an inkjet-printing technique. When it is tuned to a frequency of 406 MHz, the antenna has the dimensions of 283 millimeters by 65 millimeters by 17.5 mm mm^3, ($0.383\lambda_0$ x $0.088\lambda_0$ x $0.024\lambda_0$). The antenna was placed in a position that was perpendicular to the human body model, and the distance that separated the antenna from the model was systematically varied within the range of 0 to 200 millimeters. The effect of water on the return loss of an antenna was studied by varying the gap distance between the water and the antenna, which ranged from 0 to 120 millimeters. This allowed the researchers to examine the impact of water on the return loss. A unique system that may be worn on a life vest was presented by researchers in a recent study [4]. This system consists of two antennae that can be attached to the vest. The floating elements on the chest are coupled to one of the antennas, while the floating elements on the neck are coupled to the other antenna. When it comes to the apparatus used for saving lives, the most common type of life jacket is the one with the buoyant component attached to the chest and the neck. The antenna is attached to both areas of the buoyant component of the jacket so that it can fulfil its designated functions. Both antennas that are going to be covered in this study are going to be meandering dipole antennas, and they are going to be folded, and they are going to use a Rohacell substrate. The frequency of 406 MHz is where these antennas reach their peak state of resonance. At a frequency of 406 MHz, the antenna has dimensions of 300 millimeters by 150 millimeters by one millimeter mm^3, ($0.406\lambda_0$ x $0.203\lambda_0$ x $0.0014\lambda_0$). The proposed antenna displays a fractional bandwidth that is 4% in magnitude. When the antenna was placed on the chest, the experiment demonstrated a simulated gain of 7 dB; however, this value dropped to 1 dB when the antenna was transferred to the head position [4].

Experimentation

Antenna design

Materials

During this investigation, the antenna layout will make use of not one but two different kinds of materials. LessEMF Inc. ShieldIt Super™ is one of the conductive textiles used in the development of the antenna's conductive components, specifically the radiator and the ground plane. This textile was manufactured by the company. With a thickness of 0.17 mm, the material has an electrical conductivity that is equal to 1.18 x 10^5 S/m. In comparison, the PDMS substrate that was utilized in this investigation has a value of 2.7 for its permittivity (ε_r), a value of 0.02 for its loss tangent (tanδ), and a thickness of 3 mm. There have been previous applications of ShieldIt Super and PDMS in the field of satellite communications antennas and polarizing converter surfaces.

RECP antenna

Patch antennas are widely utilized because to their recognized advantageous characteristics, including their compact form, lightweight nature, and compatibility with Monolithic Microwave Integrated Circuits. The primary drawback of this technology is an inherent constraint in bandwidth, stemming from the resonance characteristics of the patch structure [5, 6].

In contemporary times, communication systems such as global positioning system, vehicular networks, and wireless local-area network have a growing need for antennas that are compact and cost-effective. Consequently, planar technology has emerged as a valuable and often necessary solution to meet these requirements.

The impedance bandwidth of the electromagnetically coupled patch antenna is superior to that of a typical single-layer patch antenna. One significant limitation associated with patch antennas is their limited bandwidth. There are several techniques available for enhancing bandwidth, such as augmenting patch height, reducing relative permittivity, employing stacked patches, utilizing a coplanar parasitic subarray, incorporating shorting pins, or integrating slots.

The electromagnetically coupled patch antenna is composed of a patch element that is situated on top of a two-dielectric structure, and a feed line that extends underneath the patch between the two substrates. These components are electromagnetically related to each other. The enhancement of bandwidth is achieved through the placement of the patch element atop a thicker substrate that is combined. Conversely, the mitigation of spurious radiation is accomplished by positioning the feed line in closer proximity to the ground-plane [6, 7]. Figure 1a and 1b shows the front view and side view of the antenna design. The same antenna is shown in figure 1c and 1d using CST Microwave Studio. Table 1 Shows the dimensions of the antenna parameters used for design and simulation.

The feed line refers to a microstrip line located on the lower substrate, which extends beneath the patch. By employing this arrangement, it becomes possible to place the feed in closer proximity to the ground plane, hence restricting the occurrence of undesired radiation originating from the feed network. The matching of the feed is achieved through the utilization of a suitable line-patch overlap.

Procedure

The rectangular patch antenna is widely employed as a microstrip antenna in various applications. Typically, the system is operated near resonance in order to get an input impedance that is characterized by real values. The presence of fringing fields results in an increase in the effective length of the patch. Consequently, the length of a half-wave patch is often less than half a wavelength in the dielectric medium.

The utilization of two substrates enables the placement of the feed in closer proximity to the ground plane, hence restricting the occurrence of unwanted radiation originating from the feed network. This configuration allows for the retention of a substantial combined thickness of substrate material between the patch and the ground plane. The augmented overall thickness of the composite of the two substrates leads to a wider range of impedance frequencies in comparison to a patch that employs only one substrate. The antenna is presented for search and rescue application at 406 MHz. The presented antenna has a -10 dB fractional bandwidth of 2.93% ranging from 400 MHz to 411.93 MHz and a bandwidth of 11.93 MHz.

Antenna topology of a bow-tie antenna

Modified dipole forms are frequently employed to provide broad frequency coverage without escalating the intricacy of the antenna design. The bow-tie antenna is considered to be a straightforward version of the dipole antenna; however, it exhibits satisfactory wide-band performance despite its inherent simplicity [8].

The antenna in question has gained significant popularity due to its ability to operate efficiently across a wide range of frequencies, spanning from UHF to the millimeter wave spectrum. Additionally, it has been successfully utilized in various array configurations. The performance of the bow-tie antenna exhibits insensitivity to minor fluctuations in parameters, hence enhancing its durability in the face of manufacturing tolerances. Although the bow-tie antenna has satisfactory wide-band performance, it does not possess the characteristics of a high-performance antenna. In scenarios where demanding applications are involved, more intricate designs may be required. The resistively loaded bow-tie antenna has been identified as a viable option for pulse radiation purposes, particularly in applications such as ground penetrating radar [9, 10]. The construction of the bow-tie antenna is quite straightforward, and it possesses a high level of durability. However, its size can become excessively enormous while operating at lower frequencies, which may impose limitations on its practicality. The bow-tie antenna is frequently implemented with the assistance of a dielectric substrate or fabricated using suspended metal cut-outs. To prevent the deterioration of antenna performance, it is preferable to utilize thin substrates with low permittivity while employing a substrate. Bow-tie antennas exhibit a moderate level of gain and has a wide range of operating frequencies. The primary factor limiting the performance bandwidth is pattern performance. It is possible to achieve a 3:1 operating bandwidth for applications that do not require high levels of complexity. Although a wider range of frequencies can exhibit favourable impedance characteristics, the primary beam exhibits unpredictable shifts at higher frequencies. The impedance characteristics also experience degradation when thicker substrates with higher permittivity are employed. Figure 2a and 2b shows the front and side view of the antenna design. Figure 2c and 2d depicts the design in CST Microwave Studio. Whereas table 2 shows the description of the parameters used in designing the antenna. The design guidelines for the bow-tie antenna are as follows:

- To enhance the impedance match, decrease the substrate thickness and permittivity.

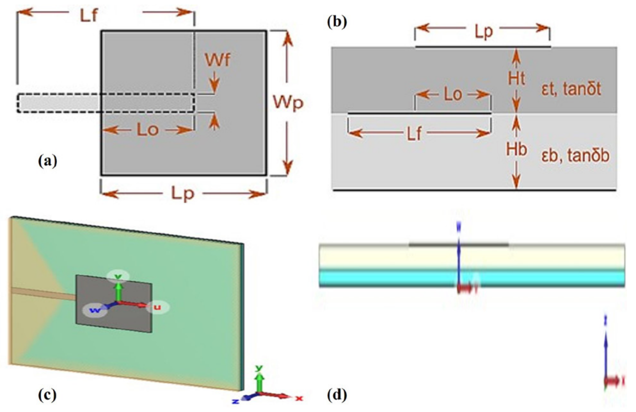

Figure 1: (a) Top view, **(b)** Side view, **(c)** Front view, and **(d)** Side view of RECP antenna in CST.

Table 1: Description of parameters used for designing the antenna.

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
H_b	9.51
ε_b	2.7
ε_t	2.7

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

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

- To increase the frequency of operation, decrease the arm length.
- To increase the frequency of operation, increase the arm length.
- Reduce the thickness of the substrate and the permittivity to achieve a higher gain.

Now the bow-tie antenna is presented for search and rescue application at 406 MHz. The presented antenna has a -10dB fractional bandwidth of 66.66% ranging from 300 MHz to 600 MHz and a bandwidth of 300 MHz.

Polymeric magneto dielectric (PDMS-Fe_3O_4) antenna substrate using nanoparticles

Need of polymeric magneto dielectric (PDMS-Fe_3O_4) antenna

A wide range of modern communication system applications, such as tracking, navigation, medical diagnostics, wireless applications, and military communication, necessitate the use of antennas that possess characteristics such as conformability, lightweight construction, compact size, and robustness. Furthermore, the enhancement of bandwidth can be utilized to increase the data transmission rate.

Furthermore, it is imperative that these systems exhibit a high gain and sufficient radiation efficiency to achieve optimal performance. The selection of substrate materials significantly influences the achievement of optimal performance and desired physical characteristics in antennas and radio frequency (RF)/microwave devices. Historically, planar antennas have been fabricated using commercially available, inflexible substrates such as FR-4, Duroid, Taconic, and similar materials. However, it is important to note that these materials do have some notable limitations, such as their lack of flexibility, restricted bandwidth, and the occurrence of large losses in specific scenarios [11, 12].

In contemporary times, there has been a growing prevalence of polymer-based substrates in the domain of antennas and other RF components. The topic under consideration deals to the various components that constitute a microwave system. The aesthetic properties of the material being examined pertain to its mechanical and electrical characteristics. Dielectric characteristics such as flexibility, lightweight, low permittivity, and low losses can be monitored and customized to suit specific RF/microwave applications. Several polymer-based substrates, such as PDMS and polyimide, have been employed for antennas in their original condition. Nevertheless, it is important to acknowledge that the materials possess restricted bandwidth when employed in their unadulterated state. Therefore, the introduction of modern production methods has enabled the utilization of polymer composites as substrates. Polymeric materials have been utilized in conjunction with other materials, such as nickel, ferrite, ceramic, titanium, and other substances, with the aim of augmenting the operational capabilities of antennas. However, prior research has not yet investigated the application of polymer-based composite substrates in the domain of search and rescue antennas. The main aim of this research is to examine the effectiveness of a flexible polymer magneto-dielectric composite substrate in enhancing the frequency range of antennas. The PDMS-Fe_3O_4 composite substrate, which exhibits magneto-dielectric properties, is synthesized through the incorporation of PDMS and magnetic Fe_3O_4 nanoparticles at different concentrations. The superior electrical and mechanical qualities exhibited by these materials make them well-suited to fulfill the requirements of modern antenna specifications [5, 11, 13-15].

Polymeric magneto dielectric (PDMS-Fe_3O_4) antenna design

The nanocomposite of Fe_3O_4 and polymer PDMS has been used in the simulation is 25% of Fe_3O_4 nanoparticles and 75% of PDMS ratio is used and is implemented as shown in figure 2e. This gives the ε_r = 2.7 and $\tan\delta_e$ = 0.001 and μ_r = 1.4 and $\tan\delta_m$ = 0.001 from the characterization results. The observation of figure 2f reveals: (a) The leftward shift in resonant frequency allows for the utilization of smaller antennas at lower operating frequencies. Typically, this relationship is inversely proportional. (b) The -10dB fractional bandwidth has increased from 2.93% (400 - 411.93 MHz) to 13.38%. It can be observed that the percentage of increase is an enhancement of 356.66% (370 - 423 MHz).

Results and Discussion

The results of the reflection coefficient for both antennas, a RECP antenna and a bow-tie antenna, are presented in figure 3a and 3b, respectively. The figure illustrates that both antennas exhibit resonance at a frequency of 406 MHz. This observation demonstrates that the antenna exhibits optimal impedance matching for the intended frequency with the bandwidth of 40.5 MHz and 67.4 MHz, respectively.

Both the RECP and the bow-tie antenna have achieved gain 3D radiation patterns, which are displayed in figure 4a and 4b, respectively, along with their respective antenna structures. The maximum gain of both antennas can be seen to be in the Z-direction, which is easy to see and confirm because the antenna will be positioned or placed on the beacon, and it will be facing upwards toward the sky, this attribute is highly significant because the antenna will be put on the beacon. If the antenna has a null at 0° or in the Z-direction. If this is the case, the antenna will not be able to send a signal to the satellite. The realized gain achieved for RECP antenna bow-tie antenna are above the recommended values for radiation patterns [16].

Figure 5a and 5b and figure 6a and 6b present the magnitude of gain in form of radiation patterns for φ = 0° and φ

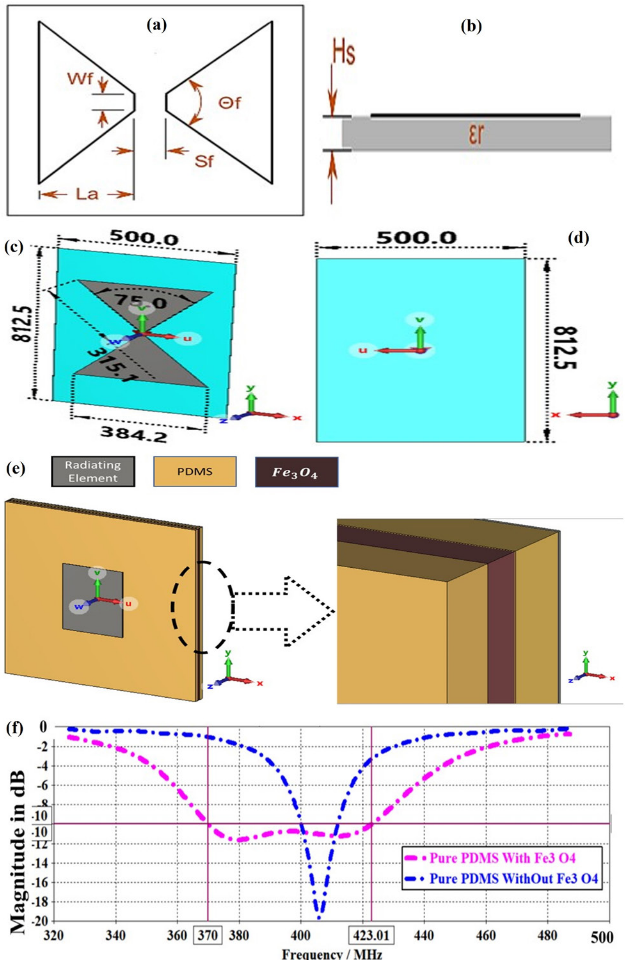

Figure 2: (a) Front view and **(b)** Side view of bow-tie antenna. Simulated **(c)** front view and **(d)** of the antenna in CST. **(e)** Magneto dielectric nanocomposite substrate (1 mm of Fe_3O_4 using 25%) the antenna in CST. **(f)** -10 dB bandwidth using with and without nanocomposite.

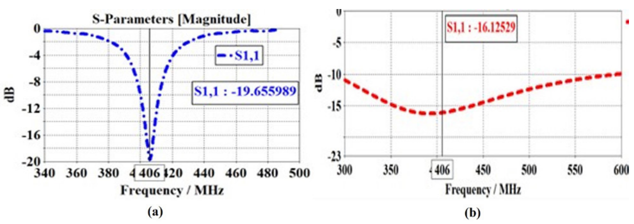

Figure 3: -10 dB reflection coefficient of **(a)** RECP and **(b)** Bow-tie antenna.

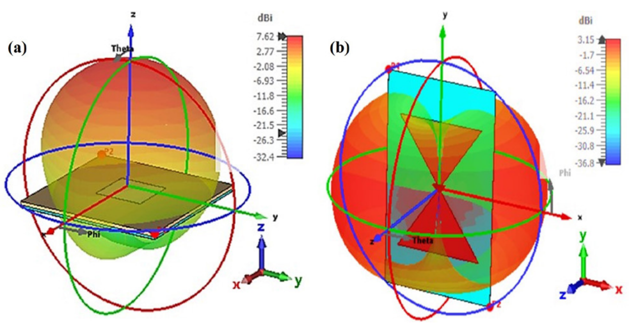

Figure 4: 3D radiation pattern with antenna in the center for **(a)** RECP and **(b)** Bow-tie antenna.

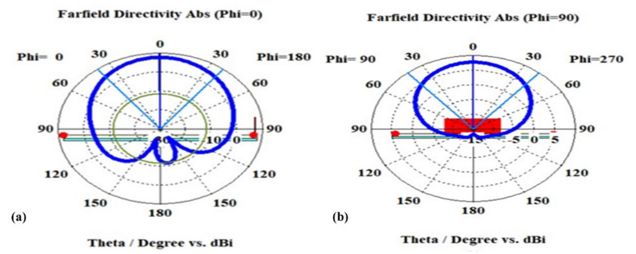

Figure 5: Simulated radiation patterns of the RECP antenna in free space: **(a)** E_φ (φ = 0°) and **(b)** E_φ (φ = 90°).

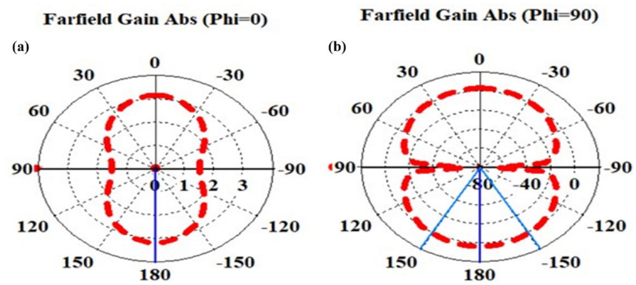

Figure 6: Simulated radiation patterns of the bow-tie antenna in free space: **(a)** E_φ (φ = 0°) and **(b)** E_φ (φ = 90°).

= 90°. It can be observed that the antenna does not have nulls at 0°.

The bow-tie antenna has a predominantly omni-directional pattern in the horizontal plane, within a proximity near the minimum frequency (f_{min} = 300 MHz). The point of maximum gain occurs when the antenna is oriented in the broadside direction. As the frequency surpasses twice the minimum frequency (600 MHz), the pattern experiences a rapid degradation. The radiation patterns shown in figure 6a and 6b are the characteristics of a bow-tie structure in an unobstructed environment, featuring a flare angle of 75°.

Conclusion

The development of an innovative flexible COSPAS-SARSAT beacon antenna is currently the subject of research that is being carried out. The frequency at which it works is 406 MHz, and its intended application is in the Mission Control Centers of COSPAS-SARSAT. The two antennas that have been presented here accomplish the two fundamental goals as follows: The first function is to achieve maximum impedance matching at 406 MHz, and the second function is to achieve maximum gain at 0°. Both functions are independent of one another. In the overall design of the construction, the conducting element is made of ShieldIt Super, while the substrate is made from PDMS. The entire structure was built to be completely flexible from the ground up. The analysis of the two antennas showed that the simulated -10dB fractional bandwidth was 2.93% under planar conditions for the RECP antenna and 66.66% for the meander line antenna, respectively. Furthermore, the construction of a low-profile rectangular electromagnetically connected patch has been implemented by incorporating Fe_3O_4 nanoparticles in conjunction with a pure PDMS substrate together and separately.

Acknowledgments

None.

Conflict of Interest

None.

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