*Progress In Electromagnetics Research B, Vol. 47, 279–295, 2013*

# DESIGN BLUETOOTH AND NOTCHED-UWB E-SHAPE ANTENNA 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 antenna 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 to simulate the antenna. Next, the effects of the Laptop structure on the antenna radiation characteristics are considered. Finally, the antenna structures are simulated by the finite difference time domain method (FDTD) to validate the results. The measured results exhibit good agreement with the simulation from CST and the Finite Difference Time Domain (FDTD) program written with matlab.

## 1. 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]. UWB antennas must cover FCC definition

*Received 14 October 2012, Accepted 12 December 2012, Scheduled 4 January 2013*

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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 [3–7]. One of the most widely studied antennas is the E-shaped antenna due to its broadband capability including 2–6 GHz wireless communication systems [8, 9]. In [10] 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 [11]. In addition, the E-shaped patch antenna is proposed in [12] for millimeter wave frequencies (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 [13]. 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 [14], T-shaped slot [15], and L-shaped slot [16]. 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 [17–19].

Furthermore, the latest trend is to build these wireless systems into portable devices through various interfaces [20–22]. 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. This maintains the computer physical outline without any affix, and also reduces the possibility of accidental breakage. 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 LCD (Liquid Crystal Display) 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 [23].

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). The antenna parameters such as return loss, antenna gain 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 [24]. To valid the results, the performance of the designed filter is assessed using the Finite Difference Time Domain (FDTD) program written with MATLAB.

The paper is organized as follows. In Section 2, the optimization algorithms are briefly presented. Section 3 describes the antenna design and numerical results, Section 4 present the degradation of the embedded E-shaped antenna in Laptop computer. Finally, Section 5 presents the conclusions

## 2. OPTIMIZATION ALGORITHM

Optimization is recognized as a challenging problem to solve. The goal of any estimation or optimization technique is to formulate an efficient method to navigate through a large parameter space in order to find the best set values. Among various Evolutionary Optimization (EO) techniques, particle swarm optimization (PSO) has attracted a lot of attention since its introduction [25]. Many researchers have worked on improving PSO performance in various ways and developed many interesting variants. In MPSO algorithm, to update the velocity matrix at each iteration $k$, every particle should know its personal best ($pbest$) and the global best ($gbest$) position vectors in addition to the neighbor best position vector [26].

An alternative method known as Bacteria Foraging Optimization Algorithm (BFOA) that is based on the foraging behavior of Escherichia Coli (E. Coli) bacteria present in the human intestine [27] has already been in use to many engineering problems including antenna design and antenna arrays. The control system of the E. coli bacteria governing their foraging process can be subdivided into four sections, which are chemotaxis, swarming, reproduction and elimination & dispersal. Some modification of BFOA is done for faster convergence such as orienting the BFOA by PSO to combine both algorithms' advantages which called Bacterial Swarm Optimization (BSO) algorithm [28]. In BFOA, a unit length direction of tumble behavior is randomly generated; random direction may lead to delay in reaching the global solution. However, in the BSO, the unit length random direction of tumble behavior is decided by the global best position and the best position of each bacterium. The applied BSO algorithm had been provided in details in [29].

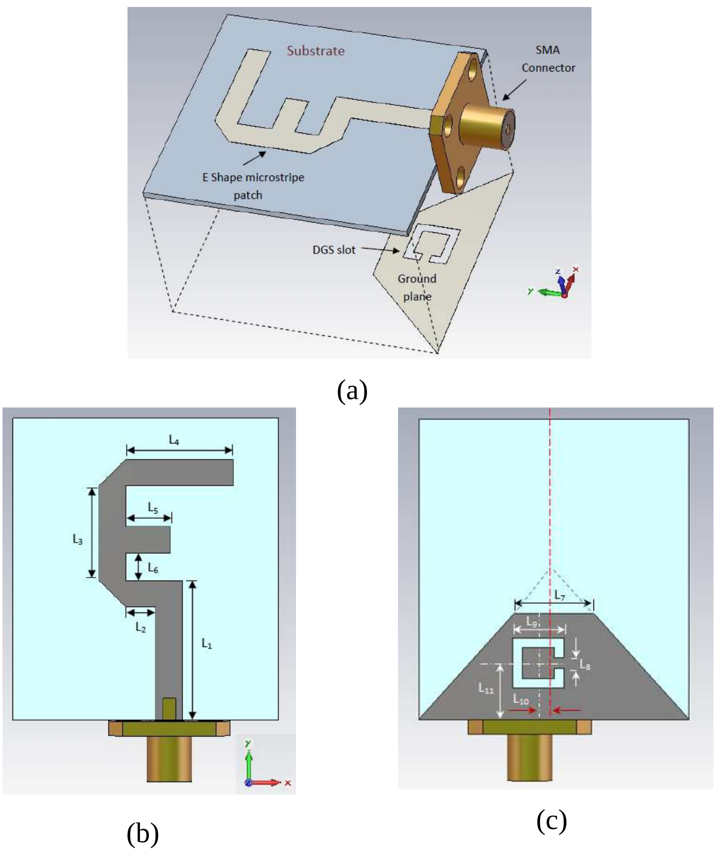



**Figure 1.** E-shaped antenna geometry structure. (a) 3-D antenna structure. (b) Front profile. (c) Back profile.

Recently, CFO algorithm was introduced as a new deterministic metaheuristic for multi-dimensional search and optimization based on the metaphor of gravitational kinematics [30]. The CFO algorithm considered in this paper is previously described in details [31].

## 3. ANTENNA DESIGN AND NUMERICAL RESULTS

The schematic of the E-patch antenna structure is shown in Figure 1(a), depicts the front and back structure of the patch antenna. The dimensions of E-shaped patch is arranged on a $28 \times 32 \times 0.8\,\text{mm}^3$ thick quartz-crystal substrate with permittivity constant $\varepsilon_r = 3$. Concrete dimension parameters are shown in Figure 1(b), where, $L_1 = 14.8\,\text{mm}$, $L_2 = 3.2\,\text{mm}$, $L_3 = 10\,\text{mm}$, and line width $w_i = 2.8\,\text{mm}$. Figure 1(c) shows the dimension parameters in ground plane such as $L_9 = 5\,\text{mm}$, $L_8 = 1\,\text{mm}$. A partial ground plane with C-shape slot is considered for band notch characteristic from 5–6 GHz. A $50\,\Omega$ 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 Studio package then other global optimization techniques such as MPSO, CFO, and BSO algorithms will be considered to compare between their capabilities in antenna design. 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-shaped patch, $L_5$ along the middle side in the E-shaped 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 $L_{11}$.

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

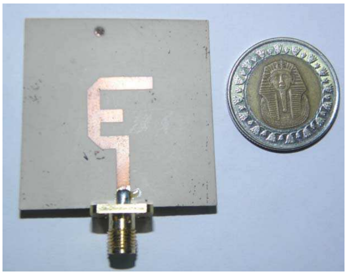
$$\begin{aligned}\text{objective function} = {} & \min(S_{11})_{(2.45\,\text{GHz})} + \min(S_{11})_{(3.1\sim 5\,\text{GHz})} \\ & + \max(S_{11})_{(5\sim 6\,\text{GHz})} + \min(S_{11})_{(6\sim 10.6\,\text{GHz})}\end{aligned}$$

The optimization algorithms programmed with MATLAB will generate antenna variables which will be sent to the CST simulator for calculating the fitness value of each individual [24].

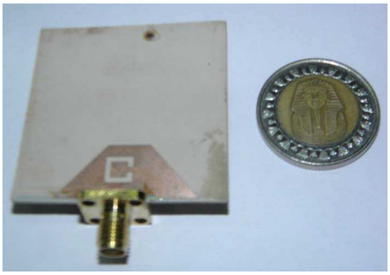
Table 1 shows the decision space for each variable and the best obtained value to achieve our goals from PSO integrated with CST

**Table 1.** The decision space for each variable and the best obtained value for the proposed antenna using different optimization techniques.

| | Decision space | Optimization Technique | | | |
|---|---|---|---|---|---|
| | | PSO Package | MPSO | CFO | BSO |
| $L_4$ (mm) | $0 \rightarrow 12.1$ | 8.8 | 11.34 | 10.52 | 9.78 |
| $L_5$ (mm) | $0 \rightarrow 12.1$ | 6.28 | 4.75 | 7.33 | 3.46 |
| $L_6$ (mm) | $0 \rightarrow 6.4$ | 3.94 | 2.93 | 5.18 | 5.37 |
| $L_7$ (mm) | $0 \rightarrow 10$ | 7.83 | 8.225 | 8.19 | 9.16 |
| $L_{10}$ (mm) | $\left(\frac{L_7}{2} - \frac{L_9}{2}\right) \rightarrow \left(\frac{L_7}{2} + \frac{L_9}{2}\right)$ | −0.527 | 1.59 | −0.18 | 1.611 |
| $L_{11}$ (mm) | $3 \rightarrow 9.8$ | 7.69 | 5.8 | 7.03 | 5.829 |



(a)



(b)

**Figure 2.** Photograph of fabricated E-shaped antenna. (a) Top view. (b) Bottom view.

Microwave Studio package and those obtained from MPSO, BSO, and CFO algorithms. The optimized E-shaped patch antenna is simulated, fabricated and measured. Figure 2 shows photographs of the fabricated structure. The return loss comparison between the measurements and those produced from different optimization techniques are shown in Figure 3. From the comparisons between CFO and the 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 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

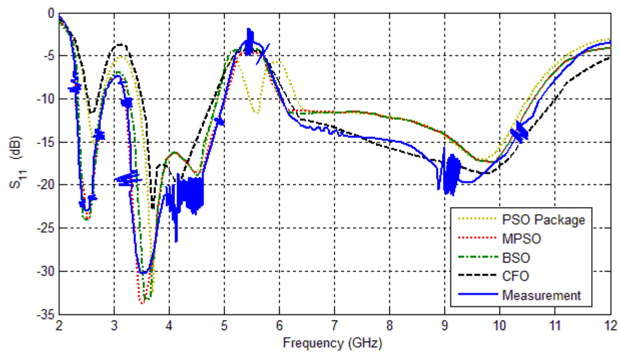



**Figure 3.** Return losses comparison for optimized E-shape antenna using PSO Package, MPSO, BSO, and CFO algorithms and measurement results.

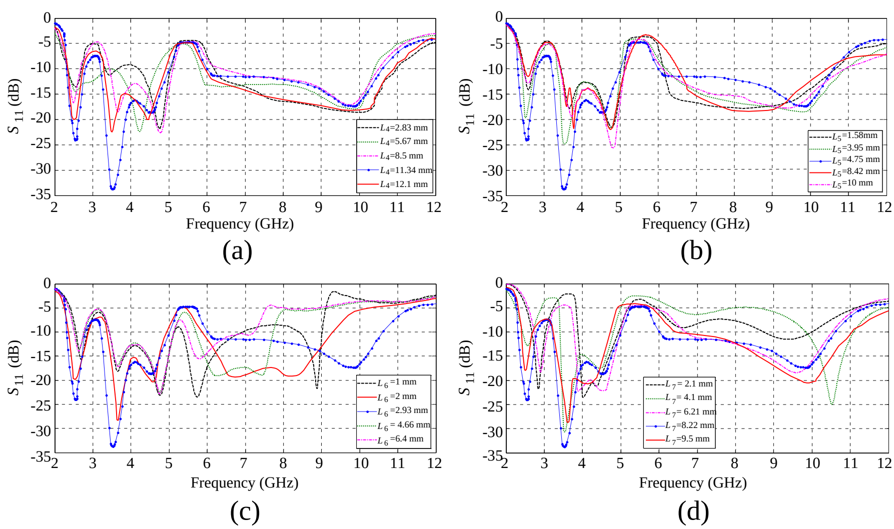
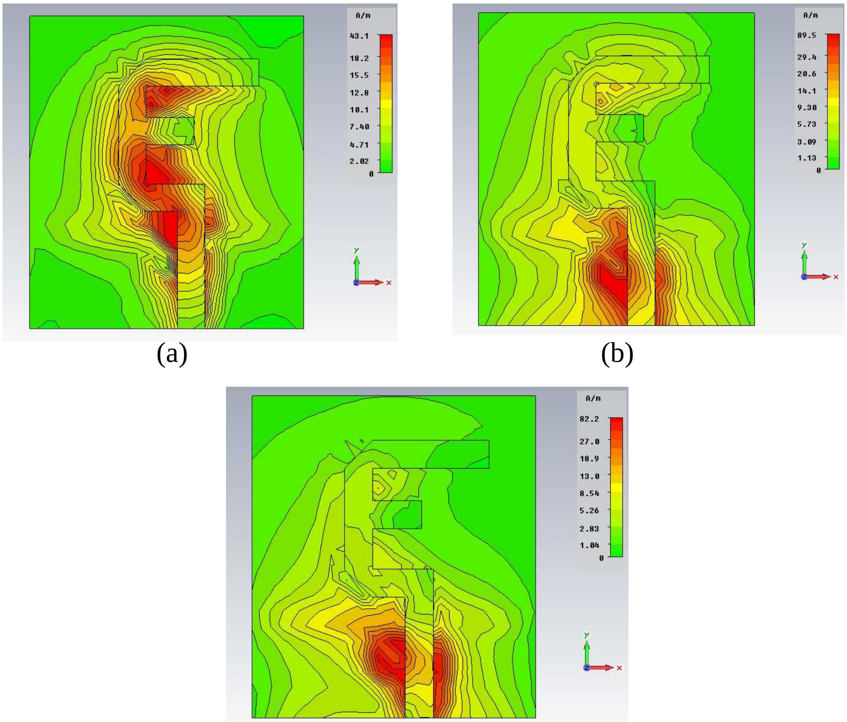



**Figure 4.** Return loss curves for different antenna parameters. (a) The variation of $L_4$ parameter on the return loss. (b) The variation of $L_5$ parameter on the return loss. (c) The variation of $L_6$ parameter on the return loss. (d) The variation of $L_7$ parameter on the return loss.

antenna to cover the ISM2450 band and UWB respectively with a notched band from 5 to 6 GHz.

To investigate the parameters effect on the antenna performance,



(c)

**Figure 5.** Simulated current distributions of the optimized E-shaped patch antenna using BSO at different frequencies. (a) $f = 2.45\,\text{GHz}$. (b) $f = 4\,\text{GHz}$. (c) $f = 9\,\text{GHz}$.

a parametric study was carried out. Figure 4(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 Figure 4(b). Figure 4(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 4(d) shows that theupper 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.

Figure 5 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 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

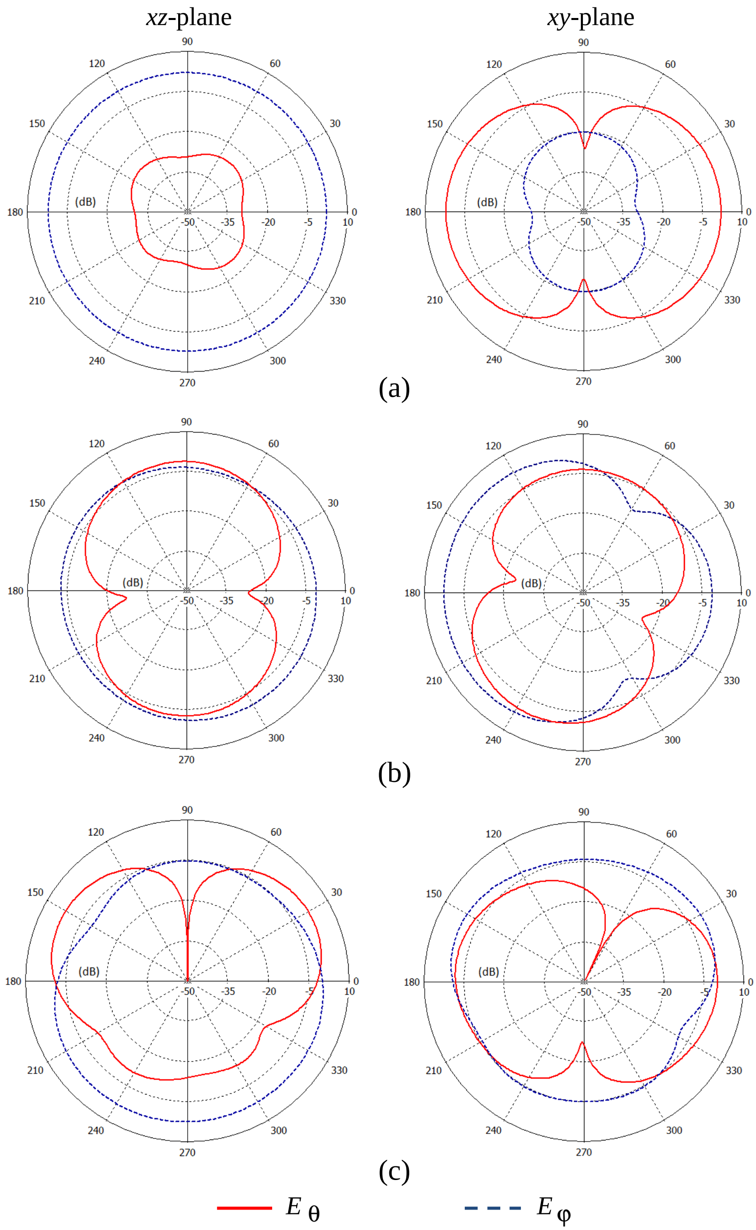



**Figure 6.** The simulated radiation patterns of the proposed E-shape antenna design in $xz$, and $xy$-planes at different frequencies. (a) $f = 2.45\,\text{GHz}$. (b) $f = 4\,\text{GHz}$. (c) $f = 9\,\text{GHz}$.

high frequencies. As shown in Figures 5(b) and 5(c), the UWB element appears more active and the Bluetooth element appears colder at 4 and 9 GHz. It can be concluded that, the top and middle rip strips are responsible to generate the Bluetooth band as indicated in Figures 5(a) and 5(b). The gain patterns of the antenna in $x$-$z$ plane and $y$-$z$ plane at 2.45, 4 GHz and 9 GHz are illustrated in Figures 6(a), 6(b) and 6(c) respectively. It is found that, the antenna has approximately omnidirectional characteristics in the $x$-$z$ plane.

## 4. 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 ($26 \times 36 \times 3\,\mathrm{cm}^3$) and screen ($25 \times 36 \times 1.5\,\mathrm{cm}^3$).

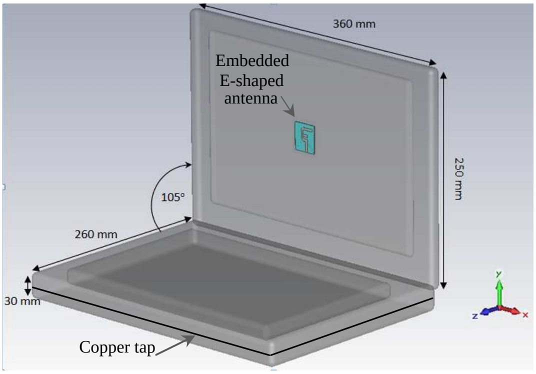



**Figure 7.** Embedded E-shaped antenna in laptop structure.

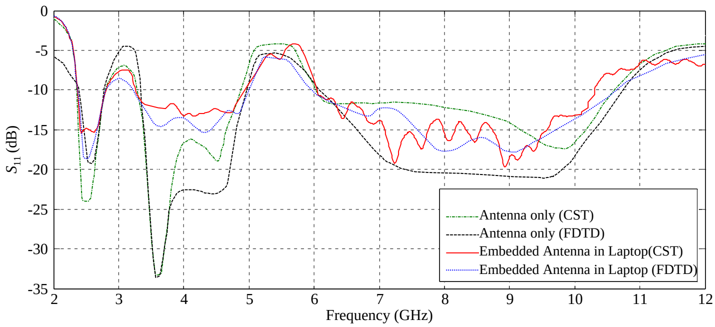



**Figure 8.** Return losses comparison between the antenna only optimized by BSO algorithm and the embedded antenna in Laptop using FDTD method and the CST MWS.

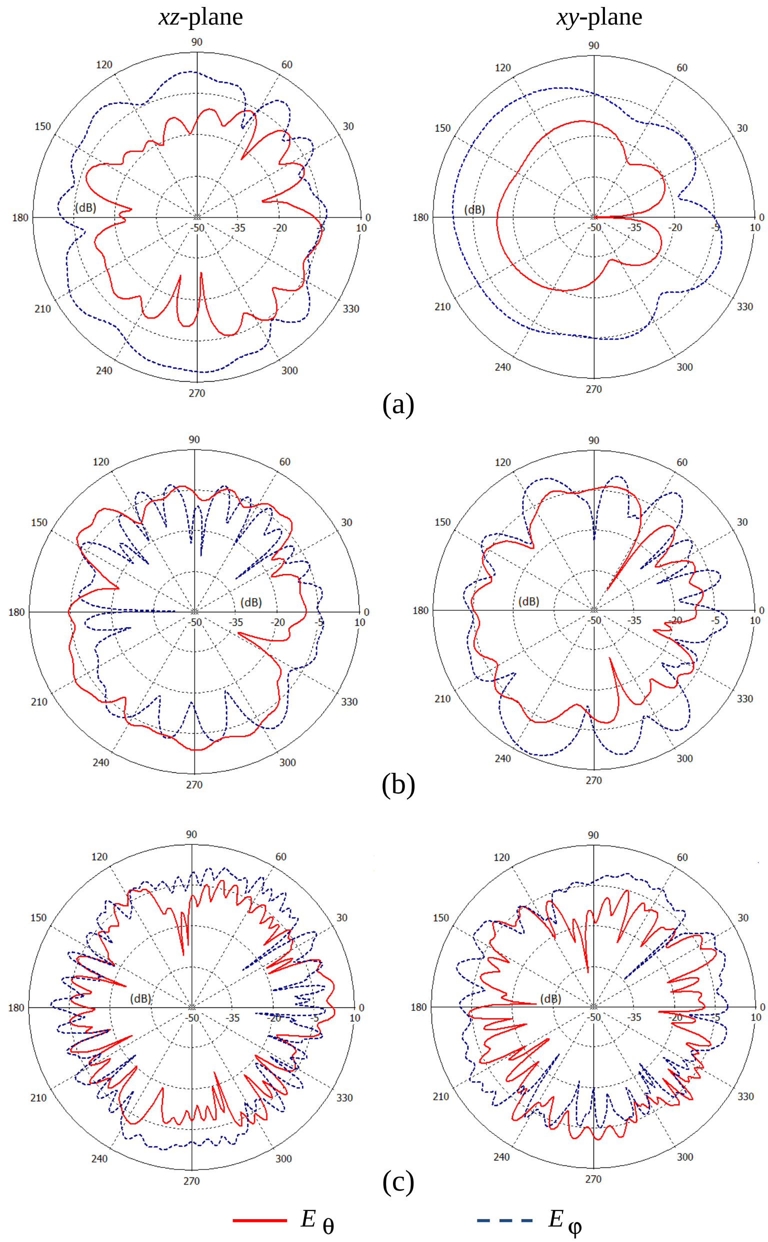



**Figure 9.** The simulated radiation patterns of the optimized E-shape antenna in $xz$, and $xy$-planes at different frequencies. (a) $f = 2.45\,\text{GHz}$. (b) $f = 4\,\text{GHz}$. (c) $f = 9\,\text{GHz}$.

The angle between base unit and screen for laptop ($\alpha$) of the computer to simulate actual operation is assumed to be 105° as shown in Figure 7. The fabricated model consists of a Lucite ($\varepsilon_r = 3.6$) body, clad in copper tape across the base unit structure, which is meant to mimic the compute'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 are studied numerically. The input matching and radiation pattern characteristics have been compared with the stand-alone antenna. Figure 8 shows a comparison between the return losses obtained from the antenna in free space and 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 optimized antenna by BSO algorithm either in free space or embedded in Laptop computer. In addition, Figures 8 shows a comparison between the simulated results with FDTD method and EM Simulator of CST Microwave Studio software for return loss in the range 2–12 GHz, respectively. 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 due to the different applied numerical techniques (FDTD and FEM). The parameters for FDTD computation were set as follows: the domain was $180 \times 200 \times 43$ 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 and a time step of 422.1 ps [32, 33].

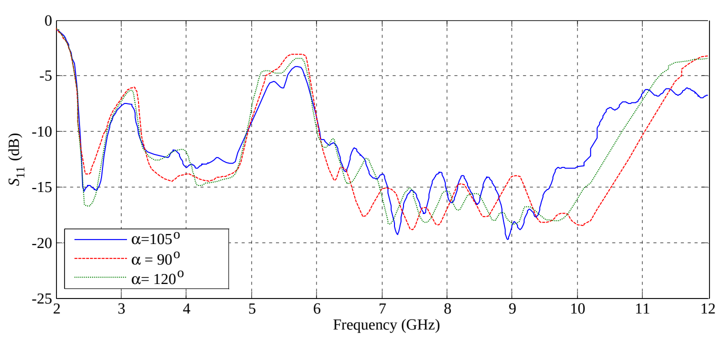



**Figure 10.** Return losses comparison for the embedded antenna in laptop with different open angles.

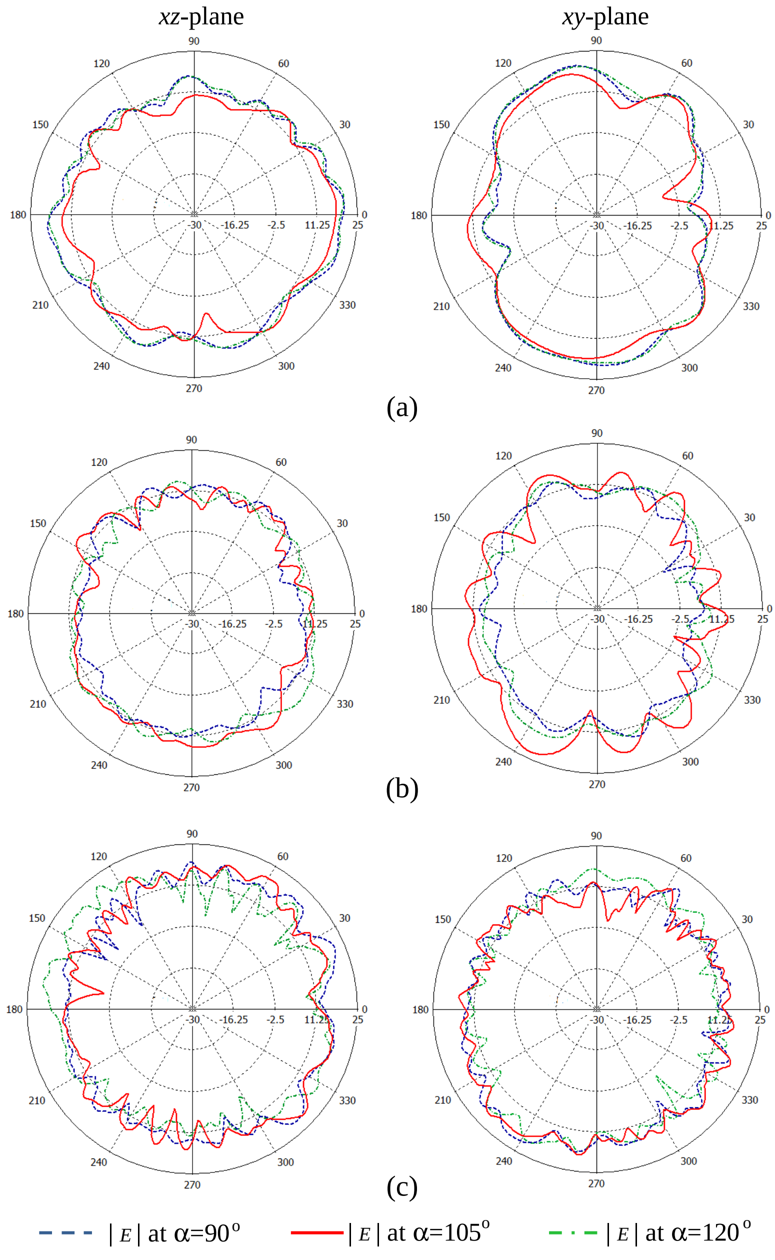



**Figure 11.** The simulated radiation patterns of the embedded E-shaped antenna in $xz$, and $xy$-planes at different frequencies. (a) $f = 2.45\,\text{GHz}$. (b) $f = 4\,\text{GHz}$. (c) $f = 9\,\text{GHz}$.

Figures 9(a), 9(b) and 9(c) show the gain patterns of the antenna embedded in laptop in $x$-$z$ plane and $y$-$z$ plane at 2.45, 4 GHz and 9 GHz respectively. 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 angle between base unit and screen for laptop ($\alpha$) on the antenna characteristics are studied. Figure 10 shows the effect of changing the angle between base unit and screen for laptop ($\alpha$) on the return loss. It is found that, the return loss in the Bluetooth band is slightly improved as the angle between base unit and screen for laptop ($\alpha$) 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 Figure 11. As shown in figure, a slight change is observed due to changing the open angle without any effect on the antenna omnidirectionality.

## 5. CONCLUSIONS

In this article, an E-shaped patch antenna is designed using recent optimization techniques such as MPSO, CFO, and BSO for Bluetooth/notched UWB applications. The algorithms have been implemented with MATLAB, and then the prototype simulations have been carried out using the CST Microwave Studio simulator Order to obtain the best results. It is found that the BSO algorithm slightly outperforms MPSO and CFO. In addition, the optimized antenna is embedded in laptop computer which slightly affects the antenna return loss without disturbing the resonant frequency and the impedance bandwidth; however the optimized antenna embedded in the screen of the laptop computer affects the antenna radiation patterns. Finally, the antenna showed satisfactory characteristics with different angles between base unit and screen for laptop ($\alpha$).

## ACKNOWLEDGMENT

We would like to acknowledge the Electronics Research Institute (ERI), Microstrip Department for the support, encouragement, help and cooperation during simulation process of this research.

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