Gradient Decent Based, Phase-Locking Controller for Free-Space Multi-path Laser Communication Systems

Ph.D. Graduate Student: Dimitrios Loizos
Advisor: Prof. Paul Sotiriadis

Department of Electrical and Computer Engineering
Johns Hopkins University, Baltimore, MD 21218

Abstract

A phase-coherency controller is proposed based on gradient decent optimization for free-space laser communication. The controller will be able to operate under a wide range of frequencies, ranging from 1MHz to 1GHz. These requirements necessitate the use of heterojunction bipolar transistors. With this in mind, the phase controller was designed using the IBM SiGe 5AM technology. The estimated size for the project is 3mm x 3mm and 40 parts LCC84M packaged will be needed.

Background and Motivation

Free-space laser communication is a very efficient approach for ground wireless links. It allows for high data rates and doesn't suffer by bandwidth congestion as RF-based communications do. Several commercial products are available in the market e.g. [1,2]. Laser communication is also a promising future solution for earth to moon as well as ground-to-satellite, inter-satellite and deep space communication [3].

In many instances of free-space laser communication it is desirable to use more than one laser beams. This has significant advantages in terms of robustness in performance (not all beams are interrupted simultaneously), better safety (since the power is more distributed and therefore is less harmful), easier design and built of stable laser sources and optics.

For multi-laser-beam transmitters to operate successfully it is critical that all laser beams hit the target point (optics and photo-diode of the receiver) coherently. To achieve this, we are requesting the fabrication of our phase control analog circuit. The general system is illustrated in Figure 1.

The proposed phase-coherency controller is based on gradient decent optimization. Similar designs have been done by our group in [5,6] where the stochastic gradient decent method was used to adjust micro-mirror arrays in MEMS.

The proposed phase controller consists of eight sub-controllers, one for every laser beam phase shifter. The structure of each sub-controller is shown in Figure 2. Our high level methodology is to feed a high frequency perturbation signal into the phase shifter and correlate it with the corresponding perturbation of the received (total) instantaneous power at the receiver.

In more detail: The instantaneous power of the received optical signal is amplified and fed to the controller (signal *U* in Figure 2). (This will be done using a secondary very low rate optical link). The

oscillator of the k^{th} sub-controller produces three sinusoidal signals *A1*-3 of the same frequency and with 120 degrees phase difference. The three signals are multiplied with the input *U* and are low-pass filtered. One of the three derived signals is selected at the multiplexer and fed into a comparator that drives a charge pump. The charge pump is clocked by the oscillator. The slow signal *G* is the DC control of the k^{th} phase shifter. In addition to *G* a small amplitude replica of the oscillators signal is also fed into the phase shifter.
Simulation of the circuit has demonstrated convergence of the DC values of the phase controlling signals.

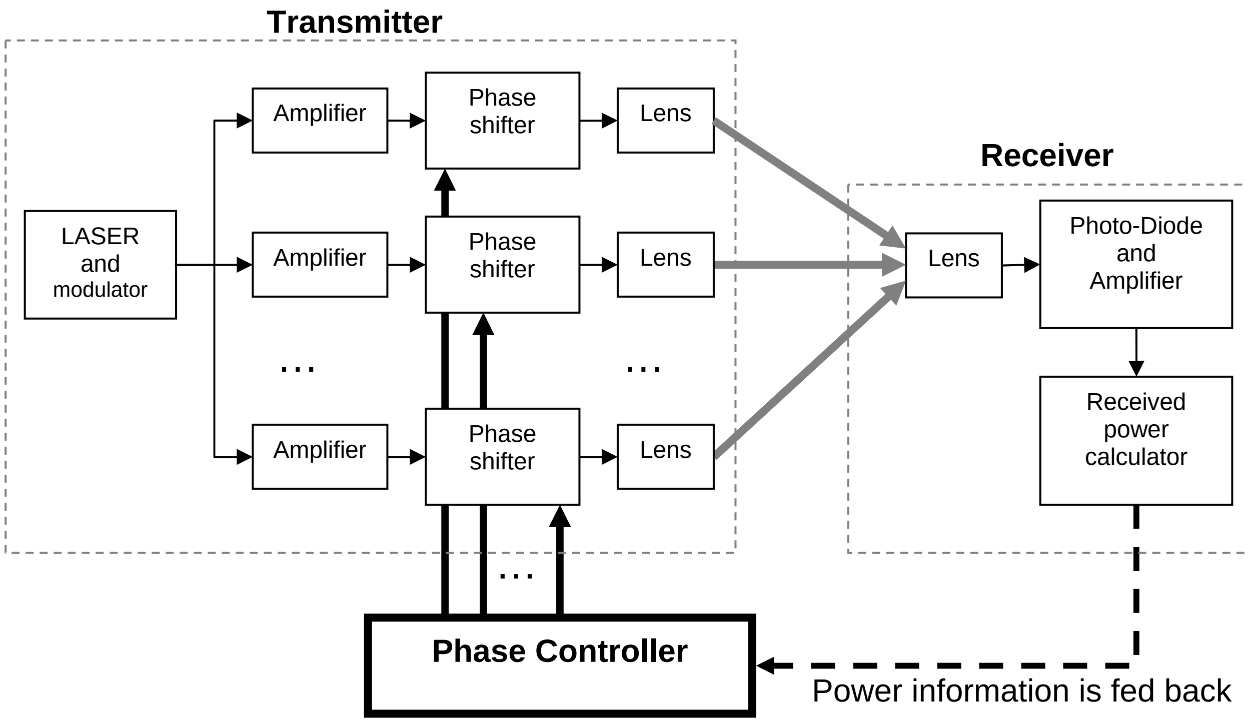

Figure 1: Structure of the multi-beam free-space Laser communication system using the proposed phase controller circuit.

Project Size and Technology

The gradient decent phase controller will consist of eight sub-controllers as illustrated in Figures 1,2. The circuit has been designed to allow for a wide range of frequency operation, with oscillation frequencies ranging from 1MHz to 1GHz. This necessitates the use of heterojunction bipolar transistors.

The IBM SiGe BiCMOS 0.5um 5AM meets our requirements. The estimated size for the project is 3mm x 3mm in the 5AM process, 40 parts LCC84M packaged.

Simulation, Testing and Measurements

This project is part of the Ph.D. research of the graduate student Dimitrios Loizos who is working in the area of high speed analog computational systems. Mr. Loizos has designed the circuit using Cadence's CAD tools and simulated it using Spectre and HSpice. The design was completed with guidance and supporting CAD infrastructure in the Adaptive Microsystems Laboratory (Prof. Gert Cauwenberghs).

To test the fabricated chips, Mr. Loizos will develop a PCB and supporting circuits. Testing will be done in two stages: a) in Prof. Sotiriadis lab at the Johns Hopkins University using an analog simulator of the free-space laser communication system that will be designed and built by Mr. Loizos using discrete components, b) at the Army Research Lab, Adelphi Maryland, using an existing multi-beam laser communication system designed and built by the group of Dr. Mikhail Vorontsov.

As part of his Ph.D. dissertation, Mr. Loizos will use the developed circuit boards to demonstrate real time laser communication.

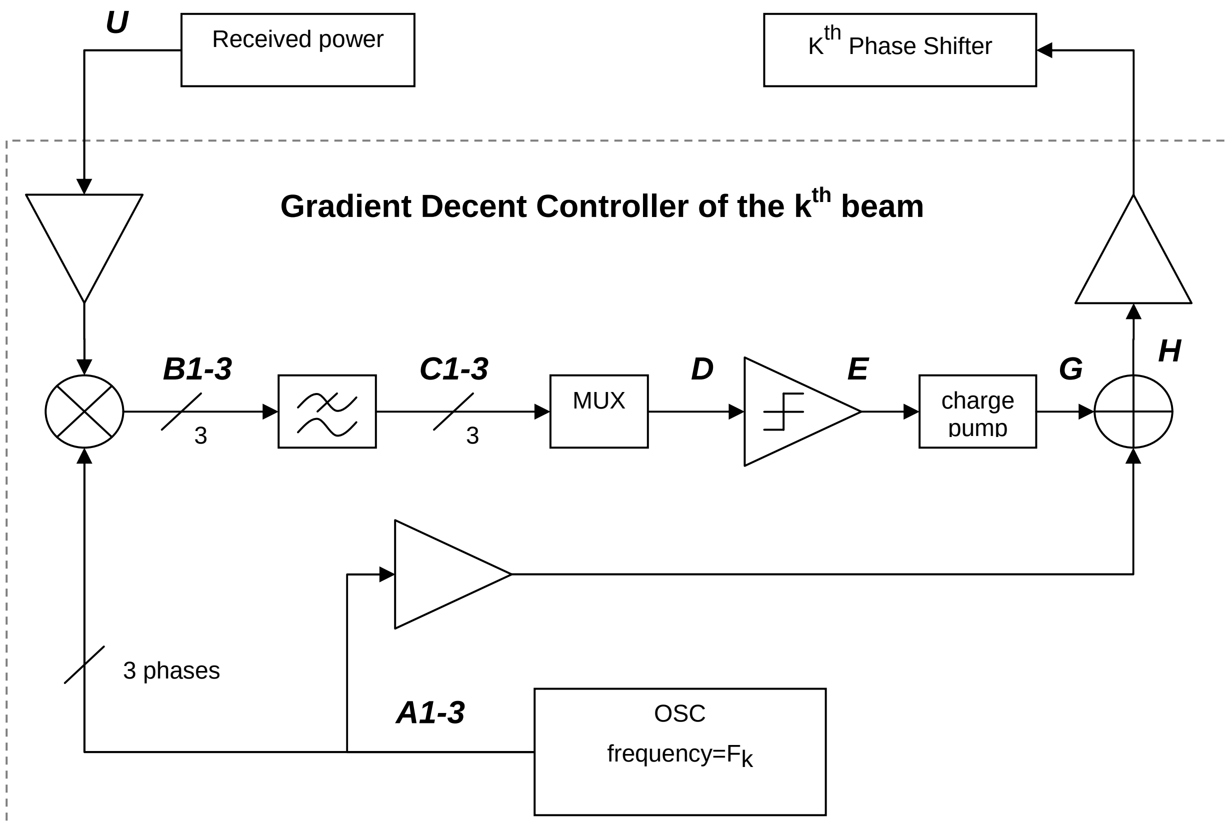

Figure 2: The architecture of the sub-controller in the phase controller circuit

References

[1] www.lsainc.com

[2] www.cablefreesolutions.com

[3] Schuster, J, Hakakha, H, and Korevaar, E, "Optomechanical design of STRV-2 lasercom transceiver using novel azimuth/slant gimbal," SPIE Vol. 2699, January 1996, pp 227-239.

[4] [internal link removed by MOSIS]

[5] "Micro-Scale Adaptive Optics: Wavefront Control with Micro-Mirror Array and VLSI Stochastic Gradient Descent Controller," T. Weyrauch, M.A. Vorontsov, T.G. Bifano, J.A. Hammer, M. Cohen, and G. Cauwenberghs, Applied Optics, vol. 40 (24), pp. 4243-4253, 2001.

[6] "Adaptive Wavefront Correction Using a VLSI Implementation of the Parallel Perturbation Gradient Descent Algorithm," G. Carhart, M. Vorontsov, M. Cohen G. Cauwenberghs, and R.T. Edwards, in High-Resolution Wavefront Control: Methods, Devices, and Applications, Proc. SPIE vol. 3760, 1999.