Ultra low power consumption 10.7 Gb/s transmission over 2 km single mode fiber optics link

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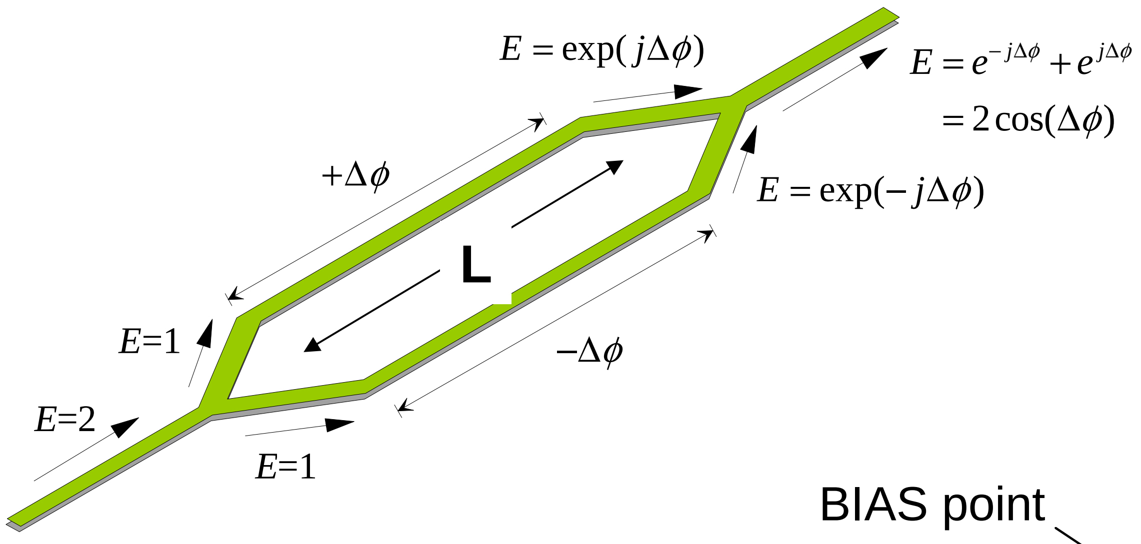
Outline

- Introduction
- Overview of Mach-Zehnder $LiNbO_3$ modulators **(MZM)**: physics and performance
- Error-free 2 km link with 0.6 Vpp modulation
- Challenges and proposals for MZM in SLHC
  - Polarization
  - Form-factor
  - Bias drifts
- Conclusions

Introduction

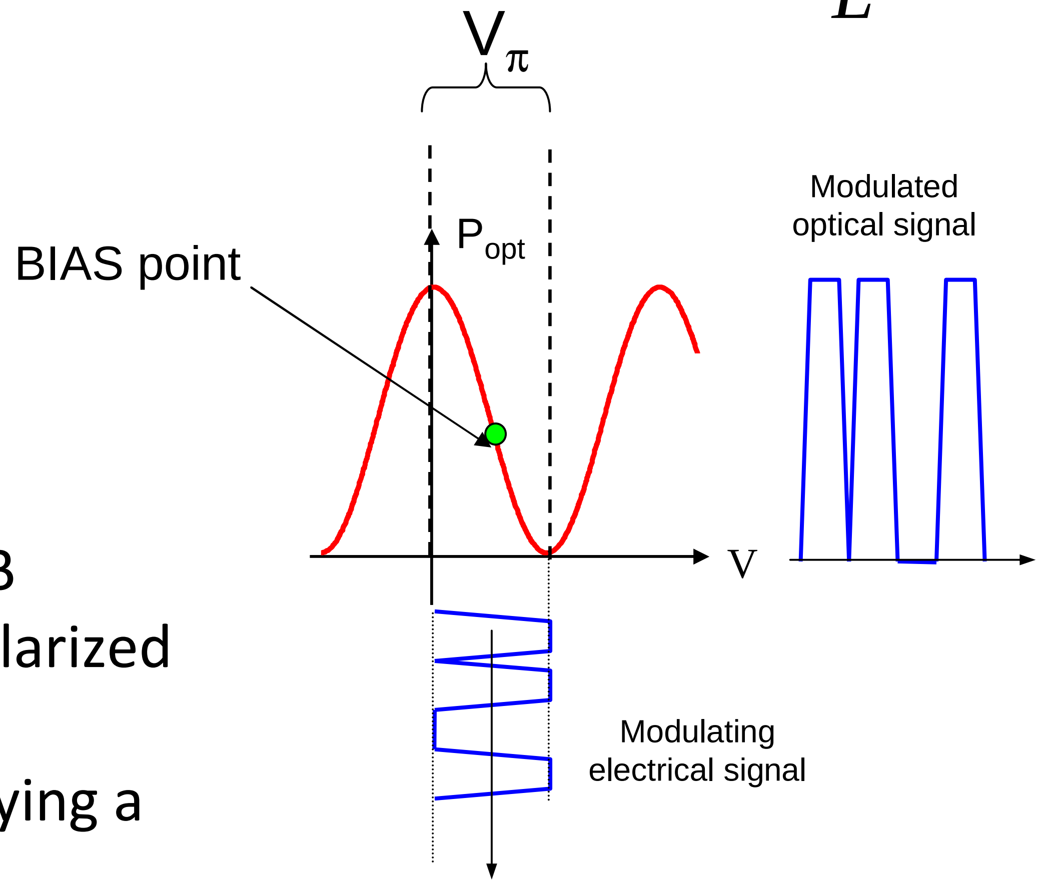
- High bit-rates will be necessary to extract data from the detectors area (Gb/s)
- External modulation allows laser sources to be out of the tracker
- Mach-Zehnder modulators (MZM) are the standard in telecom industry for 10, 20 and 40 Gb/s. (with new modulation formats like DQPSK 100 Gb/s is achievable)
- Lithium niobate ($LiNbO_3$) can operate and are used in harsh environments

Mach-Zehnder modulators



Switching Voltage:

$$V_\pi \propto \frac{\lambda}{L}$$



In commercial modulators:

- Typical extinction ratio 20 dB
- The input optical signal is polarized (integrated polarizer)
- Bias point is adjusted employing a feedback loop

Physical properties of $LiNbO_3$ MZM

- Immunity to Electromagnetic Noise, broadband operation (1300-1500 nm)
- Radiation hardness (4 x 10^{13} n/cm2, 100Mrad)
- MZM can operate at very low temperatures (demonstrated down to 4.2 °K [Yoshida 99])
- Magnetic field insensitive
- Interesting features recognized in the report CERN/DRDC 93-35(1993)
- Not employed because of linearity in analogue modulation (~100 MHz bandwidth)

Low-power link rationale

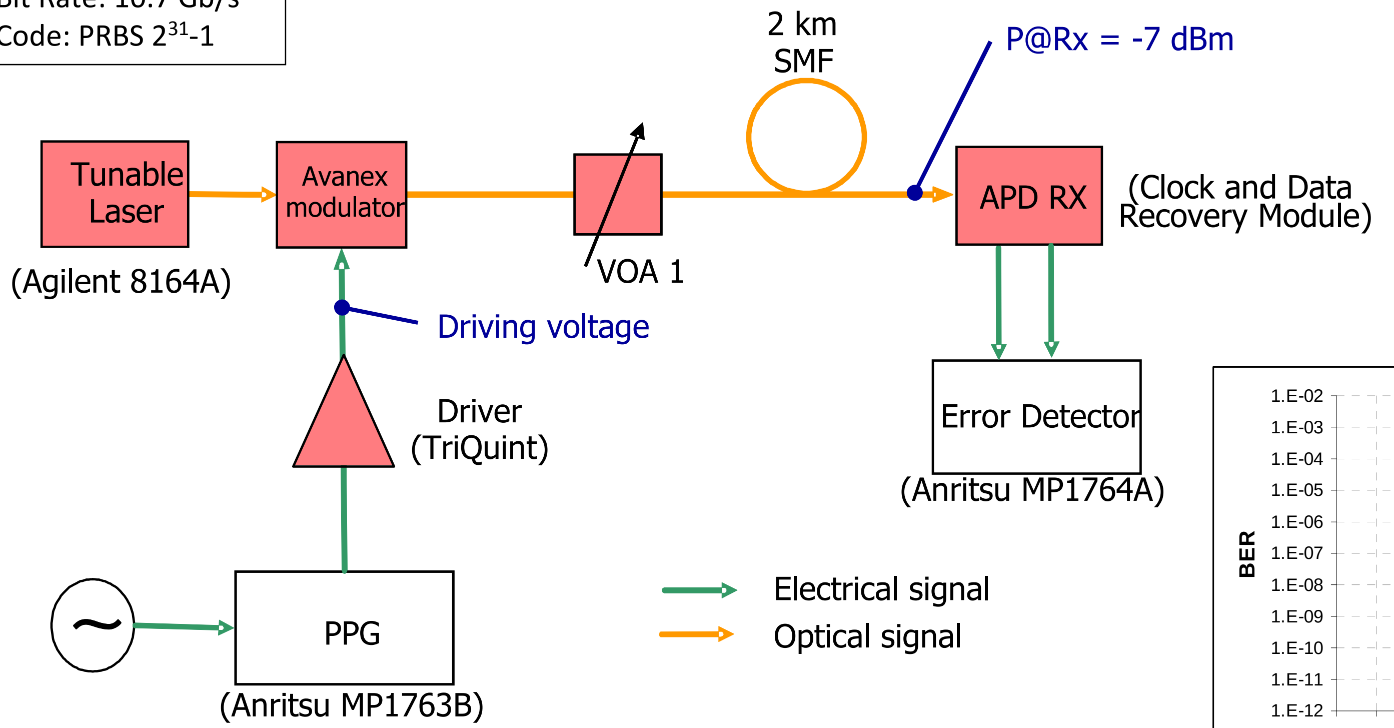
MZMs are designed for extinction rates of about 15-20 dB, in order to reach 80-100 Km long links.

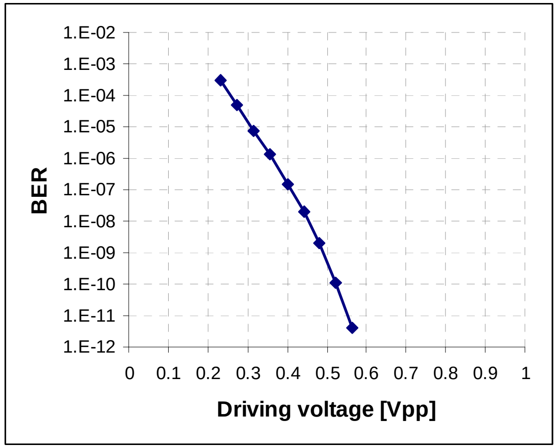
Reducing the connection length enables to strongly reduce the dynamic of the modulation and the power consumption.

Keeping laser sources outside radiation area allows more flexibility in a design phase (no need for rad hard laser) and better maintenance in operation (repair, substitute,...)

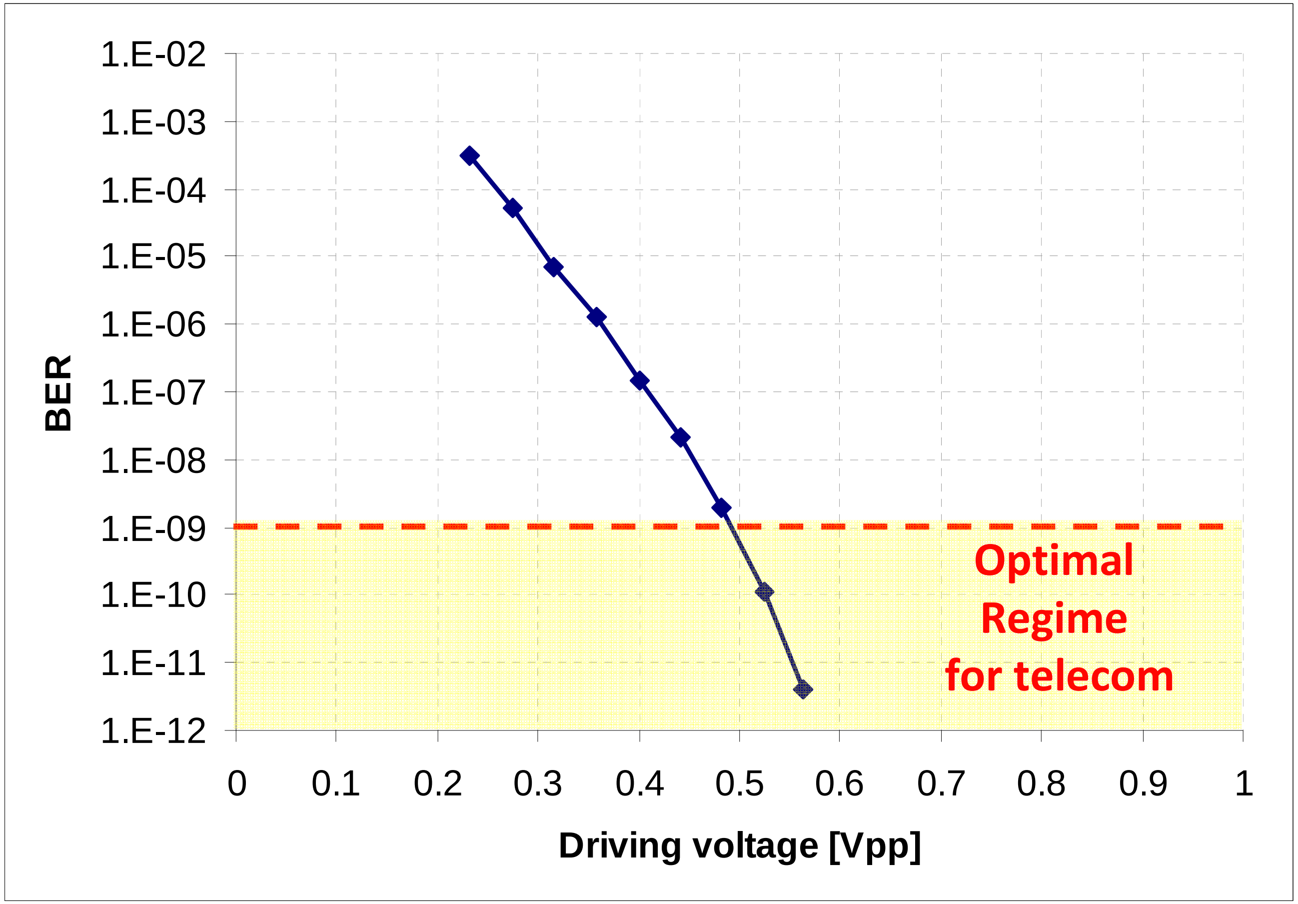
Measurement setup 2 km link

Test conditions:
Bit Rate: 10.7 Gb/s
Code: PRBS 2^{31}-1





Experimental results



No correction protocol employed

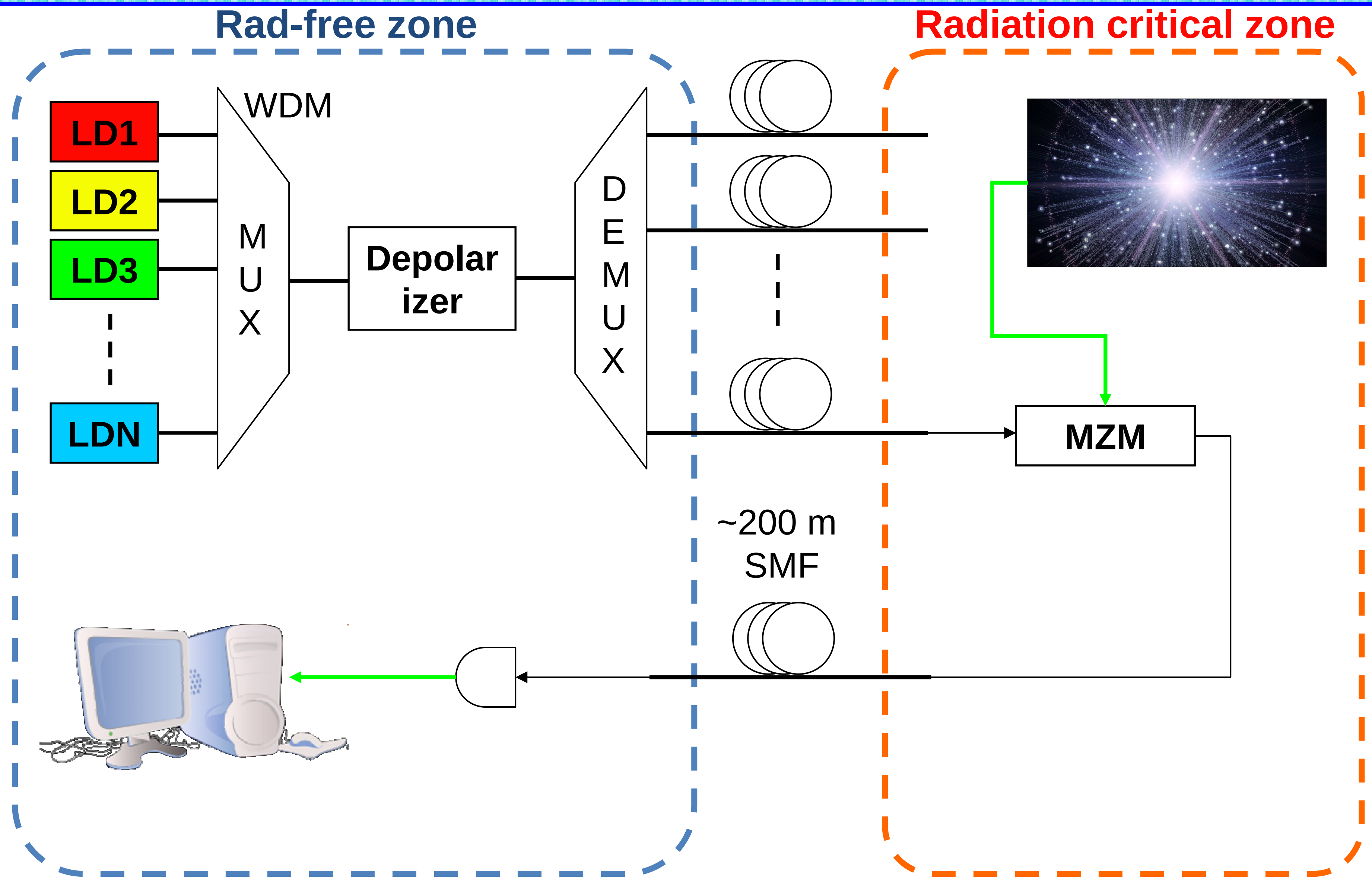
Perspectives of ultra-low power links

- 0.5-1 V driving voltage allows to use directly the output of the logic boards.
- Very low power consumption (@10 Gb/s): about 10 mW/modulator achievable.
- Ultra-low-power link key features
  - ***"Green"*** → Low power dissipation.
  - ***Scalable*** → Possibility of increasing data transfer rate with same technology (20 - 40 Gb/s).
  - ***Maintainable*** → Most delicate element (LD) outside the tracker assembly, easily replaceable.
  - ***Reconfigurable*** → Optical power can be adjusted.

Critical issues

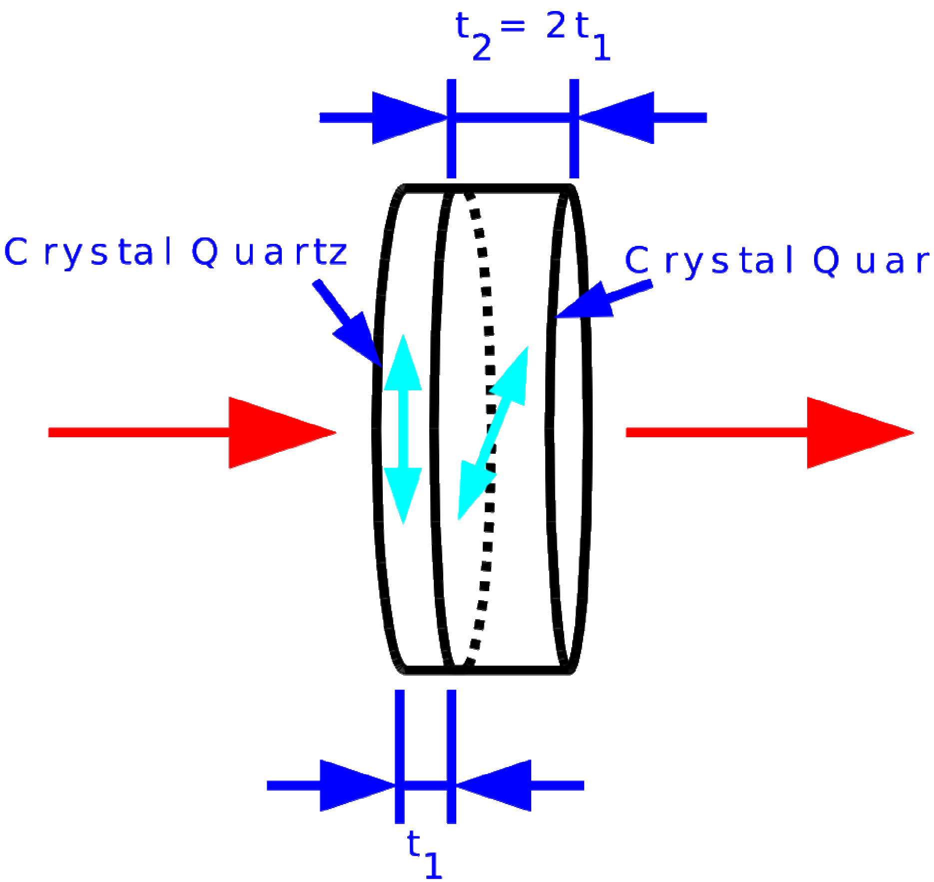
- Rad-hard high data rate serializers/logic circuits must be developed/tested (common to all modulation high data rate schemes).
- For MZM:
  - Laser polarization needs to be controlled to avoid PM fibers or power fluctuations
  - Form-factor can be further reduced to better fit on the modules
  - Bias management needs to be taken into account for constant optimal operation

Polarization management



Lyot Filter Depolarizers

Two wave plates with their fast axes 45 degrees apart, with the second plate twice the thickness of the first



Depolarizer/1

General Photonics

Features:

- For lasers with coherence length to and beyond 10 m
- Low degree of polarization
- Wide operating wavelength range
- Low insertion loss

Applications:

- Minimize polarization sensitivity of fiber sensors
- Remove polarization sensitivity of Raman amplifiers
- Eliminate polarization sensitivity of optical instruments
- Reduce PDL effects of optical components

Center Operating Wavelength	1420 nm, 1480 nm, 1550 nm, 1600 nm
Operating Wavelength Range	± 50 nm
Coherence Length of Light Source	10 m standard, others specify
Output Degree of Polarization	< 5%
Insertion Loss	1.0 dB typical, 1.4 dB max.
Residual Extinction Ratio	< 0.5 dB
Return Loss	55 dB
Optical Power Handling	300 mW min.
Operating Temperature	0 ~ 70 °C
Storage Temperature	-40 ~ 85 °C
Fiber Type	Input: PM Panda fiber, Output: Corning SMF-28
Dimensions	85 x 60 x 10 mm

(Values are referenced without connectors)

Totally passive
No electronics required

Depolarizer/2

Totally passive
No electronics required

FEATURES:

- Low DOP
- Low insertion loss
- Near zero back reflection
- All-fiber construction
- Wide wavelength operating range
- Passive operation
- Rugged packaging

DEPOLARIZER OPTIONS:

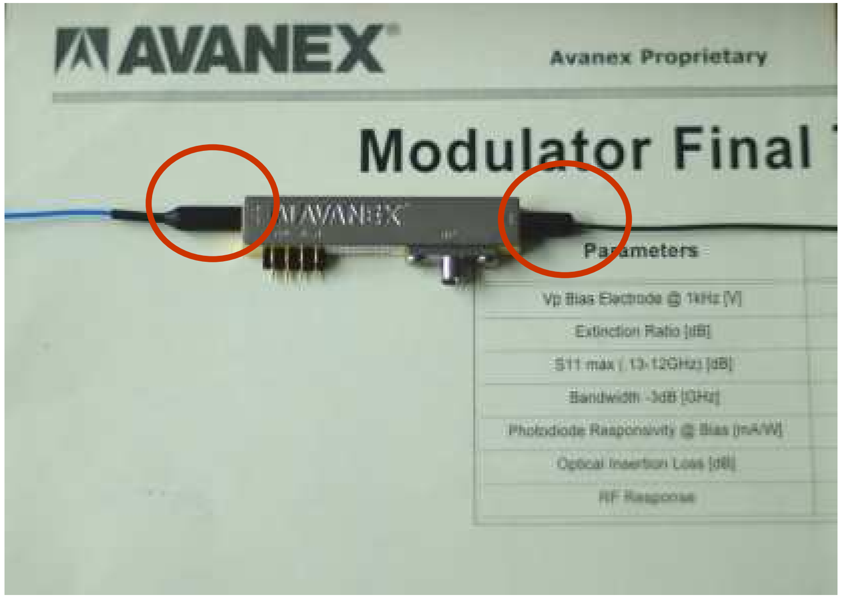
State of Polarization input		Arbitrary	Linear	Linear
Integrated Polarizer		No	No	Yes
Wavelength ranges (nm)		980, 1280-1625	1280-1625	1280-1625
Insertion Loss (dB)	BB	<1	<1	<1.5
	LS	<2	<2	<2.5
	RM	<1	<1	<1.5
Input Fiber		SM	PM	PM
Output Fiber		SM	SM	SM
Dimensions (mm) LxWxH	BB	150x95x10	150x95x10	150x95x10
	LS	160x103x35.5	160x103x35.5	160x103x35.5
	RM	N/A	150x95x10	150x95x10

All dimensions are approximate and may vary slightly.

SPECIFICATIONS:

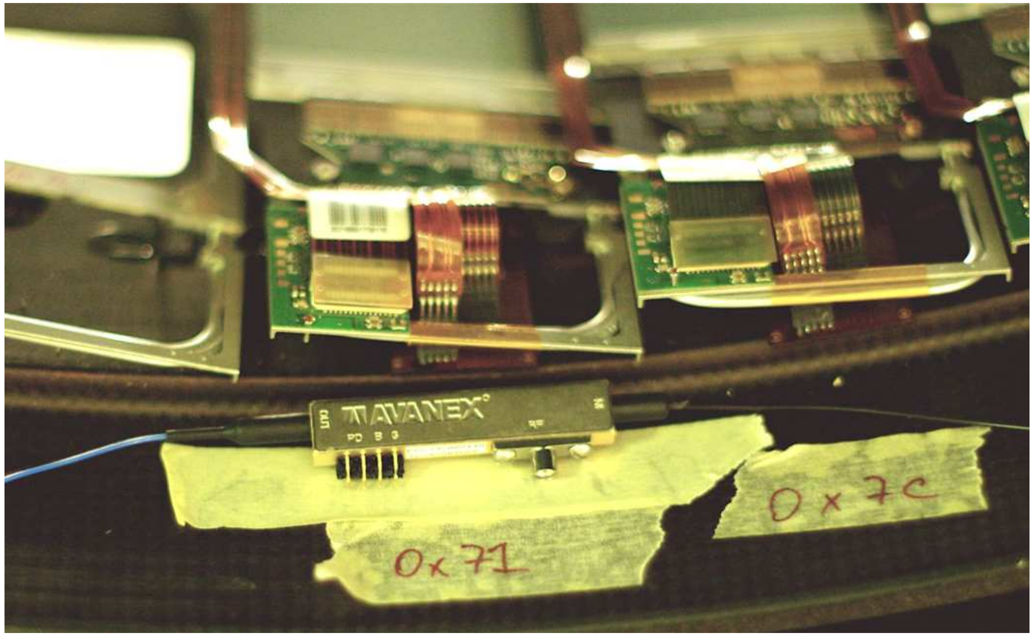
Wavelength range[1]	980nm	1280nm – 1625nm
Operational bands[1]	980nm	1300nm, 14XX, S,C,L
Residual extinction ratio[2]	<0.2 dB	<0.2dB
Degree of Polarization[3]	<5%	<5%
Insertion loss[4]	<1dB	<1dB
Return loss[5]	>70dB	
Source linewidth[6]	>0.1nm	
Operating temperature range[7]	-5°C to 70°C	
Transportation/storage[8]	-40°C to 85°C	
Input Fiber type	Corning Puremode HI 1060	SMF28(SM) PANDA (PM)
Output Fiber type	Corning Puremode HI 1060	SMF28 (SM) PANDA (PM)
Pigtails	1m fiber standard, 900μm loose tube optional	

Form factor of tested MZM

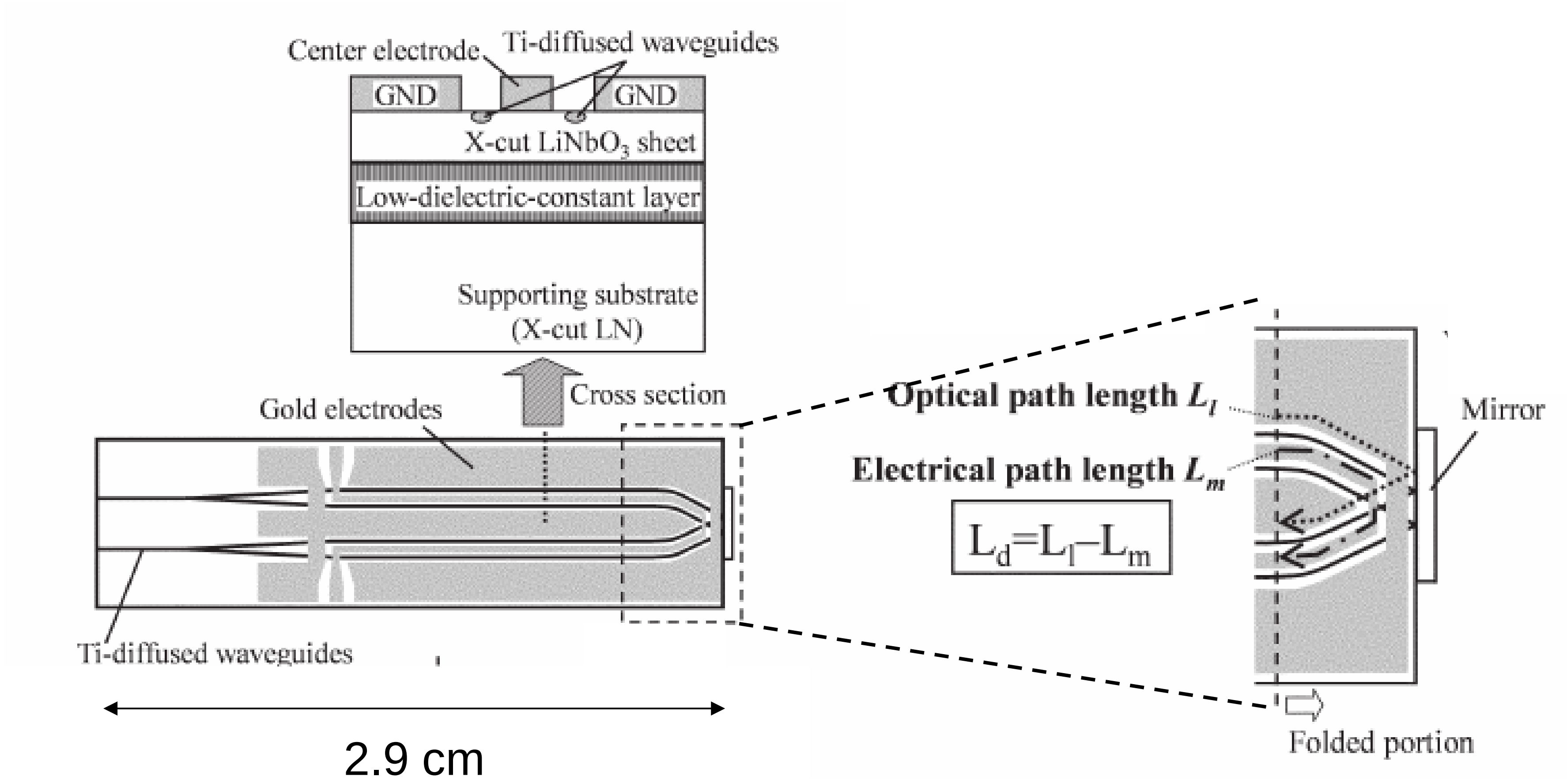


48 x 9.3 x 5.0 mm^3
(Excluding connections:
13 mm in + 18 mm out)

oclaro



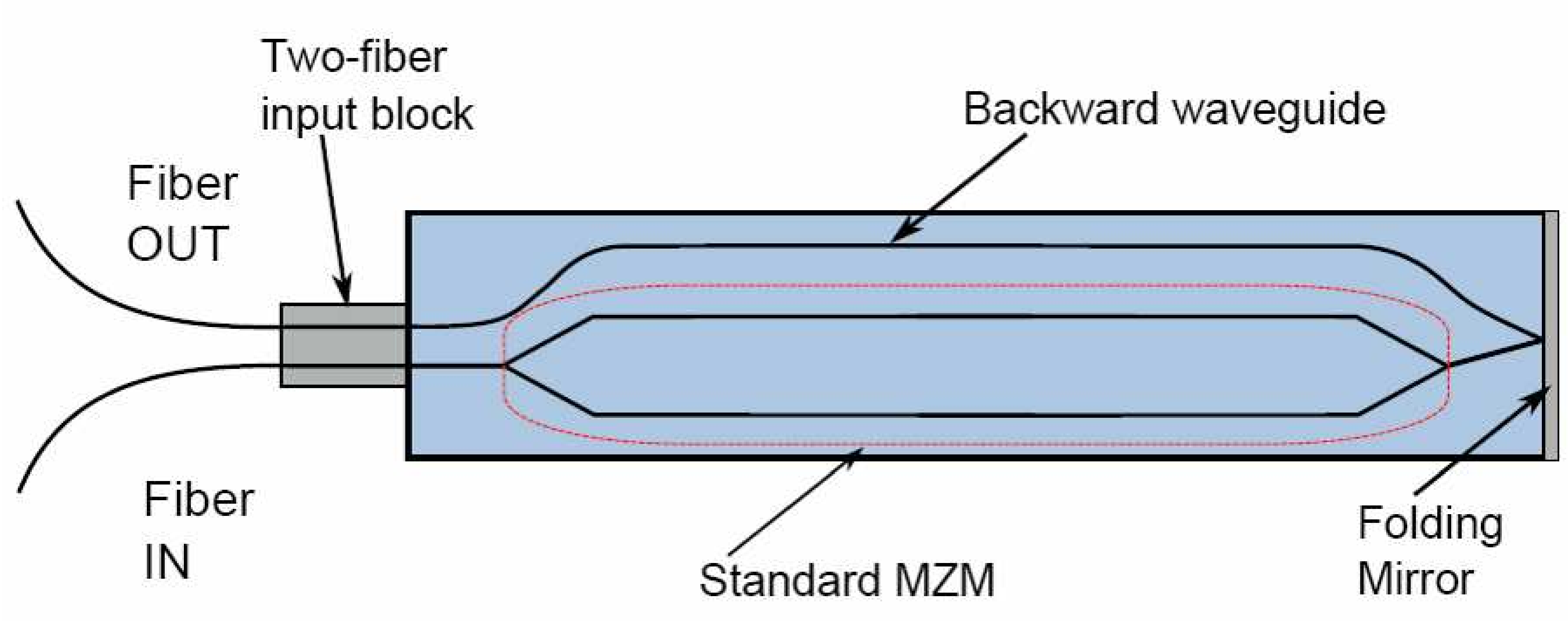
Form-factor reduction/1



Scheme for a 40 Gb/s folded modulator proposed and fabricated by Aoki in 2007

Performance similar to standard modulators

Form-factor reduction/2



Slight modification of packaging and device in current MZM
Study of packaging options for better integration on
Si detector board

Bias control

Bias point can vary in time due to thermal and DC drifts

Thermal drift is minimized by controlled temperature environment

DC drift is due to charge accumulation on $LiNbO_3/SiO_2$ interface (can be almost suppressed by optimal SiO2 deposition [Kim 2006])

Drifts are slow (typically hours)

Bias control could be performed from remote by setting the appropriate voltage on the board

Conclusions

- MZM $LiNbO_3$ are radiation hard, immune to magnetic fields and can work at very low temperatures
- Demonstration of 10.7 Gb/s error-free communication with 0.6 Vpp on a 2 km fiber link
- Proposed solutions to critical issues (polarization, form-factor and bias control)
- Tests are planned at a device and system level before and after radiation exposure

Thank you!

References

[Yoshida 99] IEEE Trans. On Appl. Superconductivity, **9**,2,pp. 3421-3424, June 1999

[CERNRD23] Project RD23: Optoelectronic Analogue Signal Transfer for LHC Detectors, http://rd23.web.cern.ch/RD23/CERN-DRDC_93-35(1993).PDF

[Kim 2006] Journal of Crystal Growth 288 (2006) pp. 188–191

[Aoki 2007] Journal of Lightwave Tech., **25**, 7,pp. 1805-1810, July 2007