Design and Analysis of a Novel Dielectric Loaded Helical Antenna

A.A.M EZANUDDIN, P.J SOH, A.A.H AZREMI, R.B AHMAD
School of Computer and Communication Engineering
Universiti Malaysia Perlis (UniMAP)
No 12 & 14, Jln Satu, Tmn Seberang Jaya, Fasa 3, 02000 Kuala Perlis
Perlis, Malaysia.
mezanuddin@student.unimap.edu.my, {pjsoh, azremi,badli}@unimap.edu.my

Abstract: - Helical antennas have been a popular antenna configuration for various applications for its simple structure. This work describes the study on a novel, custom-shaped dielectric loaded helical antenna incorporated on an advanced material, which is Barium Strontium Titanate (BST). This material, which presents the researcher with an advantage in size reduction due to its high relative permittivity, is most suitably used when desiring a miniaturized antenna compared to its conventional design of the same type. In the process of designing, a parametric study was carried out by varying the antenna geometrical parameters and the dielectric loading using the transient solver. The detailed understanding of the sensitive parameters of the proposed antenna will allow for ease of design reuse. Finally, an extended exploration was also carried out in order to determine the design's suitability for operation with two of the WLAN Access Points (APs) already available in the market. Observation from this investigation found out that the three most sensitive parameters in the design are dielectric load's height, radius of ground plane and the helical height, with the dielectric load's height as the main design criteria. On the other hand, examination on the APs' integration found out that several factors influencing the radiation performance of the design are the material used, internal spacing available and overall shape of the APs. While both APs are proven to work with the designed antenna in the desired frequency range, a degradation of up to 1 dB in gain have been observed, when applying the antenna to the less suitable AP.

Key-Words: - Helical antenna, dielectric resonator, wireless local area network, advanced material, Barium Strontium Titanate (BST).

1 Introduction

Helical antennas have been known for more than half a century during the late 40's when John Kraus first invented the helical antenna [1-2] Wireless Local Area Network (WLAN) nowadays are found to be used by most of the modern society and education centre as a way to communicate with each other despite the existing cable and fiber optic performing much better in transmitting and receiving data.

This work intends to research on the best custom shape of a novel dielectric loaded helical antenna for WLAN Access Point application. The helical antenna have been fabricated and wound around a novel supporting structure, which is made from BST [3]. This paper also investigates the effect of using advanced material such as BST when applied to a normal helical antenna, with some spacing's. Methods and techniques used to assemble the antenna are referred in [4-7].The main focus of this antenna design is to operate at the IEEE 802.11 b/g 2.4 GHz to 2.48 GHz frequency band. This project aims to build and simulate models using the CST MW software and eventually measuring all of its parameters thoroughly. The antenna S-Parameters are optimized by varying the antenna geometrical parameters, which then will provide researchers with the understanding of how certain dimension and its variation would influence the antenna gain. The dependency of this type of antenna on the size and shape of the ground plane [8-9] and dimension of the dielectric loaded itself [10] were also investigated in detail.

A custom advanced material, which was moulded and fabricated from nano-powder was examined in this work. The main reason in the consideration of BST, a kind of ferroelectric material, is that it has the ability to overcome all the limitations of MEMS, ferrite and MMIC phase shifters due to its electric-tunable dielectric constant [11]. It combines the low-loss properties of BST at microwave frequency with the distributed transmission line philosophy of the

MEMS phase shifter which provides wide bandwidth and ease of design. BST is known to be a solid solution perovskite with a field-dependent permittivity and has been used in RF and microwave applications in the recent years [12].

Table 1 summarizes the tunability characteristic in BST, which implies that the level change in the dielectric constant will determine the overall loss in this particular antenna. It is also an advantage when using this kind of advanced material, as when the size of the antenna is the main limitation in a wireless device's design, a high dielectric constant can be employed to reduce the overall dimension of the helical antenna's overall size.

Table 1
Compositional and electrical film properties for five films grown at the same total pressure of 45mTorr, but with different Ar/O_2 flow rates [8].

Ar/O_2 (sccm)	P_{O2} (mTorr)	Ba/Sr	(Ba + Sr)/Ti	ε_r	Q (1 MHz)	Tunability (100 MHz)(%)
90/10	4.5	0.84	1.00	571	41	11.36:1(91.2)
80/20	9.0	0.93	0.93	455	75	13.71:1(92.7)
70/30	13.5	0.92	0.88	241	161	7.88:1(87.3)
60/40	18.0	0.89	0.82	194	159	4.90:1(79.6)
50/50	22.5	0.87	0.78	134	42	3.74:1(73.3)

Other interesting aspects of BST are its low dielectric loss, low leakage current, low temperature coefficient and the composition-dependent Curie temperature [13]. BST are normally prepared in powder form and such way can help to store and use the material for any experiment and moulding processes. In a way, when fabricating BST into any shaped mould, heat applied will increase the dielectric constant from a few hundreds to thousands, as shown in Fig. 1. This phenomenon is due to the structural change from tetragonal to cubic perovskite.

2 Antenna Design

The geometry of dielectric loaded helical antenna or some cases dielectric resonator antenna [14], which operates at 2.45 GHz 2.48 GHz, as shown in Fig. 2 and its dimension in Table 2. To obtain the correct frequency, the height of the cylinder has been designed with a starting value of around 24 mm. The helix was constructed based on copper metal wire with the diameter of 1.63 mm

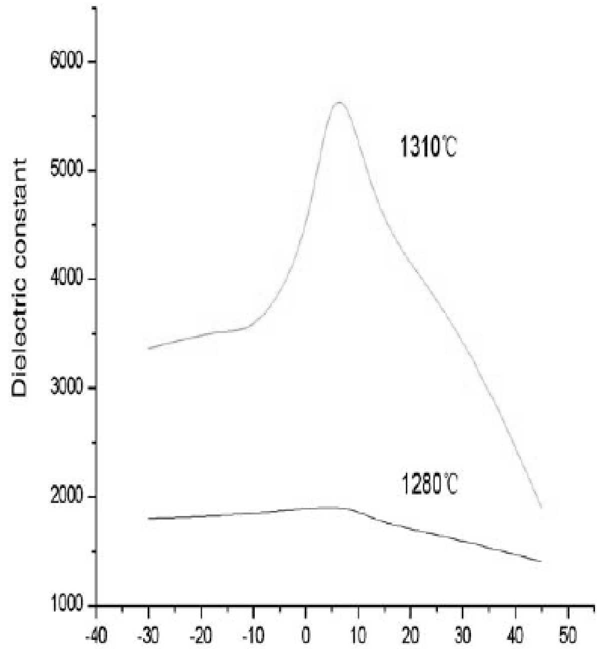

Fig. 1. Dielectric constant vs. temperature of the BST77 Ceramics sintered at 1280 °C and 1310 °C [9].

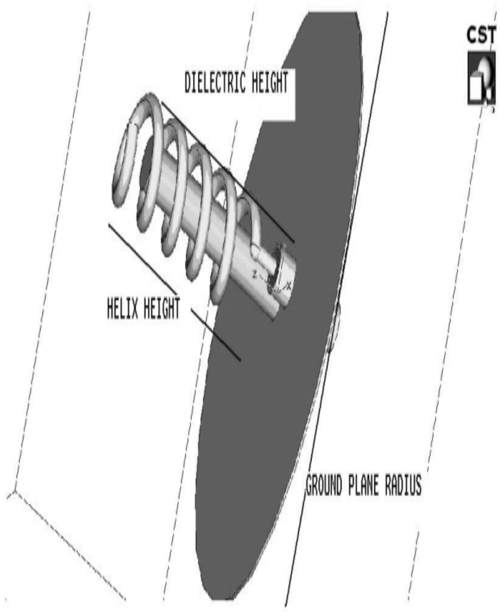

Fig. 2. Typical dimensions of dielectric loaded helical antenna.

Table 2
Dielectric loaded helical antenna geometry

Component	Dimension
Ground plane	29.0 mm (Radius)
Dielectric loaded	24.0 mm (Height) x 2.5 mm (Radius)
Helix	5 Turns (N), 1800^0 Angle 20.0 mm (Height)

Applying one important and basic formula (1), the desired frequency can be achieved by manipulating the BST cylinder height. An initial calculation is in Table 3 and was considered as a starting point for the simulation.

The mould was sized at 2.5 mm (radius) by 24 mm (height). BST's and Teflon's relative permittivity, which is $\varepsilon_r = 250$ while the Teflon as $\varepsilon_r = 2.0$, respectively, have been used in this simulation. Due to the high relative permittivity in comparison to conventional materials such as Rogers and FR4, the overall size of the antenna was reduced significantly, as was explained in the earlier section.

$$F_0(GHz) = \frac{8.553}{\sqrt{\varepsilon}\left(\frac{\Pi}{4}Dr^2 Lr\right)^{1/3}} \qquad (1)$$

D_r = Resonator diameter in inches
L_r = Resonator length in inches
E_r = Resonator dielectric constant

Calculation
Frequency desired, f_o = 2.45 GHz
Dielectric constant, ε_r = 250 (BST)

(a) D_r = 0.1969 inches

$$2.45 = \frac{8.553}{\sqrt{250}(\frac{\Pi}{4}\text{x}0.1969^2\text{xLr})^{\frac{1}{3}}}$$

$$(0.03045Lr)^{\frac{1}{3}} = 0.22079$$

$$Lr = 0.22079^3 \div 0.03045 = 0.3534 inches$$
$$= 8.9 \text{ mm}$$

(b) D_r = 0.2362 inches

$$2.45 = \frac{8.553}{\sqrt{250}(\frac{\Pi}{4}x0.2362^2 xLr)^{\frac{1}{3}}}$$

$$(0.0438Lr)^{\frac{1}{3}} = 0.22079$$

$$Lr = 0.22079^3 \div 0.0438 = 0.245 inches$$
$$= 6.24 \text{ mm}$$

(c) D_r = 0.3937 inches

$$2.45 = \frac{8.553}{\sqrt{250}(\frac{\Pi}{4}x0.3937^2 xLr)^{\frac{1}{3}}}$$

$$(0.1217Lr)^{\frac{1}{3}} = 0.22079$$

$$Lr = 0.22079^3 \div 0.1217 = 0.0884 inches$$
$$= 2.246 \text{ mm}$$

Table 3
Calculated dimension of D_r corresponding with L_r

D_r	L_r
5.0 mm	8.9 mm
6.0 mm	6.24 mm
10 mm	2.246 mm

3 Result and Discussion

3.1 Parametric Study

A parameter sweep was performed on the three most sensitive dimensions of the antenna, which are the dielectric load's height, radius of ground plane and the helical height. Observations of results are shown in Fig. 3 to Fig. 5. The resonance behaviour of the antenna between 2.45 GHz to 2.48 GHz was most affected by the BST cylinder height when compared to other parameters. The helical height provided the antenna gain and resonance, whereas on the other hand, manipulating the ground plane radius partially affected the gain, sensitivity and bandwidth.

Referring to Fig. 3, the parametric sweep conducted was focused on the dielectric height, while holding the ground plane and helical height at a constant. Observation of this figure leads to the conclusion that most return losses produced are still far from the intended band. Size wise, using BST reduces mass judging to Log Periodic Antenna for Mobile Communication bands [15] whilst obtaining greater directive gain than of one element dual-frequency rectangular microstrip antenna with asymmetric T-shaped slit loads [16].

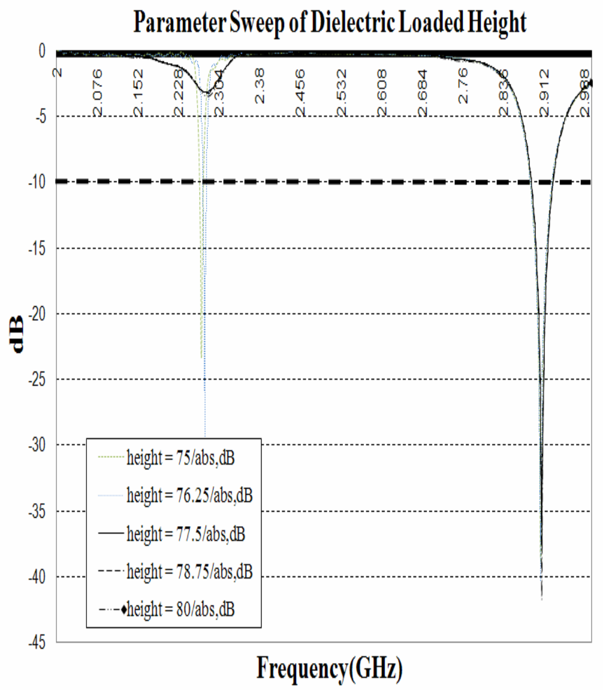

Fig. 3. Parameter sweep of the dielectric load's height.

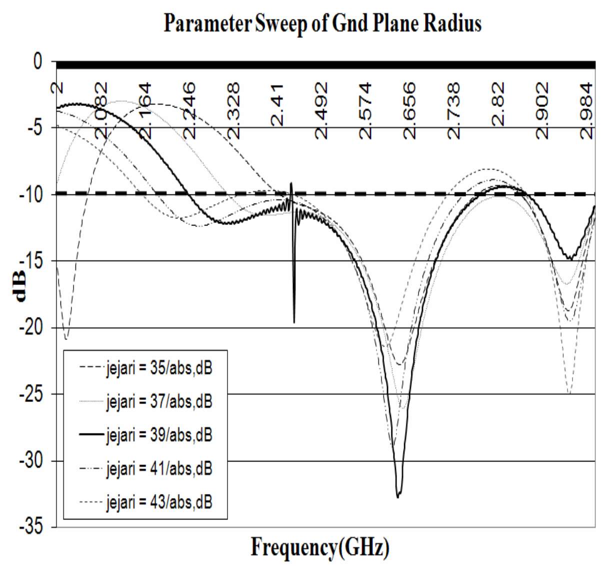

Fig. 4. Parameter sweep on the radius of ground plane.

Although from a certain perspective it potentially can be transformed into a dual band antenna, the total dielectric volume have not been absorbed efficiently and radiates back the energy given to it.

From this preliminary study, it is found out that to tune the resonance to the correct frequency would mean the cylinder volume must be increased.

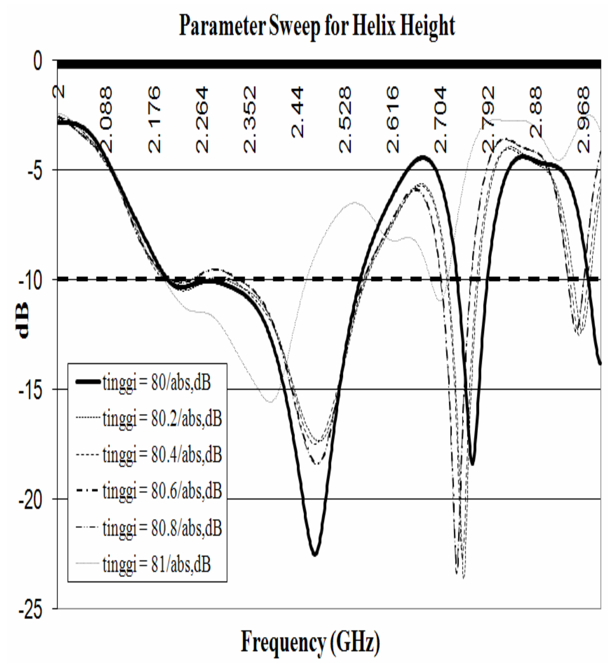

Fig. 5. Parameter sweep of the helical height.

In the next parametric study, the ground plane radius size was set as a variable, while ensuring the dielectric height and helix height remained constant. The return loss result Fig. 4 showed that at a radius of 39.0 mm, the performance achieved a good value of below -10 dB at the 2.4 GHz region. Decreasing the size will produce an additional resonance at the lower frequencies, as shown by the radius sizes of 35 mm and 37 mm. On the other hand, increasing the radius above the 39.0 mm limit produced another resonance at about 2.96 GHz, but with a declining return loss value at the design frequency, which is 2.45 GHz. Such characteristic is produced due to the fact that at such dimension, the ground plane was able to reflect most signals and have nearly the correct matching impedance.

The next investigation was done on the helical height. Fig. 5 show the findings of this parameter sweep when six varying dimensions were investigated to obtain the required bandwidth and frequency. Similar to the earlier parametric studies, the dielectric height and ground plane radius is held constant this time round.

From the observation, it was found out that at the height of 80 mm, the helix structure was capable of radiating the desired signal when coupled with the correct dielectric in the desired frequency. Increasing this dimension by another 0.2 mm has shown a slight decrease in resonance performance in the 2.45 GHz domain, steadily till the 81 mm threshold limit is breached. At the height of 81 mm, it is seen that the return loss performance dwindled and start resonating downwards in the frequency spectrum, while producing another poor resonance at the 2.7 GHz band. In a nutshell, all the dimensions must complement each other to produce the targeted output especially the volume of BST used. A 5 turn helix was used as it was the only suitable number of turns compared to using 3, 4 or 6 turns. Less turns may change the resonance whilst more turns would increase gain along with higher resonating frequencies.

3.2 Radiation Pattern

Result of dielectric loaded helical antenna return loss Fig. 6 showed 80 MHz of bandwidth, giving nearly -25 dB of return loss. Impedance obtained at 2.4 GHz is 52.55 ohm, an acceptable value slightly larger than desired 50 Ω.

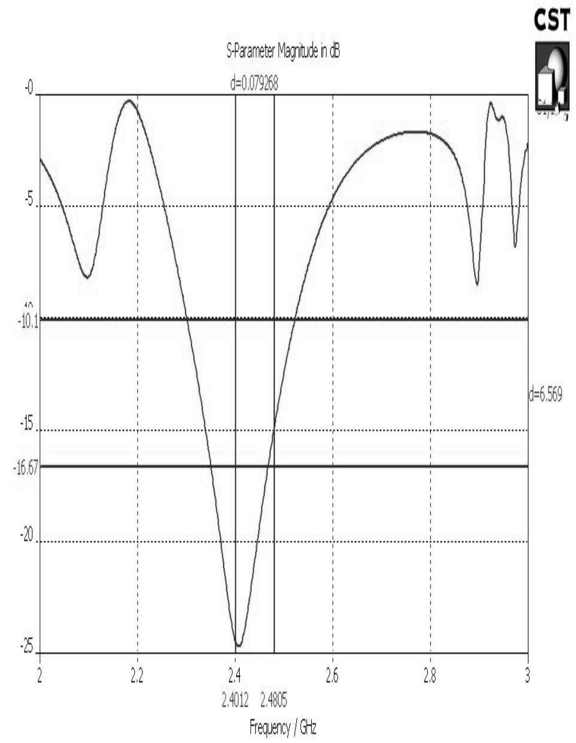

Fig. 6. Return loss obtained lower than – 10dB including bandwidth larger than 80 MHz.

As observed from Fig. 8, the radiation does not have any minor sidelobes at the rear end and its mainlobe is directed at the horizontal plane. From what can be seen in Fig. 11, the E-Plane produced an E-plane co-polarization signal with a beamwidth of 150^0 to 330^0.

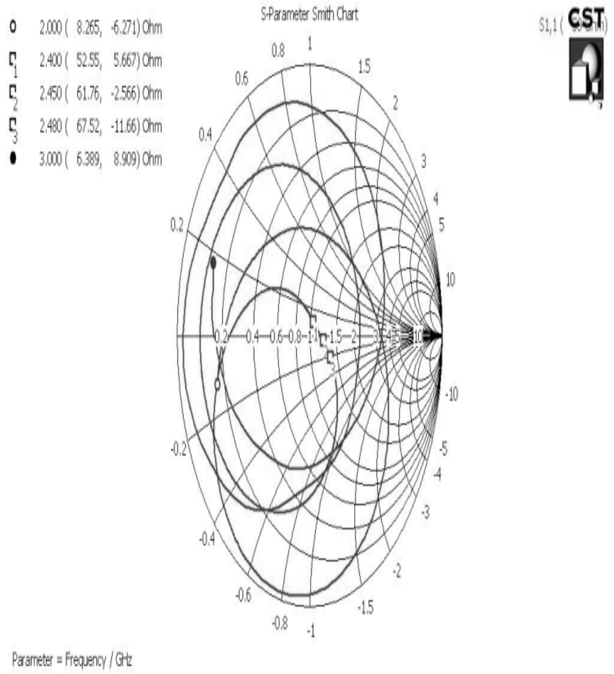

Fig. 7. Smith chart shows related frequency with its impedance.

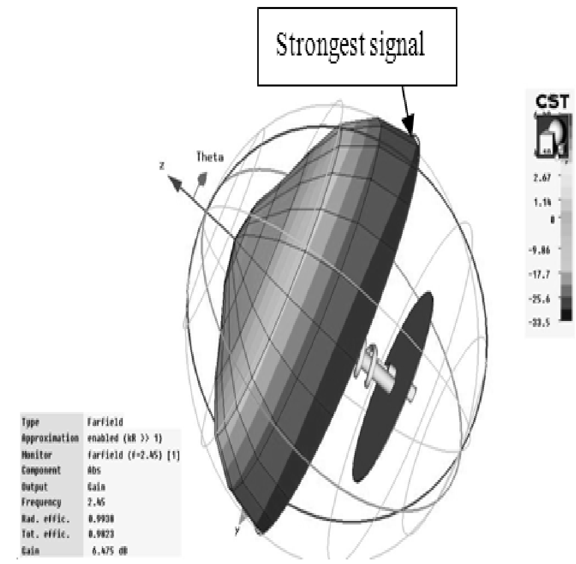

Fig. 8. Farfield above shows that the antenna radiates in the horizontal axis which implies an omni-directional antenna with a gain of 6.475 dB.

On the other hand, the E-plane cross-polarization produced a signal beamwidth which covers a complete 360^0. Observing the H-Plane, the H-plane co-polarized signal and H-plane cross-polarized signal are both radiating within 90^0 to 279^0, with minor a minor intersection.

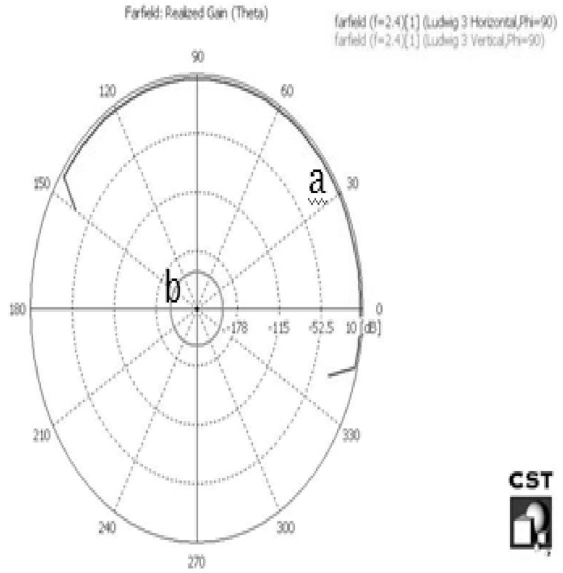

Fig. 9. E-Field co-polarization (a) and cross-polarization (b).

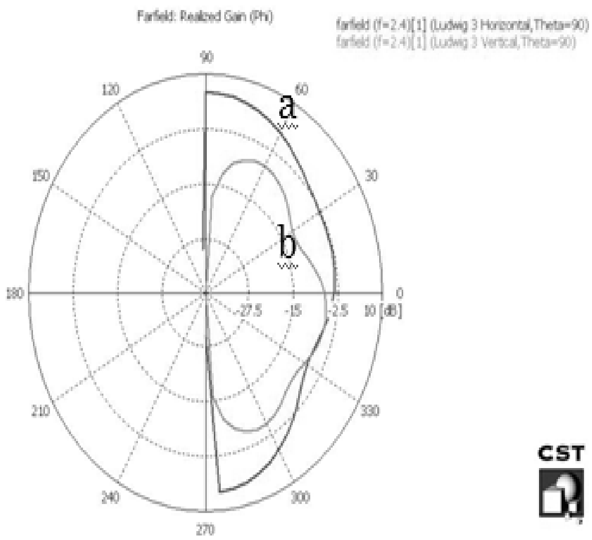

Fig. 10. H-field Co-polarization (a) and Cross-polarization (b).

Both radiation patterns do not collide or interfere with each other. The mainlobe is directed at the horizontal plane with 3 dB beamwidth of 29.2^0 (upwards from 90^0) as an alternative to the normal mode which radiates omni-directionally.

The dielectric structure located at the lower half of the antenna had entirely functioned to absorb the energy flowing across the helix and will only allow signal transmission after the helix end (z-direction).

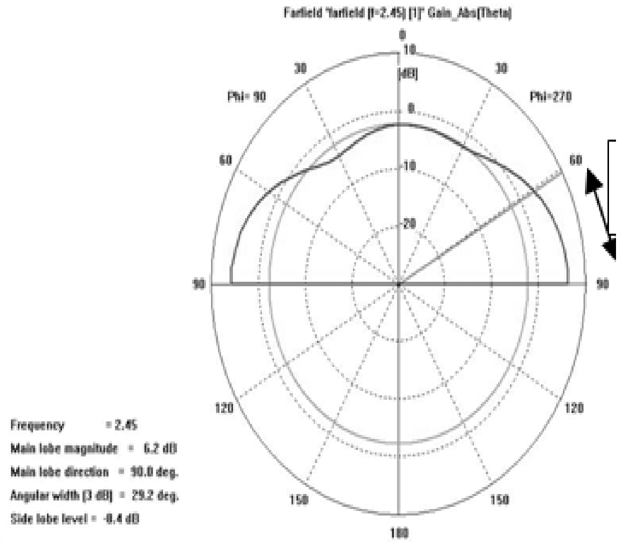

Fig. 11. Radiation pattern 3dB beamwidth obtain at 29.2^0.

Considering that dielectric is cylindrical, its upper end (z-axis) surface is flat. Hence, at this particular position, energy is released back circularly (helix structure) as the way it came in initially.

In Fig.8, the far-field radiation pattern, when observed from the top, radiates in an omni-direction horizontally at its azimuth position. These results proves that potentially, the antenna can be applied as an alternative Access Point antenna that needed semi-spherical radiation pattern and requires no signal redundancies or collision from other antennas. This is given the condition that the WLAN system is operating on a single antenna environment, and not on a multi-antenna environment such as the Multiple Input Multiple Output (MIMO) system. Moreover, the this kind of pattern ensure that no signal is wasted when the APs are mounted on flat surfaces such as ceilings and walls.

Table 4
Dimension of the 3Com MAP 3850

Item	Dimensions
Diameter	16.8 cm (6.60 inches)
Depth	5.3 cm (2.09 inches)

3.3 Integration with Access Point

3.3.1 Simulated as Access Point

Fig. 12. Original shape of 3Com MAP 3850.

A 3COM MAP 385 access point (AP 1) as shown in Fig. 12 and its dimension in Table 4, was remodelled and integrated with the designed novel dielectric loaded helical antenna inside. It was simulated to evaluate its overall performance and signal response in a real operating condition. As observed, the results were very similar to the observation of its original radiation pattern in Fig. 8. The radiation pattern in the E-Plane and H-Plane differs slightly in terms of its direction and angle. The major mainlobe is still at its strongest at the horizontal plane. In Fig. 13, a drop in terms of gain, degrading as much as 1 dB from 6.474 dB to 5.474 dB was observed. This power loss can affect the antenna gain, bounding the transmitted signal power from travelling further in distance. However, it is not considered a major drawback for WLAN indoor applications, as it typically will be applied in a small operating confinement.

Table 5
Dimension of 3Com 3CRWE920G73

Item	Dimension
Length	17.5 cm (6.9 inches)
Width	12.1 cm (4.76 inches)
Height	3.6 cm (1.4 inches)

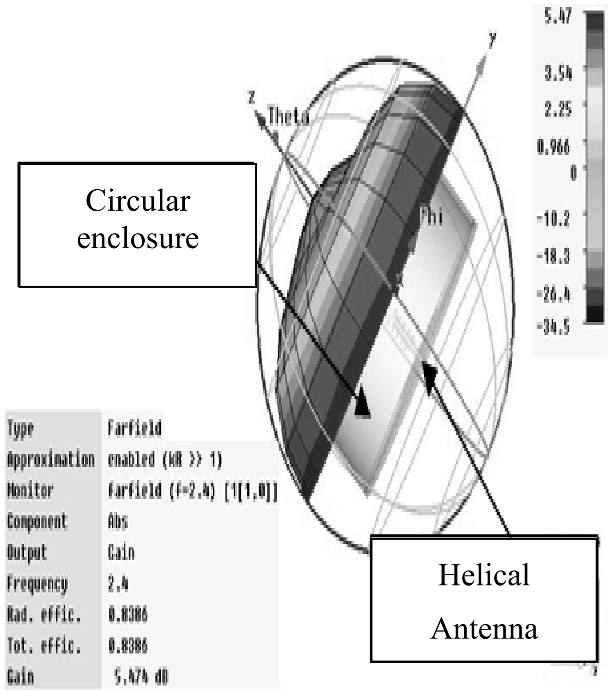

Fig. 13. Using the dimension of 3COM MAP 385.

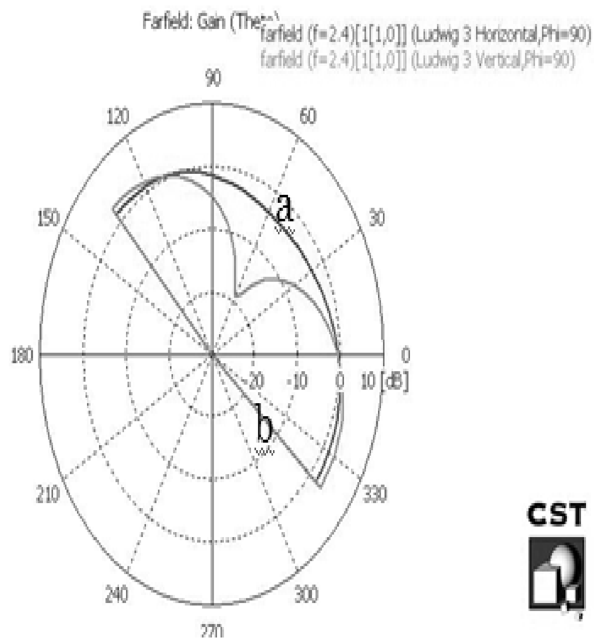

Fig. 14. E-Field co-polarization (a) and cross-polarization (b) of AP 1.

Findings from Fig. 14 and Fig. 15 specify interaction between the electric field and magnetic field. These unwanted relations were due to involvement of the circular casing simulated together. The casing is basically smaller in size and has limited internal space compared to the next casing model.

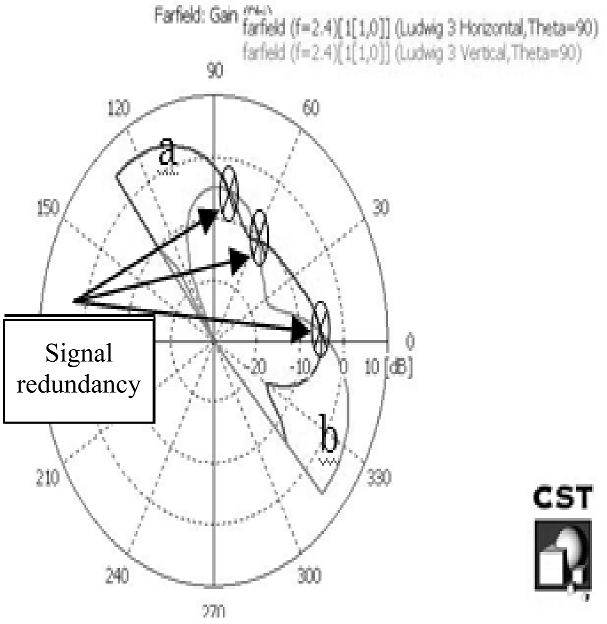

Fig. 15. H-field (a) Co-polarization and (b) and Cross-polarization of AP1.

Here, in the E-Plane, E-plane co-polarized and E-plane cross-polarized signals had totally changed its entire angle. The E-field did not evolve as expected, and Fig. 14 shows a co-polarization reduction in half power beam width (HPBW)'s size. On the other hand, the cross-polarized radiation was also not 360^0. Such findings contribute to power losses, decreasing the performance and thus limiting the antenna's radiating capabilities. As shown in Fig. 15, its cross-polarized signal is shifted nearly 30^0 to the left and not in line with co-polarized pattern when compared to Fig. 10. This evidence proves that radiation direction will shift due to insufficient space of the casing in use, and further proving that a minimal distance of λ/4 distance is necessary to ensure an optimal radiating condition.

Next, AP model 3COM 3CRWE920G73 (AP 2) is tested out on the designed antenna. Fig. 16 with its dimensions in Table 5 was remodelled with the design antenna inside as a comparison to AP 1. The simulation shows a better performance to the antenna without casing. In a way, Fig. 18 resembles very much similarly to Fig. 10 only accompanied by about 20^0 angle shift to the left, due to its proximity coupling effect on the AP's casing.

Previously in Fig. 10(a), the antenna has had its magnetic field burst out to the open air. But with this square casing incorporated, the H-plane HPBW have reduced significantly as shown in plot (a).

Fig. 16. Original shape of 3COM 3CRWE920G73 (AP 2).

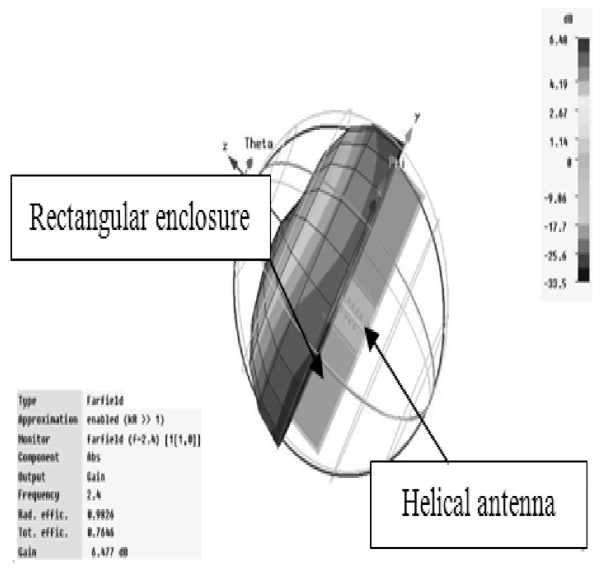

Fig. 17. Dimension of the 3COM 3CRWE920G73 (AP 2)

It proves again that the casing shape does influence the signal and cause it to be shifted in terms of signal polarization. The material used for simulating the casing is plastic, with a dielectric constant of 2.0, retaining same radiation pattern as the antenna without casing.

While most normal helical antenna has its main direction towards theta, this antenna performs differently by radiating mostly at its side or at azimuth level (phi). Such phenomenon occurred because of the cylinder BST used as the dielectric resonator.

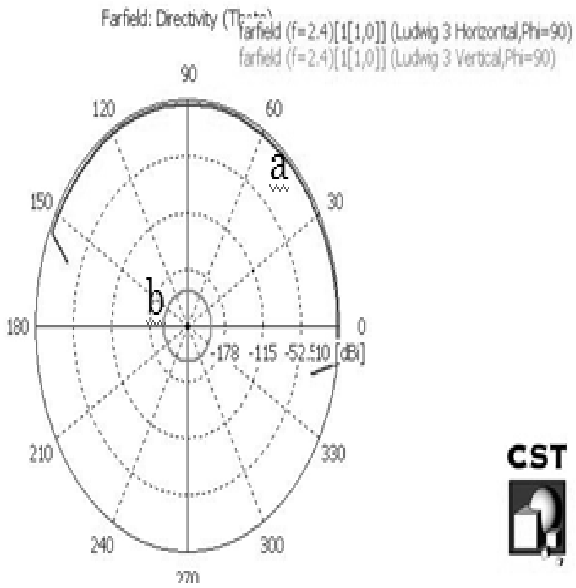

Fig. 18. E-Field co-polarization (a) and cross-polarization (b) of AP 2.

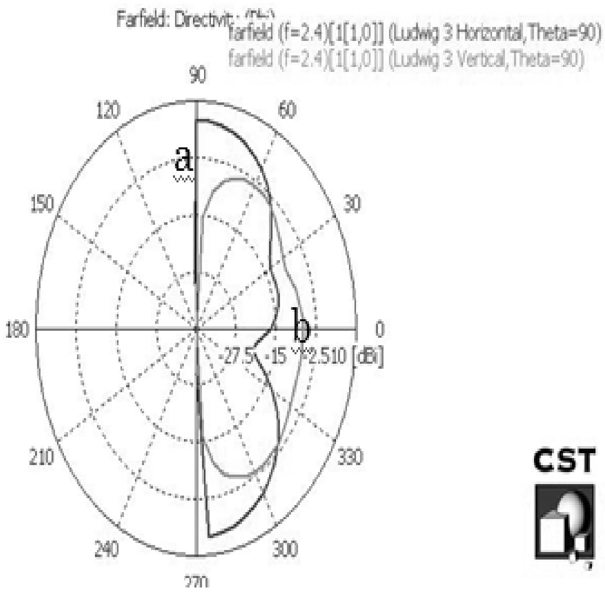

Fig. 19. H-field Co-polarization (a) and Cross-polarization (b) of AP 2.

Uncased dielectric loaded helical antenna had similar radiation weight against rectangular enclosure (AP2). Apparently, E-field co-polarized shifted slightly and H-field co-polarized (0^0) shrunk from -2.5 dBi to -15.0 dBi, while retaining everything else. When incorporating the antenna in a circular enclosure, the radiation pattern differs significantly in terms of E-field and H-field. Not only had it shifted further left with about 44.4% of displacement, its signal redundancy increased at three spots, as marked in Fig 15. It is concluded that the small space available inside the casing makes power distribution low. As a summary, Table 6 concludes the findings within three different simulation models and their produced gain. AP 1 which is circular produced a gain degradation of about 1 dB, while AP 2 presented a slightly improved operating performance of the antenna.

4 Conclusion

This work has presented the development and analysis of a novel dielectric loaded helical antenna for WLAN applications. Other than investigation of its parametric study, this paper has also extended the examination to simulating it using real, off-the-shelf Access Points (APs). Simulations of these two types of APs have given relatively different result compared to when the antenna is simulated independently, due to the shape of the APs, material used, and internal space available. The designed antenna was also proven feasible and capable for integration into readily available devices, especially a rectangular shaped AP, with sufficient spacing in order to reduce proximity coupling effect on the casing material.

Table 6
Gain comparison of designed antenna in different operating wireless devices

Operating at 2.4 GHz	Gain (dB)
Without Access Point	6.475
With AP 1 Casing	5.474
With AP 2 Casing	6.477

References:

[1] Y.A.Ho and Edward K.N.Yung, "Characteristics of a Helical Antenna with a Dielectric Resonator Core", Asia-Pacific Microwave Conference Proceedings, v01.2, pp.600-603,Oct. 1995

[2] V. Sugio et al:"Analysis for Gain Enhancement of Multiple-.Reflection Line Antenna with Dielectric Plates," T. R. of IEICE of Japan, A.P80-112, pp-7-12, January, 1981.

[3] H. T. Hui, K.Y. Chan, and E. K. N.Yung, "The Low-Profile Hemispherical Helical Antenna with Circular Polarization Radiation over a Wide Angular Range," *IEEE Trans. Antennas Propag.,* vol. 51, no. 6, pp. 1415–1418, Jun. 2003.

[4] L. Boccia, G. Amendola, and G. D. Massa, “A Shorted Elliptical Patch Antenna for GPS Applications,” *IEEE Antennas Wireless Propag*. Lett., vol. 2, no. 1, pp. 6–8, Jan. 2003.

[5] J. C. Louvigne and A. Sharaiha, “Synthesis of Printed Quadrifiliar Helical Antenna,” Electron. Lett., vol. 37, no. 5, pp. 271–272, Mar. 2001.

[6] H. Nakano, H. Yasui, and J. Yamauchi, “Numerical Analysis of Two-Arm Spiral Antennas Printed on a Finite-Size Dielectric Substrate,” *IEEE Trans.Antennas Propag*., vol. 50, no. 3, pp. 362–370, Mar. 2002.

[7] H. T. Hui, E. K. N. Yung, C. L. Law, Y. S. Koh, and W. L. Koh, “Design of a Small and Low-profile 2 by 2 Hemispherical Helical Antenna Array for Mobile Satellite Communications,” *IEEE Trans. Antennas Propag*., vol. 52, no. 1, pp. 346–348, Jan. 2004.

[8] N. K. Pervez, P. J. Hansen, and R. A. York,” High Tunability Barium Strontiu Titanate Thin Films for RF Circuit Applications,” Vol 85, No 19, 8 November 2004.

[9] Hongyan Miao & Yaohui Zhou & Guoqiang Tan & Min Dong,” Microstructure and Dielectric Properties of Ferroelectric Barium Strontium Titanate Ceramics prepared by Hydrothermal Method,” J Electroceram DOI 10.1007/s10832-007-9244-x Springer Science + Business Media, LLC 2007.

[10] Yi-Fang Lin, Chia-Ho Lin, Hua-Ming Chen*,”* A Miniature Dielectric Loaded Monopole Antenna for 2.4/5 GHz WLAN Applications,” VOL. 16, NO. 11, NOVEMBER 2006.

[11] V. Sugio et al:”Analysis for Gain Enhancement of Multiple-.Reflection Line Antenna with Dielectric Plates,” T. R. of IEICE of Japan, A.P80-112, pp-7-12, January, 1981.

[12] C. C. Chiau, , X. Chen, and C. G. Parini, “A Miniature Dielectric-Loaded Folded Half-Loop Antenna and Ground Plane Effects,” *IEEE Antennas and Wireless Propagation Letters*, VOL. 4, 2005.

[13] Piaivi Haapala and Pertti Vainikainen,” Helical antennas for multi-mode mobile phones.” 26th EuMC a 9-12 September 1996, Hotel Hilton Atrium, Prague, Czech Republic.

[14] Nicolaescu Ioan, Ioachim Andrei, Toacsan Irina,Radu Ionut, Banciu Gabriel, Nedelcu Liviu,” High K Dielectric Resonator Antenna,” WSEAS TRANSACTIONS on COMMUNICATIONS Volume 7, Issue 5, May 2008, Pages 361-371.

[15] Jaleel Azeez Hamadameen,” Analysis, design, and simulation of a Log Periodic Antenna for Mobile Communication bands,” WSEAS TRANSACTIONS on COMMUNICATIONS Issue 5, Volume 7, May 2008, pages 399 - 402.

[16] S. Kampeephat, P. Krachodnok, M. Uthansakul, and R.Wongsan,” Gain and Pattern Improvements of Array Antenna using MSAwith Asymmetric T-shaped Slit Loads,” WSEAS TRANSACTIONS on COMMUNICATIONS Issue 9, Volume 7, September 2008, pages 922 – 931.