Compact Double-ring Slot Antenna with Ring-fed for Multiband Applications

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Abstract

An enhanced double-ring slot antenna with ring-fed coupling for multiband applications is presented in this paper. Proposed two concentric slot rings to determine the certain resonated frequencies 4.92~5.84 GHz (17.10%) of desired broadband responses and the inner circular disk with the ring-fed coupling depicts the range 1.78~1.96 GHz (9.63%) and 2.25~2.63 GHz (15.57%) of resonant spectrum. It is a compact and available microstrip antenna for the DCS bands and IEEE 802.11a/b WLAN's applications. Simulation and experimental results with frequency responses and radiation patterns are presented and discussed.

1. INTRODUCTION

The applications for dual-band operations in the 2.4 GHz (2.4~2.484 GHz) and 5 GHz (5.15~5.95 GHz) bands are developed rapidly in wireless communications. In practice, IEEE802.11b is one of WLAN with frequency band from 2.4 to 2.484 GHz for the ISM band. Bands of IEEE802.11a are from 5.15~5.35 GHz, and 5.725~5.825 GHz. The HiperLAN2 is developed with frequency bands in 5.15~5.35 GHz, 5.47~5.725 GHz and 5.725~5.925 GHz. The U-NII band covers the frequency band of 5.725~5.825 GHz. Besides the individual approaches among 2.4 GHz and 5 GHz, the requirements of dual-band antenna are necessary for applications [3-6].

Using the printed circuit technique, the microstrip antenna has been proven to be an efficient and effective antenna. Owing to the advantages of easy for reproduction, low profile, lightweight, conformal to the surface of objects and efficiency of the elements, it has the wide applications in wireless communications. Physically, patch such as square, rectangle, ring, disk, triangle, elliptic, pentagonal and kite-like, etc. have been developed. In contrast to patch antenna, the antenna with slot configurations exhibits improved characteristics including wider bandwidth, less conductor loss and better isolation [7]. Especially, the double-ring structure is a versatile approach for dual-band design [8], and T-couple feed line based on the line-to-ring techniques for the circular disk is available [9]. In addition, many new multiband designs based on PIFA concepts for quad-band operation covering the GSM, DCS, PCS, UMTS and ISM bands has been implemented generally [10-13]. However, a PIFA antenna covering GSM, DSC, ISM, and WLAN are also developed recently [14].

A novel design of enhanced double-ring slot antenna with ring-fed coupling for multi-band applications is presented in this paper. For analytical approach, proposed two concentric rings determine the certain resonated frequencies of the desired broadband responses (4.92~5.84 GHz, 17.10%) and the inner circular disk with the coupling ring-fed depicts the range of 1.78~1.96 GHz (9.63%) and 2.25~2.63 GHz (15.57%). By designing a microstrip ring with feeding strip (ring-fed coupling) to couple the inner circular disk and double-ring slot respectively, therefore, it can enhance the response of the bands with impedance matching techniques simultaneously. It is an available and compact microstrip antenna for the DSC bands and IEEE 802.11a/b WLAN's applications. Both of simulated and experimental results with frequency responses and radiation patterns are presented and discussed.

2. ANTENNA CONFIGURATIONS AND OPERATIONS

A. Dual-band Operations

a. Double-ring slot configuration

For a single ring, when the mean circumference of the ring is equal to an integral multiple of the guided wavelength, the resonance is established and expressed as [1]:

$$\ell = 2\pi r_0 = n\lambda_g, \quad \text{for n=1, 2, 3 . . .} \tag{1}$$

where ℓ is the mean circumference of the ring, λ_g is the guided wavelength. The guided wavelength is related to the effective dielectric constant as:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}, \tag{2}$$

where λ_0 is the wavelength in free space, ε_{eff}' is the effective dielectric constant. Thus, the resonant frequencies can be represented as :

$$f_n = \frac{n\,c}{\ell\sqrt{\varepsilon_{eff}'}} \text{, for mode n=1, 2, 3 . . .} \quad (3)$$

where c is the speed of light.

For the double-ring structure [8-10], in Fig. 1(a), the inner ring related to the smaller ring ($\ell_1 = 2\pi r_1$) represents the upper resonant frequencies, and the outer ring related to the larger ring ($\ell_2 = 2\pi r_2$) decides the lower resonant frequencies. Thus, these two resonated frequencies with respect to the rings can be applied to determine the dual frequencies of the desired band.

b. Circular patch configuration

When the diameter of a typical circular disk with TM_{mn0} mode is related to an integral multiple of electric and magnetic field, the resonance is established by [2]:

$$f_{mn0} = \frac{c}{\pi D}\chi'_{mn}, \quad \text{for} \quad \text{m=0, 1, 2… and} \quad \text{n=1, 2, 3…} \quad (4)$$

where c is the speed of the light in the free space, D is the actual diameter of circular disk, χ'_{mn} is the zeros of the derivative of the Bessel function. For the circular disk patch shown in Fig. 1(a), there is a modification among the actual diameter D and the effective diameter D_e:

$$D_e = D\left\{1 + \frac{4h}{\pi D \varepsilon_{eff}''}\left[\ln\left(\frac{\pi D}{4h}\right) + 1.7726\right]\right\}^{\frac{1}{2}} \quad (5)$$

where h is the thickness of substrate, ε_{eff}'' is the effective dielectric constant. Thus, the zero-order resonant frequency can be represented as:

$$f_{110} = \frac{1.8412c}{\pi D_e\sqrt{\varepsilon_{eff}''}} \quad (6)$$

B. Ring-fed coupling and impedance matching technique

Generally, the bandwidth of an antenna depends upon the impedance matching condition at the coupling strip. Based on the line-to-ring techniques, an enhanced ring-strip coupling for the circular patch is proposed here shown in Fig. 1(b). The enhanced technique designated as ring-fed coupling here, which consists of a feeding strip and a microstrip ring. Firstly, the radius and strip width of the microstrip ring is $\boldsymbol{r_0}$ *mm* and $\boldsymbol{S_0}$ *mm*. By tuning the microstrip ring, the impedance matching and bandwidth response of the double-ring slot is improved. In addition, according to the quarter-wavelength transformer technique, the length and width of the feeding strip are determined with $\boldsymbol{t_1}$ *mm* and $\boldsymbol{w_1}$ *mm*. Similarly, tuning the feeding strip, the matching and bandwidth of the circular disk is achieved. This is a simple way to improve the bandwidth of antenna.

3. Simulated and Experimental Results

The FR4 substrate with dielectric constant ε_r = 4.4 and thickness h = 1.6 mm is used. A 50Ω coaxial probe directly feeds the driven element with an SMA connector. The double-ring slot antenna is designed with the circular disk $\boldsymbol{D_e}$ =34 *mm* and the ground plane $\boldsymbol{W^2}$ =50 cm^2. For the double-ring slot, the inner ring $\boldsymbol{r_1}$ = 17.75 *mm* and the outer ring $\boldsymbol{r_2}$ = 22.25 *mm*, constructed with the ring width $\boldsymbol{S_2}$ = 1.5*mm* and the ring spacing $\boldsymbol{S_1}$ = 3 *mm*. For the microstrip ring, the radius $\boldsymbol{r_0}$ = 17.075 *mm* and the width $\boldsymbol{S_0}$ = 0.3 *mm*. Meanwhile, the dimension of feeding strip $\boldsymbol{t_1}$ =21.5 *mm* and $\boldsymbol{w_1}$ =3 *mm*., then a good matching condition is achieved. To analyze the resonant frequencies, the S_{11} spectrums, two cut patterns, and the contour distribution patterns are measured and discussed. In addition, with the aid of HFSS tool, the simulated results are also presented and analyzed.

A. S_{11} Spectrums

The S_{11} spectrums of the proposed antenna are measured and simulated in Fig. 2. It is evident that the simulated and measured results of the frequency responses are in agreement. In measurement, while the return loss is smaller than -10 dB, the frequency spectrum presents multiband responses which band-I is from 1.78 to 1.96 GHz with 180 MHz (9.63%) and from 2.25 to 2.63 GHz with 380 MHz (15.57%) shown in Fig. 2(a), and band-II is from 4.92 to 5.84 GHz with 920 MHz (17.10%) shown in Fig. 2(b). For applications, the frequency responses are covered in the operation bands of the DCS band, IEEE802.11a/b and the U-NII band.

B. Radiation Patterns

In field analyses, the radiation patterns were obtained by the NFH0003 near-field scanner test system in an anechoic chamber. Figure 3 illustrates field coordinates, in which the double-ring slot antenna is located on the x-y plane, and the radiation direction is pointed to the z-direction. That is, the feeding line is located along the x-axis and points in the direction of ϕ = 0°. When θ varies from 0° to 360°, the x-z cut in the x-z plane is obtained. Similarly, in the direction of ϕ = 90°, the y-z cut in the y-z plane is obtained.

The normalized two-cut patterns with four resonant frequencies are represented in Fig. 4. Good broadside patterns are observed at 1.83 and 2.42 GHz, and butterfly-like patterns are obtained at 5.41 and 5.74 GHz in the x-z cut, and quasi-omnidirectional patterns are obtained at the four resonant frequencies in the y-z cut. Correspondingly, the simulation results are also illustrated in Fig. 5 at 1.83, 2.42, 5.41 and 5.74 GHz. Obviously, both simulations and measurements agree well with the radiation characteristics.

Meanwhile, Figure 6 depicts the contour distribution patterns with four resonant frequencies. Clearly, distribution pattern is symmetrical on the x-axis and the maximum radiation has a tilte in the x-direction. In addition, the antenna gain is tabulated as TABLE 1.

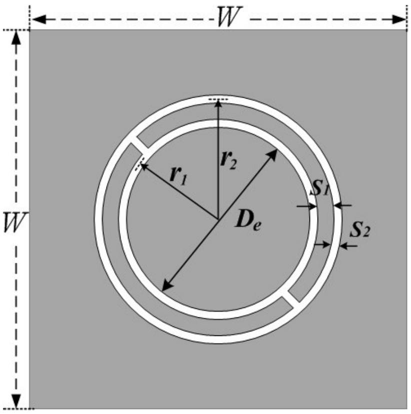
4. Conclusion

The double-ring slot microstrip antenna with mode-coupling ring has been designed, analyzed and measured in this paper. The structure is smaller in size and easy to fabricate. Its operations simultaneously cover the multiband of 1.78~1.96 GHz (9.63%), 2.25~2.63 GHz (15.57%) and 4.92~5.84 GHz (17.10%) for the return loss less than -10dB. Both simulation and measurement results agree with the verified frequency responses and radiation characteristics.

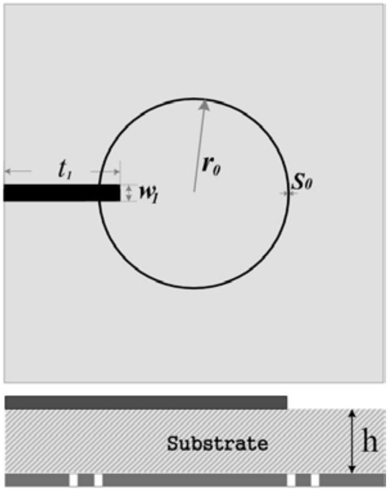
In field analysis, two-cut patterns with broadside pattern at 1.83 and 2.42 GHz, and butterfly-like patterns at 5.41 and 5.74 GHz are presented in the x-z cut. Its coupling way is constructed in coplanar and efficient. In applications, it can be applied to the DCS bands, the IEEE 802.11a/b systems and the U-NII bands.

TABLE 1: Antenna gain

Frequency（GHz）	1.83	2.42	5.41	5.74
Maximum Gain（dBi）	5.2	5.0	7.2	7.8
Average Gain（dBi）	-4.5	-4.9	-7.2	-6.7

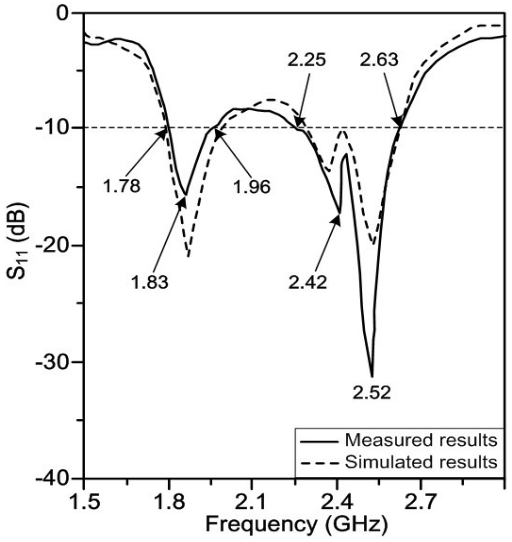


(a) Double-ring slot

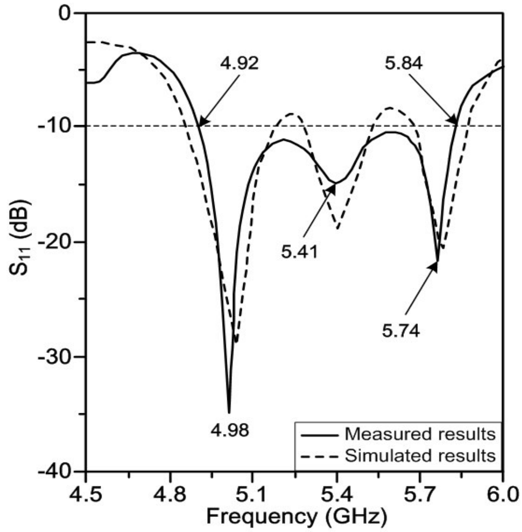


(b) Coupling ring-fed

Fig. 1: Antenna Configuration



(a) Band-I



(b) Band-II

Fig. 2: S_{11} Spectrums

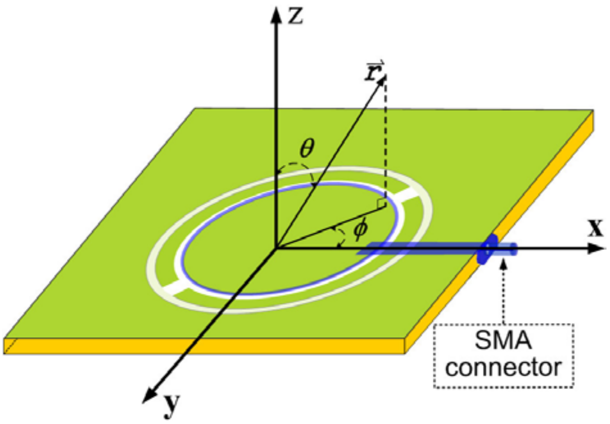
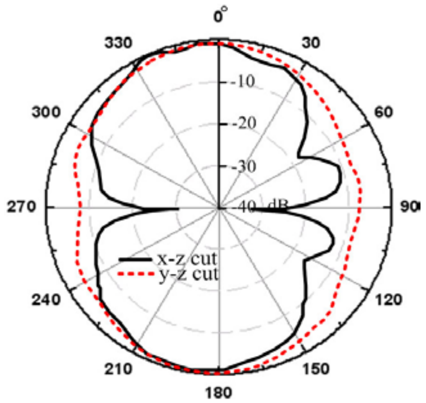
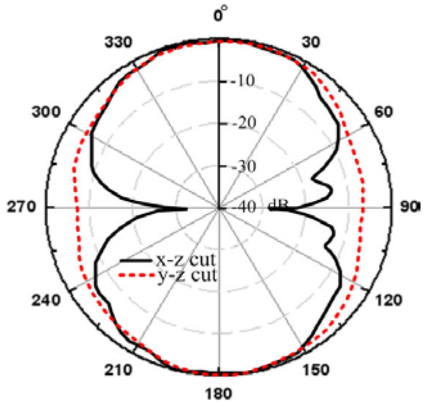


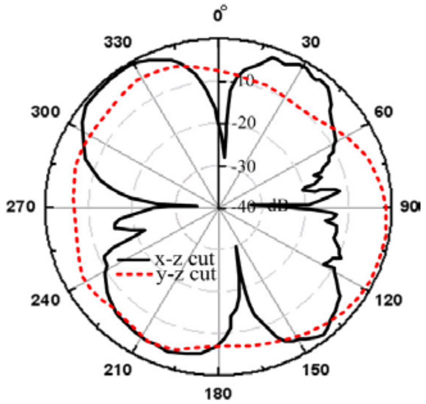
Fig. 3: Measurement System



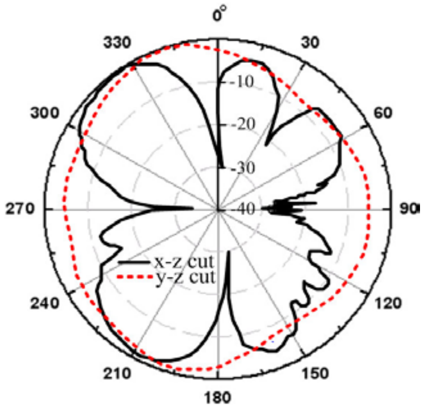
(a) 1.83 GHz



(b) 2.42 GHz

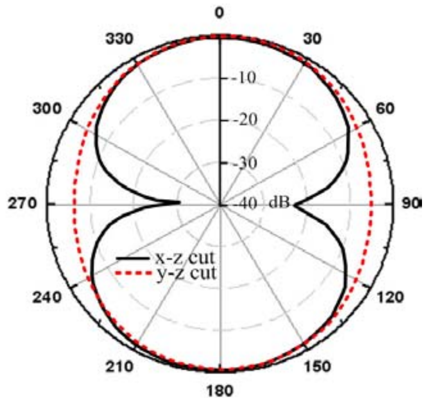


(c) 5.41 GHz

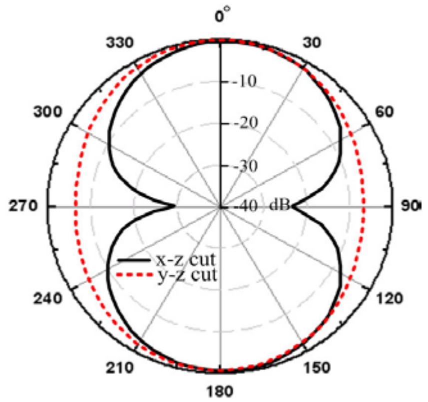


(d) 5.74 GHz

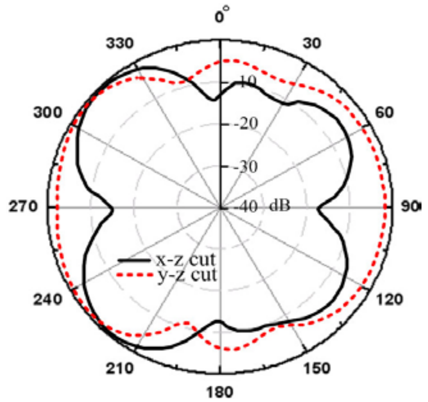
Fig. 4: Experimental results for radiation pattern



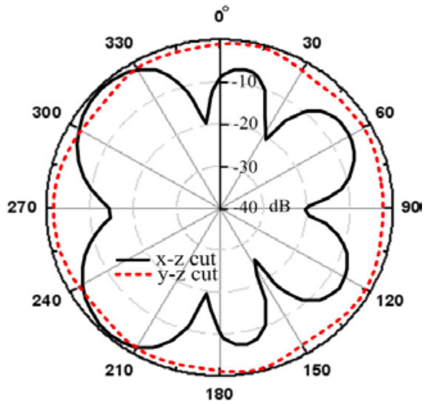
(a) 1.83 GHz



(b) 2.42 GHz

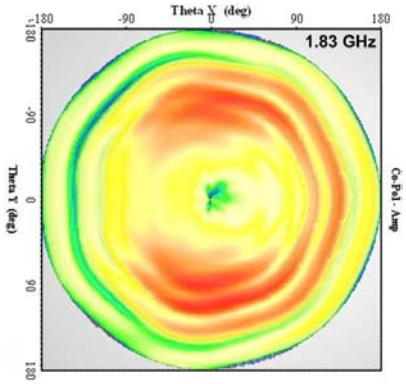


(c) 5.41 GHz

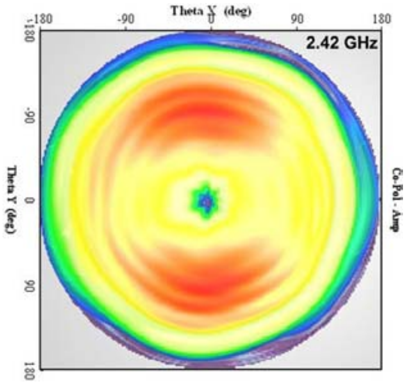


(d) 5.74 GHz

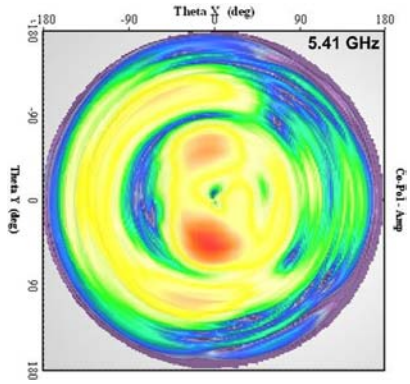
Fig. 5: Simulated results for radiation pattern



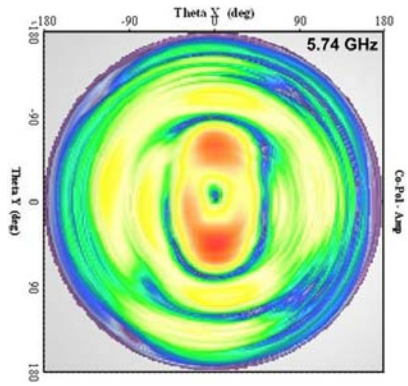
(a) 1.83 GHz



(b) 2.42 GHz



(c) 5.41 GHz



(c) 5.74 GHz

Fig. 6: Experimental results for contour distribution patterns

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