

A Low-Profile Wide-Angle Coverage Antenna

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Abstract: A low-profile wide-angle coverage antenna for Ad Hoc communication networks is presented in this letter, which consists primarily of a rotationally symmetrical structure with a microstrip patch antenna positioned at its center. Utilizing two orthogonal coupling feeds, the microstrip antenna produces circularly polarized radiation in the broadside direction. Meanwhile, the rotationally thin structure is driven by the coupling of the microstrip patch, and a linearly polarized radiation out of the range of $\pm 15^\circ$ is generated. Due to this parasitic structure, the radiation of the whole antenna at the upper hemisphere is balanced greatly, which leads to the wide-angle coverage ability enhancement of the low-profile antenna. A prototype operating at 2.7 GHz is fabricated and tested, demonstrating an impedance bandwidth of 15% (2.4 to 2.8 GHz). Measurement results show a 6 dB difference between the maximum and minimum gain in the upper hemisphere. With an overall antenna height of just 6 mm, all gains in the upper hemisphere exceed -3.5 dB.

Keywords: low profile; microstrip; upper hemisphere; wide-angle coverage

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1. Introduction

With the development of communication systems, antennas with wide-angle coverage are pursued in many applications for the reliability of systems, especially in the terminals for satellite communication and some special personal communication systems [1]. Moreover, when the polarization of the transmitting and receiving antennas are orthogonal, poor signal quality or even the complete failure of communication is caused [2]. Thus, a wide-angle coverage antenna that emits circularly polarized waves is beneficial [3]. However, maintaining circular polarization across an extended coverage area presents challenges and may be impractical. This challenge becomes more pronounced when a low-profile antenna is required for easy integration into platforms. To address this issue, one approach is to design an antenna that emits circularly polarized waves in certain regions and linearly polarized waves in others. Such antennas are particularly useful in Ad Hoc communication networks like MANET (mobile Ad Hoc network), VANET (vehicular Ad Hoc network), and UAV (unmanned aerial vehicle) scenarios, where both satellite communication with circular polarization and communication between vehicles with linear polarization are needed.

A low-profile circularly polarized antenna combining a top-loaded antenna and a bent horizontal loop is proposed in [4], achieving an impedance bandwidth of approximately 19%, although it lacks radiation directly above the antenna. Another design uses two linearly polarized inverted L antennas to synthesize circularly polarized waves with an axial ratio bandwidth of 2.9% [5], but its high profile and limited coverage restrict its applicability. A broadband dual circularly polarized microstrip antenna presented in [6], featuring two pairs of orthogonal dipole antennas and a 3 dB bridge feed, achieves a profile of 0.17λ . Similarly, a low-profile dipole antenna proposed in [7] improves bandwidth through effective matching structures, achieving a reduced profile of 0.1λ . Meanwhile, a vertically polarized antenna with a low profile proposed in [8] utilizes a centrally fed

circular patch antenna with three metal shorts and fan-shaped gaps between the metal pins, though its radiation coverage may be insufficient. Furthermore, a circular sector magnetic dipole antenna operates at its dominant TM(2/3) mode in [9]. It is seen that the antenna exhibits a good non-uniformity of less than 5.7 dB within the three principal planes. A compact printed isotropic-radiated planar antenna consisting of two crossed curved dipoles printed on one side of a substrate is proposed in [10]. For this kind of antenna, the platform of the antenna mounted will have a great effect on them.

In this letter, a low-profile antenna with wide-angle coverage is proposed. The antenna is located at a circular metallic ground plane, facilitating its integration with other platforms. Through the superposition of radiation from a circularly polarized microstrip antenna and a specially designed coupling structure, the entire antenna exhibits balanced radiation across a wide angle in the upper hemisphere. Additionally, the antenna maintains a low profile of 6 mm (approximately $0.05 \lambda_0$ at the center frequency of 2.7 GHz).

2. Antenna Design

The antenna is mainly composed of two parts on a metal disc. One part is an annular plate shorted to the metal disc, and the other part is a microstrip antenna at the center.

As shown in Figure 1, the central part of the antenna features a 90° feed network printed on an F4B substrate, 1 mm thick, with three layers of FR4 dielectric boards stacked above it. Two coupling slots are etched orthogonally on the two layers of FR4 with a thickness of 3.2 mm and 0.2 mm, respectively, while the rectangular radiating patch is printed on the top layer of FR4, 0.6 mm thick. Circularly polarized waves can be radiated by the coupling orthogonal fields with a phase difference of 90 degrees from two orthogonal slots. Additionally, four metal cylinders connect metal ring 1 and the ground plane. The antenna parameters are shown in Table 1.

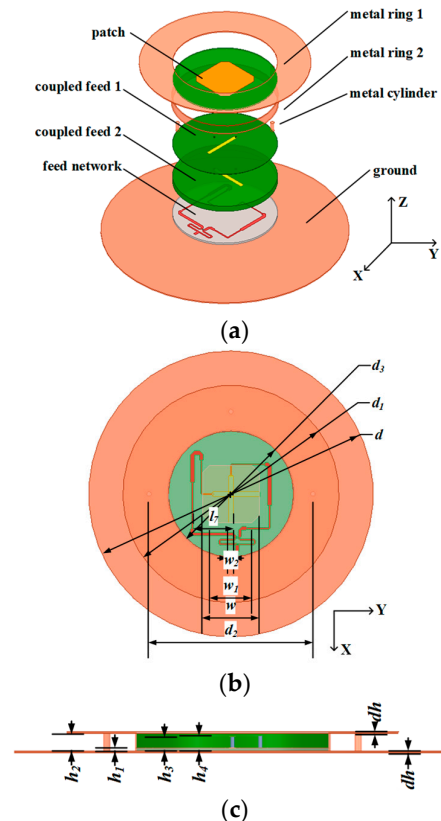
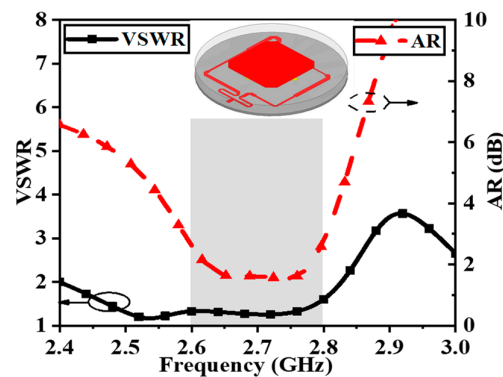


Figure 1. Geometry of proposed antenna. (a) A 3D view, (b) top view, and (c) side view.

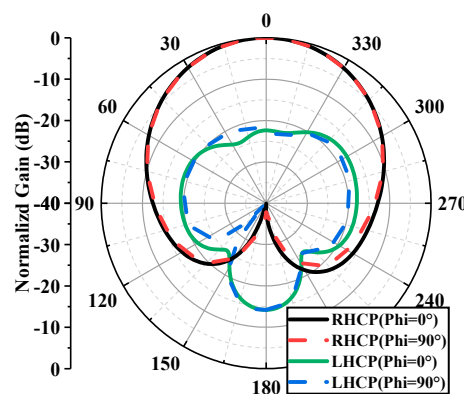
Table 1. Dimensions of proposed antenna.

Parameter	d	d_1	d_2	d_3	w	w_1
Value (mm)	125	95	72	55	24.8	18.8
Parameter	w_2	dh	h_1	h_2	h_3	h_4
Value (mm)	2	0.5	1	5	4.2	4.4

Firstly, a circularly polarized antenna was designed. Figure 2 shows the simulated VSWR and axial ratio (AR) of the circularly polarized microstrip antenna. It can be seen that both the impedance matching property and circular polarization property performed well from 2.6 GHz to 2.8 GHz.

**Figure 2.** VSWR and axial ratio (AR) of the microstrip antenna.

As shown in Figure 3, radiation sharply decreased beyond $\pm 30^\circ$. The electric field of radiation is denoted as $\vec{E}_1(\theta, \varphi)$. To enhance coverage across the entire upper hemisphere, especially in the horizontal plane, additional radiation needed to be introduced.

**Figure 3.** The radiation of the circularly polarized microstrip antenna.

The additional structure described in this letter was derived from a four-feed antenna, as shown in Figure 4a. This antenna contains a metal ring that is grounded and four coaxial feeds. The simulated radiation pattern of the antenna is depicted in Figure 5. As shown, the elevation pattern ($\varphi = 0^\circ$ plane) exhibits a null in the boresight direction ($\theta = 0^\circ$), while the azimuthal pattern ($\theta = 90^\circ$) is omnidirectional. This radiation is represented as $\vec{E}_2(\theta, \varphi)$.

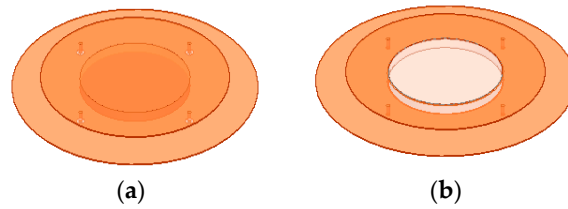


Figure 4. (a) A four-feed antenna. (b) Coupling structure.

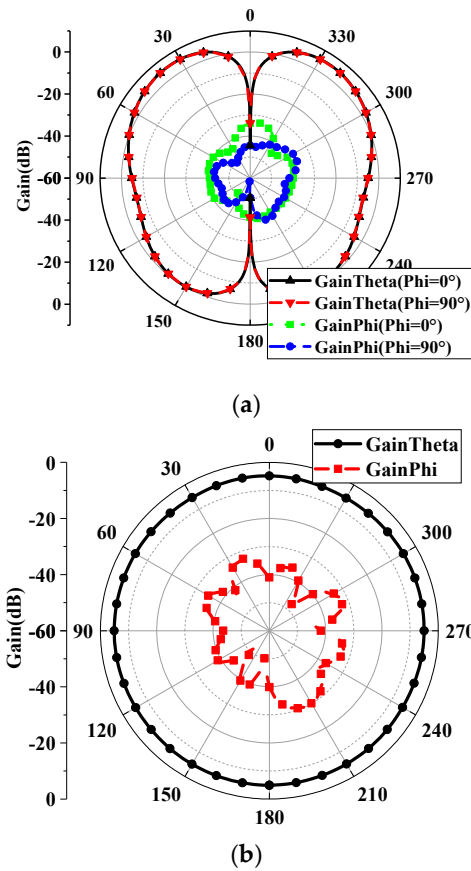


Figure 5. (a) Radiation patterns in the $\varphi = 0^\circ$ planes. (b) Radiation patterns in the $\theta = 90^\circ$ planes.

Based on the analysis above, the coupling structure shown in Figure 4b is proposed for simplifying the entire antenna design.

The total electric field of the antenna in the upper hemisphere can be derived as follows:

$$\vec{E}(\theta, \varphi) = (1 - K)\vec{E}_1(\theta, \varphi) + K\vec{E}_2(\theta, \varphi) \quad (1)$$

where “ K ” denotes the coupling coefficient and $\vec{E}_1(\theta, \varphi)$ and $\vec{E}_2(\theta, \varphi)$ represent the radiation electric fields of the previously designed microstrip antenna and the newly introduced structure, respectively.

As shown in Figure 6, as K increases, the difference between the maximum and minimum of the radiation electric field first decreases and then increases, which illustrates how the radiation can be balanced by adjusting this coupling coefficient.

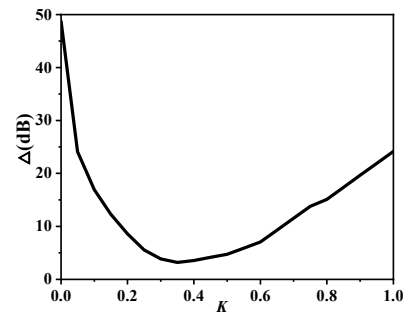


Figure 6. The maximum gain minus the minimum gain for different values of K . $\Delta = \text{dB}(|\vec{E}(\theta, \varphi)|_{\max}) - \text{dB}(|\vec{E}(\theta, \varphi)|_{\min})$.

3. Parametric Study and Discussion

To characterize the proposed antenna, a parametric study was carried out. The effect of coupling structure dimensions on the antenna performance was studied first. Figure 7a shows the simulated VSWRs as a function of frequency for coupling structure diameters of 53 mm, 55 mm, and 57 mm.

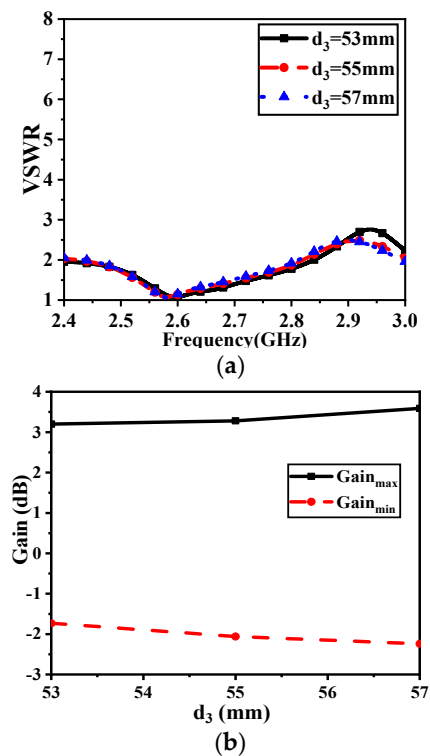


Figure 7. Simulated VSWRs and gains of the antenna for different coupling structure diameters of $d_3 = 53$ mm, 55 mm, and 57 mm. (a) VSWR. (b) The maximum and minimum values of the gain on the upper half-space.

The maximum and minimum values of the gain in the upper half-space are shown in Figure 7b. It can be ascertained that the diameter of the coupled parasitic structure had a negligible impact on the antenna bandwidth. However, increasing the diameter of the coupled parasitic structure tended to increase the maximum gain and decrease the minimum gain of the antenna.

Figure 8 shows the properties of the antenna for different heights of h_2 . When the height was greater than 5 mm, the bandwidth of the antenna remained almost unchanged.

However, when the height was less than 5 mm, the bandwidth of the antenna underwent significant changes. When the height of the antenna was 5 mm, the difference between the maximum and minimum gain of the antenna was minimized.

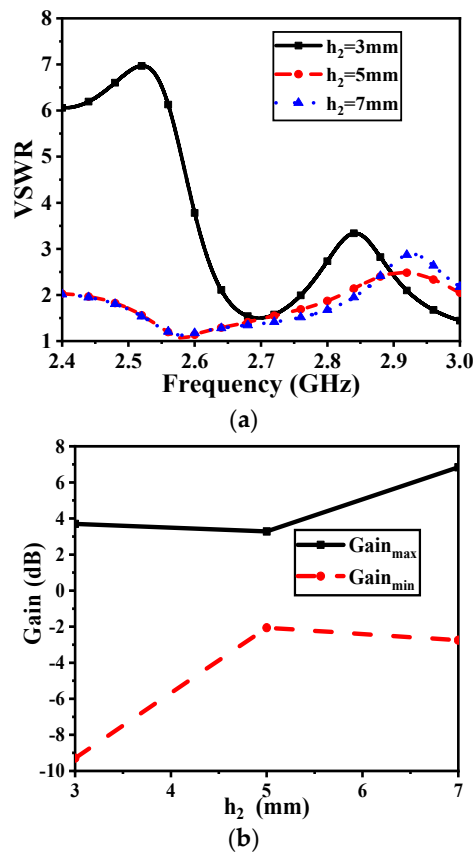


Figure 8. Simulated VSWR and gain of the antenna for different coupling structure heights of $h_2 = 3$ mm, 5 mm, and 7 mm. (a) VSWR. (b) The maximum and minimum values of the gain on the upper half-space.

4. Simulated and Measured Results

Figure 9 shows the fabrication prototype of the proposed low-profile antenna with wide-angle coverage. The antenna is measured in a microwave anechoic chamber.

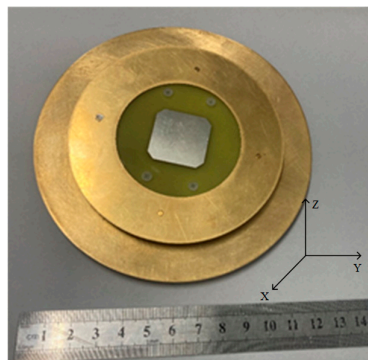


Figure 9. Prototype of the proposed antenna.

Figure 10 shows the simulated and measured VSWR of the proposed antenna. The measured results show that the antenna had an impedance bandwidth of 15% (2.4 to 2.8

GHz). The difference between the measured and simulated results of the proposed antenna mainly came from the height error during the assembly process and dielectric losses of the FR4 dielectric boards.

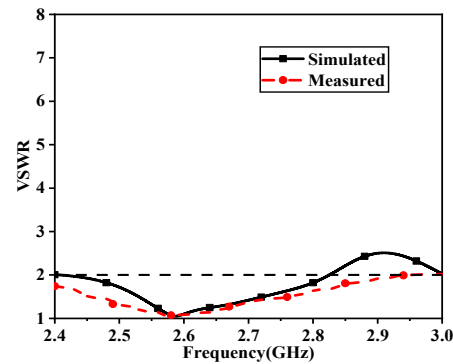
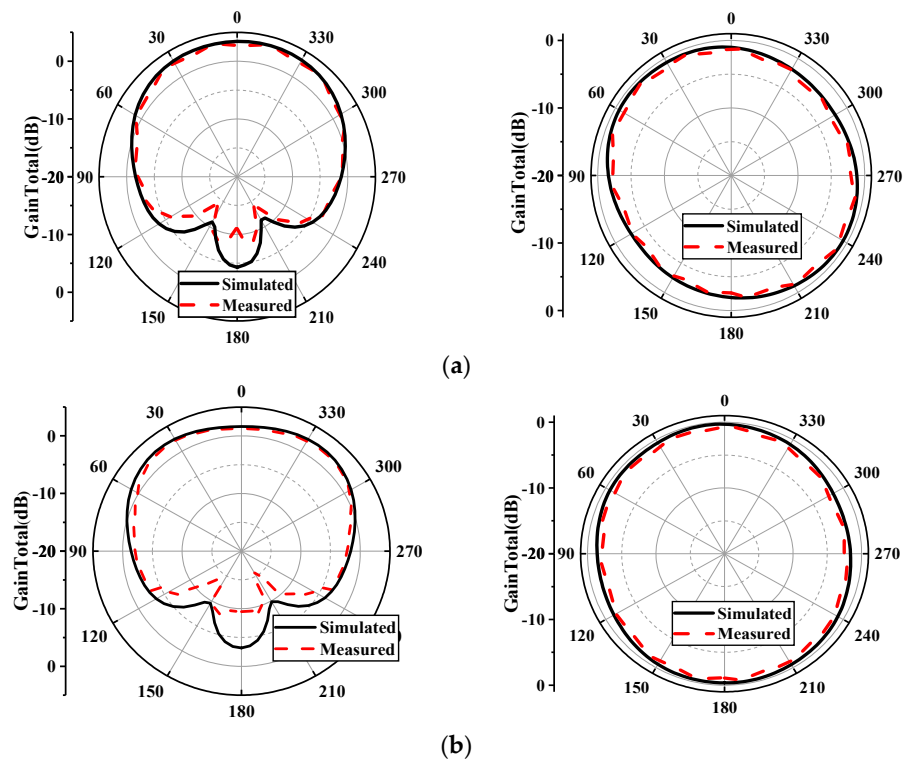


Figure 10. Simulated and measured VSWR of the proposed antenna.

The simulated and measured radiation patterns of the proposed antenna at 2.6, 2.7, and 2.8 GHz are depicted in Figure 11. On the XOZ plane, the antenna has a wide-beam radiation pattern, while on the XOY plane, the pattern is relatively omnidirectional. The minimum gain is greater than -3.5 dB. The difference between the maximum and minimum gain of the antenna is 6 dB on the upper hemisphere.



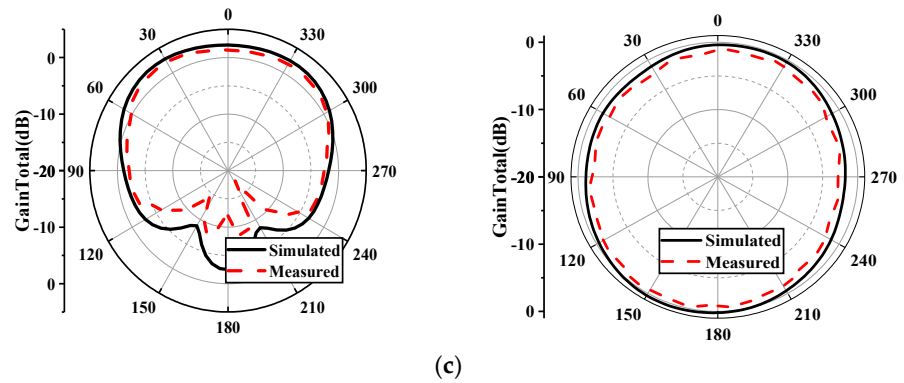


Figure 11. Simulated and measured radiation pattern results of the proposed antenna for the XOZ-plane and XOY-plane at (a) 2.6 GHz, (b) 2.7 GHz, and (c) 2.8 GHz. The black solid line represents the simulated results, and the red dashed line represents the measured results.

Figure 12 shows the simulated and measured AR of the antenna at 2.7 GHz. The measured AR agrees well with the simulated AR. The antenna is RHCP within the range of $-15^\circ < \theta < 15^\circ$ and is vertical polarization at other angles. The axial-ratio (AR) bandwidth (AR < 3 dB) is about 2.6–2.8 GHz.

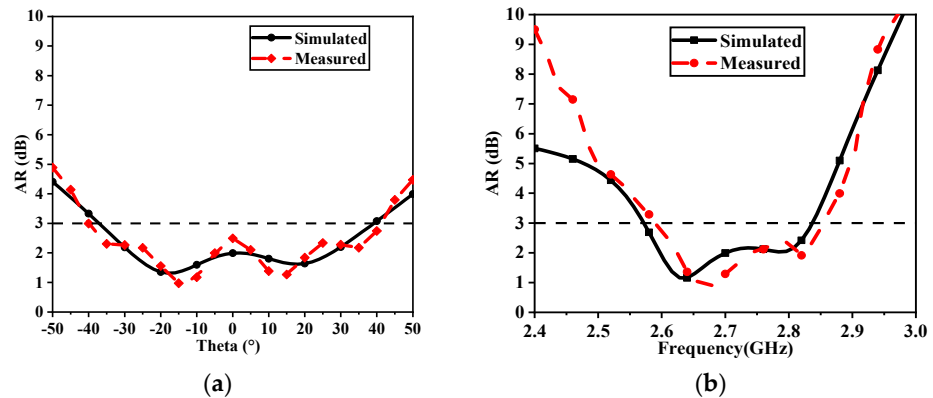


Figure 12. The axial ratio of the proposed antenna. (a) Variation with θ . (b) Variation with frequency.

Based on the antennas listed in Table 2, the radiation coverage of antennas in references [4–8,11–14] is limited, while antennas in references [4,9,10] are not suitable for mounting on a conductor platform. In this letter, the antenna exhibits a 6 dB difference between its maximum and minimum gain in the upper hemisphere. The antenna has the ability of wide-angle coverage with a profile of only $0.05\lambda_0$, which makes the antenna very easy to integrate with any platform.

Table 2. Comparison of the proposed antenna with existing works.

	Profile	Platform Effect	Δ
[4]	0.024λ	Great	40 dB
[5]	0.14λ	Little	18 dB
[6]	0.17λ	Little	13 dB
[7]	0.1λ	Little	20 dB
[12]	0.15λ	Little	40 dB
[13]	0.088λ	Little	30 dB
[14]	0.173λ	Little	15 dB

[9]	0.05λ	Great	5.7 dB
[10]	0.02λ	Great	5 dB
This letter	0.05λ	Little	6 dB

$\Delta = \text{Gain}_{\text{max}} - \text{Gain}_{\text{min}}$ (on the upper half-space). Platform effect: the effect of platforms on the antenna. The evaluation criterion is the type of antenna. Antennas without ground planes are greatly affected by the installation platform, while those with metal ground planes are less affected.

5. Conclusions

In this letter, a novel low-profile antenna with wide-angle coverage is proposed. According to the measured results, the impedance bandwidth (VSWR < 2) of the present antenna is about 2.4–2.8 GHz (15%), and the axial ratio (AR) bandwidth (AR < 3 dB) is within the range of $-15^\circ < \theta < 15^\circ$ is about 2.6–2.8 GHz (7.4%). The antenna maintains a low profile of 6 mm (approximately $0.05\lambda_0$ at the center frequency of 2.7 GHz). The minimum gain of the antenna in the upper hemisphere exceeds -3.5 dB, with a 6 dB difference between the maximum and the minimum gain.

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Conflicts of Interest: Author L.Q. was employed by the company ZTE Corporation. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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