An end fire printed monopole antenna based on electromagnetic band gap structure

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Abstract
In this paper, a moderate gain monopole antenna is proposed for GSM and Wi-Max applications. The antenna structure is constructed from a traditional printed monopole on Roger substrate of 3006 family. To enhance the antenna performance ultimately, an Electromagnetic Band Gap (EBG) layer is introduced to the antenna structure. A numerical analysis is applied based on a Finite Integral Technique (FIT) of CST Microwave Studio (CSTMWS) formulations to characterize the EBG unit cell in terms of S-parameters, dispersion and reflection diagram, as well as the constitutive electromagnetic properties. The antenna performance is tested numerically with and without the EBG structure in terms of S-parameters and radiation patterns. It is found that the proposed antenna provides an excellent matching, $S_{11} < -10 \, \text{dB}$, at 1.85 and 3.3 GHz with 2.88 dBi and 5.8 dBi gain, respectively. Nevertheless, the Finite Element Method (FEM) based on Ansoft High Frequency Structure Simulator (HFSS) software package is invoked to compute the antenna performance. The antenna structure is fabricated and tested experimentally. Finally, an excellent agreement is found between the obtained numerical results from both software packages and measurements.

1. Introduction
Recently, complex artificial metamaterial surfaces such as Frequency Selective Surfaces (FSS), Soft Surface Defects (SSD), Hard Surface Defects (HSD), Electromagnetic Band Gap (EBG) structure and Artificial Magnetic Conductors (AMC) have been utilized extremely to replace the traditional conductors in most microwave devices [1,2]. EBG structures are one of the most attractive metamaterial categories proposed to manipulate the material intrinsic parameters to produce the desired electromagnetic properties [3]. Therefore, EBG structures can be artificially engineered to utilize certain constitutive parameters with cells much smaller than the guided wavelength [4]. Moreover, these structures exhibit zero or close to zero relative permittivity ($\varepsilon_r$) and relative permeability ($\mu_r$) [4]. Hence, compact EBG structures have been utilized to the antennas for several applications including gain and bandwidth enhancements as in [5–12].

The printed circuit antenna developments explored the novelty of EBG structures to improve the desired radiation properties for different engineering industries [9]. Therefore, many researchers were attracted to realize antennas size reduction at the desired frequency bands for modern wireless communication systems [10]. Nevertheless, further advancements were achieved by defecting the printed circuit antennas parts, patches and grounds, with complicated EBG patterns as in [11,12]. In [13], the authors presented EBG defects to a microstrip antenna for gain enhancements. Several investigations based on the EBG structures use for enhancing the antenna properties were presented in [13]. Gain enhancement using EBG layer was introduced on top of a microstrip antenna as in [10,12,13], however, the proposed structures were very large.

In this article, the authors aim to provide a systematic analysis based on monopole antenna design with EBG structure for moderate gain over operating frequency range for Wi-Max applications. The monopole antenna geometry is constructed as a printed strip line on a dielectric substrate where it is presented in Section 2. The monopole antenna element is mounted on the same substrate with EBG structures to increase the antenna radiation efficiency in the end fire. The EBG properties are evaluated numerically in Section 3. The monopole antenna is fed with a 50-Ω microstrip line through SubMiniature Version A (SMA) coaxial RF connector. The proposed antenna performance is tested numerically and discussed in Section 3. Section 4 is devoted to an extensive study based on a systematic approach of the proposed EBG and antenna design to optimize the antenna parameters design. The antenna
Table 1. Geometrical dimensions (mm) of the proposed antenna and EBG structure.

| Parameter | Dimension | Parameter | Dimension |
|-----------|-----------|-----------|-----------|
| $L_{sub}$  | 50        | $m$       | 8         |
| $W_{sub}$  | 30        | $t$       | 1         |
| $L_{GRD}$  | 50        | $t_{sub}$ | 1         |
| $L_{EBG}$  | 30        | $w_{slot}$ | 1.8      |
| $W_{EBG}$  | 18.5      | $l_{slot}$ | 1.8      |
| $l$        | 22        | $d$       | 1.5       |
| $g$        | 4.2       | $h$       | 2.5       |
| $k$        | 2.1       | $w$       | 3         |

Figure 1. The antenna geometrical details: (a) 3-D antenna structure, (b) front view, (c) side view, (d) EBG structure and (e) back view.

is fabricated and tested experimentally in Section 5. Finally, the paper is concluded in Section 6.

2. Antenna geometry and EBG details

The proposed antenna is constructed from a traditional monopole with a first resonance at 1.85 GHz when printed on a Roger 3006 substrate of $\varepsilon_r = 6.15$ with $\tan\delta = 0.00134$ and backed with a partial copper ground plane. The monopole antenna is fed with a transmission line located between the monopole conductor and the substrate edge. Figure 1 shows the antenna geometrical details. The reason of choosing such EBG design is to realize a right-hand branch from a traditional transmission line conductor rows. However, the left-hand part is obtained from the air slots along the transmission line rows. Therefore, a significant advancement could be achieved by reducing the surface from the antenna due to fringing effects [1] (Table 1).

3. EBG performance

In this section, the proposed EBG structure is characterized using an analytical transmission line model in terms of phase dispersion along the x-axis. The equivalent circuit elements are evaluated based on the EBG structural model is presented in Figure 2(a). The unit cell lumped elements are evaluated based on the EBG structural dimensions [4]. Therefore, after applying the transmission line model (TLM) calculations, the S-parameters are presented in Figure 2(b). A numerical simulation based on FIT algorithm of CST MWS [14] is invoked for validation. For this, the Ohmic losses is given by $R_{conductor}$, however, dielectric losses between each couple rows are given by $G_{dielectric}$. The right-hand part of the proposed EBG layer is described by $C_{RH}$ and $L_{RH}$, while the left-hand branch is presented by $G_{LH}$ and $L_{LH}$ components. The value of $R_{load}$ is presented for the free space impedance. All relative elements are given in Table 2.

Now, the proposed EBG layer properties in terms of constitutive parameters and dispersion diagram are evaluated. In Figure 3(a), the evaluated constitutive parameters in terms of $\varepsilon_r$ and $\mu_r$ from the evaluated S-parameters are presented. It is found that the proposed layer shows no negative constitutive parameters at any frequency band, however, at certain bands $\varepsilon_r$ and $\mu_r$ approach to zero as can be seen at 1.75 GHz and 4.85 GHz from Figure 3(a). Such observation emphasizes the behaviour of the proposed layer as an EBG structure [5]. Moreover, the values of the effective constitutive parameters realize an excellent matching with free space impedance that would increase the antenna gain. Therefore, the authors decided to study the dispersion diagram at the first Brillouin zone for Transverse Electric (TE) and Transverse magnetic (TM) modes. The unit cell array properties in terms of dispersion diagram are presented in Figure 3(b) from both CSTMWS and TLM approaches for validation. It is found that the obtained results show a specific band gap at the frequency band of interest which provides excellent matching impedance. Nevertheless, the change in the
group velocity is found to be negative at TM mode with positive change at TE mode to realize a band gap [5].

4. Parametric study

In this section, an intensive study based on a systematic approach is presented to optimize the antenna performance in term of $S_{11}$ spectra, boresight gain and radiation patterns. Therefore, two EM solvers based on FIT and FEM are used to examine the properties of proposed monopole antenna and EBG structures. The strategy to optimize the antenna parameters is picked from two main parts. The first part focuses on the design of an initial monopole antenna to optimize the antenna performances at two bands, 1.85 and 3.3 GHz, for GSM and Wi-Max applications. Then, the second step begins with optimizing the EBG design based on the monopole antenna to achieve gain enhancement with end-fire radiation patterns. The systematic approach is started with changing the monopole antenna parameters such as partial ground plane width ($w$), monopole antenna length ($l$) and the proposed antenna location ($m$) from the side edge of the substrate. Next, the parametric study is extended to evaluate the effects of introducing the EBG structure numerically by considering the number of the EBG slots, distance between the EBG slots ($d$) and the number of the EBG rows. Therefore, the design methodology is realized through the following.

4.1. Antenna parametric study

4.1.1. Effect of the partial ground plane width “$w$”

In this section, a parametric study is presented to understand the effect of varying ($w$) on the antenna performance. Therefore, $w$ is swept from 1 mm up to 5 mm with a step of 1 mm to obtain the desired frequency band with best matching impedance. The influence of $w$ on $S_{11}$ spectra by fixing $l = 22$ mm and $m = 8$ mm to eliminate their effects on the antenna design is shown in Figure 4. It is proven from Figure 4, by increasing $w$: 1–5 mm; the matching impedance and frequency resonance are significantly changed. However, the bandwidth found almost stay the same without any change. Nevertheless, it is possible to achieve perfect impedance matching when we set $w$ to 3 mm which can be observed in Figure 4.

4.1.2. Effect of varying the antenna length ($l$)

As far as the monopole length is concerned, therefore, in this section, a parametric study is conducted to realize the effects of varying the monopole length ($l$) on the antenna behaviour such as $S_{11}$ spectra. Six different monopole lengths are examined; we started with $l$...
equal to $0.12\lambda_0$ mm (where $\lambda_0$ is the free space wavelength at 1.85 GHz) to $0.15\lambda_0$ mm with a step of 0.006 $\lambda_0$ mm. The other dimensions are fixed by considering $w = 3$ mm and $m = 8$ mm to eliminate their effects on the antenna design as seen in Figure 5. It is found that when $l$ is increased from 20 to 25 mm, $S_{11}$ is reduced at 1.85 and 3.3 GHz. Therefore, an enhancing in the impedance matching at the two bands is obtained when $l$ is fixed to 22 mm.

4.1.3. Effect of varying the distance ($m$)
Now, the antenna performance with respect to changing the distance between the monopole and the substrate edges given by ($m$) is investigated in this section. Therefore, the authors varied the distance $m$ from 0 to 10 mm with a step of 2 mm and keep the values of $w = 3$ mm and $l = 22$ mm to eliminate their effects on the antenna performance. Figure 6 shows the effects of varying the distance $m$ on the $S_{11}$ spectra. From
Figure 6, it is indicated that the optimal case in terms of bandwidth, matching impedance and frequency resonance when the monopole is set to 8 mm from the substrate edge. Such change in the $S_{11}$ spectra is attributed to the effects of fringing from the substrate sides [5]. Therefore, it is considered that $m = 8$ mm as an optimal distance because it presents the minimum $S_{11}$ for the frequency band of interest.

4.1.4. Effect of substrate dimensions

As far as the substrate dimensions play important role in the proposed antenna performance. Thus the authors, in this section, summarized the effects of the substrate dimensions on the proposed monopole antenna performance. It is observed from the $S_{11}$ spectra in Figure 7 that increasing the substrate dimension, the resonance frequency shifts to lower
Figure 7. Effects of substrate dimensions on $S_{11}$ spectra.

Table 3. The proposed antenna performance with different values of $w$, $l$ and $m$.

| Parameter (mm) | $f_1$ (GHz) | $f_2$ (GHz) | $S_{11}$ (dB) | Bandwidth (MHz) | Gain (dBi) |
|---------------|-------------|-------------|--------------|----------------|------------|
| $w = 1$       | 1.77        | 3.35        | -20.7        | 127            | 1.23       |
| $w = 2$       | 1.82        | 3.36        | -32.7        | 160            | 1.2        |
| $w = 3$       | 1.85        | 3.3         | -29.5        | 245            | 1.11       |
| $w = 4$       | 1.95        | 3.37        | -18.5        | 179            | 1.18       |
| $w = 5$       | 1.99        | 3.39        | -15.4        | 151            | 1.2        |
| $l = 20$      | 1.92        | 3.37        | -32          | 163            | 1.29       |
| $l = 21$      | 1.88        | 3.36        | -18.5        | 158            | 1.11       |
| $l = 22$      | 1.85        | 3.3         | -28.5        | 278            | 1.14       |
| $l = 23$      | 1.83        | 3.2         | -29.2        | 116            | 1.15       |
| $l = 24$      | 1.88        | 3.05        | -21.5        | 172            | 1.16       |
| $l = 25$      | 1.9         | 3.01        | -19.6        | 164            | 1.16       |
| $m = 0$       | 1.77        | 3.32        | -31          | 171            | 1.18       |
| $m = 2$       | 1.8         | 3.35        | -29.6        | 173            | 1.17       |
| $m = 4$       | 1.78        | 3.31        | -28.5        | 178            | 1.16       |
| $m = 6$       | 1.81        | 3.34        | -26.2        | 181            | 1.13       |
| $m = 8$       | 1.85        | 3.3         | -27          | 245            | 1.11       |
| $m = 10$      | 1.89        | 3.31        | -22          | 190            | 1.09       |

frequencies with an observable degradation in the impedance matching. Therefore, the best matching impedance is found when the substrate dimensions are $50 \times 30 \text{ mm}^2$. The substrate dimensions show a significant effect on the $S_{11}$ spectra due to the surface wave reflection from substrate edges [2]. The obtained results from the parametric study are summarized in Table 3 at the two bands of interest ($f_1$ and $f_2$).

4.2. Parametric study based on EBG structure

4.2.1. Effects of the EBG slots
In this section, the authors decided to introduce the EBG structure to utilize the proposed antenna gain enhancements. The EBG structure is integrated on the same substrate surface with the monopole structure. The EBG structure has slots; the number of these slots and the influence with respect to the antenna performance are studied in this section. In general, varying the EBG slots number with small steps, 1–4 for example is found not that effective as changing with 5 slots as step. On other hand, the maximum number of the EBG slots is considered 15 that fit in the EBG length. For this, the number of slots is changed from 5 to 15 with a step of 5 slots. It is observed from the obtained results when increasing the EBG slot number; a significant effect on the matching impedance as can be indicated in Figure 8. This potentially indicates that by increasing or decreasing the EBG slot number, the working frequency band of the antenna is shifted to the higher or lower bands [6]. Therefore, by increasing the number of the EBG slots, $S_{11}$ spectra matching at the frequency bands is
found to be $-24$ dB at 1.85 GHz and $-27$ dB at 3.3 GHz. For this, we can consider that the number of slots is 15 as an optimal case because the number of resistance in series connection realizes a magnitude equivalent to the impedance of the antenna aperture [3].

4.2.2. Effect of EBG rows

In order to provide a clear indication of the influences of the EBG rows on the antenna performance, we investigated the effect of 1, 2, 3, 4, 5, 6 and 7 of EBG rows placed 6 mm away from the monopole antenna and we demonstrated that the benefits of using the EBG could be already obtained with just 1 or 2 rows of the EBG structures. The distance between the neighbouring EBG rows is fixed with 1.5 mm. A parametric study is carried out by varying the EBG rows number from 1 to 7 as shown in Figure 9. Based on desired substrate dimensions, the authors considered the maximum number

Figure 8. Effects of EBG slots number variation on $S_{11}$ spectra.

Figure 9. Effects of EBG rows number on $S_{11}$ spectra.
of rows that fit in the available dimensions is 7. Starting from a single EBG row, in fact a significant portion of the monopole transmitted power is subtracted by this row [5]. Generally, we are interested in examining the contribution of each single EBG rows on the monopole performance. According to that, the presented results on the antenna performance with more than 5 EBG rows are dramatically differentiated in term of gain and matching impedance. Moreover, the dual operating bands are found to be shifted to the higher frequencies when the EBG rows are increased to more than 5 rows. From the above discussion, we concluded that the proposed antenna achieved our desired antenna performance in term of bandwidth and impedance matching when 5 rows of EBG are used.
Table 4. The proposed antenna performance based on a parametric study.

| Parameter          | Resonance frequency (GHz) | $S_{11}$ (dB) | Bandwidth (MHz) | Gain (dBi) |
|--------------------|---------------------------|---------------|-----------------|------------|
|                    | $f_1$ | $f_2$ | $f_1$ | $f_2$ | $f_1$ | $f_2$ | $f_1$ | $f_2$ | $f_1$ | $f_2$ |
| Separation distance (mm) | $d = 0.5$ | 1.71 | 3.43 | -11.2 | -29.1 | 42 | 209 | 2.4 | 4.7 |
|                    | $d = 1$ | 1.78 | 3.51 | -11 | -35 | 48 | 230 | 2.4 | 5.1 |
|                    | $d = 1.5$ | 1.85 | 3.3 | -24.1 | -27 | 244 | 318 | 2.9 | 5.8 |
|                    | $d = 2$ | 1.75 | 3.48 | -12.1 | -30.5 | 41 | 230 | 2.5 | 5.5 |
|                    | $d = 2.5$ | 1.7 | 3.49 | -9.1 | -27.5 | - | 237 | 2.5 | 5.5 |
| EBG Array No.      | 1 | 1.87 | 3.4 | -15.2 | -35.1 | 124 | 146 | 2.0 | 1.9 |
|                    | 2 | 1.78 | 3.21 | -10.1 | -13.7 | 21.5 | 133 | 2.1 | 2.4 |
|                    | 3 | 1.86 | 3.45 | -9 | -35 | - | 135 | 2.3 | 3.9 |
|                    | 4 | 1.78 | 3.26 | -10.2 | -17 | 25 | 151 | 2.31 | 4.1 |
|                    | 5 | 1.85 | 3.3 | -24.1 | -27 | 243 | 268 | 2.9 | 5.8 |
|                    | 6 | 1.84 | 3.4 | -8 | -17 | - | 251 | 2.7 | 5.81 |
|                    | 7 | 1.73 | 3.49 | -8.1 | -26.5 | - | 234 | 2.9 | 5.9 |
| Slots No.          | 5 | 1.72 | 3.46 | -9.2 | -34.1 | - | 204 | 2.5 | 5.4 |
|                    | 10 | 1.82 | 3.41 | -11 | -33 | 41 | 235 | 2.5 | 5.5 |
|                    | 15 | 1.85 | 3.3 | -24.1 | -27 | 243 | 268 | 2.9 | 5.8 |

Figure 12. $S_{11}$ and gain spectra.

4.2.3. Separation distance between the EBG rows

Next, the effects of changing the separation distance given by ($d$) between the adjacent EBG structures on the proposed antenna design are examined in this section. Changing $d$ from 0.5 to 2.5 mm in step of 0.5 mm is considered in this section. The best separation distance ($d$) between the EBG structures with maximize the matching impedance is obtained when $d = 1.5$ mm as illustrated in Figure 10. It is found that the separation gap exhibits a significant effect on the $S_{11}$ spectra at different values of $d$. Due to the parasitic effects such as capacitors and inductors when such EBG embedded with the proposed antenna that causes reflecting energy from the EBG structure toward the

Figure 13. Performance variation with $S$ change: (a) $S_{11}$ spectra and (b) Gain spectra.
Table 5. The proposed antenna performance with and without EBG.

| Parameters          | Without EBG | With EBG |
|---------------------|-------------|----------|
| \( f_1 \) (GHz)     | 1.85        | 1.85     |
| \( f_2 \) (GHz)     | 3.3         | 3.3      |
| \( S_{11} \) (dB)   | -26.1       | -21      |
| Bandwidth (MHz)     | 178         | 221      |
| Boresight gain (dBi)| 1.11        | 2.88     |
| Radiation efficiency| 34          | 53.6     |

4.2.4. Effect of the substrate thickness

The substrate thickness shows significant effects on the antenna performance [7]. Therefore, it is interesting to study the influence of the substrate thickness given by \( t_{sub} \), on the proposed antenna performance by varying \( t_{sub} \) from 0.5 to 2.5 mm with a step of 0.5 mm. It can be clearly seen from Figure 11, when the substrate thickness increases the frequency resonance bands decrease. Consequently, by increasing \( t_{sub} \), the resonant frequency is shifted slightly to lower frequencies. However, there is an observable degradation in the impedance matching and bandwidth. It is concluded that the optimal case in term of bandwidth, impedance matching, resonance frequency and boresight gain when the \( t_{sub} \) is set to 1 mm. The main conclusion that is obtained from the previous parametric study is summarized in Table 4.

4.2.5. Antenna performance based on EBG array

To achieve gain enhancements, the authors introduced a periodical EBG structure next to the monopole antenna mounted on the same substrate side. Therefore, a numerical simulation based on CST MWS is

Figure 14. Simulated far-field radiation patterns in the E-plane and H-plane with and without EBG at frequency: (a) 1.85 GHz and (b) 3.3 GHz.
carried out to realize the antenna performance in terms of $S_{11}$ and gain spectra. However, before introducing the EBG to the antenna structure, the monopole dimensions are adjusted numerically to operate at 1.85 and 3.3 GHz with $S_{11} < -10$ dB as aforementioned previously. The antenna performance without introducing the EBG arrays is shown in Figure 12. As can be seen in Figure 12, the antenna shows excellent matching at 1.85 and 3.3 GHz with boresight gains of 1.11 dBi and 2.25 dBi, respectively.

It is important to mention that the reason of choosing the antenna location with respect to the EBG layer maintains the wave propagation along the $x$-axis. On the other hand, due to the significant variation in the group velocity along the $x$-axis that is presented in the dispersion diagram, see Figure 3(b), it is decided to place the antenna next to the EBG layer width. Therefore, the EBG array is excited with a printed monopole parallel to the width. However, the best separation of the antenna from the EBG array is considered through a parametric study as we investigated in the previous study in this paper. Thus a numerical investigation of CST MWS is conducted to realize the best location of the antenna element with respect to the EBG array. In this study, the authors care about the miniaturization limit and the best antenna performance in terms of $S_{11}$ and boresight gain. Therefore, the antenna location from the EBG structure is swept from 6 mm down to 0 mm with a step of 3 mm. This procedure is adopted to optimize the antenna performance to obtain the maximum gain enhancement with maximum miniaturization. The obtained results from the parametric study are presented in Figure 13 in terms of $S_{11}$ and gain spectra. It is found by increasing the separation distance, a significant degradation in the antenna matching and gain occurs; this is attributed to the capacitive part increase which degrades the antenna matching and trapping the wave propagation to realize gain reduction [7].
Figure 16. Fabricated antenna and measured results: (a) fabricated prototype and (b) simulated and measured $S_{11}$.

Figure 17. Antenna radiation patterns: (a) 1.85 GHz and (b) 3.3 GHz.

Table 5 summarizes the antenna performance in terms of $S_{11}$, boresight gain, bandwidth and radiation efficiency with and without EBG structure.

The simulated radiation patterns in the E-plane and H-plane with and without EBG structure at 1.85 and 3.3 GHz are presented in Figure 14. It is found that the antenna radiation patterns are mostly oriented to the end-fire to suit the GSM and Wi-Max in portable wireless systems.

Now, the antenna 3D radiation patterns with and without EBG structure at 1.85 and 3.3 GHz are compared in Figure 15(a), 15(b), 15(d), and 15(e). It is found that the antenna radiation patterns are mostly oriented to the end-fire to suit the GSM and Wi-Max in portable
wireless systems. This is achieved due to introducing the EBG structures as can be seen from the current distribution, presented at 3.3 GHz only, in Figure 15(c) and 15(f) for the antenna without and with EBG structure, respectively.

5. Results validation and measurements

Before the antenna fabrications, the authors conducted another numerical technique for validation based on FEM simulation of HFSS software package [15]. Figure 16(a) shows the fabricated prototype, the proposed monopole antenna based on EBG structure is fabricated using chemical etching process connected with a 50-Ω SMA RF connector. The S11 spectrum is measured using an Agilent 8720C network analyser as presented in Figure 16(b). It is found that the measured result shows a reasonable agreement with the simulated S11 spectra with insignificant discrepancy due to the fabrication defects.

Finally, the antenna radiation patterns are measured at 1.85 and 3.3 GHz inside a microwave anechoic chamber. The measured radiation patterns are presented in Figure 17 and compared to the simulated results; it is found a good agreement with the simulated results.

A comparison of the proposed antenna design based on EBG structure with other published results is reported in Table 6. It is found that the proposed antenna design offers a moderate gain at the end-fire directions and relatively easy in design and fabrication which can make this technique versatile for various applications such as GSM and Wi-Max having stringent performance requirements.

6. Conclusion

The aim of this paper is to enhance the gain of the printed monopole antenna and orient the antenna radiation, mostly, in the end-fire directions. The proposed antenna is designed to suit the applications of GSM and Wi-Max bands in portable wireless systems. Therefore, the antenna design is based on a printed monopole structure attached to an EBG array mounted on 3006 Roger substrate backed with a partial ground plane. Several parametric studies based on numerical simulations of CST MWS formulations are conducted to realize the optimal antenna design. The optimal antenna performance is validated numerically with FEM based on HFSS before fabrication. It is found that the antenna shows end-fire radiation patterns with gain of 2.88 dBi and 5.8 dBi at 1.85 and 3.3 GHz, respectively. The achieved gain enhancement is due to the introduction of the EBG array which matches the antenna aperture impedance to the free space impedance. The antenna is fabricated and tested experimentally to validate the obtained numerical results in term of S11 and radiation patterns at 1.85 and 3.3 GHz. Finally, the measured results show good agreement with the simulated results.

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