Optical Communications

Chapter 1

Overview

Overview – Chapter 1

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1.1 Motivations (1)

- Lifestyle changes from Internet growth and use
  - Average phone call lasts 3 minutes
  - Average Internet session is 20 minutes
- More and more bandwidth-hungry services are appearing
  - Web searching, home shopping, high-definition interactive video, remote education, telemedicine and e-health, high-resolution editing of home videos, blogging, and large-scale high-capacity e-science and Grid computing
- Increase in PC storage capacity and processing power
  - 20G hard drives were fine around 2000; now standard is 500G
  - Laptops ran at 300 MHz; now the speed is over 4 GHz
- There is an extremely large choice of remotely accessible programs and information databases

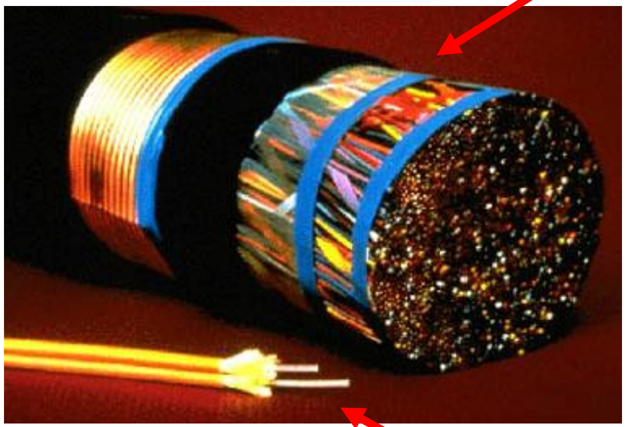
1.1 Motivations (2)

Advantages of optical fibers

- ***Long Distance Transmission***: The lower transmission losses in fibers compared to copper wires allow data to be sent over longer distances.
- ***Large Information Capacity***: Fibers have wider bandwidths than copper wires, so that more information can be sent over a single physical line.
- ***Small Size and Low Weight***: The low weight and the small dimensions of fibers offer a distinct advantage over heavy, bulky wire cables in crowded underground city ducts or in ceiling-mounted cable trays.
- ***Immunity to Electrical Interference***: The dielectric nature of optical fibers makes them immune to the electromagnetic interference effects.
- ***Enhanced Safety***: Optical fibers do not have the problems of ground loops, sparks, and potentially high voltages inherent in copper lines.
- ***Increased Signal Security***: An signal is well-confined within the fiber and an opaque coating around the fiber absorbs any signal emissions.

Why do we need optical communications?

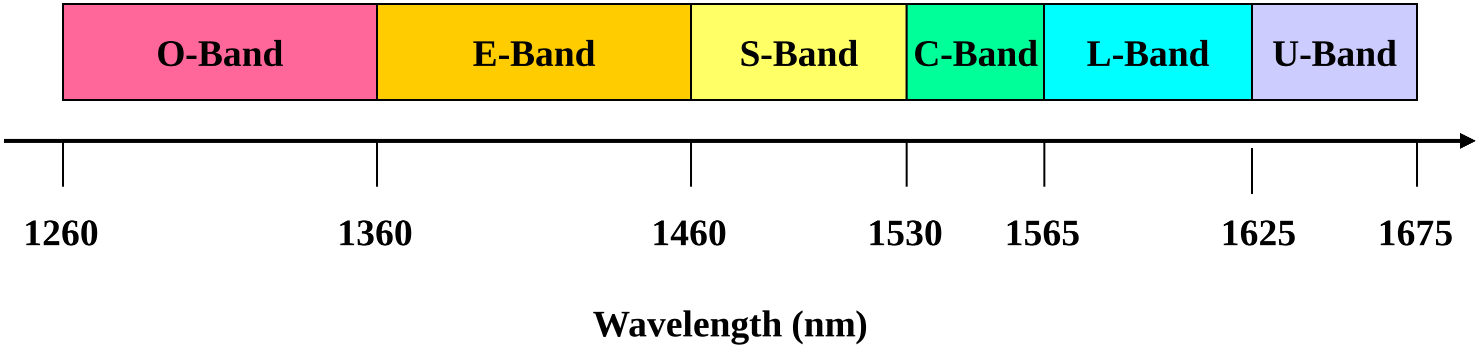
- It offers extremely high bandwidth and allows extremely high data rate ~upto 100Gbps
  - Wirless 4G (LTE, WiMax)
    - Target : 100Mbps
    - Actual : ~12Mbps
  - DSL
    - IPSL : ~upto 40Mbps
    - ADSL : ~upto 8Mbps



64kbps x 40,000,000 calls
= 2,560,000,000,000 bps
= 1.28Tbps x 2 fibers

pico : 10^{-12}	Kilo : 10^{3}
nano : 10^{-9}	**Mega : 10^{6}**
micro : 10^{-6}	Giga : 10^{9}
centi : 10^{-3}	**Tera : 10^{12}**

1.2 Optical Spectral Bands (1)



- **Original band (O-band): 1260 to 1360 nm**
  - Region originally used for first single-mode fibers
- **Extended band (E-band): 1360 to 1460 nm**
  - Operation extends into the high-loss water-peak region
- **Short band (S-band): 1460 to 1530 nm (shorter than C-band)**
- **Conventional band (C-band): 1530 to 1565 nm (EDFA region)**
- **Long band (L-band): 1565 to 1625 nm (longer than C-band)**
- **Ultra-long band (U-band): 1625 to 1675 nm**

1.3 Decibel Units (1)

- The **decibel** (dB) unit is defined by

$$\text{Power ratio in dB} = 10 \log \frac{P_2}{P_1}$$

Table 1.2 *Representative values of decibel power loss and the remaining percentages*

Power loss (in dB)	*Percent of power left*
0.1	98
0.5	89
1	79
2	63
3	50
6	25
10	10
20	1

1.3 Decibel Units (2)

- **Since the decibel is used to refer to ratios or relative units, it gives no indication of the absolute power level.**
- **A derived unit called the dBm can be used for this purpose.**
- ***This unit expresses the power level P as a logarithmic* ratio of *P referred to 1 mW.***
- ***The power in dBm* is an absolute value defined by**

$$\text{Power level (in dBm)} = 10 \log \frac{P\,(\text{in mW})}{1\ \text{mW}}$$

1.3 Decibel Units (3)

- **A rule-of-thumb relationship to remember for optical fiber communications is 0 dBm = 1 mW.**
- **Therefore, positive values of dBm are greater than 1 mW and negative values are less than 1 mW.**

Table 1.3 *Examples of optical power levels and their dBm equivalents*

Power	*dBm equivalent*
200 mW	23
100 mW	20
10 mW	10
1 mW	0
100 μW	–10
10 μW	–20
1 μW	–30
100 nW	–40
10 nW	–50
1 nW	–60
100 pW	–70
10 pW	–80
1 pW	–90

1.3 Decibel Units (4)

Example 1.3 Consider the transmission path from point 1 to point 4 shown in Fig. 1.7. Here the signal is attenuated by 9 dB between points 1 and 2. After getting a 14-dB boost from an amplifier at point 3, it is again attenuated by 3 dB between points 3 and 4. Relative to point 1, the signal level in dB at point 4 is

$$\begin{aligned}\text{dB level at point 4} &= (\text{loss in line 1}) + (\text{amplifier gain}) \\ &\quad + (\text{loss in line 2}) \\ &= (-9\text{ dB}) + (14\text{ dB}) + (-3\text{ dB}) = +2\text{ dB}\end{aligned}$$

Thus the signal has a 2-dB (a factor of $10^{0.2} = 1.58$) gain in power in going from point 1 to point 4.

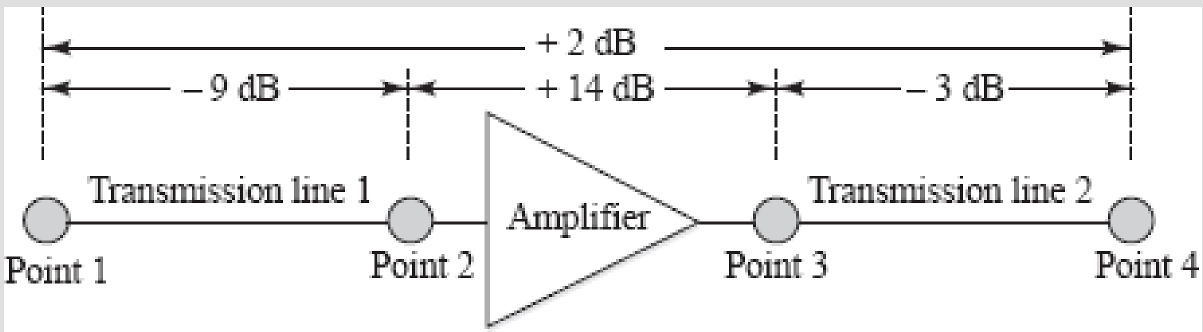


Fig. 1.7 *Example of signal attenuation and amplification in a transmission path*

Power levels differing by many orders of magnitude can be compared easily when they are in decibel form.

1.4 Network Information Rates (1)

Table 1.5 *Digital multiplexing levels used in North America, Europe, and Japan*

Digital multiplexing level	*Number of 64-kb/s channels*	*Bit rate (Mb/s)*		
		North America	*Europe*	*Japan*
DS0	1	0.064	0.064	0.064
DS1	24	1.544		1.544
	30		2.048	
	48	3.152		3.152
DS2	96	6.312		6.312
	120		8.448	
DS3	480		34.368	32.064
	672	44.736		
	1344	91.053		
	1440			97.728
DS4	1920		139.264	
	4032	274.176		
	5760			397.200

1.4 Network Information Rates (2)

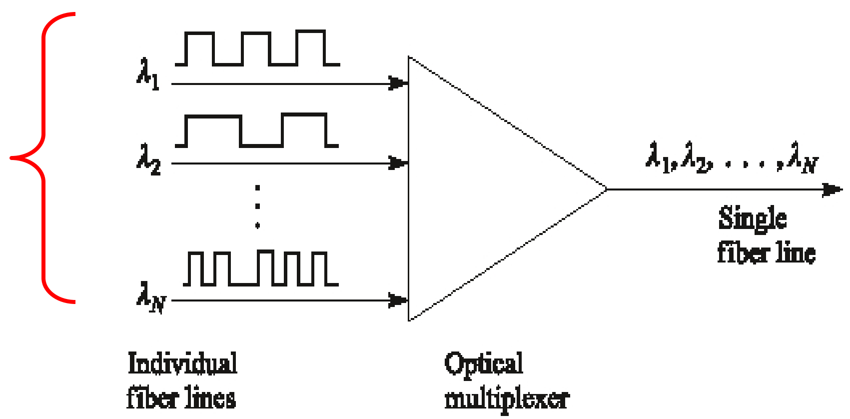
Table 1.6 *Common SDH and SONET line rates and their popular numerical name*

SONET level	*Electrical level*	*SDH level*	*Line rate (Mb/s)*	*Popular rate name*
OC-1	STS-1	—	51.84	—
OC-3	STS-3	STM-1	155.52	155 Mb/s
OC-12	STS-12	STM-4	622.08	622 Mb/s
OC-48	STS-48	STM-16	2488.32	2.5 Gb/s
OC-192	STS-192	STM-64	9953.28	10 Gb/s
OC-768	STS-768	STM-256	39813.12	40 Gb/s

- **A standard signal format called synchronous optical network (SONET) is used in North America**
- **A standard signal format called synchronous digital hierarchy (SDH) is used in other parts of the world**

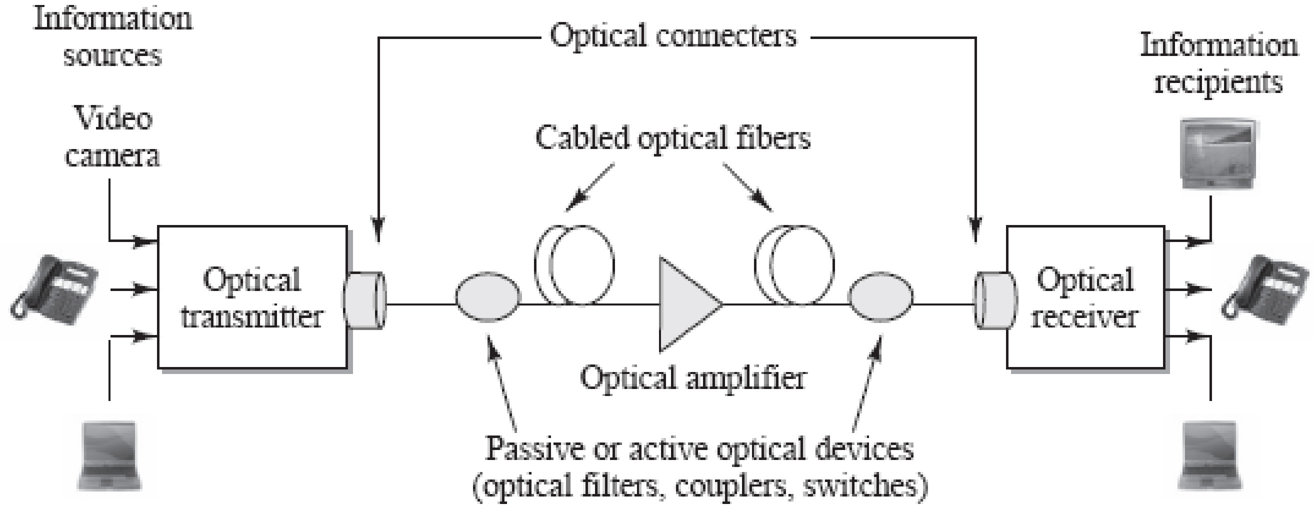
1.5 WDM Concepts

- Many independent information-bearing signals are sent along a fiber simultaneously
- Independent signals are carried on different wavelengths
- Data rates or formats on each wavelength may be different
- Coarse WDM (CWDM) and dense WDM (DWDM) are the two major wavelength multiplexing techniques
- Wavelength routing and switching techniques based on lightpaths are being developed



1.6 Key Elements of Optical Fiber Systems

- **Transmitter: a light source and signal-formatting circuitry**
- **A cable offering mechanical and environmental protection to the optical fibers contained inside**
- **A receiver consisting of a photodetector plus amplification and signal-restoring circuitry.**
- **Other components: Optical amplifiers, connectors, splices, couplers, regenerators, and passive and active devices.**



1.6 Key Elements of Optical Fiber Systems

Optical Transmitter/Receiver (Finisar)

Ref : Optical Transponder (Oclaro)

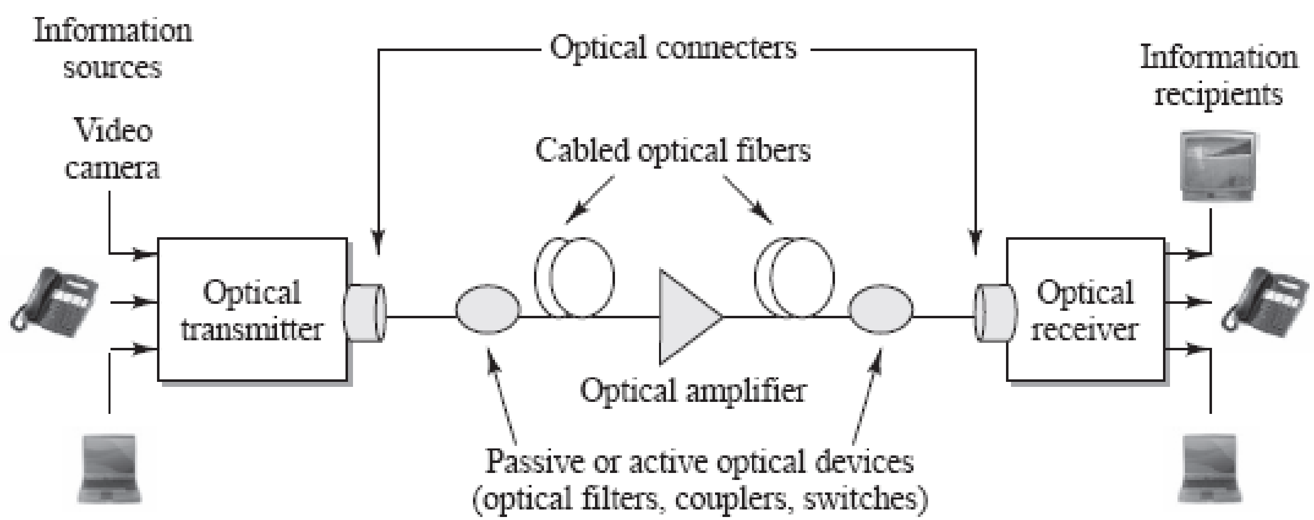
Optical Amplifier (JDSU)

Ref : Submarine Fiber Cable

DCF (from OFS Fitel LLC)

Tunable DC (from Oclaro Inc)

Ref : Terrestrial Fiber Cable



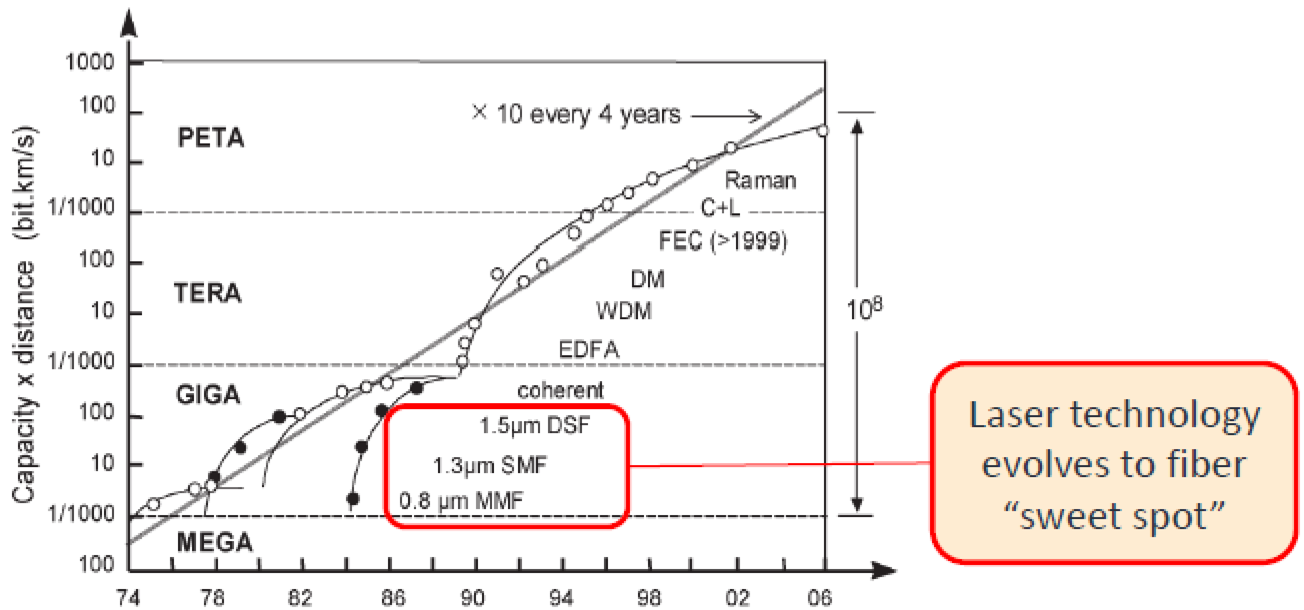
1.7 Standards

The three basic classes for fiber optics are *primary* standards, *component testing* standards, and *system* standards.

- ***Primary standards*** **deal with *physical parameters:* attenuation, bandwidth, operational characteristics of fibers, and optical power levels and spectral widths.**
- ***Component testing standards*** **define tests for fiber-optic component performance and establish equipment-calibration procedures.**
  - **The main ones are *Fiber Optic Test Procedures (FOTP)***
- ***System standards*** **refer to measurement methods for optical links and networks.**

History of Optical Capacity Innovation

A History of DWDM Capacity x Distance Innovations



Emmanuel B. Desurvire. "Capacity Demand and Technology Challenges for Lightwave Systems in the Next Two Decades" JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 24, NO. 12, DECEMBER 2006

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Ref : Optical Society of America (OSA), Corporate Webinar, G.Bennett, V.Rathore, Infinera Corp., June, 2014

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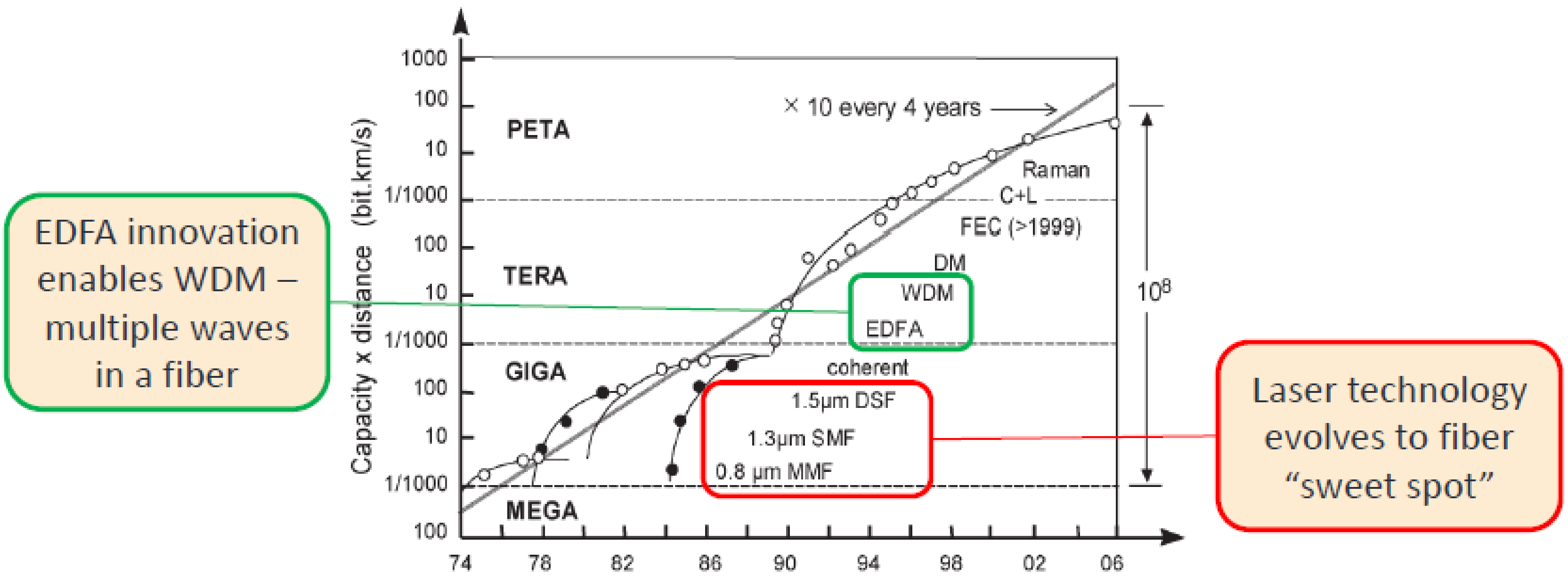

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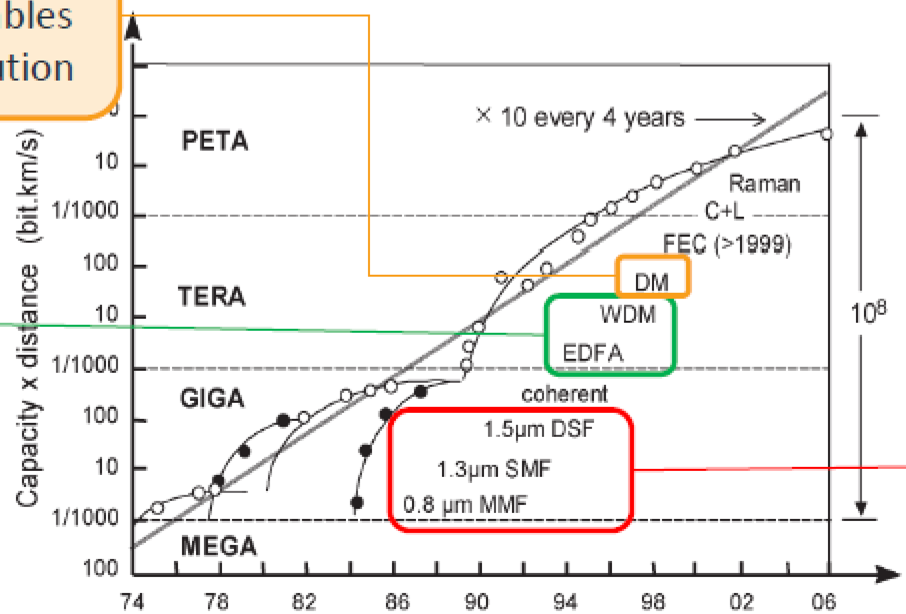
A History of DWDM Capacity x Distance Innovations

Chromatic Dispersion Management enables 2.5G to 10G evolution

EDFA innovation enables WDM – multiple waves in a fiber



Laser technology evolves to fiber “sweet spot”

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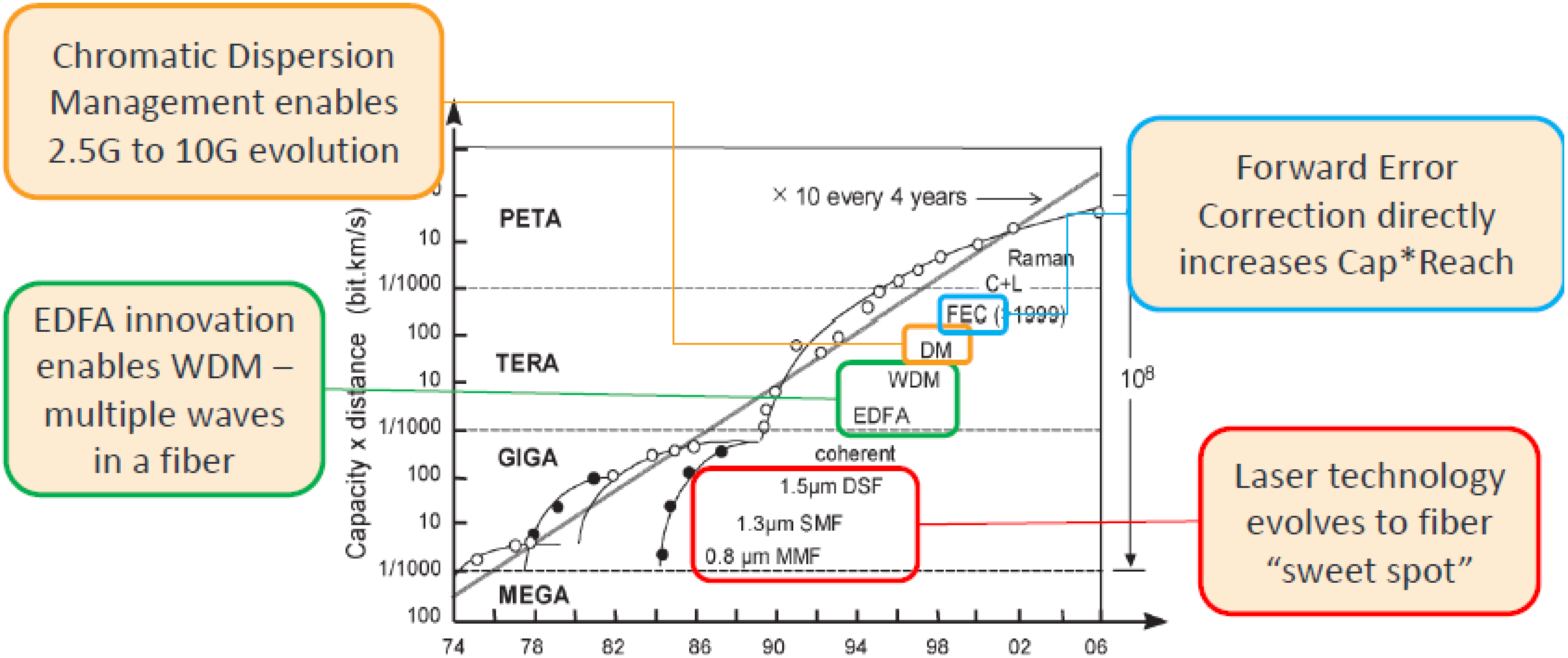

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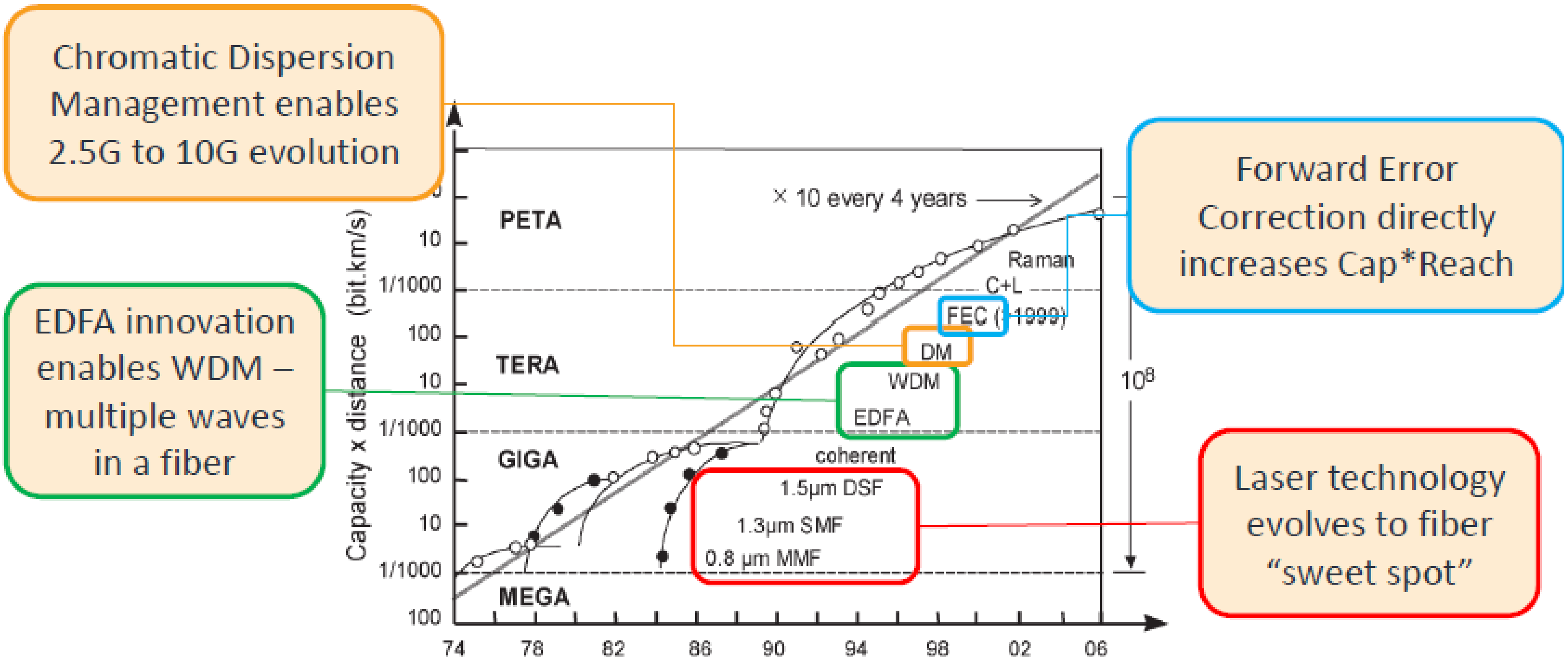

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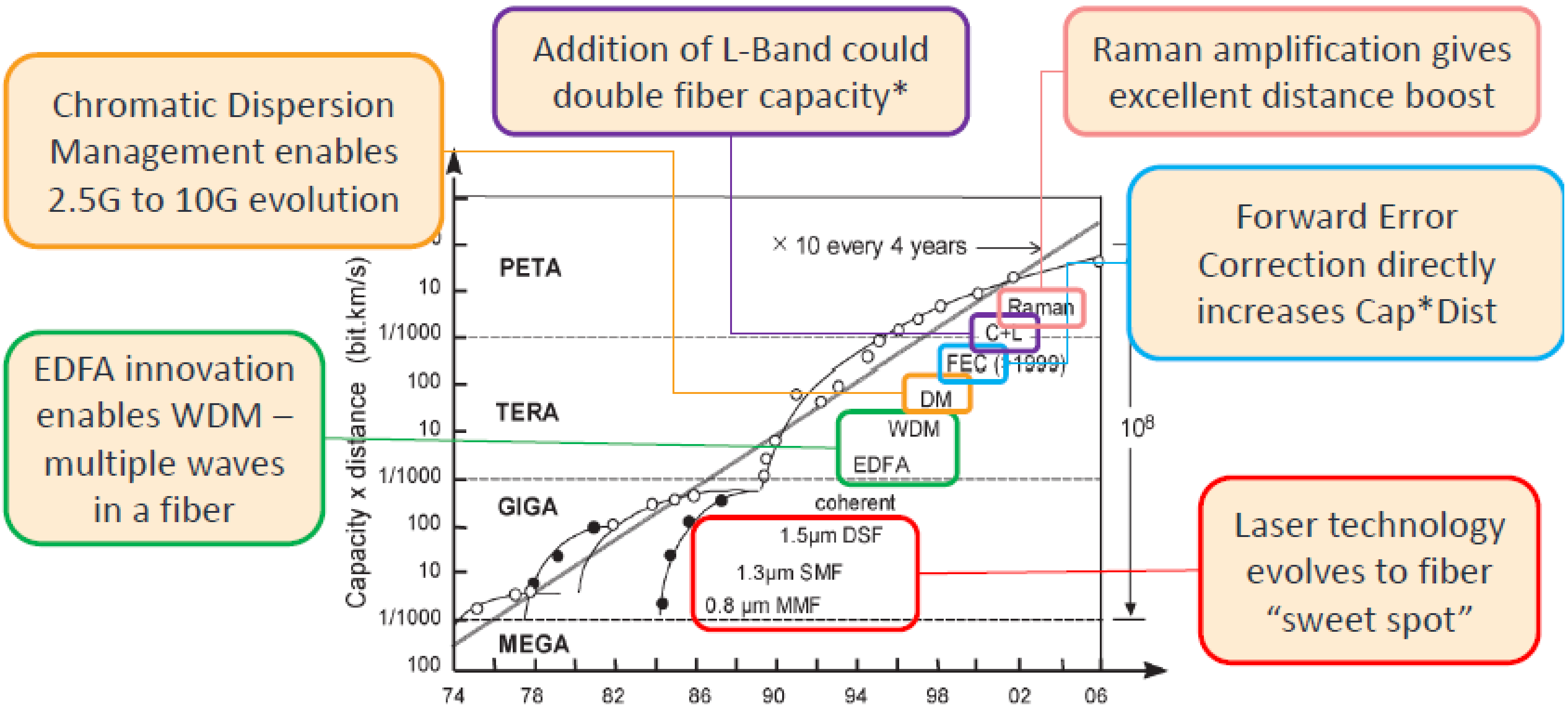

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