Two Novel Meander-Perforated Plane EBG Structures For 5G Applications

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Abstract—With the advance of 5G network, antennas are required to meet better performance as it’s the key element of 5G network. Meta-surface structure has been demonstrated to be an effective method to improve the performances of an antenna. Whereas, most of the meta-surface structures cannot be applied to 5G applications properly according to the recent research. In this paper, we propose two novel meander-perforated plane (MPP) electromagnetic bandgap (EBG) structures which are named TMPP-EBG and GMPP-EBG. The meander-shape slot of TMPP and GMPP is etched on the top and ground layer respectively. The two novel MPP-EBG structures can be applied to millimeter-wave 5G spectrum from 24GHz to 28GHz. Compared with the conventional mushroom-like EBG structure, the simulated results presented that TMPP-EBG enhances the bandwidth of S\textsubscript{21} from 1GHz to 2.5GHz with the same size and GMPP-EBG achieves 14% size reduction with the same resonant frequency.

1. INTRODUCTION

Recently, the EBG structures have been widely explored in the microwave domain such as electronically scanned phased arrays, waveguides, low-loss coplanar lines, compact integrated filters, and duplexers [1]. The metallo-dielectric EBG structure, which consists of a dielectric medium with conducting vias placed periodically, can suppress the surface wave that exists in microstrip antennas (MSAs). The EBG structure, which is also referred to as high impedance surface structure, is compact and has good potential to build a low-profile and high efficiency antenna surface [2]. Generally, the size of the conventional mushroom-like EBG structure is large for 5G applications. There are several ways to reduce the size and to broaden the bandwidth of EBG structures [3-4]. The spiral branch line type of EBG structures act as a coplanar spiral inductor in the microwave circuits [5]. Compared with the convenient mushroom-like EBG structure, the spiral branch line type of EBG structures enhance the equivalent inductance which was introduced by the spiral branch and was cascaded with the inductance formed by the plated via. The enhancement of equivalent inductance results in the size reduction and broad bandwidth of EBG structures. The MPP-EBG structure [6] enhances the characteristic impedance of the conventional mushroom-like EBG structure and improves the slow-wave effect, thus achieving the significant size reduction and the stopband enhancement.

Whereas, there are limitations for metallo-dielectric EBG structures for 5G applications. Simple square slotted-ring EBG structure [7] cannot improve the performance enough from the conventional mushroom-like EBG structure. Most of the complicated EBG structures [8] do not operate at millimeter-
wave 5G spectrum from 24GHz to 28GHz as the complicated shape slot cannot be etched on the patch layer by manufacturer under the limitations of photolithography technology. Therefore, a compact and broad bandwidth EBG structure, which can be manufactured based on current photolithography technology at millimeter-wave 5G spectrum from 24GHz to 28GHz, is needed.

In this paper, two novel MPP-EBG structures have been proposed with significant size reduction and bandwidth enhancement compared with the conventional mushroom-like EBG structure at millimeter-wave 5G spectrum from 24GHz to 28GHz.

The geometries of the two MPP-EBG structures are illustrated in Section II. The simulation results and discussions of the two novel MPP-EBG structures are shown in Section III, followed by conclusion in Section IV.

2. TWO MPP-EBG STRUCTURES DESIGN

2.1 Conventional Mushroom-like EBG Structure
A conventional mushroom-like EBG structure was analyzed and simulated to serve as a reference. Fig.1 has illustrated a conventional mushroom-like EBG structure and its equivalent circuit. The mushroom-like EBG structure consists of the EBG metal patch, metallic vias located at the centre of the top and ground metal layer. The adjacent unit cells are equivalent to parallel LC resonators. The inductance \( L \) is decided by the current flowing through vias and the capacitance \( C \) is decided by the gap spacing between two adjacent unit cells. Stop band characteristic by the suppression of surface wave is the main feature of the EBG structure. The relationship between the resonant frequency and unit size can be represented by the following formulas (1)-(3).

\[
\begin{align*}
    f_0 &= \frac{1}{2\pi\sqrt{LC}} \\
    C &= \frac{W\epsilon_0(1+\epsilon_r)}{\pi} \cosh^{-1} \left( \frac{2W+g}{g} \right) \\
    L &= \mu_0 h
\end{align*}
\]

where \( f_0 \) is the resonant frequency of mushroom-like EBG structure; \( W \) is the square patch size; \( g \) is the gap distance between two adjacent metal patches; \( \epsilon_r \) is the relative permittivity of the dielectric substrate; \( \epsilon_0 \) is the vacuum permittivity; \( \mu_0 \) is the vacuum permeability, \( h \) is the thickness of the dielectric substrate.

In this paper, the conventional mushroom-like EBG structure is printed on the dielectric substrate Rogers 6002 with the relative permittivity \( \epsilon_r \) of 2.94 and the thickness \( h \) of 0.508mm. The gap distance between two adjacent metal patches \( g \) is 0.12mm. When the mushroom-like EBG structure operates at
24-28GHz for 5G applications, the square patch size $W$ is between 0.5-0.7mm approximately. The bandwidth of $S_{21}$ is 1GHz from 26.1GHz to 27.1GHz when the square patch size $W$ is 0.59mm. Whereas, the bandwidth of $S_{21}$ is not wide enough and the square patch size $W$ is not small enough for millimeter-wave 5G applications.

2.2 The Design of Novel MPP-EBG Structures

As the square patch size $W$ of conventional mushroom-like EBG structure is between 0.5-0.7mm approximately for 5G applications, most of the complicated shape slot cannot be etched by the manufacturer under the limitations of photolithography technology.

A novel TMPP-EBG structure with the meander-shape slot etched on the top layer has been proposed, as illustrated in Fig.2(a). As the ponding pad occupies the center of the top layer, the slot surrounded the center will take full advantage of the top layer space. The minimum size of the square patch $W$ of TMPP-EBG structure is 0.59mm under the limitations of photolithography technology. Also, the meander-shape slot will produce more 90-degree corners and increase the slot length to improve the inductance of the equivalent circuit. This structure is very easy to adjust the inductance by changing the length of the total meander-shape slot. The variation of length parameters $n1$-$n4$ and $m1$-$m4$ realizes tunable frequency band characteristics without changing the period of the EBG unit cell. The dimensions of the novel TMPP-EBG structure unit cell are tabulated in Table 1. The parameters of TMPP-EBG structure dielectric substrate are the same as the conventional mushroom-like EBG structure.

Also, the meander-shape slot can be etched on the ground layer, which is called GMPP-EBG structure, as illustrated in Fig.2(b). The Ground layer has more space to etch which is helpful for the miniaturization of EBG structure. The minimum size of the square patch $W$ of GMPP-EBG structure is 0.47mm under the limitations of photolithography technology.

There are some different ways to investigate whether or not a periodic structure acts as an EBG structure in the desired frequency range. The periodic EBG structure adopted in this

![Fig. 2. (a)top layer view of TMPP-EBG structure (b)ground layer view of GMPP-EBG structure (c)top layer view of 5×5 units of TMPP-EBG structure.](image-url)
TABLE I. PHYSICAL DIMENSIONS OF THE NOVEL TMPP-EBG STRUCTURE UNIT CELL

| Parameters | Values (mm) | Parameters | Values (mm) |
|------------|------------|------------|------------|
| r2         | 0.13       | n3         | 0.12       |
| r1         | 0.05       | n4         | 0.19       |
| thik       | 0.05       | m1         | 0.22       |
| W          | 0.59       | m2         | 0.15       |
| g          | 0.12       | m3         | 0.22       |
| n1         | 0.15       | m4         | 0.12       |
| n2         | 0.15       |            |            |

The paper is placed in an ideal TEM waveguide [9]. Perfect electric conductor (PEC) and perfect magnetic conductor (PMC) surfaces are used as the ideal TEM waveguide sidewalls along the z and x-direction, respectively. The input wave is launched in free space toward the inside of the waveguide at normal incidence from each port. It can form a TEM waveguide with this boundary condition. The 5×5 EBG units are centered in the waveguide along the y-direction, as illustrated in Fig.2(c).

3. RESULTS AND DISCUSSION

Comparisons of the imaginary part of $Z_{21}$ and magnitude of $S_{21}$ when the square patch size $W$ is 0.59mm between mushroom-like EBG, TMPP-EBG and GMPP-EBG structure are shown in Fig.3 and Fig.4.

![Fig. 3. Comparison of the imaginary part of $Z_{21}$ between mushroom-like EBG, TMPP-EBG and GMPP-EBG structure.](image)

![Fig. 4. Comparison of $S_{21}$ between mushroom-like EBG, TMPP-EBG and GMPP-EBG structure.](image)
According to the imaginary part of $Z_{21}$ illustrated in Fig.3, TMPP-EBG structure and GMPP-EBG structure decrease the resonant frequency point of the imaginary part of $Z_{21}$, which represents the inductance $L$ and capacitance $C$ of the equivalent circuit. Compared to the mushroom-like EBG structure, TMPP-EBG and GMPP-EBG will result in the lower operating frequency of $S_{21}$.

As shown in Fig.4, TMPP-EBG structure has little effect on the first frequency band and great effect on the second frequency band. Therefore, TMPP-EBG structure has the widest bandwidth compared with the mushroom-like EBG structure and GMPP-EBG structure as it decreases the second frequency band of the mushroom-like EBG structure from 30.7GHz to 28.2GHz which combines dual-band into one band with the criteria of $S_{21}<-20dB$. The bandwidth of TMPP-EBG structure is from 25.7 to 28.2GHz. Compared to the conventional mushroom-like EBG structure, TMPP-EBG structure has enhanced the bandwidth of $S_{21}$ from 1GHz to 2.5GHz when the square patch size $W$ is 0.59mm.

Meanwhile, GMPP-EBG structure has the same greater effect on the first and second frequency bands. And GMPP-EBG structure decreases the first resonant frequency point from 26.8GHz to 24.1GHz. When the mushroom-like EBG structure resonates at 24.1GHz, the square patch size $W$ is 0.69mm. Therefore, GMPP-EBG structure achieves 14% size reduction from 0.69mm to 0.59mm with the same resonant frequency.

The square patch size $W$ of TMPP-EBG and GMPP-EBG structure has been optimized to operate at different frequency bands while the total length of meander-shape slot remains unchanged. When the square patch sizes $W$ are 0.59mm and 0.65mm, respectively, the $S_{21}$ of TMPP-EBG structure has been illustrated in Fig.5. As illustrated in Fig.5, TMPP-EBG structure is suitable for millimeter-wave 5G spectrum from 24GHz to 28GHz. Meanwhile, the square patch size $W$ of GMPP-EBG structure is from 0.47mm to 0.59mm when it operates at 24-26.9GHz as the $S_{21}$ illustrated in Fig.6. The TMPP-EBG and GMPP-EBG structures can also operate at higher frequency band as the decrease of the total length of meander-shape slot.

Fig. 5. The $S_{21}$ of TMPP-EBG structure when $W$ are 0.59mm and 0.65mm respectively.

Fig. 6. The $S_{21}$ of GMPP-EBG structure when $W$ are 0.47mm and 0.59mm respectively.
4. CONCLUSION
This paper has proposed two novel MPP-EBG structures for millimeter-wave 5G applications. Compared with the mushroom-like EBG structure, TMPP-EBG structure can broaden the bandwidth of $S_{21}$ from 1GHz to 2.5GHz with the same size and GMPP-EBG structure achieves a 14% of size reduction with the same resonant frequency. It is meaningful that the two novel MPP-EBG structures can be used as an alternative for surface-wave suppression in 5G antennas where call for a compact size or broad bandwidth. The two novel EBG structures have great significance for 5G applications like future smart devices, AR/VR, autonomous vehicles and 5G communications.

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