Left Hand and Right Hand Circularly Polarized Antenna for 5G Devices

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Abstract. A novel wideband circularly polarized reconfigurable antenna for 5G devices is presented in this paper. Left hand and right-hand circular polarizations were achieved using the sequential phase rotation feeding network based on 90° hybrid coupler. The proposed antenna has a bandwidth (with AR $\leq$ 3 dB) of 24.8% and 4% for right hand circular polarization (RHCP) and left-hand circular polarization (LHCP) mode, respectively. At 3.75 GHz, the degree of circular polarization is 42° in LHCP mode and 51° in RHCP mode showing the potential of this proposed antenna for modern 5G terminal devices.

Keywords: 5G antenna · LHCP antenna · RHCP antenna · 90° hybrid · Circular polarization · Sequential phase rotation technique

1 Introduction

Nowadays, 5G is one key technology attracting many attentions of industrials and researchers over the world, especially after the finalization of the 3GPP release 15. However, when the 5G bandwidth is considering for commercial products, the wideband (3.3–4.2 GHz) antenna is required for 5G research and development phase in the laboratories. In telecommunication systems where the base station antenna requires the dual polarizations ±45°, from the terminated devices point of view, the circularly polarized (CP) antennas provide the low polarization loss factor over linearly polarized (LP) antennas. In recent years, CP antennas with the capability of switching polarization between RHCP and LHCPstates have increasingly been used in wireless communication systems [1–3] but these antennas have CP in a narrow band. In general, there are two reconfigurable polarization methods for CP antennas: reconfigurable radiating element and reconfigurable feeding network [3–7]. RF switches such as PIN diodes [4] and RF-MEMS [5], have been used to create an effective radiating structure for different polarization. The latter approach is the polarization reconfigurable antenna based on the switchable 90° phase shifter feeding into the radiation elements using RF switches shown in [6, 7] but the low efficiency of radiator element is a disadvantage of these works.

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This paper proposes a RHCP and LHCP antenna based on two 90° hybrid couplers and an array antenna at 5G band. Switching between RHCP and LHCP mode is conducted by adjusting the position of exciting port so PIN-diodes element is ignored to avoid the loss and non-linear effect. The proposed antenna has an outstanding bandwidth with 37% at both two modes with total dimensions of 85 × 85 × 40 mm^3. The 3dB AR bandwidths at RHCP and LHCP mode are 24.8% and 4%, respectively. A detailed antenna design is presented in Sect. 2. Section 3 is the conclusions.

2 5G LHCP and RHCP Antenna Design

2.1 Printed Dipole Antenna Element

The 5G ground-cut dipole element with "J"-balun is proposed in Fig. 1 but having wider bandwidth and higher gain than the dipole element in [8]. The high efficiency of the dipole antenna is the advantage so that this kind of element is chosen to design LHCP and RHCP antenna. "J"-balun consists of L_b and L_{ab} microstrip line, the perfect matching is achieved when $L_b = L_{ab} = \lambda/4$. The parameters of the proposed ground-cut printed dipole antenna element with "J"-balun are listed in Table 1:

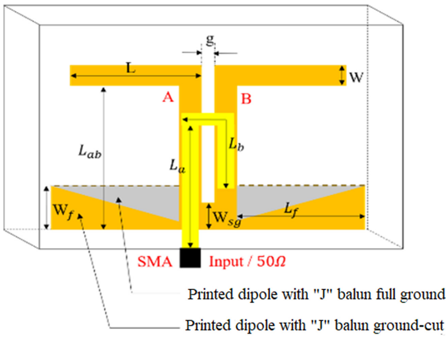


Fig. 1. The structure of ground-cut printed dipole with "J"-balun.

Table 1. Parameters of printed dipole with integrated "J" balun

Parameters	Values (mm)	Parameters	Values (mm)
L	15.5	W	2.5
L_S	14.5	W_g	8
L_g	20	g	0.9
L_a	12.92	W_{Sg}	2.5
L_b	12	W_a	1.85

The reflection coefficient of ground-cut and full ground dipole antennas is depicted in Fig. 2. The bandwidth (at S11 ≤ −10 dB) of full ground and ground-cut dipole antenna is from 3.6 GHz to 4 GHz and from 3.45 GHz to 4.14 GHz, respectively. The S11 of cutting ground dipole antenna is −39.5 dB at 3.75 GHz. The radiation pattern results are presented in Fig. 3 with the peak gain of 6.48 dBi and angular width (at −3dB) of 129.30° and the total radiation efficiency of 96.63% for full ground printed dipole antenna. The ground-cut dipole has the peak gain of 4.84 dBi, wider angular width (at −3dB) of 177.10° and the total radiation efficiency is 96.88%.

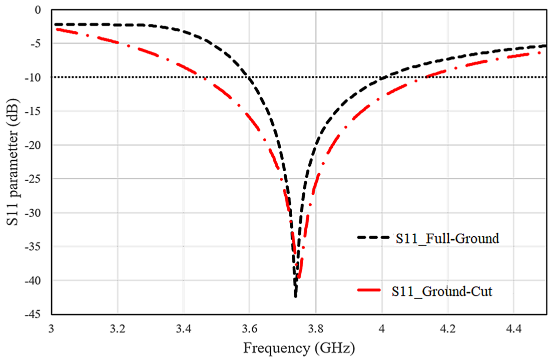


Fig. 2. Reflection coefficient of printed dipole with "J"-balun.

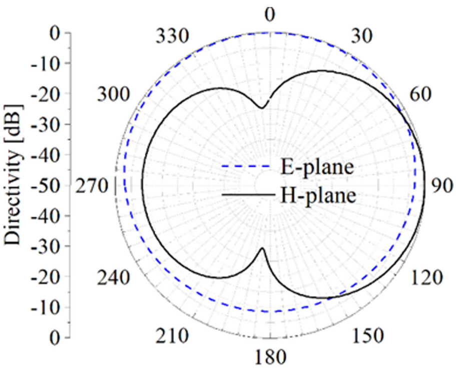


Fig. 3. Radiation pattern of the proposed ground-cut dipole element at 3.75 GHz

2.2 Proposed LHCP and RHCP Antenna

The sequential phase rotation feeding technique is used to obtain the wideband CP antenna. The difference of excitation phases at four antenna elements are arranged 0°, 90°, 180° and 270° at dipole 1, 2, 3 and 4, respectively as in Fig. 4. The RHCP or LHCP mode is chosen by selecting SMA_1 and SMA_2 through an RF switch circuit. In RHCP mode, SMA_1 is selected and SMA_2 is connected to a short circuit, that is the opposite of LHCP mode. The exciting phases of four dipoles elements at LHCP and RHCP modes are listed in Table 2. The parameters of a feeding network are listed in Table 3.

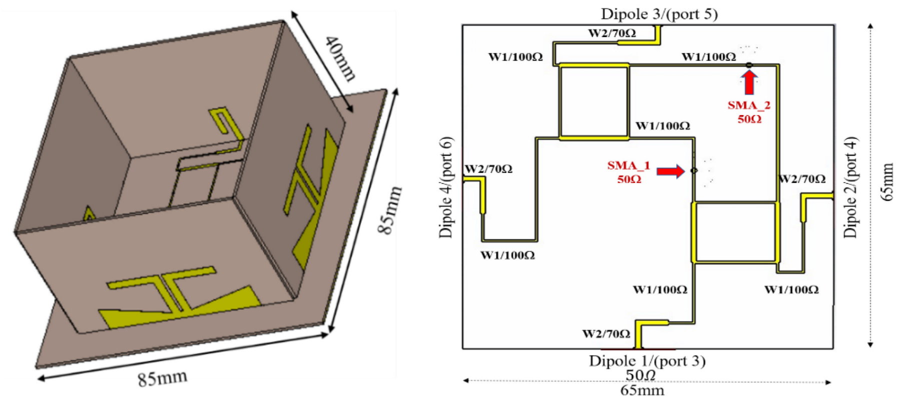
Table 2. Excited phases of antenna elements

	Dipole 1	Dipole 2	Dipole 3	Dipole 4
LHCP	0°	90°	180°	270°
RHCP	180°	90°	0°	270°

Table 3. Parameters of feeding network

Parameters	Values (mm)	Parameters	Values (mm)
W1	0.423	W2	0.95

The feeding network composes of two 90° hybrids to make the desired phase shift among dipoles as in Table 2, and the 70.7 Ω quarter-wavelength transmission lines are used to match impedance between element and feeding as in Fig. 4b.



a) b)

Fig. 4. a) Structure of LHCP and RHCP antenna. b) Proposed feeding network.

The simulated S-parameters of the feeding network corresponding with four exciting amplitudes and phases of four dipoles at RHCP mode are shown in Fig. 5a. The amplitude difference between the four ports is less than 1.6 dB and 1.8 dB at the center frequency for the RHCP and LHCP modes of operation, respectively. Meanwhile, the phases between the two adjacent elements are about 84° to 98° at RHCP mode and 80° to 100° at LHCP mode (Fig. 5b).

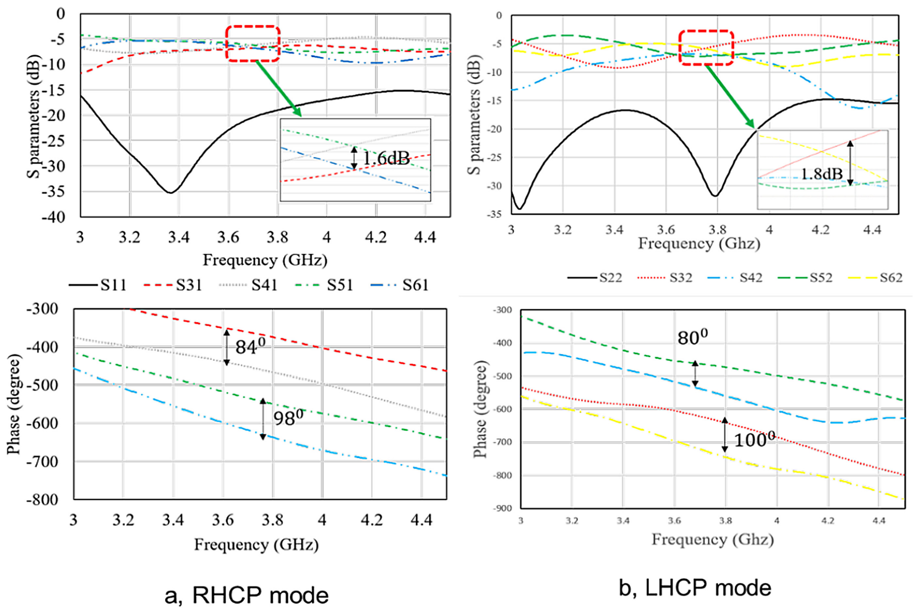


Fig. 5. Amplitude and phase distribution on feeding network. a) at RHCP mode; b) at LHCP mode

The RHCP and LHCP antenna is designed on the Rogers 4003C substrate with a dielectric constant of 3.55 and a height of 0.813 mm. The proposed 5G LHCP and RHCP antenna is shown in Fig. 6 with the dimension of 85 × 85 × 40 mm^3. This configuration of LHCP and RHCP antenna has low mutual coupling between elements. To achieve RHCP or LHCP mode, the RF sources is selected to SMA_1 and SMA_2, respectively. The reflection coefficients of LHCP and RHCP antenna are shown in Fig. 7. It is seen that the operating band of the antenna at LHCP mode is slightly higher than the operating band of an antenna at RHCP mode. At LHCP mode, the simulated bandwidth is 1.38 GHz withS11 below −10 dB. Meanwhile, the simulated bandwidth of RHCP antenna is 1.24 GHz with S11 under −10 dB. The measured bandwidth (at S11 ≤ −

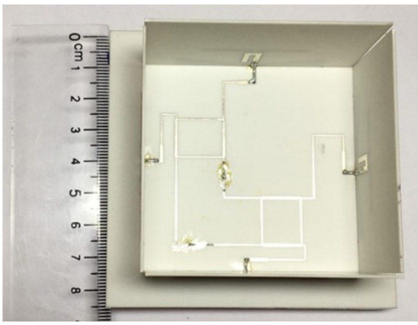


Fig. 6. RHCP and LHCP antenna prototype.

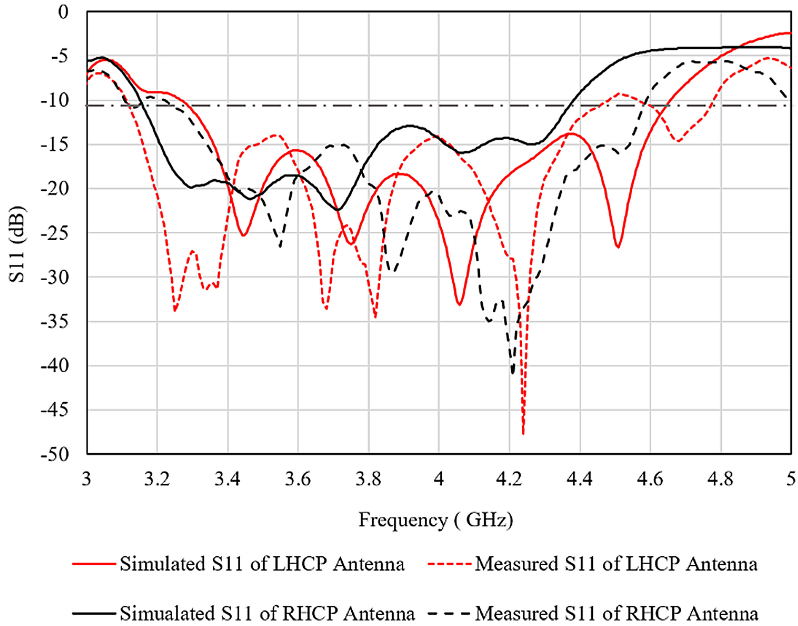


Fig. 7. Measured and simulated reflection coefficients for RHCP and LHCP modes.

10 dB) for the LHCP mode is 37.3% and the corresponding values of the RHCP mode is 37.3%. The overlapped bandwidth for both modes are 34.7% covering 3.3–4.2 GHz band for 5G technology according to 3GPP standard.

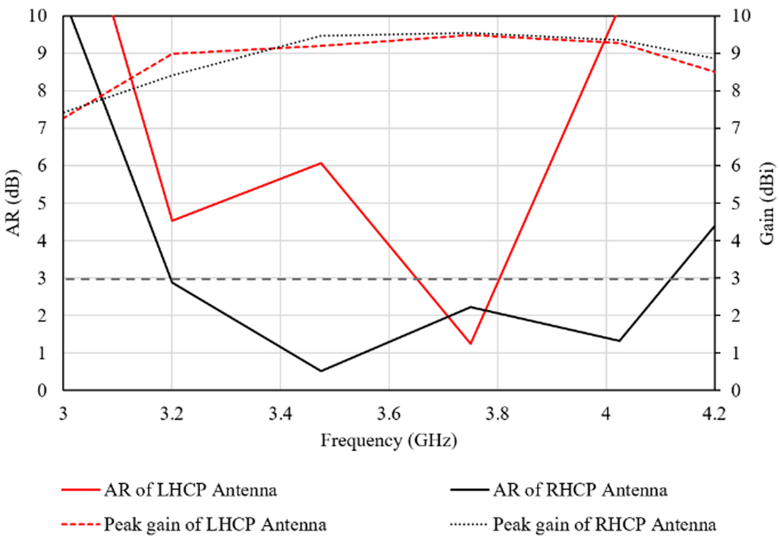
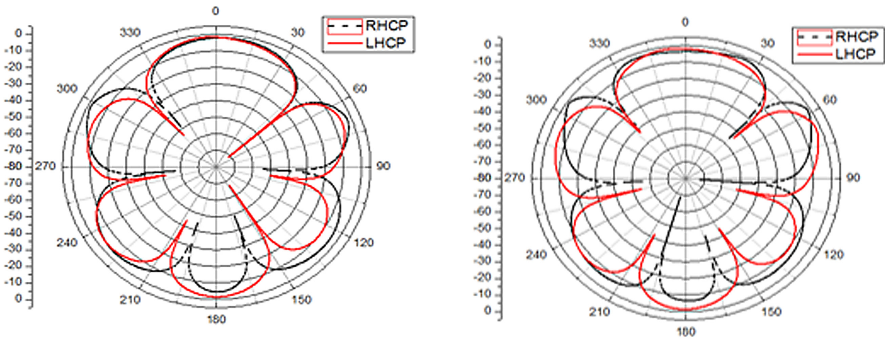


Fig. 8. Simulated AR and Gain of RHCP and LHCP antenna.

The AR and the realized peak gain of LHCP/RHCP is presented in Fig. 8. The AR of an antenna at RHCP mode is less than 3 dB from 3.2 GHz to 4.13 GHz (24.8%). Meanwhile, the AR of the antenna at LHCP mode is less than 3 dB from 3.65 to 3.81 GHz (4%).

The peak gain over the 3.2–4.2 GHz band is more than 8 dBi with a maximum value of 9.5 dBi at 3.7 GHz for both polarizations. The total radiation efficiency is up to 91.54% at LHCP mode and 91.66% at RHCP mode. At 3.7 GHz, the width of circular polarization is 42° in LHCP mode and 51° in RHCP mode as in Fig. 9.



a, Radiation pattern at 3.7GHz   a, Radiation pattern at 3.8GHz

Fig. 9. Simulated AR in RHCP and LHCP mode of the proposed antenna at 3.7 GHz and 3.8 GHz.

Table 4 summarizes several proposed LHCP and RHCP antennas. In [9], the mmWave antenna is designed with a wideband and higher peak gain than the proposed RHCP/LHCP antenna, but the radiation efficiency and total efficiency is smaller than

Table 4. Comparison with related works

Ref.		Center Freq (GHz)	Bandwidth at		Gain (dBi)
			S11 ≤ −10 dB (%)	AR ≤ 3 dB (GHz)	
[9]	LHCP	28	2.85–10.17%	27.74–29.05	14.16
	RHCP		3.1–11.07%	27.76–28.95	13.52
[10]	LHCP	2.15	0.8–37.21%	2.05–2.27	8.01
	RHCP		0.8–37.21%	2.05–2.27	8.99
[2]	LHCP	2.45	0.11–4.5%	2.34–2.57	6.4
	RHCP		0.11–4.5%	2.35–2.61	6.5
[11]	LHCP	1.6	1.5–93.75%	1.5–2.2	4.8
	RHCP		1.5–93.75%	1.45–1.9	4.8
This work	**LHCP**	**3.75**	**1.4–37.3%**	**3.65–3.81**	**9.47**
	RHCP		**1.4–37.3%**	**3.2–4.13**	**9.52**

this work. In [2, 10, 11], the antennas are designed at sub 6 GHz frequencies. They are wideband but the peak gain is smaller than the proposed antenna.

3 Conclusions

A wideband RHCP and LHCP antenna using the printed dipole antenna elements and the sequential rotation feeding technique based on 90° hybrid coupler have been studied and presented in this paper. Based on 90° hybrid coupler feeding network, the proposed antenna has a wideband CP in both RHCP and LHCP modes. The bandwidth of the antenna is 37.3% (at −10 dB) for both RHCP and LHCP modes, respectively. The antenna has 42° of circular polarization in LHCP mode and 51° of CP in RHCP. The peak gain of antenna is up to 9.5 dBi over the operating frequencies. The simple antenna is easy to be applied for 5G devices which need high gain and wideband CP antenna characteristics.

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References

1. Le, T., Park, H.-Y., Yun, T.-Y.: Simple reconfigurable circularly polarized antenna at three bands. Sensors **19**(10), 2316 (2019). https://doi.org/10.3390/s19102316
2. Lu, Y., Wang, Y., Gao, S., Hua, C., Liu, T.: Circularly polarised integrated filtering antenna with polarisation reconfigurability. IET Microw. Antennas Propag. **11**(15), 2247–2252 (2017). https://doi.org/10.1049/iet-map.2017.0283
3. Le, M.T., Nguyen, Q.C., Vuong, T.P.: Design of a high gain antenna at 5.8 GHz using a new metamaterials structure. In: The Fourth IEEE International Conference on Communications and Electronics, pp. 411–416, August 2012. https://doi.org/10.1109/CCE.2012.6315940
4. Row, J.-S., Chan, M.-C.: Reconfigurable circularly-polarized patch antenna with conical beam. IEEE Trans. Antennas Propag. **58**(8), 2753–2757 (2010). https://doi.org/10.1109/TAP.2010.2050436
5. Kovitz, J.M., Rajagopalan, H., Rahmat-Samii, Y.: Design and implementation of broadband MEMS RHCP/LHCP reconfigurable arrays using rotated e-shaped patch elements. IEEE Trans. Antennas Propag. **63**(6), 2497–2507 (2015). https://doi.org/10.1109/TAP.2015.2417892
6. Chen, H., Yang, X., Yin, Y.Z., Fan, S.T., Wu, J.J.: Triband planar monopole antenna with compact radiator for WLAN/WiMAX applications. IEEE Antennas Wirel. Propag. Lett. **12**, 1440–1443 (2013). https://doi.org/10.1109/LAWP.2013.2287312
7. Cao, Y., Cheung, S.W., Yuk, T.I.: A simple planar polarization reconfigurable monopole antenna for GNSS/PCS. IEEE Trans. Antennas Propag. **63**(2), 500–507 (2015). https://doi.org/10.1109/TAP.2014.2382091
8. Duyen, B.T., Thuy, L.M., Cuong, N.Q.: Novel wideband circularly polarized antenna for wireless applications. In: The 2017 IEEE Asia Pacific Microwave Conference (APMC), pp. 430–433 (2017). https://doi.org/10.1109/APMC.2017.8251472
9. Park, S.-J., Park, S.-O.: LHCP and RHCP substrate integrated waveguide antenna arrays for millimeter-wave applications. IEEE Antennas Wirel. Propag. Lett. **16**, 601–604 (2017). https://doi.org/10.1109/LAWP.2016.2594081

10. Yoon, W.-S., Han, S.-M., Baik, J.-W., Pyo, S., Lee, J., Kim, Y.-S.: Crossed dipole antenna with switchable circular polarisation sense. Electron. Lett. **45**(14), 717 (2009). https://doi.org/10.1049/el.2009.0391
11. Lin, W., Wong, H.: Wideband circular polarization reconfigurable antenna. IEEE Trans. Antennas Propag. **63**(12), 5938–5944 (2015). https://doi.org/10.1109/TAP.2015.2489210