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ATA - *Implementation Challenges in Low-SWaP Free Space Optical Networks*

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High photon efficiency optical communications techniques have demonstrated the ability to achieve high data rates over long distances using modest aperture sizes and laser power. These techniques were demonstrated on the Lunar Laser Communications Demonstration (LLCD), which achieved a 622 Mbps downlink from lunar orbit. These techniques have the potential to minimize the size and weight of optical communications terminals, allowing their incorporation into small satellite and airborne systems. However, the use of complex technologies, such as cryogenically cooled detectors and high overhead error correction codes, have hindered these applications. The link performance levels achievable through the use of commercially available technologies, such as fiber amplifiers, and high-performance, low-overhead coding, are analyzed to determine the performance capabilities of small optical terminal systems using low-risk component technologies. The link performance achieved by small optical terminals using available laser communications components is found to compare favorably with more complex state-of-the-art systems, enabling significant reduction in system size, weight and power, and facilitating applications including low earth orbit and geosynchronous crosslinks and downlinks, lunar downlinks, and small unmanned aerial vehicles.

High photon efficiency techniques include the use of pulse position modulation (PPM) to maximize peak transmit power, photon counting detectors, and capacity-approaching error correcting codes. While these techniques result in near quantum-limited performance, they can impose severe SWaP and cost demands on small satellite systems and ground stations. PPM trades bandwidth for signal-to-noise, and in conjunction with capacity-approaching error correction encoding and decoding, can impact the requirements of space-qualified data processing systems. The high coding rates of capacity approaching codes further increase bandwidth requirements with respect to the net data transmission rate. Photon counting detectors have included superconducting nanowire single-photon detectors (SNSPD) and arrays of Geiger-mode avalanche photodiodes (APD). SNSPD detectors require extensive cryo-cooling, typically below 10 K, with significant SWaP impacts. Geiger-mode APD arrays add significant system signal processing complexity, and pose bandwidth, efficiency, and complexity trades due to the microsecond reset time of individual detectors.

Photonic Integrated Circuits (PIC) offering integrated capability in low-SWaP packages for modulated laser sources, pre-amps & detectors require Tech Transfer to advance manufacturing maturity & increase TRL to provide space-qualified & validated components. Compact SWIR Focal Plane cameras provide high performance tracking at optical communications wavelengths (with better Sensitivity, FOV, & Accuracy compared to quadrant & position sensors), but now require space qualification and Rad Hard ROIC/ASIC. Finally, FSOC network and interface standards to facilitate integration are required, and should operate the network at transport layer with cross-layer Error Detection/Correction/Re-Transmission and data agnostic transport containers.