Retro-Modulator Links with a Mini-Rover

H. Hemmati, C. Esproles, W. Farr, W. Liu, and P. Estabrook
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr., Pasadena, California 91109

G. C. Gilbreath and W. S. Rabinovich
US Naval Research Laboratories
Washington, D.C. 20357

ABSTRACT

An optical sensors web in a star pattern is formed and tested utilizing modulating retro-reflectors, where a multitude of sensors was simulated by a retro-modulator on a mini-rover. A CCD camera provides the multi-mega-bit sensor signal. Two-dimensional acquisition of a retro-modulator located away in the field, by a base-station equipped with a laser and a receiver was demonstrated while reading out data at 10 Mbps data-rate.

Keywords: modulating retro-reflector, modulating corner cube, optical sensor web, optical communications

1. INTRODUCTION

The objective of this work was to demonstrate efficient, high data-rate, communication links to stationary or mobile mini-sensor suites, where the host platform is capable of providing very limited DC electrical power and mass to the communications subsystem. The targeted power consumption and mass are less than 50 mW and 50 gram, respectively. An application example is communication link between a spacecraft, landed on a planet, with tens to hundreds of sensors or sensor carrying mini-rovers, disbursed in the surrounding area. In this configuration, burden of mass and power consumption associated with telecommunication subsystem, is shifted primarily to one side of the link, in this example, the lander. Such a sensor web concept is shown schematically in Figure 1.

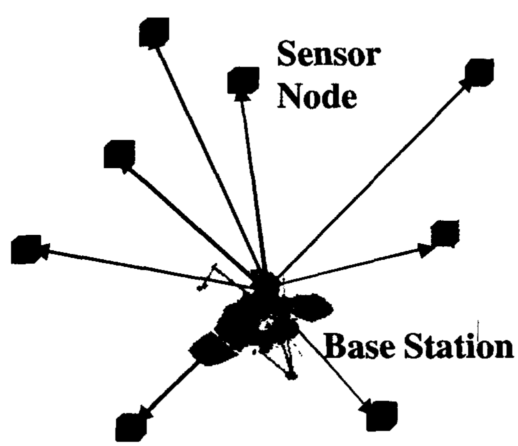
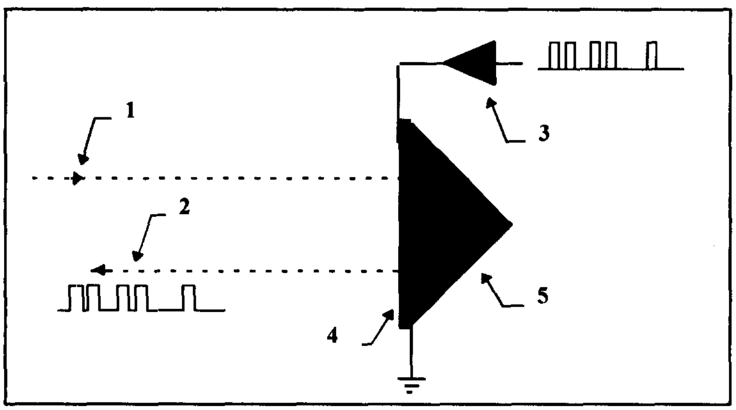


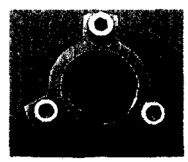
Figure (1). Schematic of a base-station equipped with a laser, receiver optic and electronics, and an acquisition and tracking subsystem reading off sensor data from remotely located low power consumption and low mass, modulating retro-reflectors.

Correspondence: hamid.hemmati@jpl.nasa.gov; 818-354-4960

The concept of using sensor webs, or networks of science elements possessing a limited suite of sensors, to explore new environments is attracting great interest. Optically linked sensor webs have become possible with the advent of miniaturized modulating retro-reflectors (MRRs), such as, quantum-well devices with tens of megabits/sec bandwidth, and the ultra small (mm scale) devices that utilize Micro-Electro-Mechanical Systems (MEMS) devices with tens of kilobits/sec bandwidth (1-3). An MRR consists of a corner-cube reflector and a mechanism to spoil the reflectance of the corner-cube. The spoiling mechanism, which carries the data back to the interrogator, may be in a transmission mode (e.g. a quantum well modulator) or in a reflection mode (e.g. movement of one-facet of a corner-cube via MEMS actuation). The reflection type MRRs work over a broad range of the spectrum, while most other techniques, for example, the quantum-well modulated devices operate at specific wavelengths. Unlike traditional free-space optical links where data is transmitted from point A to point B, in a retro-modulating link, the transmitter and the receiver are co-located. Signals returned from retro-modulators fall as $1/R^2$ when the MRR is in the near field, and as $1/R^4$ when the MRR is in the far field. Therefore, signal loss increases dramatically as range to target increases. Due to the finite size of the corner-cube's cross-section, only a small fraction of the incident light is returned. Clearly, the smaller the footprint of the interrogating beam, the larger the signal return. On the other hand, a narrower beam would require additional scanning time to acquire the target. A very attractive feature of the retro-modulator is the wide field-of-view (FOV) afforded by the corner-cube, on the order of ±25° or more in the near-field. In the far-field, the half power full angle FOV is about ±13°. This significantly simplifies the stringent beam-pointing requirement, associated with conventional optical communications. Additionally, after acquiring and storing the desired data (in memory), the MRR could be in the sleep mode until interrogated with the transmit beam from the base station, transmitting its signal at a short burst in data-rates up to several Mega-bits-per-sec (Mbps). This scenario may be repeated if the sensor data varies with time. Therefore, power consumption for the telecommunication subsystem associated with the remote sensors suite may be reduced to negligibly low levels.

A transmission-mode type MRR made by the US Naval Research Laboratory (NRL) is shown in Figure (2) where the optical path is shown schematically. The experiments discussed here were performed with an MRR of the type shown in Figure (2), operating at 980-nm.





1. Interrogation beam
2. Modulated beam
3. Electronic driver
4. Transmissive MQW modulator
5. Solid retro-reflector

Figure (2). An optical diagram of a transmitting type MRR (modulating retro-reflector), and a packaged MRR (right).

Link Analysis: The achievable communications range, given the assumptions as shown in Table (1), was calculated.

Parameter	Value	Parameter	Value
Wavelength	980 nm	APD quantum efficiency	60%
Transmit efficiency	80%	APD gain	120
Beam divergence	2 mrad	Corner-cube size	6-mm
Output power	0.2 W	Contrast ratio	0.2
Receiver diameter	5-cm	Bit rate	1 Mbps
Receiver optics efficiency	70%	Bit error rate	1.0E-4

Table (1). Assumed parameters for link analysis identifying the achievable range for a given data-rate

With the above assumptions, the maximum range is calculated at 2800m while sustaining a data-rate of 1Mbps (such as a real-time picture transmission). In actual planetary applications, the sensor data-rate is far lower (on the order of kbps). Figure (3) summarizes the results of analysis showing the calculated signal-to-noise ratio, and bit-error rate as a function of communications range.

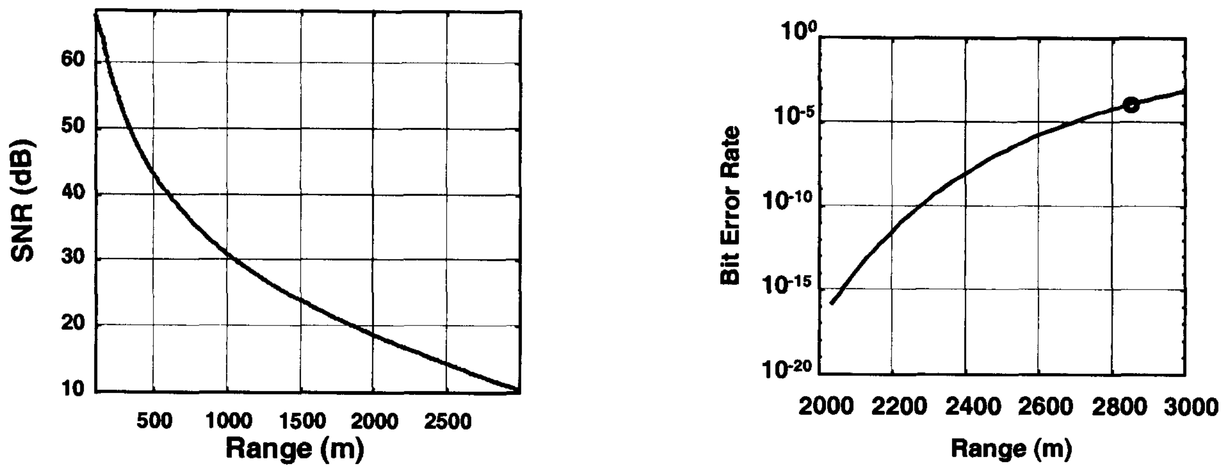


Figure (3). Signal-to-noise ratio and bit-error-rate calculated as a function of range for 1 Mbps

2. EXPERIMENTS

The experiments consisted of a base-station, including both the transmitter and the receiver, and a retro-modulator located on a mini-rover to depict multiple MRRs that are distributed around a base station. We also developed a tracking system for the base-station to demonstrate the capability of tracking a single, or multiple, rovers from a single base-station. A small CCD color camera acted as our sensor data provider. The base-station constituents and the experimental results are described below.

The Base Station: A picture of the base-station is shown in Figure (4). It consist of: a CW laser transmitter; transmit and receive optics; a Si APD (avalanche photo-diode) detector and associated signal amplifier; a two-dimensional PSD (position-sensing-detector); a two-axis coarse scanner; a micro-processor; drivers; controller; and power supplies.

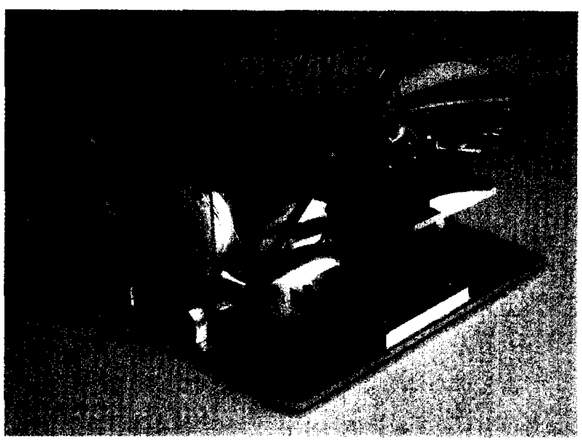


Figure (4). A picture of the base-station equipped with readout laser, receiver optics and electronics, and an acquisition and tracking subsystem.

Laser Transmitter. A fiber-coupled 980-nm semiconductor laser (from JDS Uniphase) with 190-mW of output provides the interrogating beam. The single mode fiber is terminated with a connector for simple connectivity with a fiber-coupled lens for beam shaping.

Beam-Shaping Optics. A fiber-coupled lens (from Newport) provides the designed beam-divergence of approximately 2 mrad. The receiver front optic is a 5-cm wide parabolic mirror (from Melles Griot) where a small aperture is made in the center of the mirror. The laser beam is transmitted through this aperture. The laser output power falls below 0.2 W after passing through the fiber-coupled lens. Upon travel through a 90/10 beam-splitter, the received beam is focused on to APD and the PSD, with 90% of the signal falling onto the APD. The APD is equipped with a band-pas filter to reject solar radiation during outdoor tests.

Data Detector. A Si APD (from Perkin Elmer) integrated with a post-detection electronics amplifier is used as the data detector. A 20-nm wide bandpass filter with 70% transmission 980-nm, filters out the background light present in the laboratory and during outdoor tests.

Tracking Detector. A 2-dimensional PSD (from Pacific Silicon Sensor) provides the tracking data needed by a coarse-pointing mechanism to follow the retro-modulator as it moves relative to the base-station.

Two-Dimensional Scanner. A 2-axis motor-driven coarse-pointing mechanism (from Directed Perception) can point the entire optical head (transmit/receive optics and the laser fiber, the Si APD, and the PSD) as the angles for the retro-modulator vary relative to the base-station.

Microprocessor; drivers, and controllers. A microprocessor is used to run the tracking software that interfaces the PSD to the coarse-pointing mechanism. Drivers and controllers for the laser, APD, PSD, and the coarse-pointing mechanism are included with this module.

Laboratory Characterization
A schematic of the laboratory characterization setup is shown schematically in Figure (5). A transmit and a receive bit-error-rate testers (BERTs) provide the modulated signal and analyses of quality of the received signal.

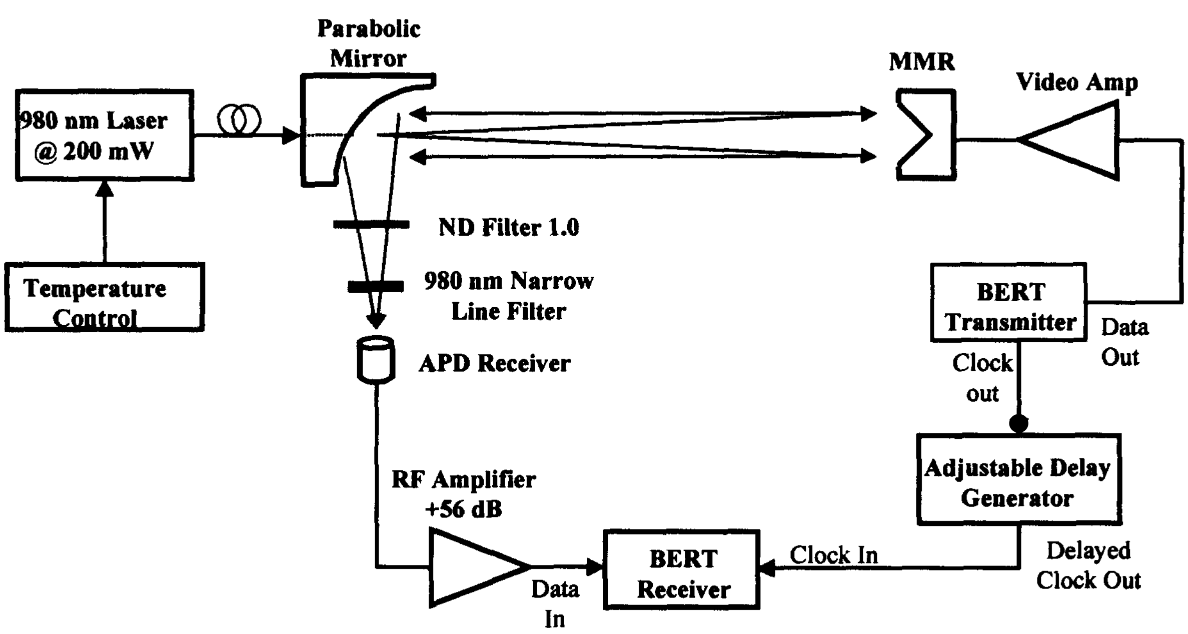


Figure (5). Schematic of the setup to characterize the communications quality of the retro-modulators.

The received signal amplitude (arbitrary units) plotted against the Voltage applied to the retro-modulator is shown in Figure (6). The optical path was nearly 2 meters long. The received signal level increases with the applied Voltage primarily due to the enhanced modulation extinction ratio as the applied Voltage to the retro-modulator increases.

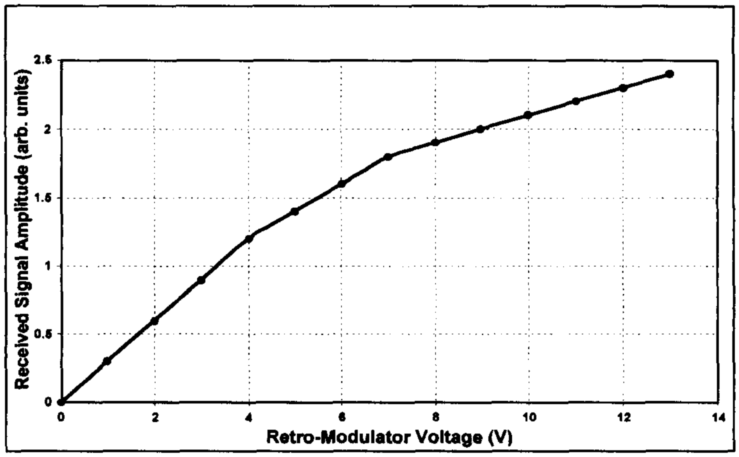


Figure (6). Received signal amplitude (arbitrary units) vs. the magnitude of Voltage applied to the retro-modulator

The bit-error-rate as a function of the applied bit-rate (in MHz) to the retro-modulator is as measured across a nearly 2-m optical path in the laboratory is shown on Figure (7). This plot indicates that the limitation of this particular device is at about 11 MHz of applied modulation rate.

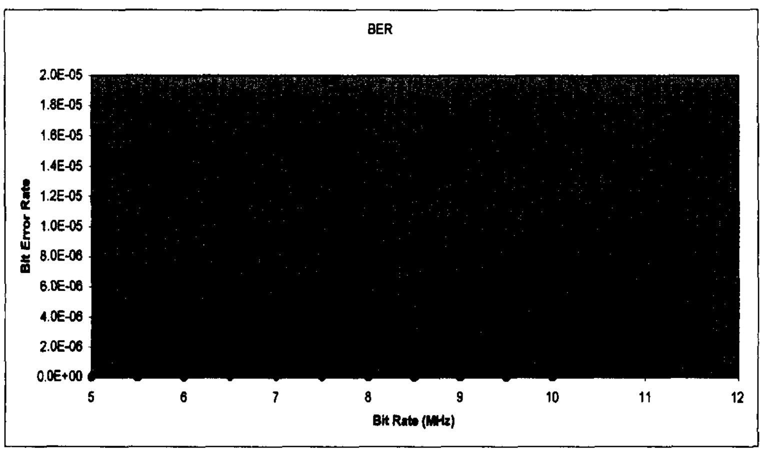


Figure (7). Measured bit-error-rate of one of the 980-nm retro-modulators showing modulation capability as high as 11 MHz

Outdoor Tests: To test the sensor web optical concept and the concept of utilizing low power, lightweight retro-modulators with rovers, a small remote-controlled car was modified to carry a retro-modulator, a color CCD camera (data-provider), and batteries to operate the rover (shown in Figure 8).

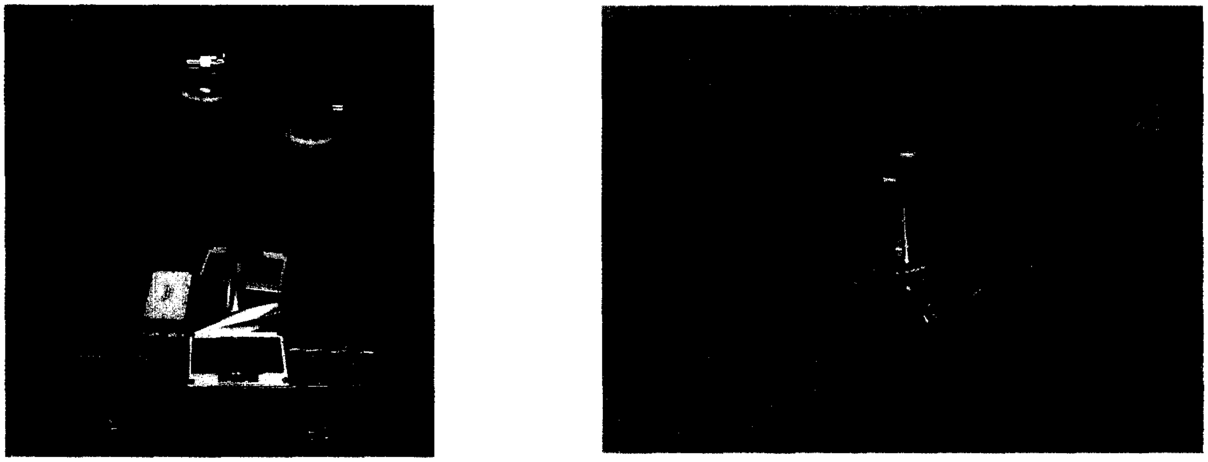


Figure (8). A retro-modulator and a CCD camera (sensor) mounted on a simple rover (left). Outdoor testing of the link (right)

Clear, real-time, analog color video pictures at bandwidth of about 5 MHz were transmitted in the field during daytime. The largest communication range performed so far under with the laser transmitter power and aperture sizes as indicated above is 2 km.

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