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Extremely Low-Profile Circular Patch-Ring Antenna with A Shorting Via for Impedance Matching Improvement

Shuai Zhang[1,2], Igor Syrytsin[1], Morten Sørensen[1, 2], Gert Frølund Pedersen[1]

***Abstract*—An extremely low-profile circular patch-ring antenna with omnidirectional radiation patterns is proposed in this paper. By simply introducing a shorting via, the impedance matching of the antenna is improved, where both TM_{31} mode and TM_{32} mode are excited efficiently to realize a dual resonance behavior. The designed antenna covers the Wi-Fi band of 2.4-2.48 GHz with the realized gain of over 1.5 dBi and the thickness of 0.005 λ (λ is the wavelength of the lowest operating frequency in free space). Since the antenna is not sensitive to size of ground plane, it is suitable to be mounted on different metallic platforms.**

1 INTRODUCTION

Recently, there is higher and higher demand for low-profile antennas with omnidirectional radiation patterns. These antennas can be widely utilized on the large metallic platforms of aircrafts, unmanned vehicles, wind turbine blade deflection sensing systems with carbon coating [1] [2], and so on. In these applications, antennas are required to be extremely low-profile in order to reduce air dragging due to aerodynamics. Furthermore, nowadays, lots of electrical or electronic devices, e.g. loud speakers and TV, are designed to have full metallic bodies. It raises challenges for Wi-Fi or Bluetooth antennas to radiate signals out of the metallic covers. An extremely low-profile antenna with omni-directional radiation is one of the good choices, which can be integrated on the external metal surface with painting to make the antenna as "invisible" as possible.

Circular Patch-ring antenna has been proposed in [3] with the antenna thickness of 0.029 λ (λ is the wavelength of the lowest operating frequency in free space). By introducing an annual ring, dual resonances of TM_{01} mode and TM_{02} mode have been excited simultaneously. To further broaden the impedance bandwidth of the antenna, two annular rings have been applied in [4] and triple resonance behavior has been achieved with the antenna thickness of 0.027 λ. Another way of exciting both TM_{01} mode and TM_{02} mode has been given in [5] by shorting a circular patch antenna concentrically with a set of *N* conductive vias. By combining the method in [3] and [5], triple resonances have also been realized in [6] with the antenna thickness of 0.016 λ. In [7], TM_{41} mode has been utilized to design an ultra-wideband antenna with the profile of 0.07 λ. However, it is very challenging to efficiently excite the dual or triple modes simultaneously with the methods in [3]-[7] if the thickness of the antennas further decreases (e.g. to 0.005 λ).

In this paper, a circular patch-ring antenna with extremely low profile and omnidirectional radiation patterns is proposed. TM_{31} mode and TM_{32} mode are excited efficiently to realize a dual-resonance behavior by adding a shorting via. By tuning the distance between the shorting via and feeding, the impedance matching of dual resonances are significantly improved. The designed antenna covers the band of 2.4-2.5 GHz with the thickness of 0.005 λ. The antenna could be mounted on different metallic platforms with the antenna performance nearly unchanged.

2 ANTENNA PERFORMANCE ANALYSIS

The configuration of the proposed circular patch-ring antenna with centrically fed is shown in Figure 1. In order to keep the antenna compact, the antenna is printed on a Rogers RO 3010 substrate with the thickness of 0.635 mm (0.005 λ), the permittivity of 10.2, and the loss tangent of 0.0022. The proposed circular patch-ring antenna is similar to that in [3].

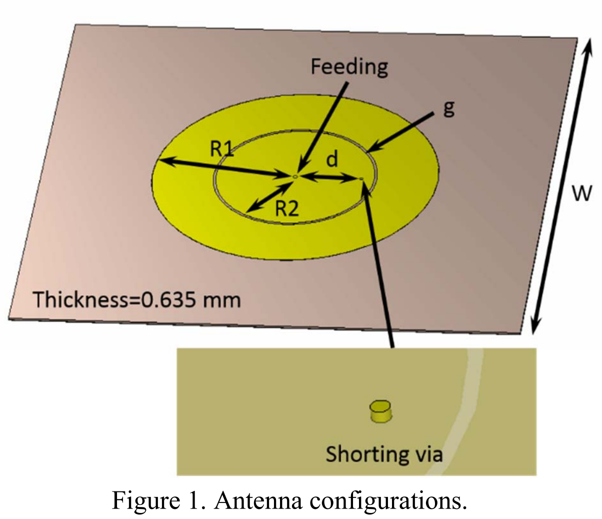

Figure 1. Antenna configurations.

Different from [3], one shorting via is introduced. By tuning the distance between the feeding and shorting via, both TM_{31} mode and TM_{32} mode can be efficiently excited with an extremely low antenna profile. The detailed dimensions of the antenna are listed in the following: R1= 42.25 mm, R2= 23.42 mm, d= 19.5 mm, and g=0.76 mm.

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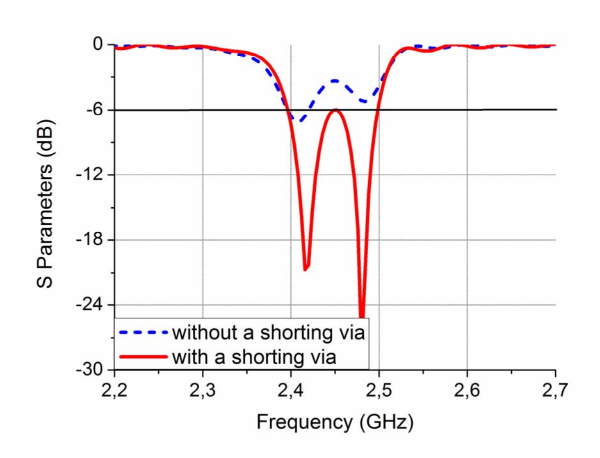
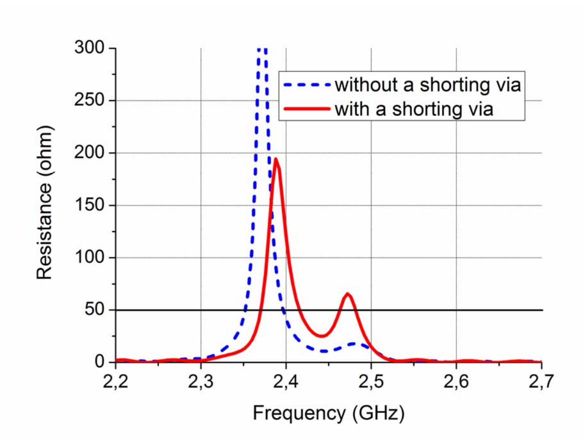
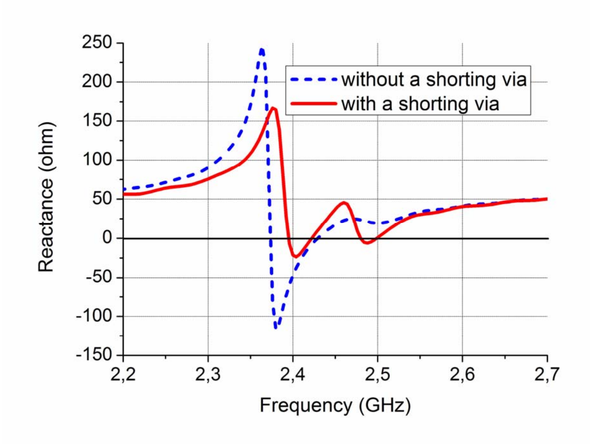


Figure 2. S parameters of the low-profile circular patch ring antenna with or without a shorting via.

In Figure 2, the S parameters of the low-profile circular patch ring antenna with or without a shorting via are shown. It can be clearly observed that the shorting via improves the impedance matching of the antenna significantly. The resonances at around 2.42 GHz and 2.48 GHz are TM_{01} mode and TM_{02} mode without a shorting via, respectively. With a shorting via, the resonances at around 2.42 GHz and 2.48 GHz have been changed to TM_{31} mode and TM_{32} mode. In addition, to better understand the mechanism, resistance and reactance of the designed antenna can be obtained in Figure 3 (a) and Figure 3 (b). The short via affects both the real and imaginary parts of the impedance.

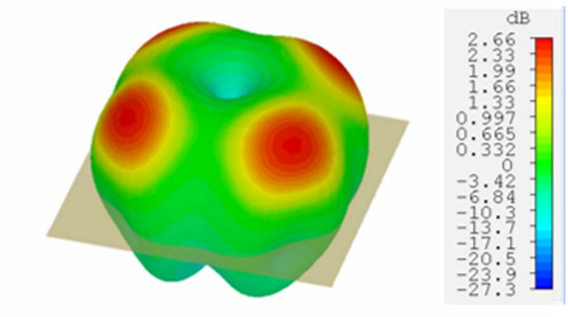


(a)

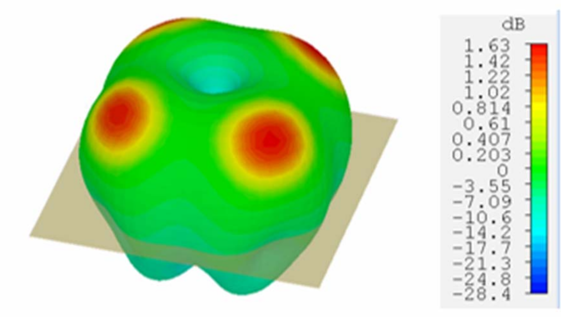


(b)

Figure 3. Impedance of the low-profile circular patch ring antenna with or without a shorting via: (a) resistance, and (b) reactance.



(a)



(b)

Figure 4. Radiation gain patterns of the low-profile circular patch ring antenna with a shorting via at: (a) 2.42 GHz, and (b) 2.48 GHz.

The radiation patterns of the designed antenna at 2.42 GHz and 2.48 GHz are shown in Figure 4. Both the TM_{31} mode and TM_{32} mode produce omnidirectional radiation patterns. It is also noticed that in the directions of ground plane corners the radiation is slightly stronger than the other directions. This is mainly because of the shape of the ground plane. Furthermore, the realized gain of the low-profile antenna is given in Figure 5. The realized gain is from 1.5-3 dBi and the total efficiency is from 45% to 60 % within the Wi-Fi or Bluetooth band of 2.4-2.48 GHz, which is sufficient for Wi-Fi or Bluetooth applications.

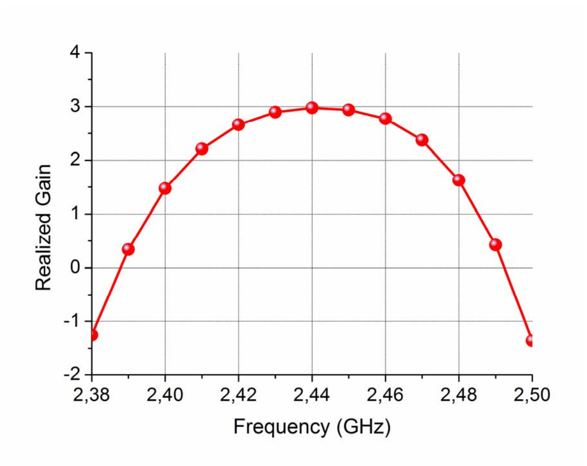
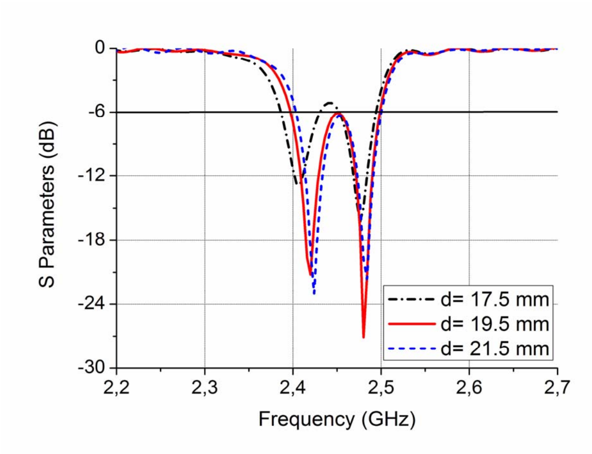
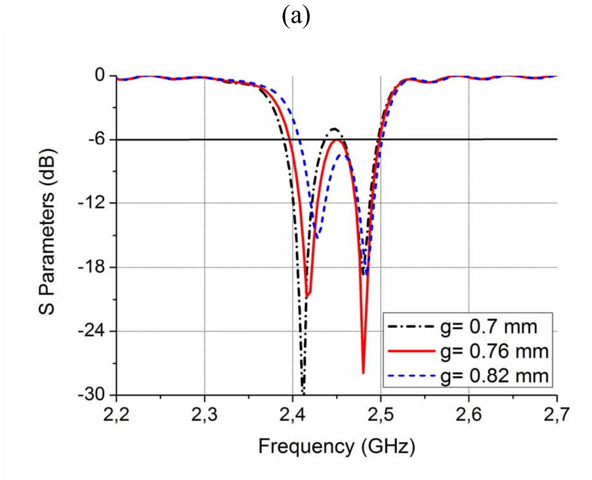


Figure 5. Realized gain of the proposed low-profile circular patch ring antenna.



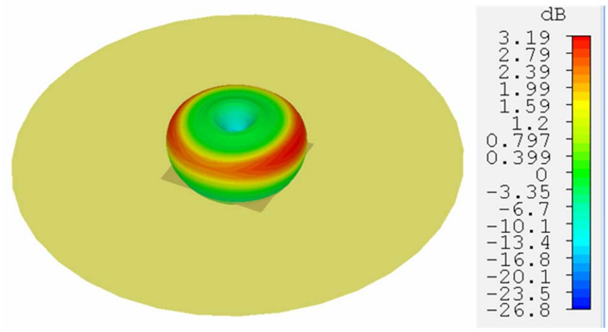
(a)



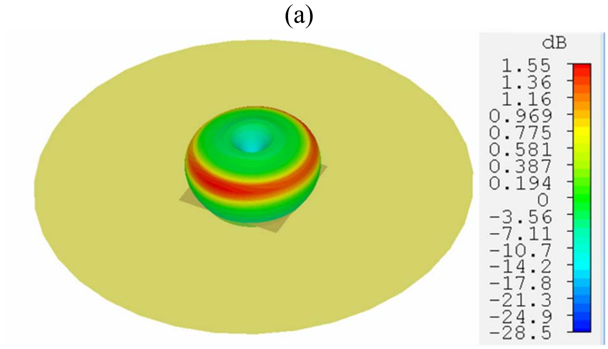
(b)

Figure 6. Parametric studies of: (a) distance of d, and (b) gap of g.

To facilitate the application of the designed antenna, parametric studies of distance d and gap g have been carried out and shown in Figure 6 (a) and Figure 6 (b), respectively. By changing the distance d, the impedance matching of both TM_{31} mode and TM_{32} mode can be adjusted, while the gap g mainly affects the location and impedance matching of TM_{31} mode.



(a)



(b)

Figure 7. Radiation gain patterns of the designed antenna on a large ground plane at: (a) 2.42 GHz, and (b) 2.48 GHz.

To investigate the antenna performance on large metallic surface, the radiation gain patterns of the designed antenna on a large ground plane with the diameter of 600 mm at 2.42 GHz and 2.48 GHz are provided in Figure 7. Similar to Figure 4, omnidirectional radiation patterns can be observed clearly on the large ground plane, where the maximum realized gain slightly stronger than those in Figure 4.

2 CONCLUSIONS

In this paper, a circular patch-ring antenna with extremely low profile and omnidirectional radiation patterns has been introduced. By utilizing a shorting via, TM_{31} mode and TM_{32} mode have been excited efficiently to achieve a dual resonance behavior. The designed antenna has covered the band of 2.4-2.5 GHz with the thickness of 0.005 λ. The realized gain within the Wi-Fi band is over 1.5 dBi. The sensitivity of antenna performance to a large ground plane has been investigated, where the performance is nearly unchanged.

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