Photonics Technology for Optical Access Networks

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Massachusetts Institute of Technology

http://cips.mit.edu

Outline

Key Points from Last Time

Burst-mode transceivers

WDM PON

Korea WDM PON

Photonic Integration in the ONU/OLT

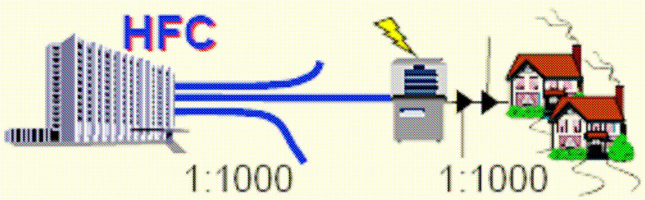
Hardware Costs

Projecting the Future

Broadband access Reference models

- Twisted wire pair
- Coaxial cable
- Fiber
- 1:24 Media sharing ratio
- Passive splitter
- Electrical power
- Remote cabinet

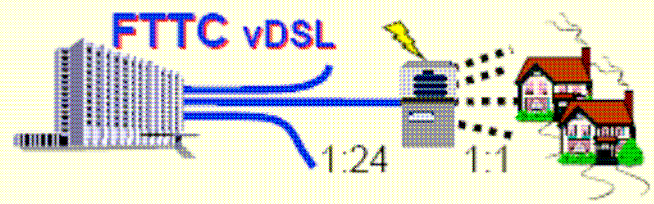
Cable TV companies



Shared fiber media
Powered node
Shared coaxial drops

5% optics
3 million users/year

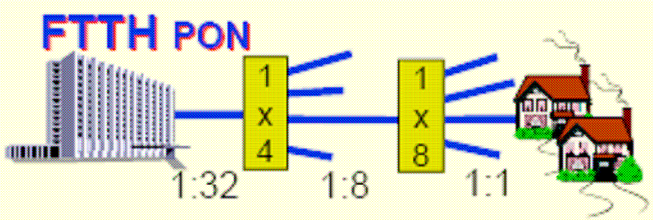
Local exchange carriers (LECs)



Shared fiber media
Powered node
Dedicated wire drops

35% optics
0.6 million users/year

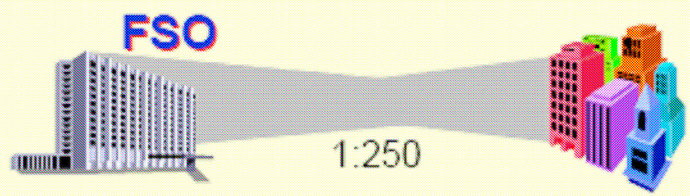
Municipalities, LECs



Shared fiber media
Passive node
Dedicated fiber drops

25% optics
0.3 million users/year

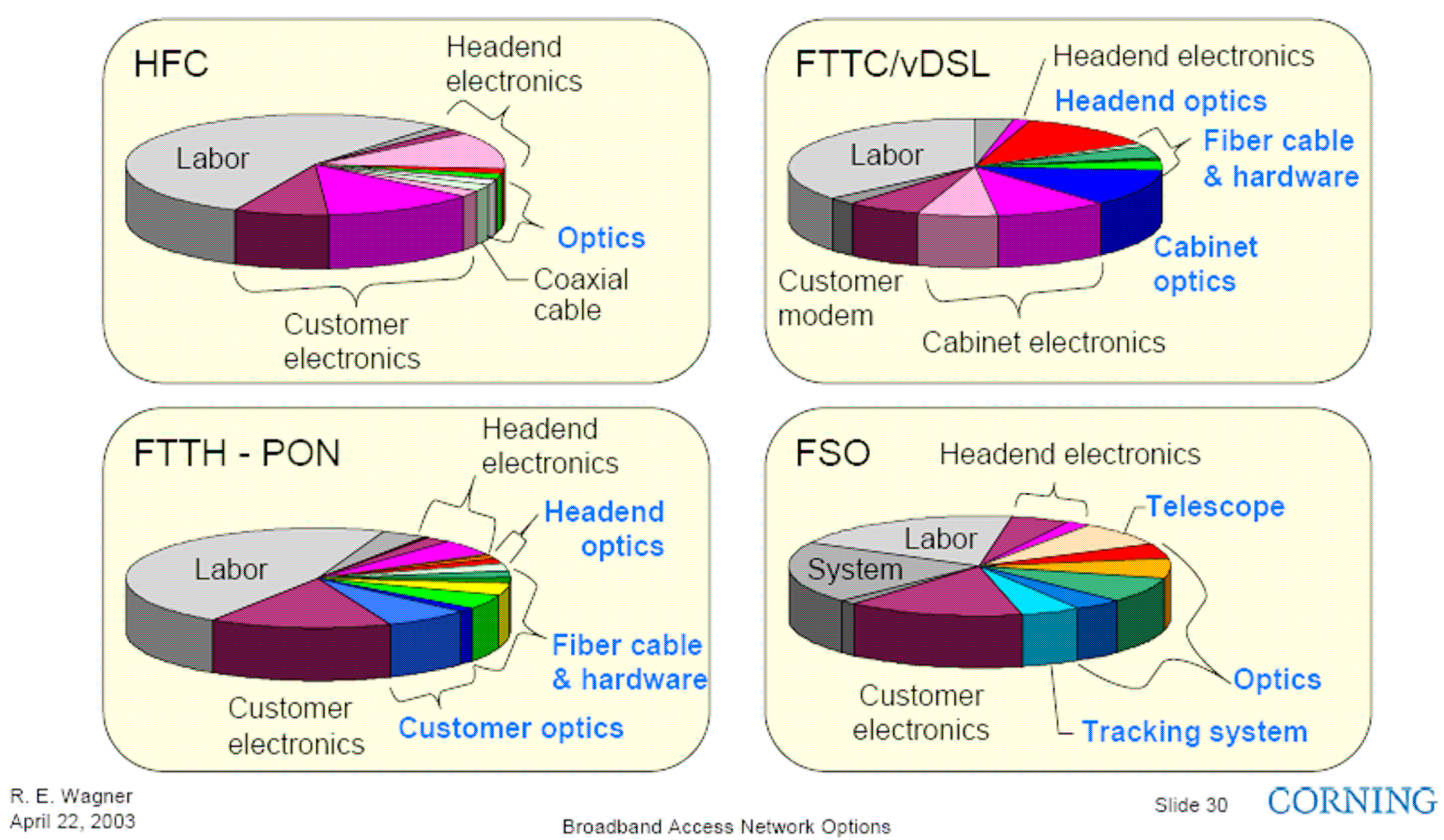
Enterprises, LECs



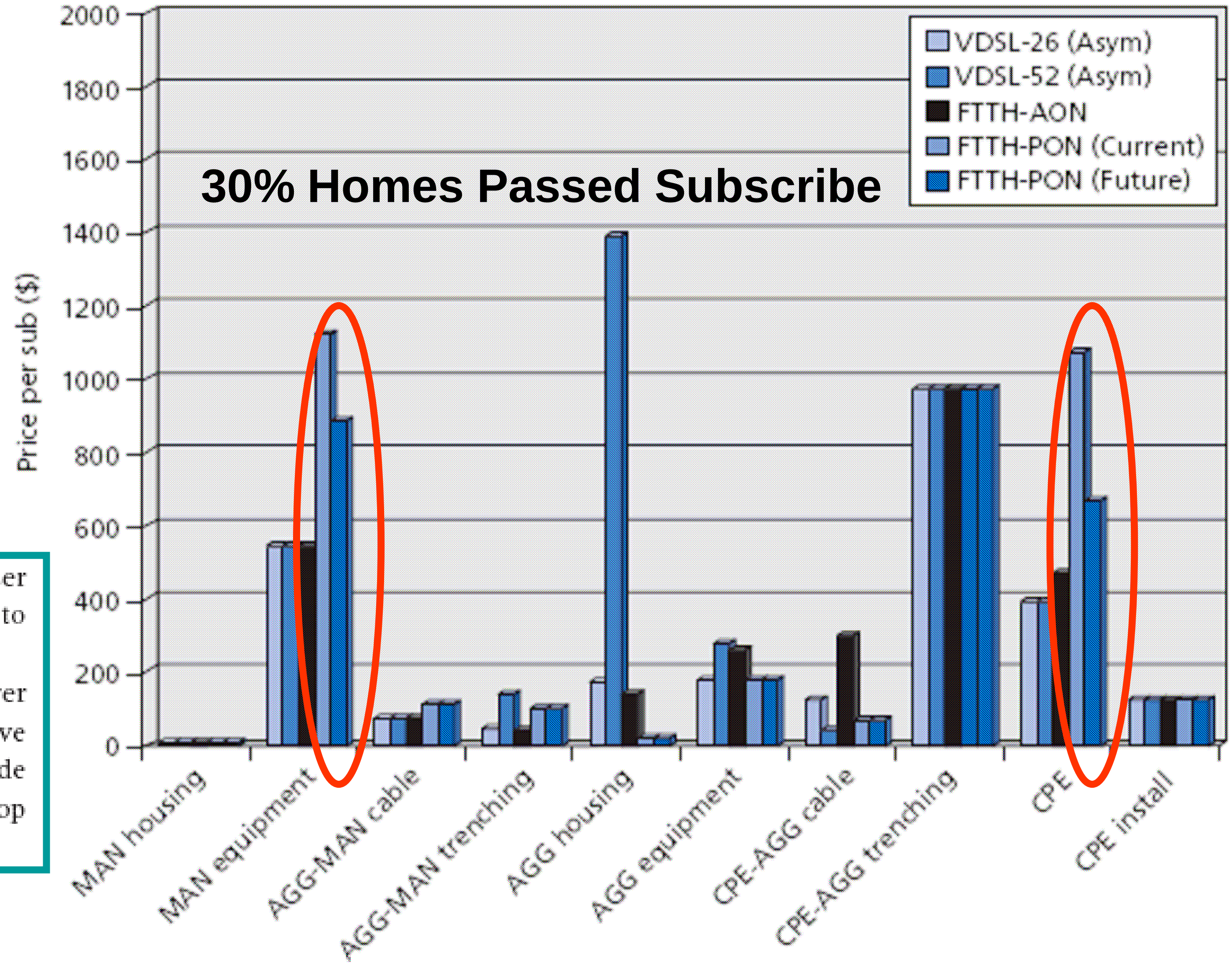
Shared media (air)
No outside plant
No drops

40% optics
1 million users/year

Corning 'Broadband Access Models' 2003



Lucent 'Economics of Fiber to the Home' 2003



CPE: Currently, $600 extra for a burst mode laser and a PON driver device. Expected to drop to $200 in the future.
MAN: Currently, $4600 extra for the high power distributed feedback (DFB) laser required to drive the PON at 1550 nm downstream, a burst mode receiver, and control electronics. Expected to drop to $2300 in the future.

AGG—Aggregatore
AON—Active optical network
CPE—Customer premises equipment
DSL—Digital subscriber line

FTTH—Fiber to the home
MAN—Metropolitan area network
PON—Passive optical network
VDSL—Very high bandwidth DSL

Bell Labs Technical Journal 8(1), 181–206 (2003) © 2003 Lucent Technologies Inc. Published by Wiley Periodicals, Inc. Published online in Wiley InterScience (www.interscience.wiley.com). • DOI: 10.1002/bltj.10053

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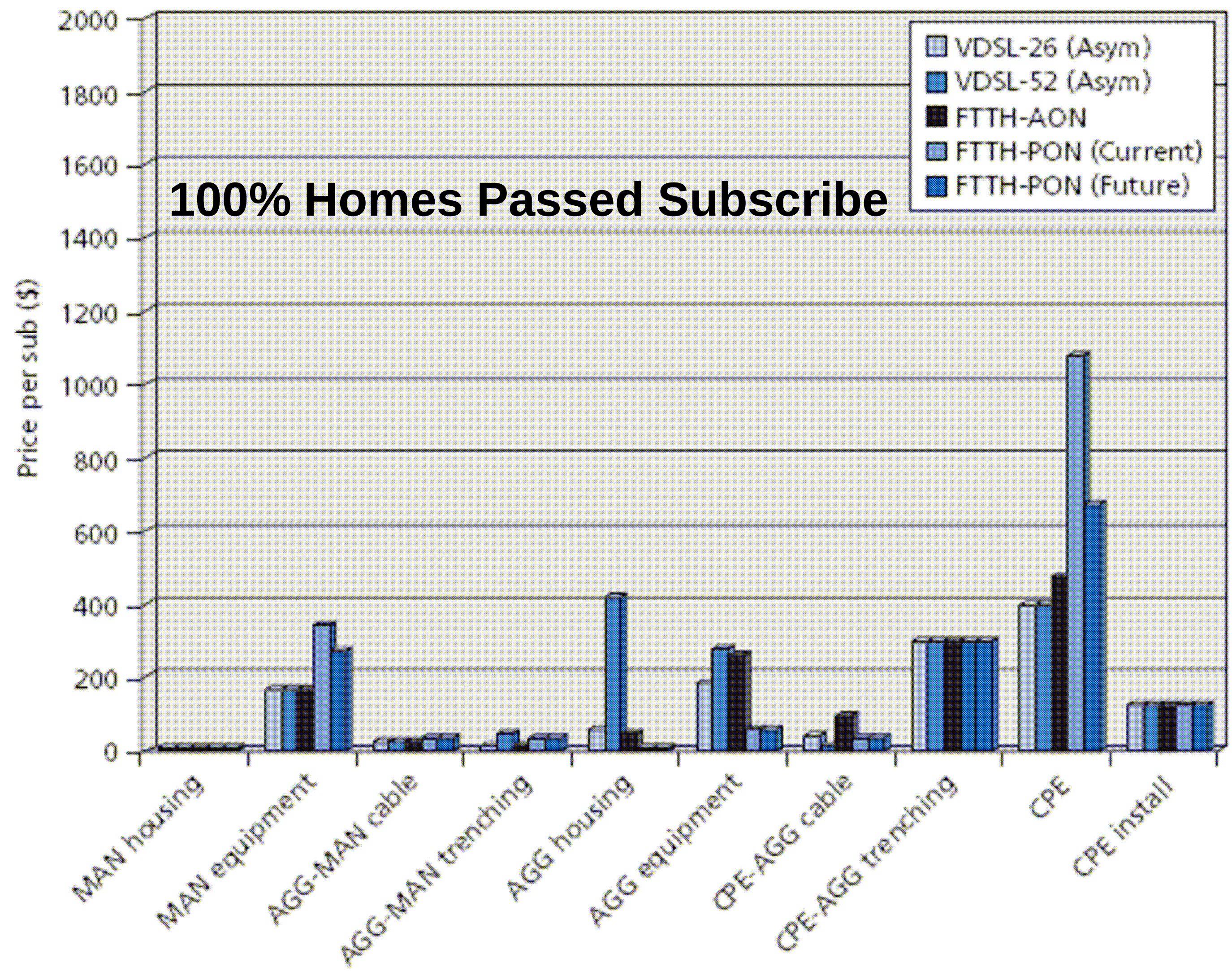

AGG—Aggregatore
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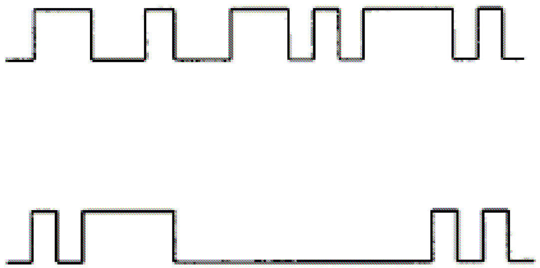
VDSL—Very high bandwidth DSL

Burst-Mode Optics for TDM-PON



Typical optical traffic (balanced)

Burst-mode traffic

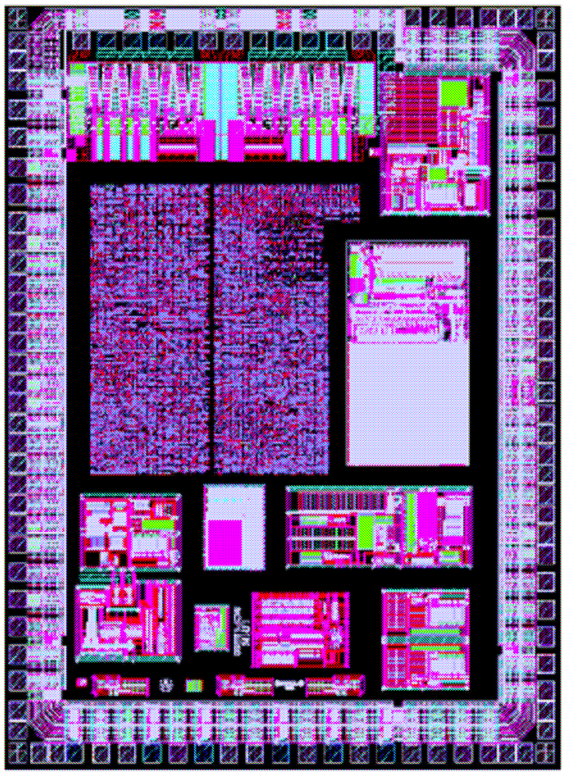
Burst mode triplexer

- optics stays the same
- need to change the low-frequency cut-off of all of the stabilization circuits
- need to sense and quickly wake-up receivers and laser drivers

If there is an additional cost associated with burst-mode, it is in the electronics

Burst-Mode Optics for TDM-PON

SCF15530



Supports Burst Mode at 155mbps or 622mbps Per G983.1

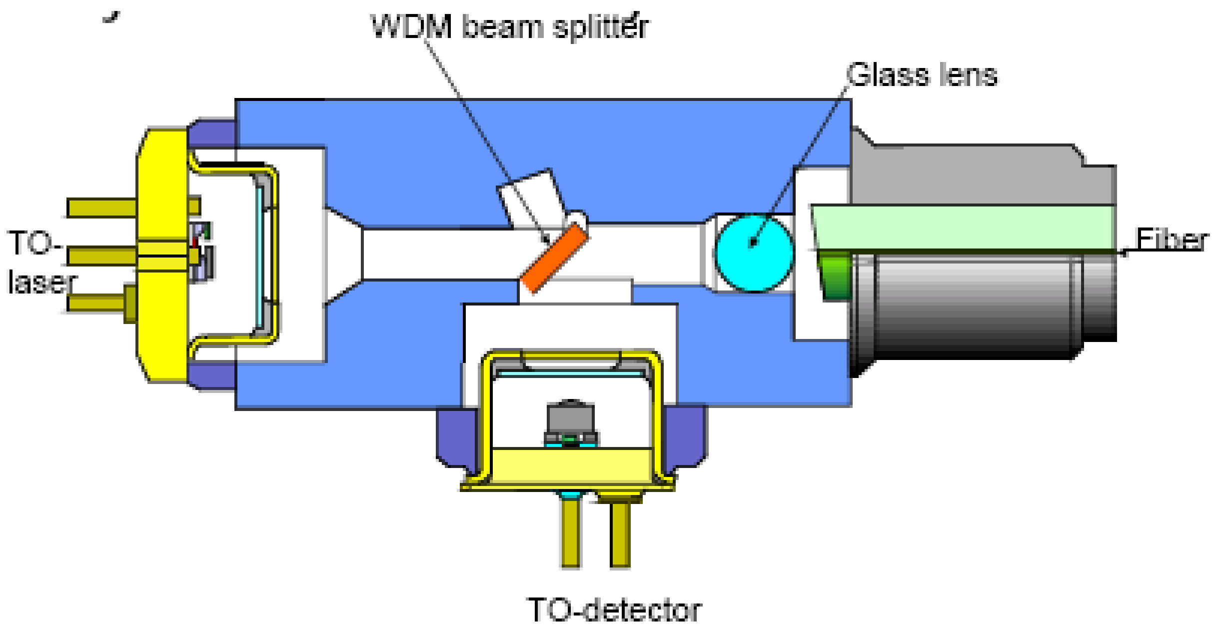
MOTOROLA
intelligence everywhere

Lucent (*2000*)
- 155 Mbps burst mode ICs
  - laser driver IC, US$25
  - receiver IC, US$23
  - clock data recovery IC, US$28

Vitesse (*March 2005*)
- 2.5 Gbps IC
  - laser driver + limiting amp
  - VSC7965 $2.25

The burst-mode optics cost has been driven down since 2003

Optical Diplexer/Triplexer Sub-Assembly



30% of ONU Cost is the optical front end

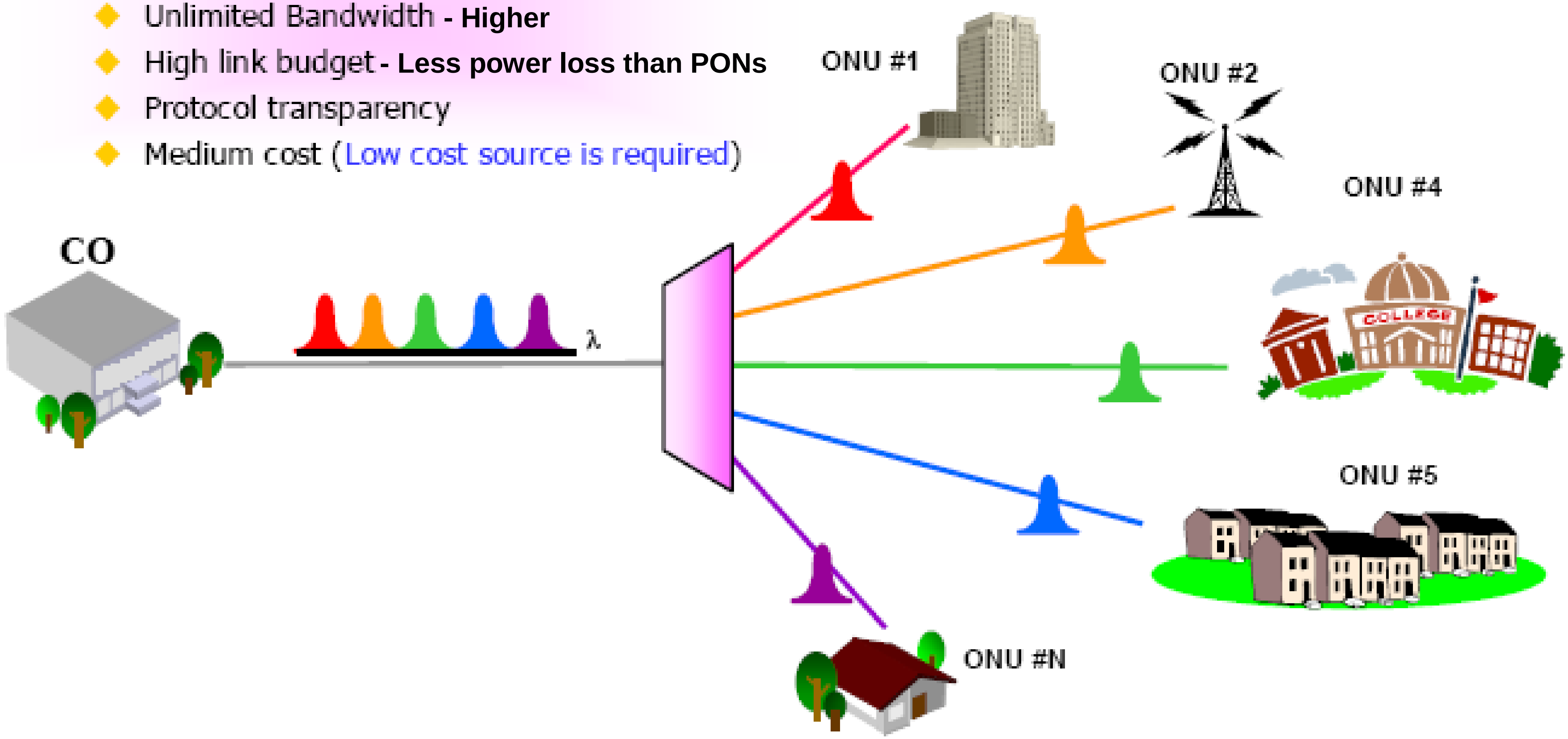
- Brecht Stubbe, Alcatel, 2002

ONU Cost is approx $100

- OFC/NFOEC 2005 in OPN News

WDM PON Architecture

- **Wavelength division multiple access**
  - High security
  - Unlimited Bandwidth **- Higher**
  - High link budget **- Less power loss than PONs**
  - Protocol transparency
  - Medium cost (Low cost source is required)



WDM PON Benefits

Access method		TDMA	WDMA
Transparency (independency)	Protocol	No	Yes
	Bit rate	No	Yes
	Collision	No	Yes
	λ	Yes	No
Legacy support		No	Yes
Graceful upgrade		No	Yes
Security and privacy		Low	High
Cost		Low	Medium (Source cost)

TDMA

- N-fold power budget penalties ⇨ due to the power splitting approach and the shared OLT source
- OLT and all ONU must work at aggregate bit rate

  Consequences:

  ↳ Limited transmission bit rate

  ↳ Complicated TDM/TDMA upgrade

- **Concerns about:**

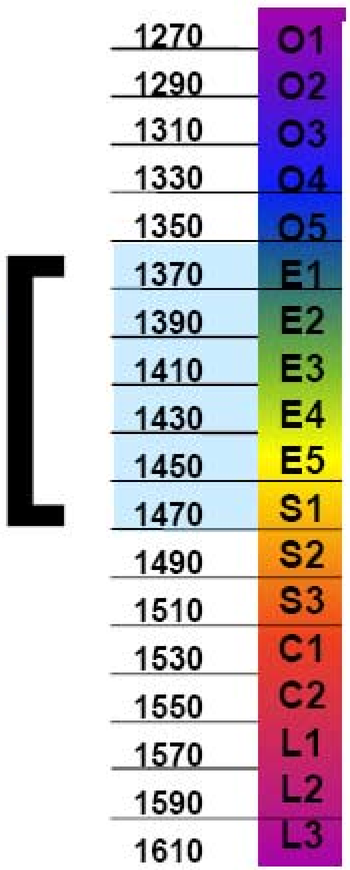
  ↳ Privacy ⇨ broadcast of the downstream information

  ↳ Network integrity ⇨ one ONU can corrupt the entire upstream transmission

CWDM: Low Cost WDM

ZWPF

- Adds 6 additional low cost optical channels



Full Spectrum Wavelength grid

- ITU G.694.2 (1270 – 1610 nm)

CWDM

- 40% lower cost than DWDM
- Multiple vendor support

- **20 nm channel spacing**
- **13 nm channel window**
- **7 nm guard band**

4-channel optical CWDM as cheap as $300
- OMRAM, Japan

Comparison of CWDM and DWDM

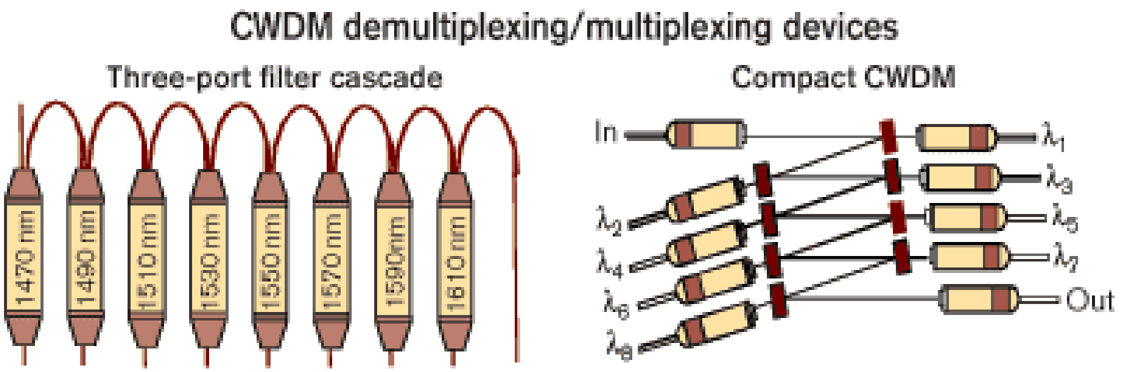
	CWDM	DWDM
Channels	**4-8, up to 18 with special metro fibers**	**16-32 (metro) and 40-80***
Bands	O+S+C+L	C+L
Channel spacing	**20 □ 6-7 nm**	**1.6 and 0.8 nm**
Laser technology	Uncooled DFB	Cooled DFB
Filter technology	Thin film	Thin film, Grating, AWG
Channel capacity	**<2.5 Gbps**	**10 Gbps and higher**
Fiber Capacity	10-20G, up to 45 Gbps	400-800 Gbps
Amplification	**Not cost effective, some regen used**	**EDFA, Raman**
Distance	Less than 80 km	Up to 1500 km and more
Cost	**Low**	**High***

46% cost of DWDM for 8 ch MUX

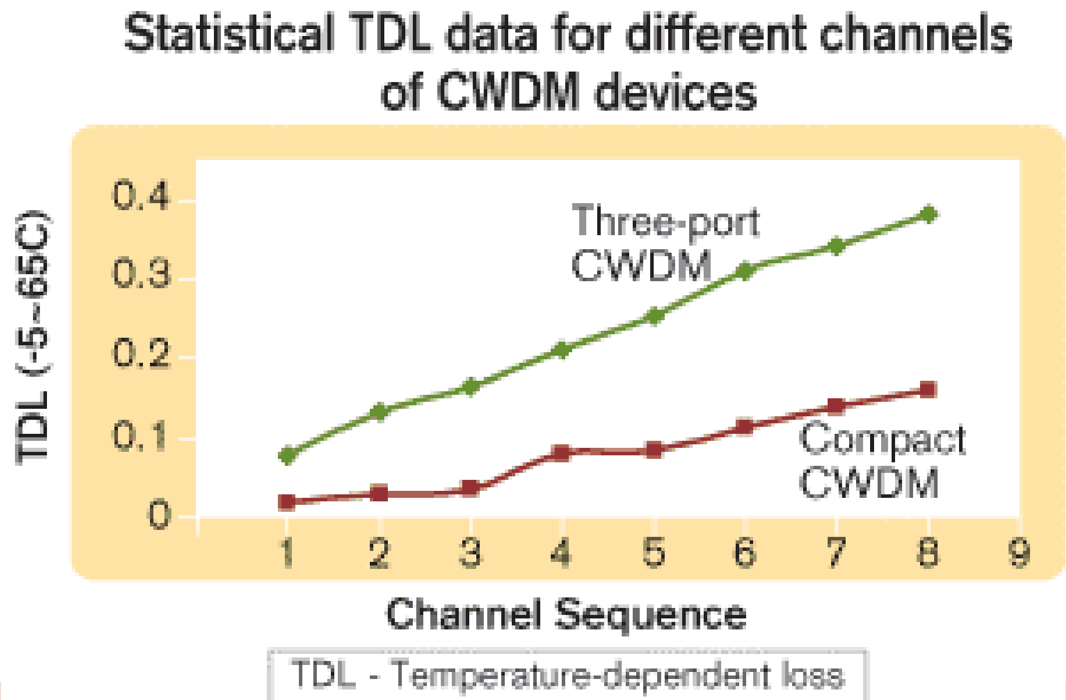
66% cost of 2.5 Gbps transponder

- Lightwave

Thermal Stability of CWDM 'Splitter'

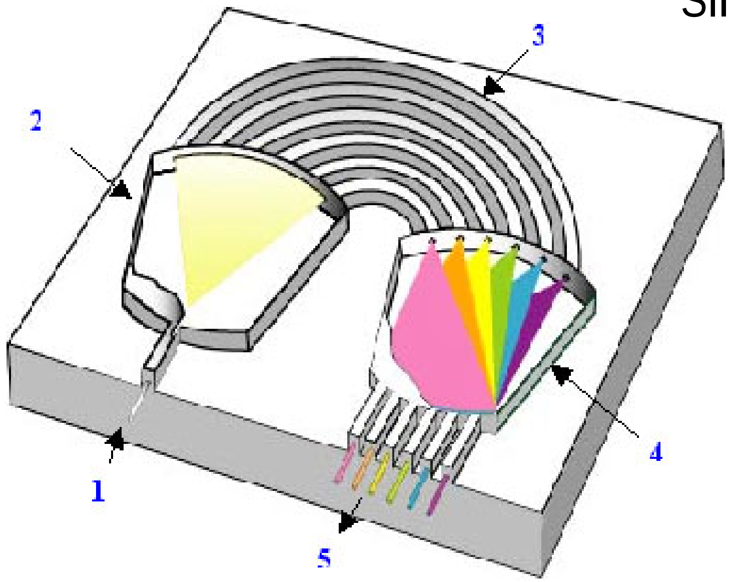


Temperature dependence dominated by alignment of microoptics

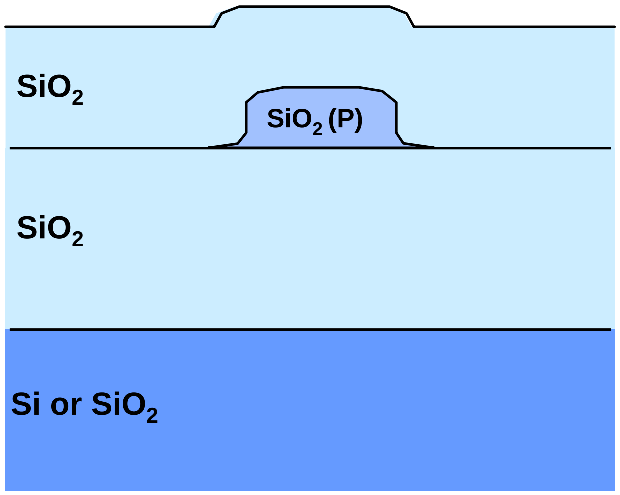


Lightwave March, 2005

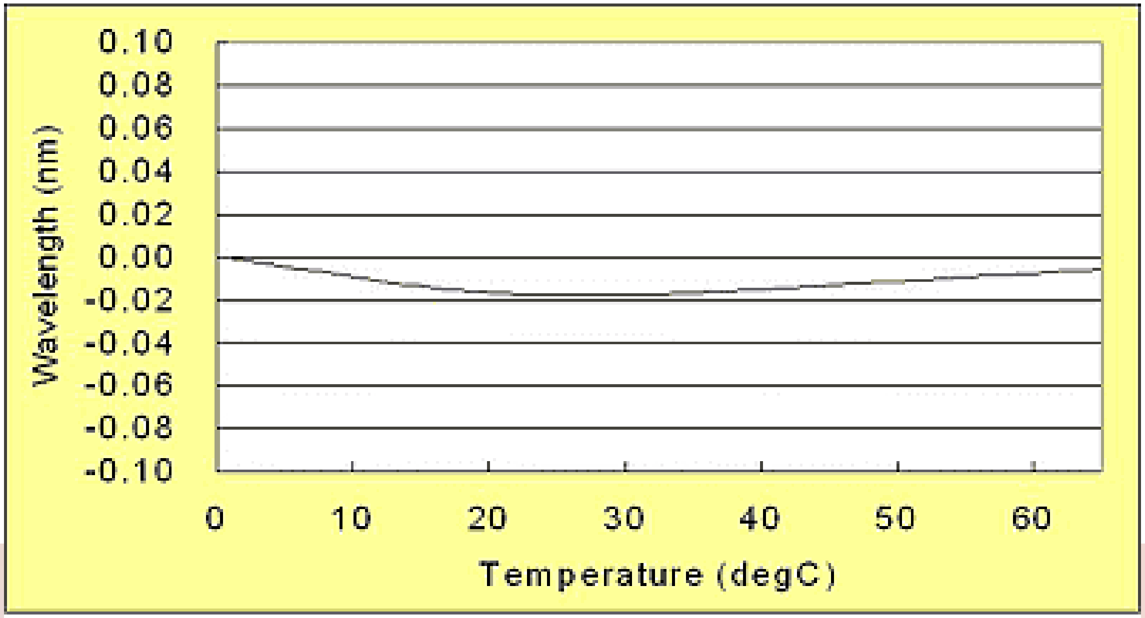
Athermal DWDM 'Splitter'



Silica waveguide + polymer for thermal compensation

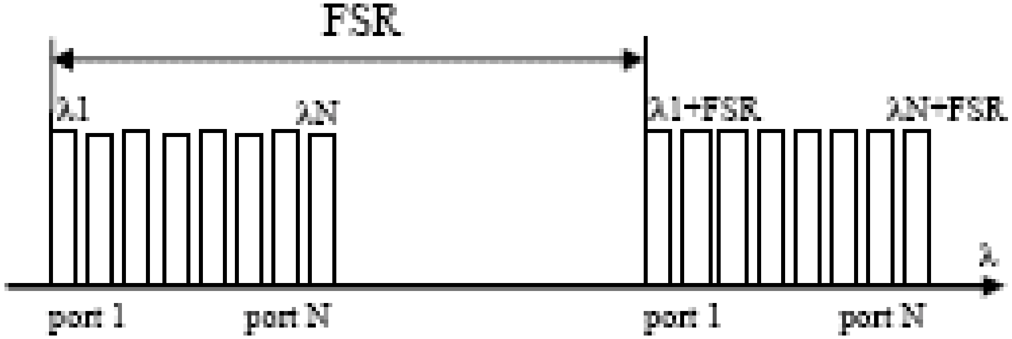


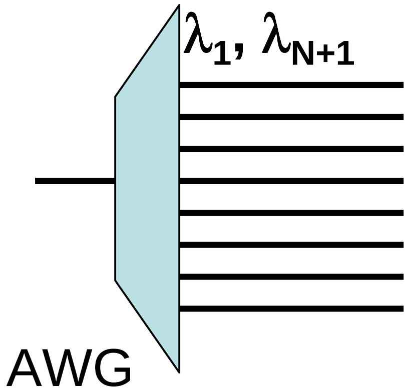
Temperature dependence dominated by change of index



Temperature stability < 30 pm at 0-60 °C

Free Spectral Range of DWDM 'Splitters'





Two-colors can be routed along the same path by virtue of the periodicity of the wavelength response for an AWG

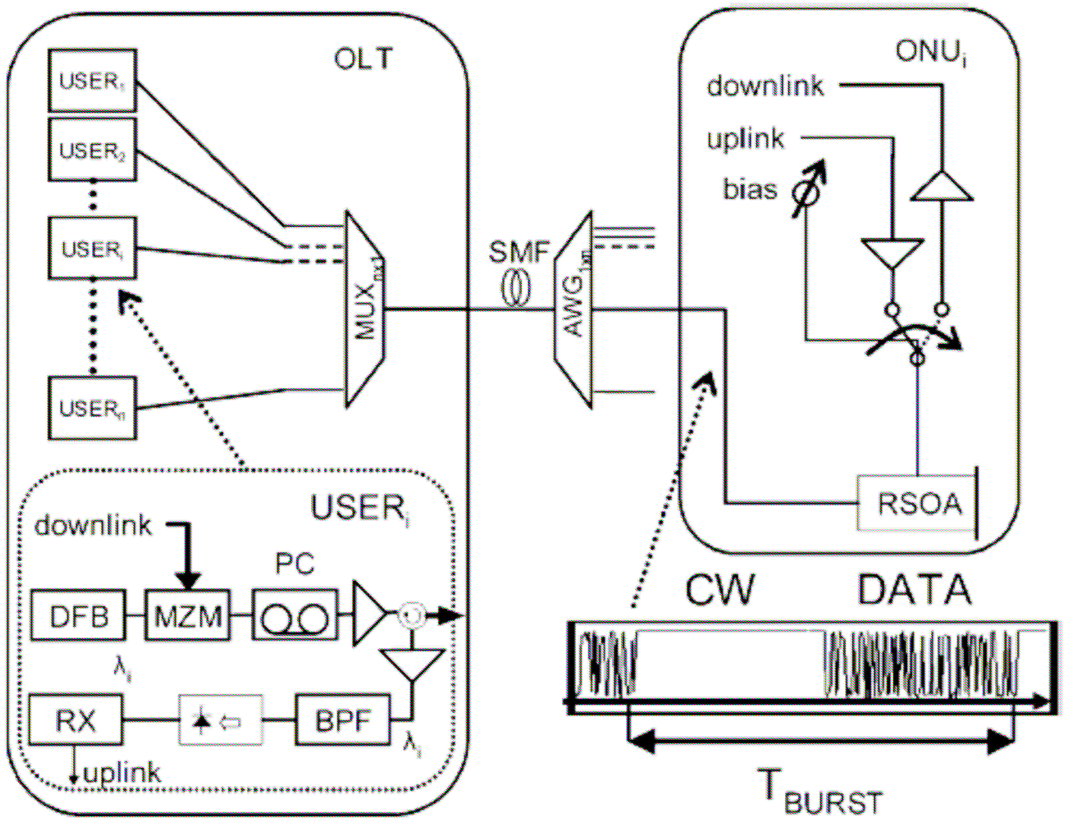
Wavelength Independent ONU

TDM for Upstream/Downstream

Single fiber for upstream/downstream

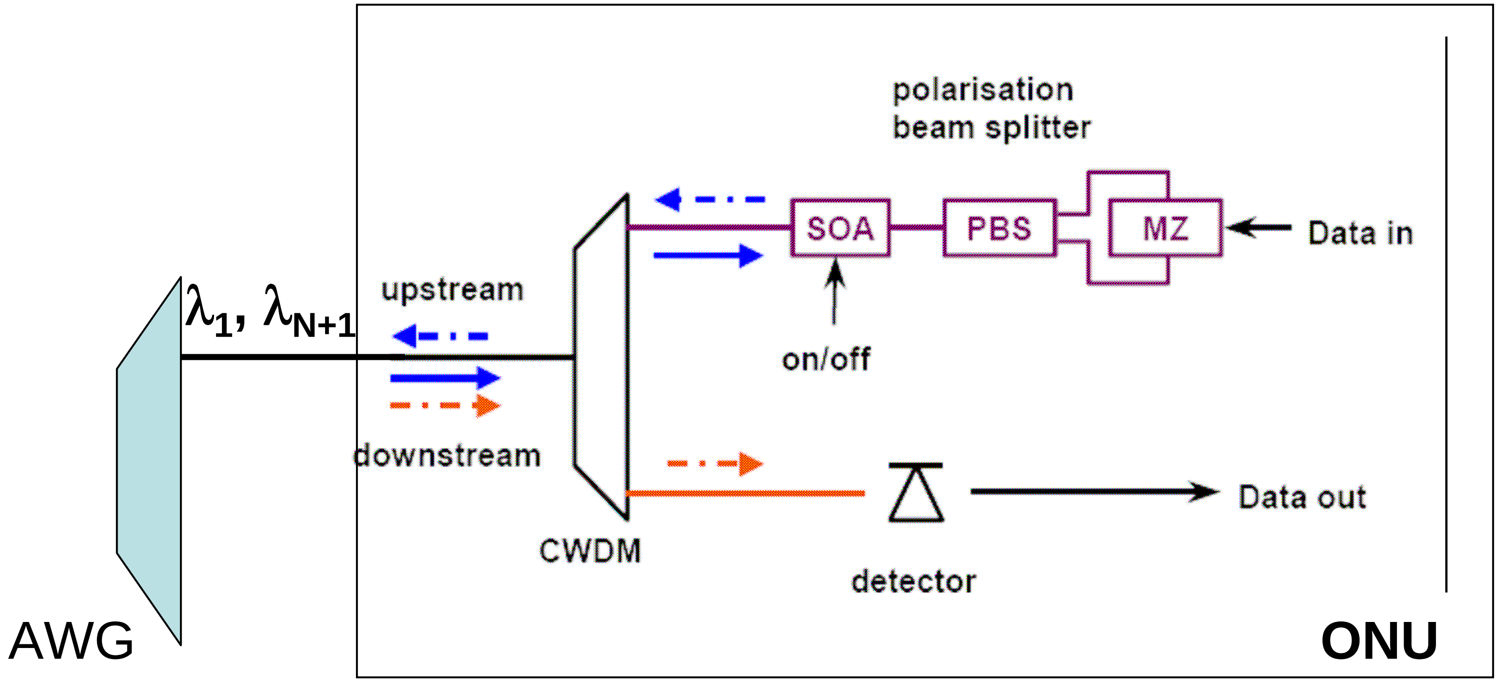
No laser at ONU

Provisioning and stabilization all at OLT



Wavelength Independent ONU

WDM for Upstream/Downstream



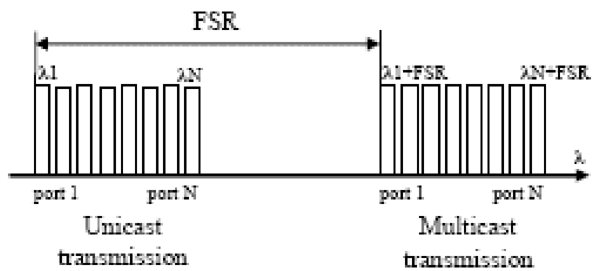
Takes advantage of periodicity of AWG type optical MUX

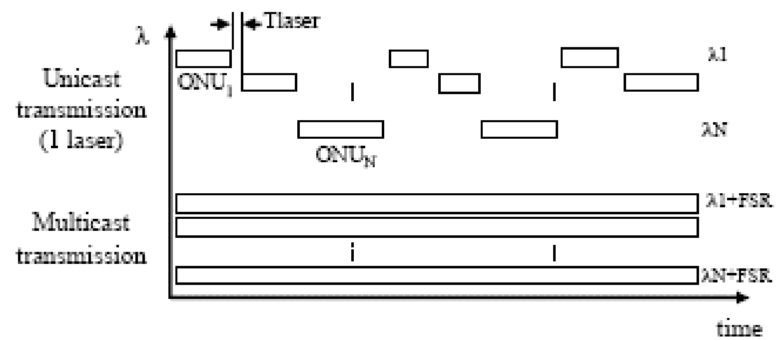
Jeroen Wellen
Bell Labs Advanced Technologies
Lucent Technologies

Wavelength Independent ONU

WDM for Upstream/Downstream

Simultaneous multicast and unicast transmission…





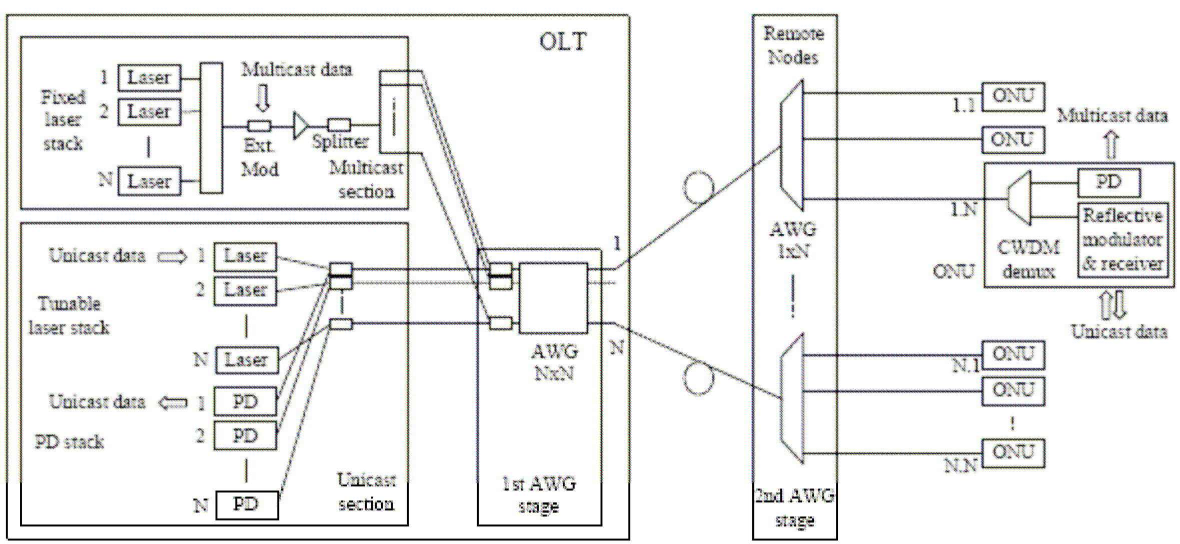
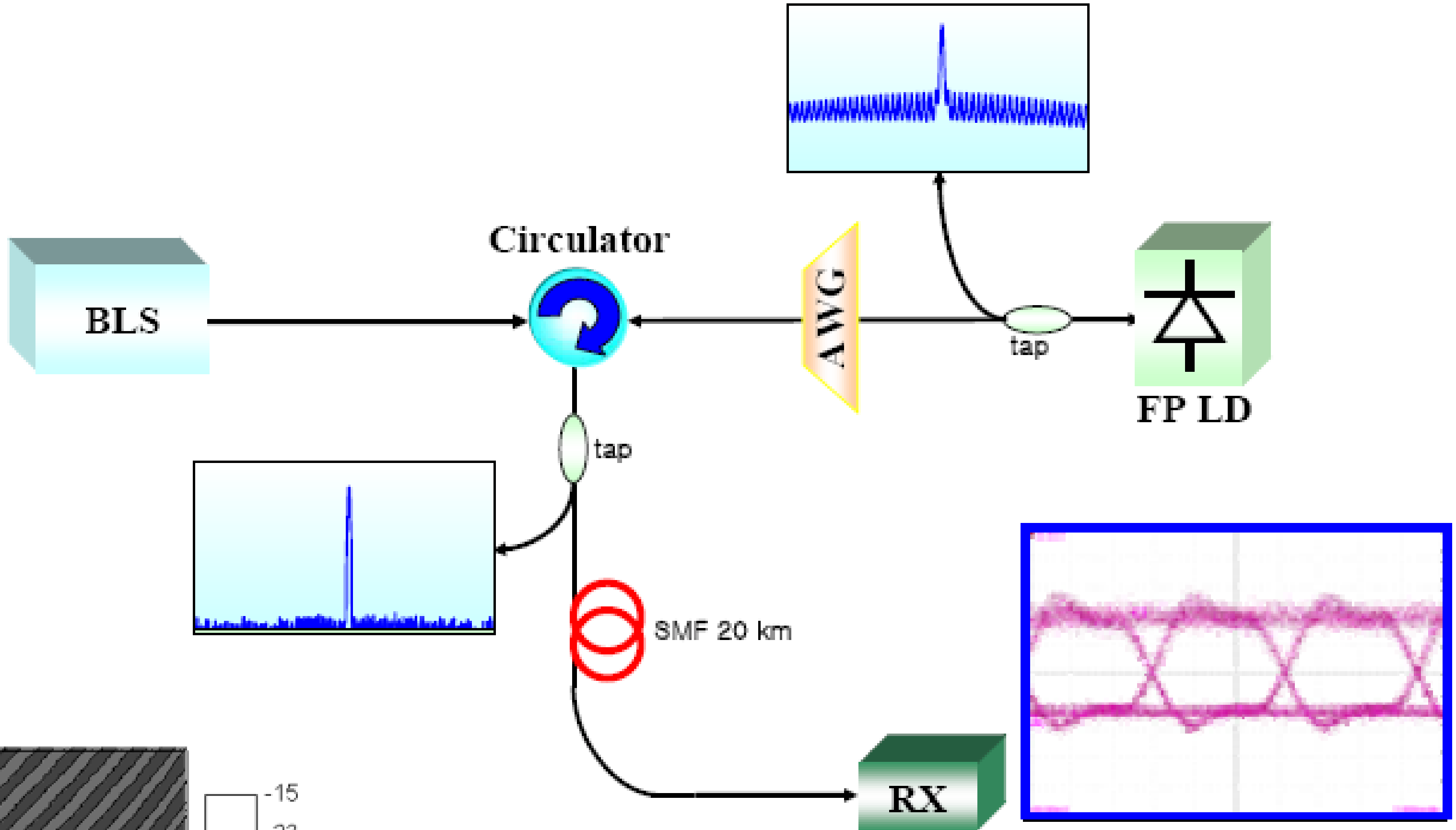


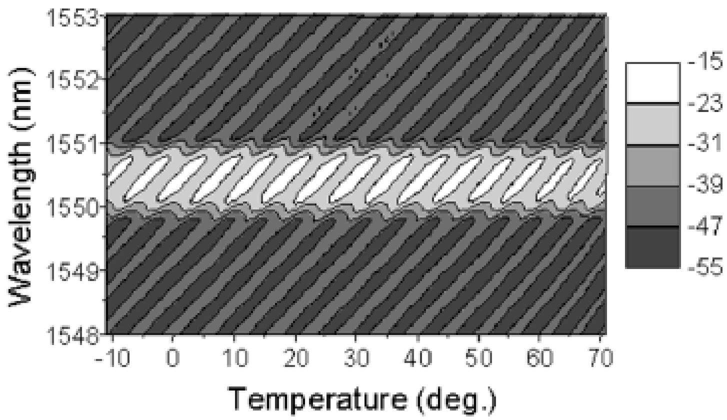
Fig. 1. Network Topology

18 April 2005 / Vol. 13, No. 8 / OPTICS EXPRESS 2888

Wavelength Independent ONU

Injection Locked Fabry-Perot Laser





Wavelength Independent ONU

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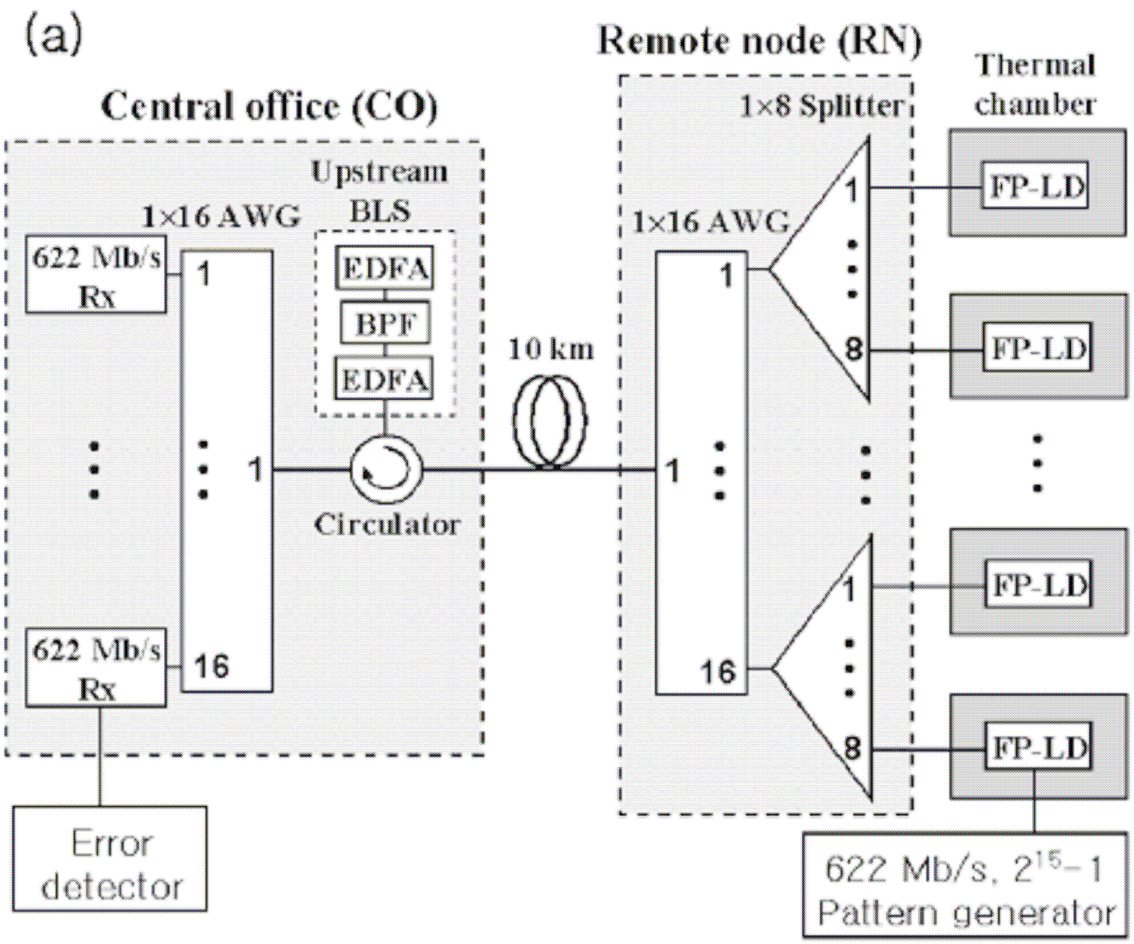
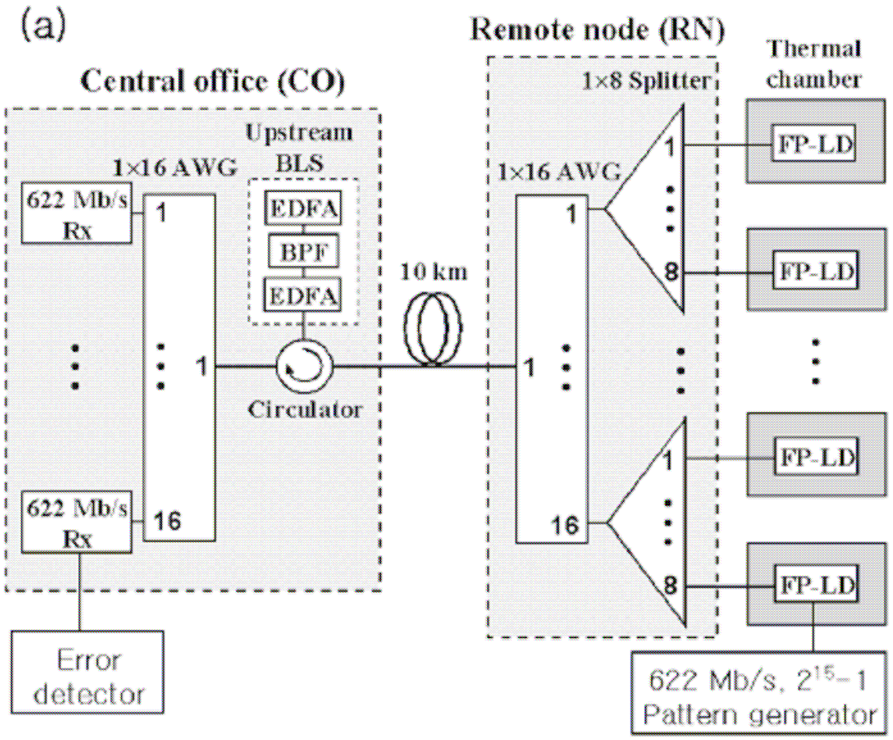


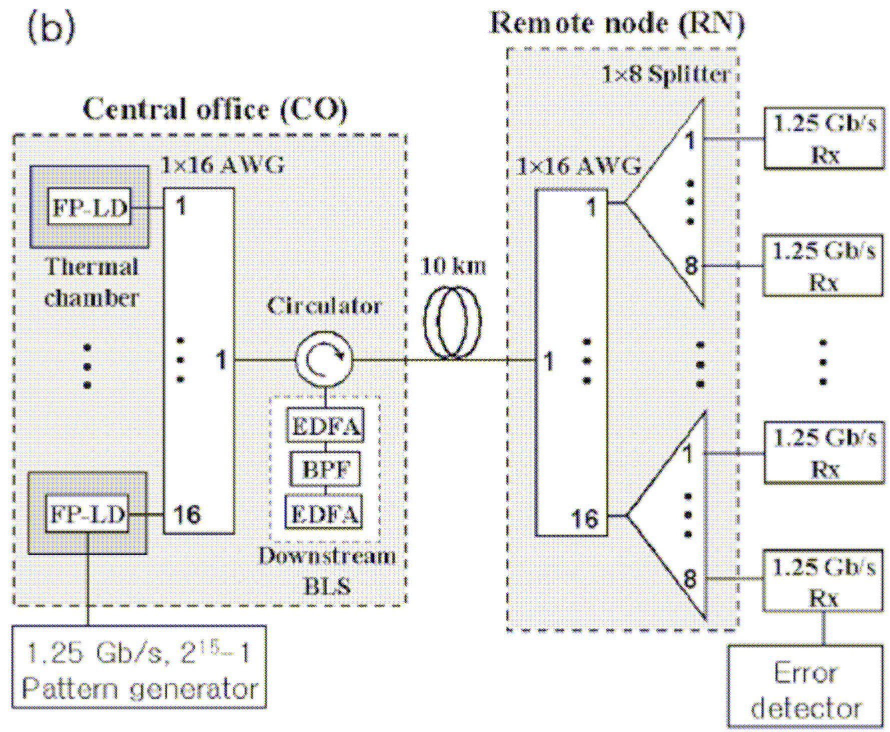
- FP-LD automatically emits at correct λ
- Can employ DWDM multiplexer without detuning loss
- Separate upstream/downstream using circulator (moderately expensive)

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 23, NO. 1, JANUARY 2005

Wavelength Independent ONU

Injection Locked Fabry-Perot Laser





A hybrid WDM/TDM-PON serving 128 subscribers at the data rates of 1.25-Gb/s downstream and 622-Mb/s upstream is presented. It has 16 100-GHz-spaced WDM channels, each of which is shared by eight subscribers in TDM. With the ASE injection of about −15 and −2 dBm provided from the 20-dBm BLS for the upstream and downstream transmissions, respectively, the single TO-packaged uncooled FP-LD presents reliable transmissions over the temperature range from 0 to 60 °C in any wavelength channel without wavelength tuning. The

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 23, NO. 1, JANUARY 2005

BcN Roadmap

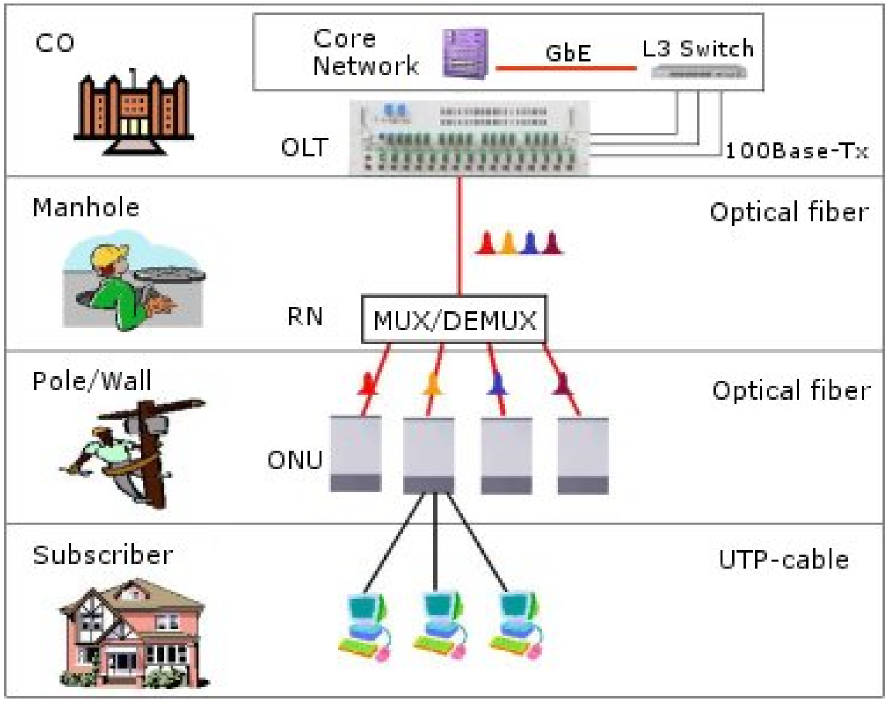
Stage	Current Stage	Mid-term Plan(~ 2006)	Long-term Plan(~ 2010)
Service	Broadband Internet access VDSL, Ntopia Metro-Ethernet	Broadband access(100Mbps) Digital broadcasting (MPEG-2) Convergence service of video, & data, Audio	Broadband access(Gbps) HDTV broadcasting Convergence of telecommunication and broadcasting High quality Internet broadcasting
Access Network	ADSL / FTTC+ADSL FTTC+VDSL / FTTP HDSL/SDSL	Ethernet PON	FTTC+VDSL / FTTH WDM-PON
Metro Core & Back Bone	Metro-Ethernet(GbE) ATM	10GbE MPLS	QoS enabled Integrated IP network
Promotion	FITL(Fiber In The Loop) on MTU / MDU Promotion of VDSL	FTTC to residential area Launching FTTH	Promotion of FTTH

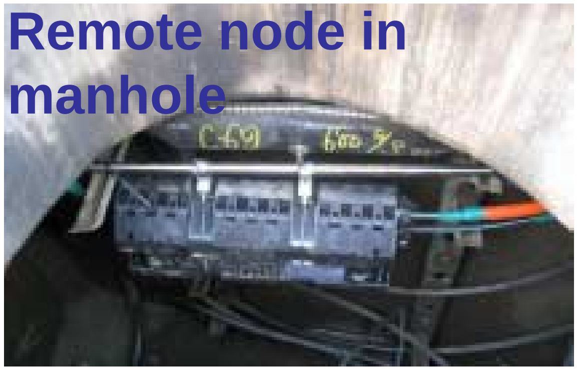
Source: Ministry of Information and Communication Republic of Korea

Korea Telecom WDM PON

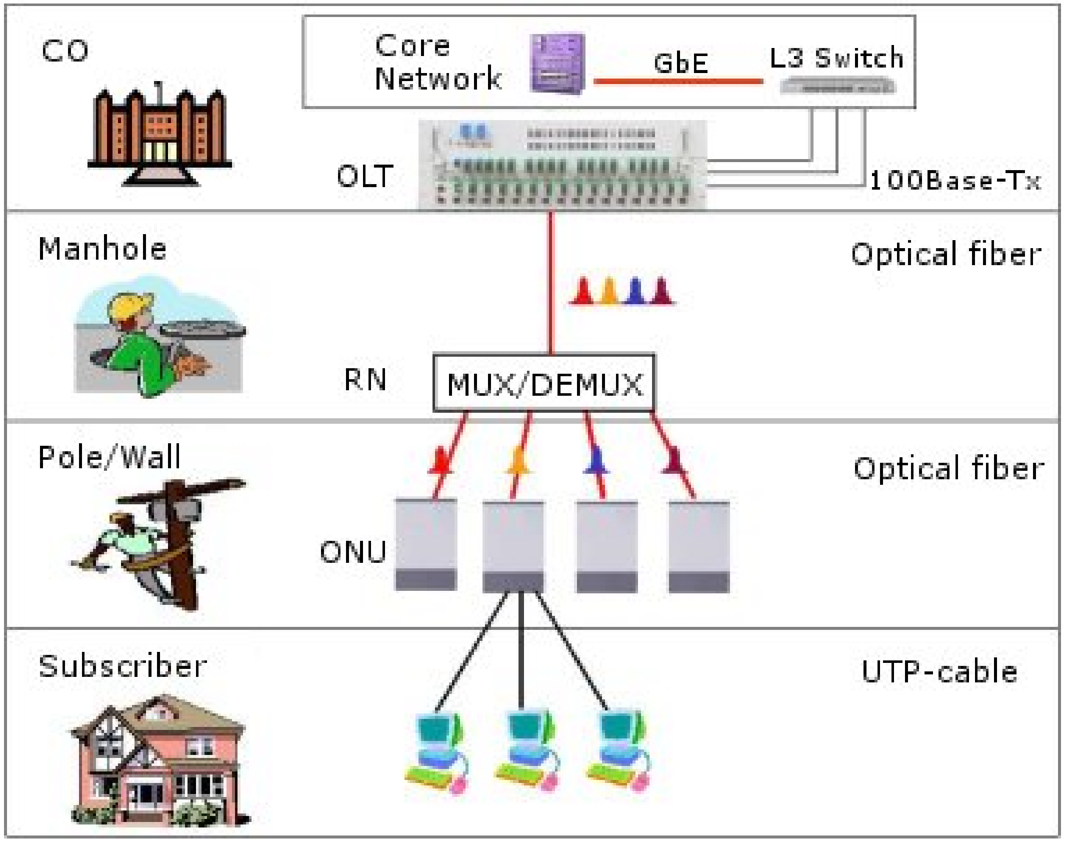
KT plans to install WDM-PON infrastructure by August this year in its first phase, procuring WDM-PON equipment of Novera Optics that can accommodate 42,000 circuits, worth approximately $13.6 million

- Friday, March 25, 2005





Korea Telecom WDM PON



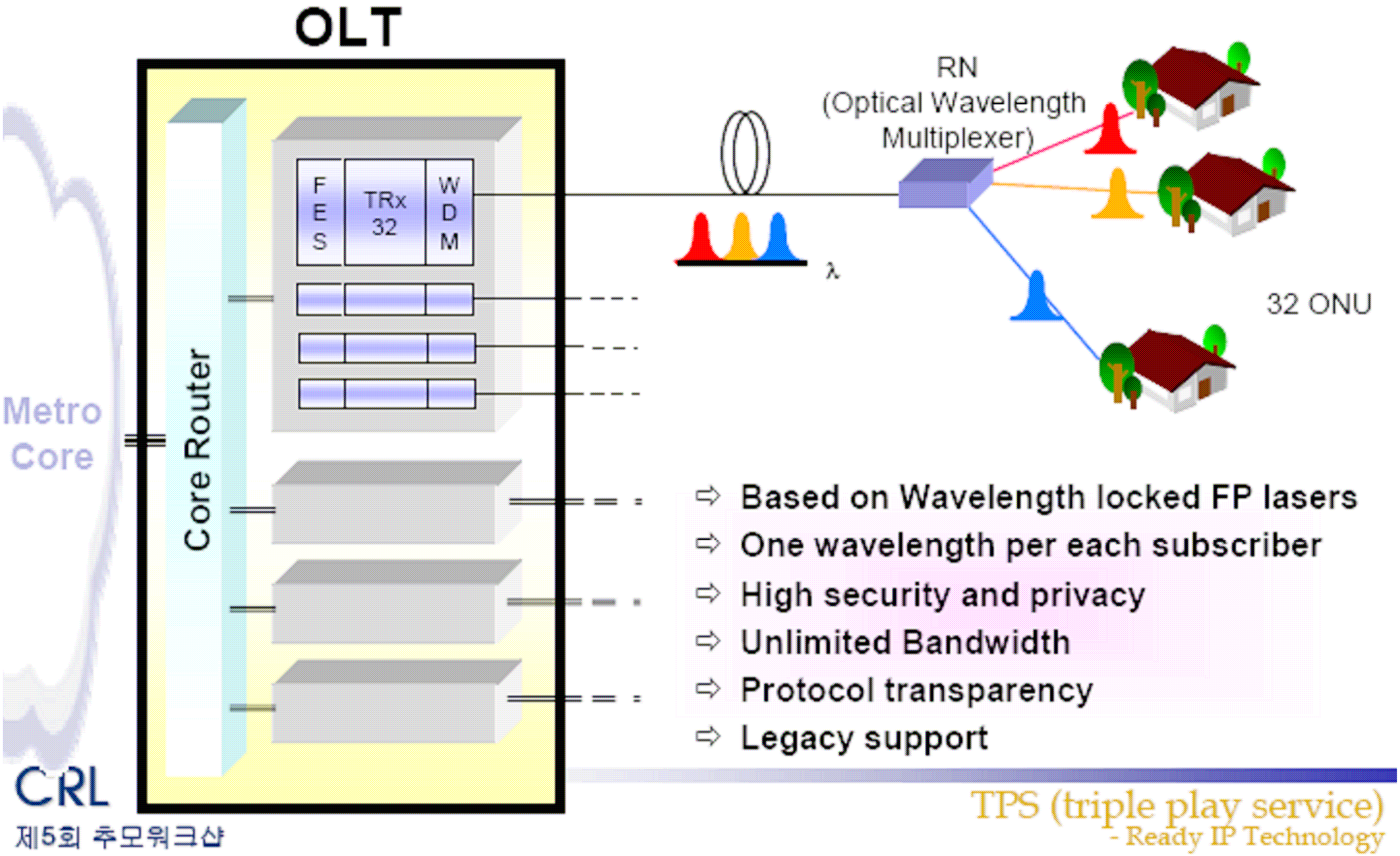
16 wavelengths
20 km
125 Mbps bidirectional

No power to the remote node (WDM splitter)

Wavelength independent ONU

24 ethernet ports per ONU

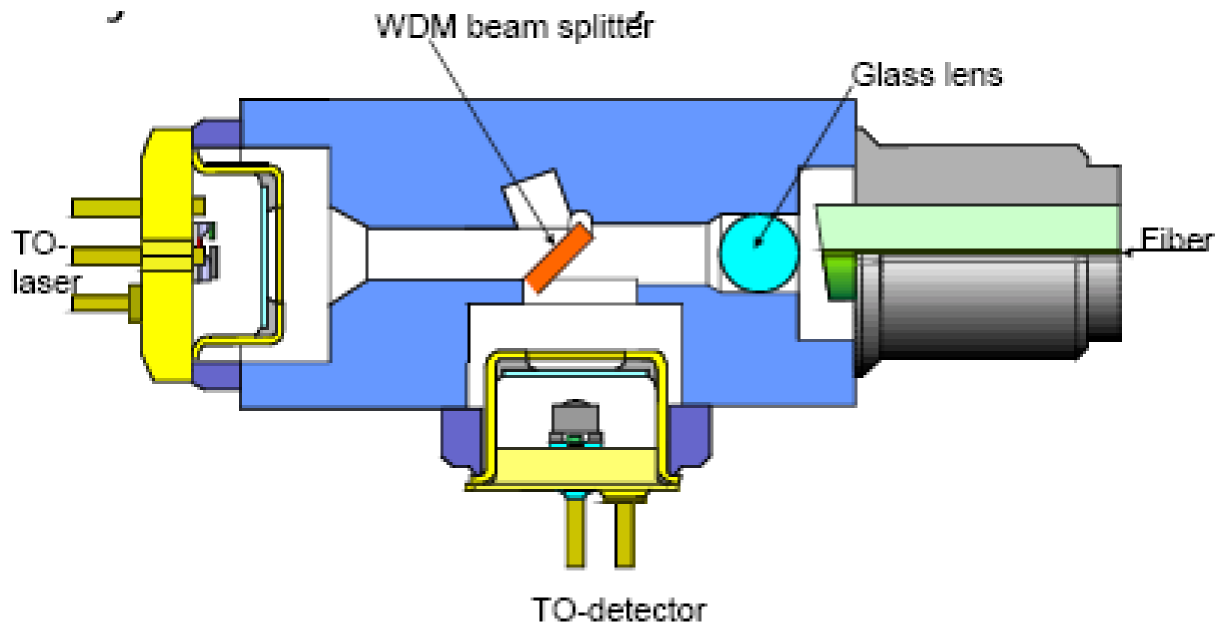
Korea NovaPON



- ⇨ Based on Wavelength locked FP lasers
- ⇨ One wavelength per each subscriber
- ⇨ High security and privacy
- ⇨ Unlimited Bandwidth
- ⇨ Protocol transparency
- ⇨ Legacy support

TPS (triple play service)
- Ready IP Technology

Driving Down Diplexer/Triplexer Cost ?



30% of ONU Cost is the optical front end

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ONU Cost is approx $100

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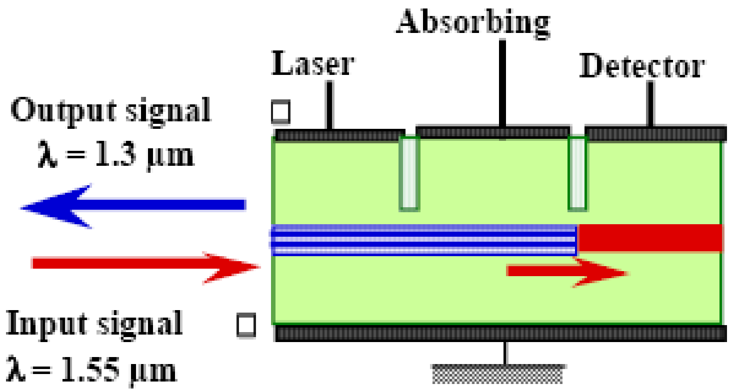
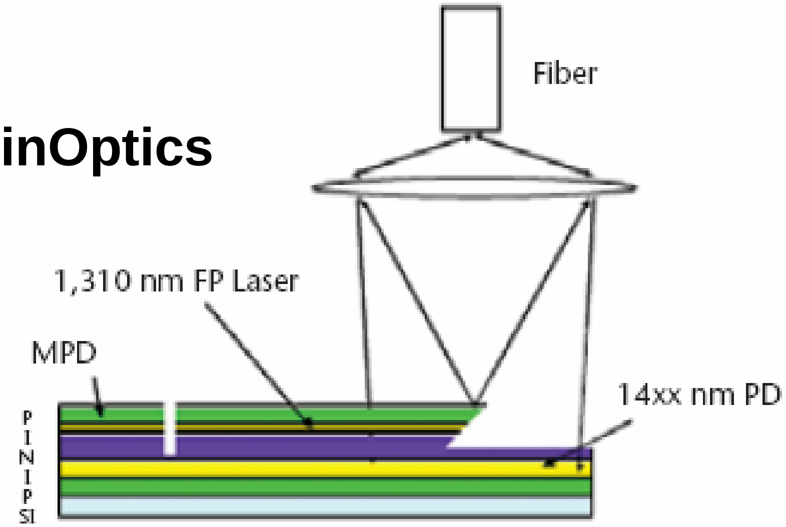
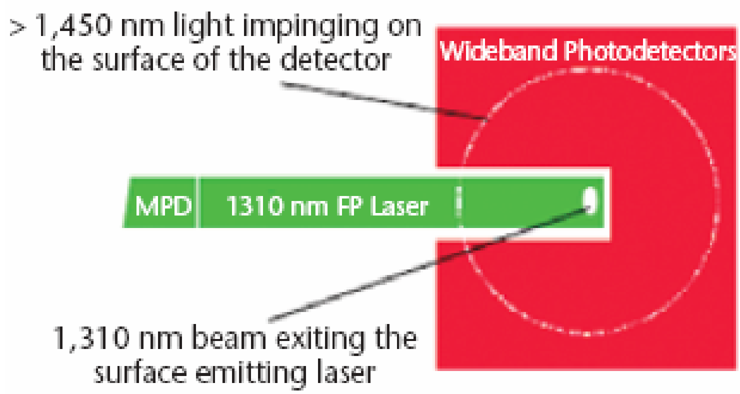
Optically Integrated Triplexers

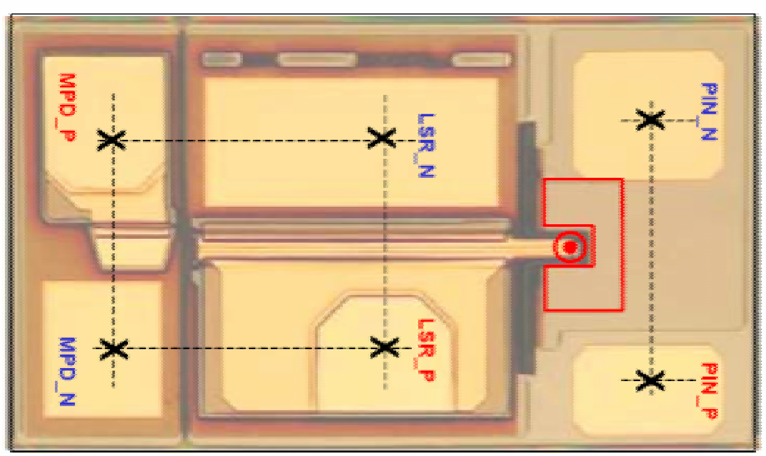


Nakajima and Charil, **France-Telecom**-CNET. France. NOC ’96. 1996

BinOptics

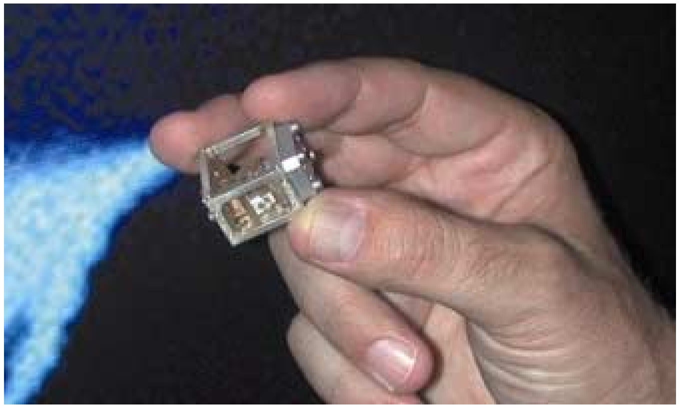




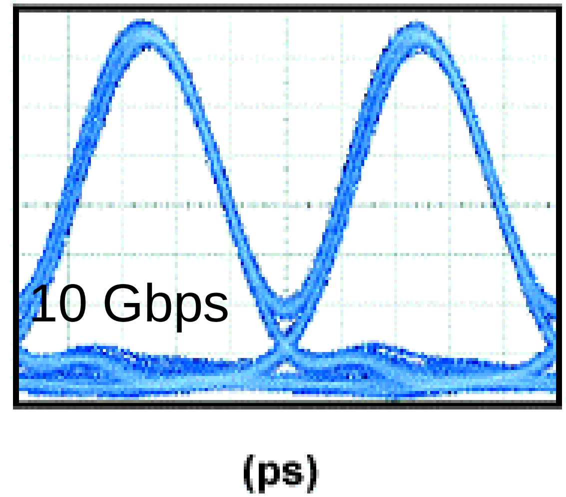


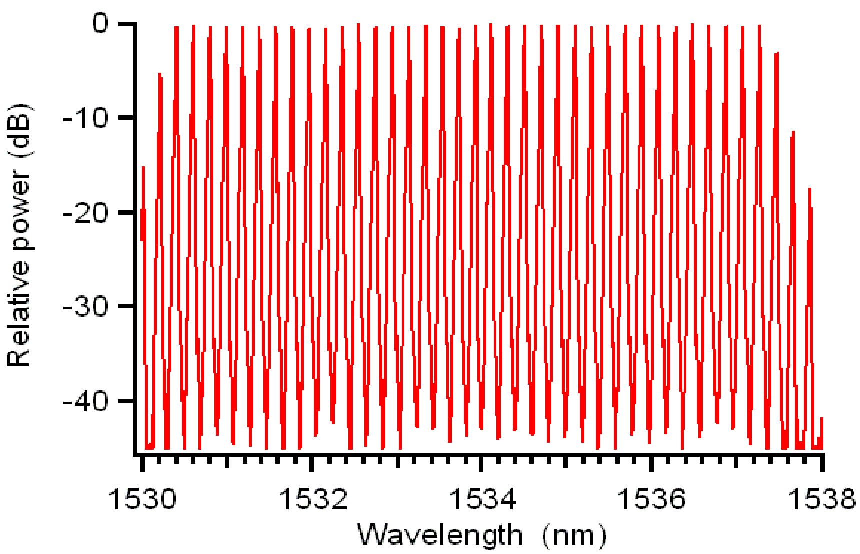
Radical Solutions: Multiwavelength Sources

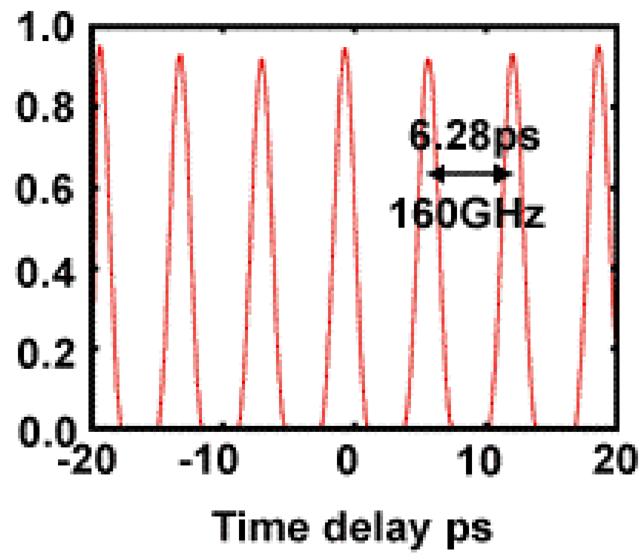
Simultaneous NRZ Pulse train for 20 channels from ps mode-locked laser



Pulses carved in the wavelength domain…



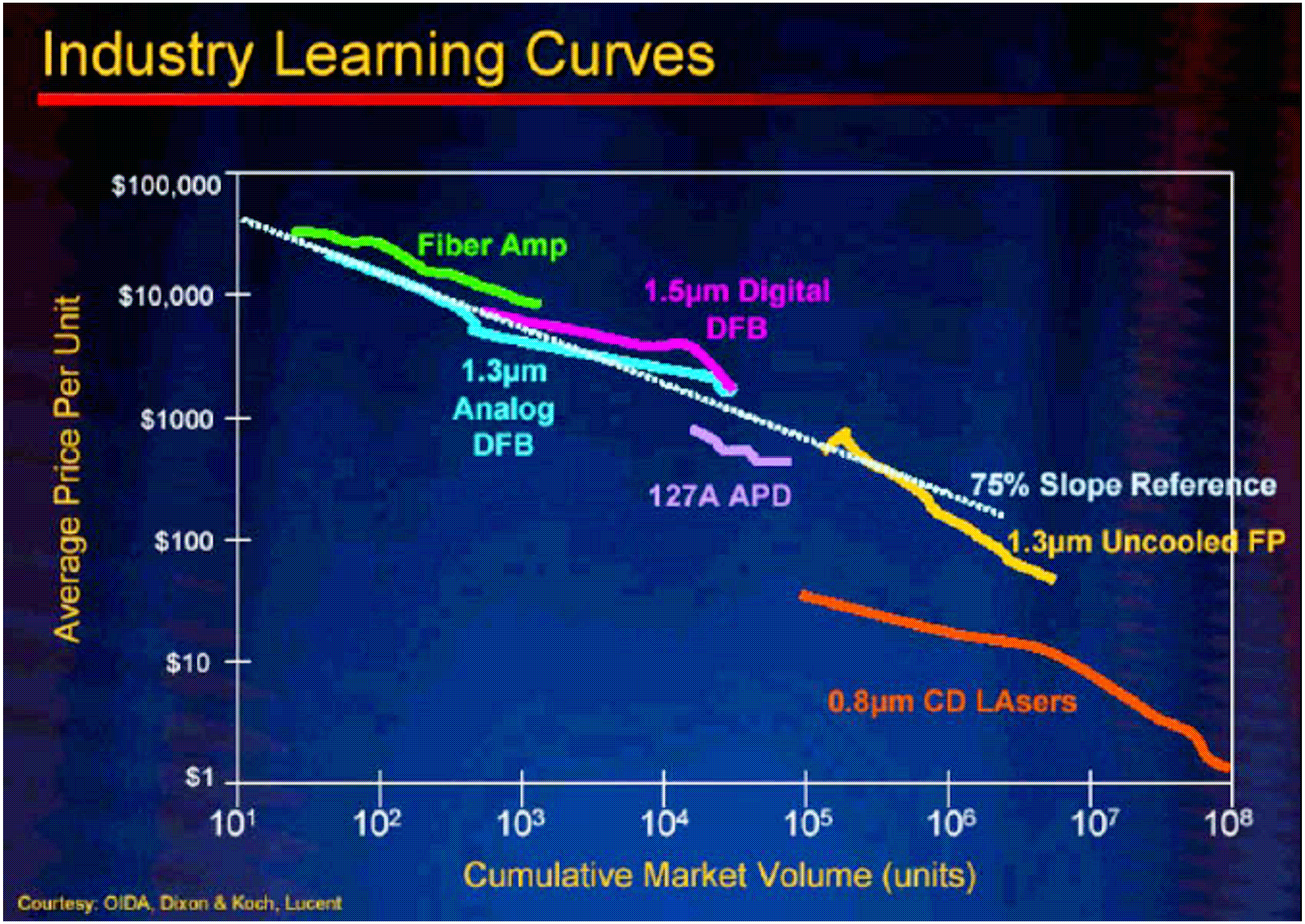




Time-Bandwidth® Products

Only for DWDM

requires power to the field

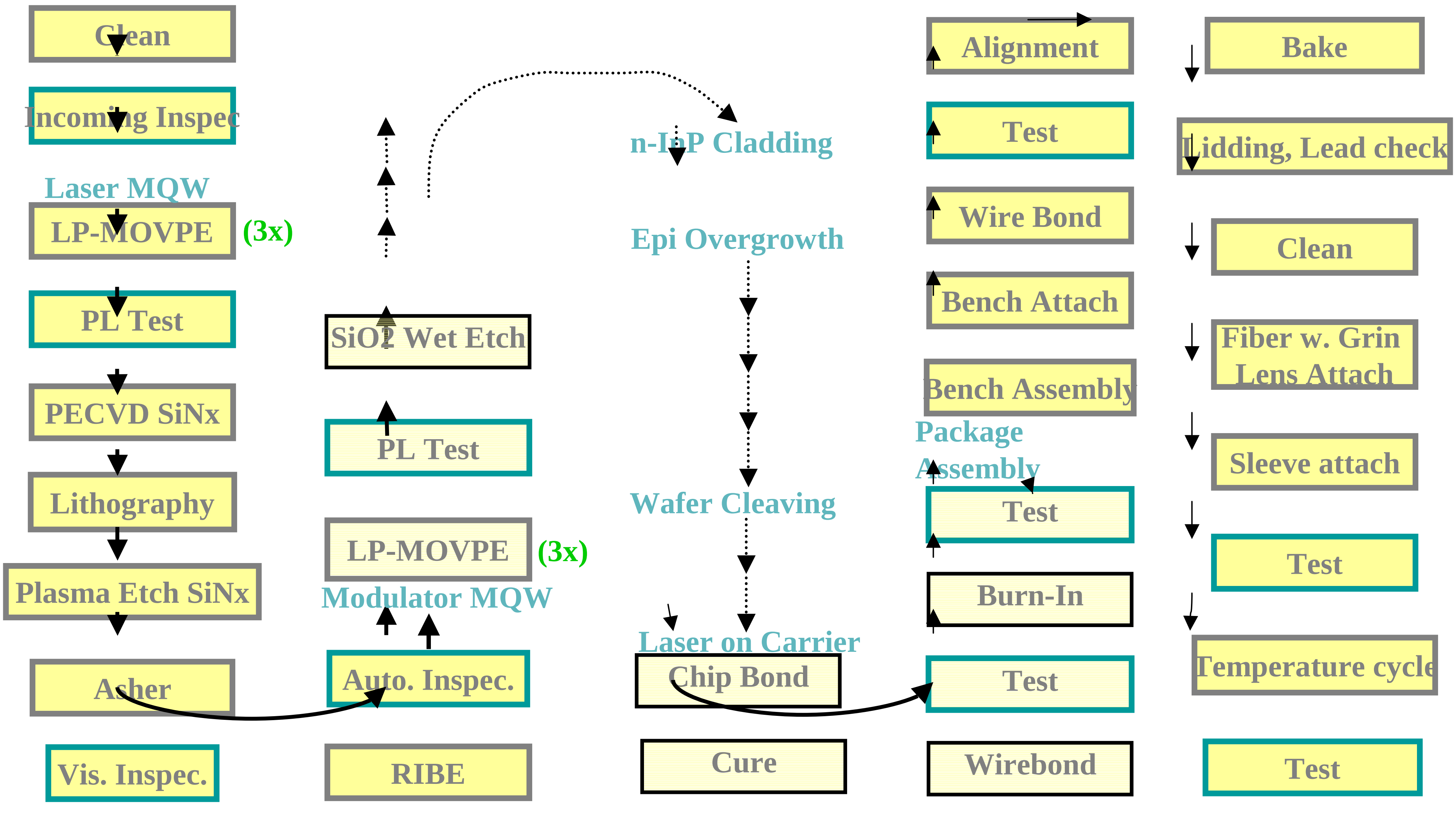

Industry Learning Curves
$100,000
$10,000
$1000
$100
$10
$1
Average Price Per Unit
Fiber Amp
1.5μm Digital DFB
1.3μm Analog DFB
127A APD
75% Slope Reference
1.3μm Uncooled FP
0.8μm CD LAsers
10¹ 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸
Cumulative Market Volume (units)
Courtesy: OIDA, Dixon & Koch, Lucent

The MIT/CTR Optoelectronics Fabrication Model

- Mimics production from bare substrate through assembly, packaging, and final test
- Provides full flexibility in building a process flow
- Captures effect of process derived yields at testing

Currently 46 Process Modules Available

Process Modules Building Blocks in Product Flow

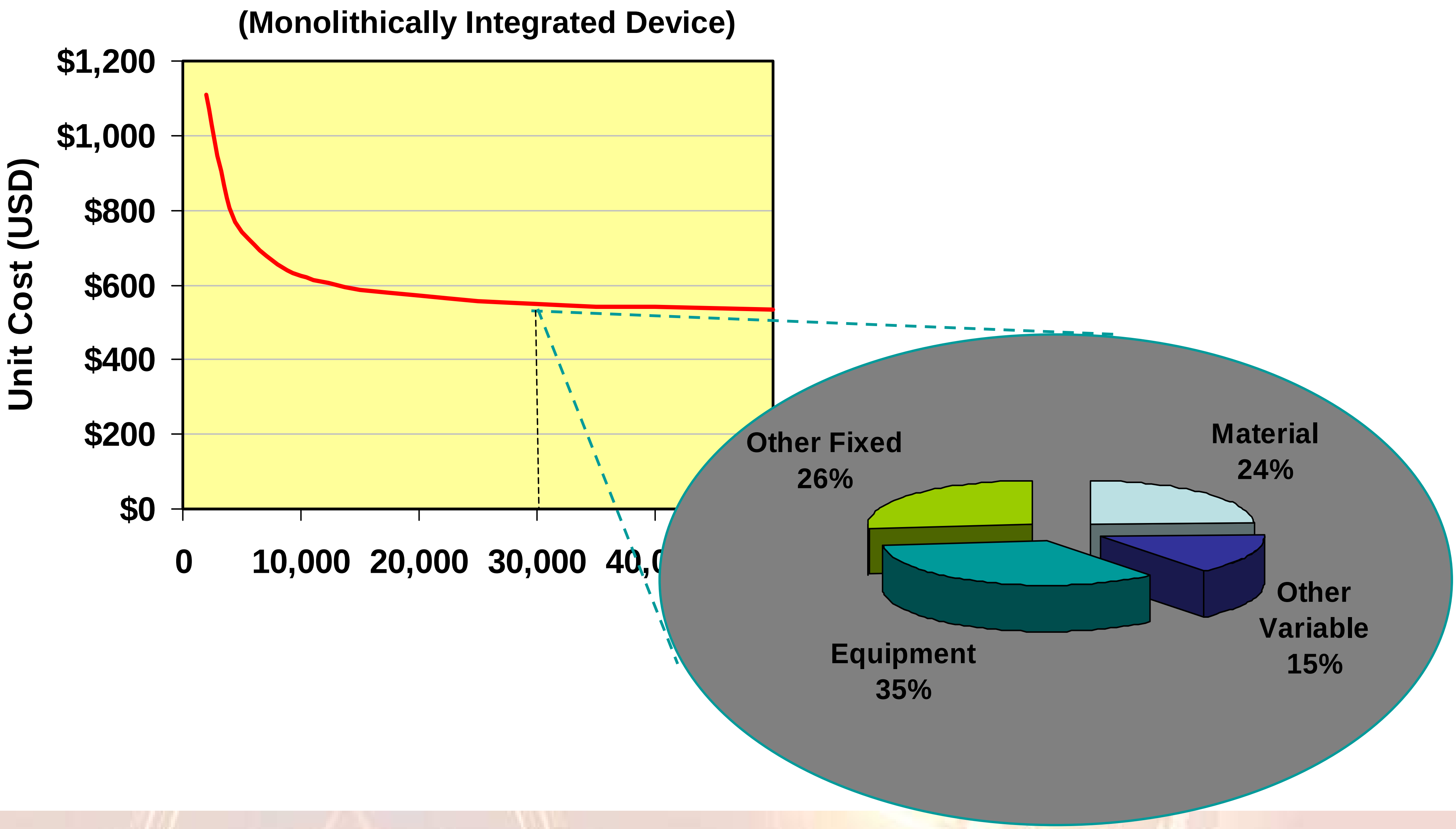


Cost Modeling Benefits to Roadmapping

1. Provides a generic platform to discuss the cost of process and product developments
2. Quantifies impact of future scale growth
3. Identifies key cost drivers
4. Quantifies necessary process performance hurdles

Quantifying Cost-Sensitivity to Scale

Models Derive Cost from Projected Optimal Fab Line



Cost Modeling Benefits to Roadmapping

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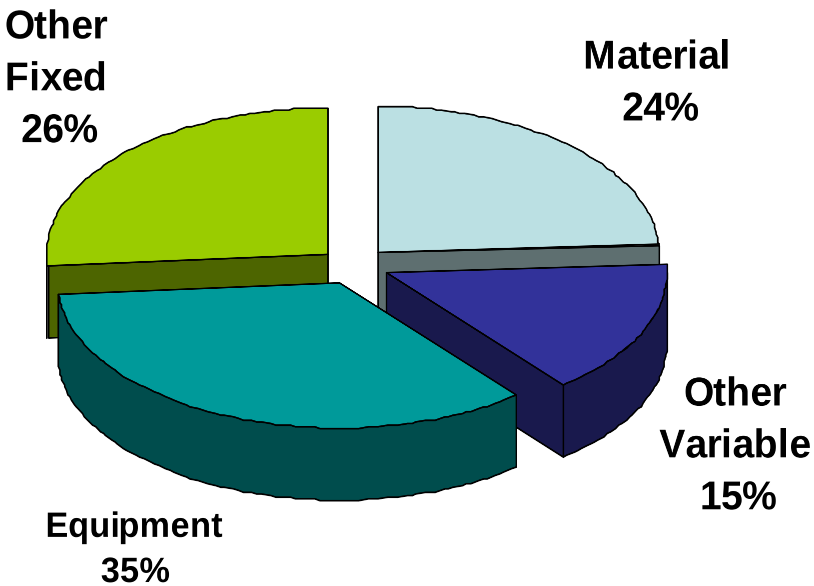
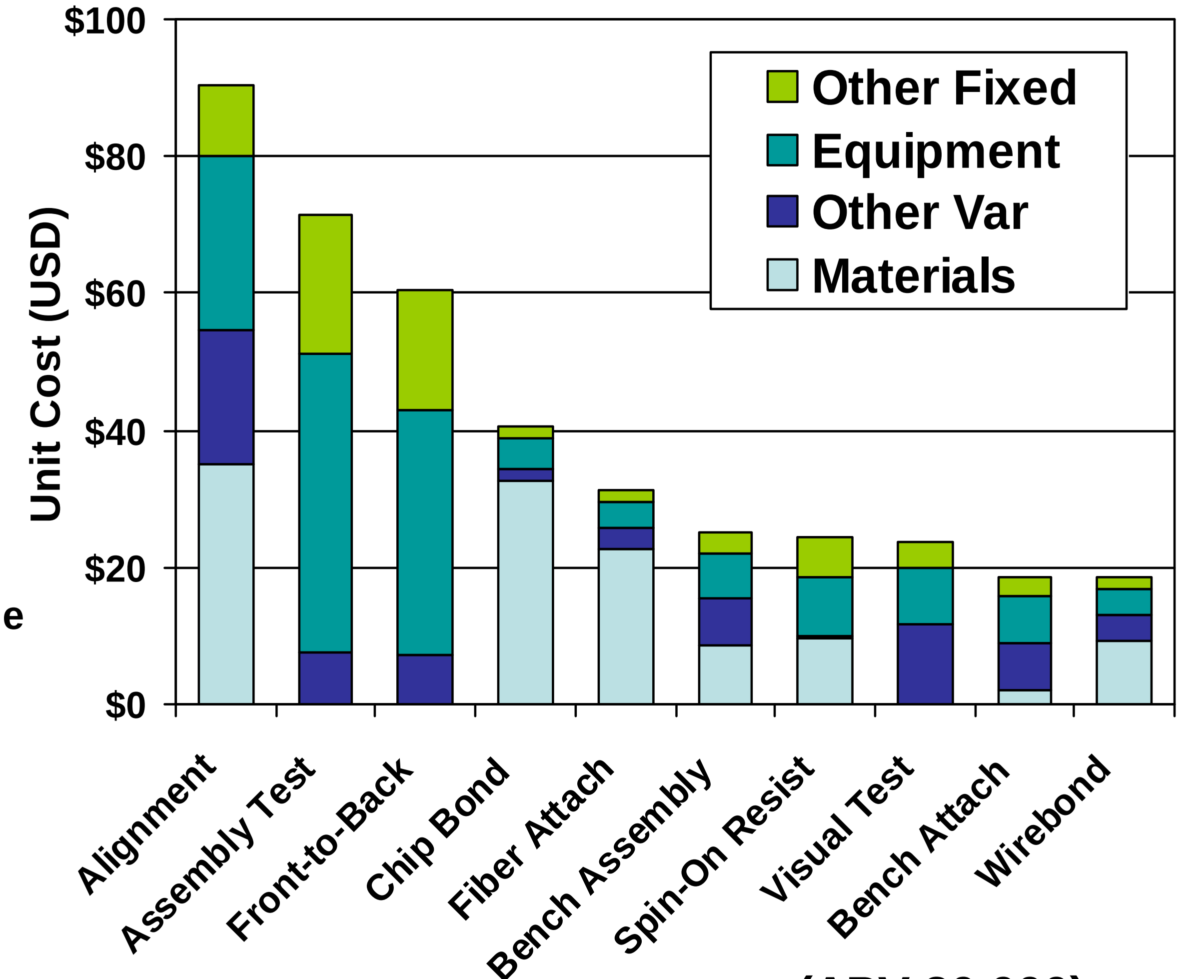
Identifying Key Cost Drivers

Models Provide Unequaled Resolution



(Monolithically Integrated Laser-Modulator)

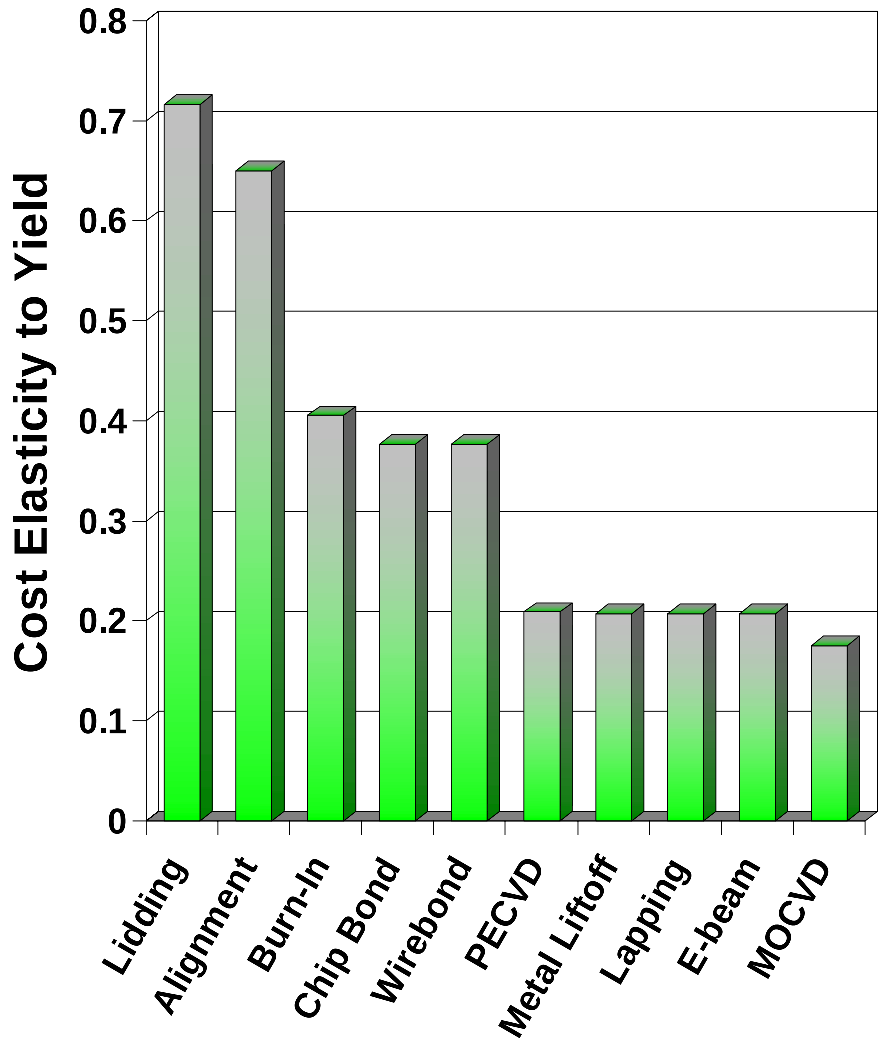


(APV 30,000)

Identifying Opportunities for Improvement:
Unit Cost Elasticity to Yield

- Yield is key issue for optoelectronics manufacturing cost
- What processes provide the most leverage?
  - Position in flow
  - Embedded yield
- Cost elasticity to yield
  - Identifies process yield impact on aggregate cost

(Monolithically Integrated Device)

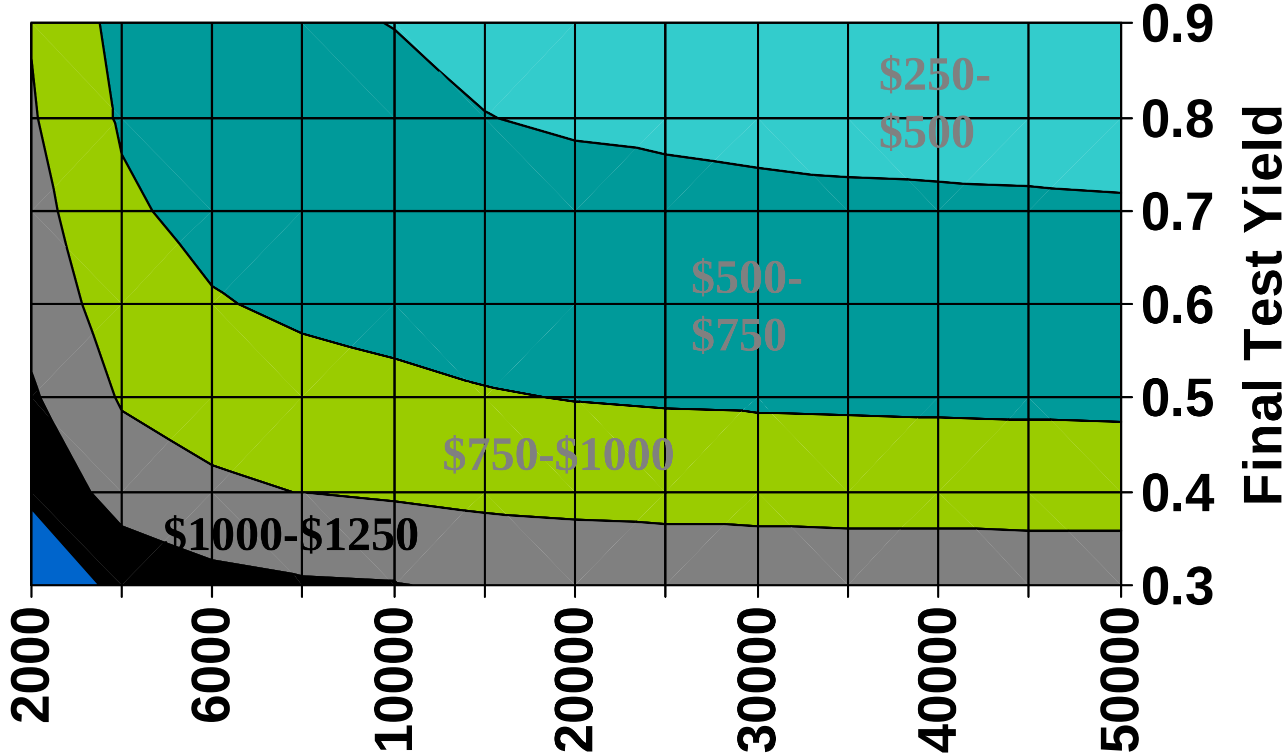


Cost Modeling Benefits to Roadmapping

1. Provides a generic platform to discuss the cost of process and product developments
2. Quantifies impact of future scale growth
3. Identifies cost drivers
4. Quantifies necessary process performance hurdles

Cost Sensitivity to Final Test Yield

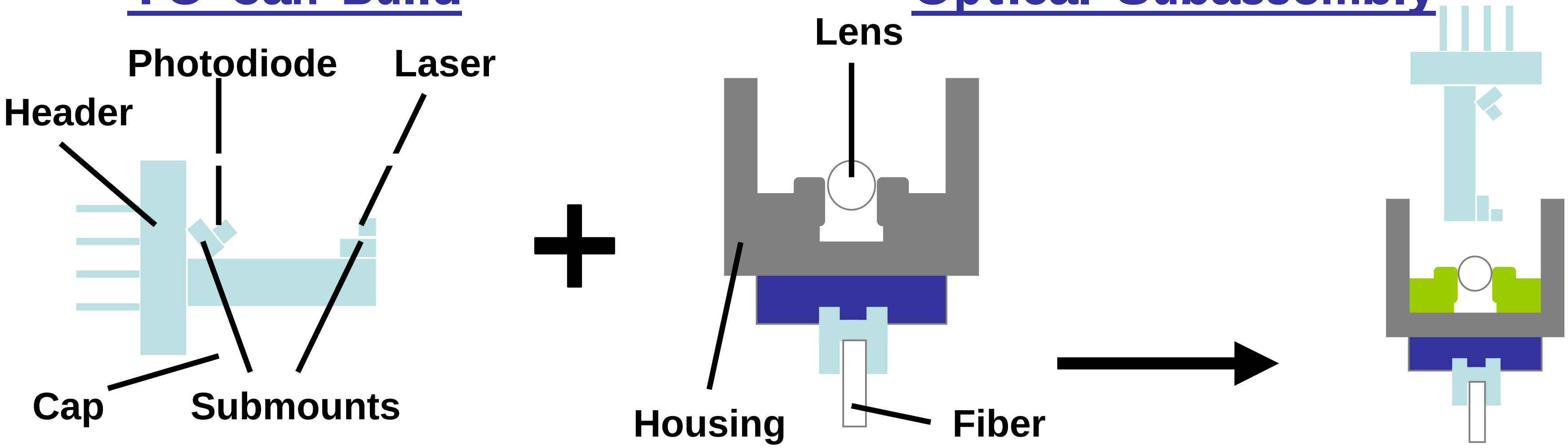
(Monolithically Integrated Laser-Modulator)



Phase II: Optoelectronics Subassembly Model

- Initial model development case:
  - 2.5G VSCEL and FP optical subassemblies
- Current work:
  - 10G DFB and 10G DWDM optical subassembly
- Upcoming work: Benefits of integration

TO Can Build **Optical Subassembly**



Cost Modeling Benefits to Roadmapping

1. Provides a generic platform to discuss the cost of process and product developments

2. Quantifies impact of future scale growth

3. Identifies key cost drivers

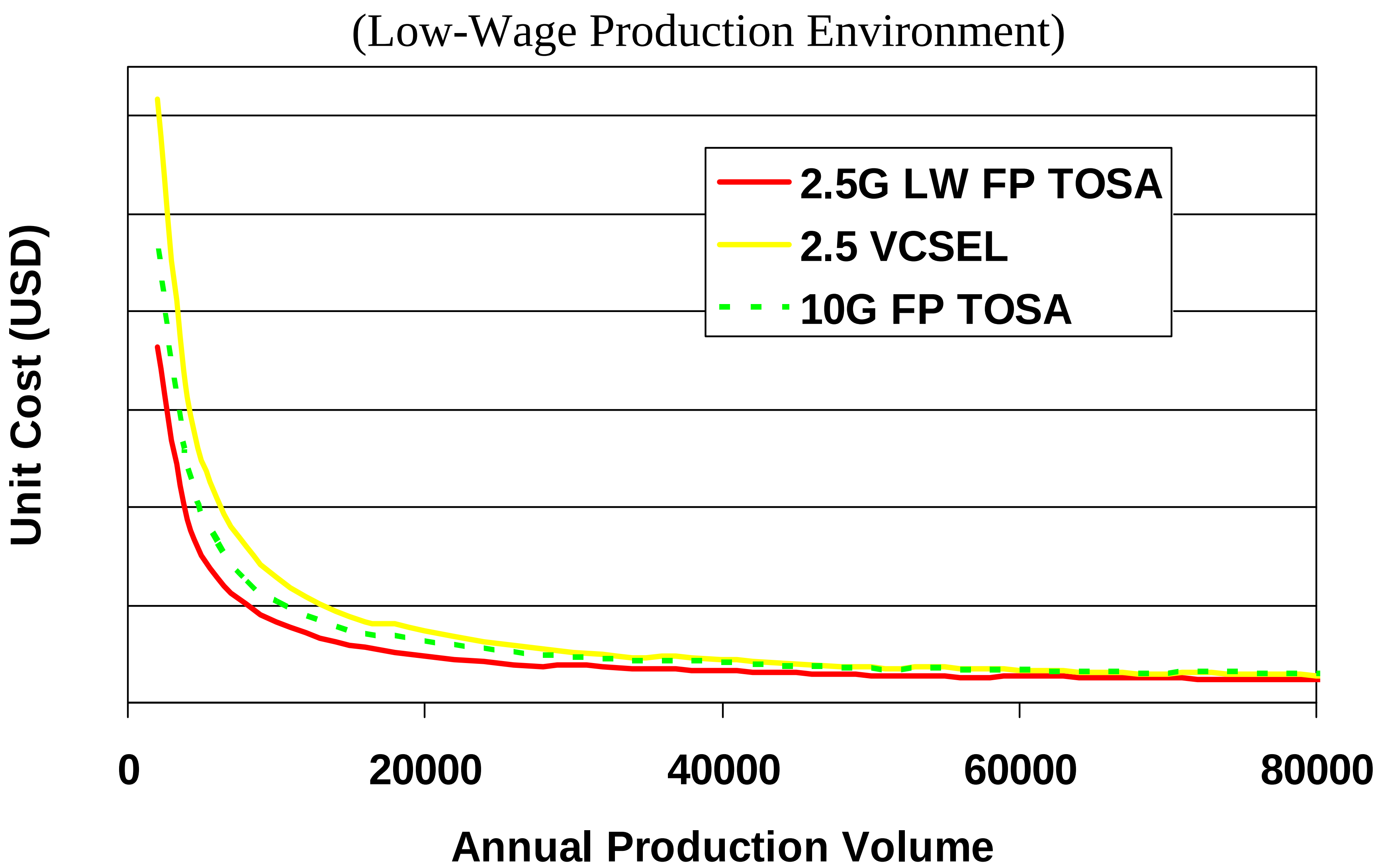
4. Quantifies necessary process performance hurdles

Phase II: Optoelectronics Subassembly Model

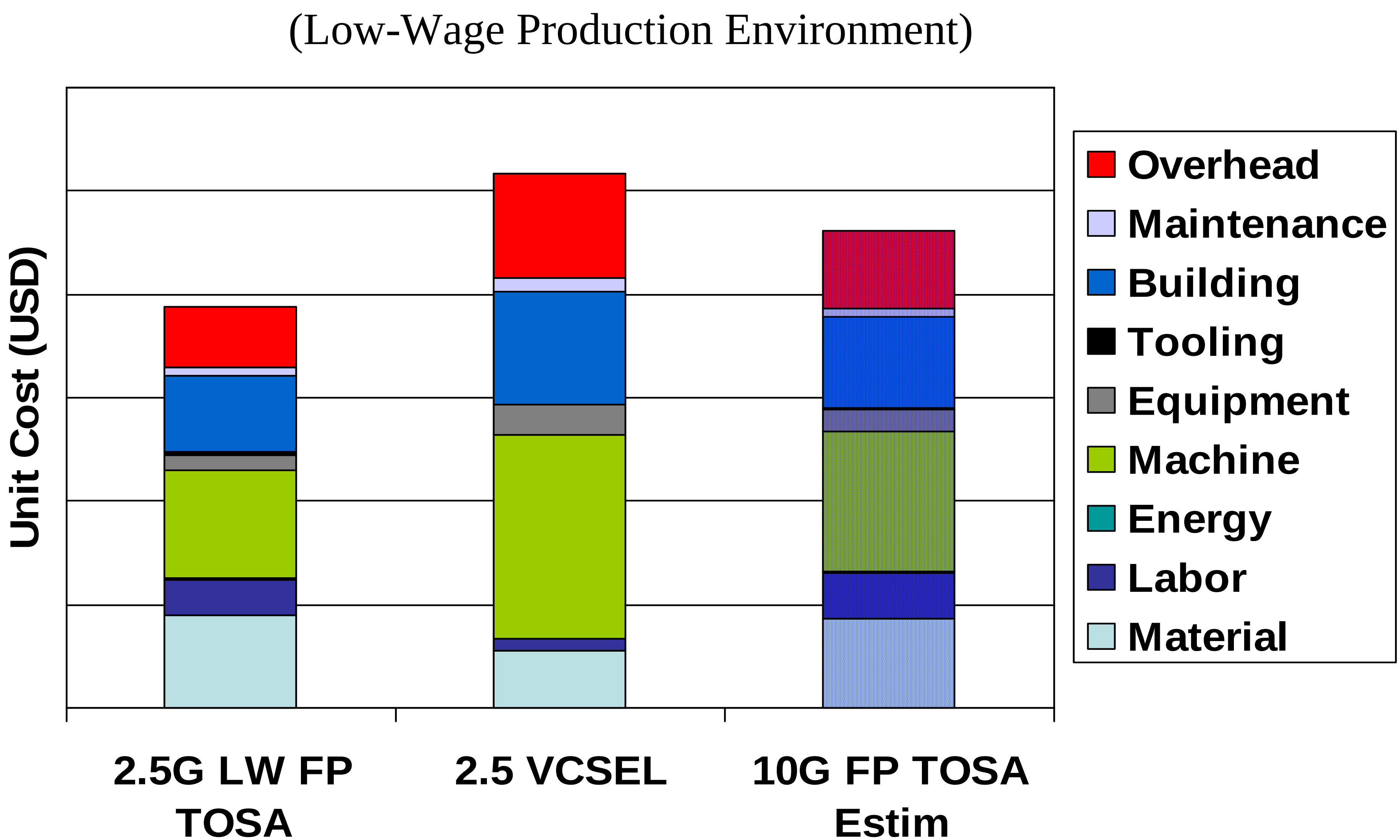
How do TOSA/ROSA design & assembly choices effect production cost?

Are the cost-optimal development paths different if producing in the U.S. vs. low-wage environments in Asia?

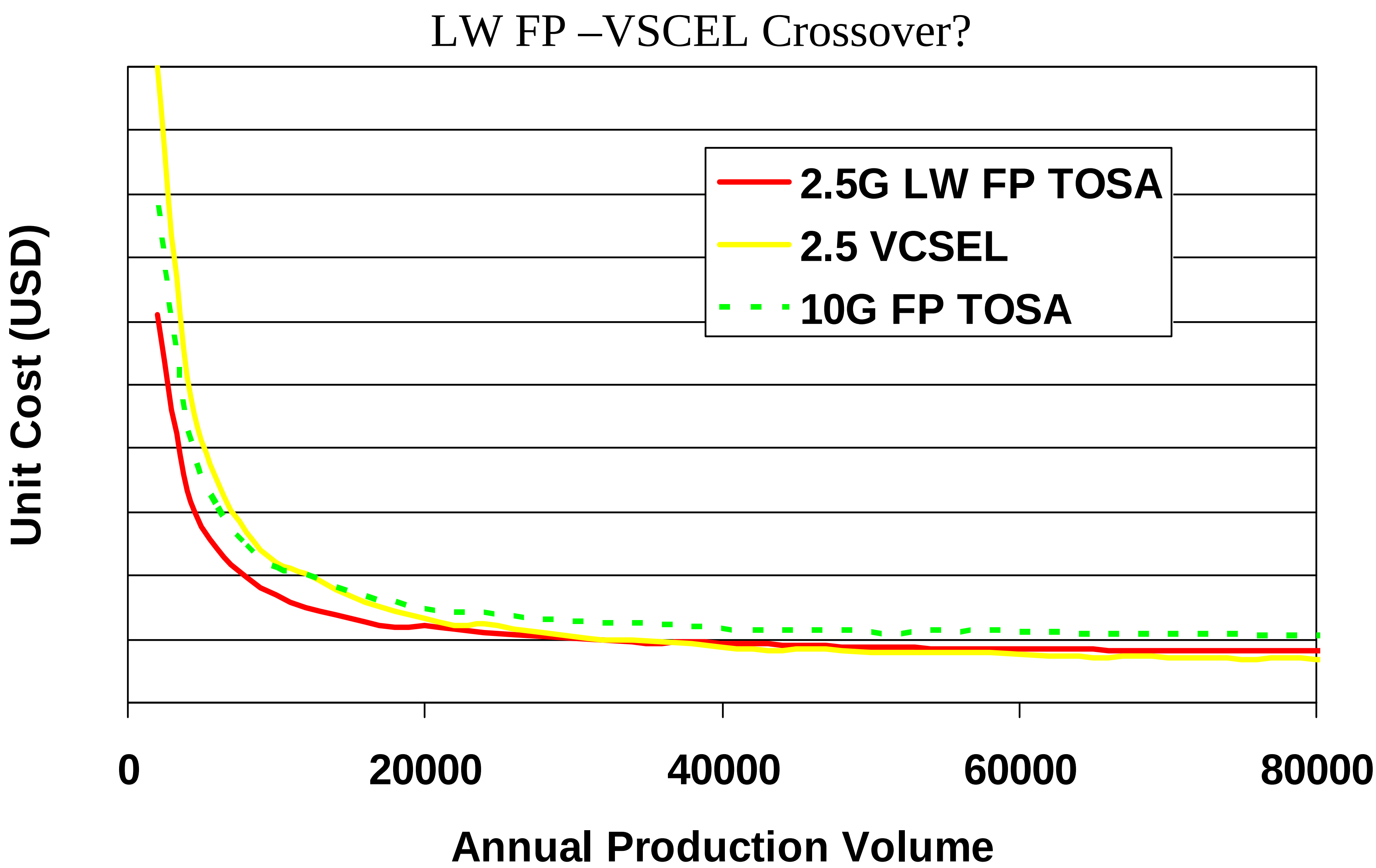
Preliminary Results: Sensitivity to Scale



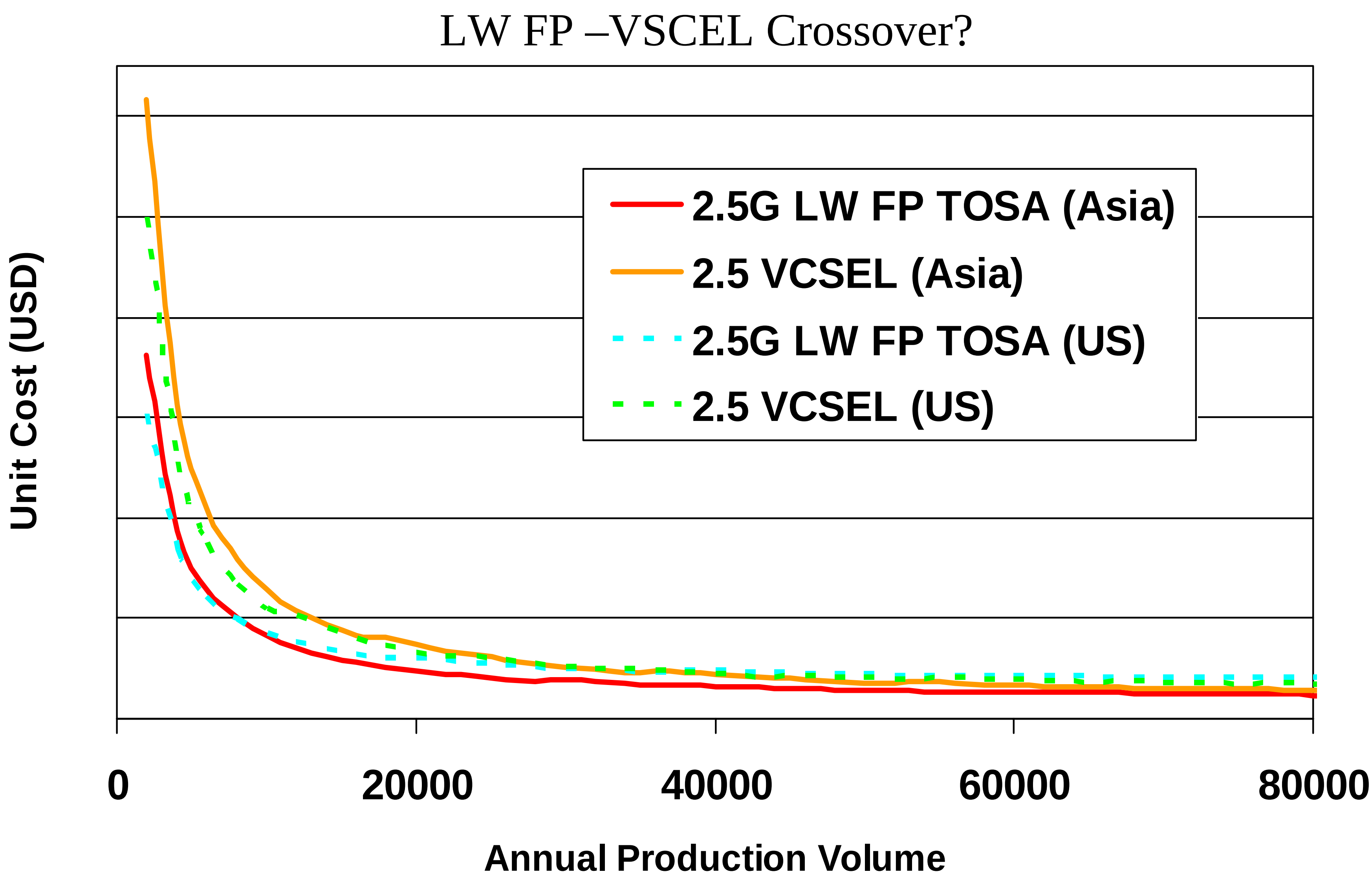
Preliminary Results: Cost Breakdown



Early Estimates: U.S. Production

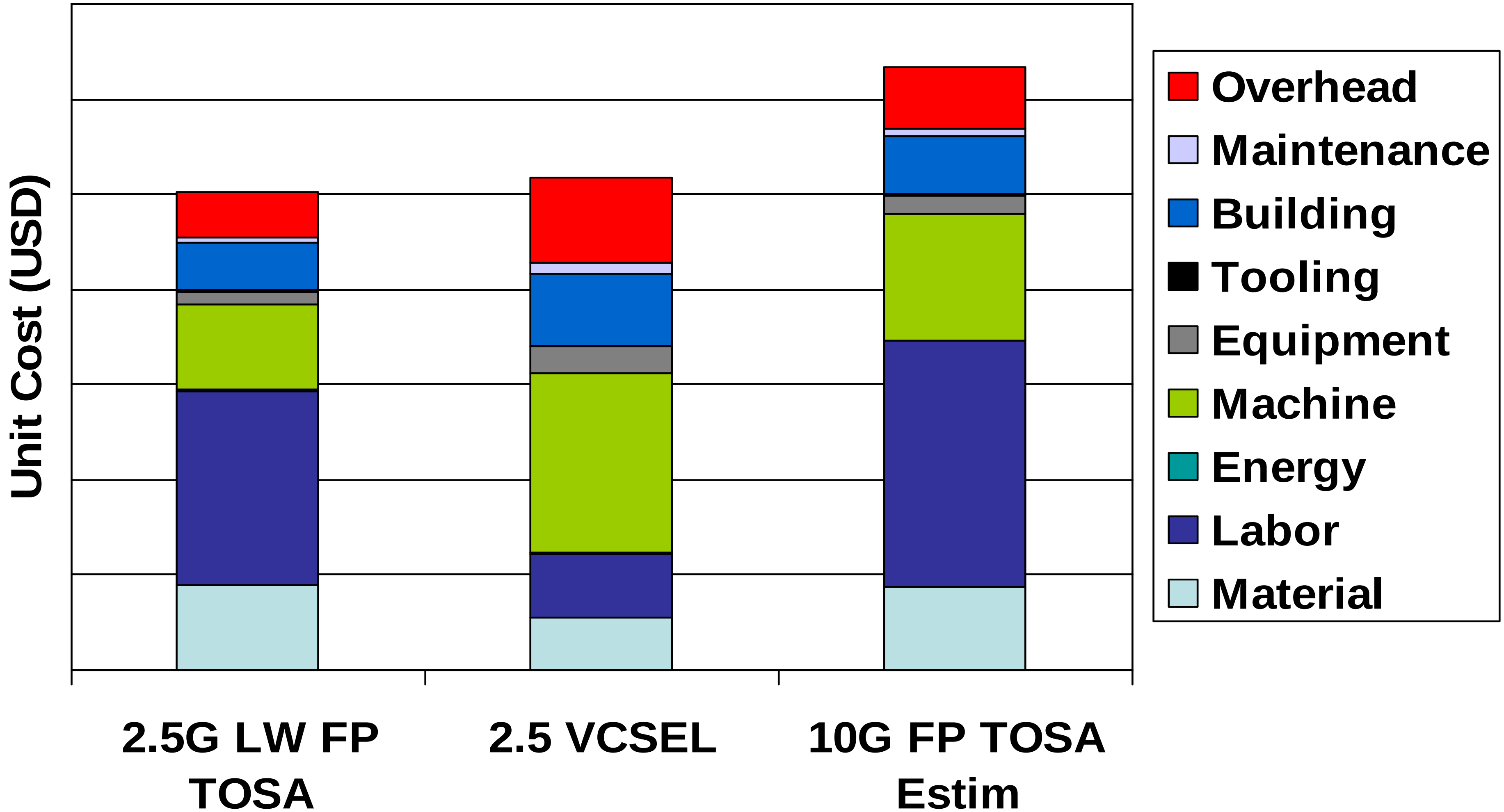


Early Estimates: U.S. vs. Asia Production



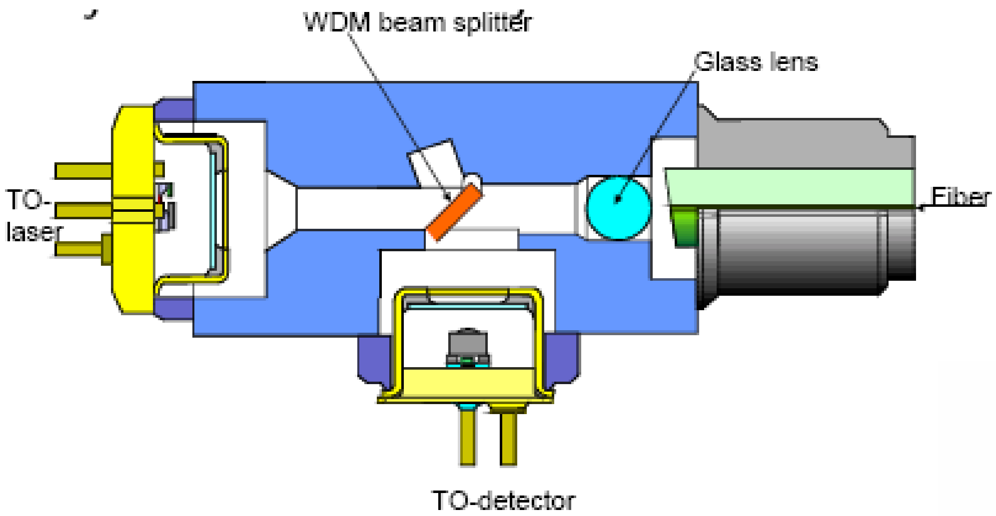
Early Estimates: U.S. Cost Breakdown

(Labor Dominant in the 2.5G and 10G FP TOSAs)

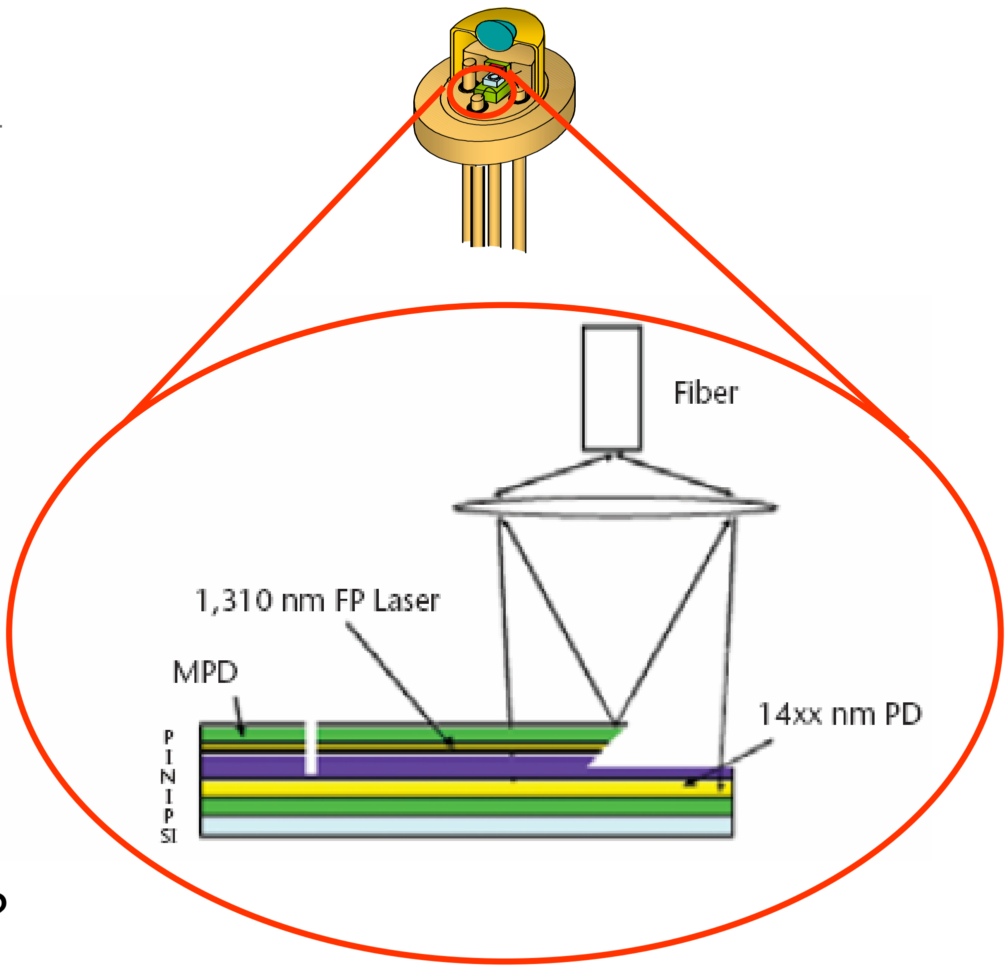


Process Based Cost Modeling for Access Technology

Dicrete Diplexer



Monolithic Diplexer



How does price scale for 1Mparts ?

Manufacturing cost for various designs ?

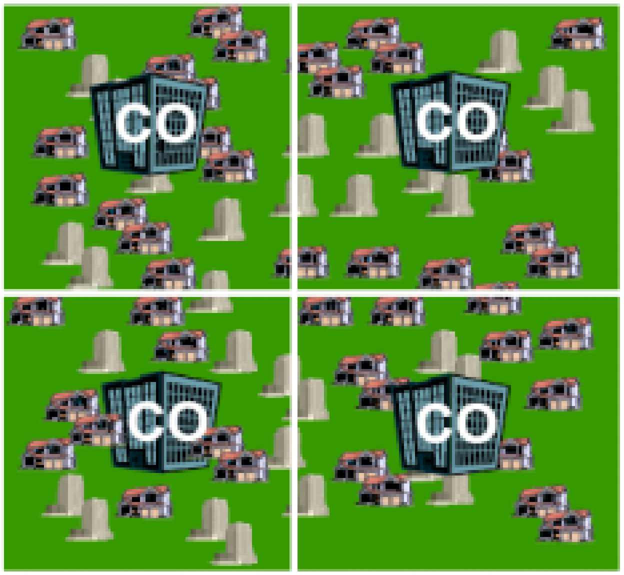
Developing a Roadmap for PON
Architectures and Components

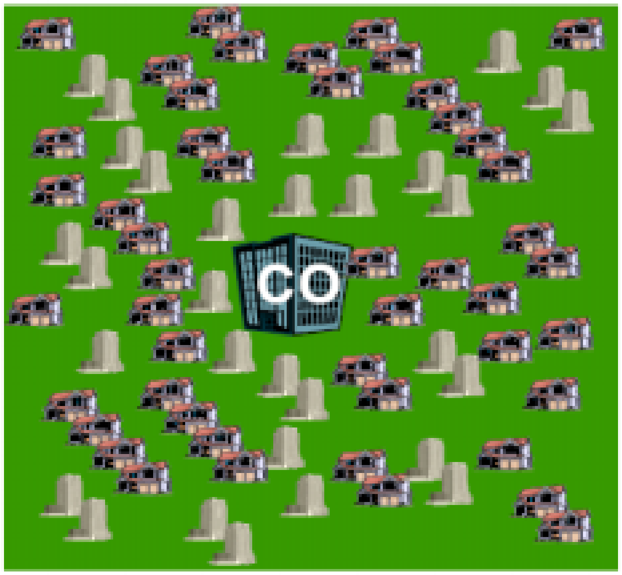
100 km at 10 Gbps **20 km at 2.5 Gbps**

Dramatically different photonic components…external vs. direct modulation,etc.

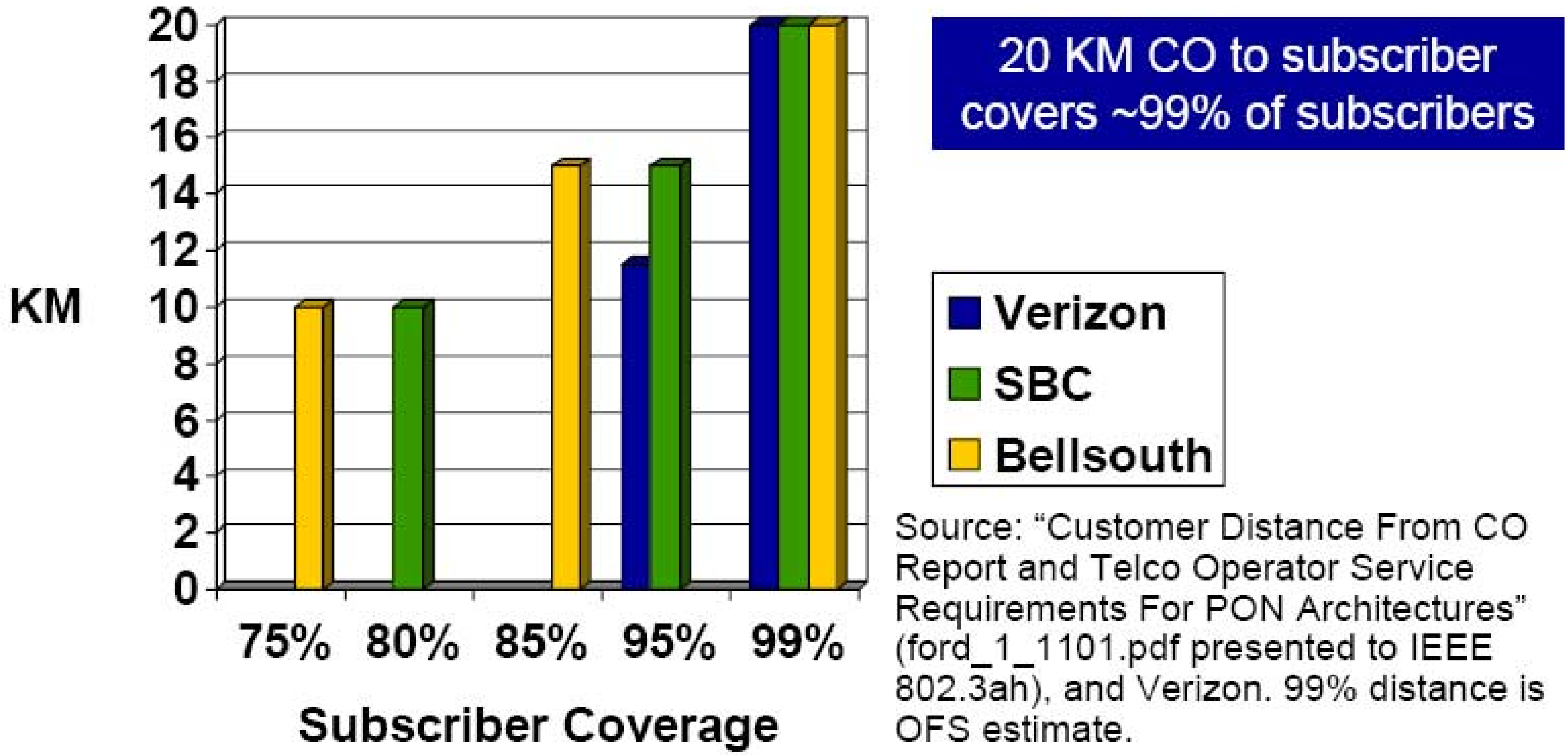
Dramatically different architectures

Dramatically different network economics





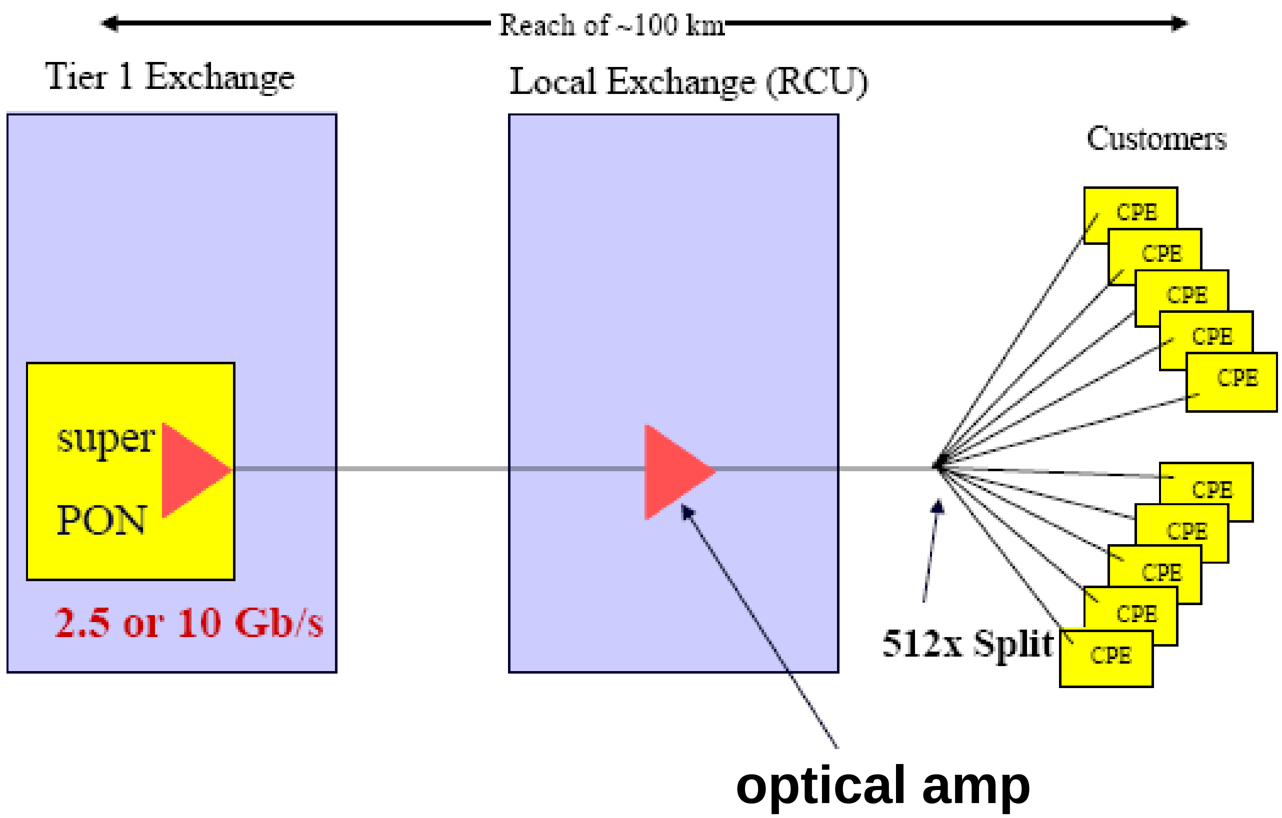
Developing a Roadmap for PON
Architectures and Components



Source: "Customer Distance From CO Report and Telco Operator Service Requirements For PON Architectures" (ford_1_1101.pdf presented to IEEE 802.3ah), and Verizon. 99% distance is OFS estimate.

Developing a Roadmap for PON
Architectures and Components

Access/backhaul integration step 1



British Telecom 21st Century Network ($19b)

Developing a Roadmap for PON
Architectures and Components