Introduction to Optical Networks

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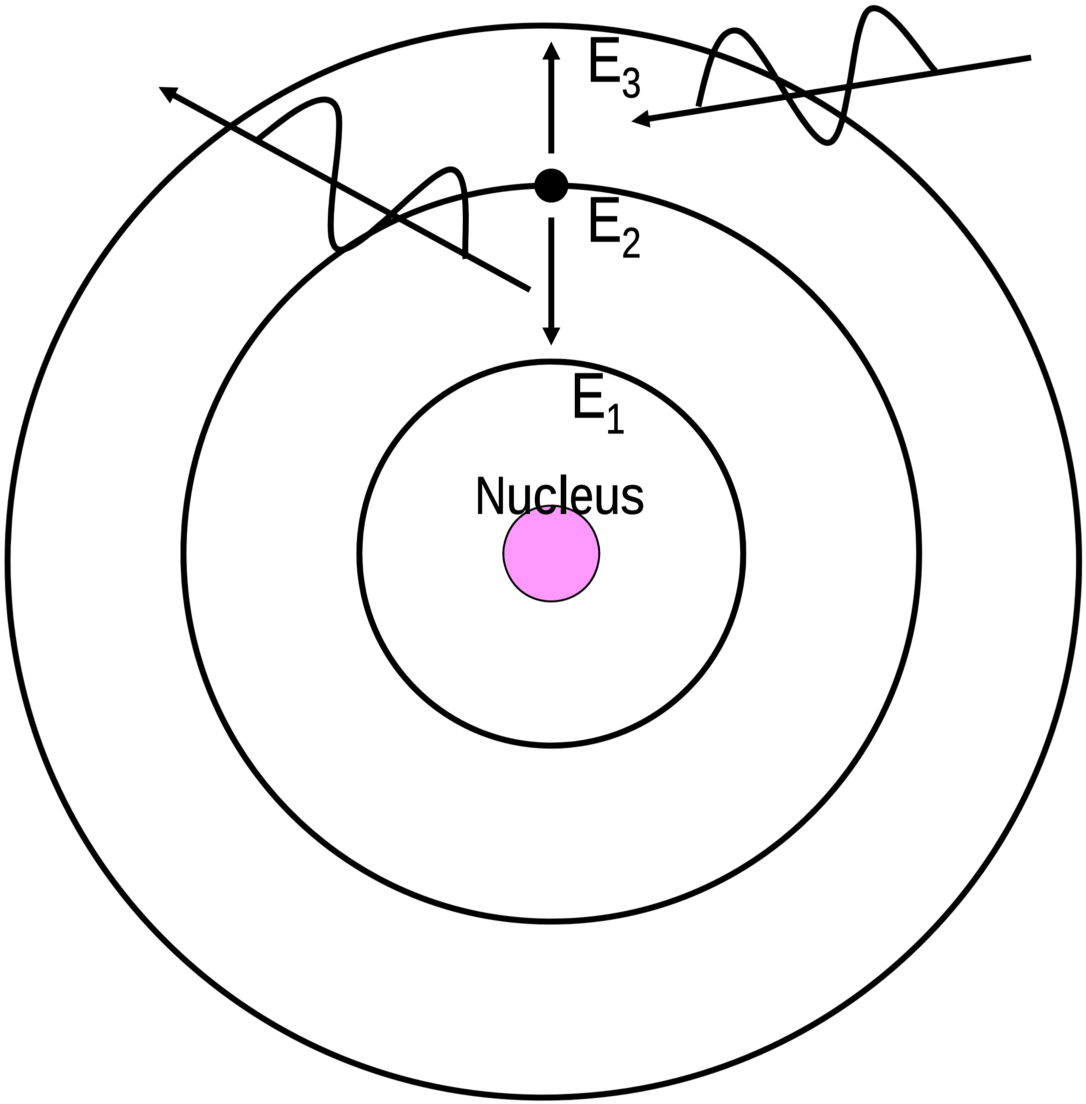
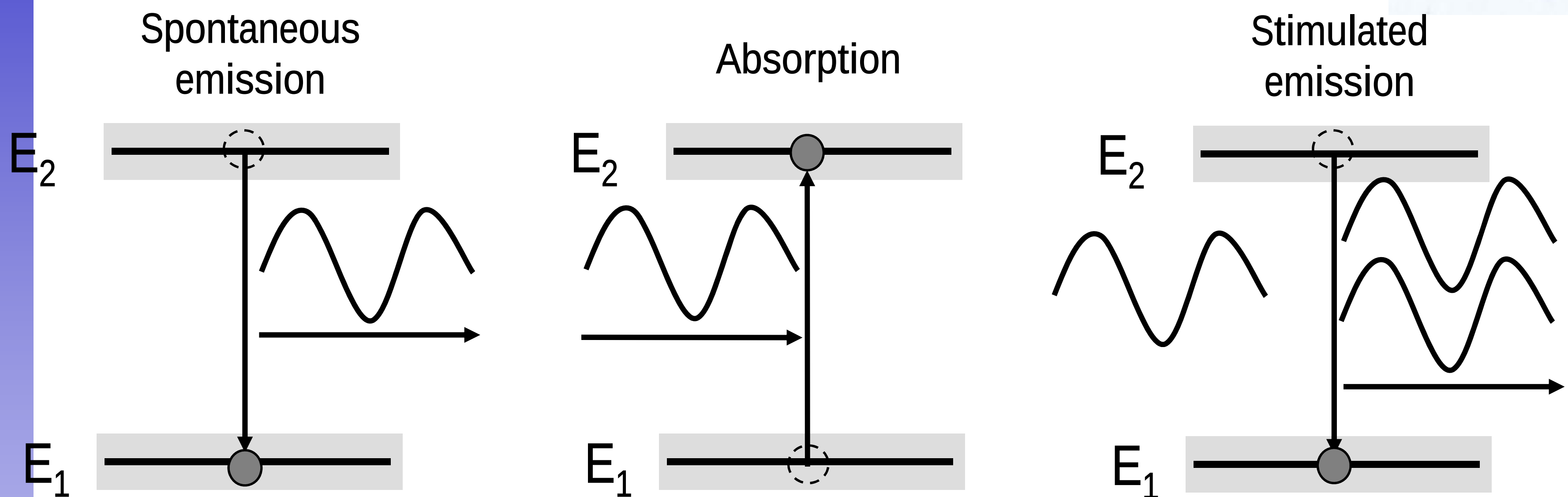
Agenda

- The physics of light
- Laser and photodetector operation
- Characteristics of optical fiber
- Optical amplifiers
- SONET
- First generation networks
- Second generation networks
- Digital wrappers
- Summary

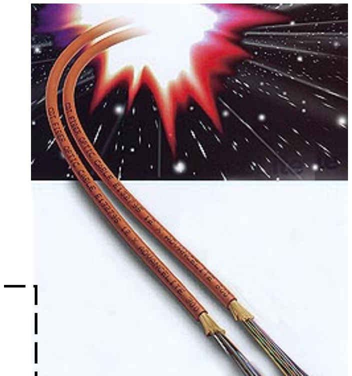
Electrons in Shells around the Nucleus

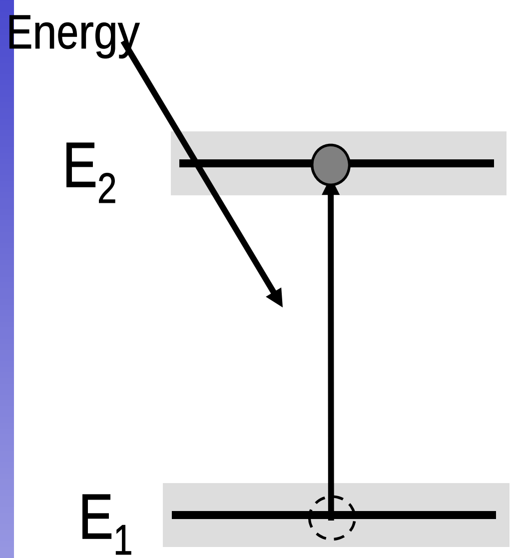


Absorption and emission of photons



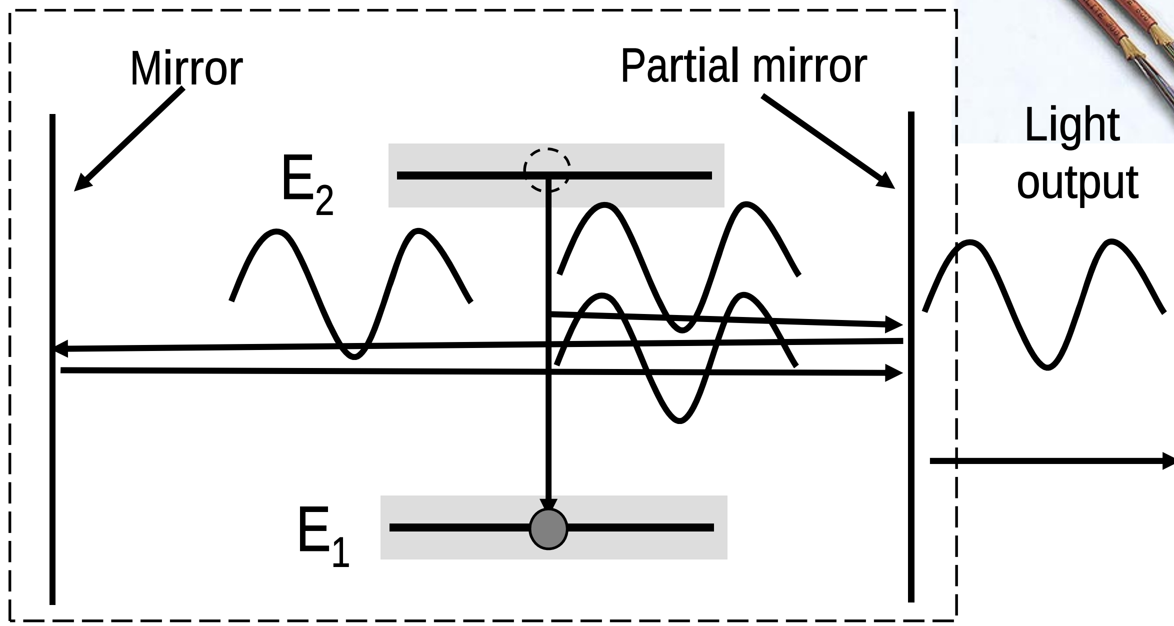
Laser operation





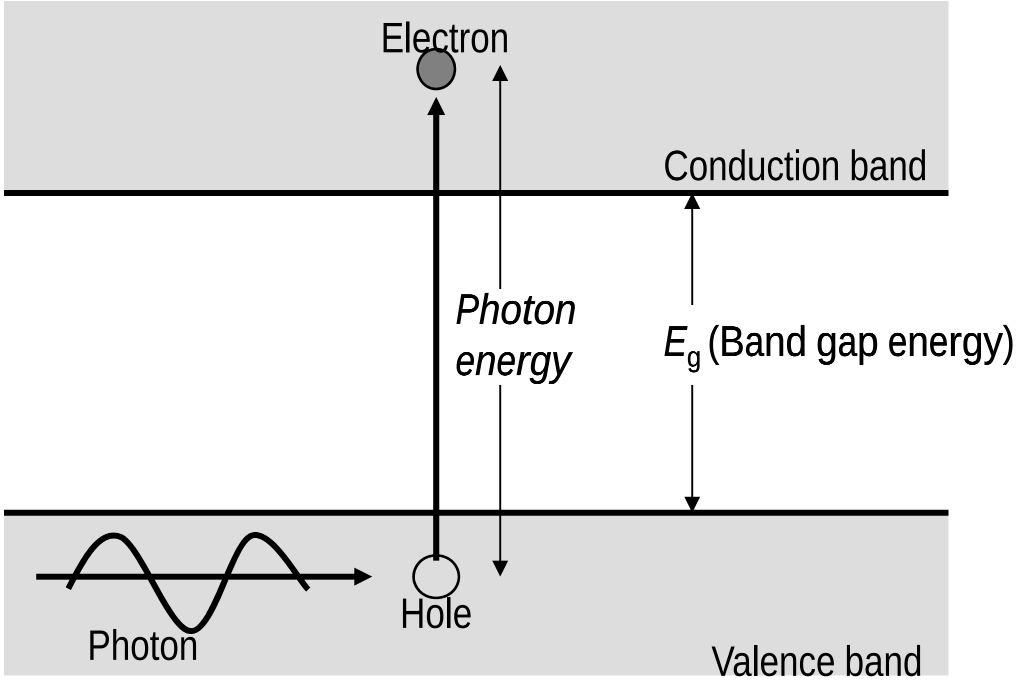
Sufficient energy is inserted to invert a significant portion of the population.

Inside the laser
All the atoms march alone
But fall together
Tom Harker
Photonics Haiku



Some photons are emitted by spontaneous emission. Those emitted at right angles to the mirrors reflect back and forth causing stimulated emission. The spacing of the mirrors causes certain frequencies to be reinforced. Some light passes through the partial mirror to become the laser output.

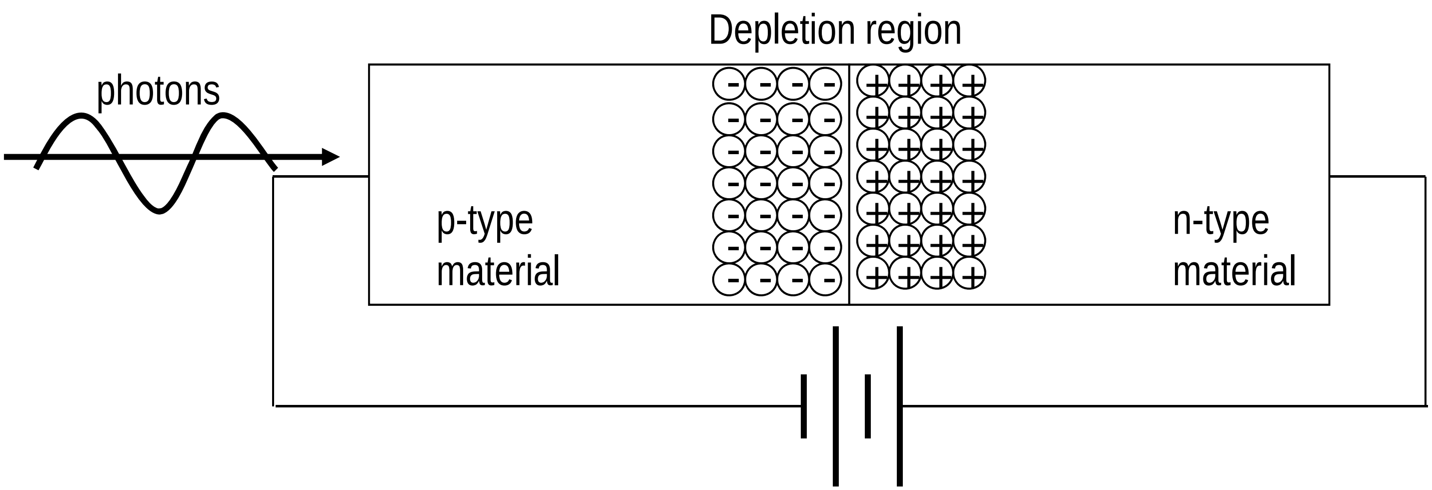
Photodetection

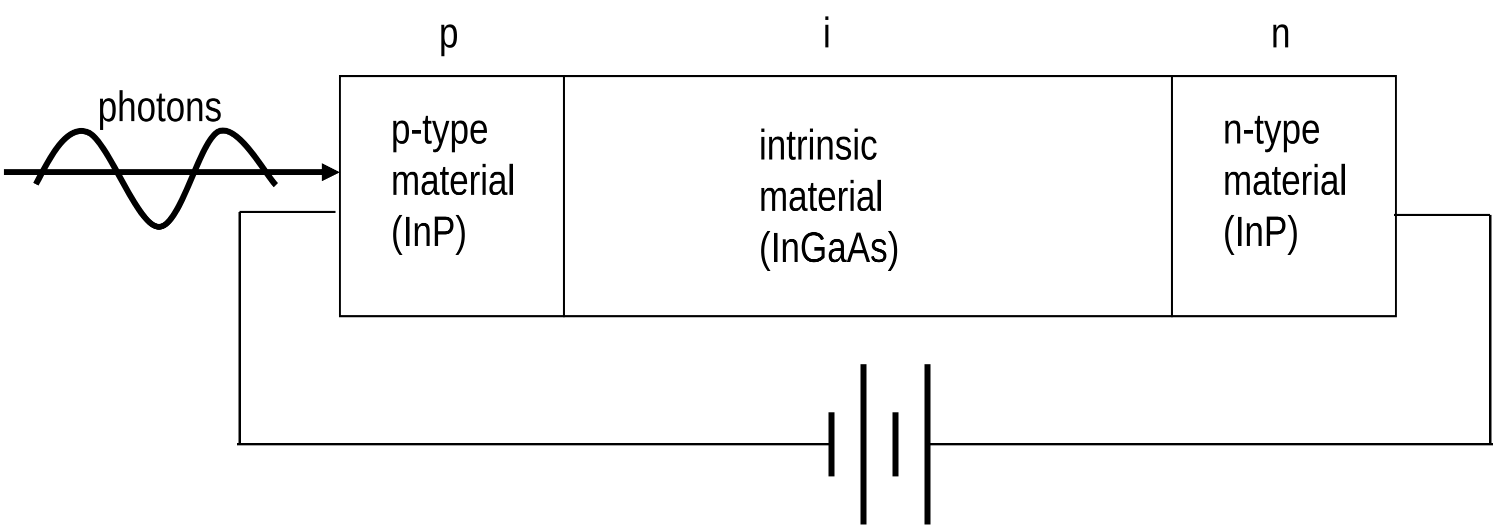


Waves are approaching
Try to capture them. You can't.
Now they're particles.
Steve Wilson
Photonics Haiku

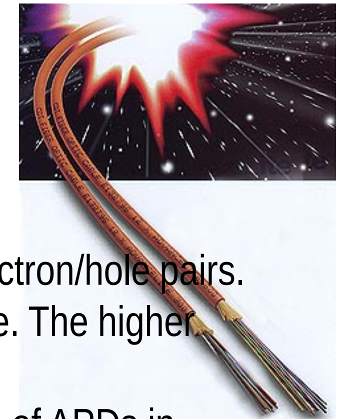
Photodiodes

Sometimes a fiber amplifier is used immediately before the photodector.



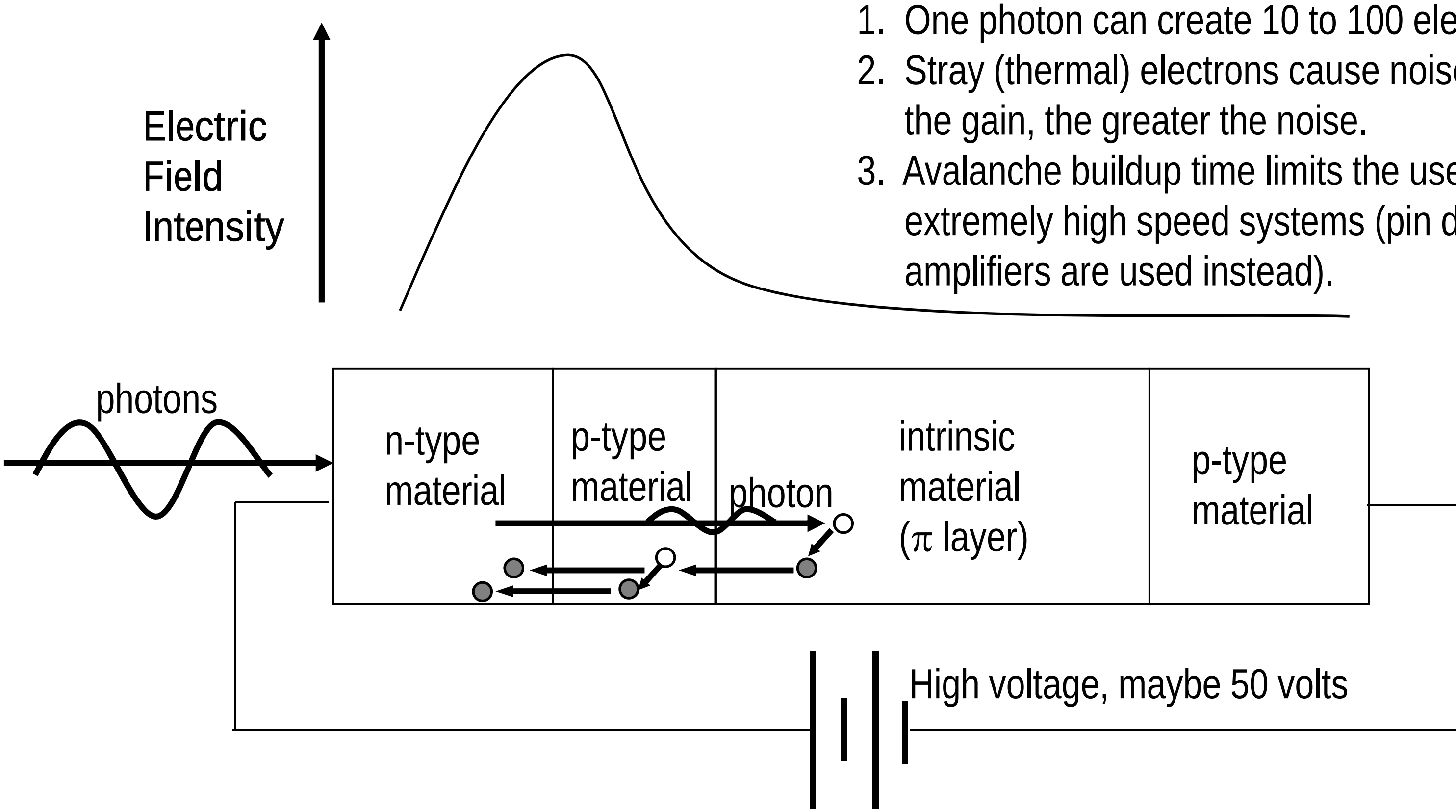


Avalanche Photodiodes (APD)



Notes:

1. One photon can create 10 to 100 electron/hole pairs.
2. Stray (thermal) electrons cause noise. The higher the gain, the greater the noise.
3. Avalanche buildup time limits the use of APDs in extremely high speed systems (pin diodes with pre-amplifiers are used instead).



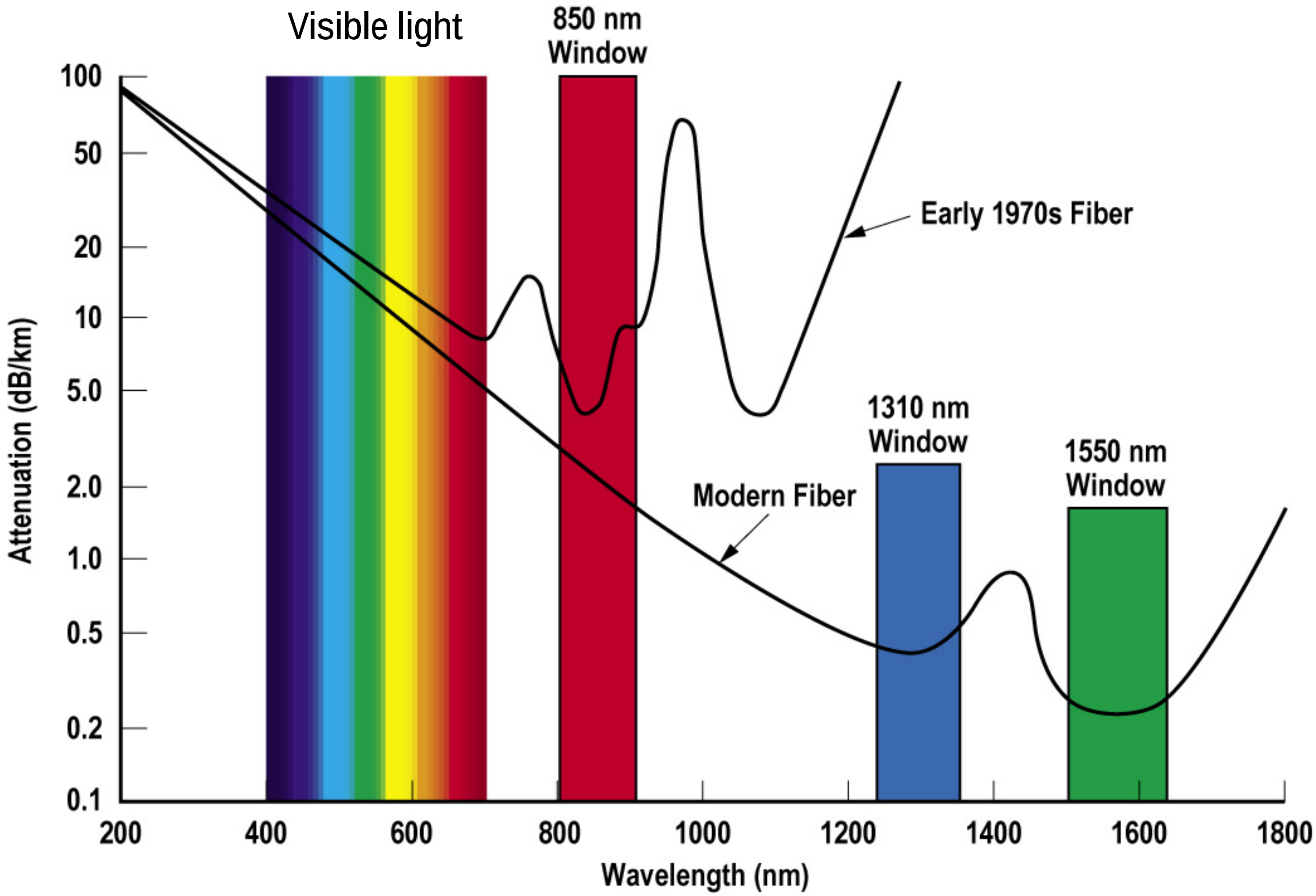
- ● electron
- ○ atom

Although not show here, holes are also created and flow in the direction opposite the electrons.

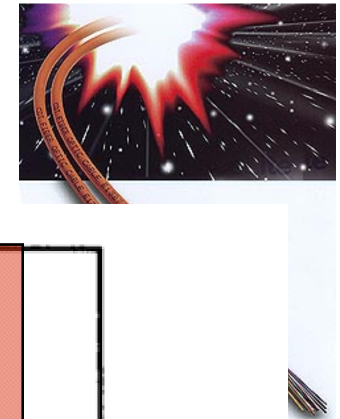
Modulation of Lasers

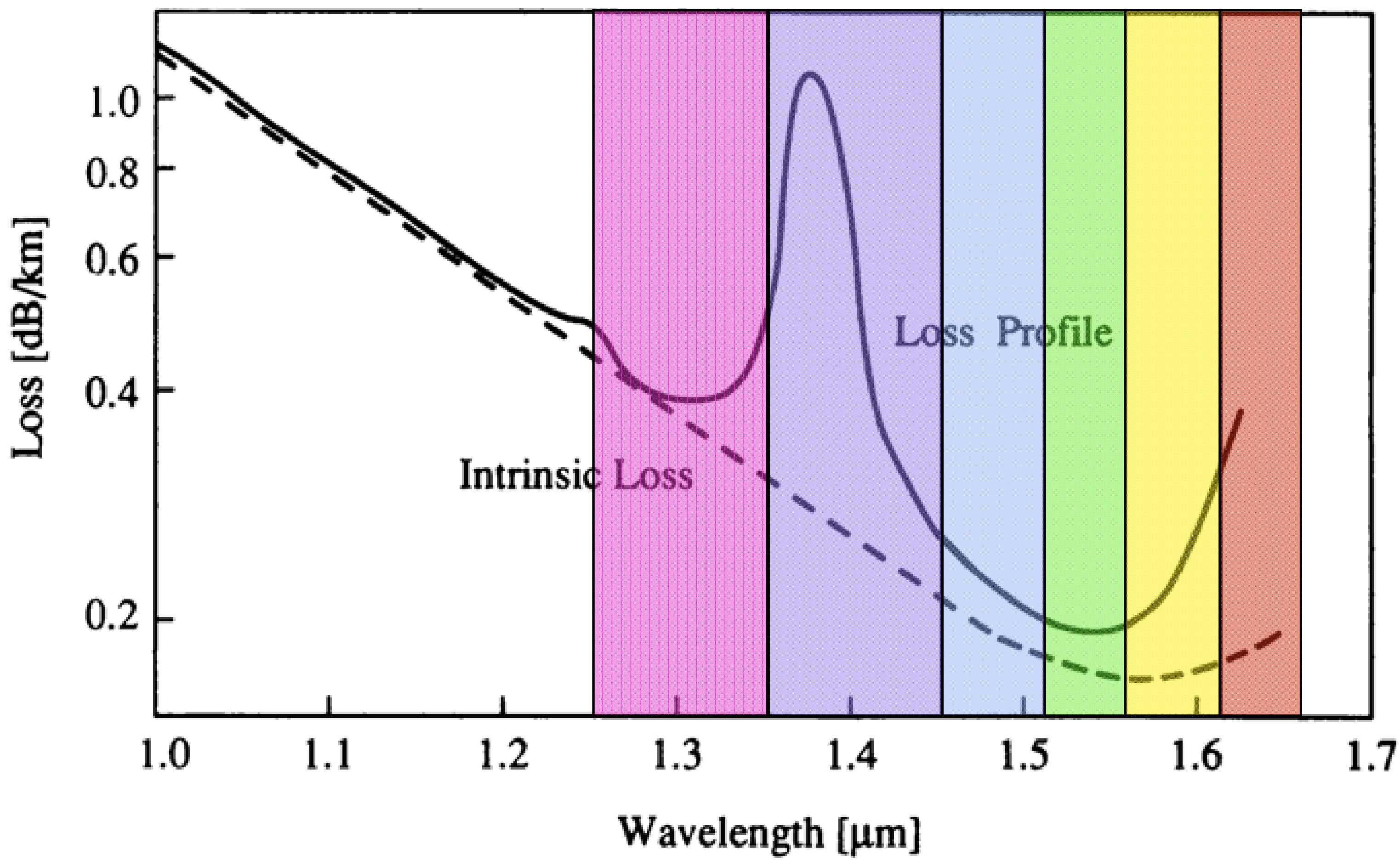
- Lasers can be modulated either directly or externally.
  - Direct modulation is done by controlling the electrical drive to the laser.
  - External modulation is done by controlling a “shutter” which sits between the laser output and the fiber. The laser operates continuously. Most common is lithium niobate.
- Direct modulation is less expensive but causes “chirp” in the output. (Chirp = a change in the frequency of the light over the pulse time).
  - Chirped pulses have much worse dispersion characteristics and thus are distance limited. Lasers in the backbone network are externally modulated.

Optical Spectrum



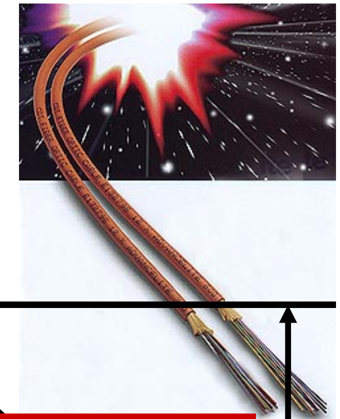
Loss in Modern Optical Fiber

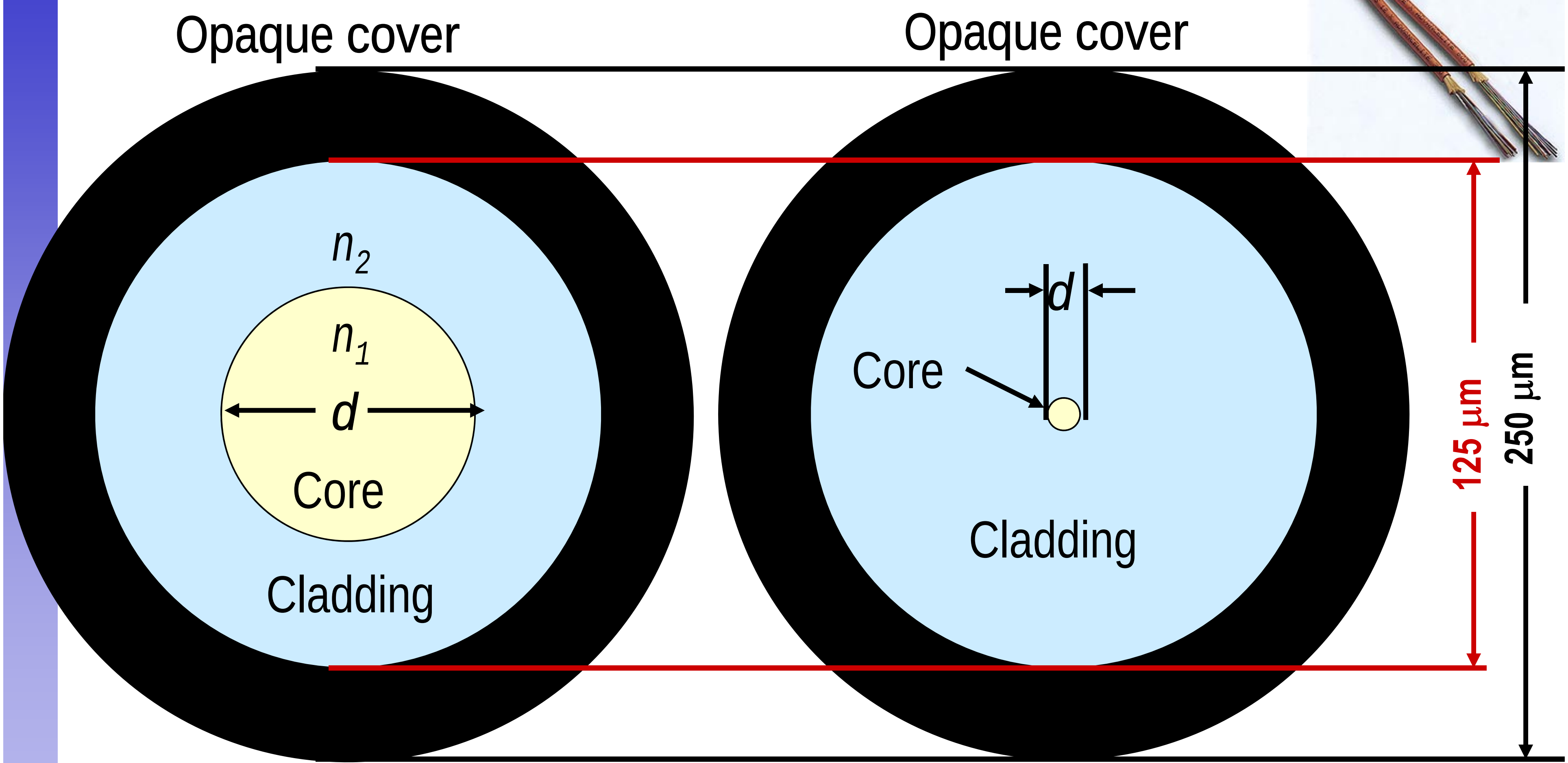




O-Band	E-Band	S-Band	C-Band	L-Band	U-Band
1260 –1360 nm	1360 –1460 nm	1460 –1530 nm	1530 –1565 nm	1565 –1625 nm	1625 –1675 nm

Multimode and single mode fiber





Multimode fiber

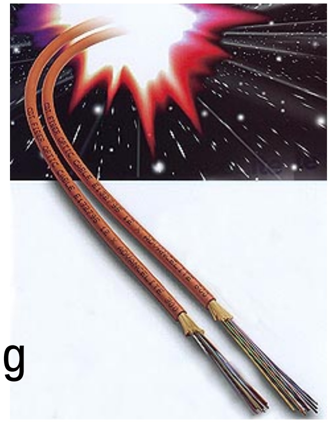
d = 50 or 62.5 μm

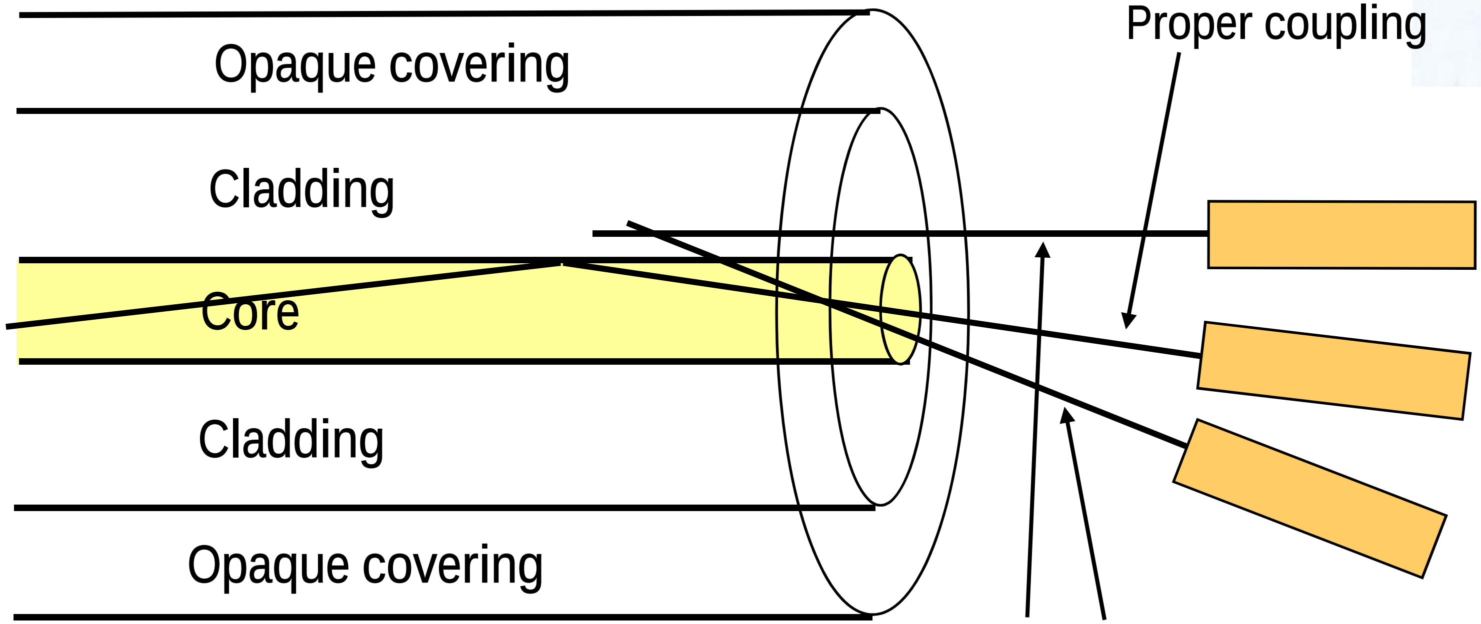
(almost all is 62.5)

Single mode fiber

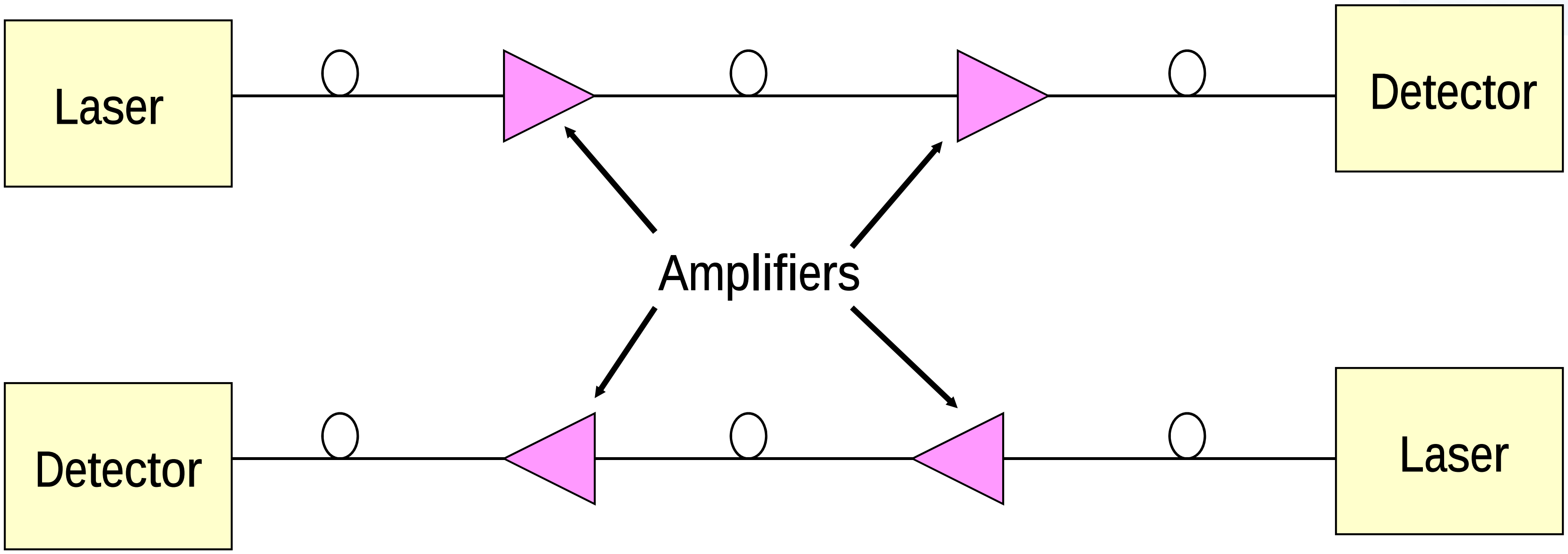
d = ~8 μm

Coupling to optical fiber



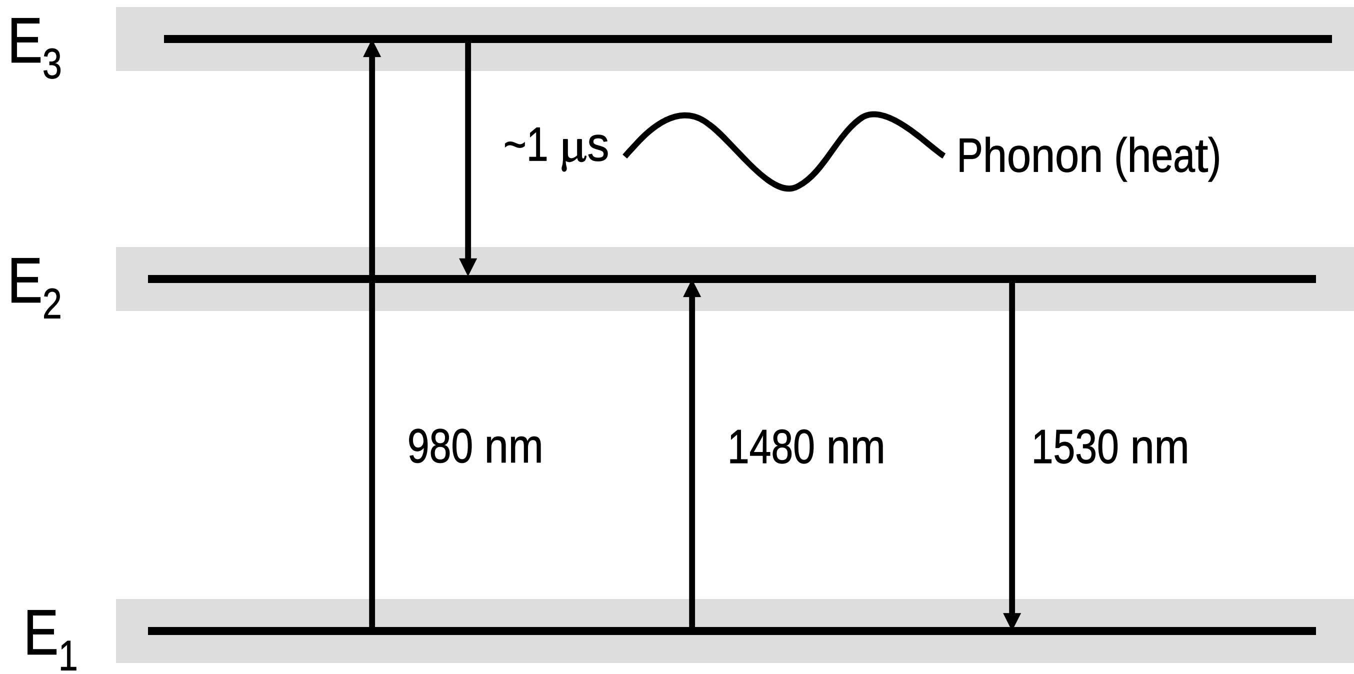


Amplifiers in Optical Links



Usually 45 to 120 km spacing between optical amplifiers but ultra long distance systems have been demonstrated with spacing of 1,000 km or more.
Imagine being able to see through a window 50 km thick!!!

Erbium band gaps

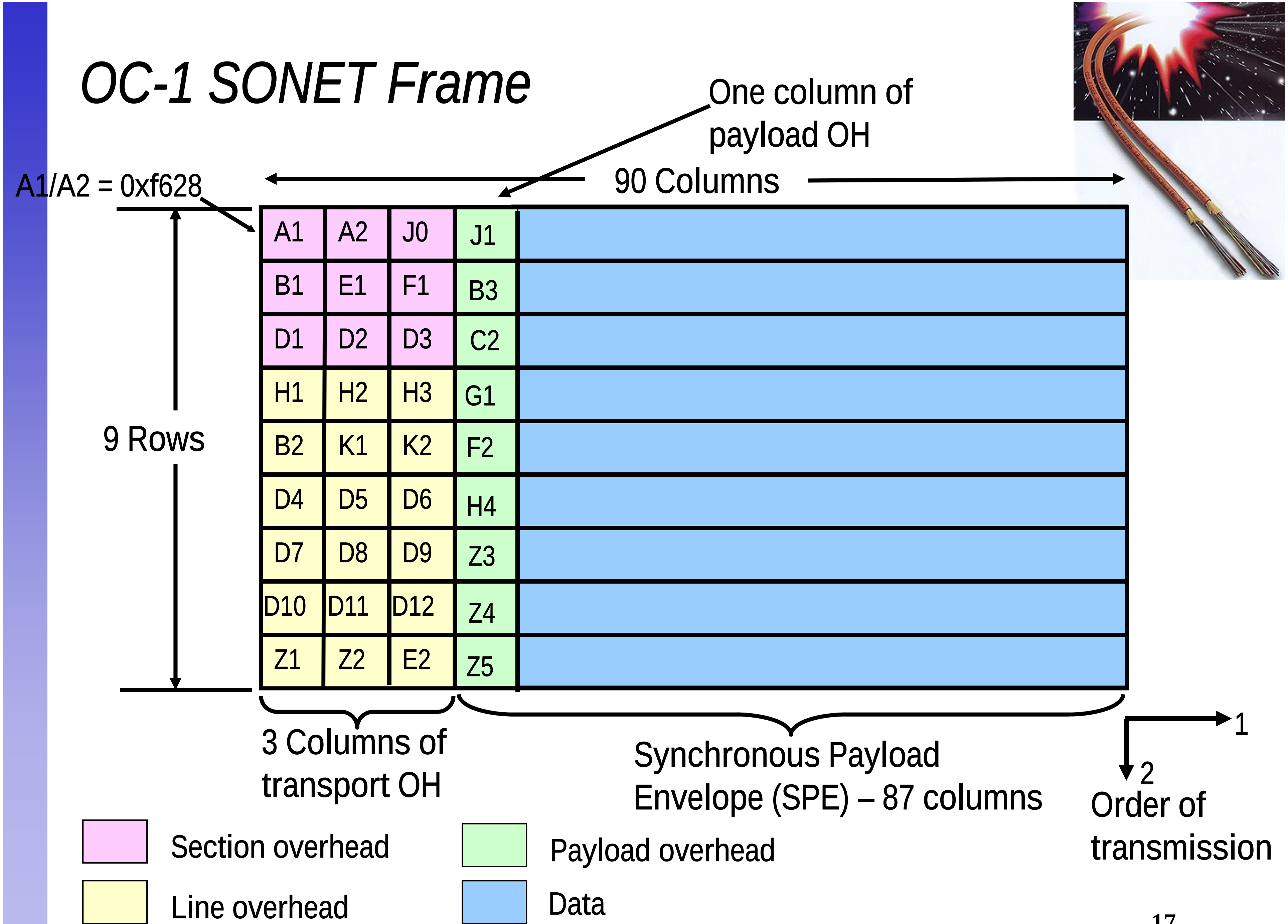


True luminescence
Is seen on a summer's eve
In a firefly's light
Ruth E. Riter
Photonics Haiku

Raman Amplifiers

- Exploits an effect known as “stimulated Raman scattering.”
  - When two signals in a fiber are within a certain frequency of each other, energy is transferred from the higher frequency signal to the lower frequency signal.
- Raman amplifiers exploit this effect by injecting a wavelength a certain frequency above the wavelength to be amplified.
  - Usually done in the “reverse” direction by injecting the wavelength towards the laser.
  - Can be done at Erbium amplifier locations.
- Used in combination with Erbium amplifiers to create cascaded amplifiers. This produces better noise figures.

OC-1 SONET Frame



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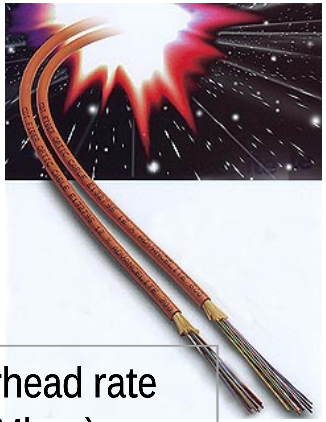
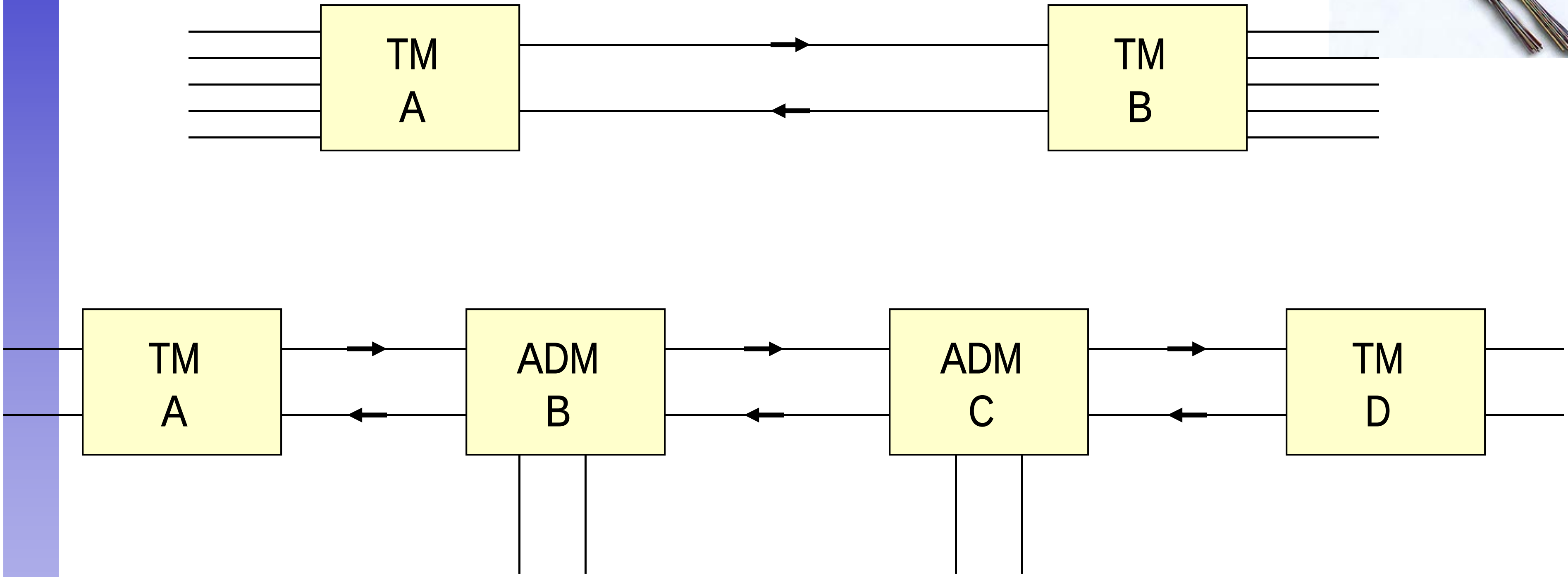
SONET/SDH Data Rates



SONET name	SDH name	Line rate (Mbps)	SPE rate (Mbps)	Overhead rate (Mbps)
OC-1	STM-0	51.84	50.112	1.728
OC-3	STM-1	155.52	150.336	5.184
OC-12	STM-4	622.08	601.344	20.736
OC-48	STM-16	2,488.32	2,405.376	82.944
OC-192	STM-64	9,953.28	9,621.504	331.776
OC-768	STM-256	39,813.12	38,486.016	1,327.104

First generation optical networks



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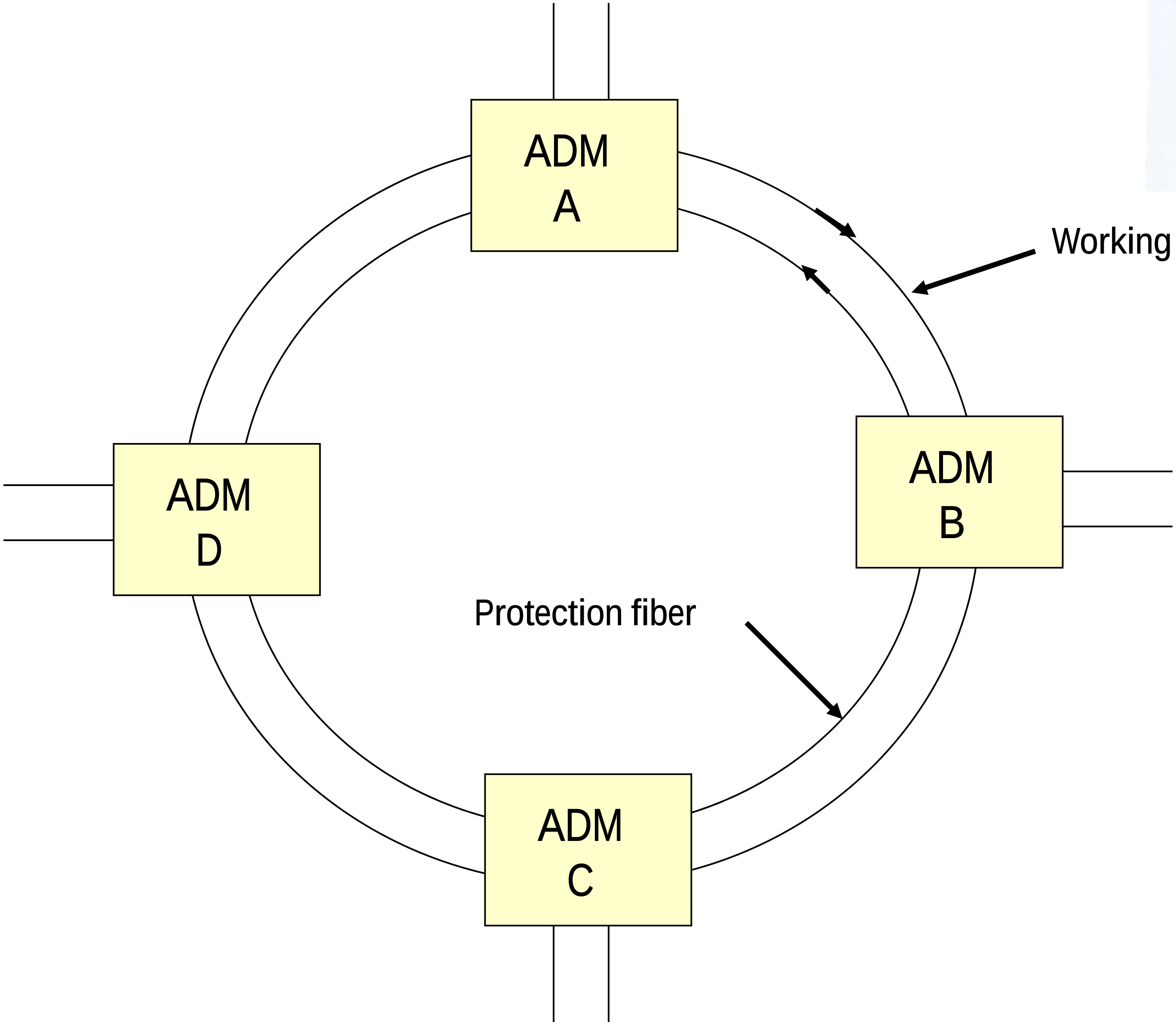
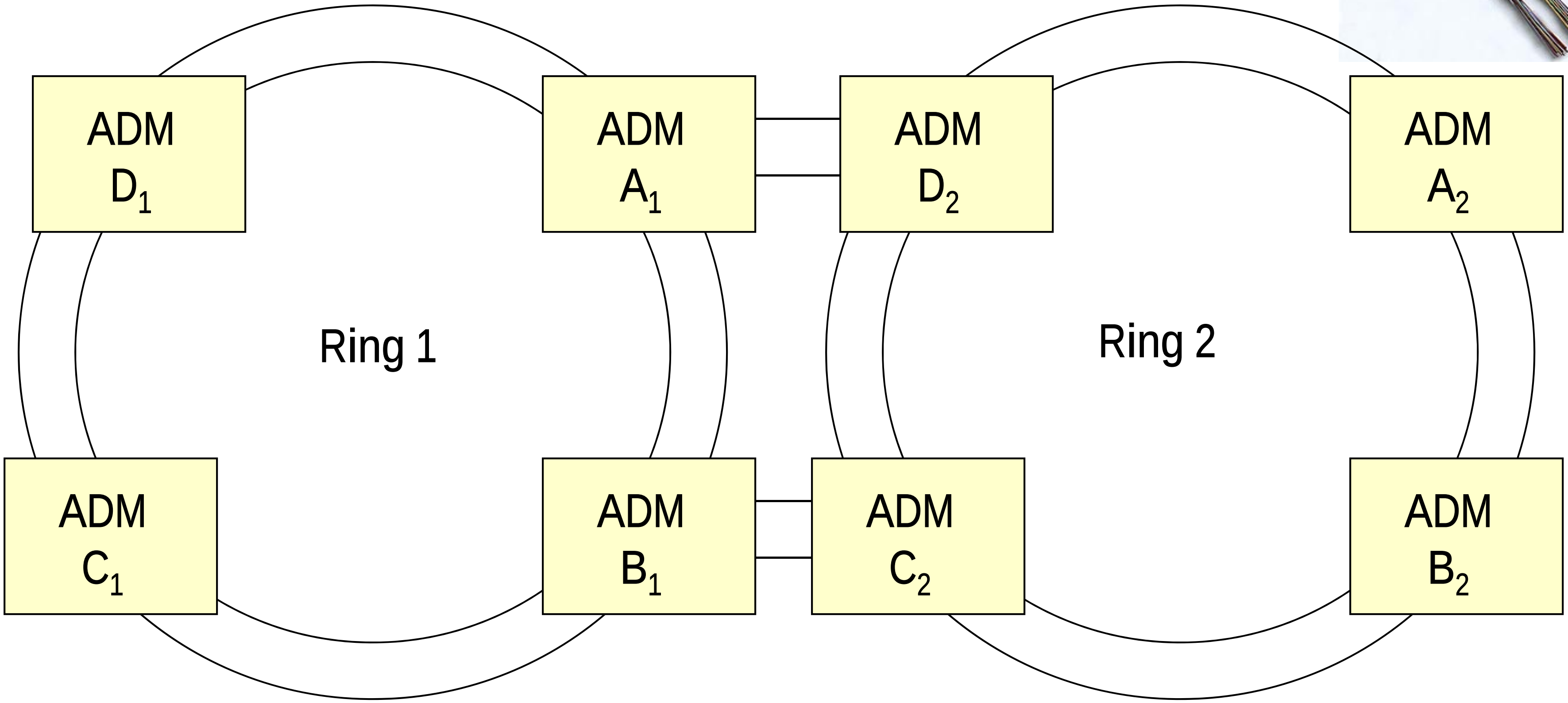
First generation optical networks - rings



Interconnecting rings – dual homing



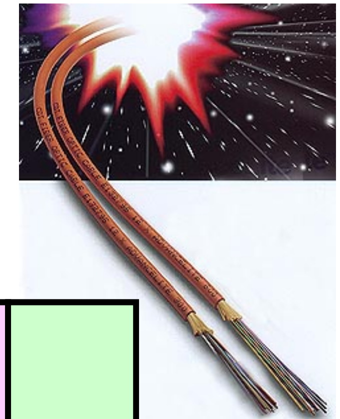
ATM and Packet over SONET

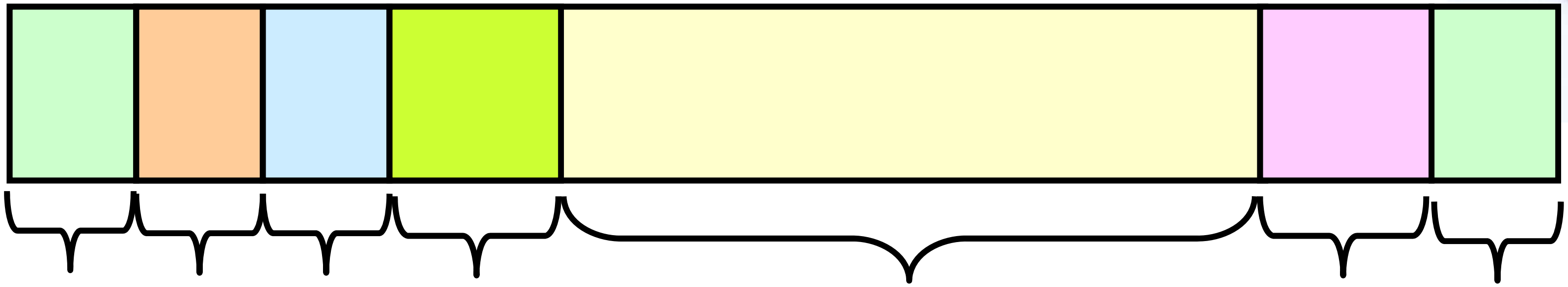
- SONET is designed to carry TDM voice, not data.
  - The frame time for SONET/SDH is 125 μs, no matter what the line rate.
- Some technique is required to frame and transport data, especially IP traffic.
  - Some techniques used are frame relay, asynchronous transfer mode (ATM) and packet over SONET (POS).

ATM

- ATM was designed to carry both voice and data.
  - Connection oriented system, with quality of service (QoS) defined.
- ATM adaptation layers (AAL) are used to frame traffic.
  - AAL5 used for data, such as IP.
  - AAL1 and AAL2 used for voice.
- In general, network providers are moving away from ATM in the backbone.
  - ATM adds an additional network layer which adds cost for equipment and must be managed.
  - The overhead for protocol conversion to AALx limits the performance of the system. ATM cannot operate at the highest optical rates.

Packet over SONET (POS)



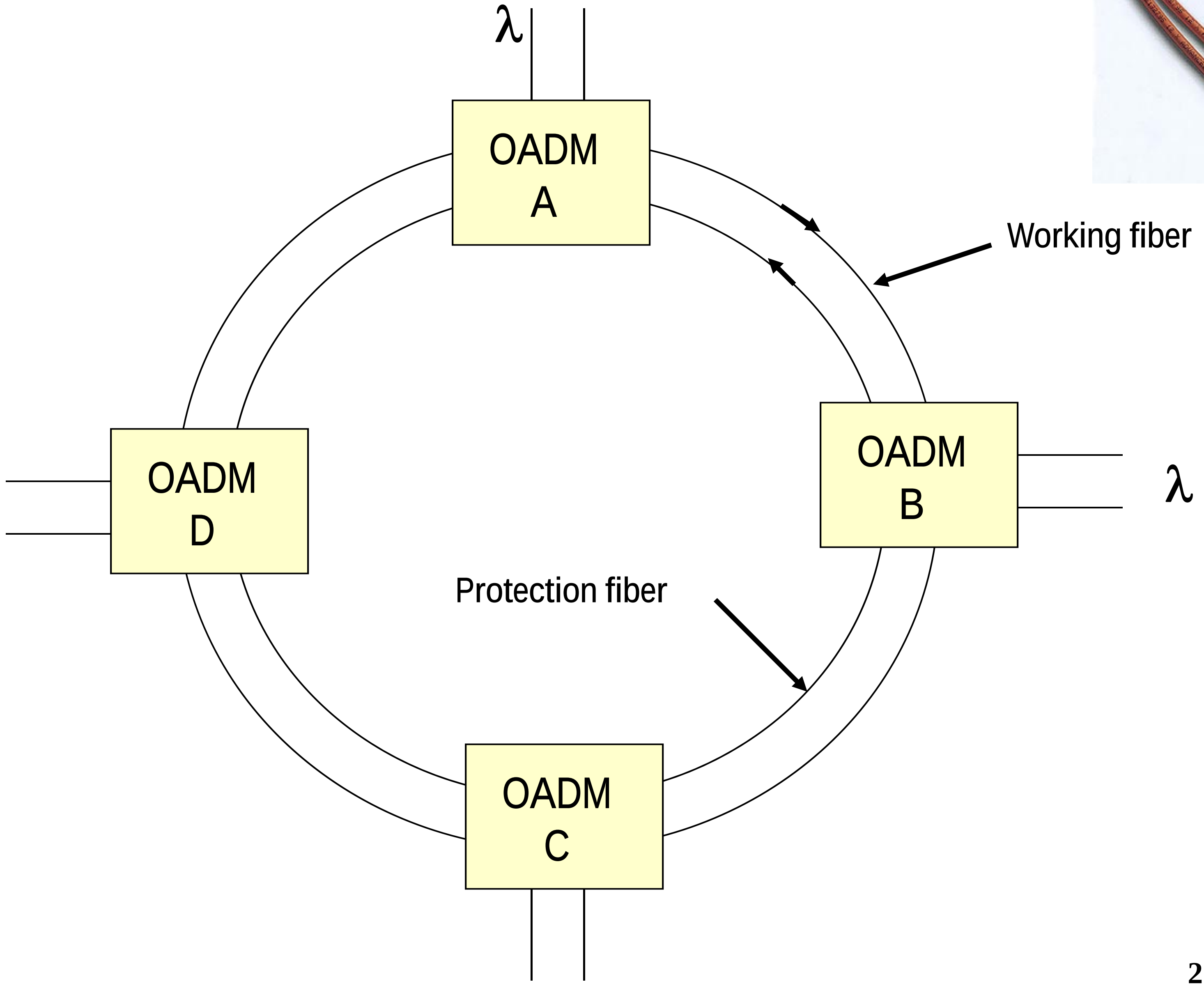


Shielding character is 0x7D

By convention, the information field is usually limited to 1500 octets. However, the packet may be of any size.

The octet is the smallest unit in POS.
Bit oriented operations (such as zero bit insertion) are NOT done because of the data rate (it would require very high speed components).

Second generation optical networks



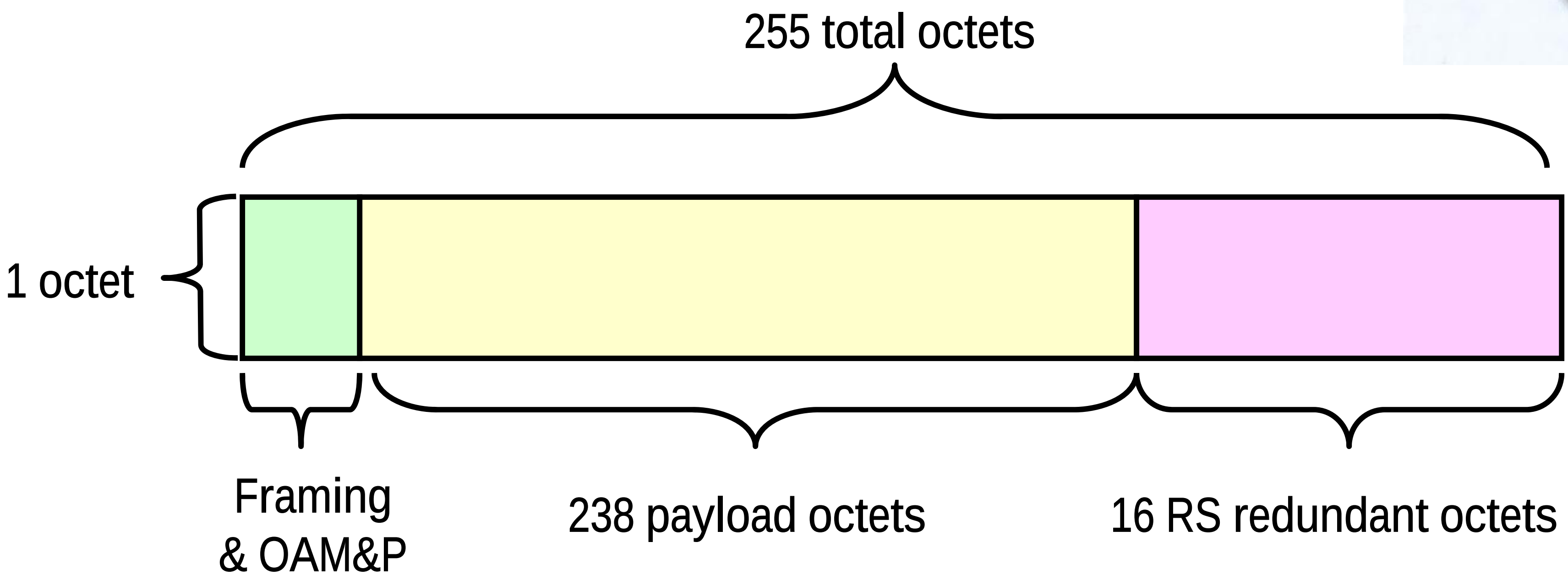
Problems of Second Generation Networks

- Since the signal stays in the optical domain, it is difficult to monitor the quality of the signal as it traverses the network.
  - Can monitor optical signal strength but does not indicate error rate.
  - Difficult to track down problems (and providers guarantee QoS).
  - Administrative control must be separate λ.
- Design decisions are frozen into the network.
  - λ spacing, laser drift, amplifier bandwidth, etc.
  - Traffic is limited by worse case route (not link). Worse case route must be known at outset. Restoration will probably be worse case.
  - Changes must be made network wide, which is extremely difficult.
- The network is analog.
  - Impairments accumulate. SNR reduced with every operation, including transmission over a link and amplification. Problems include dispersion, crosstalk, nonlinearities, noise accumulation, polarization and more.

Forward Error Correction in Optical Networks

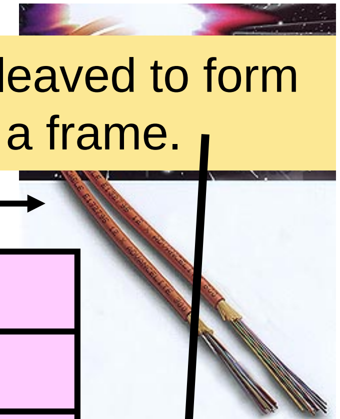
- SONET in-band.
  - For OC-48 and up.
  - Does a BCH code on the payload data in each row.
  - Redundant bits located in overhead columns of same or next row.
  - Provides error correction while maintaining line rates.
  - Only works for SONET/SDH
- Digital wrapper.
  - Takes octets and adds redundant octets for correction.
  - Uses Reed Solomon (255,239) code.
  - One octet of data area used for overhead.
  - Handles any type of payload – SONET, Ethernet, etc.
  - Increases line rate by about 15/14.
  - More on digital wrapper in next few slides.

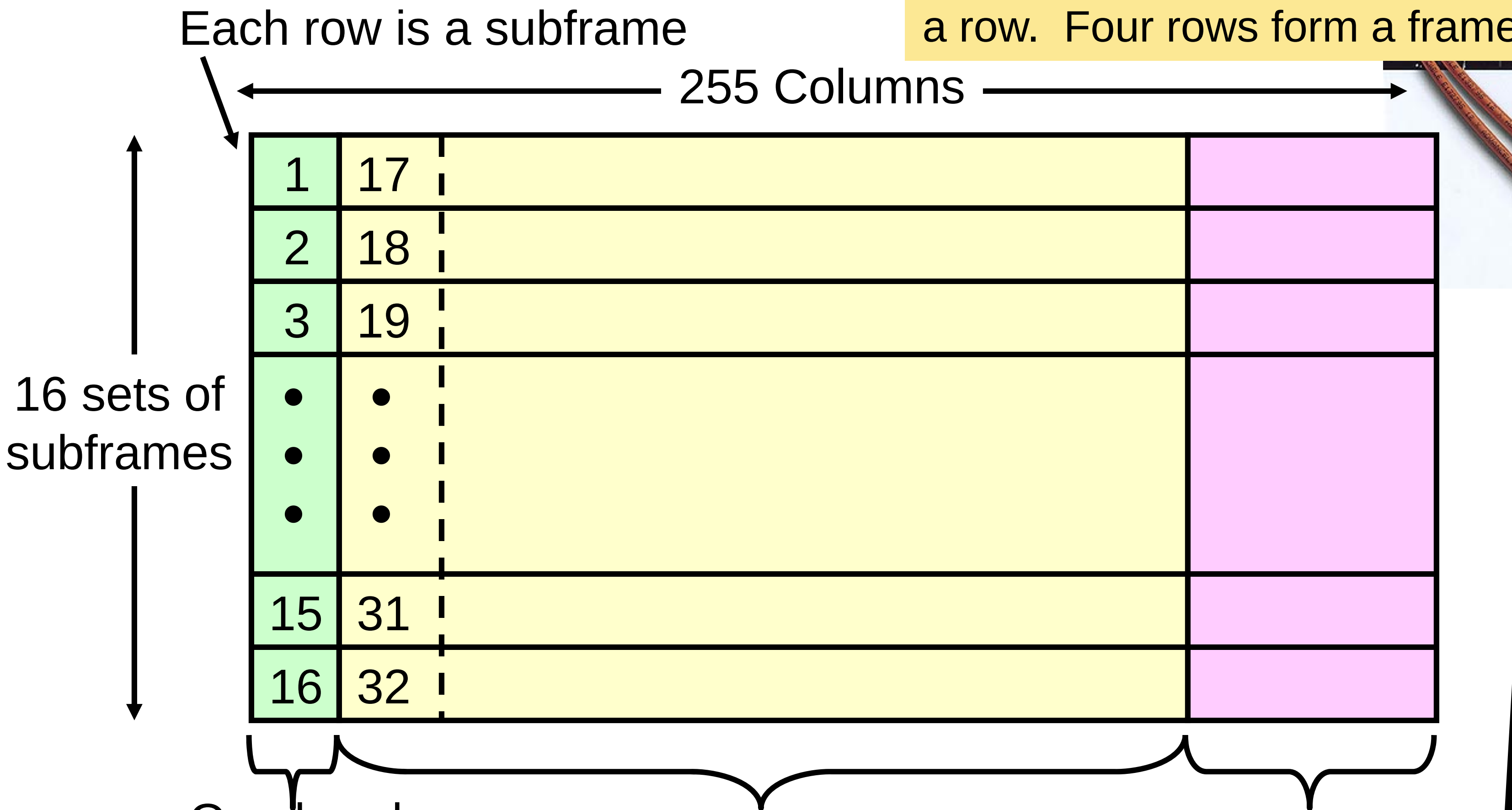
G.709 Digital wrapper



This 255 octet wide package is repeated to create a frame.

16 subframes are interleaved to form a row. Four rows form a frame.

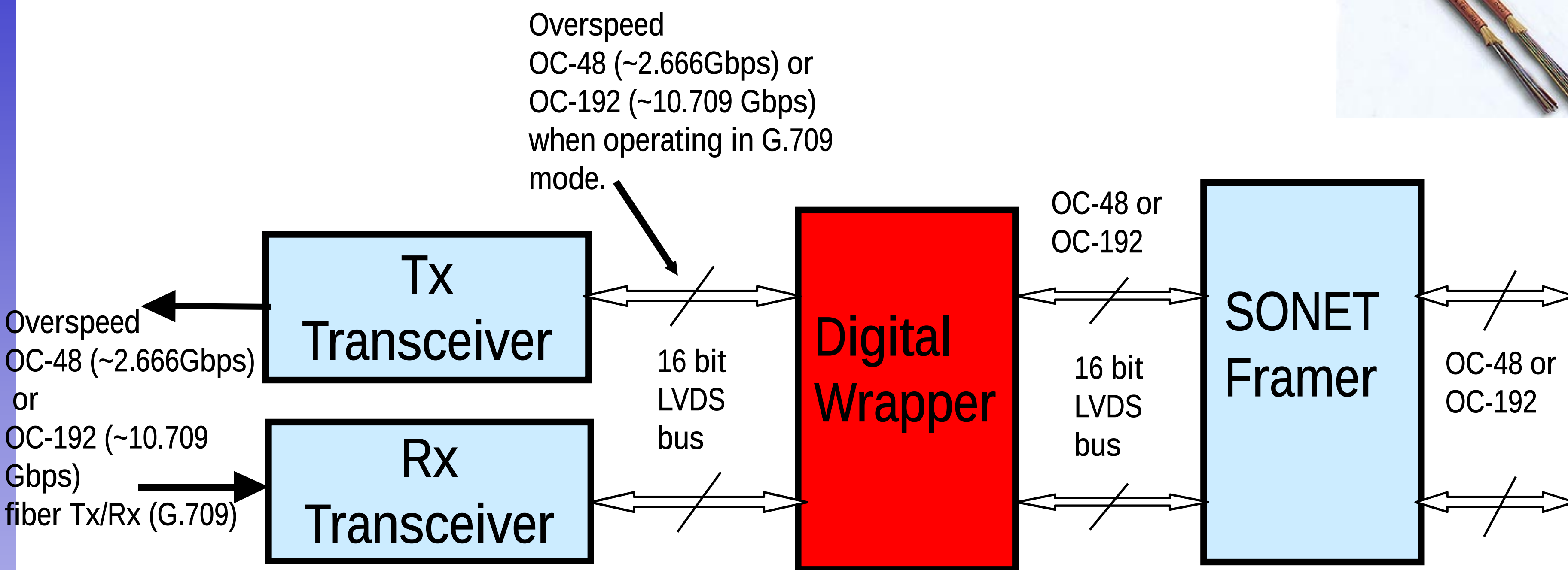




Transmit order

1	2	• • •	16	17	18	• • •	3824	• • •	4080
4081	4082	• • •	4096	4097	4098	• • •	7904	• • •	8160
8161	8162	• • •	8173	8174	8175	• • •	11984	• • •	12240
12241	12242	• • •	12256	12257	12258	• • •	16064	• • •	16320

Digital Wrapper implementation



Metropolitan/Access Area Network

- Volume expected to be very large, probably more than 10 times the size of the backbone network.
- Must be significantly lower cost than backbone network.
- Wavelength division multiplexing will almost certainly be used.
  - Cost to lay fiber in metropolitan areas is too high.
  - May use coarse WDM for lower cost.
- Gigabit and 10 Gigabit Ethernet likely to play a major role.
  - Ethernet components are simple and low cost.
  - Logical extension of the corporate LAN.

Summary

- There's a lot more to optical networks than described here.
  - This presentation only skimmed the surface.
- The network is moving towards all-optical technology.
- Still lots of electronic technology required, both at the edge and inside the network.
- Metropolitan and Access networks will be a major growth area for the future, requiring high volume and low cost.

Questions?