Simulation and optimization of the intensity profile of an optical transmitter for high-speed wireless local area networks

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ABSTRACT

The promise of high un-regulated bandwidth at a low-cost and low-power consumption makes optical wireless (OW) an attractive technical alternative for short-range wireless communication. The most important issues that an OW system designer must take into account are the amount of received optical power, background interference, and the permissible transmitter power. A possible technique that can increase the received optical power within eye safety limits, mitigate ambient light interference effects and reduce multipath dispersion is the long wavelength vertical cavity surface emitting laser (VCSEL) array-based multibeam transmitter. This paper presents the study of the intensity profile of a VCSEL array-based multibeam transmitter operating at 1.55µm wavelength. The optimization of the intensity profile, to achieve the uniform intensity distribution in the receiver plane, is also discussed.

Keywords: Beam shaping, Gaussian intensity profile, infrared radiation, optical wireless LAN, VCSELs

1. INTRODUCTION

The increased use of portable computing and multimedia terminals in recent years has led to a growth in interest in the area of high-speed wireless digital links and local area networks (LANs). For such applications, optical wireless (OW) communication has become a practical high-bandwidth access tool with many potential advantages when compared with radio frequency approaches. The two major OW transmission link configurations that can be realized are direct beam infrared (DBIR) and diffuse infrared (DFIR) radiation[1]. A high-capacity indoor optical wireless LAN architecture[2] was proposed in our earlier work that possesses the advantages of DBIR configuration and overcome the drawbacks of the DFIR links. The system has an active base station (BS) mounted on the ceiling of a room above the coverage area. To form a local area network, the BS as well as each terminal located in the coverage area is equipped with an integrated transceiver. The individual component of the transceiver consists of a light source, its paired detector and the necessary drive, control and modulation or demodulation electronics. The tracking function is achieved by the combination of a multi-element transmitter and multi-element receiver. The field of view of the transmitters as well as that of the receivers can be set from ±40˚ to ±50˚ to achieve a good coverage area in the receiver plane.

Most of the transmitters used in optical wireless systems utilize light emitting diodes (LEDs) as light sources, but they suffer from poor electrical-to-optical conversion efficiency, limited working speed and bandwidth, and broad spectral width, which make narrow-band optical filtering less effective at the receiver. The use of VCSELs as light sources is advantageous due to their well-controlled output beam properties, high modulation bandwidth and high efficiency. This paper presents the simulation and optimization of the intensity profile of a long wavelength VCSEL array-based multibeam transmitter for a star network topology based optical wireless LAN.

2. THE OPTICAL TRANSMITTER

The transmitter proposed in this work utilizes a two-dimensional 9x9 array of 10mW VCSELs operating at 1.55µm wavelength. The use of long-wavelength VCSELs make the system eye-safe, nearly immune to ambient light noise and offer the excellent power budget[2,3]. A matrix-type diffractive element[4] (DE) can be used to shape and direct the beam of each individual VCSEL. Each individual DE converts the VCSEL Gaussian beam to a super-Gaussian (flat top) beam and directs it to a desired solid angle. As a result, the overall angular range covered by the transmitter is divided into a number of narrow beam angles of individual VCSEL that can be switched electronically. The transmitters using this configuration are expected to reduce path loss compared to the diffuse transmitters, because the narrow beam experiences little path loss traveling from the transmitter to the destination receivers. Deactivating the VCSEL elements not emitting in directions of the destination receivers minimizes the transmitted power from the array of sources.

3. TRANSMITTER INTENSITY PROFILE

The VCSELs used for optical transmitter emit beams with a Gaussian intensity profile, which is relatively narrow and results in a non-uniform intensity distribution in the receiver. An exponential field distribution profile with order more than 2 is expected to provide better intensity distribution[5]. Section 3.1 presents the simulation of the Gaussian and super-Gaussian intensity profile of a VCSEL using LabVIEW-based software tool. Section 3.2 presents the simulation and optimization of the intensity profile of a VCSEL array-based multibeam transmitter for a propagation distance of Z = 2.4m in the receiver plane.

3.1 VCSEL intensity profile

VCSELs operating in the fundamental transverse mode emit beams with a Gaussian intensity profile. The intensity distribution of a Gaussian beam propagating along the Z direction is fully specified by either its beam waist radius (spot size) w_0 or its far-field divergence angle (θ). The optical intensity of a Gaussian beam is a function of the axial and radial distances Z and r, respectively and is expressed[5] as

$$I_{(r,z)} = I_0 e^{-2r^2/w^2} = I_0 e^{-2(x^2+y^2)/w^2} = \frac{2P_T}{\pi w^2} e^{-2(x^2+y^2)/w^2} \qquad - \ (1)$$

where $w = w_z$ is the radius of the $1/e^2$ contour after the wave has propagated a distance Z, and P_T is the total power in the beam. Within the transverse plane, the beam intensity assumes its peak value on the beam axis, and drops by the factor $1/e^2 = 0.135$ at the radial distance $r = w_z$. Since 86.5% of the beam power is carried within a circle of radius w_z, w_z is called the beam radius or beam width.

For large values of propagation distance $Z >> w_0^2/\lambda$, the beam radius w_z and far-field divergence angle (θ) are given by,

$$w_z = \frac{\lambda Z}{\pi w_0} \qquad - \qquad (2)$$

$$\theta = \frac{w_z}{Z} = \frac{\lambda}{\pi w_0} \qquad - \qquad (3)$$

where λ is the wavelength of the optical source.

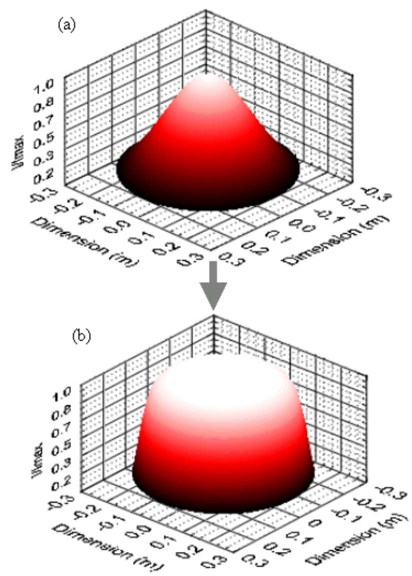


Figure 1. The normalized simulated 3-D intensity profile of a VCSEL in the receiver plane (a) Gaussian, (b) super-Gaussian order

The VCSELs[3] considered in the optical transmitter for this work have w_0 = 4.25µm, and emit P_T = 10mW at 1.55µm wavelength. Figure 1(a) shows the simulated far-field Gaussian intensity profile for a VCSEL at a propagation distance of Z = 2.4m.

The 3-D far-field Gaussian intensity profile of a VCSEL as shown in Figure 1(a) is relatively narrow and results in a non-uniform intensity distribution in the receiver plane. The super-Gaussian intensity profile with order p, where p>2, is expected to provide better intensity distribution[5]. The intensity distribution of the Super-Gaussian beam is given by,

$$I_{sg}(r) = I_{sg_0} e^{-2(r/w)^p} = P_T \frac{2^{2/p}.p}{2\pi w^2 \Gamma(2/p)} e^{-2(r/w)^p} \qquad - \ (4)$$

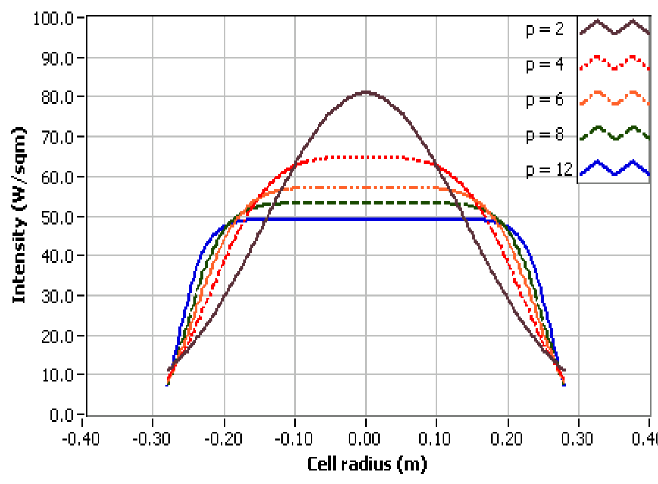


Figure 2. Super-Gaussian intensity distribution of a VCSEL at Z = 2.4m for different values of p = 2, 4, 6, 8, and 12.

Using the above expression, we have simulated the Super-Gaussian intensity profile for a single VCSEL with p = 2, 4, 6, 8 and 12 at a propagation distance of Z = 2.4m (Figure 2). The Gaussian profile is a special case of the super-Gaussian profile with p = 2 and having a peak intensity of 82.0W/sqm. For larger p, the profile tends to become flat topped with the decreasing peak intensity. Figure 1(b) shows the simulated 3-D intensity profile of a VCSEL for p = 12, which is nearly flat-topped with an optical intensity of 49.6W/sqm throughout the flat region.

3.2 Simulation and Optimization of the transmitter intensity profile

For the intensity profile simulation, we have considered the 9x9 VCSEL array transmitter mounted on the base station (BS) on the ceiling of a room, Z meter above the coverage area. The light beams emitting from the VCSEL array form a squared coverage area of light intensity cells in the receiver plane. Using the DEs, the optical axes of light beams can be aligned in such a way that the radial cells in the receiver plane overlap by angle $\theta' = 0.65\theta$. Figure 3 shows the central cell C0 and one side of the X or Y-axis radial cells (C_{1x} to C_{4x}). Other side of the radial cells is denoted by $C_{1'x}$ to $C_{4'x}$. The effective radii (R_{nx})and the propagation distances (Z') for these cells are determined as below:

The radius Ro of central cell C0 is

$$R_0 = \frac{D_o}{2} = Z.\tan\theta \qquad - \qquad (5)$$

The radius for an n[th] radial cell C_{nx} or $C_{n'x}$ is

$$R_{nx} = R_{n'x} = \frac{D_o}{2} = \frac{Z}{2}[\tan\{(2n+1)-0.65\}\theta - \tan\{(2n-1)-0.65\}\theta] \quad - \quad (6)$$

Similarly, the effective propagation distance Z' for the n[th] cell is

$$Z'_{nx} = Z'_{n'x} = Z.\sec(2-0.65)n\theta \qquad - \qquad (7)$$

The effective radii and the propagation distances for the diagonal radial cells C_{1d} to C_{4d} and $C_{1'd}$ to $C_{4'd}$ are determined using X or Y-axis radii and propagation distances.

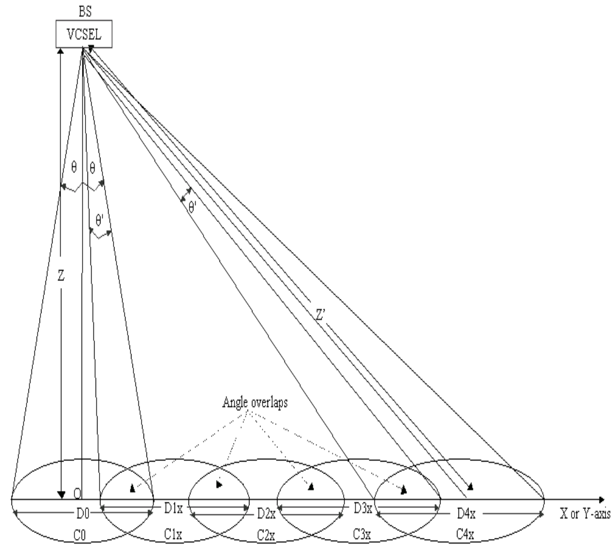


Figure 3. Axial circular cells (one side) in the receiver plane

The intensity profile for the transmitter is simulated using LabVIEW-based software tool and equations (1) to (7). Figure 4(a) shows the Gaussian (super-Gaussian order p =2) intensity distribution of the transmitter for a propagation distance of 2.4m on the X or Y-axis of the receiver plane. In the receiver plane for the cell area of 4.2mx4.2m, the intensity varies from 14.5W/sqm to 82.0W/sqm, which is non-uniform. The matrix-type DEs as mentioned earlier can be used to shape and direct the beam of each individual VCSEL[4]. Each individual DE converts the VCSEL Gaussian beam to a super-Gaussian (flat top) beam of order p = 12 and directs it to a desired solid angle. Figure 4(b) shows the intensity distribution of the transmitter in X or Y-axis dimensions using the super Gaussian order p =12 (SG-12). In the receiver plane for the cell area of 4.2mx4.2m, the intensity varies from 27.0W/sqm to 49.6W/sqm. Figure 4(c) shows the intensity distribution of the transmitter diagonally in the receiver plane, which varies from 17.5W/sqm to 49.60W/sqm diagonally. This optical intensity variation is acceptable for most of the receiver detectors having their effective area from 0.2 –0.3sqm.

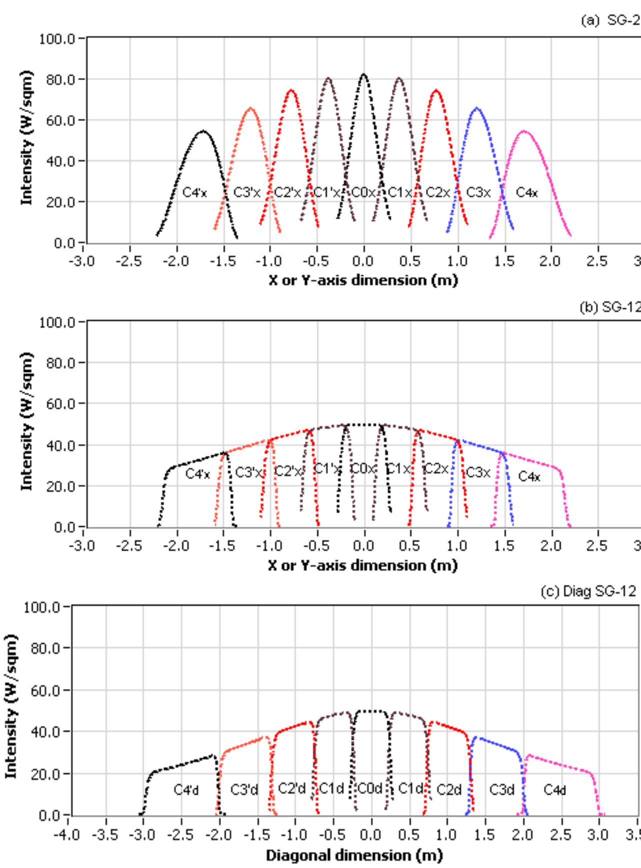
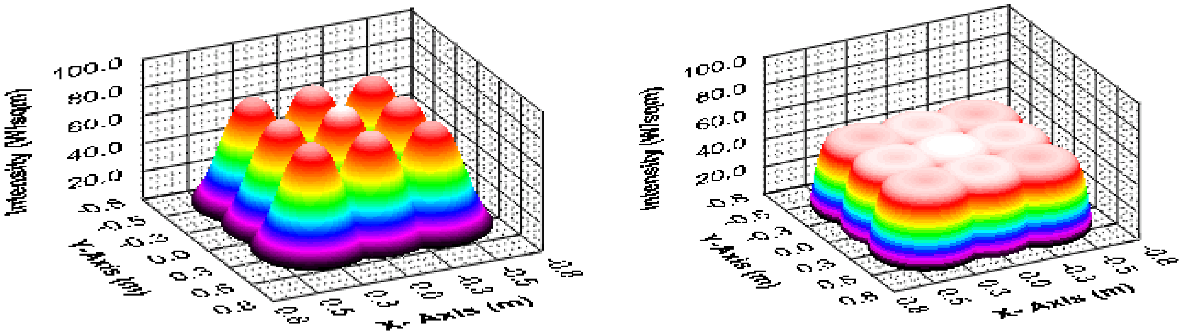


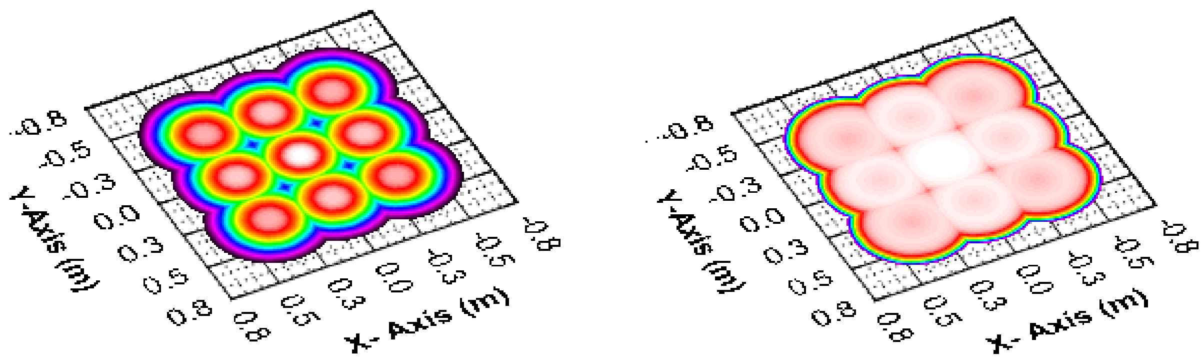
Figure 4. Intensity distribution of the 9x9 VCSELs array based transmitter (a) Gaussian, (b) super-Gaussian, (c) super-Gaussian diagonal

The simulated Gaussian and super Gaussian 3-D intensity profiles for a 3x3 VCSEL array-based transmitter are shown in Figure 5. Figure 6 shows the 2-D cross sectional views of the Gaussian and super Gaussian intensity profiles for this transmitter. The 2-D and 3-D intensity profiles can also be presented for a 9x9 VCSEL array-based transmitter.



(a) (b)

Figure 5. The simulated 3-D intensity profile of a 3x3 VCSELs array-based transmitter; (a) Gaussian profile, (b) super-Gaussian (flat-top) profile



(a) (b)

Figure 6. The simulated 2-D cross sectional views of a 3x3 VCSELs array-based transmitter (a) Gaussian profile, (b) super-Gaussian (flat-top) profile

4. CONCLUSIONS

In this paper, we have presented the simulation and optimization of intensity profile of an optical transmitter for high-speed wireless local area networks. The conversion of VCSEL's non-uniform Gaussian intensity profile into uniform super-Gaussian profile using diffractive elements is also considered. For the simulation of the intensity profile, the beam shaping elements are considered to be ideal.

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