Multi-Gigabit Data-rate Optical Communication Depicting LEO-GEO and GEO-Ground Links

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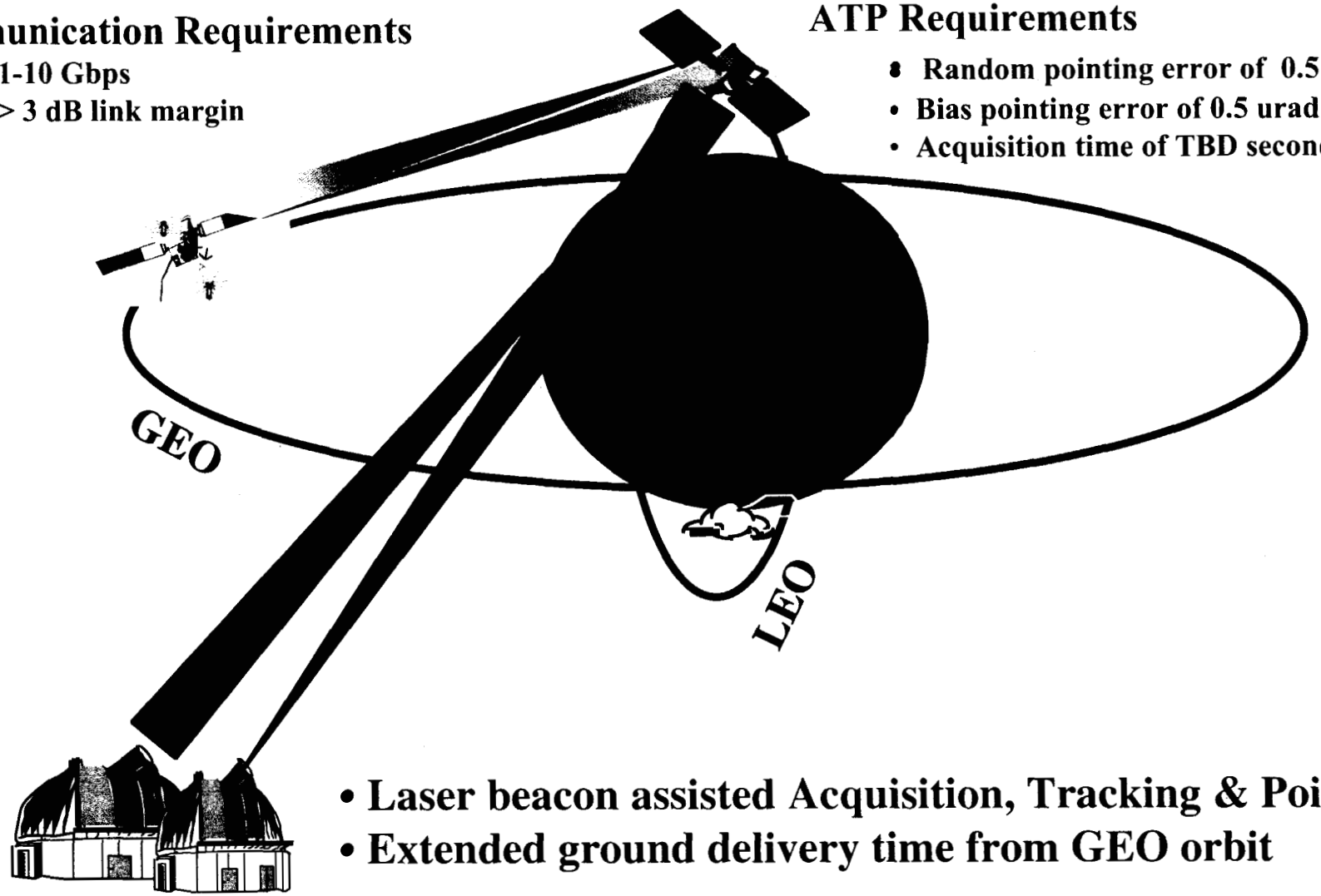
LEO-GEO & GEO-Ground Links

Communication Requirements

- 1-10 Gbps
- > 3 dB link margin

ATP Requirements

- Random pointing error of 0.5 urad
- Bias pointing error of 0.5 urad
- Acquisition time of TBD seconds



- Laser beacon assisted Acquisition, Tracking & Pointing
- Extended ground delivery time from GEO orbit

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Developments

Acquisition, Tracking & Pointing (ATP):

- Analyzed various acquisition, tracking and pointing scenarios
- Developed conceptual designs for urad pointing between two moving platforms

Communication Link

- Demonstrated error free optical transmission of an uncompressed HDTV signal(1.5 Gbps) in the lab
- Integrated and tested in the lab a communication link capable of 2.5 Gbps in a single channel and 5.5 Gbps in a 3 channel with COTS components
- Validated theoretical link analysis with further optimization in progress

Acquisition, Tracking & Pointing (ATP)

ATP Requirements: **< 2 dB pointing loss**

- Random pointing error of 0.5 urad
- Bias pointing error of 0.5 urad
- Acquisition time of TBD seconds
- S/C attitude control uncertainties: ±3 mrad
- S/C vibration: equivalent to Olympus S/C

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ATP Design Drivers

- The effect of mis-pointing probability on data loss/volume
  - duration & number of of mis-pointing events
  - the probability of loosing track and the re-acquisition time
- The sources and magnitudes of attitude uncertainty and vibration disturbances
  - S/C jitter, attitude control, sensors, orbital motion, non-constant gravity during orbit
  - the requirements placed on S/C by ATP subsystem
- The trades between narrow and wide beam acquisition
  - acquisition time, complexity (cost), loss of track probability
  - Characteristics of the beacon necessary to acquire and to lock
- The hand-off concept between two-beam ATP
  - misalignment concerns, calibration of beam powers
- Outages due to Sun and other background light in the ATP field-of-view
- Beacon wavelength
- The effect of time delay on mutual tracking

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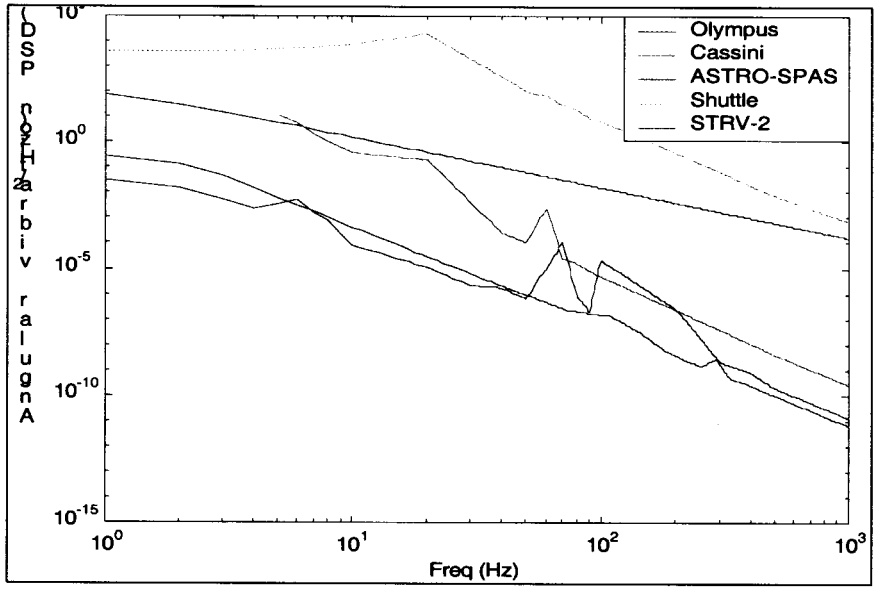
Estimated Residual Tracking Error

Calculated error contribution from spacecraft vibration for various S/C platforms assuming JPL's OCD terminal



Spacecraft Name	Estimates of Residual Tracking Error Using OCD at 1 kHz (μrad)	OCD at 2 kHz	OCD at 3 kHz	OCD at 4 kHz	OCD at 5 kHz
ASTRO-SPAS	0.03	0.018	0.015	0.014	0.014
STRV-2	0.04	0.027	0.200	0.016	0.013
RME	0.44	0.283	0.225	0.188	0.160
CASSINI	0.47	0.311	0.211	0.160	0.128
Olympus	2.73	1.910	1.552	1.340	1.190
Motorola	5.92	4.785	4.649	4.705	4.709
Landsat	7.55	4.234	3.166	2.475	2.023
Bosch	11.72	8.146	6.678	6.023	5.543
HRDLS	16.81	11.443	8.922	7.390	6.331
Iridium	142.64	106.011	82.342	68.006	58.040
Shuttle	194.45	101.075	69.188	52.764	42.519

OCD = Optical Communication Demonstrator

Sample calculation for 4 configurations

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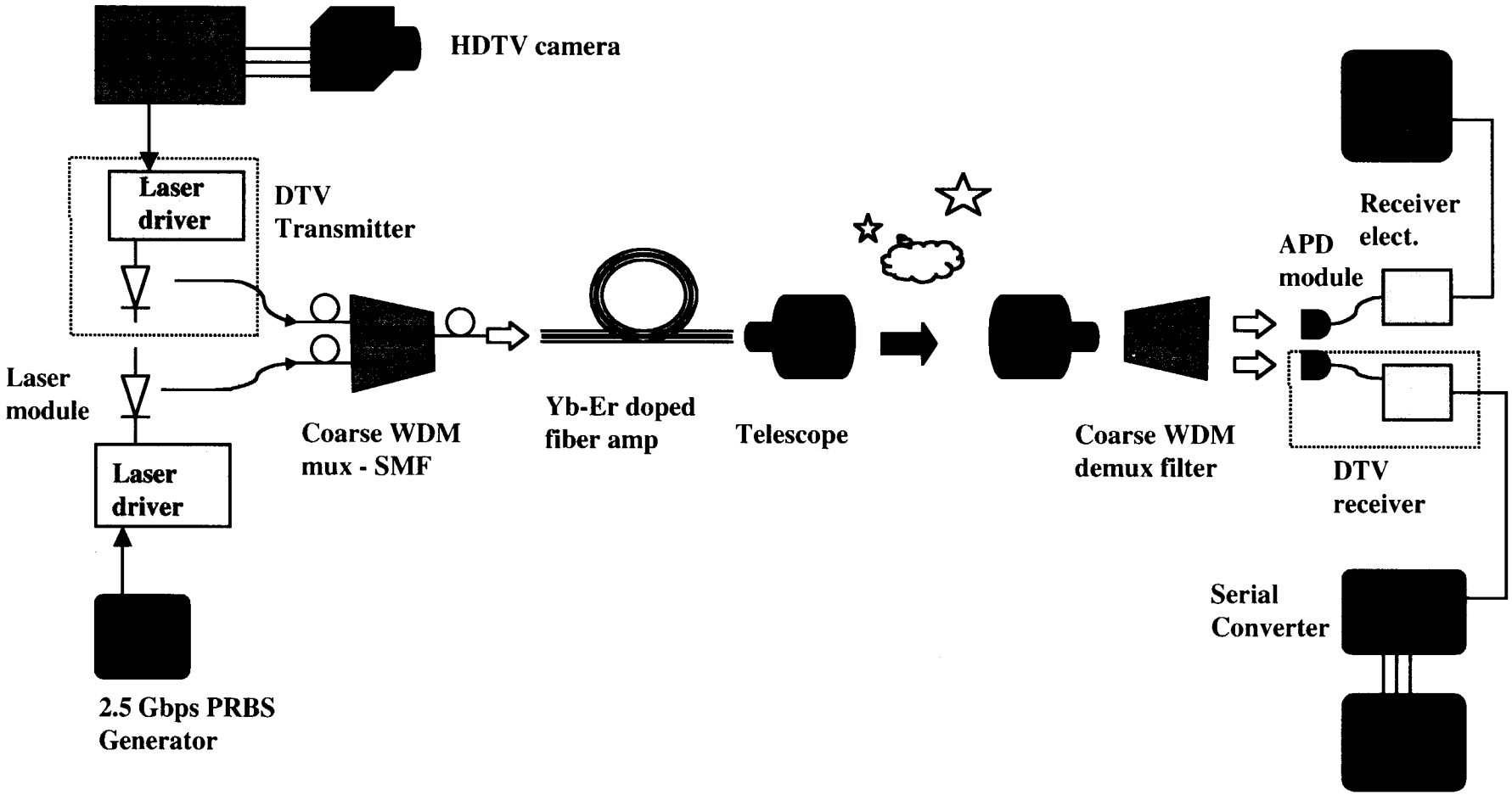
Transmit / Receive System Schematic



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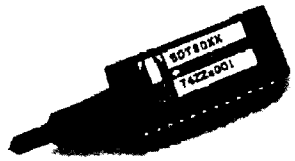
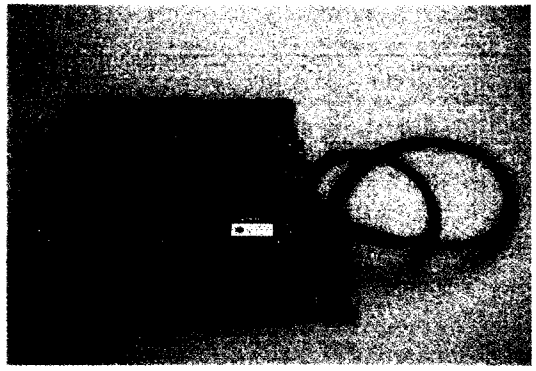
Laser Transmitter



FP Laser Source:

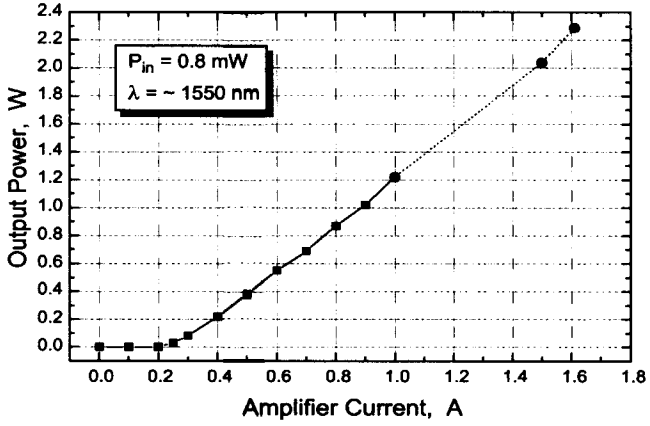
- 1550 nm
- 1 mW fiber coupled output power
- Capable of 2.5 Gbps



Er Doped Fiber Amplifier:

- 2 W saturated output power
- 1535 - 1567 nm gain bandwidth
- Dual clad diode pumped

Fiber Amplifier Output Power:



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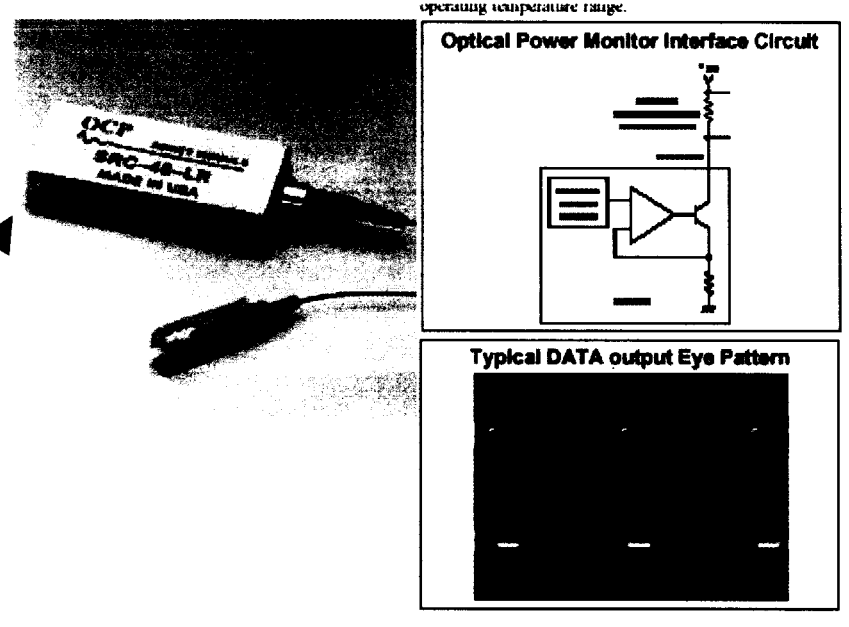
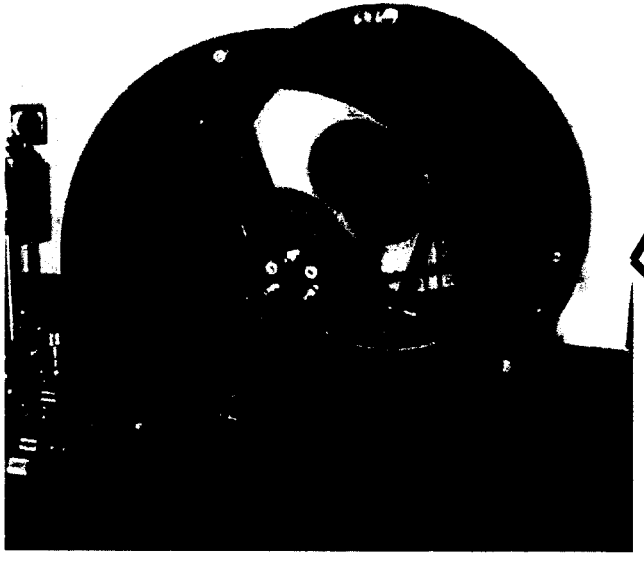
Receiver Setup

2.5 GB/s Detector and Clock Recovery



30cm Receiving Telescope



1.5 GB/s HDTV Detector

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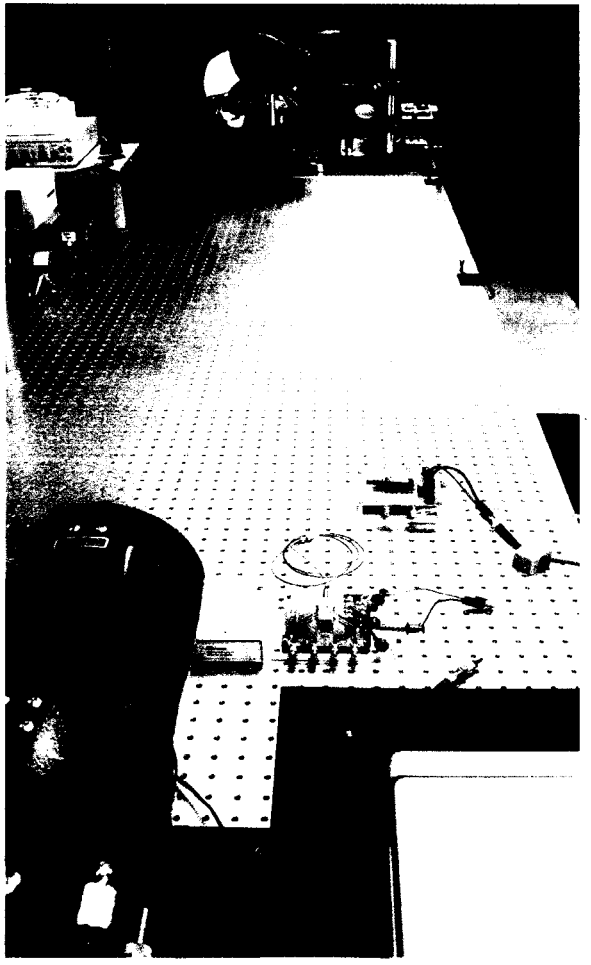
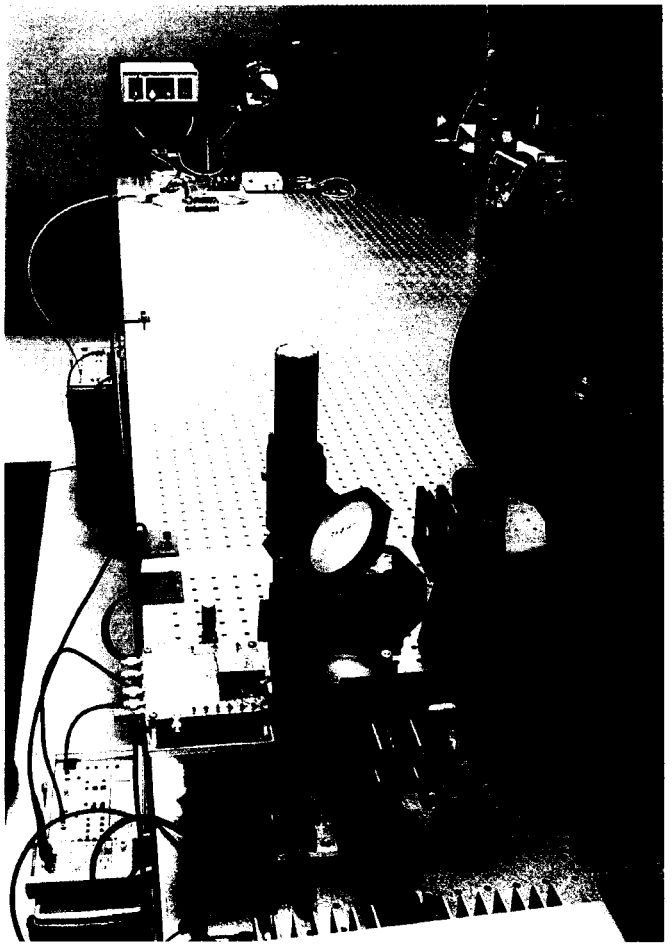
Link Setup



View from Transmitter towards Receiver



View from Receiver towards Transmitter

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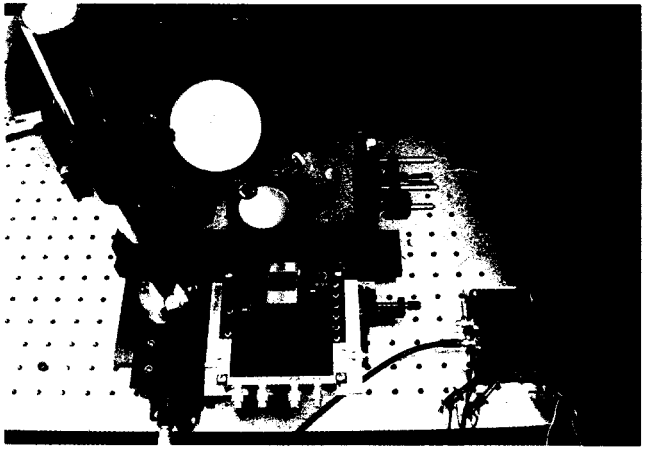
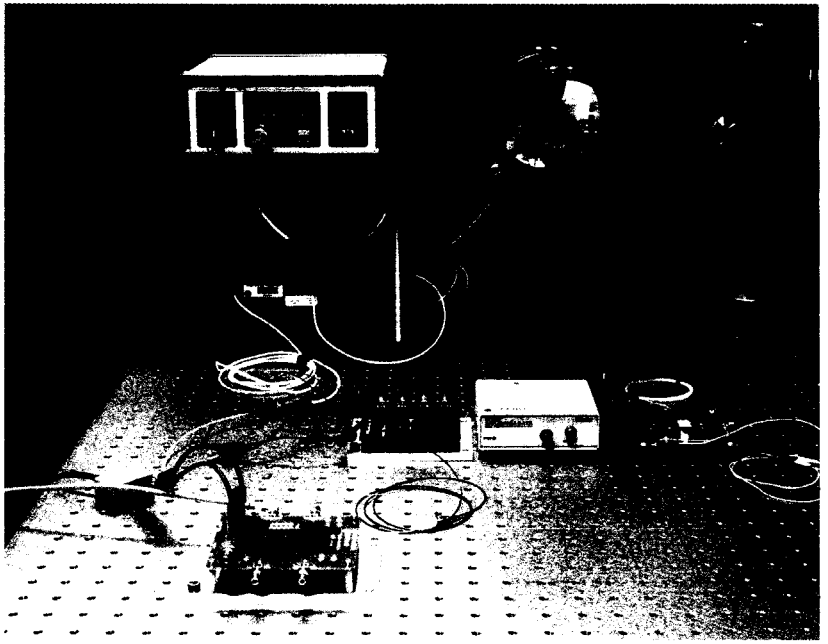
Link Setup

Close-up of receiver telescope system



Close-up of receiver optics and detectors



Close-up of transmitter system showing multiple sources

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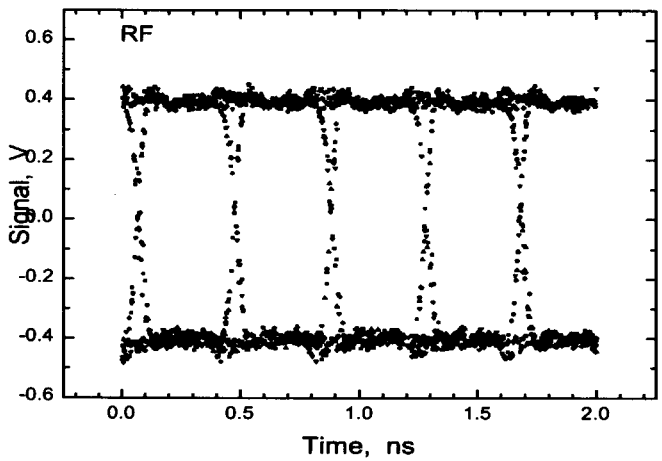
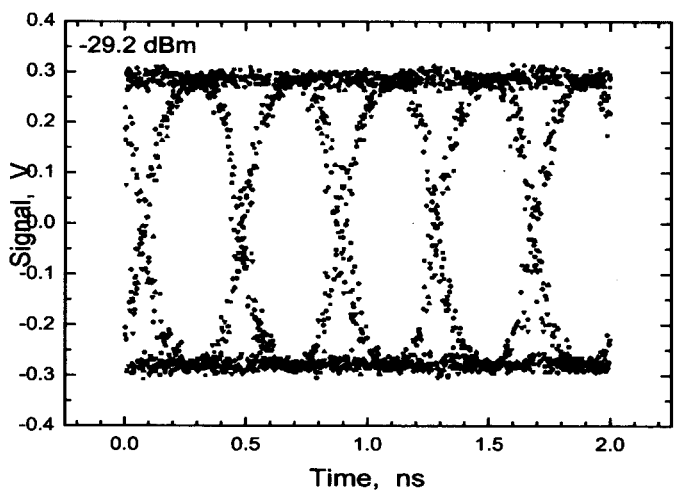
Experimental Data

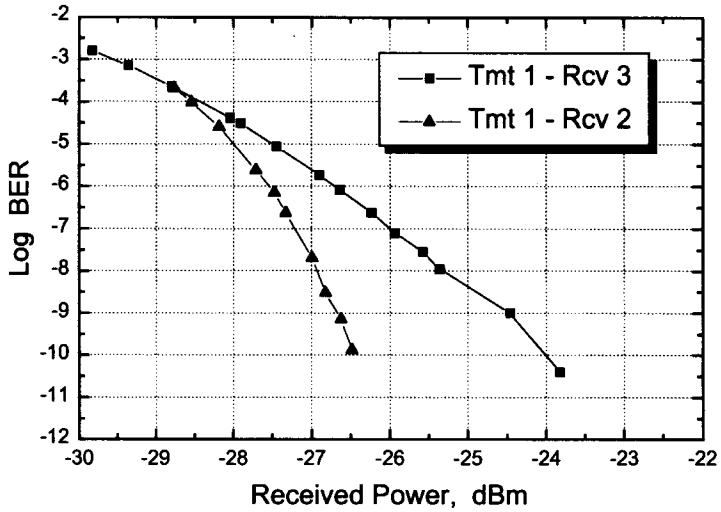


Eye pattern of input RF modulation at 2.5 Gbps

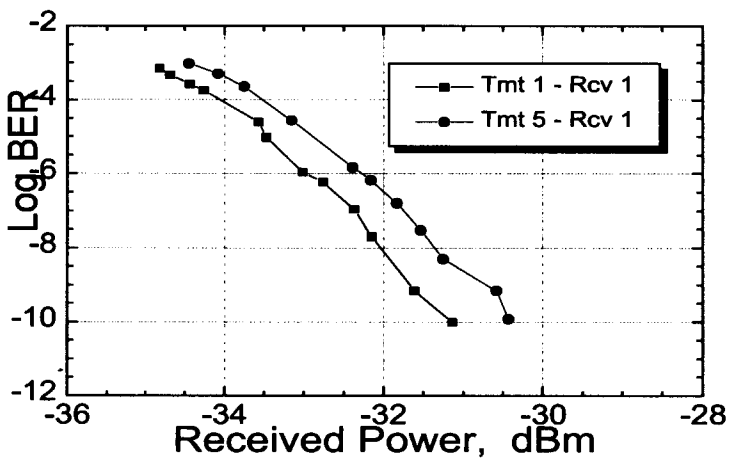


Received eye pattern at 2.5 Gbps and -29.2 dBm received power (corresponding to a BER of approx 10^{-12}) with no CDR

Experimental Data

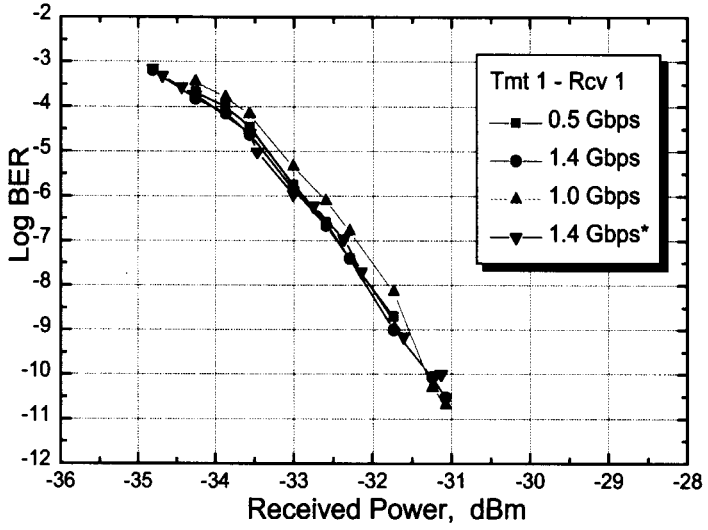


BER as a function of received power at 1.4 Gbps for various PIN based detectors with external CDR. Receiver 2 is an HDTV receiver module.

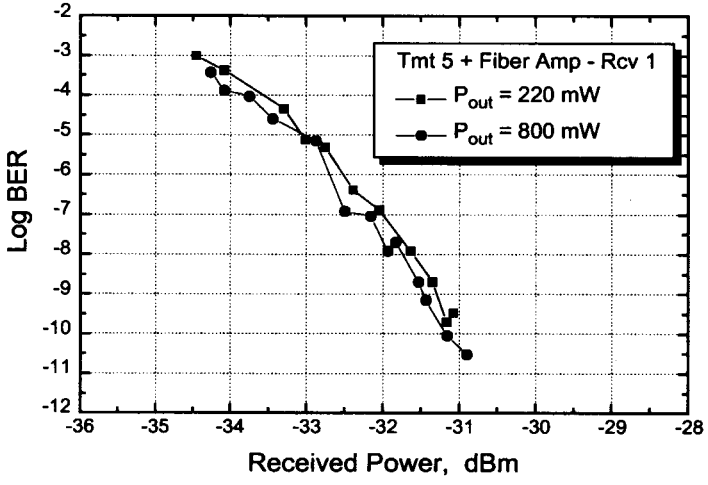


BER as a function of received power @ 1.4 Gbps for various transmitters. The receiver is an APD with external CDR.

Experimental Data



BER as a function of received power at various data rates from 0.5 to 1.4 Gbps with APD based detector and external CDR.



BER as a function of received power at 1.4 Gbps including transmission through the fiber amplifier at different power settings.

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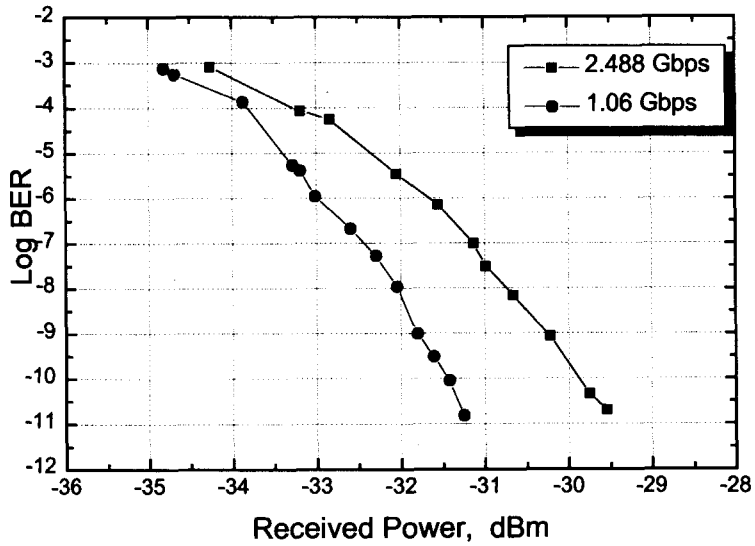
Experimental Data



Cumulative BER as a function of received power comparing OC-48 and FC data rates

(Including Fiber Amplifier gives similar performance)

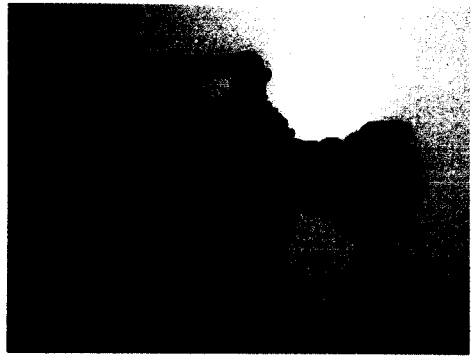
Comparison to Link Analysis:

- BERs are within 2-3 dB for APD based devices.
- Optical throughput of the overall system measured at 21% compared to 27 % in link - can be optimized further.
- Multiplexing multiple channels next step

HDTV Transmission

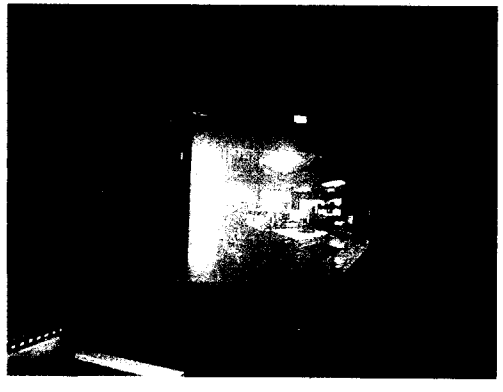
HD Source:

- Panasonic camera with wide angle lens
- Integrated Serial Digital Interface
- 1080i format - 1920 x 1080 @ 60 Hz - SMPTE 292M
- Uncompressed 1.48 Gbps data rate



HDTV Display:

- Real-time error free transmission across 10ft optical table
- BER < 10^{-8} required for high quality reception (no loss of lines) with received power ~ 6 uW (PIN receivers)



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WDM for GEO - Ground Design

Multiplexer:

- Coarse WDM
- 4 channels ~ 10-20 nm bandwidth each in 1550 nm window
- Low insertion loss, < 1 dB
- SMF coupled

Demultiplexer:

- free space optical filter
- low insertion loss, high throughput

Ongoing Developments

- Demonstration of WDM of multiple channels up to 10 Gbps
- Lab demo of ATP with micro-radian pointing while simulating a LEO-GEO link with at least one dynamic platform
- Field demo over a 47 range (resources permitting)