ELROI: A satellite license plate to simplify space object identification

Rebecca M. Holmes[a], Charles T. Weaver, David M. Palmer
Los Alamos National Laboratory
P.O. Box 1663, Los Alamos, NM 87545
[a] rmholmes@lanl.gov

ABSTRACT

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, simplifying space object identification (SOI). Using photon counting to enable extreme background rejection in real time, the ID number can be read from the ground in a few minutes by anyone with a small tracking telescope and a photon-counting sensor. ELROI is powered by its own small solar cell, and it is sufficiently compact, lightweight, and inexpensive for use on the smallest satellites. The ELROI concept has been validated in long-range ground tests, and orbital prototypes are scheduled for launch in 2018 and beyond, including a PC-104 form factor unit which was integrated into a CubeSat and is scheduled to launch in summer 2018. We describe the design and signal characteristics of this prototype and the next generation of fully autonomous units, and discuss applications for space situational awareness.

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 17,000 active and debris objects are currently tracked. Tracking these objects is an essential part of the multi-billion-USD SSA effort, and requires continuous knowledge of each object's position and trajectory. Re-identifying a lost object is significantly easier if it carries an ID beacon that can be read from the ground. 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.

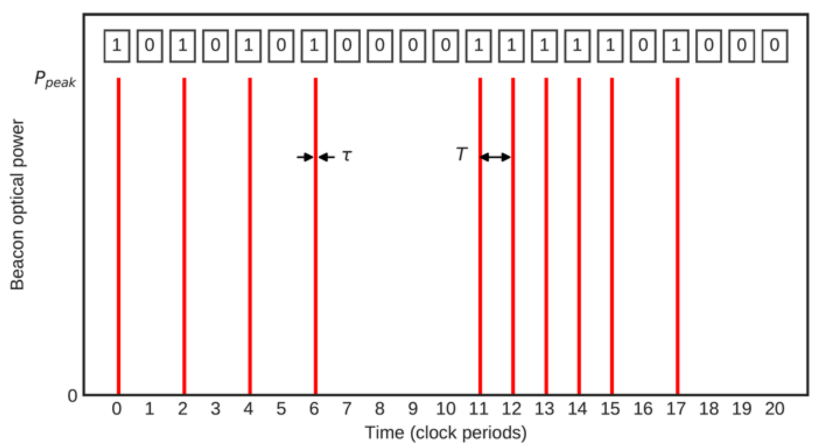

Fig. 1. Illustration of the signal produced by an ELROI beacon. The onboard laser diode emits short pulses of light (pulse width $\tau \approx 1$ microsecond) separated by a fixed period (clock period $T \approx 1$ millisecond). The peak power optical power is ~1 W, but the low duty cycle brings the 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, providing tolerance for bit errors.

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, and orbital prototypes are scheduled for launch beginning in late 2018. A comprehensive overview of the ELROI encoding/decoding scheme, including a detailed optical link budget, may be found in [3], [4]. This paper will emphasize applications for space situational awareness, and briefly describe the design and signal characteristics of the current generation of ELROI prototypes.

2. APPLICATIONS FOR SSA

The primary purpose of ELROI is to simplify space object identification (SOI) when an object is tracked but not identified. Because most satellites and debris cannot be identified easily without matching them to a radar track that has been maintained continuously from launch, an "uncorrelated track" may occur, e.g., when radar observations are interrupted, when solar activity causes sudden increases in atmospheric drag, when satellites make unexpected maneuvers, or when two orbits become nearly identical. By enabling rapid optical identification, ELROI reduces the number of costly observations that may be needed to resolve these uncorrelated tracks in radar systems, freeing up resources to monitor new objects and potential threats. With a global network of perhaps a dozen ELROI ground stations, most tagged and tracked objects could be re-identified at will.

ELROI also enables rapid post-deployment identification of small satellites and secondary payloads. Small satellites, particularly CubeSats, are being launched in increasingly larger groups ranging from a dozen to more than a hundred satellites [5], [6]. A typical CubeSat operator does not have the resources to determine which of the resulting radar objects is their satellite. ELROI beacons would allow individual CubeSats to be identified as soon as they are visible from a suitable ground station, even in a crowded field containing multiple objects from the same launch. As small satellites and secondary payloads become a larger part of the space ecosystem, rapid post-deployment identification of individual satellites from these launches is increasingly important to both commercial and government operators, and to the future of SSA [7].

Table 1: Comparison with other current and proposed SOI schemes. Costs are estimates.

	CURRENT PRACTICE	**RFID+GPS SUBCARRIER (RILDOS)**	**RFID+GPS DEDICATED**	**ELROI (PRODUCTION DESIGN)**
Applicability	Trackable maintained objects	Payload only ✘	Payload and intentional debris	Payload and intentional debris
Initial track	Confused ✘	Valid	Valid	Valid
Track Lifetime	While maintained ✘	Operational life ✘	Orbital life	Orbital life
Track recovery	Difficult ✘	Operational life	Easy ✓	Easy ✓
Integration	None ✓	Early in design	Radio compatibility, GPS & antenna	Stick-on autonomous small module ✓
Size, Weight, and Power (SWaP)	None ✓	Continuous xmit power (few watts) ✘	Significant fraction of a CubeSat ✘	Trivial (few cm^3, few grams, self-powered) ✓
Complexity/fragility	Ground-based ✓	Moderate (payload) ✘	Moderate (GPS) ✘	Low ✓
RF Interference	None	Low-Moderate ✘	Moderate ✘	None
Ground station cost	$900M (space fence) ✘	$10k	$20k	$500k
Space segment cost	None	$100k NRE/design	$1k/spacecraft	$1k/spacecraft

A license plate on every object that goes into space would greatly simplify SOI and ease the burden on SSA resources. ELROI would also directly address existing requirements identified by the space community for improved trackability and identification (e.g., [8]).

Compared to other current and proposed SOI solutions (Table 1), ELROI is lower in SWaP (size, weight, and power), can operate autonomously for the entire orbital lifetime of the host object, and does not produce RF interference. These characteristics make it attractive for voluntary adoption by satellite operators. The ELROI encoding scheme can support millions of unique ID numbers, sufficient to identify all new intentional objects in Earth orbit for the foreseeable future. An optical beacon also has the potential to be a "black box" for satellites, transmitting low-bandwidth emergency telemetry information if the host satellite is disabled.

3. FLIGHT HARDWARE

ELROI PC-104

ELROI-PC104 is a 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 receives power from the host satellite. It carries four laser diodes on two opposite faces of the satellite (Fig. 2).

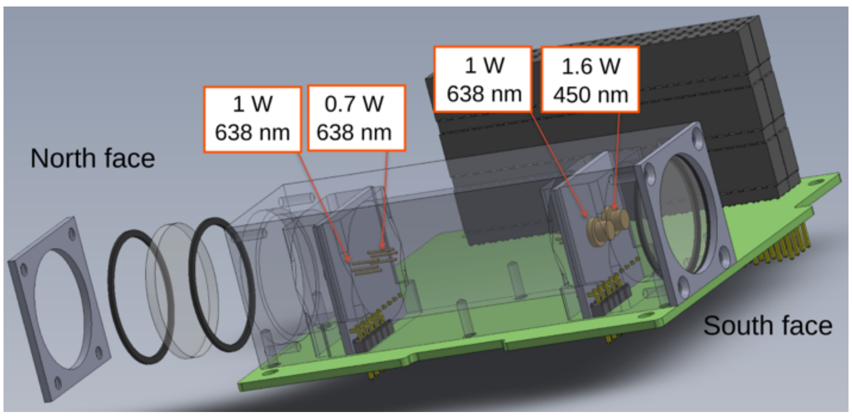

Fig. 2. Components of the ELROI-PC104 board, with laser diodes shown.

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 [9]. NMTSat is funded by the NASA ELaNa CubeSat Launch initiative and is scheduled to launch on a Rocket Lab Electron mission in December 2018. Additional technical details about ELROI-PC104 and its integration into NMTSat may be found in [4].

After launch, we will 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 [10]. Less expensive single- or few-element photon-counting sensors may also be used to observe ELROI, with correspondingly stricter requirements on the tracking and pointing accuracy of the telescope and mount system (details in [4]). We encourage others to consider observing this test flight and future flights.

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 will be 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.

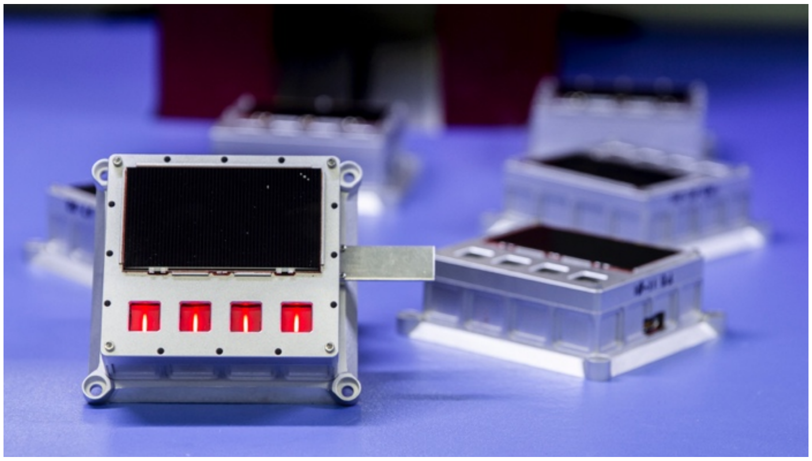

Fig. 3. ELROI-UP units.

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. 4. 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.

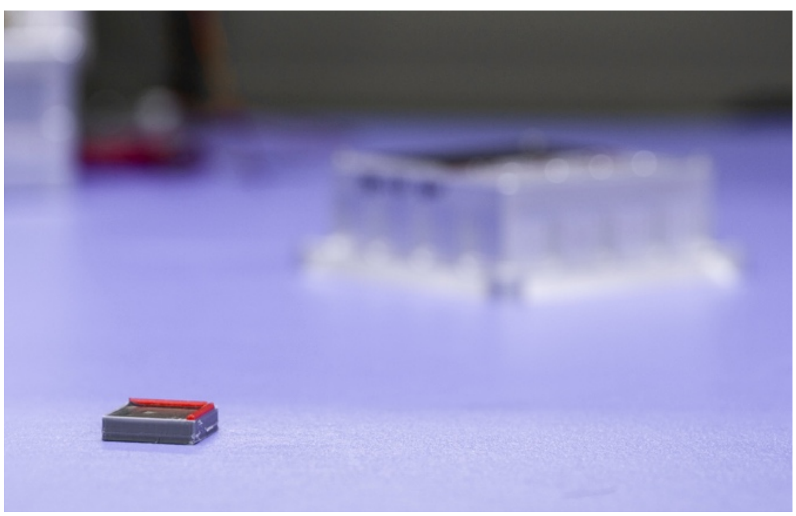

Fig. 4. Concept design of an ELROI production unit compared to ELROI-UP.

4. ACKNOWLEDGEMENTS

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