Seven bands Loop antenna optimized by using particle swarm optimization algorithm

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ABSTRACT: *A novel design of Seven band loop antenna for the frequency range from 0.7Ghz to 6Ghz covering all Wireless systems, is described and simulated.the antenna is planar inverted F, optimized using Particle swarm optimization with non-uniforms chromosome matrix to locate the slot on the resonator part of the PIFA.The optimized antenna is simulated by both software Ansoft HFSS and computer simulation technology microwave studio CST). The simulation result shows that both software are in good agreement and the antenna provide a minimal gain of 3dBi and a maximal gain of 7dBi.*

Keywords: Loop Antenna, Multiband, Particle Swarm Optimization, Matlab, CST, Chromosome Matrix

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1. Introduction

Nowadays the wireless communication systems require higher data rate especially with the upcoming 5*G* and the technologies that coming with it such as internet of things, autonomous driving and virtual reality.this demand of higher data rate has trigged the design of new antenna structure and the development of new transmission techniques such us MIMO and MU-MIMO.To accommodate all the bands of the wireless systems, the antenna must support several resonance frequencies, hence the multiband character of the antennas received last great interest, and antenna designs are becoming more challenging to implement more than wireless system in one antenna.several researches were conducted on several types of antenna, in this work we are interested to the PIFA antenna, many works are proposed for creating a multiband PIFA, in [1] the authors Use the famous Particle swarm optimization to create a slots in the ground plane, in [2] they use multi shorting pins to create multibands PIFA, in this work we use the Particle swarm optimization algorithm to locate the slot place in the patch of the antenna PIFA, our approach based one a non-uniforms chromosome matrix.

The planar inverted-F antenna (PIFA) is a prevalent antenna for portable terminals because of its minimized size and great performance. The good performance of a PIFA is due to the ground plane which forms part of the radiator. A consequence of this is that a lot of current is present on the ground plane inside the mobile terminals. The currents on the ground plane can be diminished while keeping up great performance by using a self-balanced structure such as a folded loop antenna[6] Loop antennas on the other hand have smaller bandwidths than PIFAs, so the six mode loop antenna incorporates widened sections in the loop as well as a monopole/dipole parasitic element to increase the bandwidth.

This papers presents a technique to obtain a seven bands antenna, by combining the use of slots on the resonant part of the antenna and the particle swarm optimization algorithm (PSO).this combination is carried out by linking programming language MATLAB, and electromagnetic simulator (CSTMWS). the purpose of using the slots on the resonator of the antenna is is to create more current path and therefore more resonator frequencies, and we use the PSO to determine the localization of each slot.the paper is organized as follow section 1 is an introduction, section 2 present the antenna structure and methodology in section 3 we depict a discussion of the simulation result and finaly a conclusion in section 4.

2. Antenna Structure And Methodology

2.1 Particle swarm Optimization

The optimization technique that has been used is based on PSO,which is one of the most popular nature-inspired metaheuristic optimization algorithm developed by James Kennedy and Russell Eberhart in 1995 [7], [8] It uses concept of social interaction among particles in a swarm, it's guided by personal experience (*Pbest*), overall experience (*Gbest*) and the present movement of the particles to decide their next positions in the search space.Further, the experiences are accelerated by two factors $c_1$and c_2, and two random numbers generated between [0, 1] whereas the present movement is multiplied by an inertia factor w varying between $[w_{min};w_{max}]$.

The initial population (swarm) of size N and dimension D is denoted as $X = [X_1, X_2,..., X_N]^T$, where '$T$' denotes the transpose operator. Each individual (particle) $X_i(i = 1, 2,..., N)$ is given as $X_i = [X_{i,1}, X_{i,2},...X_{i,D}]$. Also, the initial velocity of the population is denoted as $V = [V_1, V_2, ...V_N]^T$. Thus, the velocity of each particle $X_i(i = 1, 2,..., N)$ is given as $V_i = [V_{i,1}, V_{i,2},...V_{i,D}]$. The index i varies from 1 to N whereas the index j varies from 1 to D. The detailed algorithms of various methods are described below for completeness.

$$V_{i,j}^{k+1} = w \times V_{i,j}^{k+1} + c_1 \times r_1 (Pbest_{i,j}^k - X_{i,j}^k) + c_2 \times r_2 \times (Gbest_j^k - X_{i,j}^k) \tag{1}$$

$$X_{i,j}^{k+1} = X_{i,j}^k + V_{i,j}^{k+1} \tag{2}$$

In equation. 1 $Pbest_{i,j}^k$represents personal best j^{th} component of i^{th} individual, whereas $Gbest_j^k$ represents j^{th} component of the best individual of population up to iteration k. The different steps of PSO are as follows :

1) Set parameter w_min, w_max, c_2 of the PSO

2) Initialize population of particles having positions X and velocities V

3) Set iteration $k = 1$

4) Calculate fitness of particles $F^k_i = f(X_i^k)$, $\forall i$ and find the index of the best particle b

5) select $Pbest^k_i = X^k_i$, $\forall i$ and $Gbest^k = X^k_b$

6) $w = w_{max} - k \times (w_{max} - w_{min}) / Maxite$

7) Update velocity and position of particles

$V_{i,j}^{k+1} = w \times V_{i,j}^{k+1} + c_1 \times r_1 (Pbest_{i,j}^k - X_{i,j}^k) + c_2 \times r_2 \times (Gbest_j^k - X_{i,j}^k)$

$X_{i,j}^{k+1} = X_{i,j}^k + V_{i,j}^{k+1} \forall i$ and $\forall j$

8) Evaluate fitness $F_i^{k+1} = f(X_i^{k+1})$, $\forall i$ and find the index of the best particle $b1$

9) Update Pbest of population $\forall i$

if $F_i^{k+1} \{ F_i^k$ then $Pbest_i^{k+1} = X_i^{k+1}$ else $Pbest_i^{k+1} = Pbest_i^k$

10) Update Gbest of population

11) if $F_{b1}^{k+1} \{ F_{b}^{k}$ then $Gbest^{k+1} = Pbest_{b1}^{k+1}$ and set b = b1else $Gbest^{k+1} = Gbest^{k}$

12) If $k \{ Maxite$ then $k = k + 1$ and goto step 6 else goto step 12

13) Print optimum solution as $Gbest^{k}$

The used parameters for this works are as follows:

• Inertial weight: 0.9 to 0.4

• Acceleration factors ($c1$ and $c2$): 2 to 2.05

• Population size: 10 to 100

• Maximum iteration (Maxite): 500 to 10000

• Initial velocity: 10 % of position

A detailed flowchart of PSO considering the above steps is shown in Figure 1

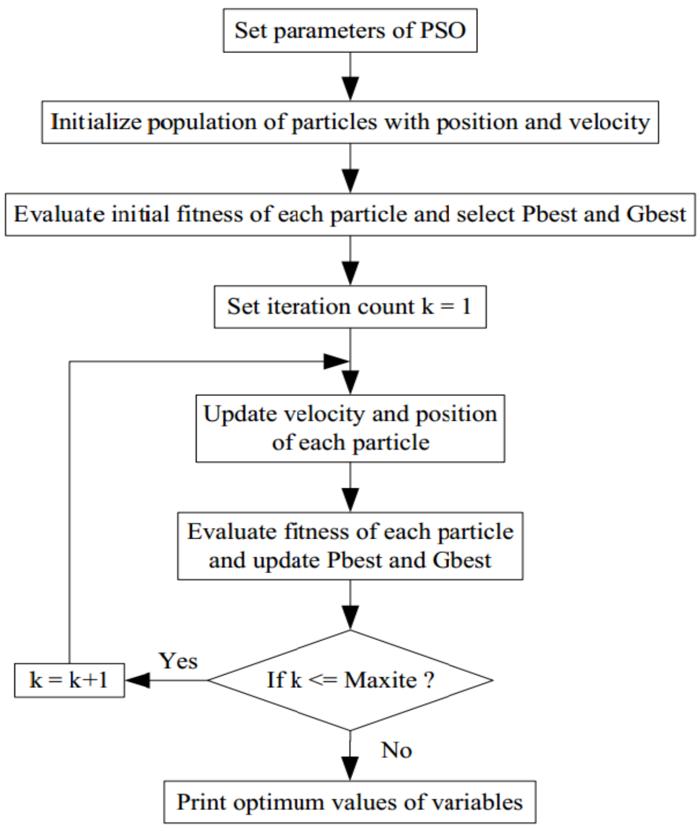


Figure 1. Flowchart of a PSO algorithm

2.2 Antenna Geometry

Figure 2 depicts the geometry of the proposed multiband loop antenna.The antenna is formed by taking a planar patch of dimensions $W_p \times L_p$ and folding it around a dielectric block $w_p \times L_p \times H_d$. The antenna is situated on a substrate (Rogers 5880) of dimensions $W_g \times L_g \times h$ with the top of the substrate forming the ground plane . The ground plane does not extend underneath the dielectric block. The antenna has two connections to the substrate a feed point ($w_{g1} \times H_d$) and a grounding point ($W_i \times H_d$). The feed is extended onto to the substrate as a CPW line. Two parasitic elements are situated next to the feed, the closest to the feed of which only extends from the ground plane to the top of the dielectric block ($W_i \times H_d$). The second parasitic element extends past the top and is folded onto the top face of the dielectric block ($W_i \times H_d$). the substrate and dielectric characteristic are depicted in tables 1, 2 bellow.

Rogers RT5880(lossy) Parameters	**values**
Dielectric constant ($\in_r$)	2.2
Substrate thickness	0.708 mm
Loss tangent (δ)	0.0009
Dimensions (mm^2)	120×79.4

Table 1. RT/Rogers 5800 substrate parameters

Air normal Parameters	**values**
Dielectric constant ($\in_r$)	1.00059
Substrate thickness	5.29 mm
Dimensions (mm^2)	10.5×79.4

Table 2. Dielectric parameters

The proposed loop antenna has the dimensions in table 3.

The loop antenna is fed with a CPW line running on the substrate. The center conductor of the CPW line connects with the feed line of the loop where the feed line meets the substrate.

parameters	**values**
W_p	79.4mm
W_g	79.4mm
L_p	10.5mm
L_g	120mm
H_d	5.29mm
W_i	1.1mm
h	1.6mm
W_{g1}	1.1mm

Table 3. Antenna parameters

In this works, particle swarm optimization (PSO) is used to determine the slot location and dimensions in order to get multiband loop antenna, the patch area is divided into 9×5 non uniform cells, where each cell can be assigned ether conducting or non conducting properties, the patch is fragmented int 45 cells, with 1*mm* overlapping between parallel cells as depicted in the picture 3 .

The fitness function is the summation of reflection coefficient values from 0.7 to 6*GHz* band's frequencies. the fitness function *F* which is minimized in the the search for the optimum solution is written as:

$$F = \Sigma S_{11} (f(i)) / 10 N \tag{3}$$

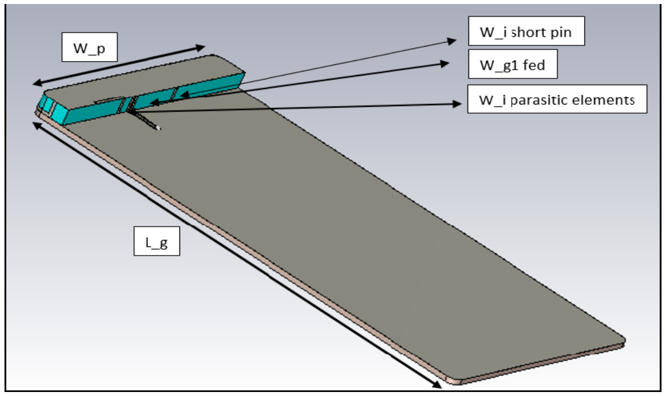


Figure 2. The geometry of the proposed antenna

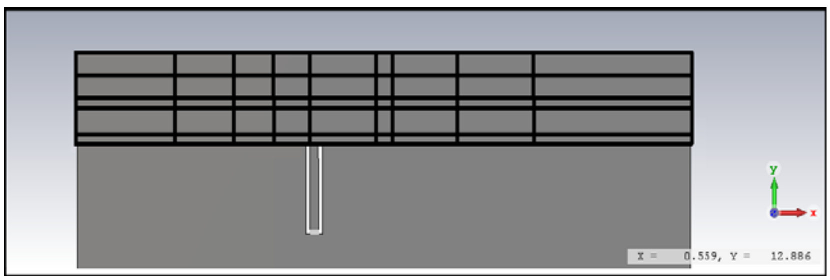
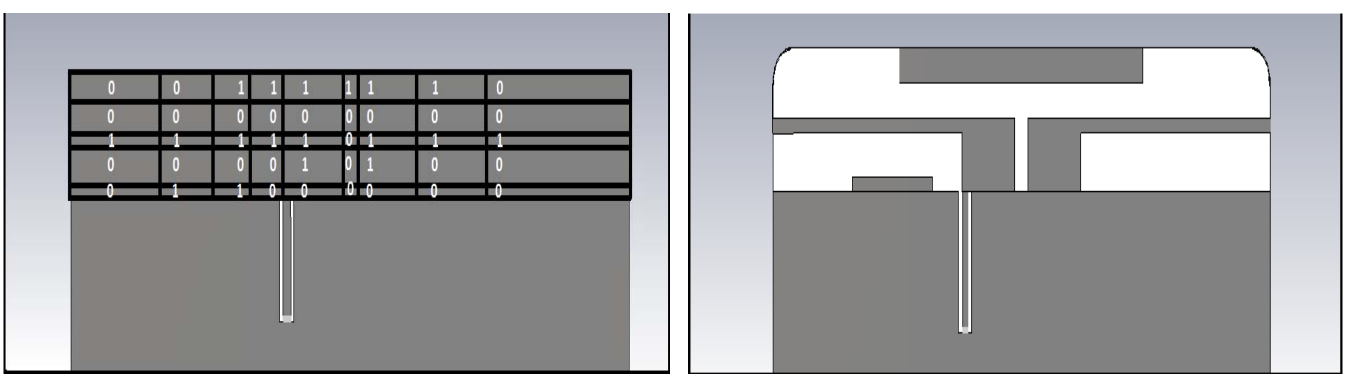


Figure 3. Division of the patch into 9×5 non-uniforms cells

where $f(i)$ is the sampling frequency, N is the number of the sample, and S_{11} is the reflection coefficient.

Our aim is to find a patch with the shape that achieve a reflection coefficient less than -10dB, PSO operates on a matrix chromosome, which describes the shape of the patch, In this matrix, the cells containing 1 corresponds to metalized cells and the cells with 0 correspond to slots. the results of the PSO algorithm is represented in the picture 4.

For the position of the fed line, short pin and two parasitic elements are optimized by Nelder Mead simplex algorithm which is integrated in CST microwave.



(a) Chromosome Matrix

(b) A front view of the ground plane

Figure 4. The results of the PSO algorithm

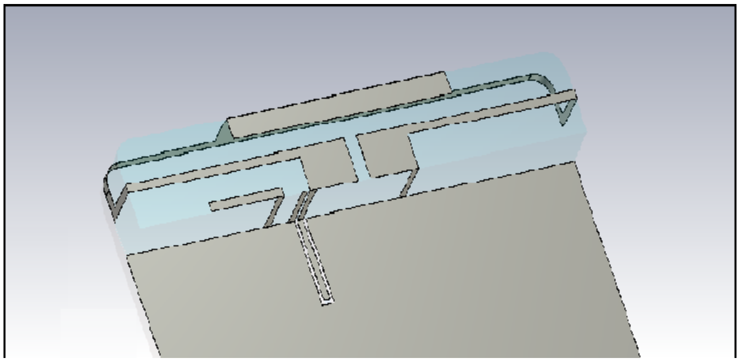


Figure 5. The final antenna obtained after optimization with PSO

3. Simulation Result And Discussion

The finalized optimized antenna has the shape bellow.

3.1 Reflection coefficient

The optimized antenna was simulated by CST software and validated using HFSS software, which is another electromagnetic software using the integral equation to solve the electromagnetic problems contrary of CST that it Finite discrete time domain solving, from the picture its clear that the two software are in good agreement, and that our optimized antenna, resonate in seven bands, Which coincides will all wireless mobile communication, *GSM*, *3G*, *LTE*,*Wimax*, and the new generation 5*G* with the band Beyond 6*GHz*.

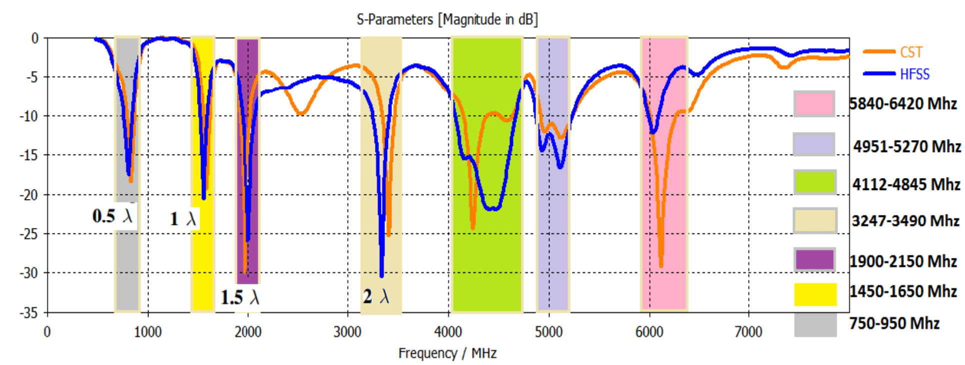


Figure 6. The reflection coeficient of the proposed loop antenna

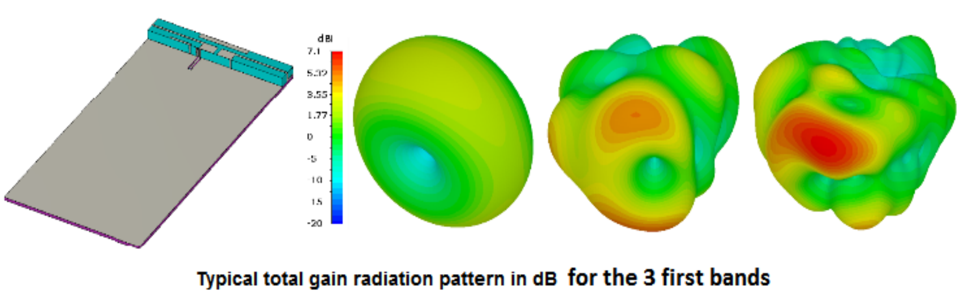


Figure 7. Typical total gain radiation pattern in dB

3.2 Radiation Characteristics

The antenna does not have a uniform radiation pattern, but has a dipole-like doughnut shape at the lowest band which becomes more multipath at the higher bands. it noticed that that the minimum gain obtained is 3*dB* and the maximum gain is 7*dB*.

3.3 Discussion

Although the balanced modes of loop antennas have less surface current on the ground plane thus making them more robust for user interaction, their bandwidths are usually narrower than that of PIFAs/IFAs. The six mode loop antenna, however, has increased bandwidths through the use of widened sections added to the loop while the parasitic elements extend the upper frequency range of the antenna. The techniques employed for increased bandwidth do not affect the lowest band (0.5 λ loop mode), so a high pass matching network may be required to cover the desired band.

3.4 Summary results

In table 4 we summarize the characteristic of the proposed antenna.

Quantity	Typical value	Minimum	Maximum
Polarization	linear	-	-
Radiation pattern	Multipath	-	-
Gain	5 dBi	3 dBi	7dBi
Performance bandwidth	-	15%	31%
Complexity	Medium	-	-
Impedance	50Ω	-	150Ω
Popular application	GSM/3G/LTE/5G/Wimax	-	-

Table 4. Summarized simulation Results

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4. Conclusion

In this papers a six loop antenna was designed by gridding the patch to slots conducting and non conducting,by implementing PSO algorithm, the final design shows that our antenna has a size compatible for integration on mobile phones and portable devices, the simulation results have shown that our antenna resonates in seven bands covering almost all wireless systems, from GSM to the future 5G and Wimax. While offering a maximum gain of 7 dBi and a minimum gain of 3 dBi.

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