2015.7.15

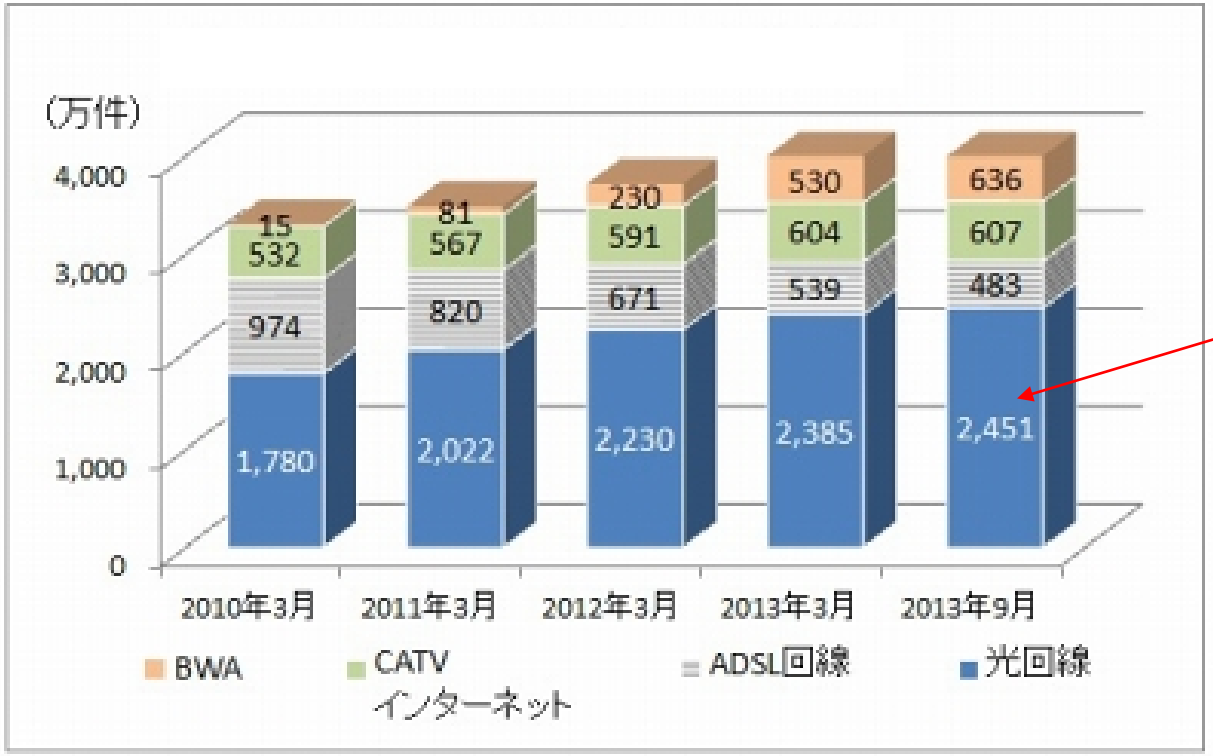
Optical Transmission Technologies

presented by

K. Inoue

Optical communication is widely spreading

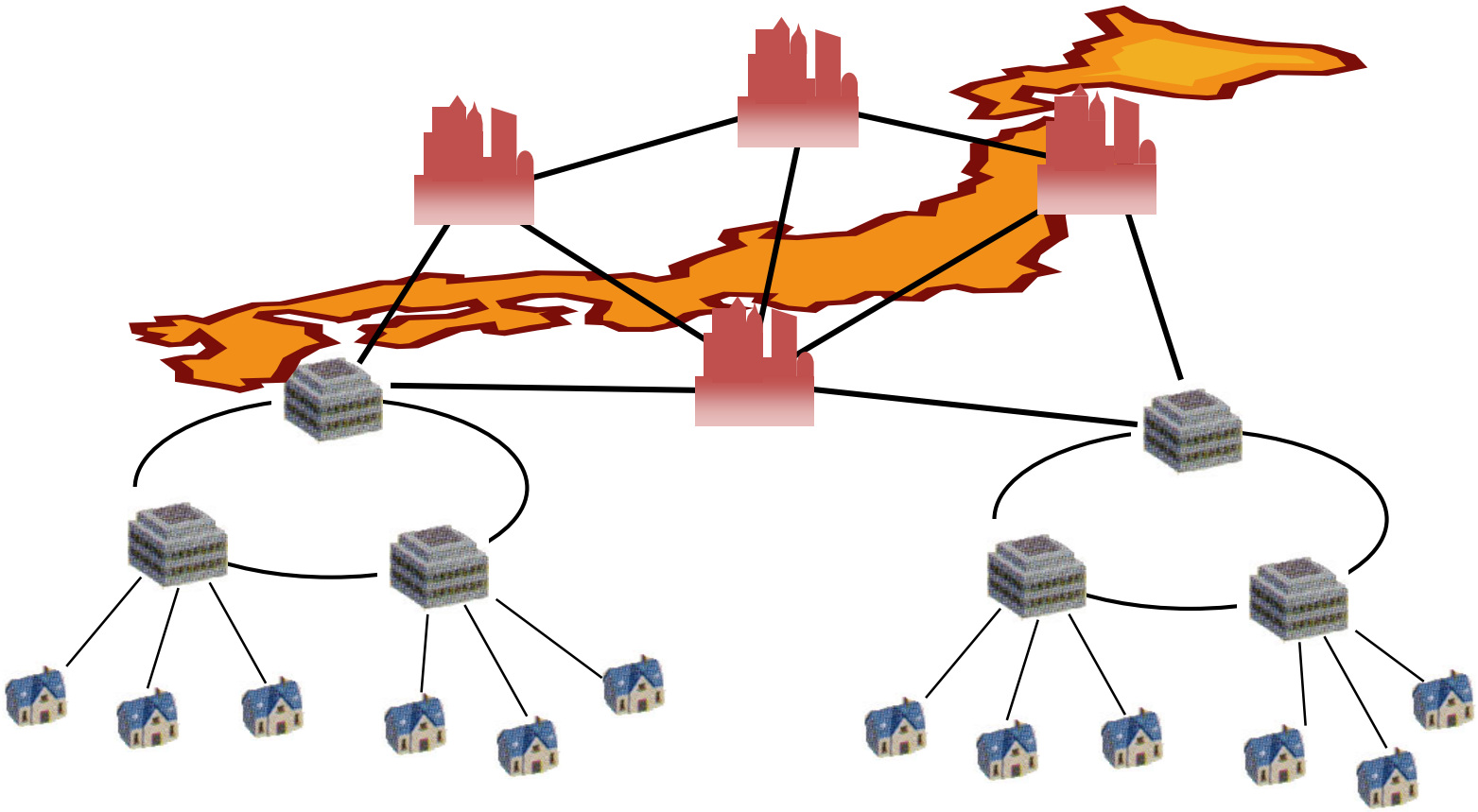
Number of subscribers for broadband service



optical line

＊総務省のデータおよびICT総研調査結果を元に作成。

All trunk transmission lines are optical



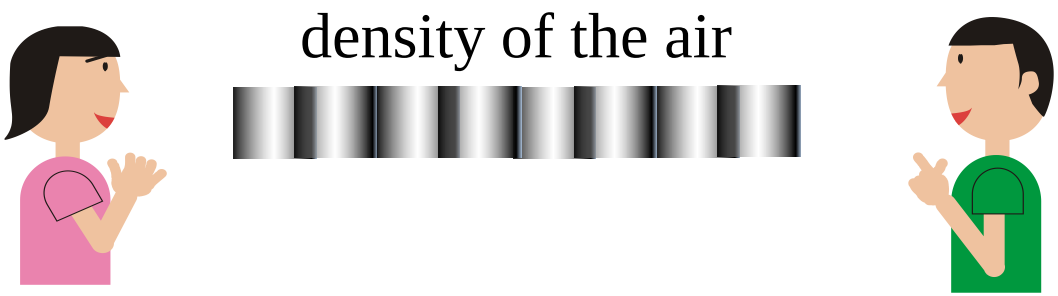
this talk

What is optical communication ?

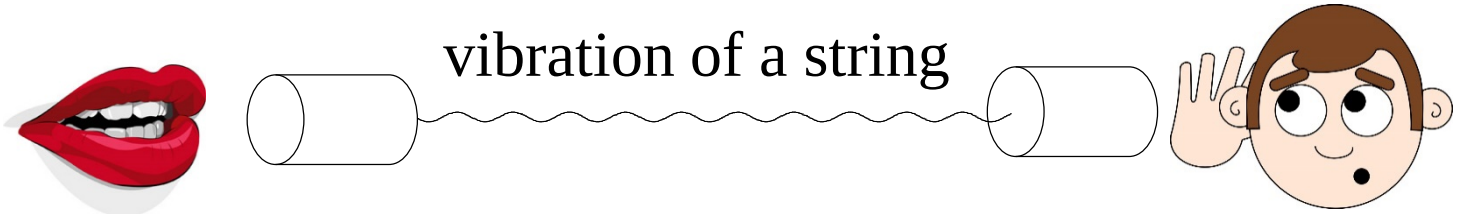
Why it is beneficial ?

Signal transmission is made via a physical quantity

Voice transmission via the air

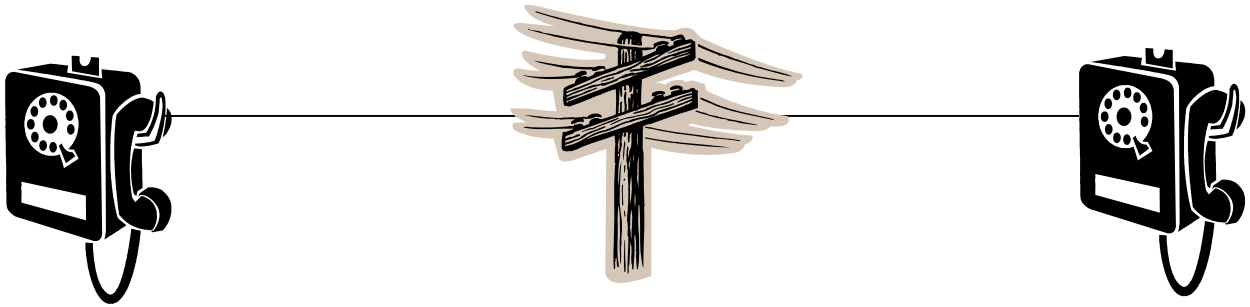


Voice transmission via a string



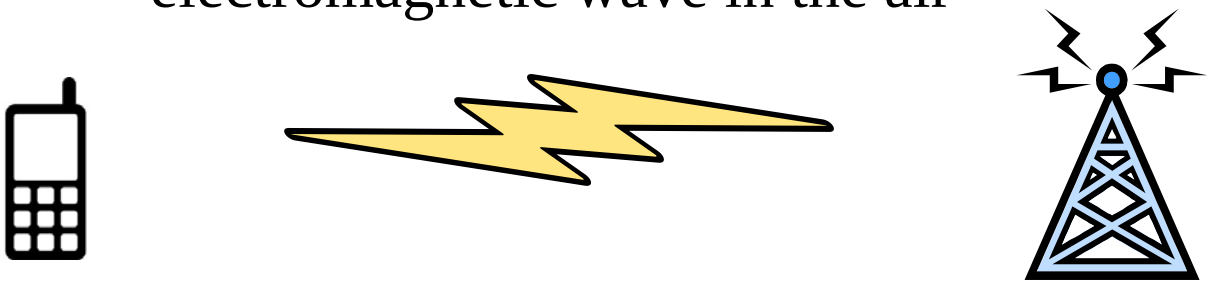
Copper wired communication

electrical vibration within copper



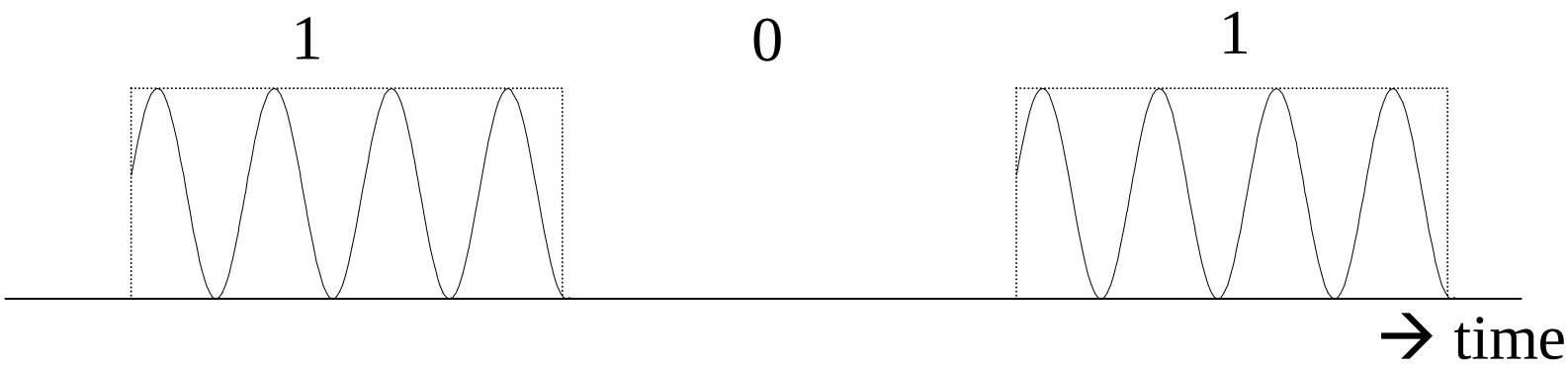
Wireless communication

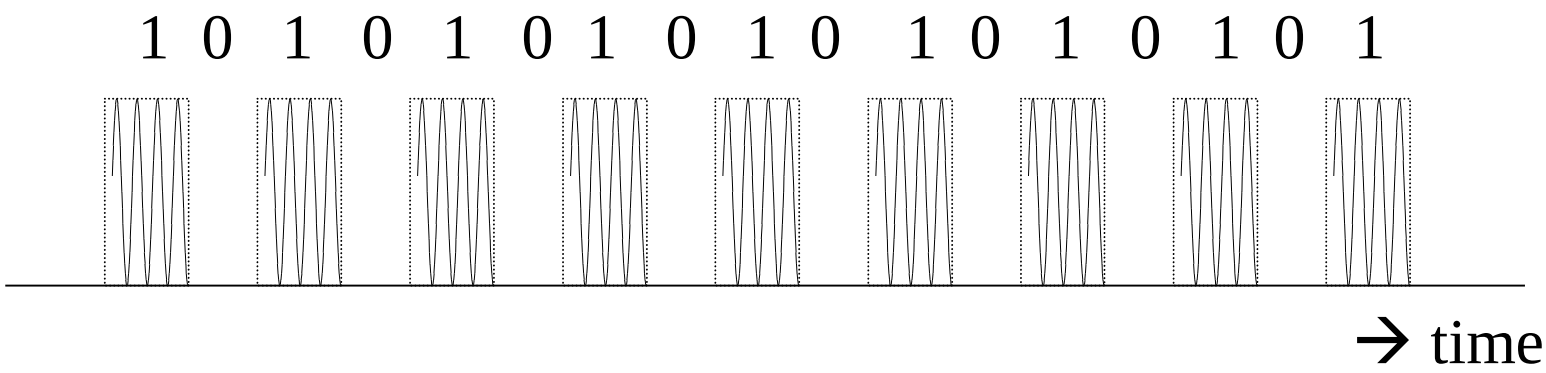
electromagnetic wave in the air



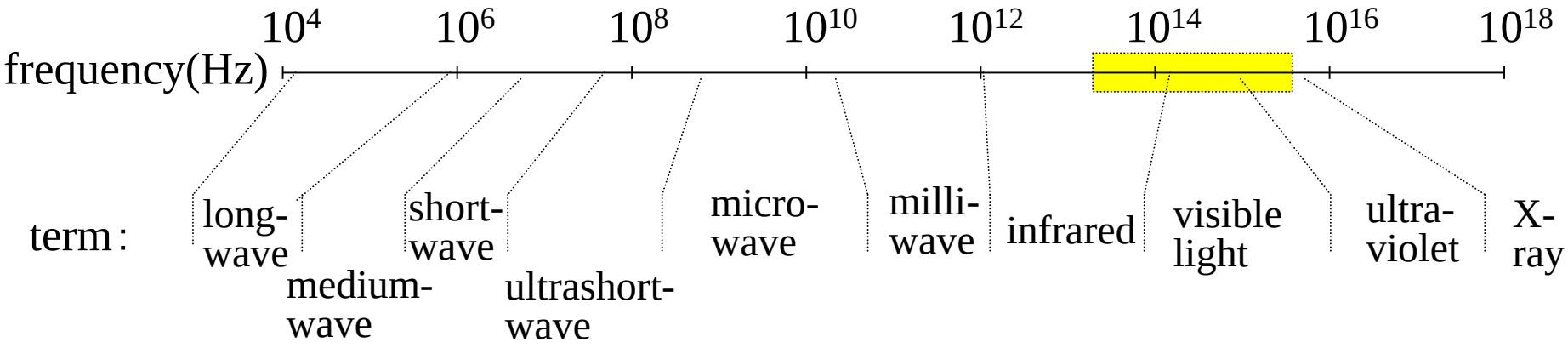
A physical quantity conveying signal is called "*carrier*"

Carrier vibrating at a high frequency can convey a large amount of information





Light is an electromagnetic wave with a quit high frequency



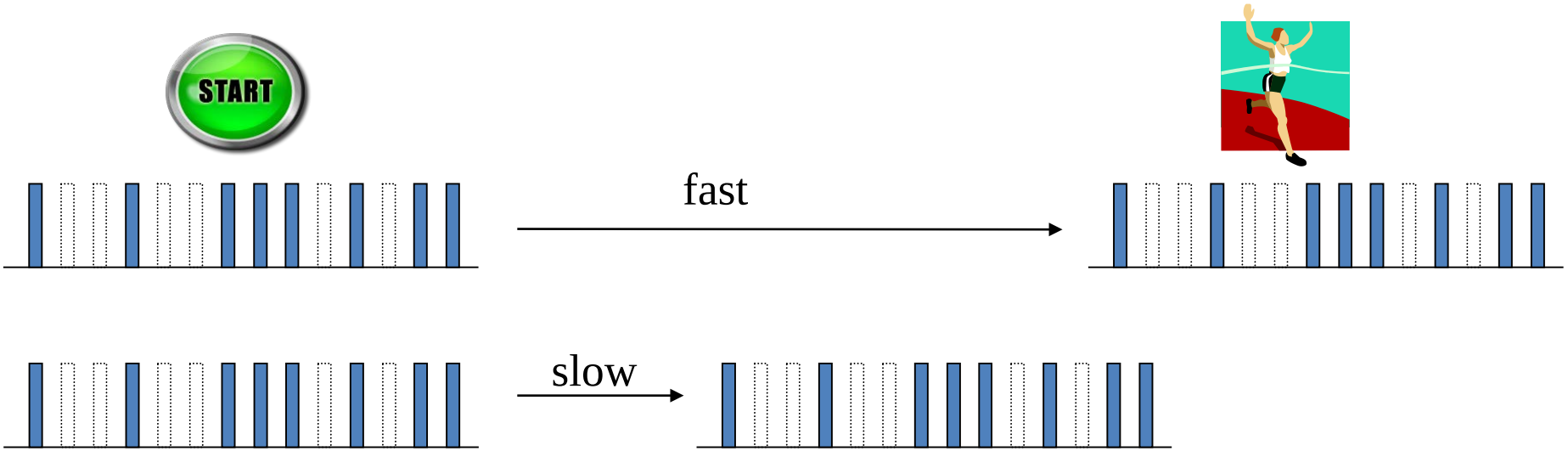
Lightwave is potentially preferable for signal carrier

by the way

Frequent misunderstanding

"Light is good for communication because its traveling speed is fast"

But, *the traveling speed has nothing to do with the date speed.*

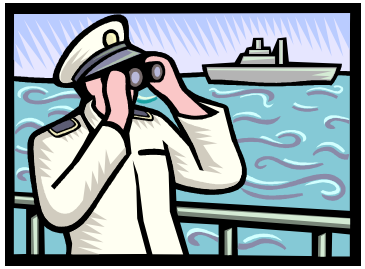


The arriving time is different, but
the number of pulses is the same.

Data speed = Frequency of pulses representing data

How to convey signal using light ?

A primitive way is to ON/OFF shutter a signal lamp.



But, this method has crucial defects for high speed communication.

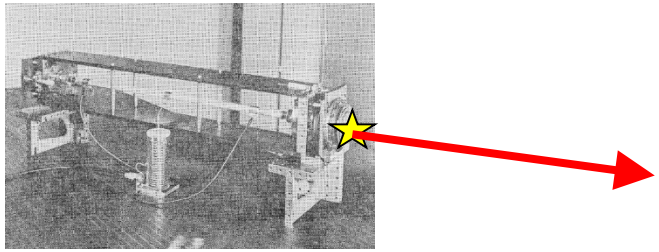
- Shuttering speed is quite slow.
- Transmission is not made when there is an obstacle.
- Transmission is not made on rainy or cloudy days.
- Light spreads and becomes week while traveling long.
- How to convert optical signal to electrical signal ?

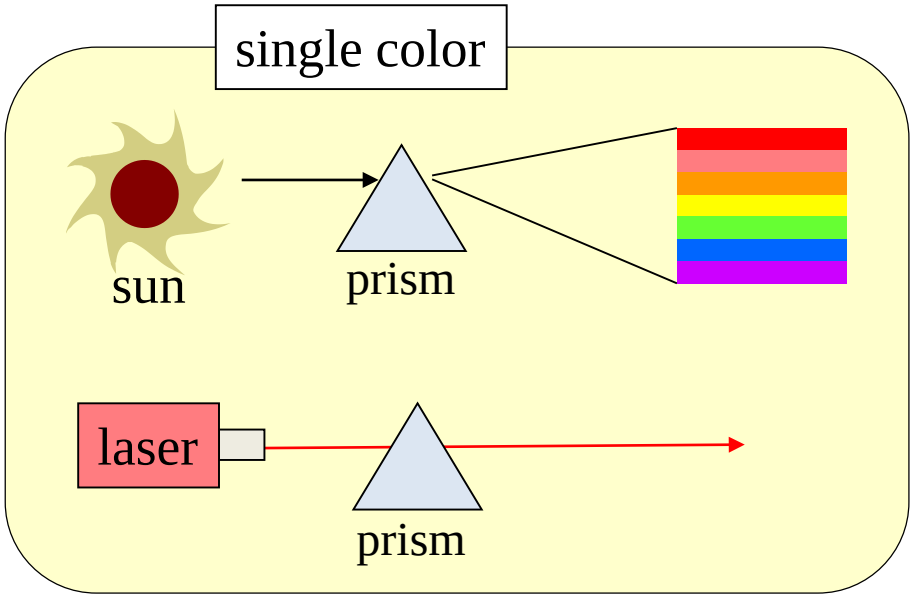
Issues are signal light generation/transmission/detection

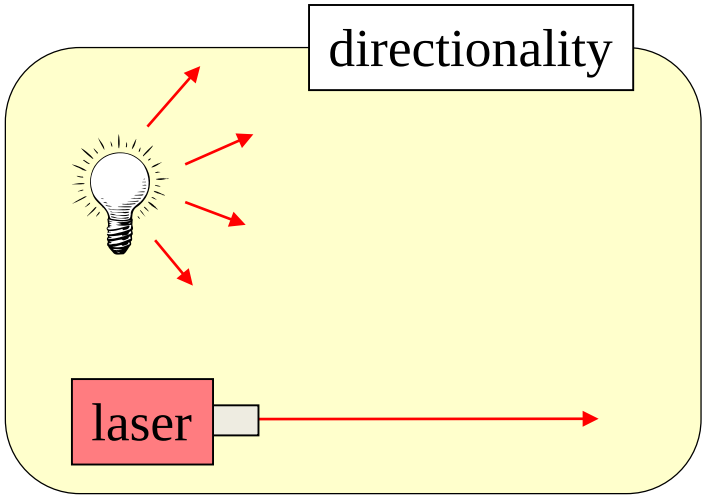
Laser was invented in 1960

It generates light with quite unique properties.

- good directionality
- high power density
- single wavelength (color)





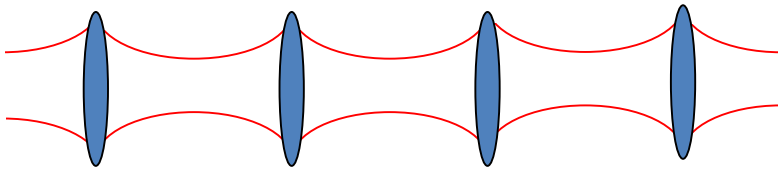


possibility for multi-channels

Optical communication research started in 1960's

Space transmission experiment

Lens waveguide



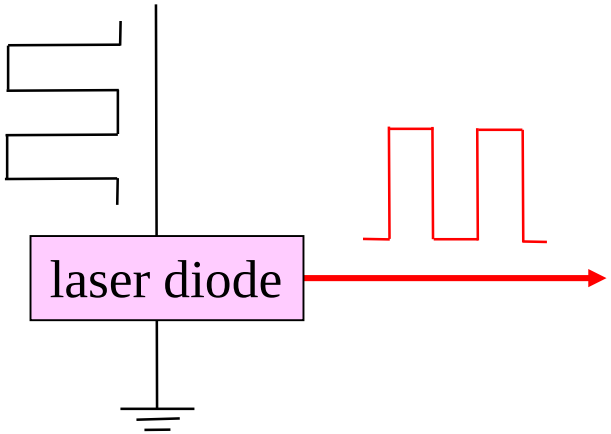
Impractical those days, unfortunately

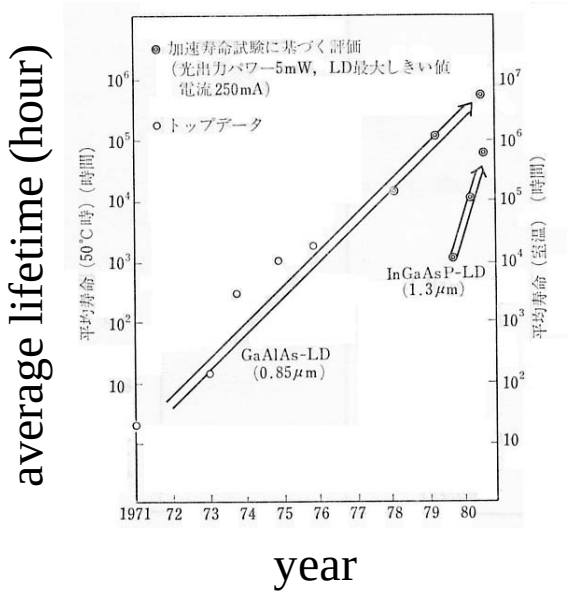
breakthrough 1

Semiconductor laser firstly operated at room temperature in 1970

Semiconductor laser is suitable for communication systems

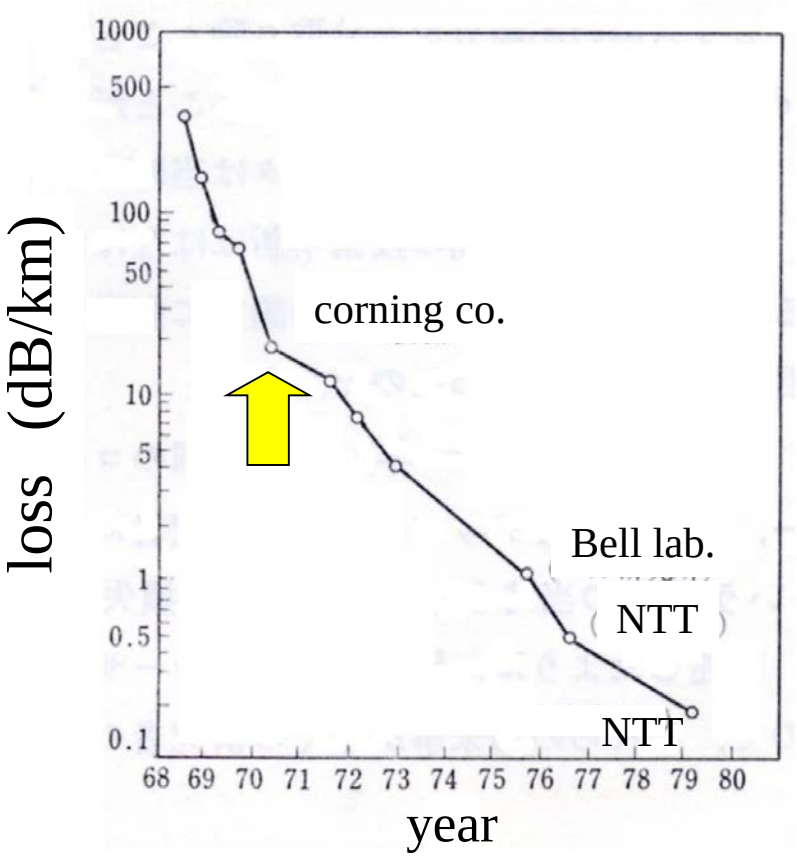
- Compact
- Light emission is ON/OFF by injection current





breakthrough 2

Low-loss glass fiber was fabricated in 1970



loss L	transmittance T
0 dB	1.0
10 dB	0.1
20 dB	0.01
30 dB	0.001

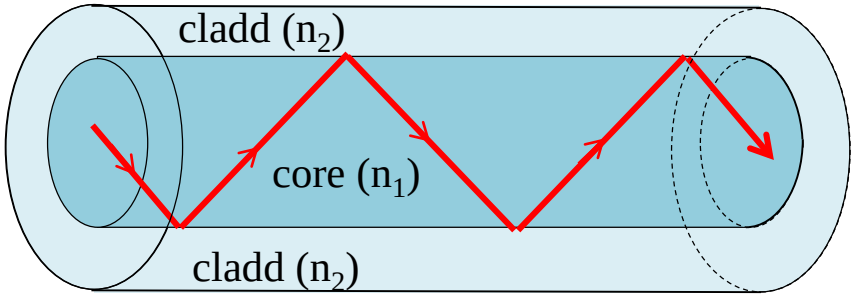
$$T = 10^{-L/10}$$

Research activity was triggered by these two innovations

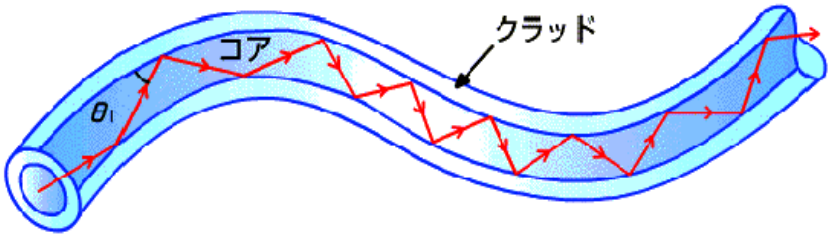
Optical fiber

High-refractive index glass (core) is surrounded by low-index glass (clad)

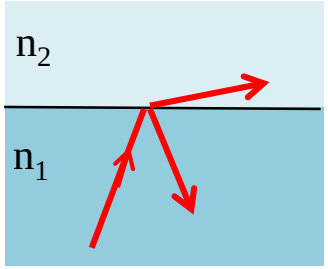
Light propagates along fiber, being totally reflected.

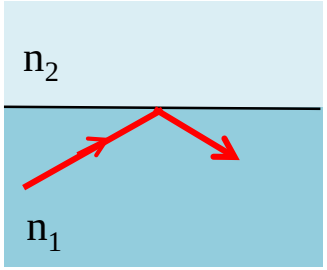


$n_1 > n_2$



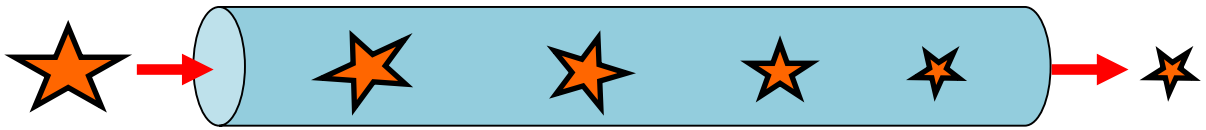
refraction/reflection





$n_1 > n_2$

The propagation loss in fiber is quite low



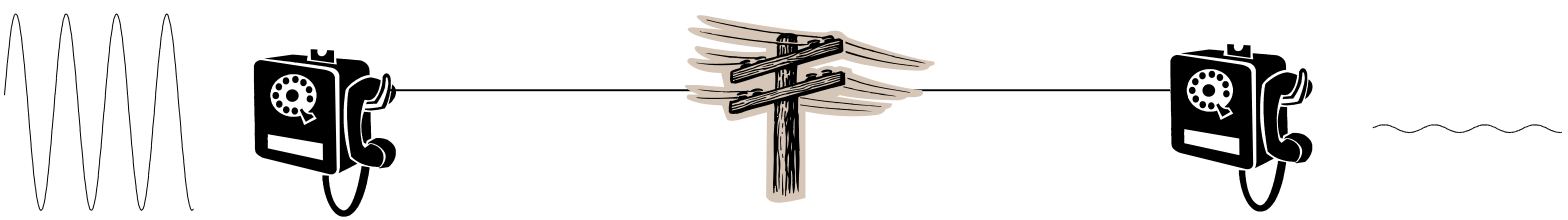
0.2dB-loss @ 1km（transmittance = 95.5%）

2.0dB-loss @ 10km（transmittance = 63%）

on the other hand

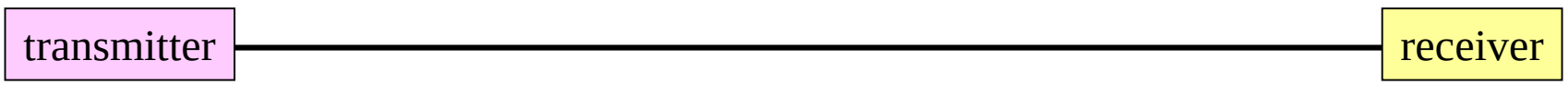
Copper wire is lossy for *high* frequencies.

(ex. 10dB/km for 10MHz)

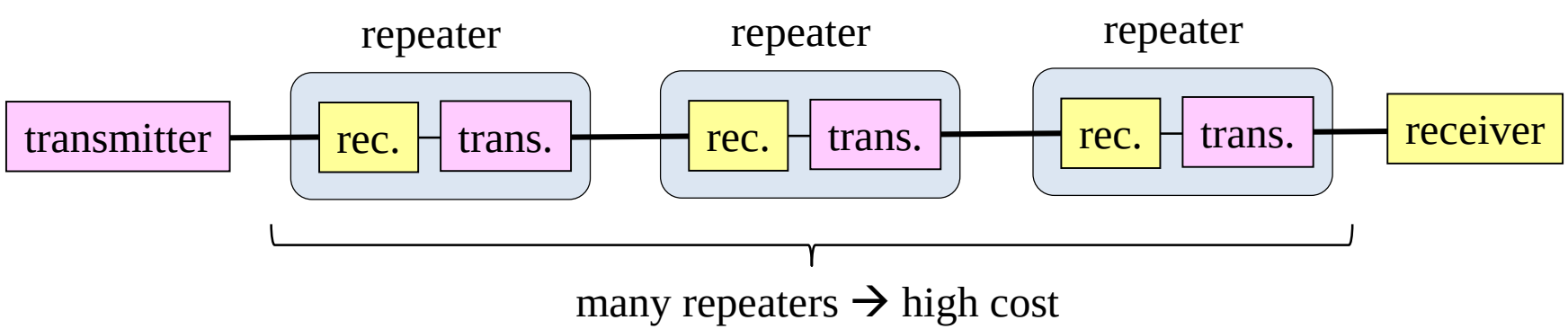


Why low-loss is preferable ?

Optical



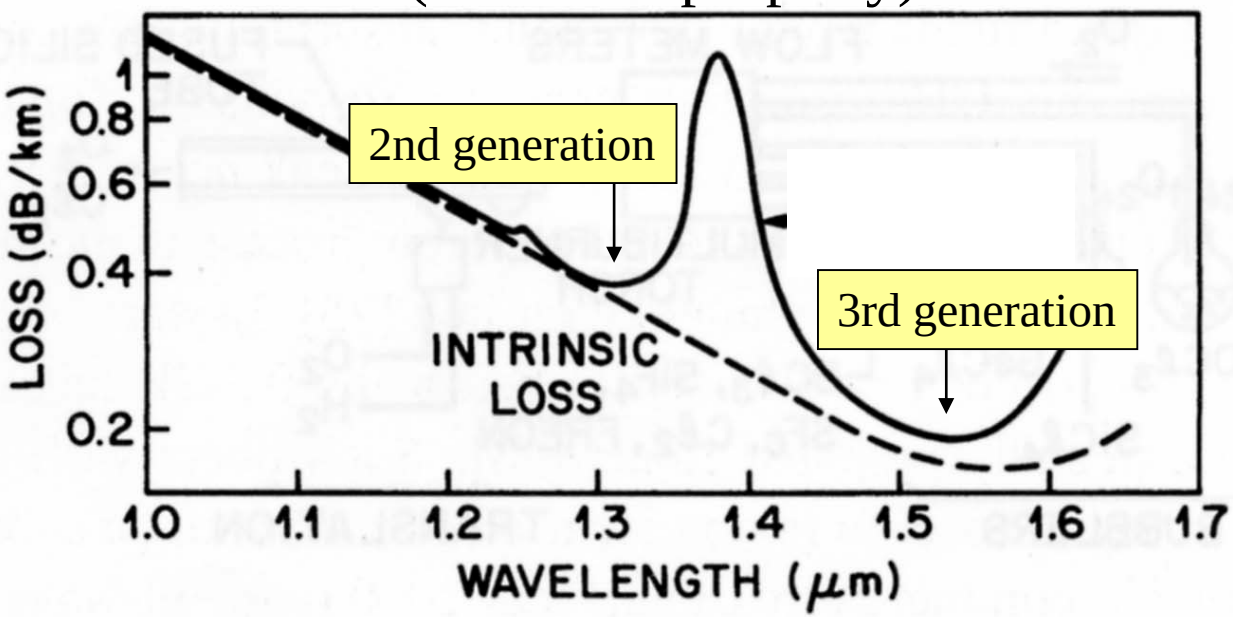
Electrical



Fiber transmission is superior for long-distance & high-speed communication

Optical communication has been developed, pursuing to fully utilize the low-loss property.

(fiber loss property)



Transmission medium is the most important matter in general

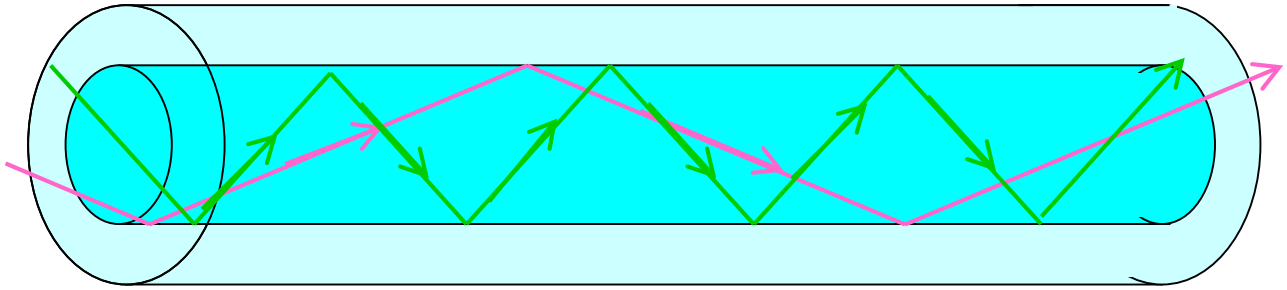
1st generation (0.8μm): first semiconductor laser
2nd generation (1.3μm): zero-dispersion
3rd generation (1.5μm): minimum loss

Crucial issue is dispersion

Dispersion: The property that light velocity is not unique.

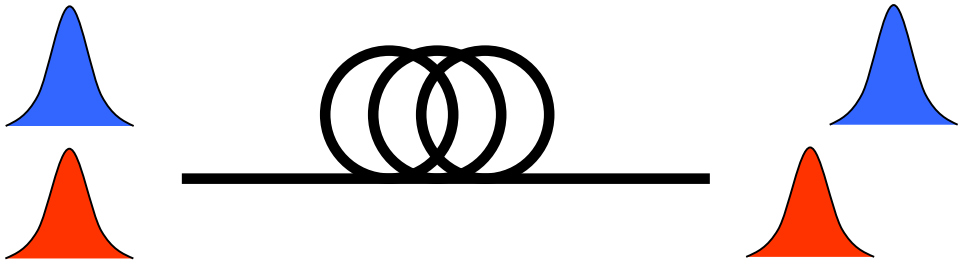
Mode-dispersion

The propagation velocity is different for different propagation angles.

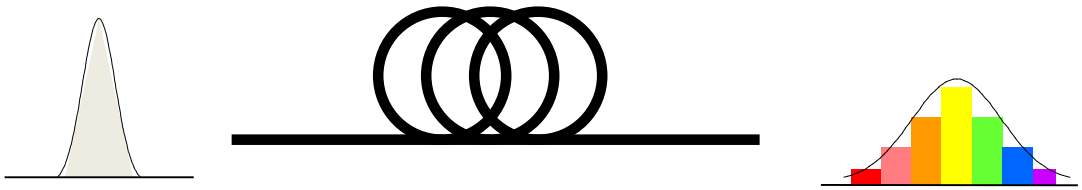


Chromatic-dispersion

The propagation velocity is different for different wavelength (color).

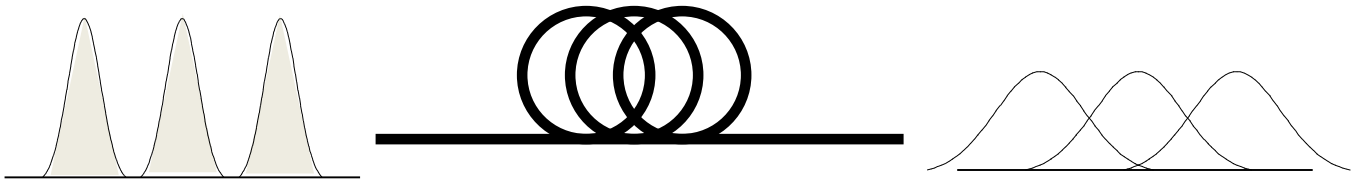


When the velocity is different.....



Pulse width broadens.

In case of a pulse train,

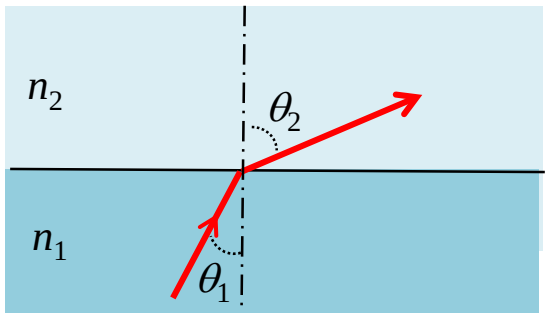


Data are not correctly received

By the way

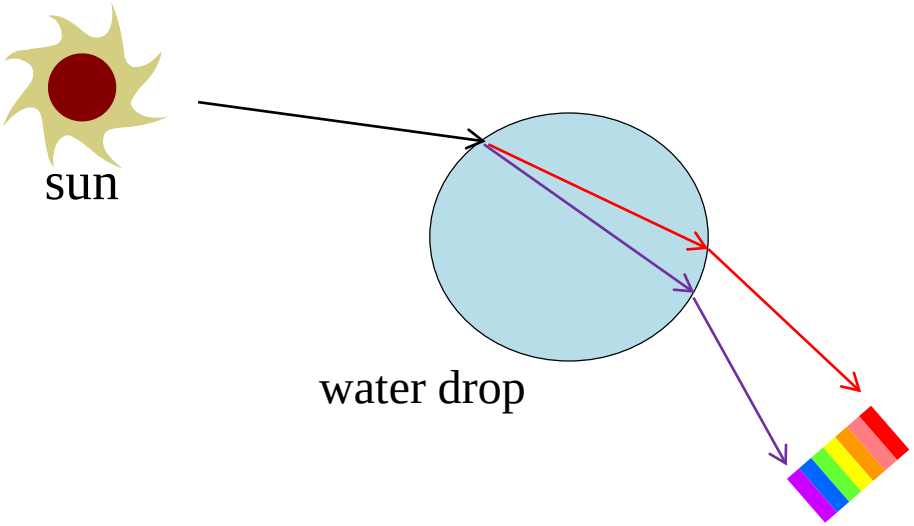
Rainbow is caused by dispersion

Light is refracted at the boundary between materials with different refractive indices. The refraction angle is determined by the ratio of the refractive indices.



$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2}$$

Thus, the refraction angle is different for different color due to the dispersion. Then,

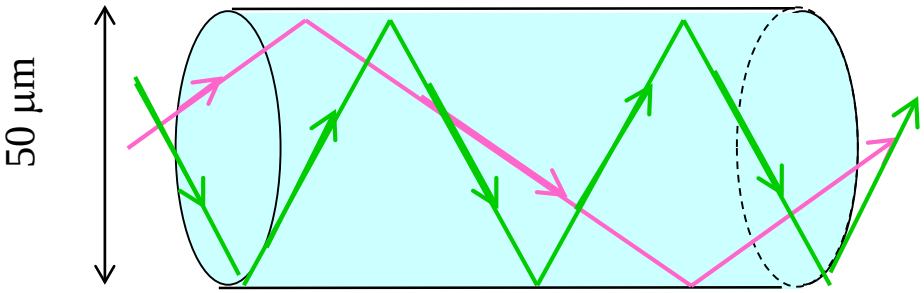


research effort

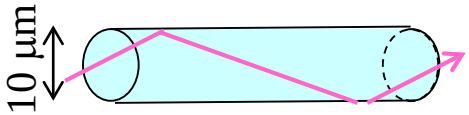
Combat with mode-dispersion

A fiber with a small core-area allows just one propagation angle.

multi-mode fiber



single-mode fiber



$$\left(10\ \mu\text{m} = \frac{1}{100}\ \text{mm}\right)$$

Several techniques have been studied and developed.

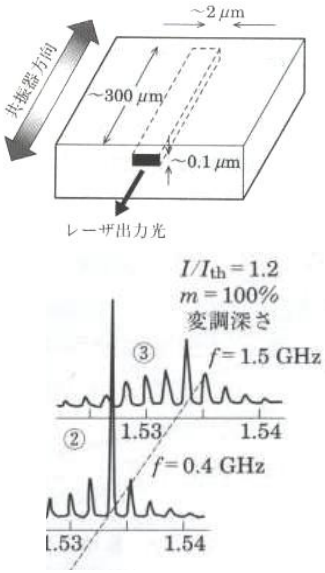
- Fabrication process
- How to input laser light into a fiber
- How to connect fibers

Combat with chromatic-dispersion (1)

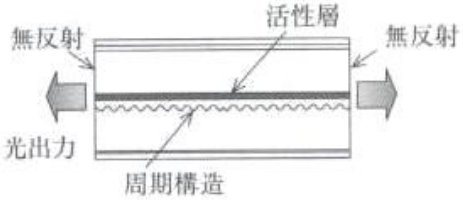
Strategy 1: Use of signal light with a narrow wavelength width

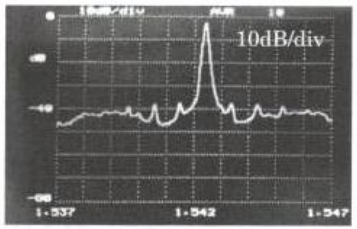
◆ Development of single-mode lasers

Fabry-Perot type



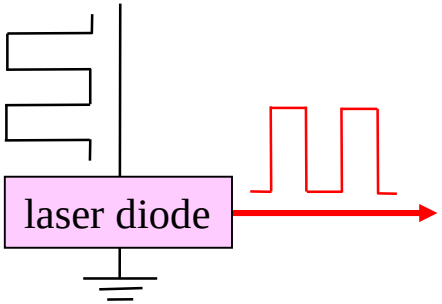
DFB type

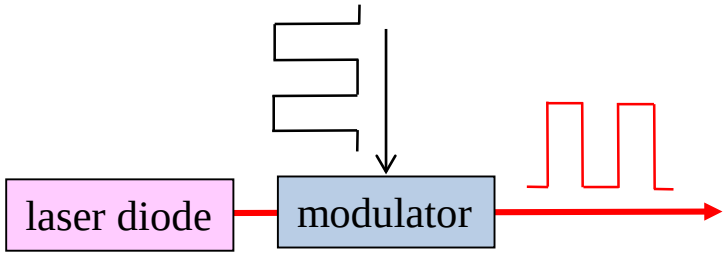




1 542 nm 1 nm/div

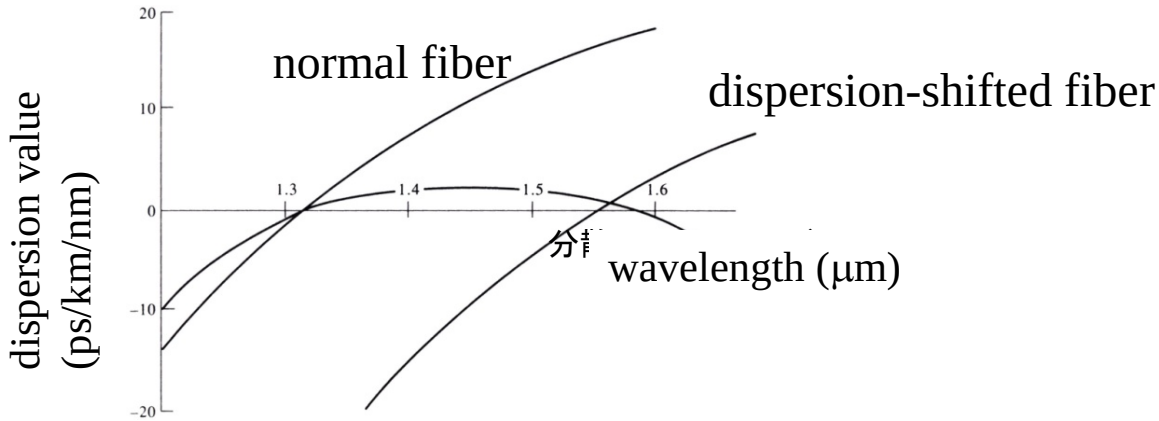
◆ Develop of optical modulators





Combat with chromatic-dispersion (2)

<u>Strategy 2</u>: Use of a wavelength at which fiber dispersion is zero.

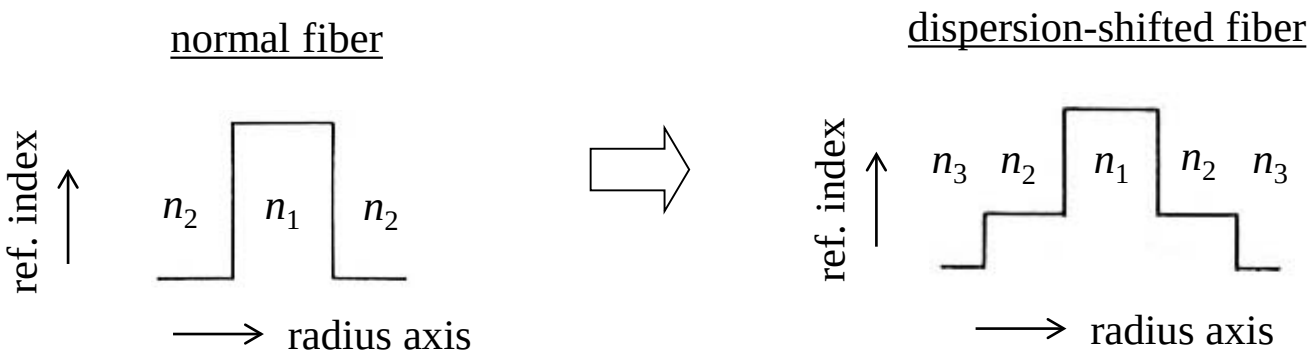


◆ Development of laser diodes emitting 1.3-μm wavelength light

Unfortunately, however, 1.3 μm is not loss-minimum wavelength.

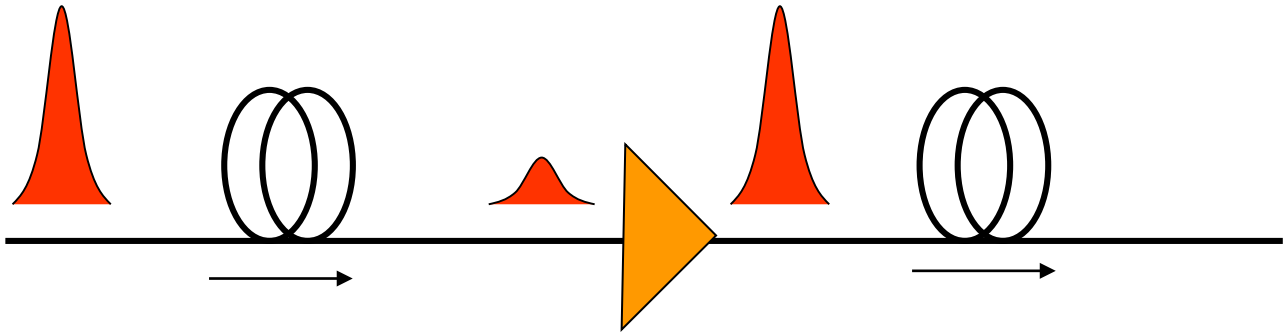
↓

◆ Development of fibers with zero-dispersion at the loss-minimum wavelength



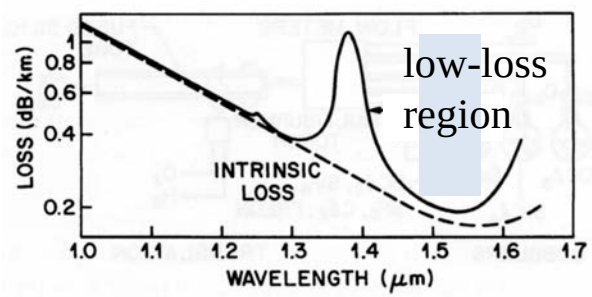
Even though fiber is low-loss,
researchers wanted to expand the transmission length.

Combat with fiber loss

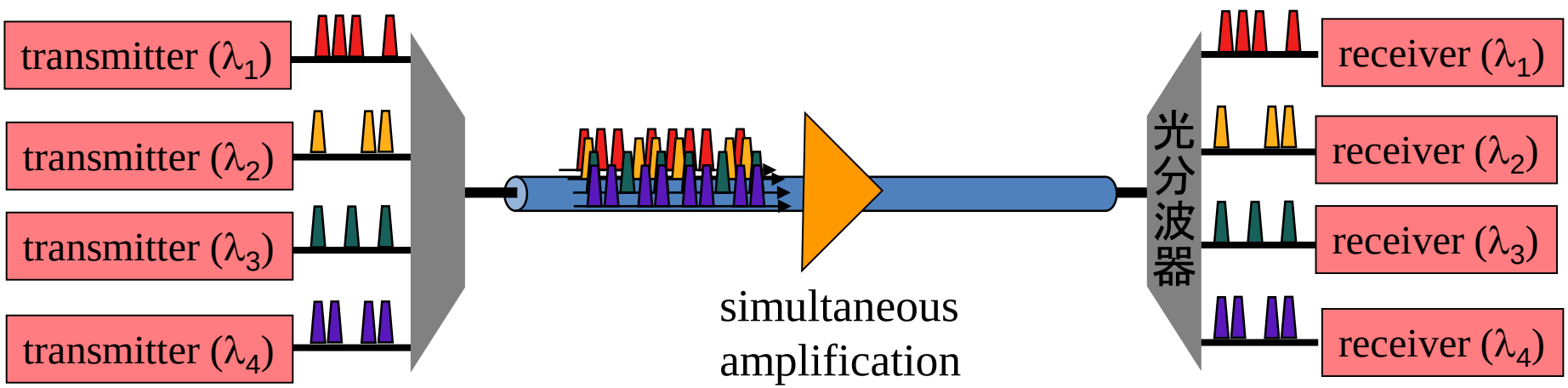


Optical amplifiers have been developed

WDM technologies have been developed to fully utilize the low-loss property of fiber

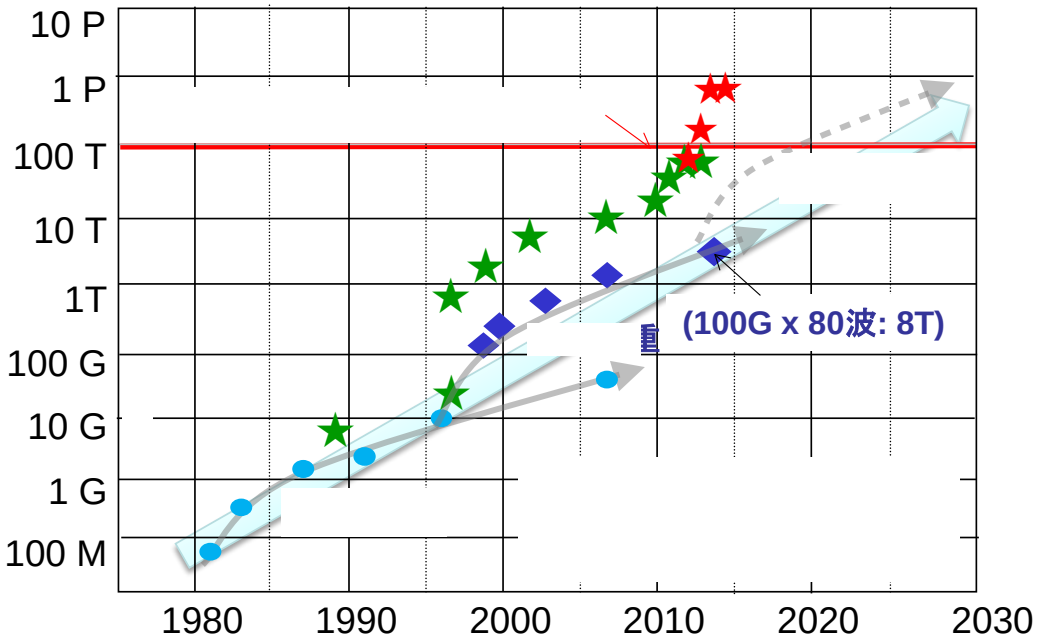


Wavelength Division Multiplex (WDM) System



The transmitted data amount is increased by using a number of wavelengths (colors)

With the above technologies, the transmission capacity has increased.



Then

Optical technologies are basic infrastructure supporting the present communication networks