San Diego
Welcome to OFC
OSA
Welcome to OFC

OFC: 3-7 March 2019

- Technical Conference
  - ~550 Oral presentations
    - 10 parallel sessions
  - ~100 Poster presentations
  - Symposia & Workshops
  - Short Courses
- Industrial Exhibition
  - 683 Exhibitors spread over 17000 m^2
  - Industrial workshops
- 15400 attendees

A typical day's programme

Agenda of Sessions — Tuesday, 5 March

	Room 1	Room 2	Room 3	Room 6C	Room 6D	Room 6E	Room 6F	Room 7	Room 8	Room 9
07:30–08:00	**Plenary Morning Coffee,** *Upper Level, Ballroom 20 Lobby*							**Plenary Morning Coffee,** *Upper Level, Ballroom 20 Lobby*		
08:00- 10:00	**OFC Plenary Session,** *Ballroom 20BCD*							**OFC Plenary Session,** *Ballroom 20BCD*		
10:00–14:00	**Unopposed Exhibit-only Time,** *Exhibit Hall* (coffee service 10:00–10:30)							**Unopposed Exhibit-only Time,** *Exhibit Hall* (coffee service 10:00–10:30)		
10:00–17:00	**Exhibition and Show Floor,** *Exhibit Hall* (concessions available) **OFC Career Zone Live,** *Exhibit Hall C*							**Exhibition and Show Floor,** *Exhibit Hall* (concessions available) **OFC Career Zone Live,** *Exhibit Hall C*		
12:00–14:00	**OFC and Co-Sponsors Awards and Honors Luncheon,** *Upper Level, Ballroom 20A*							**OFC and Co-Sponsors Awards and Honors Luncheon,** *Upper Level, Ballroom 20A*		
14:00–16:00	**Tu2A • High Speed Silicon Photonics I**	**Tu2B • Optical Solutions for 5G**	**Tu2C • Panel: Optical and RF Photonic Signal Processing Based on Frequency Combs**	**Tu2D • Symposia: Photonics for IoT and Sensing: Manufacturing, Packaging and Application 1**	**Tu2E • AI in Network Operation 2**	**Tu2F • Short Reach II** (Ends at 15:45)	**Tu2G • Special Chairs' Session: The Role of Optics in Future Data Center and Computing Applications 1**	**Tu2H • Silicon Modulator**	**Tu2I • Photonic Integration for Data Centers** (Ends at 15:30)	**Tu2J • Filters and Couplers**
16:00–16:30	**Coffee Break,** *Upper Level, Exhibit Hall*							**Coffee Break,** *Upper Level, Exhibit Hall*		
16:30–18:30	**Tu3A • Laser Driving and VCSELS** (Ends at 18:15)	**Tu3B • PON Standards and Developments**	**Tu3C • Panel: Space Photonics: Disruptive Satellite Laser Communications and Astrophotonics**	**Tu3D • Symposia: Photonics for IoT and Sensing: Manufacturing, Packaging and Applications 2**	**Tu3E • Photonic Integrated Circuits and Novel Technology**	**Tu3F • Wideband Transmission**	**Tu3G • Special Chairs' Session: The Role of Optics in Future Data Center and Computing Applications 2**	**Tu3H • Control of Disaggregated Networks**	**Tu3I • Microwave Photonic Chip-scale Subsystems**	**Tu3J • Transmission Fibers and Cables** (Ends at 18:00)
17:00–18:30	**Exhibitor Happy Hour,** *Center Terrace*							**Exhibitor Happy Hour,** *Center Terrace*		
18:30–20:00	**Conference Reception,** *Ballroom 20BCD*							**Conference Reception,** *Ballroom 20BCD*		
19:30–21:30	**Rump Session,** *Room 6D*							**Rump Session,** *Room 6D*		

Exhibit Hall B, Expo Theater I	Exhibit Hall E, Expo Theater II	Exhibit Hall G, Expo Theater III
Exhibit Hall Opens 10:00		
■ **MW Panel I: State of the Industry–Analyst Panel** 10:30–12:30 ■ **MW Panel II: Market Projections for Wireline and Wireless Technologies to Support 5G** 12:30–14:00 ■ **MW Panel III: High Capacity Long Distance Optical Transport: Challenges and Business Reality** 14:30–16:00	**Interoperability – The Foundation of Ethernet Success** *Ethernet Alliance* 10:15–11:15 ■ **Data Center Summit: The importance of "Open Transport" DCI Innovations in the Evolution of Metro and Long-Haul Optical Networks** 11:45–13:45 **Coherent Equivalence Beyond 400G – Milestones And Industry Guidance For Aligning Technology Roadmaps** *Session sponsored by Juniper* 14:00–17:00	**Product Showcase: Optical Intelligence** *Huawei Technologies Canada Co., Ltd.* 10:15–10:45 **Simplifying Transport Network Operations with Declarative, Vendor-neutral Configuration Management** *OpenConfig* 11:00–12:30 **Smart Cities Connecting Future Communities** *IEEE Smart Cities Technical Communites* 12:45–14:15 **The Disaggregated Transport Network** *TIP* 14:30–15:30 **Innovation Opportunities in Transport Networks from Network Analytics and Machine-Learning** *IEEE Future Directions* 15:45–17:00
Exhibit Hall Closes 17:00		

- Each session contains a mix of
  - Tutorial papers (1 hr)
  - Invited papers (30 mins)
  - Regular papers (15 mins)

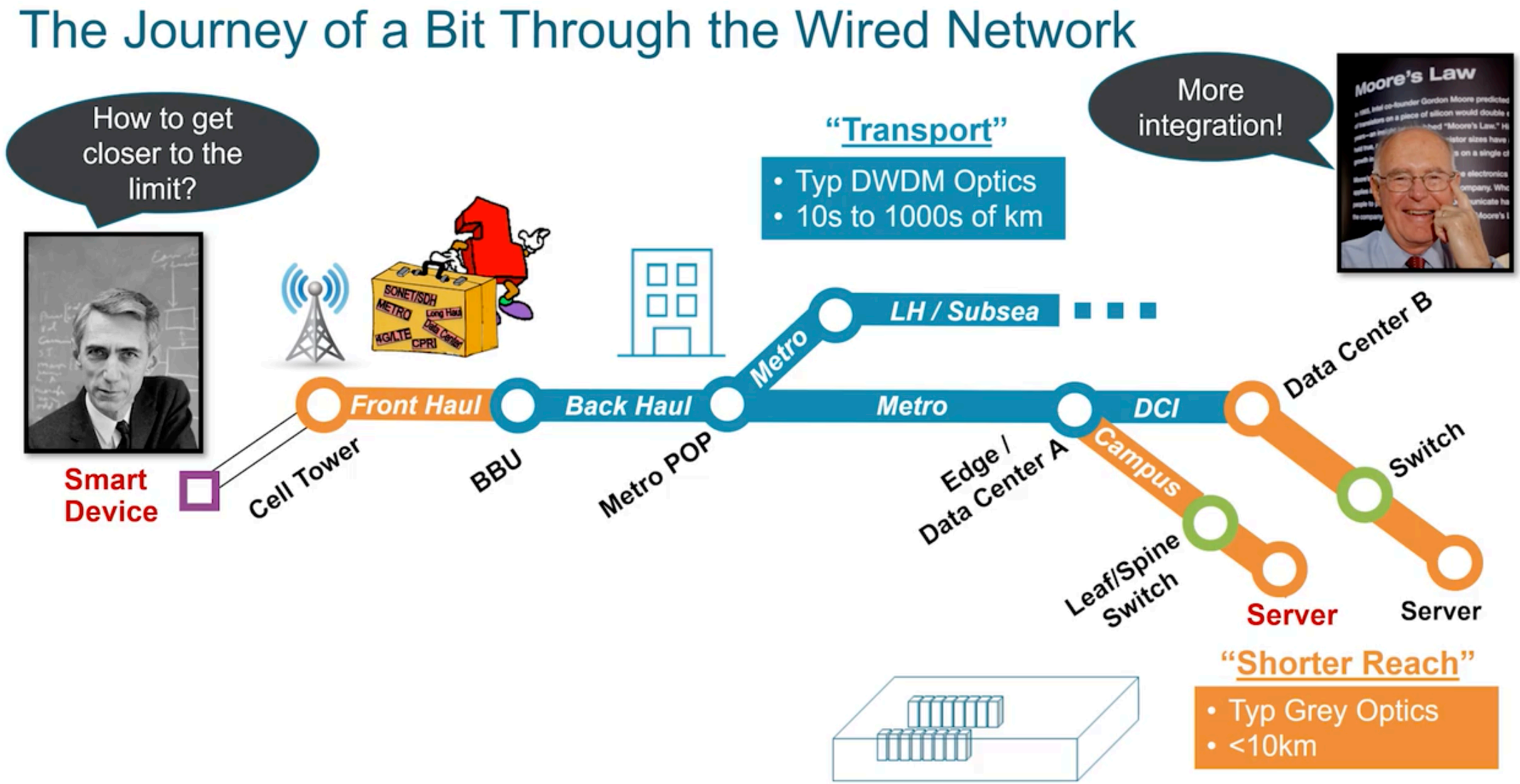
Disclaimer

- We did not manage to attend all the sessions 🙃
- What follows are a collection of personal impressions
  - Thanks to Lauri for providing his input
  - Rather hardware-centric, although many papers on network management and operation

Why attend?

- The one place to go to find out
  - Trends in data-rate, modulation formats, form factors
  - Where is the market being driven and by what/who?
- Understand how to continue to profit from the advances being made by industry in order to build more capable readout systems for CERN (and HEP) applications

Optical Communication Networks

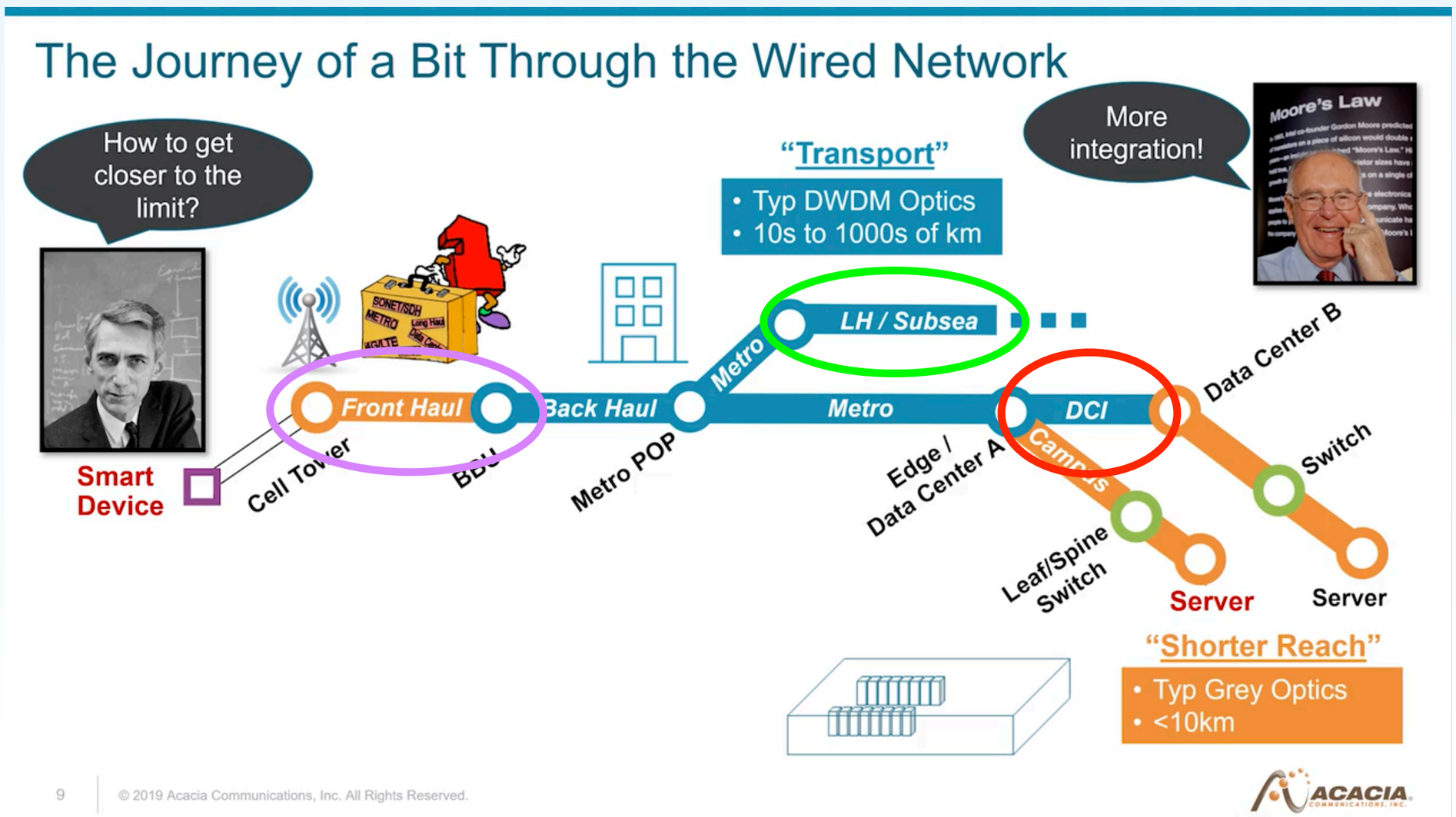


Material shown at OFC2019 by: Benny P. Mikkelsen, Founder and CTO, Acacia Communications, USA

Areas of Innovation

Several key areas presented as drivers of future innovation:

- Data Center Interconnects (DCI)
- Coherent Systems
- Optical Technologies for 5G access networks

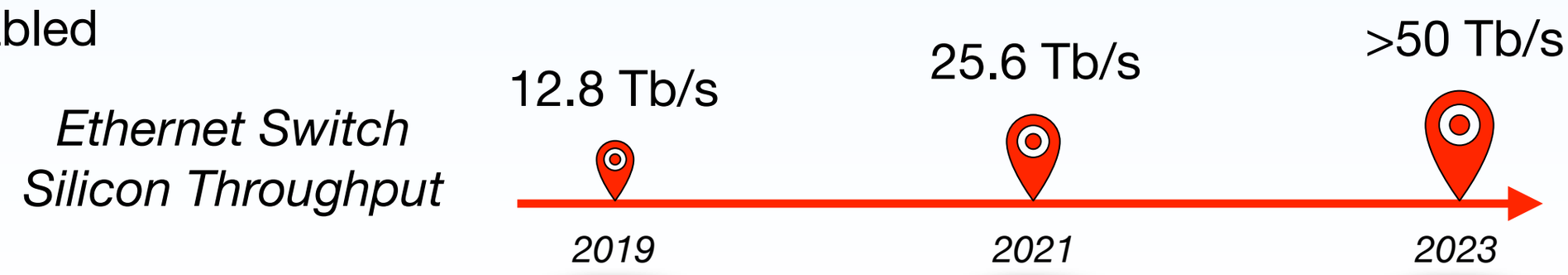


Data rates

- The big talk was about 400 Gb/s in terms of components and systems becoming available
  - The technology is starting to be rolled out, with take-up having been a bit slower than expected due to high cost vs 100 G
- New announcements:
  - 400 Gb/s ZR – 400 Gb/s for 100km DCI, QSFP/OSFP, OIF std
  - 400 Gb/s FR4 – 2km single fiber 4x100 Gb/s CWDM transmission
  - 400 Gb/s DR4 – 500m 4x parallel fiber 4x100 Gb/s transmission
  - 100 Gb/s DR1 – 500m single fiber 1x100 Gb/s transmission; four modules can connect with DR4 to provide breakout of individual 100 Gb/s signals.

100 Gb/s and above is achieved using PAM-4 signalling

- DSP-enabled



Data Rates (2)

- Demos of interest shown at the Exhibition
  - Xilinx 56G NRZ with a SiPh TRx chipset
    - Not yet integrated into an FPGA, but they are looking at it…
  - Xilinx 112G PAM-4
    - Committed to putting this into the next Generation 7 nm FPGAs (after UltraScale+)

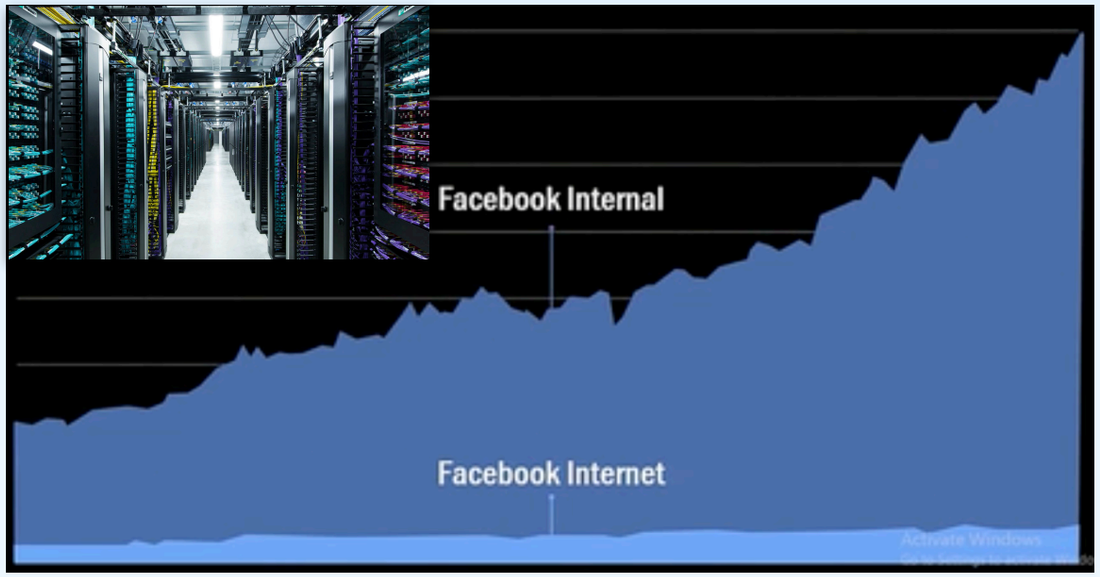
Reminder: lpGBT 10G, LHC Phase 2 Trigger links 28G

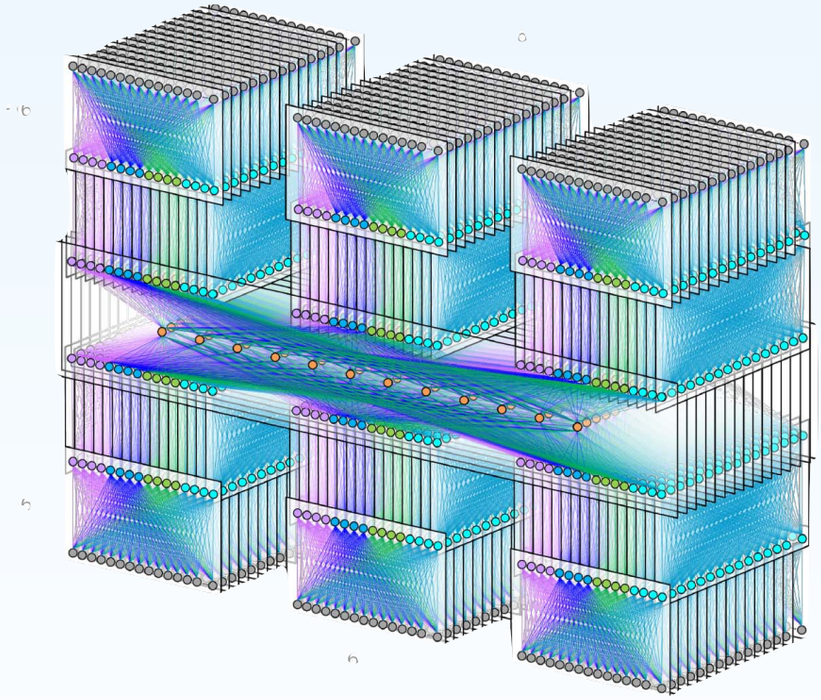
Areas of Innovation

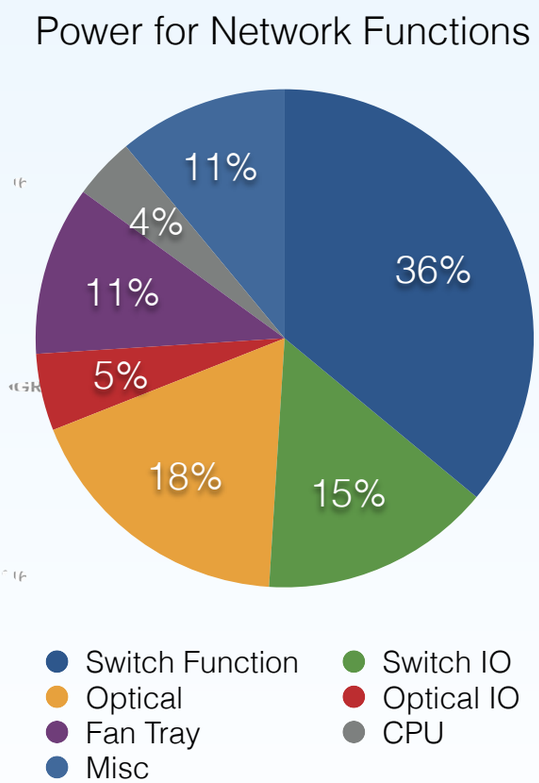
- Several key areas presented as drivers of future innovation:
  - **Data Center Interconnects (DCI)**
  - Coherent Systems
  - Optical Technologies for 5G access networks

Why is DCI† important?

- Facebook Case shown (similar for GAA)
- 4x 100G Single-mode fibre per rack today
  - Not enough bandwidth
- Drivers for future DCI products:
  - Optimize power
  - Increase Supply Volume
  - Decrease Cost

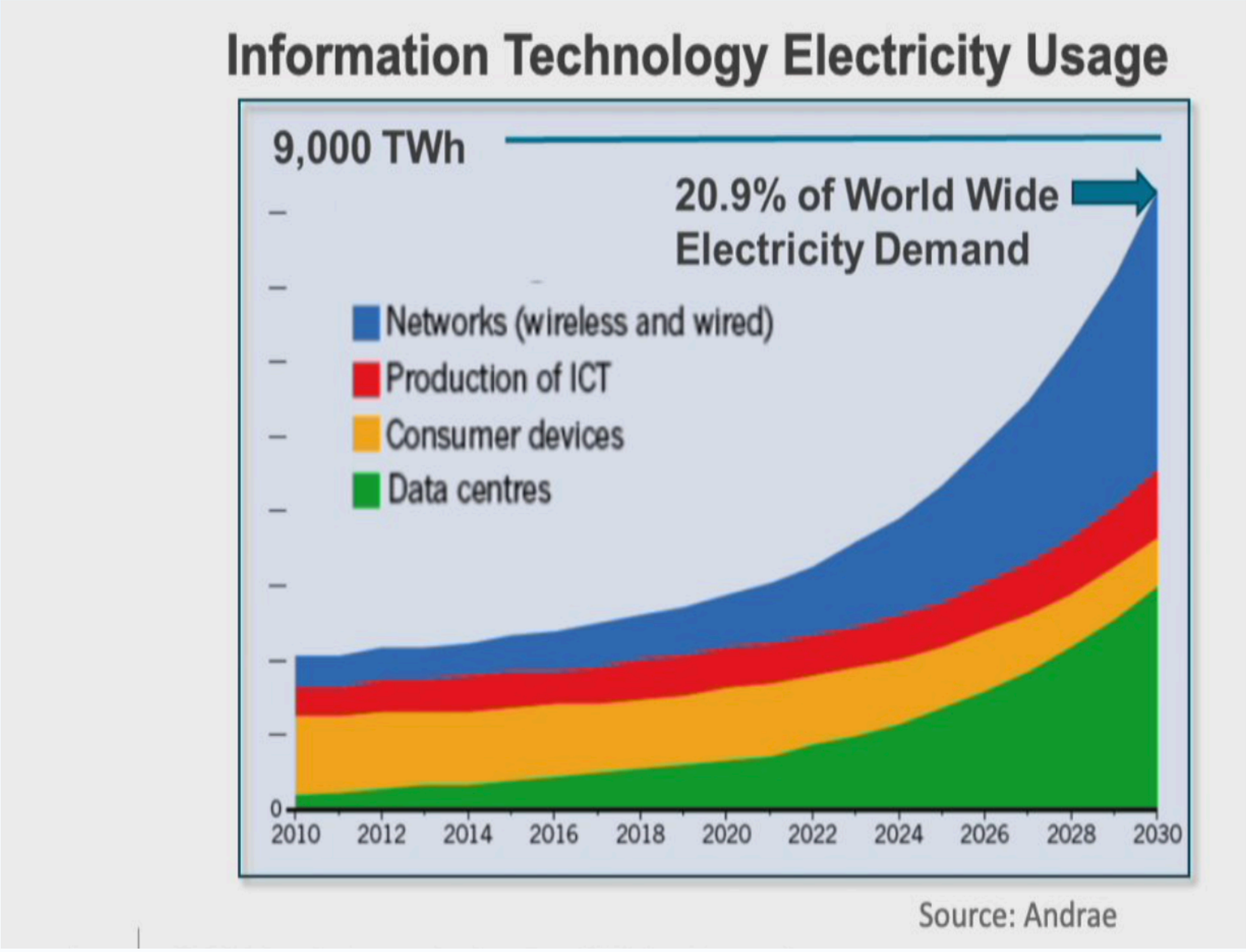






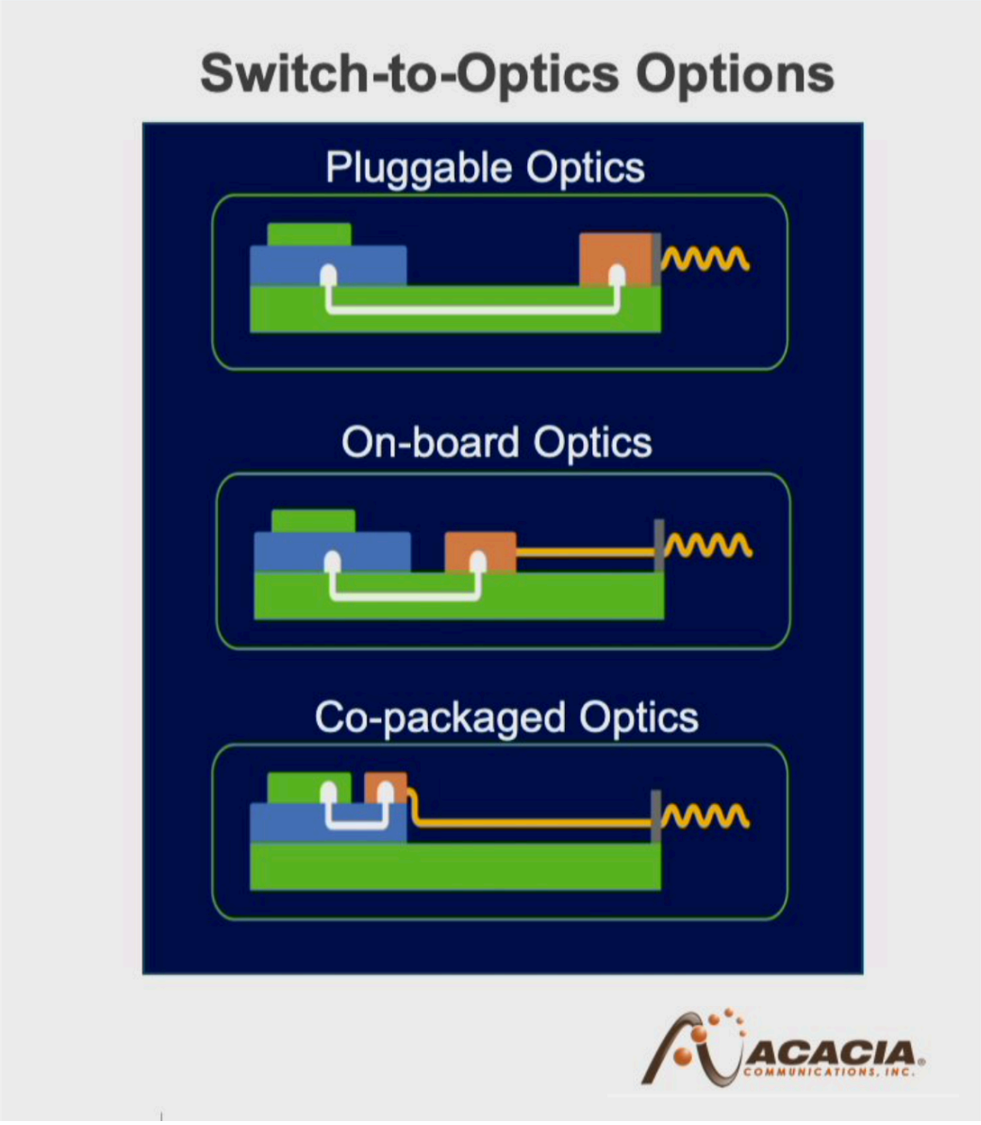
Material shown at OFC2019 by: Najam Ahmad, Vice-President, Network Engineering, Facebook, USA

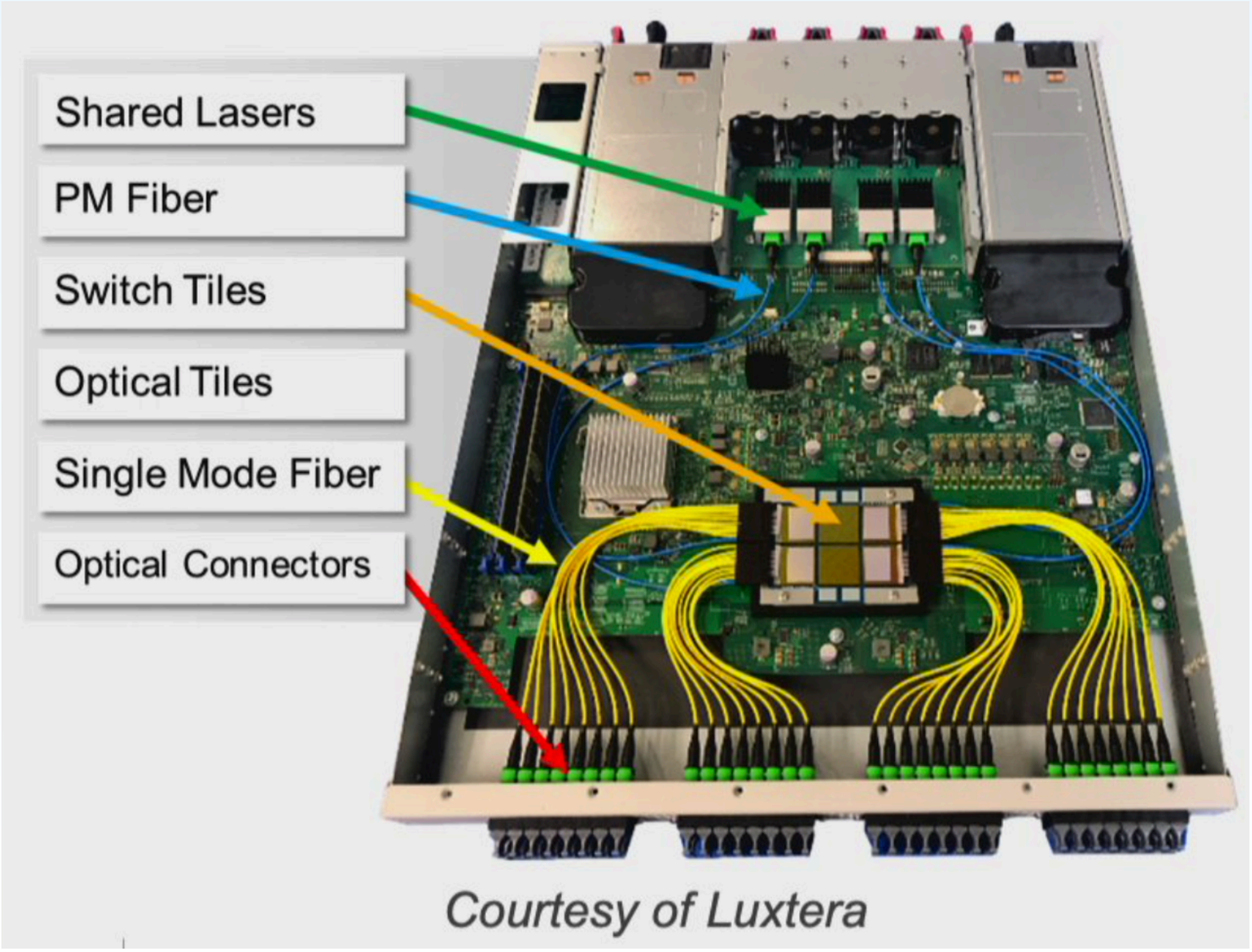
†DCI = Data Center Interconnect


Information Technology Electricity Usage
9,000 TWh
20.9% of World Wide Electricity Demand
Networks (wireless and wired)
Production of ICT
Consumer devices
Data centres
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Source: Andrae

Form factors

- Many seriously talking about package-level integration of Optics and Electronics
  - e.g. Plenary
  - Move to “Chiplets” enabling discrete functions at package level

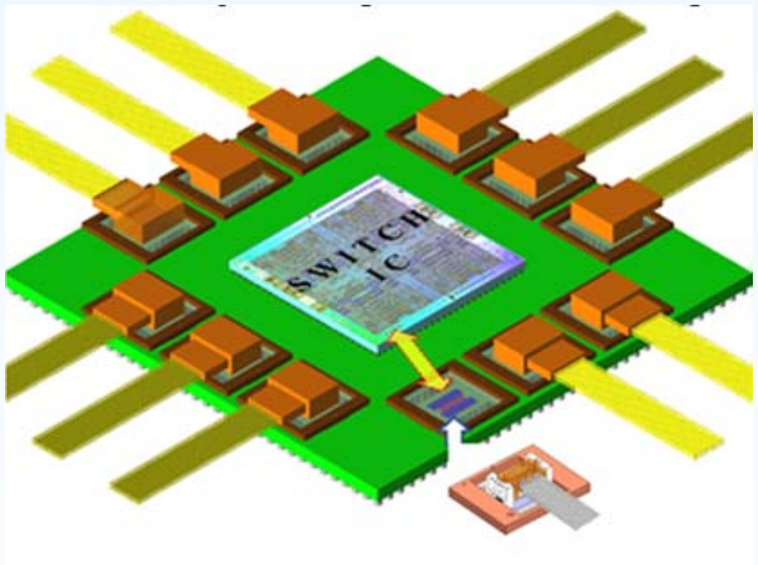




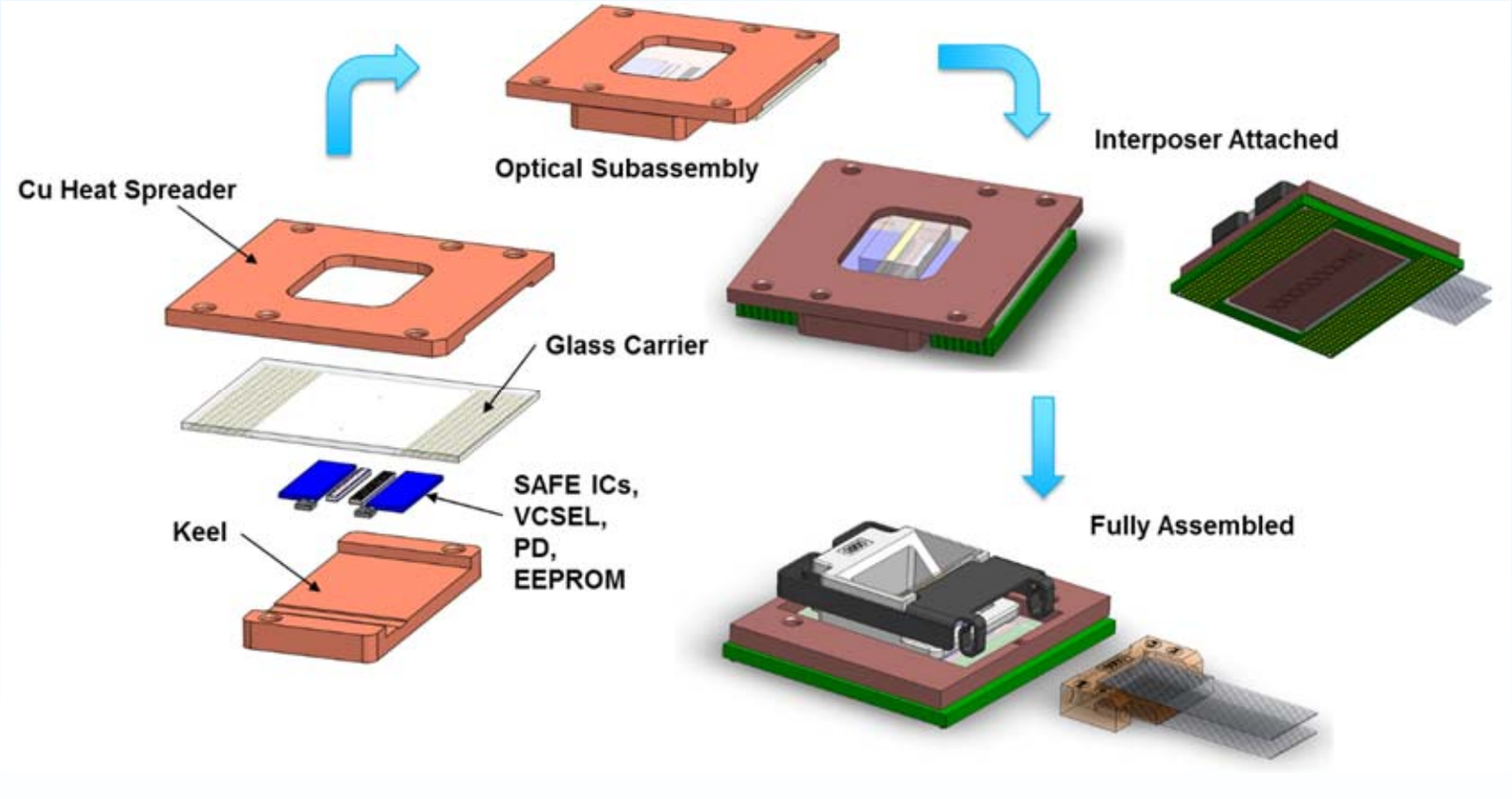
Form factors (2)

- Workshop - Which One Will Succeed in Data Center Applications, Multi-chip or Monolithic Integrated Optoelectronic Chip?
  - Multi-chip, with Remote Optical Power supply
  - Technology exists, Market still figuring out how to organise making money…

e.g. IBM & Finisar, for HPC



Parameter	Value
Data Rate	56 Gb/s NRZ
# channels, full duplex	16
Temperature	0 to70ºC
Electrical Interface	XSR (6dB budget)
Optical Margin	2 dB, supporting 30m OM4
Energy	< 4 pJ/bit
Dimensions	13 x 13 x 4 mm
BER	< 1E-12, No FEC

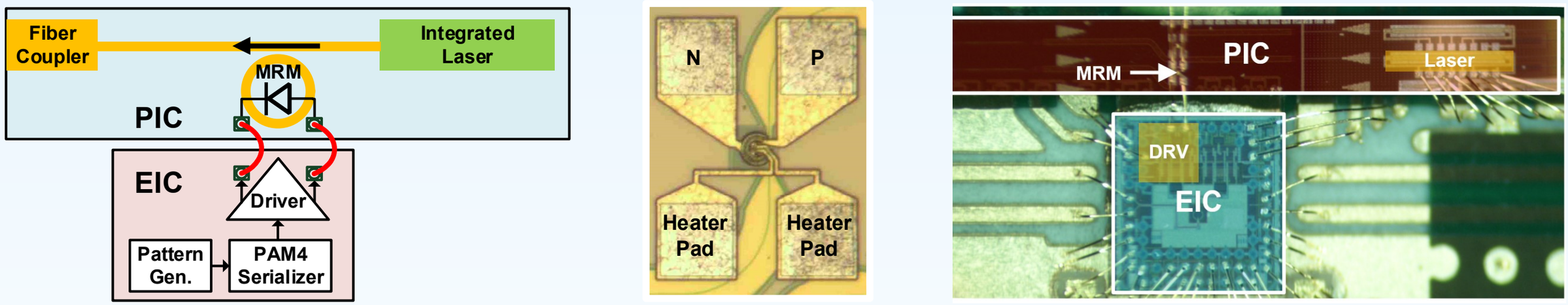


Reliability

- Data Center operators want cheaper components, higher product volumes
  - Also faster development/time-to-market cycles
- If DCI spec is for only 3-5 yr lifetime, does the product get cheaper?
  - e.g. Facebook for 100G SM QSFPs measure
    - ~2000 FIT for DML (DFB), many fail as soon as powered-up in application
    - “a few” FIT for EML (inc. SiPh)
- The component/module vendors all basically say
  - Should not cut Qualification time
  - It does not drive final module cost, although it does take time
  - “Reliability is never a problem until word of it reaches upper management”

Late news Silicon Photonics

- "A 112 Gb/s PAM4 Transmitter with Silicon Photonics Microring Modulator and CMOS Driver"
  - H. Li et al., Intel Santa Clara
  - Targeting 400 Gb/s architectures with 56 Gbaud PAM4



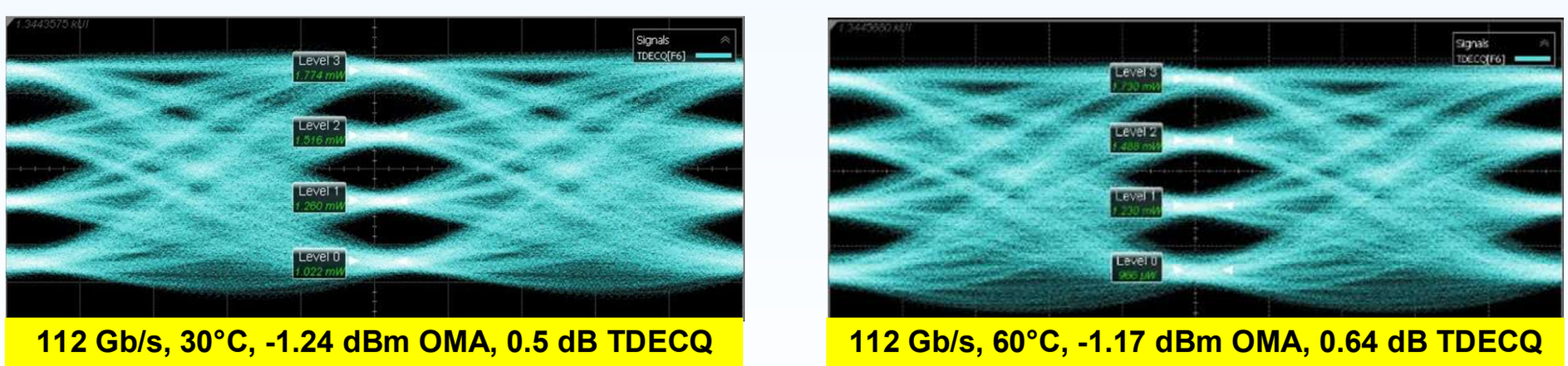
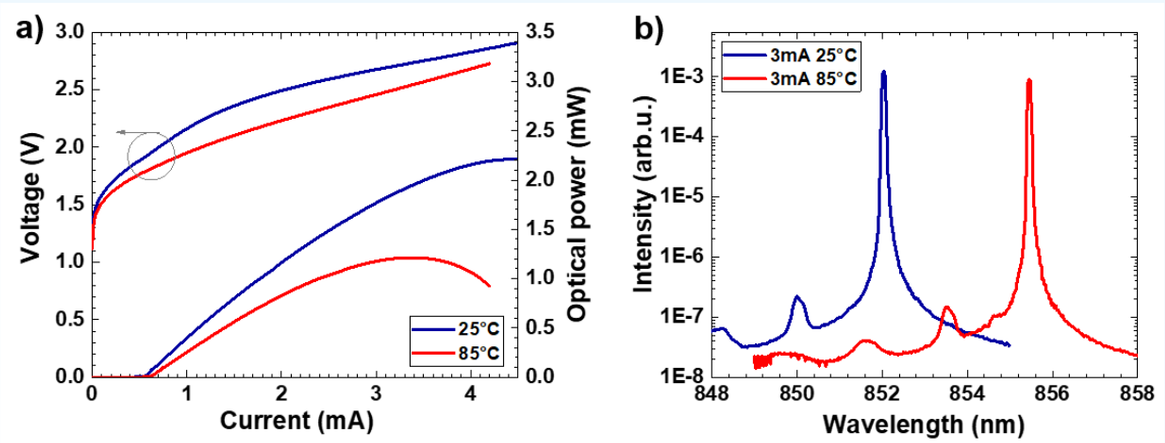
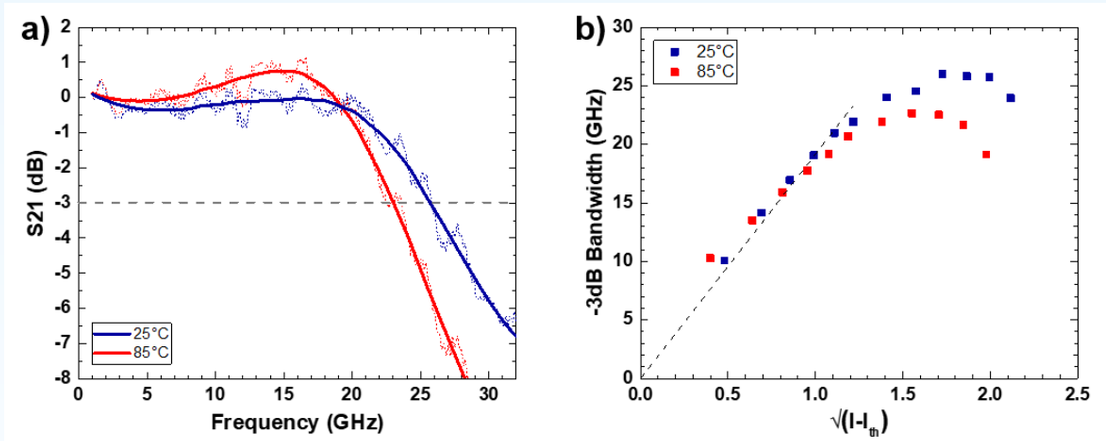


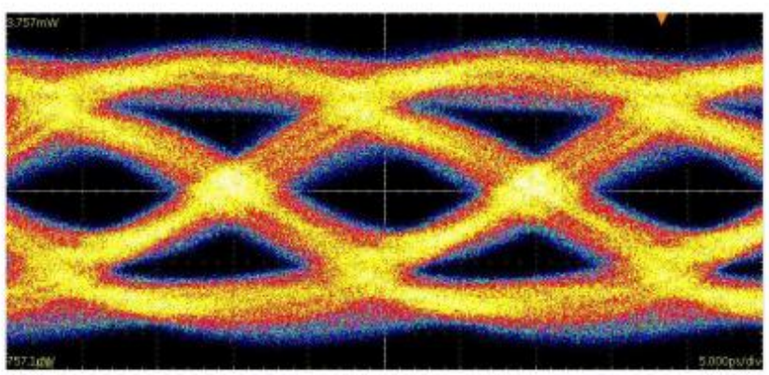
Fig. 6. Measured 112 Gb/s PAM4 optical eye diagrams at 30°C and 60°C with nonlinear FFE enabled.

Late News High Speed VCSELs

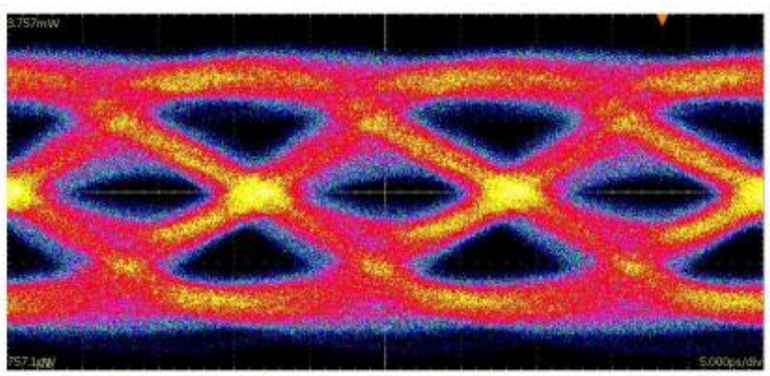
- "850 nm single-mode VCSEL for error-free 60 Gbit/s OOK operation and transmission through 800 m of multi-mode fiber"
  - N. Ledentsov Jr. et al. (VI Systems, Warsaw Uni)
- Achieved Error-free operation (BER < 10^{-12})



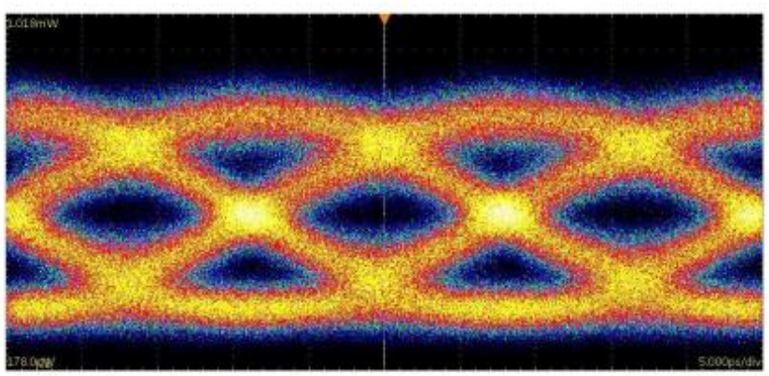




a) 50 Gbit/s back-to-back



b) 60 Gbit/s back-to-back



c) 60 Gbit/s 800m MMF

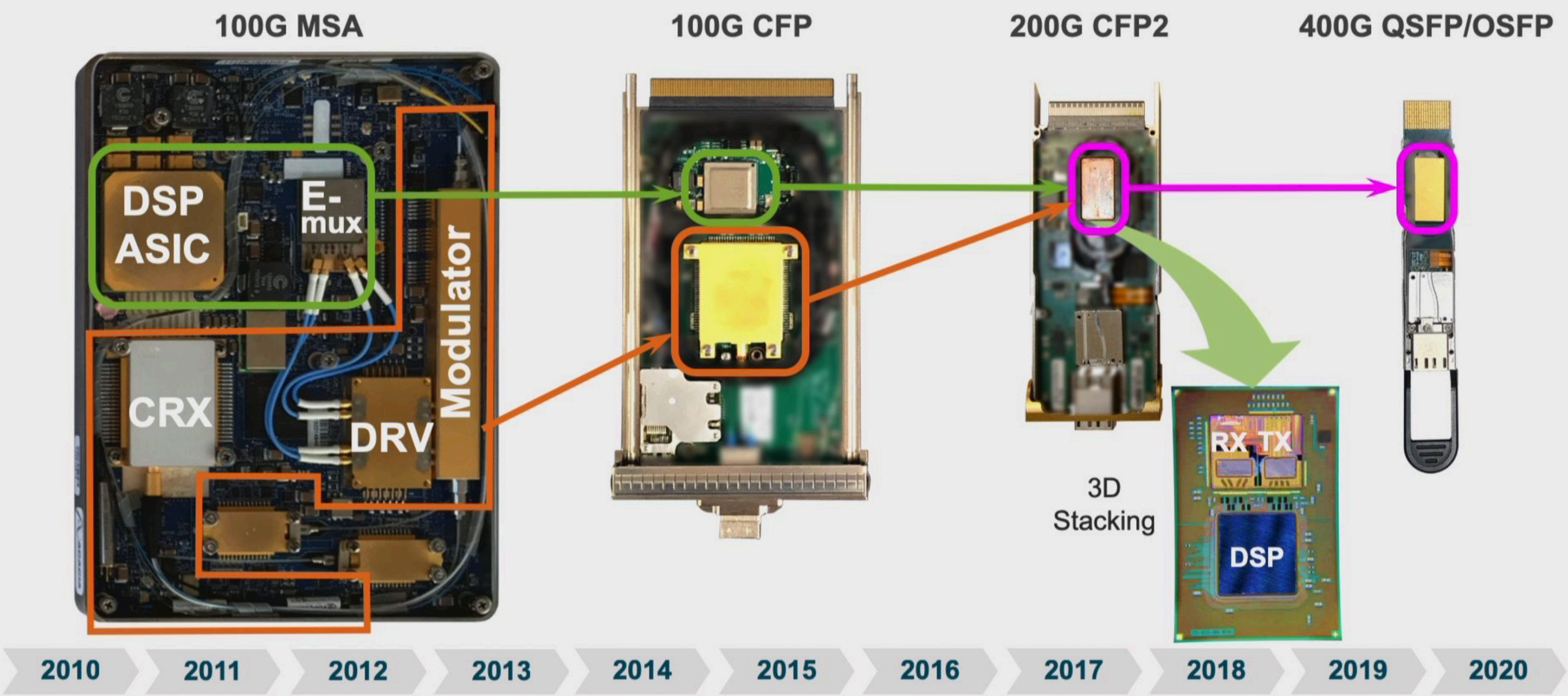
Areas of Innovation

- Several key areas presented as drivers of future innovation:
  - Data Center Interconnects (DCI)
  - **Coherent Systems**
  - Optical Technologies for 5G access networks

Long-haul transmission systems

- This covers national, trans-continental and inter-continental data transmission systems
  - The key is to pack as much data into as small a number of optical fibres as possible
  - Signals are regenerated en-route via optically-pumped fibre amplifiers
- All modern high-capacity systems use coherent detection and higher-order modulation systems to achieve their goal of transmitting hundreds of Gb/s per wavelength

Integration Achievements in Transport



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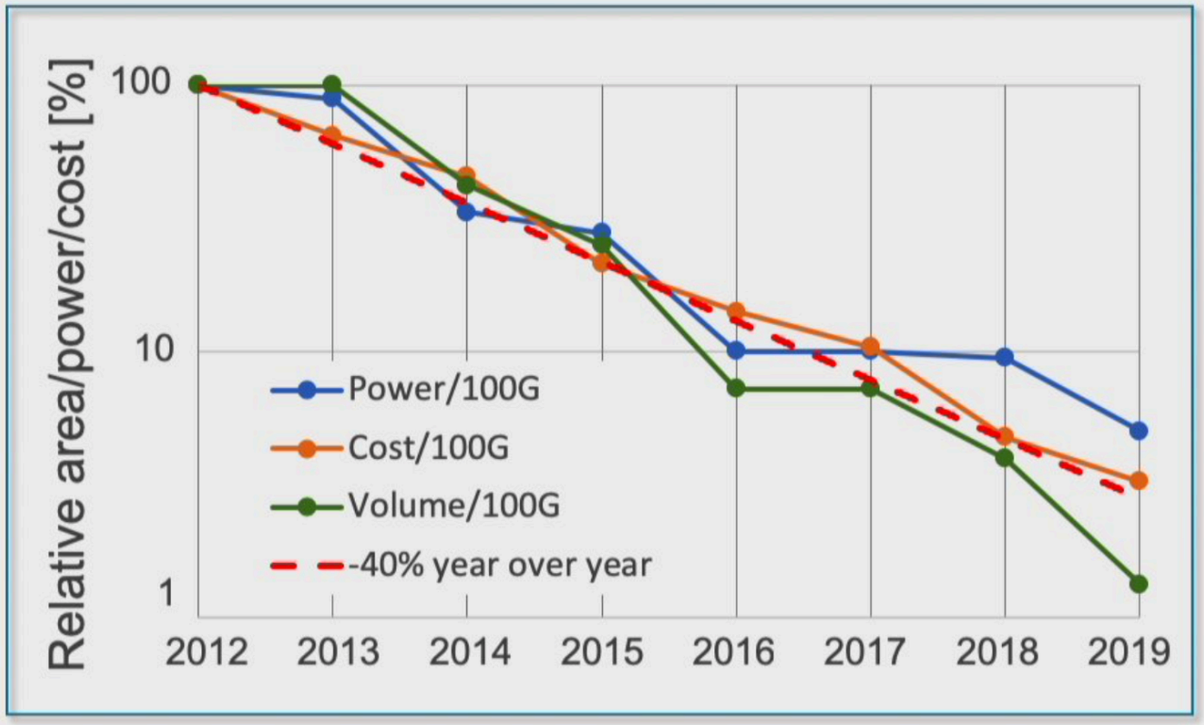
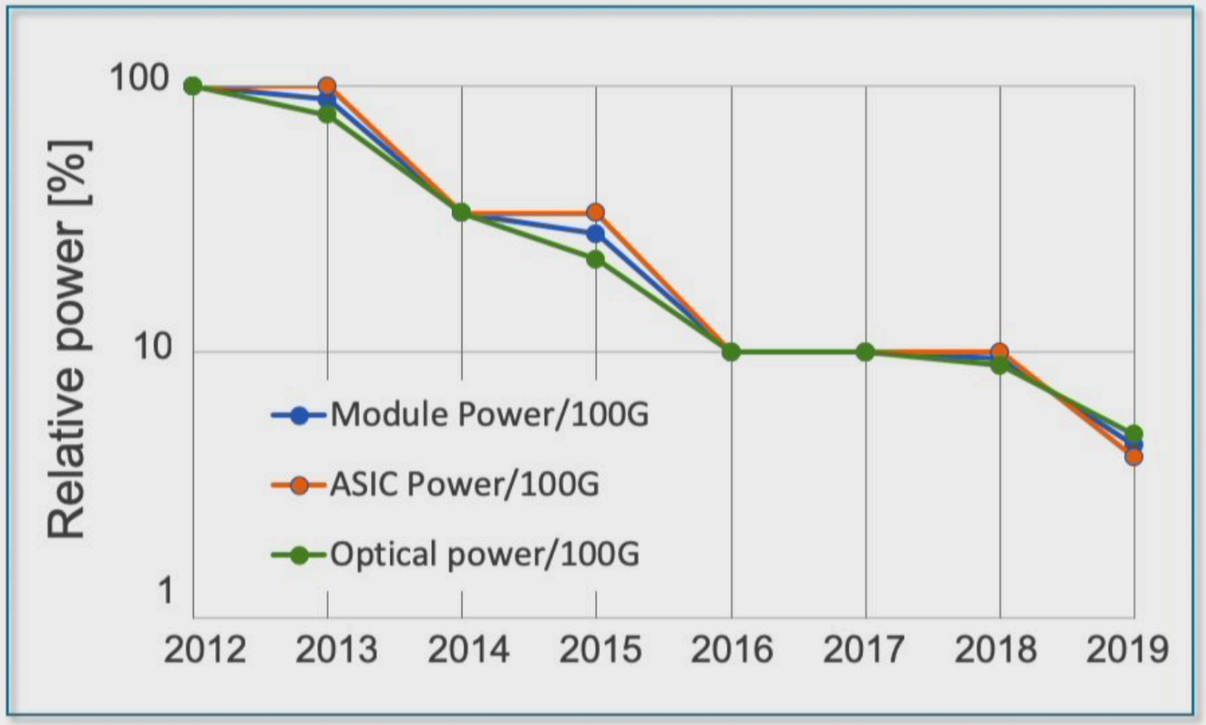
Trends in Coherent Transceivers





- 30-40% year over year reduction in size, power and cost – beating Moore's law
  - Power / 100G likely less than 1W in 3-4 years
- Optics keeping up with ASICs despite no Optical Moore's law
  - More efficient optics, Co-optimization of Driver and Modulators, GaAs to SiGe, Discrete circuitry into ASICs

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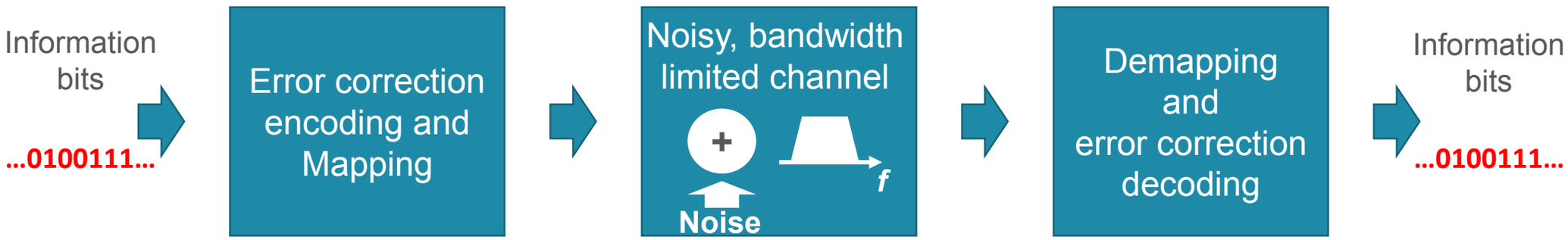
Reaching the Shannon limit

Shannon capacity theorem



$$\text{Maximum error-free information rate} = \text{Channel bandwidth} \times \log_2\left(1 + \frac{\text{Signal power}}{\text{Noise power}}\right)$$

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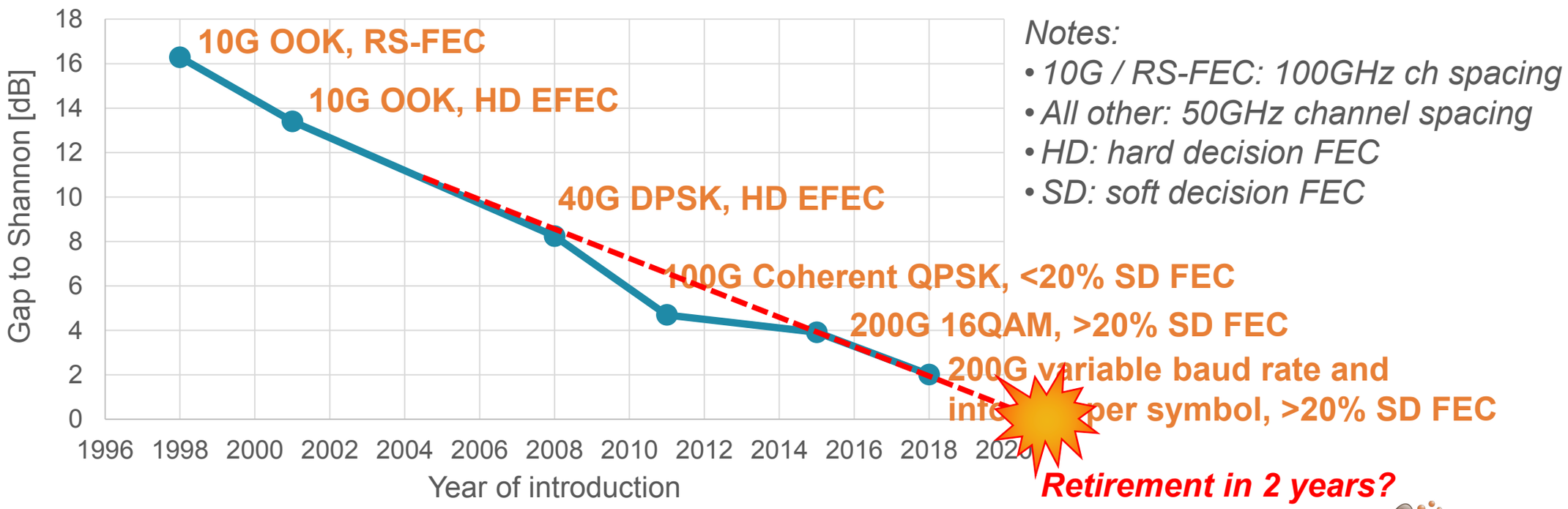
Reaching the Shannon limit (2)

Gap to Shannon for various generations of transport equipment

- Gap to Shannon due to bandwidth under-utilization, modulation, and FEC type
  - ***Not*** including implementation penalties (fixed point DSP, ADC/DAC, RF, Optics) yet!
- Gap to Shannon reduced from 16dB to 2dB in 20 years



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What is a ‘Rump Session’?

- Short introductory presentation by session organizer
- One slide presentations from diverse group of industry provocateurs
- Vigorous audience participation after each presentation, with organizer facilitating wide ranging discussion
- Attendees come prepared with tough questions and insightful comments, and challenge the presenters

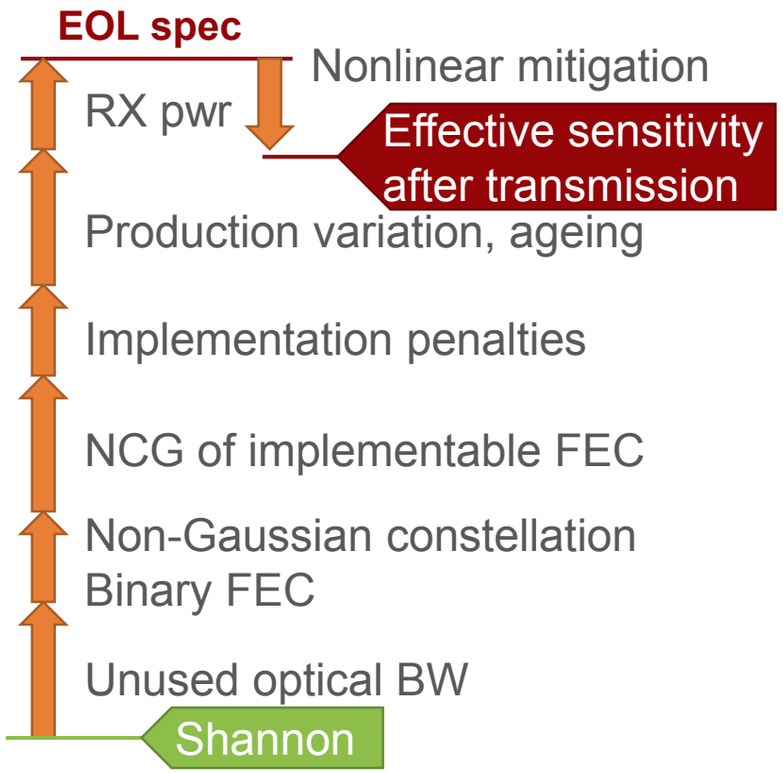
OFC Rump session 2019

- Are We Done With Digital Processing Innovation And Is Integration All That's Left To Do?
  - Are the long haul guys done increasing channel utilisation?
  - Within touching distance of the Shannon limit
    - Coherent transmission systems, enabled by DSP, reaching close enough to the Shannon limit to ask whether its worth continuing
    - Is increasing fibre/core count the only way forwards?
    - Wasn't all the real work done for ADSL in the 80's?
  - It was, as often, a fun session in which the industry big hitters get to take cheap shots at each other while the rest of us learn something about the technology (and industry sociology…)

One response…

All hands on deck to further close the gap to Shannon

- Should be pragmatic and look at the whole stack
- Identify where we get most improvement per watt or $
- Globally optimize in the areas of
  - DSP / modem design
  - Nonlinear mitigation
  - FEC design
  - Digital ASIC design
  - Mixed signal ASIC design (ADC/DAC)
  - Optics BW and imperfections
  - RF electronics BW, thermal noise, linearity, power
  - Control loops
  - Production variation
  - *…while pushing up capacity per wavelength*



- Potential improvements vs 200G 16QAM: 2-5x reach, 35-85% capacity, 25-50% cost/bit
- *All hands on deck in the DSP & optics community!*

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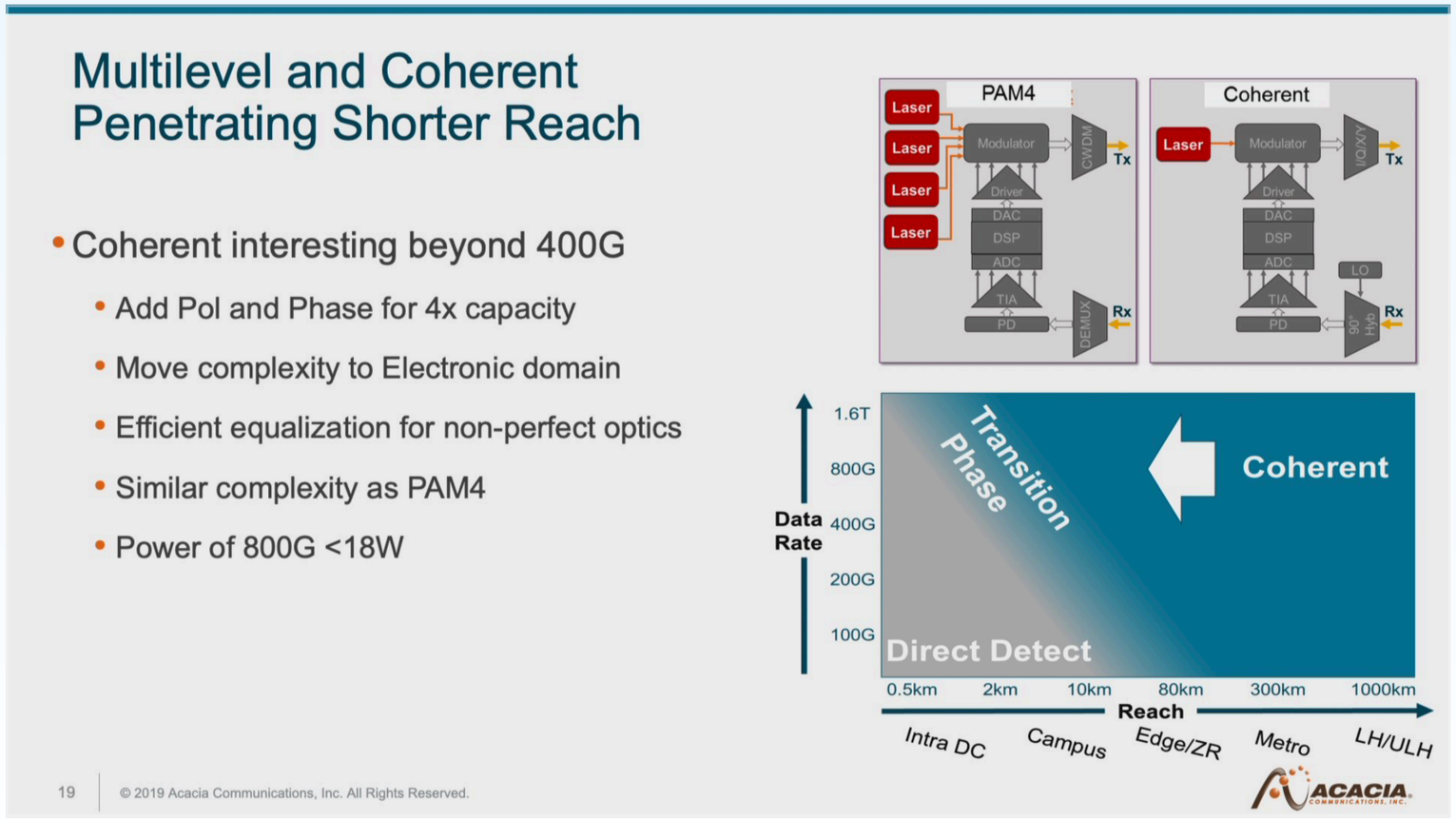
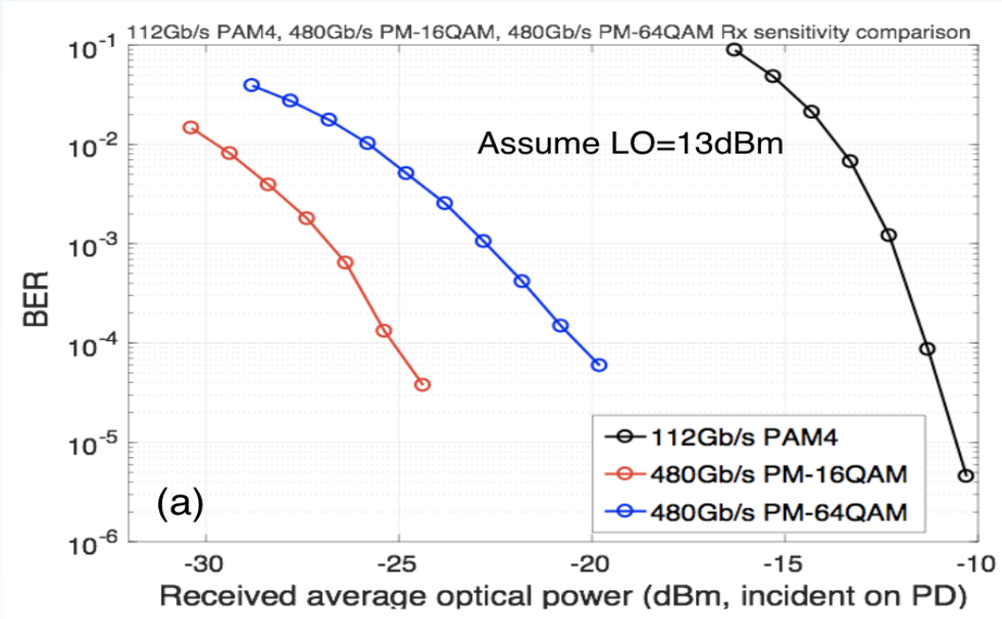
Material shown at OFC2019 by: Christian Rasmussen, Acacia Communications, USA

Coherent for DCI?

- Coherent techniques are coming also for shorter reach applications in large DataCenters, at 400G
  - The DSP techniques developed for Coherent transmission are being moved into shorter range interconnects to mitigate channel impairments
    - Some argue its easier to do this than enhance the components

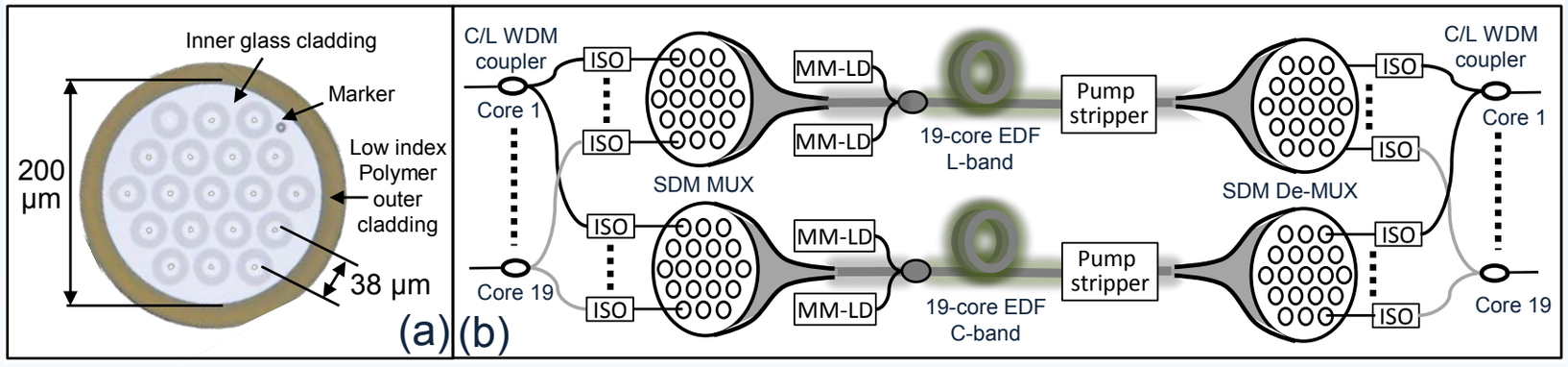


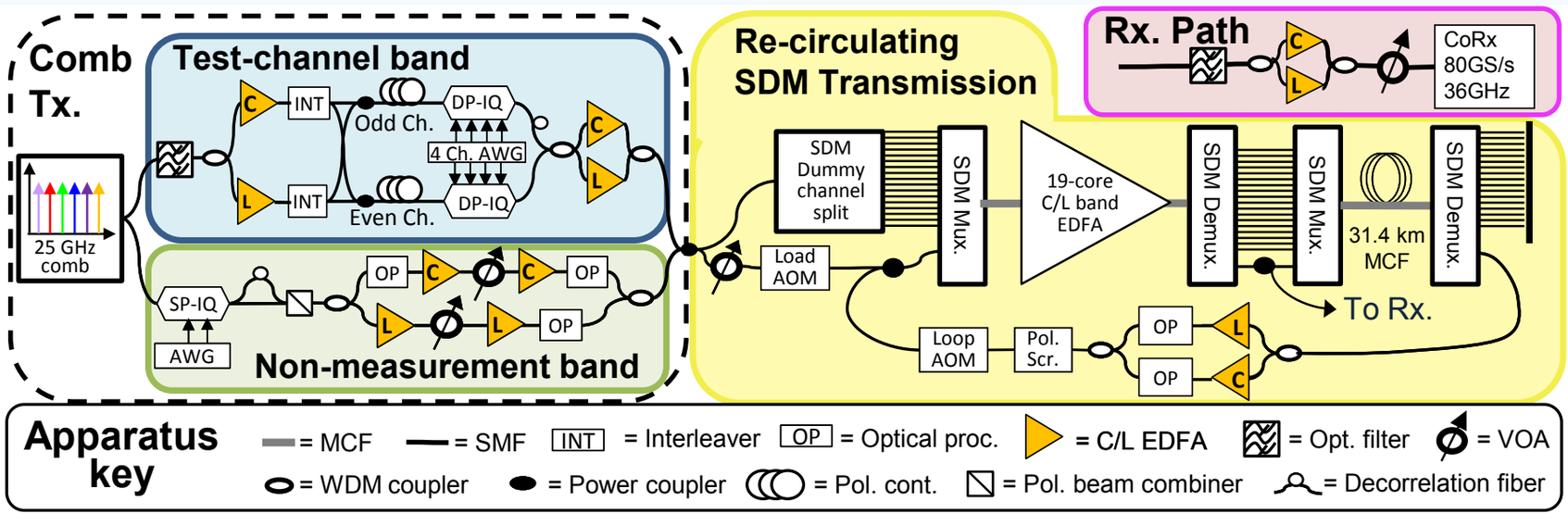


"Beyond 1Tb/s Datacenter Interconnect Technology: Challenges and Solutions", X.Zhou, R.Urata, and H.Liu , Google Inc. , OFC2019 Tu2F5

Late News ‘Hero Transmission’

- “0.715 Pb/s Transmission over 2,009.6 km in 19-core cladding pumped EDFA amplified MCF link”
  - B. J. Puttnam et al. (NICT, Furukawa, KTH)
- Wavelength range from 1530.52 nm to 1605.52 nm
- 715 Tb/s & 1.44 Exabit/s×km





Areas of Innovation

- Several key areas presented as drivers of future innovation:
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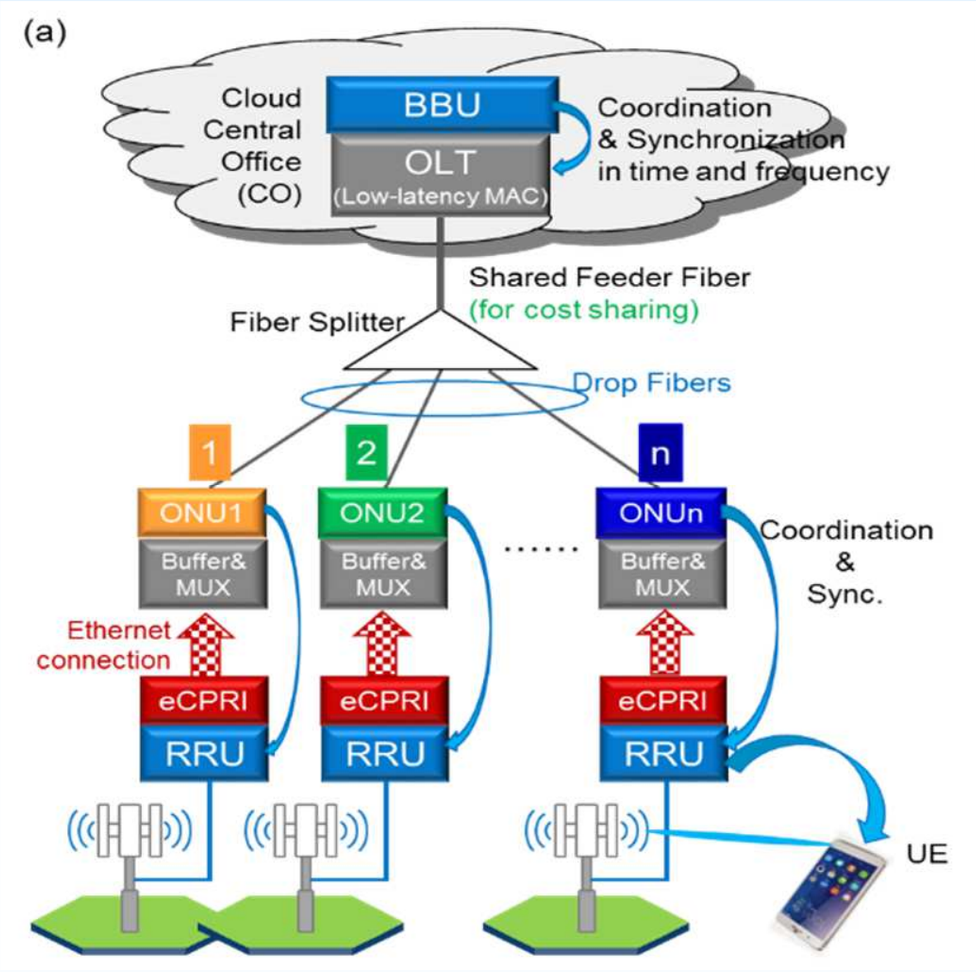
  - Coherent Systems
  - **Optical Technologies for 5G access networks**

Access Network Optical Links

- Passive Optical Network are deployed to provide fibre to the home/building
- Next generation mobile networks (5G) will require optical connections from antenna to ‘exchange’
  - New important concept is latency for critical applications
- Another cost-sensitive application that shares some requirements with HEP
  - e.g. latency

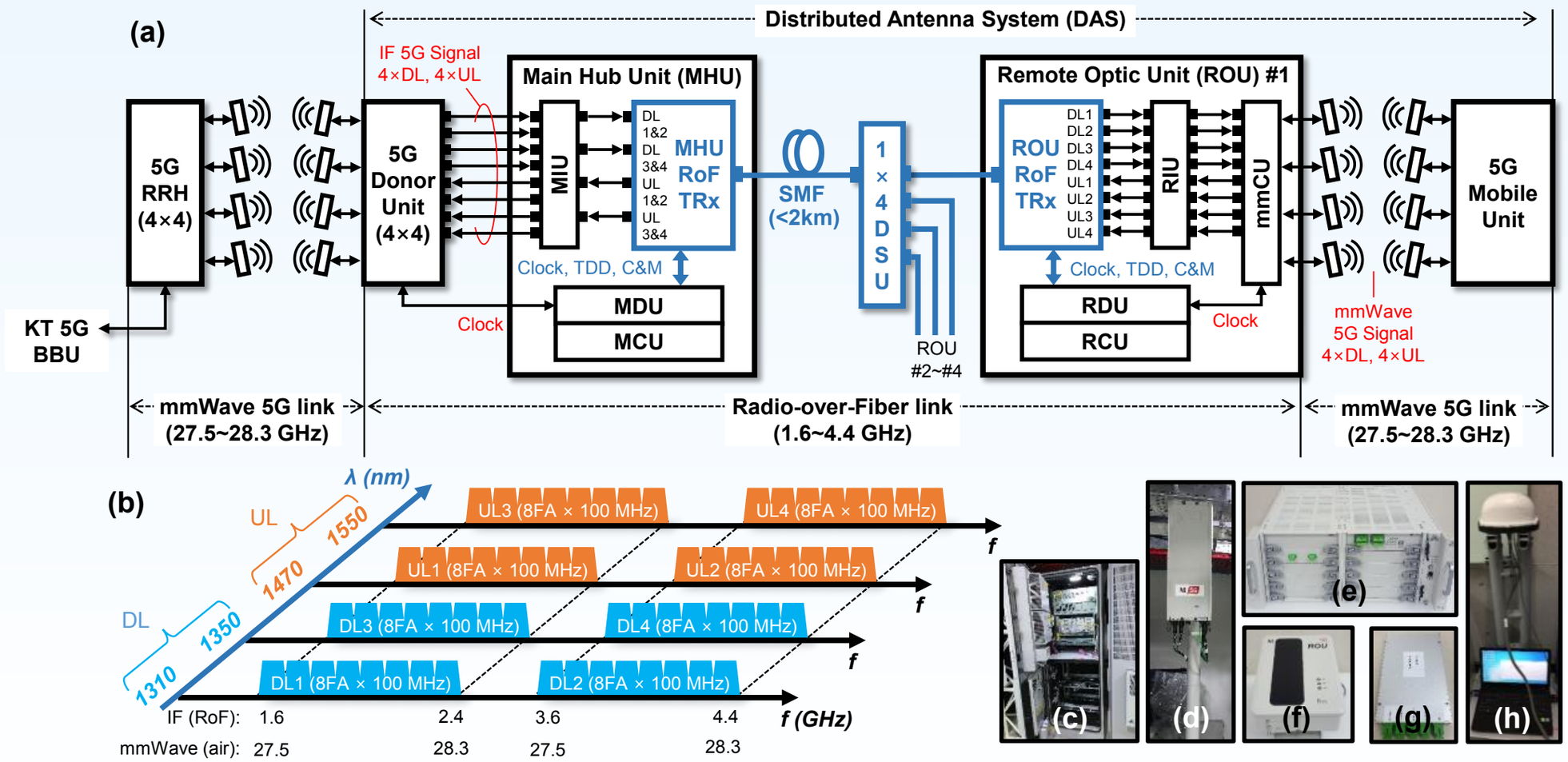
e.g. 5G PON



OFC2019 Tu2B.4, “Enabling Technologies for 5G-Oriented Optical Networks”, X. Liiu et al.

Late news: 5G application demo

- "OTA enabled 147.4 Gb/s eCPRI-equivalent-rate radio-over- fiber link cooperating with mmWave-based Korea Telecom 5G mobile network for distributed antenna system"
  - J. Kim et al, ETRI (Korea)



Summary

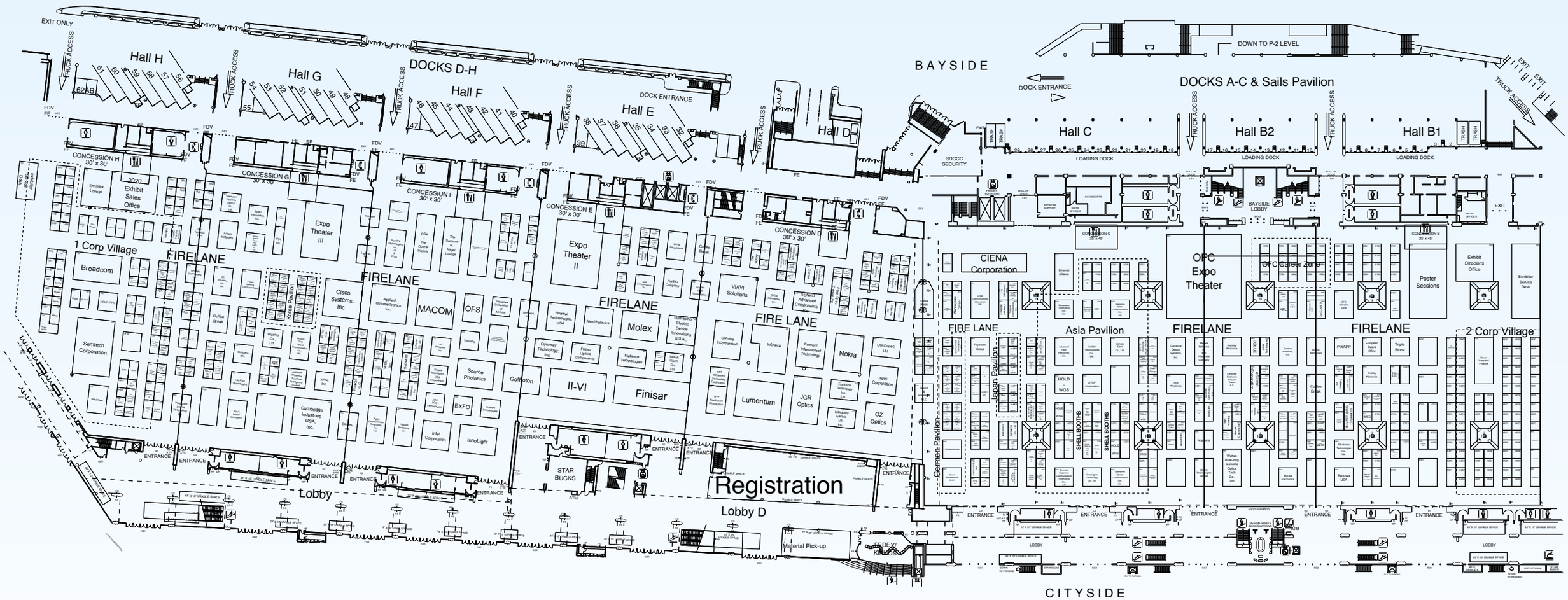
- Amazing to have all the experts under one roof
  - Excellent for discussions, networking…
- The quality of the talks (especially Tutorials/Invited) is very high
- Interesting synergies for future
  - Co-packaging of chiplets
    - For switch ASIC read front-end readout ASIC, where tight integration with optical readout could really enable new classes of detector
      - Provided Power and Cost can be controlled (this is not a unique requirement…)
  - Reliability is not going to be diminished any time soon
    - Still important for high initial yield and network availability
  - Silicon Photonics (photonic integration) is a requirement for future high-speed communications systems
    - Continue to investigate applicability to HEP systems

Additional Material

Lab Automation Hackathon

- Sunday evening session
  - Opportunity for young researchers to show off cool stuff they've done in their labs
    - Speeding up Python execution by cross-compilation with C++
    - Lab instrument basic control
    - Complex test bench control and test protocol definition

The Maze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Hall D
DOCK ENTRANCE
BAYSIDE
DOWN TO P-2 LEVEL
DOCKS A-C & Sails Pavilion
Hall C
Hall B2
Hall B1
LOADING DOCK
SDCCC SECURITY
BAYSIDE LOBBY
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CONCESSION G 30' x 30'
CONCESSION F 30' x 30'
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CONCESSION D 30' x 30'
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