Multiple Quantum Well Retromodulators for Low Power, Covert Infrared Data Links

by

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ABSTRACT

In this paper, we describe progress in the development of the Multiple Quantum Well retromodulator for compact, covert data transfer which is uniquely suited to unmanned vehicles. Device power draw is quite low and can be sun-powered with possible laser light augmentation in some strategies. Carrier wavelengths are in the infrared so interference is not an issue and shutter speeds can support up to 10 Mbps. Progress in demonstrating solar-powered burst communications for a UAV in flight will be presented. Alternative power schemes using photovoltaics will be presented to show how a low cost, low power communications terminal can be configured.

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Introduction

An optical or infrared communications link can provide significant relief to payload power and packaging requirements for unmanned vehicles as well as provide a much more covert link from Low Probability of Intercept (LPI). The Naval Research Laboratory is developing an efficient, low power method to communicate in the infrared at 10 Mbps [1]. An optical retroreflector is coupled with an electro-absorptive "shutter" which modulates incident light and returns an On-Off signal directly to the interrogator along line-of-sight. The modulating retroreflector uses multiple quantum well (MQW) technology and has been demonstrated to support data rates up to approximately 10 Mbps over a near-infrared carrier wavelength of 970 nm using a laser diode[2]. An implementation concept is illustrated in Figure 1. A ground-based laser interrogates a UAV, which is instrumented with a digitized video signal. The digitized stream modulates the MQW shutter which is coupled to a retroreflector. The modulated return light is reflected along line-of-interrogation and the received signal demodulated. The receiver would provide data recovery, video reconstruction, photonics, and communications channel characterization (e.g. bit error rate). By using multiple modulating retros configured in an array, there is no need to fly a laser with a gimballed telescope to close a two-way link.

Concept

NRL has made considerable progress in the development of this device over the past several years. A recent demonstration using the device for tagging employed a device which supported 1 Mbps using 75 mW of power [3]. In an effort to produce a self-powered system, we consider a method to incorporate photovoltaics to replace the onboard batteries. We present here preliminary results of a proof-of-concept experiment using commercial off-the-shelf GaAs solar cells illuminated by simulated solar light to power the device. In addition, we investigate the concept of using the incident laser light to power the system through the application of specialized photovoltaic devices.

First Experiments

In these initial, proof-of-concept experiments, standard 2x2 cm^2 GaAs solar cells were wired in an array to provide power to a 0.5 cm diameter MQW retromodulator through a circuit utilizing capacitor storage. A schematic of the solar array/MQW retromodulator circuit used is shown in Figure 2. The solar array-powered retromodulator with its drive electronics was placed in the path of an optical transmit/receive configuration consisting of a 976 nm laser, 2 milliradian optics, and an avalanche photodiode. The retromodulator was situated at close range, about 170 cm from the optical transmit/receive system, and the spot size at the modulator was about 2 cm in diameter which overfilled the 0.5 cm diameter retromodulator aperture. The modulator with small solar array and the interrogation optics are shown in Figure 3.

A halogen light source was used in the laboratory environment to illuminate the mini-solar array. The system was operated in a burst communication mode where the solar array charged the capacitor to a pre-set level, and then modulator drive circuitry was switched on, the modulator was activated, and the returned laser light was modulated until the capacitor discharged. As the white light intensity incident on the on the solar array increased, the burst communications rate increased.

A 0.5 F capacitor was used to store the solar energy to power the modulator. When the voltage on the capacitor reached the set level, the modulator drive circuitry "turned on" and the modulator was activated. Returned laser light was modulated until the capacitor discharged to a set level. In this way, burst communications was enabled.

A square wave at a rate of 2.5 kHz was used as the data source. The 0.5 Farad capacitor enabled a burst period of 680 ms with a duty cycle of 12% using the halogen source located near the cell array.

The modulation rate affects the duty cycle of the bursts. The power draw of the modulator and drive electronics consisted of a static component and a component that is a linear function of modulation frequency. For a modulation frequency up to about 100 kHz, the static component will be the major source of power draw; above this threshold, the frequency-dependent component dominates.

It should be noted that the data rate was limited by the components on hand, not the retromodulator or incident laser light level. The solar array electrical conversion efficiency was approximately 8.5%. The individual solar cell efficiency, however, was approximately 18.5%. Therefore, with improved array fabrication techniques, a 2x improved is expected. In addition, by substituting multijunction solar cells, available as commercial off-the-shelf parts operating at approximately 25% efficiency, an addition 50% improvement can be expected.

We also considered exploiting the incident energy from the laser source. Because the laser is specifically tuned to be transparent to the GaAs wafer of the modulating retroreflector, the standard GaAs-based solar cells cannot be used for this application. Instead, lattice-mismatcehd In0.17Ga0.83As/GaAs devices can be used. These devices were fabricated by the Fraunhofer Solar Energy Institute in Frieburg Germany [4].

To gain insight into solar cell response to the interrogation laser, laboratory samples of these devices were placed in front of the 976 nm laser. The solar cell photovoltaic response was measured at varied incident laser power levels.

Preliminary Results and Plans

Traces of the communications signals received by the Tx/Rx breadboard are shown in Figures 4 through 6. As can be seen from these graphs, data was successfully transmitted over the link using the small solar-array of conventional GaAs solar cells as described above. The circuit required a charge-up time on the order of 1.4 ms and discharged in 15 ms for this set up.

The power required for the modulator electronics, driver, data source and DC/DC converter was ~50 mW. The solar cells were able to deliver ~5.5 mW. A duty cycle of 12% indicates that we had minimal loss using the charge and dump technique of driving the modulator. It should be noted that 5.5 mW * (1/.12) = 45.8 mW. This is actually less than the 50 mW required to drive the modulator continuously. We believe this apparent discrepancy is from the variation in conversion efficiency of the DC/DC converter for varying input voltage. We plan to modify the circuitry to support higher communications rates including that which will support video using these techniques.

Results from the separate experiments to determine solar cell response to the light from the interrogation laser are shown in Figure 7. These preliminary results indicate that energy from the incident laser can be converted to usable energy for the retromoudlator using these types of cells. The next step in the concept development is to design a circuit that will operate the modulating retro circuit at these low-level incident power levels.

Summary

Our preliminary results indicate that compact, lightweight, covert communications terminals for unmanned vehicles using solar-powered retromodulators are quite feasible. An implication of the technique is that the size and weight of the communications terminal can be further reduced by substantially decreasing, if not eliminating, the need to fly an onboard battery for power. The system can be designed with solar panels in such a way that it can serve as a ground-based sensor as well, to be interrogated from above or remotely, with a small laser interrogator system. A photonic powered vehicle with light-powered communications has utility not only in the DOD but in the civil sector as well.

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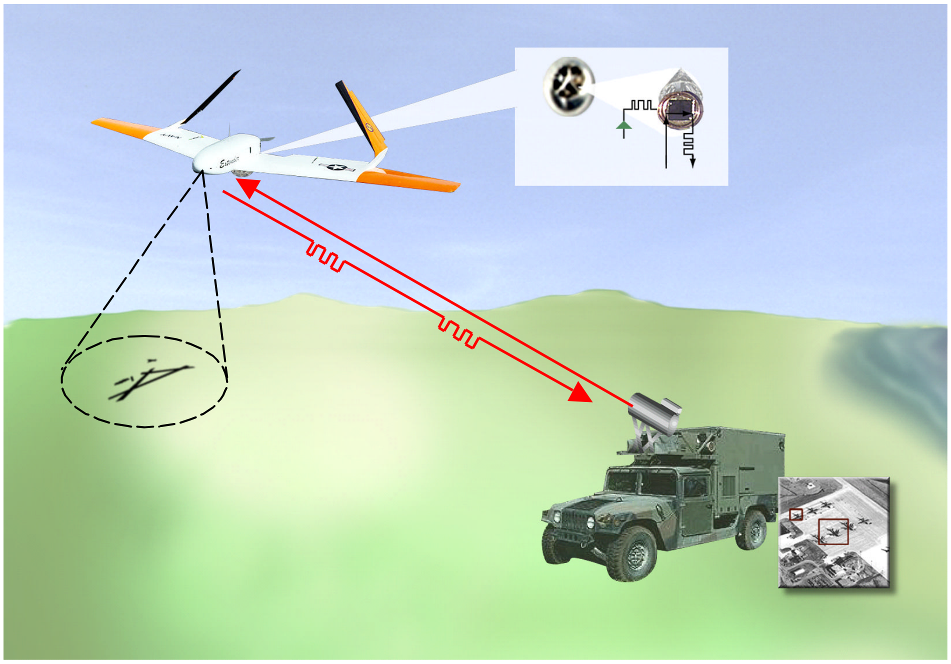


Figure 1. The MQW modulating retroreflector incorporated into an airborne reconnaissance concept using an Unmanned Aerial Vehicle is shown above. When configured into an array, the MQW modulating retroreflector concept significantly reduces the parasitic payload requirements for the onboard communications system.

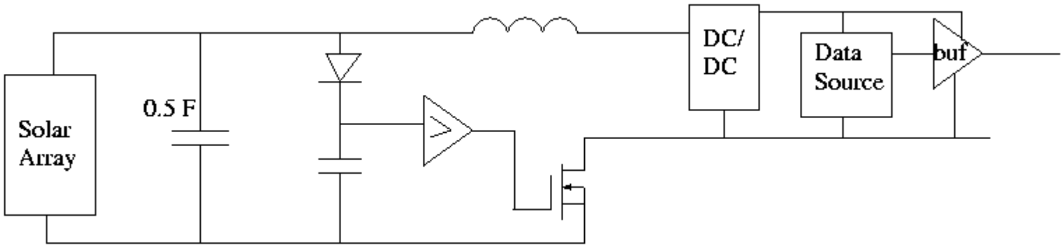
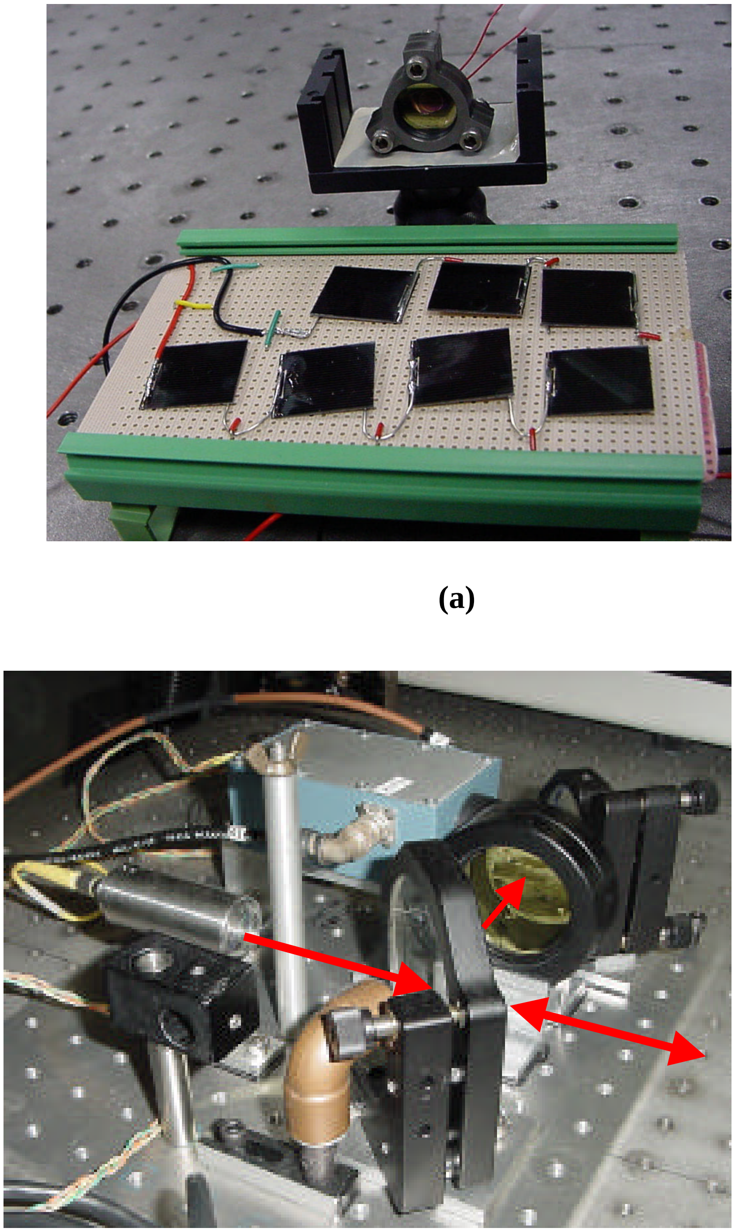


Figure 2. Schematic diagram of the circuitry that coupled the solar array to the MQW retromodulator and driver, using a capacitor for energy storage.



(a)

(b)

Figure 3(a). Photo of mounted MQW retromodulator coupled with 7 GaAs photovoltaic cells for solar powered communication; (3b) Photo of Transmit/Receive optical configuration used to illuminate retromodulator and detect return signals (red line indicates laser light direction).

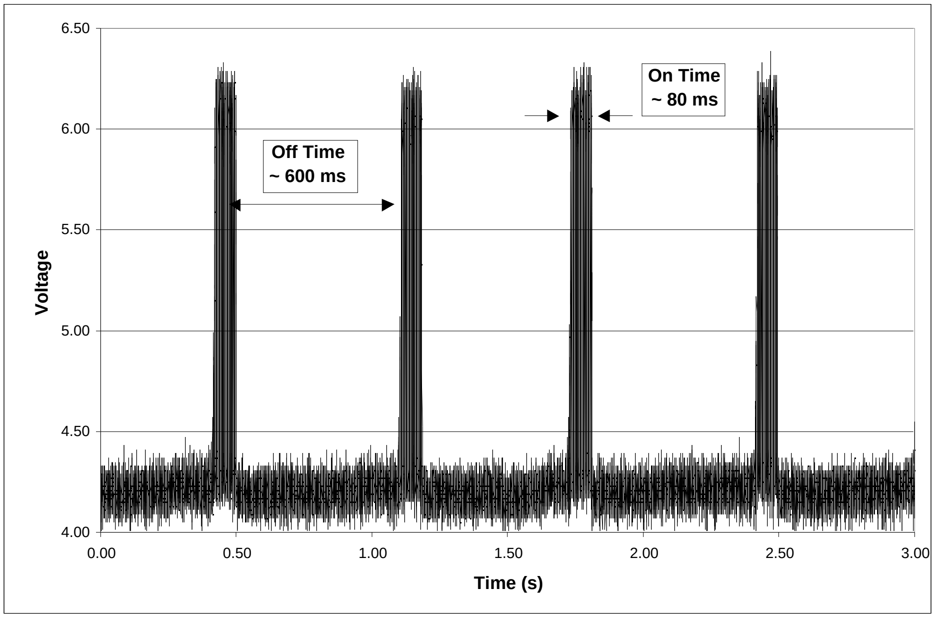


Figure 4. First results using solar powered capacitive storage to support onboard burst communications from a MQW retromodulator. Data rate is 2.5 kbps.

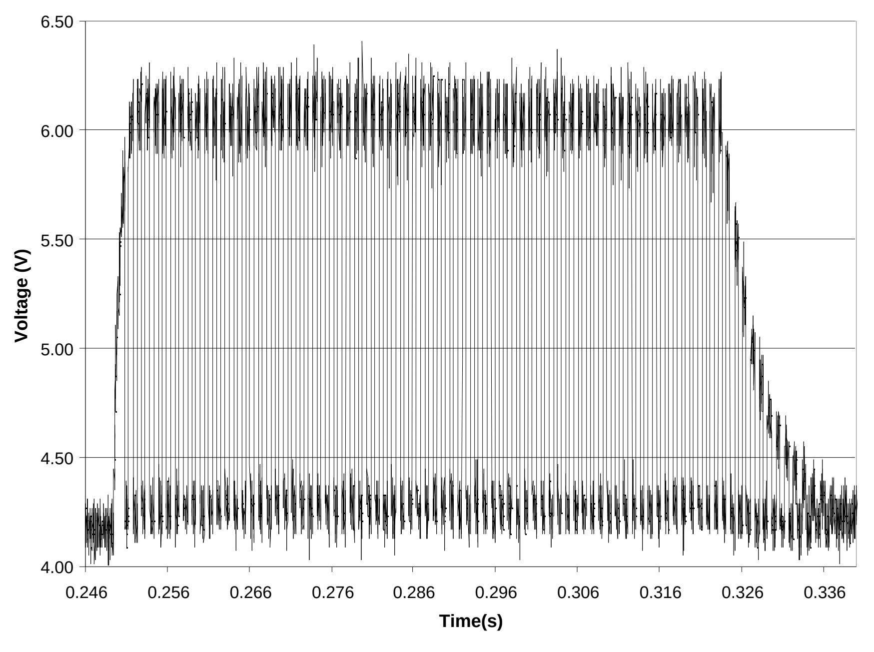
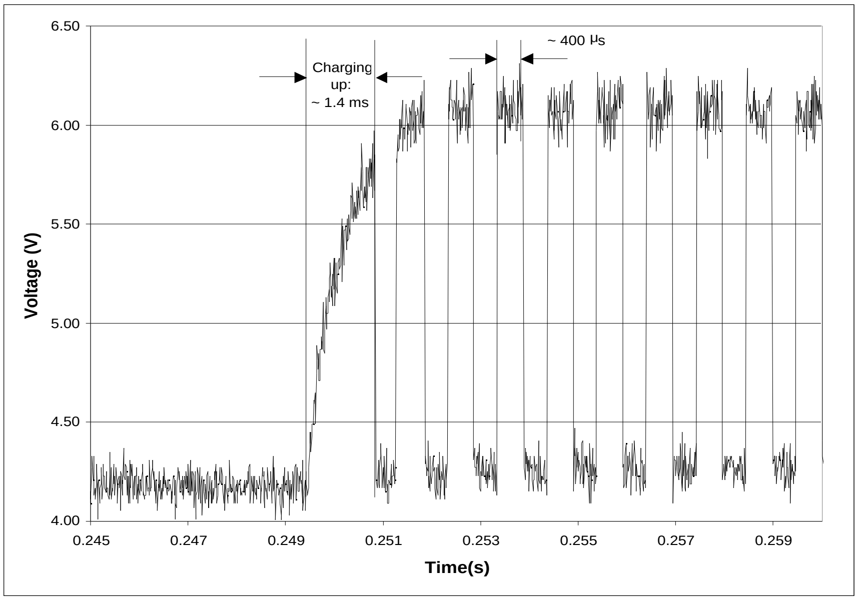
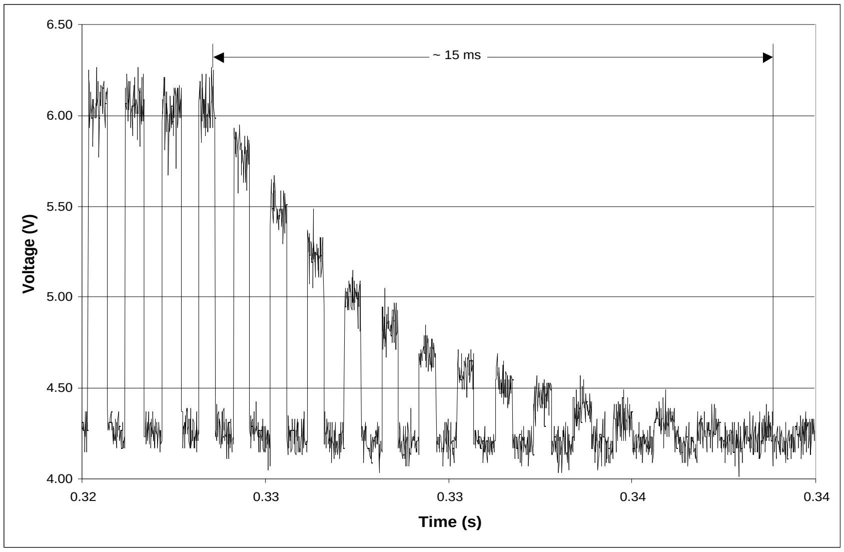


Figure 5. Detail of results showing transmission of 2.5 kbps pulse train from solar powered retromodulator.



(a)



(b)

Figure 6. (a) Charging and (b) discharging detail on solar-powered retromodulated signal.

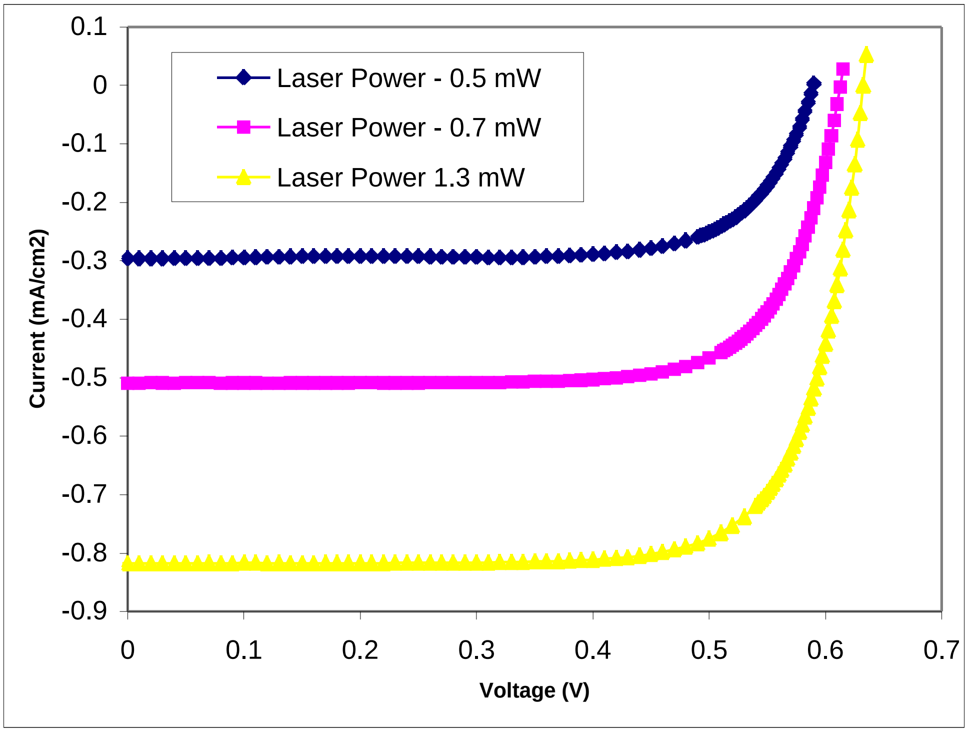


FIGURE 7. Example photovoltaic curves measured in the lattice-mismatched In0.17Ga0.83As/GaAs solar cells under 976 nm laser illumination at various intensities.