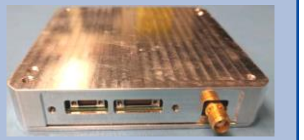
Cobalt Optical Crosslink Transceiver for SWaP-constrained Missions

Ryan Kingsbury

History of Blue Cubed

Cobalt
Optical Crosslink

Bluefin
X-band Transmitter



TRL6, flying in late 2021

- Formed 2018
- Our focus:
  low-SWaP, cost-effective, mass-produced RF & optical comm solutions
- Core optical technology:
  self-alignment with differential tracking of TX and RX signals
- Funding strategy: private investment, SBIRs, strategic partnerships

Scott Palo, PhD
CEO

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Chief Scientist

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CLO

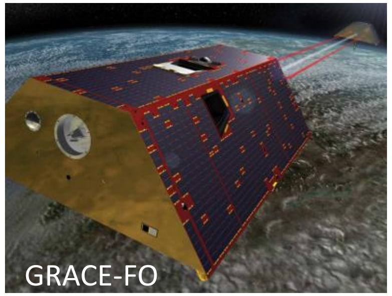
Why crosslinks?

- Communications Infrastructure
  - SpaceX Starlink
  - Amazon Kuiper

STARLINK

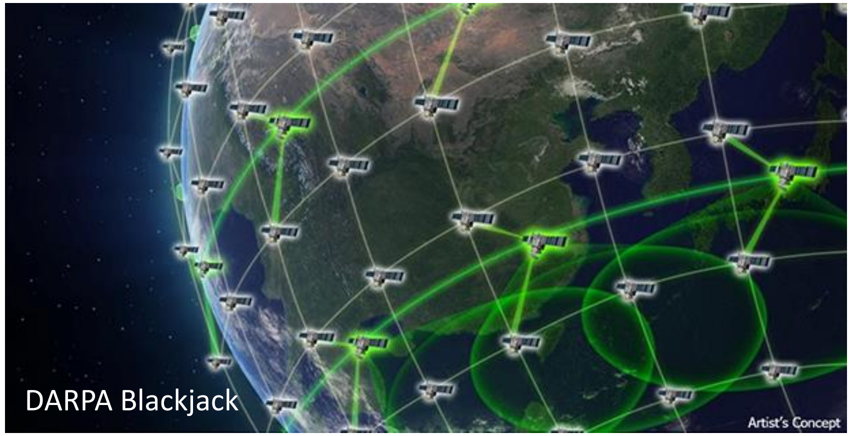
- Science applications
  - Distributed apertures: precision OD, timing
  - Swarm concepts


MIT CLICK B/C


GRACE-FO

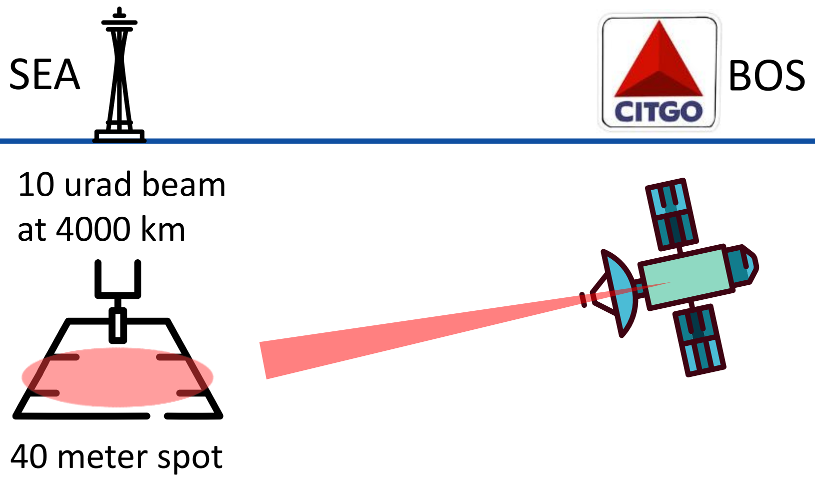
- Defense applications
  - SDA's Proliferated LEO vision
  - DARPA Blackjack

- High rate radio crosslinks aren't viable
  - Low data rates due to antenna restrictions
  - Limited spectrum (S-band and Ku-band)

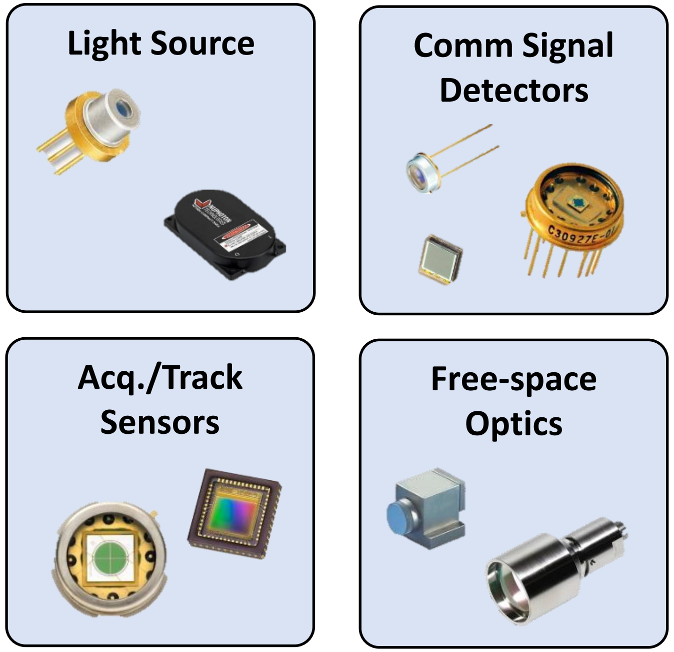


DARPA Blackjack

Lasercom 101



- **Fundamentally a pointing problem**
  - Beamwidths of 10 urad (2 arcsec) are common
  - Pointing requirement is a small fraction of the beamwidth
- Key components:
  - Power-efficient light source
  - Low-noise, high-bandwidth comms detector
  - Acquisition/tracking detectors
  - Free-space optics (telescope, pointing)
- Common Design Trades
  - **Wavelength**: component availability, performance
  - **Aperture Size / Configuration**
  - **Platform vibration ("jitter")**: power to compensate

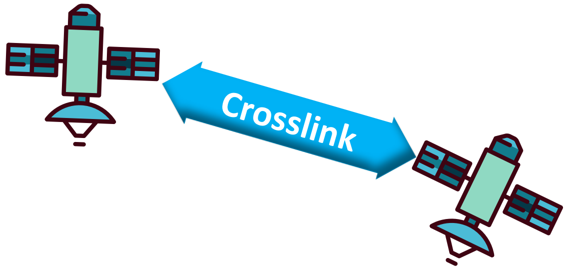


Optical Downlinks vs Crosslinks

Downlinks

- Usually asymmetric
  - Fast downlink
  - Slow (or no) uplink
- **Easier**:
  - Ground apertures can be large
  - No power constraints on ground
  - Shorter path lengths (< 2000 km)
- **Harder**:
  - Atmosphere
  - Clouds
  - Beacon safety/licensing

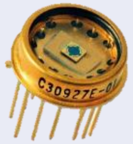
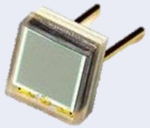
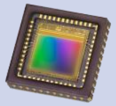
Crosslinks



- Symmetric
  - full-duplex operation
- **Easier**:
  - No atmosphere, clouds
- **Harder**:
  - Path lengths to 4000 km for LEO-LEO
  - Limited aperture size
  - Satellite power constraints
  - RX/TX co-alignment
  - Terminal “handedness”

Crosslinks are more challenging. But a crosslink terminal can be used for downlink.

Wavelength Trades: Components

Component	1550 nm (IR, fiber telecom operates here)	450-800 nm (visible, "silicon friendly")
Transmitter Type	Telecom modulator (100 Gbps) + EDFA (<10% efficiency) 	Directly modulated diode laser, (>30% efficiency) 
Communications Detector	InGaAs APD (noisy) OR optical preamp (power) 	Si APD (less noisy)  OR Silicon photomultiplier 
Acquisition & Tracking Sensor	Quad-cell,  SWIR camera ($$$) 	Silicon camera (cheap, fast, good!)  

1550 nm is not the power-efficient choice for moderate data rate (~1 Gbps) crosslink systems

Aperture Trades: Gain & Topology

- Two functions:
  - Free-space photons → detector
  - Laser → free-space

Aperture Gain

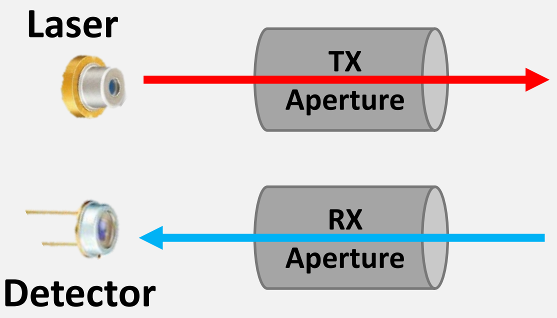
$$G = \left(\frac{\pi D}{\lambda}\right)^2$$

- Aperture Gain/Directivity
  - Function of diameter (D) and wavelength (λ)
  - 850 nm from 11 mm aperture → 92 dBi (!)
  - Note that large apertures become expensive in terms of mass. $M \propto D^3$

- Space optics are hard
  - We want diffraction limited performance
  - Thermal defocus
  - Launch loads
  - Radiation darkening

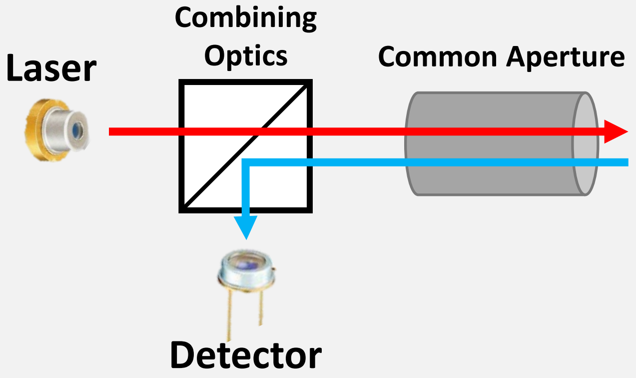
Dual Aperture Optics

- Good TX/RX isolation
- Co-alignment is hard
- Mass inefficiency due to second aperture



Single Aperture Optics

- Requires combining optics with good isolation (~70 dB)
- Easier to maintain co-alignment
- Mass efficient

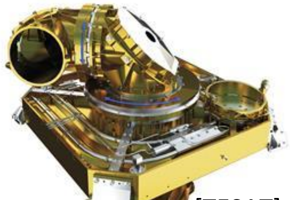


Single aperture designs offer mass savings and reduced alignment complexity.

Pointing Trades: Actuators & Sensors

Coarse steering:

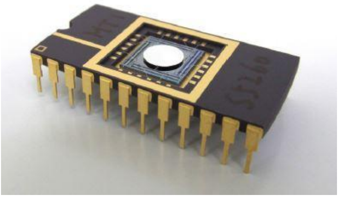
- Establishes pointing to within the range of the fine steering system
- Approaches
  - Body-pointing (best for a CubeSat)
  - Gimbal (move the whole terminal)
  - Beam director (steer a collimated beam)



[TESAT]

Fine steering:

- Achieve sub-beamwidth pointing accuracy
- Commonly used to compensate for vibrations from reaction wheels and other mechanisms
  - Better yet: address jitter at the source!
- Requires knowledge of pointing error
- Fast-steering mirrors: MEMS, voice coil, etc.



To close pointing control loops, we need a measurement of system pointing error.

For crosslinks: relative error between TX and RX signals is the key measurement.

Blue Cubed: Cobalt Optical Transceiver

Full Duplex

up to 3 Gbps#
Data Rate

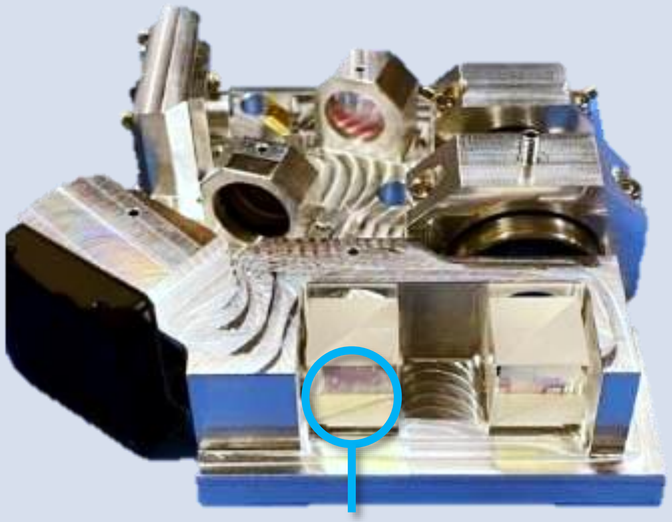
9x9x5 cm
size

< 900 g
Mass

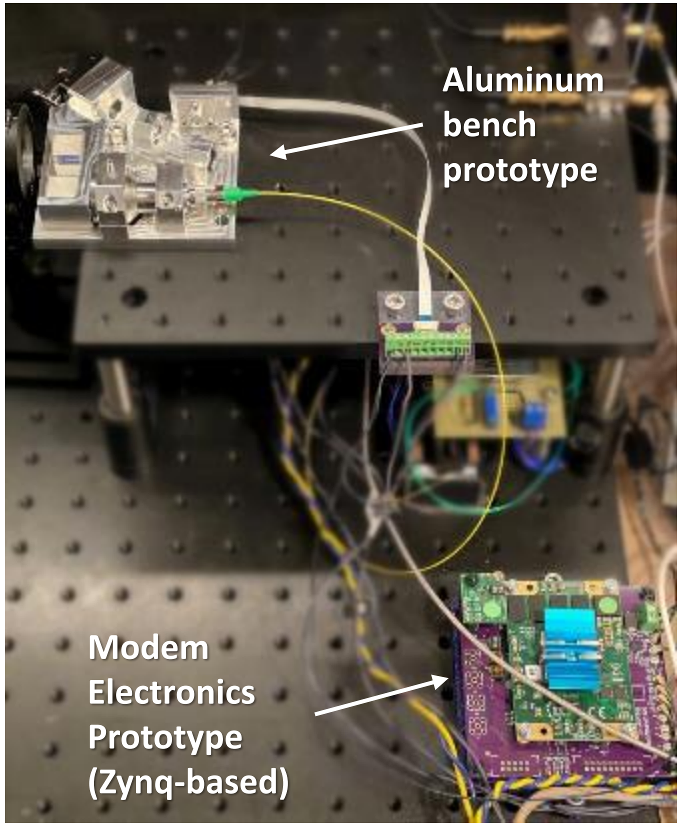
< 10 Watts
Power

- expandable via WDM

Cobalt Optical Transceiver
(qualification unit)

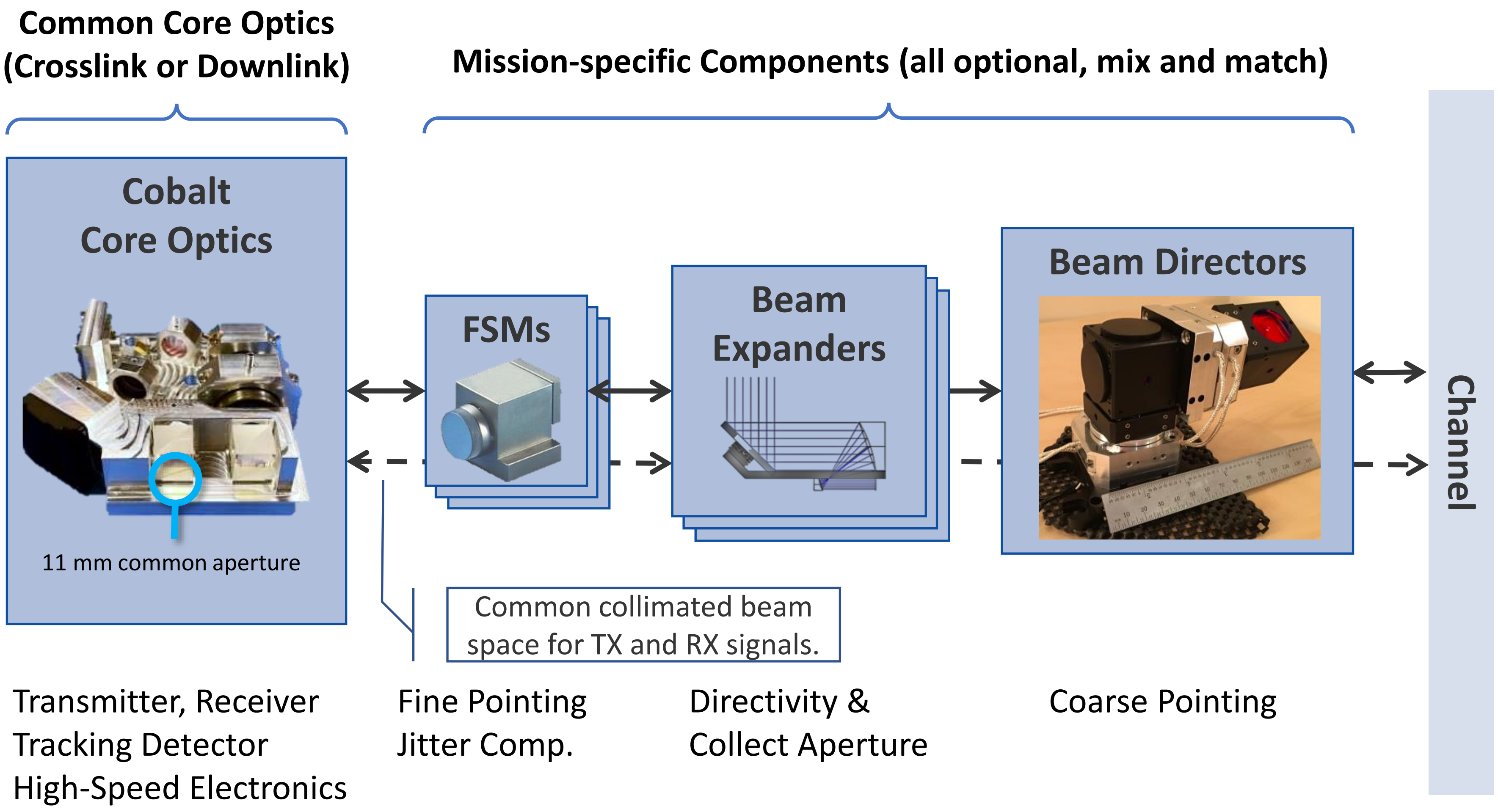


11 mm common aperture



Industry Leader in Size, Weight and Power Terminal per Mbps

Blue Cubed: Modular Approach

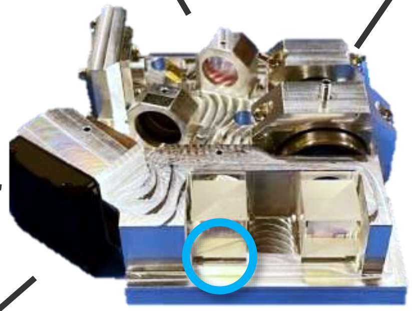


Modular terminal approach is able to meet a wide range of mission requirements.

Cobalt Crosslink: Key Advantages

Self-alignment approach → **Relaxed manufacturing tolerances**

Directly modulated laser diode **High power efficiency**



Wide field of view (~1 deg) → **fast acquisition, link setup**

Basic Specifications:

- > 3 Gbps, full duplex
- Small: 9 x 9 x 5 cm
- < 10 W
- < 900 g

High speed (kHz) tracking sensor → to **reject bus vibration**

Common TX/RX aperture → **simplifies alignment, one aperture**

Closing Remarks

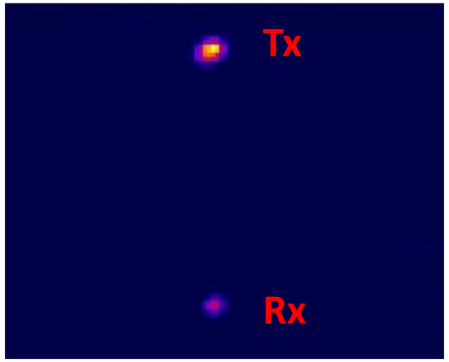
- Optical crosslinks are feasible on SWaP-constrained CubeSats today!

- Visible and NIR wavelengths are CubeSat-friendly
  - High efficiency diode lasers
  - Silicon detectors: low cost, power efficient

- Blue Cubed is developing lasercom products tailored for SWaP-constrained applications
  - Differential tracking performance validated
  - Full environmental qual (TRL6) late 2021

- Contact Us: info@bluecubed.net www.bluecubed.net

Differential Tracking Approach



Demonstration of link closure across 4000 km path: 500 Mbps OOK, BER of 9.6 x 10^{-4}