Nigerian Journal of Technology (NIJOTECH)
Vol. 36, No. 3, July 2017, pp. **904 – 909**

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v36i3.33

MULTIBAND MILLIMETER WAVE T-SHAPED ANTENNA WITH OPTIMIZED PATCH PARAMETER USING PARTICLE SWARM OPTIMIZATION

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ABSTRACT
This paper proposed a simple T-shaped patch antenna for millimeter waveband frequency operation. Millimeter wave is a frequency ranges between 30GHz to 300GHz in an electromagnetic spectrum. The proposed antenna consists of T-shape radiating patch mounted on rectangular substrate (FR4-4) and microstrip line for antenna feeding. An evolutionary algorithm called particle swarm optimization was used to optimize the length and width of the proposed antenna patch. The proposed antenna gives triple bands with central frequencies at 42GHz, 51.5GHz and 60GHz. The antenna offers minimum return loss of -19db, -24db and -19.5db at 42GHz, 51.5GHz and 60GHz respectively. The return loss impedance bandwidth of 5GHz for the first band, 8.4GHz for the second band and 5GHz for the third band was obtained. The proposed antenna was analyzed using Ansoft High Frequency Structure Simulator (HFSS) and MATLAB 2013. Radiation characteristics of this patch antenna are observed at various resonating frequencies.

Keywords- *Millimeter-wave, multiband, return loss, optimization*

1. INTRODUCTION

Wireless technology is experiencing an incredible progress and growth because of an ever-increasing demand of wireless device in communication systems [1]. Microstip patch antenna provides multiple bands opportunities and have a compact structure, hence it emerged as a promising candidate for hand held devices. Microstrip patch antenna has various advantages such as low cost, light weight, easy to manufacture etc. Despite of various advantages, a major pitfall that microstrip patch antennas suffers is narrow bandwidth. With the massive upgrade of networks, the current spectrum assigned for wireless communication has theoretically reached its maximum system utilization. Millimeter-waves are anticipated to be promising candidate for the upcoming wireless solutions [1]. Unused available spectrum at millimeter wave frequencies has a potential to compete with the requirements of future 5G systems where high capacity and fast speed are the distinguishing features to achieve. On the other hand there are several critical limitations necessary to be resolved at millimeter wave spectrum, such as the atmospheric attenuations and absorptions, which becomes more obvious at high frequencies [1].

It is suggested that antenna should be offering high bandwidth to support a wide range of system services to function simultaneously and high gain to overcome the atmospheric absorptions at these range frequencies [2]. Moreover, the antenna should be low profile, low cost and light weight that are convenient to be integrated with planar and non-planar surfaces.

Recent work used defected ground structure in their design [1] which is one among several techniques applied to enhance the operating range of the patch antenna. Defective ground structures enhances the performance of an antenna by creating a partial ground in the ground plane [3]. The added slot is responsible of altering the excitation process of ground plane. However, the structure creates additional effective inductance and capacitance as well; maintain the thin profile characteristics of the plane [1]. The desired frequency can be obtained by changing the length, width and the position of the slot. A lot of research has been carried out in the development of multiband, wideband and ultra-wideband using defective ground structures [4-8]. Most of the antennas that used defective ground structure are low frequency band, single band operation and multiband millimeter wave operation [9]. This proposed antenna did not use defective ground structure. The

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return loss bandwidth of the patch antenna can be calculated as

$$\%\mathrm{BW} = \frac{F_H - F_L}{F_C} * 100 \qquad (1)$$

In (1), F_H is High cut off frequency, F_L is Low cut off frequency and F_C is the Centre frequency .

2. PSO TECHNIQUES

Pso is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. In pso, particles potentials solutions fly through the problem space. Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far (the fitness value is also stored) and is called the personal best [10]. Following a similar pattern another value is tracked, this value is named as the best value obtained so far by pso and is known as the global best. An N-dimensional coordinate is used to represent each position, in which each dimension is equivalent to a parameter to be optimized. The velocity (VN) and position (XN) of one particle is updated as [11] [12].

$$V_N = W \times V_N + C_1 rand\,() \times (PBEST, N\text{-}X_N) + C_2 rand\,() \times (GBEST\text{-}X_N) \qquad (2)$$

Here W is called the inertia weight and its value chosen between 0 and 1 for the mathematical convenience, evaluates the extent to which the path of the particle doesn't deviate due to the influence of PBEST and GBEST. C1 and C2 are the factors that govern the deviation due to PBEST and GBEST [12]. The amount of deviation due to PBEST is determined by C1 and C2 is a factor determining how the particle is affected by the rest of the swarm. The random function (rand) is used to introduce the slight randomness or unpredictable nature of swarm behavior. According to [13] the position (or location) of each particle is updated as:

$$X_N = X_N + \Delta T \times V_N \qquad (3)$$

For a given time step ΔT whose value is chosen to be unity. Pso use to solve power system [16], feature selection for structure-activity correlations in medical applications [17], biological applications [18], size and shape optimization [19, 20], environmental applications [21], analysis in chemical processes [22], bioinformatics [23] and task assignment problems [24].

3. PSO BASED OPTIMIZATION OF LENGTH AND WIDTH OF THE ANTENNA

The objective of the particle swarm optimization in this work is to optimize the length and width of the proposed antenna.

3.1 Verification of pso Using Rosen Brock function

In mathematical optimization, the Rosen brock function is used as a performance test problem for optimization algorithm. In order to analyze the pso benchmark function is used in experiment, whose equation is given as in equation (4) [14].

$$f(x, y) = (a - x)^2 + b(y - x^2)^2 \qquad (4)$$

Equation (4) above has global minimum at (x, y) = (a, a^2) where f(x, y) = 0. Usually these parameters are set such that a = 1 and b = 100. Only the trivial case where a = 0 is the function symmetric and the minimum at the origin. The range selected for optimization of parameter is as follows:

Width of the patch: 0.1mm to 2mm

Length of the patch: 0.1mm to 2mm

The effective length and width of the patch is evaluated using the below equation (v)

Value =

$$\left(\frac{3\times10^8}{2\times60\times10^9}\sqrt{\frac{2}{\varepsilon_r+1}}\times1000-u\right)^2+\left(\frac{3\times10^8}{2\times60\times10^9\sqrt{\varepsilon_r}}\times1000-v\right)^2 \qquad (v)$$

Where u and v stand as length and width of the patch

4. ANTENNA GEOMETRY

The geometry of the proposed antenna is presented in table 1 below. Initially the antenna was designed with defected ground structure at the center of the ground but the result we are having was a single band then we removed the DGS in order to have multiband frequencies. The design parameters is summarized in table I also the length and patch of the proposed antenna was calculated using the below equations [15].

$$P_L = \frac{C}{2F_r\sqrt{\varepsilon_r}} \qquad (6)$$

$$P_w = \frac{C}{2F_r}\sqrt{\varepsilon_r} \qquad (7)$$

In (6) and (7), P_L is the Length of the patch, P_W is the Width of the patch, C is the Speed of light as 3×10^8 m/s, F_r is the Solution frequency, ε_r is the Dielectric constant or permittivity of the material.

Table 1: Design Parameters of Patch Antenna

S/N	Parameter Name	Proposed Dimensions		
		Length(mm)	Width(mm)	Height(mm)
1	Substrate	12	12.5	1.2
2	Ground plane	12	12.5	0
3	Patch	3.1	8	1.2
4	Feed line	6.15	1.4	1.2
5	Port	6	1.2	1.2

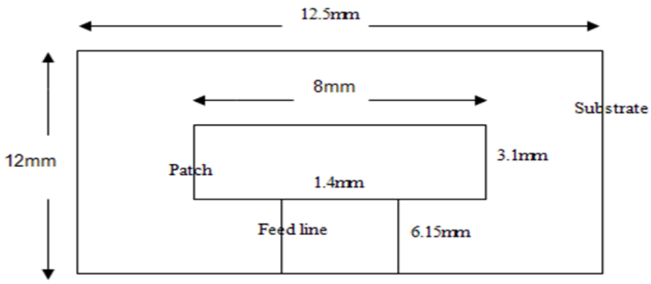

Figure 1: Top view of the proposed antenna

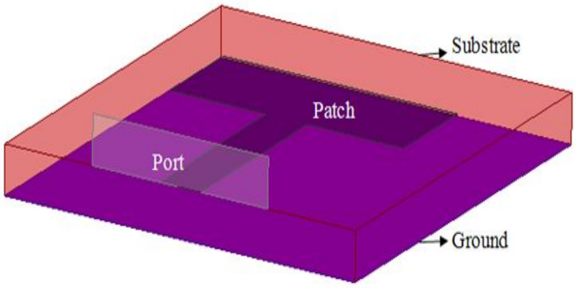

Figure 2: 3D View of the proposed antenna

5. RESULTS AND DISCUSSION

To analyze the antenna performance, High Frequency Structure simulation tool based on finite element method was used. The simulated return loss and voltage standing wave ratio are shown in figure 3 and Figure 4. It is clear from the figures that the antenna is operating at millimeter wave band with resonance frequencies 42GHz, 51.5GHz and 60GHz. The bandwidth obtained is 5GHz, 8.4GHz and 5GHz. Minimum return loss of -19db, -24db and -19.5db is observed at 42GHz, 51.5GHz and 60GHz respectively. The voltage standing wave ratio versus frequency plot in figure 4 shows good agreement in specified bandwidth. The radiation pattern and 3D radiation polar plot was also shown in Figure 5, 6, 7, 8, 9, and 10 respectively.

For pso the investigation is made at a microwave frequency of 60GHz; number of particles are 50; inertia is 1.0; iteration 30; C1 =C2= 2.0, the figure 11, 12 and 13 shows the result of the optimization in which the width and length converges to 1.5422mm and 1.127mm respectively.

Table 2. Performance Summary of T-shaped Antenna

	Freq. band F_L-F_H(GHz)	*Return Loss(db)*	*BW(GHz)*	*%BW*	*FBR (db)*
1	45.5-40.5	-19db	5	8.33	3.0214
2	54.2-45.8	-24db	8.4	14	2.2007
3	63.5-58.0	-19.5db	5.5	9.17	6.7274

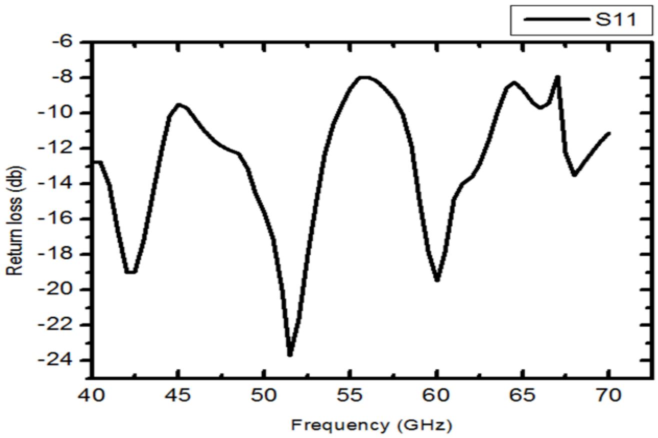

Figure 3: Return loss vs frequency plot

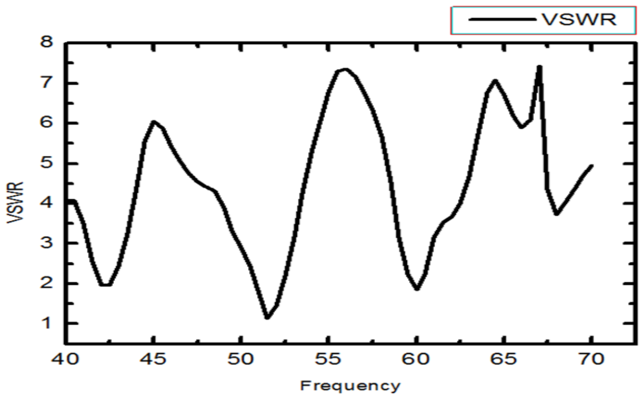

Figure 4: VSWR vs frequency plot

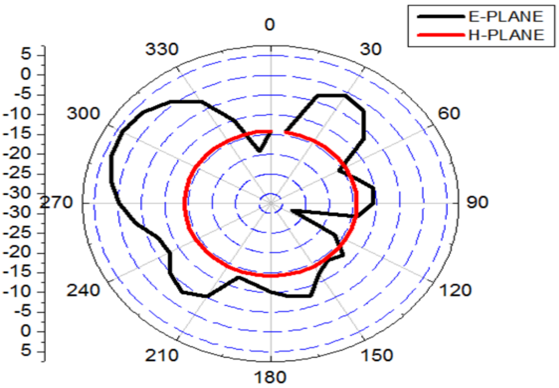

Figure 5: Radiation Pattern at 42GHz

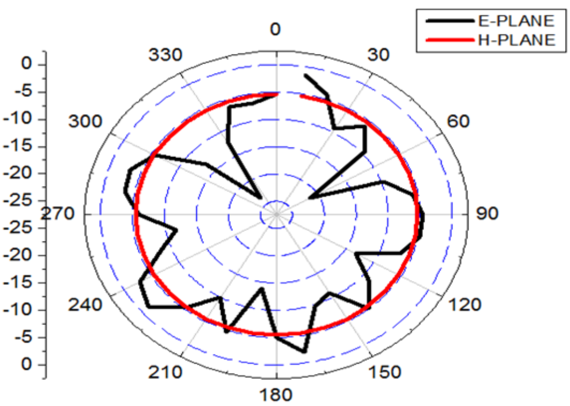

Figure 6: Radiation Pattern at 51.5GHz

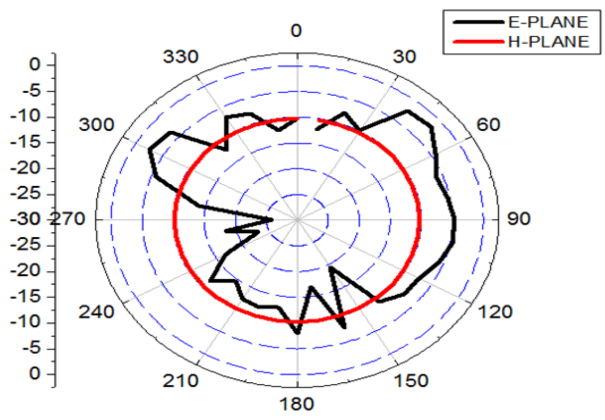

Figure 7: Radiation Pattern at 60GHz

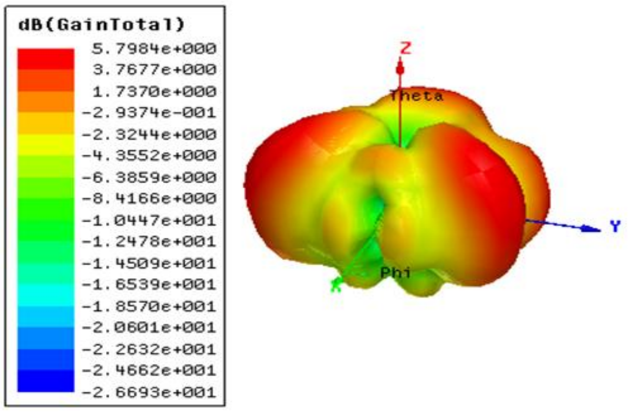

Figure 8: 3D Polar plot at 42GHz

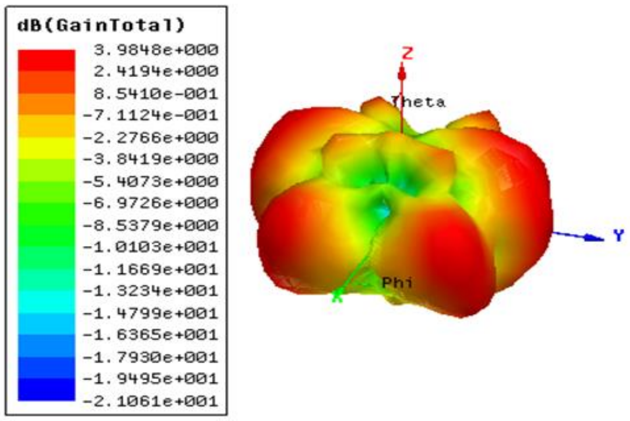

Figure 9: 3D Polar plot at 51.5GHz

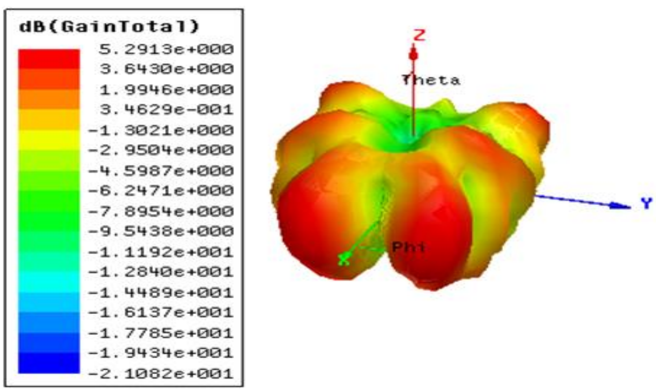

Fig. 10. 3D Polar plot at 60GHz

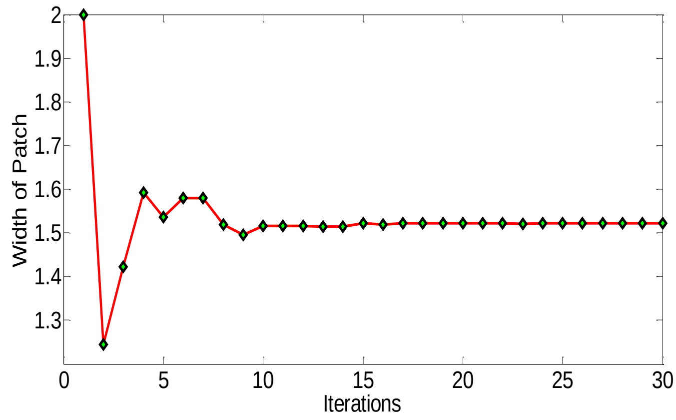

Figure 11: Width of Patch vs iteration

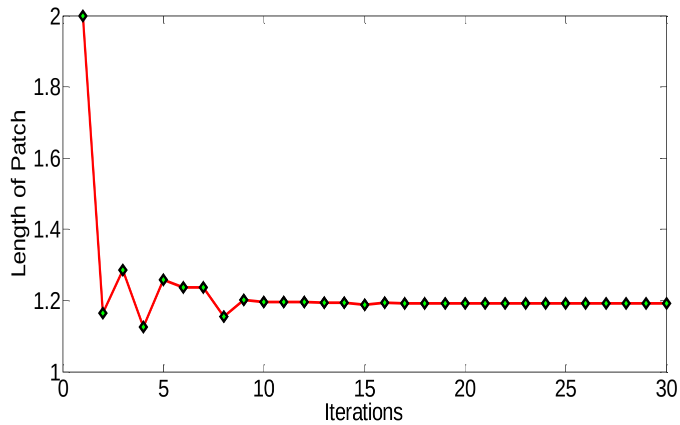

Figure 12: Length of patch vs iteration

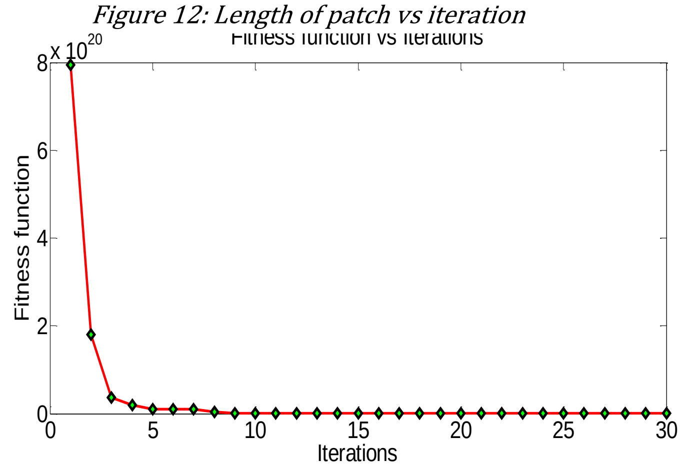

Figure 13: Fitness function vs iteration

6. CONCLUSION

This paper presents an efficient antenna design at millimeter wave band. The top geometry of the proposed antenna consist of a T-shaped radiating patch. The proposed antenna has demonstrated a high impedance bandwidth which can be used for microwave applications typically used at millimeter wave band of 42GHz, 51.5GHz and 60GHz, the distinguishing performance attributes of designed antenna suggest its applications in future 5G wireless networks and cellular operations. The patch antenna offers total bandwidth of 31.5%, high front to back ratio and good gain. The particle swarm optimization procedure for optimizing the width and length of rectangular T-shaped patch antenna and results of its optimized parameters are described. From the graphical results, we can conclude that the fitness function value becomes 0 after 30 iteration. Optimized width found to be 1.5422mm and length of patch to be 1.127mm. On the basis of results obtained, it can be concluded that the pso can be efficiently used for optimization of different parameters of antenna.

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