Innovations for Overcoming Technology Limits

Fundamental Technologies Supporting the Transition to 400G - 800G- 1.2Tb Optical WAN's
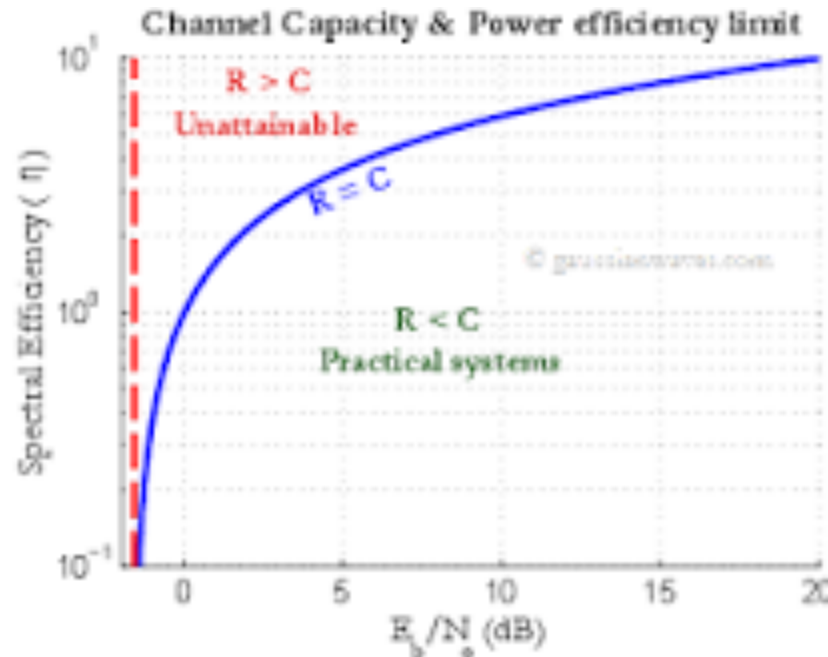
Rodney G. Wilson
Chief Technologist, Innovation Research
CTO Group
Ciena Corporation

All About This…..

Claude Shannon (1916-2001)
Father of Information Theory
Noisy-channel Coding Theorem 1948

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

Channel Capacity & Power efficiency limit

R > C
Unattainable

R = C

R < C
Practical systems

Spectral Efficiency (η)

E_b/N_o (dB)

Or maybe this….

a quest for the Holy Grail?

Defining the next generation performance-centric design
Investment driven by network needs

Metrics evaluated	Considerations	High Level Design Objectives

Metrics evaluated
- Channel Capacity ($/bit and power/bit)
- Spectral Efficiency

Considerations
- What's needed for 800G everywhere
- Optimal transport of 400GE, 800GE clients
- 1.6T / λ for optimal network economics
- Variable capacity at variable baud
- Ease of adoption
- Full and real-time visibility into the network

High Level Design Objectives
- Programmable modem capacity up to to **1.6Tbps / λ**
- Performance: **800G _Everywhere_** – ULH & Submarine
- Fiber capacity / S.E. gains
- **Significant** power/bit reduction
- Mated modem support for 400GE/800GE to maximize fiber capacity in both C and L-band
- Customer provisioning simplicity through automatic line performance optimization
- Dedicated hardware acceleration for high-speed PM telemetry streaming with hardware timestamping

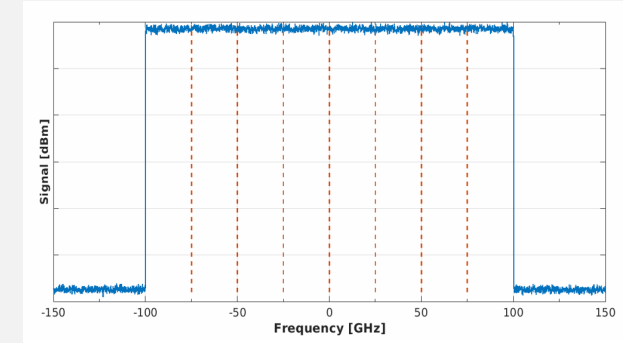# Yes, it is possible to achieve spectral efficiency improvements
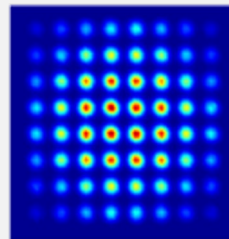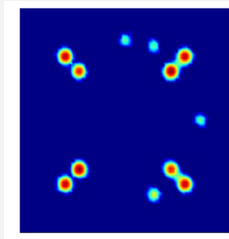## DSP Innovations
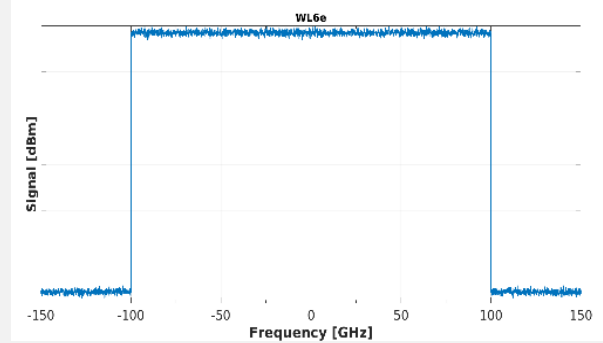
Edgeless Clock Recovery
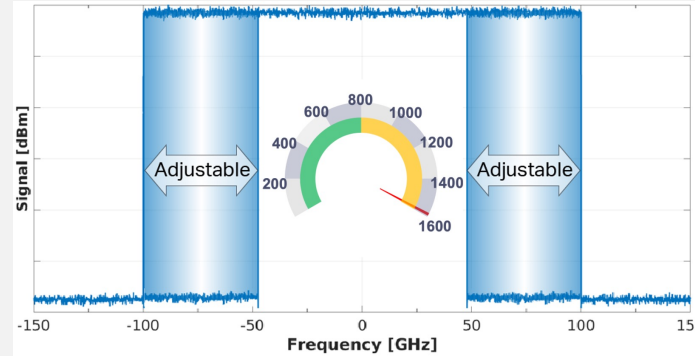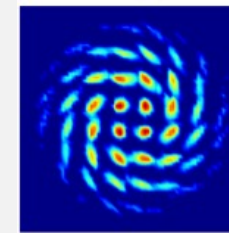
Variable Line Rate and Baud

Optimized FDM (from 1 to 8)

Non-linear PCS

Multi-Dimensional constellations

Non-linear Compensation

Create a single technology for optimal capacity over *any* fiber in terrestrial or submarine applications
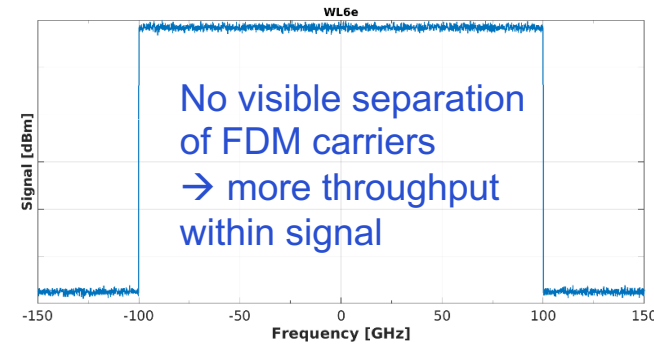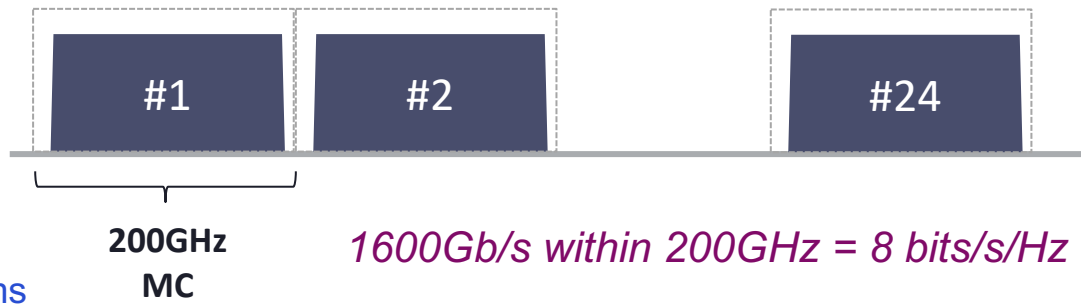
Performance-centric DSP innovation: Edgeless clock recovery

- **Tx spectral shaping was first introduced in the industry by Ciena in 2010**
  - RRC spectrum shaping bounds the signal bandwidth occupancy
    - → Improves spectral efficiency (S.E.)
  - Improves tolerance to cascaded filters resulting in better performance

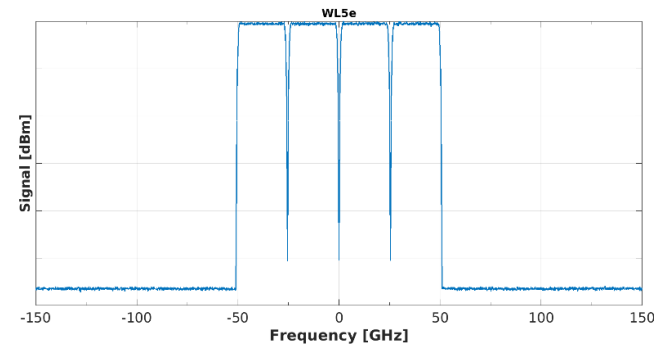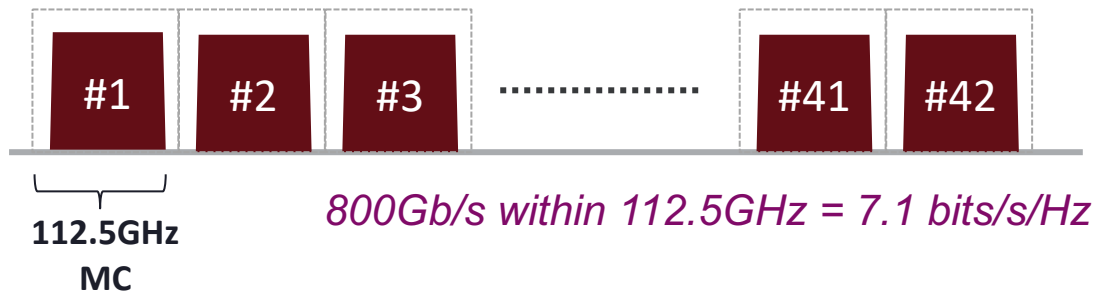A DSP perfects Tx shaping with Edgeless Clock Recovery

Spectral width = baud

New 185GBd

+12.5% S.E. AND fewer modems AND better performance

| #1 | #2 | #24 |

200GHz MC

1600Gb/s within 200GHz = 8 bits/s/Hz

Old 95GBd

| #1 | #2 | #3 | .... | #41 | #42 |

112.5GHz MC

800Gb/s within 112.5GHz = 7.1 bits/s/Hz

WL6e

No visible separation of FDM carriers → more throughput within signal

Spectrum width=baud → pack signals closer

Signal [dBm]

Frequency [GHz]

WL5e

Signal [dBm]

Frequency [GHz]

Conservation of Spectrum

Variable baud and line rate: Optimize spectrum / capacity based on client connectivity and available spectrum

Variable baud: 95Gbaud to 200Gbaud
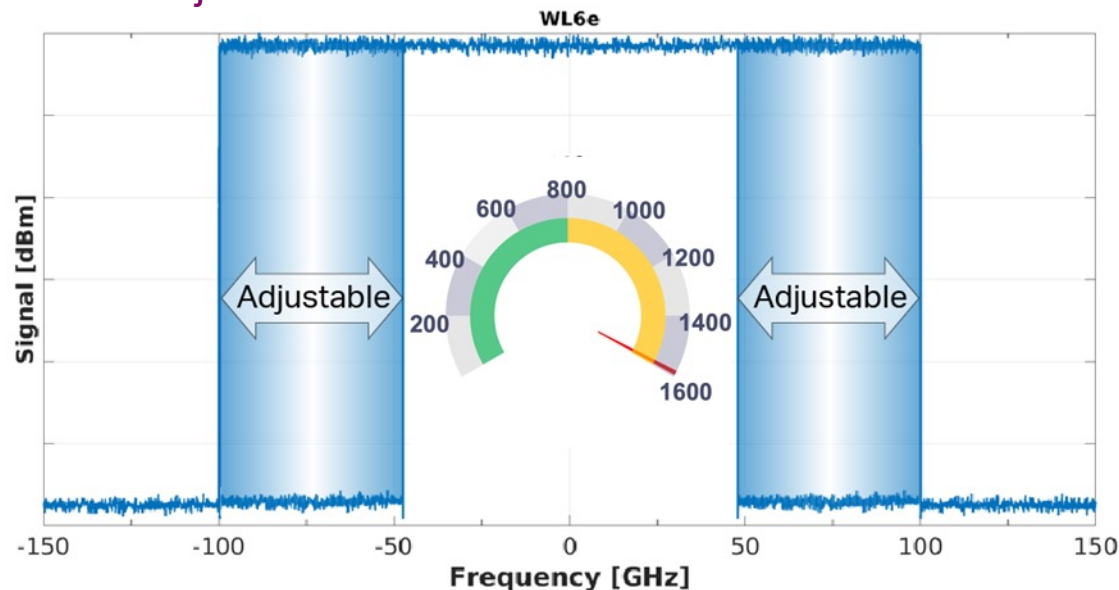**Adjustable line rate: 200Gb/s to 1600Gb/s**
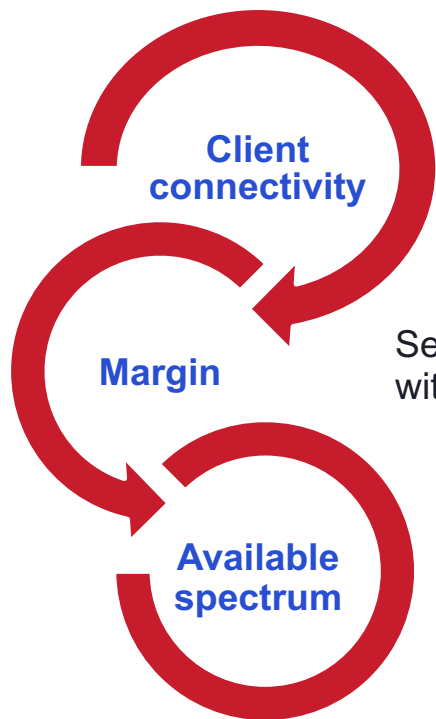

100GE to 800GE
FlexO-1-RS to FlexO-4-RS

Select baud for "x" capacity
with "y" dB margin

- Maximize spectral efficiency using all available spectrum
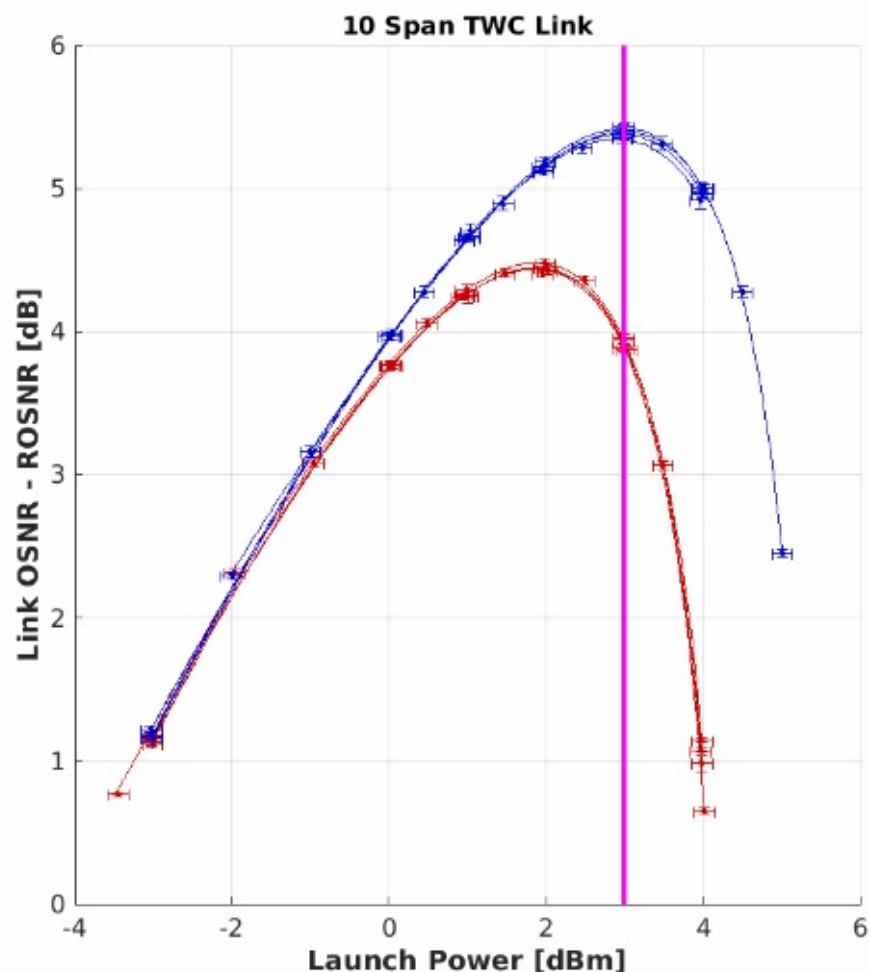- Adjust to desired channel spacing

Client connectivity → **Margin** → **Available spectrum**

Integrated system intelligence and tools will provision optimal settings

PlannerPlus | MCP Domain Controller | SNR Optimizer | Real-Time Sensor
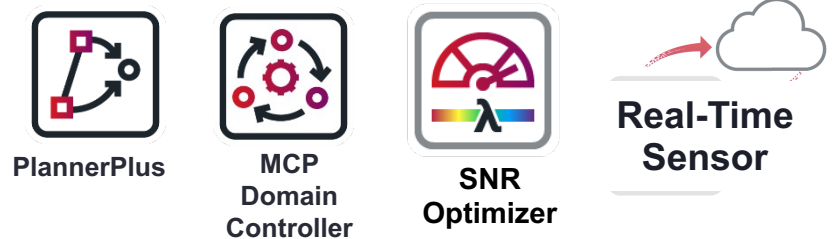
DSP innovation: Nonlinear compensation
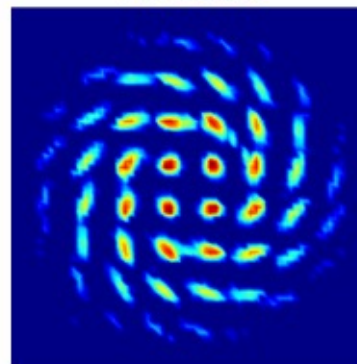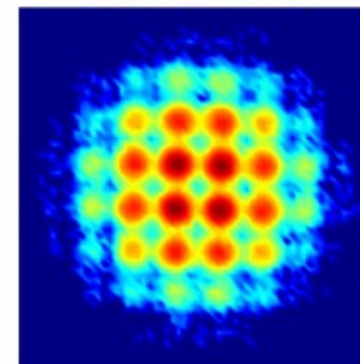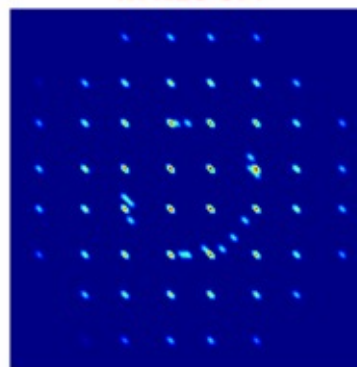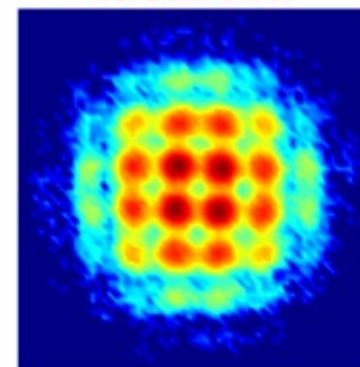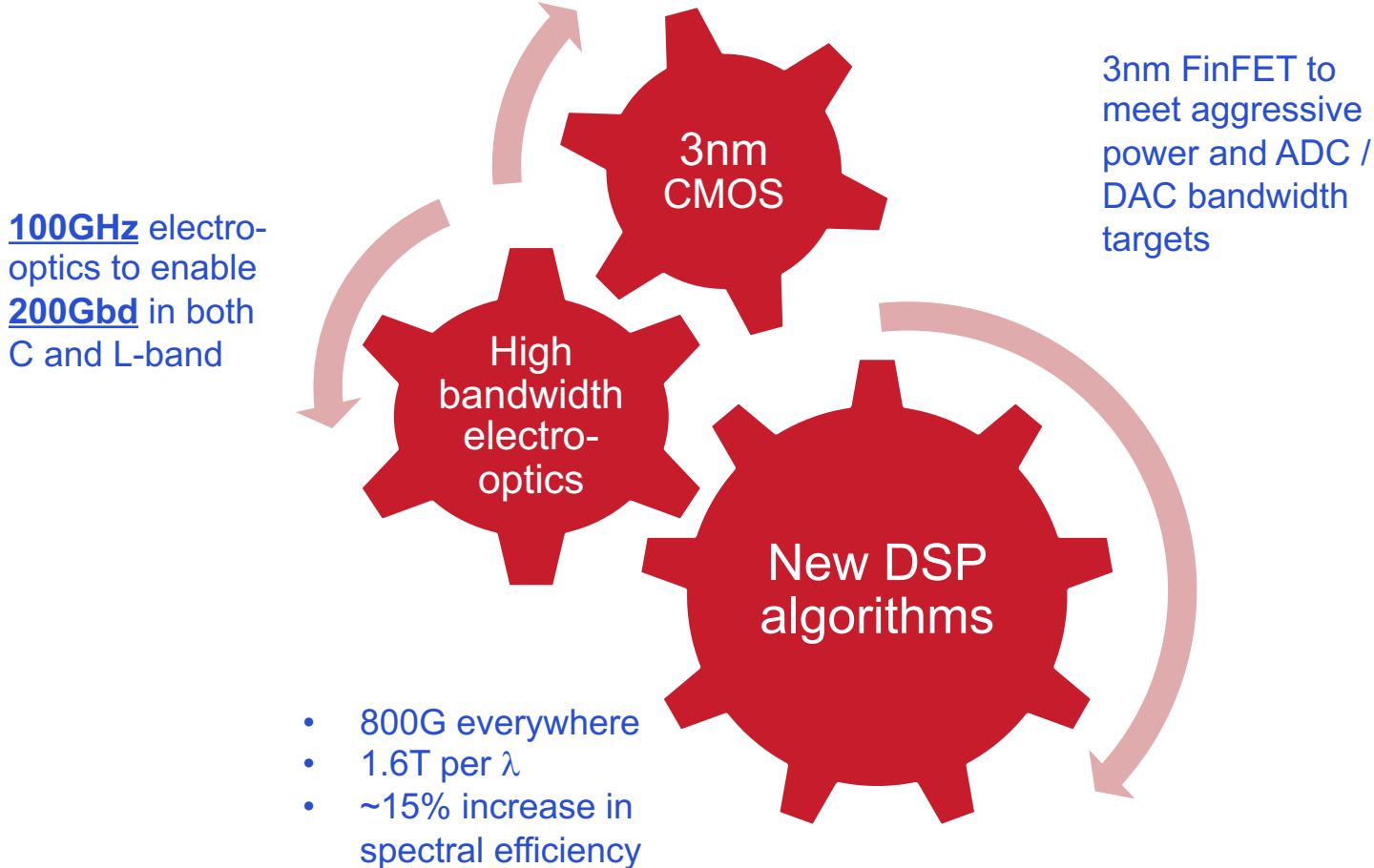

Nonlinear compensation feature provides ability to launch at higher power.
Up to 1dB improvement in SNR margin in nonlinear environments

Next generation networking requirements

3nm CMOS

High bandwidth electro-optics

New DSP algorithms

100GHz electro-optics to enable **200Gbd** in both C and L-band

3nm FinFET to meet aggressive power and ADC / DAC bandwidth targets

- 800G everywhere
- 1.6T per λ
- ~15% increase in spectral efficiency

Delivering on High Level Design Objectives

Performance benefits of high baud modems

- **185Gbd [800Gb/s] offers similar LH reach to 95Gbd [400Gb/s] with higher total fiber capacity**
  - C-Band requires **48** WL6e modems (19.2Tbps) versus **84** WL5e modems (16.8Tbps)

- **185Gbd [800Gb/s] offers similar LH reach and total fiber capacity to 135Gbd [600Gb/s]**
  - C-Band requires **48** modems (19.2Tbps@800Gb/s) versus **64** modems (19.2Tbps@600Gb/s)
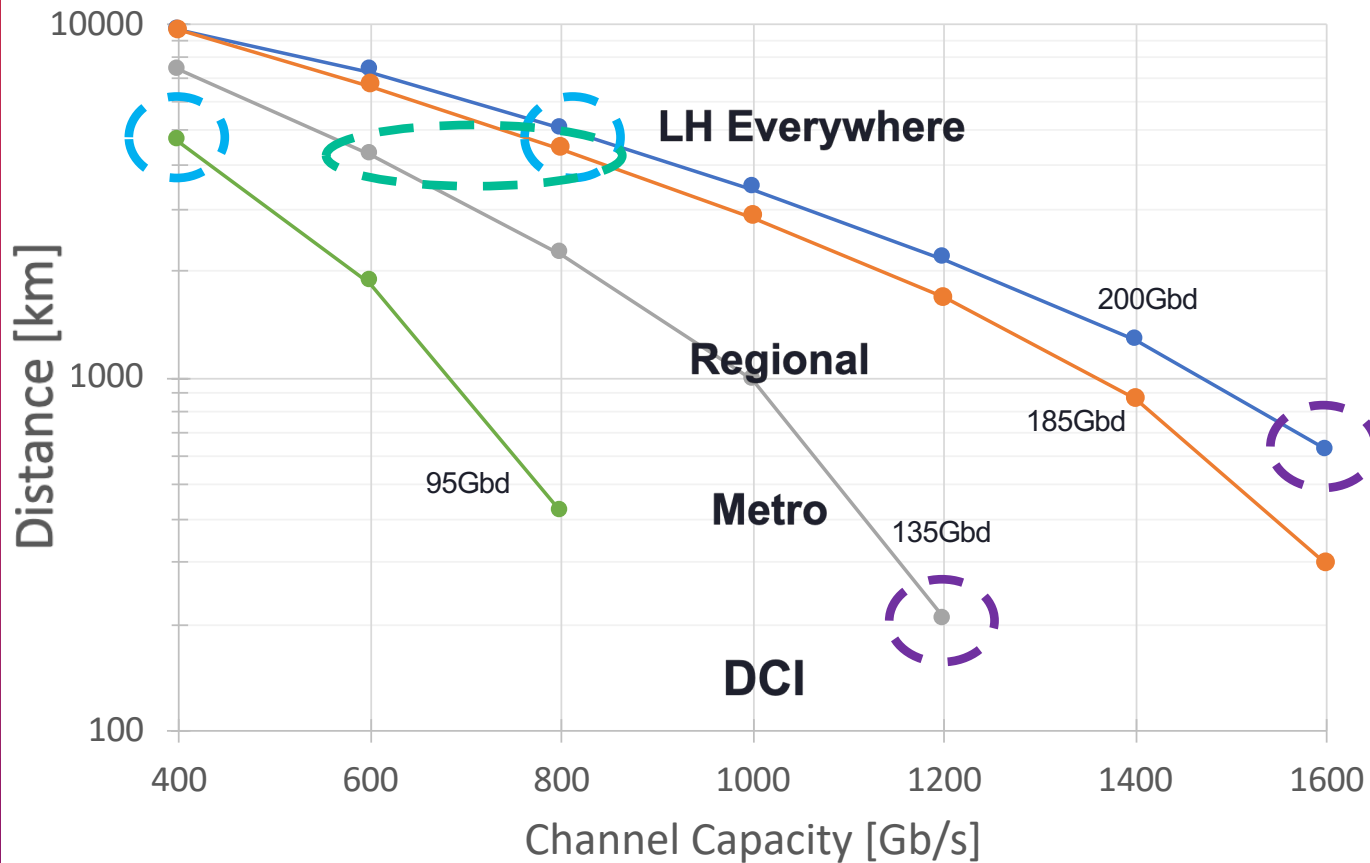
Even with all DSP enhancements, higher bauds required for 800G everywhere

Two high baud capable modems with 400G of mate-to-mate links allows optimal transport of 400GE and 800GE clients
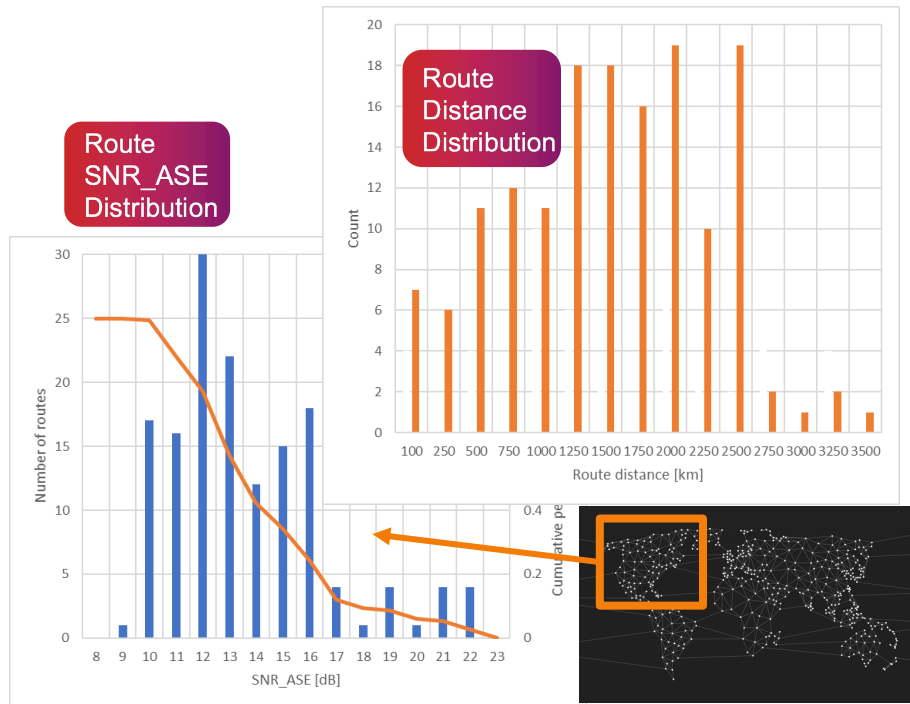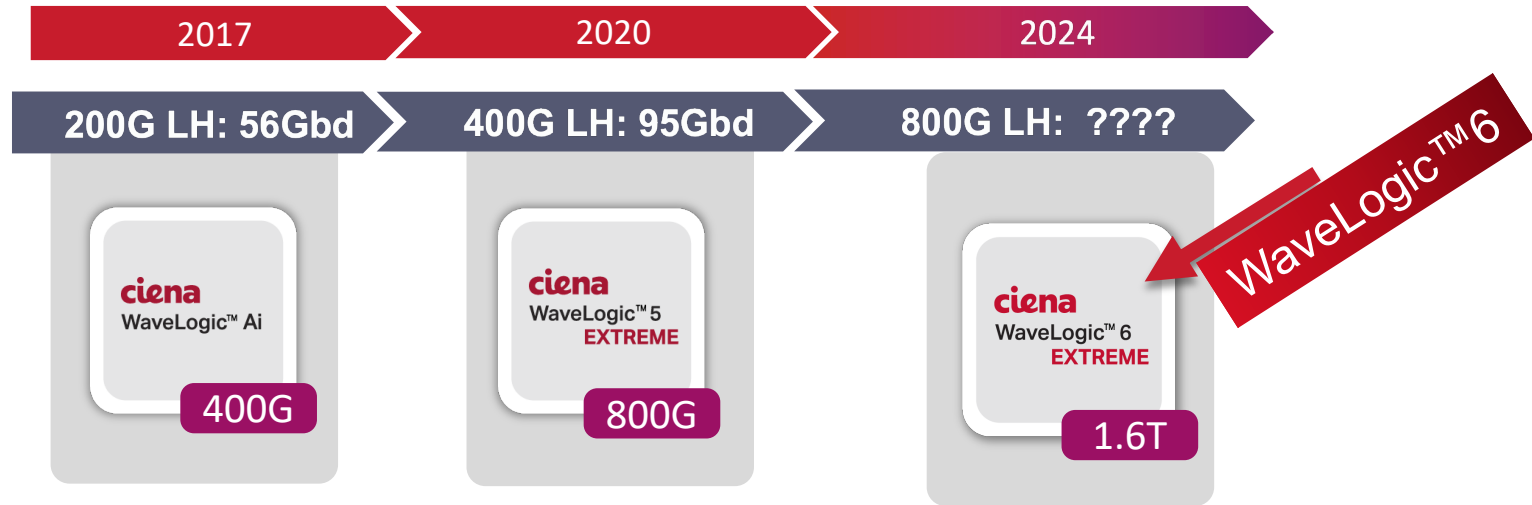
Maximum channel capacity link budgets:
- **200Gbd [1.6Tb/s]** = Metro-ROADM
- **135Gbd [1.2Tb/s]** = DCI

Optimal Reference Network:
20dB NDSF per span @ 0.22dB/km
Raman amplified
Single (Network Media Channel) per (Media Channel)

Ciena R&D has made these Technology Investments driven by real network needs

Long Haul / Submarine

10,000km

100s to 1000s km

- *Performance; Spectral Efficiency*

Route SNR_ASE Distribution

Route Distance Distribution

2017	2020	2024
200G LH: 56Gbd	**400G LH: 95Gbd**	**800G LH: ????**

WaveLogic™ 6

ciena WaveLogic™ Ai — 400G

ciena WaveLogic™ 5 EXTREME — 800G

ciena WaveLogic™ 6 EXTREME — 1.6T

The first true industry 200G LH solution was introduced in 2007 @ **56Gbd**

The first true industry 400G LH solution was introduced in 2020 @ **95Gbd**

The next industry performance-centric designs must enable 800G LH *everywhere* networking

Technology innovations for next generation performance centric modems in 2024

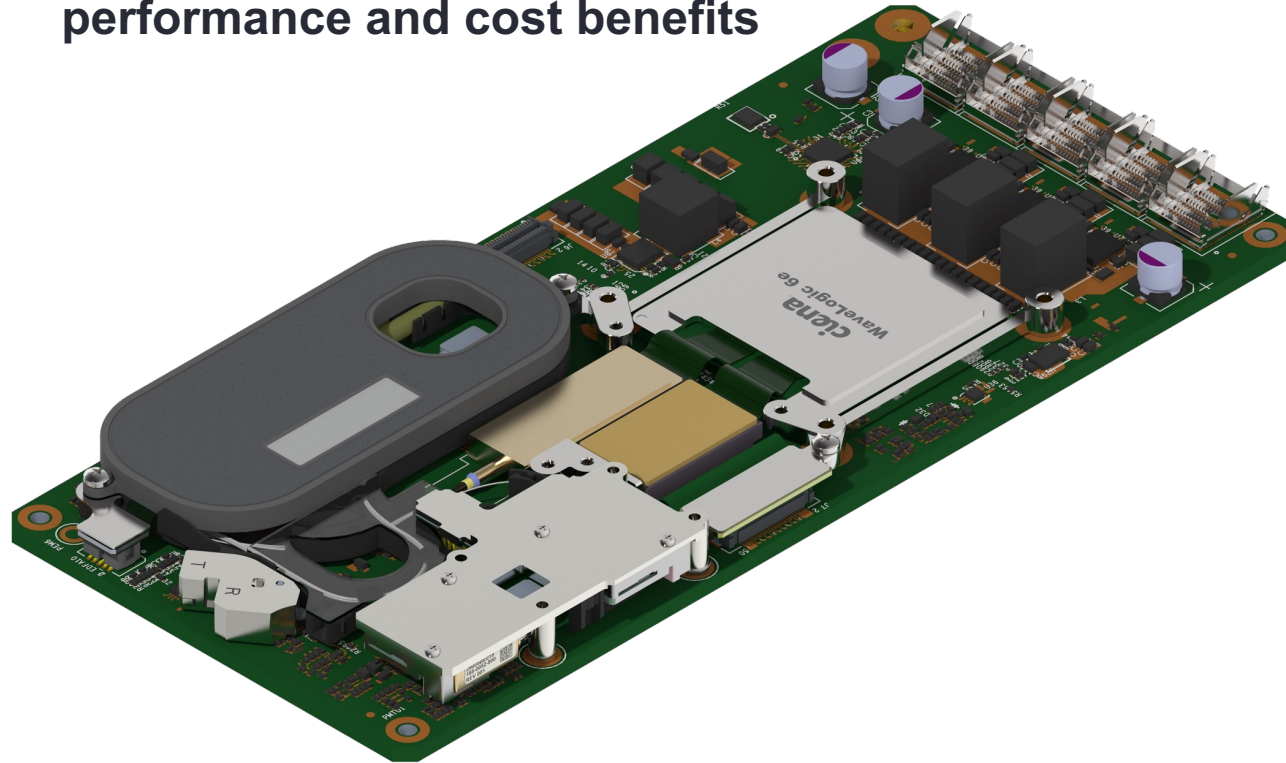
Ciena WaveLogic™ 6 EXTREME 1.6T

- Variable baud up to **200Gbd**

- Programmable capacity up to to **1.6Tbps / λ**

- Performance: **800G _Everywhere_** – ULH & Submarine

- Spectral efficiency improvements: **baud = spectral width**
  - **15%** Fiber Capacity / S.E. Gain vs WL5e

- Greener than previous performance generations
  - **50%** power/bit reduction vs WL5e

- Dedicated hardware acceleration for streaming telemetry

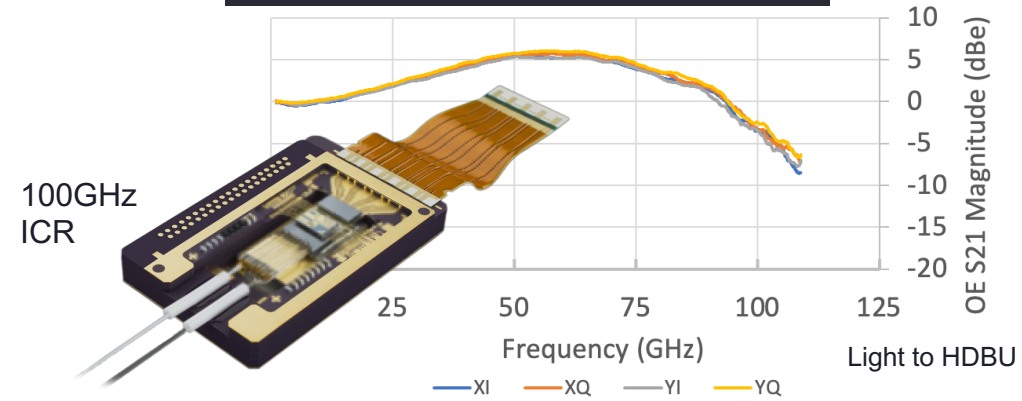- Line optic mating for max support of high-capacity clients
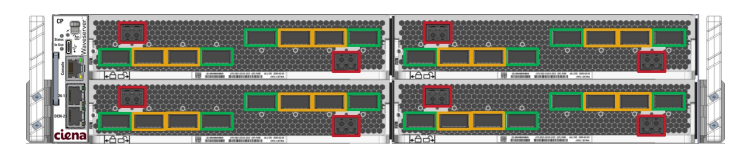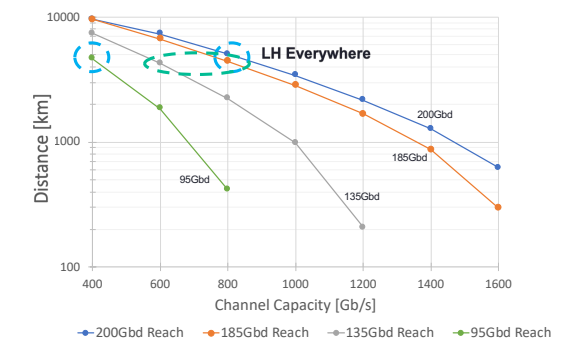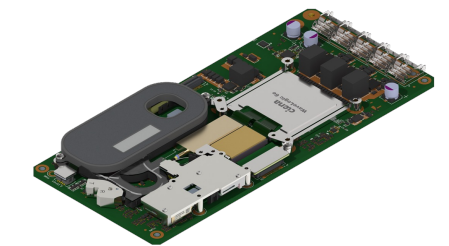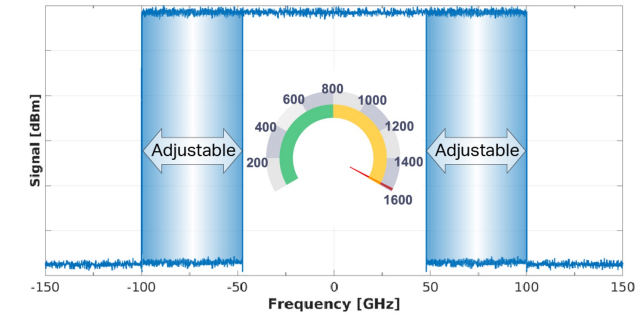
WS
12.8T
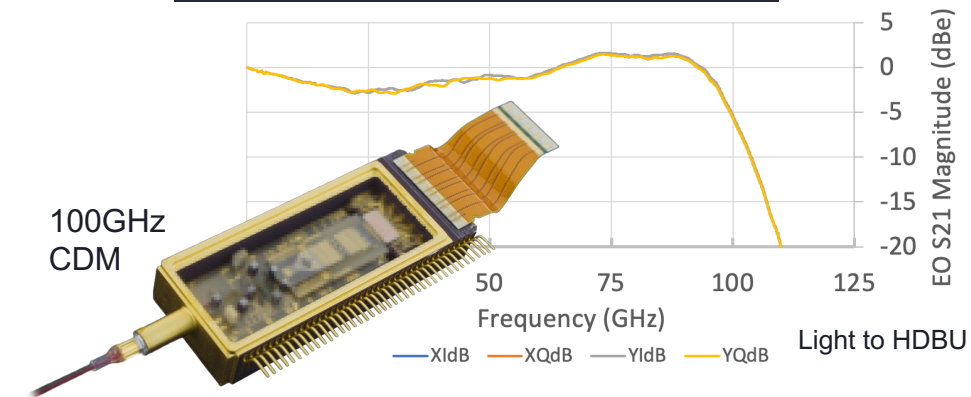2 RU

The heart of WL6 Extreme

- **200Gbd** modem enabled by **100GHz** Tx/Rx analog FE bandwidths
- Tx EO (CDM) and Rx OE (ICR) using RF flex interfaces to minimize interconnect *losses* and *crosstalk*
- Tx EO and Rx OE have their own optimized technology for performance and cost benefits

OE S21 RF Response

100GHz ICR

Light to HDBU

— XI — XQ — YI — YQ

EO S21 RF Response

100GHz CDM

Light to HDBU

— XIdB — XQdB — YIdB — YQdB

Multi-dimension optimizations achieved through vertical integration

Thank you…. Questions?

Rod Wilson

rwilson@ciena.com