Cybersecurity

Electronic and Communication Technologies

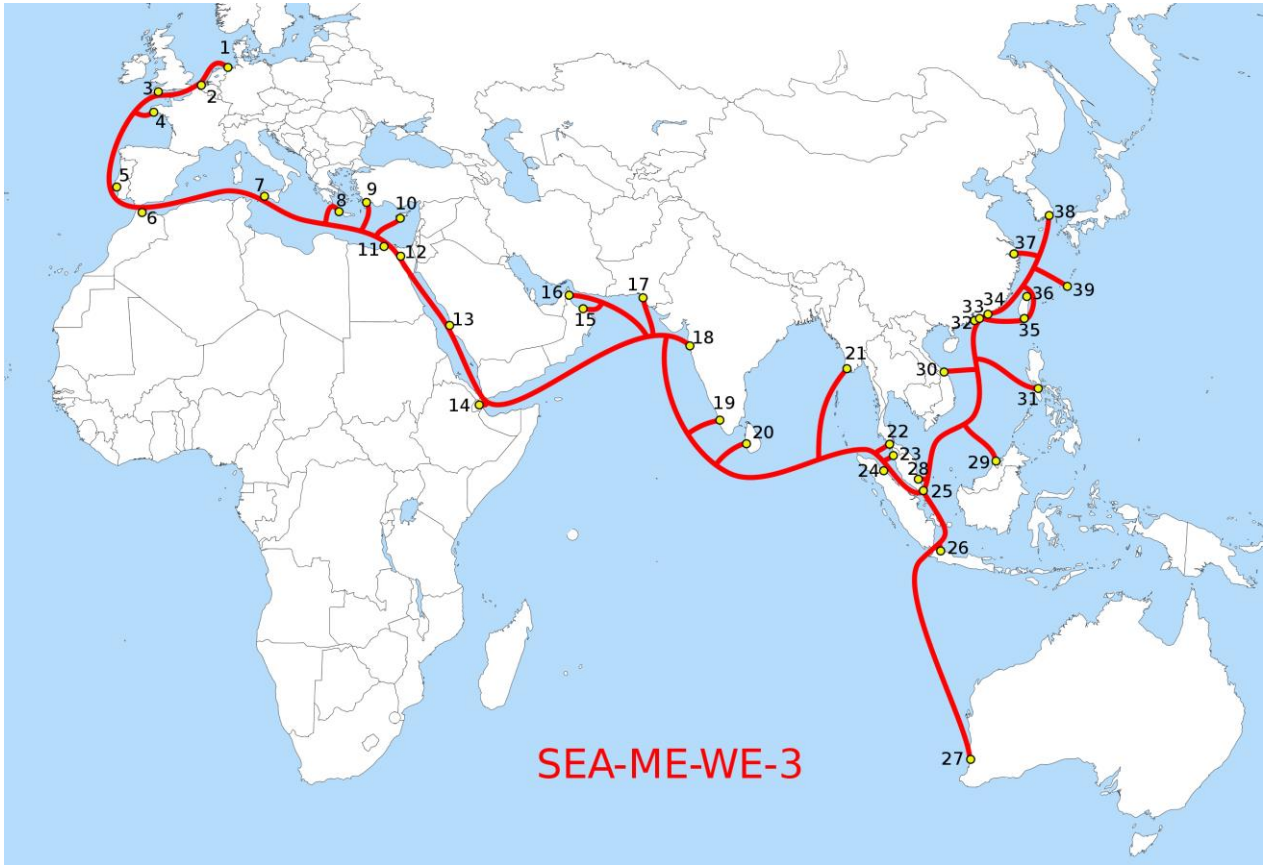
Fiber Optic Communications

Marco Luise

marco.luise@unipi.it

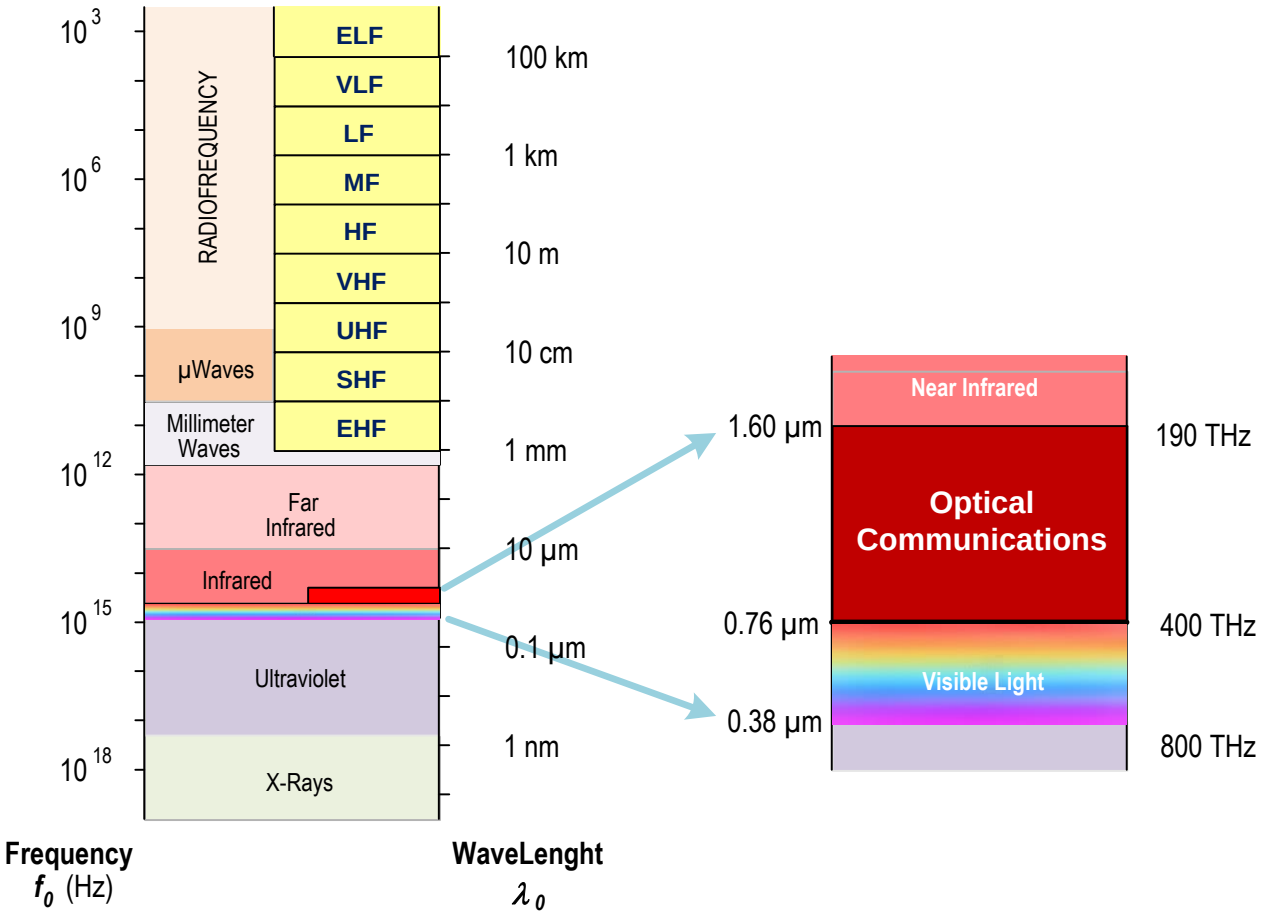
Dip. Ingegneria dell'Informazione, Univ. Pisa, Pisa, Italy

Optical Backbones: Submarine Cable



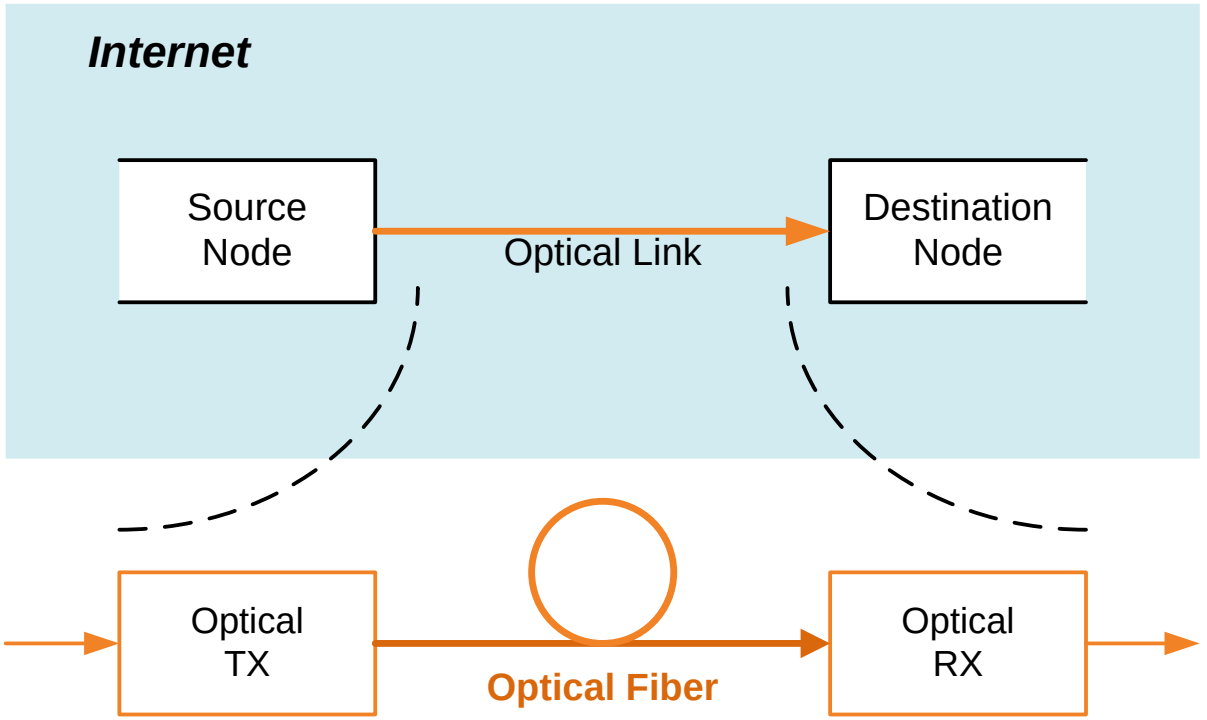
Uninterrupted 39,000 km cable

EM Waves Spectrum



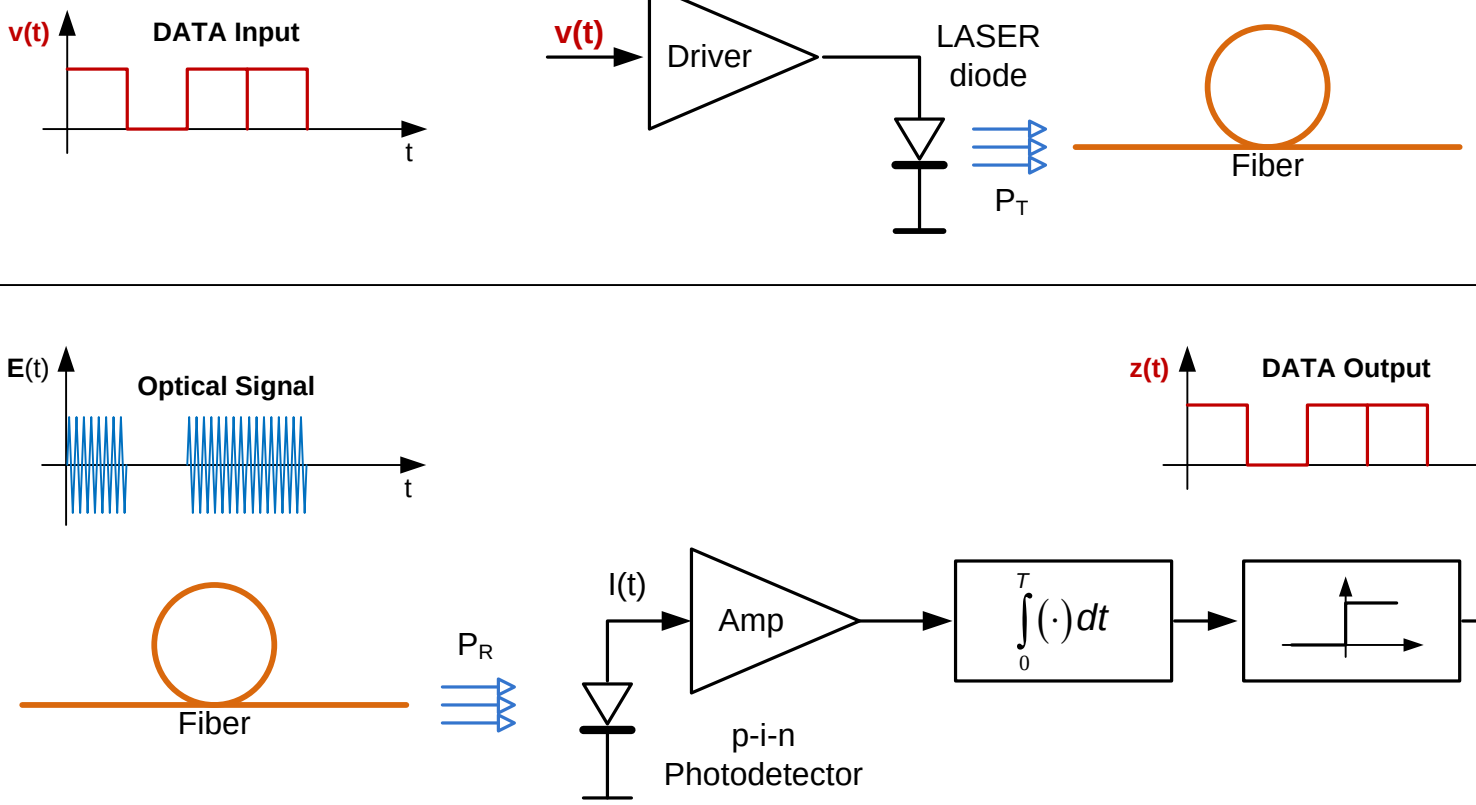
$$f_0 = c/\lambda_0$$

Optical Backbones



The bit-rate R_b is of the order of hundreds of Gbit/s

Optical Link Technology

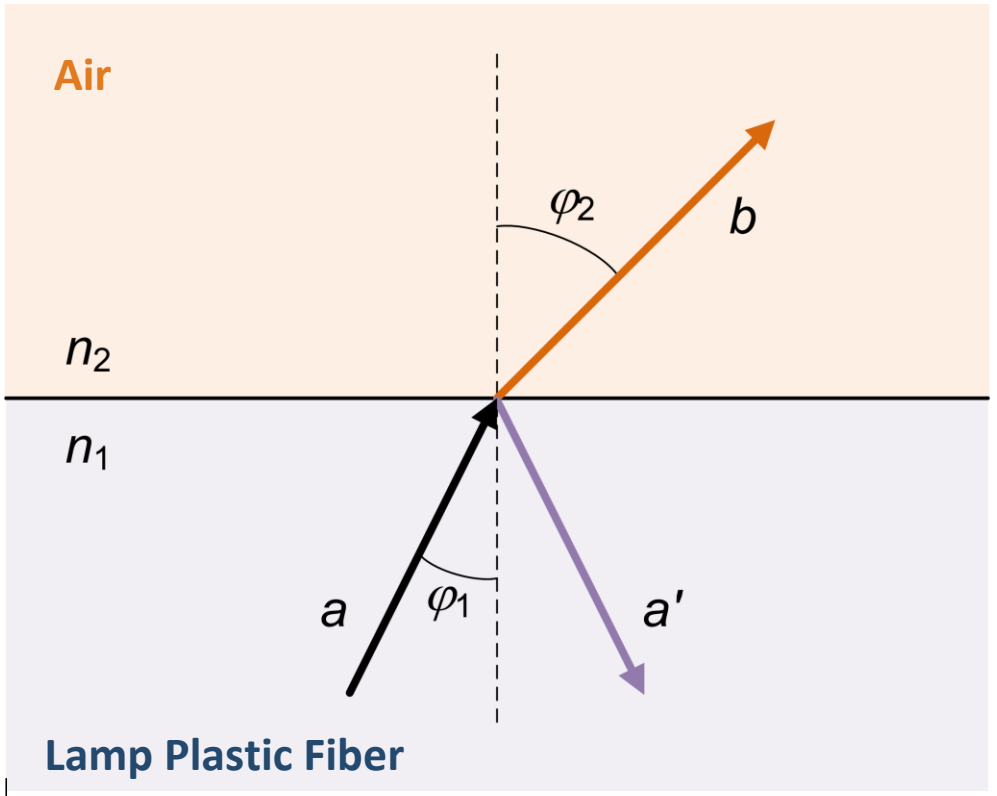


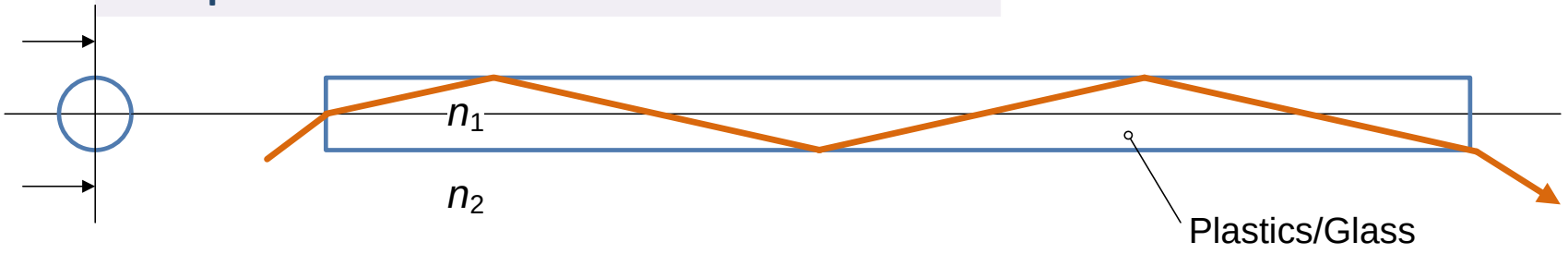
Key Components: LASER and Photodetector (photodiode)

Optical Fibers…

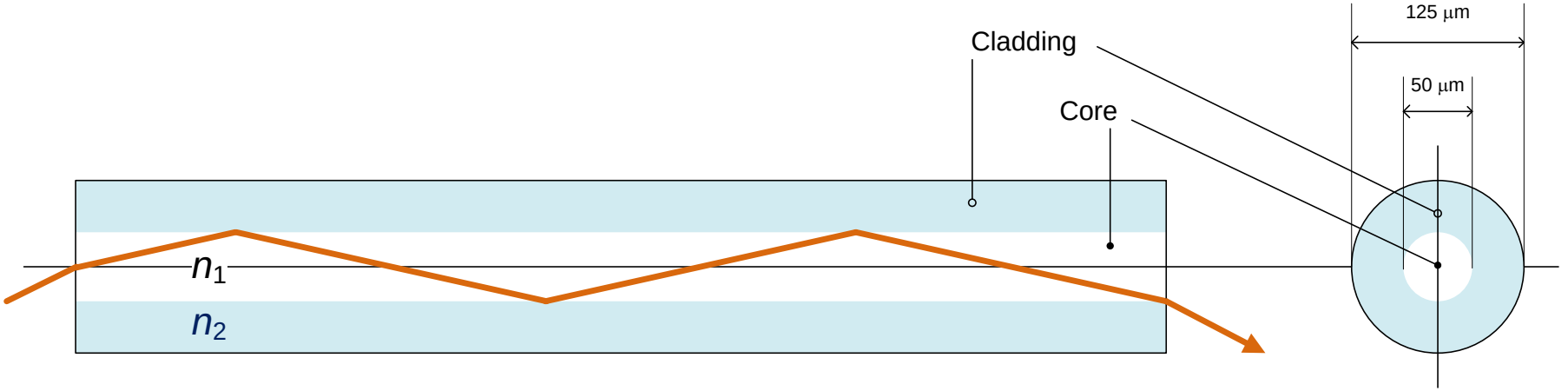
How does it work?

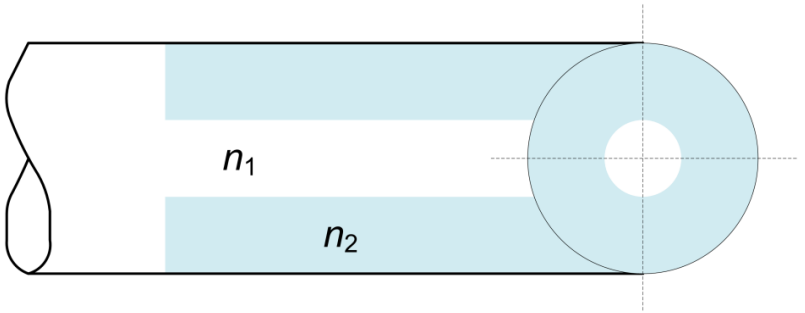
The Fiber Lamp and Snell's Law

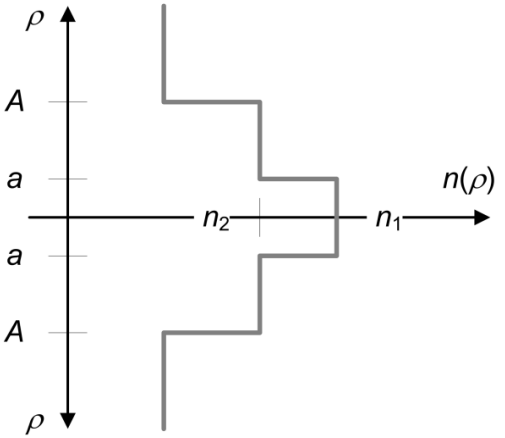




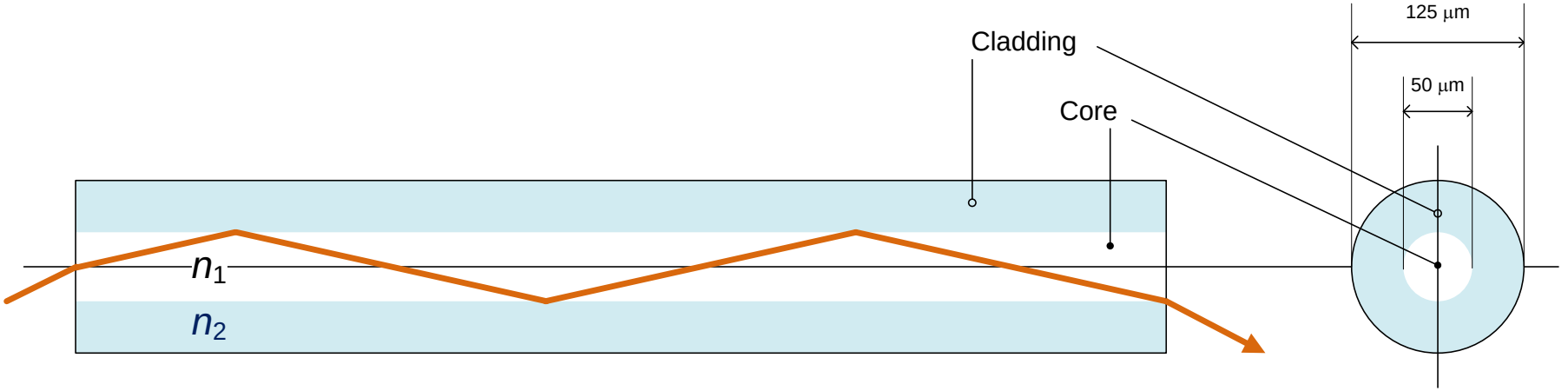
The MultiMode Step-Index (MM-SI) Optical Fiber

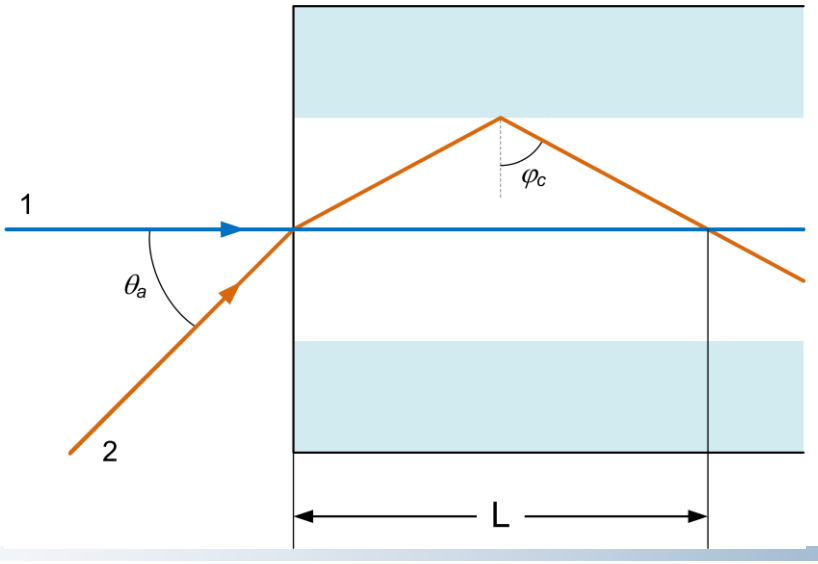




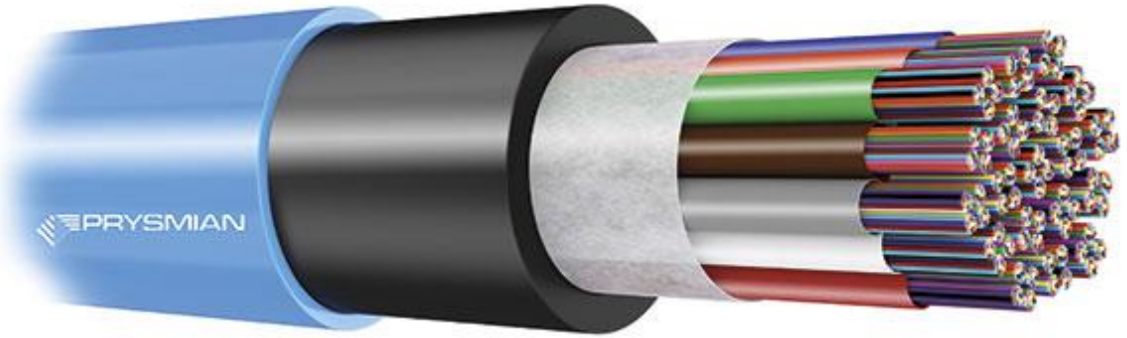


Multi-Mode !

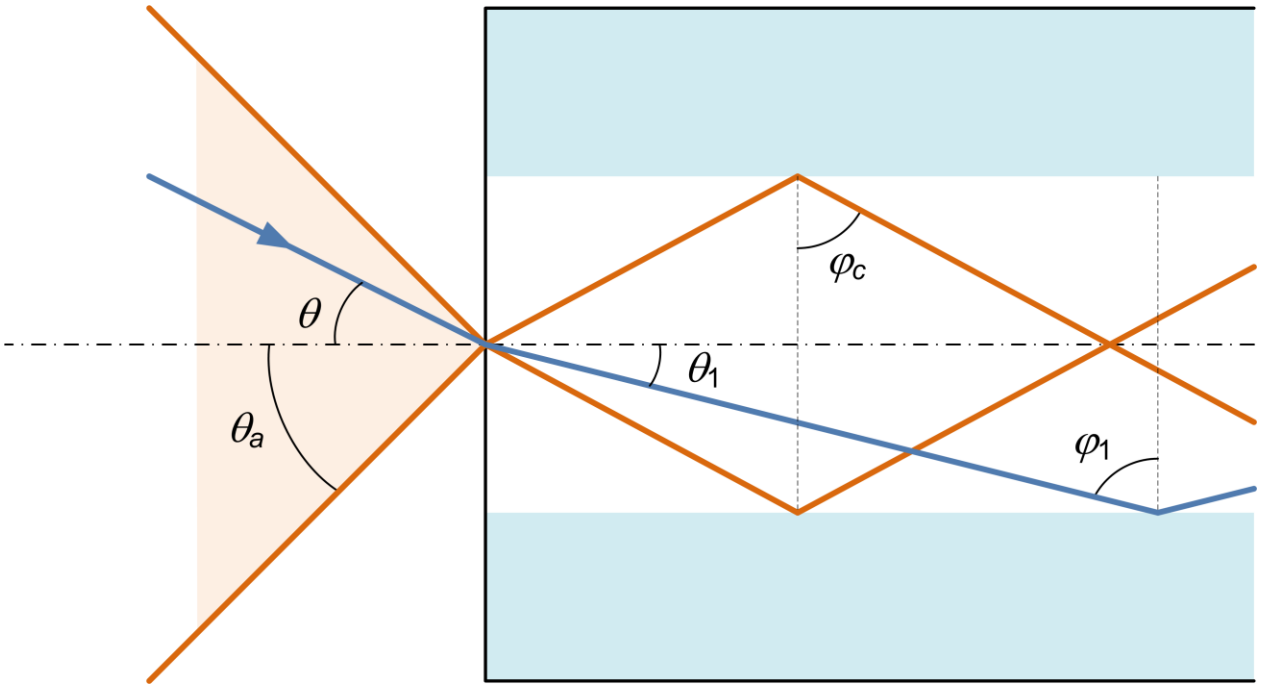




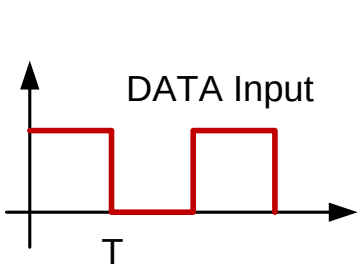
Fiber Cable

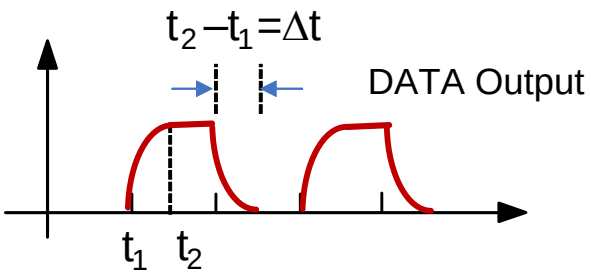


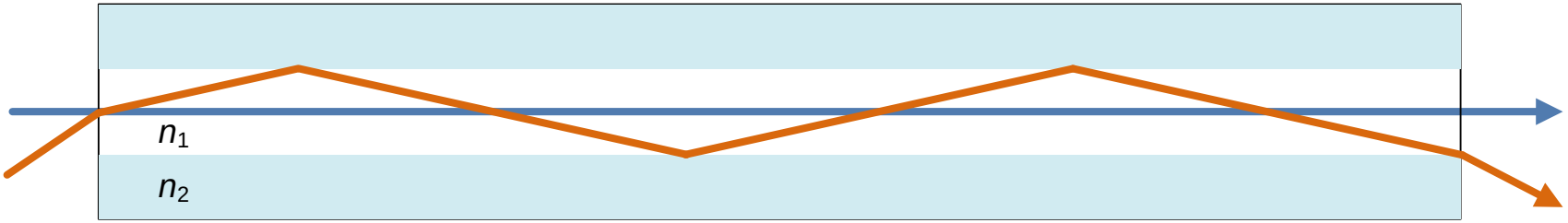
Numerical Aperture



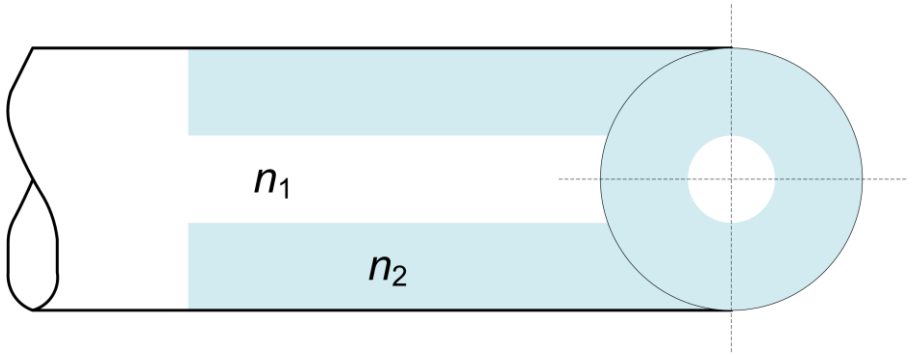
InterModal Dispersion

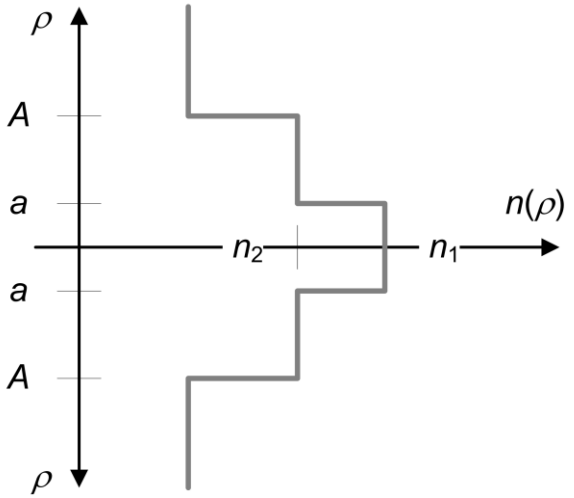


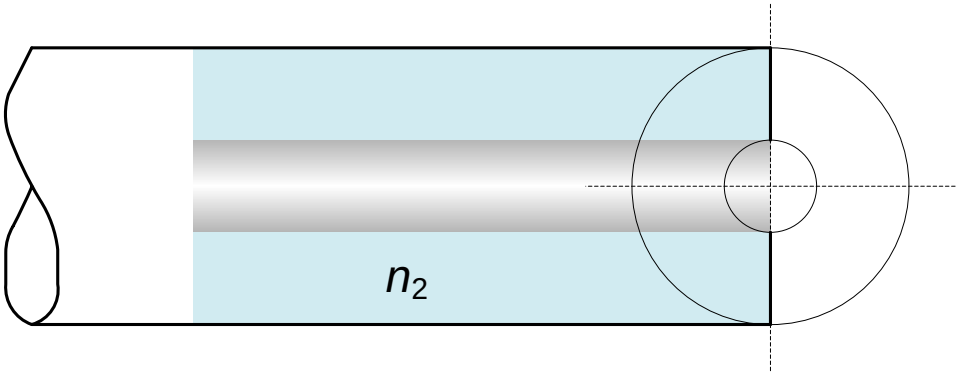


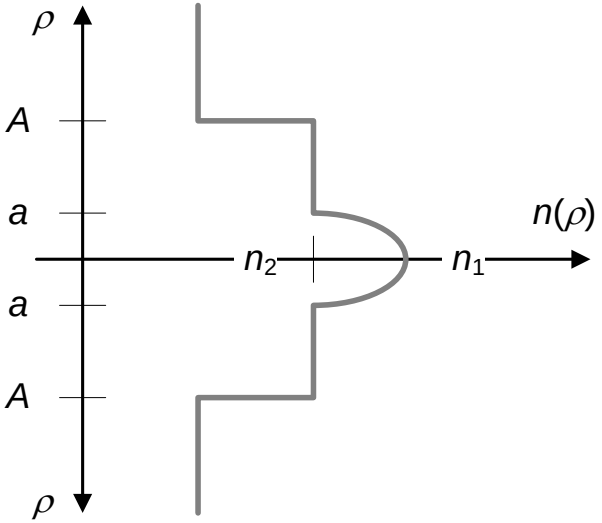


Step-Index vs. Graded-Index Fibers

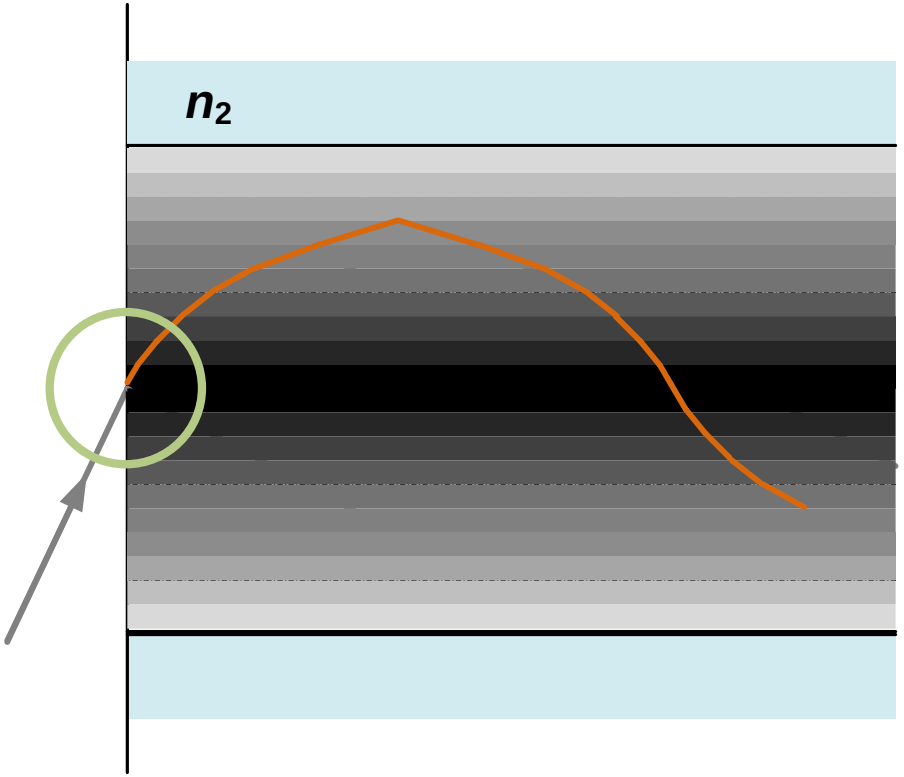


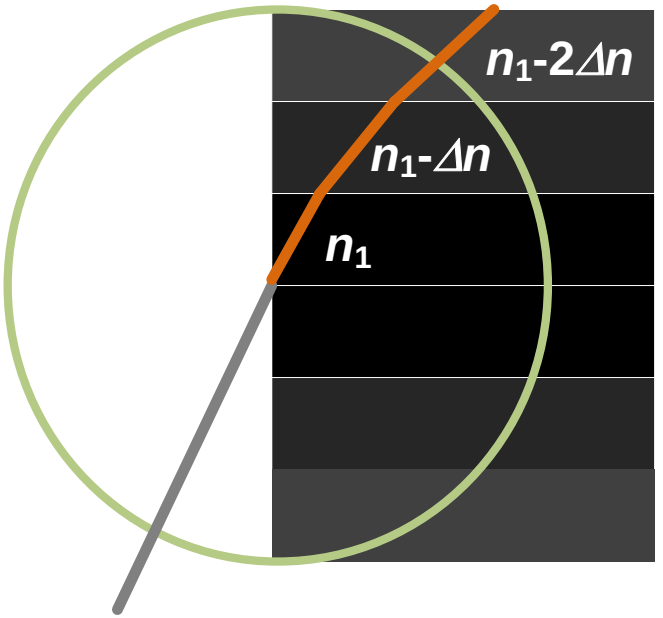




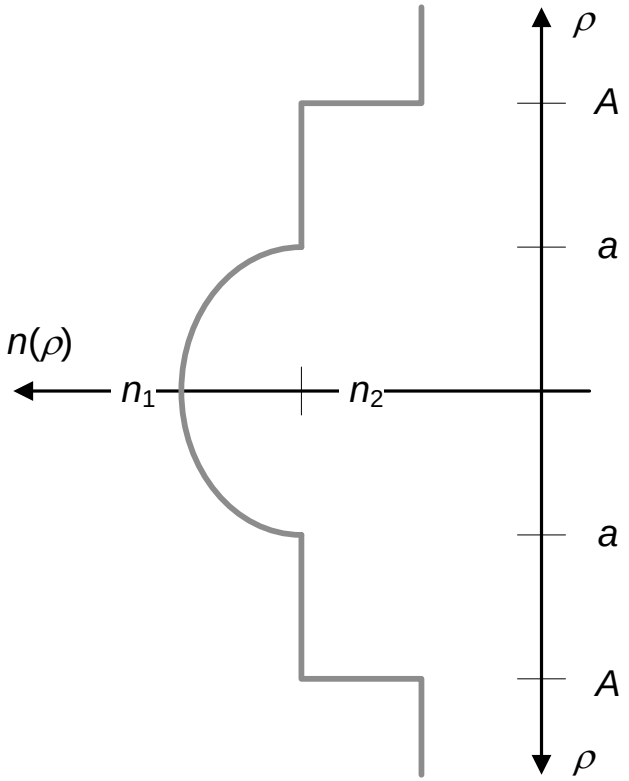


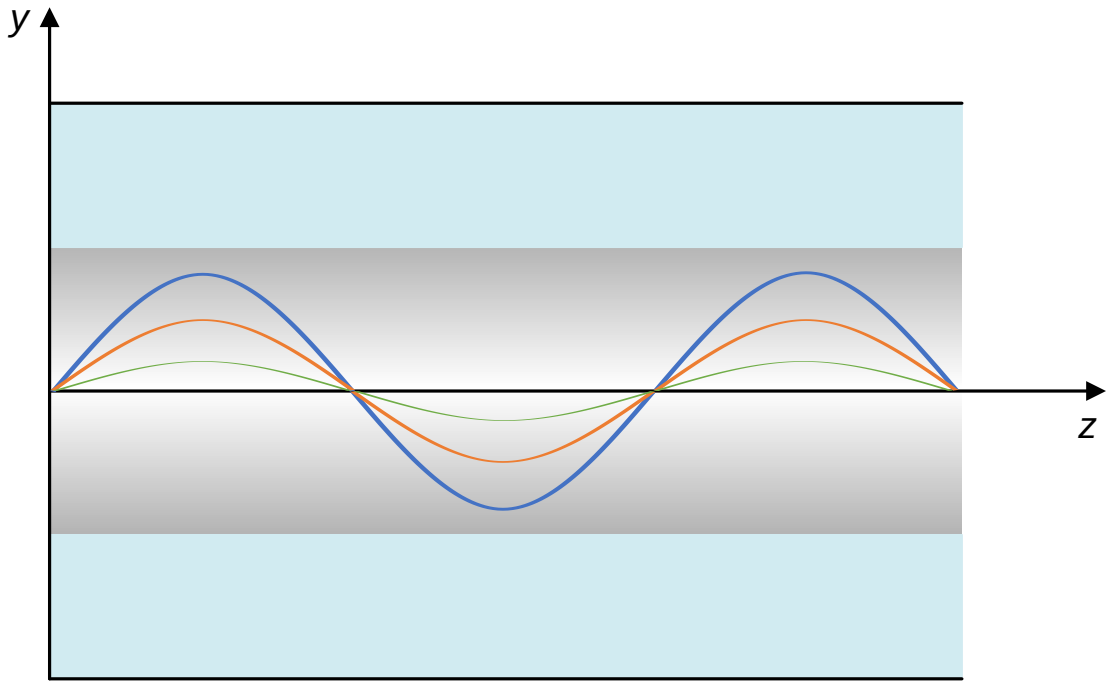
Curved Rays in MM-GI Fibers





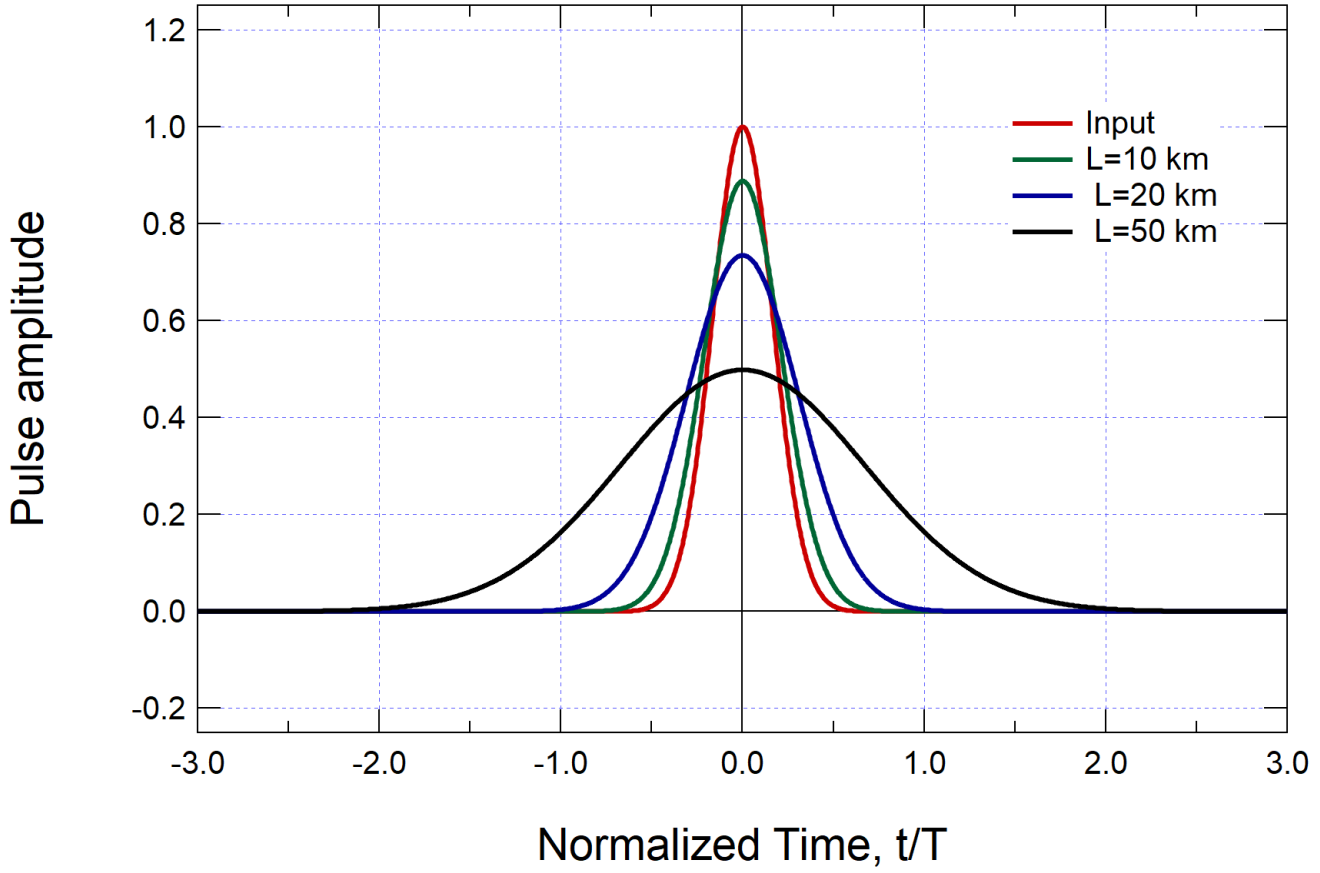
Stil Intermodal Dispersion, but…



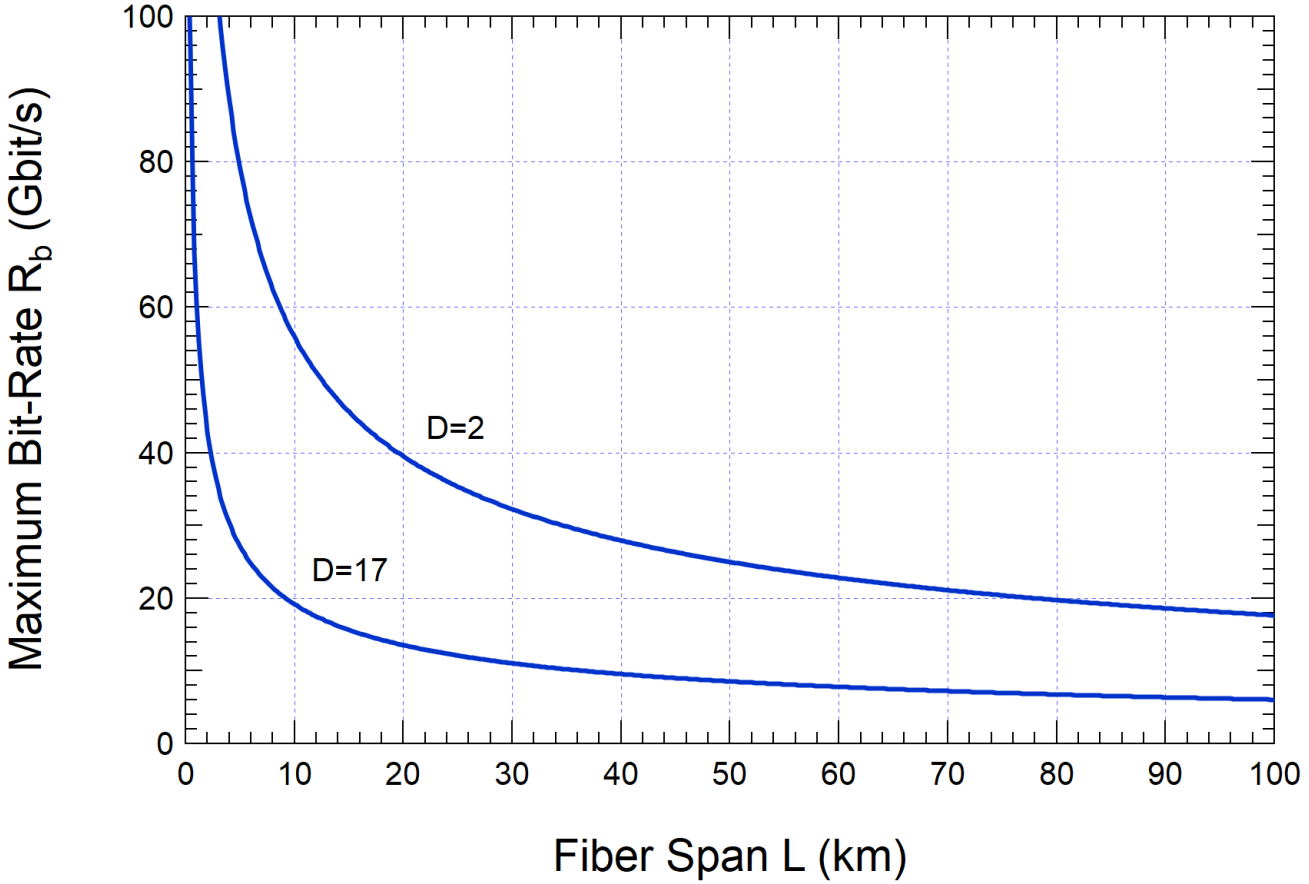


Chromatic (Intra-Modal) Dispersion

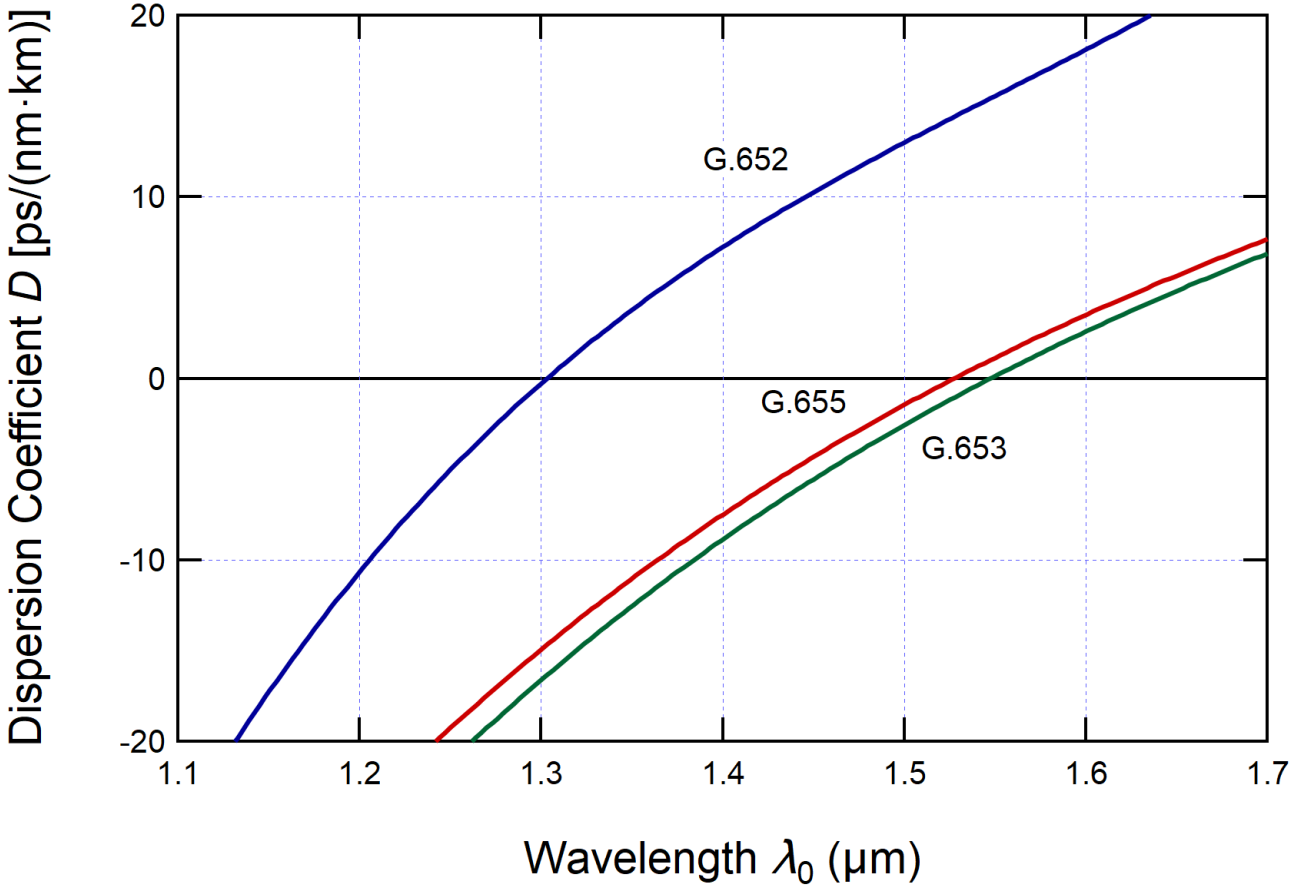
Pulse Broadening



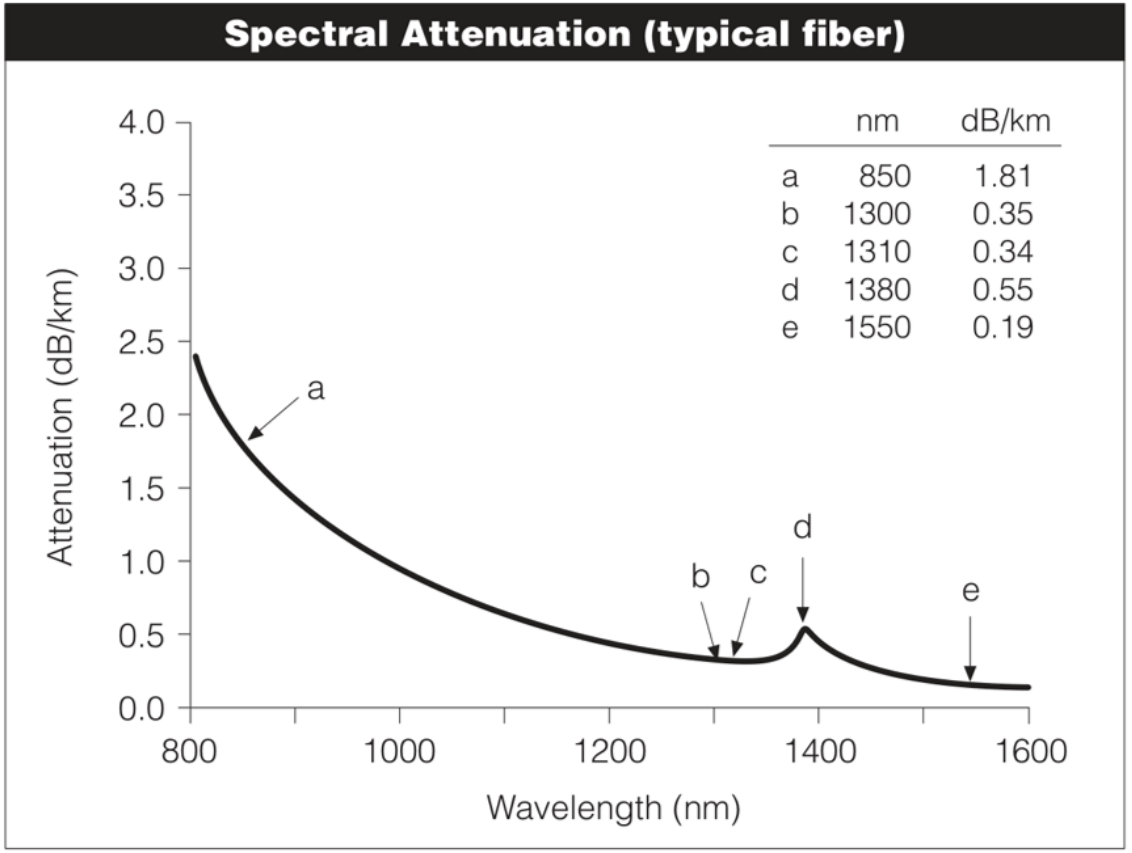
Limitation Due to Intramodal Dispersion



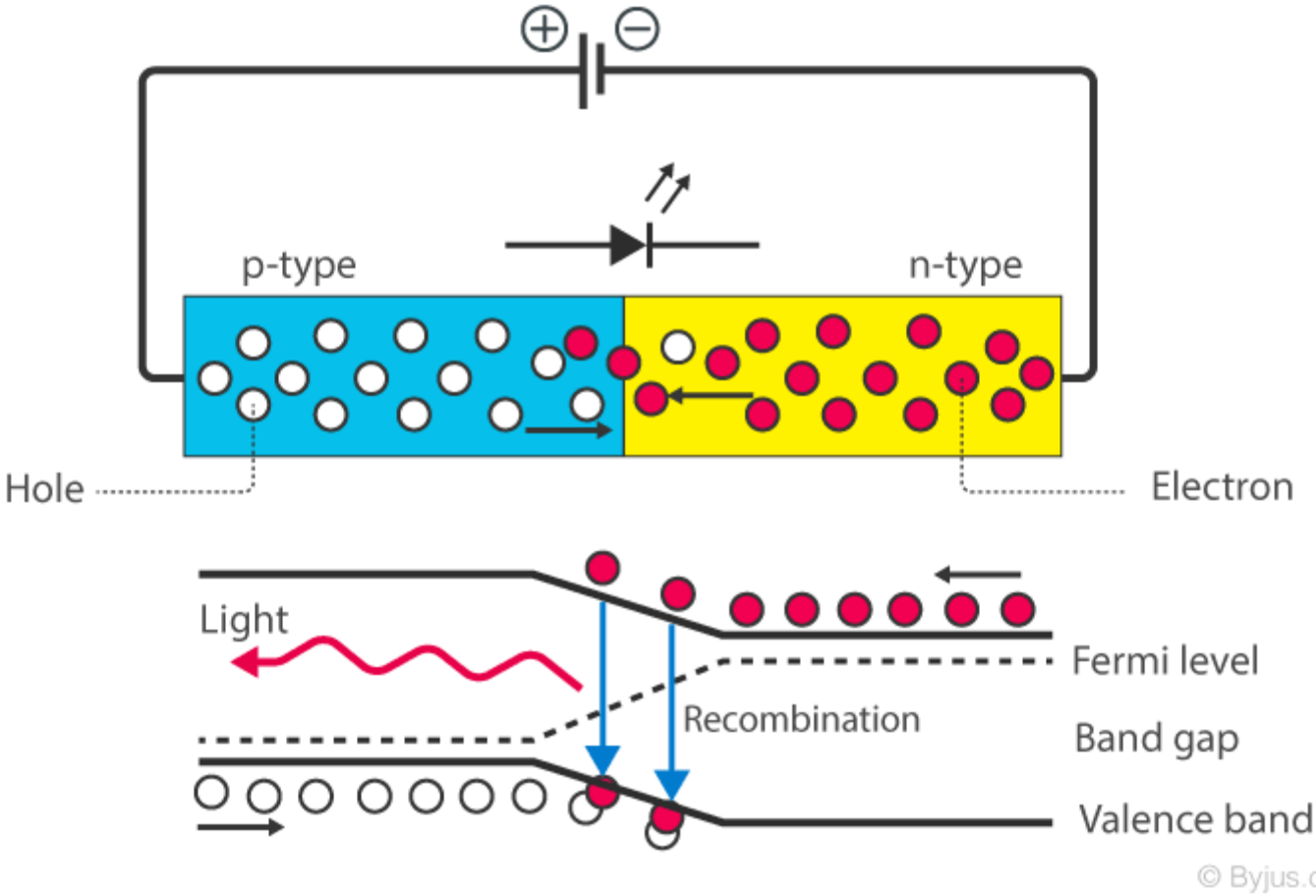
Variability of *D*



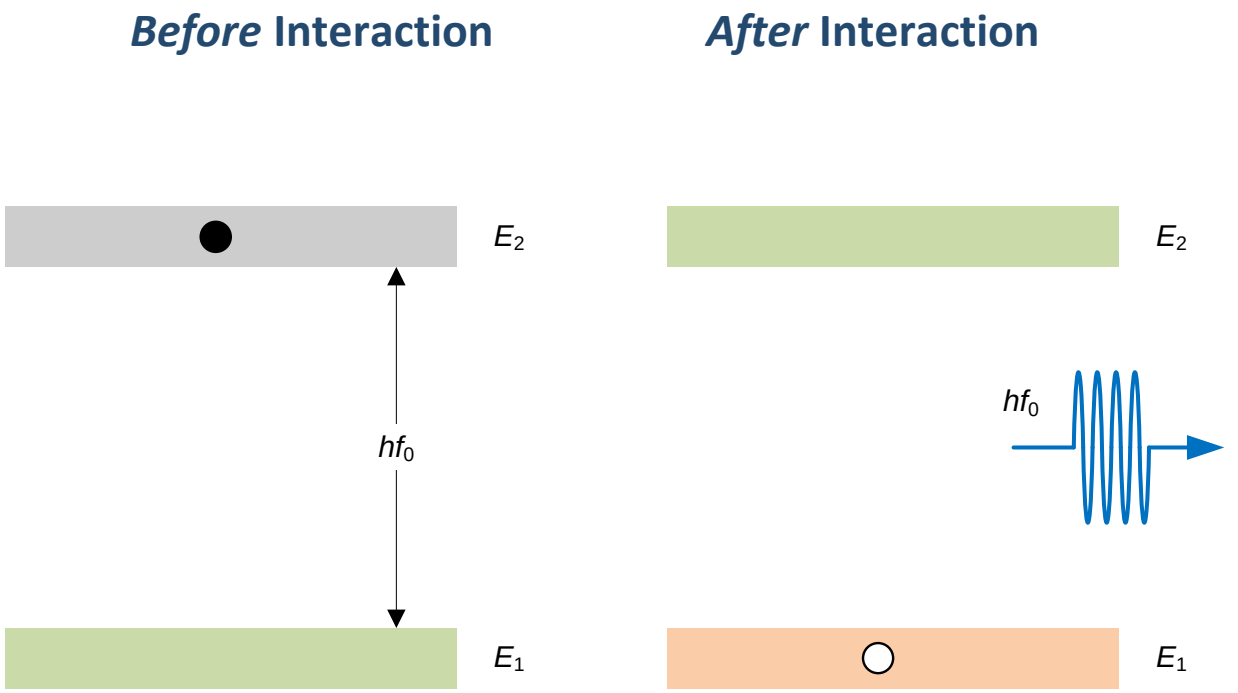
Why 1.55 ?


Spectral Attenuation (typical fiber)
nm dB/km
a 850 1.81
b 1300 0.35
c 1310 0.34
d 1380 0.55
e 1550 0.19
Attenuation (dB/km)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
800
1000
1200
1400
1600
Wavelength (nm)
a
b
c
d
e

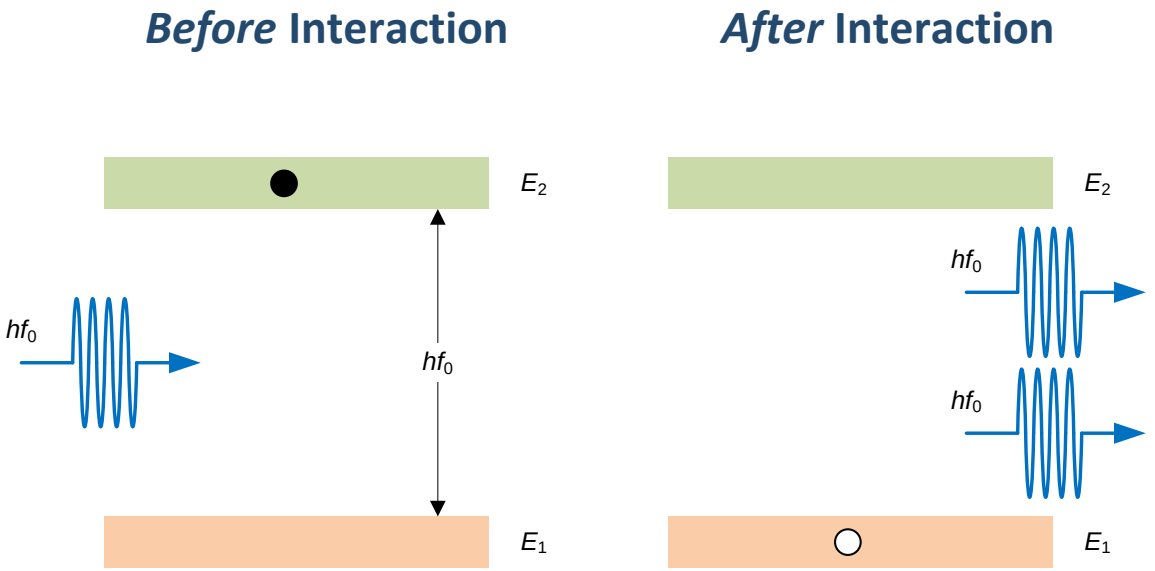
The Light-Emitting Diode (LED)



Spontaneous Emission

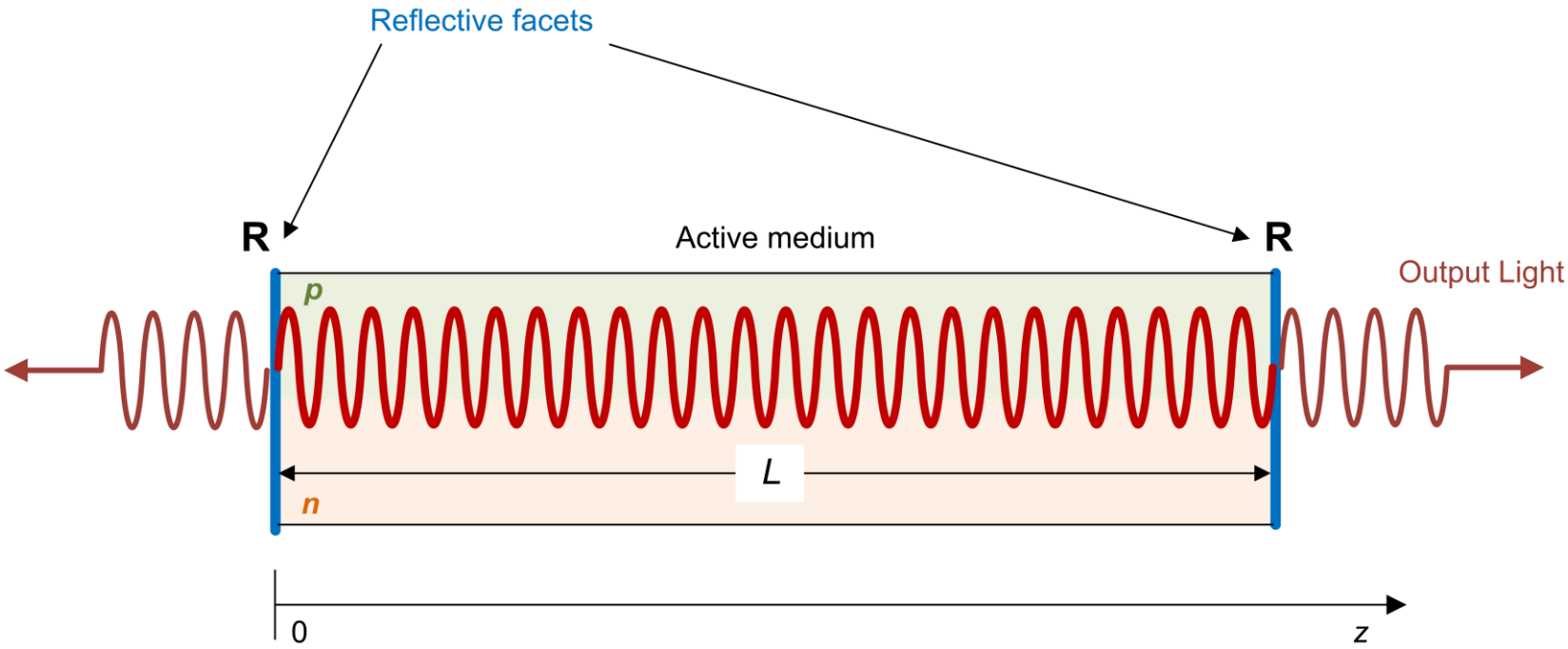


Stimulated Emission

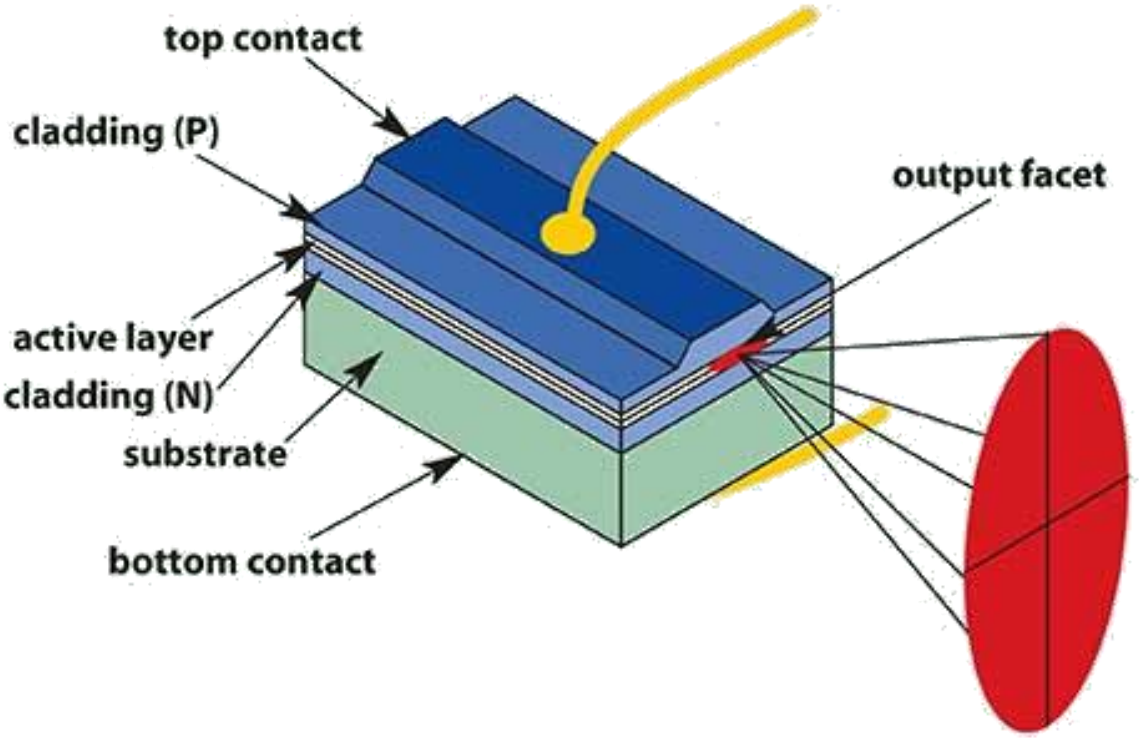


It s the basis of Light Amplification through Stimulated Emission of Radiation: LASER

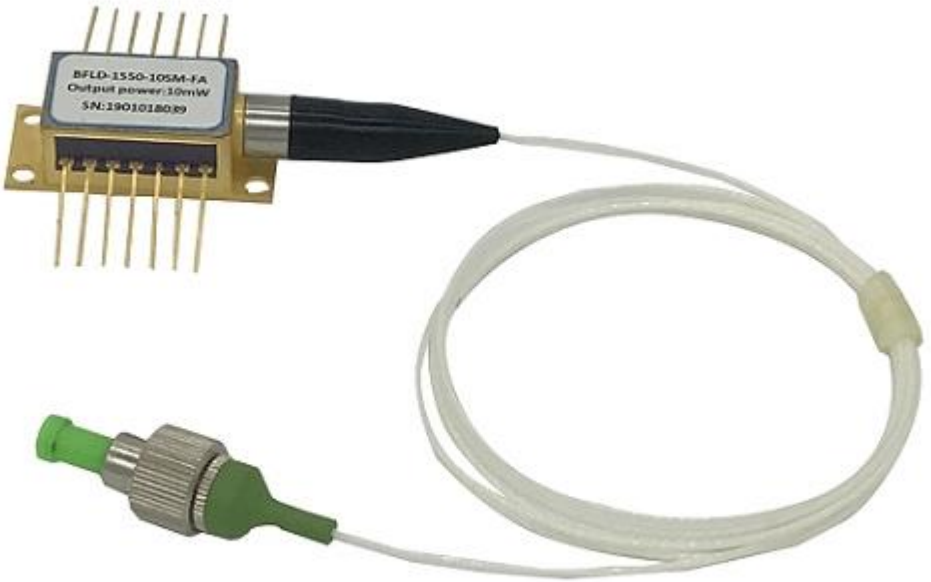
Fabry-Pérot LASER



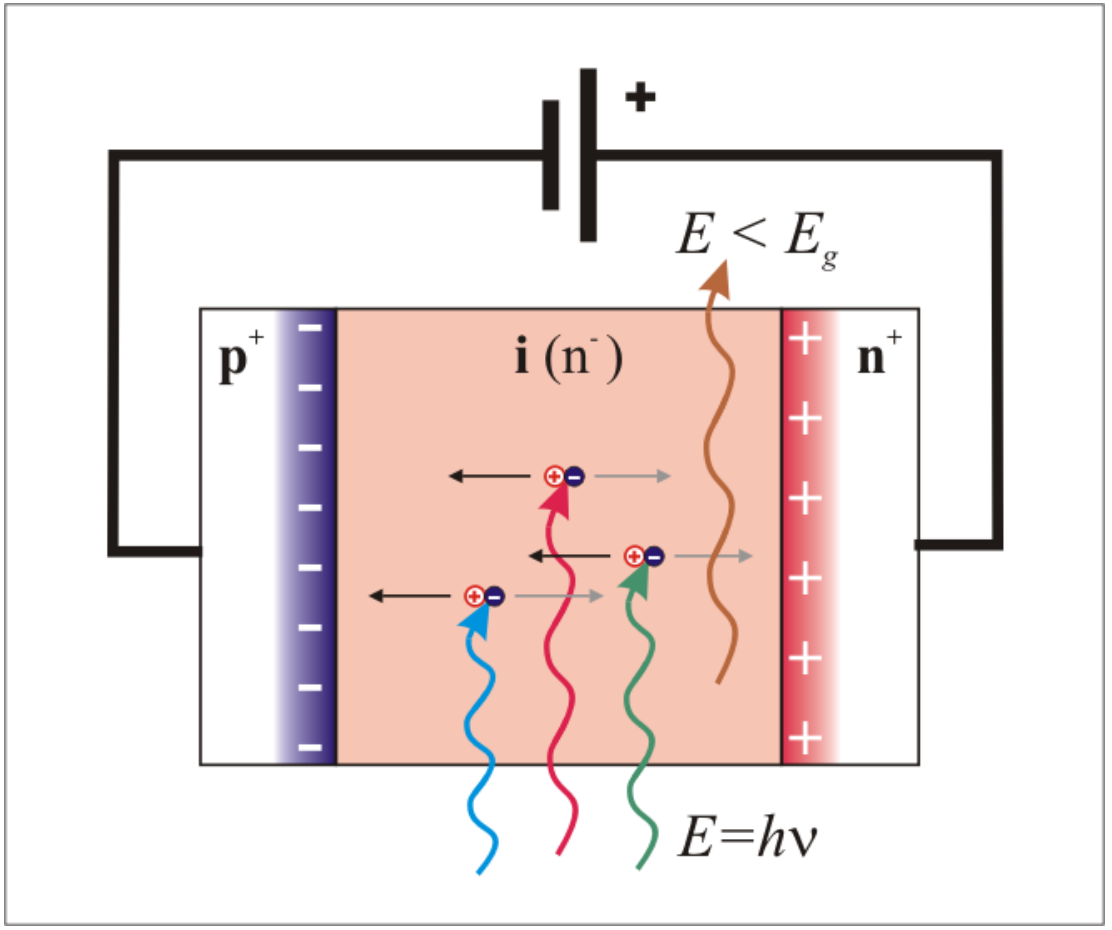
Semiconductor Lasers for Optical Communications



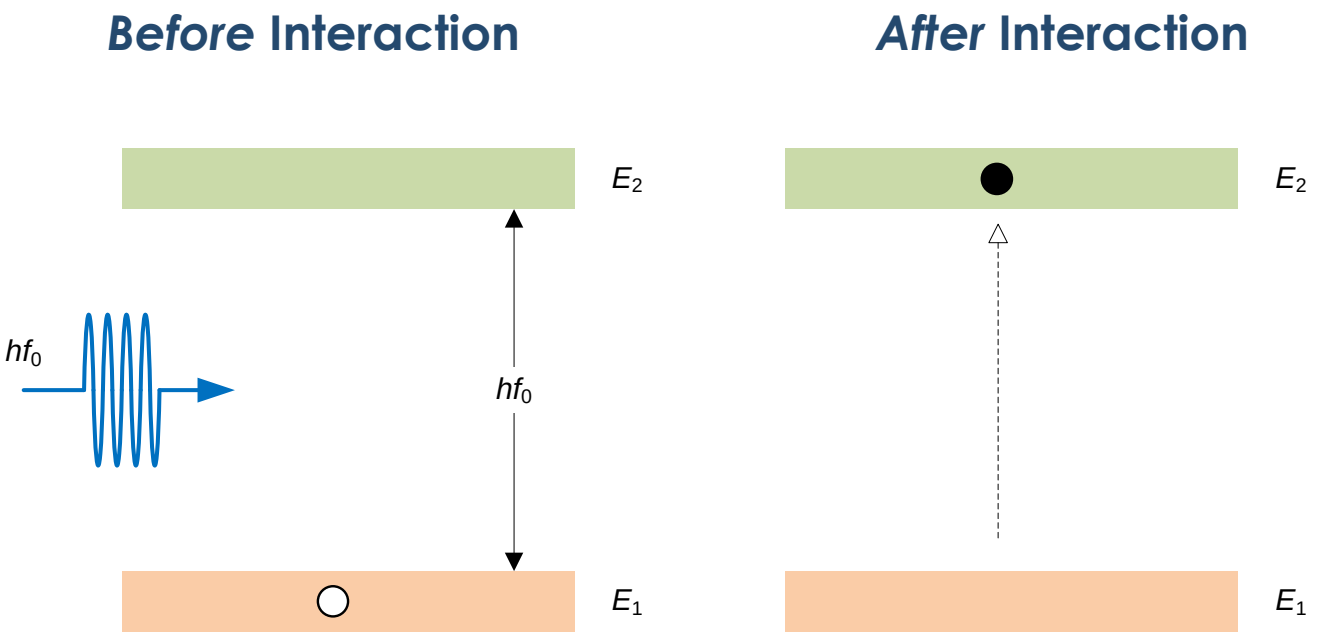
Semiconductor Lasers for Optical Communications



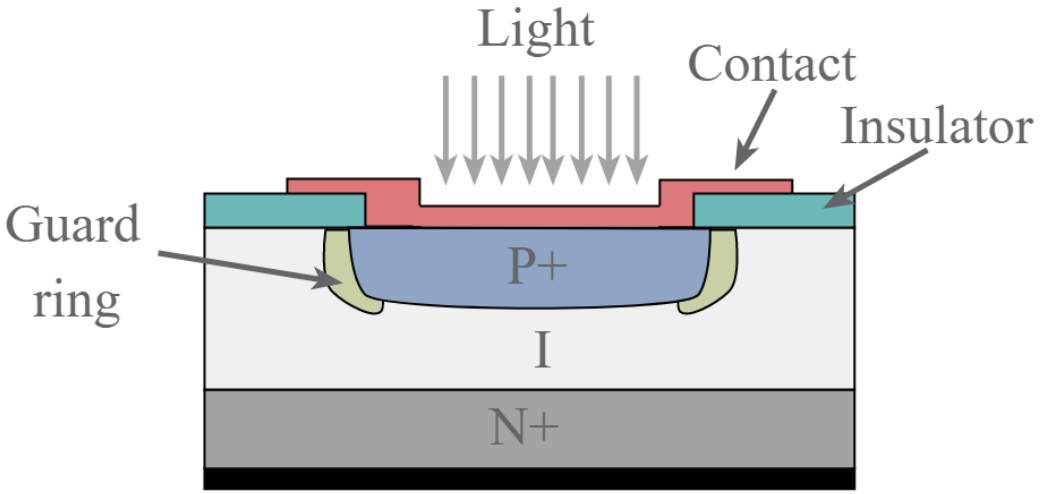
The p-i-n Photodiode



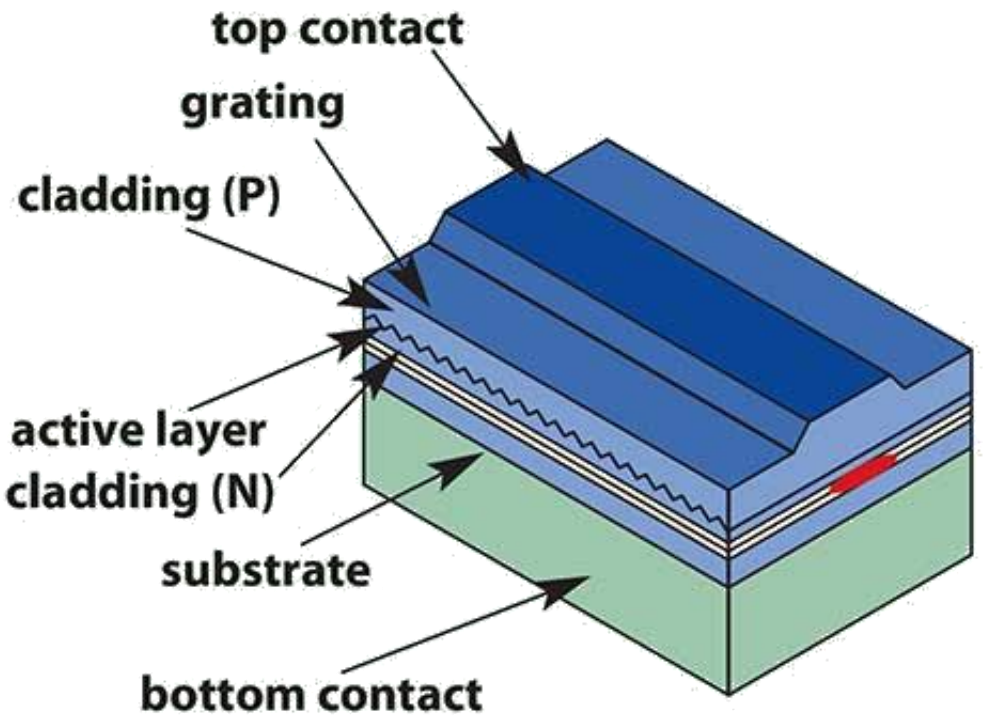
Absorption



The p-i-n Photodiode - structure

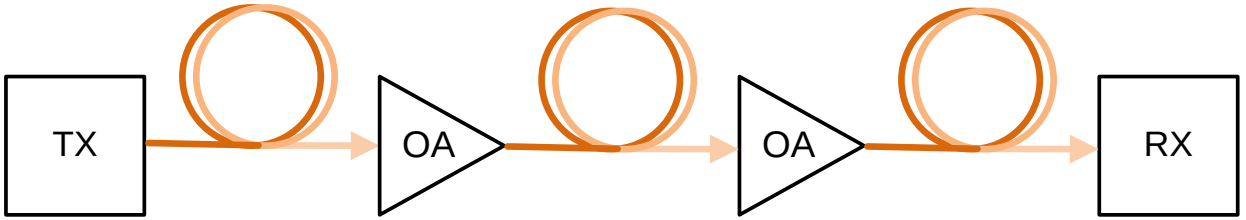


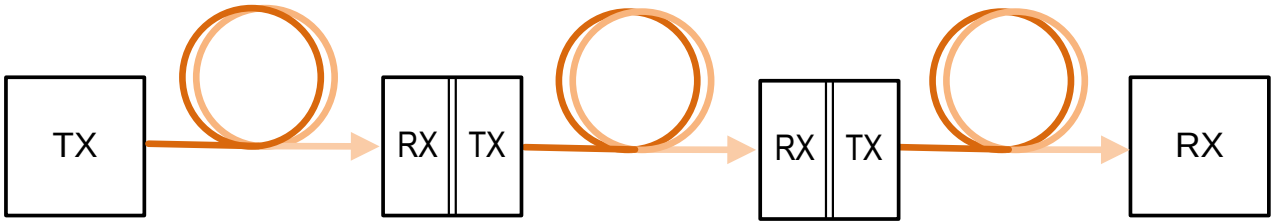
DFB Laser


top contact
grating
cladding (P)
active layer
cladding (N)
substrate
bottom contact

Multi-Hop Backbones

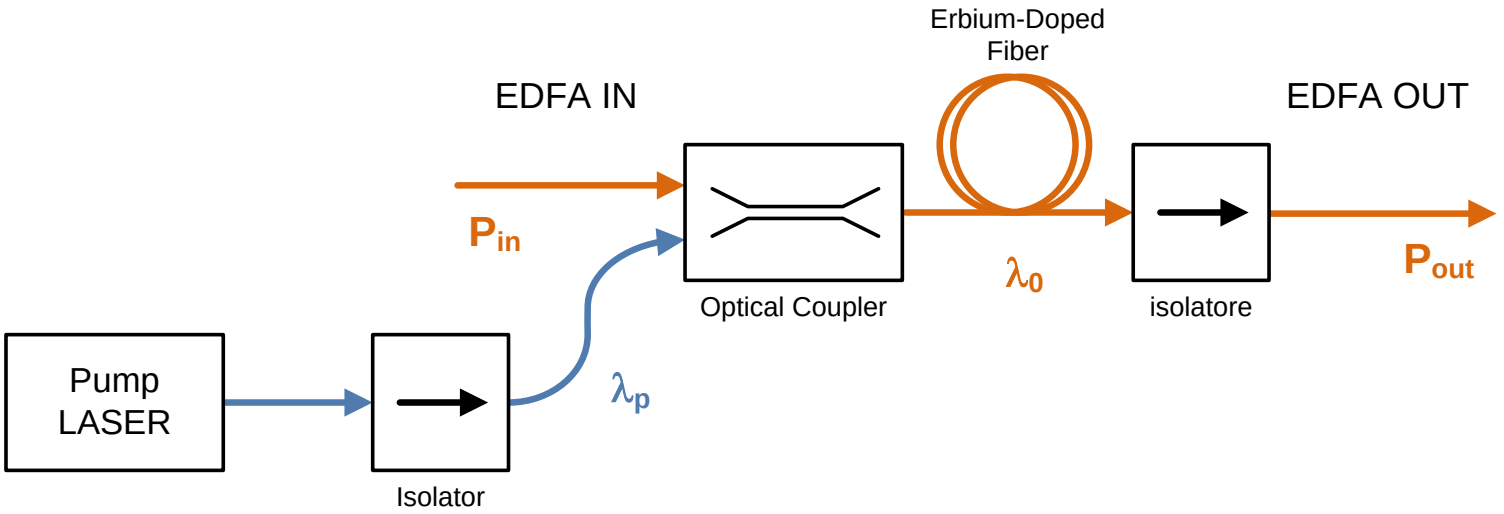
Transparent





Regenerative

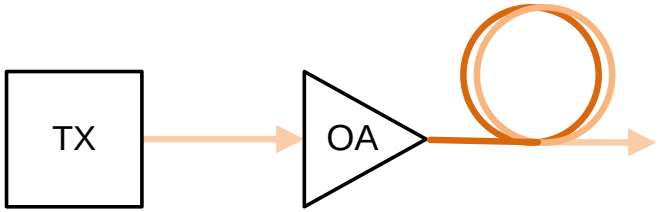
Optical Amplifiers



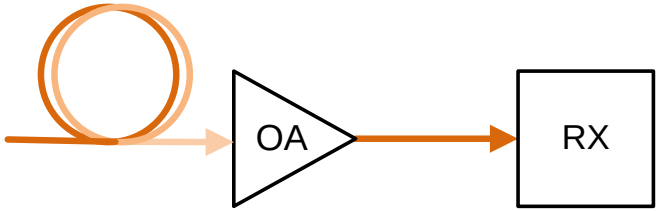
EDFA

Usage of Optcal Amplifiers

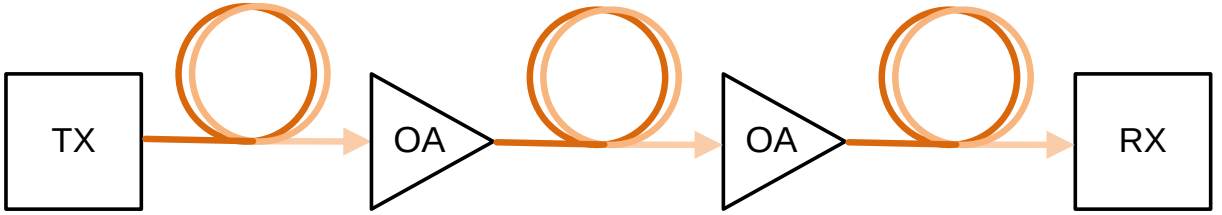
- **Booster**



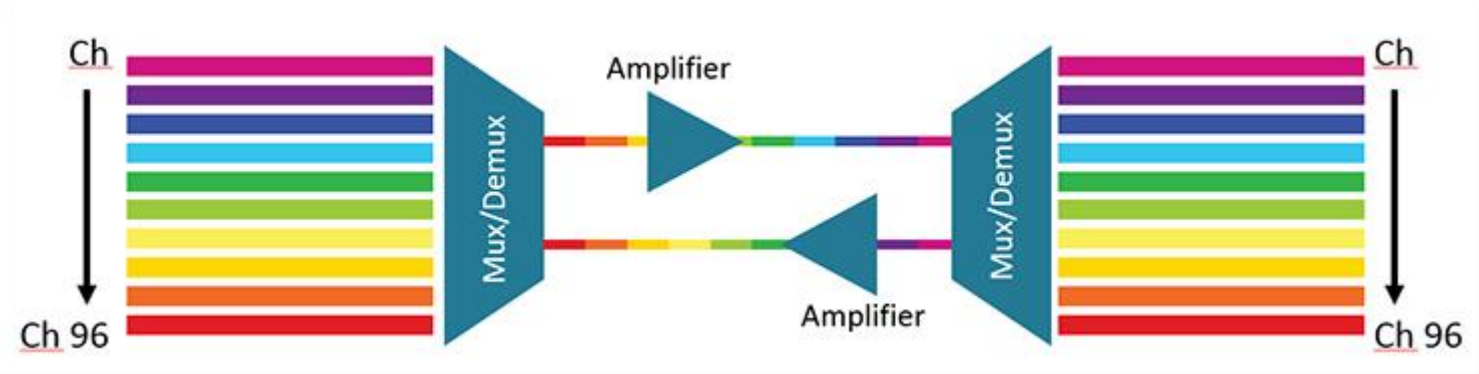
- **Pre-Amplifier**

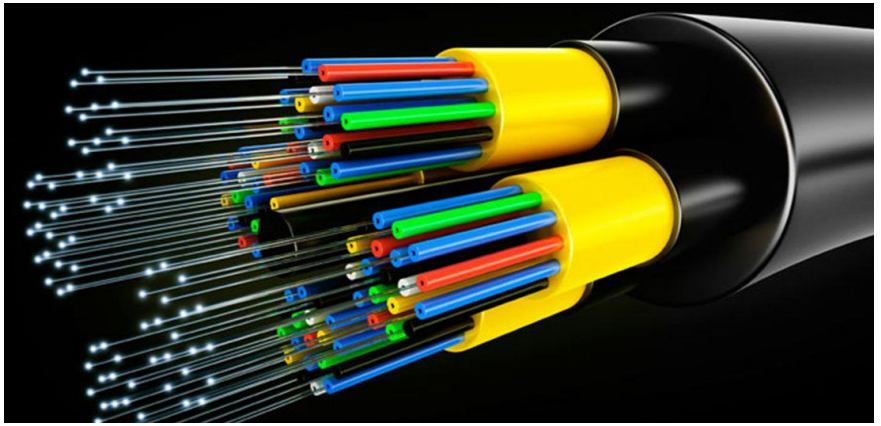


- **(Transparent) Repeater**



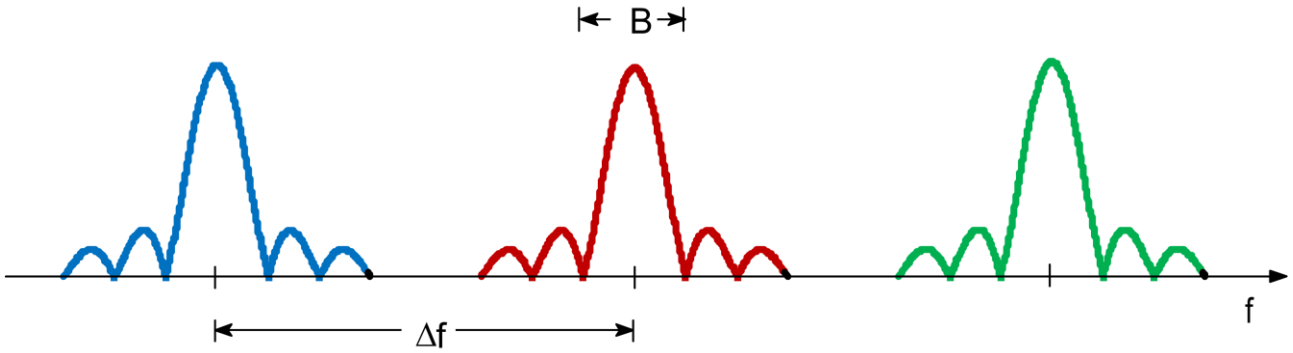
WIRED Systems for the Transport Network





Optical (D)WDM

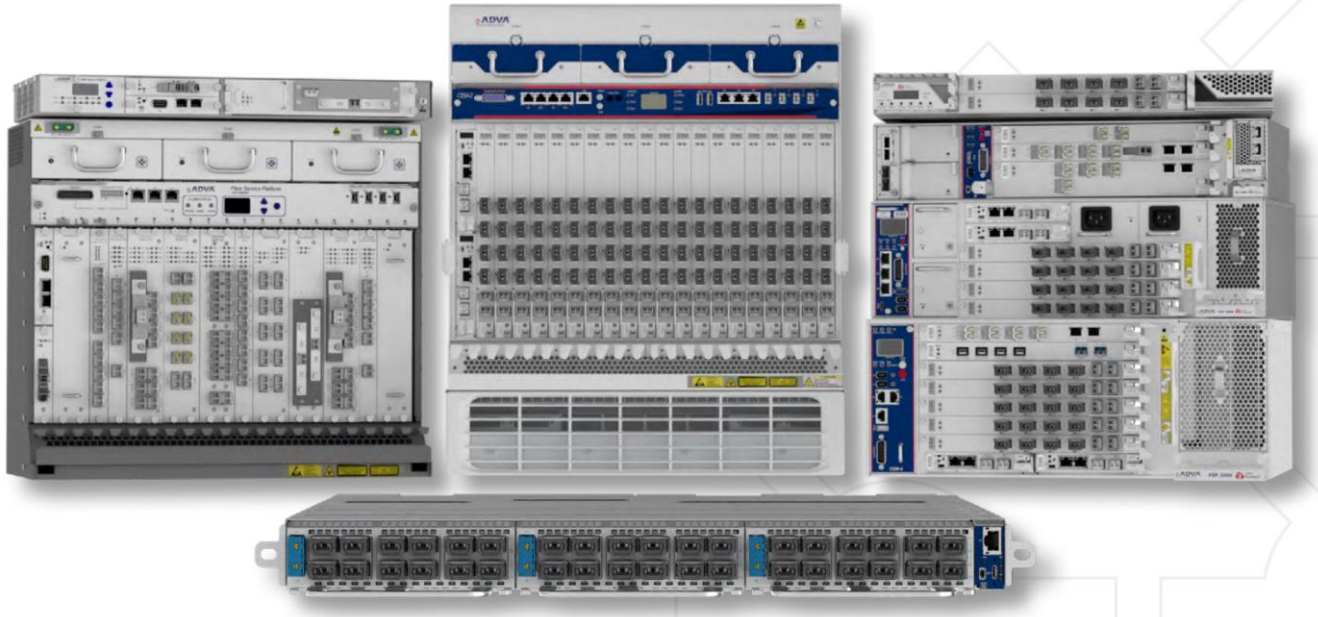
Why Transparent? WDM !



- **COARSE WDM (CDWM): Few channels, high Δf**
- **DENSe WDM (DWDM): Many channels, low Δf**

ITU channel	Frequency (THz)	Center Wavelength (nm)
61	196.1	1528.77
60	196.0	1529.55
59	195.9	1530.33
58	195.8	1531.12
57	195.7	1531.90
56	195.6	1532.68
55	195.5	1533.47
54	195.4	1534.25
53	195.3	1535.04
52	195.2	1535.82
51	195.1	1536.61
50	195.0	1537.40
49	194.9	1538.19
48	194.8	1538.98
47	194.7	1539.77
46	194.6	1540.56
45	194.5	1541.35
44	194.4	1542.14
43	194.3	1542.94
42	194.2	1543.73
41	194.1	1544.53
40	194.0	1545.32
39	193.9	1546.12
38	193.8	1546.92
37	193.7	1547.72
36	193.6	1548.51
35	193.5	1549.32
34	193.4	1550.12
33	193.3	1550.92
32	193.2	1551.72
31	193.1	1552.52
30	193.0	1553.33
29	192.9	1554.13
28	192.8	1554.94
27	192.7	1555.75
26	192.6	1556.55
25	192.5	1557.36
24	192.4	1558.17
23	192.3	1558.98
22	192.2	1559.79
21	192.1	1560.61
20	192.0	1561.42
19	191.9	1562.23
18	191.8	1563.05
17	191.7	1563.86

(ITU 100 GHz)



Your benefits

- **Scalability**
  Up to 600Gbit/s per wavelength and 38.4Tbit/s duplex capacity per fiber pair with best-in-class metrics; up to 3.6Tbit/s per 1RU chassis
- **Flexibility**
  From complete turnkey systems including all equipment necessary for end-to-end transport applications to disaggregated solutions
- **Pay-as-you-grow design**
  Modular and scalable architecture that ensures both low initial cost and flexibility into the future
- **Fully open and programmable**
  Open line system (OLS) architecture and YANG-based APIs (OpenConfig) for network disaggregation and easy integration into SDN-based environments
- **Dynamic and scalable optical layer**
  Multitude of ROADM options from metro-optimized 2-degree ROADM to multi-degree ROADM for flexgrid optical layer
- **ConnectGuard™ encryption technology**
  Certified data encryption with 100% throughput for any service on the transport layer