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ENERGY-AUTONOMOUS OPTICAL CAMERA COMMUNICATION NODE FOR INTRA-SATELLITE LINKS

OCC4SAT

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1 THE PROBLEM

- Intra-satellite links are still mostly **wired harnesses**: added mass, poor modularity, and costly re-qualification (updated Test Procedures, Test Readiness Reviews) whenever a subsystem is moved.
- **Optical Camera Communication (OCC)** reuses ordinary LEDs as transmitters and cameras as receivers, yet transmitter energy is ignored: it is assumed permanently powered.
- A node that is wireless for *both* power and data remains unproven for spacecraft interiors.

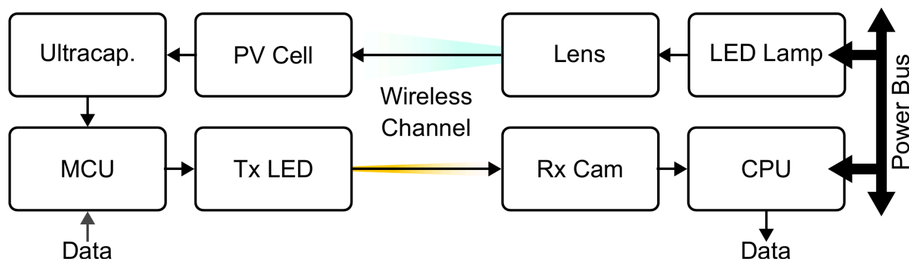

Fig. 1: Node architecture. Energy path: illumination → PV cell → ultracapacitor drives an MCU + LED transmitter; bursts reach the camera receiver + CPU (vision + DSP). No power-bus connection.

2 CURRENT SOLUTIONS

- **Wired RF & harness links:** power-dependent, rigid topology, added mass.
- **Photodiode optical links:** wide field of view causes cross-talk, reintroducing placement constraints.
- **Solar-as-receiver VLC:** harvests *while receiving*; the reverse, a transmitter on harvested light, is unexplored.
- **Continuously-powered OCC transmitters:** no energy autonomy.

3 OUR CONTRIBUTION

An energy-autonomous OCC transmitter node, powered solely by harvested optical energy and validated on a laboratory demonstrator.

- **Photovoltaic harvesting** of ambient optical energy, stored in a 5 F ultracapacitor.
- **Threshold-triggered bursts:** a hysteresis policy switches the node ON at $V_{high} \approx 3.3$ V and OFF at $V_{low} \approx 3.0$ V, with no prior knowledge of the harvesting cycle.
- **Wireless for power & data:** free placement inside the spacecraft, with no harness routing or re-qualification.
- **Camera spatial segregation:** each transmitter occupies distinct pixels, so many autonomous nodes coexist without cross-talk.

> **Key insight:** energy availability, not modulation, governs the effective throughput, motivating *energy-aware* OCC design for modular spacecraft subsystems.

PROTOTYPE AT A GLANCE

- **PV cell:** Mikroelektronika SW0.4M, 0.4 W (V_{mp} 4.0 V, I_{mp} 100 mA)
- **Storage:** 5 F ultracapacitor
- **MCU:** Arduino Nano Every (ATmega4809), ≈18–20 mA active
- **Link:** single LED, OOK @ 15 bps → Raspberry Pi Camera v2 @ 30 fps, 1000 µs exposure
- **Regime:** line-of-sight, dark-room, TRL-5-oriented proof of concept within **OCC4SAT**

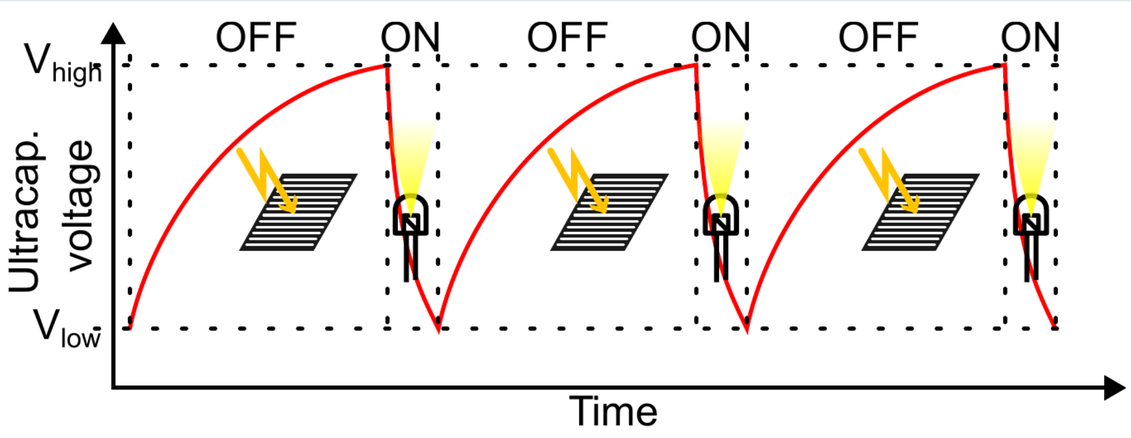

Fig. 2: Charge–activate–transmit cycle. Burst-mode transmission occurs only when enough energy is stored between the two ultracapacitor voltage thresholds, giving repeatable charge–transmit operation.

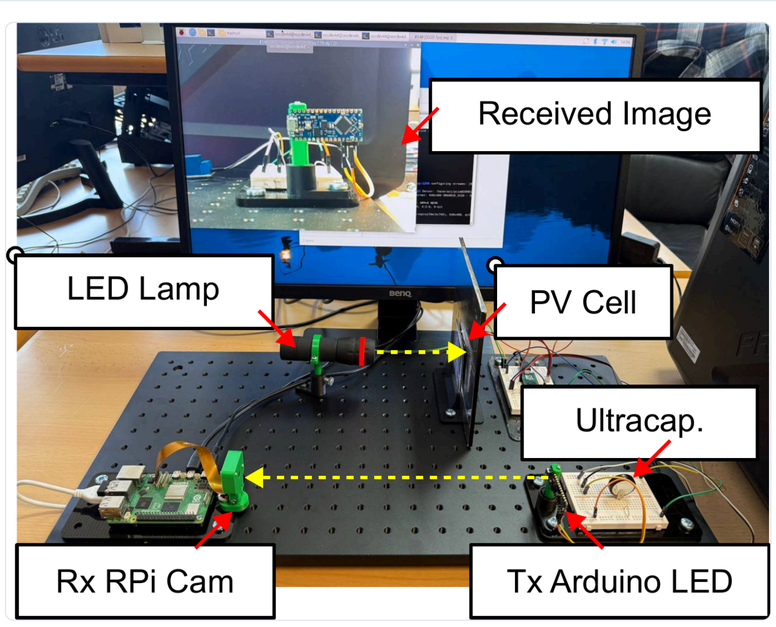

Fig. 3: Laboratory setup. Dark-room optical breadboard: an LED lamp illuminates the PV cell; the Arduino LED transmitter emits OOK bursts captured by the camera and decoded offline. Aluminium tape emulates a satellite panel.

4 RESULTS

199 s CHARGE / CYCLE	**21 s** BURST DURATION
315 bit PAYLOAD / BURST	**9.6 %** DUTY CYCLE
1.43 bps THROUGHPUT	**<2·10⁻⁵** BIT ERROR RATE

Over a **10-hour run (≈163 cycles)**, all 51,345 delivered bits decoded correctly. Charge energy ≈ 4.7 J per cycle.

$$E_{stored} = \tfrac{1}{2}\, C\, (V_{high}^{\,2} - V_{low}^{\,2}) \approx 4.7\ J \rightarrow E_{bit} \approx 14.9\ mJ/bit$$

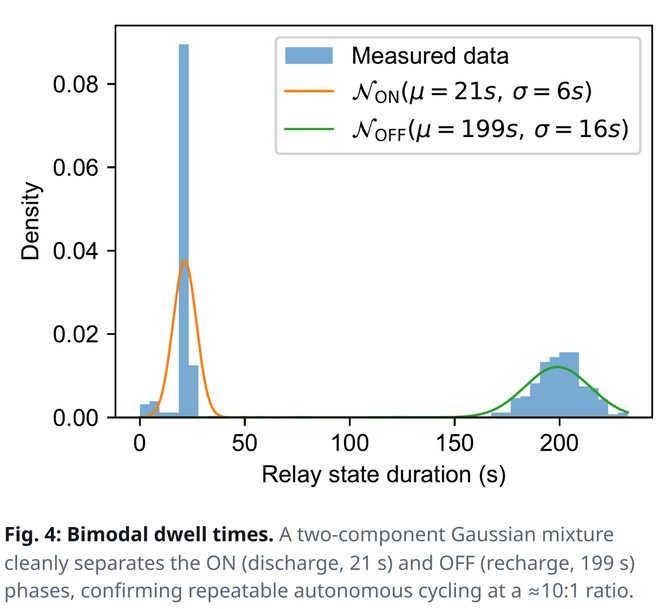

Fig. 4: Bimodal dwell times. A two-component Gaussian mixture cleanly separates the ON (discharge, 21 s) and OFF (recharge, 199 s) phases, confirming repeatable autonomous cycling at a ≈10:1 ratio.

5 NEXT STEPS

Burst operation is a **design feature** matched to low-duty-cycle intra-satellite telemetry, not a limitation.

- Scale throughput by **spatial multiplexing**: hundreds of ROIs per colour channel.
- Self-powered comparator to replace external threshold circuitry (flight-ready).
- Reflective (non-LoS) links and real machined-aluminium panels.
- On-orbit validation toward higher TRL within OCC4SAT.

SPONSORS

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