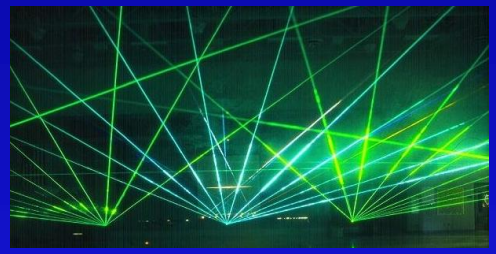
15 years ago…

The optics revolution

1960 The beginning of the 20th century optics renaissance...



1998 Dawn of the optics revolution...

National Report Predicts Optics Revolution

May 15, 1998

National Research Council

HARNESSING LIGHT

Optical Science and Engineering for the 21st Century

Source: Han Le & Assoc

INFORMATION TECHNOLOGY

Charge of the Light Brigade

Next-generation optical gear is entering the local market

… Over the past year, optical-networking companies have become the darlings of the technology world. Just check out Sycamore Networks Inc. Its stock has rocketed sevenfold since its initial public offering in October, for a market cap of $21 billion--even though it has a minuscule $19 million in revenues. Contender Qtera Corp., with almost no revenues, got scooped up by telecom-equipment giant Nortel Networks Corp. (NT) last month for $3.25 billion. And on Jan. 17, equipment maker JDS Uniphase Corp. (JDSU) agreed to acquire an optical-networking player called E-Tek Dynamics Inc. for $15 billion.

What do these “light brigade” companies do?

Some make small components (NetOptix, OCA, Oak Industries, E-Tek dynamics, AMP…)

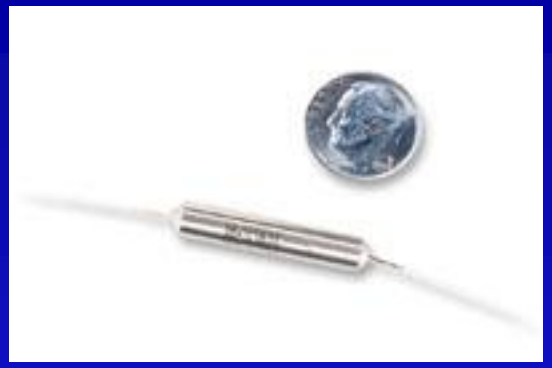
Some make modules, sub-systems (Corning, Oak Industries, JDS Uniphase, AMP, …)

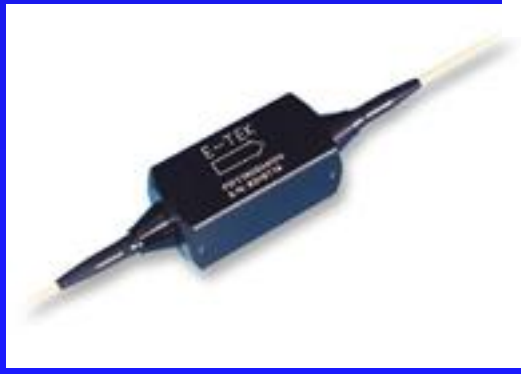
Some make system equipment (Ciena, Corvis, Cisco, Avanex, ONI, Sycamore, Fujitsu, Lucent …)

Some build networks and providing services (MCI WorldCom/Uunet, PSINet, phone companies…)

They all have to do with optical network for communication

Small components





Modules, sub-systems

Wavelocker™

JDS Uniphase's WL5000 features a unique design that enables a single device to lock on to any wavelength on a 50 GHz or 100 GHz grid. The device does not require any

Fiber Mining

Waveshifter 300, Smartshifter, WDM, SmartCoupler

- Recover fiber for new services
- Universal solutions for legacy transmission equipment
- WDM and DWDM
- Active WDM
- Couplers and splitters designed to overcome backreflection issues

10.66 Gbit/s RZ Data Modulator

The 10.66 Gbit/s RZ Data Modulator is a return-to-zero (RZ) data modulator designed for medium and long haul TDM and WDM transmission at 10.66 Gbit/s. This product is also well suited for applications with transmitters requiring RZ modulation at 10.66 Gbit/s. RZ data formatting is accomplished in a single component with standard 10 GHz drive electronics.

100/200 GHz Multi-channel DWDM (WD150X M/D)

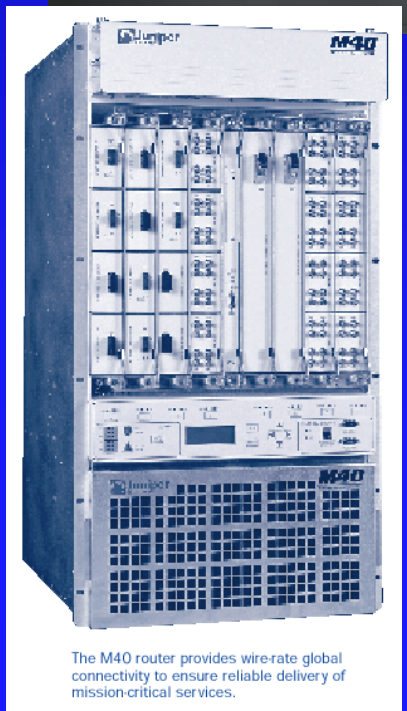
A variety of cassette and low-profile type packaging options are available for 4, 8, and 16 channel configurations. Custom channel counts, wavelength plan, and packaging can be designed to meet specific customer applications.

System equipment

Optical XC

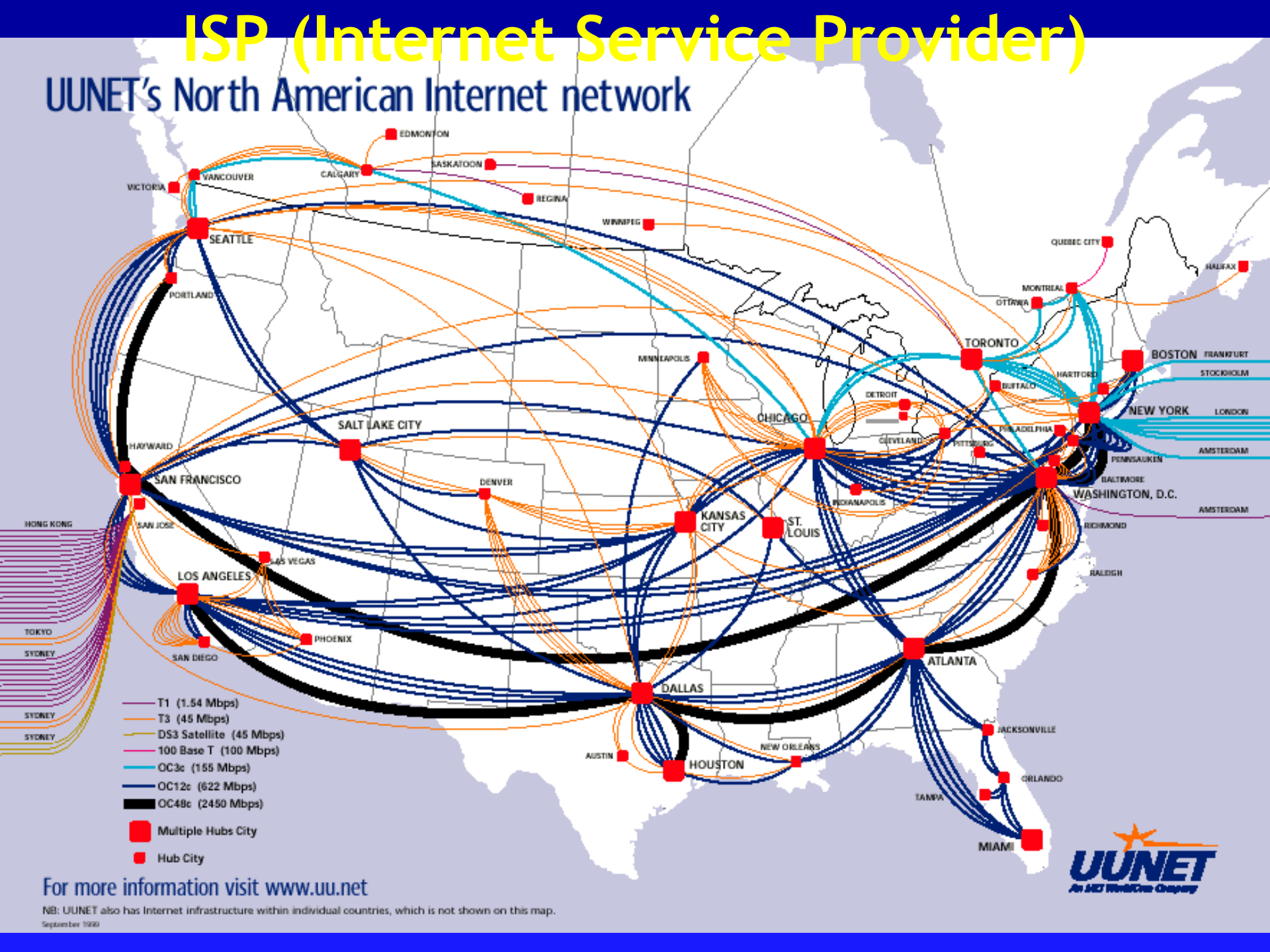
Optical Cross Connect (OXC) (Lucent/Aurora)

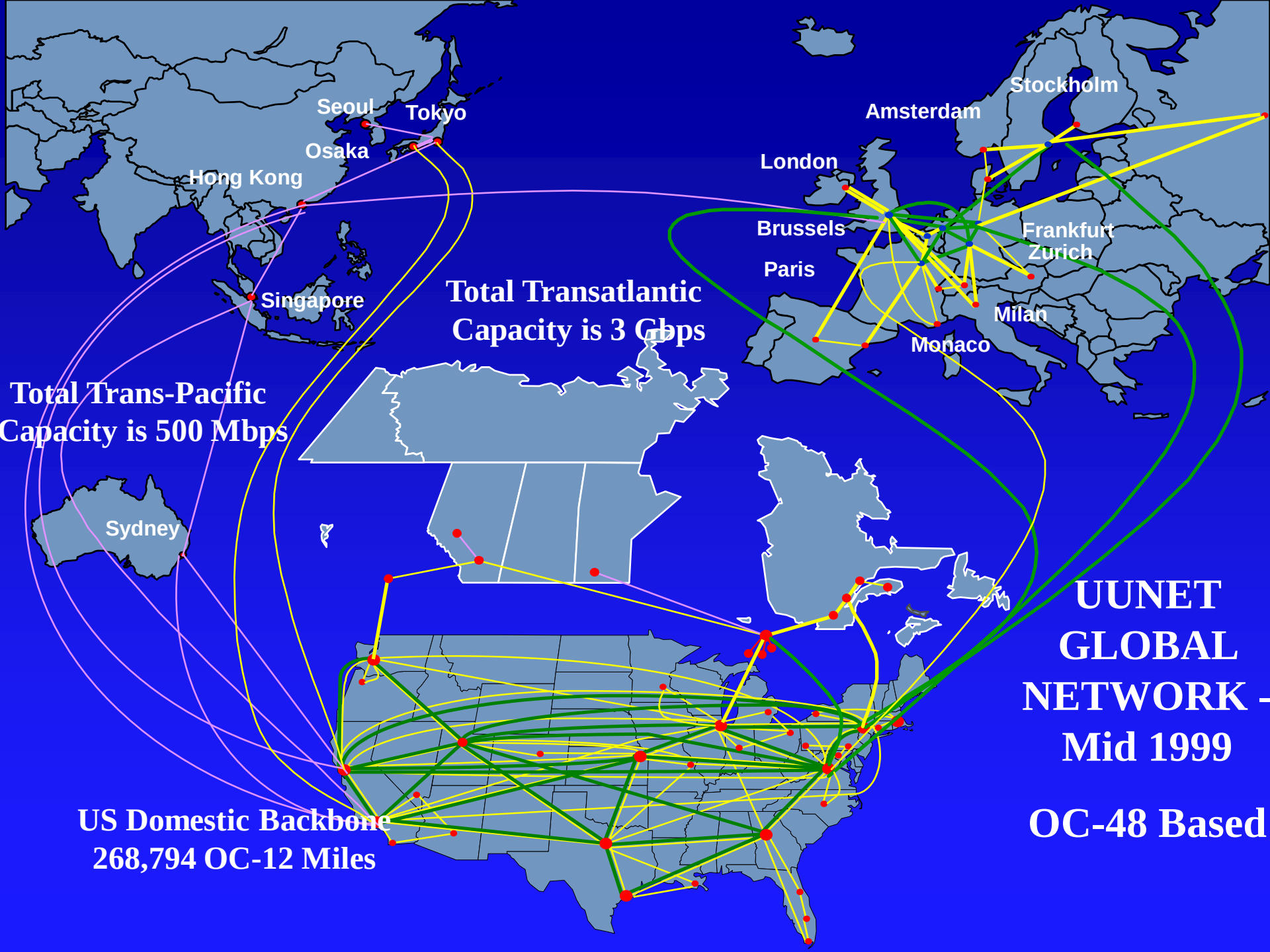
Terabit P-P link (*Ciena*)

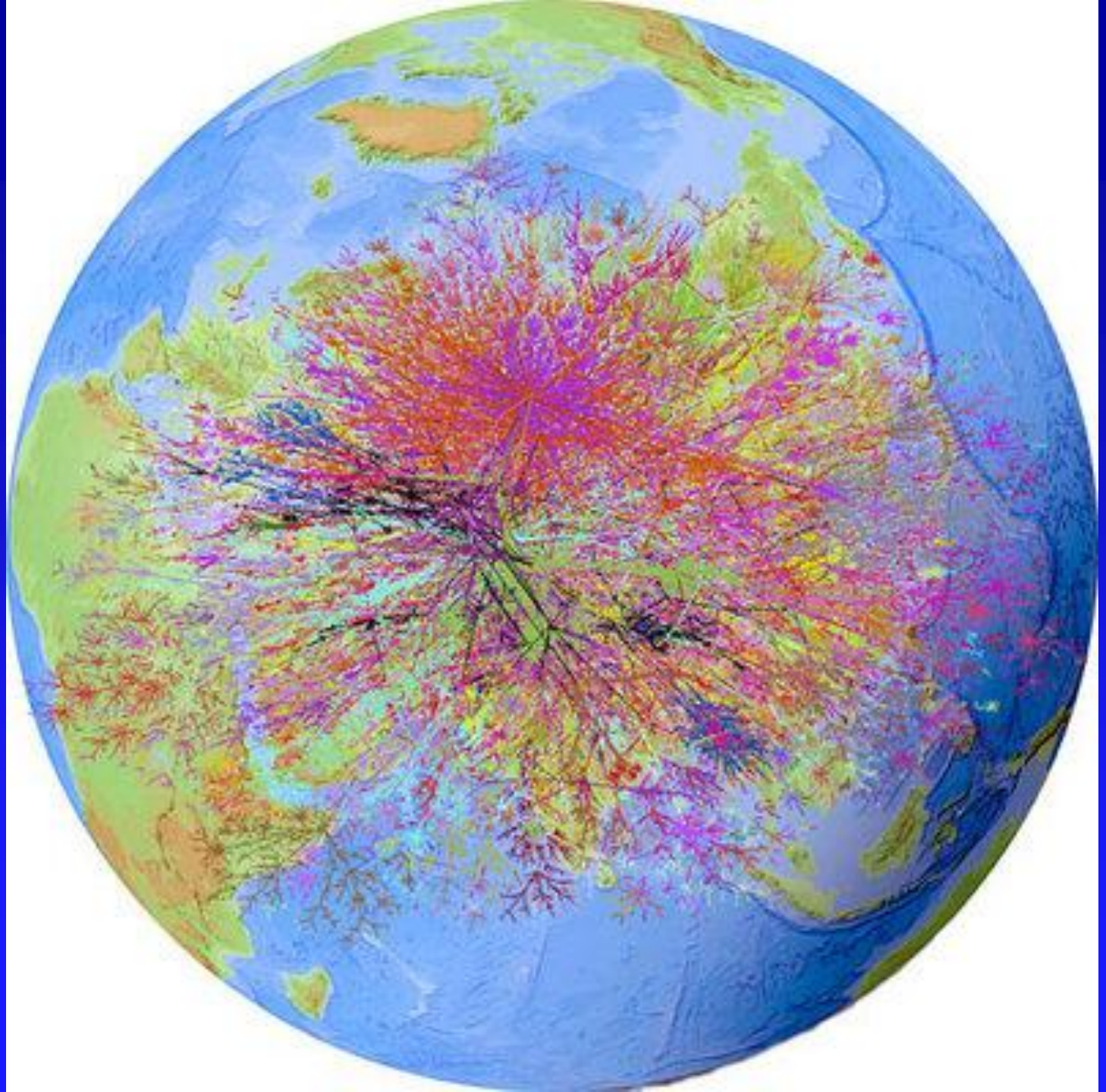


Terabit Router

ISP (Internet Service Provider)




Seoul
Tokyo
Osaka
Hong Kong
Singapore
Sydney
Stockholm
Amsterdam
London
Brussels
Paris
Frankfurt
Zurich
Milan
Monaco
Total Transatlantic Capacity is 3 Gbps
Total Trans-Pacific Capacity is 500 Mbps
US Domestic Backbone 268,794 OC-12 Miles
UUNET GLOBAL NETWORK - Mid 1999
OC-48 Based



BusinessWeek
1/31/00

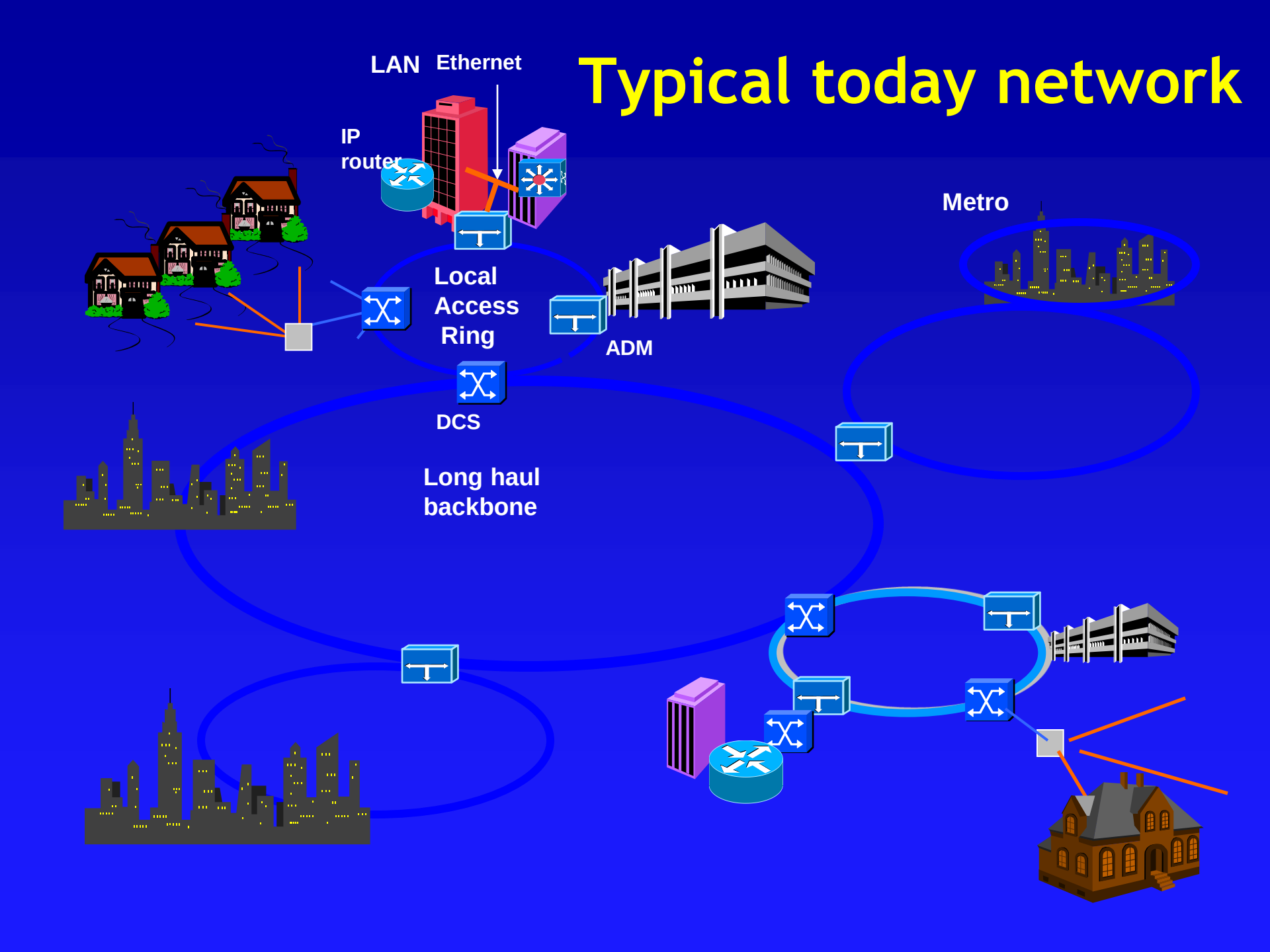
Why is optical networking all the rage on Wall Street?

The technology could be crucial in realizing the promise of the Internet. Right now, the rickety old telephone networks are straining as the flood of Net traffic in the country doubles every month. Optical technology has the potential to boost the capacity of telephone companies' networks a millionfold. "You're not going to be a player in the next generation without optics," says Michael O'Dell, chief scientist at MCI WorldCom Inc.'s UUNet Internet unit. "It's life and death."

A short history of the telecommunication wars

- **1970's: Long-haul carriers (IXCs), AT&T, MCI, GTE,…**
  - War gears: microwave link, electronic switches
- **Early 1980's: IXCs (AT&T, MCI, GTE, LDDS, …), Cables vs. TV network**
  - War gears: optical fiber trunking, coax cables network, high-speed electronics
- **Late 1980's – early 1990's: The war of all against all: IXCs (AT&T, MCI, GTE, WorldCom, …), RBOCs (Baby Bells), Wireless (cellular phones), Cables, DSS, TV network, Contents vs. Carriers,…**
  - War gears: more optical fiber trunking, coax, microwave bands, higher-speed electronics, digital signal processors, networking gears
- **Late 1990's: The war of all against all: IXCs, ILECs, CLECs, Wireless, Cables, DSS, TV network, ISP (new comer)**
  - War gears: optical fiber trunking, coax, modems, super ASICs, advanced electronics and optical networking gears.

Typical today network



A glossary (evolving!)

- **LAN** (Local Area Network) – **10 m to 10 km**
  - It has to do with your computer in a building complex or campus
  - Proprietary premise and/or campus network, owned and operated by user.
- **Local Access** – < **1 km to few km**
  - It has to do with your ISP retailer or phone company
  - RBOC Public network (PSTN), connects subscribers to central office.
- **MAN/WAN** (Metro/Wide Area Network) - **few km to 100's km**
  - It has to do with your bandwidth broker, wholesaler, ISP, large private enterprises, local and long distance phone companies
  - Owned and operated by private enterprise, ILEC, CLEC, IXC
- **Long Haul** – **100's km to 10,000's km**
  - It has to do with you when you make a long distance connection
  - Owned and operated IXC or large ISP

Typical today network

Conduits: copper, wireless

Ethernet

IP router

Architectures: LAN, MAN, Long haul (Ethernet, ATM, FR, SONET/SDH, IP)

Local Access Ring

ADM

DCS

Long haul backbone

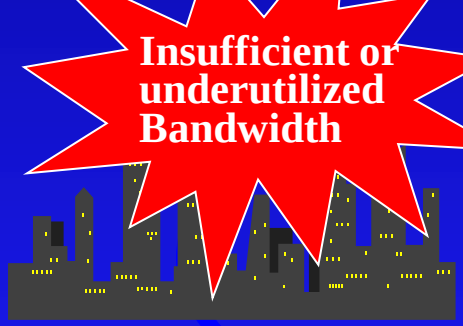
Insufficient or underutilized Bandwidth

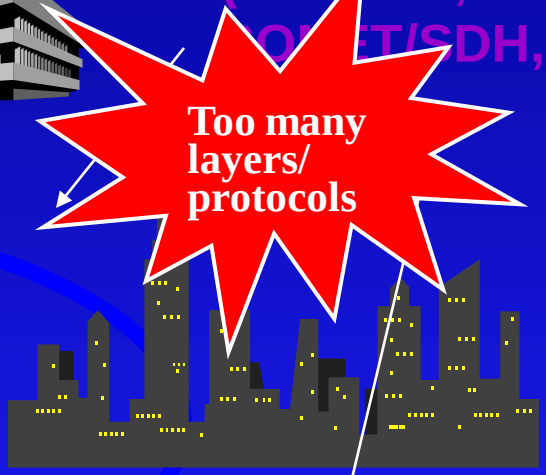
Too many layers/ protocols

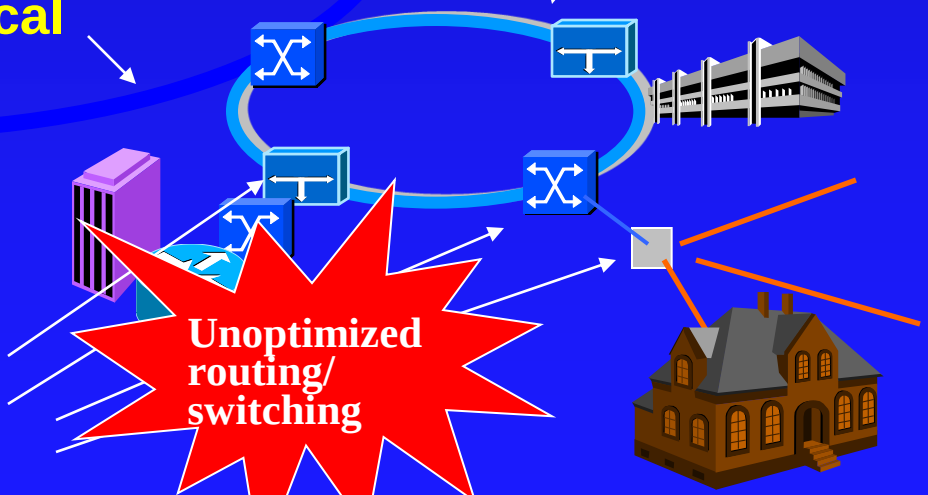
Conduits: Optical fiber

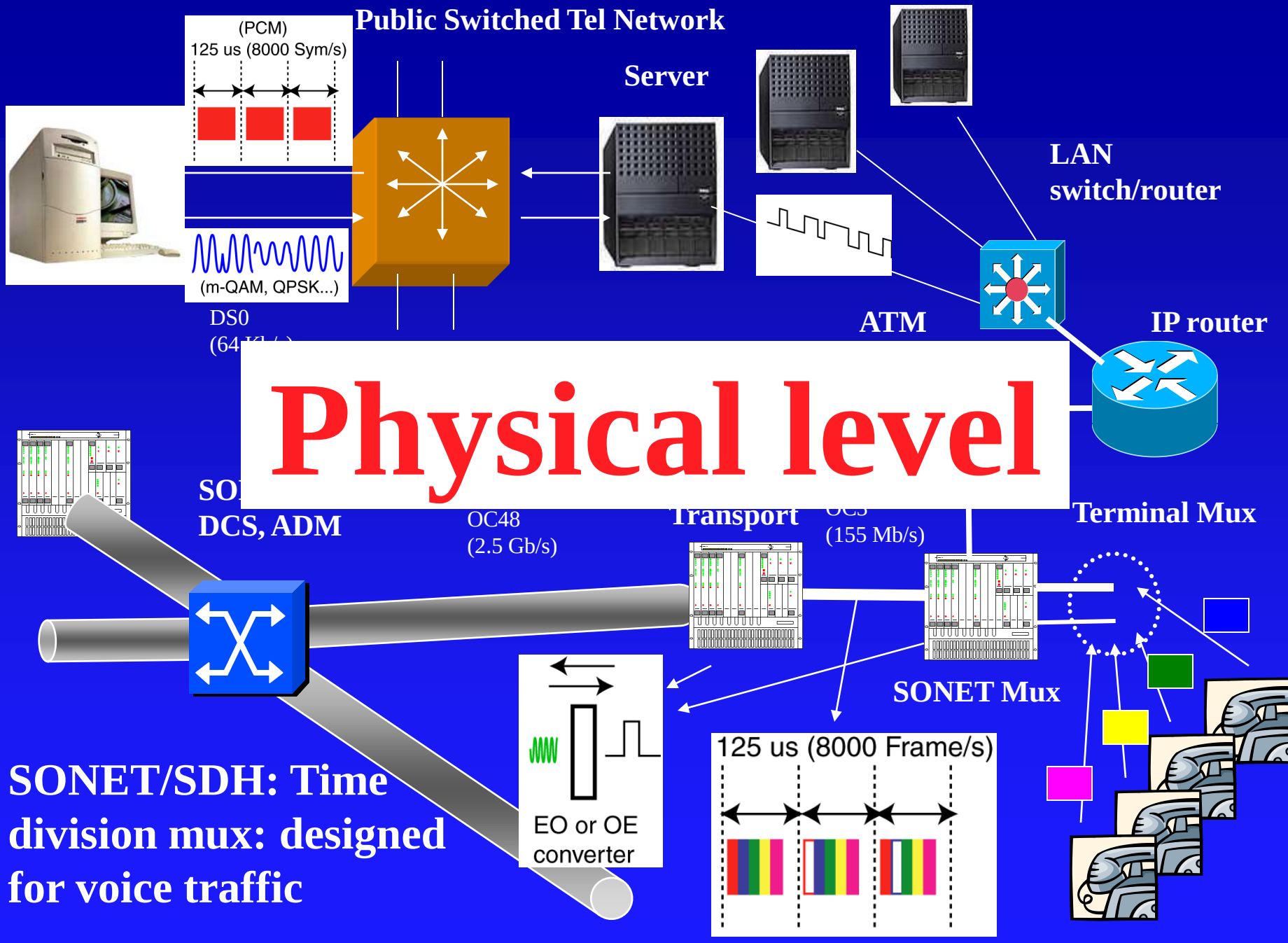
Gears: modem, terminal mux, router, (O)ADM, (O/D)XC, (C,D,UD)WDM

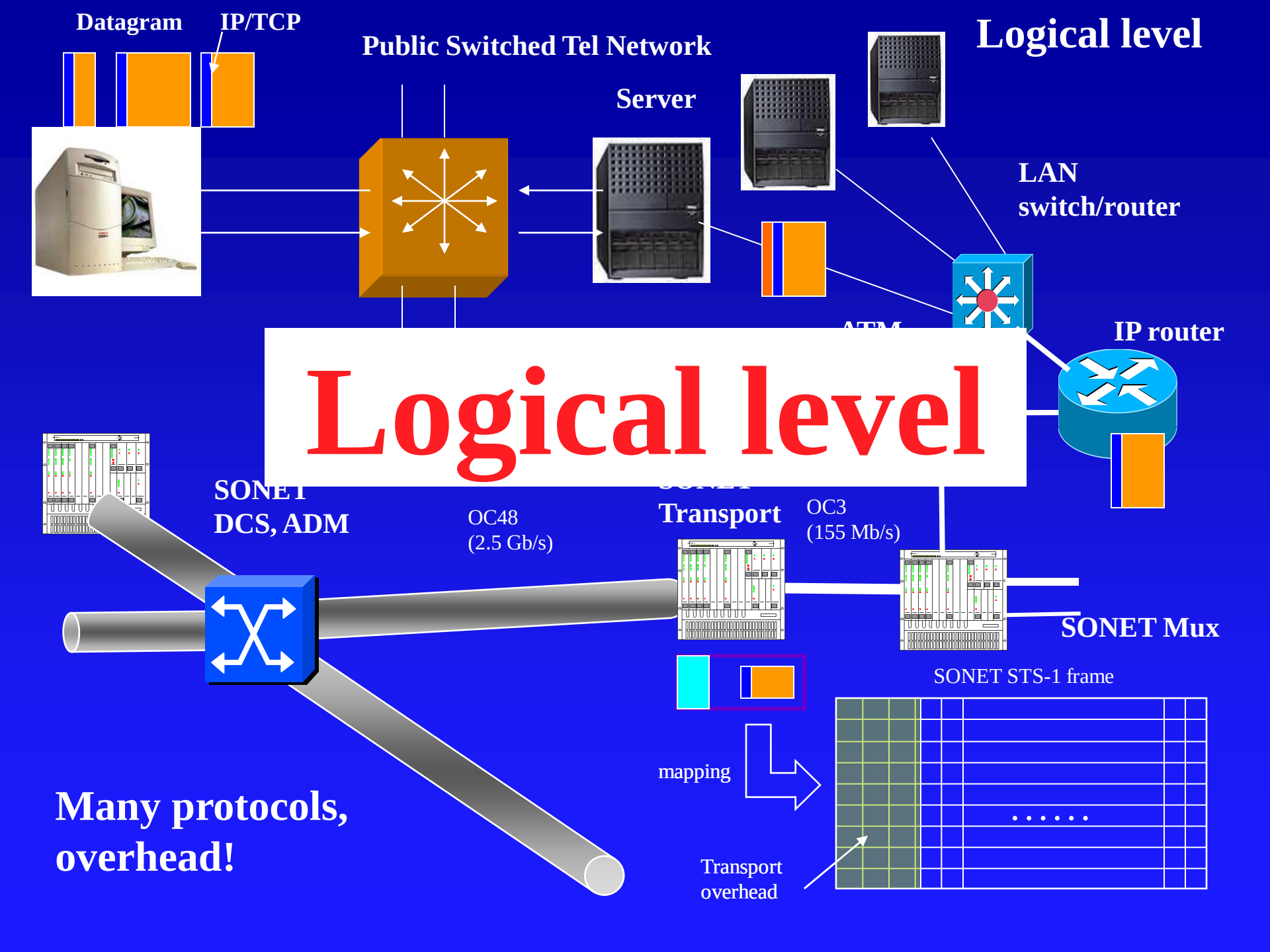
Unoptimized routing/ switching

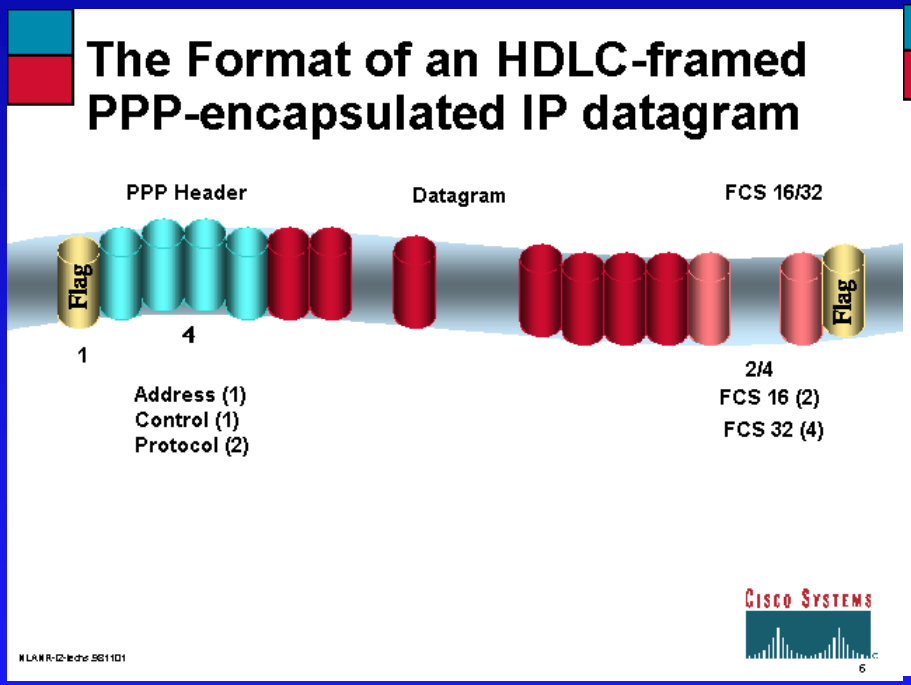


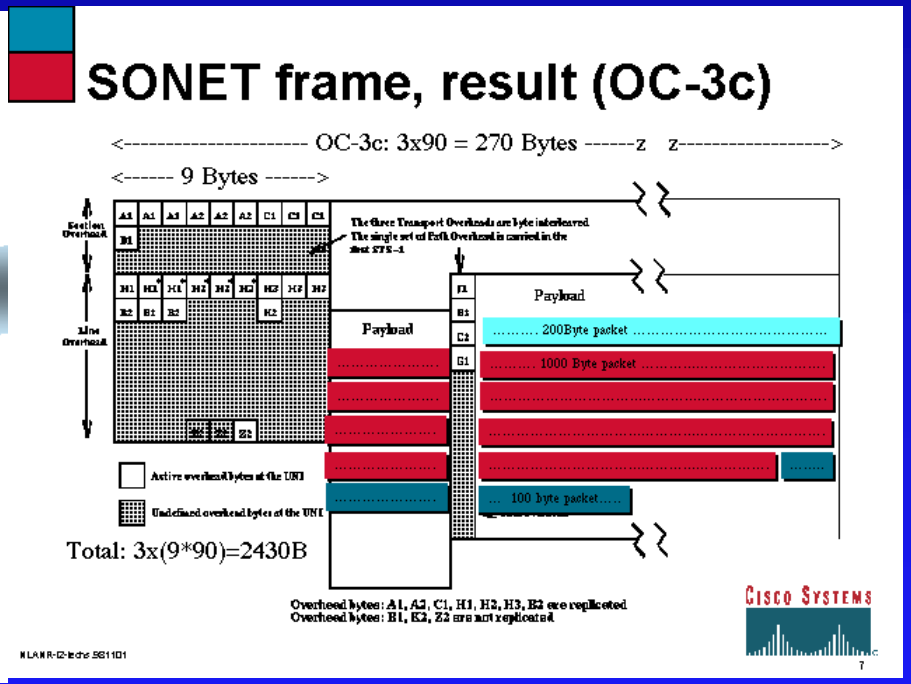





(PCM)
125 us (8000 Sym/s)
Public Switched Tel Network
Server
LAN
switch/router
(m-QAM, QPSK...)
DS0
ATM
IP router
Physical level
DCS, ADM
OC48
(2.5 Gb/s)
Transport
(155 Mb/s)
Terminal Mux
SONET Mux
EO or OE
converter
125 us (8000 Frame/s)
SONET/SDH: Time
division mux: designed
for voice traffic

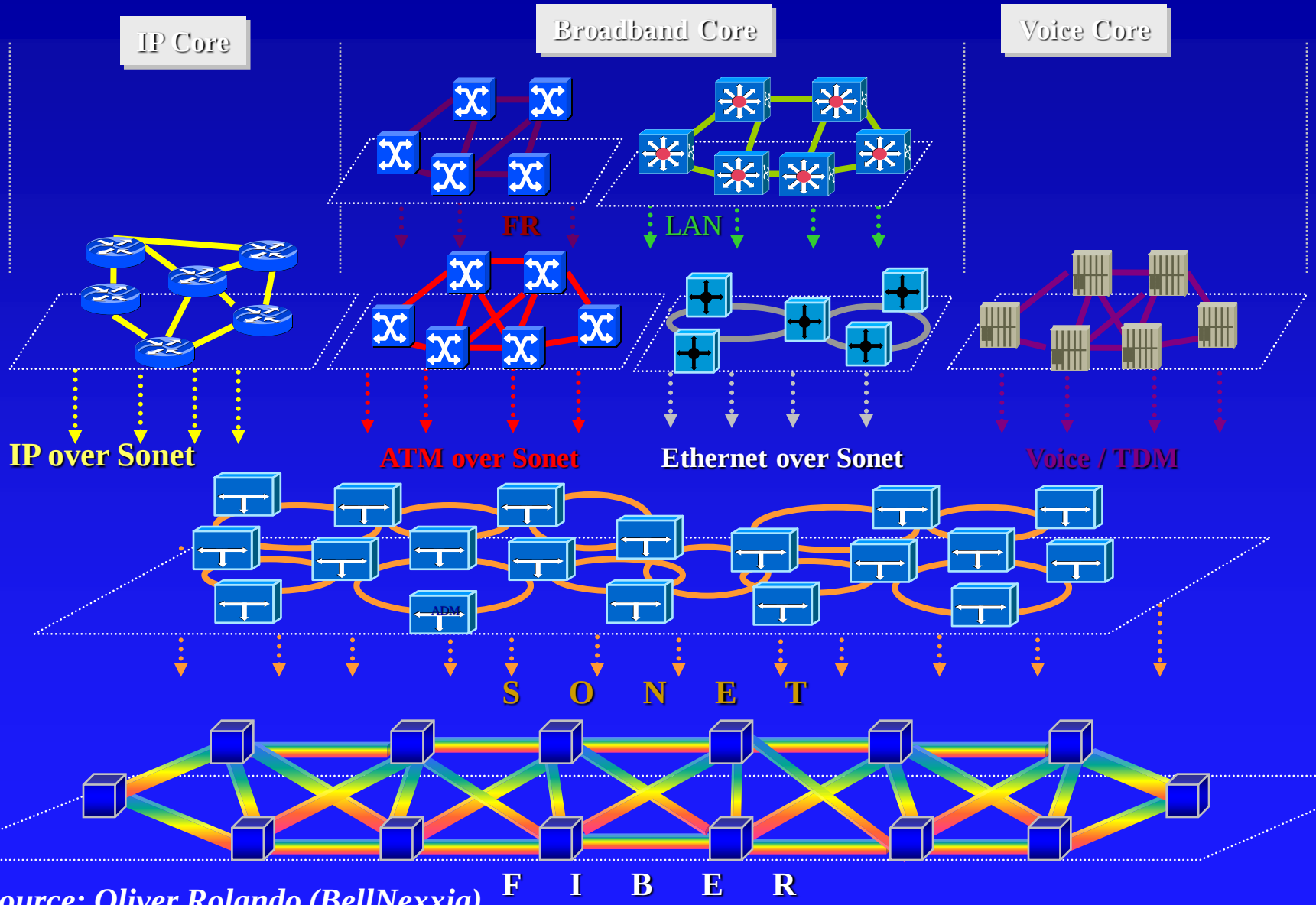

Datagram
IP/TCP
Public Switched Tel Network
Server
Logical level
LAN
switch/router
IP router
Logical level
SONET
DCS, ADM
OC48
(2.5 Gb/s)
Transport
OC3
(155 Mb/s)
SONET Mux
SONET STS-1 frame
mapping
Transport
overhead
Many protocols,
overhead!





Source: Cisco System

Today's Networks

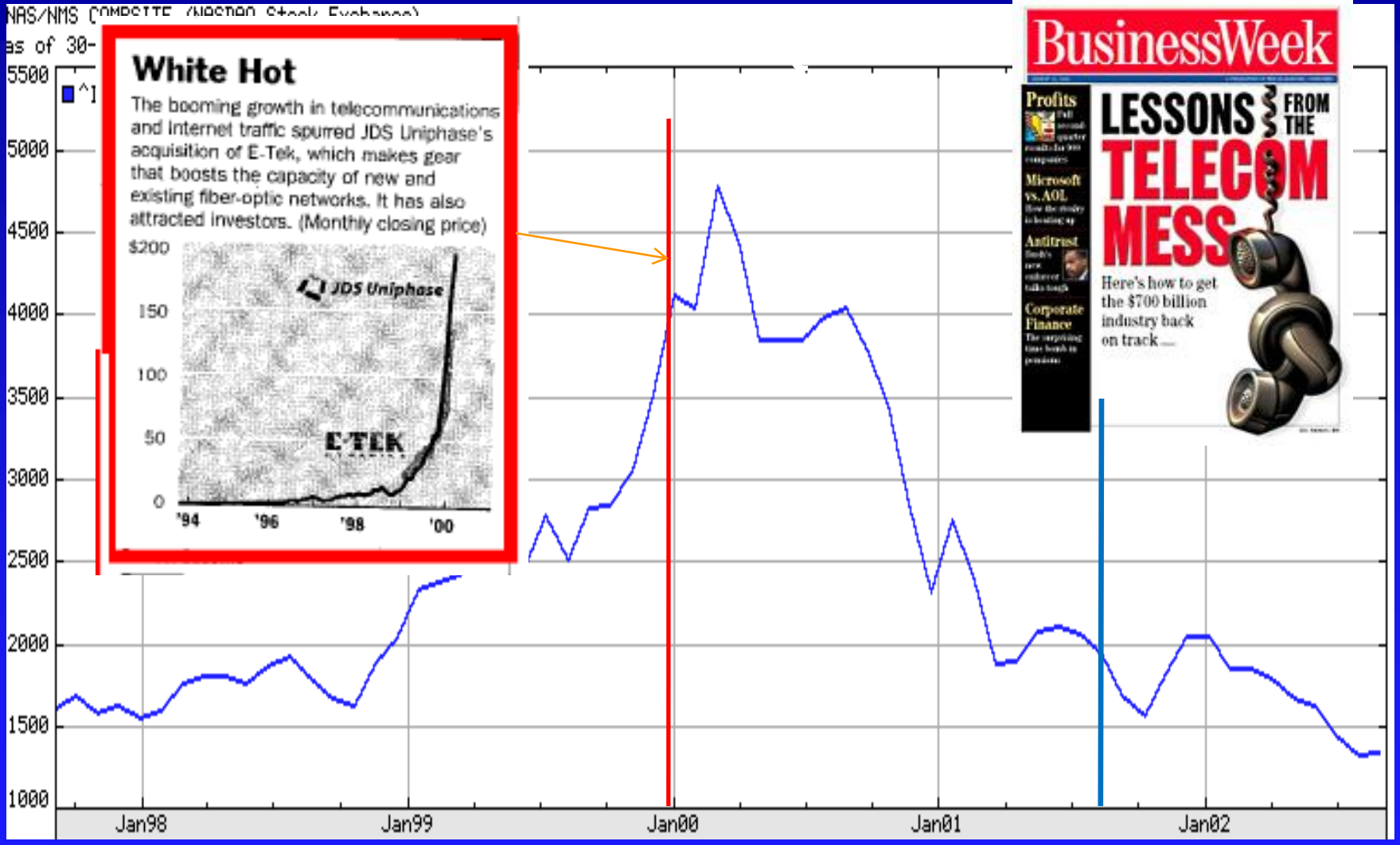


Source: Oliver Rolando (BellNexxia)

Technology issues

- Network architecture: LAN, MAN, WAN independently evolved: Ethernet, FDDI, SONET/SDH, ATM, IP (Internet): heavy overhead layers; complex OAM&P (operations, administration, maintenance & provisioning) to get compatibility
- Network equipment: unoptimized, electronic speed limit
- Conduit: Old copper network vs. optical fiber; capacity x reach
- Network usage: Voice traffic vs. data traffic; circuit switch vs. packet switch; use phone line to hook up to the Internet (data on voice circuit) and use Internet to make phone call (voice over IP)

Then… What Happened?


White Hot
The booming growth in telecommunications and Internet traffic spurred JDS Uniphase's acquisition of E-Tek, which makes gear that boosts the capacity of new and existing fiber-optic networks. It has also attracted investors. (Monthly closing price)
$200
150
100
50
0
JDS Uniphase
E-TEK
'94
'96
'98
'00
BusinessWeek
Profits
Microsoft vs. AOL
Antitrust
Corporate Finance
LESSONS FROM THE TELECOM MESS
Here's how to get the $700 billion industry back on track
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Jan98
Jan99
Jan00
Jan01
Jan02


Telecom Nuclear Winter

Disruption to The Century-Old Industry

Source: Han Le & Assoc

Wall Street Journal 2/15/00

NORTEL NETWORKS CORP.

Expansion of Operations In Canada, U.K. Is Planned

Nortel Networks Corp., seeking to accommodate demand in its booming optical-networking business, said it will spend $260 million and create 3,400 jobs to expand manufacturing operations in Canada and the United Kingdom. Nortel, Brampton, Ontario, said $186 million is earmarked for new manufacturing operations in Ottawa and Montreal, while most of the remainder will be invested in the U.K. The new jobs will be in manufacturing, engineering, supply management and customer service. The expansion will be completed by year end and is required to meet fast-growing demand for equipment that allows large amounts of data and voice communication to travel over fiber-optic networks, Nortel said. The expansion will give Nortel greater capacity to produce lasers, which are used to send optical signals through glass fiber strands.

Wall Street Journal 1/15/09

TECHNOLOGY | JANUARY 15, 2009

Nortel Networks Files for Chapter 11

Credit Crisis Swamped It After Struggles With Weak Sales, Currency Swings and Rising Pension Costs

Article | Comments

Nortel Networks Corp. sought protection from creditors in the U.S. and Canada, falling victim to the economic downturn and years of struggle to turn around what was once Canada's largest company.

The Chapter 11 filing further weakened the ranks of major telecom-equipment makers and sent chills through suppliers already coping with declining sales of network gear and handsets. Phone carriers more than ever are seeking suppliers with good products and better balance sheets.

It’s NOT the technology…
It’s the business corruption and financial abuse

The technology is TOO disruptive to the business model!

History of the Telephone

- When telephone was first introduced it was promoted as a device for:
  - Home shopping – order goods over the phone
  - Tele-medicine – consult with a doctor
  - Tele-church – hear church services over the phone
  - Sound familiar?
- The concept that there would be a market to use the telephone just for talking or chatting was inconceivable
  - But that turned out to be the biggest market
- The Internet was designed on a set of protocols to allow computers to talk
  - There will be multimedia applications
  - But the biggest application might be computers chatting and talking

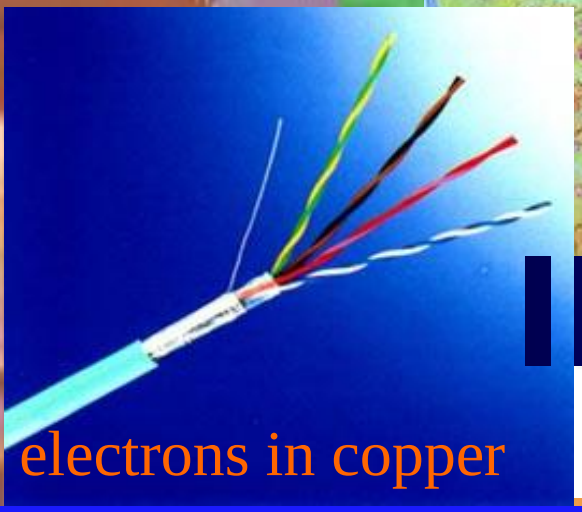
Source: B. St. Arnaud

Technology of The First Optics Revolution

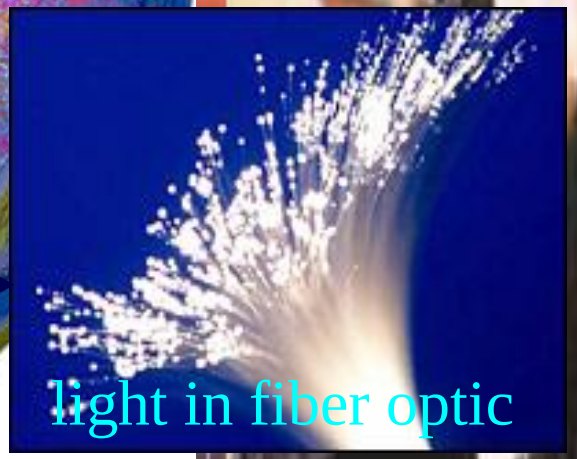
The Optical Internet and Telecom World

1999-2005: The quiet industrial revolution:

"*The optocentric paradigm shift*"



electrons in copper



light in fiber optic

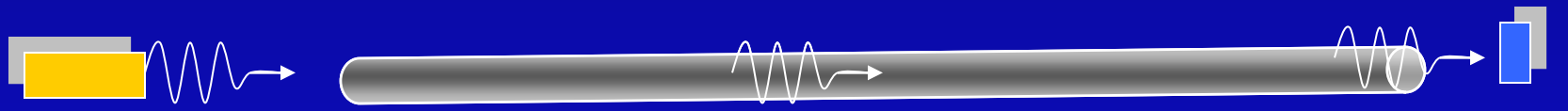
Source: Han Le & Assoc

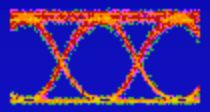
Problem meets solution?

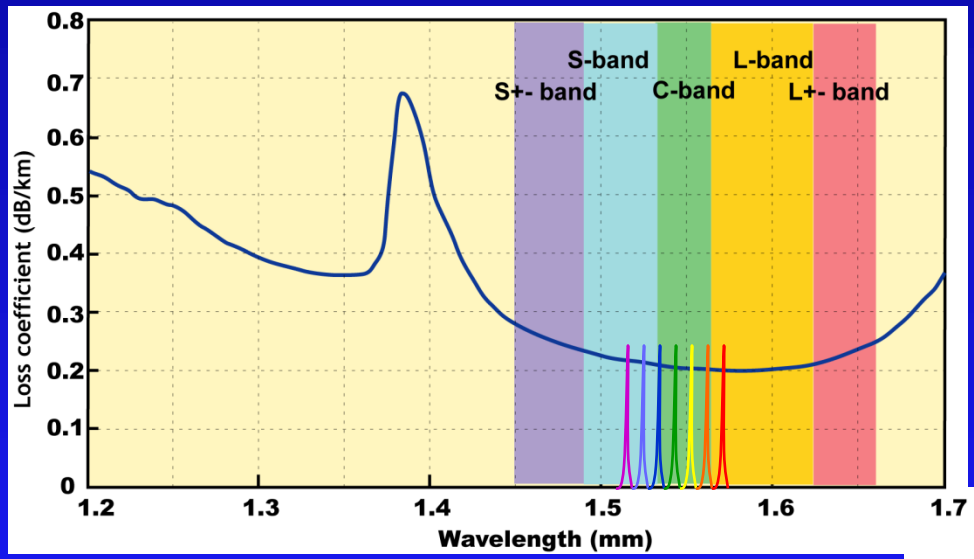
Photonics: Coarse, Dense, UltraDense Wavelength Division Multiplexing (WDM), Optical Amplifier (OA), and other advanced OE technology: a new optical communication paradigm

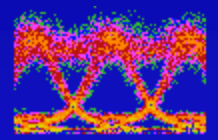
- **DWDM for long-haul trunking (raw bandwidth)**
- **DWDM for optical network (bandwidth + service)**
  - **The optical Internet: IP over DWDM (http://www.ietf.org)**
  - **DWDM for Metro Core and Access (MAN) ($B's)**
- **WDM, CDWM optical network for the mass**
  - **Will Gigabit Ethernet (GbE) LAN be everywhere?**

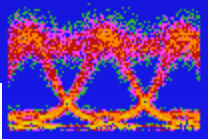
DWDM & OA for trunking

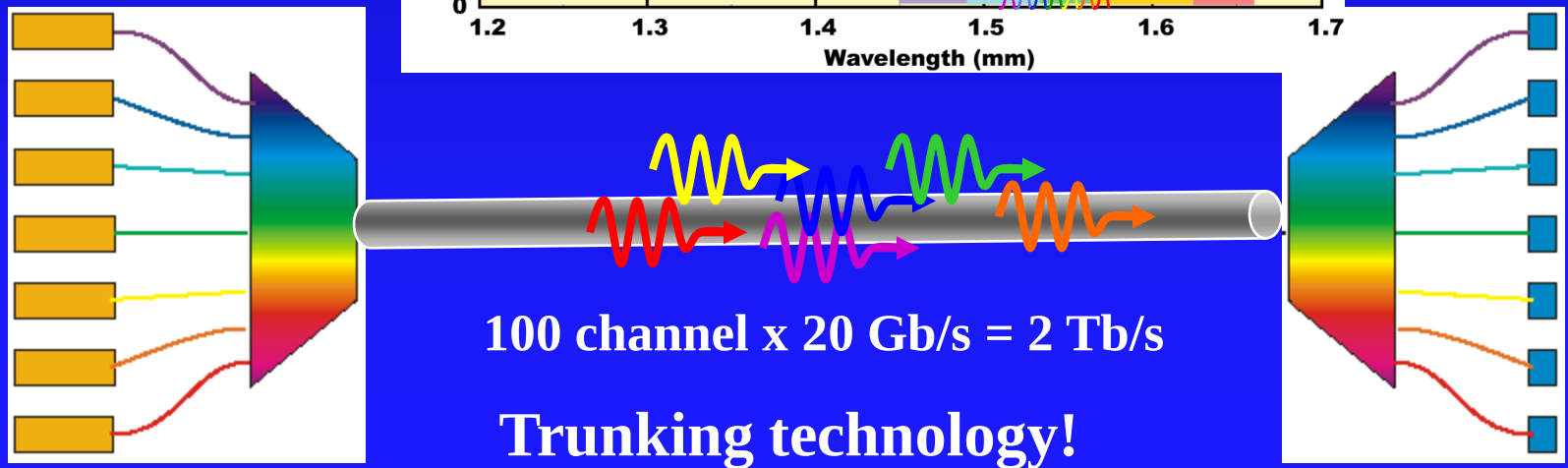








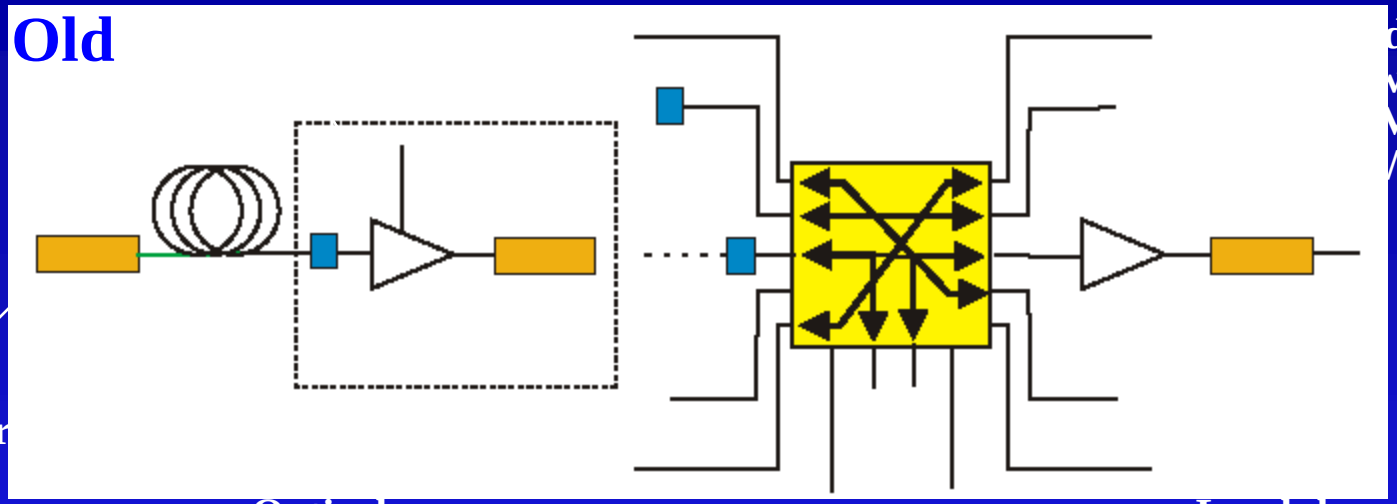




100 channel x 20 Gb/s = 2 Tb/s

Trunking technology!

Old vs. new optical network



d electronic
witch, TDM
M, DXC
/SDH, ATM,

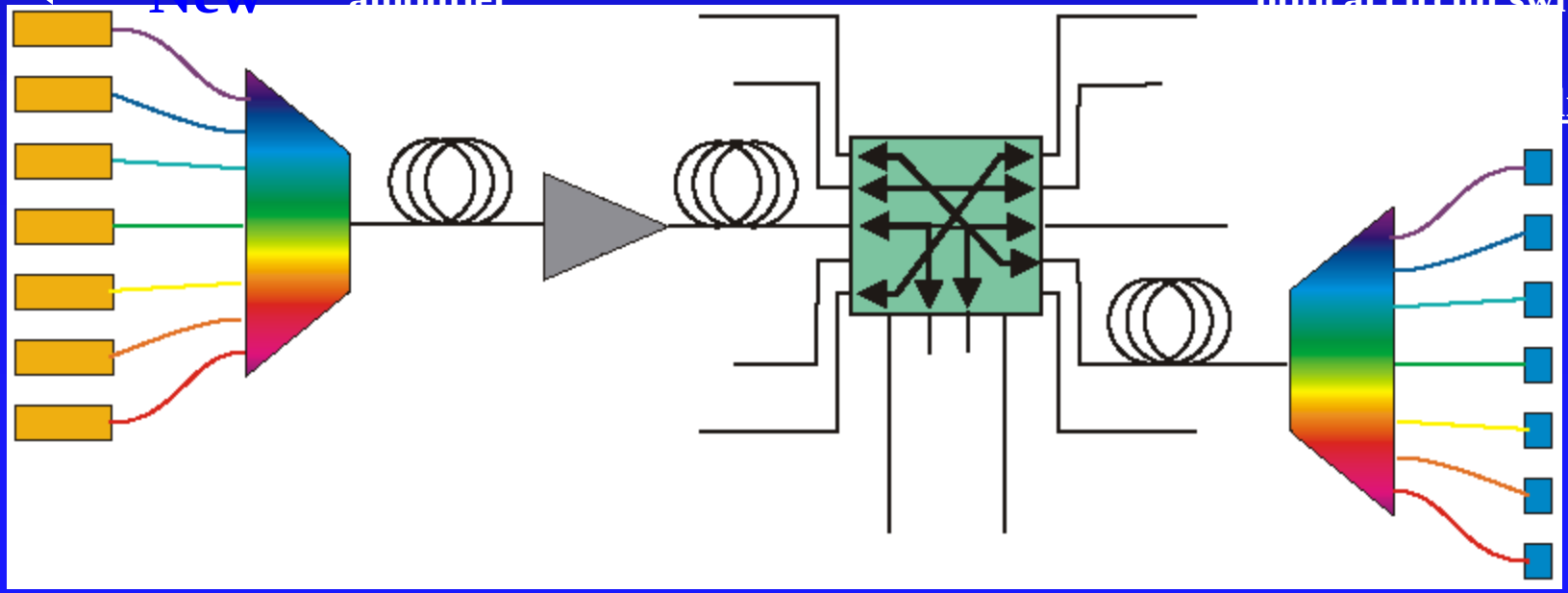
Laser
transmitter

New

Optical
amplifier

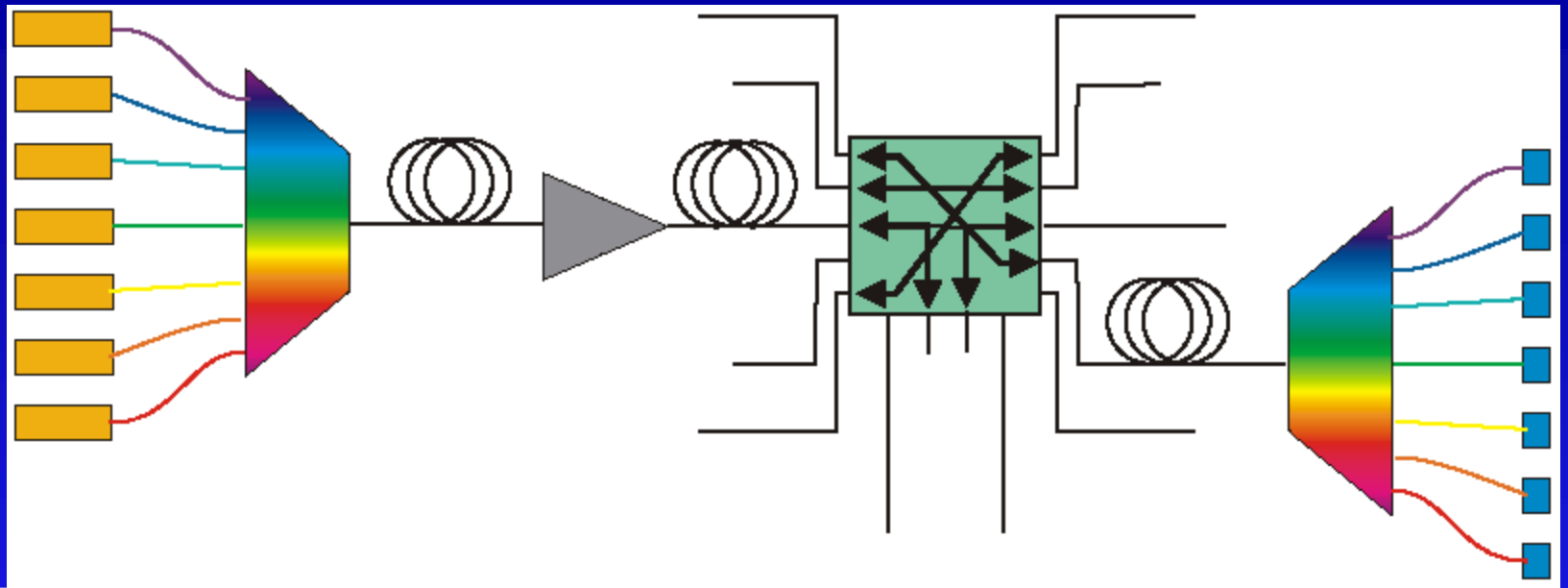
Lambda-switch/route,
optical circuit switch,

ities



Meet the enabling technology…

Optical/DWDM networking technology



Transmitter

- Laser
  - DFB, DBR, VCSEL
  - Tunable, fiber
- Modulator
  - Electro-optic
  - Electroab-sorption

WDMux

- TF filters
- Fiber Bragg G
- Array wave-guide grating
- Diffraction G
- Other gratings

Fiber

- Convent. fiber
- DSF, NZDSF
- Improved fiber

Optical amplifier

- Erbium-doped Fib. Amp (EDFA)
- Semicond. (SOA)
- Others (Raman)

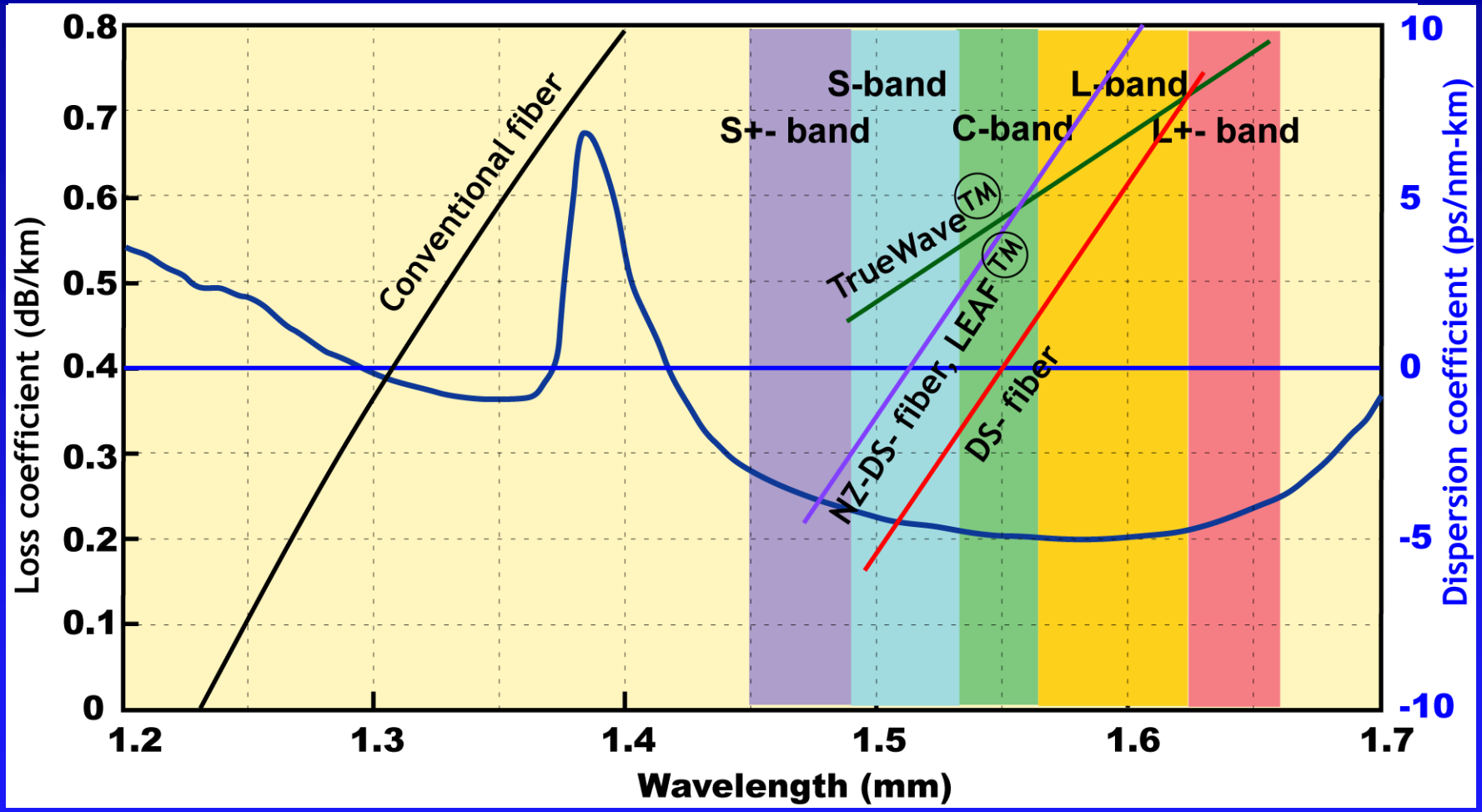
Optical switch

- Path switch
- Add/Drop mux
- λ-router
- Cross connect
- Couplers
- circulators

Receiver

- Ultrafast PD

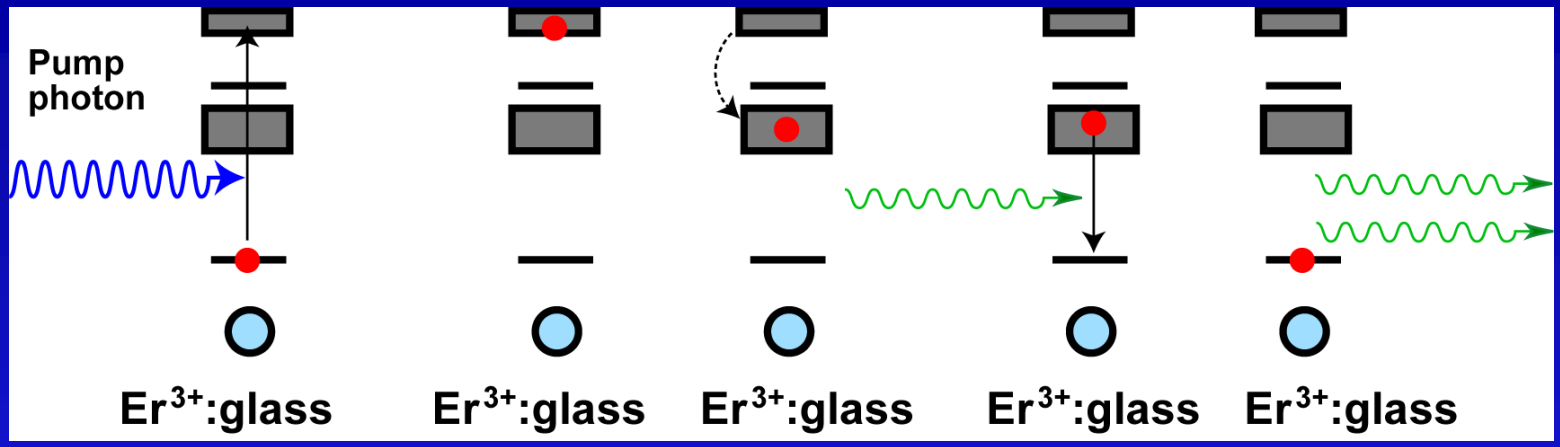
Improved fibers

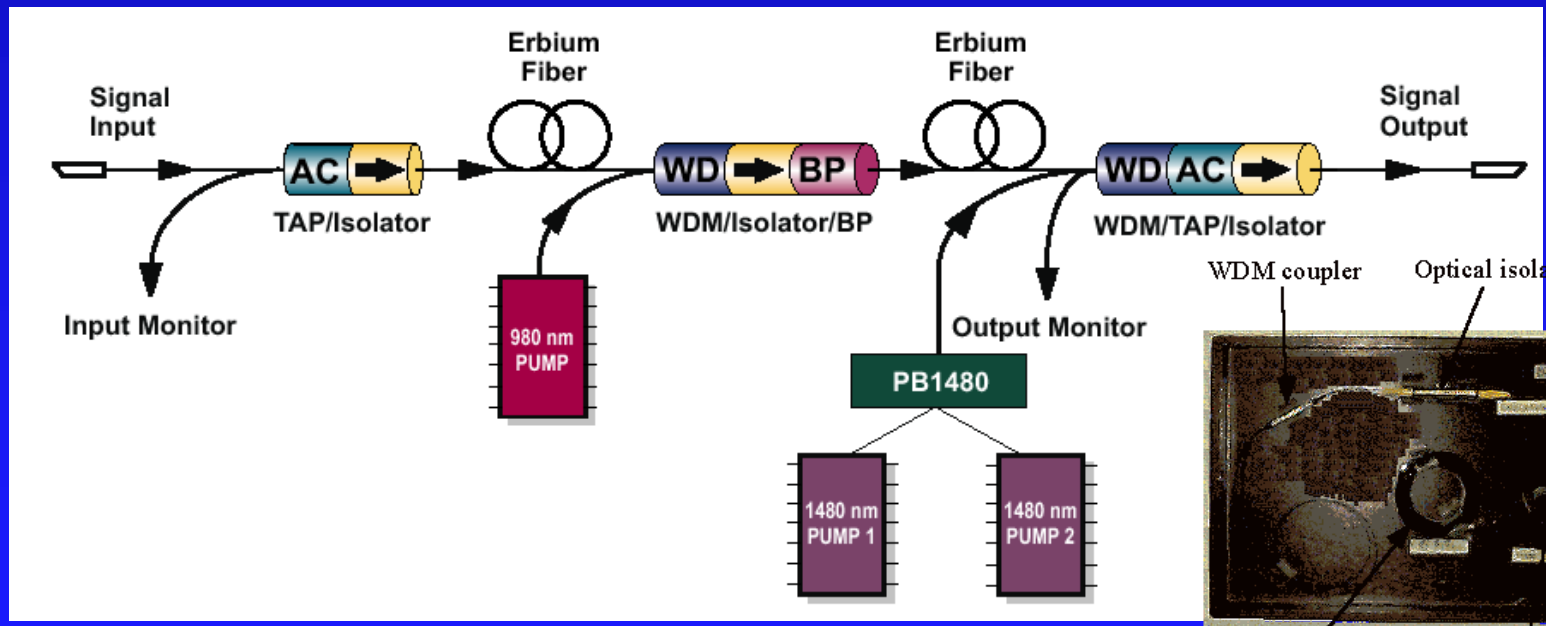


Dispersion data source: Corning, Lucent

LEAF™: less nonlinear effects; Truewave™ less GVDispersion
→ Longer reach, higher capacity

Fiber amplifier



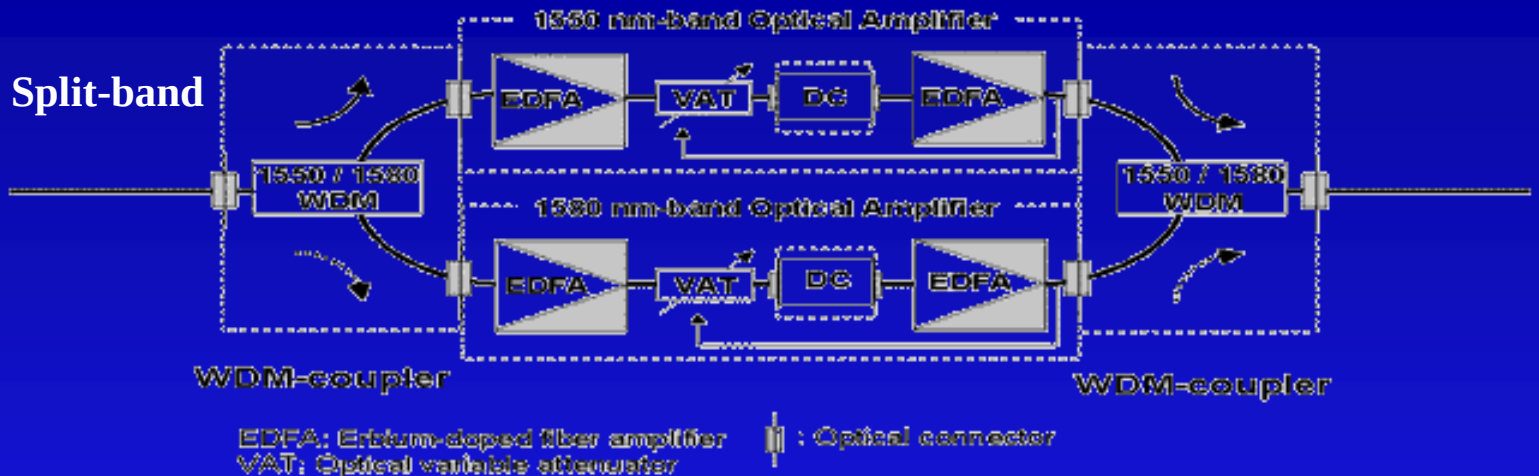


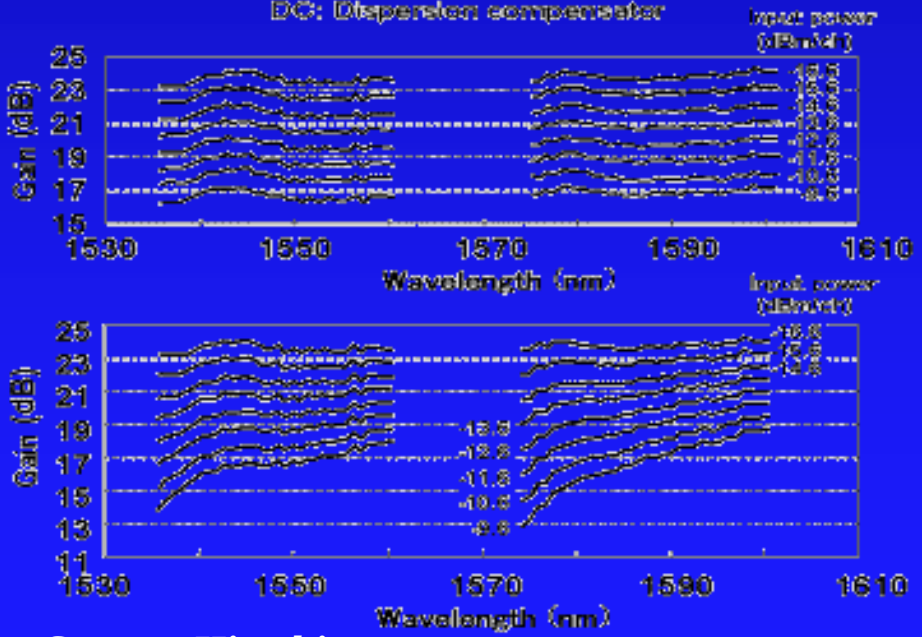
Source: KDD submarine

EDFA

Optical Amplifier

Split-band



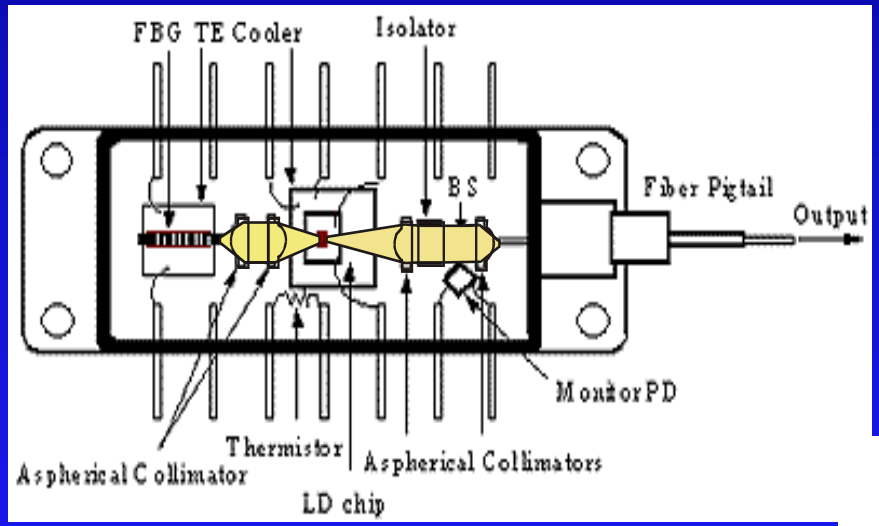


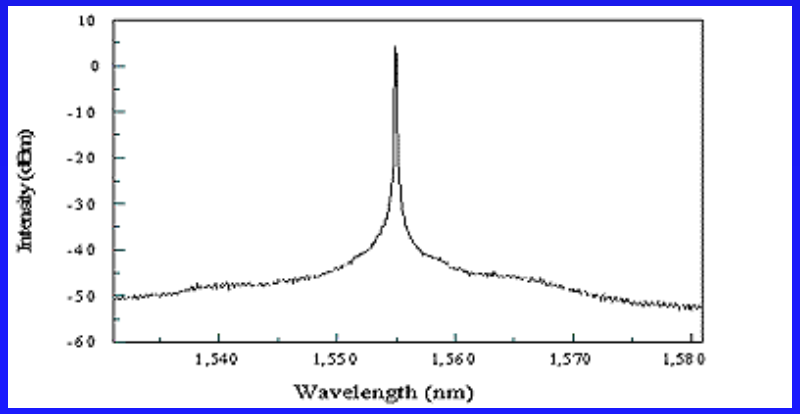
Source: Hitachi

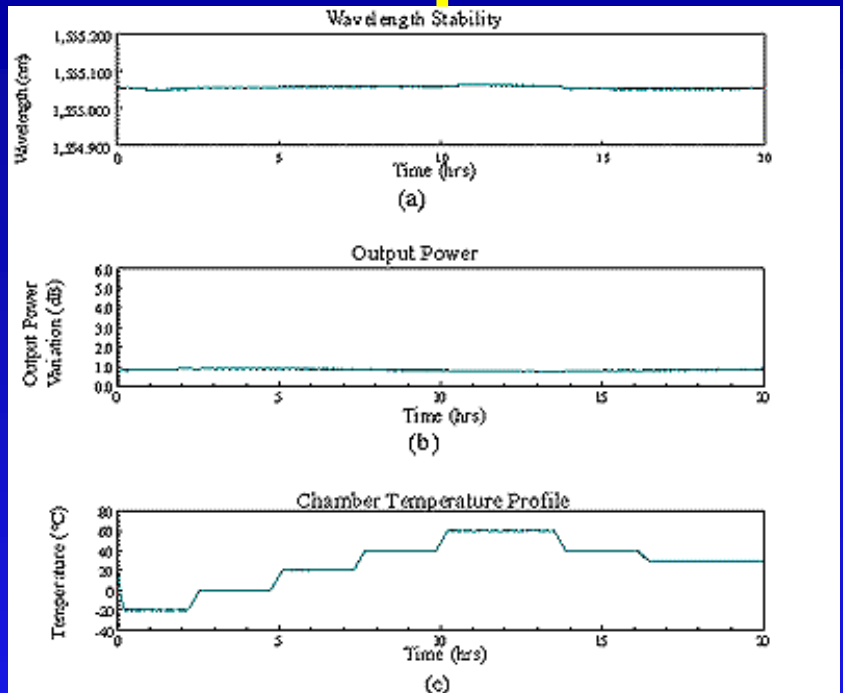
- New materials: Fluoride
- Dopants: Er/Yb co-doped, praseodymium, thulium, telluride
- Raman fiber amplifier: can be deployed this year (2000) for L band.

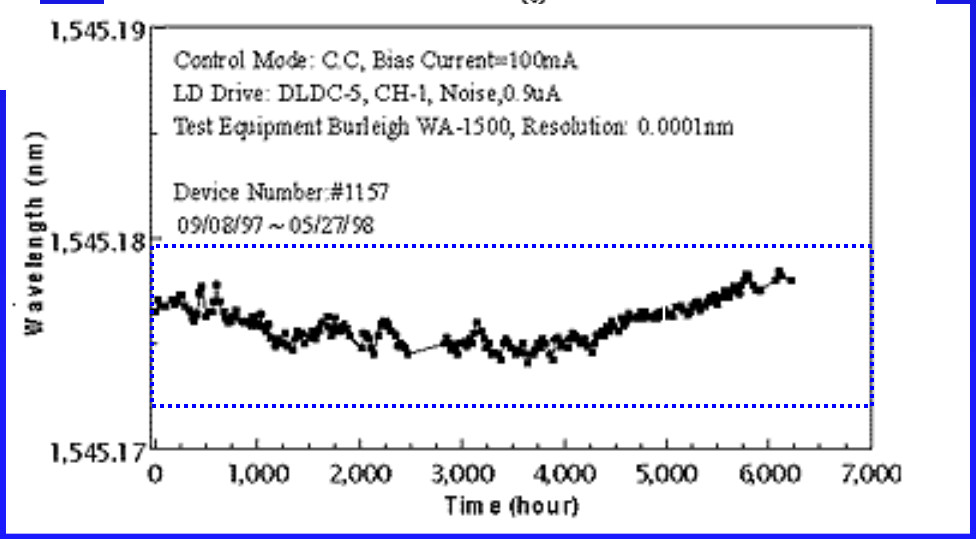
Transmitter example: FBG-coupled laser

Source: J. J. Pan (E-Tek Dyn.)



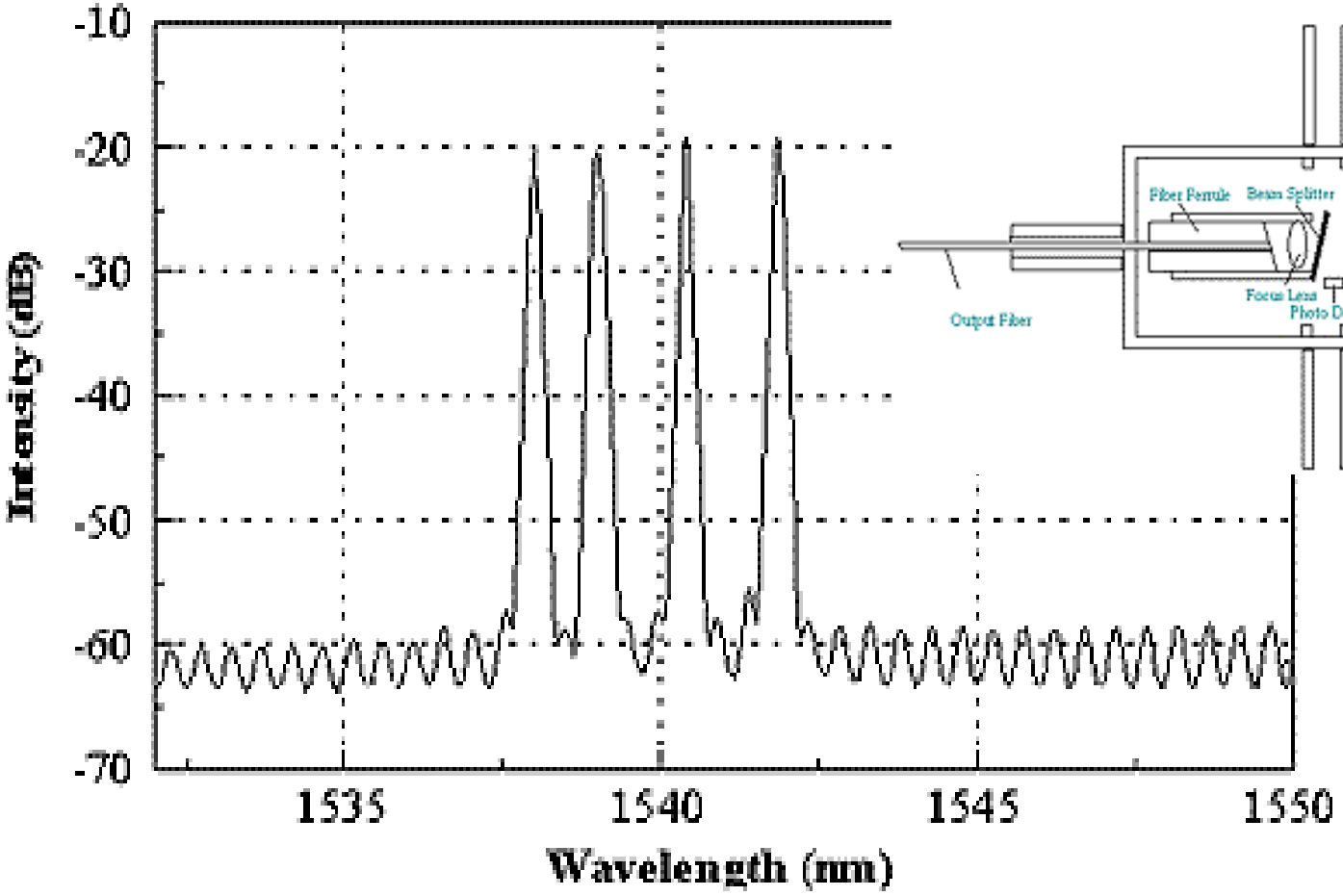


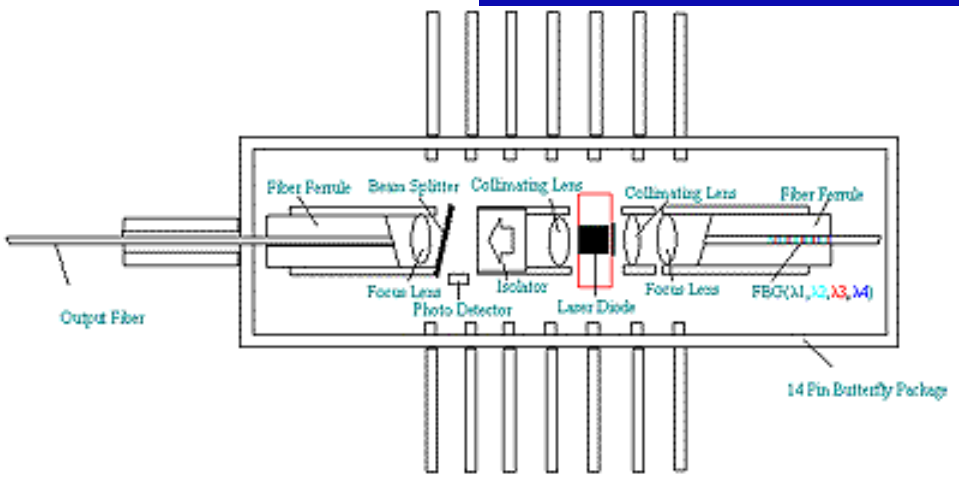




Multi-wavelength transmitter

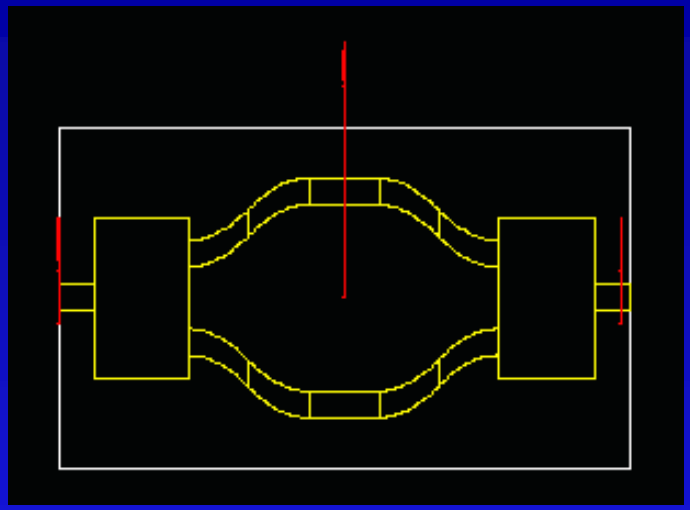
•Single gain elements, multi-λ FBG, single package (cost effectiveness)

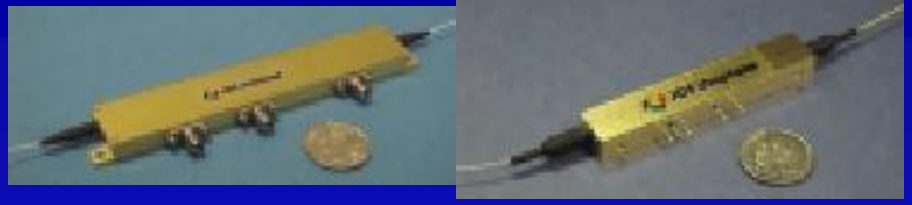


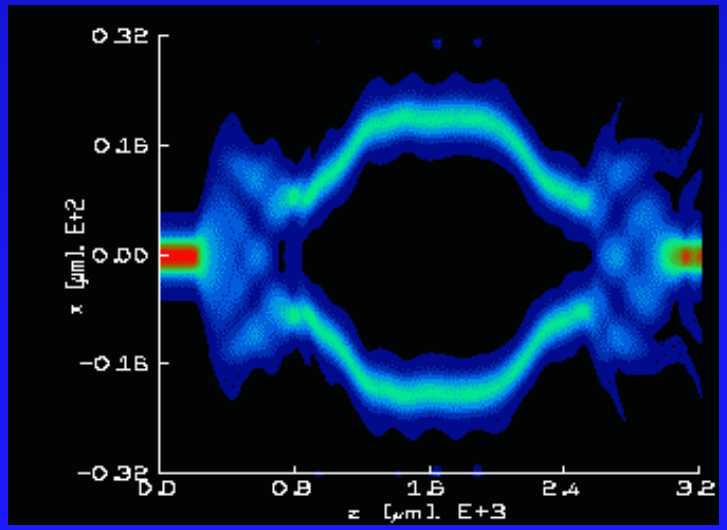


J. Pan (E-Tek Dyn.)

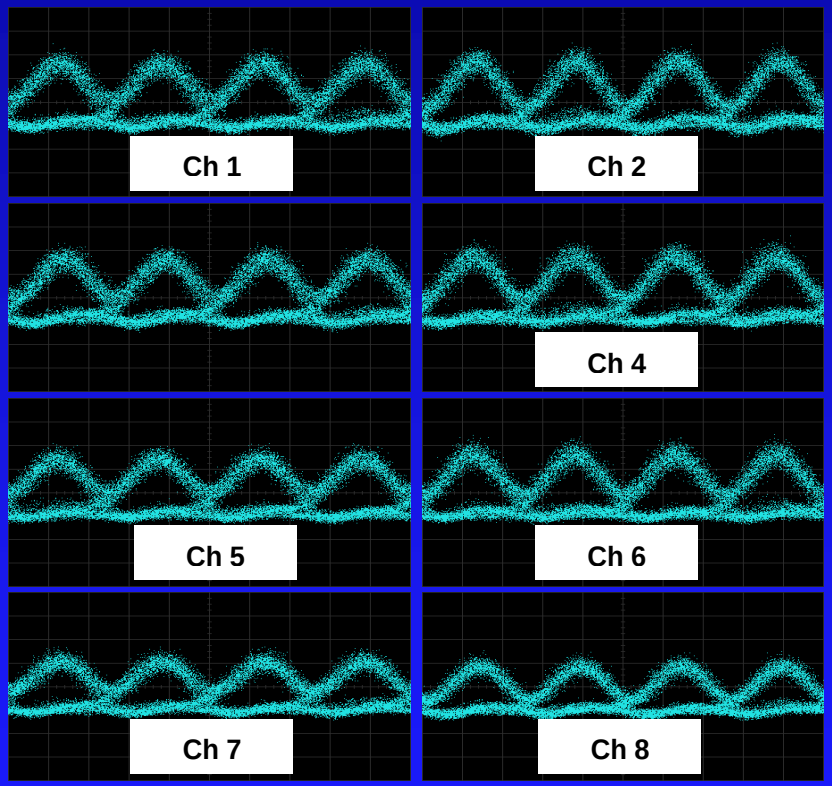
Transmitter ex.: MZ EO modulator







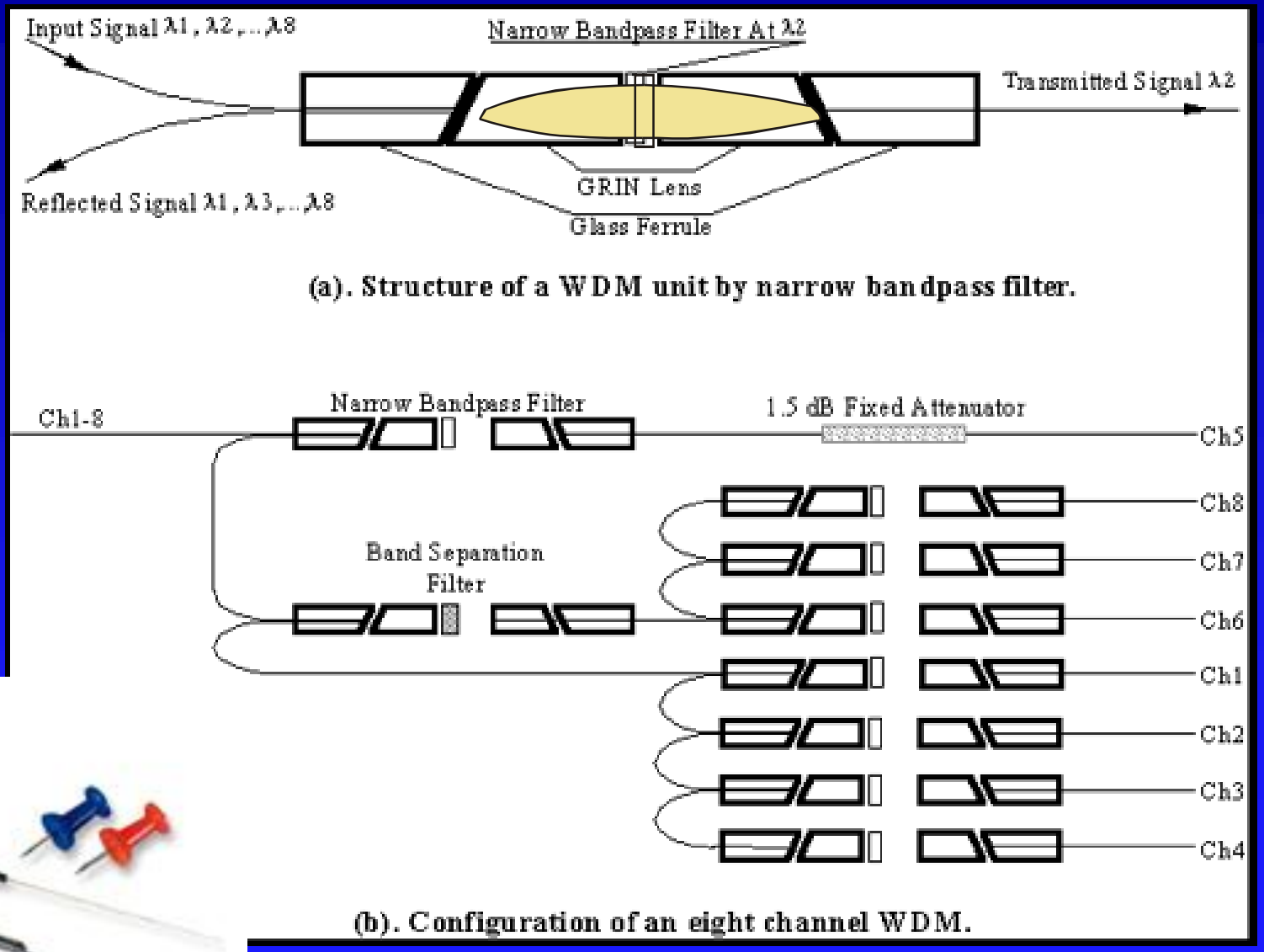
Software simulator: BBV



- **LiNbO3 still is the #1 seller**
- **Semiconductors in specialized cases**

Back

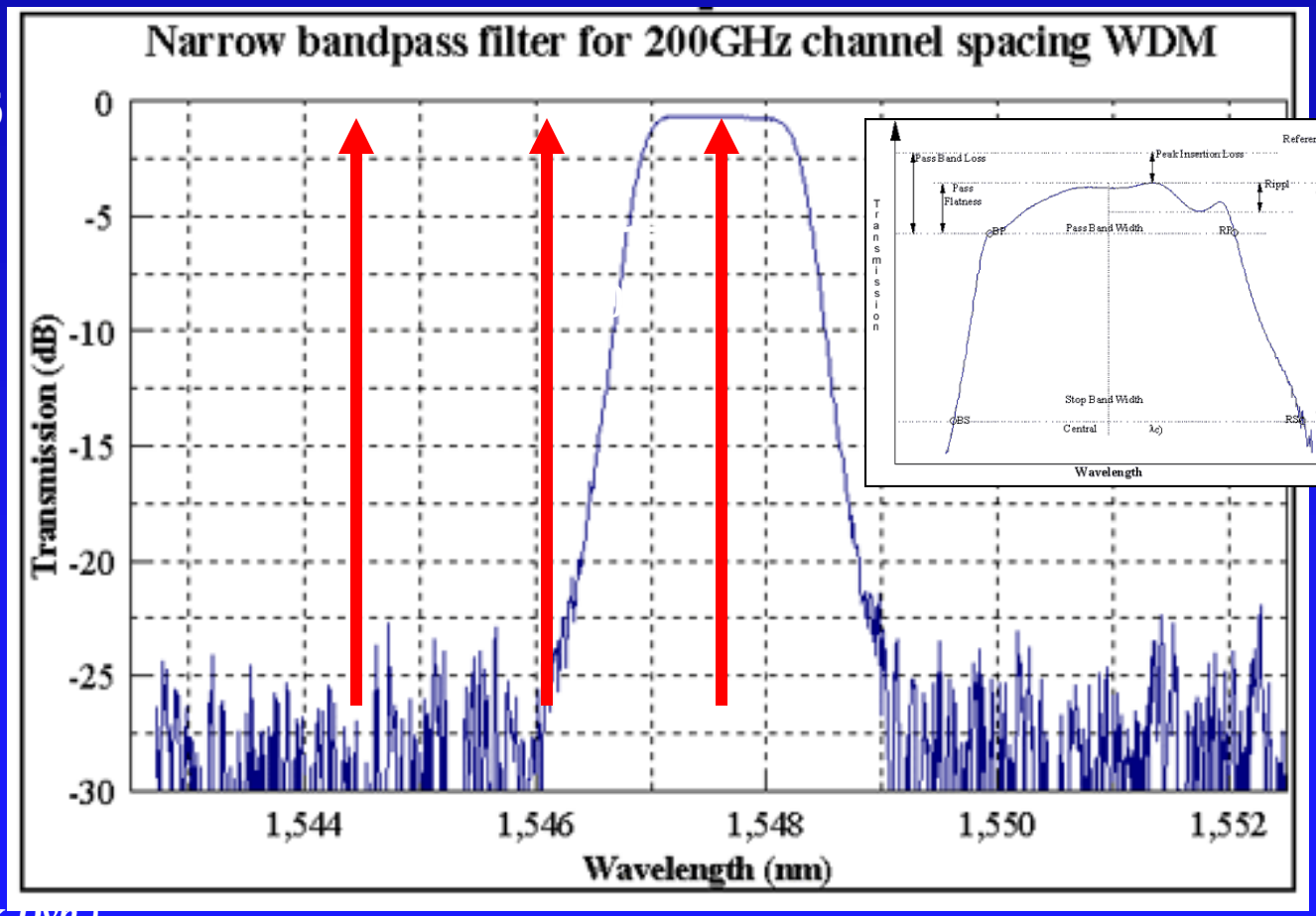
WDM channel filter



Source: J. J. Pan (E-Tek Dyn.)

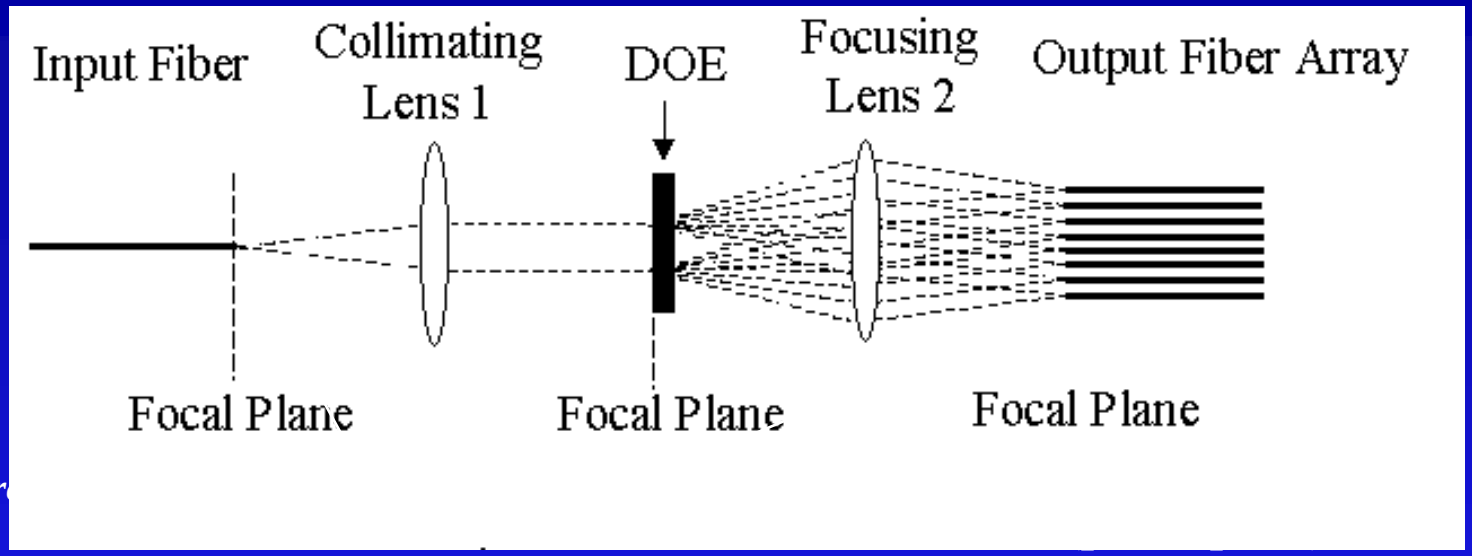
Thin film filter for WDM

- Plasma assisted deposition (covalent-like bonding instead of Van der Walls)
- 90 to 150 layers, 3 to 7 cavities
- Advanced in-situ monitoring
- Test: Mil-C-675

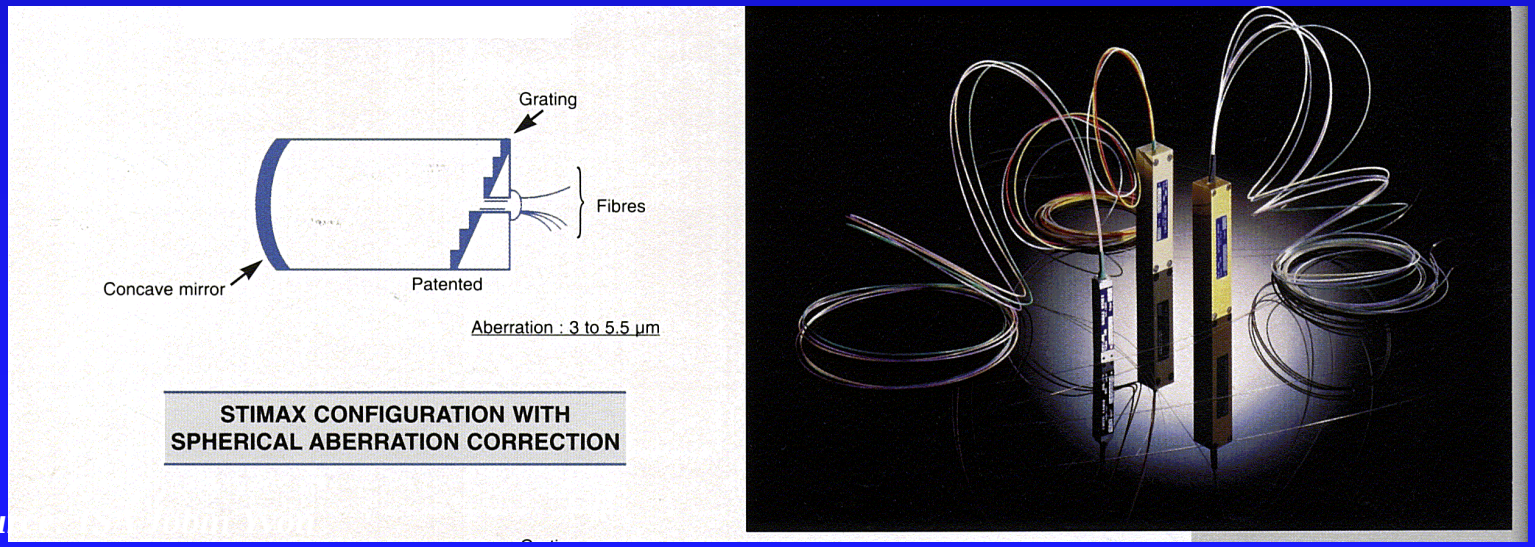


Source: J. J. Pan (E-Tek Dyn.)

Grating: free space λ mux/demux

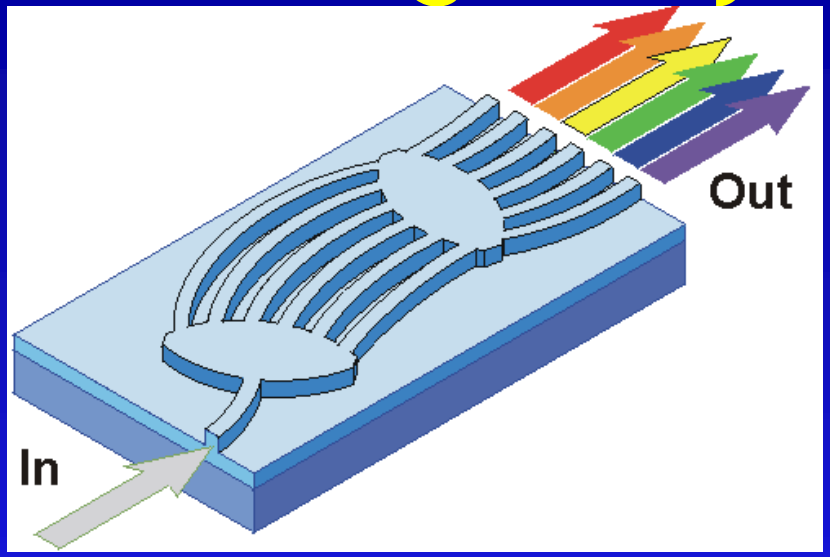


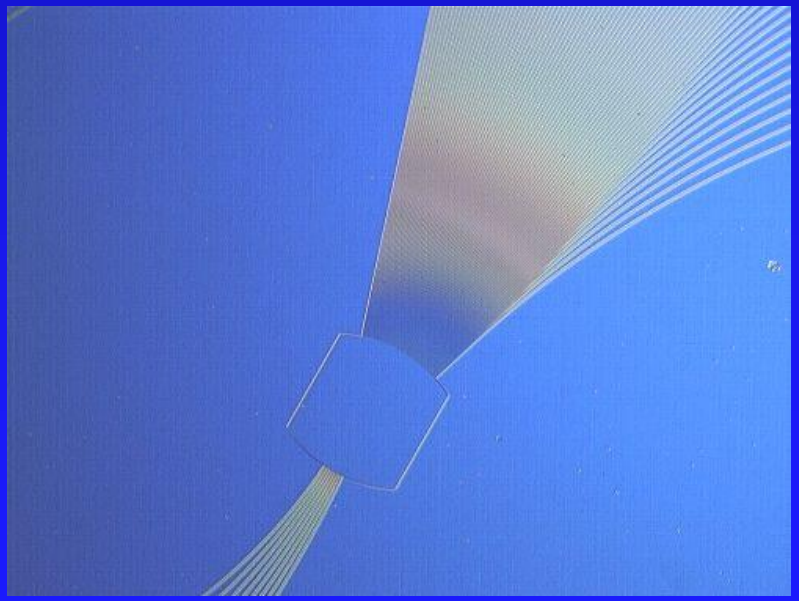
Sour



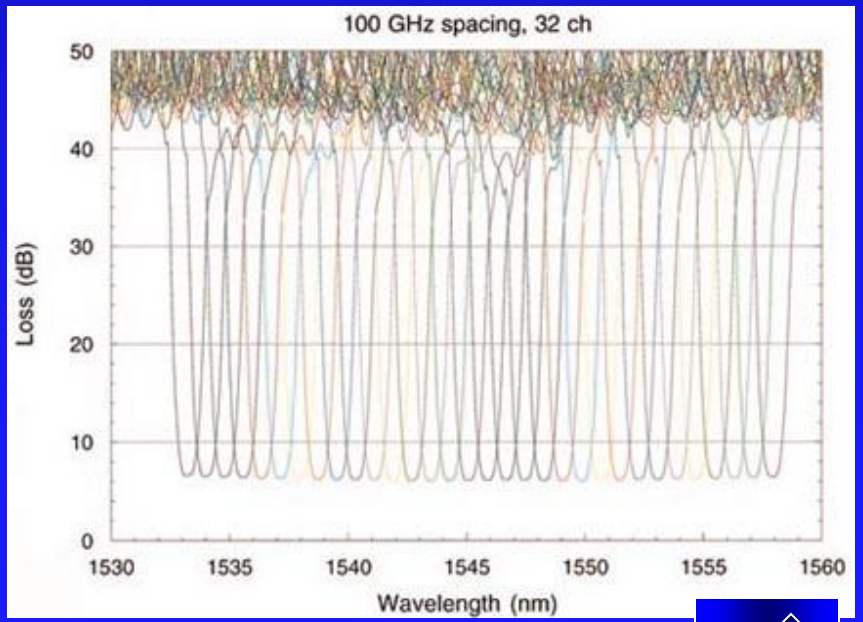
Sou

Grating: array waveguide (AWG)



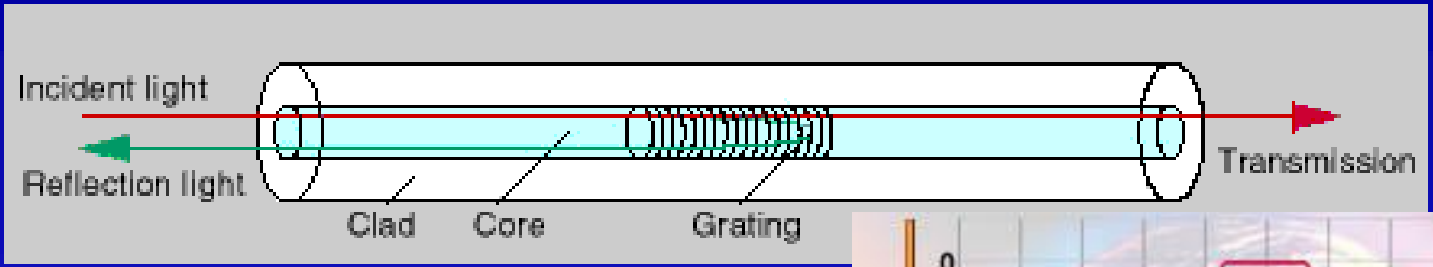


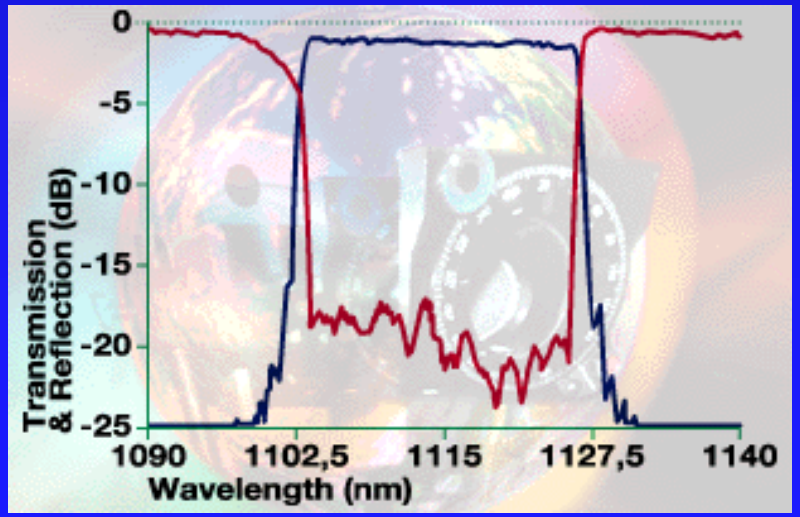
Source: IBM Zurich



Source: NTT

Grating: fiber Bragg (FBG)



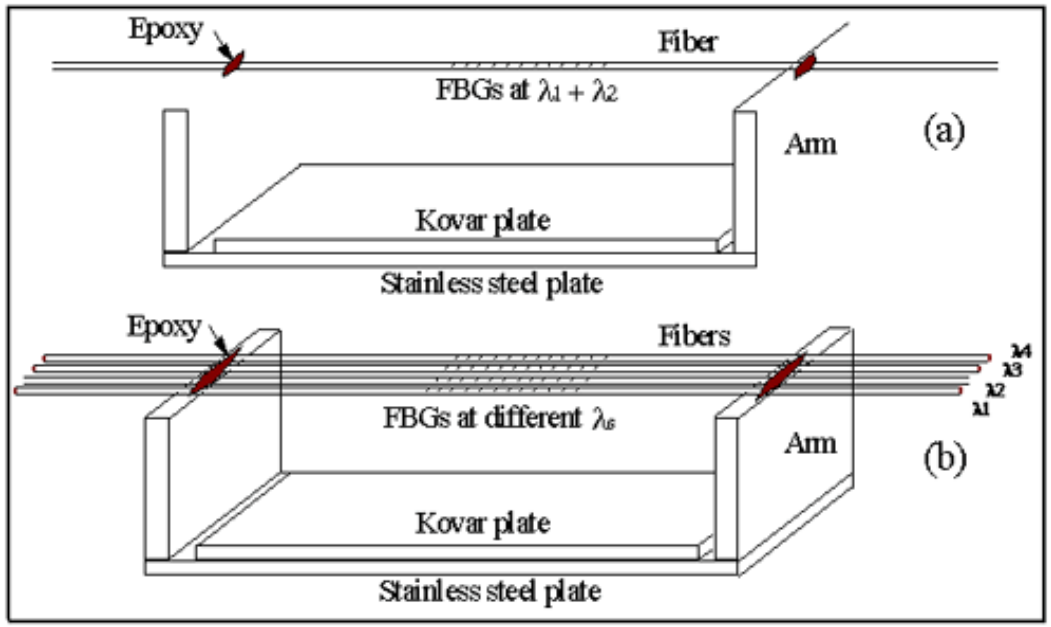


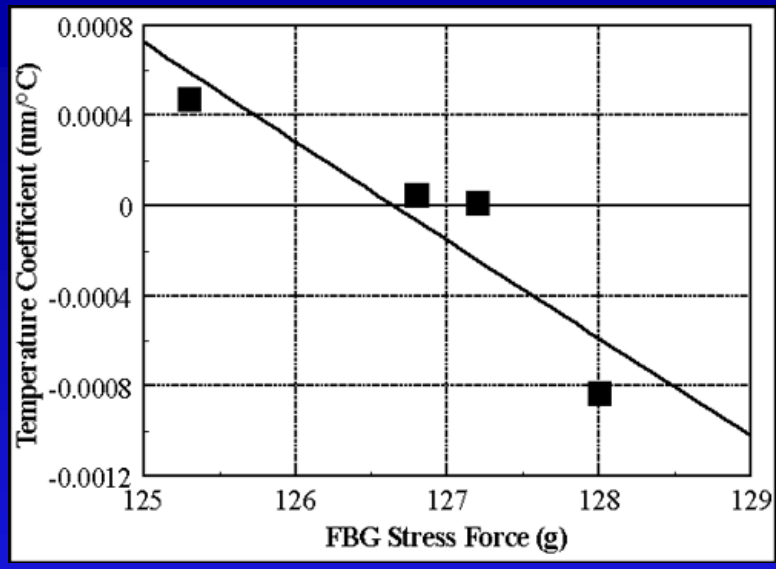
FBG: Use in numerous apps: WDM coupler, disp. comp., sensors

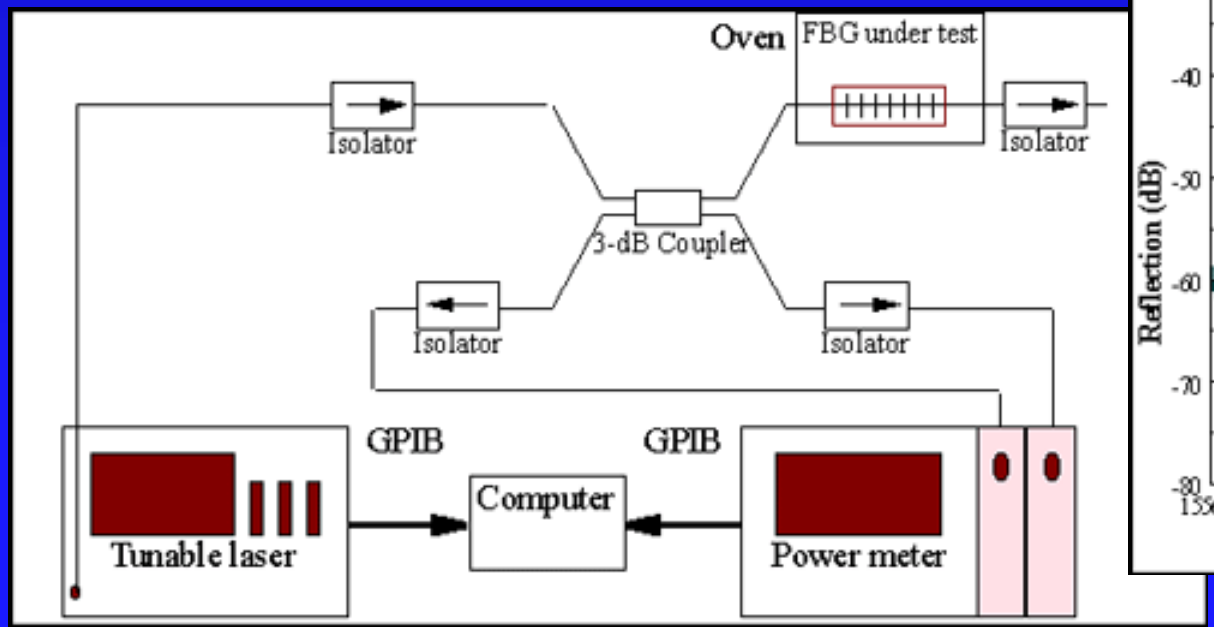
Source: NEL, Infibers

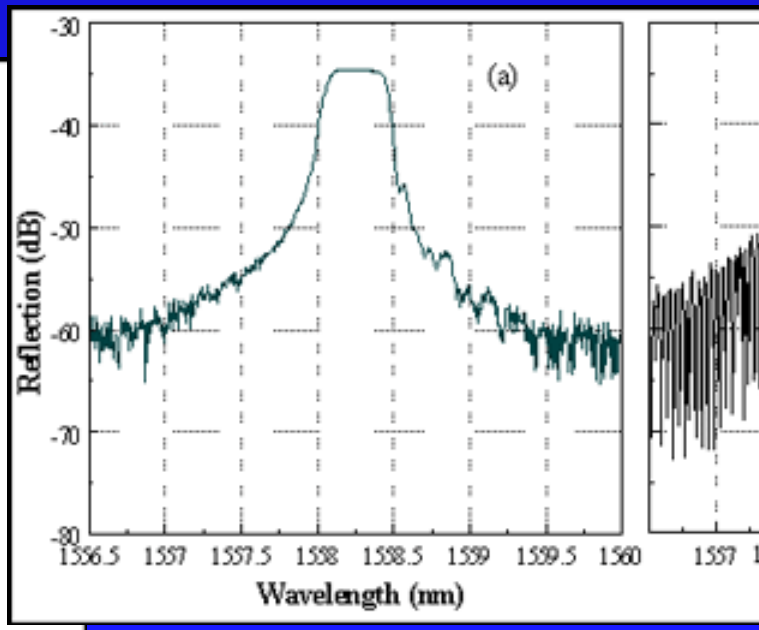
Back

Module engineering

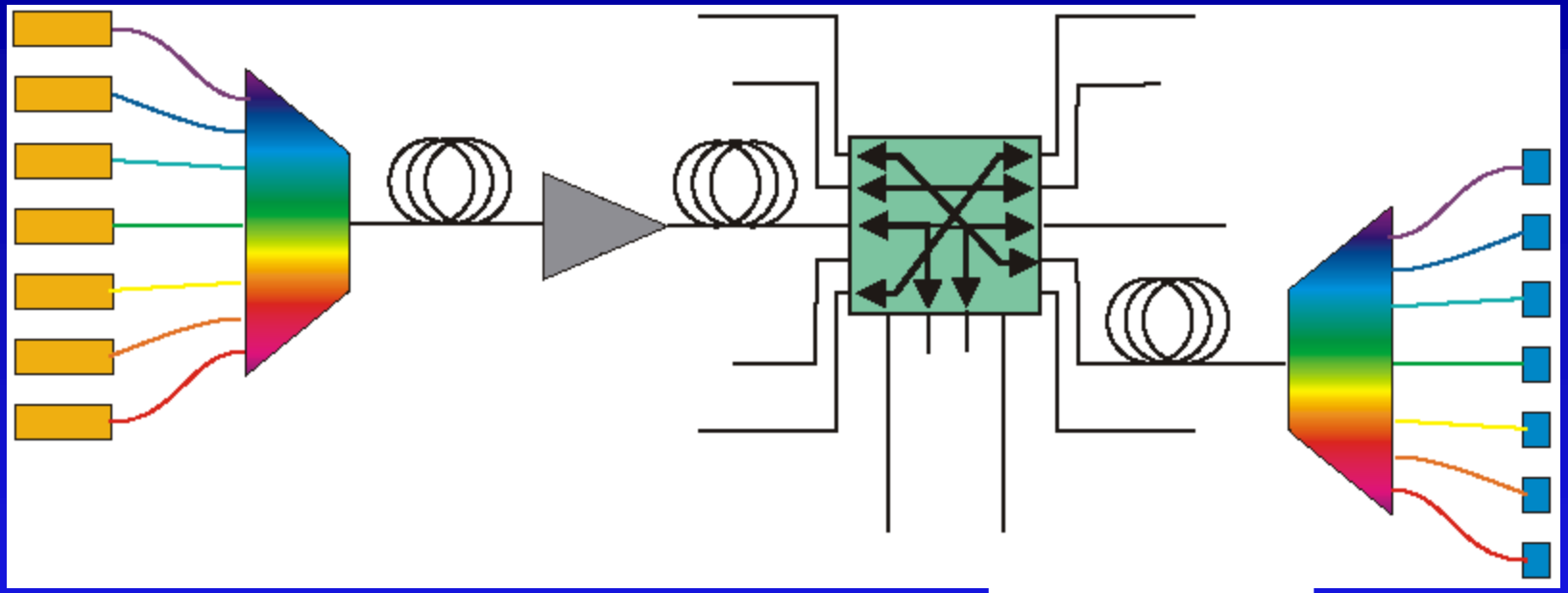








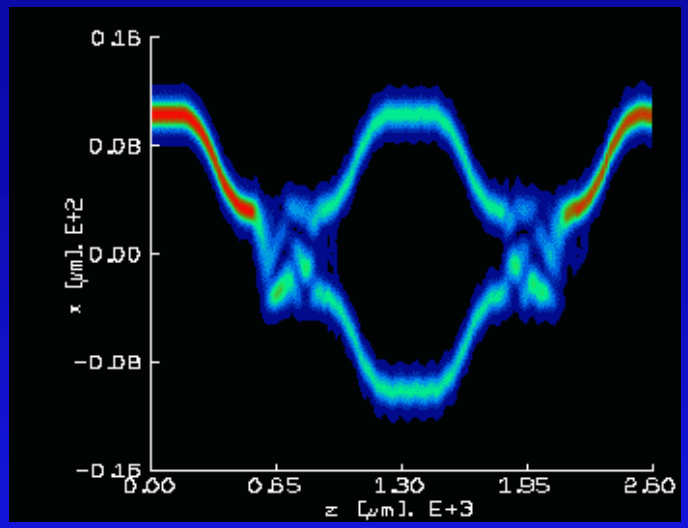
Optical/WDM networking technology

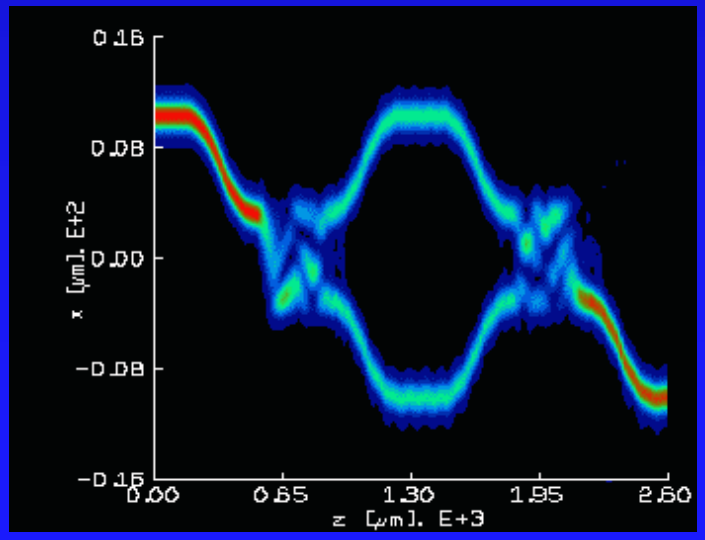


- The biggest business in optical networking right now (where the $Billions come from)
- Highly competitive, shrouded in secrecy
- Plug in legacy/existing network as well as new network (architectural compatibility)
- From simple modules to very complex system engineering
- (All)-optical multi-Tb/s IP-router?

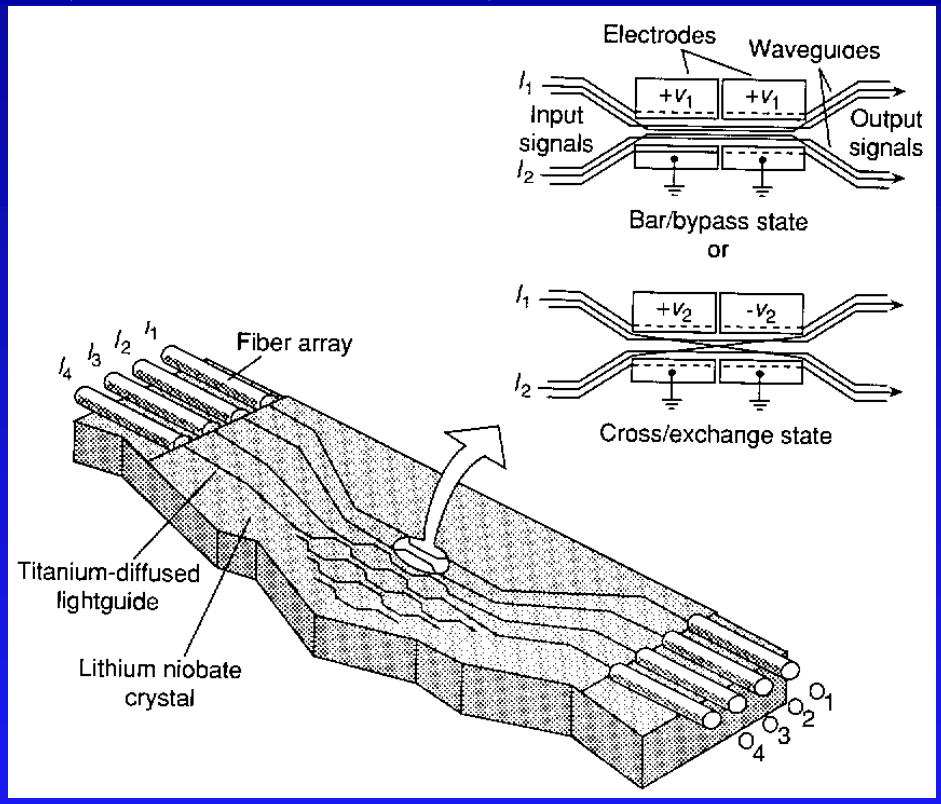
- Path switch
- Add/Drop mux
- λ-router
- Cross connect
- Couplers
- circulators

Module level: interferometer switch (cross bar)



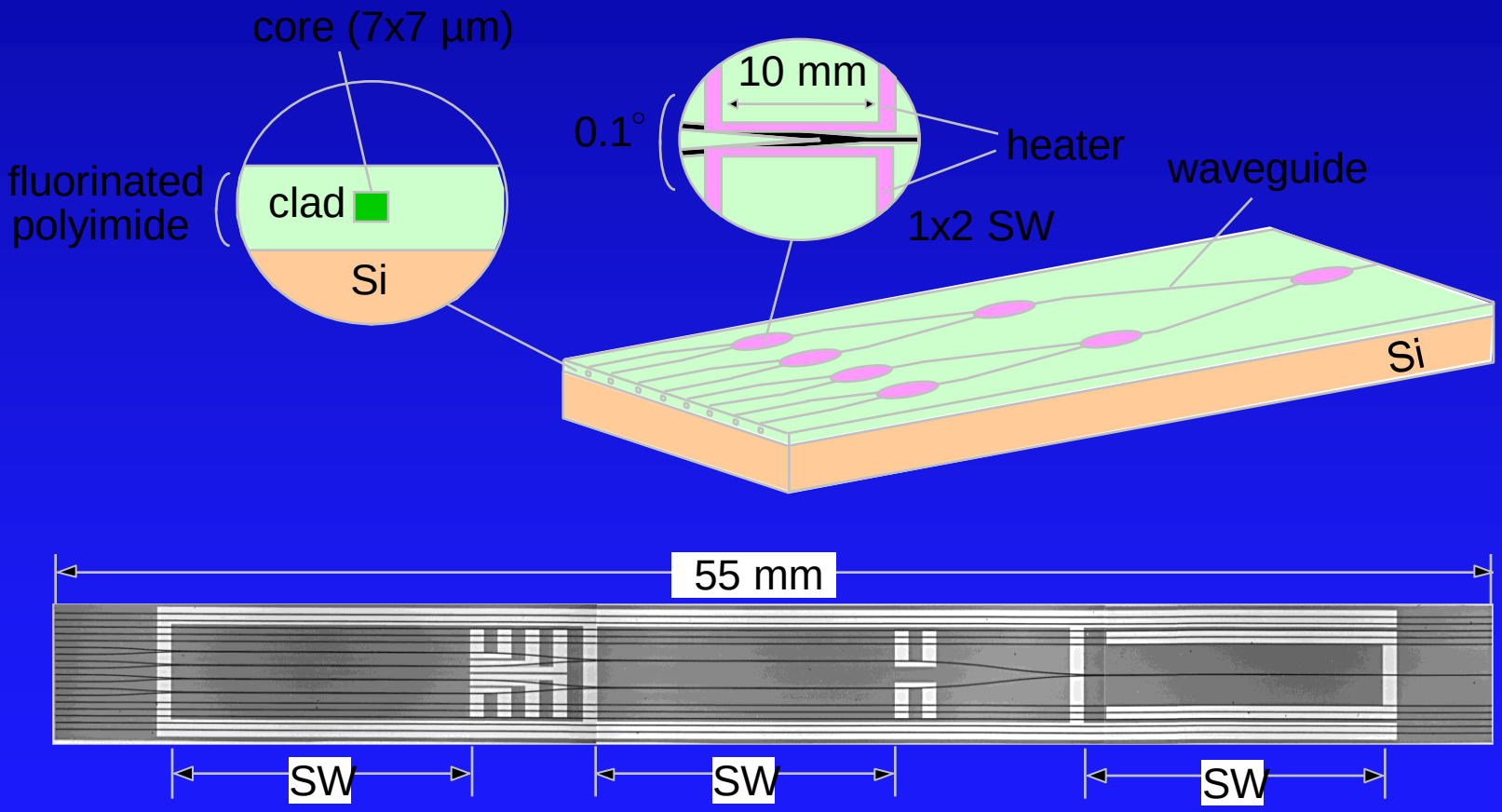


Source: BBV simulation



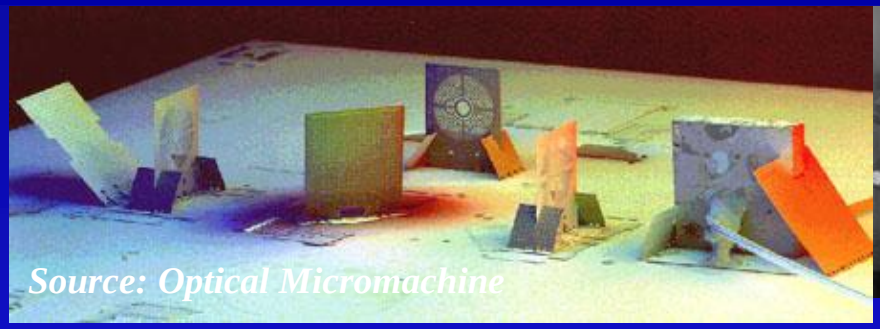
- **E-O, Thermo-optic, AO switch**
- **Can also be designed for λ-switching**
- **Oxide (LiNbO3), EO organic/polymers, SOI, Polyimide**

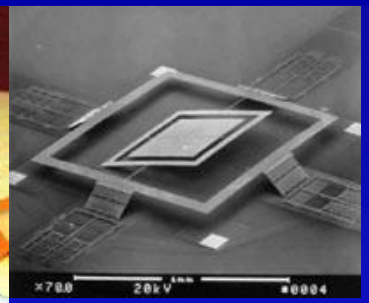
1 x 8 Polymeric Digital Optical Switch

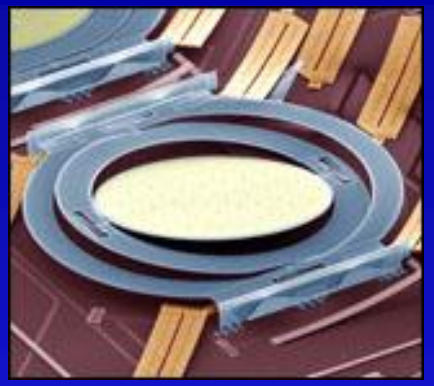


Source: Hitachi Central Research Lab.

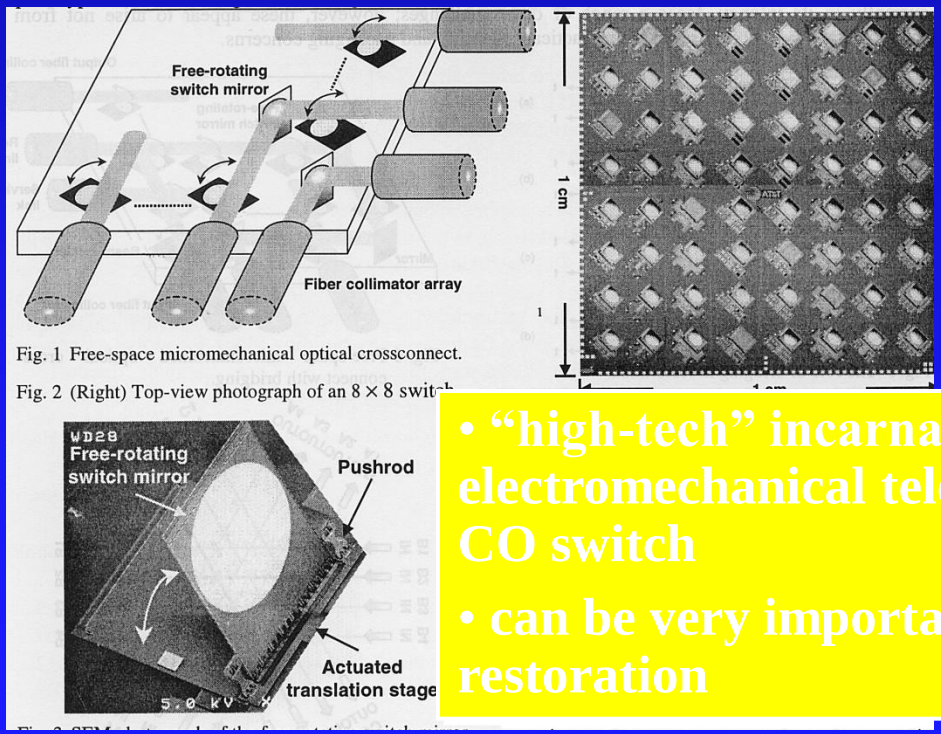
Module: MEMS mirror switch







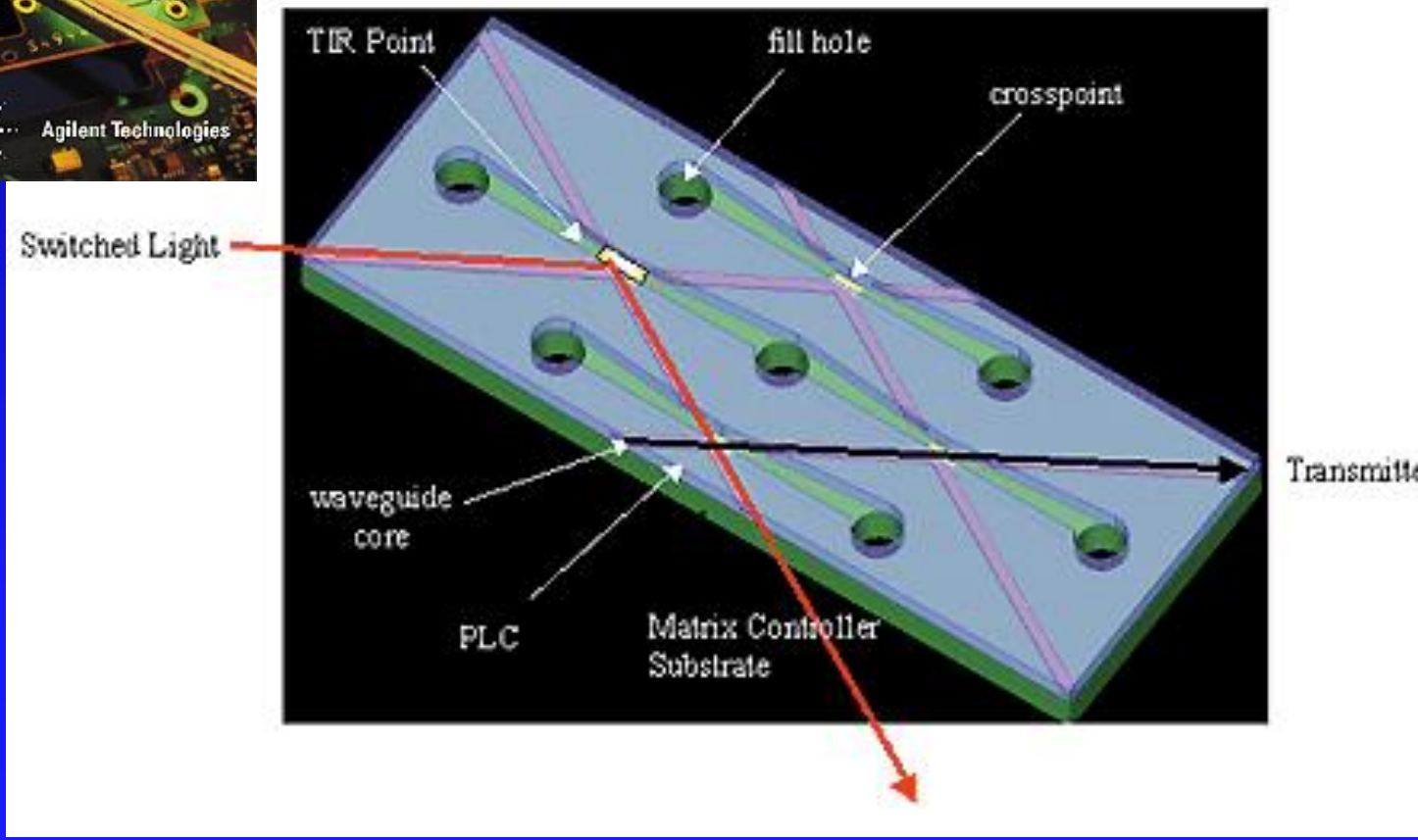
Lucent WaveStar™ mirror



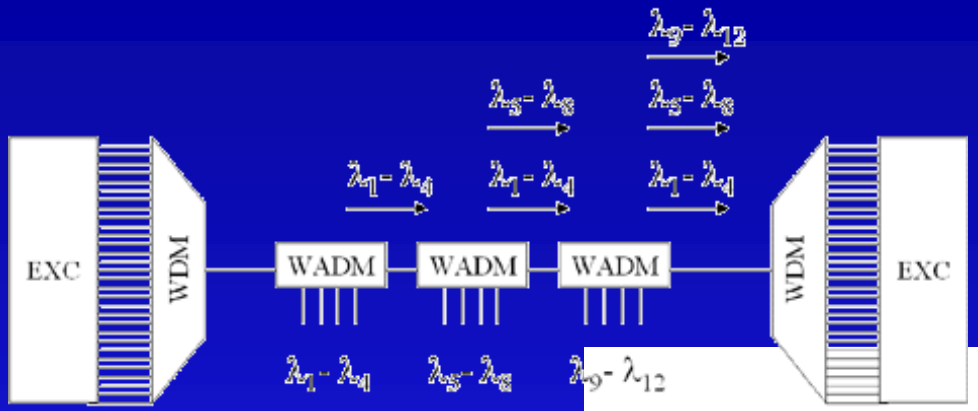
- "high-tech" incarnation of electromechanical telephone CO switch
- can be very important in restoration

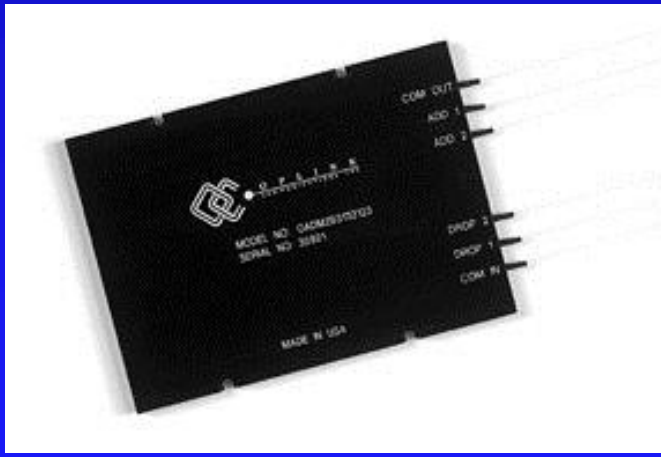
Source: AT&T Labs

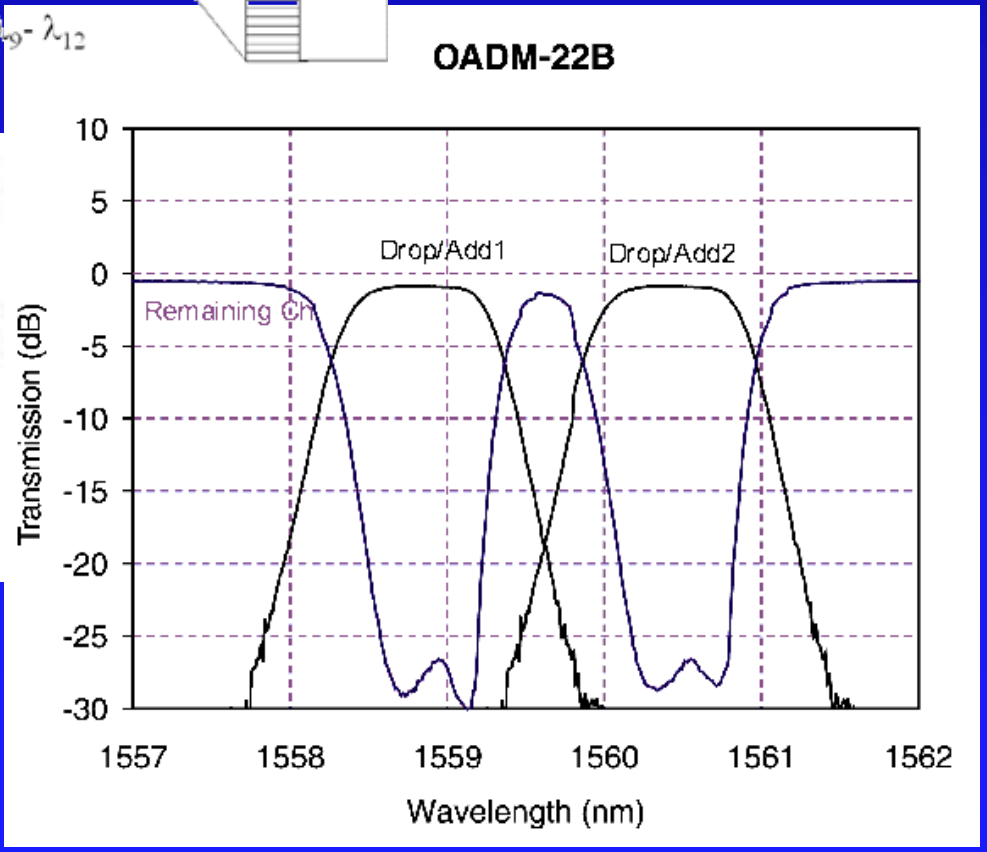
Bubble Jet-Actuated Switching



Module: Wavelength Add/Drop

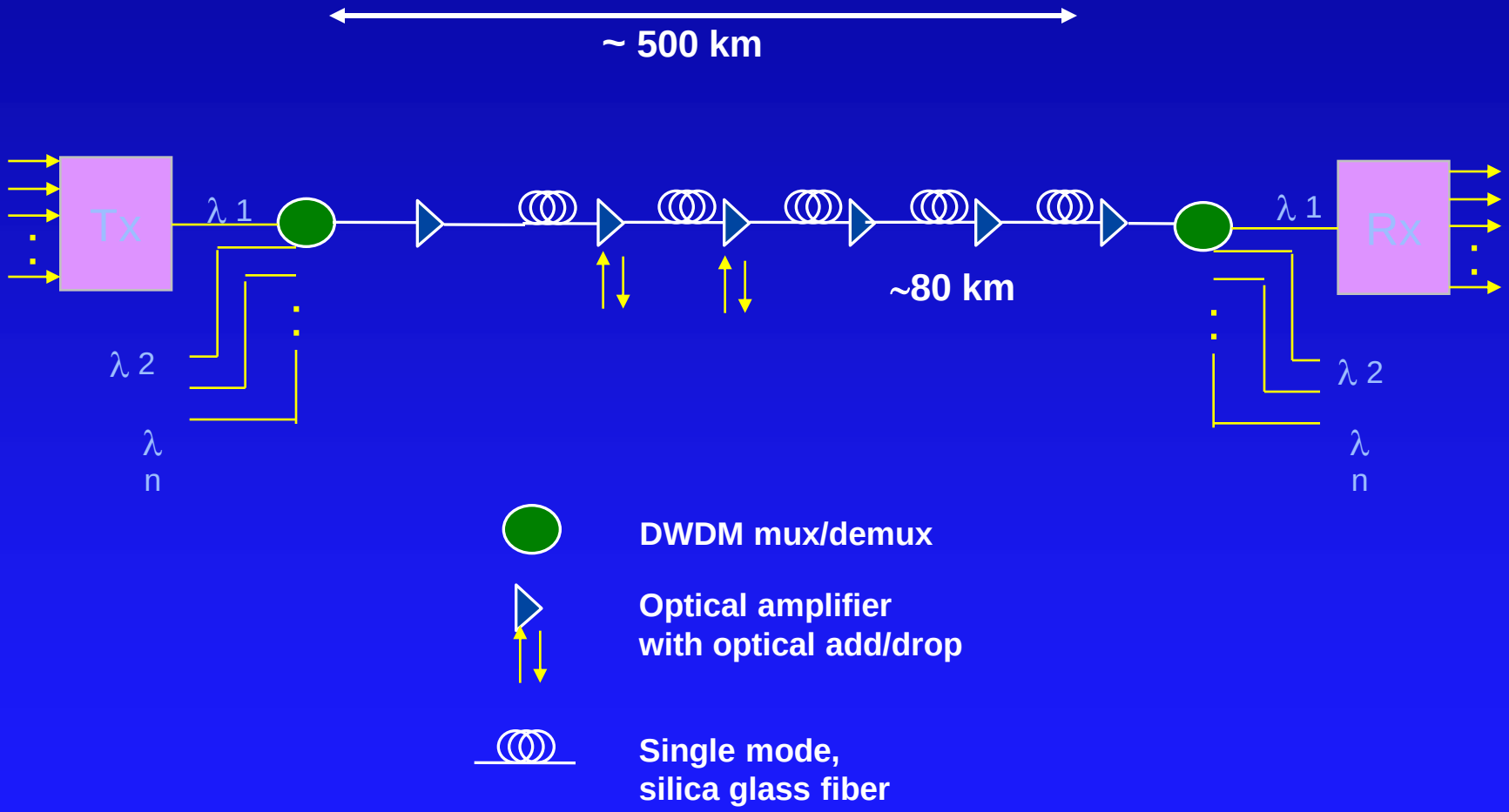






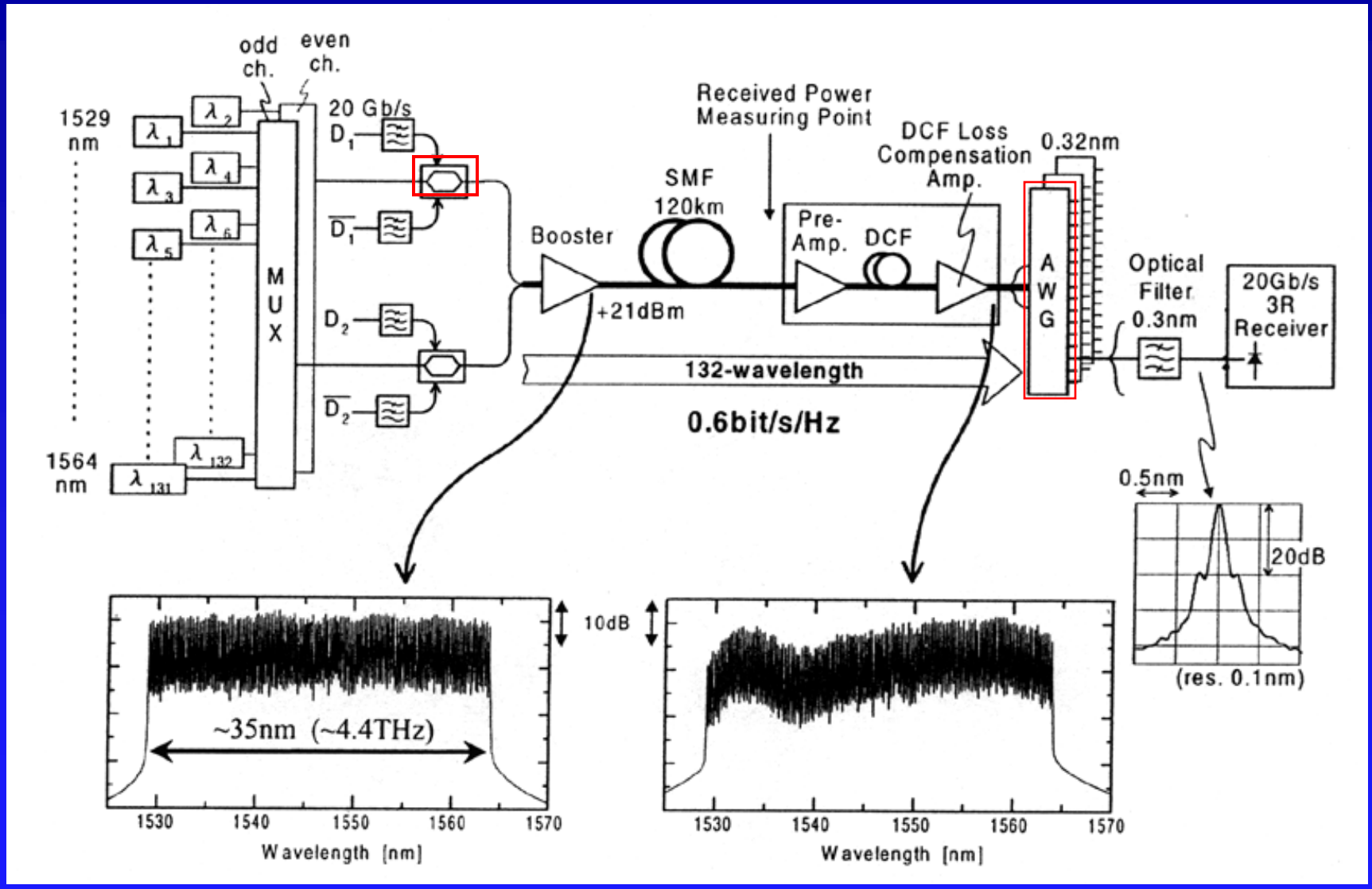
Technology in action…

Long-haul: Elements of a typical DWDM Transmission System



Source: R. Cowper, Nortel Networks

Full scale engineering of a DWDM



Source: NEC (1998)

Present Fiberoptic LAN Standards

Standard	*Baud Rate*	*Length*	*Fiber Core Dia.*	*Optical Sources*
FDDI	125 Mbd	2 km	62.5 µm	1300-nm LED
Fibre Channel	1.062 Gbd	1 km	single-mode	1300-nm Fabry-Perot Laser
ATM	155 Mbd	2 km	62.5 µm	1300 nm LED
	622 Mbd	500 m	62.5 µm	1300 nm LED
Ethernet	20 Mbd	2 km	62.5 µm	770 nm – 860 nm LED
	125 Mbd	2 km	62.5 µm	1300 nm LED
Gigabit Ethernet	1.25 Gbd	220 m	62.5 µm	770 nm – 860 nm Lasers
		550 m	62.5 µm	1300 nm Fabry-Perot Laser
		6 km	single-mode	1300 nm Fabry-Perot Laser

Example LAN transceiver technology

Simplex "Sugarcube" TX and RX. 820-nm LED, GaAs PIN. 10 Mb/s to 155 Mb/s.

Duplex-SC Transceiver "1x9 package". 1300-nm LED, InGaAs PIN. 100 Mb/s to 622 Mb/s.

Duplex-SC Transceiver "1x9 package". 850-nm VCSEL or 1300-nm FP-Laser. Gigabit Ethernet, Fibre Channel.

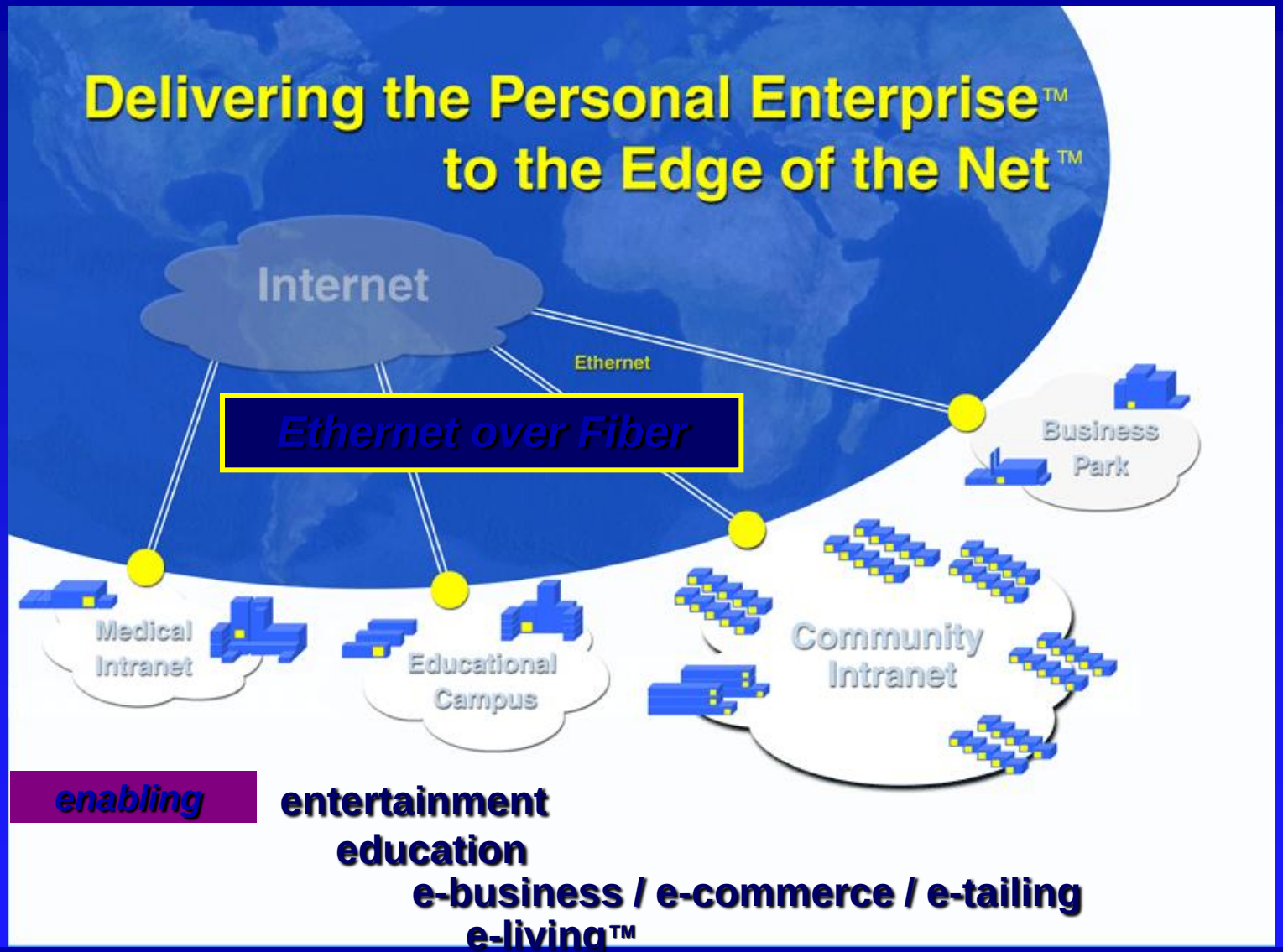
MT-RJ "Small Form Factor" Transceiver. 1/2"-wide package now replacing 1-inch "1x9" package at all data rates.

IEEE 802.3ae (Ethernet): MOUNTAIN VIEW, Calif.--(BUSINESS WIRE)--Feb. 8, 2000-- 3Com, Cisco Systems, Extreme Networks, Intel, Nortel Networks,
Sun Microsystems, and World Wide Packets Join Forces to Promote 10-Gigabit Ethernet Technology- IEEE802.3ae is an official name. Standard is being formed.
http://grouper.ieee.org/groups/802/3/10G_study/public/index.html

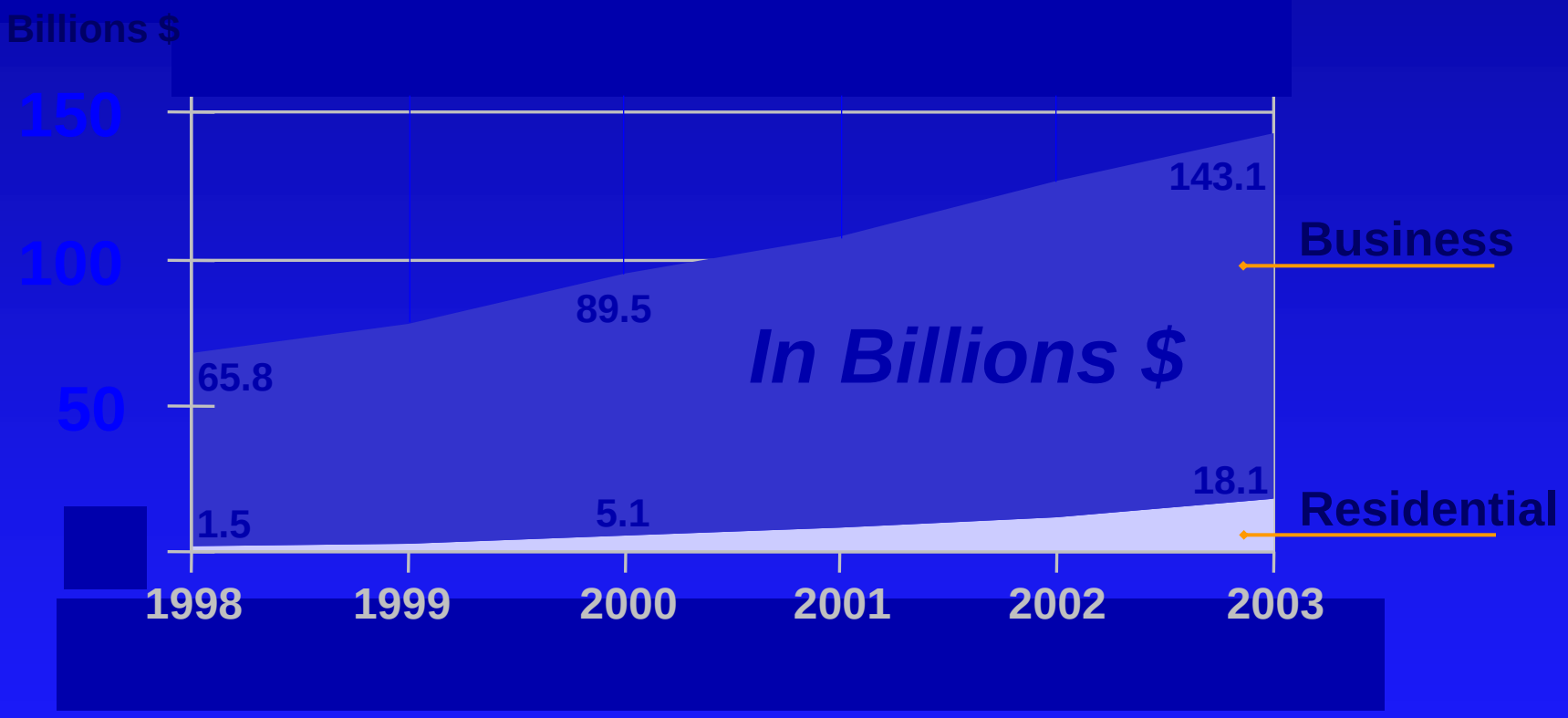
Optical Internetworking Forum (OIF): Industry organization is considering “low-cost” technologies for short-reach OC-192 (10-Gb/s).
(Virtually all players in optical networking, shown earlier…)

Some current views…

the Edge of the Net™



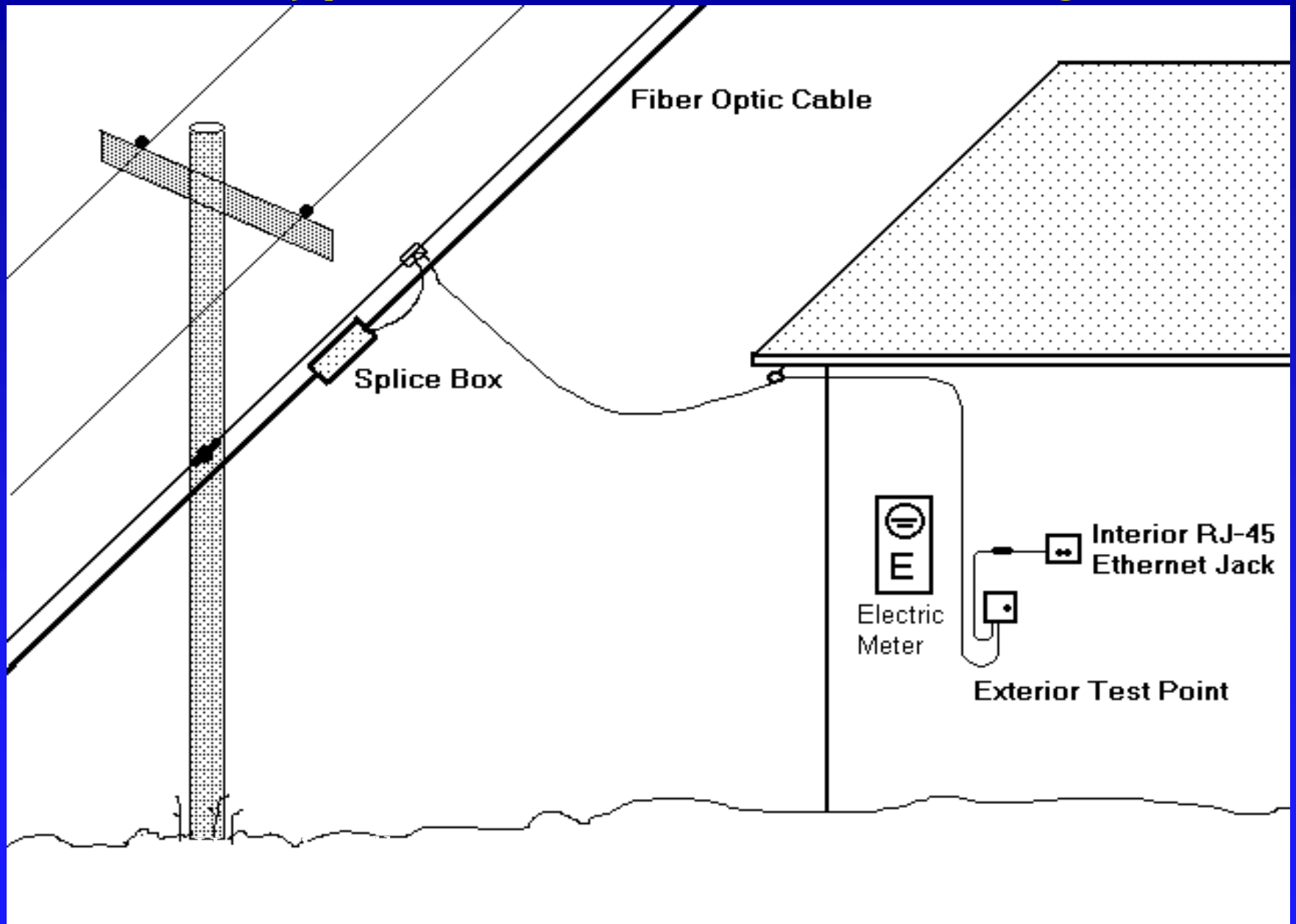
Broadband Access Revenues



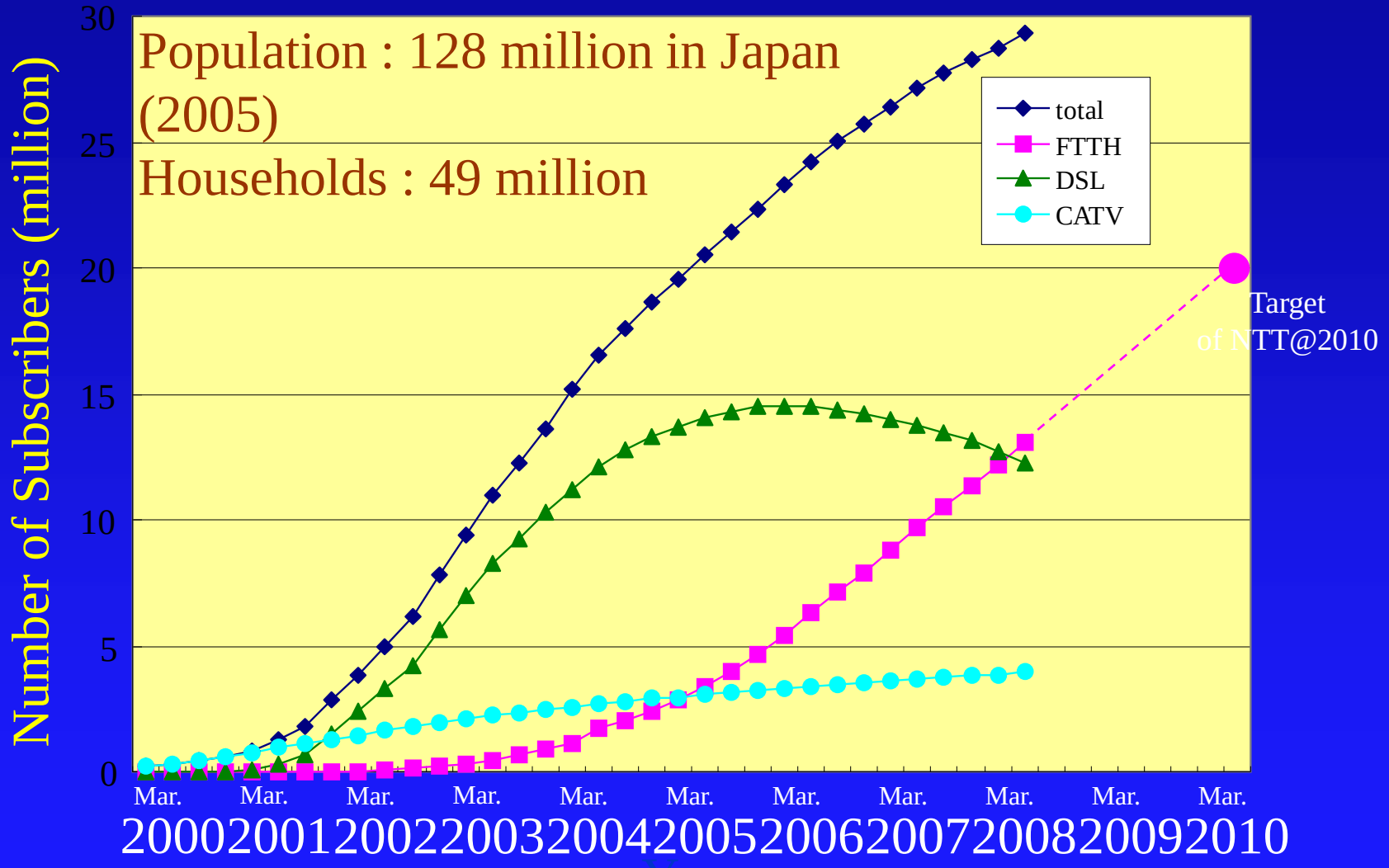
Source: Strategis Group 1999

“Unlimited” bandwidth to the home?

Typical Pole to Home Wiring



Broadband Services in Japan

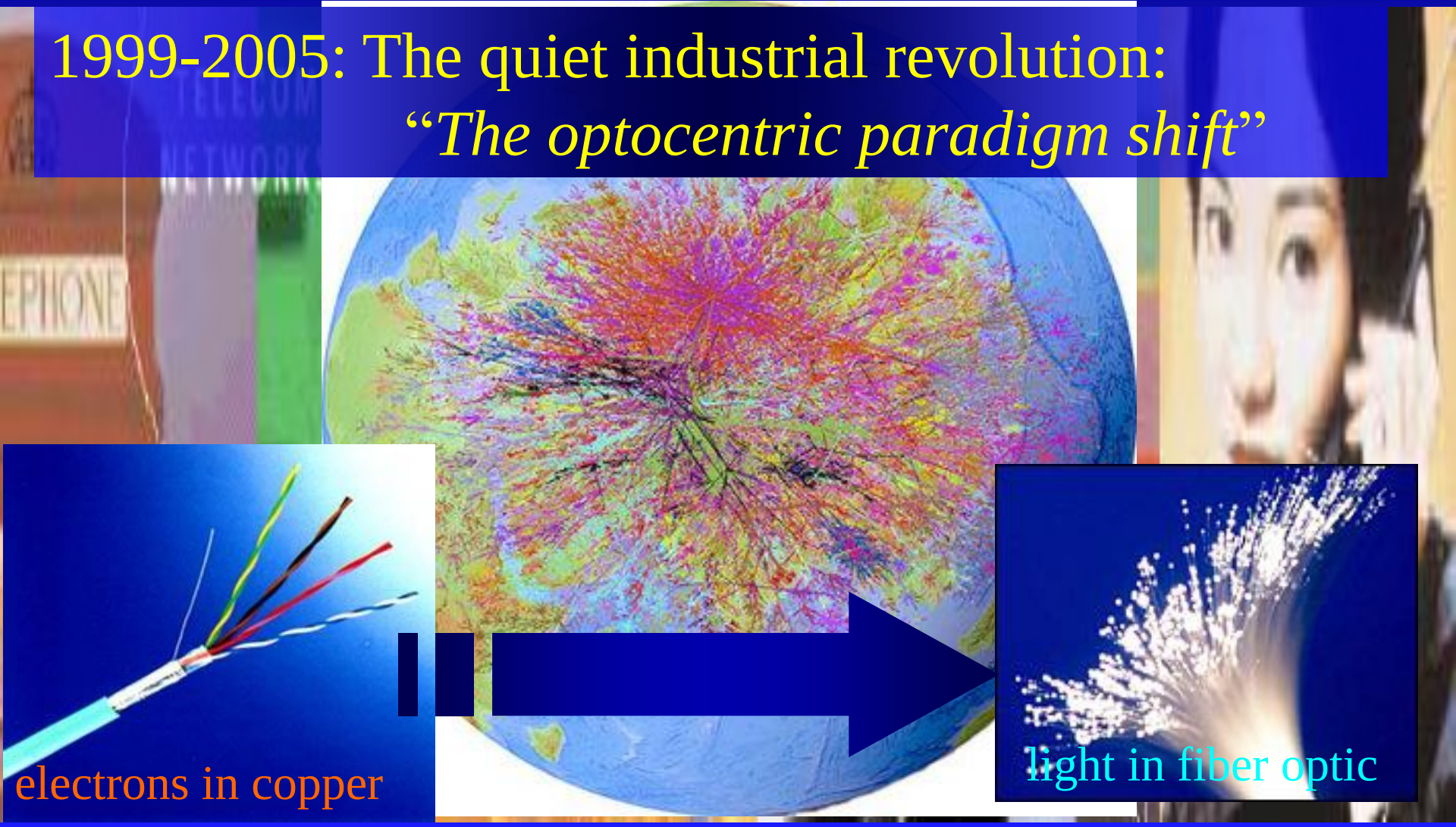


Japan Ministry of Internal Affairs and Communications

The Optical Internet and Telecom World

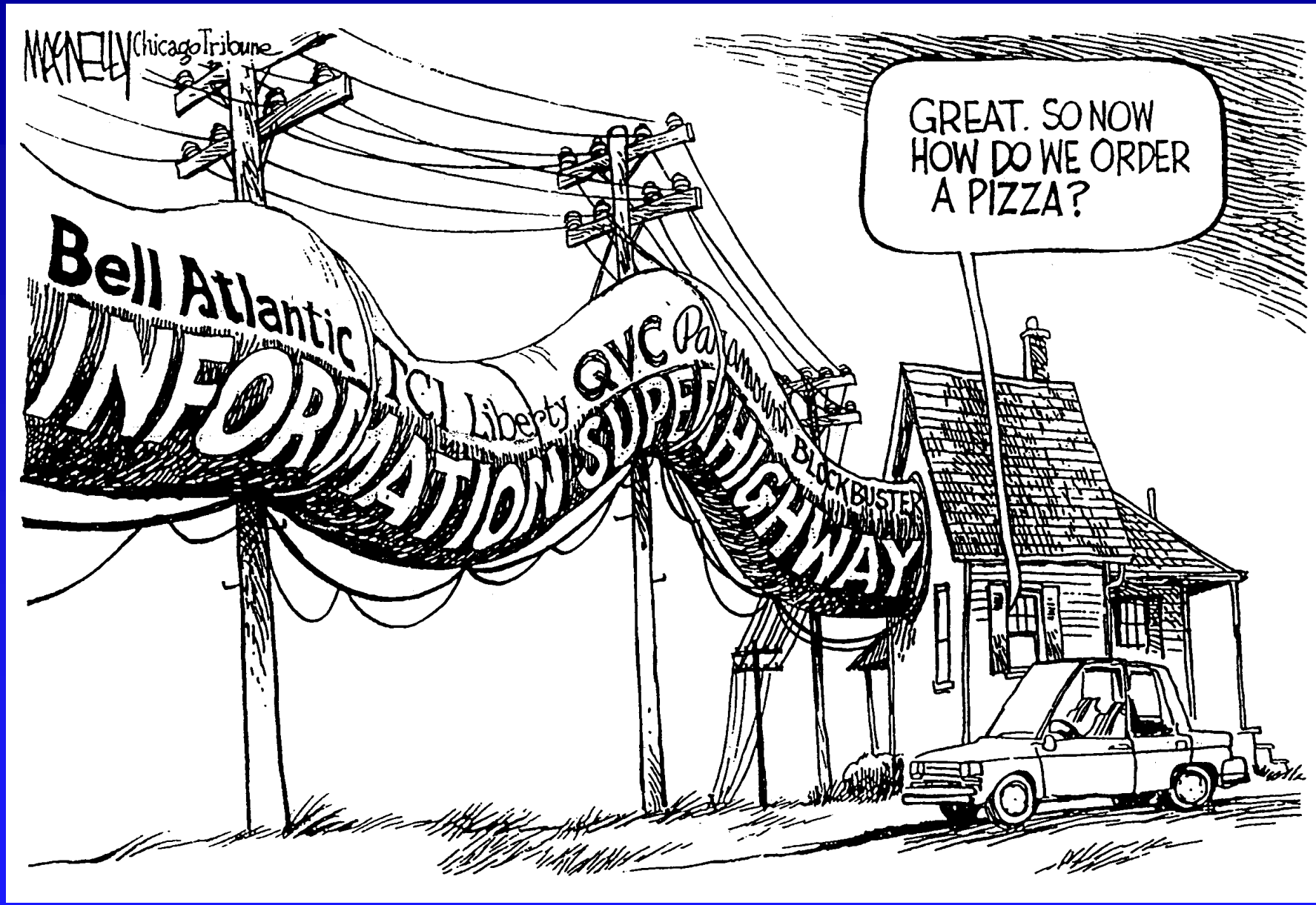
1999-2005: The quiet industrial revolution:

"*The optocentric paradigm shift*"



Source: Han Le & Assoc

What use is all that bandwidth?



Source: "Beaucoup Bandwidth to the Bungalow"

The McGraw-Hill Companies

BusinessWeek

JUNE 25, 2001 / www.businessweek.com

Telecom Back From The Dead

How a business almost buried by the dot-com bust is reviving itself and invigorating the economy

by SPENCER E. ANTE

(PAGE 43)

BLOOMBERG

Lessons of the CEO Mayor

(PAGE 58)

FORECLOSURE 'RESCUES'

Why They Hurt Homeowners

(PAGE 39)