Integration of An Optimized E-Shaped Patch Antenna into Laptop Structure for Bluetooth and Notched-UWB Standards using Optimization Techniques

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Abstract **─** In this article, an optimized E-shaped patch antenna for Bluetooth (2.4 - 2.484 GHz) and UWB (3.1- 10.6 GHz) applications with WLAN (5.15 - 5.825 GHz) band-notched characteristics is proposed. The dimensions of the E-shaped structure in addition to the position of the slotted C-shape in the ground plane are optimized using recent optimization techniques such as modified particle swarm optimization (MPSO), bacterial swarm optimization (BSO), and central force optimization (CFO). The optimization algorithms were implemented using MATLAB-software and linked to the CST Microwave Studio Suite® version 2011 to simulate the antenna. Next, the effects of the laptop structure on the antenna radiation characteristics are considered. To validate the results, the antenna structures are simulated by the finite difference time domain method (FDTD).

Index Terms - E-shape antenna, FDTD method, notched-UWB, optimization techniques.

I. INTRODUCTION

The commercial usages of ultra-wideband (UWB) frequency band from 3.1 GHz to 10.6 GHz, was approved by Federal Communications Commission (FCC) in 2002 [1]. Recently, UWB technology has been widely used in various radars and has attracted much attention for communication systems [2-4]. UWB antennas must cover FCC definition for the indoor and handheld UWB applications, have electrically small size, and hold a reasonable impedance match and omnidirectional radiation patterns over the entire band. With the development of UWB technology, various types of planar UWB antennas have been developed with many various shaped planar elements, such as rectangular, circular, elliptical, pentagonal, and triangular geometries for UWB applications [5-12]. One of the most widely studied antennas is the E-shaped antenna due to its broadband capability including 2-6 GHz wireless communication systems [13,14]. In [15], a wideband circularly polarized E-shaped patch antenna for wireless applications are proposed. Recently, a new miniaturized E-shaped printed monopole antenna is designed for UWB applications [16]. In addition, the E-shaped patch antenna is proposed in [17] for millimeter wave frequencies

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(31.6-40 GHz).

Over past years, Bluetooth has been widely used in portable devices such as mobile phones, PDAs and notebooks etc. In 2006, the Bluetooth Special Interest Group selected the multi-band orthogonal frequency division multiplexing (MB-OFDM) version of the UWB to integrate with the current Bluetooth wireless technology. However, consumers usually prefer lighter and thinner products, and one of the solutions is to have a single antenna to work in both UWB and Bluetooth. On the other hand, some existing narrow bands for other communication systems, such as WLAN (5.15–5.825 GHz) cause interference with UWB systems. To solve this problem, it is desirable to design antennas with band-notched characteristic to minimize potential interference [18]. The undesired frequencies can be rejected using different techniques so that the system performance may be enhanced well. One simple way is to etch thin slots on the antenna surface, such as U-shaped slot [19], T-shaped slot [20], and L-shaped slot [21]. Moreover, a planar integrated antenna working on both Bluetooth and UWB applications with WLAN band notched characteristics has been recently introduced for systems operating in those two communication systems [22-24].

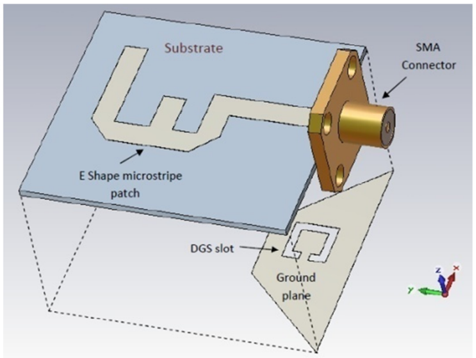
Furthermore, the latest trend is to build these wireless systems into portable devices through various interfaces [25-27]. For embedded solutions, the antennas are required to reside with the devices such as the laptop computer itself, underneath the plastic, composite, or metals covers. However, one has to suffer from the degraded performance of embedded antennas. The embedded antennas usually do not perform as well as external ones due to greatly reduced space required for optimal designs, being partially hidden within semi-conducting or conducting materials and the proximity effect of metallic cover and/or liquid crystal display (LCD) panel. To achieve acceptable performance of embedded antennas, the commonly used method is to keep the antenna away from any metal component of a laptop computer. Depending on the design of laptop computers and type of antennas, the distance between the antenna and metal components should be as large as possible [28].

In this study, an E-shaped patch antenna is optimized using recent optimization techniques such as modified particle swarm optimization (MPSO) and bacterial swarm optimization (BSO) in addition to central force optimization (CFO) which are completely described before in [29], [30], and [31], respectively. However in [30,31], simple antennas are considered with one or two variables to be optimized. In this paper, the antenna design is more complicate with multivariable and constraints. The antenna parameters such as return loss and radiation patterns are discussed. Then, the optimized E-shaped antenna will reside in a laptop computer to study the degradation performance of embedded antenna. The antenna is analyzed completely using CST Microwave Studio which linked with MATLAB to optimize the antenna via Visual Basic for Applications (VBA) programs. Interchanging information between CST Microwave studio and Matlab allows the implementation of optimization algorithms not included in the Microwave studio environment itself [32]. The paper is organized as follows. In Section II, the antenna design and numerical results are presented. Section III presents the degradation of the embedded E-shaped antenna in Laptop computer. Finally, Section IV presents the conclusions.

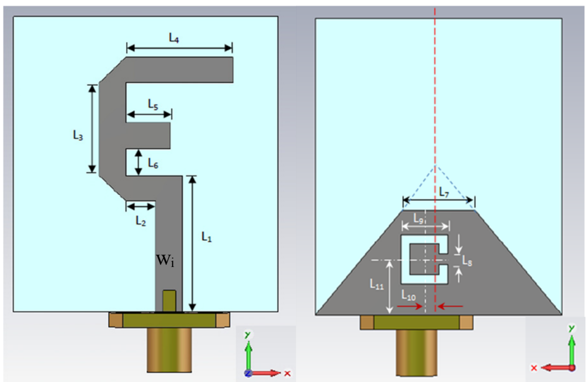
II. ANTENNA DESIGN AND NUMERICAL RESULTS

The schematic of the E-patch antenna structure is shown in Fig. 1(a), depicts the front and back structure of the patch antenna. The dimensions of E-shaped patch are arranged on a 28 x 32 x 0.8 mm^3 thick quartz-crystal substrate with permittivity constant $\varepsilon_r = 3$. Concrete dimension parameters are shown in Fig. 1(b), where, $L_1 = 14.8$ mm, $L_2 = 3.2$ mm, $L_3 = 10$ mm, and line width $w_i = 2.8$ mm. Fig. 1(c) shows the dimension parameters in ground plane such as $L_9 = 5$mm, $L_8 = 1$mm. A partial ground plane with C-shape slot is considered for band notch characteristic from 5 – 6 GHz. A 50 Ω SMA is connected to the end of the feeding strip L_1 and grounded to the edge of the ground plane.

In this paper, the E-shape patch antenna dimensions are optimized firstly using the PSO algorithm integrated with the CST Microwave



(a) 3-D Antenna structure



(b) Front profile (c) Back profile

Fig. 1. E-shaped antenna geometry structure.

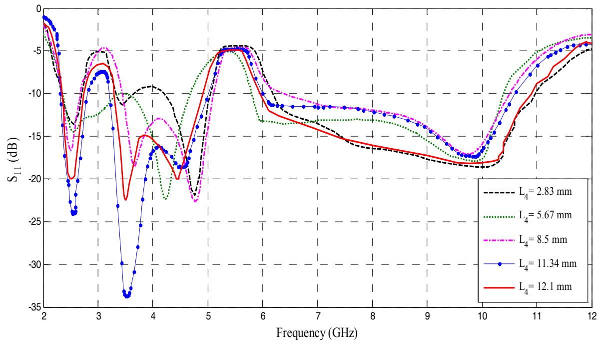
Studio package then other global optimization techniques such as MPSO, CFO, and BSO algorithms is considered to compare between their capabilities in antenna design using random initial values with the same number of evaluations (1000 evaluations). The antenna dimensions are optimized to operate in the Bluetooth band in addition to UWB notched at the WLAN communication band (5 – 6 GHz) by appropriate adjustment of the antenna parameters. As a result of this study, we focus on the following antenna parameters: L_4 along the upper side in the E-shape patch, L_5 along the middle side in the E-shape patch, L_6 the distance between the middle rib and lower rib, L_7 the upper side of the partial ground plane, finally the position of the etched C-shape in the partial ground plane through L_{10} and L_{11}. From the parametric studies, it is found that the top and middle rip strips of lengths are strongly affects the Bluetooth operating band. The width L_6 affects the return loss at the Bluetooth and high frequency bands. The upper side of partial ground plane L_7 is a very critical parameter on the antenna performance where it completely affects the return loss curve. The lengths L_4 and L_5 are allowed to vary between 0 to 12.1 mm, L_6 vary from 0 to 6.4 mm and L_7 from 0 to 10 mm. For the position of the slotted C-shape, the decision space for L_{11} start from 3 to 9.8 mm, however the decision space of L_{10} depending on L_7 and L_9 to be from $(L_7\text{-}L_9)/2$ to $(L_7+L_9)/2$.

The first step is to define the objective function focusing on the antenna return loss (S_{11}) to be less than -10dB at the required operating bands. According to these remarks the objective function is calculated by using the following Equation:

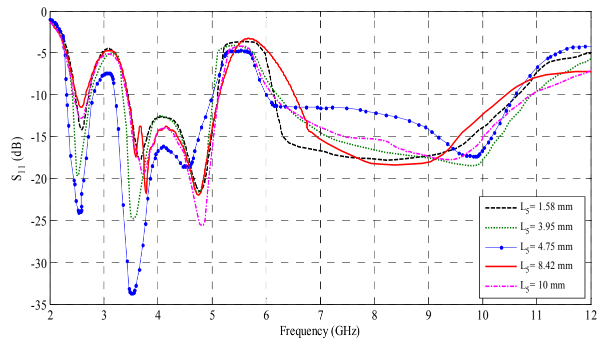
$$Objective\ function = \ min|S_{11}|_{2.45\ GHz} + min|S_{11}|_{3.1\sim5\ GHz} + max|S_{11}|_{5\sim6\ GHz} + min|S_{11}|_{6\ \sim\ 10.6\ GHz}. \quad (1)$$

The optimization algorithms programmed with MATLAB will generate the antenna variables which will be sent to the CST simulator for calculating the fitness value of each individual [32].

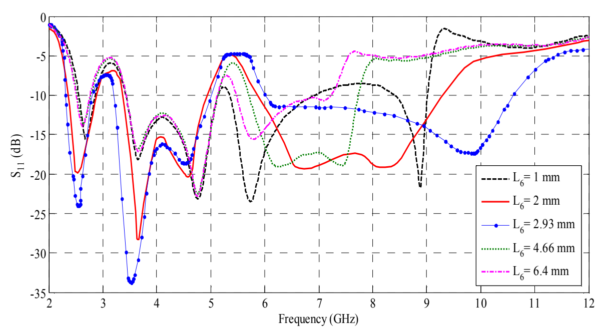
To investigate the antenna parameters effect on the antenna performance, a parametric study was carried out. It is found that the parameters which have a significant impact and remarkably on return loss S_{11} such as: L_4 along the upper side in the E-shape patch, L_5 along the middle side in the E-shape patch, L_6 the distance between the middle rib and lower rib, L_7 the upper side of the partial ground plane, finally the position of the etched C-shape in the partial ground plane through L_{10} and L_{11}. Figure 2(a) shows how the top rip strip length L_4 strongly affects the Bluetooth operating band. Also, the effect of varying the middle rip strip L_5 on the antenna performance has been presented in Fig. 2(b). Figure 2(c) describes the return loss based on increasing and decreasing the width L_6. It can be noticed that the width L_6 affects the return loss at the Bluetooth and high frequency bands. Figure 2(d) shows that the upper side of partial ground plane L_7 is a very critical parameter on the antenna performance where it is completely affects the return loss curve. As



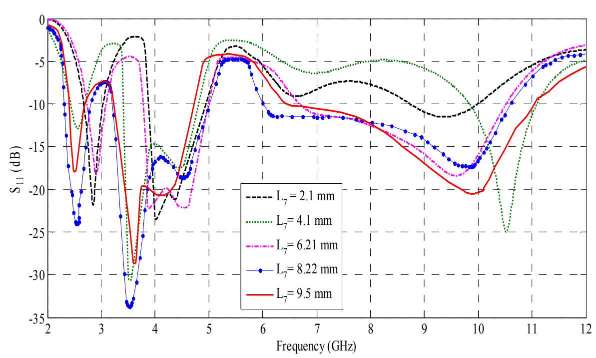
(a) The variation of L_4 parameter on the return loss.



(b) The variation of L_5 parameter on the return loss.



(c) The variation of L_6 parameter on the return loss.



(d) The variation of L_7 parameter on the return loss

Fig. 2. Return loss curves for different antenna parameters.

for the rest of the parameters such as L_1, L_2, L_3 has no significant effect on return Loss S_{11}.

Table 1 shows the optimized values for selected antenna parameters from different optimization algorithms to achieve our goals. Figure 3 shows a comparison between the return losses obtained from different optimization techniques. From the comparisons between CFO and PSO, it can be seen that CFO had significantly better performance on the notched band. However, the CFO algorithm yielded slightly worse results on the Bluetooth band compared to PSO. It is clearly seen that, the BSO algorithm slightly outperformed to the MPSO algorithm in the Bluetooth band. However, approximately exact notch is obtained using MPSO (5.01 – 6 GHz) with a minimum S_{11} of -4.7 dB compared to the notch obtained by BSO (4.88 – 6 GHz) with an S_{11} of -4.15 dB. In summary, it can be found that the BSO algorithm outperformed PSO and CFO algorithms and was comparable to the MPSO for this antenna design. The simulated return loss results illustrate the ability of the proposed antenna to cover the ISM2450 band and UWB respectively with a notched band from 5 to 6 GHz. Table 1 shows also the required computation time for each algorithm on Toshiba laptop, Pentium(R) Dual core CPU @ 2GHz, 2.00 GB RAM, 32 bit operating system.

Table 1: The optimized antenna parameters using different optimization techniques

	Optimization Technique			
	PSO	**MPSO**	**CFO**	**BSO**
L_4(mm)	8.8	11.34	10.52	9.78
L_5 (mm)	6.28	4.75	7.33	3.46
L_6(mm)	3.94	2.93	5.18	5.37
L_7(mm)	7.83	8.225	8.19	9.16
L_{10} *(mm)*	-0.527	1.59	-0.18	1.611
L_{11}*(mm)*	7.69	5.8	7.03	5.829
Time (day)	3.91	3.98	4.05	4.11

In the CST Microwave Studio simulator, which based on frequency domain solver (finite element), the following settings were used for time domain simulations: the minimum mesh step = 0.7, maximum mesh step = 2.605 and the mesh cells = 15,925 (Nx = 36, Ny = 36, Nz = 14). The mesh line ratio limit was set to 50 with an equilibrate mesh ratio of 1.19. Open add space boundary condition is applied in all directions with thermal boundaries isothermal (T = constant), while the parameters for FDTD computation were set as follows: the domain was 152 x 138 x 45 cells with a cell size of Δx = 0.29 mm, Δy = 0.29 mm, Δz = 0.29 mm. The FDTD lattice needs to be terminated by perfectly matched layer (PML) on all sides; a spatially varying conductivity should be used in order to avoid numerical reflections at the interface of FDTD/PML regions. The computational domain was terminated with 8 cells perfectly matched layer in all directions (PML) with a time step of 551.7 ps and number of time step is 3000 time step.

Figure 4 illustrates the simulated current distribution on the optimized antenna by BSO algorithm at 2.45, 4, and 9 GHz. One can observe that, most current concentrated under the patch and more areas are needed for low frequency (2.45 GHz) than for high frequencies (4 and 9 GHz). The electric currents are mainly concentrated around the feeding strip at high frequencies. As shown in Figs. 4(b) and 4(c), the UWB element appears more active and the Bluetooth element appears colder at 4 and 9 GHz. Therefore, the top and middle rip strips are concluded to be responsible to generate the Bluetooth band.

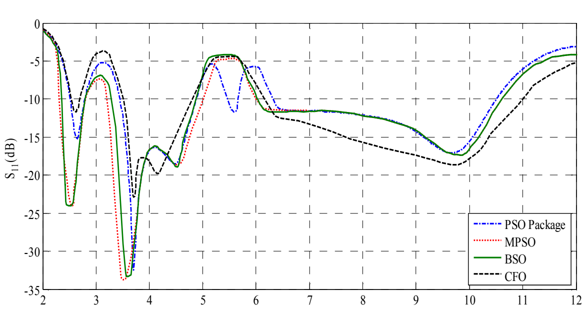
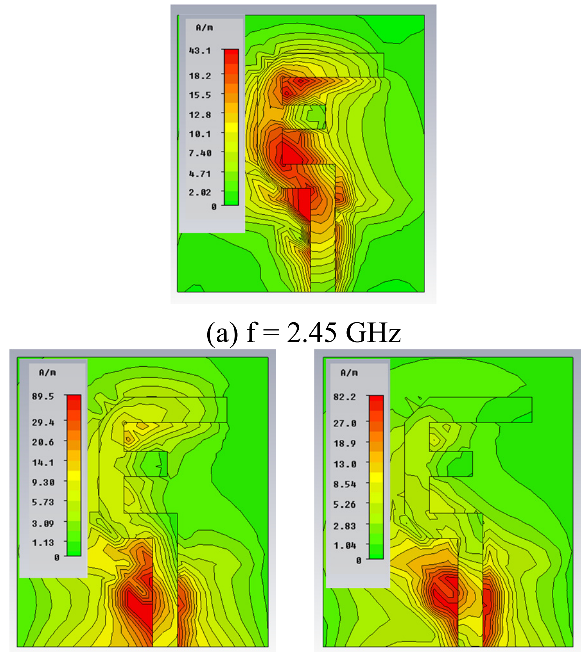


Fig. 3. Return losses comparison for optimized antenna using different optimization algorithms.



(a) f = 2.45 GHz

(b) f = 4 GHz (c) f = 9 GHz

Fig. 4. Simulated current distributions of the optimized antenna using BSO at different frequencies.

III. EMBEDDED ANTENNA IN LAPTOP COMPUTER

To perform the study of integration and packaging, a generic model of a laptop computer is assumed. The overall dimensions of the laptop structure are: base unit (2.6 x 3.6 x 3 cm^3) and screen (2.5 x 3.6 x 1.5 cm^3). The open angle (α) of the computer to simulate actual operation is assumed to be 105^o as shown in Fig. 5. The fabricated model consists of a Lucite (ε_r = 3.6) body, clad in copper tape across the base unit structure, which is meant to mimic the computer's internal shielding. The optimized antenna using BSO algorithm is embedded in the center of the screen.

In this section, the effects of the laptop structure on the E-shaped antenna properties have been studied numerically. The input matching and radiation pattern characteristics have been calculated and compared. Figure 6 shows a comparison between the return losses obtained from the antenna in free space and

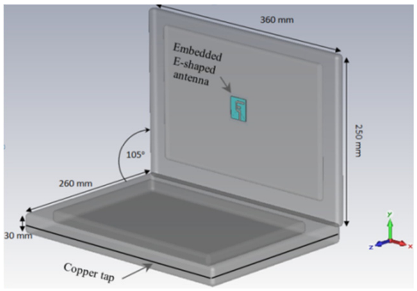


Fig. 5. Embedded E-shaped Antenna in Laptop.

those embedded in the Laptop structure with CST MWS package. It has been shown that the laptop structure slightly affect the antenna input reflection coefficient without disturbing the antenna resonant frequency and the impedance bandwidth. To validate the results, a finite difference time domain (FDTD) program code written with MATLAB is used to simulate the antenna either in free space or embedded in Laptop computer [33-35]. In addition, Fig. 6 shows a comparison between the simulated results with FDTD method and EM simulator of CST Microwave Studio software which based on a finite element method (FEM) for return loss in the range 2 – 12 GHz. A good agreement between the FDTD simulated results and those produced by CST Microwave Studio are achieved. The differences between the calculated results using the FDTD method and the CST MWS are related to the applied numerical techniques difference (FDTD and FEM). The parameters for FDTD computation were set as follows: the domain was 180 × 200 × 43 cells with a cell size of $\Delta x = 0.2$ mm, $\Delta y = 0.2$ mm, $\Delta z = 0.283$ mm. The computational domain was terminated with perfectly matched layer (PML) of 8 cells in all directions.

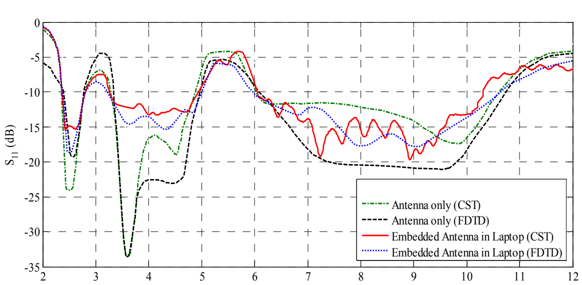


Fig. 6. Return losses comparisons between the antenna only and the embedded antenna in Laptop using FDTD method and the CST.

Figures 7(a), 7(b), and 7(c) show the radiation patterns of the antenna in free space and that embedded in laptop in x-z plane and x-y plane at 2.45, 4 GHz, and 9 GHz, respectively. It is found that, the antenna has approximately omni-directional characteristics in the x-z plane.

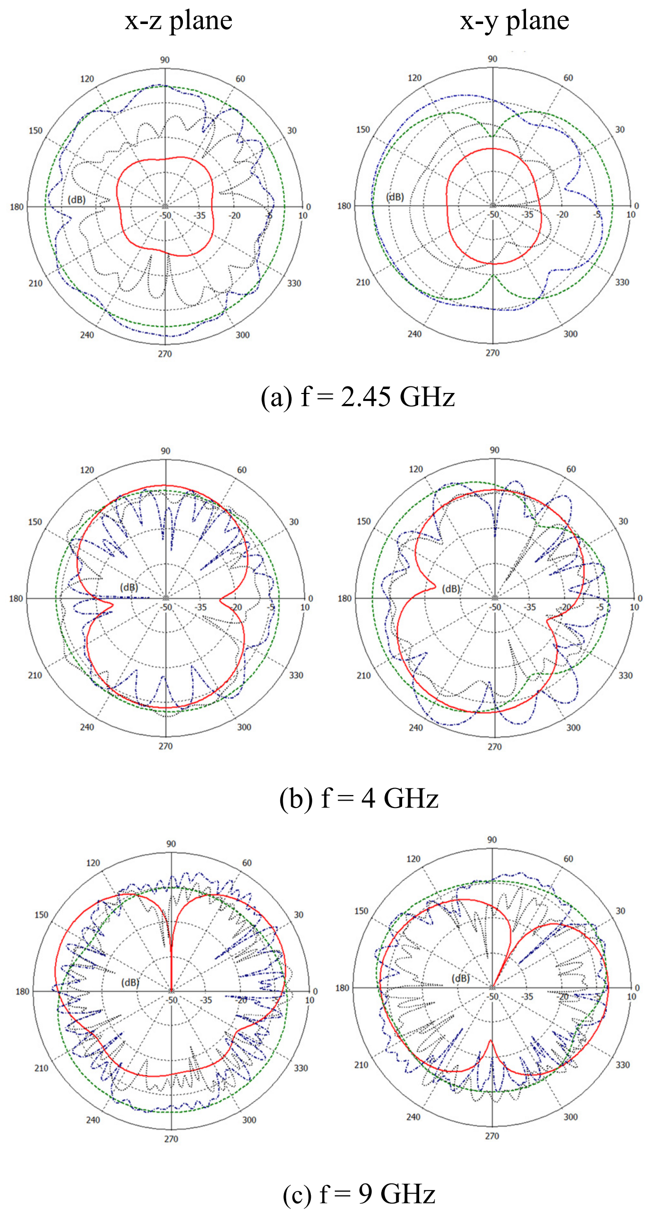


Fig. 7. Simulated radiation patterns of the proposed antenna at different frequencies.

——— E_θ - - - - E_φ (Antenna in free space)

.... E_θ — · — E_φ (Embedded Antenna)

As expected, the presence of the laptop structure affects the antenna radiation pattern due to the interference of the reflected wave from the keyboard with the direct wave radiated from the antenna element. In the horizontal plane, in spite of the presence of the keyboard structure, the (total power) radiation pattern is almost omnidirectional in both front and back hemispheres.

Finally, the effects of changing the open angle on the antenna characteristics are studied. Figure 8 shows the effect of changing the open angle on the return loss. It is found that, the return loss in the Bluetooth band is slightly improved as the open angle increase. In addition it affects the UWB range by decreasing and increasing the high cutoff frequency. The effect of changing the open angle on the radiation patterns are depicted in Fig. 9. As shown in figure, a slight change is observed due to changing the open angle without any effect on the antenna omnidirectionality.

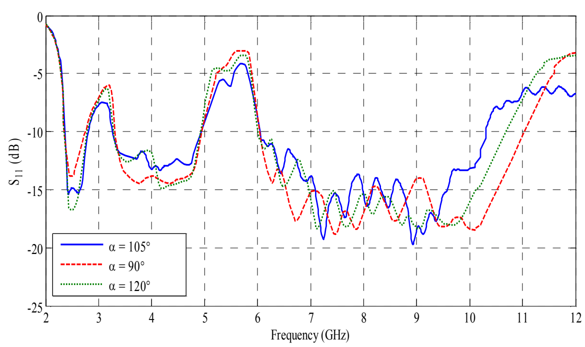


Fig. 8. Return losses comparison for embedded antenna with different open angles.

IV. CONCLUSIONS

In this article, an E-shaped patch antenna is designed using recently optimization techniques such as MPSO, CFO, and BSO for Bluetooth/notched UWB applications. The algorithms have been implemented in MATLAB and the prototype simulations have been carried out using the CST Microwave Studio simulator. It is found that the BSO algorithm is slightly outperformed than MPSO and CFO. In addition, the optimized antenna is embedded in laptop computer which slightly affect the antenna return loss without disturbing the resonant frequency and the impedance bandwidth; however, it affects the antenna radiation patterns without any disturbance on the antenna omni-directionality.

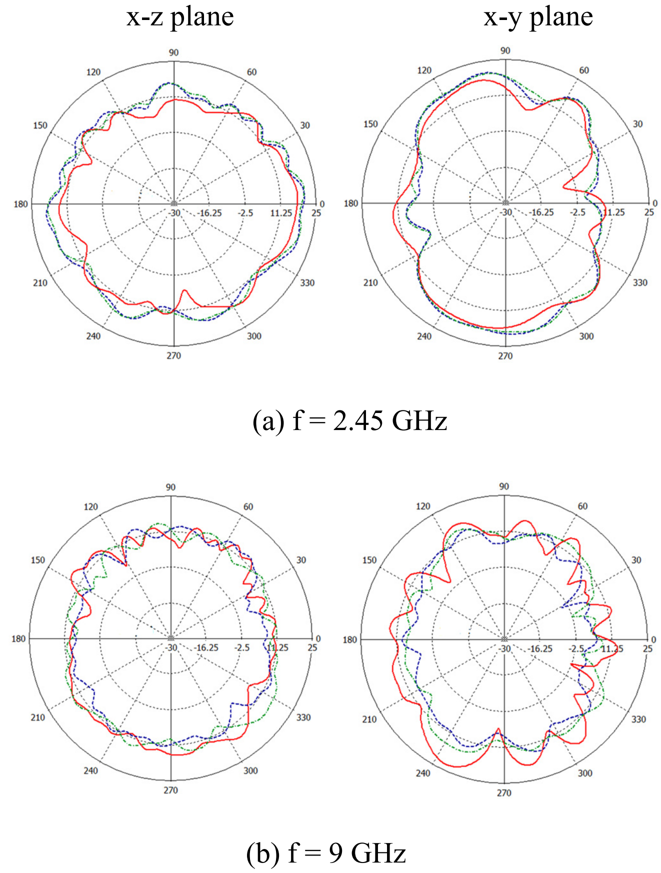


Fig. 9. The simulated radiation patterns of the embedded antenna in x-z, and x-y planes at different frequencies.

α = 90° α = 105° α = 120°

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