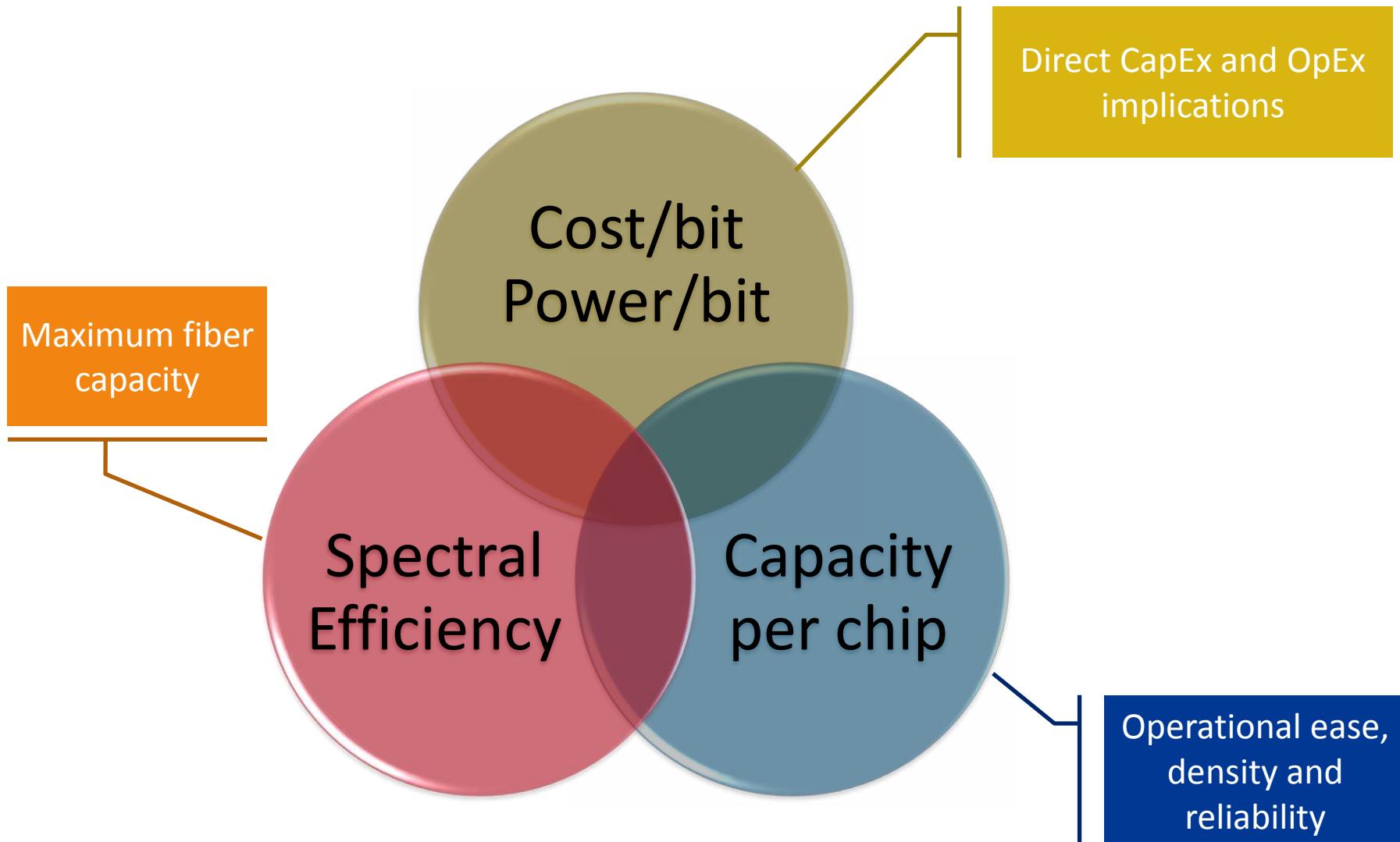


# Large-Scale Photonic Integrated Circuits

Fred Kish

# Telecom Applications

## Metrics that truly matter ....

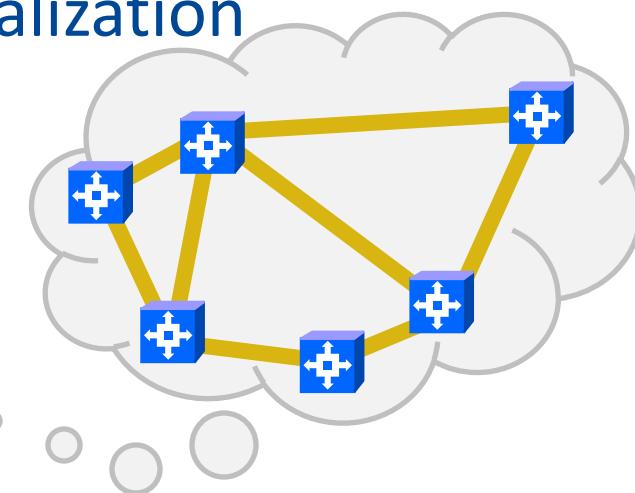


# Why PICs?

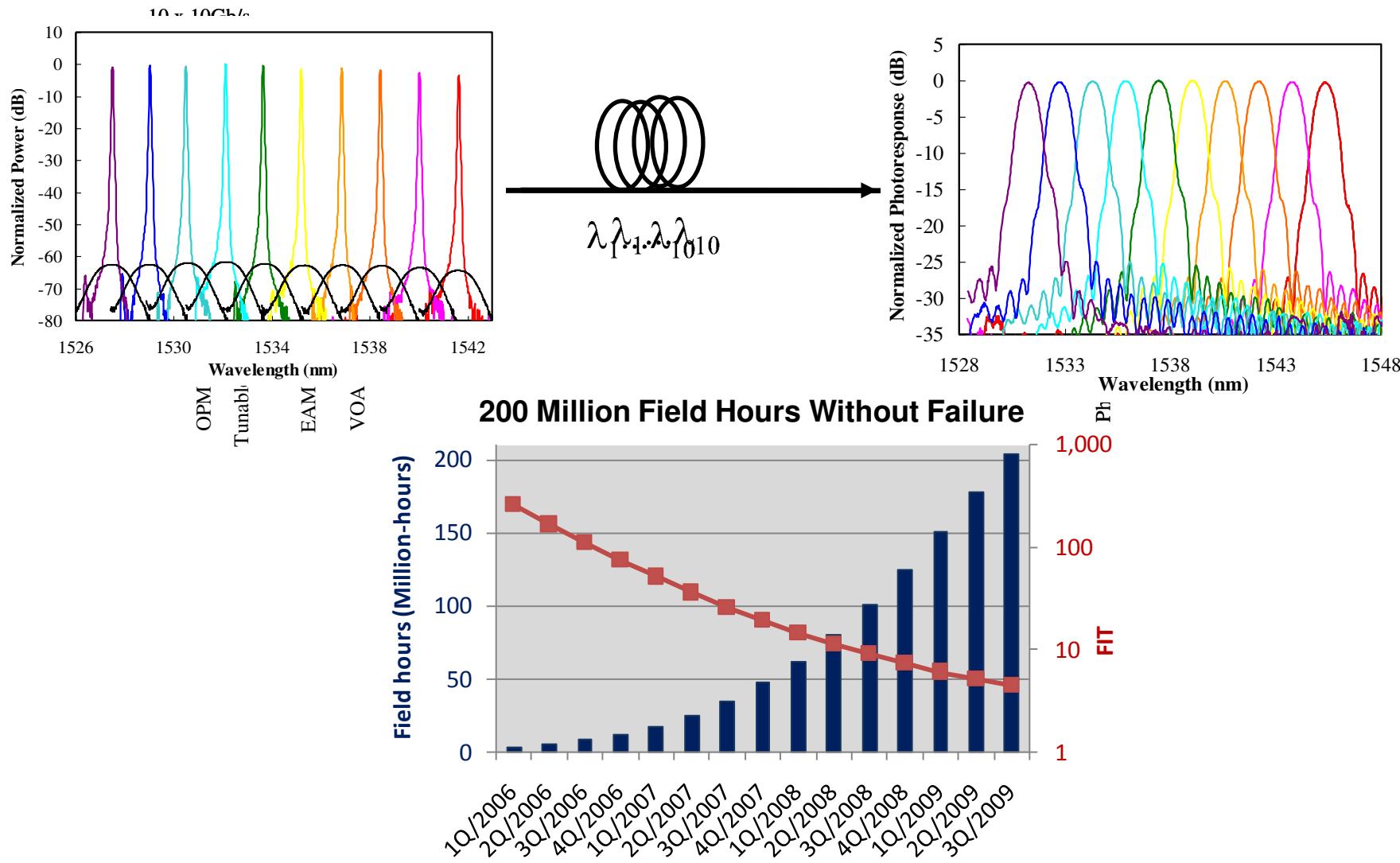
## Providing Value to Network Solutions

- PIC disruption
  - Space
  - Reliability
  - Power
  - Cost

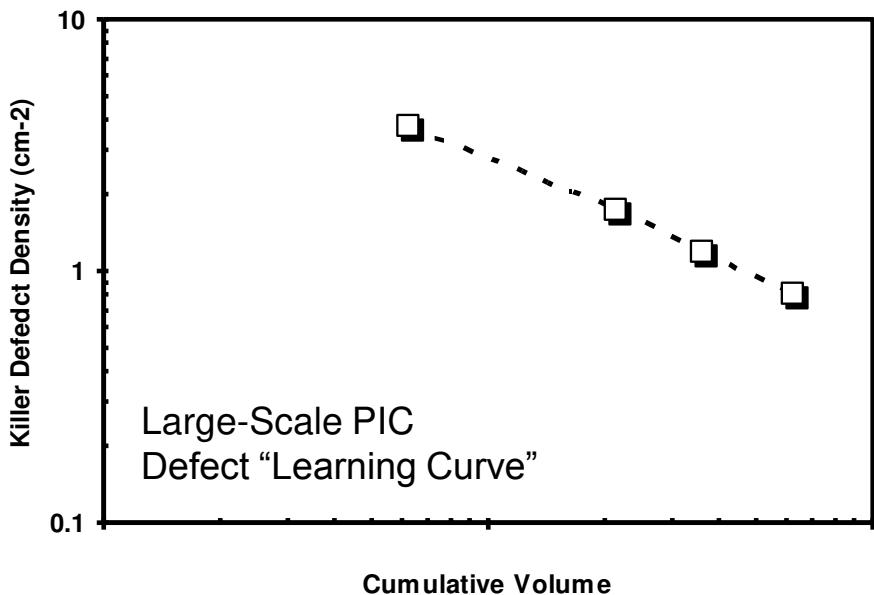
- “Digital experience” Disruption
  - Speed
  - Intelligence
  - Bandwidth
  - Virtualization



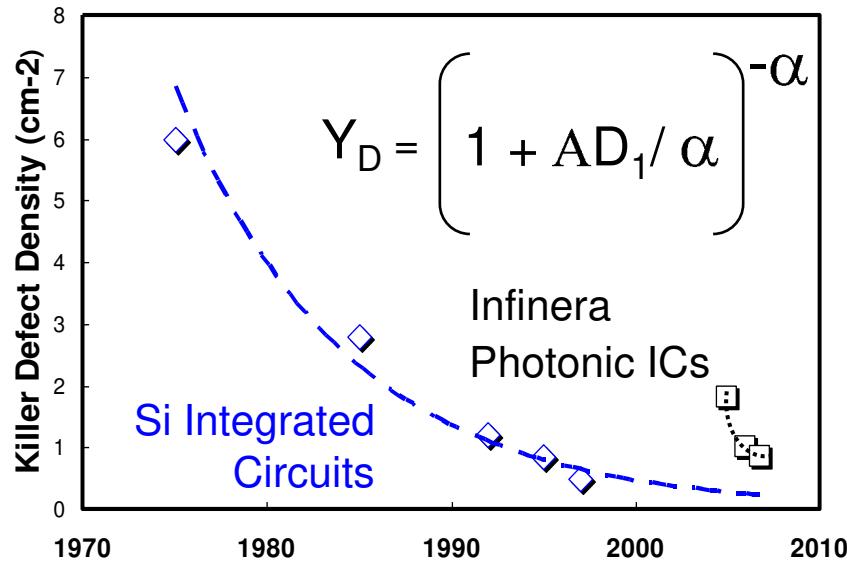
# Large-Scale 100 Gb/s Commercial PICs Enable Scaling of the Network



# Large-Scale Photonic IC Defect Density



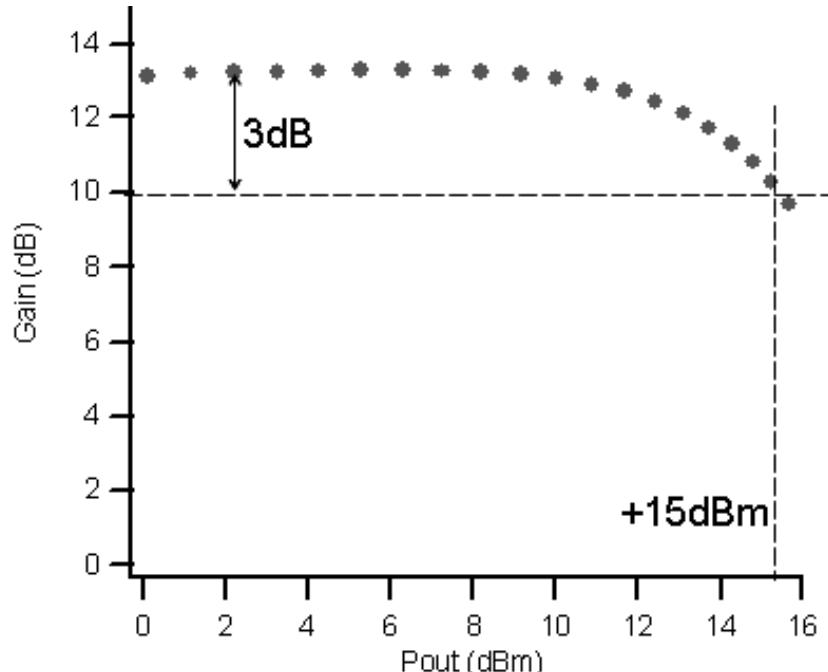
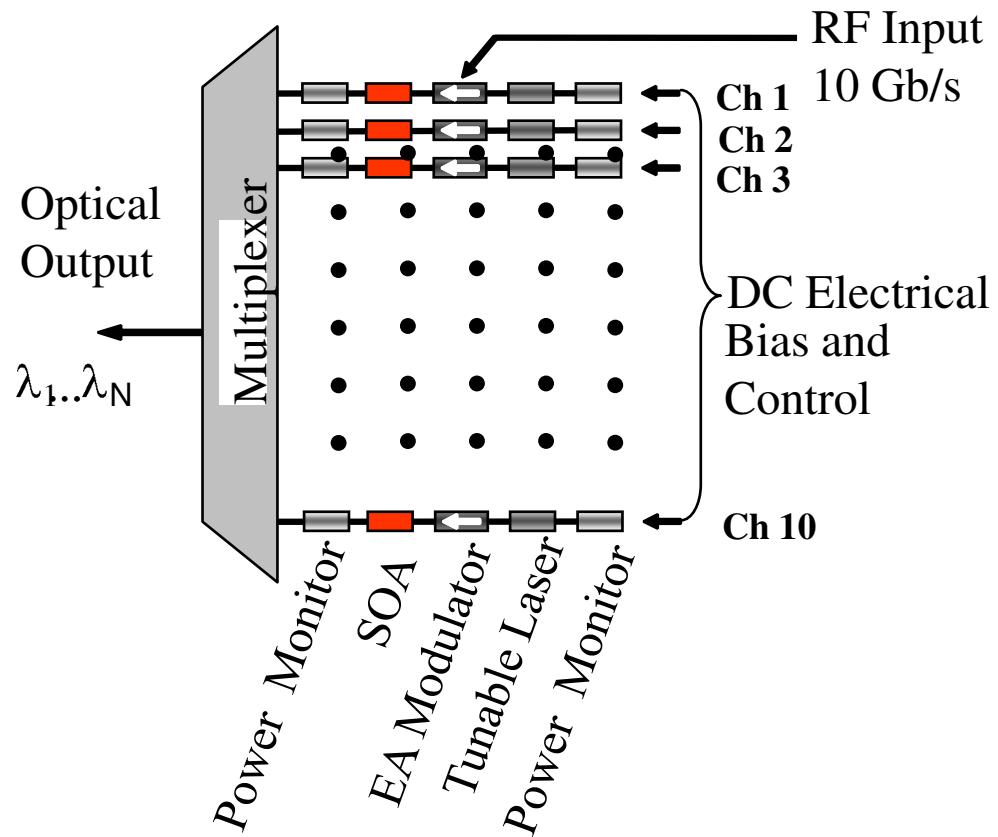
Volume Manufacturing  
Enables Defect "Learning Curve"



Killer defect density of  
Infinera PICs comparable to  
Si circa 1993

Random defect density reduction most important for higher capacity / complexity PICs

# Transmitter PIC with Integrated SOAs

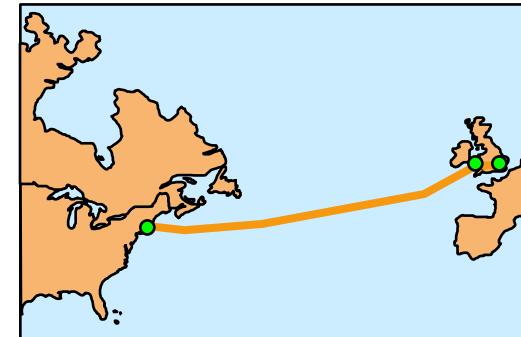


SOA used for both gain (increased launch power), power flatness and/or pre-emphasis control

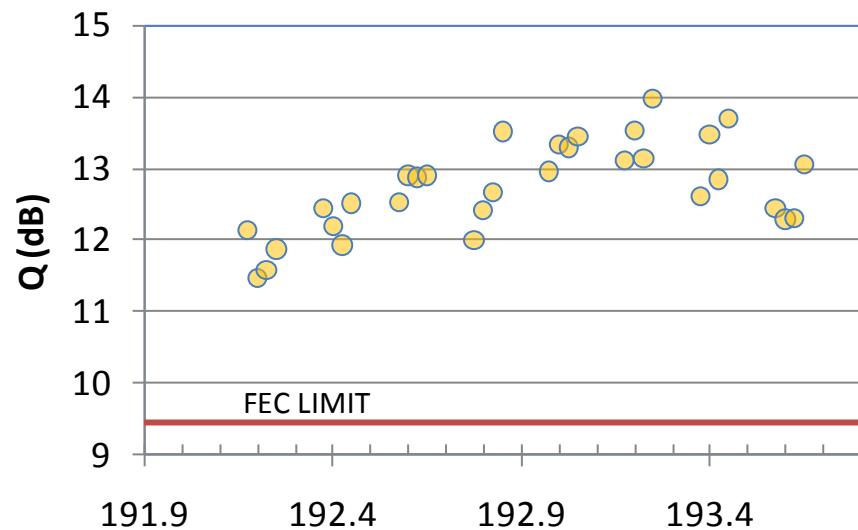
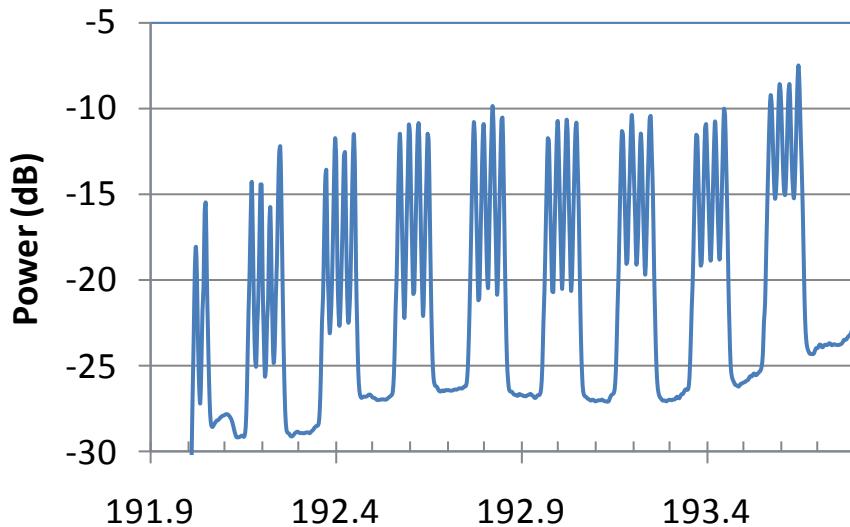
# 100Gb/s PICs in ULH Applications Submarine Networks

- 25 GHz and high density
- > 6,000 km links
- >50,000 km of routes deployed
- Operational simplicity

>6100km Trans-Atlantic System

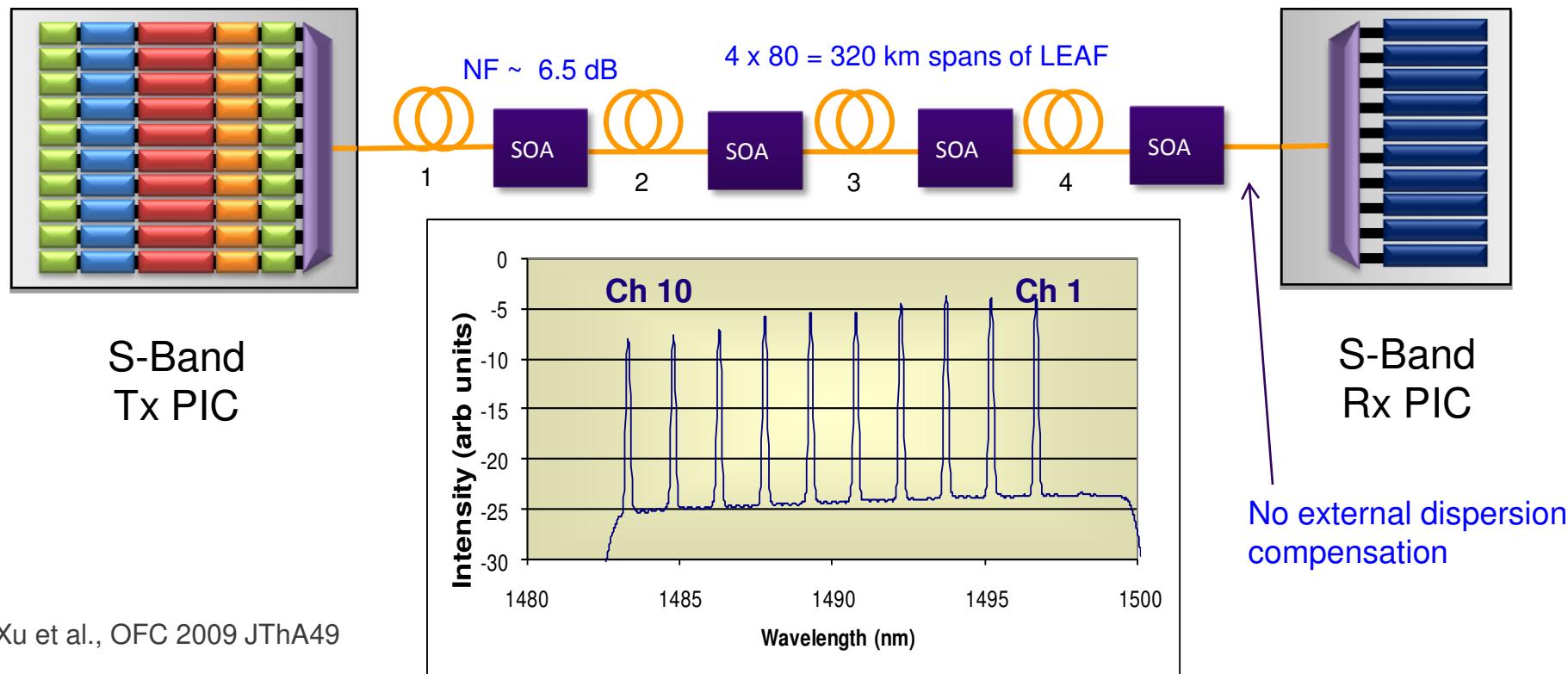


31 channels @ 25 GHz spacing

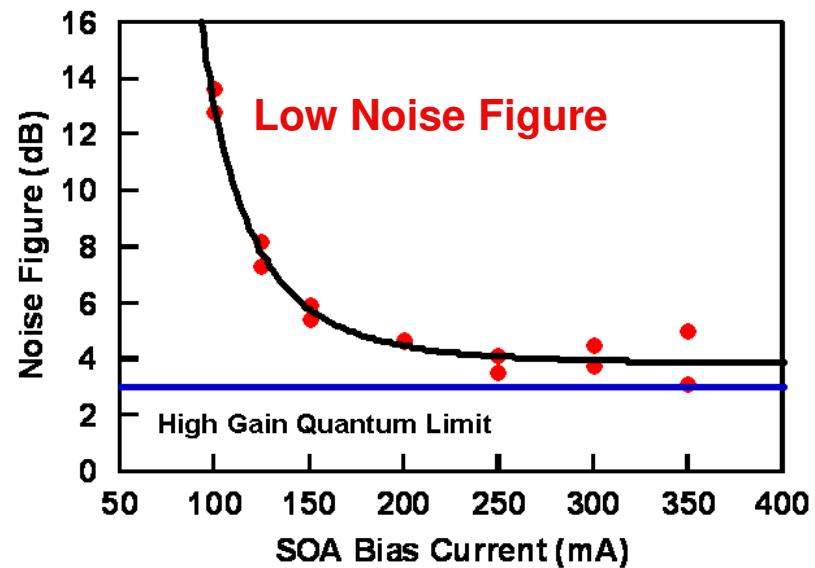
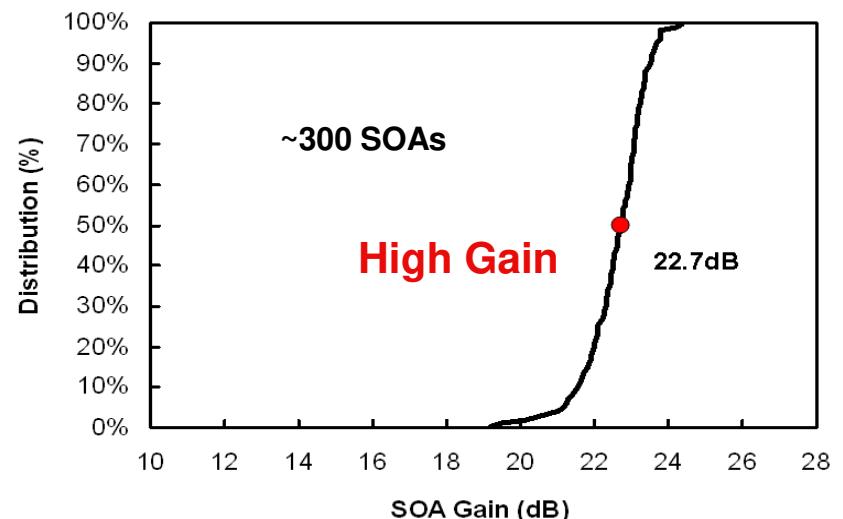
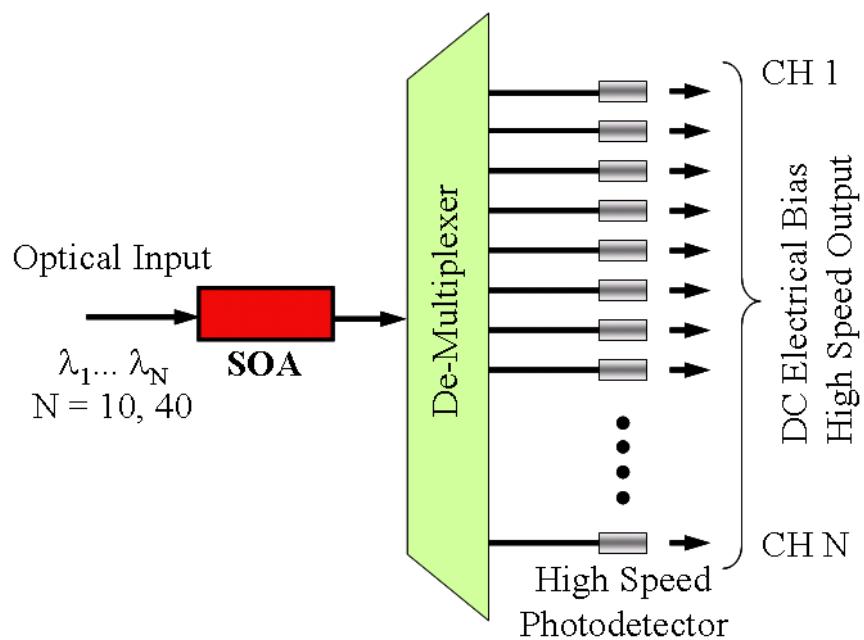


# PICs & SOA Enable Use of The Entire Fiber Bandwidth

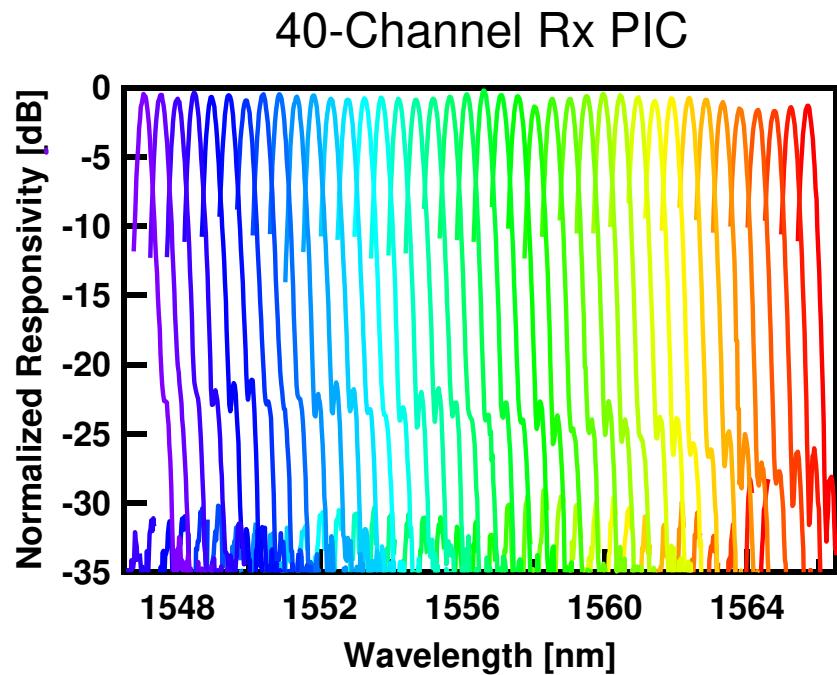
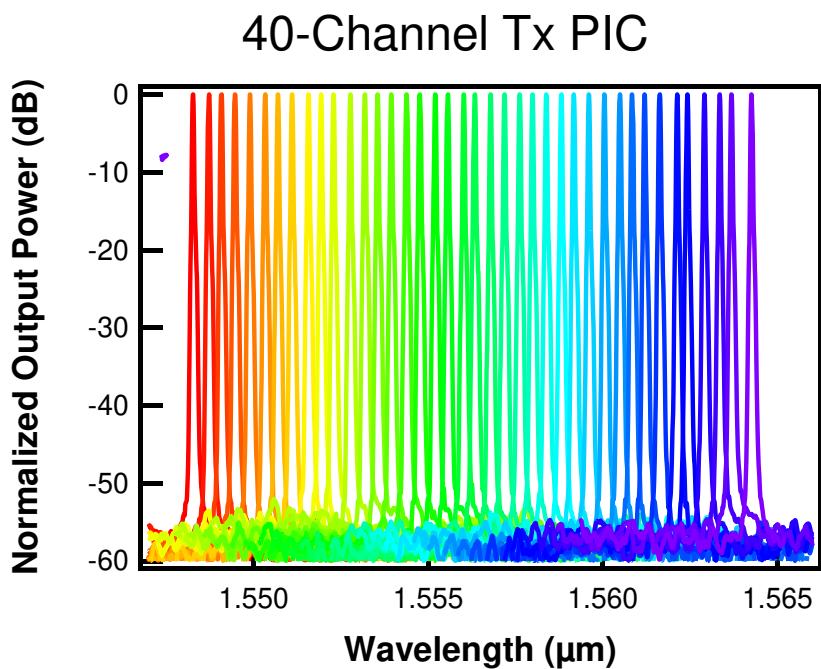
- S, C and L band PICs demonstrated.



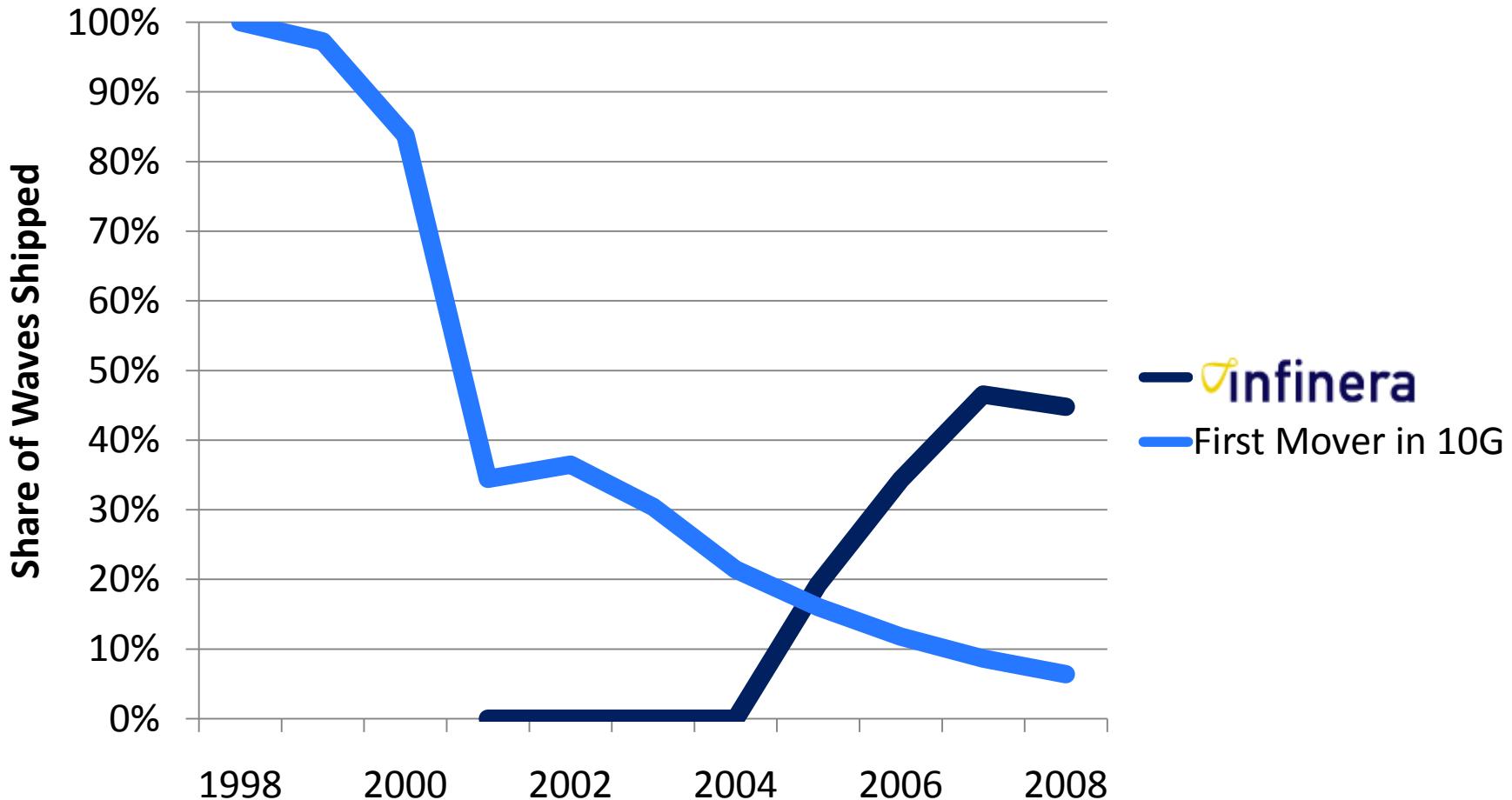
# Receiver PIC with Integrated SOA



# PIC Platform Scalable to 40 Channels

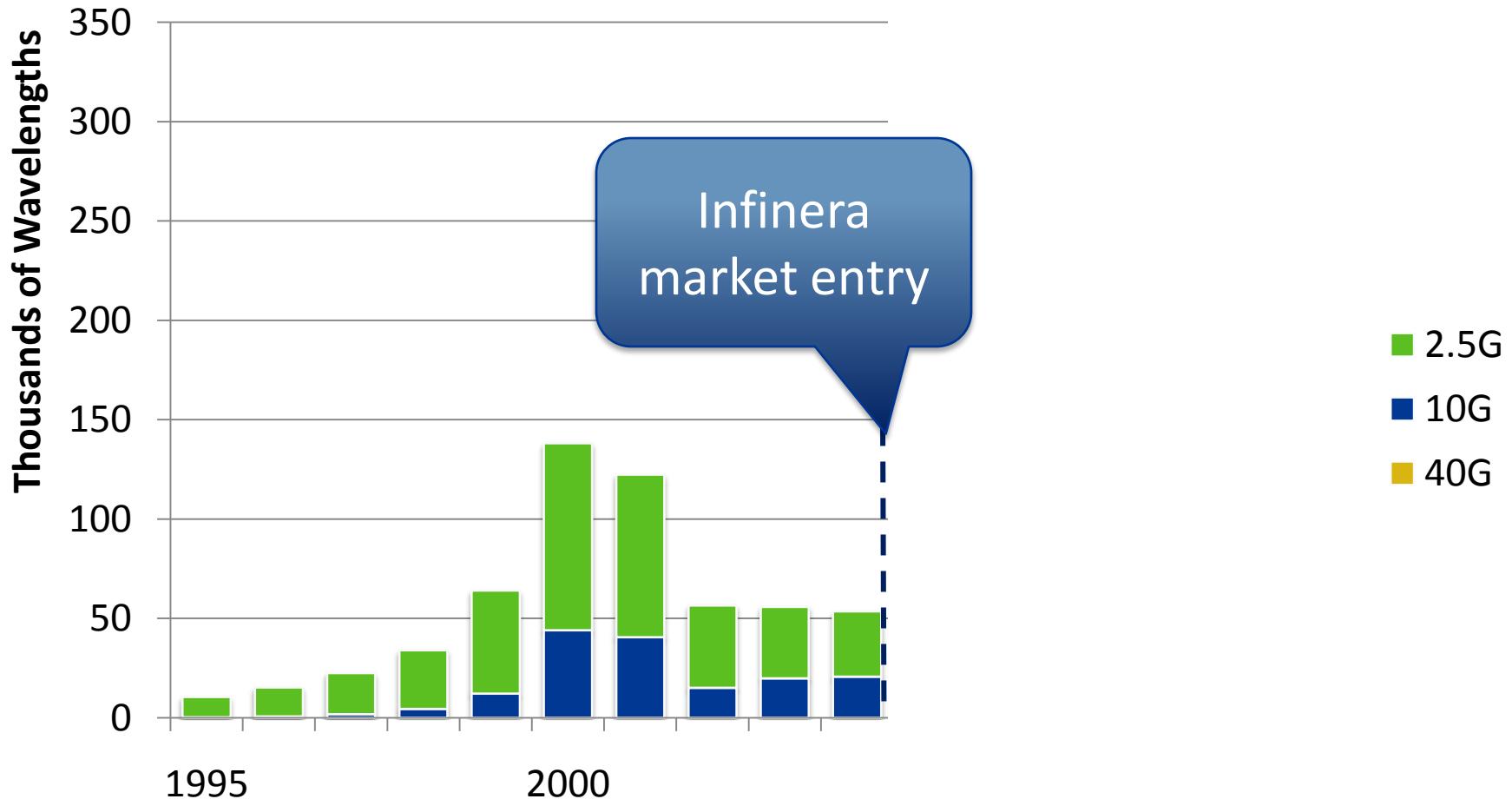


# Unit Share for 10G Waves



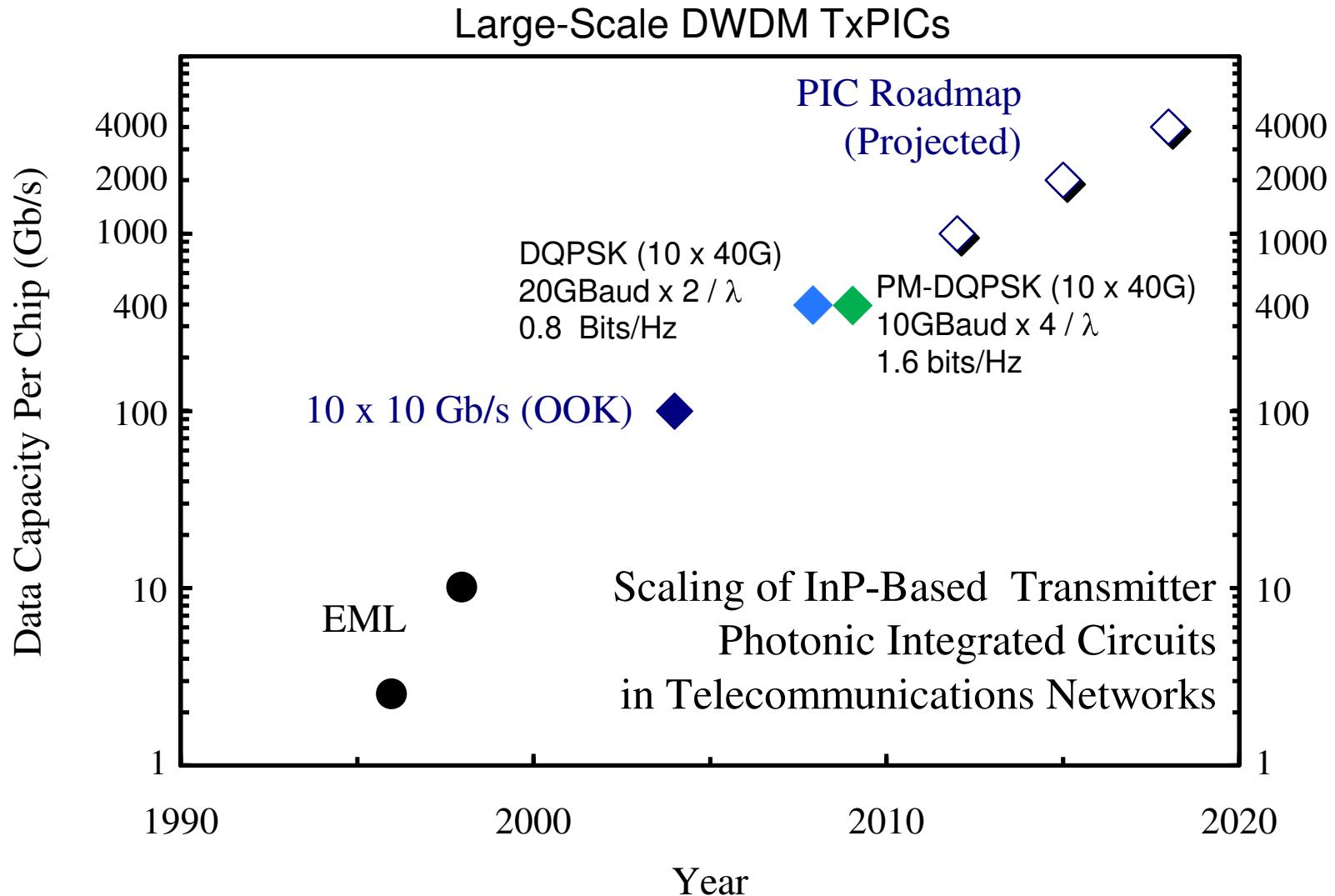
Source: Infinera and analyst estimates

# Worldwide Wavelength Shipments

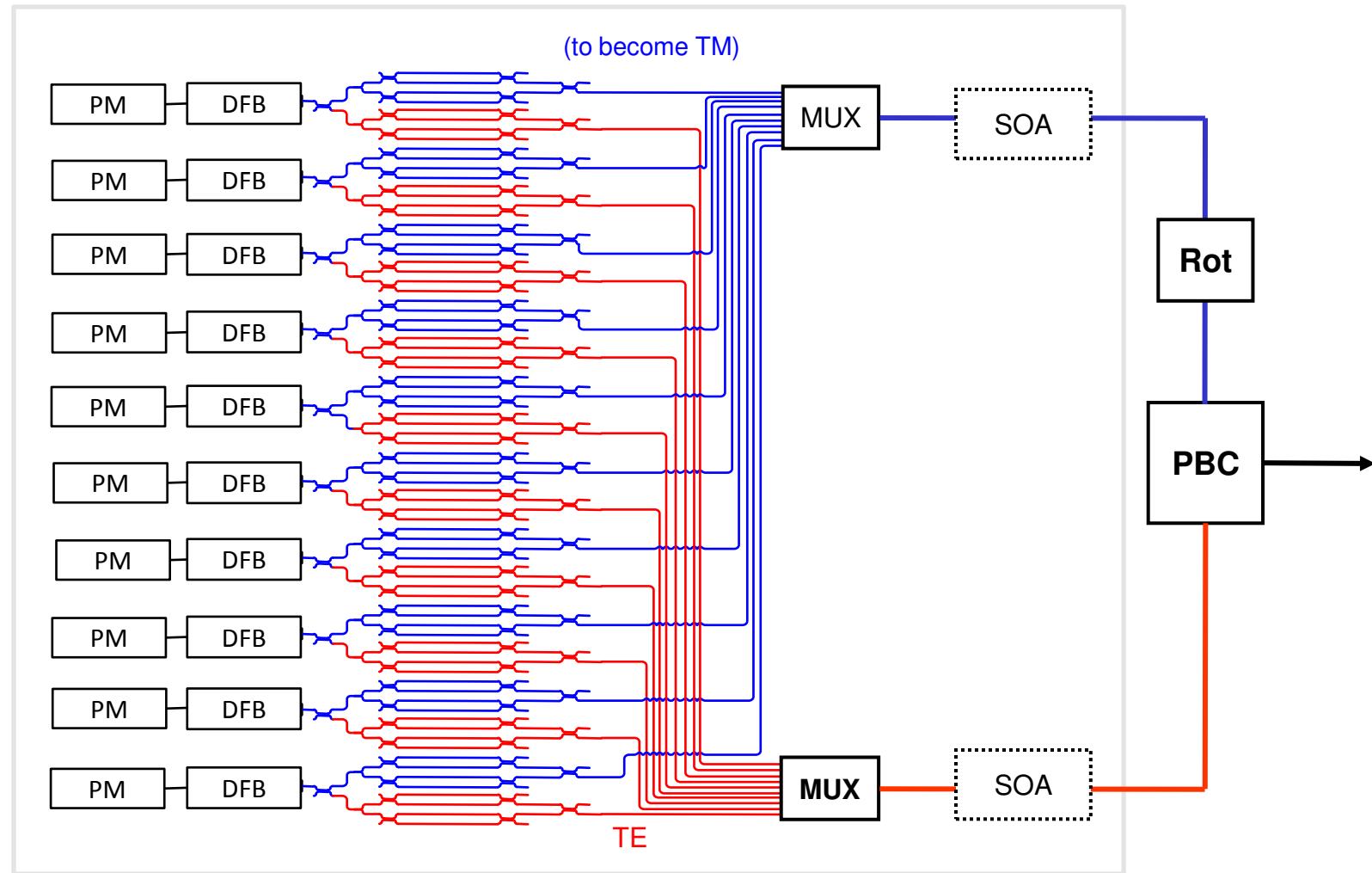


Source: Ovum and Infinera analysis

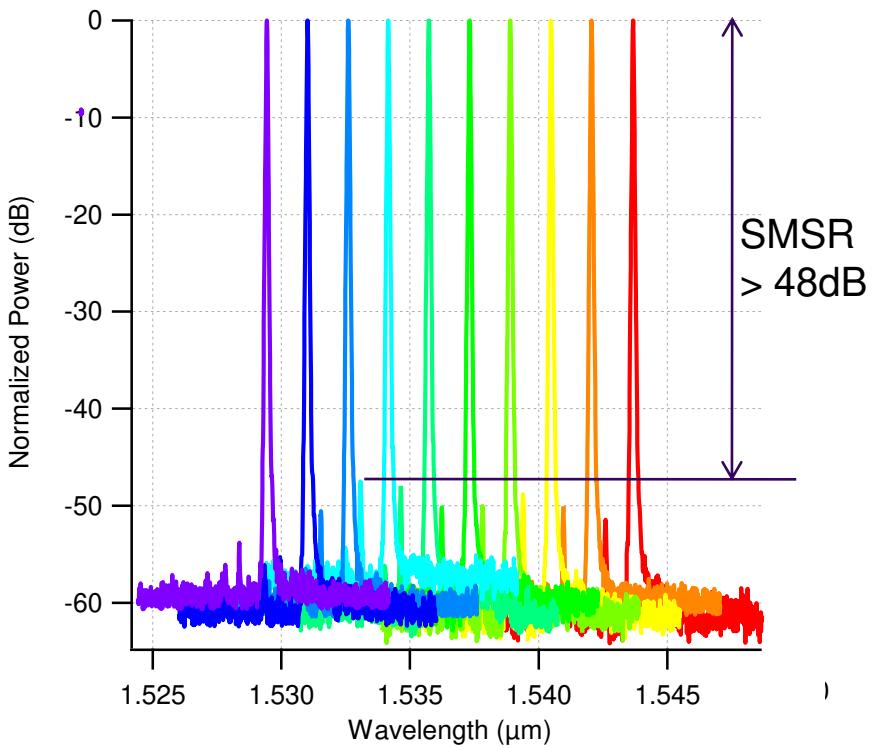
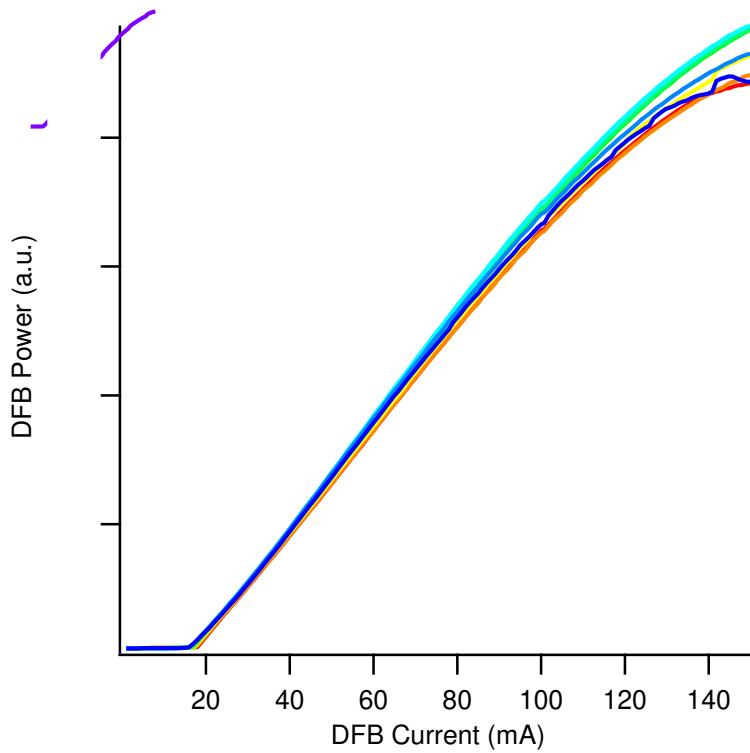
# Photonic Integrated Circuit Capacity Scaling History and Roadmap



# 400 Gb/s Transmitter Architecture

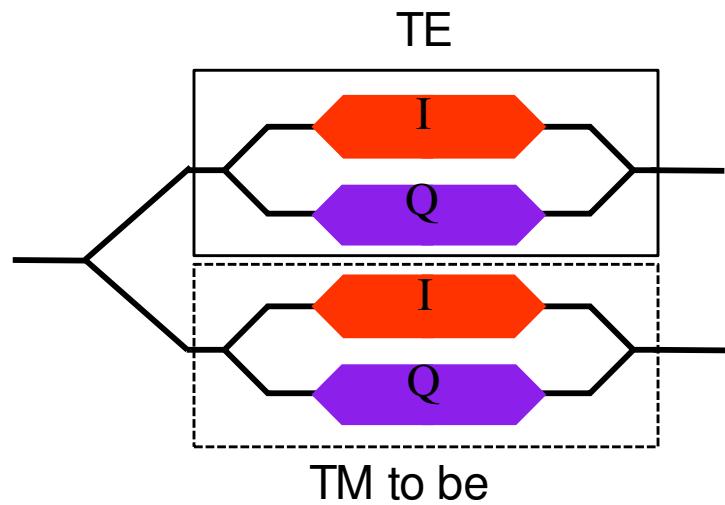
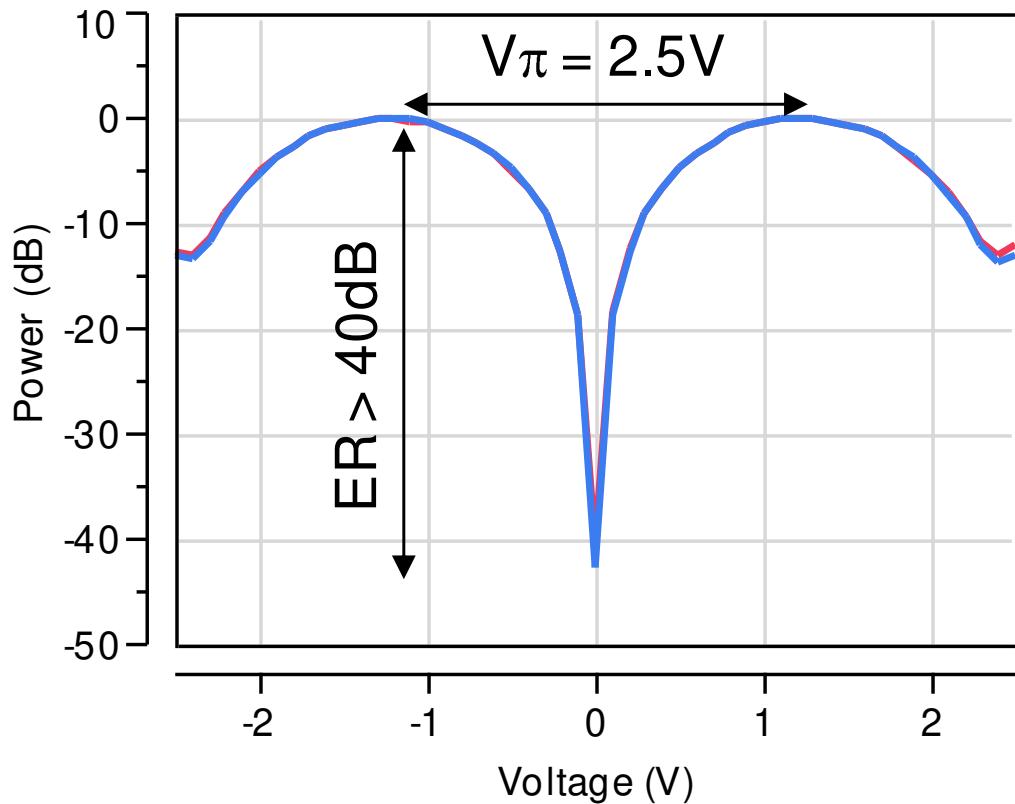


# 400 Gb/s PIC: 10-Channel DFB L-I and Spectra

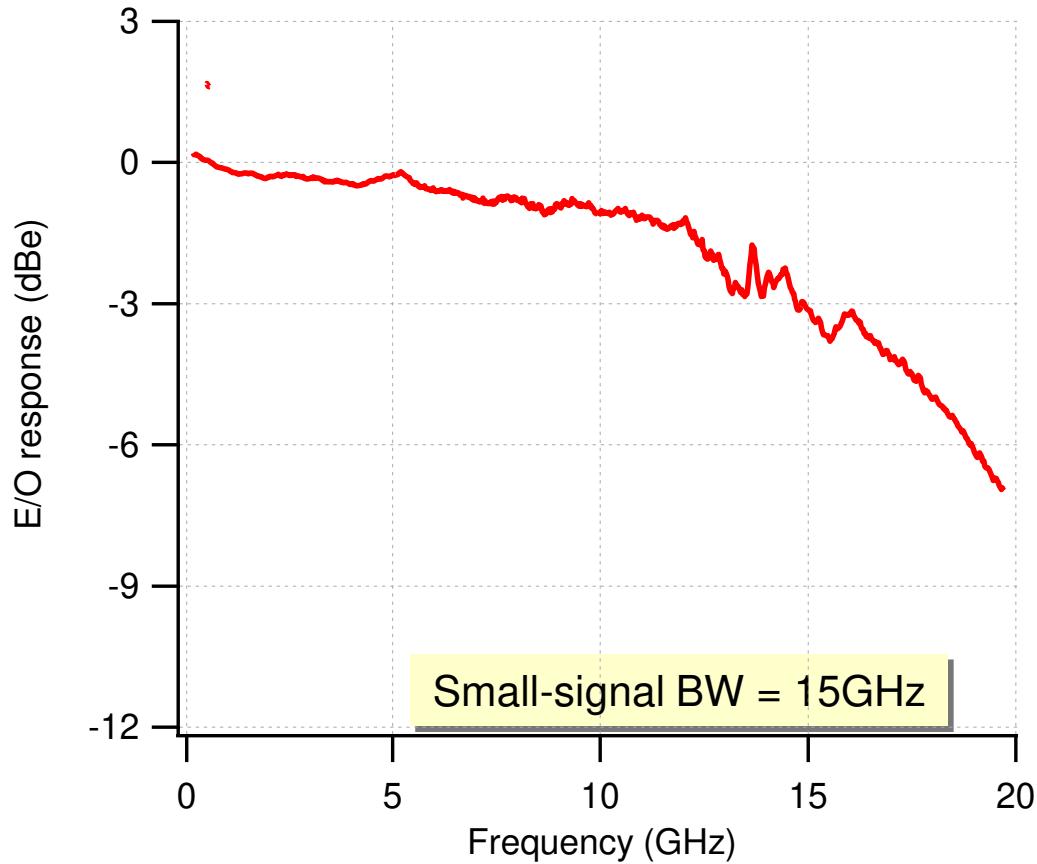


# 400 Gb/s Tx PIC: MZM Performance

$$V_{\pi} \text{ (material)} = 2V_{\pi} \text{ (switching)}$$

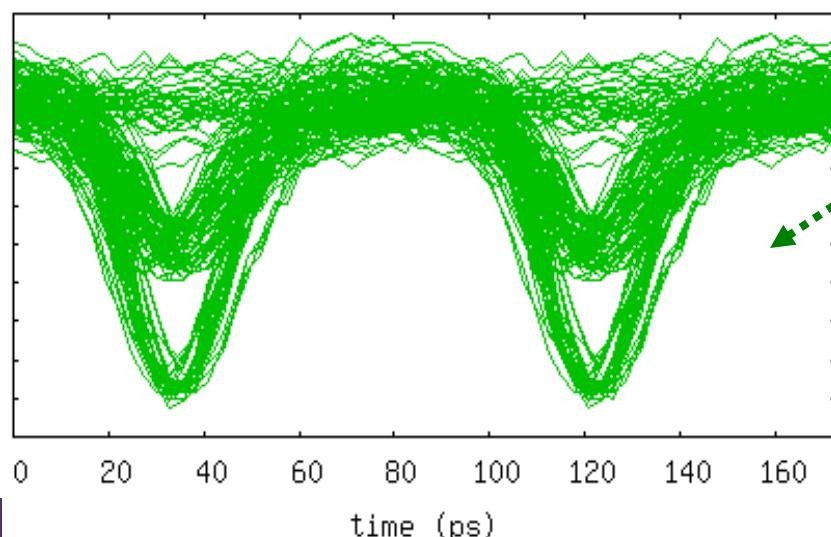
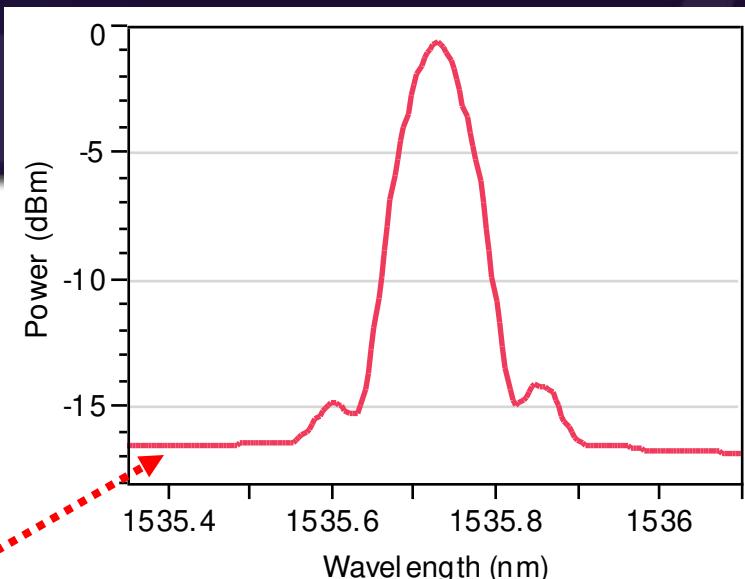
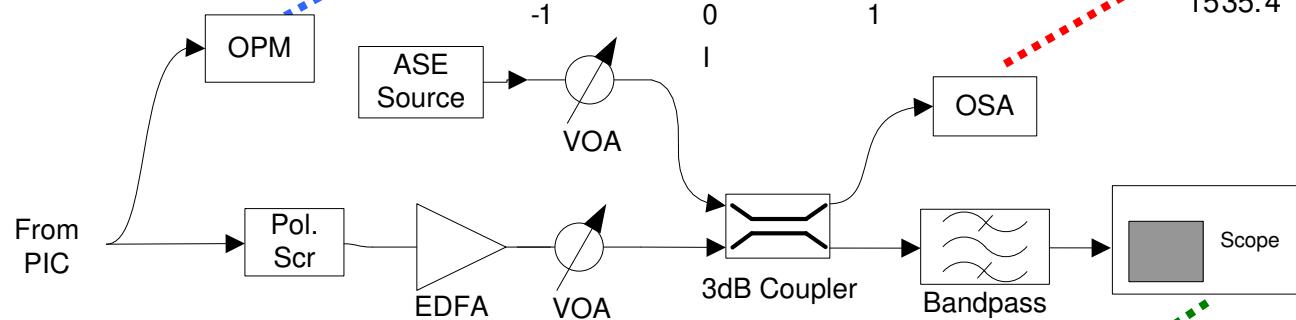
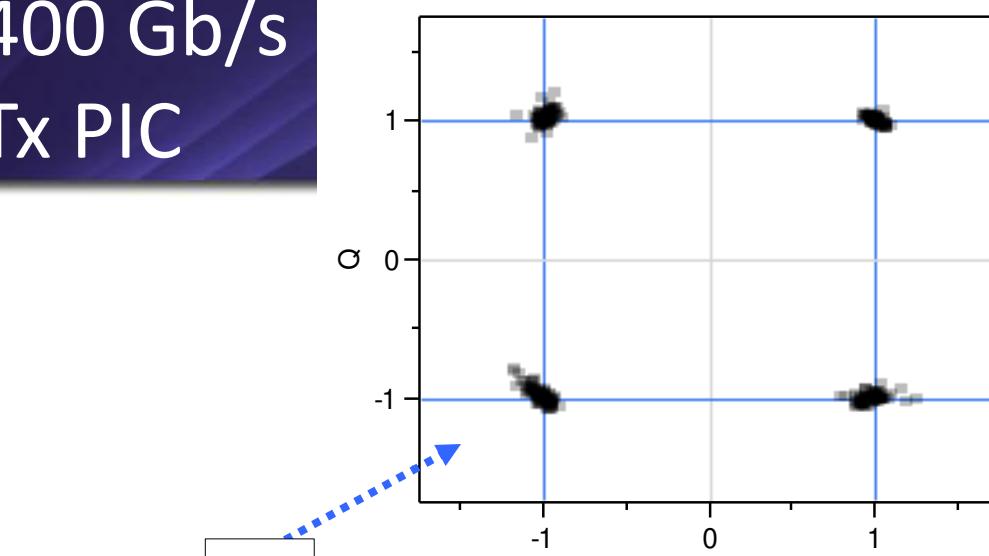


# 400 Gb/s PIC: MZM Bandwidth Characterization



# 400 Gb/s

## Tx PIC



# Wrap-up

Now .....

## 100G + 400G PICs

- Match discretes in performance
- Unmatched space, power and reliability
- Deliver lowest cost/bit with high spectral efficiency

Going Forward.....

## PIC Scaling

- Double capacity per chip every three years
- Ability to support advanced modulation schemes and receiver designs
- Expansion to other bands - L-band, S-band

