A Novel Circularly Polarized Filtering Antenna with High Out-of-band Radiation Rejection Level

Meijun Qu[1,a)], Mingxing Li[2], Lidan Yao[2], Menlou Rao[3], Shufang Li[1,b)], Li Deng[1]

[1]School of Information and Communication Engineering, Beijing Key Laboratory of Network System Architecture and Convergence, Beijing University of Posts and Telecommunications, P. O. Box. 171, Beijing, 100876, China.

[2]School of Electronic Engineering, Beijing Key Laboratory of Work Safety Intelligent Monitoring, Beijing University of Posts and Telecommunications, P. O. Box. 282, Beijing, 100876, China.

[3]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, USA.

Abstract: *In this paper, a circularly polarized filtering antenna with high out-of-band radiation rejection level is proposed. The entire design consists of a patch and a filtering feeding network, which are connected by metallic pins. Firstly, a high-selectivity filtering power divider is constructed utilizing two shunted bandpass filter. Next, a 90° phase difference could be realized by adjusting the length of the two outputs of the power divider. The measured transmission coefficient of the feeding network is 6.3 dB at 2 GHz. The measured axial ratio is below 3 dB within the operating band of the proposed antenna, which represents the effectiveness of the proposed feeding network. In addition, the obvious radiation nulls can be found from the antenna measurement because of the transmission zeros introducing by the filtering power divider. The measured gain is 5.73dB at 2GHz and decreases dramatically in stopband. Specially, the measured gain is -30 and -41 dB at 1.95 and 2.06 GHz. The proposed antenna has an excellent filtering characteristic compared with those without the filtering feeding network. To sum up, the proposed antenna and filtering power divider are promising in the modern wireless communication systems.*

Key words: *Circularly polarized antenna, bandpass filter, feeding network, filtering response, radiation null.*

[a]qumeijun@bupt.edu.cn.
[b]bupt_paper@126.com.

I. Introduction

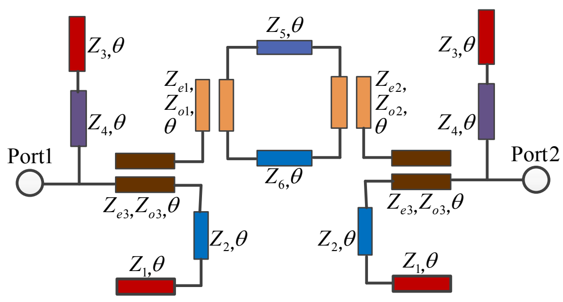
Filters and antennas are two indispensable components in RF front-end. Traditionally, they are designed separately and then are cascaded into the system. The input ports are assumed to be ideal 50 Ohm interface in the designing of filters and antennas individually, which are not accurate in practical and leading a deteriorated performance. Recently, the integration of bandpass filter and antenna into a subsystem has drawn increasing attentions. The match circuit is greatly simplified compared with the traditional cascaded design while the insertion loss caused by filter is decreased. The common method to obtain the filtering antenna is using the antenna radiator as the last-stage resonator of the filter [1-3]. Whereas, implementing multiple resonators increases the size of the design and the gain of this kind of filtering antenna is relatively low.

There are many approaches [4-8] reported to realize filtering antennas, featuring filter-like frequency response both for return loss and antenna gain, nowadays. In [4], a second order bandpass filter with microstrip patch antenna is coupled by a rectangular aperture. Thus, a sharp transit is achieved from out-band to in-band at both sides of the operating frequency band. The multistub microstrip line is adopted to excite two separate U-shaped patches at different frequencies [5]. The multistub feed line can generate two controllable resonant modes as well as two nulls in realized gain at boresight direction. In [6], modified metasurface is introduced to generate a radiation null near the upper band edge. A shorting via is embedded in the feeding circuit to provide another radiation null at the lower band edge. However, the aforementioned references are about the designing of the linearly polarized antenna. In [7], a nearly square patch radiator with truncated corners is excited by a bandpass filter circuit through a metallic pin. The feeding position of the pin on the patch is offset from the center in order to obtain low circularly polarized axial ratio [8]. To obtain a filtering circularly polarized antenna, a filtering quadrature coupler is adopted to excite a hollow dielectric resonator antenna.

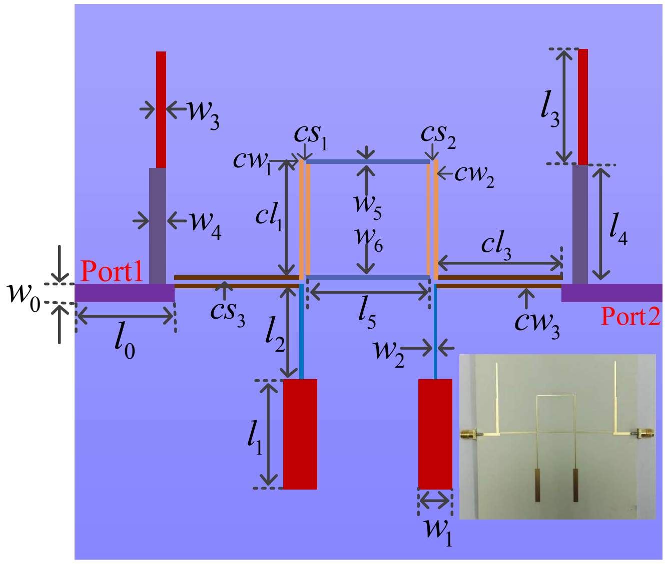
In this paper, a right-handed circularly polarized antenna implanting the filtering response is proposed. A bandpass filter and power divider are designed in section II. The proposed filtering power divider offers several advantages, including high selectivity, low insertion loss, wide stopband suppression and excellent in-band isolation. The filtering circularly polarized antenna is presented in section III. By adjusting the lengths of the two outputs of the proposed filtering power divider, 90° phase difference of the feeding network is realized. Therefore, the circularly polarized wave is excited by feeding network to the patch antenna. Due to the transmission zeros of the filtering power divider, the obvious radiation nulls can be found. Hence, a high out-of-band radiation rejection level of the proposed antenna is achieved. From the measured results, a gain of 5.35 dB at 2 GHz is obtained while the gain decreases dramatically in stopband.

II. Bandpass Filter and Filtering Power Divider Design

A. Bandpass Filter Loaded with Open Stubs Based on Dual-band Resonator



(a)



(b)

FIG. 1. The circuit structure (a) and layout (b) of the proposed bandpass filter with physical-size definition.

The circuit structure and layout of the proposed bandpass filter (BPF) are illustrated in Figure 1 (a-b). The proposed BPF is based on a quarter-wavelength side-coupled ring resonator (Z_{e1}, Z_{o1}, θ and Z_{e2}, Z_{o2}, θ), which can be seen from Figure 1(a). The input/output Ports1, 2 are connected the ring resonator by a coupled line (Z_{e3}, Z_{o3},

θ) which links stepped impedance transform elements (Z_1, Z_2). Two stepped open stubs (Z_3, Z_4) are shunted connected in the input/output Ports1, 2 respectively. The characteristic impedances of the two microstrip lines at input/output ports are all Z_0 = 50 Ω and all the electric length θ is 90 degree. The introduction of the stepped impedance transform elements and open stubs are used to realize four additional transmission zeros near the passband. The four out-of-band transmission zeros can be adjusted by varying the impedances (Z_1, Z_2, Z_3, Z_4). A conventional uniform ring resonator is dual-mode [13-14] and can be adopted as the basic cell resonator for higher order bandpass filter applications therefore.

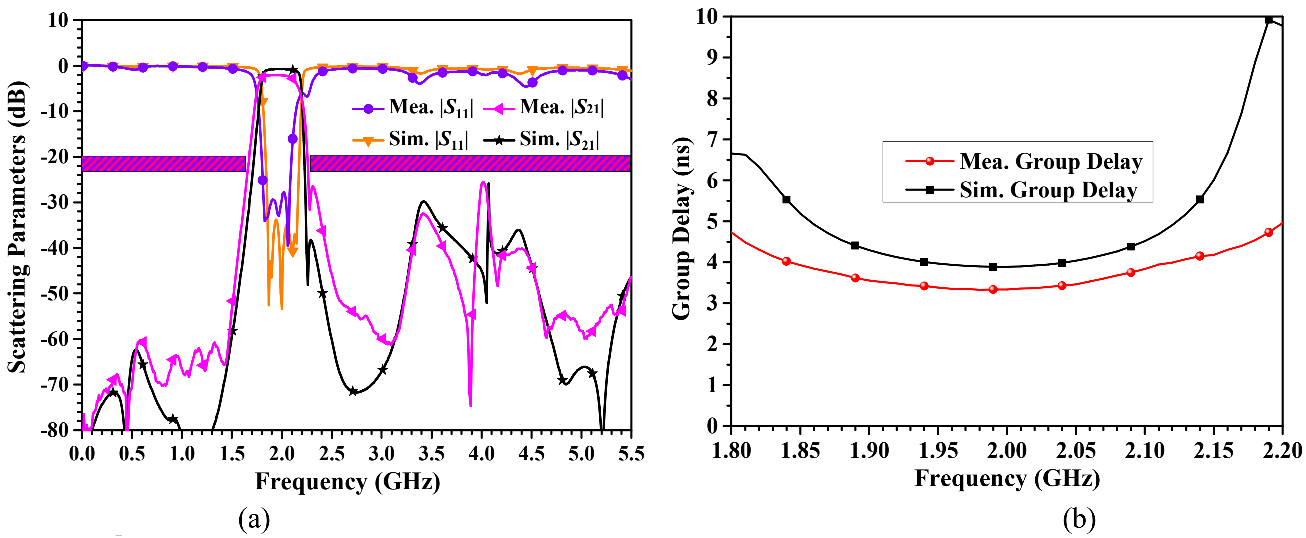


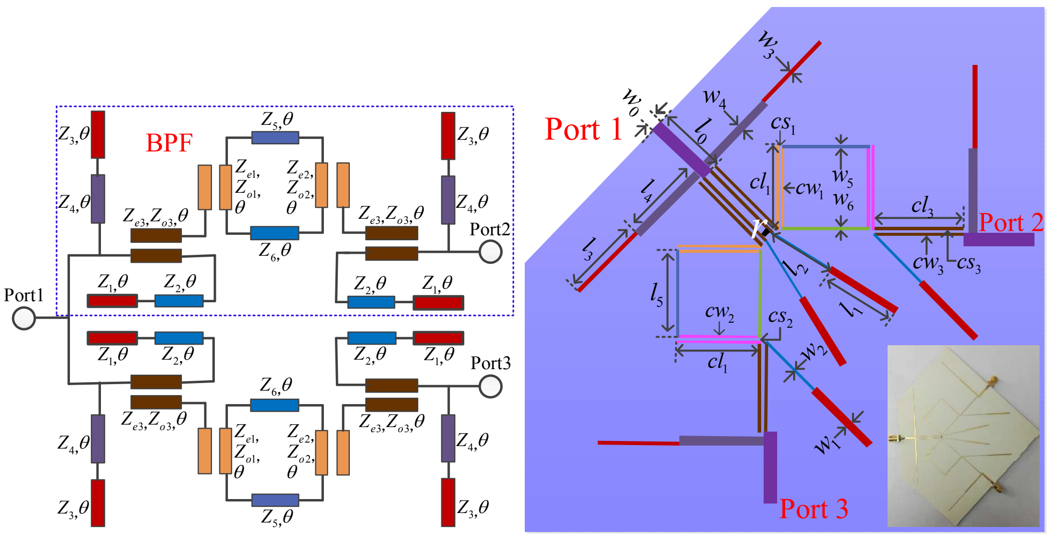
FIG. 2. The measured and simulated results of proposed BPF: (a) scattering parameters, (b) group delay.

A prototype of the BPF is fabricated on substrate of RO4350B with relative permittivity constant of 3.48, thickness of 30 mil and loss tangent of 0.0037. Figures 2(a) and (b) indicate the scattering parameters of the proposed BPF. It can be seen from the Figure 2(a) that the measured reflection coefficient below -10 dB over a bandwidth of 18.9% from 1.77 to 2.14 GHz while the insertion loss is close to 2 dB due to the error of fabrication and the connector. Obvious transmission zeros can be found in Figure 2(a), and the reflection coefficient below -20 dB is greater than the band which is from 0 to 1.67 GHz and 2.26 to 5.5 GHz, thus wide out-of-band suppression and high selectivity of the proposed BPF can be realized. The measured group delay of the proposed BPF from Figure 2(b) is below 5 ns within the frequency band from 1.8 to 2.2 GHz, and is 3.34 ns at 2 GHz. There is an excellent agreement between the simulated and measured results. The final optimized geometrical parameters of the proposed BPF are tabulated in TABLE I.

TABLE I. The geometrical parameters of the proposed BPF (Unit: mm).

Parameters	Values	Parameters	Values	Parameters	Values	Parameters	Values
w_0	1.66	l_0	15	w_1	2.83	l_1	21.64
w_2	0.27	l_2	23.4	w_3	0.915	l_3	22.67
w_4	1.42	l_4	22.3	w_5	0.36	l_5	23.42
w_6	0.25	cw_1	0.17	cs_1	0.48	cl_1	23.73
cw_2	0.17	cs_2	0.48	cw_3	0.14	cl_3	23.8
cs_3	0.465	/	/	/	/	/	/

B. Design of the Filtering Power Divider Based on the Proposed BPF



(a) (b)

FIG. 3. The circuit structure (a) and layout (b) of the proposed filtering power divider with physical-size definition.

Two BPFs can be integrated into a power divider to achieve improved frequency selectivity [15-16] and decrease the interference and noise hence. The proposed filtering power divider (FPD) shunts two aforementioned BPFs. Note that the characteristic impedances of the input (Port 1) and two outputs (Port 2, 3) are 50 Ω. The port impedance of the BPF should be viewed as 100 Ω because of the shunting connection. The circuit scheme and layout of the FPD are plotted in Figure 3 (a-b) while the design parameters are listed in TABLE II. An isolation resistor is add to improve the isolation of the two outputs of the FPD (r = 600 Ohm).

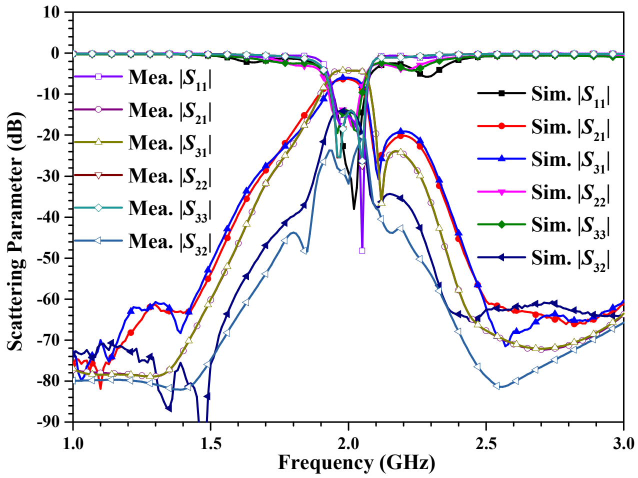
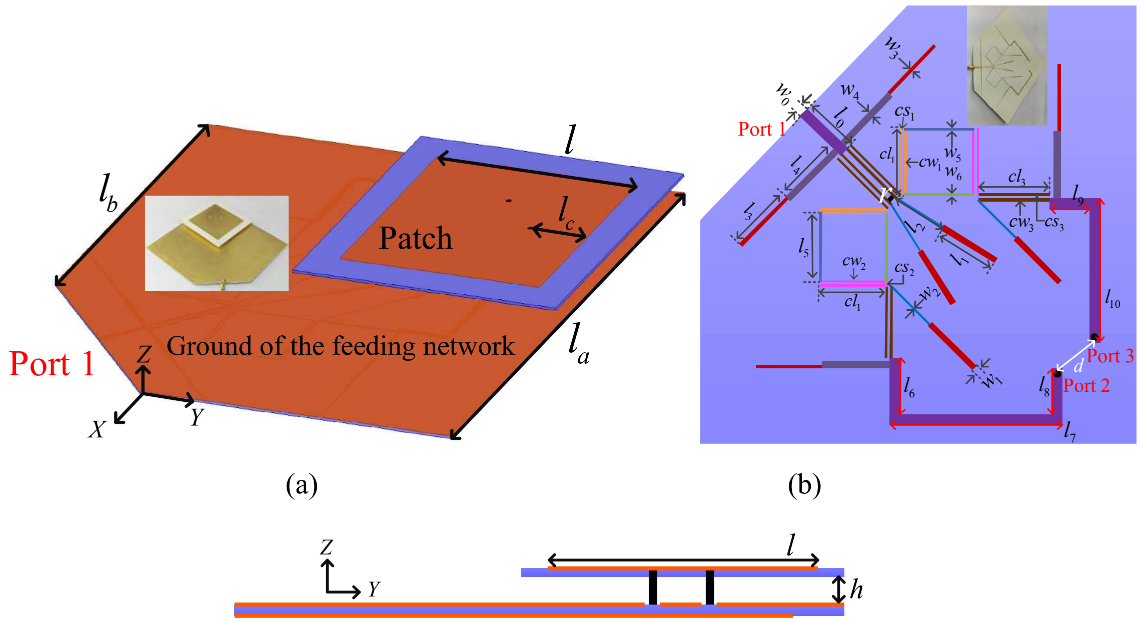


FIG. 4. The measured and simulated scattering parameters of proposed FPD.

To validate the effectiveness of the proposed FPD, a prototype is also manufactured on substrate of RO4350B. Figure 4 displays the measured and simulated scattering parameters of the proposed FPD. The measured results show that the proposed FPD is operating from 1.95 to 2.06 GHz. The measured transmission coefficient is 6.3 dB at 2 GHz, which represents that the proposed FPD has a low insertion loss relatively. Nevertheless, the insertion loss is increased dramatically out of the working band and sharp skirt selectivity is achieved. The measured stopband below -20 dB is greater than the band which is from 1 to 1.79 GHz and 2.09 to 3 GHz. The $|S_{21}|$ is -59 dB at 1.45 GHz and -62 dB at 2.56 GHz for instance. To enhance the isolation between two outputs, an isolation resistor (r) is added in proposed FPD. The measured in-band isolation is better than 14 dB ranged from 1.95 to 2.06 GHz, a relatively high isolation is obtained hence. Excellent agreement between the simulated and measured results is acquired. In addition, it can be expected that this power divider will be widely applied in the modern wireless communication systems.

III. Filtering Circularly Polarized Antenna Design

Figure 3 displays the 3-D geometry of the proposed filtering circularly polarized antenna (FCPA). It consists of the feeding network based on the proposed FPD in the bottom layer and a rectangular patch in the top layer. The feeding circuit excites the patch antenna with two metallic pins when the feeding position is properly adjusted. To achieve the circularly polarized wave, the lengths of the two outputs of the FPD are modified. The length of the Port 2 is longer than that of the Port 3, a quarter wavelength approximately, a 90° phase difference is realized between the two outputs of the feeding network. Note that the values of the parameters of feeding network are the same with those of the FPD, except the added variables l_6, l_7, l_8, l_9, and l_{10}. The final optimized geometrical parameters are listed in TABLE II.

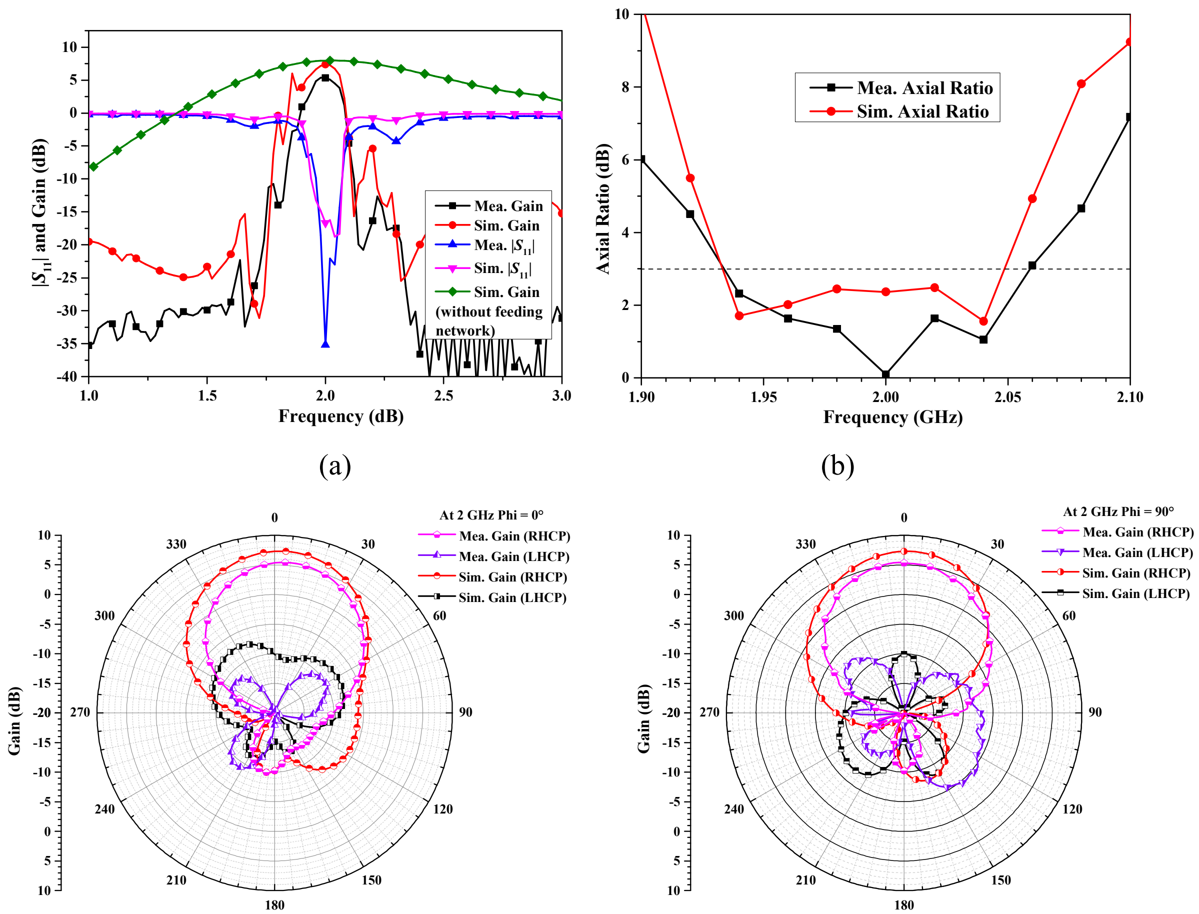


(a) (b)

(c)

FIG. 5. Schematic of the proposed FCPA: (a) 3-D view of the proposed FCPA, (b) layout of the feeding circuit in the proposed FCPA, and (c) lateral view of the proposed FCPA.

The proposed FCPA is fabricated and measured for demonstration. The substrates of the patch antenna and feeding circuit are both RO4350B. As seen from Figure 6, the 10-dB impedance bandwidth is from 1.96 to 2.07 GHz, agreeing reasonably with the simulated value (1.94 to 2.06 GHz). Thanks to the transmission zeros of the FPD, the obvious radiation nulls can be found in Figure 6(a). Hence, high out-of-band radiation rejection level is achieved. A measured gain of 5.34 dB at 2 GHz is obtained a little bit lower than the simulated value (7.36 dB). The gain decreases significantly in stopband. Specially, the measured gain is -30 and -41 dB at 1.95 and 2.06 GHz. There is an excellent filtering feature compared with antennas without the filtering feeding network. The measured axial ratio is below 3 dB within the operating band from the Figure 6(b). It also proves that the pure circularly polarized wave feeds the patch antenna by the proposed feeding circuit. The Figure 6(c-d) plot the 2-D radiation pattern of the proposed FCPA in *XOZ* and *YOZ* plane at 2 GHz. The gain of right-handed circularly polarization is much stronger than that of the left-handed circularly polarization. Thus, the proposed antenna is a filtering right-handed circularly polarized antenna. Changing the length of the two outputs of the feeding network, a left-handed circularly polarized antenna can also be obtained. It should be mentioned that the scattering parameters of the BPF, FPD and FCPA are measured by Vector Network Analyzer (Rohde & Schwarz ZVA-8), the gain of the FCPA is obtained in SATIMO measurement system in a microwave anechoic chamber.



(c) (d)

FIG. 6. The measured and simulated scattering parameters and gain (a) of the proposed FCPA, (b) axial ratio, (c-d) radiation pattern of the proposed FCPA in *XOZ* and *YOZ* planes at 2 GHz.

TABLE II. The geometrical parameters of the proposed FPD and FCPA (Unit: mm).

Parameters	Values	Parameters	Values	Parameters	Values	Parameters	Values
w_0	1.66	l_0	15	w_1	0.915	l_1	22.65
w_2	0.24	l_2	22.65	w_3	0.3	l_3	23.36
w_4	1.05	l_4	22.55	w_5	0.37	l_5	24
w_6	0.24	cw_1	0.26	cs_1	0.9	cl_1	23.44
cw_2	0.214	cs_2	0.72	cw_3	0.15	cl_3	23.76
cs_3	0.42	l_6	10.25	l_7	54.23	l_8	10.25
l_9	14.17	l_{10}	53.36	l	60.8	l_a	130
l_b	95	l_c	17.6	h	5	d	18

VI. Conclusions

In this paper, a right-handed circularly polarized antenna with the filtering feeding network is presented. To excite the circularly polarized wave, a filtering power divider based on a bandpass filter is designed first. By adjusting the lengths of the two outputs of the proposed filtering power divider, 90° phase difference is realized. The proposed filtering power divider offers several advantages, including high selectivity, low insertion loss, wide stopband suppression and excellent in-band isolation. Then, the feeding network is connected to the patch antenna by metallic pins. From the measured results, high out-of-band radiation rejection level is achieved. A measured gain of 5.34 dB at 2 GHz is obtained while the gain decreases dramatically in stopband. Specially, the gain is -30 and -41 dB at 1.95 and 2.06 GHz. There is an excellent filtering feature compared with antennas without the filtering feeding network. Therefore, this proposed FCPA is suitable in modern wireless communication systems to prevent the interference and noise.

Acknowledgments

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