
Circularly Polarized Microstrip Patch Antenna with Optimized Patch Parameters Using Particle Swarm Optimization

By

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ABSTRACT

A compact, circularly polarized, dual band patch antenna is presented. The structure involves three design parameters with their associated constraints, particle swarm optimization algorithm is developed to determine the patch parameter values. The related constraints are the radius and height of the circular patch. The axial ratio and s-parameter for a 3.9GHz and 7.8GHz is realized. Good agreement is achieved between the measurement and simulation, which indicates that a -10dB impedance bandwidth of 4.2% from 3.8166GHz to 3.9390GHz and 7% (7.6621 – 7.9390GHz) at two frequency bands, respectively, are covered in the design antenna. The antenna is designed and fabricated on FR4 substrate with dielectric constant of 4.4 and dimension of (40mm x 40mm x 1.4mm.) at a frequency of 3.95GHz.

Keywords: Dual band, PSO, axial ratio, probe feed, circular polarization

INTRODUCTION

Circularly polarized patch antennas are useful in wireless communication systems because, they can allow flexible orientations between the transmitter and receiver antennas and reduce multipath reflections. But, the impedance bandwidth and axial ratio are always narrow [1], [2]. The techniques used in improving the AR bandwidths is by introducing parasitic elements [1], [3], [4], loading of pins [5], stacked arrangements [6]. But, they have some disadvantages, for example adding some parasitic patches around the main patch will require more area also stacking the parasitic patches with similar configurations will also lead to

increase in height of the antenna while always our goal is to maintain compactness in our antenna.

Particle Swarm Optimization is a method that minimizes a problem by iteratively trying to amend a prospect solution with regard to a given measure of lineament. Its optimizes a given problem by improving the candidate solution in the design space towards the optimal solution iteratively where each particle is a candidate solution [7]. The PSO algorithm involves three steps: generation of initial population with random position and velocity vectors for the design parameters, velocity update and eventually position update. The speck adjusts

its position in the search space from one move to another based on the update of velocity [8], [9].

The circular patch antenna is simply fed using probe feed as a feeding method. To achieve a 3dB AR bandwidth, a very good impedance matching and maintaining the antenna's low profile, the radius of the probe feed has been increased from 2mm to 2.2mm. A prototype of a circularly polarized, compact, dual band patch antenna has been fabricated and measured. Both results verify that the antenna exhibits a -10-dB impedance bandwidth of 4.2% (3.8166 – 3.9827GHz) for the lower band and 7% (7.6621 – 7.9390GHz) for the higher band. A 3dB AR is also realised. The numerical simulation and the optimization were performed using ANSYS High Frequency Structure Simulator version 2015 and a Matlab programming environment version 2016.

PSO ALGORITHM

The particle swarm optimization as present by Kennedy and Eberhart, shares many features or aspect with stochastic optimization approach such as ant colony optimization, Genetic algorithm, differential evolution, invasive weed optimization, firefly algorithm and simulated annealing [10], [11], [12], [13], [14], [15]. The scheme starts with randomly chosen population and searches for optimum by updating contemporaries. The potential solutions called speck fly through the problem space by following the current optimum speck. The ease of use and few variables to set are two important characteristics of PSO unlike GA. The position of the particle can be modelled mathematically according to the following two step equations as also shown in figure 1.

$$V_i^{k+1} = w^k v_i^k + c_1 r_1^k \cdot i(p_i^k - x_i^k) + c_2 r_2^k \cdot i(g_i^k - x_i^k) \tag{1}$$

$$X_i^{k+1} = x_i^k + (v_i^{k+1} \Delta t) \tag{2}$$

Where k refers to the current iteration, i is the index of each particle, with v_i^k and x_i^k current velocities and position, respectively, w^k contains the inertia weights, p_i^k gives each particle best location, and g_i^k is the global optimum. The parameters C_1 and C_2 are two random constants which determines whether a particle has a tendency towards the best position or towards the global position. r_1^k, i and r_2^k, i are arbitrary

numbers uniformly distributed in [0,1], and Δt is the time step, normally set to unity.

Objective Function

The objective function is generated from the effective radius and height of a circular patch antenna as according to the previous literature [2], we have

$$a_e = a \left(1 + \left(\frac{2H}{faV_r} \right) \left[\frac{\ln(fa)}{2H} + 1.7226 \right] \right)^{1/2} \tag{3}$$

Where, v_r is the relative permittivity of the material, a_e is the effective radius of the patch, and H is the substrate height. From

equation (3) our objective function will be evaluated as

$$B = \left(\frac{(1.84118 \times c)}{2fa_e \sqrt{v_r}} \right) - f, \tag{4}$$

By putting equation (3) in to (4) our objective function will be

$$B = \left(\frac{1.84118}{2f(x_1) \sqrt{\frac{1+2(x_2)}{4.4f(x_1)} \times \log\left(\frac{f(x_2)}{2(x_1)} + 1.7726\right)} \times 4.4} - f \right)^2, \tag{5}$$

From (6), the radius and height of the patch to be minimize are X_1 and X_2 . When the calculated solution frequency matches the desired value of the same, the value of the objective function B becomes zero. In this paper, number of iterations =80, correction factor $C_1 = C_2 = 2.0$, inertia $w = 1.0$ and swarm size = 20 is used.

ANTENNA GEOMETRY AND DESIGN

The antenna geometry is shown in figure 5, which consist of three parts: A circular patch, a substrate and a ground structure. The radiating patch dimension of 10.6 x 1.4mm² was realized from PSO are placed on FR4 substrate with a loss tangent of 0.02 and relative permittivity of 4.4. The dimension of the substrate is 40 x 40 x 1.4mm³. The proposed antenna is placed above a metallic reflecting ground whose size is 40 x 40mm². The analysis and simulation for the antenna are performed by using High Frequency Structure Simulator (ANSYS HFSS), the antenna parameters are enumerated in Table 1. By increasing the radius of the port, it is clear that a 3 -dB axial ratio is realized at 3.9GHz which is circularly polarized but the upper band which is 7.8GHz is linearly polarized. Figure 6 is the parametric analysis of various feeding location.

Optimization results

The goal of the optimization process is to minimize the important parameters of circular patch antenna that is, radius and height while keeping the solution frequency to 3.95. Figure 2 below shows the fitness function vs number of iterations, figure 3 shows the minimized radius of the patch and figure 4 shows the minimized height of the patch respectively. The values are then taken to electromagnetic solver (HFSS) for design, simulation and further analysis.

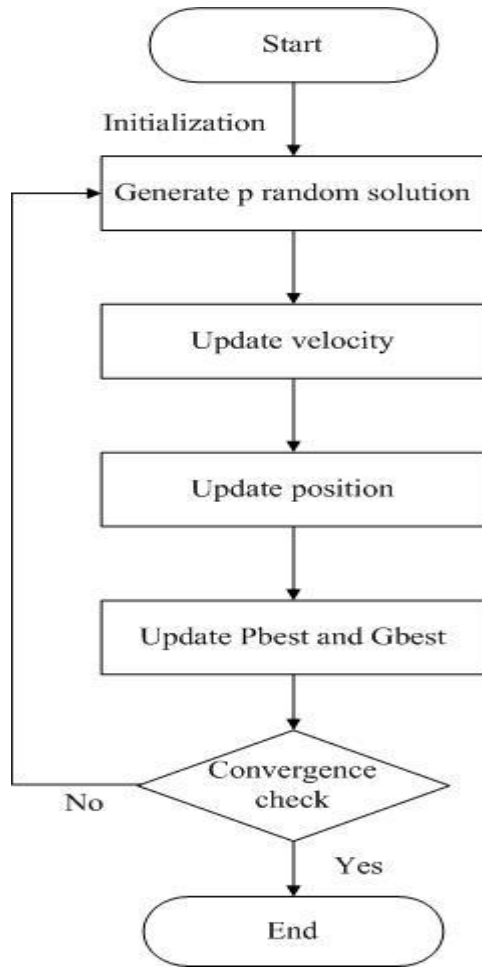


Figure 1. Flowchart of the PSO algorithm.

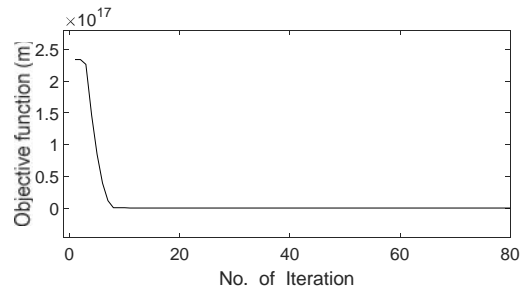


Figure 2. Objective function vs iteration.

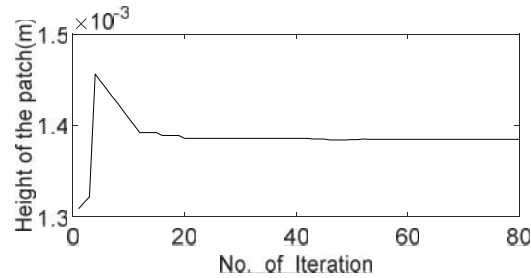


Figure 3. Minimized height of the patch

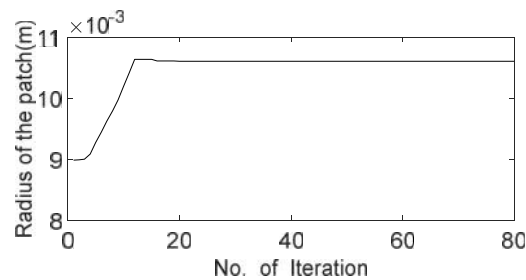


Figure 4. Minimized radius of the patch.

RESULTS AND DISCUSSION

A prototype of a compact, circularly polarized patch antenna based on the parameters indicated in table I is fabricated and tested to verify the performance. The fabricated photo is shown in figure 14. A network analyzer is employed to measure S-parameter of the fabricated antenna as well as the simulated. The s-parameter as well as the voltage standing wave ratio for both the simulated and measured is presented as shown in figure 7 and 8. The simulated

radiation pattern for the two bands are presented in figure 9 and 10. The result demonstrates that the proposed antenna achieves a circularly polarized frequency at 3.9GHz with an impedance bandwidth of 4.2% (3.8166 – 3.9827GHz) and 7% (7.6621 - 7.9390GHZ) for the two bands. The design displays symmetry unidirectional radiation in both E and H plane. Figure 12 and 13 are the surface current distribution of the antenna at 3.9GHz and 7.8GHz respectively.

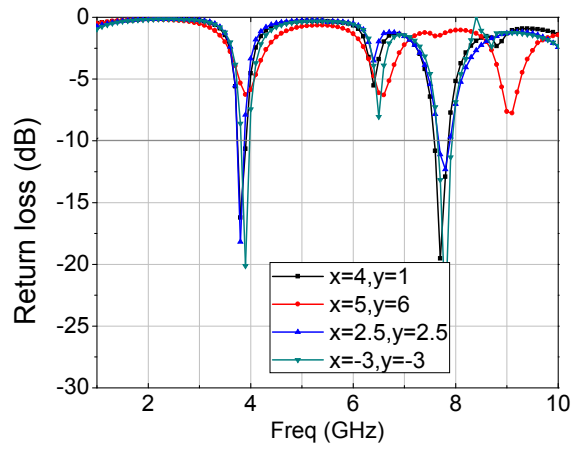
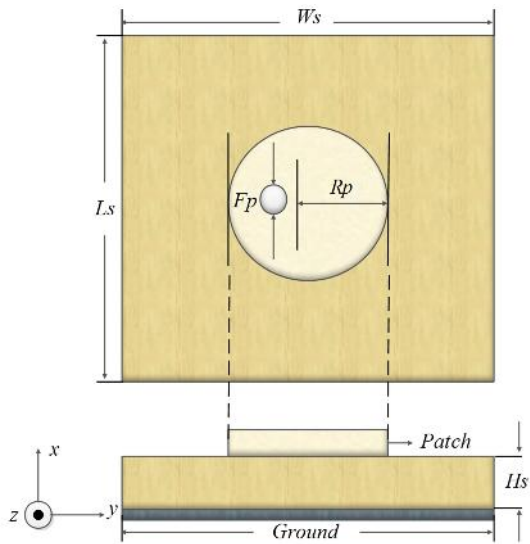


Figure 5. Circular patch geometry. Figure 6. The parametric analysis of various feeding points.

Table I. Design parameters of circularly polarized patch antenna

Parameters	Values (mm)	Parameters	Values (mm)
L_s	40	R_p	10.6
W_s	40	F_p	3, 3
H_s	1.44	E_R	4.4

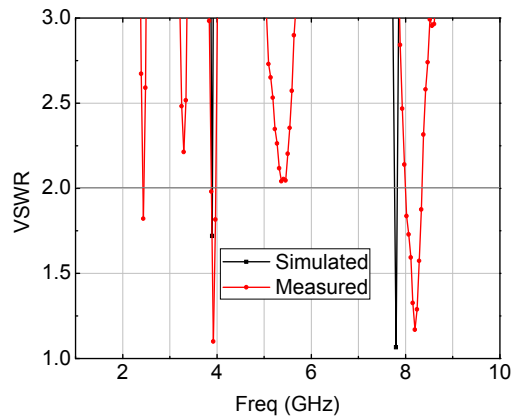
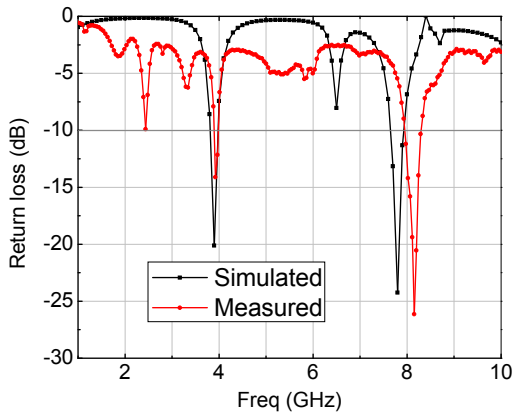


Figure 7. S_{11} of circularly polarized antenna. Figure 8. VSWR of circularly polarized antenna.

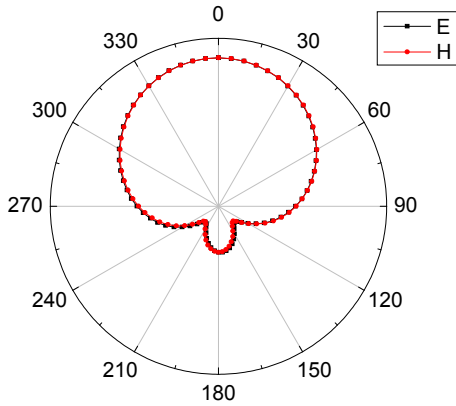


Figure 9. Radiation pattern at 3.9GHz.

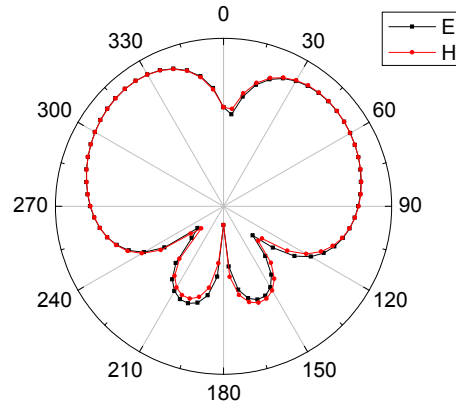


Figure 10. Radiation pattern at 7.8GHz.

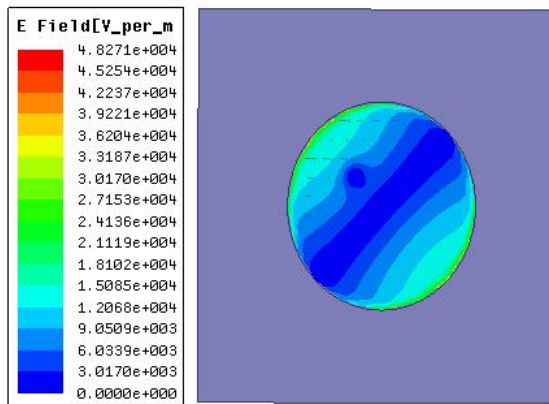


Figure 11. Current distribution at 3.9GHz.

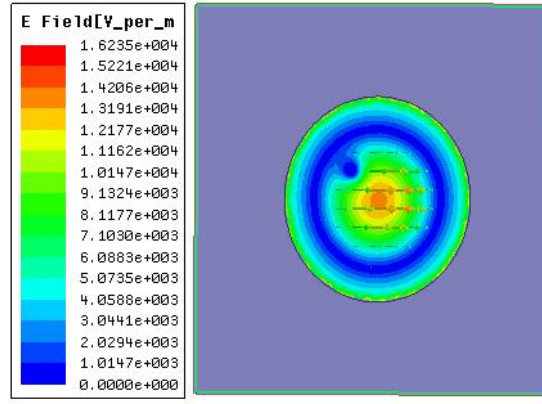


Figure 12. Current distribution at 7.8GHz.

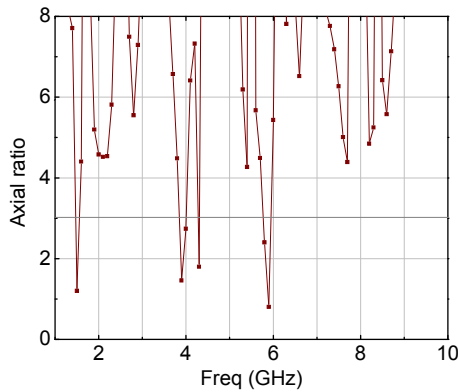


Figure 13. Axial ratio at 3.95GHz & 7.8GHz.

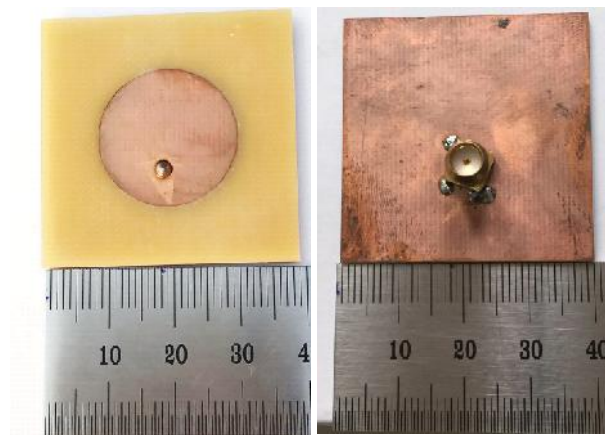


Figure 14. Fabricated photo (a) front (b) back.

CONCLUSION

By increasing the radius of the feeding port, it manages to enhance the performance

of the reflection coefficient and it also helps in realizing a circularly polarized frequency for the lower band. PSO method has been

used for optimization of patch dimensions (radius and height). Impedance bandwidth of 4.2% (3.8166 – 3.9827GHz), 7% (7.6621 – 7.9390GHz) and 3dB AR is realized. Consequently, the antenna achieved a dual band frequency.

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