Progress on the ELROI satellite license plate

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ABSTRACT

The Extremely Low Resource Optical Identifier (ELROI) beacon is a laser "license plate" for satellites that can be read from the ground using a small telescope and a photon-counting sensor. A reliable way to identify satellites is urgently needed. Over 20,000 objects are currently tracked and monitored in the crowded space around the Earth, and most cannot be easily identified if conventional tracking (which relies on orbit determination) fails. Small satellites such as CubeSats are also being launched in increasingly larger groups, making them difficult to distinguish after launch and presenting a challenge to their operators and to the tracking infrastructure. While there are many proposed solutions, no identification beacon technology has yet become standard or widely used. A challenge is designing a beacon which is both small and light enough for the smallest satellites, and which can operate continuously without conflicts such as RF interference.

ELROI is one concept for a beacon that uses short, omnidirectional flashes of laser light at milliwatt average power to encode a unique ID number. ELROI is powered by its own small solar cell, and can safely operate for the entire orbital lifetime of the host object without needing power or interfering with other systems. The ID number can be uniquely determined from the ground in a single pass, even if the ground station detects only a few photons per second, using single-photon algorithms to isolate the signal and reject background. The ELROI IDs are open and designed to be readable by anyone with a suitable ground station, which requires a small telescope, a spectral filter, and a photon counting sensor such as a SPAD.

The ELROI concept has been validated in long-range ground tests, and several orbital prototypes have been delivered for (or are progressing toward) launch. We will discuss the design and testing of these prototypes, including updated launch schedules and the most recent designs.

1. INTRODUCTION

The Extremely Low-Resource Optical Identifier (ELROI) beacon is a concept for a milliwatt optical "license plate'" that can provide unique ID numbers for everything that goes into space [1]–[3]. ELROI is designed to help address the problem of space object identification (SOI) in the crowded space around the Earth, where over 20,000 active and debris objects are currently tracked. Current SOI methods typically rely on orbit determination, and require frequent observations to update each object's position and trajectory. Orbit changes, conjunctions, and rideshare launches can cause confusion about an object's identity. Re-identifying a lost object is significantly easier if it carries an ID beacon that can be read from the ground; however, there is currently no standard beacon technology that is small and light enough for the smallest satellites, and radio beacons have the additional drawback of RF interference.

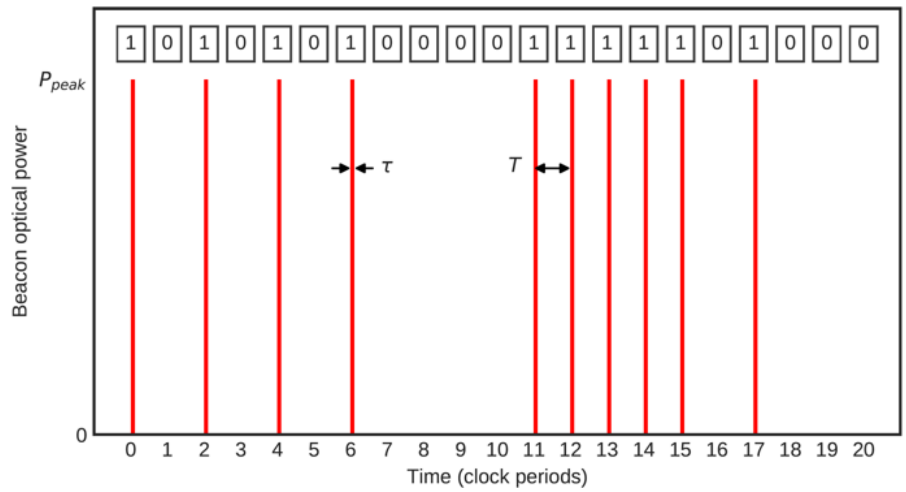

Fig. 1. Illustration of the signal produced by an ELROI beacon. The onboard laser diode emits short pulses of light (pulse width $\tau \approx 1$ microsecond) separated by a fixed period (clock period T ≈ 1 millisecond). The peak power optical power is ~1 W, but the low duty cycle brings the average power to just a few milliwatts. Each clock period encodes one bit of the beacon ID number. An error-correcting code is used to generate the ID numbers.

ELROI is a new concept for an autonomous optical beacon that uses short flashes of laser light with only a few milliwatts of average optical power to encode a unique ID number (Fig. 1). The light is diffused in all directions, so there is no strict pointing requirement. The ID can be read from the ground by anyone with a small tracking telescope and a photon-counting sensor. ELROI is smaller and lighter than a typical radio beacon, it is powered by its own small solar cell, and it can safely operate for the entire orbital lifetime of the host object. Using spectral filtering and photon counting to enable extreme background rejection in real time, the ID number can be uniquely identified in a few minutes, even if the ground station detects only a few photons per second.

The ELROI concept has been validated in long-range ground tests. An early prototype has been flown (see next section) and others are scheduled for launch beginning in 2021. A comprehensive overview of the ELROI encoding/decoding scheme, including a detailed optical link budget, may be found in [3], [4]. Reference [5] provides additional details about signal processing. This paper will focus on ELROI flight prototypes and their progress toward launch.

2. FLIGHT HARDWARE

ELROI PC-104

ELROI-PC104 was an early prototype designed in a standard PC-104 form factor, a common footprint for CubeSat payloads. Although the mature version of ELROI is designed to be autonomous and powered by its own small solar cell, this prototype received power from the host satellite. It carried four laser diodes on two opposite faces of the satellite (Fig. 2).

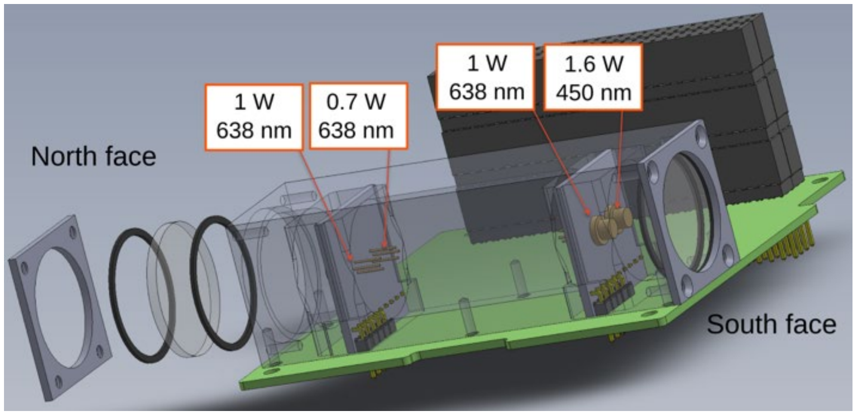

Fig. 2. Components of the ELROI-PC104 board, with laser diodes shown.

The ELROI-PC104 payload was built at Los Alamos National Laboratory and delivered for integration into NMTSat, a 3U CubeSat designed and built by students at New Mexico Institute of Mining and Technology in Socorro, NM [6]. NMTSat was funded by the NASA ELaNa CubeSat Launch initiative. Additional technical details about ELROI-PC104 and its integration into NMTSat may be found in [4].

NMTSat was launched on a Rocket Lab Electron in December 2018. After launch, we attempted to observe ELROI-PC104 from a Los Alamos National Laboratory ground station at Fenton Hill, near Jemez Springs, NM. Our receiver consists of a 36-cm aperture commercial telescope, optical bandpass filters, computerized mount, and a LANL-developed photon-counting camera [7].

As discussed in [8], NMTSat was one of 13 other CubeSats launched on the ELaNa XIX mission. Seven of these satellites were contacted by radio after launch and six remain unidentified. NMTSat is presumed to be one of the six uncontacted objects. After several months of observations, we did not detect the ELROI signal from any of the six candidate objects. Because the ELROI-PC104 prototype is powered by the host satellite, our hypothesis is that NMTSat did not power on after launch. Newer ELROI prototypes include solar cells and can provide their own power, allowing them to operate even if the host satellite fails.

ELROI-UP

The ELROI Universal Prototype (ELROI-UP) is a more advanced, fully autonomous design (Fig. 3). ELROI-UP carries its own small solar cell, and can receive power and commands from a host satellite, but does not require them. ELROI-UP can contain up to four laser diodes. The first test flight units are populated with four 638-nm red laser diodes with peak power 2.5 W. Different combinations of the four emitters will be pre-programmed to allow testing at up to 10 W peak power. Each diode was measured to emit over approximately 1.3π steradians solid angle.

ELROI-UP is designed to be attached to any host that can accommodate it. ELROI-UP is 98 × 92 × 34 mm in size, its mass is 310 g, and the power (if externally supplied instead of provided by the solar cell) is less than 100 mW. The unit can also be mounted in a passive mechanical structure and launched as a free-flying CubeSat in 1/3U, 1/2U or larger form factor. We are willing to provide these flight-qualified units to interested launch opportunities.

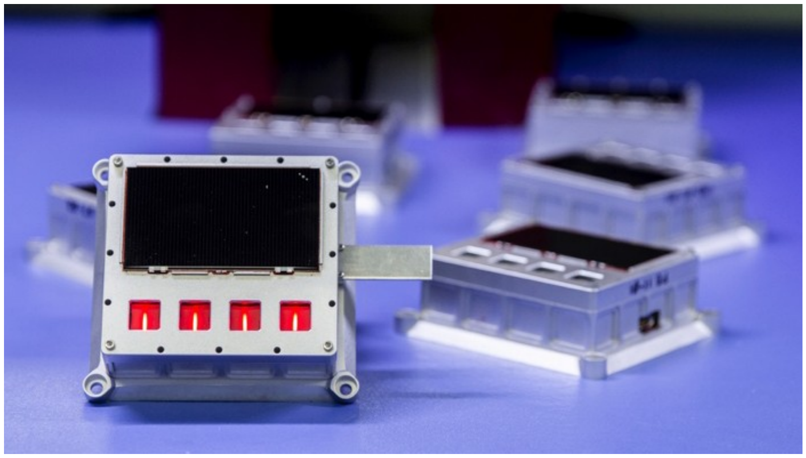

Fig. 3. ELROI-UP units.

ELROI-UP-X

Two ELROI units (see Fig. 4) were delivered in August, 2018 for launch on the Laser Communications Experiment (LaCE), a pair of research CubeSats being developed by the Naval Information Warfare System Command. These ELROI-UP-X (X for eXternal power) units are powered by the spacecraft to allow them to turn the units on and off, to eliminate the potential for interference with the primary laser communication mission. The LaCE satellites are currently planned to launch in 2021.

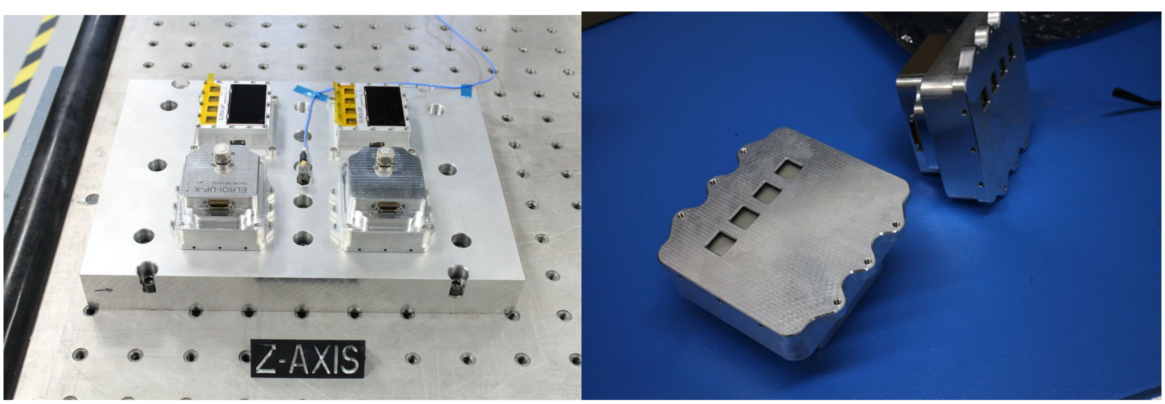

Fig. 4. Left: ELROI-UP and ELROI-UP-X units in vibration testing (laser diodes on ELROI-UP-X units are pointing down). Right: ELROI-UP-X units showing optical diffusers.

PRODUCTION DESIGN

The final target size of the mature ELROI design is a few centimeters square, similar to a thick postage stamp. The minimum size is limited by the solar cell needed to power the laser diode(s).

A concept illustration is shown in Fig. 5. This design will be suitable for the majority of low-Earth orbit (LEO) CubeSats and many larger satellites. Larger, higher-power designs may be used for some larger or more distant satellites.

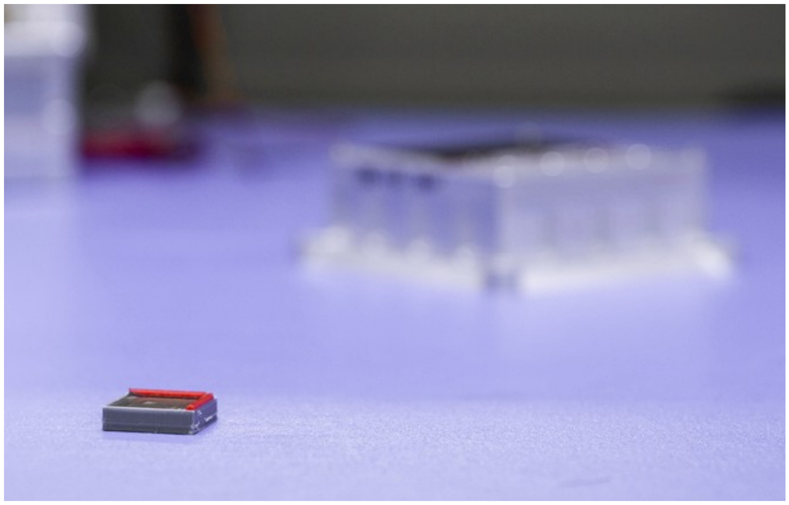

Fig. 5. Concept design of an ELROI production unit compared to ELROI-UP.

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