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Polymer-based COSPAS-SARSAT Flexible U-slotted Patch and Meander Line Antenna Design Using Iron Oxide (Fe_3O_4) Nanoparticles

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Abstract

This study focuses on the creation of a low-profile meander line-based antenna as well as a U-slotted patch antenna that was developed exclusively for the needs of search and rescue (SAR) operations. The meander line antenna and U-slotted patch antenna under consideration are designed on a substrate composed of polydimethylsiloxane (PDMS). PDMS is chosen for their desirable properties such as durability, flexibility, water resistance, and suitability for deployment in challenging environmental conditions. The utilization of the search and rescue application mandates the operation at a comparatively lower frequency of 406 MHz, hence necessitating the use of antennas with a longer electrical length. As a result, these antennas exhibit a tendency towards bigger physical dimensions. The issue can be overcome with the utilization of patch antenna and an incorporation of meander-based structure, hence ensuring a small size. The results of the simulation demonstrated that the antenna operated at a central frequency of 406 MHz, exhibiting a bandwidth of 40.5 MHz and 67.49 MHz for the U-slotted patch antenna and meander line antenna, respectively. These bandwidths corresponded to a -10 dB fractional bandwidth percentage of 9.9% and 16.55% for the two antennas. In addition to utilizing a pure PDMS substrate, the design of a meandered line antenna has been used using iron oxide (Fe_3O_4) nanoparticles along with PDMS. After adding this magneto dielectric substrate into the substrate there has been a noticeable enhancement in the parameters of the antenna.

Keywords

Wearable antennas, Flexible antennas, Compact antennas, Search and rescue, COSPAS-SARSAT

Introduction

COSPAS, which stands for "Cosmicheskaya Systyema Poiska Aariynyich Sudov", and SARSAT, an acronym for "Search and Rescue Satellite technology Assisted Tracking System", are integral components of a globally collaborative satellite-based radiolocation system. This system is designed to provide assistance in search and rescue operations for individuals in distress, including aviators, mariners, and land travelers. Whereas SARSAT was concurrently developed by France, Canada, and the USA. COSPAS-SARSAT refers to an intergovernmental network of emergency rescue satellites that serves a humanitarian purpose. The joint effort, initiated in 1979 by Canada, France, the United States, and the Soviet Union, involves the participation of 45 nations. The COSPAS-SARSAT system facilitates the transmission of SAR data, which includes emergency

location information, to the respective authorities of the 45 nations that have signed the agreement. This exchange of data enables effective coordination and implementation of search and rescue operations. At present, the program encompasses a total of 62 active satellites [1].

Numerous scholars have contributed to the field by presenting studies focused on the advancement of antennas specifically designed for this particular application. These studies have taken into account the crucial requirement of ensuring the antennas' resilience under challenging environmental conditions, employing a range of durable materials. In [2], a study has been conducted on the presentation of two designs of meandering dipole antennas operating at a frequency of 406 MHz. There are two textile materials under consideration, one of which is non-conductive. The first textile material exhibits a permittivity (ε_r) of 1.44 and a loss tangent (tanδ) of 0.044. It has a thickness of 3 mm. The second textile material is referred to as a shield. Conductive elements are included in the design of the suggested antennas. The thickness of the layer is measured to be 0.17 mm, while its conductivity is determined to be 1.18 x 10^5 S/m. The -10 dB fractional bandwidth of the antenna under consideration is 10.05%. The dimensions of the suggested antenna are 200 x 75 x 3 mm^3, which may also be expressed as $0.271\lambda_0$ x $0.102\lambda_0$ x $0.0041\lambda_0$. The antenna described in reference [3] is a patch type antenna that operates at a frequency of 406 MHz. It utilizes a low-loss foam material as the substrate, and the conductive parts are fabricated using an inkjet-printing technique. The dimensions of the antenna are 283 x 65 x 17.5 mm^3 ($0.383\lambda_0$ x $0.088\lambda_0$ x $0.024\lambda_0$) when operating at a frequency of 406 MHz. The antenna was positioned parallel to the human body model, and the separation spacing between the antenna and the model was systematically adjusted within the range of 0 to 200 mm. The impact of water on the return loss of an antenna was investigated by the manipulation of the gap distance between the water and the antenna, ranging from 0 to 120 mm. In a recent study [4], researchers introduced a novel system consisting of two antennas that may be worn on a life vest. One antenna is attached to the floating elements on the chest area, while the other is coupled to the floating elements on the neck area. In the context of life-saving equipment, a conventional life vest is utilized, whereby the antenna is affixed to both the chest and neck regions of the buoyant component of the vest, serving their respective purposes. Both antennas discussed in this study are meandering dipole antennas that are folded and utilize a Rohacell substrate. These antennas exhibit resonance at a frequency of 406 MHz. The dimensions of the antenna measure 300 x 150 x 1 mm^3 ($0.406\lambda_0$ x $0.203\lambda_0$ x $0.0014\lambda_0$) at a frequency of 406 MHz. The suggested antenna exhibits a -10 dB fractional bandwidth of 4%. The experiment yielded a simulated gain of 7 dB when the antenna was positioned on the chest, however this value decreased to 1 dB when the antenna was relocated to the head position.

Experimentation

Antenna design

Materials

In this study, the antenna design will incorporate two distinct types of materials. One of the conductive textiles utilized for the formation of the antenna's conductive components, namely the radiator and ground plane, is ShieldIt Super™, manufactured by LessEMF Inc. The material has an electrical conductivity of 1.18 x 10^5 S/m, with a thickness of 0.17 mm. In contrast, the PDMS substrate employed in this study possesses 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 has already been used for satellite communications antennas and polarizing converter surfaces.

Antenna topology pin-fed rectangular patch with U-slot

Microstrip antennas, sometimes referred to as patch antennas, have gained significant popularity within the microwave frequency spectrum due to its inherent simplicity and seamless integration with printed circuit board technology. The pin-fed rectangular patch is widely utilized as a microstrip antenna in various applications.

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 presented rectangular U-slot patch from figure 1a to 1d has a bandwidth of approximately 9.9%, whereas the U-slot patch demonstrates a significantly higher bandwidth reaching up to 40.5 MHz. The U-slot patch antenna refers to a rectangular patch on a dielectric substrate, with a ground plane beneath it. A U-shaped slit is expunged from the patch. The

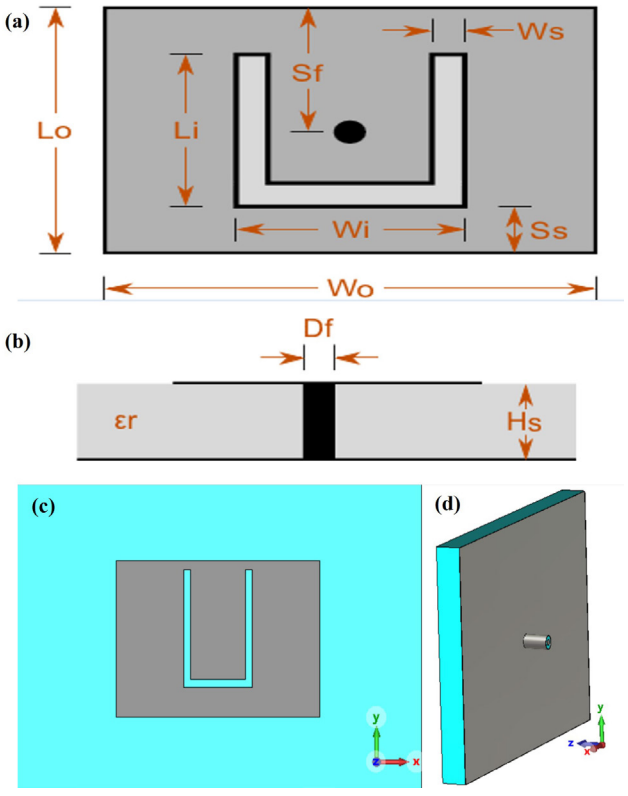


Figure 1: (a) Front view and **(b)** side view of slotted patch antenna. **(c)** Front view and **(d)** side view of slotted patch antenna in CST.

parallel arms of the slot exhibit parallelism with the length side of the patch.

The antenna is supplied with power through a coaxial feedline. The outside conductor is linked to the ground plane, while the center conductor establishes an electrical connection with the patch by means of a hole in both the substrate and the ground plane. Table 1 gives information antenna parameters used in simulation.

Weigand et al. [5] observed that the U-slot patch exhibits four distinct resonance frequencies. According to Weigand et al. [5], the initial resonant frequency, denoted as *fres1*, exhibits a linear relationship with the overall slot length. However, its radiation efficiency is limited due to the presence of a high input impedance. The 2nd resonant frequency, denoted as *fres2*, exhibits a significant correlation with the *TM01* mode of the patch. The present trajectory is oriented in the Y-direction, indicating that the dimensions of both the patch and the slot will significantly impact *fres2*. This phenomenon occurs due to the influence of the measured distance between the feed point and the two primary radiating horizontal edges.

The third resonant frequency, denoted as *fres3*, has a higher level of intricacy. An increase in the width of the inner element leads to an increase in *fres3* for specific values of the inner element length. Given that the distance between the feed-point and the bottom radiating edge has increased, it is reasonable to anticipate a reduction in the Fresnel zone clearance, denoted as *fres3* [6]. According to Weigand et al. [5], the presence of an increase indicates the existence of a current path in the X-direction. This is supported by the fact that the only paths that significantly reduce the distance between the feed point, and the two vertical edges are the ones mentioned.

The relationship between the fourth resonant frequency, *fres4*, is established in relation to the slot and the little "*pseudopatch*". The "*pseudopatch*" referred to in this context possesses distinct properties, including an effective permittivity and effective patch width. These parameters are utilized in the calculation of *fres4* [5].

The operational bandwidth of the antenna is comprised of the second, third, and fourth resonant frequencies.

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

Parameter	Value (mm)
ε_r	2.7
Hs	40.18
Ss	33.75
Df	8.618
Ws	9.042
Lo	176.1
Wo	253.2
Li	131.6
Wi	85.74
Sf	96.18

Antenna topology meander line antenna

The meander line antenna finds the massive applications in radio frequency identification tag 911 MHz and 13.56 MHz. The passive (does not require power supply) radio frequency identification tags are stimulated by an induced voltage that arises from an incoming query signal, which is transmitted reader antenna. The voltage that is generated at the terminals of the tag antenna serves as the voltage source and amount of voltage is sufficient for activating the chip and also serves as the energy source for charging a capacitor with a large capacity. The chip adjusts its input impedance with the complex conjugate impedance of the tag in accordance with the established protocols, resulting in the transmission of a back-scattered signal that is subsequently recognized by the reader antenna.

Now the meander line antenna is presented for SAR application 406 MHz. The presented antenna has a -10 dB fractional bandwidth of 16.55% ranging from 0.37394 GHz to 0.44143 GHz and a bandwidth of 67.49 MHz.

A conventional T-match configuration is comprised of a lengthy dipole with a length denoted as L_1 in figure 1a and table 2. This dipole is accompanied by a folded dipole, also known as a *T-stub*, with a length denoted as L_2. The *T-stub* is joined to the long dipole at a specific distance, referred to as *d*. It is a prerequisite that the length L_1 is greater than the length L_2, and it is commonly seen that the widths W_1 and W_1 of the respective strips are not identical. In the study conducted by, the *T-match* configuration was altered by adjusting the diameter of the arms of the *T-stub* to be different from that of the feed terminals. Consequently, the width of the strip of the long dipole is greater in the region where it is connected to the folded dipole. The reduced resistance and larger bandwidth attained by this device are attributed to this phenomenon. The simulation results indicate that the optimization process facilitates the blending of two neighboring resonances, resulting in a wider bandwidth. The uniform meander dipole is addi-

Table 2: Description of parameters used for designing the meander line antenna.

Parameter	Value (mm)
ε_r	2.70
L_P	26.97
W_P	27.22
H	30.26
Wl_1	3.28
Wl_2	6.65
LM_2	16.10
LM_2	96.18
S_1	1.22
S_2	7.56
H_S	3
H_M	85.74
WM_1	2.94

tionally equipped with rectangular patches positioned at both ends L_P and W_P. As anticipated, the resonant frequency is influenced by the length of the patch, whereas the impedance of the structure and its bandwidth are affected by the breadth of the patch.

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

Need of polymeric magneto dielectric (PDMS-Fe_3O_4) antenna

The majority of contemporary communication system applications, including tracking, navigation, medical diagnostics, wireless applications, and military communication, require antennas that are conformal, lightweight, small in size, and robust in nature. In addition to this, the augmentation of bandwidth has the ability to be applied in order to boost the transmission rate of data.

In addition, it is necessary for these systems to possess high gain and adequate radiation efficiency in order to attain optimal performance. The choice of substrate materials has a substantial impact on the attainment of optimal performance and desirable physical properties in antennas and RF/microwave devices. Traditionally, planar antennas have been manufactured utilizing commercially accessible, rigid substrates such as FR-4, Duroid, Taconic, and so forth. Nevertheless, the primary drawbacks of these materials include their inflexibility, limited bandwidth, and the presence of significant losses in certain cases [7, 8].

In recent times, there has been an increasing utilization of polymer-based substrates in the field of antennas and other RF components. The subject matter at hand pertains to the many constituents that comprise a microwave system. The mechanical and electrical qualities of the material under consideration are aesthetic in nature. Dielectric features like flexibility, lightweight, low permittivity, and low losses can be observed and can be tailored to accommodate particular RF/microwave applications. Various polymer-based substrates have been utilized for antennas in their pristine state, including PDMS and polyimide. However, it should be noted that the materials discussed have limited bandwidth when utilized in their pure form. Hence, the advent of contemporary manufacturing techniques has facilitated the application of polymer composites as substrates. Polymeric materials have been combined with many materials, including nickel, ferrite, ceramic, titanium, and others, in order to enhance the performance of antennas. Nevertheless, previous studies have not yet examined the utilization of polymer-based composite substrates in the context of SAR antennas. The primary objective of this study is to investigate the efficacy of a versatile polymer magneto-dielectric composite substrate in improving the bandwidth of antennas. The magneto-dielectric composite substrate, known as PDMS-Fe_3O_4, is created by combining PDMS and magnetic Fe_3O_4 nanoparticles in varying concentrations. The electrical and mechanical properties of these materials are advantageous in meeting the demands of contemporary antenna specifications [7, 9-12].

Polymeric magneto dielectric (PDMS-Fe_3O_4) antenna design

The nanocomposite of magnetite: Polymer PDMS and used in the simulation is 3:10 ratio as shown in figure 2g. This gives the ε_r = 4 and $tand_e$ = 0.02 and μ_r = 4 and $tand_m$ = 0.025 from the characterization results [9, 13-15]. The observation of figure 2g reveals: (i) the leftward shift in resonant frequency allows for the utilization of smaller antennas at lower operating frequencies. Typically, this relationship is inversely proportional and (ii) the frequency bandwidth has increased from 16.55% to 17.11%.

Results and Discussion

The results of the reflection coefficient for both of the antennas, a slotted patch antenna and a meander line 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 slotted patch and the meander line 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

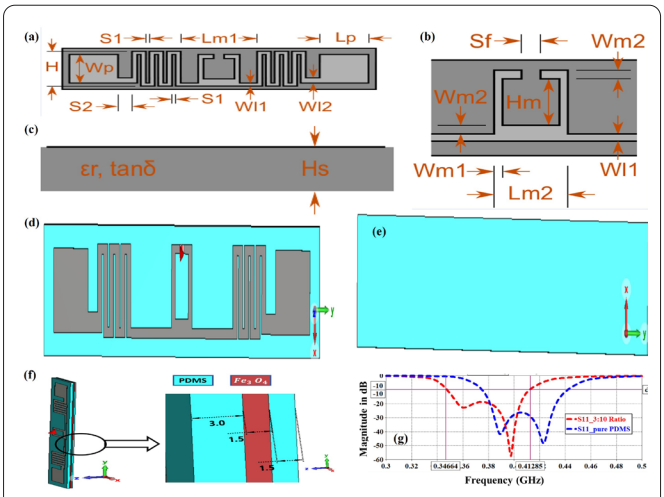


Figure 2: (a) Front view, **(b)** detail front view, and **(c)** side view of meanderl line antenna. **(d)** Simulated front view and **(e)** simulated back view of the antenna in CST. **(f)** Magneto dielectric substrate (dimensions in mm). **(g)** Effect of 3:10 ratio mixing on antenna resonant frequency.

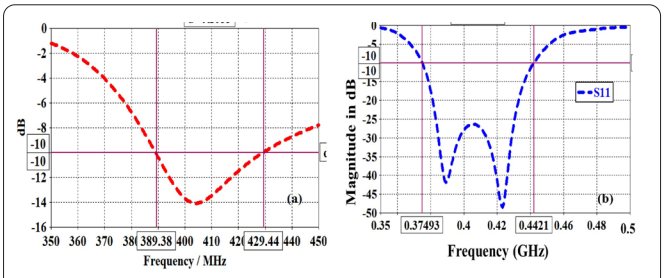


Figure 3: -10 dB reflection coefficient **(a)** slotted patch antenna and **(b)** meander line antenna.

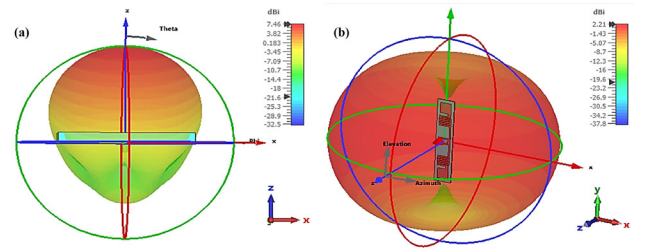


Figure 4: 3D radiation pattern with antenna in the center for **(a)** slotted patch antenna and **(b)** meander line antenna.

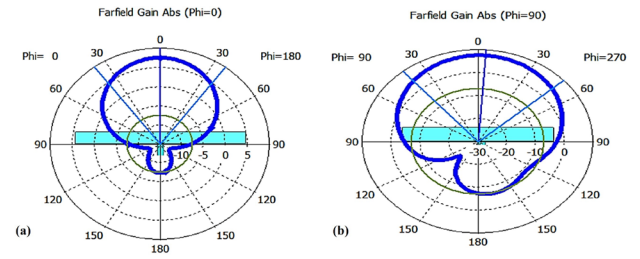


Figure 5: Simulated radiation patterns of the slotted patch antenna in free space: **(a)** Eφ (φ = 0°) and **(b)** Eφ (φ = 90°).

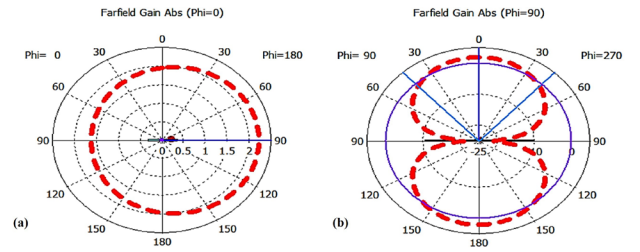


Figure 6: Simulated radiation patterns of the meander line antenna in free space: **(a)** Eφ (φ = 0°) and **(b)** Eφ (φ = 90°).

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. In the event that 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. Figure 5 and figure 6 present the magnitude of gain in form of radiation patterns for φ = 0° and φ = 90°. It can be observed that the antenna does not have nulls at 0°.

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 0.406 gigahertz, 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 0.406 GHz, and the second function is to achieve maximum gain at 0°. Both of these functions are independent of one another. In the overall design of the construction, the conducting element is made out of ShieldIt Super, while the substrate is made out of PDMS. The entire structure was built to be completely flexible from the ground up. The analysis of the two antennas showed that the simulated -10 dB fractional bandwidth was 9.9% under planar conditions for the slotted patch antenna and 16.55% for the meander line antenna, respectively.

Acknowledgments

None.

Conflict of Interest

None.

References

1. COSPAS-SARSAT. Satellite Missions Catalogue. [https://www.eo-portal.org/satellite-missions/cospas-sarsat] [Accessed March 08, 2024]
2. Hussin EFNM, Soh PJ, AbdulMalek M, Jamlos MF, Fauzi MAF, et al. 2016. A wearable textile dipole for search and rescue application. In 5th International Conference on Electronic Devices, Systems and Applications, Ras Al Khaimah, United Arab Emirates.
3. Lilja J, Pynttäri V, Kaija T, Mäkinen R, Halonen E, et al. 2013. Body-worn antennas making a splash: lifejacket-integrated antennas for global search and rescue satellite system. *IEEE Antennas Propag Mag* 55(2): 324-341. https://doi.org/10.1109/MAP.2013.6529385
4. Serra AA, Nepa P, Manara G. 2011. A wearable two-antenna system on a life jacket for Cospas-Sarsat personal locator beacons. *IEEE Trans Antennas Propag* 60(2): 1035-1042. https://doi.org/10.1109/TAP.2011.2173151
5. Weigand S, Huff GH, Pan KH, Bernhard JT. 2003. Analysis and design of broad-band single-layer rectangular U-slot microstrip patch antennas. *IEEE Trans Antennas Propag* 51(3): 457-468. https://doi.org/10.1109/TAP.2003.809836
6. Bhalla R, Shafai L. 2001. Resonance behavior of single U-slot and dual U-slot antenna. In IEEE Antennas and Propagation Society International Symposium. 2001 Digest. Held in conjunction with: USNC/URSI National Radio Science Meeting, Boston, MA, USA.
7. Alqadami AS, Mohammed B, Bialkowski KS, Abbosh A. 2018. Fabrication and characterization of flexible polymer iron oxide composite substrate for the imaging antennas of wearable head imaging systems. *IEEE Antennas Wireless Propag Lett* 17(8): 1364-1368. https://doi.org/10.1109/LAWP.2018.2841879
8. Alqadami AS, Bialkowski KS, Mobashsher AT, Abbosh AM. 2018. Wearable electromagnetic head imaging system using flexible wideband antenna array based on polymer technology for brain stroke diagnosis. *IEEE Trans Biomed Circuits Syst* 13(1): 124-134. https://doi.org/10.1109/TBCAS.2018.2878057
9. Alqadami ASM, Jamlos MF, Soh PJ, Vandenbosch GA. 2015. Assessment of PDMS technology in a MIMO antenna array. *IEEE Antennas Wirel Propag Lett* 15: 1939-1942. https://doi.org/10.1109/LAWP.2015.2513960
10. Elobaid HAE, Rahim SKA, Himdi M, Castel X, Kasgari MA. 2016. A transparent and flexible polymer-fabric tissue UWB antenna for future wireless networks. *IEEE Antennas Wirel Propag Lett* 16: 1333-1336. https://doi.org/10.1109/LAWP.2016.2633790
11. Alqadami ASM, Jamlos MF, Soh PJ, Rahim SKA, Vandenbosch GA, et al. 2017. Miniaturized dual-band antenna array with double-negative (DNG) metamaterial for wireless applications. *Appl Phys A* 123: 22. https://doi.org/10.1007/s00339-016-0678-3
12. Hung YC, Liu CH. 2016. Stretchable frequency selective surfaces for large-area-tuning and high-power applications. In International Symposium on Antennas and Propagation, Okinawa, Japan.
13. Alqadami ASM, Jamlos MF. 2015. Compact and conformal multilayer antenna based on polymer nanocomposite substrate. In IEEE International RF and Microwave Conference, Kuching, Malaysia.

14. Alqadami AS, Nguyen-Trong N, Mohammed B, Stancombe AE, Heitzmann MT, et al. 2019. Compact unidirectional conformal antenna based on flexible high-permittivity custom-made substrate for wearable wideband electromagnetic head imaging system. *IEEE Trans Antennas Propag* 68(1): 183-194. https://doi.org/10.1109/TAP.2019.2938849
15. Alqadami ASM, Jamlos MF, Lago H, Babarinde OJ. 2014. Bandwidth enhancement of a microstrip antenna array using magneto-dielectric polymer substrate (PDMS-Fe_3O_4). In IEEE Symposium on Wireless Technology and Applications, Kota Kinabalu, Malaysia.