Omni-directional Free Space Optical Laser Communication

MERIT 2007

Kenneth Tukei

University of Maryland, College Park

Dr. Christopher Davis

Faculty Advisor

Navik Agrawal

Graduate Student Advisor

Maryland Optics Group

Department of Electrical and Computer Engineering

University of Maryland, College Park

Abstract

In a communication system high bandwidth is often highly desirable. Laser based optical communication systems offer advantages in bandwidth and speed over traditional radio frequency (RF) communication systems. This project aims to build a miniature FSO high speed high bandwidth laser communication system that operates at around 10Mb/s. This system will operate either by direct line-of-sight or possibly by diffuse reflection from one or more laser transmitters to one or more photo-receivers. Each photo-receiver unit will utilize a compound parabolic concentrator (CPC), which has a large angular field of view and whose purpose is to collect and concentrate as much laser light as possible onto the photodiode. The CPCs will be made by a molding and electroplating process. Subsequently, the photo-receiver units will be integrated into a hemispherical structure with lasers and photodiodes to make a multi-beam transceiver.

More importantly, the outcome of this project will serve as a prelude to a combined laser-RF communication system. Because laser systems perform better where RF systems are limited and vice versa, the strengths of one can be used to overcome the weaknesses of the other.

Introduction

Presently, high speed laser communication systems in use cost over tens of thousands of dollars and are not widely available; they are primarily used by big corporations and the military. However, the rapidly growing use of broadband services like television, phone, internet and wireless communication has created congestion in RF telecommunication networks and placed new bandwidth requirements on carriers. Customers require fast connections through these networks to fully exploit the available multimedia services and thus the need for high capacity data links. Laser transceivers offer an immediate, low-risk way of introducing desired network functionalities at high bandwidth and speed. The main benefit of point-to-point laser connection is that bandwidth is dedicated between the points, so this can make high speed communication possible between different places on earth. Because of its direct line of sight operation, point-to-point laser communication, especially in outdoor applications, can be plagued by environmental factors: physical obstacles, wind, rain, fog, and snow. The effects of these include reflection, refraction, and diffraction of light and can be sources of data loss. However, the scope of this project did not include a lossy outdoor environment. This laser communication system design is based on indoor applications which can also be approximated to an ideal outdoor environment (no wind, rain, fog, or snow).

Speeds of laser links can potentially reach ranges of gigabits per second and faster. Some applications might include computer networking, internet, cellular communication, and high definition television broadcasts. Small beam divergence, small size, and large information bandwidth due to operation at a higher frequency are all advantages of a laser system. Additionally, the advantages of light weight, small volume, and lower power consumption provide laser communication a potential edge over RF communication. At the moment, laser communication has few FCC requirements and restrictions because most of the high frequency bands (60GHz and above) are primarily used by the military and have less congestion.

Methods and Materials

To ensure high speed operation, the photodiodes used (S8314) have a maximum cutoff frequency of 500MHz and peak wavelength response between 800 and 900nm. The laser diode (VCSEL-850) has a peak wavelength of 850nm and high speed data operation speed of up to 2.5Gb/s, well suited for our goals.

Task 1:

Design current driver (transconductance amplifier–TCA) for laser diode transmitter using op-amps. The laser diode transmits a modulating signal to a photodiode receiver. At the receiver end, a photodiode (used with transimpedance amplifier–TIA) and CPC are used to convert the photocurrent generated into voltage, and a Schmitt trigger to sense transmitted voltage levels. Finally a multiplexer passes the TIA output or a zero voltage depending on the voltage registered on the Schmitt trigger (see fig 2, 3, 4).

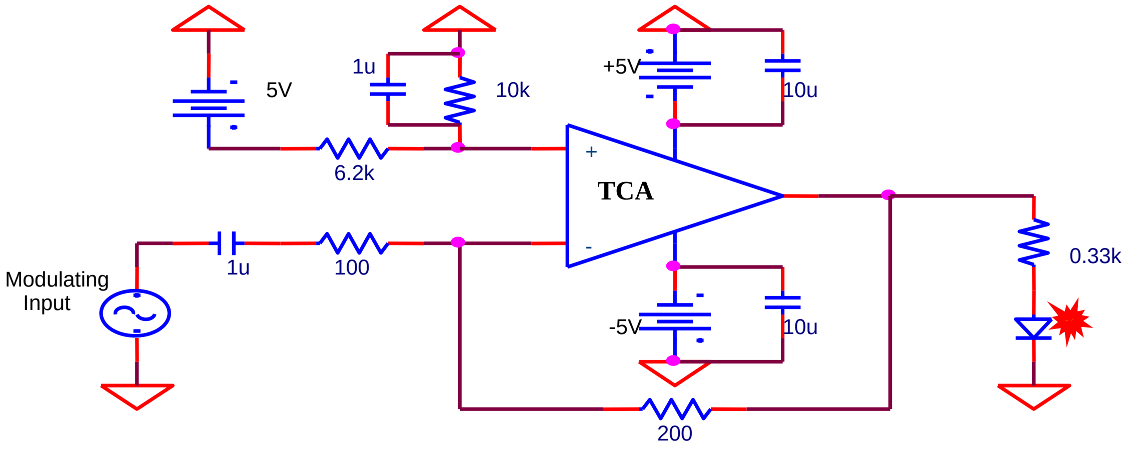


fig 2: Transconductance amplifier driving laser diode

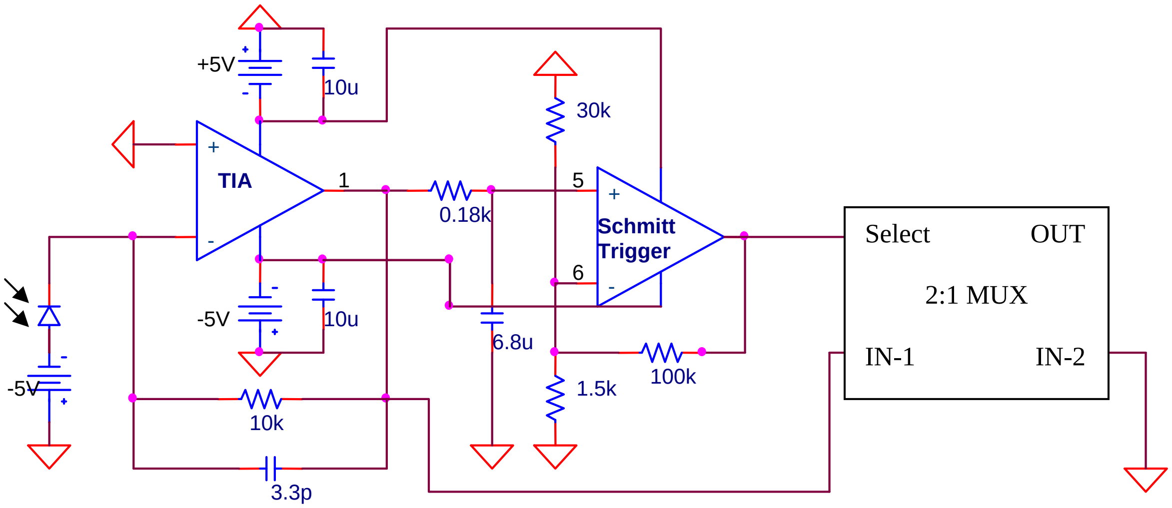


fig 3: Transimpedance amplifier, Schmitt trigger and Multiplexer

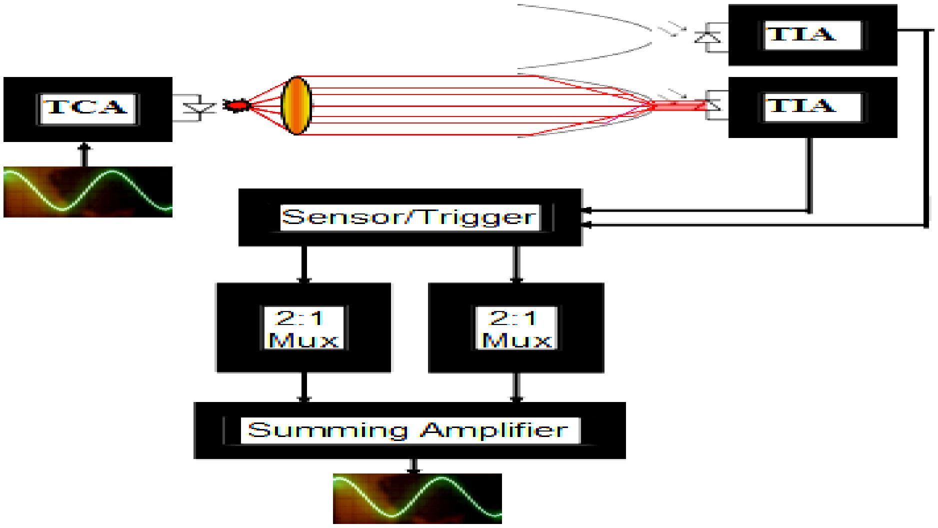
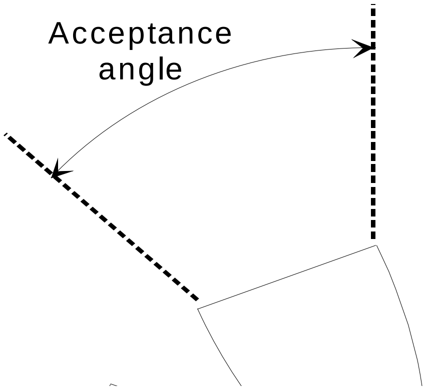


fig 4: Dual-CPC transceiver setup

Task 2:

Fabricate CPCs by electroplating a metallic mold with copper. A CPC operates on the principle that rays entering within its acceptance angle will undergo total internal reflection to appear at the exit aperture (fig 6).



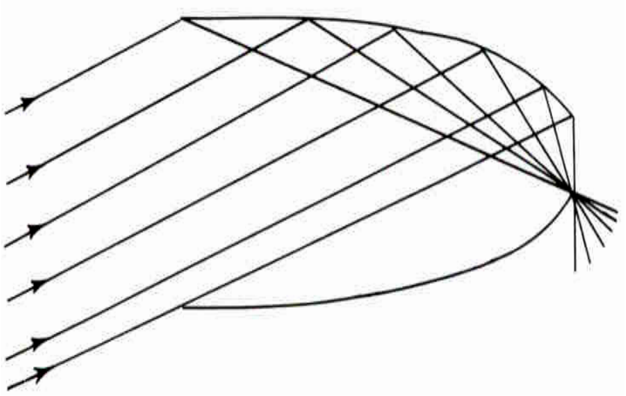


fig 5: CPC acceptance angle

fig 6: rays entering CPC at extreme angle

Because a laser beam expands with distance, each photodiode will use a Compound Parabolic Concentrator (CPC) to maximize its light capturing efficiency by collecting and directing stray laser emission towards the photodiode active area.

The starter mold was machined from aluminum as a solid cone. Because the electroplating is still in investigational stages, a solid cone, which was easily machined, was used first. The electroforming solution was made of copper sulfate and sulfuric acid. The cathode is the mold and the anodes are the copper plates. Experiments are still being conducted to determine the appropriate strength, thickness, and texture for the electroformed copper exterior. The electroformed exterior was removed by placing the plated solid into an ultrasonic bath, which uses sound waves in water to crash against and shake the electroplated surface off the mold.

One of the electroformed hollow cones was used as part of a photodiode receiver unit and the tests yielded good results. This proves, in principle, the CPC operation.

Next, a solid paraboloid will be machined to electroform a CPC and tests will be done on the resulting CPC. If the results are also good, as we expect, then the solid paraboloid mold will become a master mold for creating many more plastic CPCs.

Plastic CPCs weigh only a few grams, are cheap and as viable as copper ones.

Results

The figures below show the electroplating setup, resulting prototype CPC, and data transmission at 5MHz.

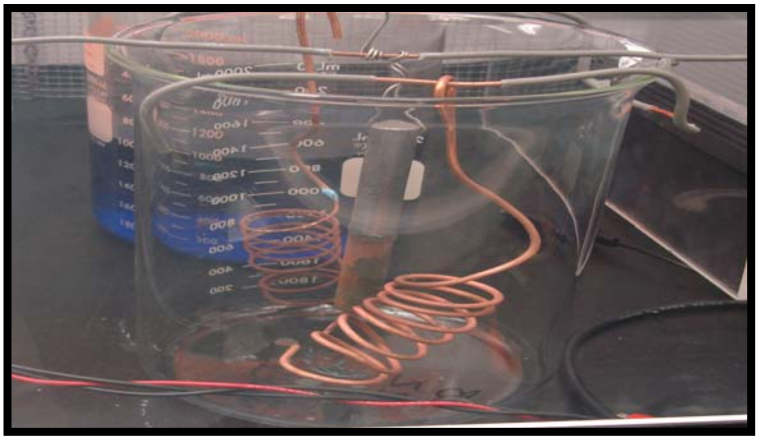


fig 7: Electroplating setup

fig 8: Prototype CPC

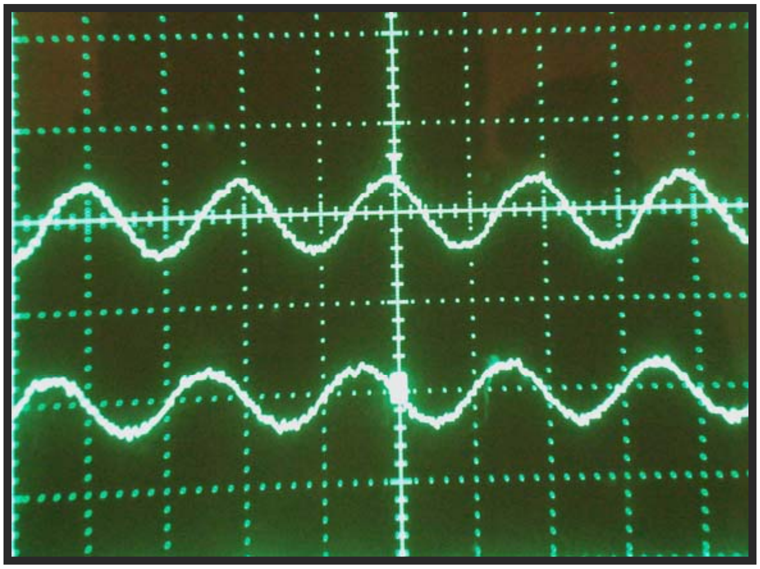


fig 9: Data transmission at 5MHz

Discussion

The Schmitt trigger is turned on only when the output voltage from the TIA is above 0.3V and holds until output voltage falls below 0.16V (see equation below).

$$\mathbf{V_{trigger} = \frac{1.5k||30k||100k}{30k} * 5V + \frac{1.5k||30k||100k}{100k} * V_{out}}$$

$$\mathbf{V_{hold} = \frac{1.5k||30k||100k}{30k} * 5V - \frac{1.5k||30k||100k}{100k} * V_{out}}$$

According to our tests, when the TIA output voltage was below 0.16V, the modulating input registered at the receiver end started to show considerable distortion. Therefore to avoid lossy transmission, biasing for the Schmitt trigger was set at a minimum hold voltage of 0.16V.

Conclusion

As part of ongoing work on this project, several receiver units each with a photodiode and laser will be arranged in a dome-like configuration to constitute the multi-beam transceiver.

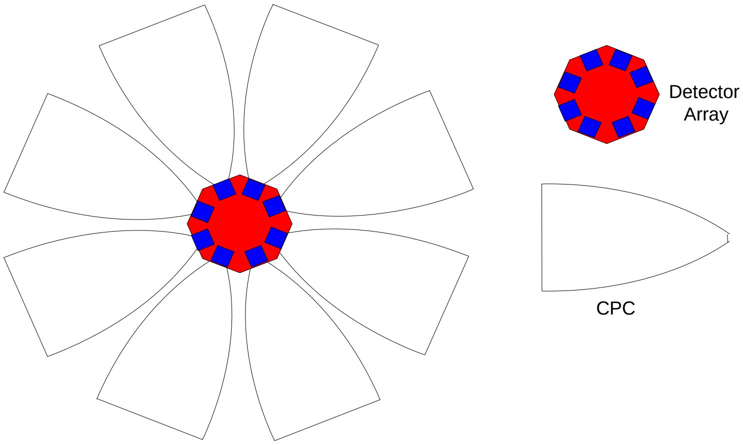


fig10: Multi-CPC Receiver Array

The dome of photodiodes and CPCs together ensure that there will always be a constant data link between transmitter and receiver by automatically switching between receiver photodiodes depending on voltage levels registered on the Schmitt triggers. We intend for the system to be flexible enough to align itself.

The most challenging task thus far has been with producing the CPCs. Because we are not very familiar with electroplating, there have been many challenges that we have faced especially with producing the right texture, thickness, and strength of CPCs. We are still experimenting with different techniques to produce an acceptable quality CPC.

References:

Sedra, Adel and Smith, Kenneth. Microelectronic Circuits. New York: Oxford University Press, 1998

Graham, Kenneth. Electroplating Engineering Handbook. New York: Chapman & Hall 1962

Ewart, Roberta M.E. (2000). Free Space Laser Communications. IEEE Communications Magazine: 124-125.