Secure Free-Space Optical Communication Between Moving Platforms

Joseph M. Kahn
EECS Department, University of California, Berkeley, CA 94720 USA
Voice: (510) 643-8848, Facsimile: (510) 642-6061, E-mail: `jmk@eecs.berkeley.edu`

***Abstract*—We describe an architecture for secure, bursty free-space optical communication between rapidly moving platforms, e.g., aircraft. An optimized link protocol minimizes acquisition time. Key enabling components include fast two-dimensional microscanners and photodiode arrays with dual-mode readouts.**

I. INTRODUCTION

It is desirable in certain applications to establish bursty, high-speed, free-space optical links over distances up to several km between rapidly moving platforms, such as air or ground vehicles, while minimizing the probability that a link is detected or intercepted. In a collaboration between University of California, Berkeley, Stanford University, Princeton University and Sensors, Unlimited, we have undertaken research toward this goal.

There are several key elements of our approach to covert optical links. In order to minimize atmospheric scattering, we use a long transmission wavelength; 1.55 μm is chosen because of the availability of key transmitting and receiving components. Combining a high-power laser and a two-dimensional beam scanner employing micromirrors, we obtain a steerable transmitter with mrad beamwidth and sub-ms aiming time. We combine a wide-angle lens and InGaAs photodiode array with dual-mode readout IC (ROIC) capable of both imaging and high-speed data reception, obtaining an electronically steerable receiver with wide field-of-view (FOV) and angular resolution in the mrad range.

Covertness is defeated most easily during the link acquisition phase, when at least one communicating party must perform a broad-field scan to acquire the position of the other party, and risks revealing his presence to an observer. We adopt a protocol [1] designed to exploit the steerable transmitter and receiver, minimizing the time required for the parties to mutually acquire positions and verify identities. Data is transmitted at a high bit rate in short bursts, alternating with brief intervals for position reacquisition, in order to accommodate rapid motion between the parties.

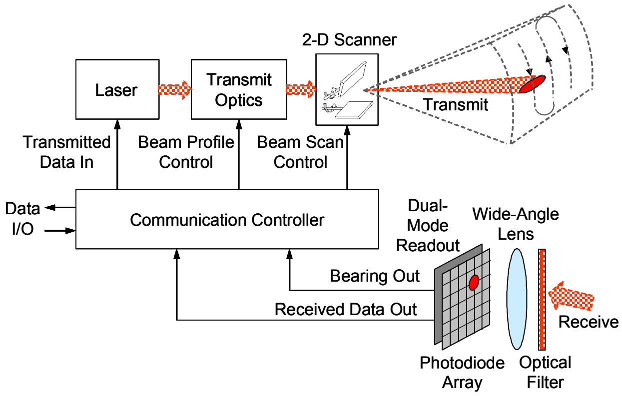

Fig. 1. Schematic configuration of a transceiver.

II. TRANSCEIVER DESIGN AND ENABLING COMPONENTS

Each communicating party employs a transceiver as shown in Fig. 1. The transmitter laser emits at least 1 W peak power at 1.55 μm, and is capable of modulation at 1 Gb/s. We are currently fabricating asymmetric, twin-waveguide, distributed Bragg reflector, master oscillator/power amplifier devices in InGaAsP/InP [2].

The transmitter uses a two-dimensional scanner based on a pair of micromirrors. Each mirror will have a diameter of about 1 mm, leading to a diffraction-limited beamwidth of about 1 mrad (half-angle). Mirrors fabricated previously of single-crystal silicon in the staggered torsional electrostatic combdrive (STEC) process [3] achieved a resonant frequency up to 68 kHz, scan angle up to 25° (full angle), and dynamic deformation $<\lambda/20$. In this project, we have developed a self-aligned STEC (SASTEC) process to increase yield and improve performance [4]. A pair of SASTEC micromirrors is shown in Fig. 2.

The transceiver of Fig. 1 employs a wide-angle lens to achieve a FOV of the order of 1 rad × 1 rad. The InGaAs photodiode array is solder bump-bonded to a dual-mode CMOS ROIC, as shown in Fig. 3. In stare mode, the ROIC yields an image of all pixels in the array (or a selected subset), a key capability required

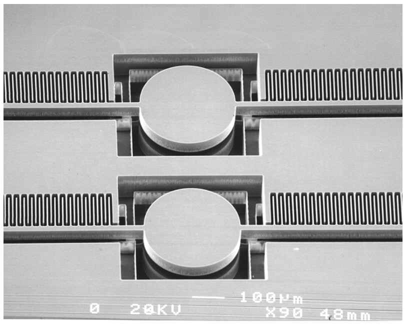

Fig. 2. Pair of scanning micromirrors fabricated in the SASTEC process [4]. Each mirror has a diameter of approximately 300 μm.

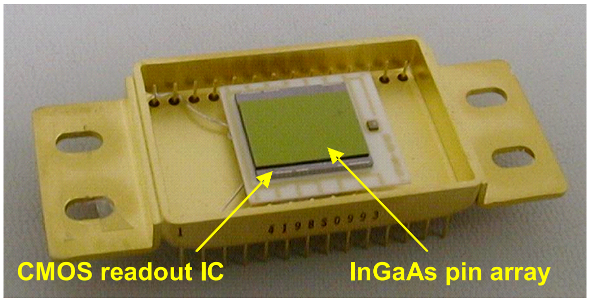

Fig. 3. Dual-mode receiver consisting of InGaAs photodiode array solder bump-bonded to a dual-mode CMOS readout IC.

for accurate bearing acquisition. When an active transmitter is detected, the ROIC switches to data-receiving mode, in which it monitors one (or several) pixels, detecting high-speed data. For field deployment, the dual-mode receiver will have 1000 × 1000 pixels and be capable of 100 Mpixel/s readout rate in stare mode and of detecting 1 Gb/s data in receiving mode. Initially, we are demonstrating a 32 × 32 pixel prototype.

III. LINK PROTOCOL

The link acquisition and data-transfer protocol [1] is a crucial aspect of our secure communication architecture. Our protocol assumes that the communicating parties (initiator and recipient) have no prior knowledge of one another's positions and identities. Prior to communication, both parties have lasers off and receivers in stare mode. The protocol has three phases.

In Phase 1, the initiator raster-scans the search field using an elliptical beam. Because a wide field is being scanned by a relatively broad beam, the communication is most vulnerable to detection in this phase. As shown in [1], under typical conditions, the use of an elliptical beam minimizes the time required to complete Phase 1 under constraints of limited scanner speed, diffraction-limited beamwidth, limited receiver bandwidth, and a minimum signal-to-noise ratio requirement.

During Phase 1, the initiator first raster-scans a portion of the search field, transmitting an all-1 code to aid the recipient in coarse acquisition of the initiator's bearing. Then, the initiator rescans the same portion of the search field using a double-looped raster scan. In the double-looped scan, the initiator first transmits an all-1 code, allowing the recipient to more accurately determine the initiator's bearing. The initiator then loops back and transmits an identity-verifying (IV) code to allow the recipient to verify the initiator's identity. The intervals between the various scans correspond to the time required for the dual-mode receiver to read out data and switch modes.

When the recipient has verified the initiator's IV code, Phase 2 begins. The recipient steers a diffraction-limited circular beam toward the initiator, and transmits an IV code. In Phase 3, after both recipient and initiator have mutually verified IV codes, payload data transfer occurs. Data is transmitted in short bursts, alternating with brief bearing reacquisition sequences.

In a typical example [1], the parties move at a relative speed of 660 m/s (Mach 2) and are separated by 3 km. The transmit laser emits 5 W peak power at 1.55 μm, and the 1 mm scanner diameter leads to a diffraction-limited beamwidth of 1 mrad (half-angle). During Phase 1, the initiator scans the 1 rad × 1 rad search field using a 1 mrad × 4 mrad beam. The 50-bit IV code is transmitted at 500 Mb/s. The maximum acquisition time is found to be <100 ms.

IV. ACKNOWLEDGMENTS

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