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Research on Fresnel Lens Optical Receiving Antenna in Indoor Visible Light Communication

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Abstract: In order to collect more optical signals at the receiving end of the visible light communication (VLC), a Fresnel lens is designed, and at the same time, a hemispherical lens is added at the receiving end in order to increase the field of view angle and the receiving optical gain. The results show that the field of view reaches 40° and the optical gain is 4.6.
Keywords: VLC, the field of view, optical gain.

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1. INTRODUCTION

At present, the research on the optical receiving antenna of the indoor VLC system has attracted much attention. The addition of an optical receiving antenna at the receiving front end can collect more signals and improve the communication quality of the system. The optical receiving antennas mainly include plano-convex lenses, hemispherical lenses, compound parabolic concentrators, and Fresnel lenses. Among them, the Fresnel lens is a part of the material that does not change the optical path in the conventional flat lens, so as to reduce the attenuation of light in the lens. Compared with ordinary lenses, Fresnel lenses have the advantages of high light transmittance, small size, light weight, and economical application. Fresnel lenses have a good application prospect as a refractive optical receiving antenna in the field of optical communications.

One research built a VLC system. The system uses ultra-bright white light-emitting diodes, low-cost commercial photodiodes and Fresnel lenses, and LED drivers consist of power MOSFETs and MOSFET drivers. In order to increase the system bandwidth, a Fresnel lens was added in front of the PIN photodiode to increase the signal-to-noise ratio by 40 dB [1]. For the problem that indoor VLC could not satisfy both high gain and large field of view, one research designed an antenna combining a Fresnel lens and a compound surface concentrator. The simulation results show that the field of view reaches 40°. Using Matlab, the received power distribution of the designed optical receiving antenna is analyzed. The results show that the

average power is increased by 7dBm compared with the case where no optical antenna is added at the receiving end [2].
Therefore, this paper designs a Fresnel lens as the optical receiving antenna of the VLC system to collect light energy in free space and improve the communication quality of the system.

2. FRESNEL LENS DESIGN

The Fresnel lens consists of a series of concentric circles that look like a circle of thread, also known as a threaded lens [3-6]. In the study of Augustin Fresnel, the refraction of the incident light on the lens surface mainly comes from the continuous surface, and the incident light does not change through the uniform lens material on the surface. Therefore, Augustin Fresnel believes that the part of the lens that does not affect the optical path are intercepted and the remaining part are translated to a plane. Fresnel lens [7, 8] is formed by using this method.
Each prismatic groove in the Fresnel lens corresponds to an independent refractive surface, and the incident light converges to a common focal point through these independent refractive surfaces. The main structural parameters of the Fresnel lens are: ring-to-band spacing d, number of prisms p, working side angle $a(i)$, and material refractive index n. Performance parameters are: lens diameter D, focal length f. The Fresnel lens designed in this paper is a planar point focusing structure as shown in Figure 1.
In Fig.1, the incident ray is incident from the left side of the lens and is focused on the right side of the lens F, which focuses on the angle $\omega(i)$ between the central ray of the prism and the central axis of the lens. The basic parameters of the Fresnel lens can be derived from the optical refraction law and the plane geometry. The specific calculation is as shown in (1)
From the sine formula:

$$\tan\omega(i) = \left(\frac{(i-1/2)d}{f}\right) \tag{1}$$

Available from the lens structure:

$$2pd = D \tag{2}$$

From the inverse trigonometric function:

$$\omega(i) = \arctan\left(\frac{i-1/2}{2pf/D}\right) \tag{3}$$

The plane geometry we can see from Fig. 1:

$$\angle\beta_n = \angle\alpha(i) \tag{4}$$

$$\angle\beta_n' = \angle\alpha(i) + \angle\omega(i) \tag{5}$$

The law of refraction of light shows:

$$n = \frac{\sin\beta_n'}{\sin\beta_n} \tag{6}$$

Substituting equations (3), (4), and (5) into equation (6) is simplified:

$$\alpha(i) = \arctan\left(\frac{\sin\omega(i)}{n - \cos\omega(i)}\right) \tag{7}$$

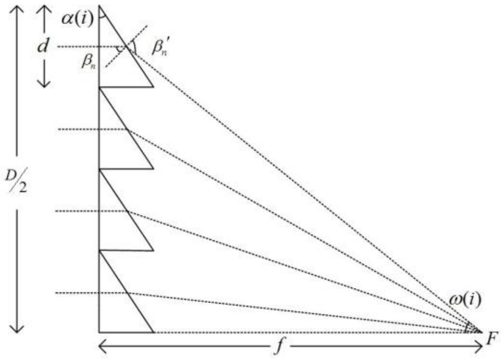

Figure 1. Fresnel lens prism structure

Fresnel lens material is optical plastic PMMA, caliber $D = 40\text{mm}$, $F = 1$, lens ring number $p = 20$. The focusing performance of the designed Fresnel lens is simulated. Figure 2 shows the simulated ray tracing of the Fresnel lens.

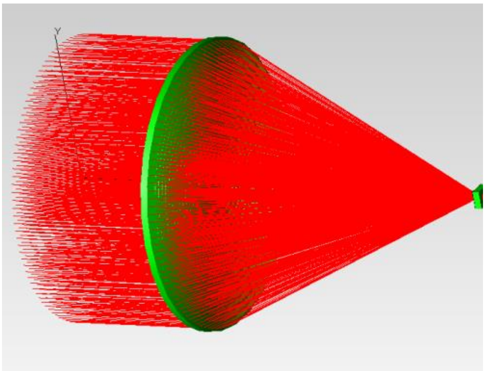

Figure 2. Fresnel lens ray tracing

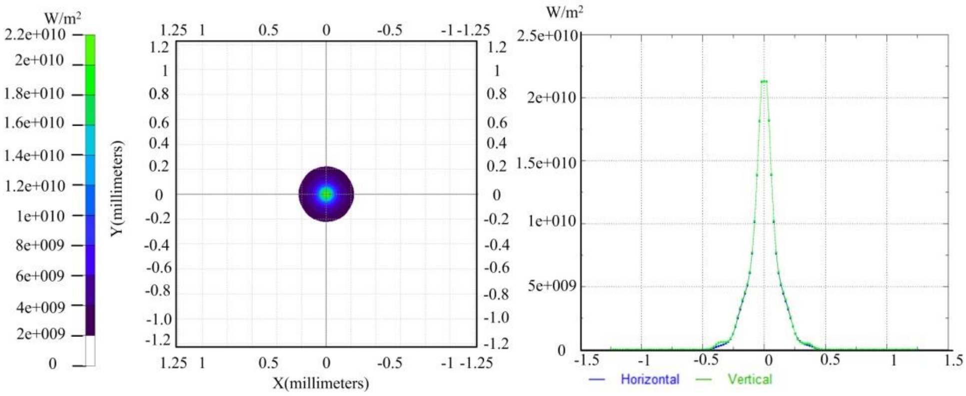

Figure 3. Distribution of irradiance at the receiving surface of the Fresnel lens

Figure 3 shows the illuminance distribution of the fresnel lens on the receiving surface. The maximum irradiance at the receiving surface is $2.13\times10^{10}\,\mathrm{W/m^2}$, the average irradiance is $1.64\times10^{8}\,\mathrm{W/m^2}$, and the lens condensing efficiency reaches 90%. The influence of the receiving field of view on the concentrating performance of the designed Fresnel lens is analyzed. The incident angles of the parallel rays are changed in order to simulate the plane irradiance simulation of the Fresnel lens at the receiving angles of 0.5°, 1°, and 1.5°, respectively, as shown in Figure 4.

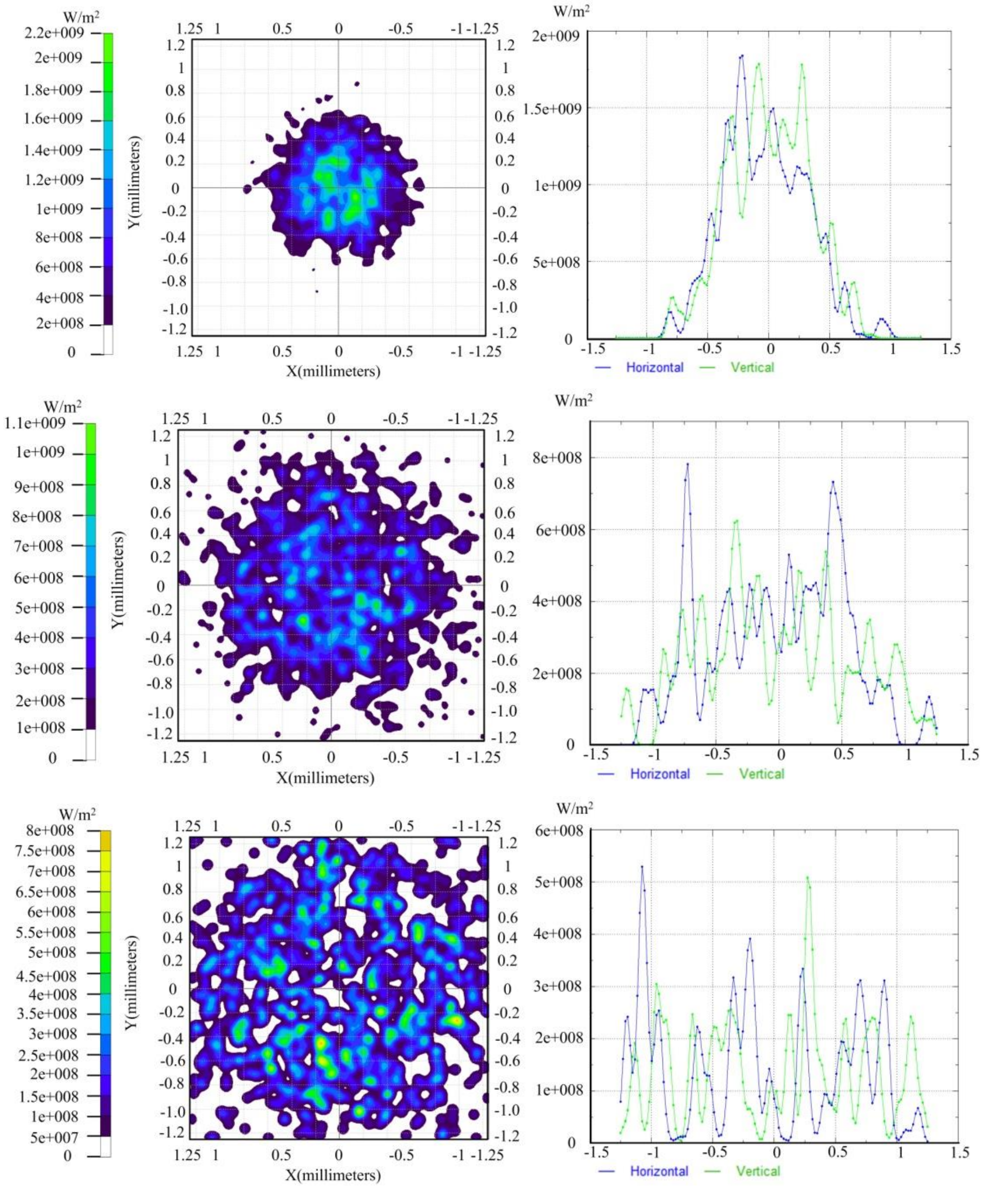

Figure 4. Distribution of irradiance at the receiving surface of the Fresnel lens

According to the simulation results in Fig. 4, when the angle of incident light incident on the Fresnel lens is within 0.5°, the maximum irradiance at the receiving surface is $2.13\times10^{9}\,\mathrm{W/m^2}$, the average irradiance is $1.64\times10^{8}\,\mathrm{W/m^2}$, and the lens condensing efficiency reaches 90%. The radius of the spot is 0.6mm; when the angle of incidence of incident light on the Fresnel lens is within 1°, the maximum irradiance at the receiving surface is $1.07\times10^{9}\,\mathrm{W/m^2}$, the average irradiance is $1.58\times10^{8}\,\mathrm{W/m^2}$, and the lens condensing efficiency reaches 86%. The radius of the spot is 1.2mm. When the angle of incidence of incident light on the Fresnel lens is within 1.5°, the maximum irradiance at the receiving surface is $7.92\times10^{8}\,\mathrm{W/m^2}$, the average irradiance is $1.35\times10^{8}\,\mathrm{W/m^2}$, and the lens condensing efficiency reaches 74%. The spot radius of the spot has increased; therefore, when the angle of incidence of incident light on the Fresnel lens increases, the optical efficiency of the Fresnel lens decreases, and the area of the focused spot increases. Diffusion spots in the image point become larger.

3. THE FIELD OF VIEW OPTIMIZATION

The study shows that the optical gain of the hemispherical optical antenna is constant in the large field angle, which is suitable for the light collection in the wide FOV. Therefore, combined with these two kinds of optical antenna characteristics, we optimize the fresnel antenna.

The light ray is collected by Fresnel lens, and focused by the hemispherical lens on the photoelectric detector. we set the hemispherical lens which the radius of is 5mm, the refractive index is 1.517. the distance between the Fresnel lens and hemispherical lens is set to 40mm (Fresnel lens focus). Via Tracepro, The light from the randomly distributed point light source is used to simulate the light. When the divergence half angle of random light source is α, the angle of incident light is evenly distributed between 0~α. The optical gain is defined the ratio of the amount of light rays are received by the same detector with and without the optical antenna at the same angle α. The distribution of the received irradiance of the system on the receiving surface is obtained at the FOV of 40°. The amount of rays collected by non-optical antenna the fresnel lens receiving antenna, and fresnel and hemispherical receiving antenna which are 40, 50 and 186, respectively as shown in Fig. 6

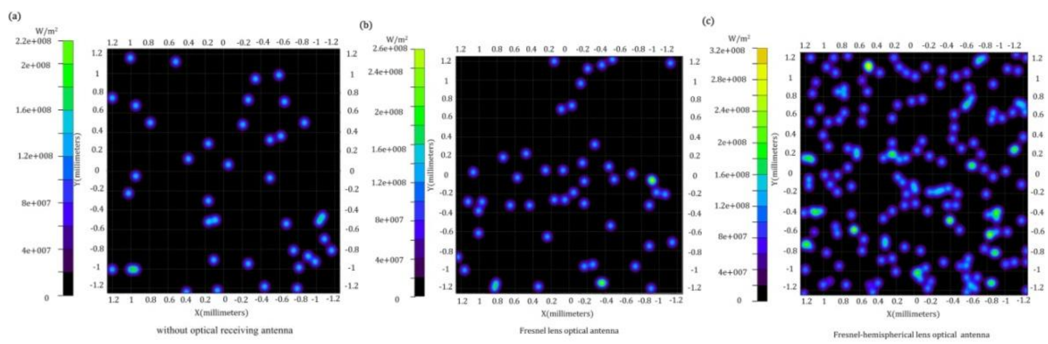

Figure 5. Power received by: (a)non-optical antenna (b) single Fresnel (c) Fresnel and hemispherical antenna

Table 1. The gain of the different optical antenna at different FOV 40°

Optical receiving antenna	Only fresnel lens	Fresnel and hemispherical lens
gain	1.25	4.6

The result show that the gain of the Fresnel and hemispherical receiving antenna is 4.6, when the Fresnel lens is 1.25. By comparison, the Fresnel and hemispherical lens optical antenna meets the required field of view, which has a high optical gain as shown in table 1

4. CONCLUSION

This paper design a Fresnel lens optical receiving antenna to collect light energy in free space and improve the quality of the VLC system. The results show that the viewing angle reaches 40° and the optical gain is 4.6.

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