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IEEE 802.3 Physical Layers for increased-reach Ethernet optical subscriber access (Super-PON)

Wavelength-Tunable DBR laser for Burst Mode TWDM PON applications

Finisar Corp.

Yasuhiro Matsui, Leo Lin, Daniel Chen, Tsurugi Sudo

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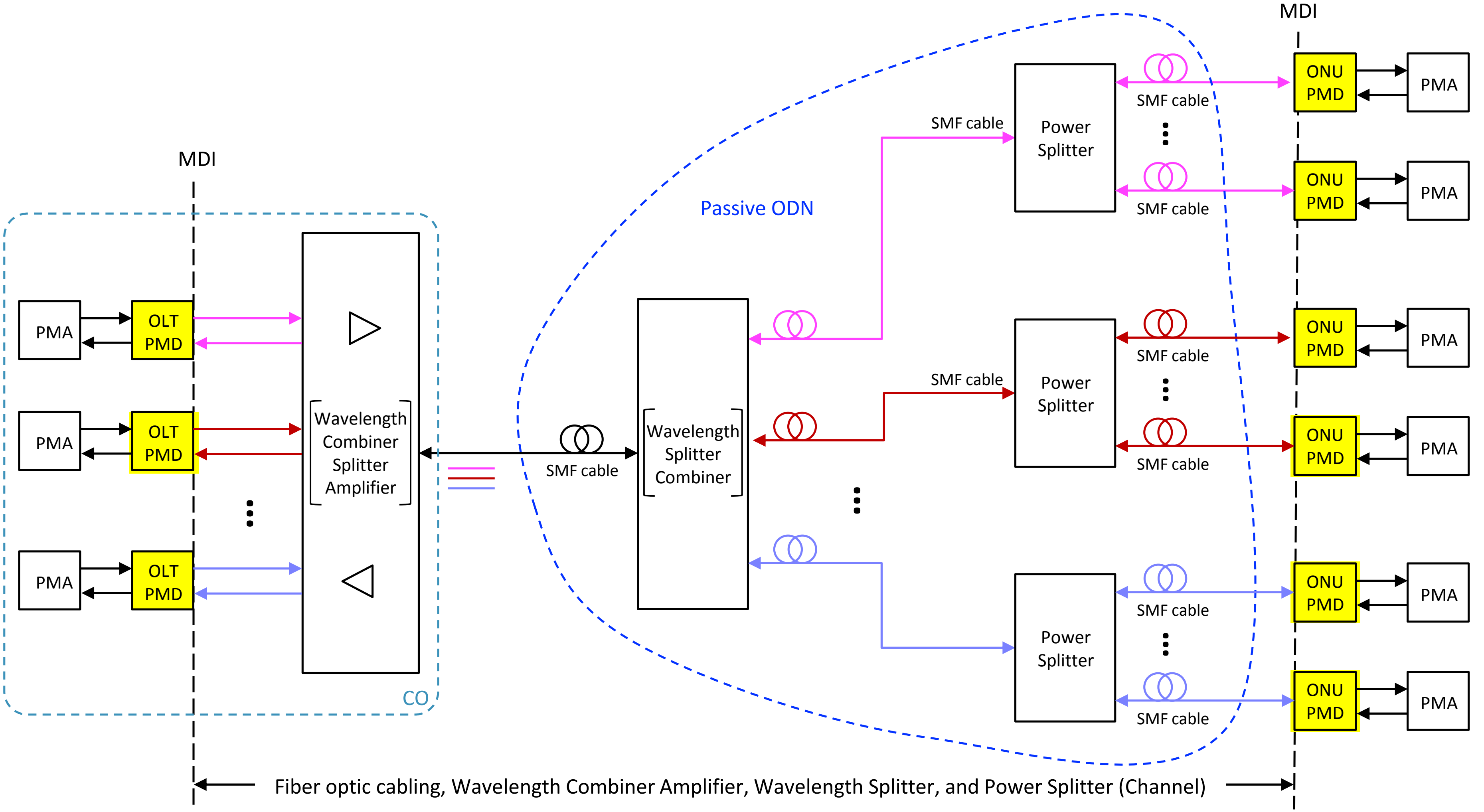
Outline

- Introduction
- DML for 20km transmission at 10 Gb/s
- 40km reach at 25 Gb/s – Chirp Managed Laser technology
- Bust-mode wavelength control by tunable DBR laser
- Path to ~ 50 GHz BW laser
- Summary

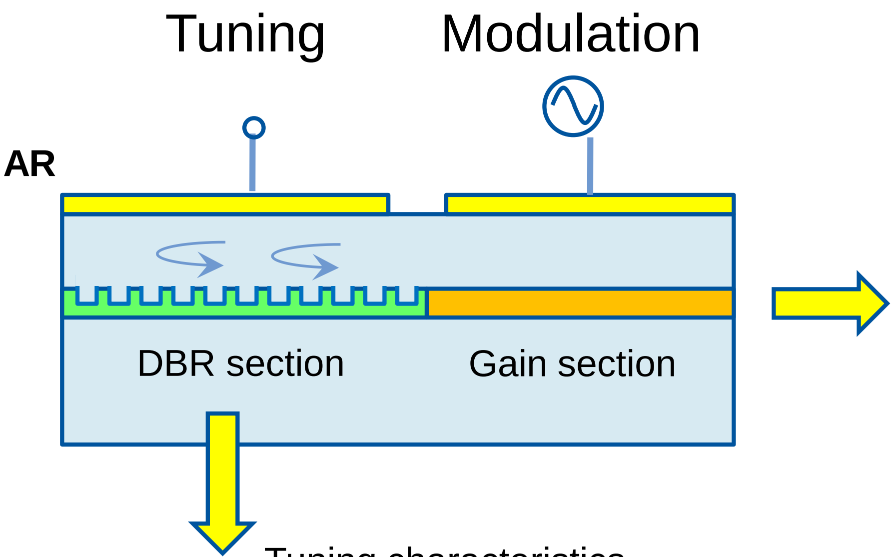
Example PMDs

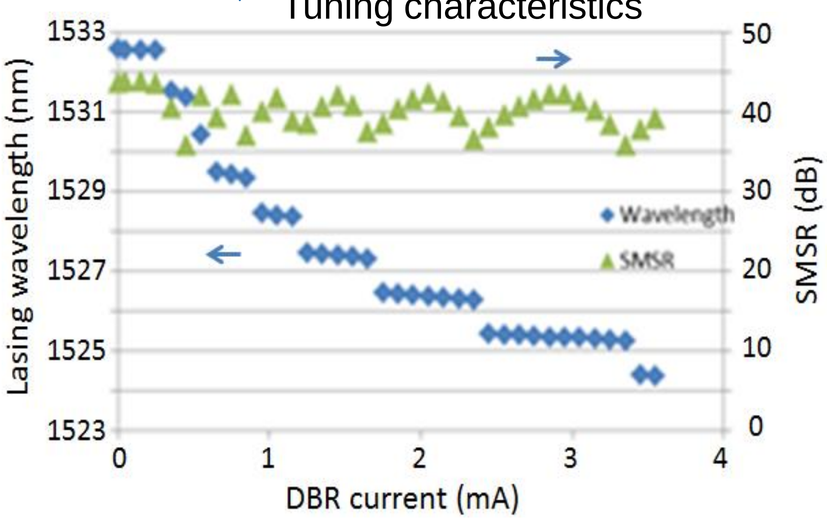


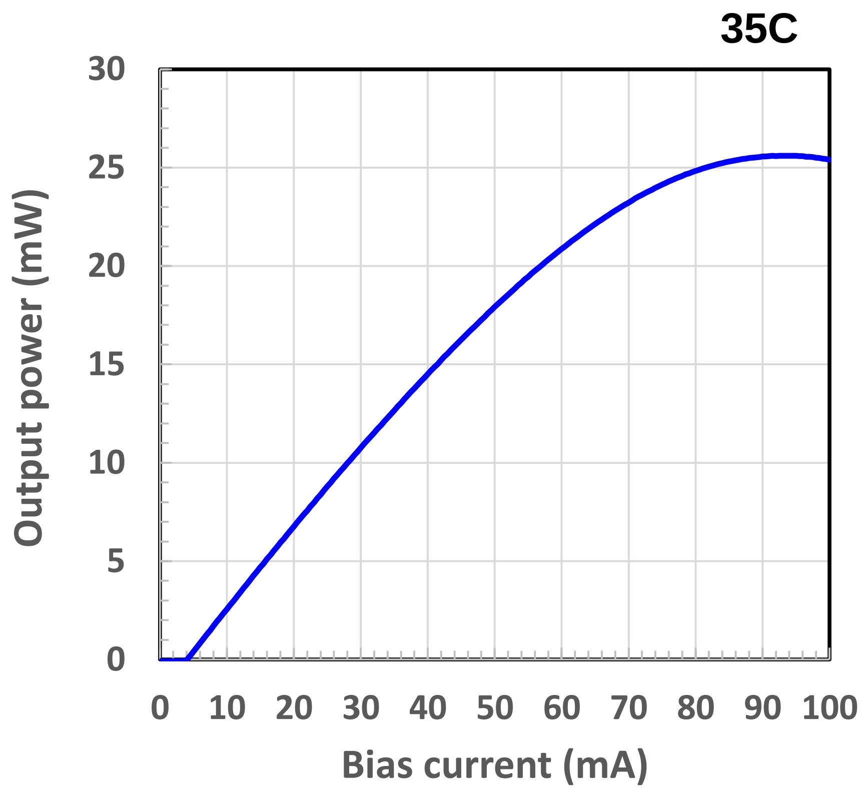
Advantages of DBR laser

- Tunable over ~ 12 nm
  - Easily cover 4 x 100 GHz WDM channels
  - Burst mode thermal chirp (~ 50 GHz, ~ micro second) can be easily compensated by wavelength tuning with ~ 0.2 mA current.
- 20km at 10Gb as DML or 200km using CML
  - Cavity effect can suppress undesirable transient chirp and extend the reach.
- High-power
  - 10 mW possible. Power is not limited by laser. It can be as high as driver can get.
- Possible > 25 GHz BW
- Lens-free and isolator-free under development

Basic idea of DBR laser







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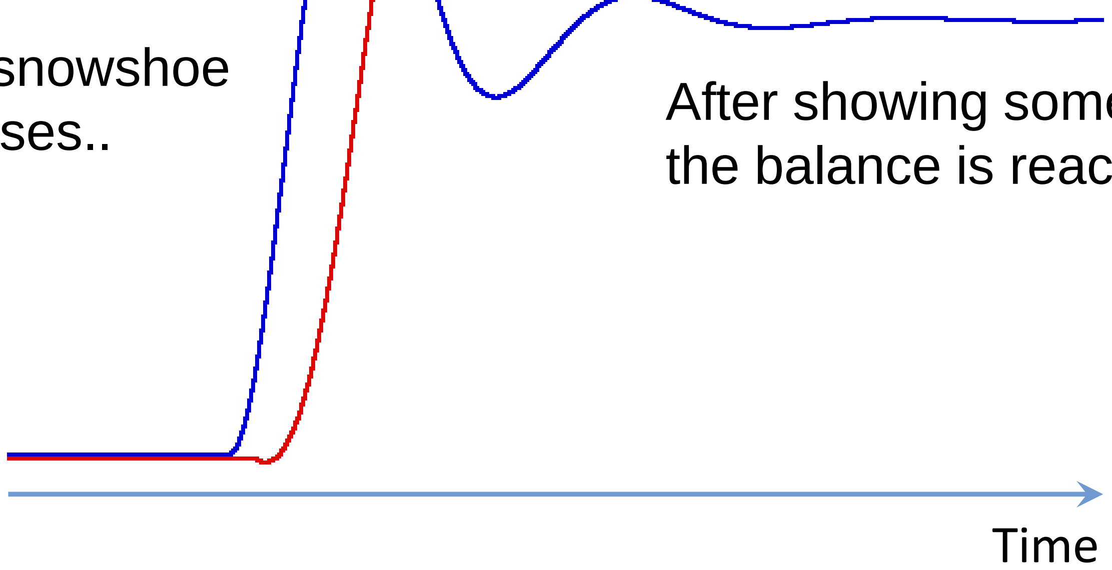
Rate Equation for laser has something common with predictor-pray relation

Lotka-Volterra equation (1910), study supported by Hudson's Bay Company – fur trading company

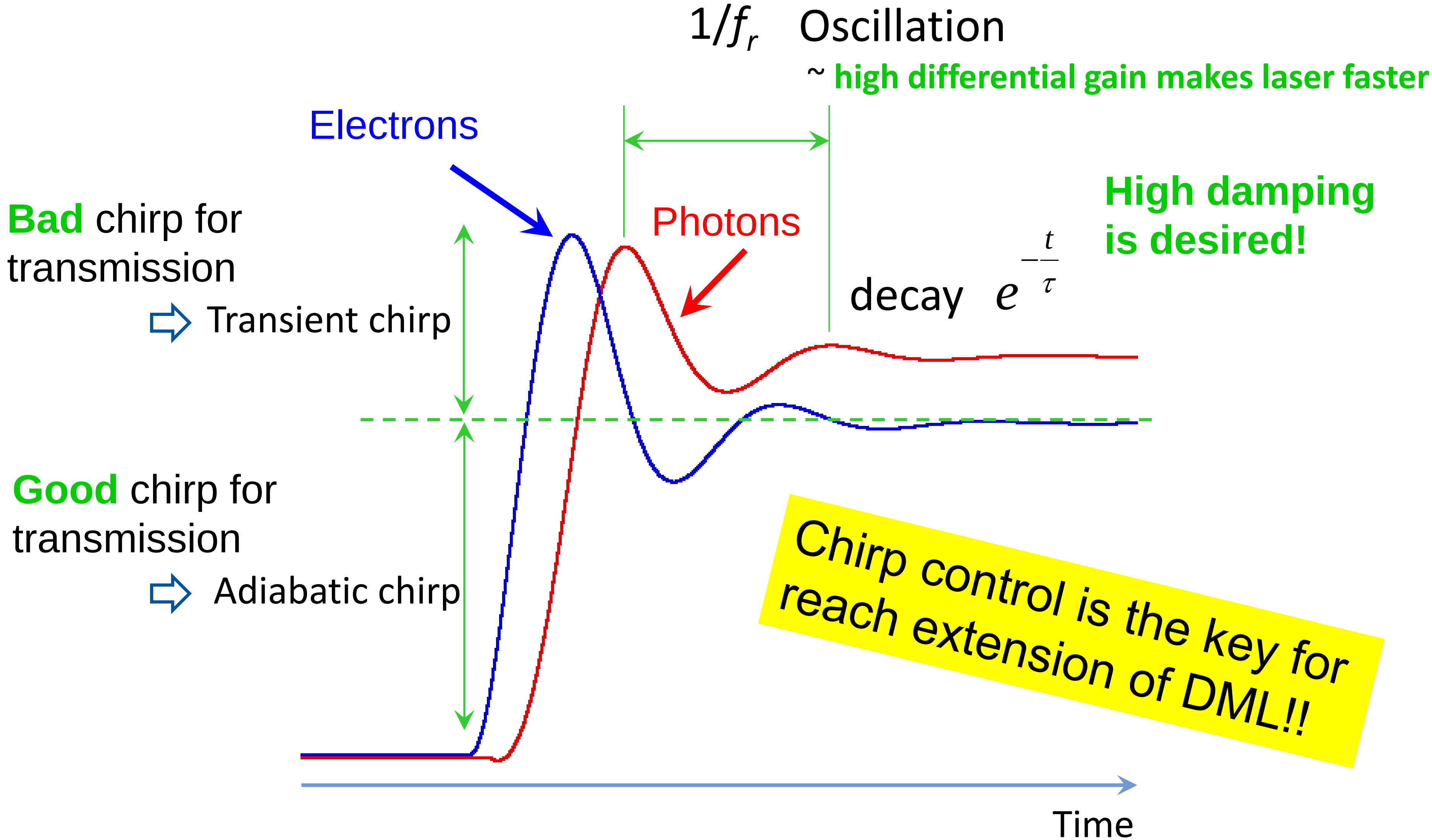
# of lynx increases after some delay.

When # of snowshoe hare increases..

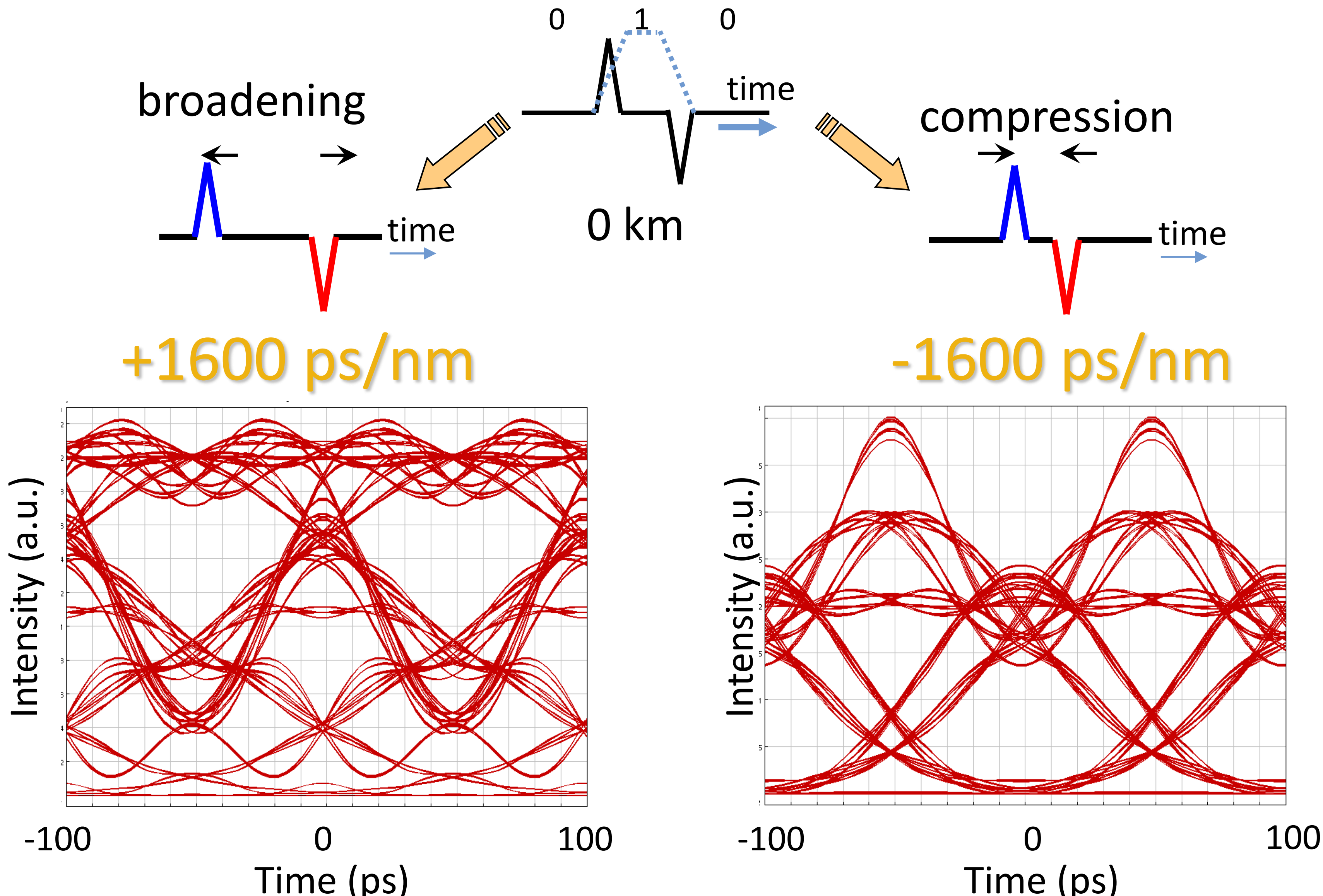


After showing some oscillation, the balance is reached.

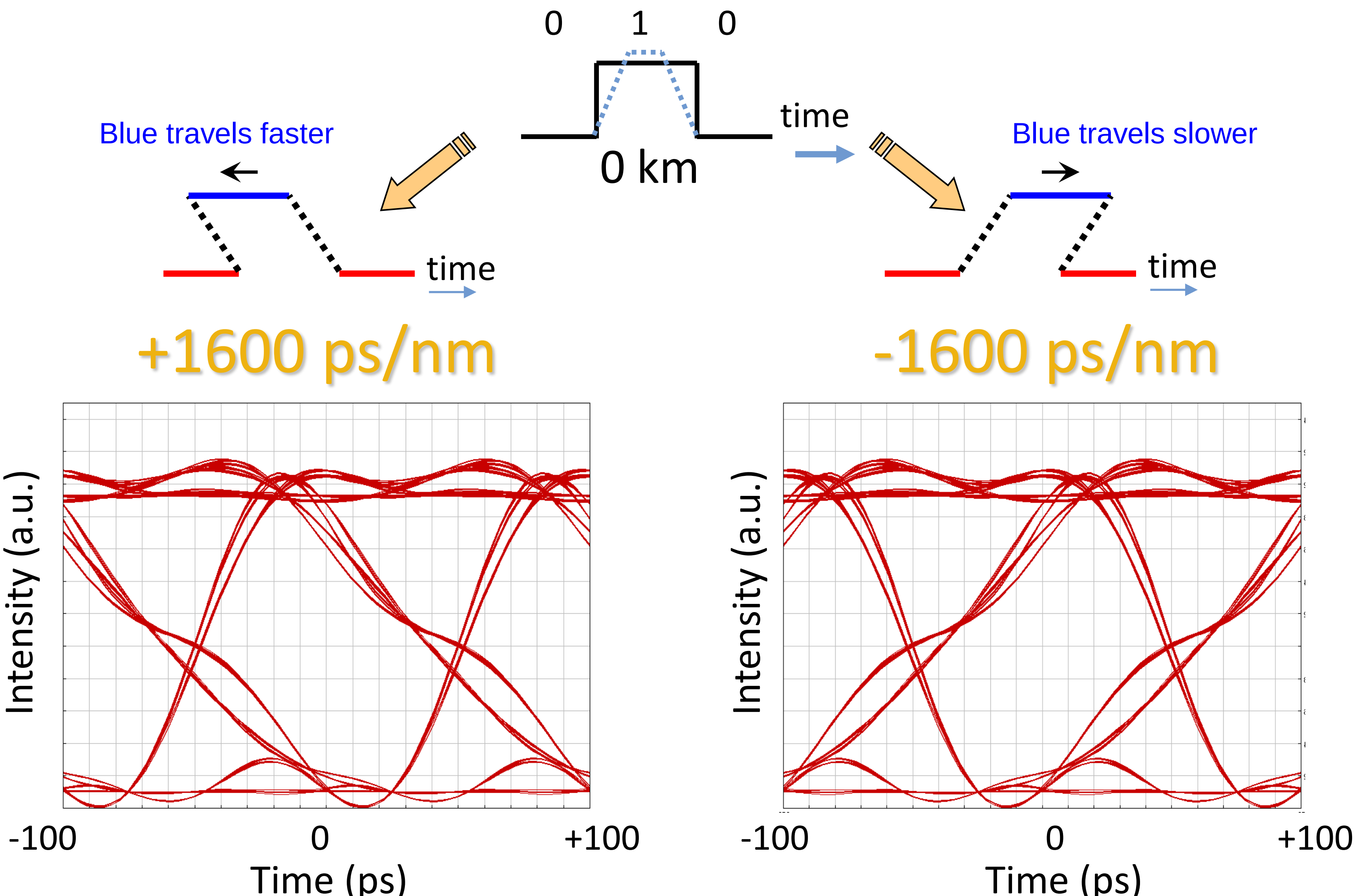
In case of laser diodes



Bad chirp as we all know – transient chirp

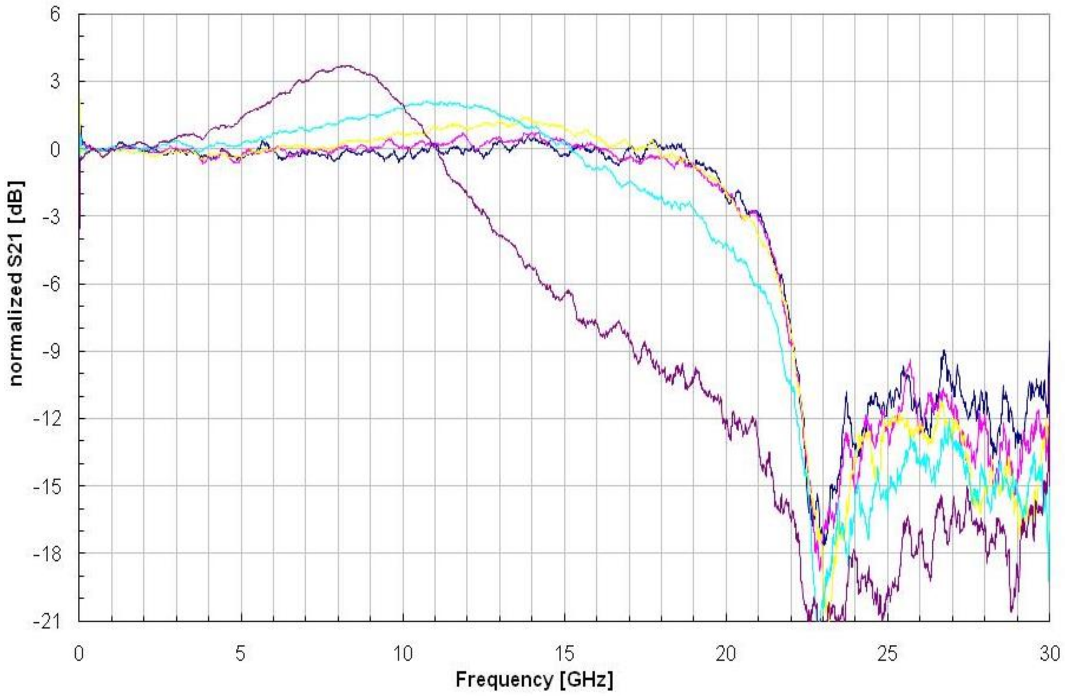


Good chirp makes DML as good as “Optical duo-binary”

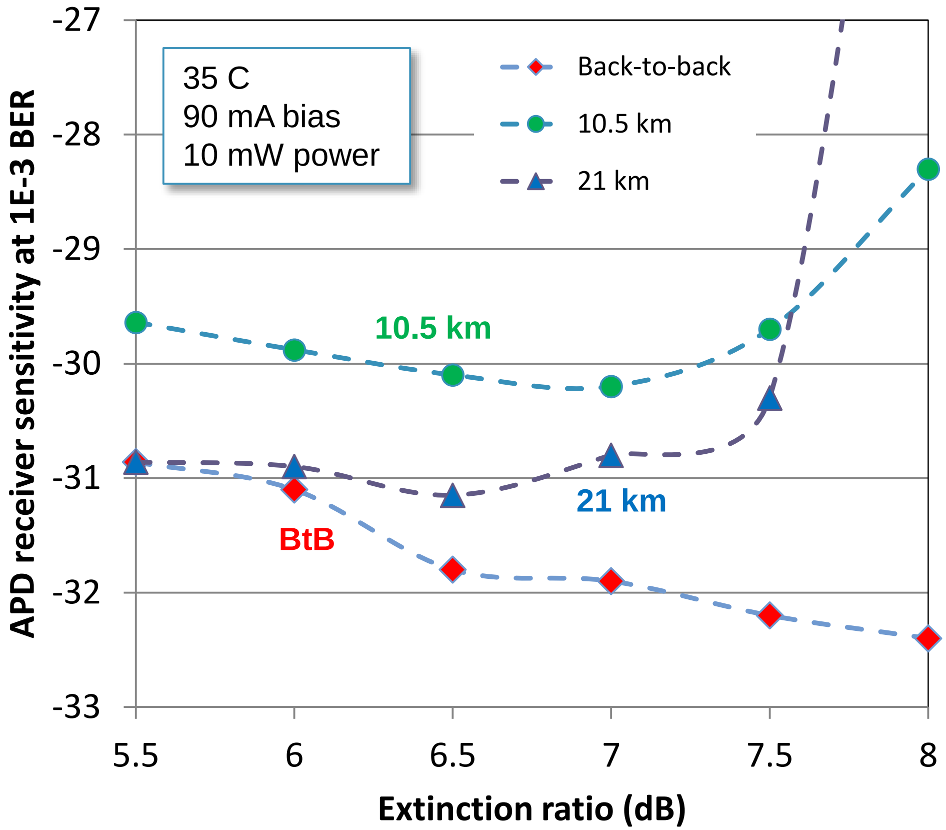


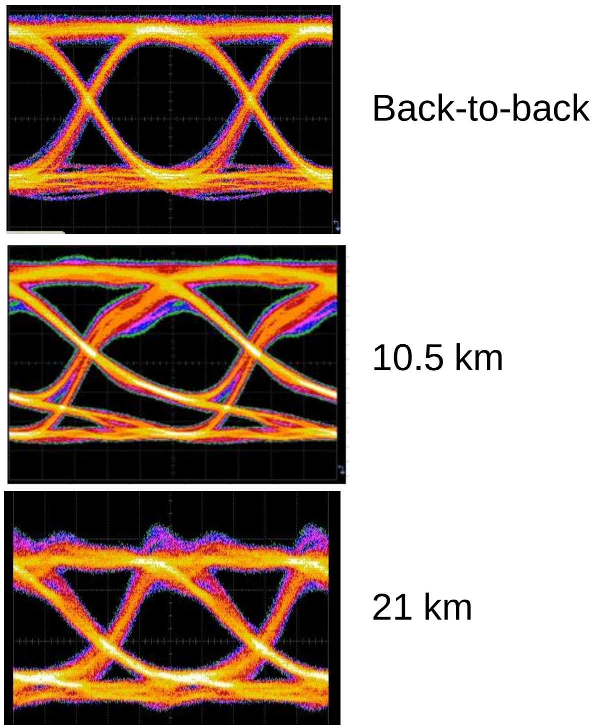
“Linearized DML” – very flat response with no peaking

- High damping is realized to suppress the Transient chirp by design
- Very flat S21 response is achieved as a result



Transmission performance over 21km

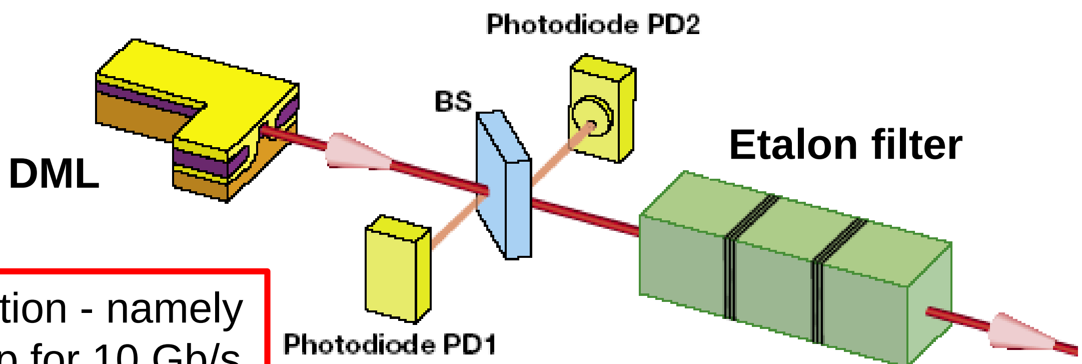


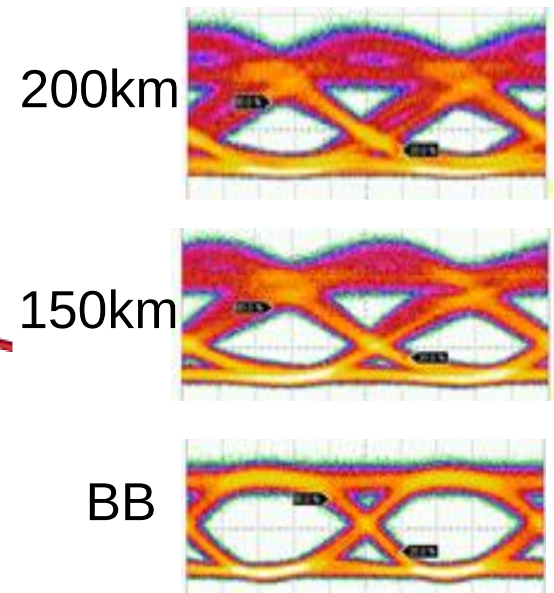


- -30 dBm sensitivity at 10 km and -31 dBm at 20km at 6.5 dB ER.
- 10km sensitivity becomes better for lower bias (higher transient chirp helps)
- > 7.5 dB ER increases dispersion penalty (higher transient chirp hurts)
- 10 dBm fiber <u>coupled</u> power is possible with proper design

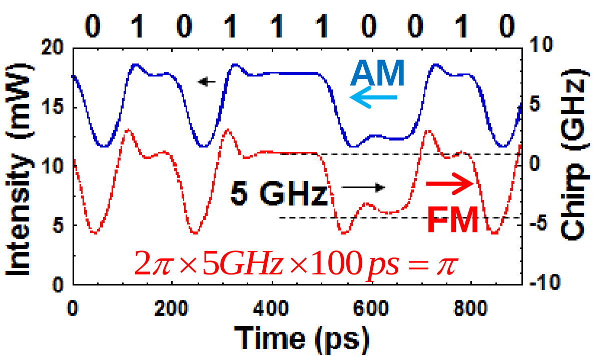
Chirp Managed Laser (CML)

Y. Matsui *et. al*., "Chirp-Managed Directly Modulated Laser (CML)," *IEEE Photon Technol. Lett., vol. 18,* 2006

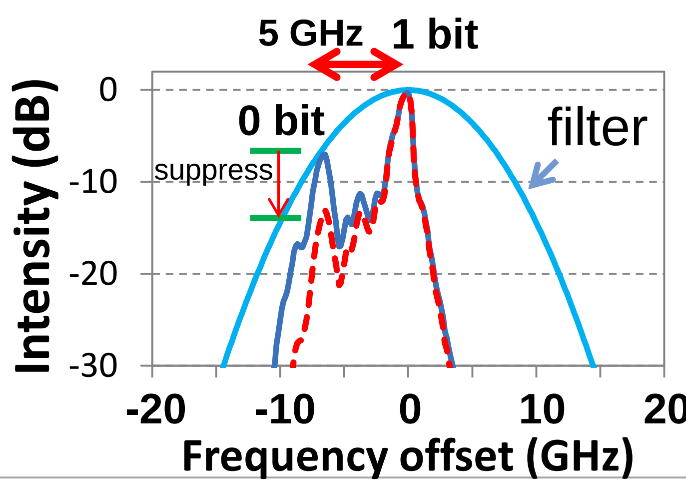


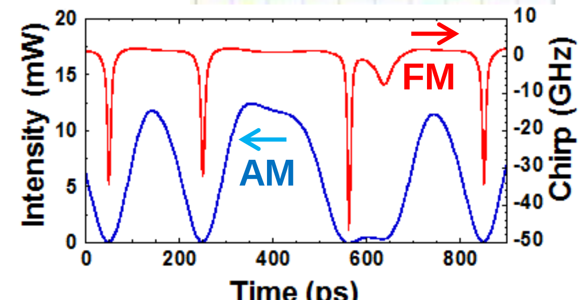


MSK condition - namely 5 GHz chirp for 10 Gb/s π shift between the bits



SSB generation by filtering FSK signal





High bias, low ER suppresses transient chirp

- >10 dB ER in BtB
- <u>*Abrupt*</u> π phase shift (Duo binary effect)

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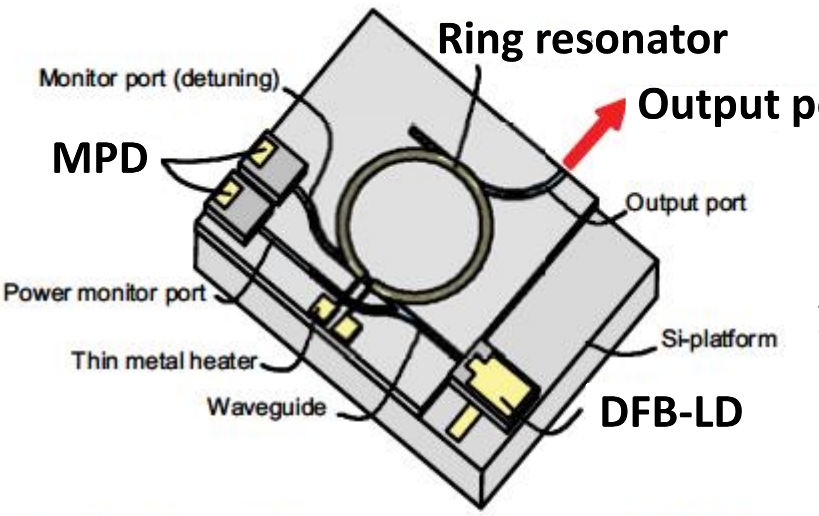
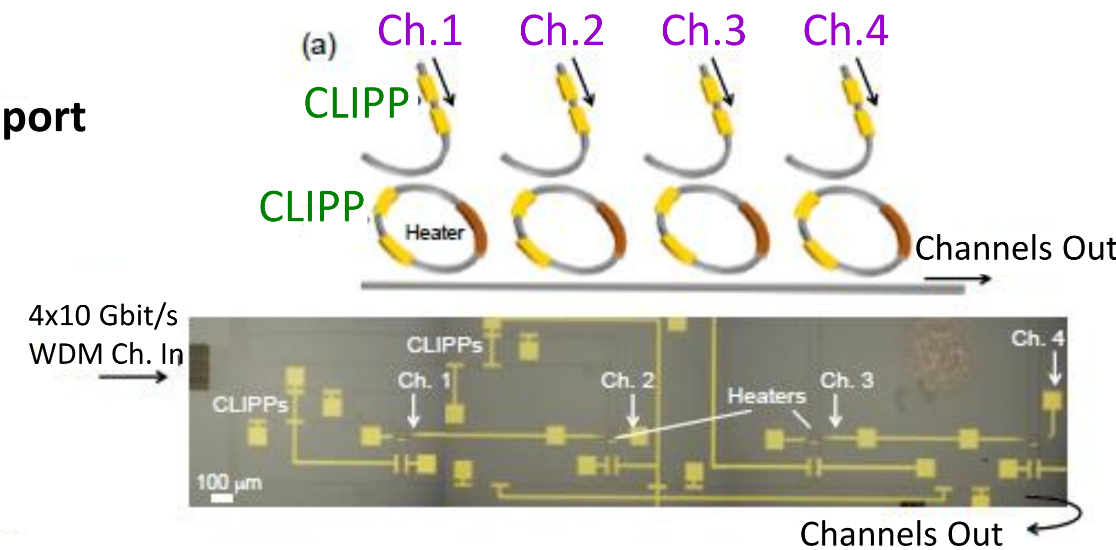
CML on PLC platform



(a)



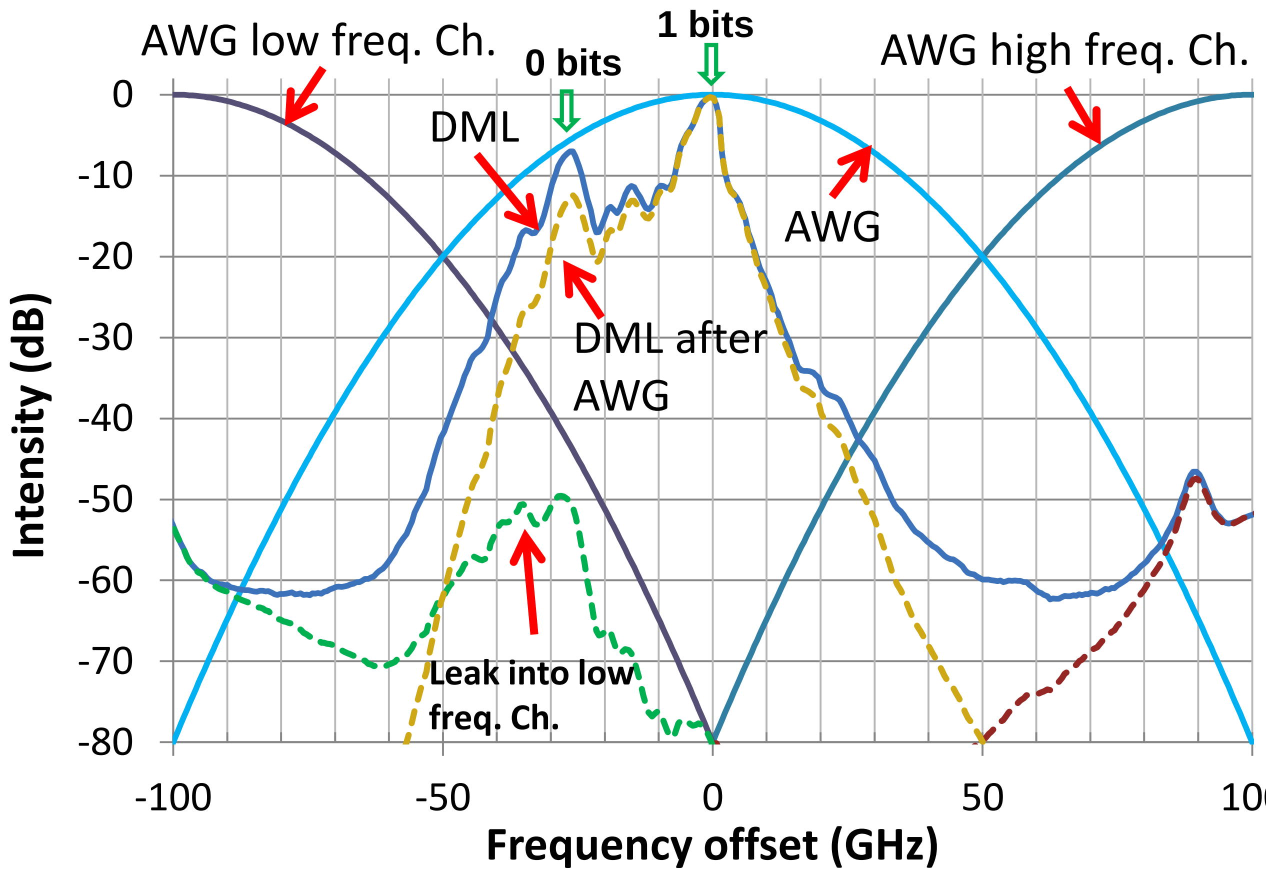
(b)

Y. Yokoyama et al., European Conference on Optical Communication (ECOC), paper We.1.C.4, 2010.

S. Grillanda et al., IEEE J. Lightwave Technol., vol. 35, pp. 607-614, 2017.

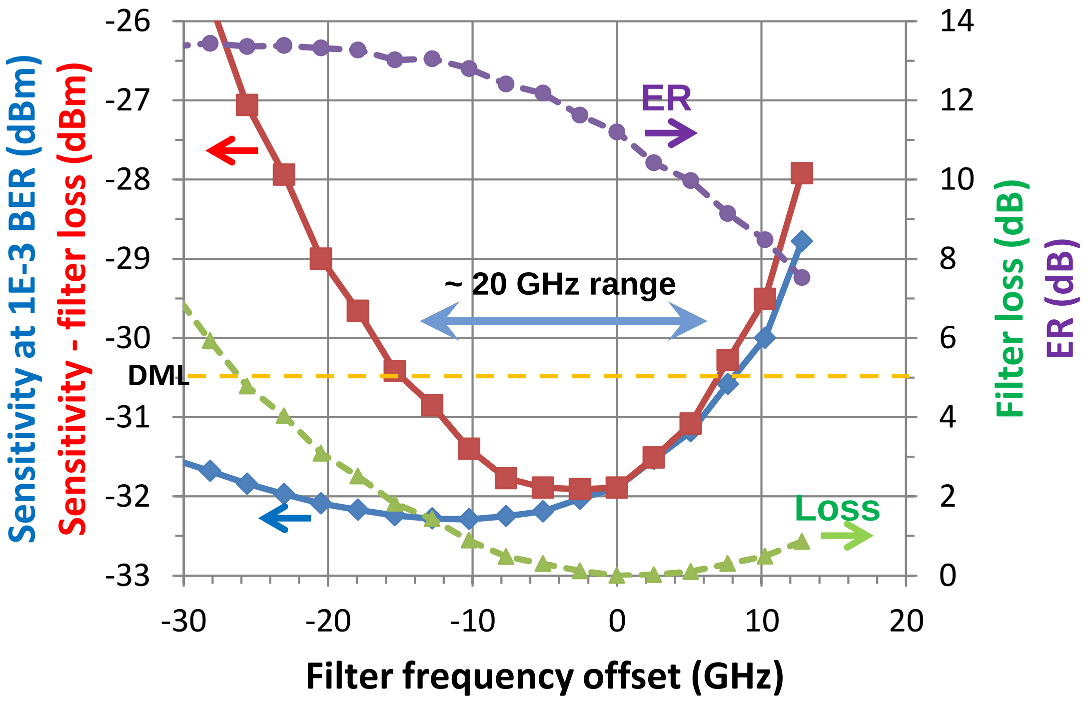
AWG filter shape and DML spectrum

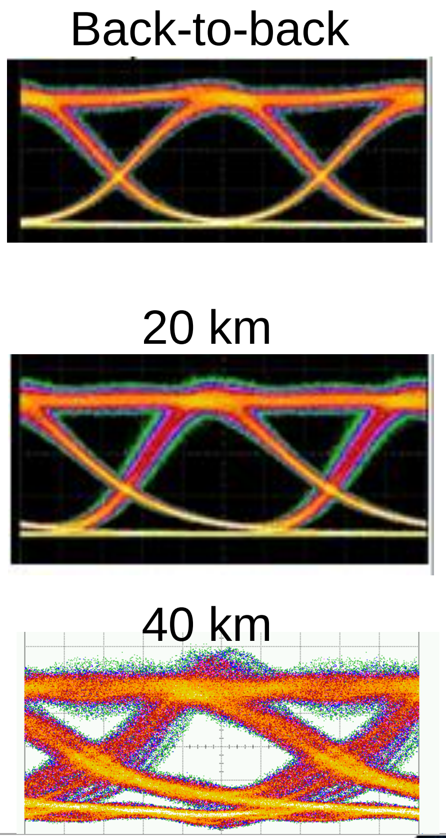
- AWG filter shape: 1-dB BW ~ 22 GHz, 3-dB BW ~ 40 GHz
- Adiabatic chirp ~ 30 GHz
- ER before AWG filter ~ 6.5 dB, after filter ~ 11 dB
- Leak energy into low-freq. Ch. ~ -50 dB



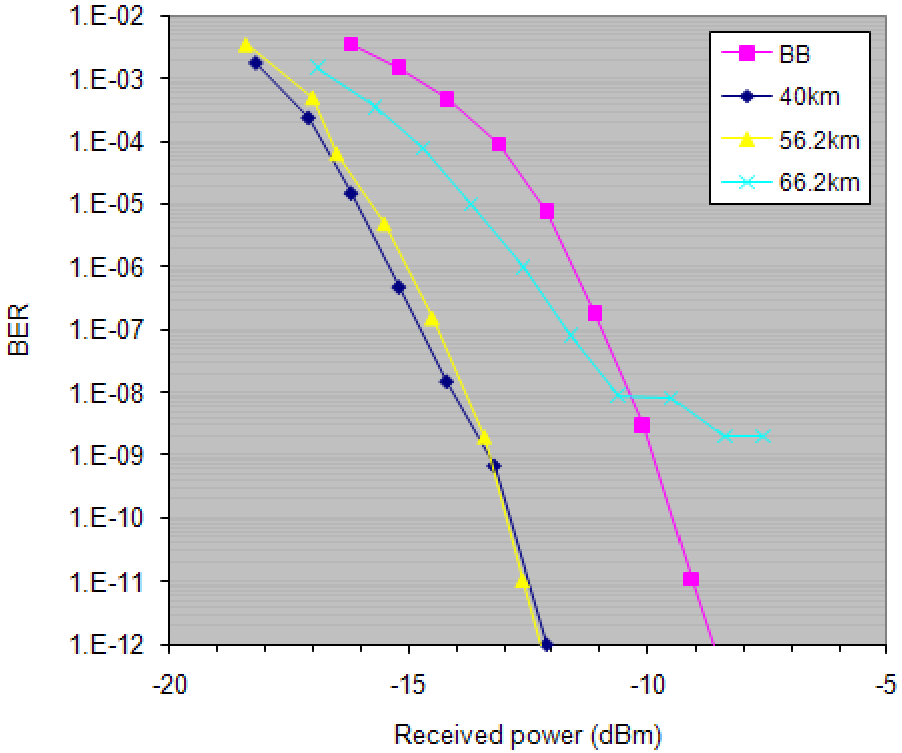
CML based on AWG filter

- Negative offset improves ER to > 11 dB
- Sensitivity ~ -32 dBm at the best position (-5 GHz offset from the filter center)
- Filter loss increases with offset (1-dB loss BW ~ 22 GHz).
- Better performance than DML from -15 GHz to + 5 GHz
- 40 km possible



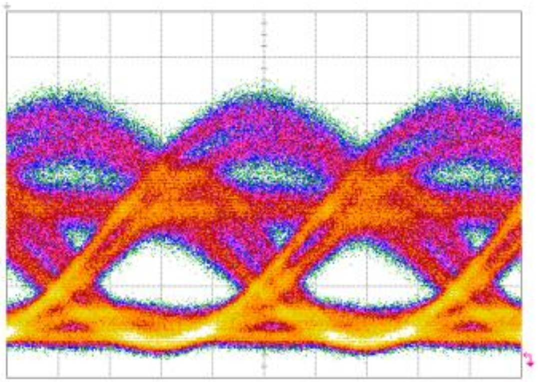


25.6Gb CML transmission experiment over 66km

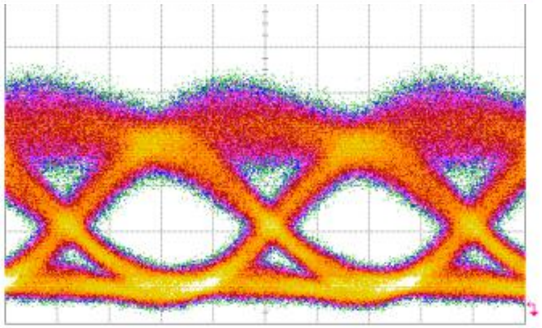


- The same DBR chip as 10Gb/s PON.
- BB can be improved if the filter locking position is optimized for 0-40km range.

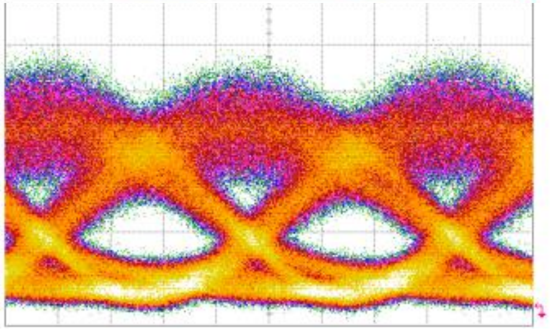
BB



56.2 km



66.2 km

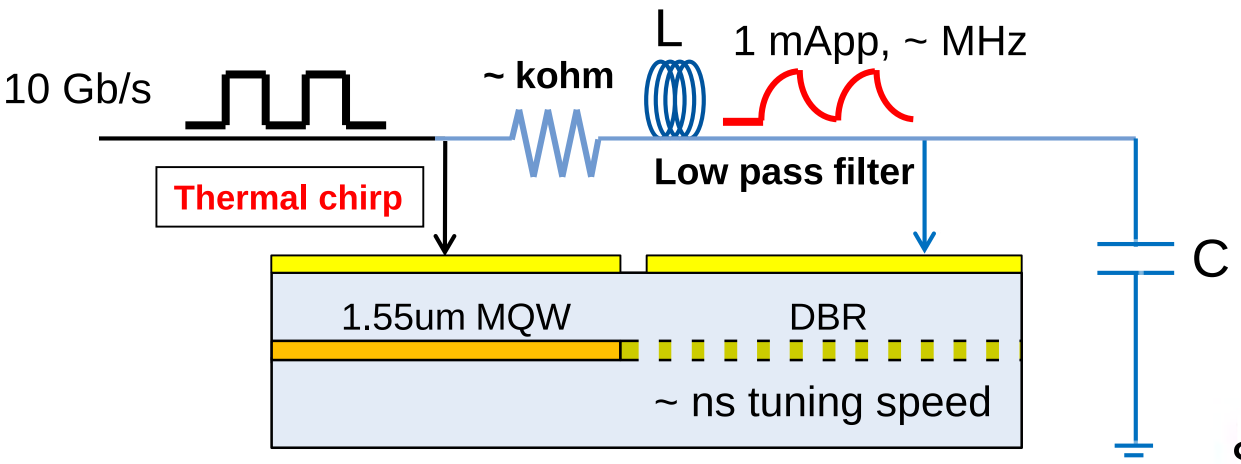


430km equivalent at 10Gb!

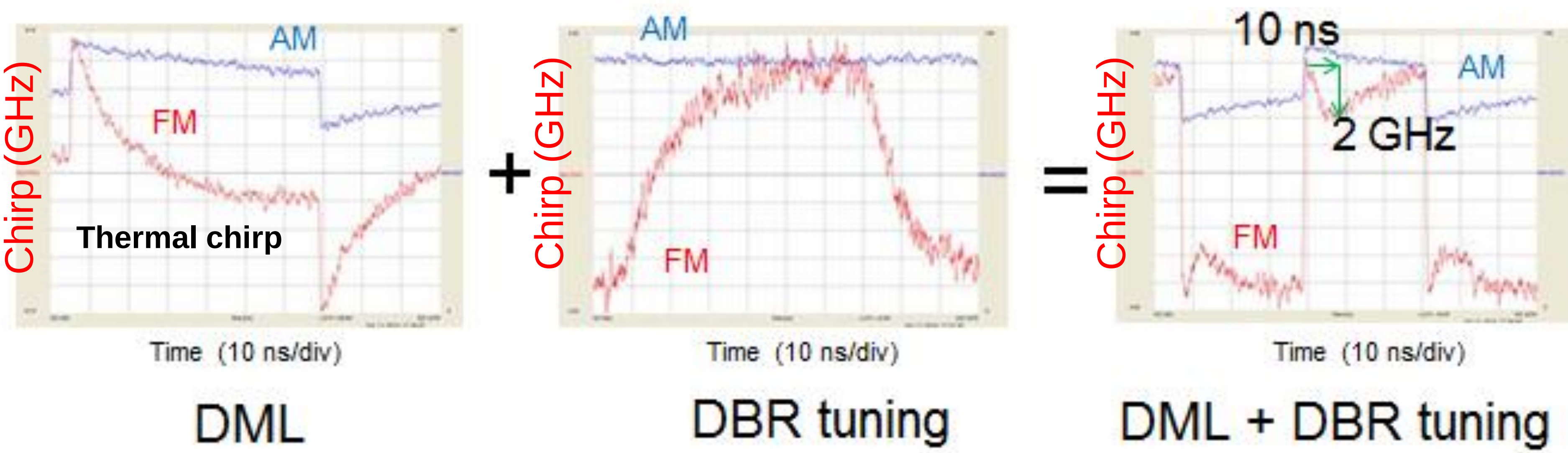
Thermal Chirp Compensation basics for DBR laser

Gain modulation

Thermal chirp compensation

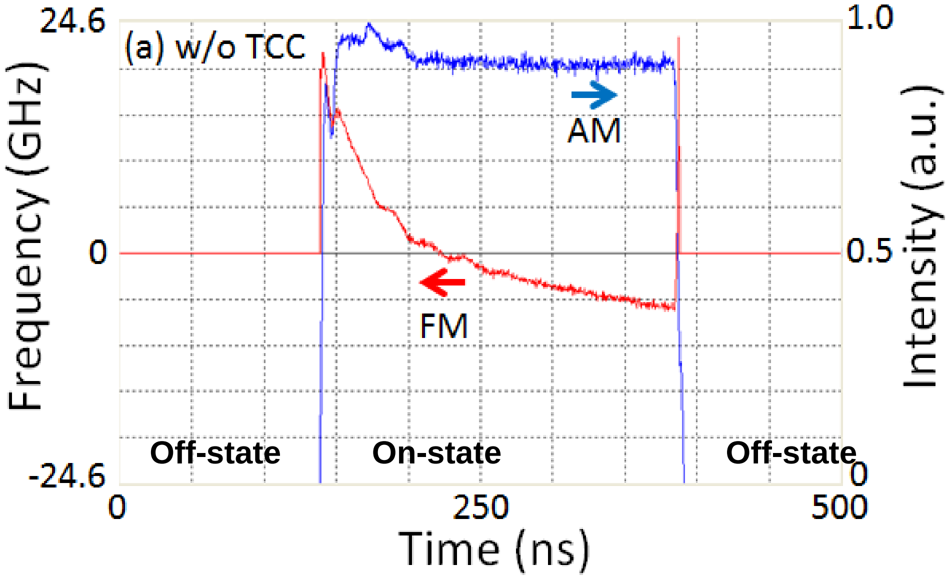


Stabilization within 10 ns

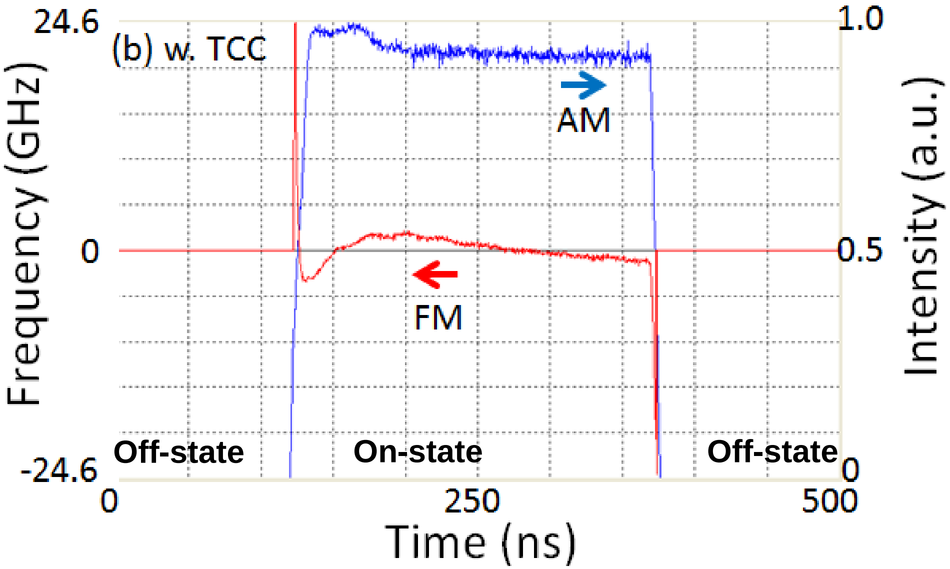


TCC over longer time range (~ 250 ns)

Without TCC



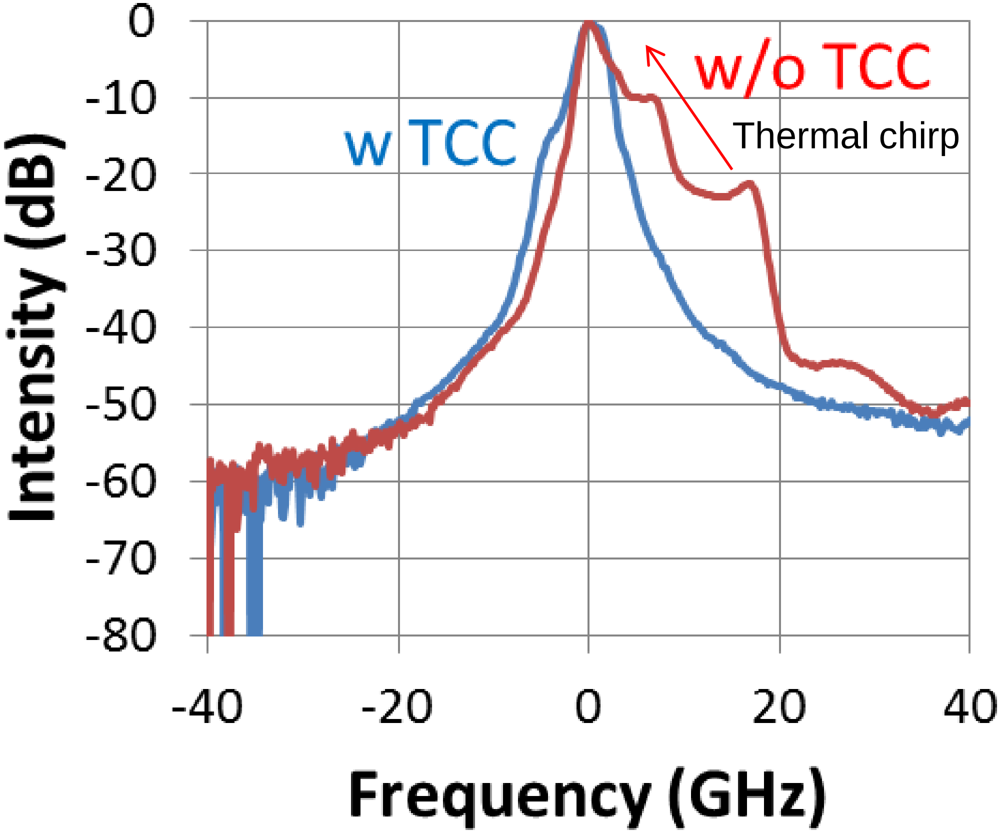
With TCC



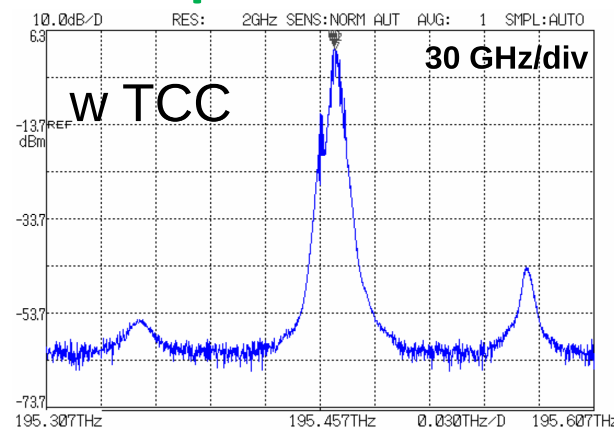
Thermal chirp spectrum-domain testing

- Time averaged optical spectrum narrows with TCC

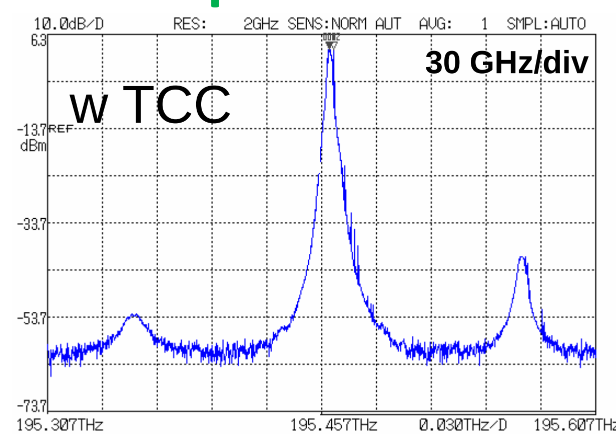
250 ns pulse



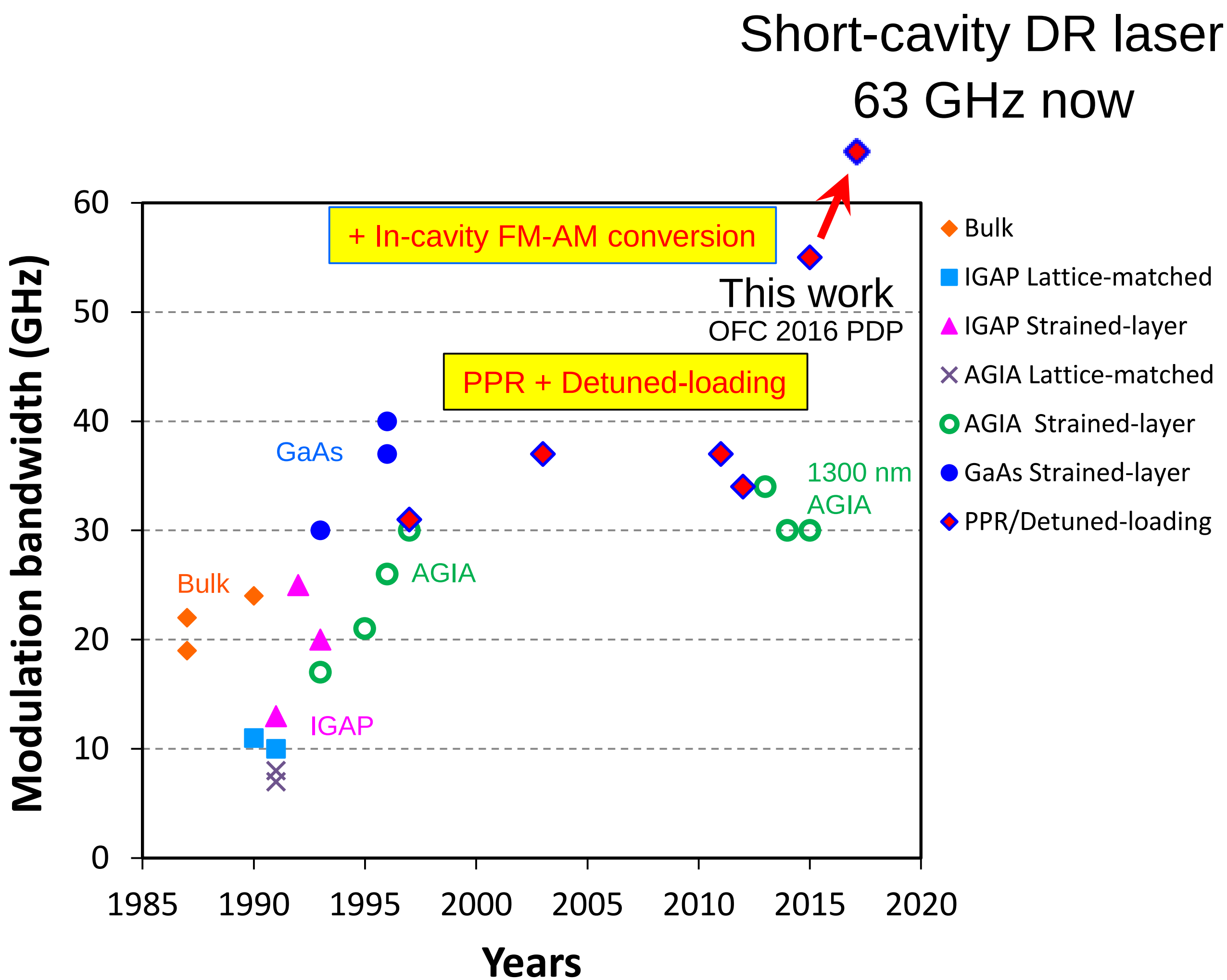
40us pulse



45ms pulse



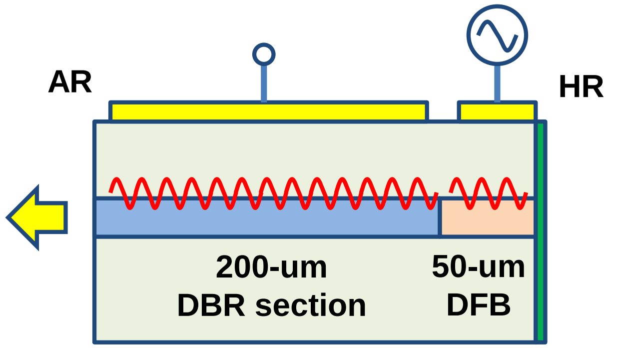
Evolution of modulation bandwidth

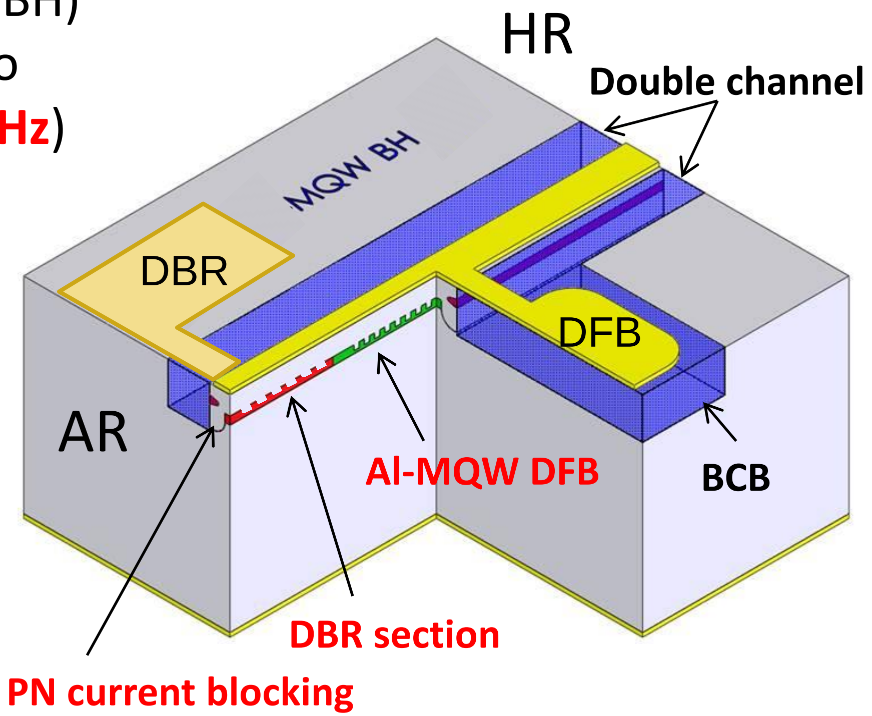


Book Chapter: "Datacenter Connectivity Technologies: Principles and Practice", Y. Matsui

1310-nm Al-BH short-cavity DR laser

- AlInGaAs-based strained-MQW structure
- 50 μm length DFB section
- DBR section 200 μm
- HR on back facet of DFB section
- **PN-blocking** buried-heterostructure (BH)
- Double channel and BCB under pad to reduce capacitance (**RC cutoff ~ 22 GHz**)



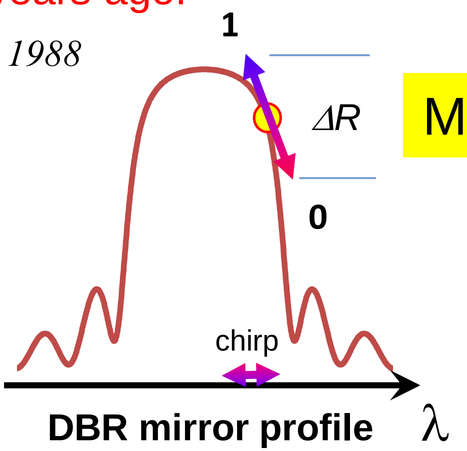


2016 OFC PDP, Y. Matsui et al.

Detuned-loading effect in DBR laser

K. Vahala and A. Yariv, APL, 45, 501, 1984
Klaus Petermann, "Laser Diode Modulation and Noise," 1988

34 years ago!

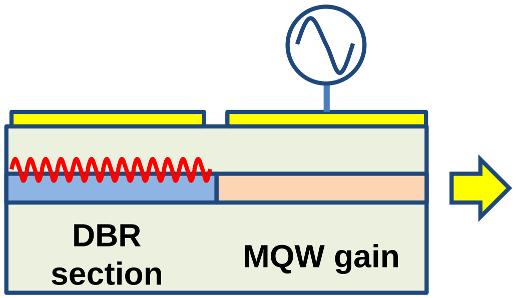


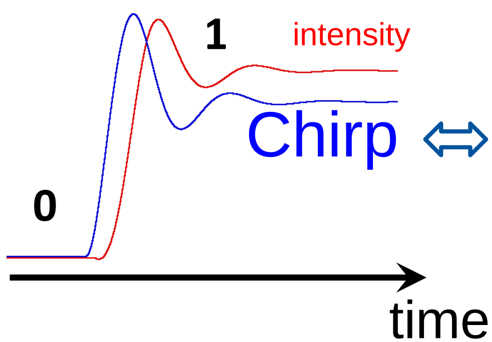
Mirror loss modulation

∝ Chirp

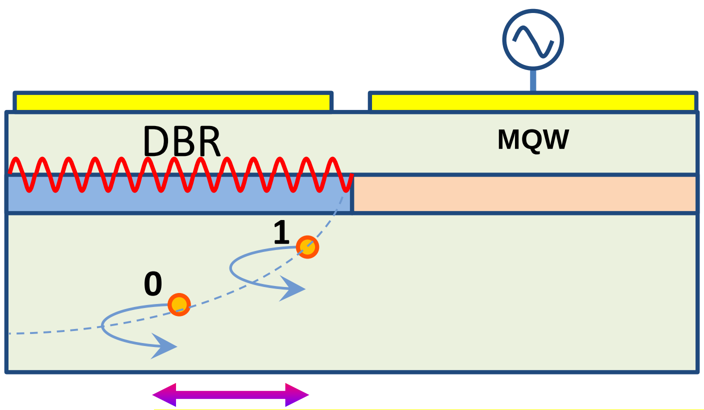
Effective differential gain increase

DBR laser
Modulation of gain section





Chirp ⇔ Carriers ⇕ Gain



Reduction of damping

Cavity length modulation

$$\Delta\nu(t) = \frac{\alpha}{4\pi}\left(\frac{1}{P}\frac{d}{dt}P + \frac{2\Gamma\varepsilon P}{\eta h\nu \cdot vol}\right)$$

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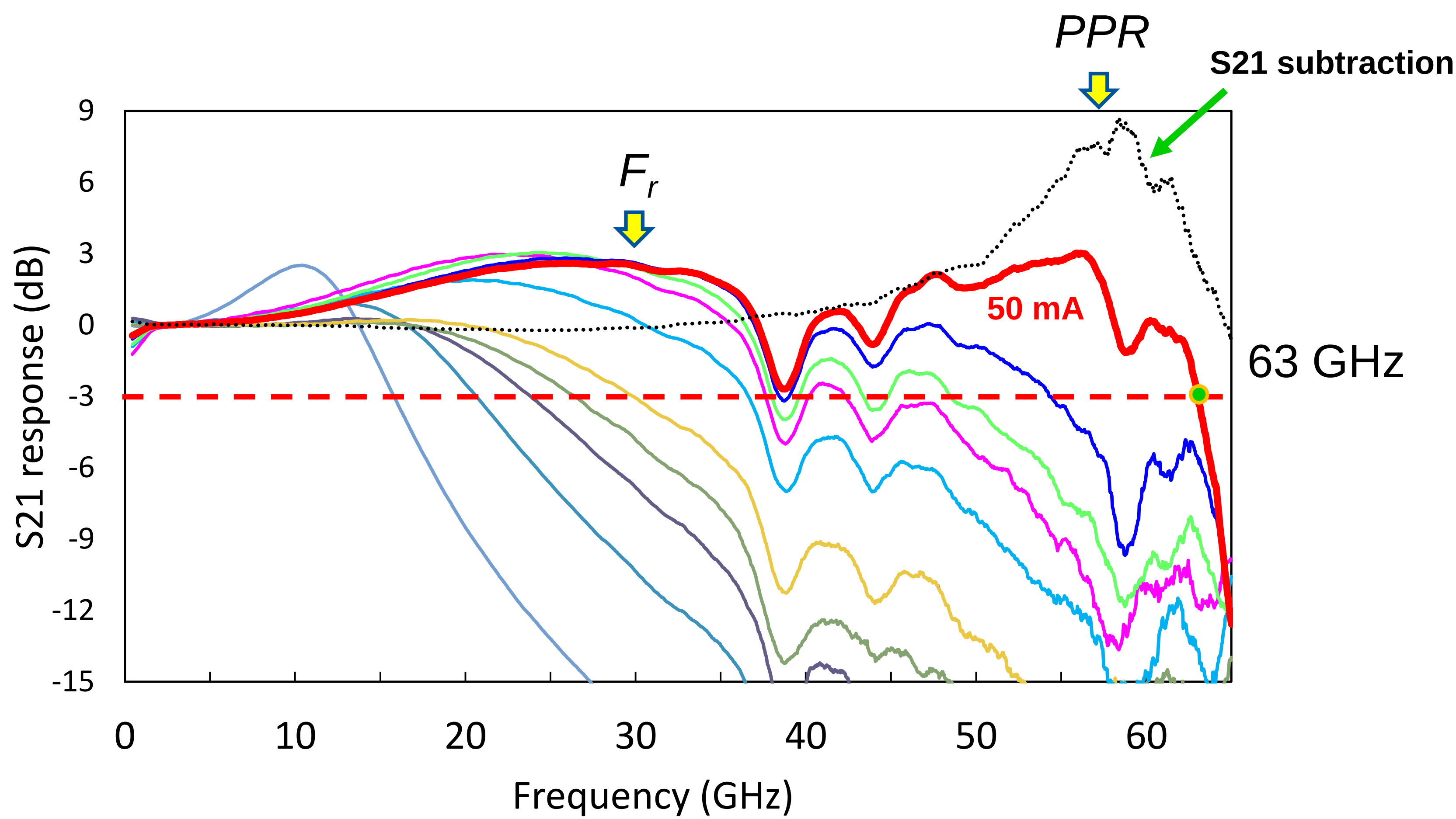
63 GHz BW DR laser

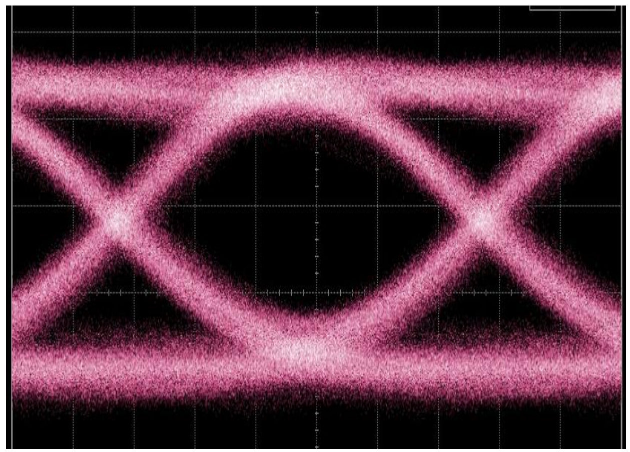


106.2 Gb/s PAM4 eye diagram

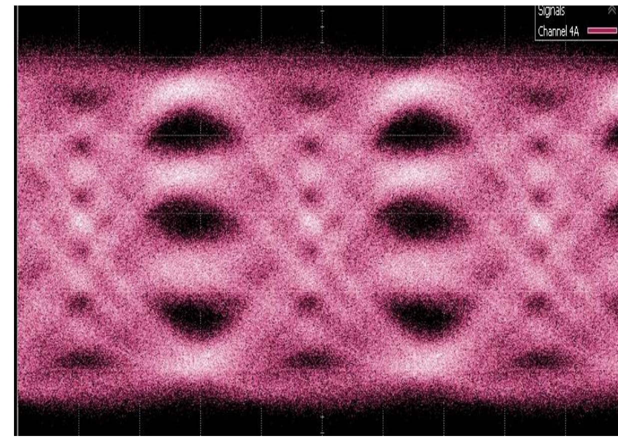
92 Gs/s AWG
SHF AMP
SHF Bias-T
DR
PIN ROSA
160 Gs/s DSO

Offline DSP
Up sampling
Low pass filtering
Down sampling
FFE/DFE
BER

53.1 Gb/s NRZ



106.2 Gb/s PAM4



DR laser BW is much faster than the BW of AWG.

Combined BW does not change as DML is modulated.

This suppresses non-linear behavior of DML.

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Conclusions

- DML chirp tailored for 20km transmission was described.
- 60km transmission at 25Gb/s using CML demonstrated
- Wavelength tunable over ~ 12 nm
- Fiber-coupled power can be ~ 10 dBm
- Fast tuning in DBR is used to suppress the thermal wavelength drift in bust mode.
- DML can be fast – 60 GHz BW demonstrated at 1310nm
- Lens-free and isolator-free DML under development