Compact Filtering Monopole Antennas Based on the Miniaturised Coupled Filter

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***Abstract*— In this paper, two co-designed linear and circular polarized compact filtering monopole antennas based on the recently developed miniaturized coupled filter, namely the two-stage split ring resonator (SRR)-inspired high-frequency-selective filter, are proposed and demonstrated. The used filter is consisting of two groups of twist-modified SRRs and is inserted in the feeding line of the conventional wide band planar monopole antennas to filter out the unwanted out-of-band antenna gain. The measured results show that such filtering antennas have sharp dropped out-of-band radiation gain feature. These filtering antennas is suitable for the Internet of Things devices application.**

Keywords—filtering antenna; monopole antenna; modified SRR; high-freqeuncy-selectivity

I. Introduction

Recently, there is a highly motivation for combining more than one function components/circuits into one device to minimize the component size and improve the overall performances of wireless communication systems [1]. Specifically, antennas and filters are commonly the two basic components of RF front-end and conventionally such two components are designed separately [2]. In such a case, the overall performances of the system will be degraded when connecting directly these two components together. Meanwhile, the two separated components will occupy quite large place in limited space of the developed portable wireless communication terminators. To solve this problem, recently, researchers have proposed a kind of co-designed filtering antenna, which possesses the functions of both antenna and filter, and has compact dimensional size [3–5]. Moreover, by integrating filter units into the conventional circularly polarized (CP) antenna, researchers developed the co-designed CP filtering antennas, such as the microstrip antenna with coupled stripline open-loop resonators [6, 7] and the dielectric resonator antenna with quadrature coupler based on the snowflake-shaped patch [8]. Most of the proposed filtering antennas, however, still suffered from the large size, poor frequency selectivity, low gain or narrow bandwidth.

In this paper, we propose two easy-to-design, low-profile and low-cost linearly polarized (LP) and CP filtering antennas based on the monopole and the bent-loop-resonator coupled filter. Such filter unit with high-frequency selective performance is integrated directly into the microstrip feed line without the side-effects on the radiation pattern of the original monopoles. The designed LP and CP filtering antenna are demonstrated by both numerical simulation and experimental verification, and good agreements are obtained.

II. Filtering LP Monopole Antenna

A schematic diagram of the proposed filtering antenna is firstly presented in Fig. 1(a). It consists of the conventional planar printed monopole antenna with rectangular radiation patch and gradient ground plane, and the compact filter unit based on the twist- modified spring-ring resonators which is inserted into the feeding line of the antenna. Due to the highly compact size of the resonators, such design does not need to add more space for the integrated filter unit. The details of the filter unit can be found in Fig. 1(b). Here the filtering antenna is assumed to work around 2.4 GHz, so both the conventional antenna and filter should have a working bandwidth located at such frequency band. The 0.8-mm Rogers Ro4003 dielectric substrate (ε_r = 3.55, tanδ =0.0027) is used here for fabrications of the filtering antenna. After careful optimizations by HFSS, the structural parameters of the finalized filtering antenna are obtained, as presented in Table 1. The fabricated filtering antenna sample can be found in Fig. 1(c).

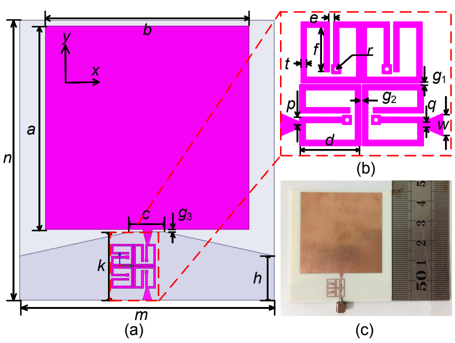

Fig. 1 Schematic diagram of the LP filtering antenna.

TABLE I. Optimized structural parameters of the LP filtering antenna (unit: mm).

a	*b*	*c*	*d*	*e*	*f*	g_1	g_2	g_3
40	40	6.7	4.325	0.4	3.125	0.1	0.05	0.5
h	*k*	*m*	*n*	*p*	*q*	*r*	*t*	*w*
8.7	13.4	50	55	0.4	0.4	0.15	0.4	1.76

The co-designed filtering antenna are demonstrated. The simulated and measured reflection for the filtering antenna with the optimized dimensional parameters concluded in Table 1 are shown in Fig. 2(a). It can be seen that the filtering antenna has working bandwidth (measured bandwidth is about 0.3 GHz centered at 2.4 GHz). The simulated and measured radiation gain total for both the conventional monopole antenna and the co-designed filtering antenna is concluded in Fig. 2(b). The good agreements between simulations and measurements for both antennas are obtained. It clearly shows the filtering feature on the gain curves of the filtering antenna. The measured 3-dB gain bandwidth is about 0.4 GHz centered at 2.4 GHz. Meanwhile, the measured peak gain is about 2.4 dBi.

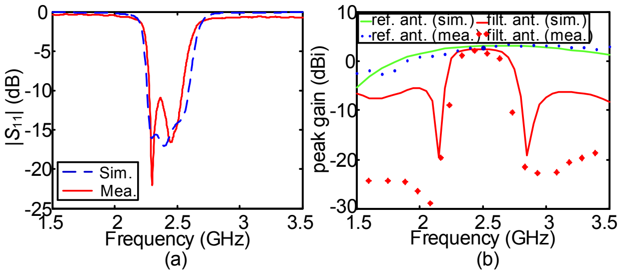

Fig. 2 Demonstrations of the LP filtering antenna.

Moreover, the far-field radiation patterns for the co-designed filtering antenna at 2.4 GHz are measured in the Satimo StarLab field measurement system and the results are presented in Fig. 3. The simulated and measured results are agreed with each other very well. The measured E-plane and H- plane co-polarizations indicate the typical "8" shaped radiation and omnidirectional radiation, respectively. The measured cross-polarizations for the E-plane and H-plane are slightly worse than the corresponding simulations due to the measurement errors, but still smaller than -20 dB.

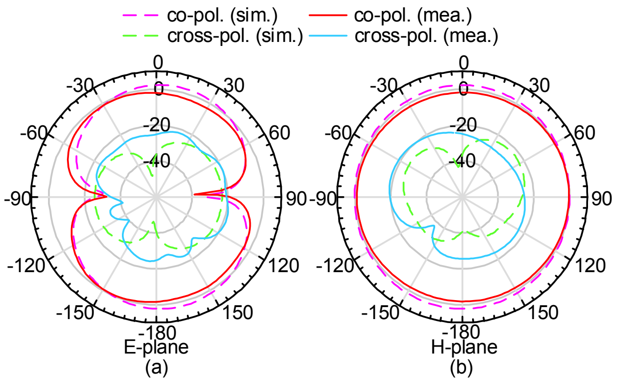

Fig. 3 Radiation patterns of the LP filtering antenna.

III. FILTERING CP MONOPOLE ANTENNA

The proposed CP filtering antenna is schematically shown in Fig. 4(a). As can be seen, the falcate-shaped monopole which is used to achieve the CP radiation is composed of a main metallic circular patch with radius R and centered at (x_R, y_R) and subtracted by a second circular patch with radius r and centered at (x_r, y_r). The CP monopole is fed by the microstrip line and, therefore, the ground plane is placed at the backside of the 0.8-mm dielectric substrate (Rogers Ro4003). The compact and high frequency-selectivity filter unit is integrated into the feed line. The parameter definitions for the filter can be found in Fig. 1(b). For the co-optimizations of the proposed CP filtering antenna, the key parameters, e.g. g_1, g_2 are used to determine the passband performance of the filter [9], and the positions of the two circular patches of the monopole are used to decide the axial ration. As an example, the proposed CP filtering antenna is worked at 2.45 GHz which is the standard industrial scientific medical band. Finally, such antenna is co-optimized by finite-element method-based software (HFSS) to achieve the good CP performance and the good frequency selectivity. The obtained structural parameters are concluded in Table 2. One fabricated antenna sample based on the optimized parameters is shown in the inset of Fig. 4(b).

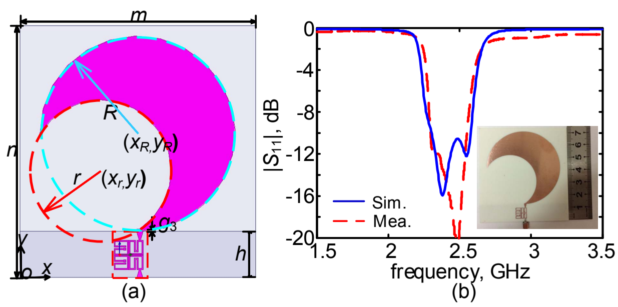

Fig. 4 (a) Schematic diagram of the CP filtering antenna, (b) return loss

TABLE II. OPTIMIZED STRUCTURAL PARAMETERS OF THE CP FILTERING ANTENNA (UNIT: MM).

m	n	R	r	x_R	y_R	x_r	y_r	g_3	h
70	75	29	21	34.9	42.96	23.9	31.96	0.2	13.8
e	f	t	R_0	p	d	g_1	g_2	q	w
0.4	3.13	0.4	0.15	0.9	4.33	0.08	0.08	0.7	1.76

The port reflection of the co-designed and co-optimized CP filtering antenna is experimentally demonstrated as shown in Fig. 4(b). The far-field radiation peak gain and the axial ratio at the peak gain direction are measured at different frequency points ranged from 1.5 to 3.5 GHz in the Satimo StarLab measurement system, and the results are concluded in Fig. 5. The corresponding numerical simulation results for the port return loss, far-field radiation peak gain and axial ratio at the peak gain direction are shown in Figs. 4 and 5 as well for the comparisons. It can be known that all the simulations and

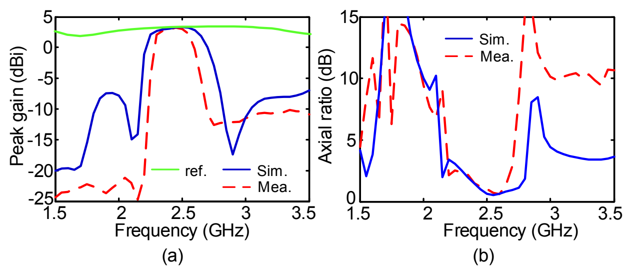

Fig. 5 Demonstrations of the CP filtering antenna.

measurements are consistent. Specifically, the measured port return loss is larger than 10 dB in the frequency range from 2.32 to 2.55 GHz, and the measured 3-dB gain bandwidth and 3-dB axial ratio bandwidth are 0.3 and 0.5 GHz, respectively. Two nulls located at 2.15 and 2.75 GHz are found for both the gain and axial ratio curves, which indicate the good frequency selective performances.

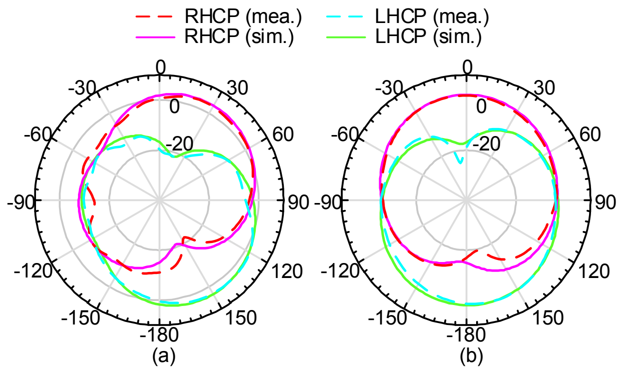

Fig. 6 Radiation patterns of the CP filtering antenna.

Moreover, the simulated and measured left-handed circularly polarized (LHCP) and right-handed circularly polarized (RHCP) far field radiation patterns at yoz and xoz planes are shown in Fig. 6. The corresponding simulations are plotted in such figure as well. It is seen that the measurement and simulation results are in agreement very well. It indicates that the proposed antenna radiates RHCP in the +z-direction and LHCP in the −z-direction. This is to be expected since CP monopole is known to generate bidirectional radiation patterns. The peak gain direction is located around 30° offset from the +z direction.

IV. Conclusions

We have derived the easy-to-design, low-profile and low-cost LP and CP filtering antennas based on the bent-loop-resonator coupled filter. Compared with previously reported LP and CP filtering antennas, the presented antennas had comparable radiation performances and good frequency selective performances for the return loss, gain and axial ratio. It has very important potential applications for the active RFID readers, wireless sensors, wearable devices and other Internet of Things devices.

Acknowledgment

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