

Design of Dual Band Patch Antennas for Cellular Communications by Genetic Algorithm Optimization

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Abstract

Designing multiband antennas with low volume becomes of practical interest for mobile telecommunications. This paper presents the designs of five small dual band patch antennas for GSM1800 (1710-1880MHz) and Bluetooth (2400-2483.5MHz) applications using a genetic algorithm combined with MoM (Method of Moments). A substrate with dielectric constant 3.2 and height 8mm is used for the first two dual band designs. The height is reduced thanks to the optimization process to 6mm in the third design by inserting a shorting pin to the fragmented patch antenna. The height is further reduced to 4mm in the by inserting two shorting pins. In the final design with three shorting pins, the height is only 3mm. The patch dimensions are similar to that of the conventional rectangular patch for the center frequency of the lowest frequency band but with the advantage of having dual-band operation at the desired bands. Genetic algorithm optimization is used to optimize the patch geometry, feed position and shorting positions. HFSS is used to carry out simulations. The antenna thickness is reduced from 8mm to 3mm by incorporating shorting pins which position is optimized by the genetic algorithm.

Keywords: *Genetic algorithm optimization, Multi band microstrip antennas, Bluetooth, GSM*

1 Introduction

Initially cellular communications were used only for voice communication, utilizing a single band. After several years, frequency bands at 1800MHz and 1900MHz were allocated to increase the network capacity, thus creating a need for dual-band antennas and afterwards for more bands. Mobile phone systems were available as automobile telephone systems those days, but have evolved into hand-held phone systems [1]. Patch antennas introduced an interesting alternative for external terminal antennas in mobile phones. Moreover, size of mobile phones could be reduced with optimized patch antennas. As a result, it was possible to introduce nice tiny mobile phones, instead of bulky models. The demand for patch antennas has increased due to its advantages such as versatility when feeding the antenna, size, and efficiency.

Patch antennas consist basically of three layers, a metallic layer with the antenna element pattern, dielectric substrate and another metallic layer as the ground plane [2]. These antennas are relatively inexpensive to design and manufacture, because of their simple planar configuration and the compact structure. They are light in weight and have the capability to integrate with microwave integrated circuits.

With the development in the field of wireless mobile communication, many researches started to design multi band patch antennas which cover GSM 900, GSM 1800, UMTS , Bluetooth, WLAN, etc [3]-[10]. Inserting a single shorting pin [11], [12] or more number of shorting pins [7, 8, 13] are proposed in the literature. Also, fractal-shaped antennas have been useful to design multiband antennas [4], [14], [15]. The volume constraints, often combined with large bandwidth and high efficiency specifications, make the antenna design a challenging task. But the most important parameter in designing mobile antennas is to keep the size of the antenna small while functioning well.

From the GSM standard at 900 MHz, two systems have been developed: DCS 1800 and PCS 1900, which use the same infrastructure and technology as GSM. In Europe, DCS 1800 complement the existing GSM networks. Bluetooth is more of a personal productivity wireless technology, with a range of about 10 meters. It is designed to eliminate all those pesky cables that hamper the use of high-tech gadgetry. The connections enabled by Bluetooth will be quite novel: headsets to cellular telephones; cellular telephones to portable computers; electronic wallets to point-of-sale systems; portable computers to Internet connections in airports or hotels, and on and on [16].

Genetic Algorithm (GA) is a powerful optimization technique used in patch antenna design [17]-[20]. It is a robust, stochastic-based search method, which can handle the common characteristics of electromagnetic optimization problems that are not readily handled by other traditional optimization methods. GA has been used to design dual band patch antennas [18-19] by optimizing different antenna parameters.

It is an interesting research problem to design multi band mobile antennas while keeping the size of the antenna small. In this paper, GA are used to design a dual band patch antenna for GSM1800 (1710-1880 MHz) and Bluetooth (2400-2483.5 MHz) applications. Three techniques, which are designing the patch geometry, optimizing the feed position and inserting shorting pins to optimum positions are used alone and as combinations using GA to achieve dual band performance. The simulation of the patch antennas and analysis of results is carried out by using HFSS (High Frequency Structure Simulator), which is a highly accurate electromagnetic solver based on MoM. The operation is written using Visual Basic Script Writer and the .VBS file is called into HFSS environment. Radiation patterns, reflection coefficient plots and current distribution patterns are obtained for each optimized design and their performance is analyzed.

The present paper is divided into the following sections. The architecture of the GA is presented in section 2. Section 3.1 presents the performance of a rectangular shaped patch antenna with 8mm thickness. In section 3.2, the patch geometry and the feed position are optimized to achieve dual band performance. A shorting pin is included into the rectangular shape patch in section 3.3 and dual band performance is obtained. Section 3.4 presents patch antennas with 6mm thickness, where a shorted patch with optimization of the patch geometry, the feed position and the shorting position leads to dual band performance. In Section 3.5, a patch antenna with 4mm thickness incorporating two shorting pins and GA is used to obtain dual band operation. In Section 3.6, a patch antenna with 3mm thickness and smaller cells incorporating three shorting pins and GA is used to obtain dual band operation. Finally, conclusions are given.

2 Antenna Configuration and GAO parameters

The antenna dimensions are similar to that of a rectangular patch operating in the fundamental mode [2]. The substrate is Neltec NX9320(IM) (tm), which has relative permittivity of 3.2 and loss tangent of 0.0025. The length and the width of the patch are 44 mm and 57 mm respectively which have been adjusted to have the fundamental mode at the frequency of 1800MHz. It is fragmented into 48 cells as shown in Fig.1 to search the best solution of conducting cells. A 50 Ω coaxial cable is used to feed the antenna and it is positioned on the symmetrical axis, which is parallel to the x axis. As the symmetry is considered, only 24 bits are used to define the patch geometry, by assigning conducting or non-conducting

properties to each cell. This approach keeps number of genes in the chromosome less and makes it possible to simulate within several hours using a single CPU. As there are only two possible values, binary coding is used. Another four genes of the chromosome are used to define the feed position. When the shorting pins are included in the design, the corresponding genes are added into the chromosome subsequently.

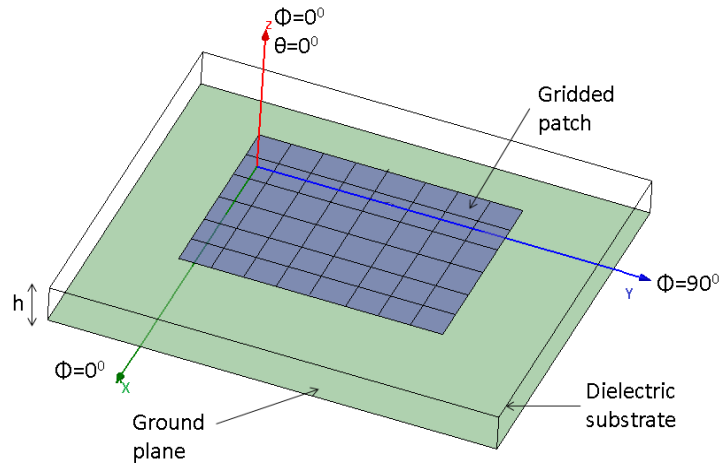


Fig. 1: Antenna configuration showing the 48 cells used for the GO

The fitness function is the summation of reflection coefficient values taken at 10MHz intervals including the two required bands, from 1710 MHz to 1880 MHz and from 2400MHz to 2480MHz. Typical requirements for cellular communication antennas today is a reflection coefficient of less than -6 dB within the frequency band [8], [21], [22]. Therefore, the fitness function F which is maximized in the search for the optimum solution can be written as

$$F = - \left(\sum_{n=1}^{n=27} L(n) \right) \quad (1)$$

where L is defined as

$$L = \begin{cases} \rho & \rho \geq -6dB \\ -6dB & \rho < -6dB \end{cases} \quad (2)$$

and ρ is the reflection coefficient values obtained in the linear scale at 10 MHz frequency steps in the frequency range 1710-1880MHz and 2400-2480MHz, which results in 18 and 9 samples in the first and second band, respectively. The optimization process constrains the reflection coefficient which means that no restrictions are forced to the kind of radiation pattern. If other restrictions were required the fitness function can be modified accordingly.

There are 20 chromosomes per generation in all designs. The cross over operation is performed with probability of 100% and one bit is mutated in 60% of the individuals within a generation. At the end of each generation replacement, the highest fitness value is checked against the termination criteria. The termination criteria is defined as

$$F_{highest} = 162 \quad (3)$$

This can be achieved when all 27 reflection coefficient values over the two frequency bands are less than -6dB. The script is written so as to modify the fitness function after termination criterion is met. A 20MHz bandwidth is included to both sides of each band so as to search better designs with more bandwidth. Then the termination criterion becomes 210. If the fitness value reaches that termination criterion too then another 20MHz bandwidth is included again, updating the termination criterion to 258. The modified fitness function is written as

$$F = \begin{cases} -\left(\sum_{n=1}^{n=27} L(n)\right) & , bestfitness < 162 \\ -\left(\sum_{n=1}^{n=N} L(n)\right) & , 6(N-8) \leq bestfitness < 6N \end{cases} \quad (4)$$

where

$$N = 27 + 8m \quad (5)$$

and m is any integer.

This process is repeated over iterations until the fitness value converges. Tournament selection method is used for generation replacement and preservation of higher fitness values is guaranteed.

3 Results

For simulations, a Pentium-IV processor with 2.8GHz speed and a RAM with 2GB capacity have been used. Initially, the performance of a rectangular shape conventional patch antenna is checked. Thereafter, five designs are simulated using GA for optimization of patch antenna performance by tuning antenna parameters. All the simulations consider an infinite ground plane.

3.1 Rectangular shaped Patch: height $h=8\text{mm}$

The performance of the rectangular shape conventional patch antenna is shown in Fig.2. The substrate thickness is $h=8\text{mm}$ and the feed position is changed along the symmetrical axis. The best position which gives maximum bandwidth in the required regions is selected as the optimum feed position after several trials. The antenna resonates around the lower frequency band well, but there is no resonance in the Bluetooth band. It radiates well perpendicular to the patch plane with maximum gain of 6dB (Fig.2c). Current distribution shows that the patch is operating in the fundamental mode having a half cosine distribution with the maximum at the center of the patch (Fig.2).

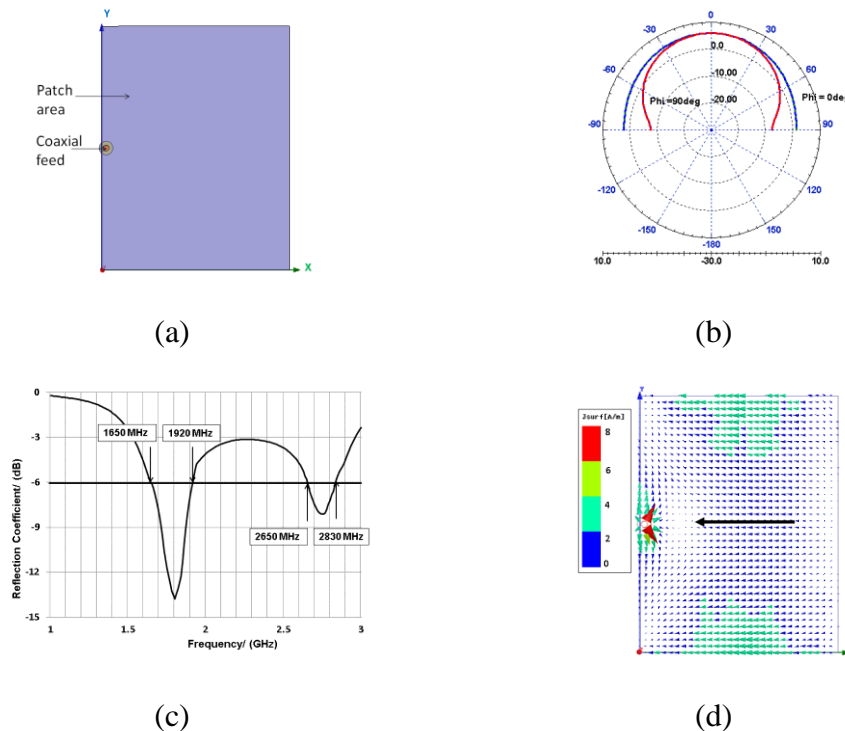


Fig. 2: Simulation results of the rectangular shape patch: (a) patch antenna (b) radiation pattern at 1800MHz (c) reflection coefficient (d) current distribution at 1800MHz. The black arrow indicates the main current contribution as a qualitative approach

3.2 Genetic generated patch: height $h=8\text{mm}$

To achieve dual band performance in the sense of reflection coefficient, the patch geometry and the feed position are optimized using the proposed GA. First 24 genes of the chromosome define the patch geometry, while next four genes define the feed position. The format of the chromosome is shown in Table1. The solution space is consisted of 2^{28} chromosomes. It takes about one minute to run one design and a generation is consisted of 20 designs. The script was run 95 iterations until meet the termination criteria. It shows that the optimum solution has found after testing 0.0007% chromosomes in the solution space.

Table1: Format of the chromosome for genetic generated patch ($h=8\text{mm}$)

Patch geometry				Feed position			
0	1	23	24	25	26	27

Fig. 3a shows the optimized patch antenna and Fig. 3b shows the corresponding reflection coefficient plot. The antenna resonates at two required frequency bands from 1710MHz to 2000MHz and from 2400MHz to 2540MHz. In Fig. 3e and Fig. 3f, the single arrows symbolize the main contribution of current distribution. The antenna has the maximum radiation perpendicular to the patch at the band of 1800MHz which is the typical of the fundamental mode behavior described before. In this regard, the current distribution shown that the mode for this new antenna follows the X direction. However, for the 2450MHz band, the mode presents two main parts pointing the y direction in an opposite sense. This results in a deep at the zenithal direction ($\theta=0^\circ$). As a conclusion, GA is useful in order to allocate the bands in terms of reflection coefficient but no control over the radiation patterns is achieved unless it is introduced in the fitness function. At this present point, reflection coefficient optimization is the main objective of the current research and multiband research, that is, similar radiation patterns at different bands, may be considered by modifying the fitness function. This topic is underway.

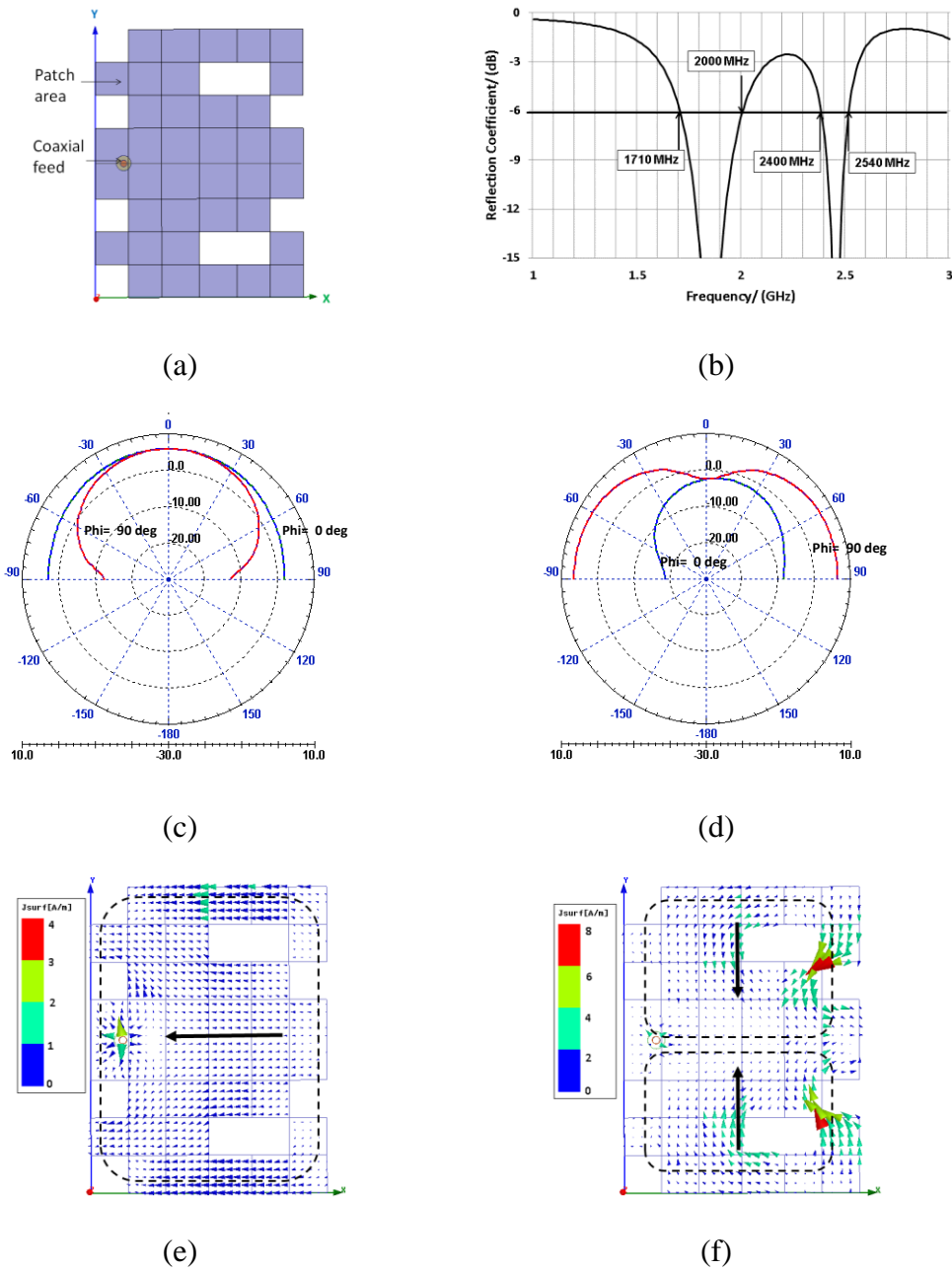


Fig. 3: Simulation results of the patch antenna when optimize the patch geometry and feed position (a) patch antenna (b) reflection coefficient (c) radiation pattern at 1800MHz (d) radiation pattern at 2450MHz. (e) current distribution at 1800MHz (f) current distribution at 2450MHz

3.3 Patch with one short ($h=8\text{mm}$)

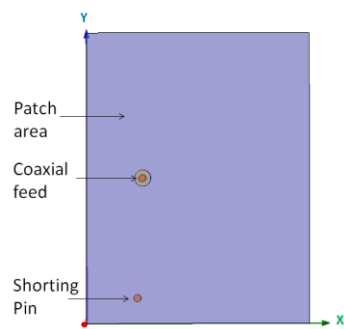
In this section, a shorting pin is included into the rectangular shape patch. The feed position and the shorting position are optimized using GA. The chromosome includes only 9 genes, first four genes to define the feed position and the rest to define the shorting position. The solution space consists of only 2^9 chromosomes. The termination criterion is met within five generations consuming only one hour. The antenna resonates from 1670MHz to 1940Hz and from 2300MHz to 2840MHz which clearly shown enough bandwidth (Fig. 4b). At the GSM1800 band, the maximum radiation is perpendicular to the patch plane (broadside direction) with 6dB gain. At the Bluetooth band, the radiation pattern is almost broadside with a gain at $\theta=0^\circ$ of 3dB. Current distribution shows a mode which indicates that the radiated field presents both components in the broadside direction as confirmed in the simulated radiation pattern cuts (Fig.4c, d).

3.4 Genetic generated patch with one short ($h=6\text{mm}$)

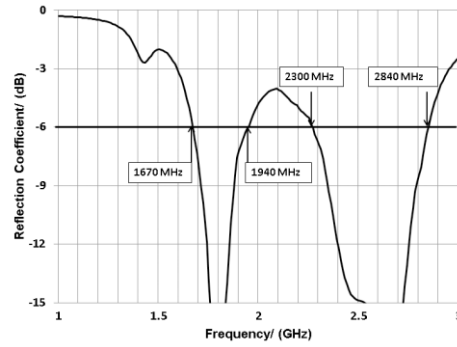
A substrate with 6mm thickness is used in this section. The geometric shape and the feed position are optimized as in the section 3.2. Results show that the fitness converges without achieving the termination criteria (Fig. 7). Therefore, the optimized design will not cover the required bands.

Thereafter, the feed position and the shorting position are optimized in a rectangular shaped patch with 6mm thickness as in section 3.3. The fitness reached the maximum value after 10 generations as the solution space is smaller than the former design (Fig. 7). The optimized design doesn't fulfill the dual band requirements.

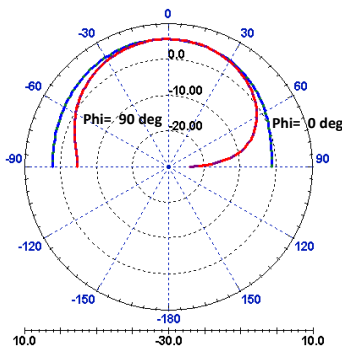
Therefore, all three parameters; geometric shape, feed position and shorting position are optimized in a shorted fragmented patch antenna. As a result, the number of genes in a chromosome increased to 31 bits. The optimized design, the reflection coefficient plot, the radiation patterns and the current distribution patterns are shown in Fig.5. It covers the frequency bands from 1710MHz to 1900MHz and from 2310MHz to 2550MHz. The antenna has the maximum radiation of 6dB perpendicular to the patch plane at 1800MHz. Radiation is highest along the direction $\theta = 40^\circ$ at 2450MHz with gain of 4.8dB. Current distribution for the first band (1800MHz) follows the X axis resulting in a broadside radiation pattern. However, the current for the second band (2450 MHz) follows not only X axis but also Y axis having some current areas out-of-phase resulting in a small deep in the zenithal direction ($\theta=0^\circ$).



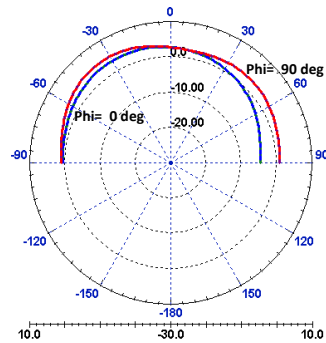
(a)



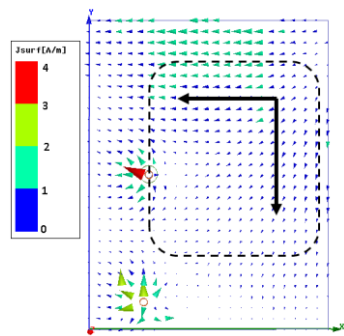
(b)



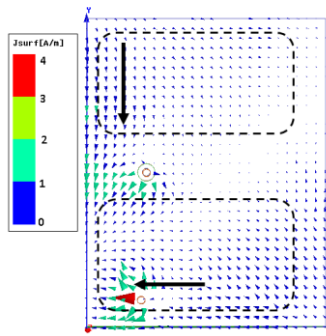
(c)



(d)



(e)



(f)

Fig. 4: Simulation results of the patch antenna when optimize the feed position and the shorting position (a) patch antenna (b) reflection coefficient (c) radiation pattern at 1800MHz (d) radiation pattern at 2450MHz. (e) current distribution at 1800MHz (f) current distribution at 2450 MHz

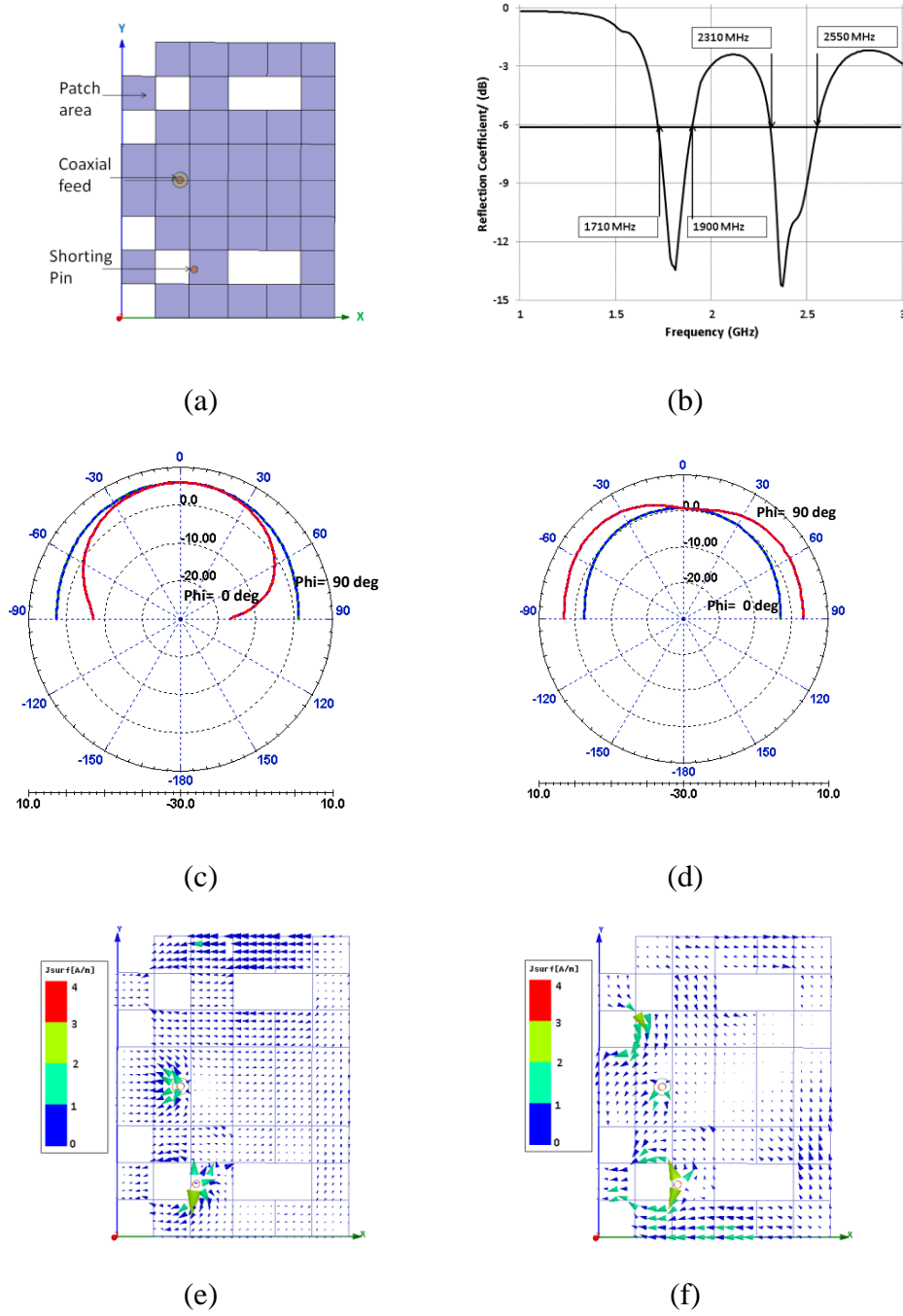


Fig. 5: Simulation results of the optimized patch antenna with a shorting pin (a) patch antenna (b) reflection coefficient (c) radiation pattern at 1800MHz (d) radiation pattern at 2450MHz . (e) current distribution at 1800MHz (f) current distribution at 2450 MHz

3.5 Genetic generated patch with two shorts (h=4mm)

It is tried to reduce the substrate height further by following the method described in section 3.4. The optimized design does not cover the required bands because the fitness function converges as shown in Fig. 7.

Therefore, another design is tried using a substrate with 4mm thickness by including another shorting pin. The position of the second shorting pin is also included to be optimized, where the chromosome thereafter consisted of 34 bits. The optimized design with two shorting pins is shown in Fig. 6a. The antenna operates in the two frequency band from 1710MHz to 1900MHz and from 2400MHz to 2500MHz (Fig.6b). This antenna has the best radiation along the direction $\theta=22^\circ$ at 1800MHz with gain of 5dB. At 2450MHz, the maximum radiation is 4.2dB along the direction $\theta=40^\circ$. Current distribution present both x and y direction resulting in a radiated field having both x and y directions (Fig.6e,f).

3.6 Genetic generated patch with three shorts (h=3mm)

In order to reduce the patch volume more, the procedure presented in section 3.5 is followed to design a patch antenna with 3mm thickness. The fitness function is converges as shown in Fig.7 without performing dual band operation. Therefore, three shorting pins are used and three more genes are added to the chromosome. In that case also, the fitness function converges without fulfilling the bandwidth requirements (Fig.7).

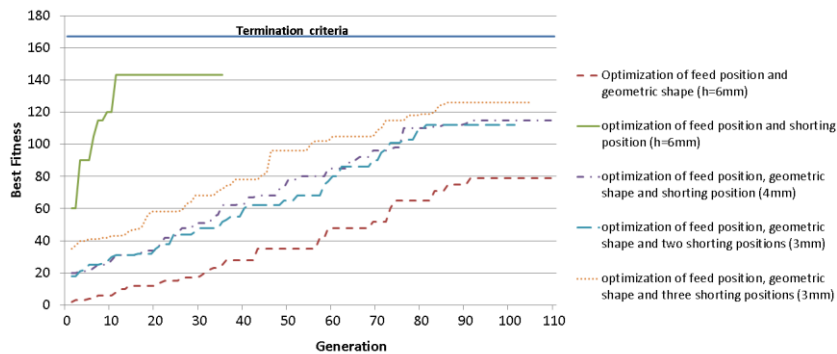
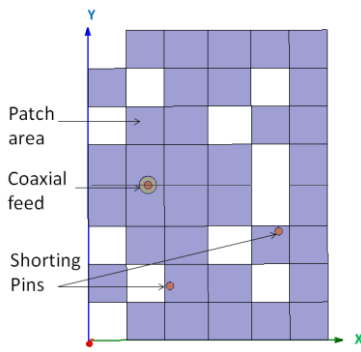
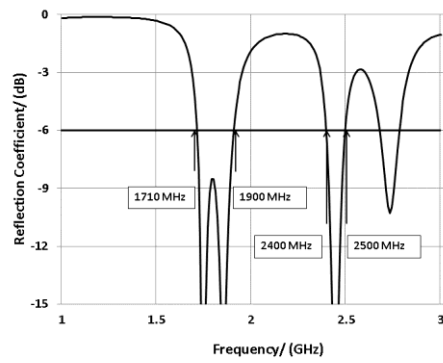


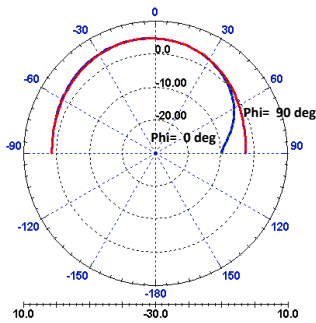
Fig. 7: Fitness convergence rate comparing the best fitness values over iterations in unsuccessful designs



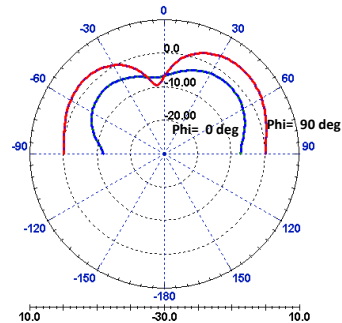
(a)



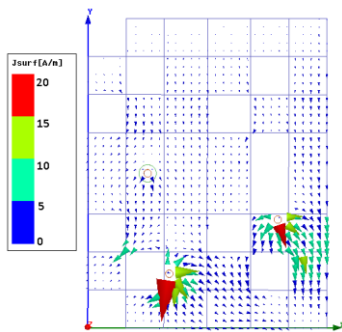
(b)



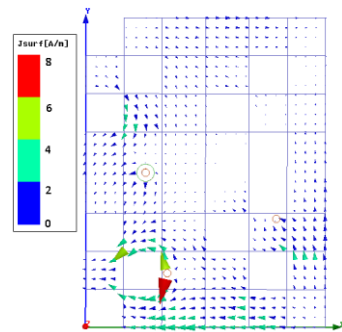
(c)



(d)



(e)



(f)

Fig. 6: Simulation results of the optimized patch antenna with two shorting pins (a) patch antenna (b) reflection coefficient (c) radiation pattern at 1800MHz (d) radiation pattern at 2450 MHz . (e) current distribution at 1800MHz (f) current distribution at 2450 MHz

Another design is tried using three shorting pins, but with smaller cells. Instead of dividing the patch area into 48 cells, it is divided into 70 cells as shown in Fig.8. Therefore, the initial 35 genes in the chromosome are used to define the patch geometry and more genes are added to define the feed position and shorting positions. The format of the chromosome is shown in Table2.

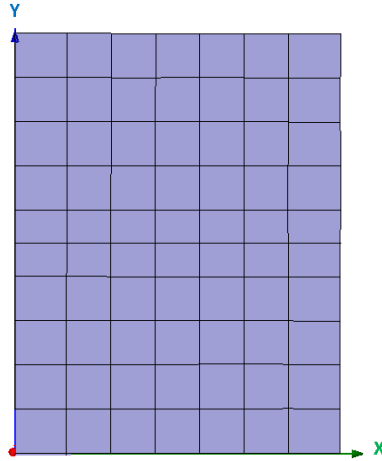


Fig. 8: Patch geometry

Table2: Format of the chromosome for genetic generated patch with three shorts (h=3mm)

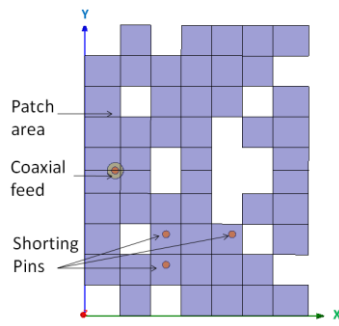
Patch geometry		Feed position				First shorting pin			Second shorting pin			Third shorting pin		
0	134	35	36	37	38	39	40	41	42	43	44	45	46	47

The optimized design is shown in Fig.9. The antenna operates from 1710MHz to 1880MHz and from 2390MHz to 2500MHz. In the GSM1800 band, the maximum gain is 5dB along the direction $\theta = 10^0$. In the Bluetooth band, the maximum gain is 4.6dB along the direction $\theta = 36^0$.

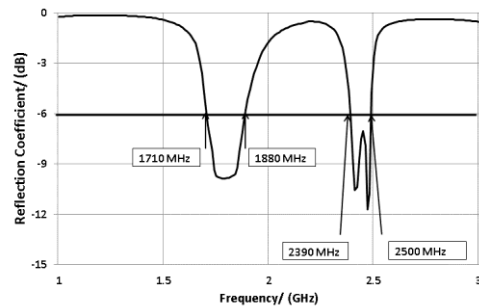
4 Conclusion

It is difficult to obtain multiband performance using conventional rectangular shaped patch antennas since bands are dictated by the mode distribution. To overcome such problem, GA patch antennas with the combination of adding shorting pins is proposed in this paper.

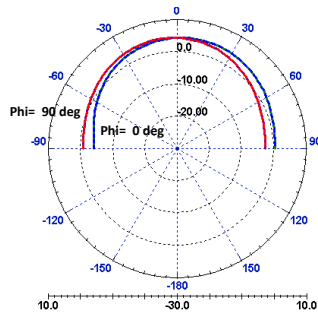
A patch size of $44 \text{ mm} \times 57 \text{ mm}$ over a dielectric substrate of $\epsilon_r = 3.2$ is used to design dual band patch antennas operate in GSM1800 and Bluetooth frequency bands. While optimizing the patch geometry and the feed position of the small patch antenna using GA, two well-matched bands can be obtained. Further, the antenna height is reduced by inserting a shorting pin between the patch and the ground plane. Insertion of more shorting pins creates the possibility to reduce the antenna height furthermore, while performing dual band in terms of reflection coefficient operation successfully. The shorting pins are placed by using GA for selecting the optimum shorting positions. In the end, a patch operating at GSM1800 and Bluetooth having $44 \text{ mm} \times 57 \text{ mm}$, printed on a $\epsilon_r = 3.2$ substrate 3mm height including three shorting pins have been obtained with quite broadside patterns which is interesting for wireless applications such as hot-spots.



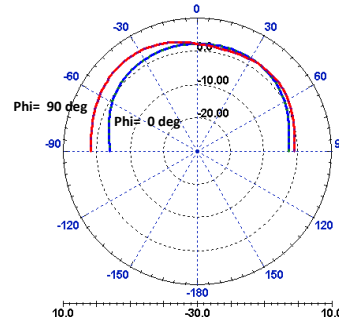
(a)



(b)



(c)



(d)

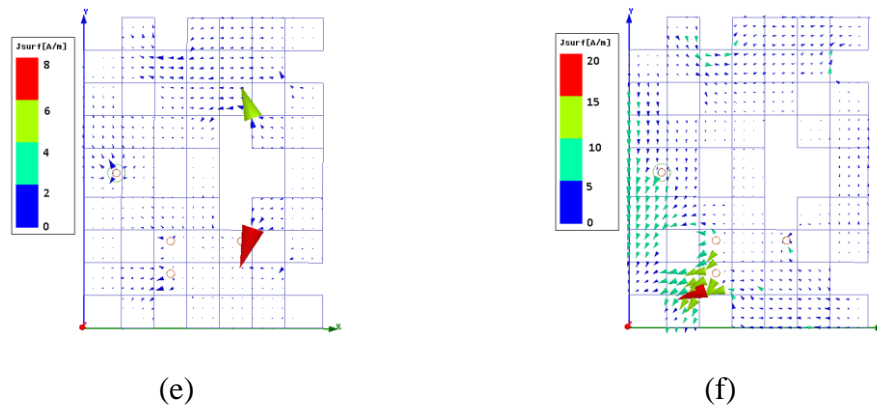


Fig. 9 Simulation results of the optimized patch antenna with three shorting pins (a) patch antenna (b) reflection coefficient (c) radiation pattern at 1800MHz (d) radiation pattern at 2450MHz . (e) current distribution at 1800MHz (f) current distribution at 2450MHz

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