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3D Coverage Area Analysis of Indoor Mobile Optical Wireless Antenna for Portable Devices

Syam Challa and Banmali S. Rawat*

Department of Electrical and Biomedical Engineering
University of Nevada, Reno, NV 89557-0260, U.S.A.
Tel: 1-775-784-1457; Fax: 1-775-784-6627; E-mail: rawat@ee.unr.edu

***Abstract* - A high demand for bandwidth and data rates has paved way for optical fiber and optical wireless (OW) communications to become last mile solutions for optical communications. This paper focuses on providing a solution to obtain OW for indoor mobile portable devices. A new optical antenna model is proposed for such portable devices. Optical sweeping in 3D using Acousto Optics Cell Arrays (AOCAs) is proposed. This method has better and precise beam divergence manipulation capabilities. Its geometry and coverage area have been thoroughly analyzed. The optical antenna can sweep through the hemispherical shape in the direction of optical beam focal plane using AOCAs. The link budget analysis is done using commercially available component ratings. The limitations on the nodes such as size and power consumption are investigated and the model is designed to run efficiently on power ratings of the portable device battery.**

***Index Terms* – Optical Antenna, Optical Coverage area, portable devices, VCSEL Transceivers.**

I. INTRODUCTION

The face of communication has completely changed with the introduction of optical fiber technology in 1970. A large bandwidth of data is being transmitted each day through optical fibers both in long and short distance communications. Optical communication is known for its high speed and large bandwidth capacity. Optical communication can be classified into two categories namely Optical fiber communication and Free Space Optical (FSO) communication. Free Space Optics also known as FSO or OW (Optical Wireless) uses similar sources and detectors as that of optical fiber communication but uses atmosphere or air as its transmission medium. This paper investigates the feasibility of using FSO technology for indoor mobile applications with portable devices. The main limitation on FSO systems is that they need a clear LOS. The loss of LOS results in the loss of signal and it also affects the communication parameters like data rates and Bit Error Rates (BER). LOS can be achieved using direct LOS method or nondirected LOS method [1].

FSO finds most of its applications in solving the last mile connectivity problems in optical communication. FSO is widely used in MANs (Metropolitan Area Networks) for connectivity between buildings and short range CANs (campus area networks). Several researchers have proposed different methods of using FSO for indoor optical fiber less communication using Infrared links and LEDs [2]. This paper focuses on applying OW to indoor mobile to mobile portable devices and mobile to stationary nodes. 3D mobile OW for indoor systems has been thoroughly investigated. The proposed optical antenna provides better coverage area and mobility than previously published research papers [3-4]. This Opto-electronic method provides better coverage area for Line Of Sight optical link establishment and reconnection. The proposed method also has superior and precise beam divergence manipulation capabilities. A model to incorporate these optical components into optical antenna that can be placed in portable devices is investigated.

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II. COVERAGE AREA ANALYSIS

The total area where an optical transceiver can establish a successful LOS with another transceiver can be defined as coverage area. Fig 1 represents a general form of single transceiver coverage area where θ is the divergence angle, h is the radius of the beam intensity on the focal plane; L is the spatial distance between the transceiver and the focal plane.

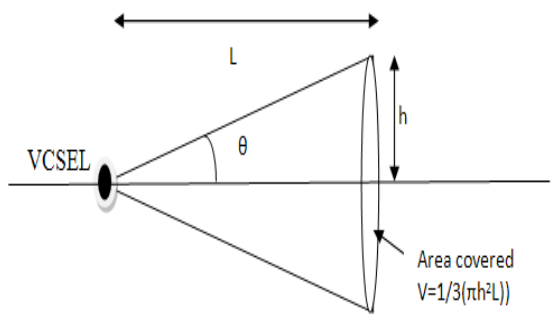

Fig 1: Single Transceiver coverage Area

Assuming the power received at a distance L from the source is higher than the receiver's minimum sensitivity, a successful LOS can be established within the spatial volume of the cone. Then the spatial volume of the cone would become the coverage area of the VCSEL.

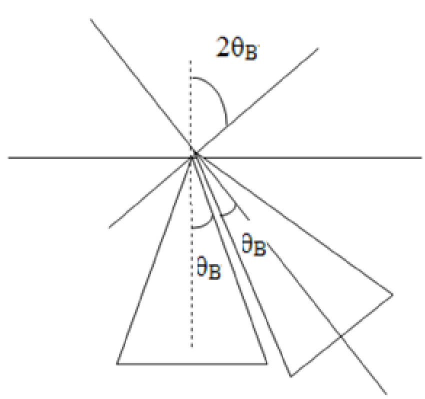

Fig 2 Minimum angle between focal planes

To increase the coverage area for diodes placed closely, the focal planes should be different. By changing the focal plane of beam directivity higher spatial resolution for coverage area can be achieved. Fig 2 shows two diodes at a two focal planes separated by $2\theta_B$. To optimize the area covered the overlap should be zero between the two beam projections. The minimum separation angle between the two beams to avoid overlap is $2\ \theta_B$ as seen from Fig.2. For a node with divergence angle of θ_B, and a deflection angle of $\Delta\Phi$, the diode can sweep the total angle obtained as,

$$\theta_S = 2\theta_B + \Delta\Phi. \qquad (1)$$

where θ_S is the total sweep angle.

Total number of diodes for optimal coverage area of the entire spatial range in the direction of beam propagation can be obtained as

$$N_V = \left(\frac{}{4\theta B + 2\Delta\Phi.}\right) \qquad , \qquad (2)$$

and the average angle of deviation for each diode in a focal plane is given by

$$\theta_{avg} = \frac{}{N_V} \qquad . \qquad (3)$$

The AOCAs work on the principle of Acousto-Optic effect of diffraction. A transducer is attached to AOC which is subjected to RF signal in the range of MHz to GHz depending on the deviation of beam required. These cells are made of anisotropic materials such as LiNbO3. The generalized deflection angle for 3D deflection angle is given by [5-6]

$$\theta_{drm} = \prod_{m=1}^{M} \prod_{n=1}^{N} \left[\cos * \sin^{-1} \left\{ \left(\frac{\lambda_{in}}{n_0} \right) \right. \right. \left[\right.$$

$$\left. \left. \left((-1)^n \sum_{n=1}^{N} (-1)^n \frac{f_{arm}}{\upsilon_{arm}} \right) + (-1)^n \sin\theta_{i1} \right\} \right] \left[\vec{a}_x + \vec{a}_y \right]$$

$$+ \left[\left(\frac{\lambda_{in}}{n_0} \right) \left((-1)^n \sum_{n=1}^{N} (-1)^n \frac{f_{anm}}{\upsilon_{anm}} \right) + (-1)^n \sin\theta_{i1} \right] \vec{a}_z$$

(4)

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where, n = number of cells from 1, 2, 3…..N and m = number of stages from 1, 2.....M.

Deflection angles of up to 5 to 20^0 are achieved and are also commercially available [3-4]. The wide ranges of deflection angle that are achieved by the AOCAs are very useful for optical scanning. A larger spatial distribution can be covered by an optical antenna using AOCAs without using any mechanical rotation.

III. RESULTS AND DISCUSSION

By employing AOCA the total sweeping angle of the transceiver increases as seen from Fig 3. Fig 3 shows the area covered by sweeping the antenna at a deflection angle of 0.2 rad.

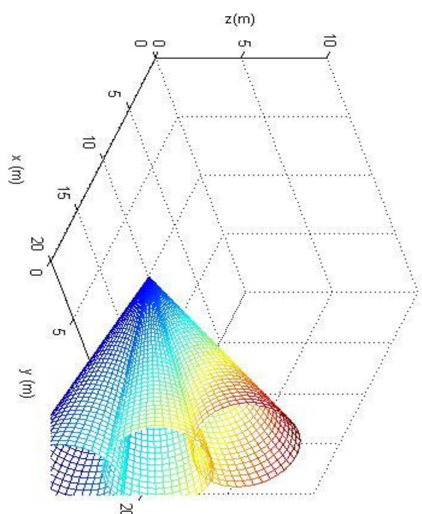

Fig.3: Coverage area by sweeping across deflection angle.

The coverage area can be further increased by scanning the optical beam from the VCSEL diode in 3D using AOCAs. AOCAs can be used to manipulate the beam in X, Y and Z directions. This beam manipulation can be done in horizontal direction, vertical direction or in combination of both. The ability to scan the optical beam in any of these sweeping directions, optimizes the number of optical sources needed to cover any given spatial distribution. By limiting the number of optical components the size of the total packaging, power consumed and the cost of the equipment can be reduced considerably, thus making OW a viable competitor for commercial mobile applications.

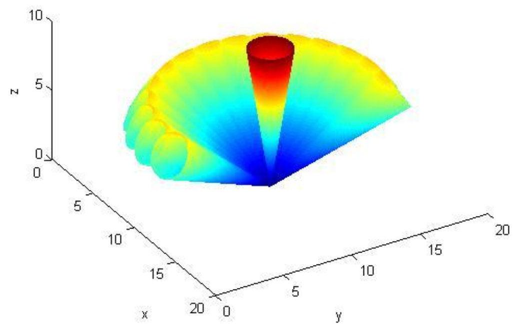

Fig 4 Coverage Area by azimuth sweep

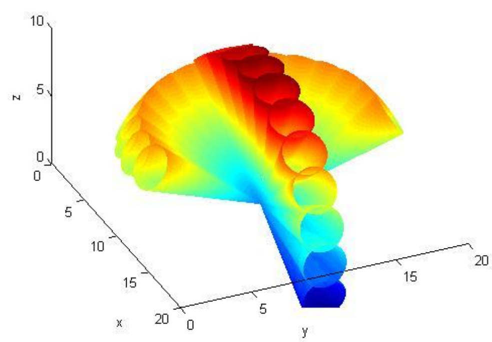

Fig 5 Coverage Area by horizontal and vertical sweep

The area and volume covered in 3D by horizontal and vertical sweeps are shown in Figs. 4 and Fig 5, respectively. The different colors represent the variations in optical intensity with distance. The combination of horizontal and vertical sweeps in 3D covers the entire hemisphere in the direction of the focal plane. Fig 4 shows a transceiver beam projected in Z direction that is swept in multi circular spot diffusion manner. Fig 5 shows a transceiver beam projected in Z direction that is swept in a combination of linear and circular multi spot diffusion manners. Each spot can be

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viewed as a sub region to scan for new nodes. An optical antenna can be defined as a device that has the ability to scan for other nodes optically and establish an optical communication link with it. The optical antenna proposed in this paper is a combination of VCSEL transceivers and AOCAs.

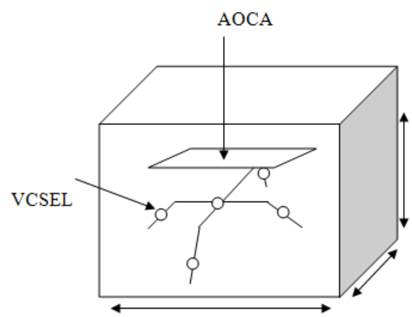

Fig 6 Geometry of Optical Antenna

Fig 6 shows the geometry of the proposed optical antenna. The cube covering the optical antenna can be as small as 2x2x2 mm depending on the fabrication process. This assumption is made based on the size of the optical components that are commercially available. The combination of N_V VCSEL diodes with θ_{avg} deviation angle forms one optical antenna. The Optical antenna consists of VCSEL diode arrays on multiple focal planes. Fig 6 shows a sample optical antenna with two arrays and three focal planes. Using 3D AOCAs the same deflection angle can be achieved in all three directions. This allows the optical antenna to sweep through the total deflection angle in 3D uniformly. The size of AOCA arrays are in the order of few µm to mm [3-4] which makes multiple stages to be incorporated ergonomically. This method provides very high directionality and power/area which allows small receiver apertures to be utilized. Indoor dimensions of Height (5m), Width (20m), and Length (20m) are considered. The following AOCA parameters are used for the calculations: Access time: 1 µs; Acoustic Velocity $4 * 10^3$ m/s; Dimensions: .5 mm x .5 mm; RF power needed = 0.56 W; RF frequency = 15 MHz; Deflection angle Φ= 0.348 radians.

IV CONCLUSIONS

A new optical antenna model is proposed and realized analytically for indoor mobile portable devices. Its geometry, coverage area and mobility are analyzed. The optical antenna can cover the entire spatial distribution of an indoor area. The coverage area of the proposed optical antenna includes the entire hemisphere in the direction of the focal plane. This is achieved by using a combination of VCSEL diodes on different focal planes along with AOCAs. The AOCAs provide the deflection angle that can be used to sweep the entire spatial distribution with a fixed divergence angle of the VCSEL source. The dimensions of the optical antenna need to fit the portable devices they are mounted on. The optical antenna dimensions are as small as 2x2x2 mm.

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