Practical Examples from HEP

- The TTC system
  - The system
  - Data format
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  - TTCrx: Architecture
  - Limiting amplifier
  - Clock recovery
  - Jitter measurements
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  - The linear laser-driver
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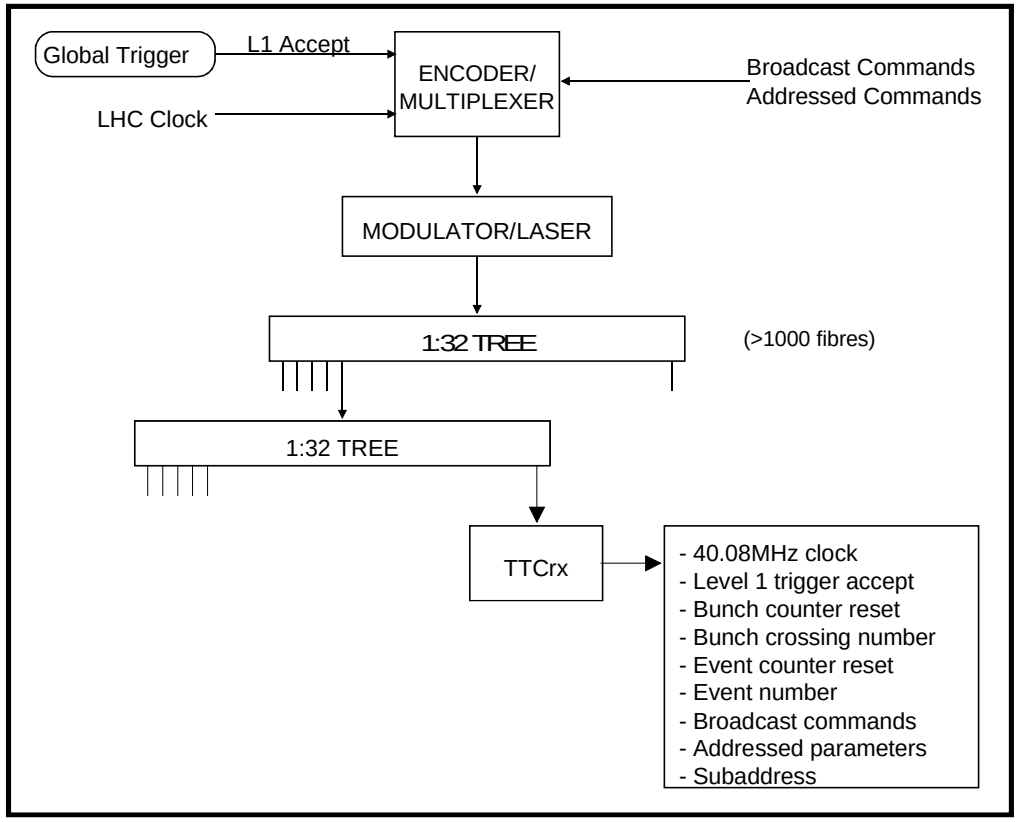
The TTC system

Timing **T**rigger and **C**ontrol distribution system:

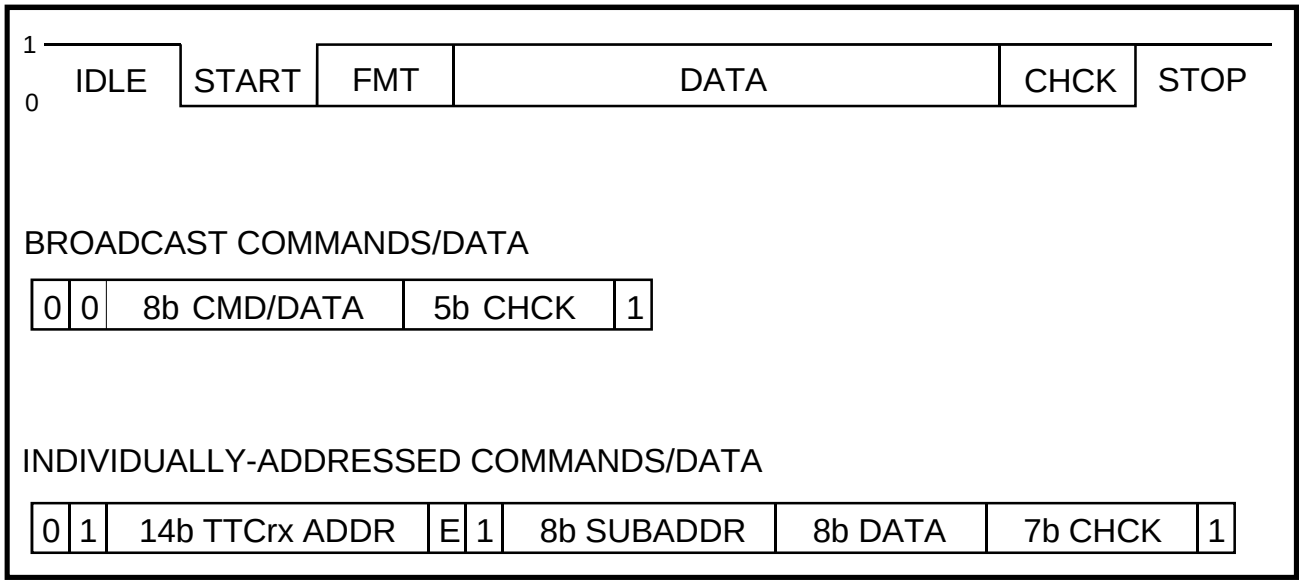
- Broadcast system:
  - Single laser source λ=1300nm
  - Up to 1024 destinations
  - Data rate 80Mbit/s
- Point-to-point span: 100m
- Uses time division multiplexing to transmit two channels simultaneously
  - Trigger channel: low latency
  - Data channel:
    - Broadcast commands
    - Addressed data
- Main objective:
  - Detector synchronization



The TTC system

Data format:

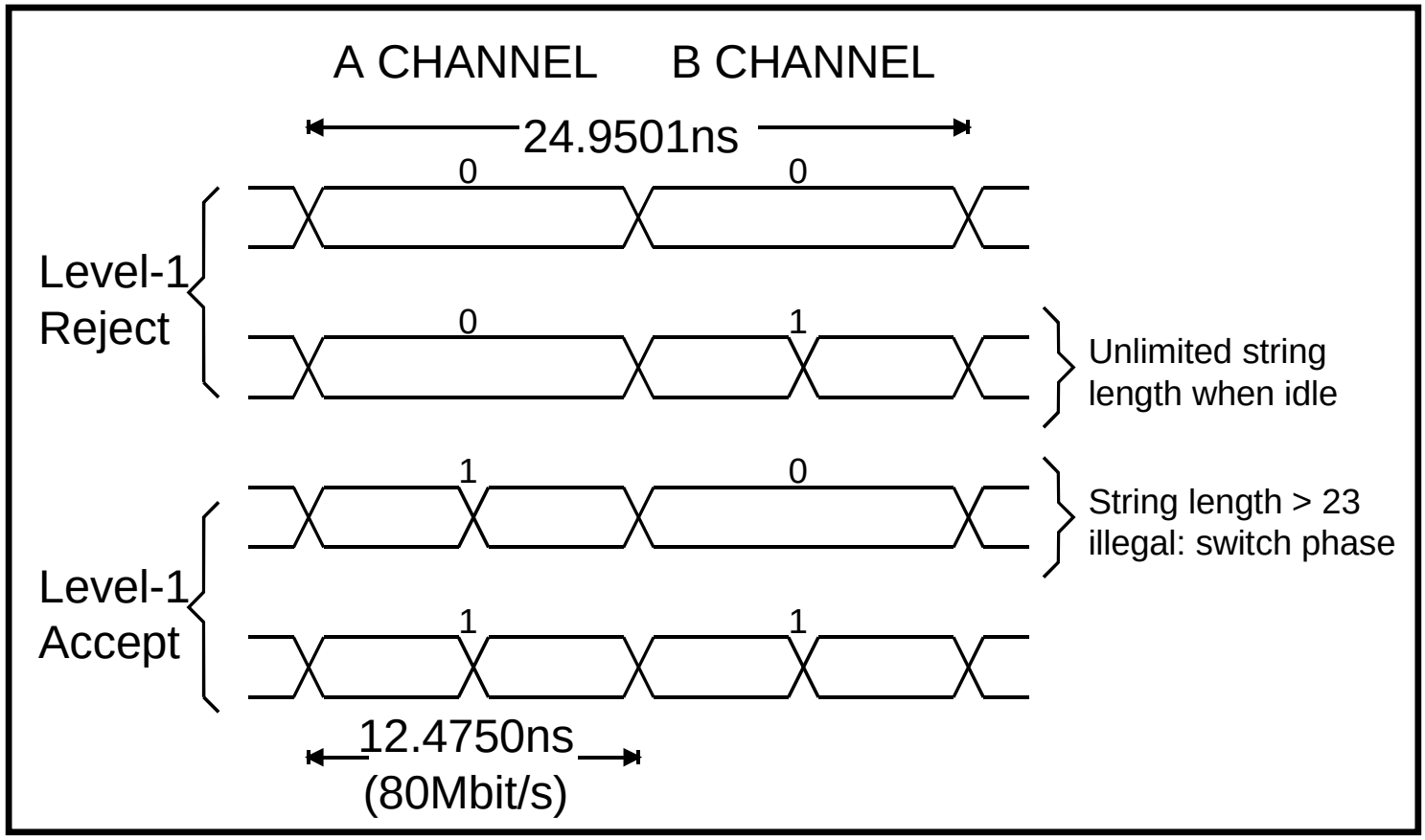
- Trigger channel:
  - single bit yes/no decision per cycle (40MHz)
  - minimum latency
- Data channel:
  - Addressed data: 42-bit frame (maximum latency)
  - Broadcast commands: 16-bit frame (reduced latency)
  - Hamming code: detection of double bit errors and correction of single bit errors
  - Idle sequence: stream of “1”



The TTC system

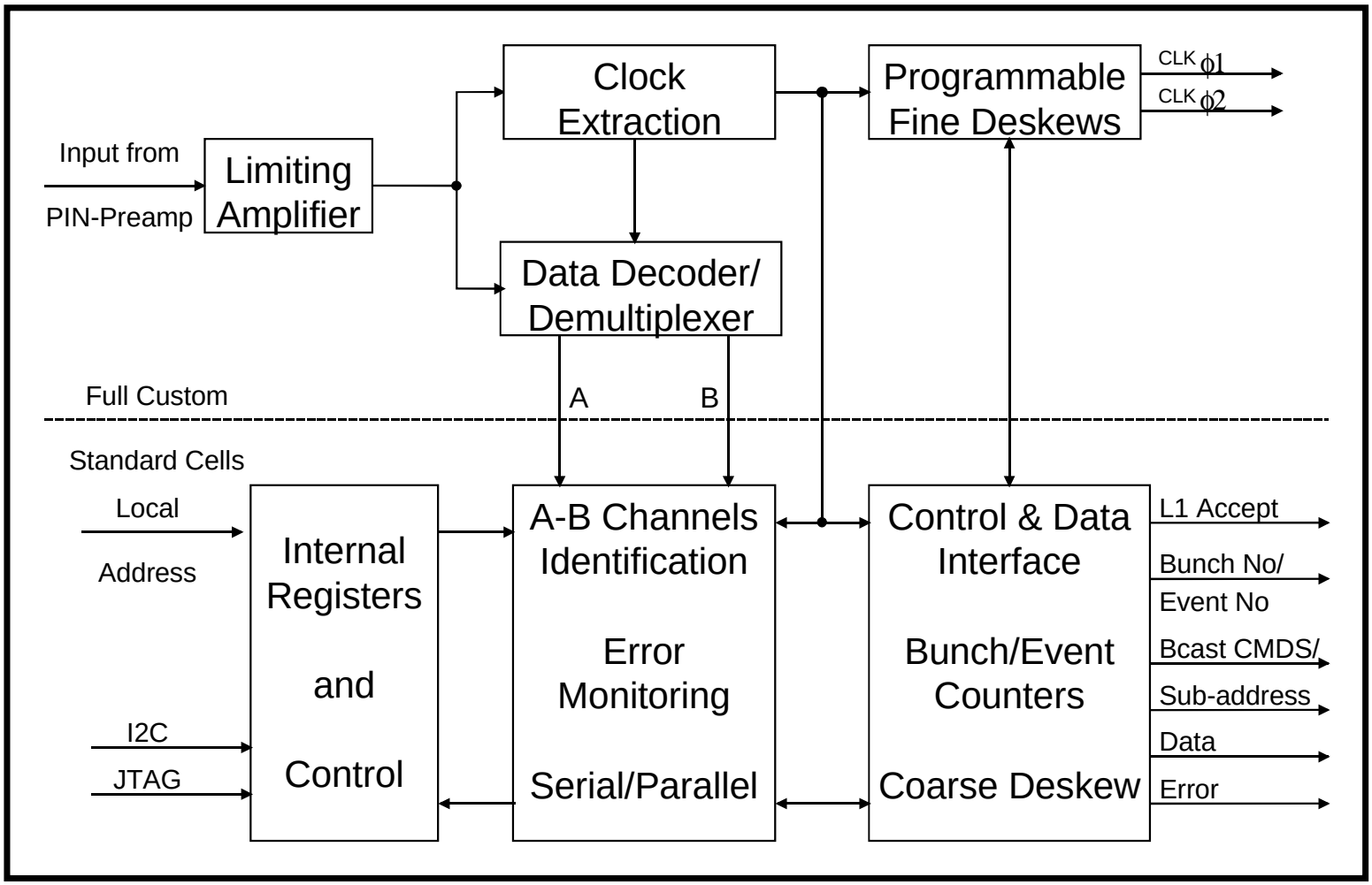
Line coding:

- BiPhase Mark code: very low DC unbalance



The TTC system

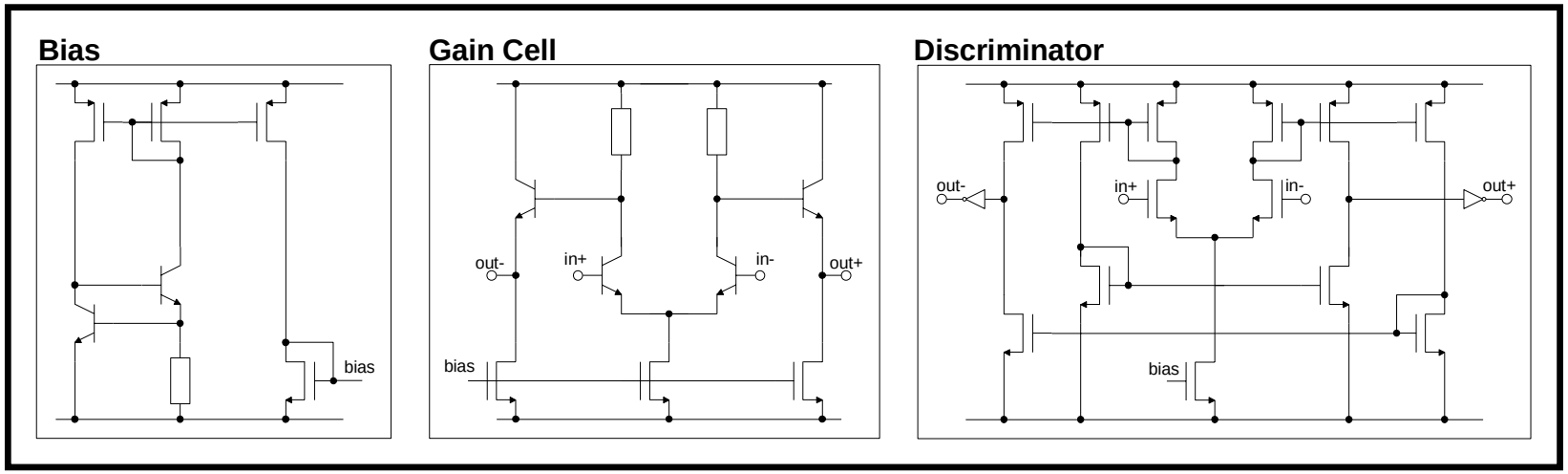
TTCrx: Architecture



The TTC system

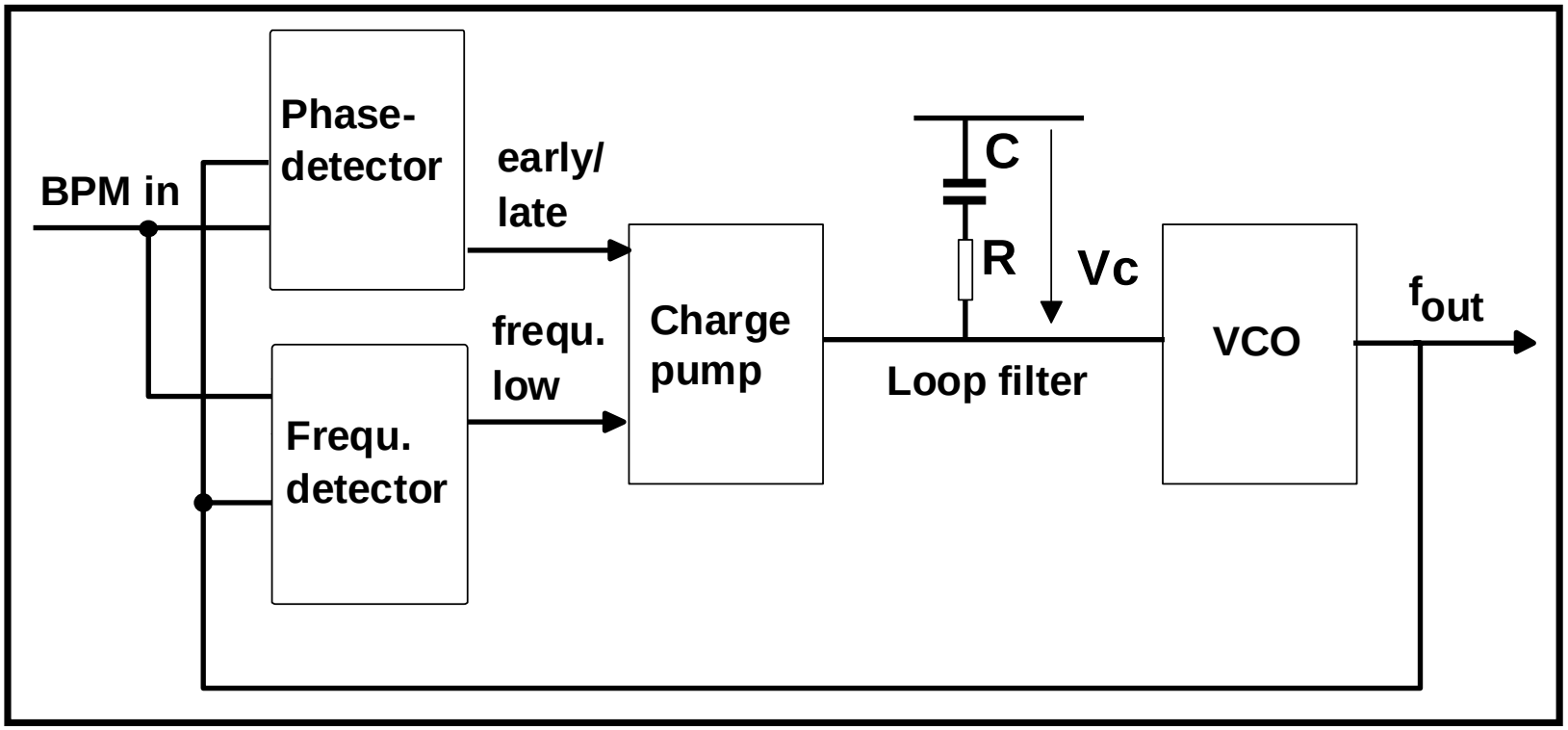
Limiting Amplifier:

- Fully differential:
  - Cascade of four identical gain cells
  - + Transconductance amplifier
- High-Gain bandwidth product:
  - Gain: 99dB
  - Bandwidth: 100MHz
- Implemented in radiation hard technology



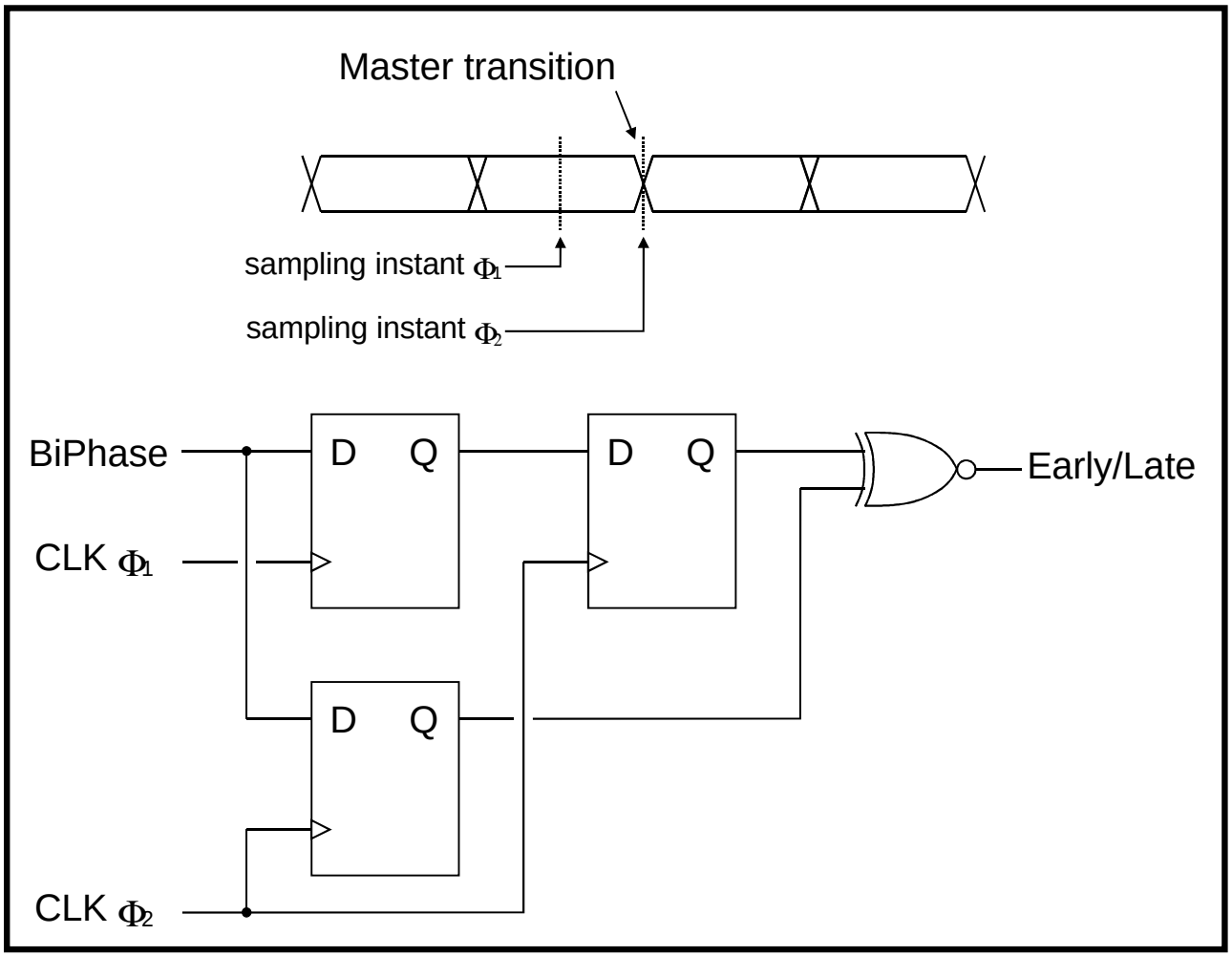
The TTC system

Clock recovery: PLL



The TTC system

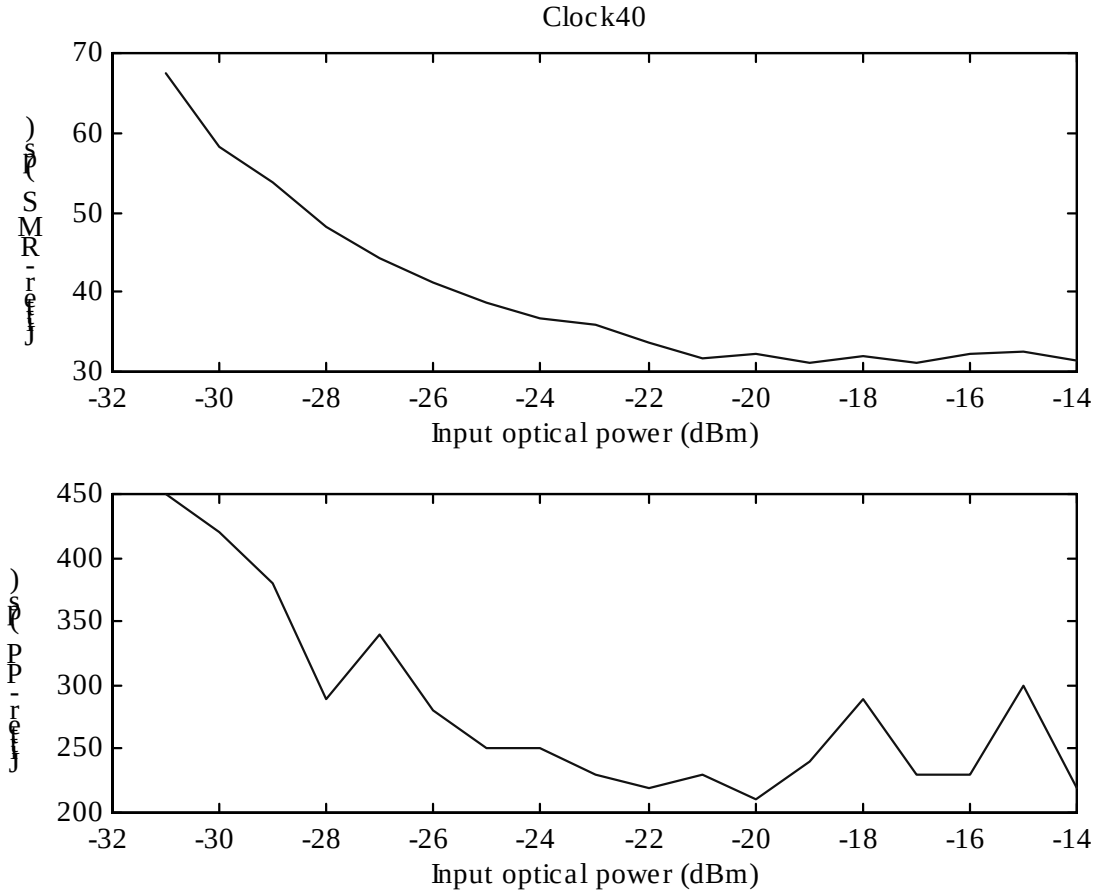
Clock recovery: Phase Detector



The TTC system

Jitter measurements:

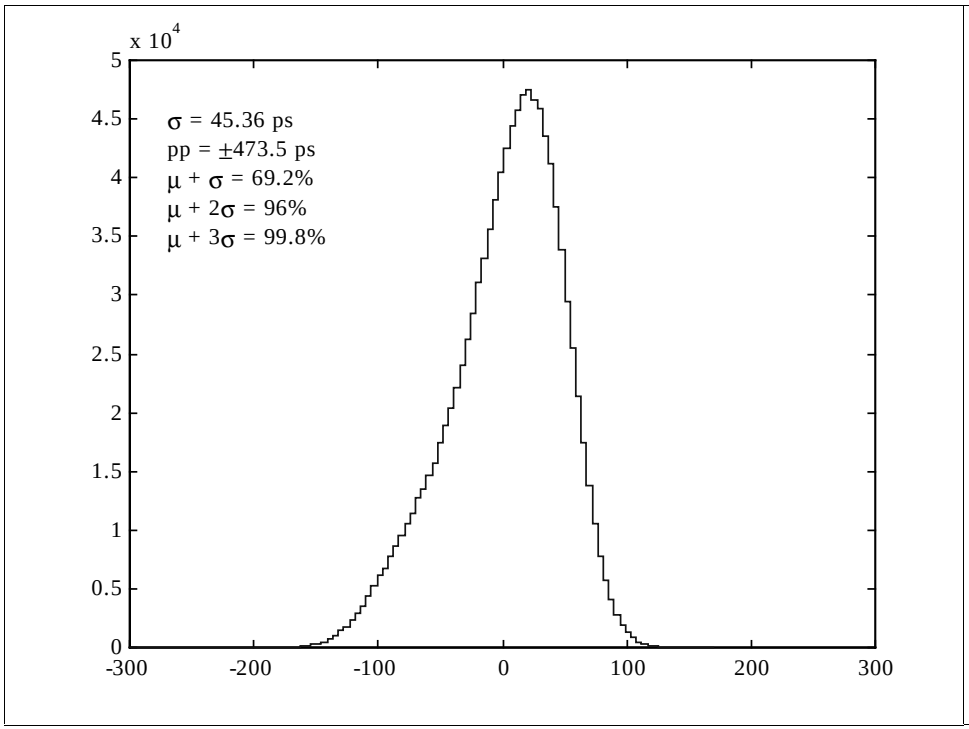
- Jitter versus optical power



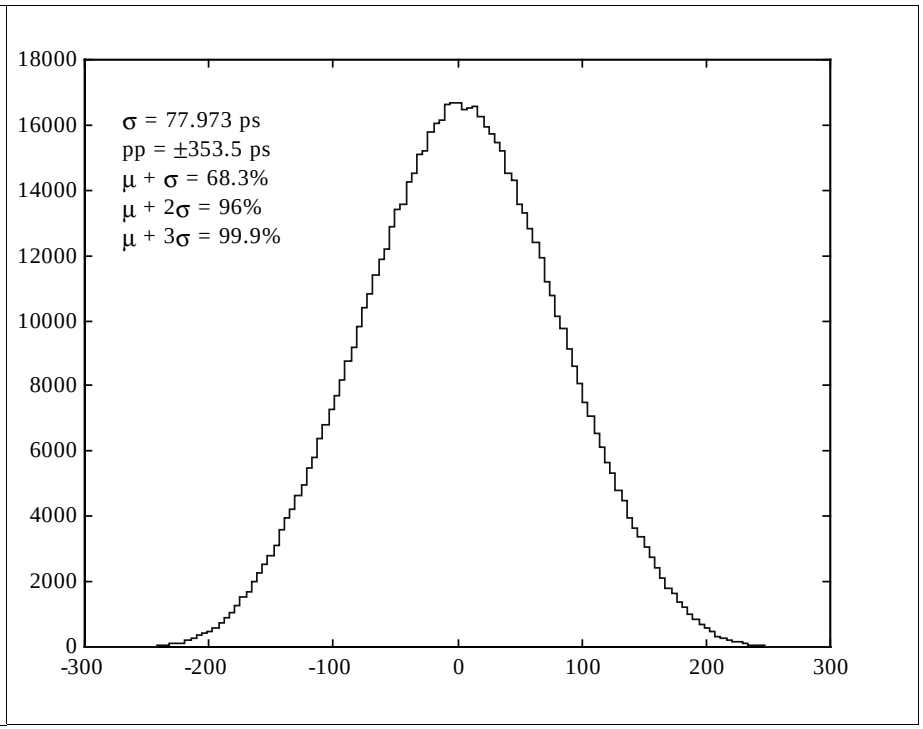
The TTC system

Jitter measurements:

TTCrx vs Reference (13h:48min)

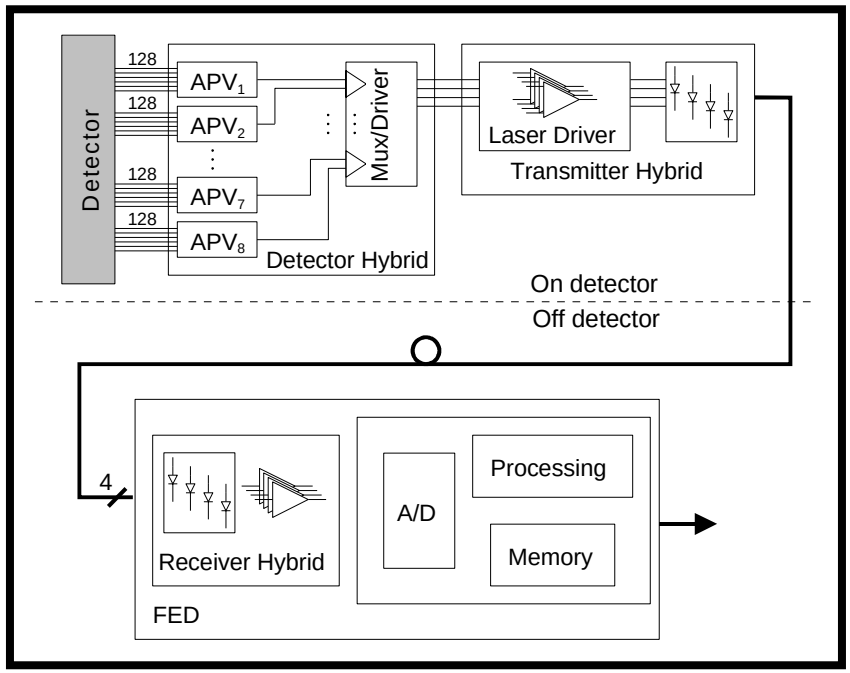


TTCrx vs TTCrx (9h:14min)



The CMS tracker data path

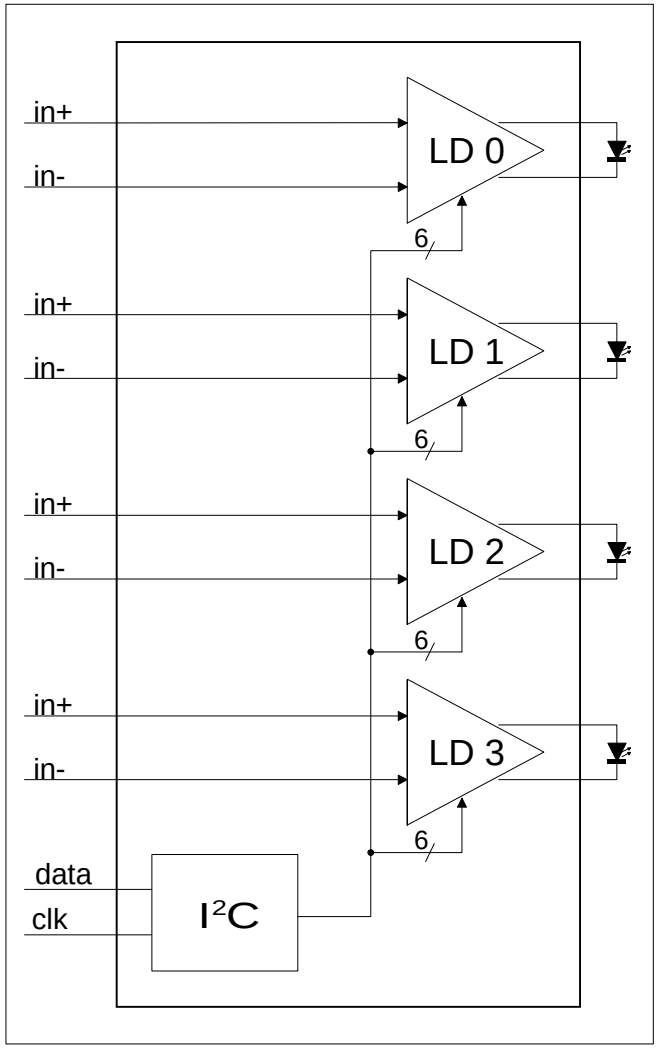
- CMS tracker detector:
  - Silicon microstrips
  - Microstrips gas chambers
- 128 Detector-Channels per APV
- Data from 2 APVs Multiplexed
  - 40Ms/s Communication
- Electrical-to-optical conversion
  - Direct amplitude modulation analogue optical transmission
- 1M detector channels
  - 50K optical read-out links
- Major system requirements:
  - Radiation hardness
  - Length: < 120m
  - Peak SNR: 48dB
  - Non-linearity: < 2.5%
  - Settling time to 1%: < 18ns



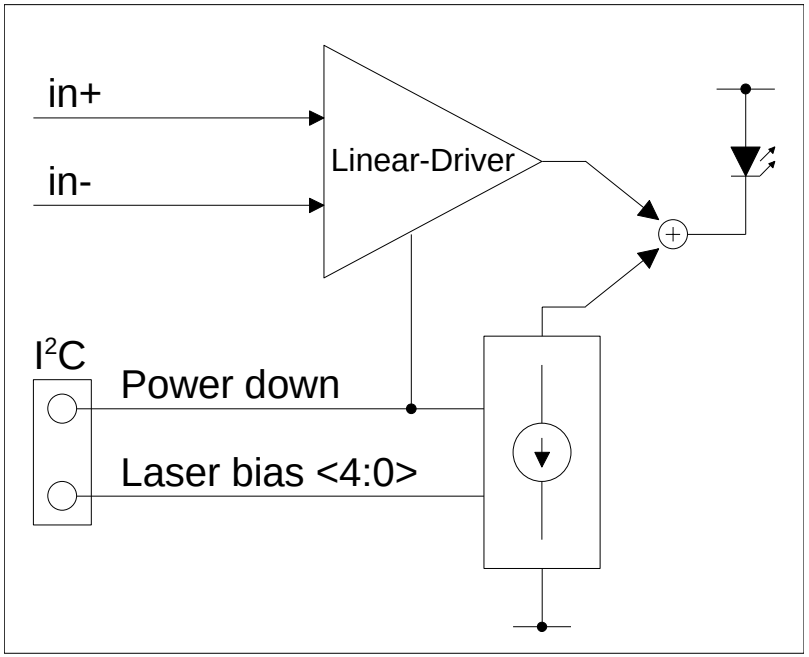
The linear laser-driver

- Major requirements:
  - Radiation hard technology
    - Currently: prototype in 0.8μm standard BiCMOS
  - Four channels per IC
  - Dynamic range: 8 bits
  - Integral nonlinearity: < 1%
  - Equivalent input noise: < 1mV
  - Settling time: < 10ns to within 1% of the final value
  - Crosstalk: < 0.3%

The linear laser-driver

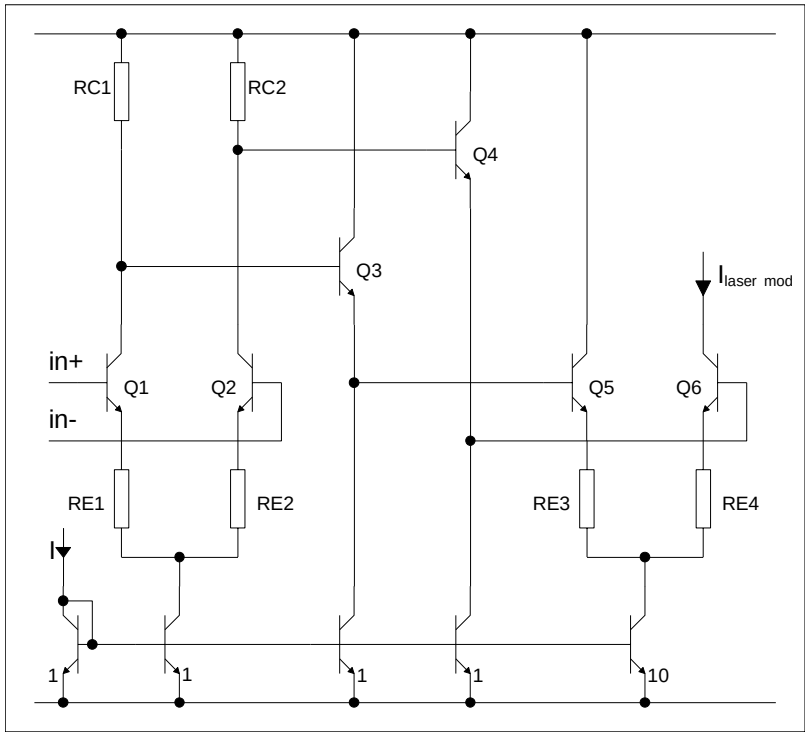


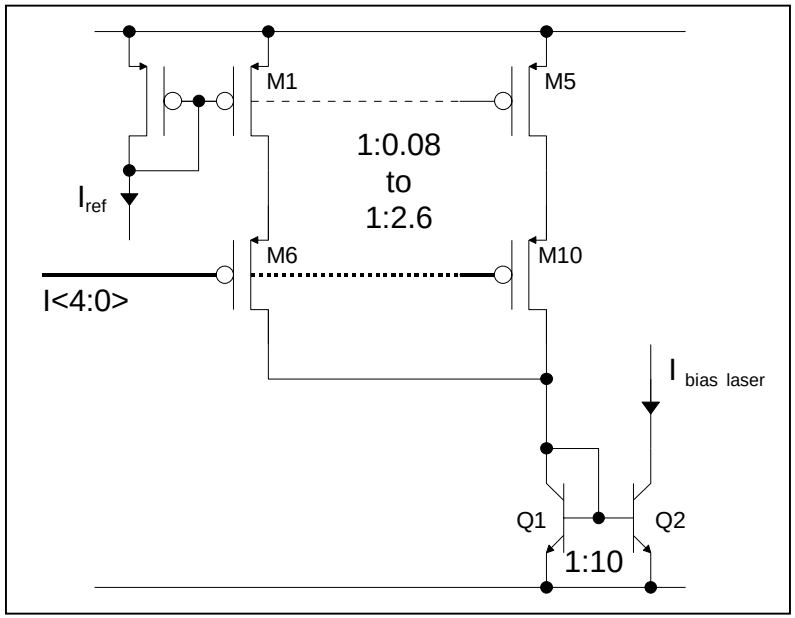
- Four linear drivers per IC
- Programmable laser bias
- I²C interface
- Per channel power-down



The linear laser-driver

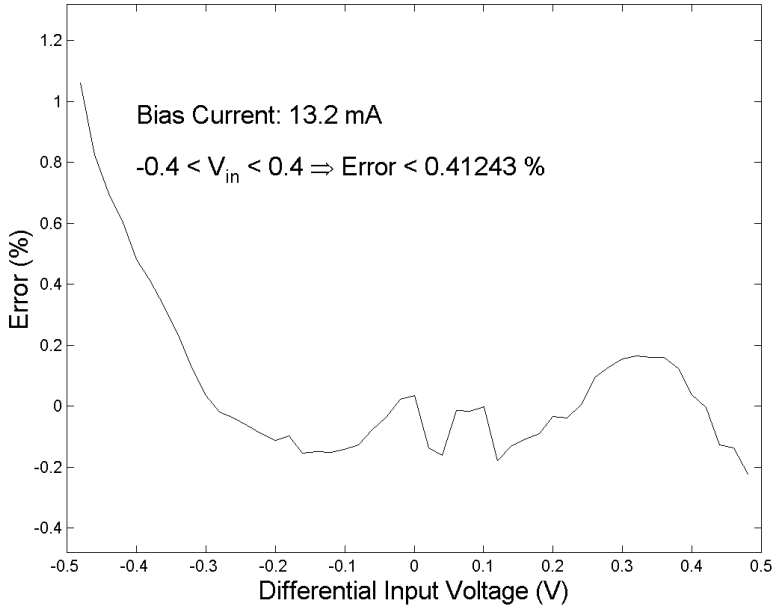
- Transconductance linearisation:
  - Emitter degeneration resistors
- I_{bias}: programmable through the I^2C interface
  - I_{bias}: 4.5 to 28mA in steps of 0.8mA

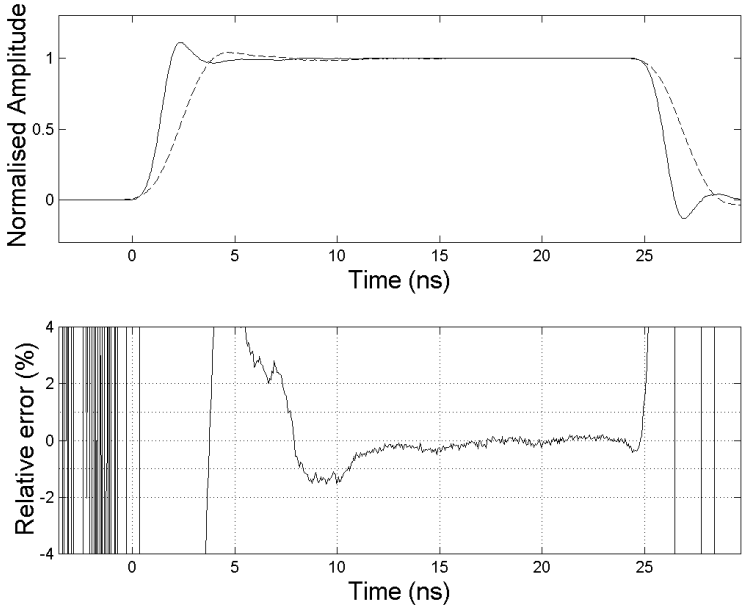




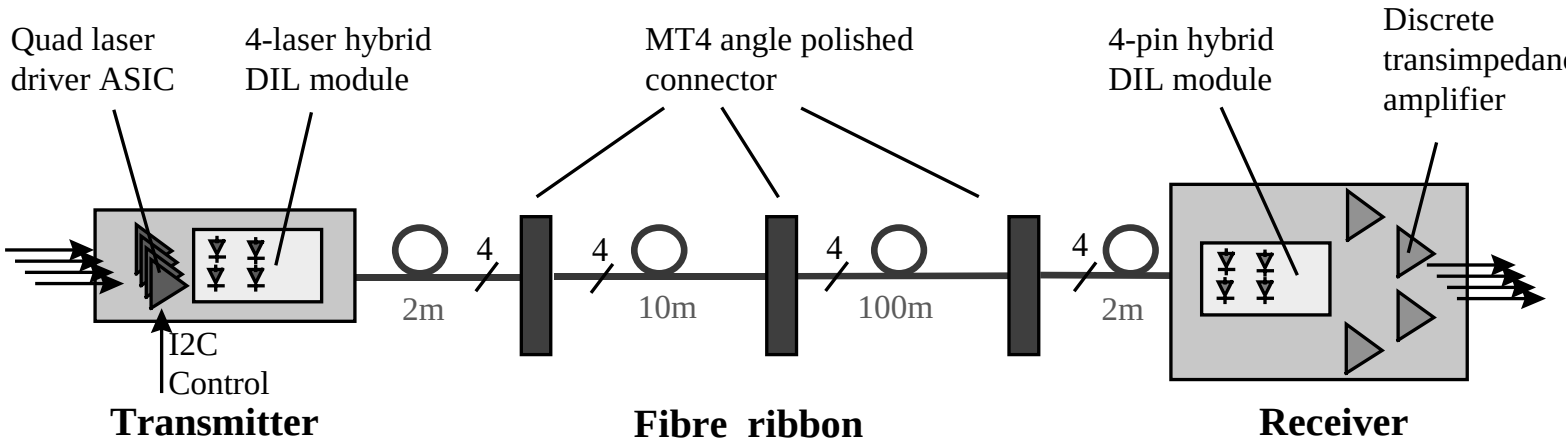
The linear laser-driver

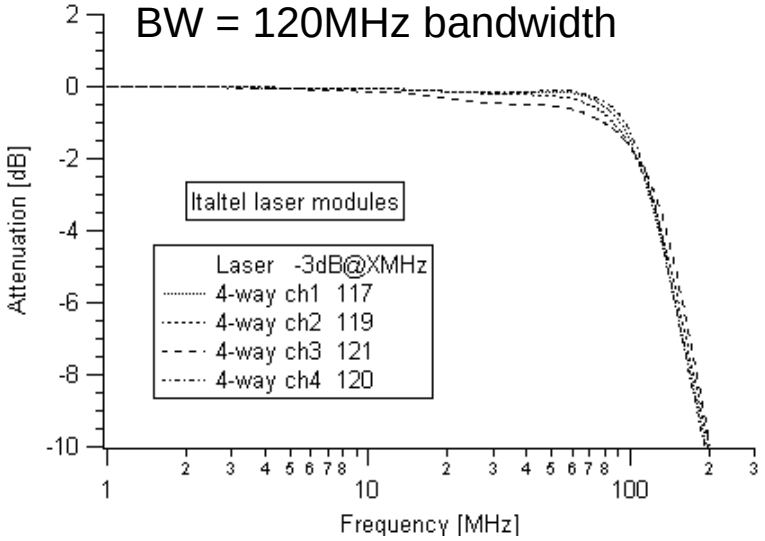
- Modulation current: 5mA for $|V_{in}| \leq 400$ mV
- Integral nonlinearity:
  - Electrical: < 0.14%
  - "Optical": < 0.42%
- APV-Mux out: ≈ 5ns rise/fall
  - Settling time: < 11ns to 1%
  - Crosstalk: < 0.27%

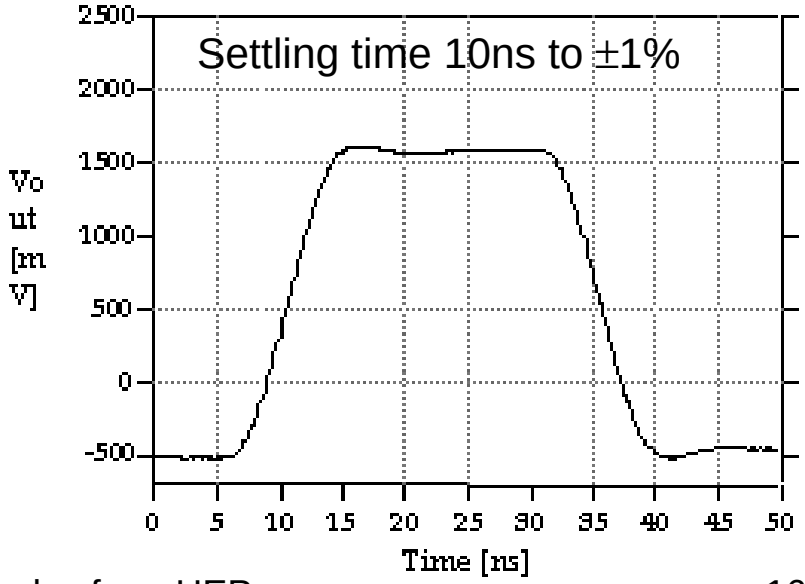




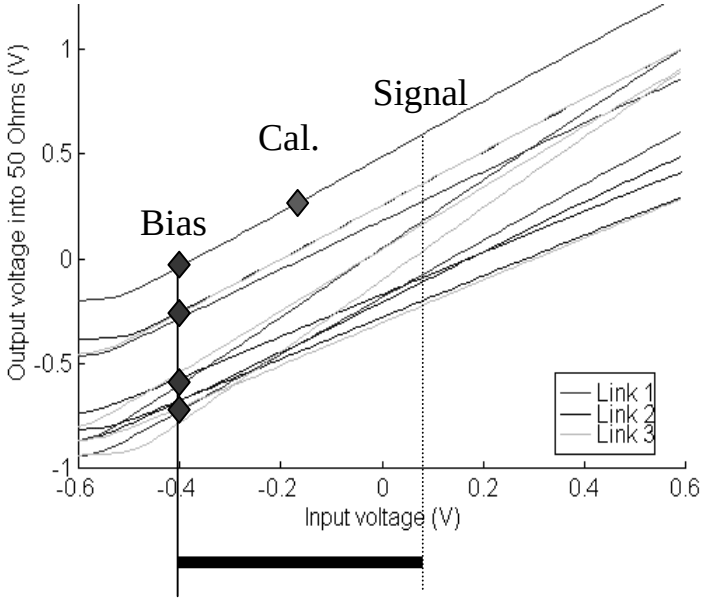
Optical link prototype

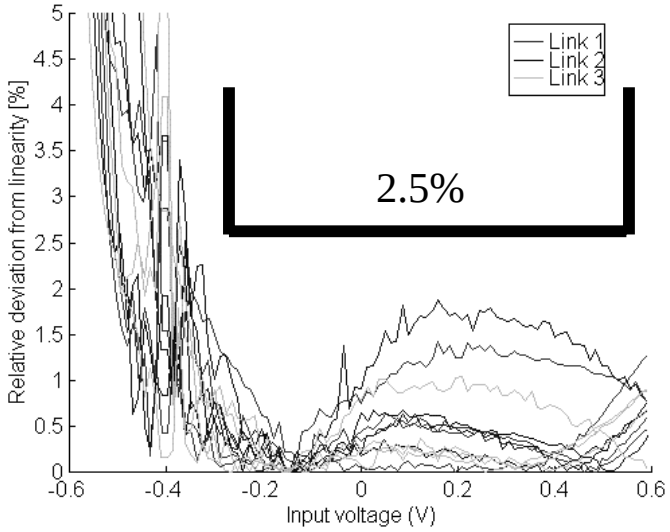


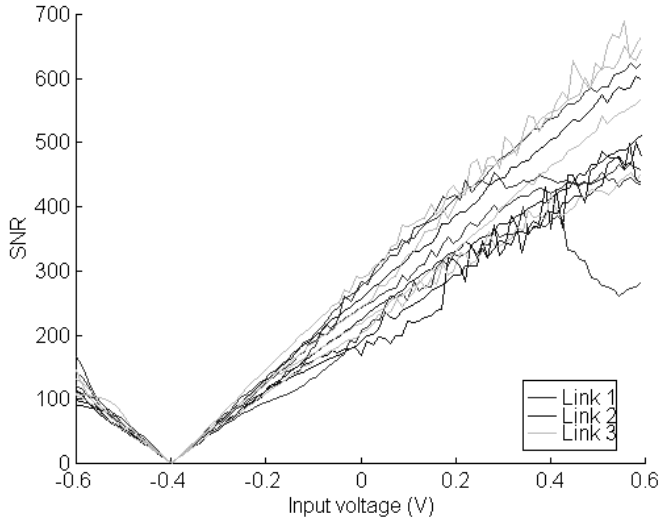




Optical link prototype







- Bias point : -400mV
- Calibration point : -150mV
- Input signal : 0 to 800mV

Optical link prototype

	Specified			Measured			
characteristic	*min*	*typ*	*max*				*unit*
Length	60	100	120	114			m
Gain (into 50 Ω)	0.7	1.43	2.85	0.98	1.2	1.7	V/V
Peak SNR		48		>50.9			dB
Relative linearity deviation		2.5		<2.5			%
Bandwidth		70		120			MHz
Settling time to 1%		18		<10			ns
Crosstalk at $t_s \geq$20ns		-48		<55			dB