Laser Communication Requirements Drive Cost-Effective Solutions

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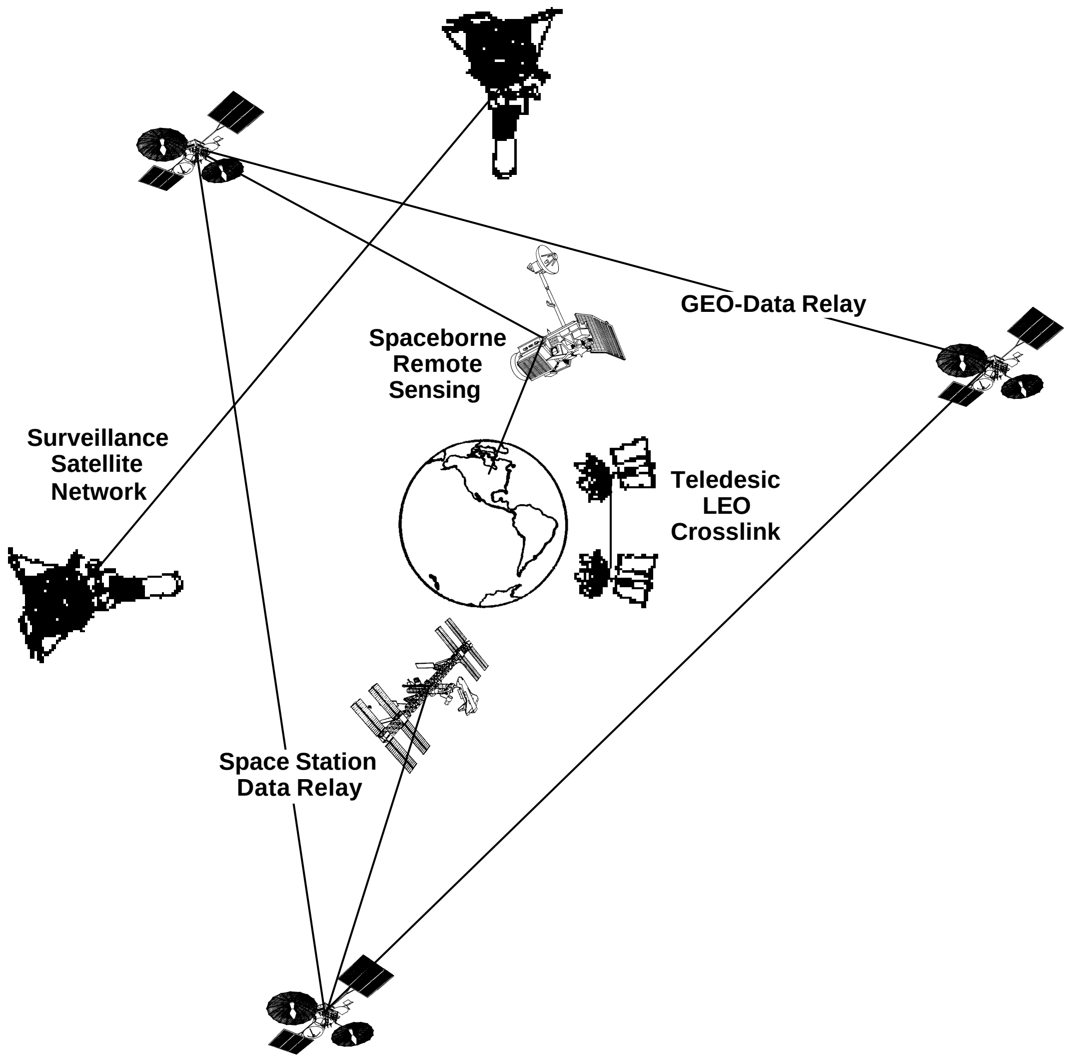
Outline

- ❍ Crosslink applications and system requirements
- ❍ Benefits of laser communications
- ❍ Design trades
- ❍ LEO short-range links
- ❍ LEO medium-range links
- ❍ LEO and GEO long-range links
- ❍ Common and modular hardware solutions
- ❍ Development risk
- ❍ Summary

Crosslink Applications Support Commercial, Military and Scientific Users



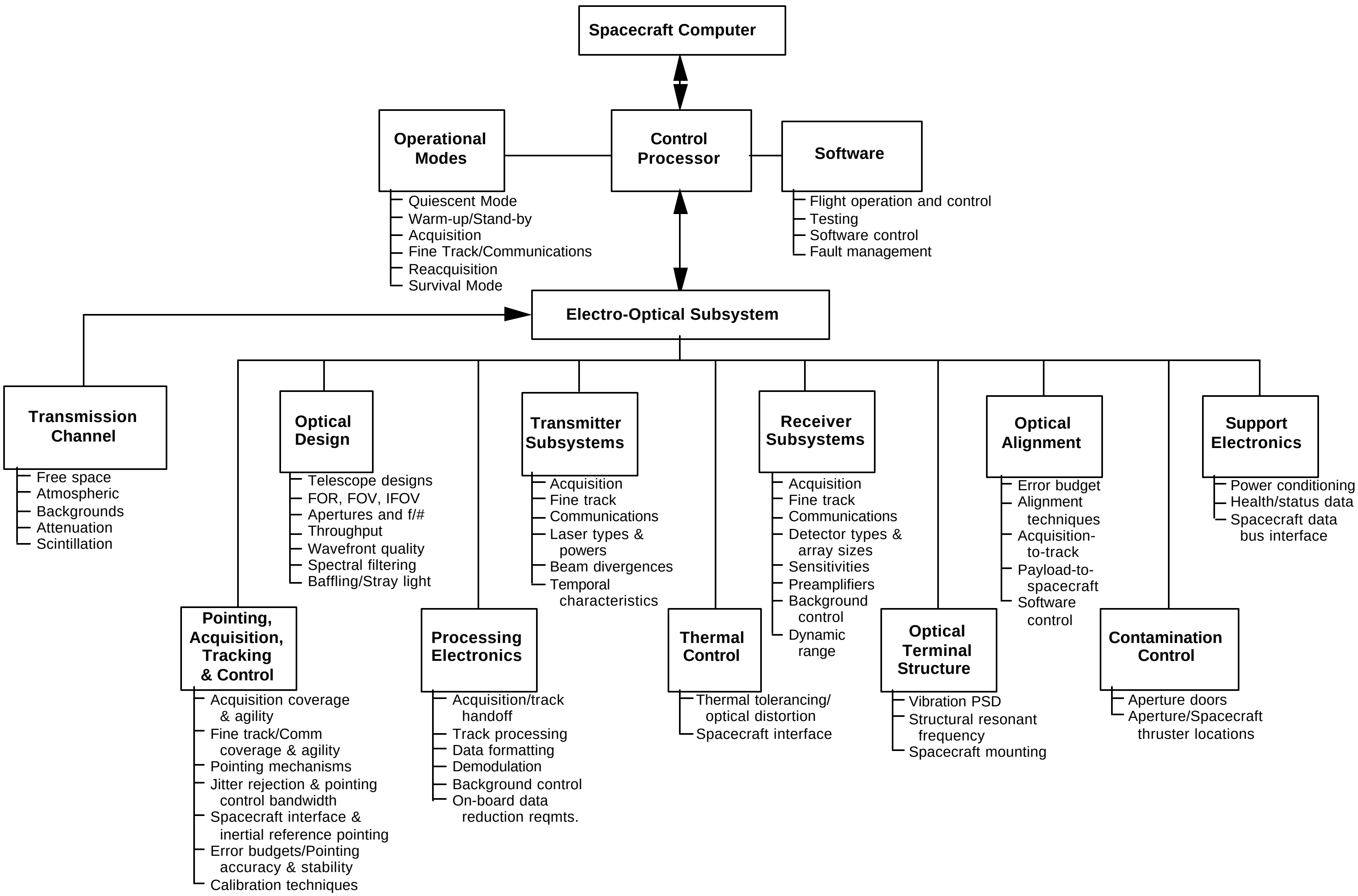
Space-to-Space Applications Stress Different Aspects of the Design

- LEO-to-LEO crosslinks
  - Short range: Up to 1 Gbps over 5000 km
  - Medium range: Up to 7.5 Gbps over 10,000 km
  - Limited attitude knowledge increases acquisition search cone
  - Platform base motion drives residual pointing jitter
- LEO-to-GEO uplinks
  - Up to 10 Gbps over 44,000 km
  - Good attitude knowledge reduces GEO search cone
  - LEO platform base motion drives residual pointing jitter
- GEO-to-GEO crosslinks
  - Up to 10 Gbps over 84,000 km
  - Good attitude knowledge reduces acquisition search cone
  - Reduced platform base motion lowers residual pointing jitter

Benefits of Laser Communications

- Increased bandwidth (large carrier frequency)
- Small antenna and swept volume (large antenna gain)
- Secure communication (narrow beam with low probability of intercept and negligible interlink interference)
- Jam resistance (small receive FOV)
- Track and communicate through the sun (small receive FOV)
- Full-duplex communications
- Spectral separation from existing communication systems (non-regulated spectrum)
- Reduced weight and power
- Lower recurring cost

Laser Terminal Comprised of Several Key Subsystems



Key Design Trades Define Cost-Effective Solutions

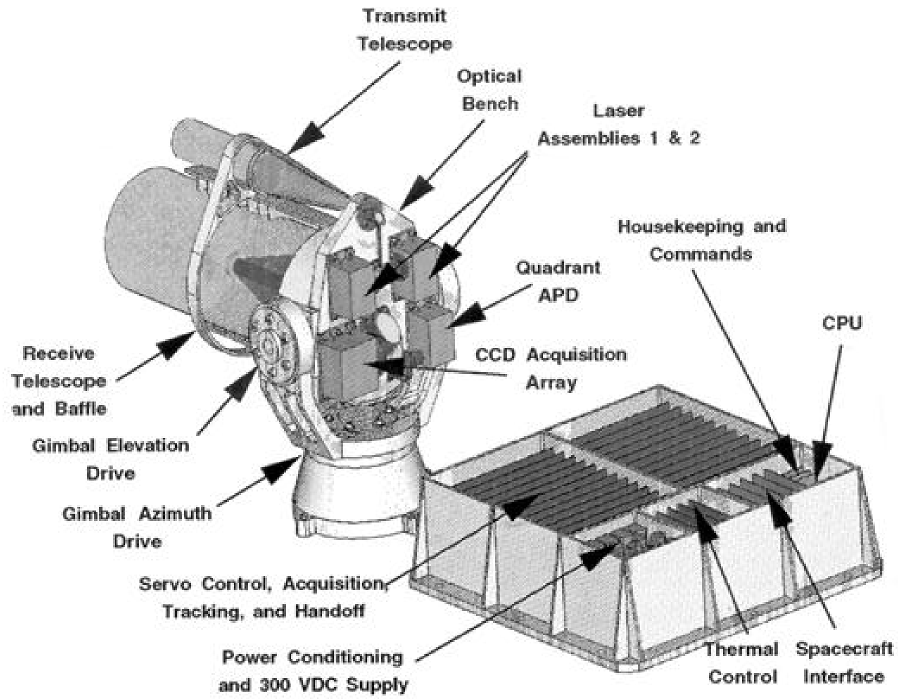
- Laser transmitter and receiver: 0.85-um AlGaAs Diode with Direct Detection; 1.06-um Nd:YAG with Coherent Detection; 1.55-um EDFA with Direct Detection Preamplifier
- Optical design: On-axis vs. off-axis telescope; Transmit/receive isolation; Solar background rejection; Wavelength multiplexing
- Coarse pointing: Gimbaled telescope vs. gimbaled mirror vs. gimbaled package
- Acquisition: Scanned beacon and quadrant or array position sensor
- Fine pointing: High bandwidth steering mirror; High-bandwidth control system; Sensitive position sensors (quadrant vs. nutation)
- Point-ahead: Accurate orbital data; High-precision point-ahead mirror
- Support electronics: Central processor; Servo control; Thermal control; Power conditioning

Example Trade: Coarse Pointing Options

Pointing Approach	Pro	Con
Gimbaled Terminal	Smaller laser terminal envelope Fewest optical components that satisfy necessary slew & agility Straightforward telescope baffling Stabilization between laser terminal and platform base motion Near-hemispherical angular coverage	Larger gimbaled mass increases payload mass & power (bearing size, motor size, etc.) Data, electrical, power & some thermal transfer across gimbal Higher pointing-induced momentum & torque
Gimbaled Telescope w/ Coude' Optical Path	Lighter gimbaled mass No thermal or data transfer across gimbal Limited electrical and power transfer across gimbal Straightforward telescope baffling Near-hemispherical angular coverage	Coude' fold mirrors decrease throughput & increase complexity Initial assembly and alignment more complicated Base motion directly imparted to focal plane Moderate pointing-induced momentum & torque
Gimbaled Flat Mirror	Lighter gimbaled mass No thermal or data transfer across gimbal Limited electrical and power transfer across gimbal	Additional large optic Requires larger envelope to separate pointing & fold mirrors More-difficult telescope baffling Stiff structure more difficult to achieve Base motion directly imparted to focal plane Less-than-hemispherical angular coverage Moderate pointing-induced momentum & torque

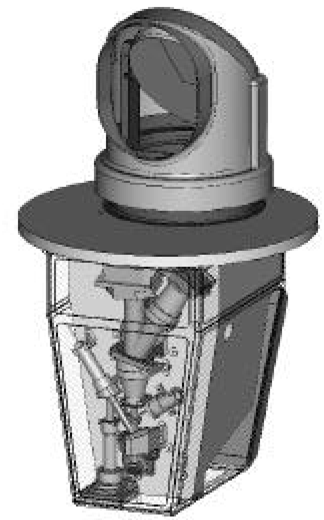
LEO Short-Range or Low-Data-Rate Applications

- 10 Mbps at 5000 km range
- 1 @ 75-mW AlGaAs transmitter
- Si CCD acquisition receiver; Si quadrant APD track and communications receiver
- BPPM modulation
- 1.2 inch transmit telescope, 4 inch receive telescope
- Gimbaled payload
- 15 lbs, 15 W

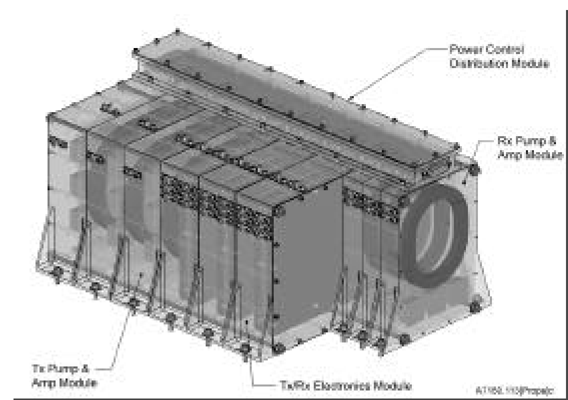


LEO Medium-Range Applications

- 7.5 Gbps at 6000 km range
- 3 @ 0.3-W EDFA transmitters
- EDFA LNA with 3 @ InGaAs pin photodiode receivers
- OOK modulation
- 7 inch transmit/receive telescope
- Gimbaled flat mirror
- 25 kg (55 lbs), 100 W



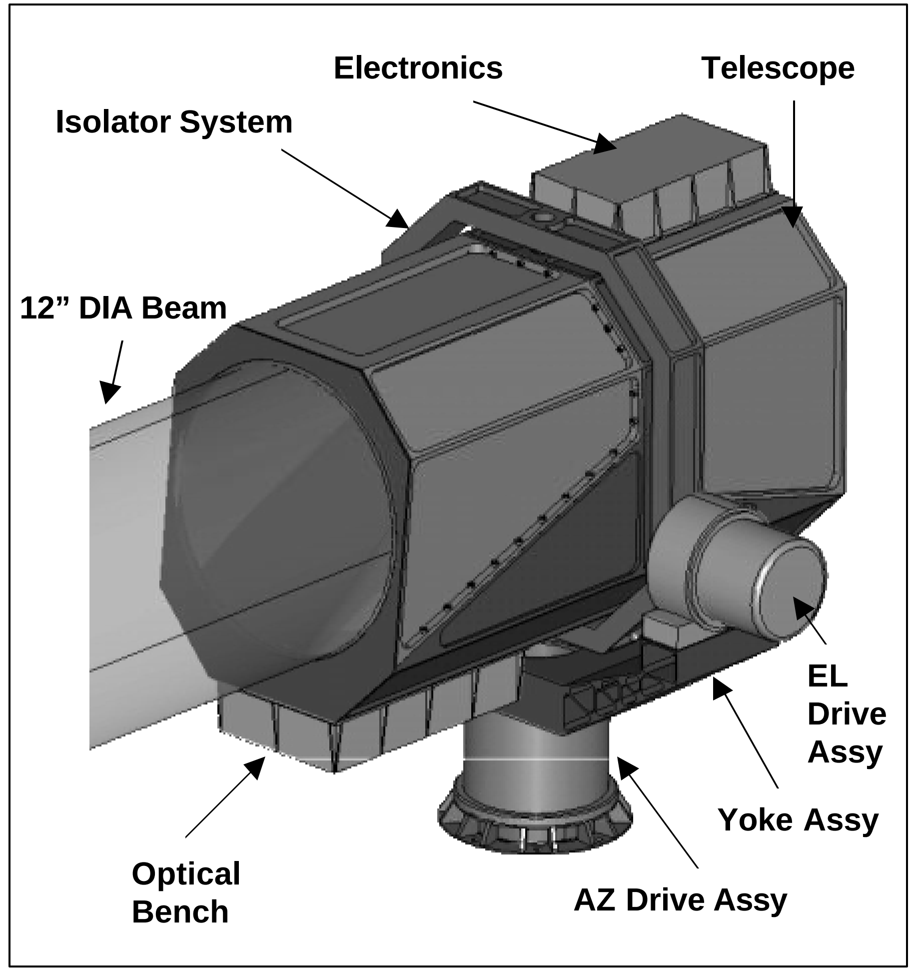
Optical Bench Assembly



Tx/Rx Electronics Assembly

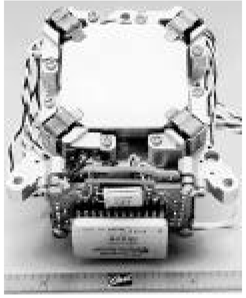
LEO and GEO Long-Range Applications

- 10 Gbps at 84,000 km range
- 4 @ 3-W EDFA transmitters
- EDFA LNA with 4 @ InGaAs pin photodiode receivers
- DPSK modulation
- 12-inch transmit/receive telescope
- Gimbaled telescope
- 90 kg (200 lbs), 300 W

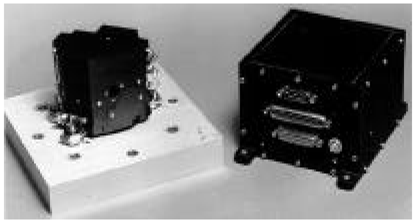


Several Hardware Elements Support a Variety of Applications

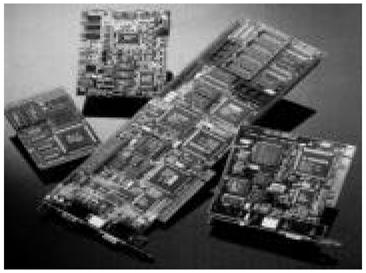
- ❍ Fine pointing mirror
- ❍ Point-ahead mirror
- ❍ Processing electronics
- ❍ Optical bench
- ❍ Thermal radiator



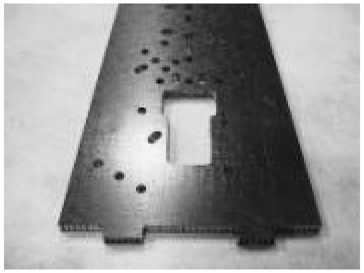
Fine pointing mirror



Point-ahead mirror and electronics



Processing Electronics



Optical Bench

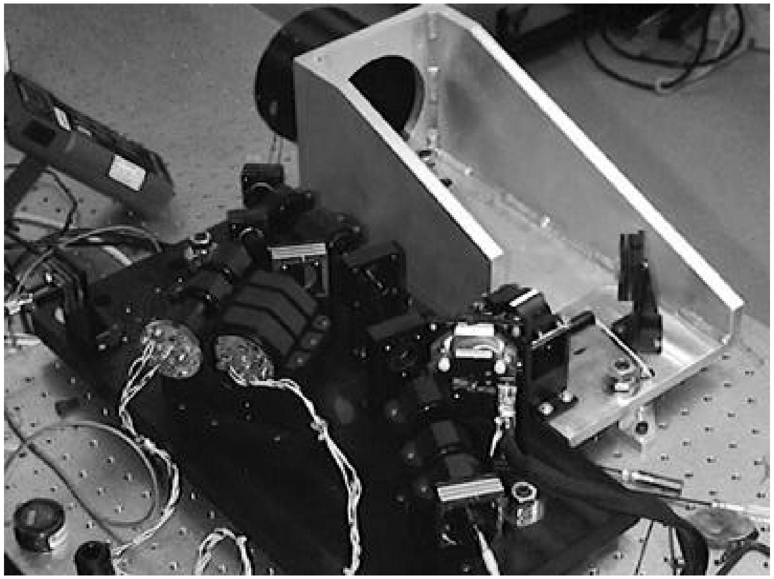
Radiator

Development Risk Is Manageable

- ❍ **Laser and receiver reliability and lifetime must be fully verified**
- ❍ **Coarse and fine pointing requirements are met with flight-proven concepts that are modified to meet specific needs**
- ❍ **Electro-optic instrument development is similar to other proven flight systems**
  - **Optical design for telescope and bench**
  - **Thermal control**
  - **Flight processor**
  - **Software control**
  - **Heat rejection**
  - **Radiation effects**
  - **Contamination control**
  - **Telemetry and commands**
  - **Power conditioning**
- ❍ **Cost-effective system integration must be demonstrated**

Laboratory Demonstration System Reduces Performance Risk

- Demonstrated 2.5 Gbps simultaneous Transmit/Receive operability
- Characterized optical components
- Developed software terminal control and data collection capability
- Demonstrated optical system performance
- Demonstrated performance of fine steering mechanism
- Performed characterization of gimbal
- Demonstrated tracking capability to comply with single-mode fiber coupling requirements
- Demonstrated track loop's ability to reduce pointing errors
- Validated acquisition scenario



Summary

- Laser communications hardware is ready for flight insertion
- Key engineering issues have been conquered on prior electro-optic payloads
  - Optical designs
  - Pointing systems
  - Support electronics
  - Software control
  - Thermal control
- Increased data rate requirements will establish a user pull
  - Communications networks
  - Hyperspectral imaging systems
- Cost control will result after the first system is demonstrated

Acronyms

AlGaAs	Aluminum gallium arsenide
APD	Avalanche photodiode
AZ	Azimuth
BPPM	Binary pulse position modulation
CCD	Charge coupled device
DPSK	Differential phase-shift keying
EDFA	Erbium-doped fiber amplifier
EL	Elevation
FOR	Field of regard
FOV	Field of view
FSM	Fast steering mirror
GEO	Geostationary Earth orbit
IFOV	Instantaneous field of view
InGaAs	Indium gallium arsenide
LEO	Low Earth orbit
LNA	Low-noise amplifier
Nd:YAG	Neodymium-doped yttrium aluminum garnet
OOK	On-off keying
PAM	Point ahead mirror
Tx/Rx	Transmit/Receive