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Free-Space Optical Communication for CubeSats in Low Lunar Orbit (LLO)

P. M. Goorjian peter.m.goorjian@nasa.gov
NASA Ames Research Center, M. S. 258-1, Moffett Field, CA 94035-1000

1 INTRODUCTION

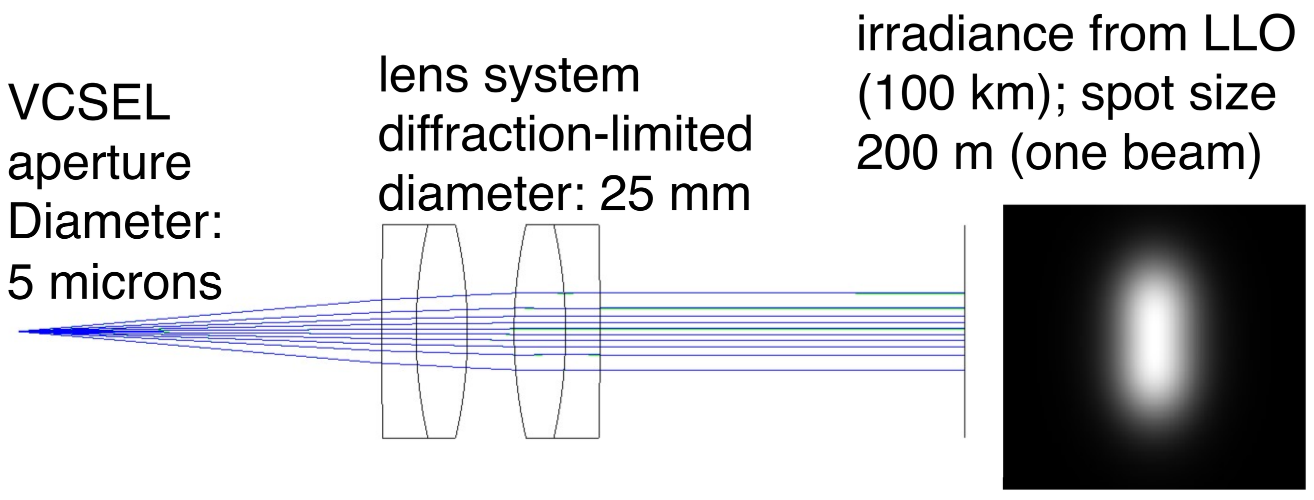

Figure 1: Propagation of two overlapping laser beams.

The NASA ARTEMIS Program will include LunaNet, a highly extensible, open architecture, lunar communications and navigation network. A constellation of CubeSats in Low Lunar Orbit (LLO), 100 km, could form an optical communications and navigation network as part of LunaNet, with terminals on the lunar surface, including mobile ones such as with astronauts and rovers. The proposed CubeSat nodes should provide data relay and navigational aid services. *The proposed effort herein is to develop a fine pointing capability for laser beam pointing to augment body pointing by CubeSats.* Body pointing was used by Aerospace Corporation for the CubeSats in LEO in NASA's Optical Communications and Sensors Demonstration (OCSD) program [1]. Previously, this fine pointing capability was computer simulated for the OCSD program [2,3]. With fine pointing, the spot size on the Earth was reduced by a factor of eight with a reduction in laser output power by a factor of sixty-four, thereby mitigating the thermal load challenge on the CubeSats. The same reductions in spot size and laser output power can be achieved for CubeSats in LLO.

A new method is described for optical data transmissions from satellites, which uses laser arrays for laser beam pointing. It combines a lens system and an array of vertical-cavity, surface-emitting lasers and photodetectors, an VCSEL/Photodetector Array, (both mature technologies), in a novel way. This system is applied to CubeSats in low lunar orbit, (LLO), which use body pointing. Also, It may be able to replace current architectures which use dynamical systems, (i.e., moving parts) to point the laser, and which may also use vibration isolation platforms.

The computer simulations used the optics code, OpticStudio, from Zemax, LLC, which has the capabilities to model the laser source and diffraction effects from wave optics. These capabilities make it possible to model laser beam propagation over long space communication distances.

2 NEW CONCEPT FOR LASER BEAM POINTING

2.1 Technical Approach

As Fig. 2 shows, an incoming laser beam (green or blue, with rightward arrows), transmitted from a ground terminal, enters the lens system, which directs it to an element of the pixel array (gray rectangle). Each element, or pixel, consists of a VCSEL component/Photodetector pair. The photodetector detects the incoming beam, and the VCSEL component returns a modulated beam to the lens system (green or blue, with leftward arrows), which sends it to the ground terminal.

As the incoming beam changes direction, e.g., from the blue to the green incoming direction, this change is detected by the adjacent photodetector, and the laser paired with that photodetector is turned on to keep the outgoing laser beam on target. The laser beams overlap so that the returning beam continues to point at the ground terminal. The VCSEL component may consist of a single VCSEL or a cluster of VCSELs

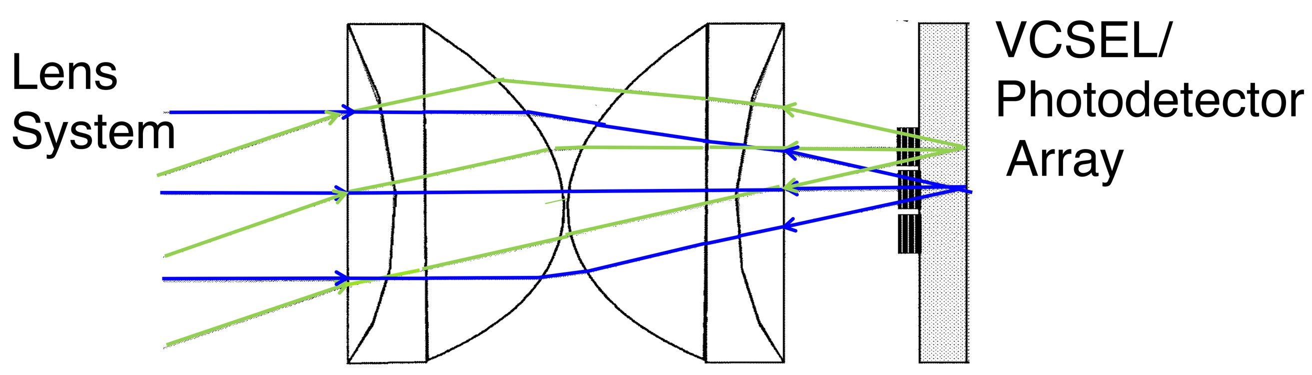

Figure 2: Space Optical Communications using a Lens System with a Vertical Cavity Surface Emitting Laser (VCSEL)/ Photodetector Array

2.2 VCSEL/ Photodetector Array

Figure 3 shows a candidate VCSEL/ Photodetector Array. In this array the pitch, (i.e. the distance between elements), is the same for the VCSEL clusters and the photodetectors. Also, this packing pattern makes the distance between adjacent elements equal.

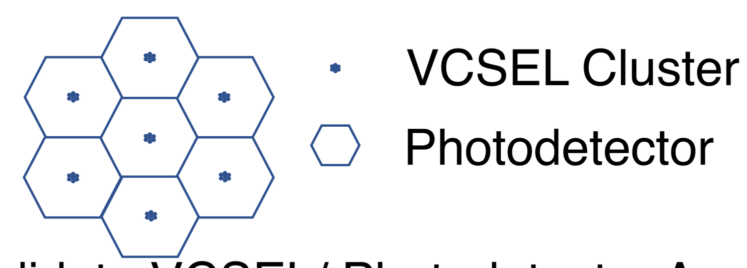

Fig. 3: Candidate VCSEL/ Photodetector Array

Figure 4 shows a fabricated VCSEL/ Photodetector Array and a fabricated VCSEL/Photodetector pair. The Photodetectors are p-type/intrinsic/n-type (PIN) detectors

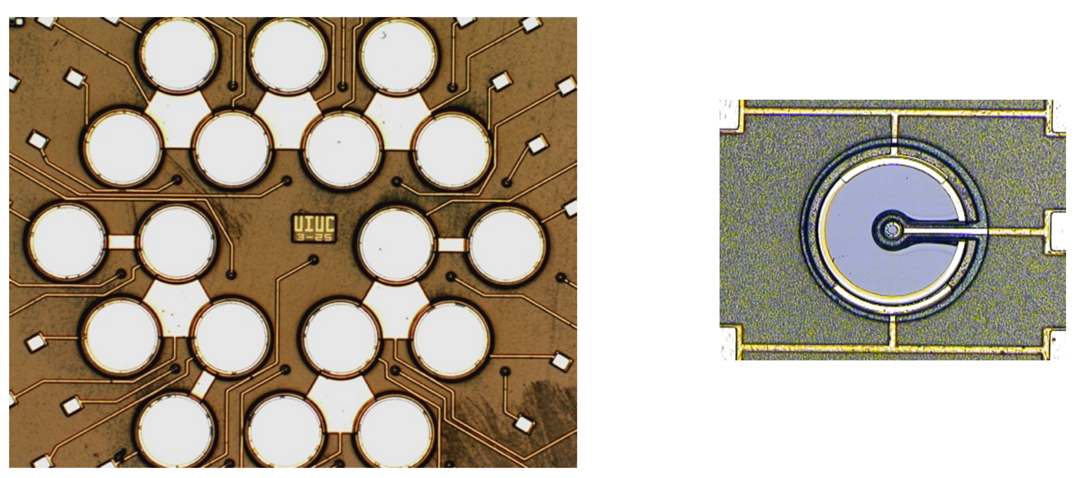

Figure 4: a) Top-view of a 37-element VCSEL / PIN detector array. VCSELs are small black dots and photodetectors are large white circles, b) Top-view of a VCSEL /Photodetector pair

3 LLO APPLICATION

An application will be made to show how this new pointing system can be used to augment a laser pointing system on a CubeSat in LLO that uses star trackers for body pointing. The new pointing system would provide a fine pointing capability to the CubeSat pointing system. With the resulting more accurate pointing, the power requirement would be substantially reduced and the resulting thermal load also reduced, thereby mitigating the thermal load challenge. Figure 5 shows the irradiance and phase of the wave front at 100 km of propagation, a LLO distance, for a laser beam with a divergence of 0.46°, without using fine pointing. The laser beam wavelength is 1064 nm and the laser output power is 2 W. The irradiance has a Gaussian profile, and the phase is essentially flat, so that this beam is diffraction limited. The units for the distances in Fig. 5 are in mm and the diameter of the spot is about 1600 m.

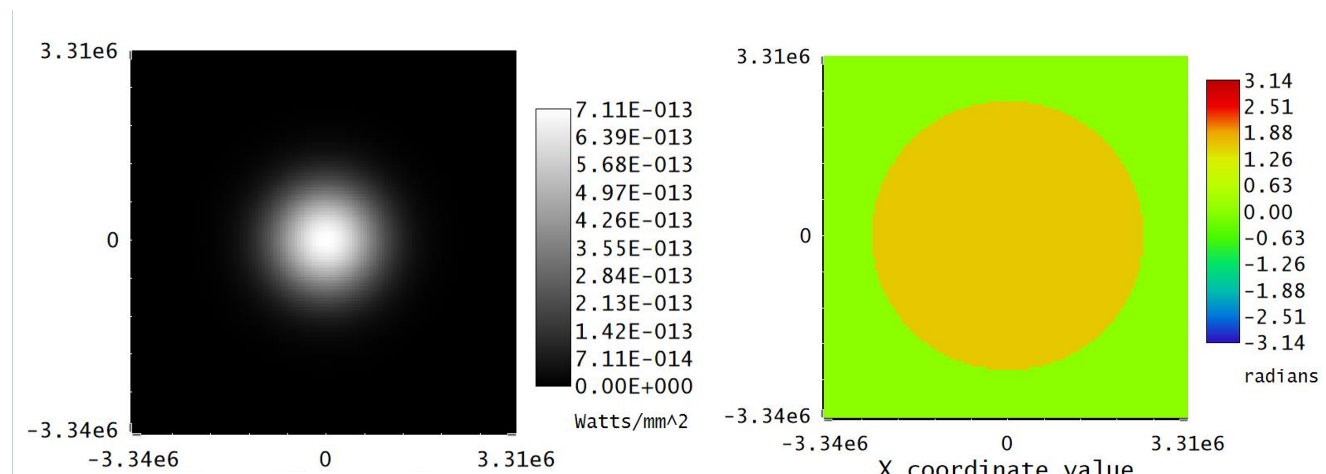

Figure 5: a) irradiance, b) phase

Figure 6 shows the irradiance and phase of the wave front at 100 km for the laser beam from the new lens system. The laser beam has a divergence of 0.057° and the diameter of the spot is about 200 m. The laser beam wavelength is 850 nm and The output power from the laser cluster is 30 mW. The irradiance has a Gaussian profile, and the phase is essentially flat, so that this beam is diffraction limited. The units for the distances are again in mm

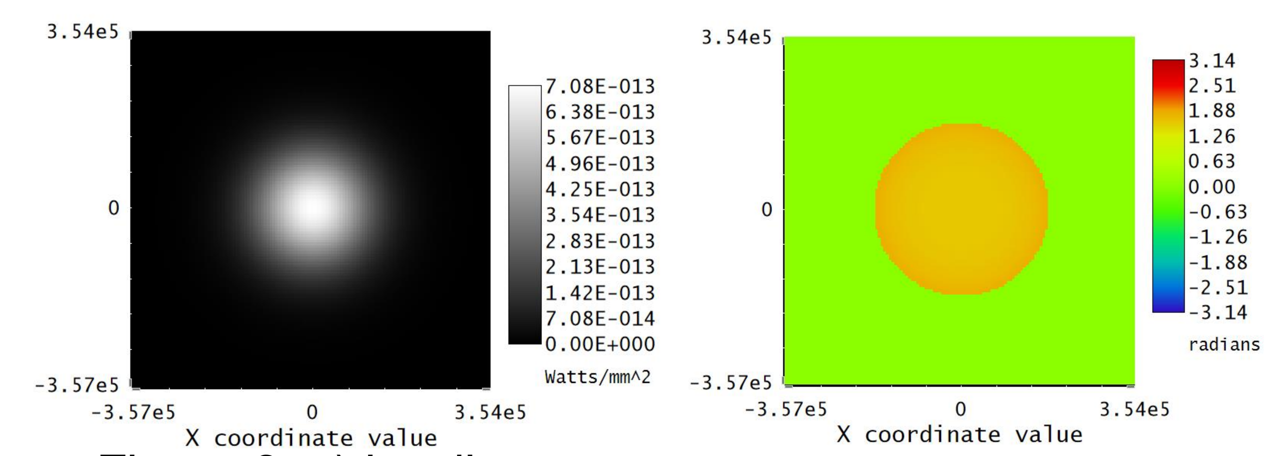

Figure 6: a) irradiance, b) phase

By using a laser/photodetector array with 64 elements, the laser beams would cover the same area as the single laser shown in Fig. 5. By detecting the incoming beam from the ground terminal, only one laser would need to be turned on to send the data down, leading to a significant reduction in required laser output power.

Simultaneous optical multiple access (OMA) is possible from different transceivers within the area covered by the laser array.

The lens system is described in detail in the manuscript. For it, the spots from two adjacent laser beams from the satellite in LLO overlap on the Moon, so there is no loss of coverage of the ground terminal by the beam as the direction from the lens system to the ground terminal changes. The length of the entire lens system is 47 mm.

4 CONCLUSIONS

A new method has been described for optical data transmissions from satellites using laser arrays for fine laser beam pointing. It combines a lens system and a VCSEL/Photodetector Array, both mature technologies, in a novel way. Also, It may be able to replace current architectures which use dynamical systems (i.e., moving parts such as fast-steering mirrors (FSM), and/or gimbals) to point the laser, and which may also use vibration isolation platforms.

REFERENCES

[1] T.S. Rose et al., "Optical communications downlink from a 1.5U CubeSat: OCSD program" Free-Space Laser Communications XXXI, SPIE Photonics West 2019, San Francisco, CA, February, 2019.
[2] Goorjian, P. M., "A New Laser Beam Pointing Method Using Laser Arrays", SPIE PW 2019, February, 2019.
[3] Goorjian, P. M., "Free-Space Optical Communication for Spacecraft and Satellites, including CubeSats in Low Earth Orbit (LEO)", OSA Advanced Photonics Congress, July, 2019.