Broadband Circularly Polarized Antennas with Improved Gain

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Abstract **─** A broadband circularly polarized (CP) antenna with improved gain is proposed. The broadband CP antenna consists of two folded off-center-fed dipoles. Due to the two-dipole configuration, the antenna gain is improved by almost 2 dB. It is shown by simulation and experiment that the broadband CP antenna achieves an impedance bandwidth of 52% (1.71-2.89 GHz) for reflection coefficient<-15 dB and an axial ratio (AR) bandwidth of 45% (1.75-2.73 GHz) for AR<3 dB. The average antenna gain is about 10 dBi. A differentially-fed broadband CP antenna is also developed. Simulated and measured results show that the differentially-fed CP antenna fulfills an impedance bandwidth of 60% (1.53-2.83 GHz) for differential reflection coefficient <-15 dB and a 3-dB AR bandwidth of 44% (1.76-2.75 GHz). The average antenna gain is about 10 dBi. The gain-improved broadband CP antennas feature a simple planar configuration, which are suitable for applications in satellite/wireless communications.

Index Terms **─** Broadband antenna, circularly polarized antenna, differentially-fed antenna.

I. INTRODUCTION

Circularly polarized (CP) antennas have been widely used in satellite and wireless communications. Modern high-speed satellite and wireless communications usually require broadband CP antennas. For the long-distance wireless communication, an antenna with a high gain may show outstanding advantages in increasing the signal strength, improving the data rate and enhancing the communication quality. In recent years, a number of broadband CP antennas have been developed [1-11]. The performances of impedance bandwidths, bandwidths for axial ratio < 3dB, and the antenna gains of those CP antennas are listed in Table 1. The bandwidths of the antennas presented in [1-3] are not wide enough. Though the CP antennas in [4-11] have wide overlapped bandwidth for impedance matching and AR, these CP antennas have an average antenna gain of 6-8 dBi, which cannot meet the requirement for high-gain applications.

Differential circuits are important for communication systems due to their superior advantages of noise immunity, mode current elimination, and fundamental harmonic rejections [12]. Several differentially-fed CP antennas have been proposed in [13-21]. However, most of the antennas either have an overlapped bandwidth of less than 40% for impedance matching and AR or have an antenna gain no higher than 10 dBi. Some can neither meet the requirement of wide bandwidth nor high gain [13], [16]. Therefore, broadband CP antennas with high gain is desirable for long-distance wireless communication applications.

In this paper, we propose a broadband CP antenna with an average gain of 10 dBi and an overlapped bandwidth of 45% for reflection coefficient<-15 dB and AR<3 dB. A differentially-fed broadband CP antenna is also developed, which achieves an impedance bandwidth of 60% (1.53–2.83 GHz) for differential reflection coefficient<-15 dB and a 3-dB AR bandwidth of 44% (1.76–2.75 GHz) with an antenna gain of 10 dBi.

Table 1: The performances of the CP antennas

Ref.	Impedance BW	AR BW	Gain (dBi)
[1]	13.9%	8.3%	8
[2]	20.5%	11.5%	5.8
[3]	24%	24%	8
[4]	50.2%	27%	6.2
[5]	54.9%	53%	7
[6]	60%	55%	8
[7]	62.3%	61.7%	6
[8]	66.2%	41.3%	6
[9]	74.4%	70.8%	7.4
[10]	93.1%	90.9%	5
[11]	106.1%	89.7%	6
[13]	5.3%	5.3%	-
[14]	18%	17.9%	14
[15]	18%	16.7%	14.6
[16]	25.4%	22.8%	6.9
[17]	35.5%	24.69%	9.32
[18]	53.9%	35%	7.6
[19]	60.5%	31%	8
[20]	46.9%	49.5%	4.7
[21]	52%	32%	11.1

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II. BROADBAND CP ANTENNA

A. Antenna configuration

The configuration of the broadband CP antenna is illustrated in Fig. 1. It consists of two folded off-centre-fed dipoles which are fed by a co-planar strip line. A T-shaped probe is used to feed the CP antenna through the co-planar strip line. The folded dipoles are printed on the back side of a dielectric substrate (Rogers 4350B, ε_r = 3.48 and thickness = 0.76 mm) while the T-shaped probe is etched on the front side of the substrate, featuring a planar configuration. A coaxial line is used to excite the antenna through the port. At the port, there is a non-metallic via through which the inner conductor of the coaxial cable is connected to the T-shaped probe. The outer conductor of the coaxial cable is soldered to the coplanar strip line.

The broadband CP antenna is placed above a metal reflector for unidirectional radiation pattern. The total height of the antenna is 33 mm, about $0.24\lambda_0$ (λ_0 is the free-space wavelength at the center frequency 2.2 GHz).

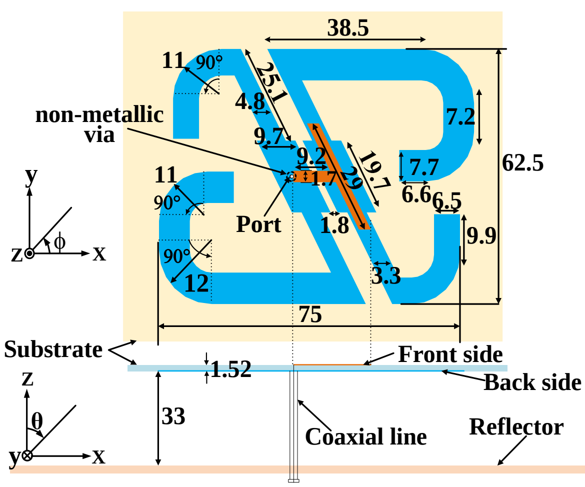


Fig. 1. Configuration of the broadband CP antenna (unit in mm).

B. Operating principle

To explain the operating principle of the broadband CP antenna, the current distributions on one of the two folded off-centre-fed dipoles at 1.8 and 2.6 GHz are plotted in Fig. 2. The magnitudes of the currents at 1.8 and 2.6 GHz have no significant difference. A 90° difference in phase is observed at both frequencies for the currents on two perpendicular sections (ABCD and DEF, AB⊥EF and CD⊥DE) of the folded dipole, which is required for circular polarization.

For dipole antennas, it is known that the distance between the antenna and the reflector plays an important role for the impedance matching and axial ratio due to effects from the image currents. For this broadband CP antenna, the antenna height also influences the antenna gain. As displayed in Fig. 3, with the increase of the antenna height, the antenna gain first gets improved then turns worse. The optimized value for the antenna height is 33 mm when a high gain of about 10.5 dBi is obtained.

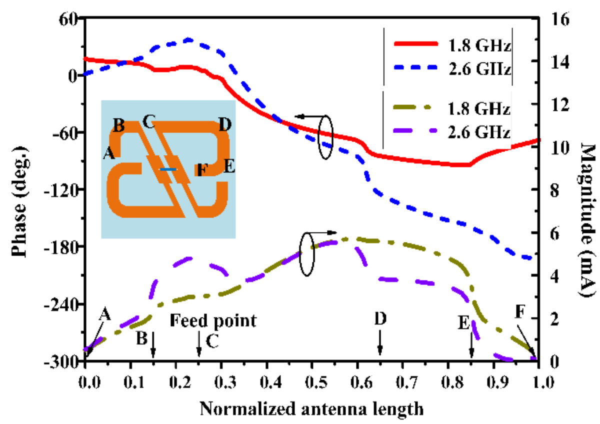


Fig. 2. Current distributions on one of the two folded off-center-fed dipoles of the broadband CP antenna.

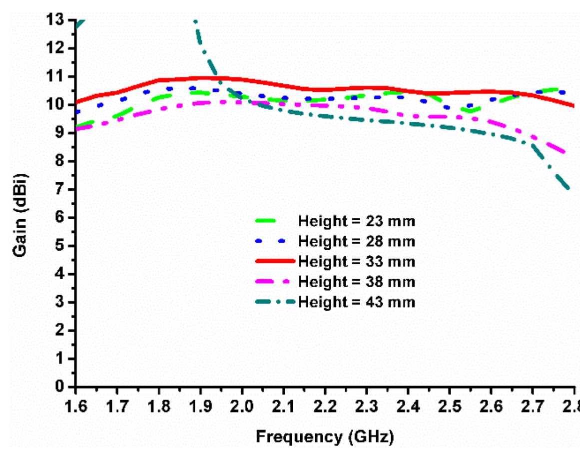
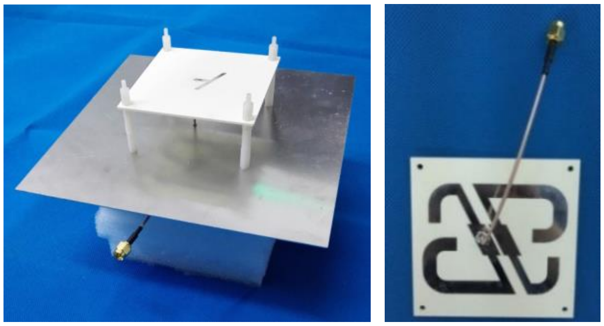


Fig. 3. Antenna gain of the CP antenna with different antenna height.

C. Results

The broadband CP antenna has been fabricated and measured. Figure 4 shows a prototype of the fabricated antenna. A semi-rigid coaxial cable is connected to the feeding port for measurement. The simulated and measured S-parameters are plotted in Fig. 5. The impedance bandwidth for refection coefficient (|S11|) <-15 dB is about 52% (1.71–2.89 GHz). The simulated and measured results for axial ratio (AR) and gain are demonstrated in Fig. 6. The bandwidth for AR<3 dB is about 45% (1.75–2.73 GHz). The averaged antenna gains are about 10 dBi. The improved gain is due to the two-dipole configuration. The simulated and measured radiation patterns at 1.75, 2.2, and 2.7 GHz are depicted in Fig. 7. The radiation patterns are stable over the frequency range 1.75–2.7 GHz.



(a) (b)

Fig. 4. Prototype of the broadband CP antenna: (a) perspective view and (b) back view.

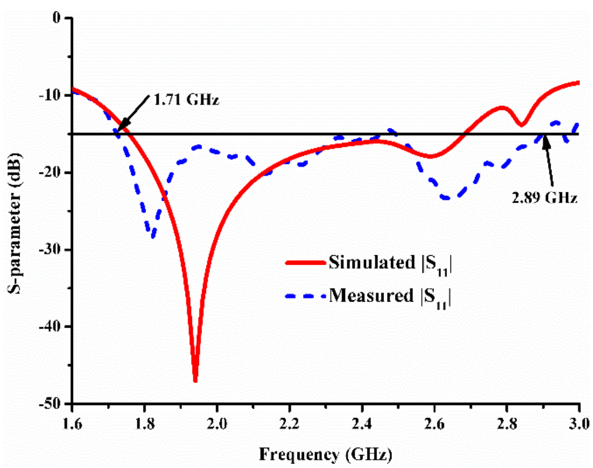


Fig. 5. S-parameters of the broadband CP antenna.

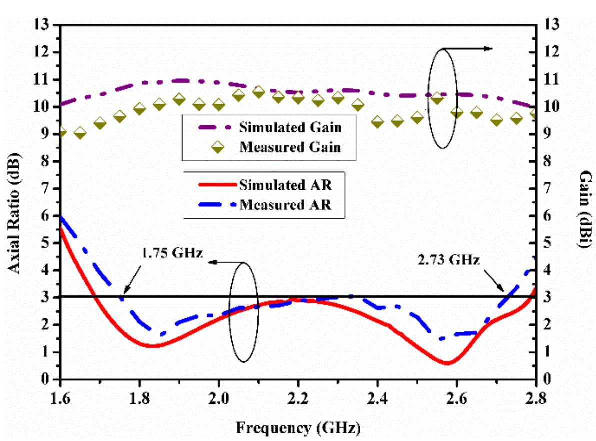


Fig. 6. Axial ratio and gain of the broadband CP antenna.

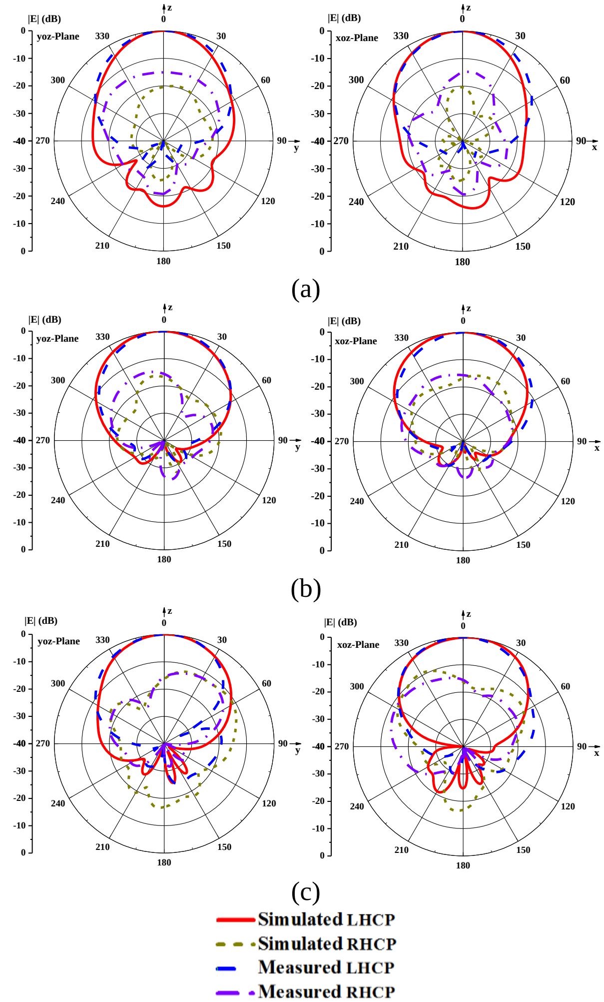


Fig. 7. Radiation patterns of the broadband CP antenna: (a) 1.75 GHz, (b). 2.2 GHz, and (c) .2.7 GHz.

III. DIFFERENTIALLY-FED CP ANTENNA

A. Antenna configuration

The configuration of the differentially-fed CP antenna is illustrated in Fig. 8. The CP antenna consists of two folded off-center-fed dipoles which are excited by a co-planar strip line. A short stub is used to bridge over the two strips of the coplanar strip line at the center of the two folded dipoles. The CP antenna is differentially fed through two coaxial cables at ports 1 and 2. The folded dipoles are printed on the back side of a dielectric substrate (Rogers 4350B, ε_r = 3.48 and thickness = 0.76 mm) while the short stub is etched on the front side of the substrate, featuring a planar configuration. The total size of the CP antenna is 74 mm × 56 mm ($0.54\lambda_0 \times 0.41\lambda_0$). The differentially fed CP antenna is placed above a flat square metal reflector with a size of 200 mm × 200 mm. The antenna height is H=33 mm ($0.24\lambda_0$). Four plastic posts are employed to support the CP antenna.

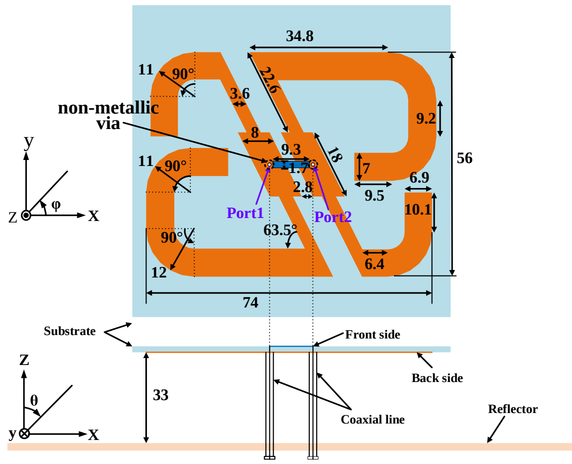


Fig. 8. Configuration of the differential-fed broadband CP antenna (unit in mm).

B. Operating principle

An equivalent circuit for impedance matching of the differentially-fed CP antenna is sketched in Fig. 9. The input impedance of each folded off-center-fed dipole is found to be Z~260 Ω. The input impedance required to match the differential feed is Z_{in}~100 Ω. Therefore, the coplanar strip line is composed of two sections: one with a characteristic impedance of Z_{01}~260 Ω matching to the folded dipole and the other with a characteristic impedance of Z_{02}~200 Ω matching to the differential feed.

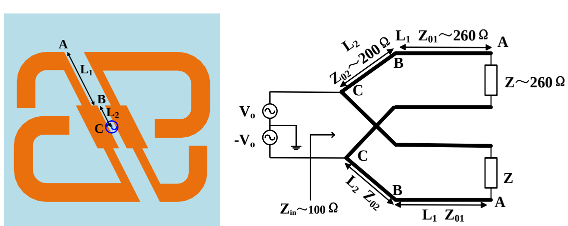


Fig. 9. Equivalent circuit for impedance matching of the differential-fed CP antenna.

The effects of the antenna height on the AR and gain is displayed in Fig. 10 and Fig. 11, respectively. The antenna height has significant influences on the AR. It can be observed that the antenna gain gets improved with the decrease of the antenna height. The optimized value is determined to be 33 mm for the trade-off between the optimized AR and antenna gain.

C. Results

The broadband differentially-fed CP antenna has been fabricated and measured. A prototype of the fabricated differentially-fed CP antenna is picture in Fig. 12. The simulated and measured differential coefficients |Sdd| are plotted in Fig. 13. The bandwidth for $|S_{dd}|$<-15 dB is about 60% (1.53–2.83 GHz). The simulated and measured for AR and gain are depicted in Fig. 14. The measured 3-dB AR bandwidth is about 44% (1.76–2.75 GHz). The averaged antenna gains are about 10 dBi. The measured radiation patterns at 1.7, 2.2, and 2.7 GHz are compared in Fig. 15; good agreement is observed.

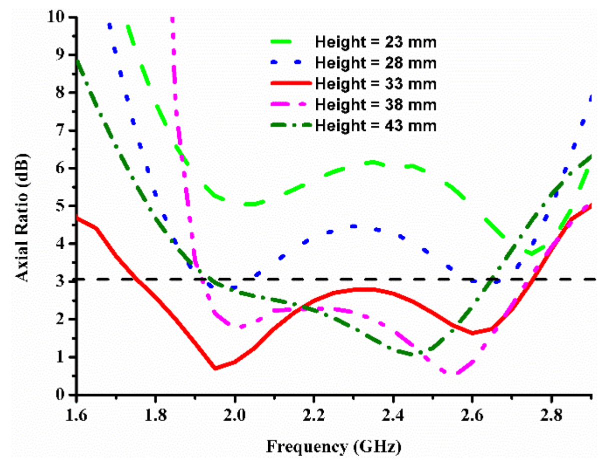


Fig. 10. Axial ratio of the differential-fed CP antenna with different antenna height.

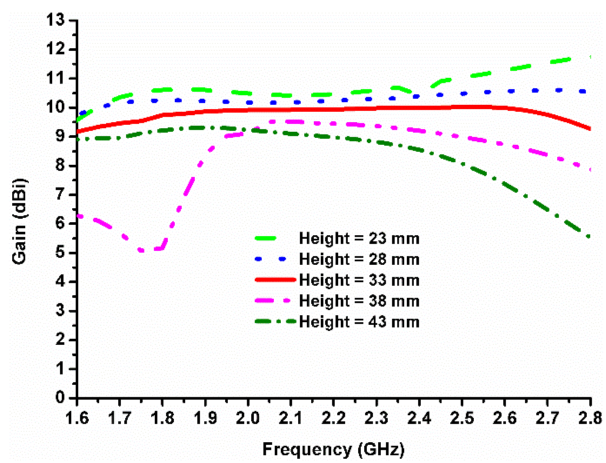
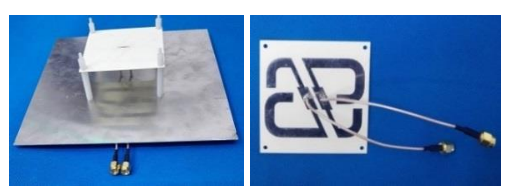


Fig. 11. Antenna gain of the differential-fed CP antenna with different antenna height.



(a) (b)

Fig. 12. A prototype of the differential-fed broadband CP antenna: (a) perspective view and (b) back view.

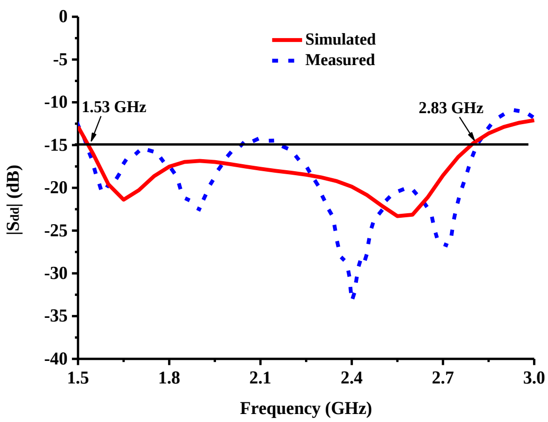


Fig. 13. Differential coefficient ($|S_{dd}|$) of the differential-fed broadband CP antenna.

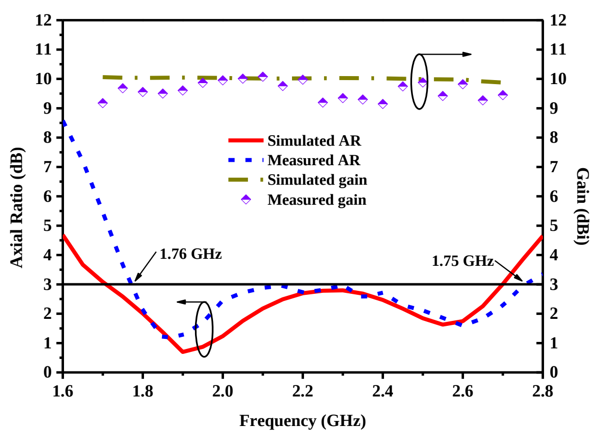
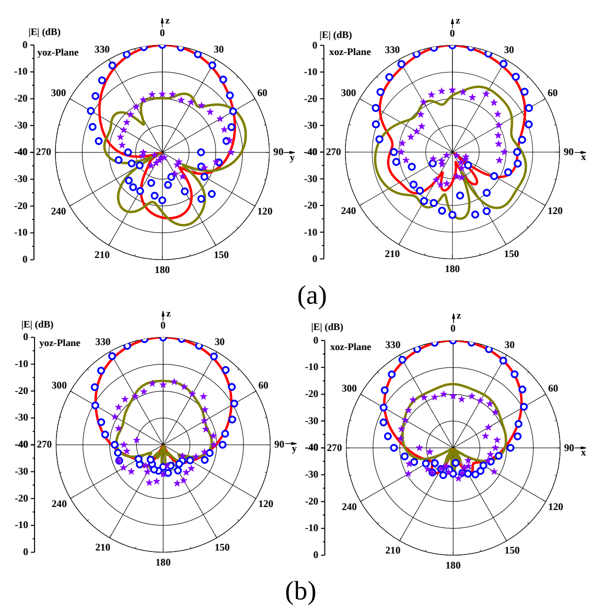


Fig. 14. Axial ratio and gain of the differentially-fed broadband CP antenna.



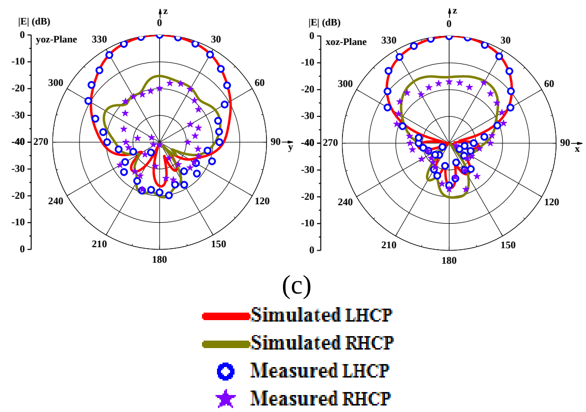


Fig. 15. Radiation patterns of the differential-fed broadband CP antenna: (a) 1.8 GHz, (b) 2.2 GHz, and (c) 2.7 GHz.

IV. CONCLUSION

A broadband CP antenna with improved gain is developed. The broadband CP antenna achieves an average antenna gain of about 10 dBi, ~2 dB higher than most existing CP antennas in literatures. The gain improved CP antenna also has better impedance matching than most CP antennas; the impedance bandwidth for reflection coefficient<-15 dB is about 52%. A differentially-fed broadband CP antenna is also developed. The impedance bandwidth achieved by the differentially-fed CP antenna is about 60% (1.53–2.83 GHz) for differential reflection coefficient<-15 dB and the 3-dB AR bandwidth obtained is 44% (1.76–2.75 GHz). The averaged antenna gain is about 10 dBi. The broadband CP antennas feature a simple planar configuration and thus may find applications in satellite/ wireless communications.

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