

COURSES

Agilent Customer Training Seminar

ABOUT THIS
CATALOG

Elements of Lightwave Technology

© Copyright 1999 Agilent Technologies



Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT - 1
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



Table of Content

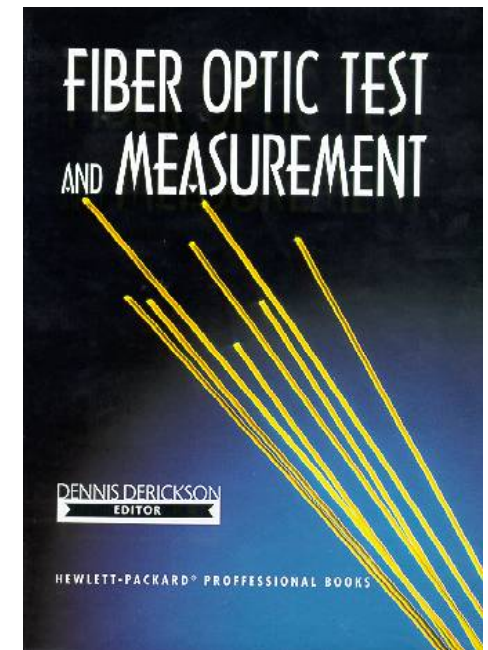
1. Introduction
2. Physical Basics
3. Standards
4. Fibers, Cables, Splices & Connectors
5. Passive Components
6. Transmitters & Receivers
7. Optical Amplifiers
8. Dense Wavelength-Division Multiplexing



Lightwave Test Literature

Agilent employees have published many white papers, product notes, and application notes discussing most lightwave measurements.

See handouts for a list of literature references.



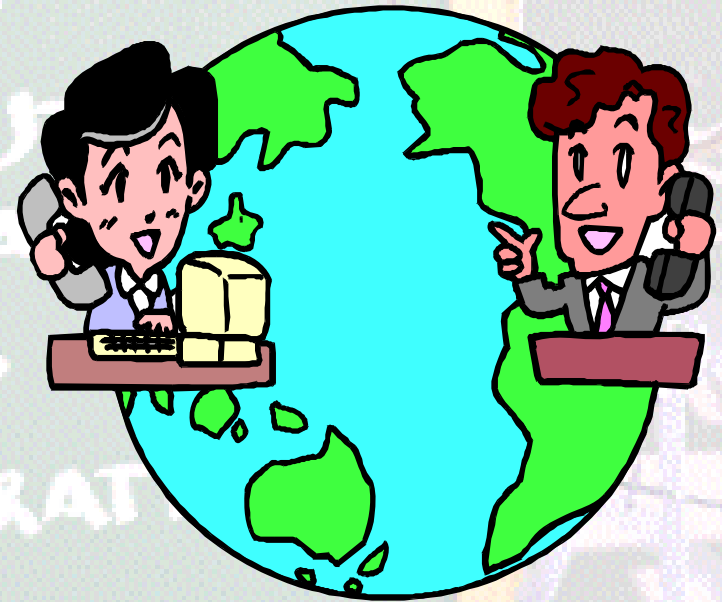
Thank You
For Choosing
Agilent Technologies
As Your Partner In
Lightwave & High Speed Digital
Transmission Test



Agilent Technologies
Innovating the HP Way



LW Technology



Introduction



Agilent Technologies
Innovating the HP Way

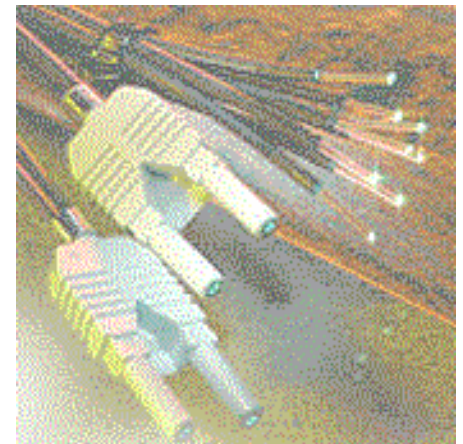
LW Technology (Cover, Appendix).PPT - 5
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008

 **Lightwave**
Division

What is lightwave technology?

- Lightwave technology uses light as the primary medium to ***carry information.***
- The light often is guided through optical fibers (***fiberoptic technology.***)
- Most applications use ***invisible (infrared) light.***



(HP)



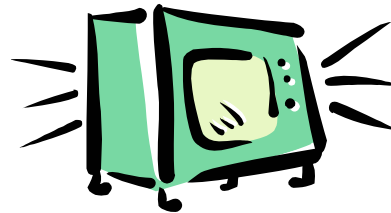
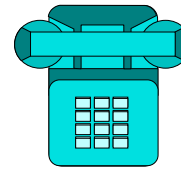
Why lightwave technology?

- ***Most cost-effective way*** to move ***huge amounts of information*** (voice, data) ***quickly and reliably.***
- Light is ***insensitive*** to electrical ***interference.***
- Fiberoptic cables have ***less weight*** and ***consume less space*** than equivalent electrical links.



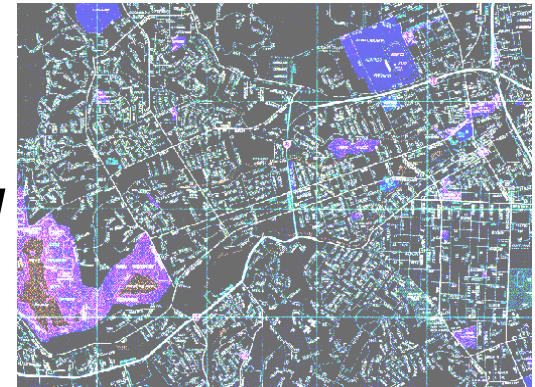
Use Of Lightwave Technology

- Majority applications:
 - Telephone networks
 - Data communication systems
 - Cable TV distribution
- Niche applications:
 - Optical sensors
 - Medical equipment
 - Displays & signs



Telephone Networks

- Long distance telecommunication
 - up to 600 km repeater spans, up to 9000 km total link length
 - Most demanding, most expensive
 - *Keywords: submarine, longhaul*
- Access network (1 km - 20 km)
 - Cost driven, less competition
 - *Keywords: local exchange, regional interexchange, MAN, FTTC, FTTH*

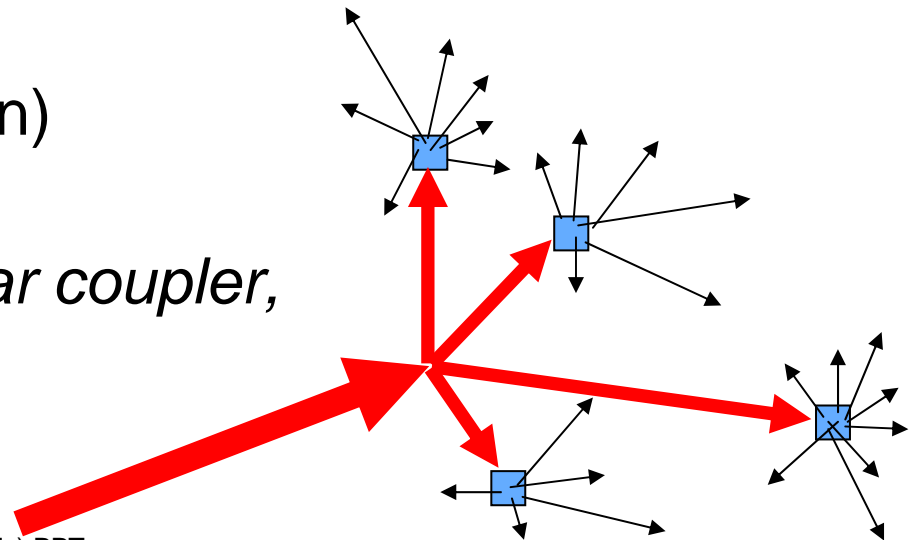


Other Networks

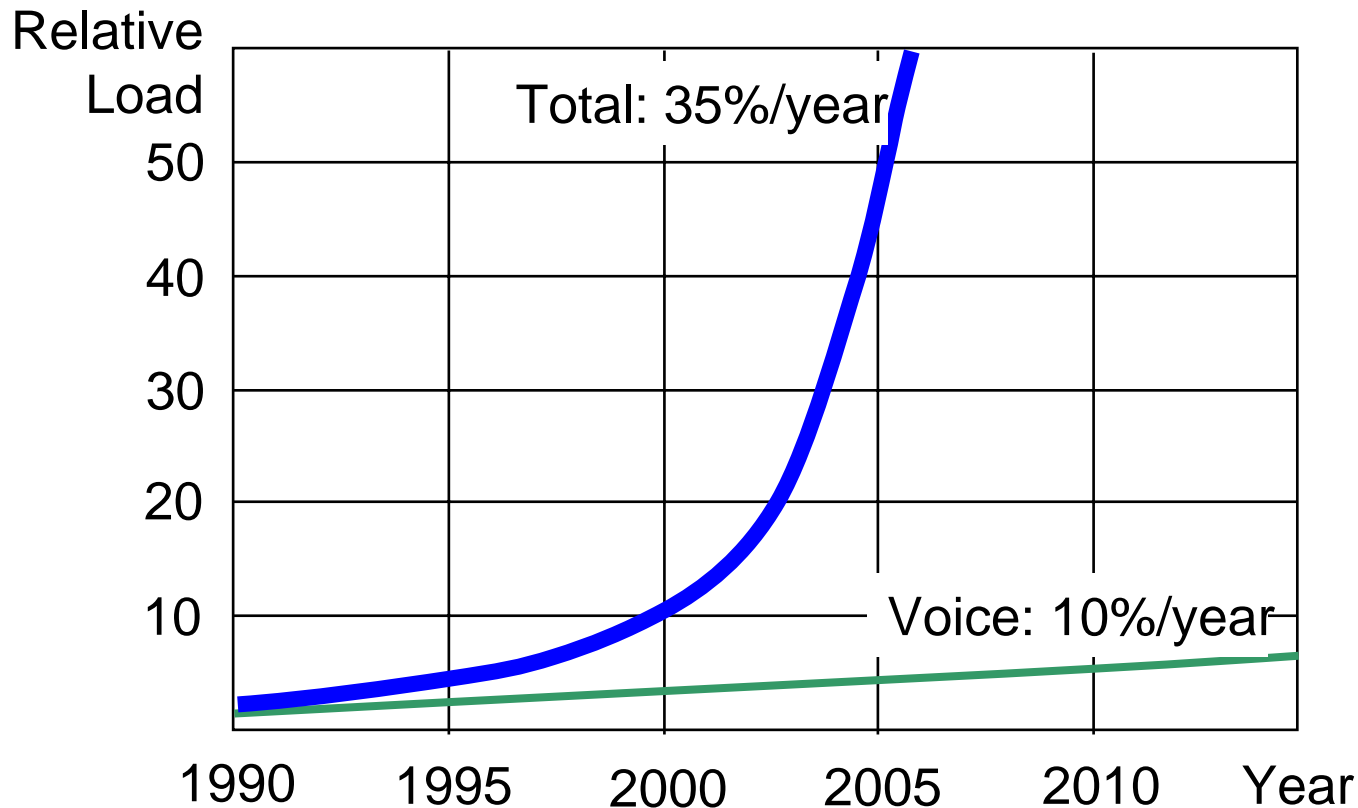
- Data communication (1 m - 500 m)
 - As cheap as it can get
 - *Keywords: premises network, LAN, backbone, FDDI, Gigabit-Ethernet, Fibre Channel*
- Cable TV (urban distribution)
 - Analog network
 - *Keywords: head end, star coupler, subcarrier*



HP Journal 12/97



Telecommunication Network Bandwidth Trend



Source:

EC ELECTRONiCAST
CORPORATION



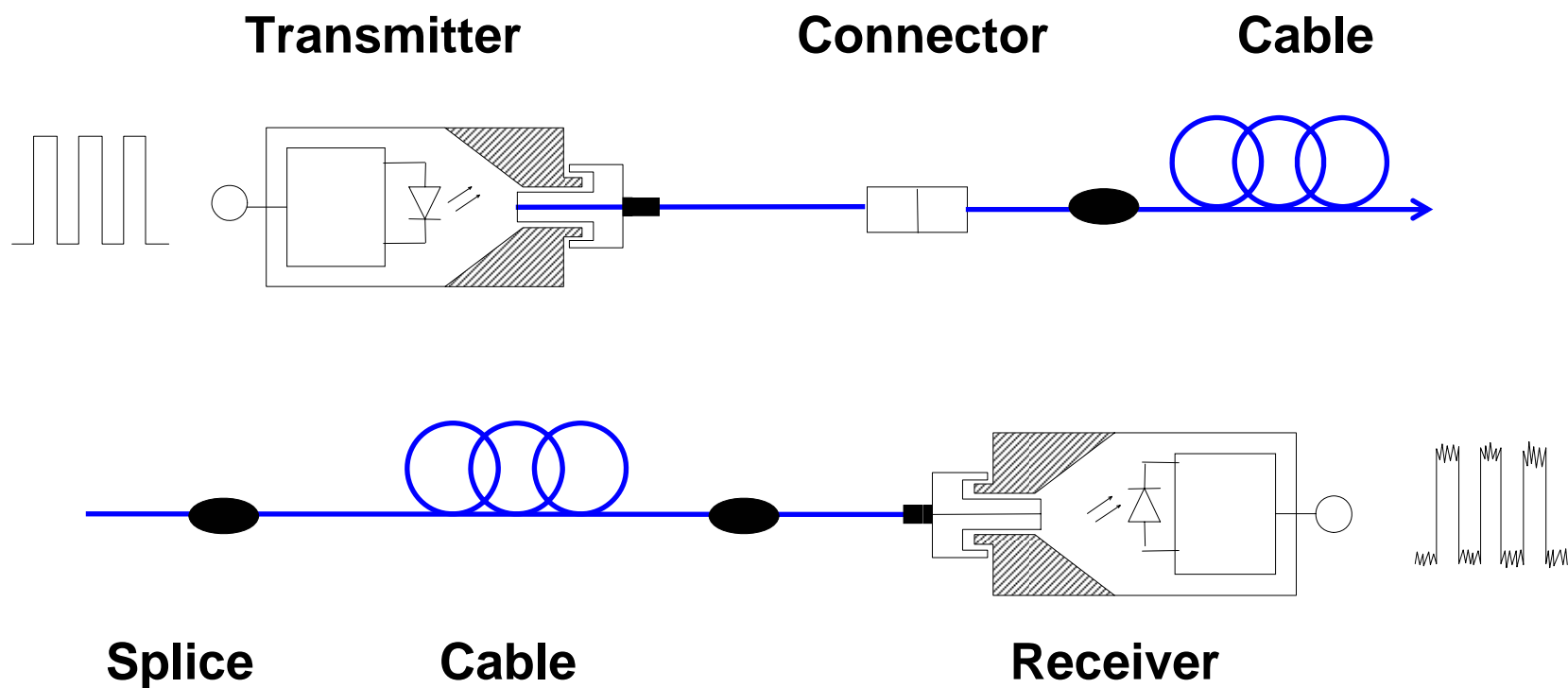
Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT -
11
© Copyright 1999, Agilent Technologies

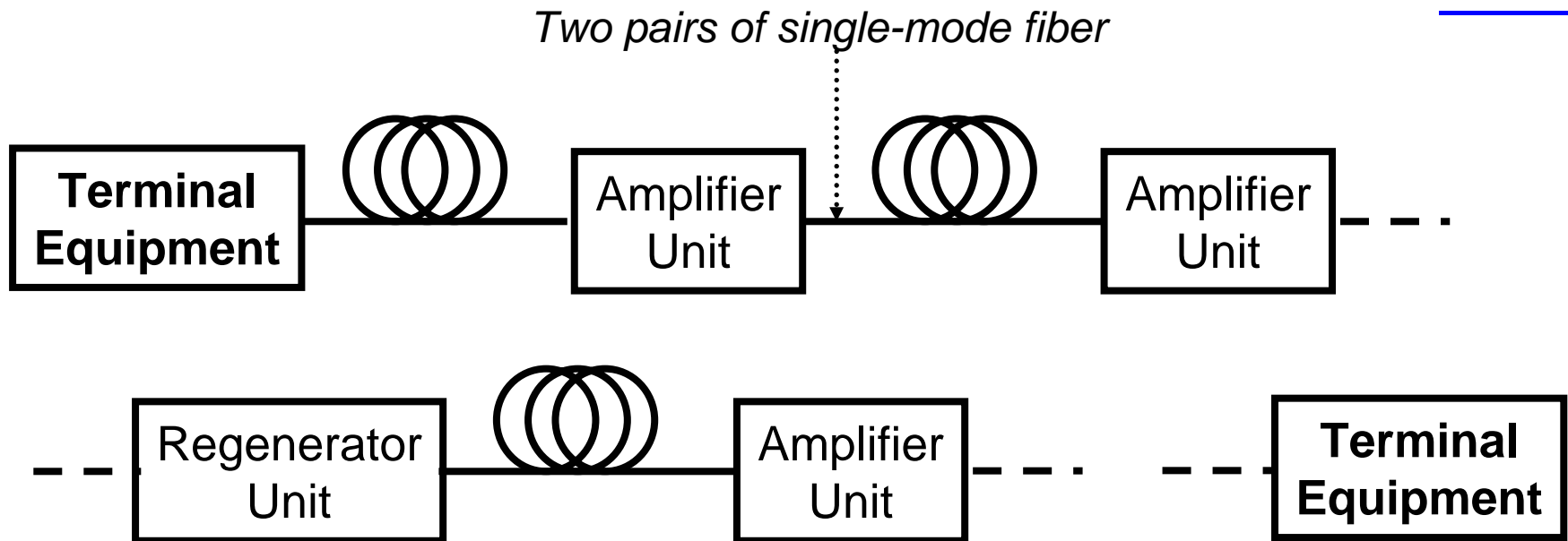
Revision 1.1
September 10, 2008



Basic Link Design



Typical Long-haul System



Amplifier spans: 30 to 120 km
Regenerator spans: 50 to 600 km
Terminal spans: up to 600 km (without regenerators)
up to 9000 km (with regenerators)

Typical Regenerator Unit

Pulse re-shaping & re-timing

*Modulation & bit
rate dependent!*

Power
Supply

Telemetry &
Remote Control



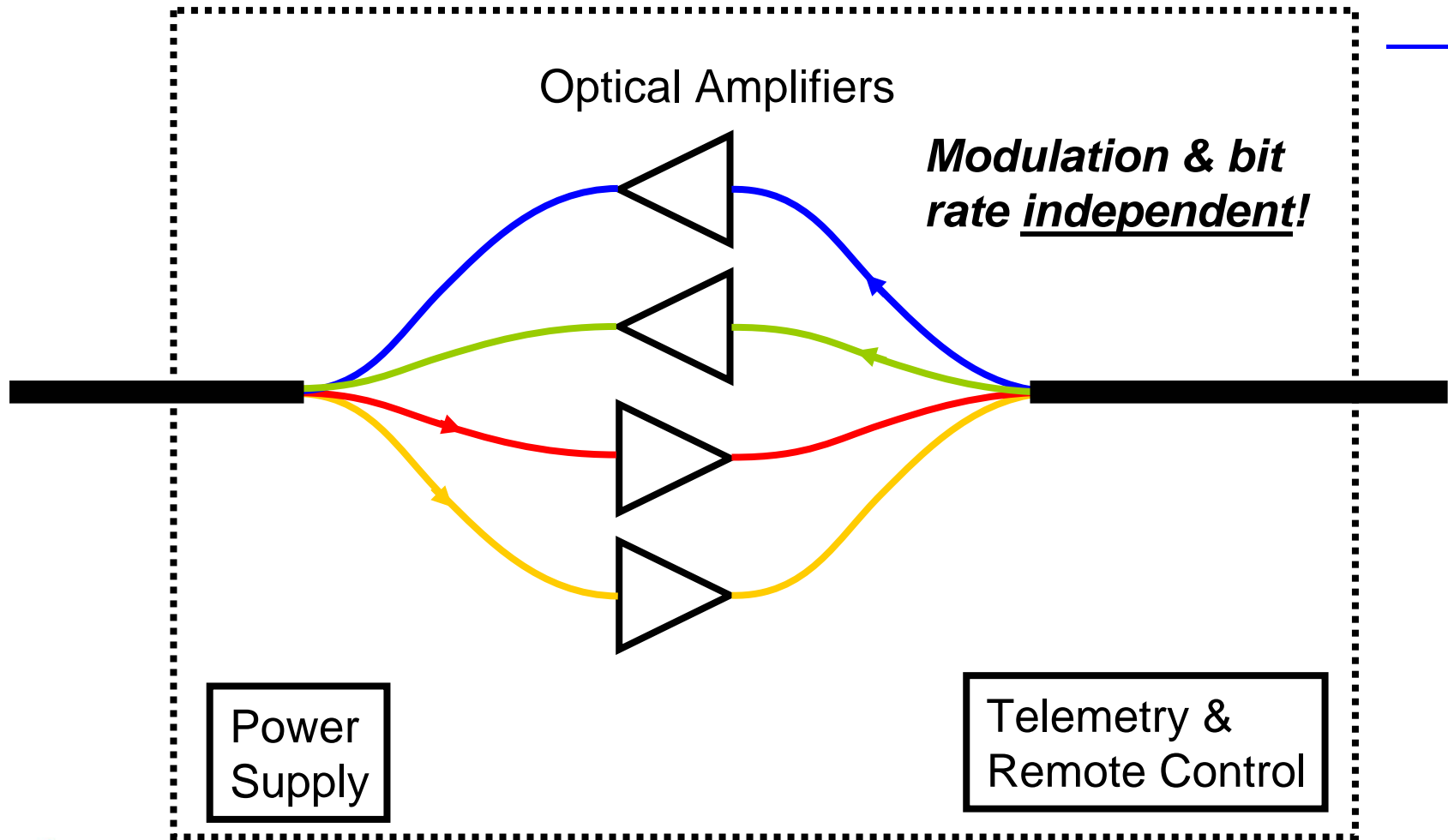
Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT -
14
© Copyright 1999, Agilent Technologies

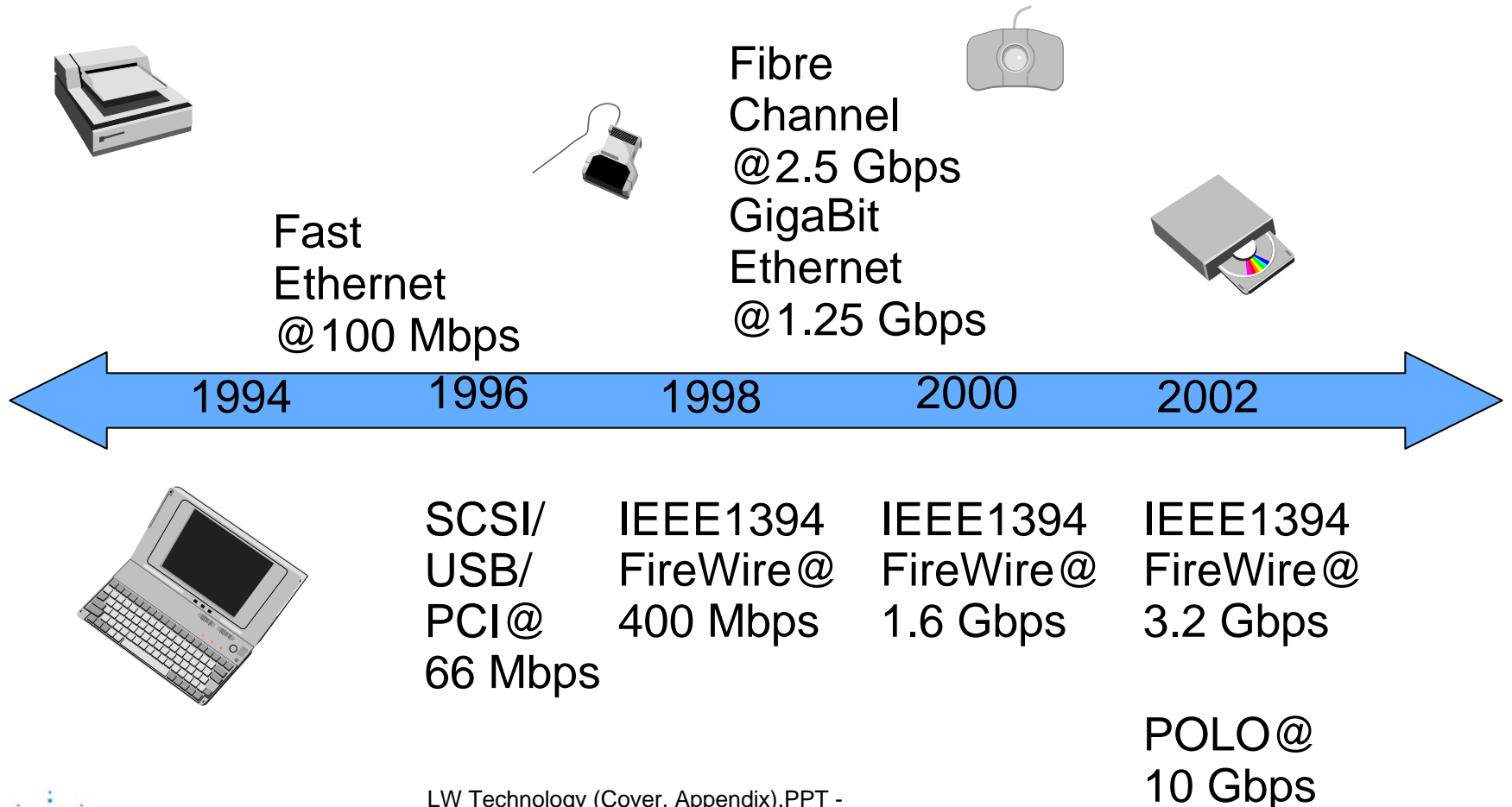
Revision 1.1
September 10, 2008



Typical Amplifier Unit

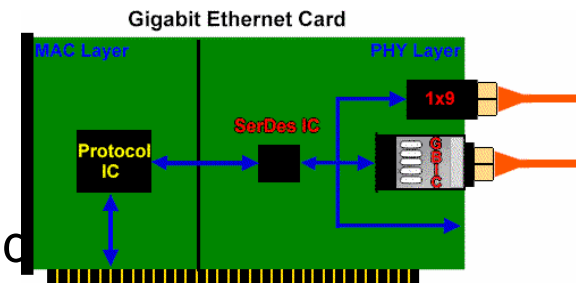


Data Communication Trends



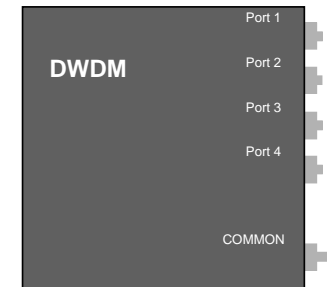
Data Communication Buzzwords

- Wide Area Network (WAN)
 - Nationwide or global data network
 - Often provided or operated by multiple long-distance service providers
- Metropolitan Area network (MAN)
 - Regional or local data network
 - Often owned by a local service provider
- Local Area Network (LAN)
 - Private computer network
 - Often shielded from the outside by firewalls
- Dial-Up Network
 - Connects a PC via modem & telephone to a computer



Company Types

- Component Manufacturers
 - *Lasers/LEDs, photodetectors, couplers, multiplexers, isolators, fibers, connectors*
- Subsystem Manufacturers
 - *Transmitters, receivers, amplifiers (EDFA), repeaters*
- System Manufacturers
 - *Point-to-point, SONET/SDH, WDM*
- Installers & Service Providers
 - *Link signature, fault location*



Review Questions

1. What advantages does the lightwave technology offer?
2. Who is using fiberoptics extensively?
3. What modulation (analog or digital) is used in the telephone network?

LW Technology



Physical Basics



Agilent Technologies
Innovating the HP Way

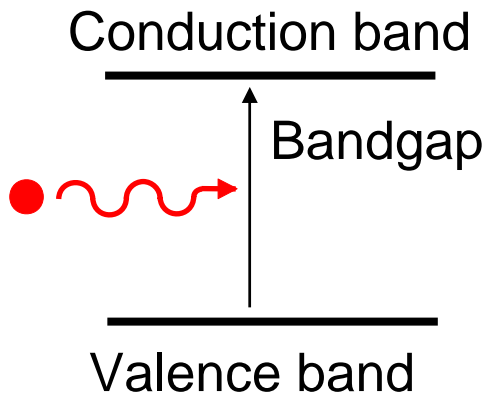
LW Technology (Cover, Appendix).PPT -
20
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



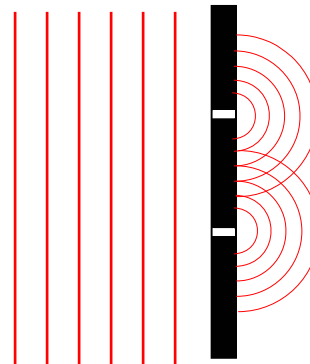
The Carrier - Light

Particles



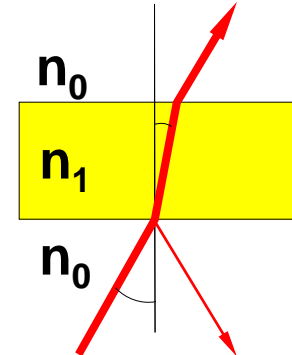
Absorption
Emission

Waves



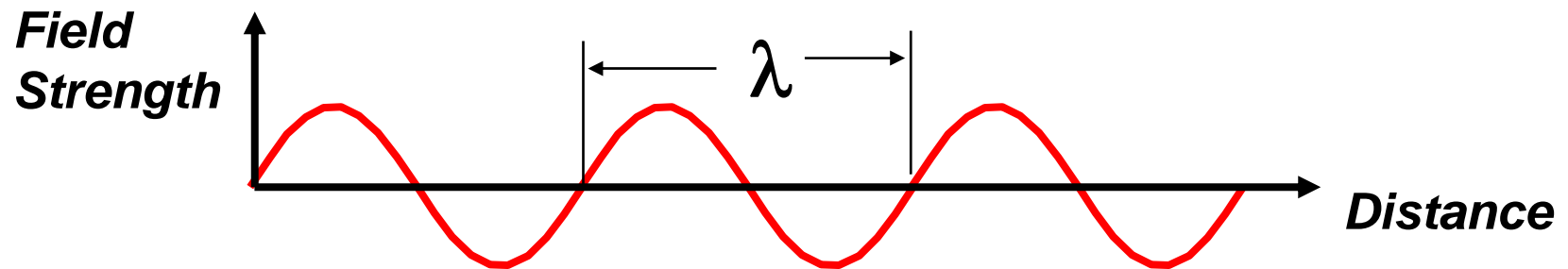
Interference

Rays



Refraction
Reflection

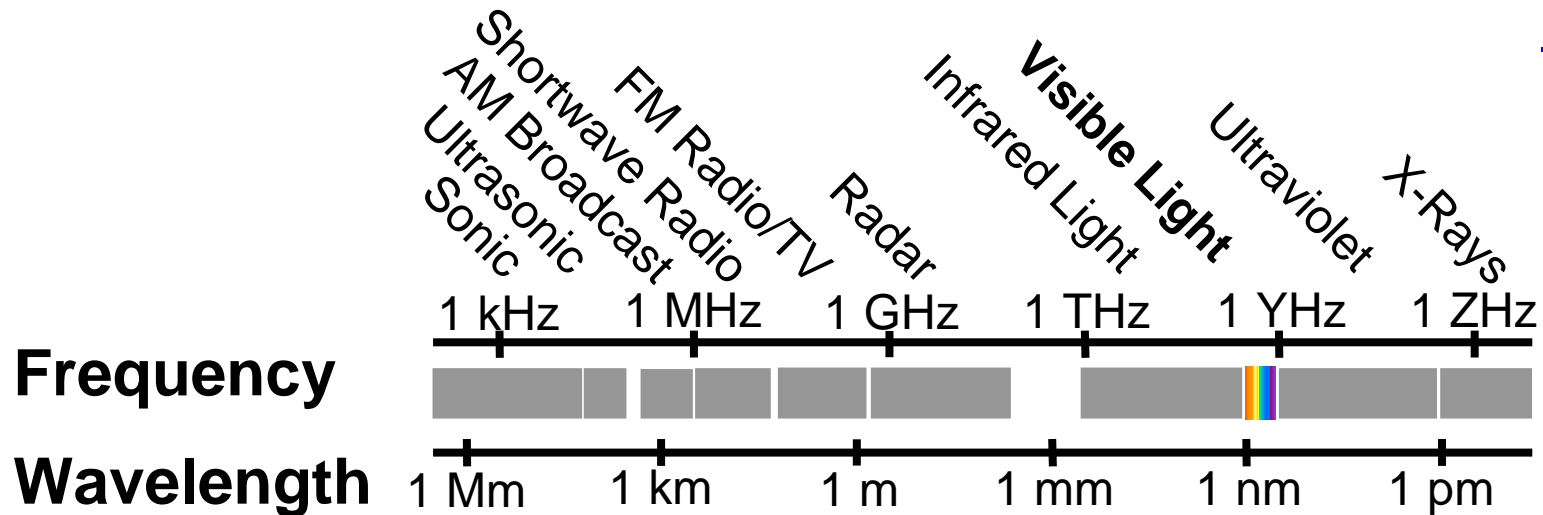
Light Properties - Wavelength



Wavelength λ : **distance to complete one sine wave**

1000 pm (picometer)	= 1 nm (nanometer)	1000 μm	= 1 mm (millimeter)
1000 nm (nanometer)	= 1 μm (micrometer)	1000 mm	= 1 m (meter) (~40 inches)

Electromagnetic Spectrum



$$c = f \cdot \lambda \cdot n$$

c: Speed of light (2.9979 m/μs)

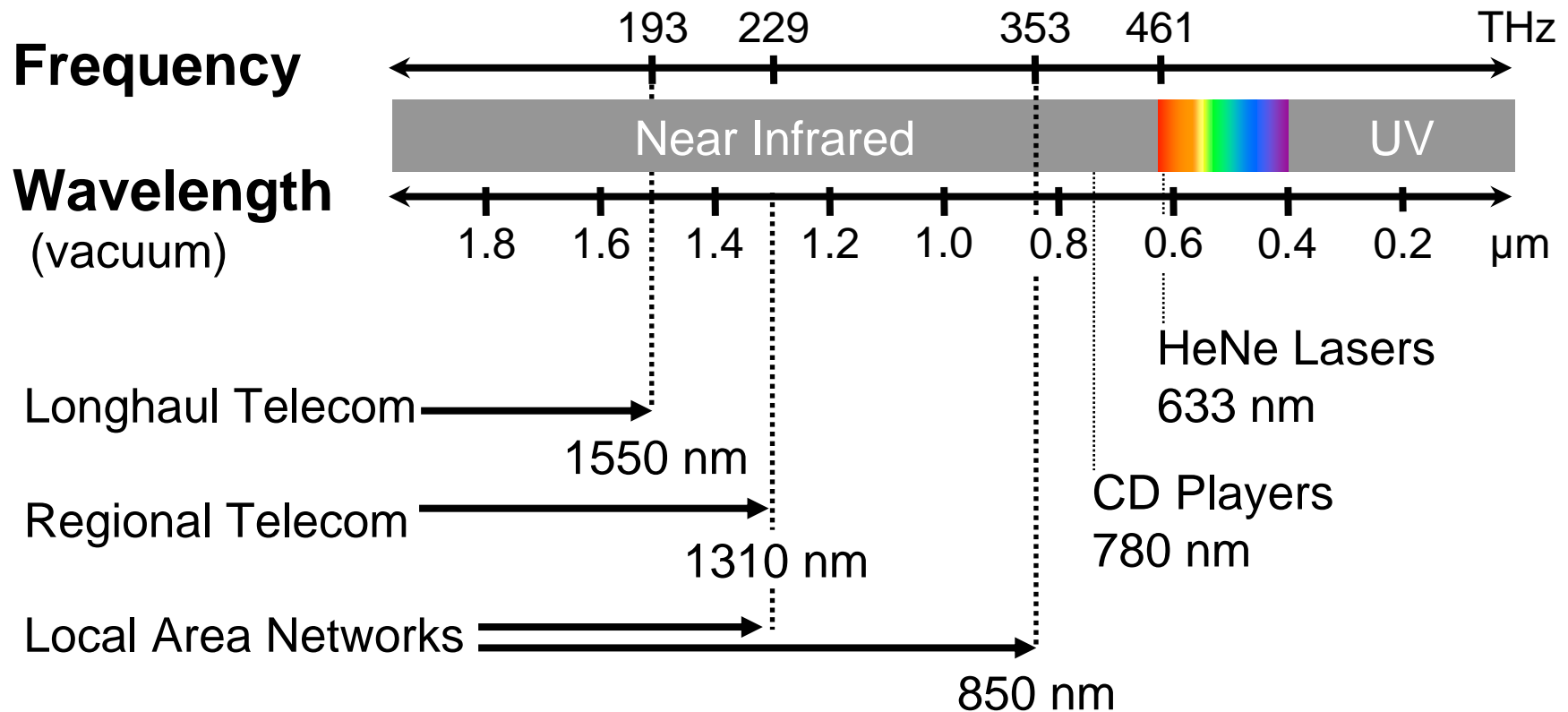
f: Frequency

λ : Wavelength

n: Refractive index

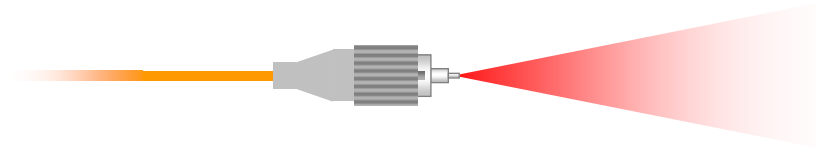
(vacuum: 1.0000; standard air: 1.0003; silica fiber: 1.44 to

LW Transmission Bands



Optical Power

- Power (P):
 - *Transmitter: typ. -6 to +17 dBm (0.25 to 50 mW)*
 - *Receiver: typ. -3 to -35 dBm (500 down to 0.3 μ W)*
 - *Optical Amplifier: typ. +3 to +20 dBm (2 to 100 mW)*
- Laser safety
 - International standard: IEC 825-1
 - United States (FDA): 21 CFR 1040.10
 - Both standards consider **class I** safe under reasonable foreseeable conditions of operation (e.g., without using optical instruments, such as lenses or microscopes)



Laser Power Limits Of Class I

(for test equipment applications)

21 CFR 1040.10

Wavelength	Fiber / NA	Limit
850 nm	MM / 0.15	2.8 mW
1060 to 1400 nm	MM / 0.15	4.9 mW
	SM / 0.10	1.9 mW
1400 to 2500 nm	SM / 0.10	7.84

(1984)



Agilent Technologies
Innovating the HP Way

IEC 825-1 (EN 60825-1)

Wavelength	Fiber / NA	Limit
850 nm	MM / 0.15	0.44 mW
1200 to 1400 nm	MM / 0.15	8.9 mW
	SM / 0.10	8.9 mW
1400 to 4000 nm	SM / 0.10	10 mW

(11/1993)

LW Technology (Cover, Appendix).PPT -
26
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



The Logarithmic Scale

$$\text{dB} = 10 \cdot \log_{10} (P_1 / P_0)$$

$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

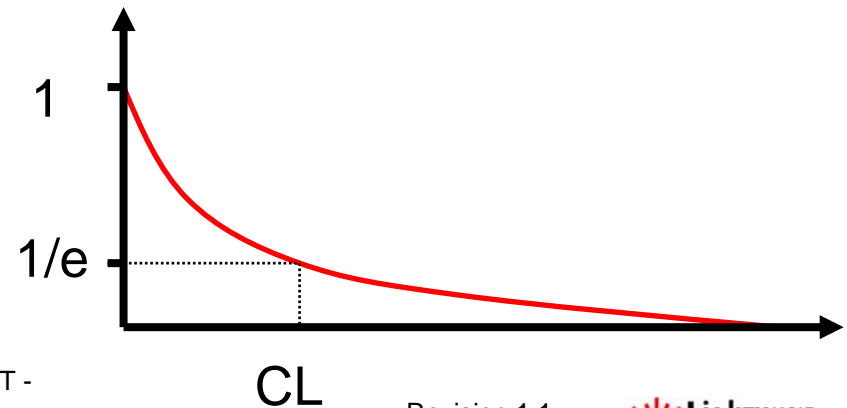
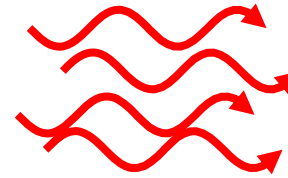
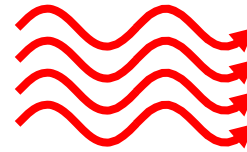
$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$



Coherence

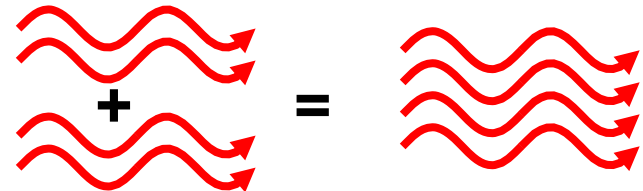
- **Coherent light**
Photons have fixed phase relationship (laser light)
- **Incoherent light**
Photons with random phase (sun, light bulb)
- **Coherence length (CL)**
Average distance over which photons lose their phase relationship



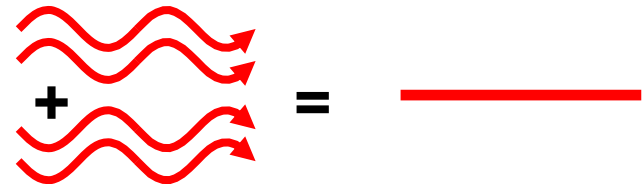
Interference

- Incoherent light adds up *optical power*
- Coherent light adds *electromagnetic fields*

- Zero phase shift:
constructive interference



- 180° phase shift:
destructive interference



Reflections

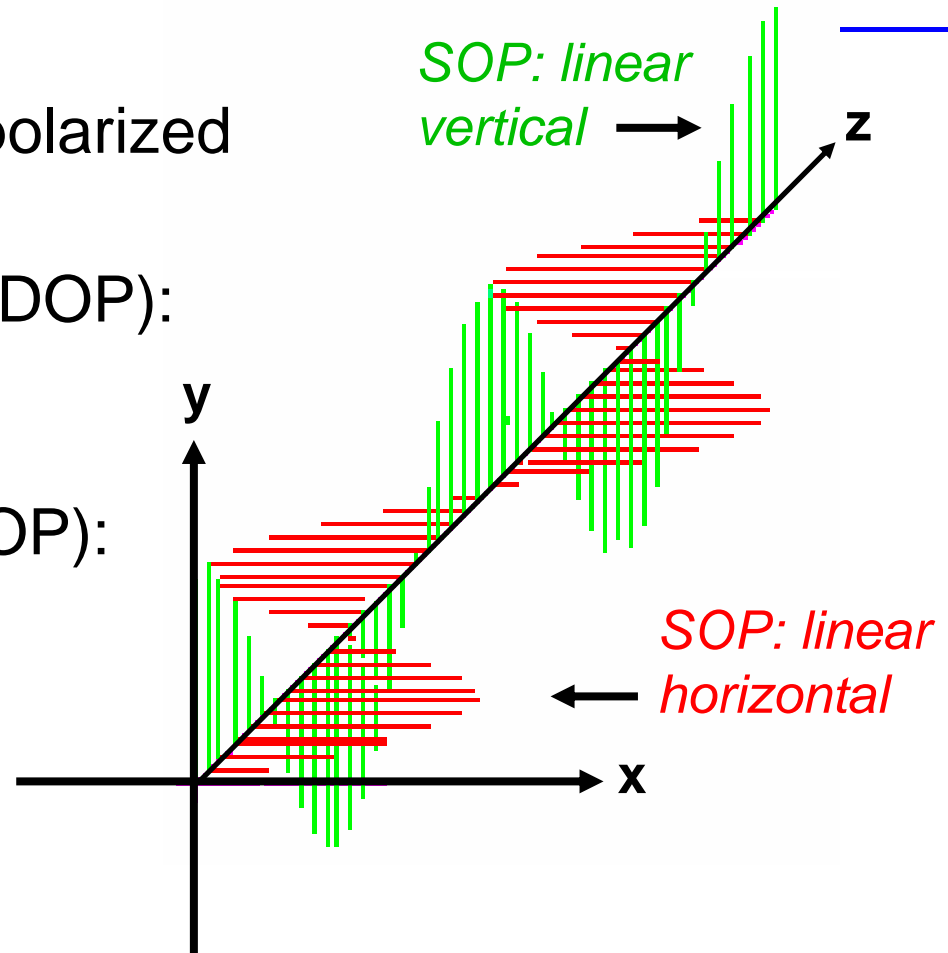
- Reflections: root cause for many problems
Return loss definition:

$$RL = 10 * \log \frac{P_{\text{incident}}}{P_{\text{reflected}}}$$



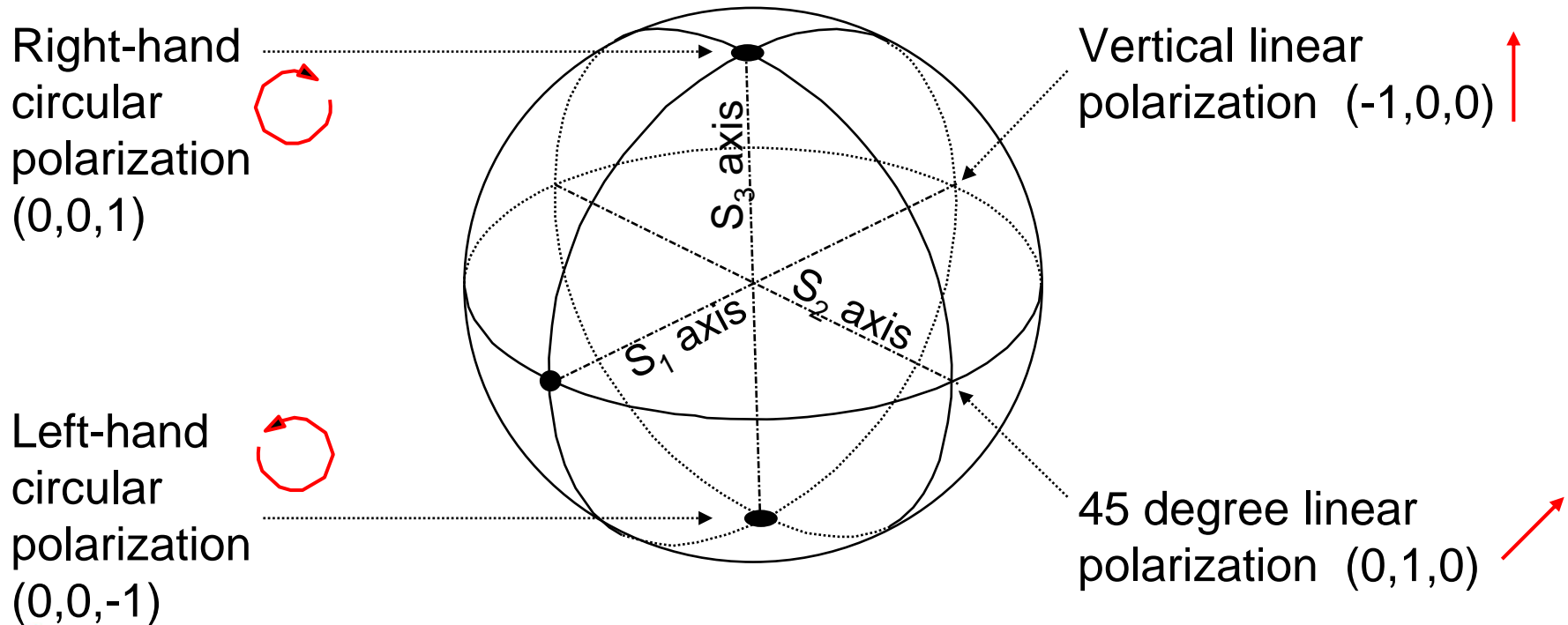
Polarization

- Most lasers are highly polarized
- Degree of polarization (DOP):
$$\text{DOP} = P_{\text{polarized}} / P_{\text{total}}$$
- State of polarization (SOP):
describes the orientation
and rotation of the
polarized light



Poincaré Sphere

Graphical representation of **state** of polarization using Stokes parameters (S_1 , S_2 , S_3)



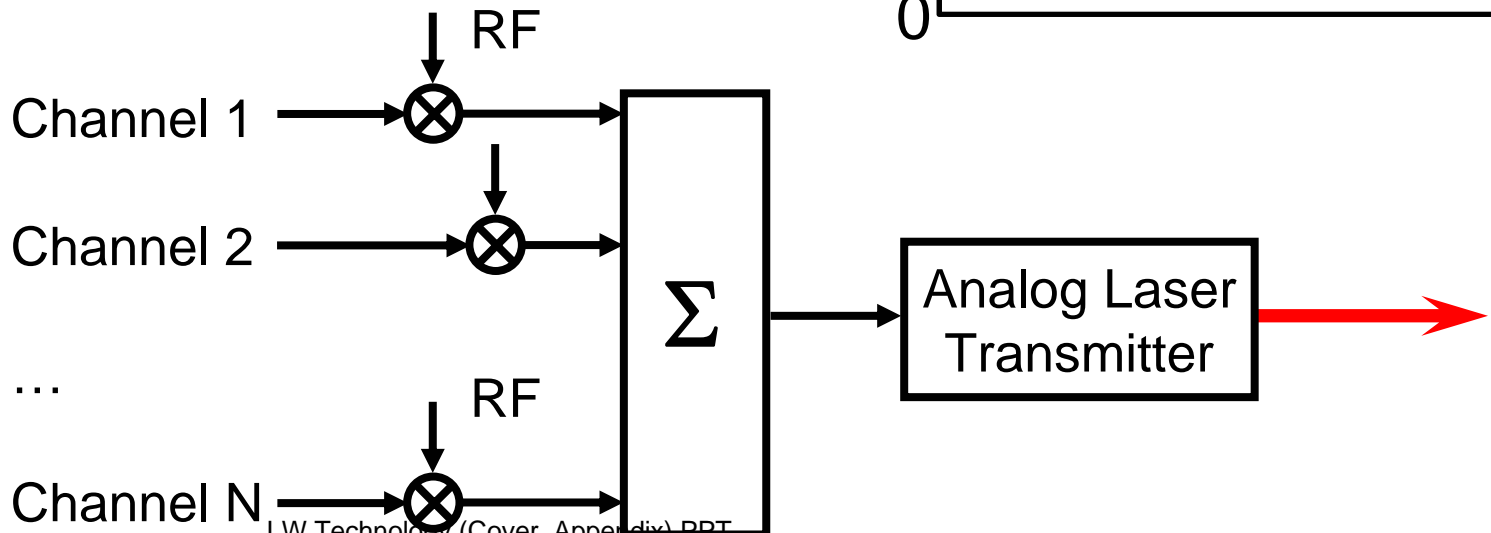
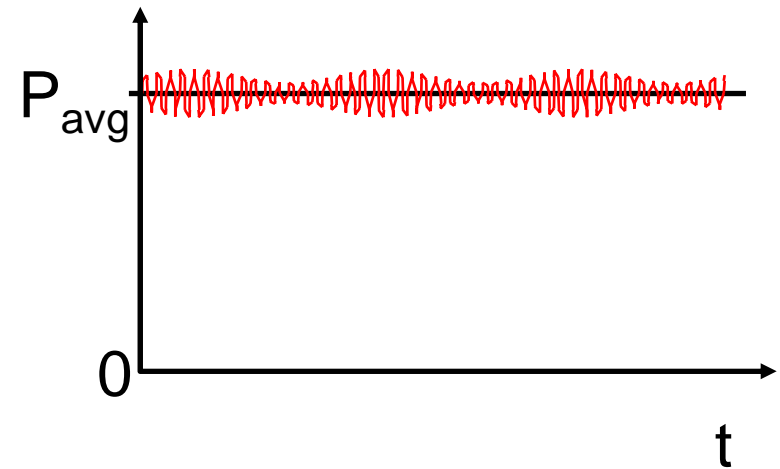
Digital Modulation

- Digital Modulation:
 - Extinction ratio = P_1 / P_0
 - Time-division multiplexing (TDM)
 - ~1.5 Mb/s to 10 Gb/s
- Bit Error Rate (BER):
 - $BER = N_{\text{incorrect}} / N_{\text{total}}$
 - Standards: 1E-9 to 1E-12
 - Lightwave systems: down to 1E-15



Analog Modulation

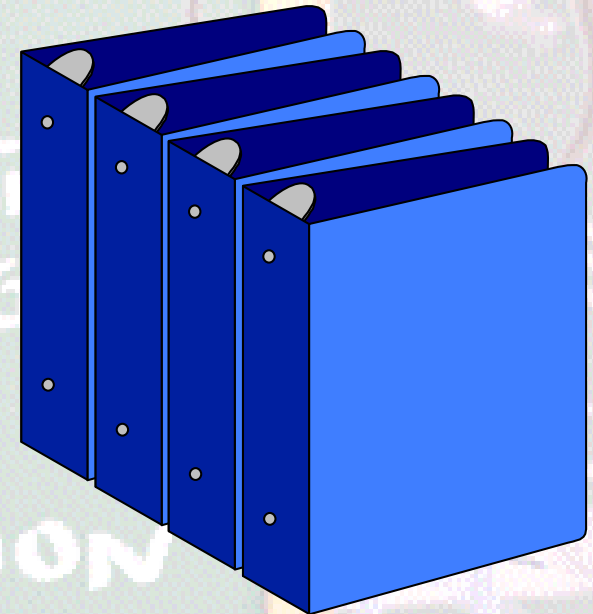
- AM modulation around P_{avg}
 - Mostly for video signals
 - Modulation index $\sim 2\%$
 - Frequency-domain multiplexing
 - 50 to 500 MHz



Review Questions

1. What are the three key parameters of light?
2. How much power is +13 dBm? -27 dBm?
How much loss is 6 dB? 15 dB?
3. What is TDM?
4. Where on the Poincaré sphere is the horizontal linear polarization state?

LW Technology



Standards



Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT -
36
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



Lightwave Standards Evolution

Basics - Measurement of power and wavelength



Point-to-point custom solutions



Agreement on parameter characteristics



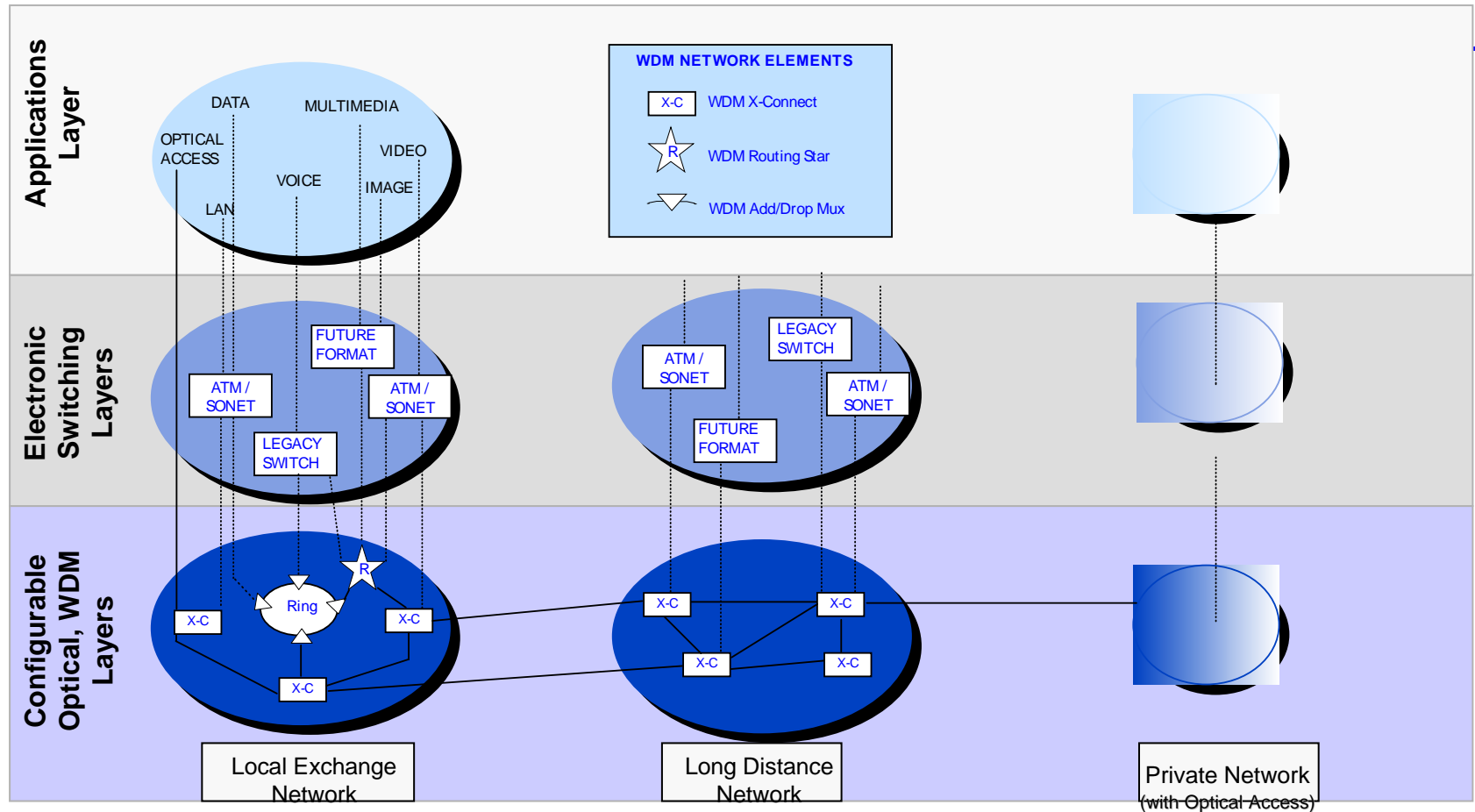
Multi-vendor market emerges



Interoperability - still elusive



Network Model



Key Standards

- Telecom Standards
 - Plesiochronous Digital Hierarchy (PDH)
 - Synchronous Optical Network (SONET) / Synchronous Digital Hierarchy (SDH)
 - Asynchronous Transfer Mode (ATM)
 - Dense Wavelength-Division Multiplexing (DWDM)
- Datacom Standards
 - Ethernet, Fast Ethernet (coax or twisted air cable)
 - Gigabit-Ethernet (IEEE 802.3z)
 - Fiber Distributed Data Interface (FDDI)
 - Fibre Channel (FC-PH)
 - Internet Protocol (IP)

PDH Networks

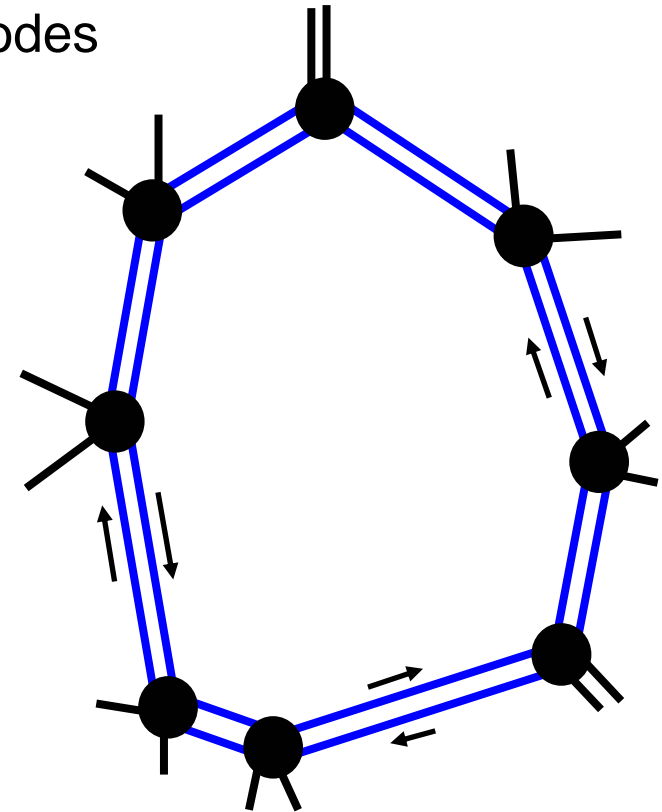
- Developed in the early 1970's
 - Still many systems in place, especially for low speed traffic
- Multiplexes digital voice circuits (64 kb/s)
 - North America: DS1 (1.5 Mb/s) to DS4 (139 Mb/s)
 - Europe: E1 (2 Mb/s) to E4 (139 Mb/s)
 - Japan: 2 to 98 Mb/s
- Drawbacks
 - Not perfectly synchronized: extra bits needed
 - Difficult to add/drop low speed stream from high-speed stream
 - No standard on line interfaces & coding (interoperability!)
 - Seconds to minutes to restoration time after a failure

SONET / SDH

- THE standard for new telecom networks:
 - North America: SONET version
 - International: SDH version
 - Optimized for voice traffic
 - Virtual container technology can carry many different traffic types & speeds
- Definitions include:
 - Optical requirements
 - Modulation and BER
 - Functional layer (e.g., frames)
 - Protection and restoration
 - Network management

Typical Ring Structures

- Two pairs of fibers between nodes
 - One fiber for each direction between nodes
 - One restoration fiber for each direction
- Network cut (single fault)
 - Traffic rerouted in opposite direction
 - Restoration within 0.5 sec
 - 100% protection!
- Nodes types
 - Add/drop multiplexers (ADM)
 - Digital cross-connects (DTE)

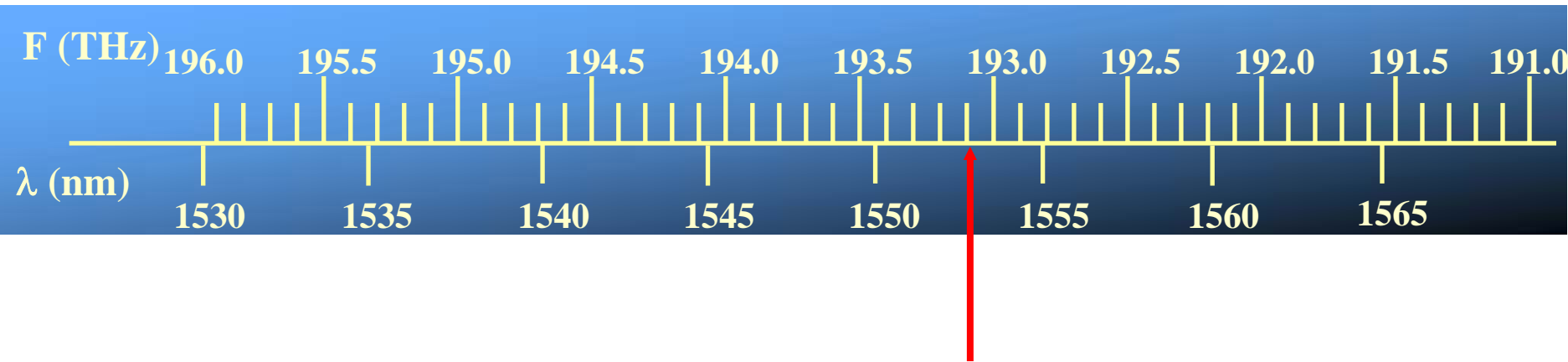


DWDM Standards

- ITU Draft Recommendation G.692:
“Optical Interfaces for Multichannel Systems
with Optical Amplifiers”
 - Specifies interfaces for the purpose of providing future transverse compatibility among such systems.
 - Defines the wavelength grid for multichannel systems.
 - Currently on hold pending resolution of intellectual property issues.
 - Large backlog of proposed changes/additions.



The Frequency Grid From G.692



- Channels anchored at a 193.1-THz reference
- 100-GHz spacing with no defined lower or upper bound.

The U.S. (TIA) will formally propose a change to 50-GHz spacing.

Asynchronous Transfer Mode (ATM)

- High performance data transfer standard
 - Uniform cell: 5 header bytes, 48 data bytes
 - Simple and efficient cell switching
 - Optimizes use of available network capacity
- Quality of Service (QoS)
 - Bandwidth and delay guarantees
 - Admission control to satisfy QoS
- Compatibility with installed networks
 - Can run over PDH or SONET/SDH systems

Internet Protocol (IP)

- WAN / MAN / LAN protocol for data
 - Originally designed for data (e-mail, file transfer)
 - Voice & video applications under development
- Layered design
 - Key contribution to widespread deployment
 - Can be easily adapted to new technologies
 - Higher layers can run over other data networks as long as they provide compatible services
- Point-to-Point protocol (PPP)
 - Common data link layer to connect PCs to LANs or to the internet via phone lines (e.g., home PC with modem)

7 - Application
6 - Presentation
5 - Session
4 - Transport
3 - Network
2 - Data link
1 - Physical

Common Transmission Speeds

- **SONET/SDH rates:**

- OC-3, STM-1: 155.52 Mb/s
- OC-12, STM-4: 622.08 Mb/s
- OC-48, STM-16: 2488.32 Mb/s
- OC-192, STM-64: 9953.28 Mb/s

- **Datacom rates:**

- FDDI: 125 (100) Mb/s
- FireWire: 100 - 800 Mb/s
- Fibre Channel: 266 - 1063 Mb/s
- Ethernet: 10 or 100 Mb/s
- G-Ethernet: 1250 Mb/s

- **PDH:**

North America:

- DS1: 1.544 Mb/s
- DS2: 6.312 Mb/s
- DS3: 44.736 Mb/s
- DS4: 139.264 Mb/s

Europe:

- E1 2.048 Mb/s
- E2: 8.448 Mb/s
- E3: 34.368 Mb/s
- E4: 139.264 Mb/s

Review Questions

1. Why do most operators like SONET/SDH ?
2. What is the advantage of a layered design?
4. What are the key properties of DWDM?



LW Technology



Fibers, Cables, Splices & Connectors



Agilent Technologies
Innovating the HP Way

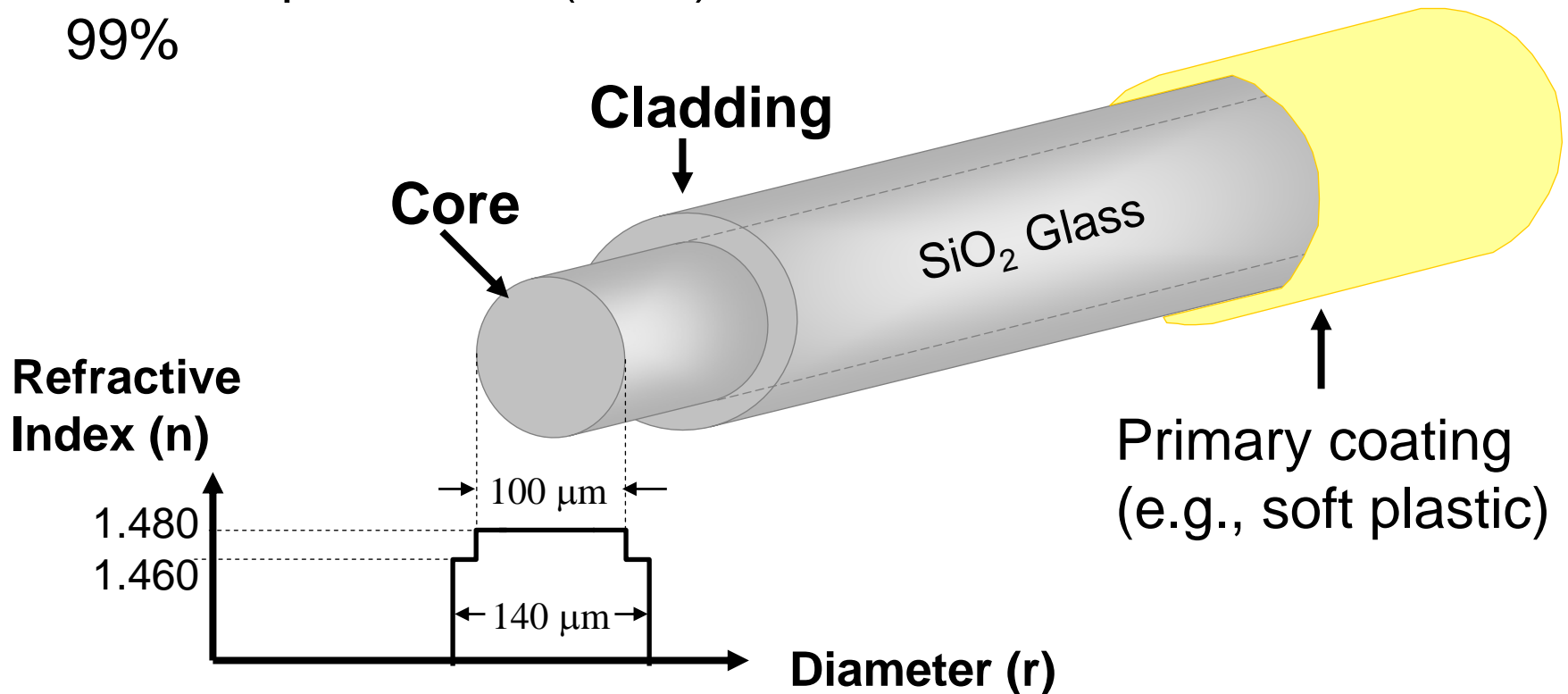
LW Technology (Cover, Appendix).PPT -
49
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



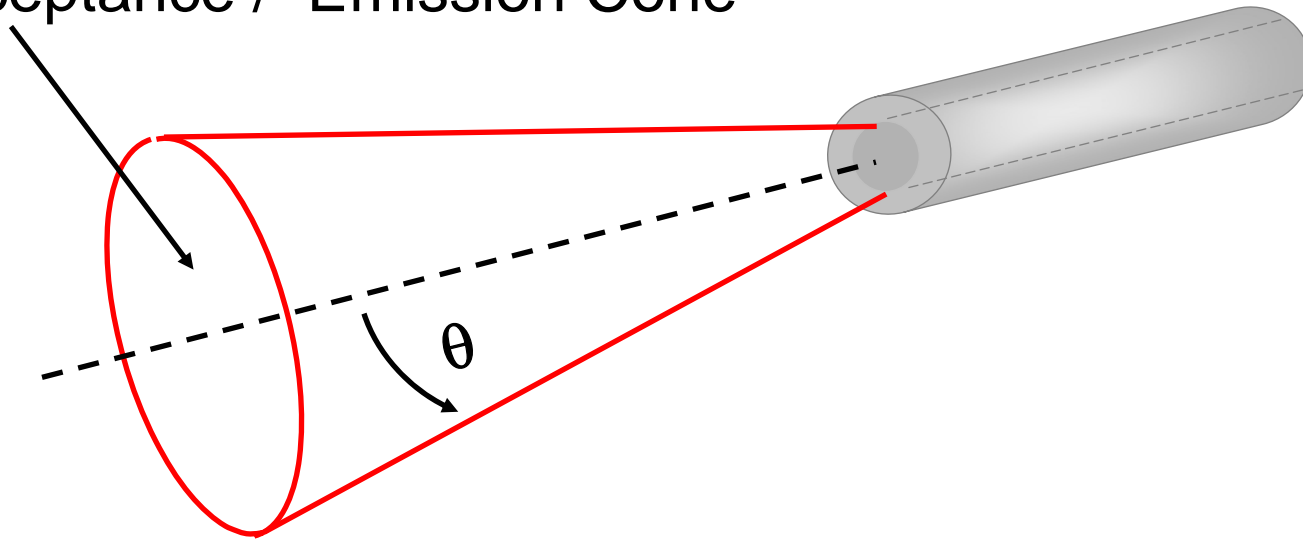
Basic Step-Index (SI) Fiber Design

- Most common designs: 100/140 or 200/280 μm
- Plastic optical fiber (POF): 0.1 - 3 mm \varnothing , core 80 to 99%



Numerical Aperture (NA)

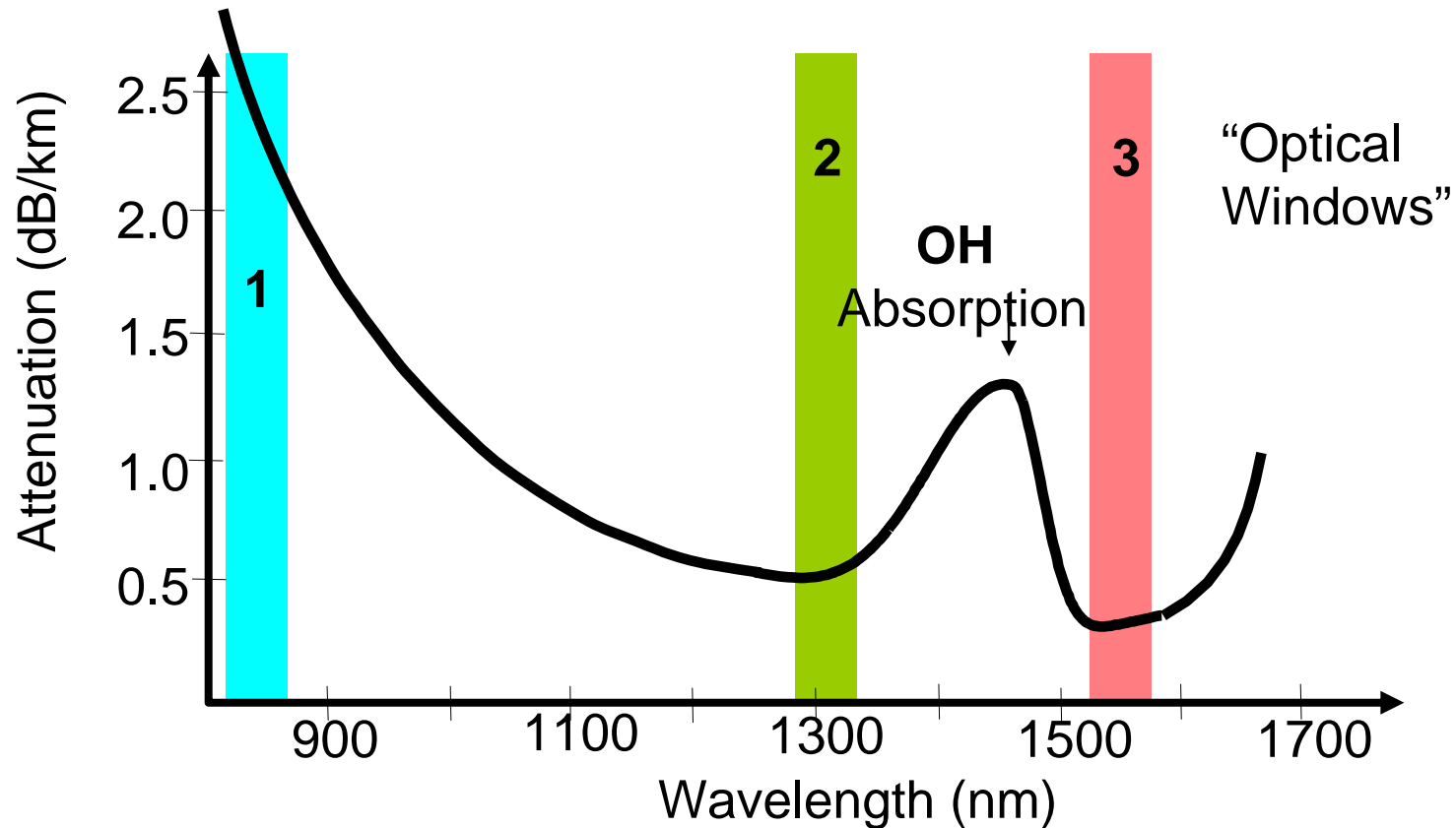
Acceptance / Emission Cone



$$NA = \sin \theta = \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$$



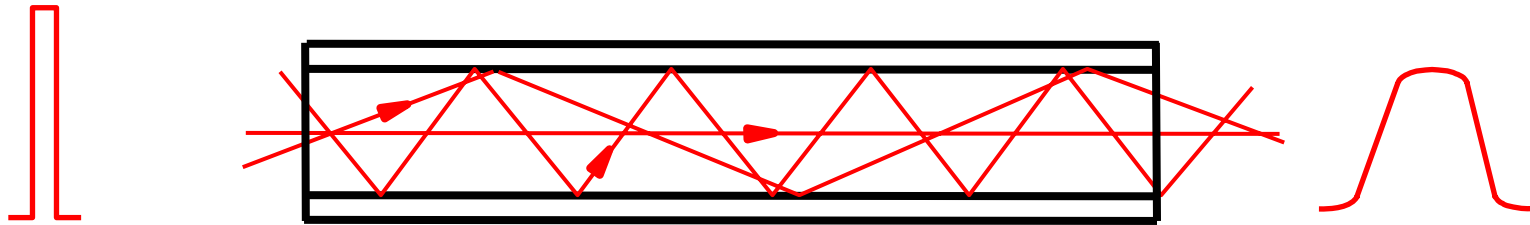
Attenuation In Silica Fibers



Main cause of attenuation: Rayleigh scattering in the fiber core



Step-Index Multimode (MM) Dispersion



Pulse broadening due to multi-path transmission.

Bitrate x Distance product is severely limited!

100/140 μm Silica Fiber:

~ 20 Mb/s • km

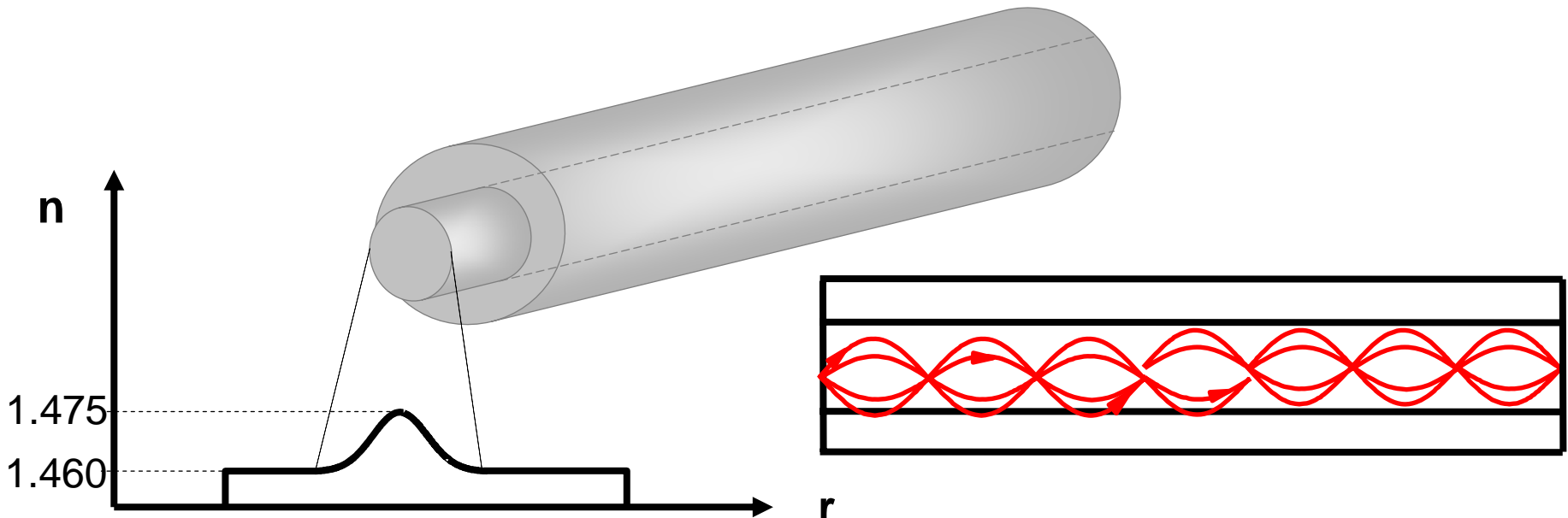
0.8/1.0 mm Plastic Optical Fiber:

~ 5 Mb/s • km



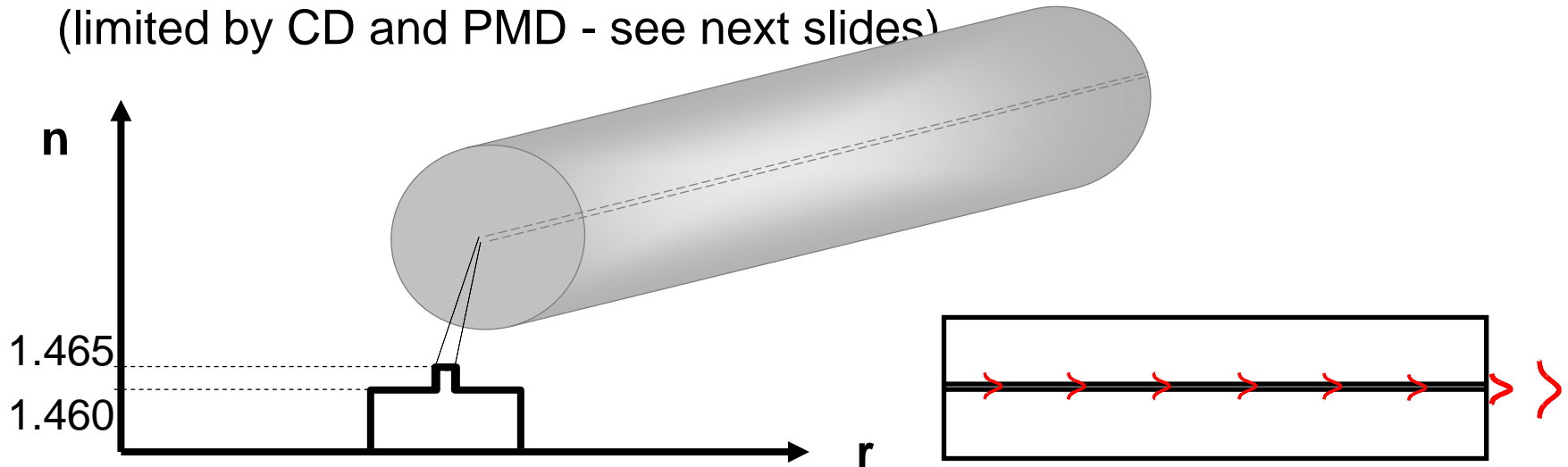
Gradient-Index (GI) Fiber

- Doping profile designed to minimize “race” conditions (“outer” modes travel faster due to lower refractive index!)
- Most common designs: 62.5/125 or 50/125 μm , NA ~ 0.2
- Bitrate x Distance product: $\sim 1 \text{ Gb/s} \cdot \text{km}$



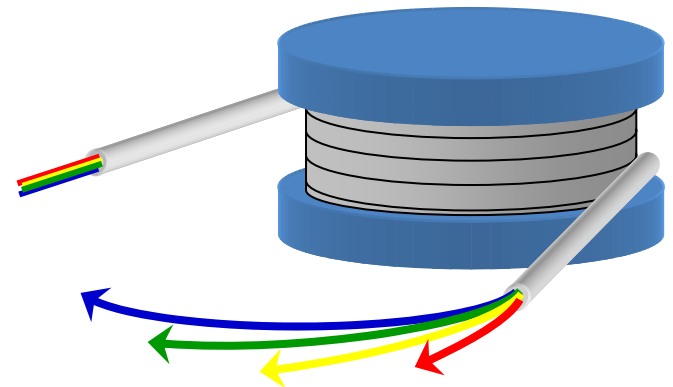
Single-Mode Fiber (SMF)

- Step-Index type with very small core
- Most common design: 9/125 μm or 10/125 μm , NA ~ 0.1
- Bitrate x Distance product: up to 1000 Gb/s • km (limited by CD and PMD - see next slides)



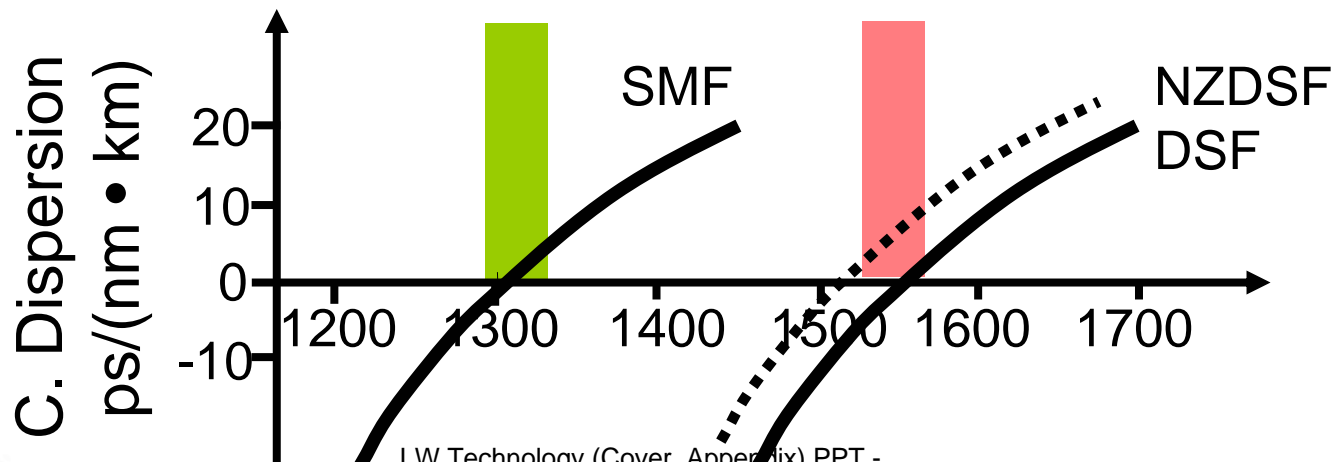
Chromatic Dispersion (CD)

- Light sources are NOT monochromatic
(linewidth of source, chirp effects, modulation sidebands)
- Different wavelengths travel at slightly different speeds
(this effect is called “Chromatic Dispersion”)
- Chromatic dispersion causes pulse broadening
(problem at high bit rates over long distances)
- Standard single-mode fiber:
 - 1300 nm window has lowest CD
 - 1550 nm lowest loss



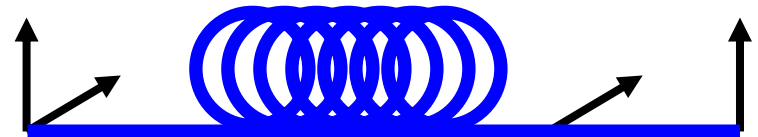
Dispersion-Shifted Fiber (DSF)

- Additional doping to shift zero dispersion to 1550 nm
 - Now 1550 nm lowest loss AND lowest dispersion
 - Can cause nonlinear effects in DWDM systems (see later)
- Non-Zero Dispersion Shifted Fiber (NZDSF)
 - Low dispersion around 1550 nm and low nonlinear effects
 - Requires chromatic dispersion compensators on long distances



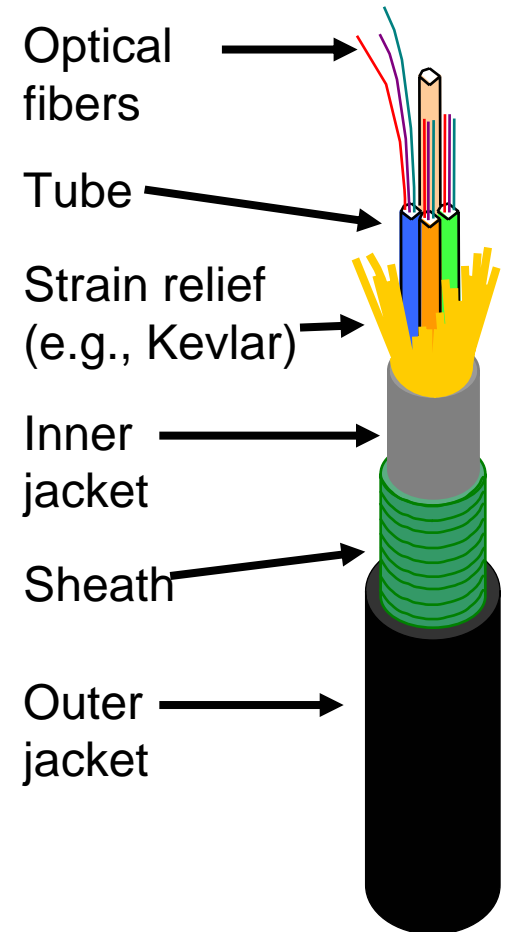
Polarization Mode Dispersion (PMD)

- Single-mode fiber actually transmits two modes
 - Modes have opposite states of polarization
 - Severe limitation at 10 Gb/s over distances > 50 km
- Power is randomly coupled between the two modes
 - PMD of a link fluctuates significantly over time
- Components can exhibit PMD as well
 - mostly constant PMD
 - manufacturers trying to minimize it by design



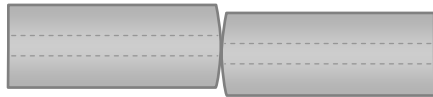
Cable Designs

- Mechanical design:
 - Indoor, outdoor, submarine
 - Local or national building and construction codes may apply
- Electrical designs:
 - No metal or electrical wires at all
 - Power wires (supply for remote amplifiers or regenerators)

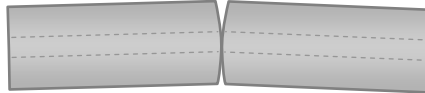


Issues Of Connecting Fibers

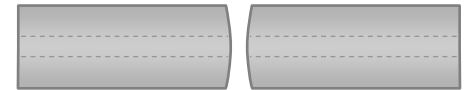
Offset



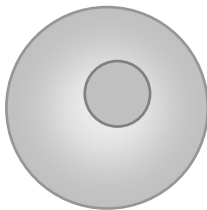
Angular Misalignment



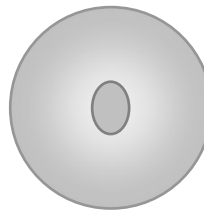
Separation



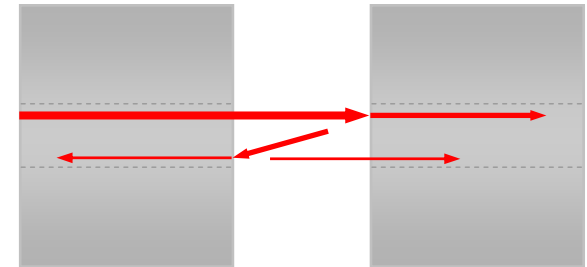
Core Eccentricity



Core Ellipticity

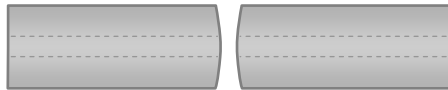


Reflections & Interference



Connector Types

Air Gap

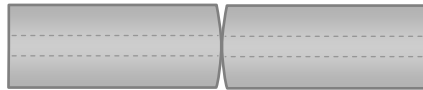


Medium insertion loss:
typ. 0.5 dB

Worst return loss:
< 14 dB (Fresnel)

Common multimode
fiber connector

Physical Contact (PC)

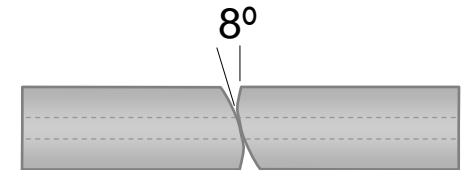


Lowest insertion loss:
< 0.25 dB

Good return loss:
> 40 dB

Common single-mode
fiber connector

Angled Physical Contact (APC)



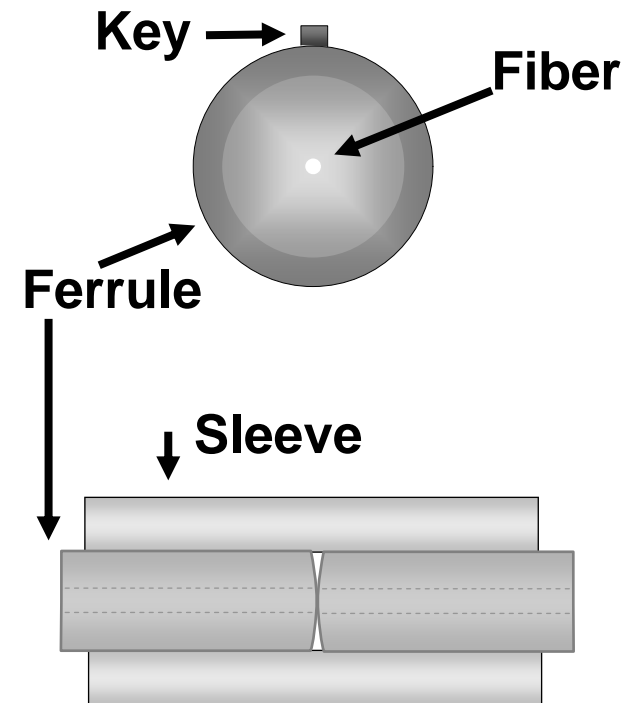
Highest insertion loss:
0.4 to 0.9 dB

Best return loss:
> 60 dB

Cable TV, high
performance systems

Connector Technology

- Ultra-high precision
 - Optical axis aligned to better than ± 1 μm (single-mode)
 - Physical contact of the glass end surfaces necessary
- Connector cleanliness is paramount
 - special cleaning and inspection required



Connector Brands

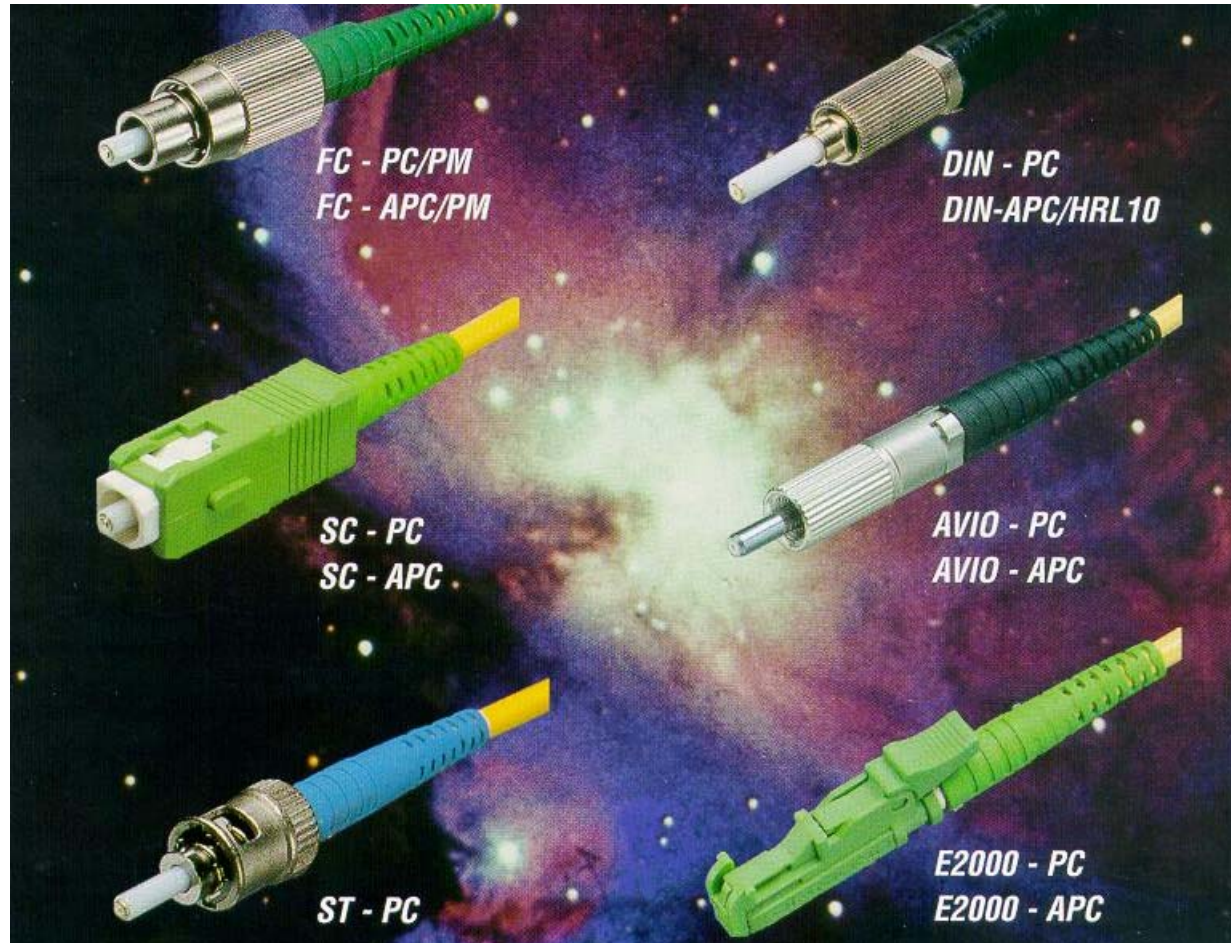


Photo courtesy
of: Diamond SA



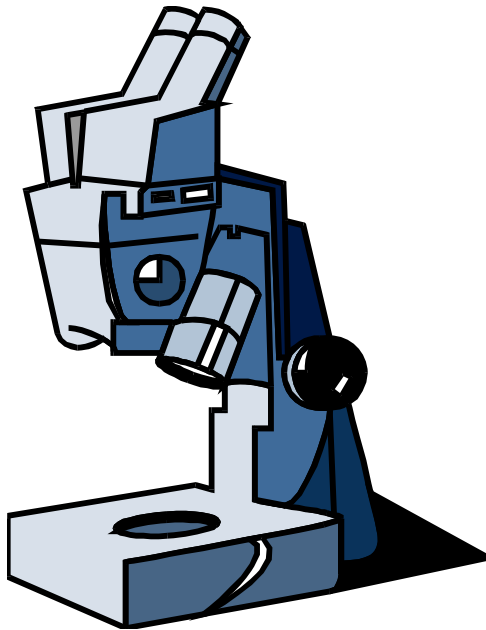
Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT -
63
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



Connector Inspection



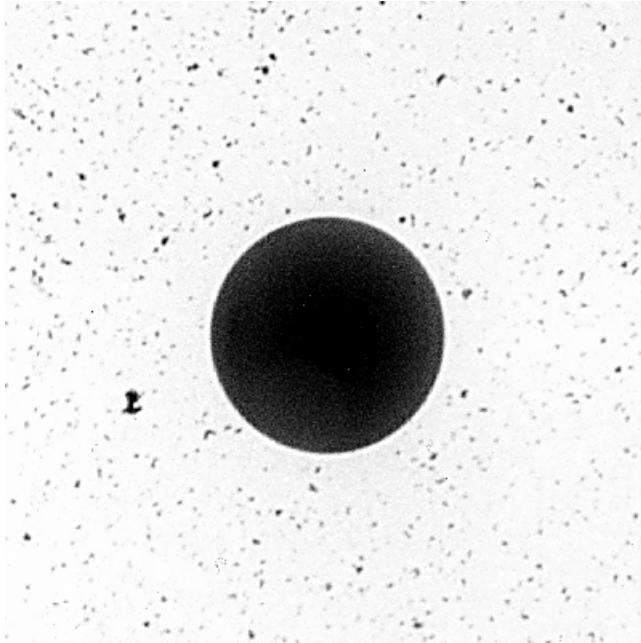
Inspection Tool



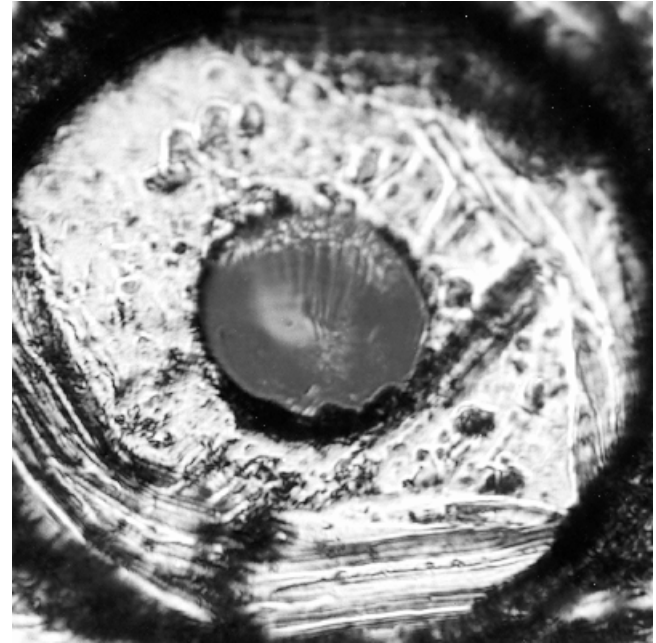
**Don't stare into the
laser beam**
(with your remaining eye)



Connector Care



New Connector



Damaged Connector



Agilent Technologies
Innovating the HP Way

LW Technology (Cover, Appendix).PPT -
65
© Copyright 1999, Agilent Technologies

Revision 1.1
September 10, 2008



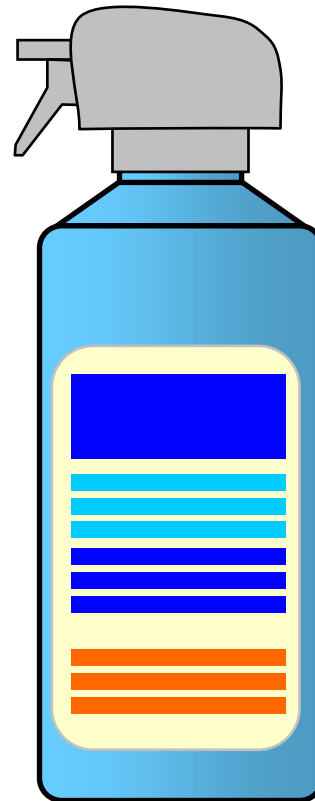
Connector Cleaning

Variety of cleaning methods in use today

Example:

Clean connector tips with Isopropyl (96% medical alcohol) using *adhesive free* cotton swabs

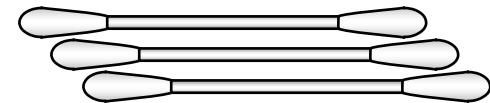
Immediately dry it with *dust-free, non residue* compressed air



Filtered Air



Isopropyl Alcohol



Pure Cotton Swabs

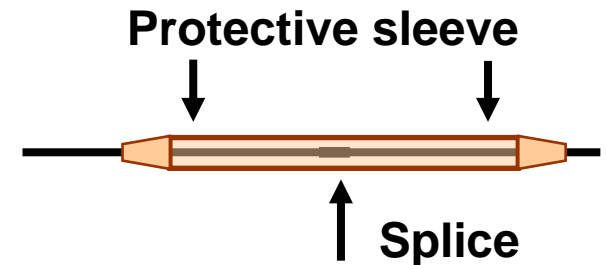
Splices

- Fusion Splices

- Most common permanent fiber connection
- Very high performance and reliability
- Insertion loss 0.01 to 0.1 dB, no reflection
- Automated splicing tool costs \$10k to \$50k

- Mechanical Splices

- Permanent and non-permanent types
- Insertion loss 0.1 to 0.5 dB
- Index-matching liquid used to minimize loss & reflections
- Epoxy or UV hardened elastomer based
- Less expensive tools (\$100 to \$1,000) required



Review Questions

1. What are commonly used fiber types?
2. What is dispersion and what can cause it?
3. What are good connector care habits?