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# Optimal Design of Microstrip Antenna for UWB Applications using EBG Structure with the Aid of Pigeon Inspired Optimization Technique

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**ABSTRACT-** Ultra-wideband (UWB) technology has become influential among academic research and industry because of its vast application in the wireless world. However, several drawbacks have in UWB based antenna. To tackle this, EBG (Electromagnetic Band Gap) structures have proposed. Furthermore, the design of EBG structures is very complex due to the uncertain EBG properties dependence upon unit cell parameters. Therefore, to the optimal design of micro strip antenna for applications of UWB, EBG-PIO (pigeon inspired optimization) on the basis of micro strip patch antenna has been proposed to enhance micro strip antenna's performance in terms of directivity, gain, bandwidth and efficiency. To select design parameters optimally, the PIO technique is proposed with substrate material of Rogers RT/Duroid 6010 with height h = 1.6 mm. Proposed antenna return loss remains –34.6 dB to cover applications of UWB (3.1–10.6 GHz). Also, results exhibited by both proposed technique and fabricated model-based antenna has outperformed than existing techniques regarding directivity, return loss, bandwidth, gain and radiation efficiency.

**General Terms:** Wireless communication, unit cell, substrate material of Rogers RT/Duroid 6010.

**Keywords:** EBG (Electromagnetic Band Gap), efficiency, micro strip antenna, Pigeon Inspired Optimization (PIO), ultra-wideband (UWB).

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## 1. INTRODUCTION

Ultra-wideband (UWB) communication technology is becoming a very attractive in recent days and also in forthcoming wireless communication systems [8,9]. With the FCC's (Federal Communications Commission) announcement for a frequency range about 3.1–10.6 GHz is considered to be of unlicensed band for UWB applications, UWB antennas have received a lot of interest from academics and industry [18]. Features like low cost, high data rate and low power consumption are advantages of UWB [4]. However, UWB based antenna has several drawbacks. To tackle this, EBG (Electromagnetic Band Gap) structures have proposed [14]. In micro strip antenna performance enhancement domain in wireless applications, the EBG structures have emerged as a promising technique in recent years. It includes materials may use to create innovative structures and shapes, whereas materials that have several applications in industry as well as the military [5].

Furthermore, the design of EBG structures is very complex due to the uncertain dependence of the EBG properties on the unit cell parameters. Besides, performance and miniaturization are two major problems obtained in communication systems over UWB band [19]. That is, all wireless devices must have antennas that are as compact as feasible with high performance. It is critical to create an antenna that combines the intended features of UWB with greatest degree of miniaturization [10]. Also, with the increasing growth as well as progression of wireless applications, there is need to design an antenna [15].

Due to its lighter weight, plane geometry and easy to integrate with remaining electronic components, microstrip patch antennas have been attractive candidates for applications of UWB [6]. A Multi-Band Notched Antennas with compact structure for UWB Applications [1]. It is fact that micro strip antennas grew in popularity because its compactness and low profile, they might be significant drawbacks which includes low return loss, narrow bandwidth, and less gain [20]. These is a huge demand in current days for antenna designs within portable devices necessitate reduction of size while keeping good performance [11]. The micro strip patch antennas performance parameters may be improved using a variety of methods. To improve micro strip patch antenna performance, Differential algorithm [16], PSO (particle swarm optimization algorithm) [12] and, adaptive bacterial foraging optimization [17] was presented.

The antenna of circular patch having circular fractals is chosen using Descartes theorem for UWB applications [2]. A two-dimensional electromagnetic band gap structures antenna for WIFI applications to improve antenna parameters [3]. However, performance of these antenna is not enough. Therefore, in this paper, to optimal micro strip patch antenna design in applications of UWB, PIO technique is proposed for improve performance of antenna.

The paper has been organized as: proposed methodology is discussed in *Section 2*. *Section 3* describes the results and discussion of the paper. Whereas *section 4* is detailed with simulation results. At last, the conclusion has been summed up in *Section 5*.

## 2. PROPOSED METHODOLOGY

### 2.1 Overview

The purpose of the paper is to optimal design of micro strip antenna to applications of UWB using structure of EBG to increase the micro strip antenna's performance as well as efficiency. For this, prominent design parameters and control factors such as Gap width between EBG and main patch (mm), Length of Substrate (mm), Width of EBG patch (mm), Height of the substrate (mm), Width of Substrate (mm) must be optimized. Therefore, to select design parameters optimally, pigeon inspired optimization technique is proposed. Also, in this paper, Rogers RT/ Duriod 6010 substrate designed proposed antenna. Proposed micro strip patch antenna design's the architecture depends upon flow model. An antenna's design can be defined by its value of initial geometry, which includes radiation properties such as antenna gain, directivity, return loss, and antenna efficiency. *Figure 2.1* shows design of the planned technique because the characteristics are dependent on the material type and geometric size of the antenna, physical and proper antenna size selection could be critical.

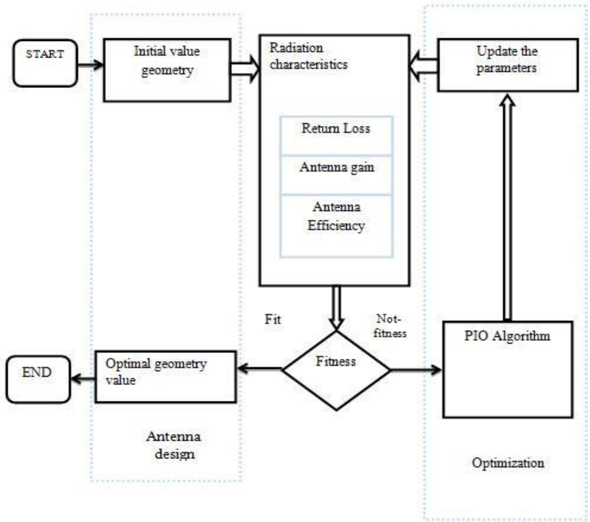


**Figure 2.1**: Flowchart of structural design of proposed antenna

### 2.2 Selection of Antenna Design Parameters Optimally Using PIO Algorithm

#### 2.2.1 Mathematical Model of PIO

The models of map along with compass operator in algorithm of PIO depend upon magnetic field and sun, whereas landmark operator model depend upon landmarks [22]. Two operators have been constructed below mentioned specific guidelines in attempt for idealizing pigeons' homing qualities:

***(1) Map and compass operator:***

Pigeons normally use magneto reception to record a shape of map in their brains that allows them feel earth's magnetic field. Sun's altitude is used as a compass to modify their direction. They depend less on sun and also on magnetic particles as they are flying towards their target.

Virtual pigeons are naturally employed in the PIO model. Rules have specified using pigeon *i* position Xi and velocity Vi for this map and compass operator, then positions as well as velocities in search space of D-dimension have been upgraded during every iteration. Below mentioned equations computed pigeon novel position of Xi and velocity Vi from t$^{th}$ iteration:

$$V_i(t) = V_i(t-1).e^{-Rt} + rand.(X_g - X_i(t-1)) \quad (1)$$

$$X_i(t) = X_i(t-1) + V_i(t) \quad (2)$$

Here map and compass factor referred by R, random integer meant by rand, whereas Xg refers to current global best position, acquired through comparison of every pigeons' position. *Figure 2.2* illustrates model of PIO's map and compass operator. Here, utilizing map and compass guarantees optimal positions for every pigeon. When entire flown positions are compared, it is clear position of right-centered pigeon considered to be the best. Following this, individual bird according to *equation (1)* can be represented by thick arrows, allows each pigeon to modify its direction of flying. Thin arrows represent direction of earlier flying positions, which is then linked to $V_i(t-1).e^{-Rt}$ in *equation (2)*. Its next direction of flying position is the vector sum of those two respective arrows.

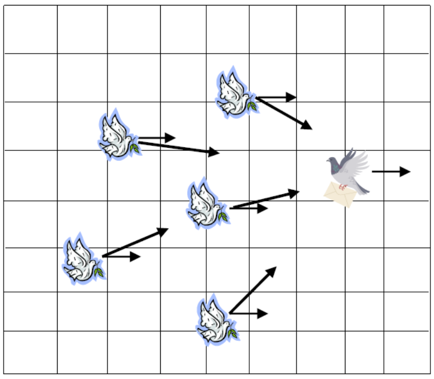

**Figure 2.2:** PIO model of map and compass operator

***(2) Landmark operator:***

While pigeons are getting near with its destination, they will depend upon nearby landmarks and will fly directly towards

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destination only by familiarity of landmarks they have recorded. Remaining pigeons will follow the one those are familiar with respective landmarks that have been distant from destination and unfamiliar with landmarks.

Every generation, half of pigeons in the landmark operator are reduced by $N_p$. However, pigeons are still a long way from their objective to be unfamiliar with landmarks. Assume that $X_c(t)$ is centre position of few pigeon's in t-th iteration, then entire pigeons may directly fly towards destination. At t-th iteration, rule of position updation for pigeon i may be written as:

$$N_p(t) = \frac{N_p(t-1)}{2} \quad (3)$$

$$X_c(t) = \frac{\sum X_i(t).fitness(X_i(t))}{N_p \sum fitness(X_i(t))} \quad (4)$$

$$X_i(t) = X_i(t-1) + rand.(X_c(t) - X_i(t-1)) \quad (5)$$

Here (5) represents fitness which shows quality of each pigeon. Thus, for every individual pigeon, Nc-th iteration's optimal position is referred with $X_p$ and $X_p = \min(X_{i1}, Xi_2 \ldots, XiNc)$.

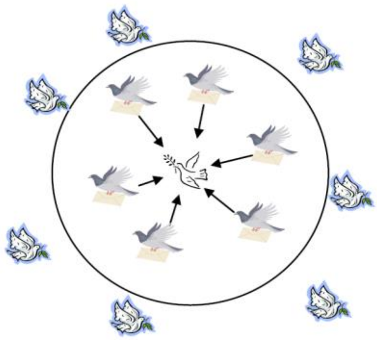

**Figure 2.3:** Model of Landmark operator

In *figure 2.3*, PIO's model of landmark operator is seen. Centre of every pigeon (pigeon within centre of circle) indicates destination of its own iteration. Where half the pigeons (shown outside the circle) could be distant from destination will be following pigeons closest towards its destination, which means two pigeons possibly from same spot. Pigeons closest towards its destination (pigeon within circle) will fly rapidly within the destination.

The following is a detailed description of the PIO implementation technique for antenna design parameter selection.

**Step 1**: Initialize $Nc_2$ max > $Nc_1$ max, the two operators have number of iterations like $Nc_1$ max and $Nc_2$ max, $N_p$ being population size, map and R as compass factor, and solution space dimension D in the PIO method. Also, initialize the design parameters of antenna.

**Step 2: Fitness calculation:** Best result can be acquired through assessing every solution fitness. In this case, two fitness functions are considered. $Fit_1$ is referred to minimize function and $Fit_2$ is referred to maximize function.

$$F_1 = \left[\frac{f_{BG.\max} + f_{BG.\min}}{2} - f_c\right]^2 - \left[\frac{f_{BG.\max} - f_{BG.\min}}{f_c}\right] \quad (6)$$

$$E_1(f_1) = W_a\left[\left(|S_j| + S_j\right)/2\right] \quad (7)$$

$$S_j = \left|S_{11}(f_j) - (S_{11desired})\right| \quad (8)$$

$$E_2(f_j) = W_b\left(G_{desired}(f_j) - G(f_j)\right) \quad (9)$$

$$F_2 = E_1 + E_2 \quad (10)$$

$$Fit_1 = \min(F_1 + F_2) \quad (11)$$

$$Fit_2 = \max(E_R) \quad (12)$$

**Step 3**: Randomized velocity and also path of each pigeon has been set. Distinguishing every pigeon's fitness, and then determining the present finest path.

**Step 4**: Operation of map operator and also compass operator is being done. Through *equations (1) and (2)*, it has updated each pigeon's velocity and path. And it has compared entire fitness of pigeons which discover latest finest path.

**Step 5**: If Nc> $Nc_{1max}$ then stop both map operator and compass operator thereby starting the succeeding operator. If not, repeat the previous step.

**Step 6**: Sort pigeons into groups based on their fitness levels. According to *equation (3)*, half of poor fitness pigeons will follow high fitness pigeons. The centre of all pigeons is then found using *equation (4)*, and this centre is the desired destination. Through altering its flight direction according to *equation (5)*, all pigeons will arrive at their destination. Best solution parameters and best cost value should then be saved.

**Step 7**: Stop the landmark operator if Nc > $Nc_{2\ max}$, and report the results (*i.e.* design parameters of antenna). If not, go to Step 5. Also, *Table 2.1* indicates that pseudo code of PIO algorithm for selecting optimal design parameters of antenna

**Table 2.1: Pseudocode for PIO algorithm**

| |
|---|
| **Input**<br>$N_p$ : Number of individual pigeons within the swarm<br>D : Dimension of search space<br>R : map and factor of compass<br>Search range : borders of search space<br>$Nc_{1max}$: maximum number of generations performed with map and compass operation<br>$Nc_{2max}$: maximum number of generations performed during landmark operation<br><br>**Output**<br>$X_g$ : fitness function's global optima or better design parameters |

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**1.Initialization**
Set initial values in search range, D, $Nc_{1max}$,$Nc_{2max}$,Np, and R
Set intial path as $X_i$ and velocity $V_i$ for every individual pigeon
Set $X_p$=$X_i$ and $N_c$=1
Set the initialize the design parameters of antenna.
Compute fitness value of various pigeon individuals using equation (11) and (12)

**2. Map and compass operation**
For Nc=1to $Nc_{1max}$ do
For i=1 to $N_p$ do
While $X_i$ is beyond search range do
Based on equations (1) and (2), compute $V_i$ and $X_i$
End while
End for
Evaluate $X_i$ and update $X_p$ and $X_g$
End for

**3.Landmark operations**
For Nc=$Nc_{1max}$+1 to $Nc_{2max}$ do
While $X_p$ is beyond search range do
According to their fitness values, Rank all avilable pigeon individuals
$N_p$=$N_p$/2
Keep half of individuals with better value of fitness,then abondon remaining half
Xc=average other pigeon individuals path value
Based on equation (5), compute $X_i$
End while
Evaluate $X_i$ and update $X_p$ and $X_g$
End for

**4.Output**
$X_g$ is output to be fitness function's global optima or optimal antenna design parameters

## 3. RESULTS AND DISCUSSION

Here, results and discussion of antenna proposed has been explained and analyzed. Proposed antenna is implemented using HFSS software. This is extremely useful for antenna engineers who need to optimize antenna parameters. The recommended approaches for the first phase are implemented in MATLAB. The antenna design is then verified by HFSS utilizing the optimal findings received from MATLAB. In *Table 3.1*, Optimized antenna design parameters of EBG_ PIO-based proposed structure are stated. This structure is comprised using the optimal parameters obtained by PIO algorithm which saves time for multiple debugging during the calculation of antenna parameters. In different bands, geometric considerations such as the patch width of EBG (v), via radius (r), substrate thickness (h) or via and the gap between the main patch and EBG structure (g) will have its role. In this study, the substrate material taken as Rogers RT/Duroid 6010 with height h = 1.6 mm is being selected because of its effective parameter results produced at higher frequencies [20]. Also, proposed antenna design configuration is shown in *figure 3.1*. To increase proposed antenna output parameters, mushroom EBG structures are inserted [21] as shown in *figure 3.2*. Gain degradation is not an issue with this strategy. Moreover, the major lobe's gain is almost constant with respect to steering angles for E-plane, with no discernible degradation in case of H-plane. Applications of wireless and satellite have a lot of potential for this arrangement. Also, the antenna being proposed is fabricated for measurement. *Figure 3.3* shows that the photograph of fabricated proposed antenna. Similarly *figure 3.4* shows photograph related to testing process of fabricated antenna.

**Table 3.1: Proposed antenna with optimized design parameters**

| Parameters | W | L | $W_f$ | $L_f$ | $W_r$ | $L_r$ | $W_s$ | $L_s$ | $D_s$ | $L_{sr}$ | $W_{fs}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Value (mm) | 24.6 | 37.8 | 3.18 | 12.05 | 18.1 | 20.9 | 11.9 | 12.1 | 2.05 | 7.8 | 0.9 |
| **Parameters** | $S_d$ | $L_g$ | $W_u$ | $L_u$ | $D_u$ | $D_g$ | $S_u$ | v | g | R | H |
| **Value (mm)** | 4.4 | 8.8 | 7.46 | 3.1 | 2.5 | 5.45 | 1 | 6 | 0.89 | 0.6 | 1.6 |

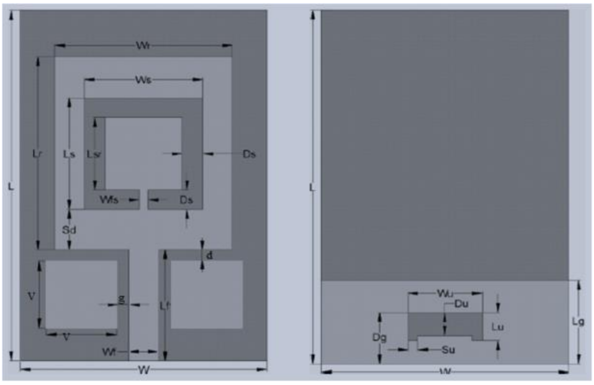

**Figure 3.1:** Front and back view of EBG- PIO based proposed antenna

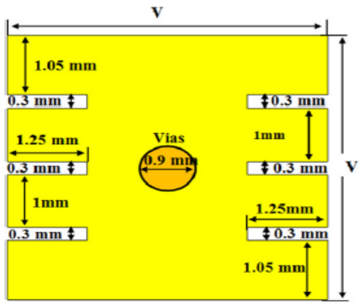


**Figure 3.2:** EBG structure

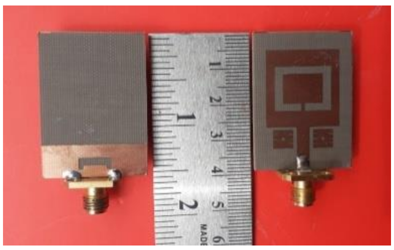

**Figure 3.3:** Photograph of the fabricated prototype

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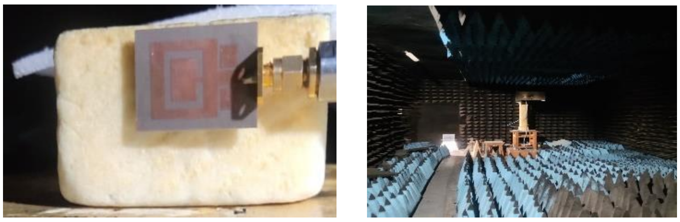


**Figure 3.4:** Photograph related to testing process of fabricated prototype

## 4. SIMULATION RESULT

The comparative analysis of performance of proposed technique-based antenna and existing techniques-based antenna is shown in *table 4.1*. As shown in the table, the proposed technique-based antenna has been attained the maximum performances, i.e. directivity, bandwidth and gain of the proposed antenna are 9.80 dB, 6.1 GHz and 9.46 dB. Also, the return loss is attained by proposed model as -34.6 dB. The proposed antenna has been attained the maximum radiation efficiency as 96.53 % at 6.9 GHz, whereas existing antenna has been attained radiation efficiency as 93 %. Additionally, *figure 4.1* shows comparative analysis of performance of proposed antenna and existing antenna. When compared to existing techniques-based antenna such as,

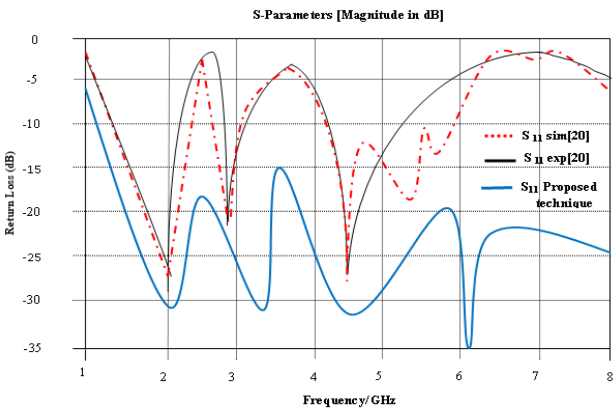
**Table 4.1: Comparison of proposed technique with existing techniques**

| Parameters | MPSA [21] | EBG [23] | MFO [7] | Proposed Technique | |
|---|---|---|---|---|---|
| | | | | Simulation | Fabrication |
| Directivity (dB) | 11.59 | 11.78 | 12.6 | 9.80 | 9.76 |
| Return loss (dB) | 17.34 | 28.24 | -20 | -34.6 | -31.53 |
| Bandwidth (GHz) | 1.5 | 2.4 | 3.1 | 6.1 | 5.9 |
| Gain (dB) | 7.33 | 8.55 | 8.9 | 9.46 | 9.48 |
| Efficiency (%) | - | - | - | 96.53 | 96.73 |

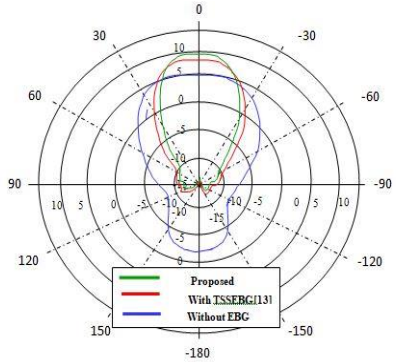
However, efficiency for the respective results can be calculated using the expression given by

$$G = KD$$

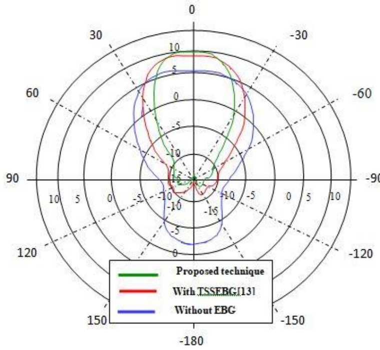
Where G = Gain, D = Directivity, K = Efficiency factor




(a) Return Loss analysis

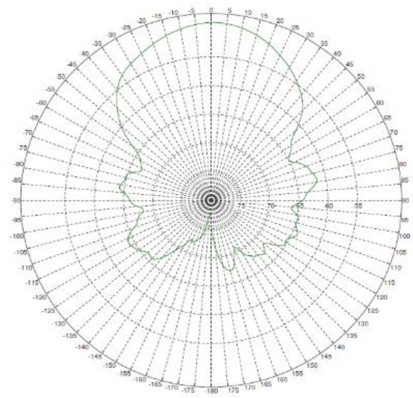



(b) Gain for proposed antenna

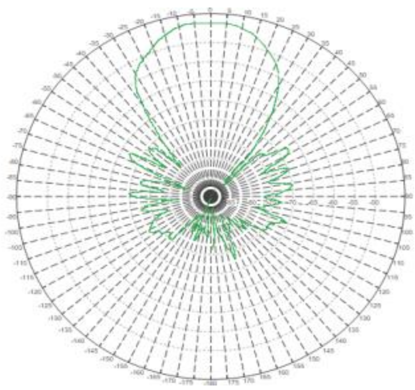



(c) Directivity for proposed antenna

**Figure 4.1:** Comparative analysis of proposed antenna and existing antenna performance results (simulation) covering UWB frequency range



(a) Gain for proposed antenna (9.48 dB)



(b) Directivity for proposed antenna (9.76 dB)

**Figure 4.2:** Performance of proposed fabricated antenna (measured) covering UWB (3.1–10.6 GHz) frequency range

## 5. CONCLUSION

In this paper, high-performance micro strip patch antenna for UWB applications, EBG-PIO based rectangular micro strip patch antenna was proposed to design inexpensive. Here, to optimize antenna design, PIO algorithm has been used to choose the design parameters optimally. Also, the EBG structure is included in the proposed antenna for enhancing the performance. The design of the proposed antenna has been done using HFSS. Additionally, the proposed antenna performance is analyzed as well as compared with other techniques regarding directivity, gain, return loss, bandwidth, and efficiency of radiation. Proposed antenna has obtained maximum directivity, gain, and radiation efficiency as 9.80 dB, 9.46 dB, and 96.53 %. The proposed method's return loss value is – 34.6 dB with a bandwidth of 6.1 GHz. Finally, results showed that proposed technique has been better performed than existing techniques. Additionally, the outcomes indicate proposed antenna simulation results to be compared with measured results of fabricated proposed antenna whereas a good agreement is found between them.

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