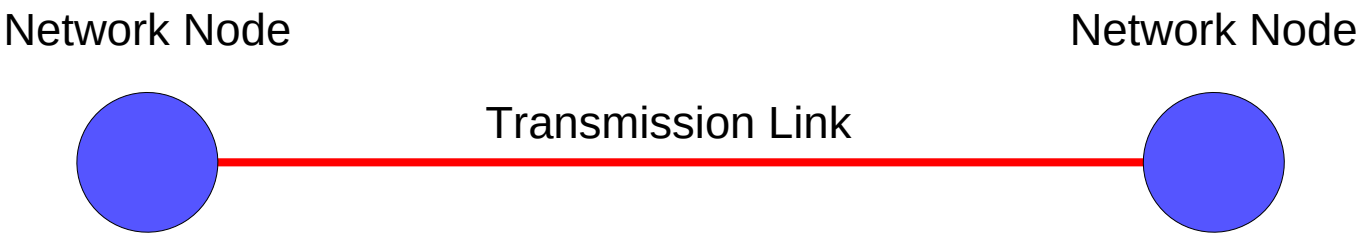
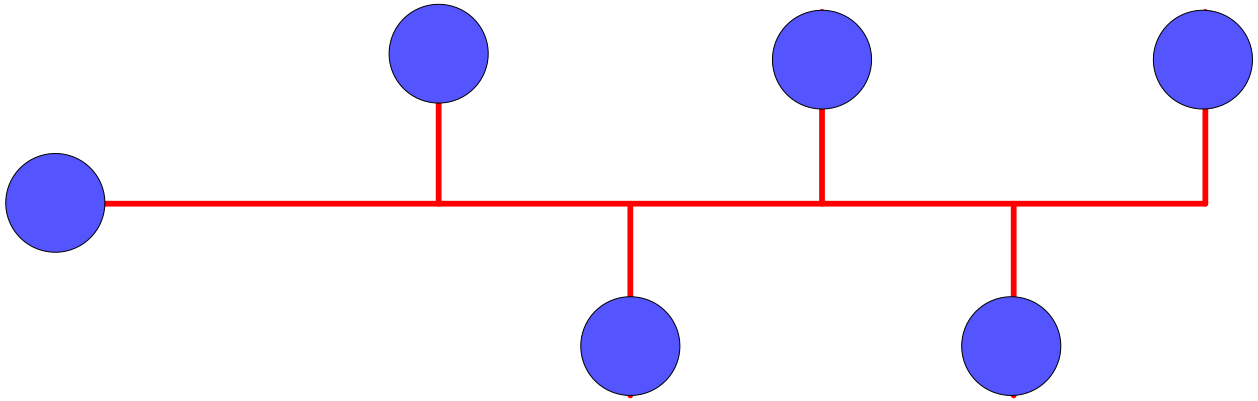
# Optical Networks and Transceivers

OPTI 500A, Lecture 2, Fall 2012

# The Simplest Network Topology

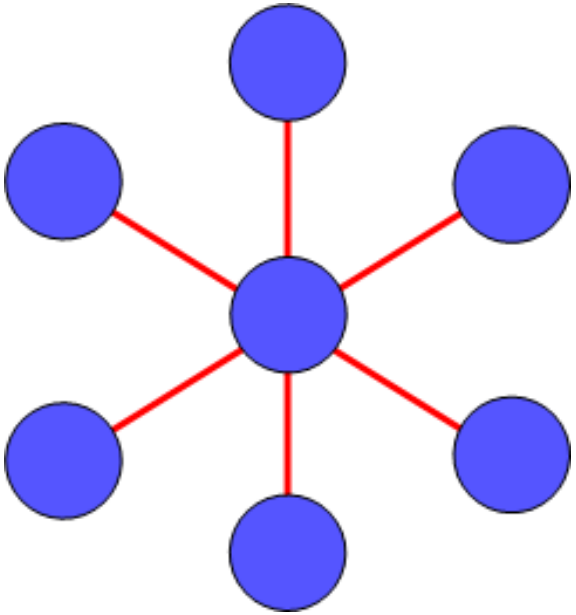


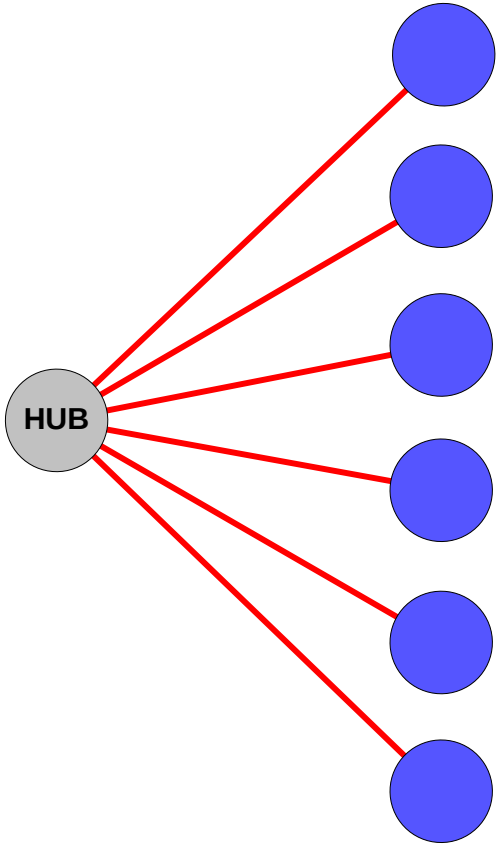
# Bus Topology



- Very easy to add a device to the bus
- Common topology for connecting devices by Ethernet
- The network must handle “Collisions”

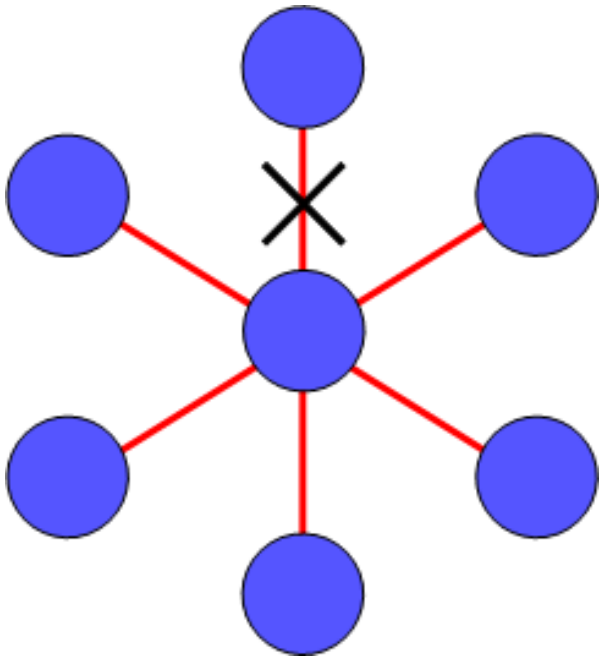
# Star and Hub Topology





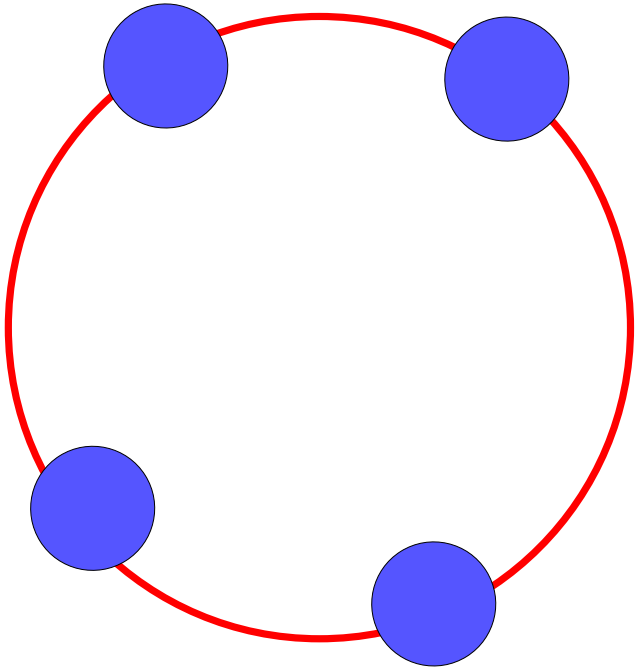

- No collisions
- Devices easily added by connecting them to the hub, but may require more wiring than a bus

# Recovery from Link Failure



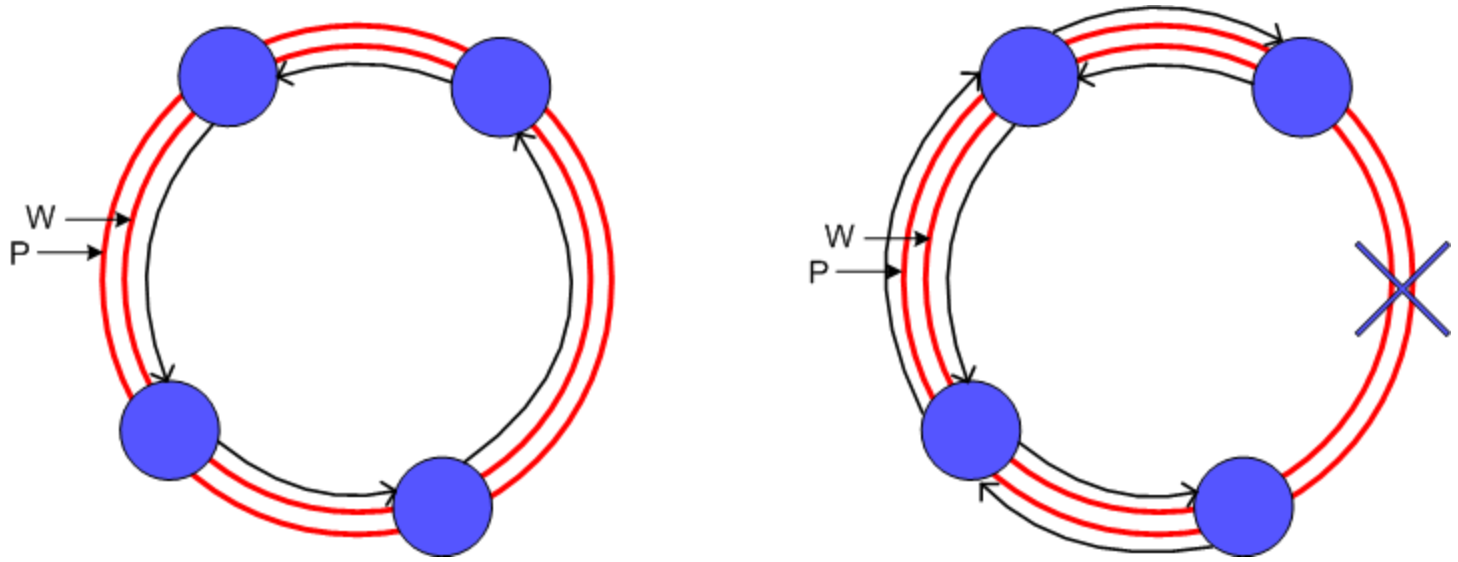
- A link failure isolates a node in a network with star topology until the link can be repaired.

# Ring Topology



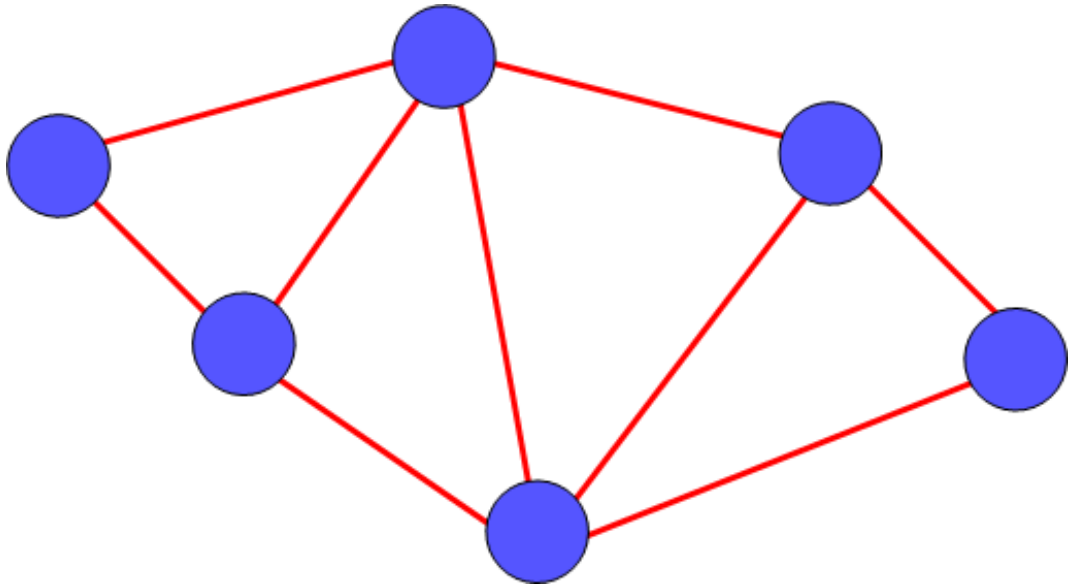
- A ring is the simplest topology for which all nodes remain connected after a link failure.

# Dual Rings



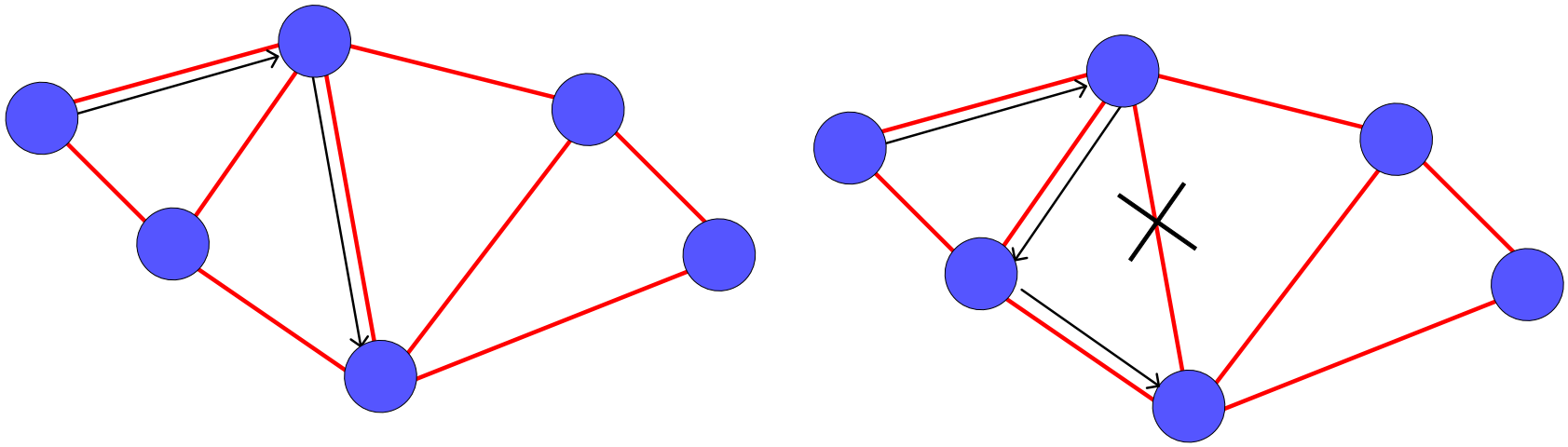

- Dual uni-directional rings, with working (W) and protection (P) rings are are part of the popular SONET networking protocol

# Mesh Topology



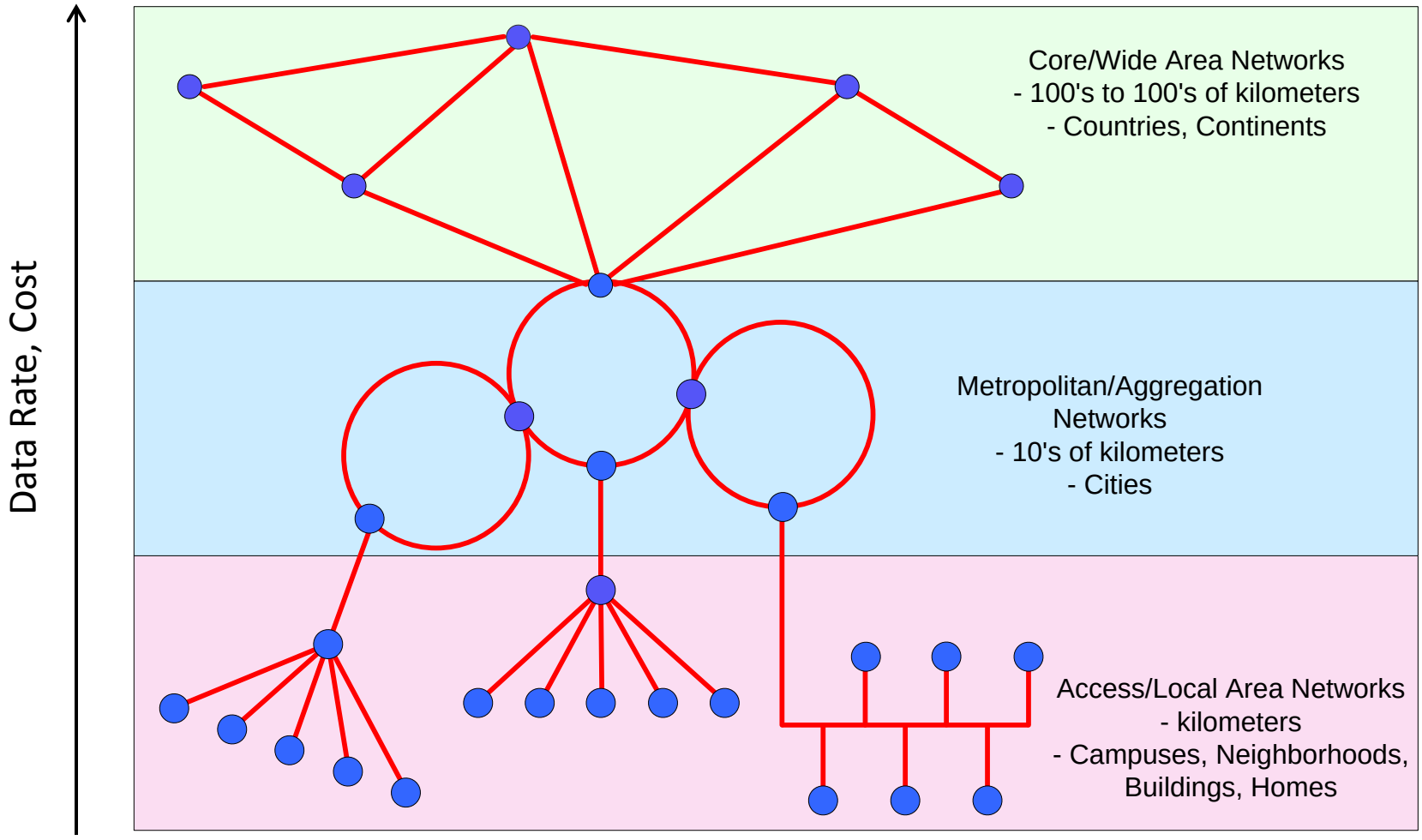
- Mesh networks are used to connect nodes that are distributed over large geographical areas.

# Recovery from Link Failure

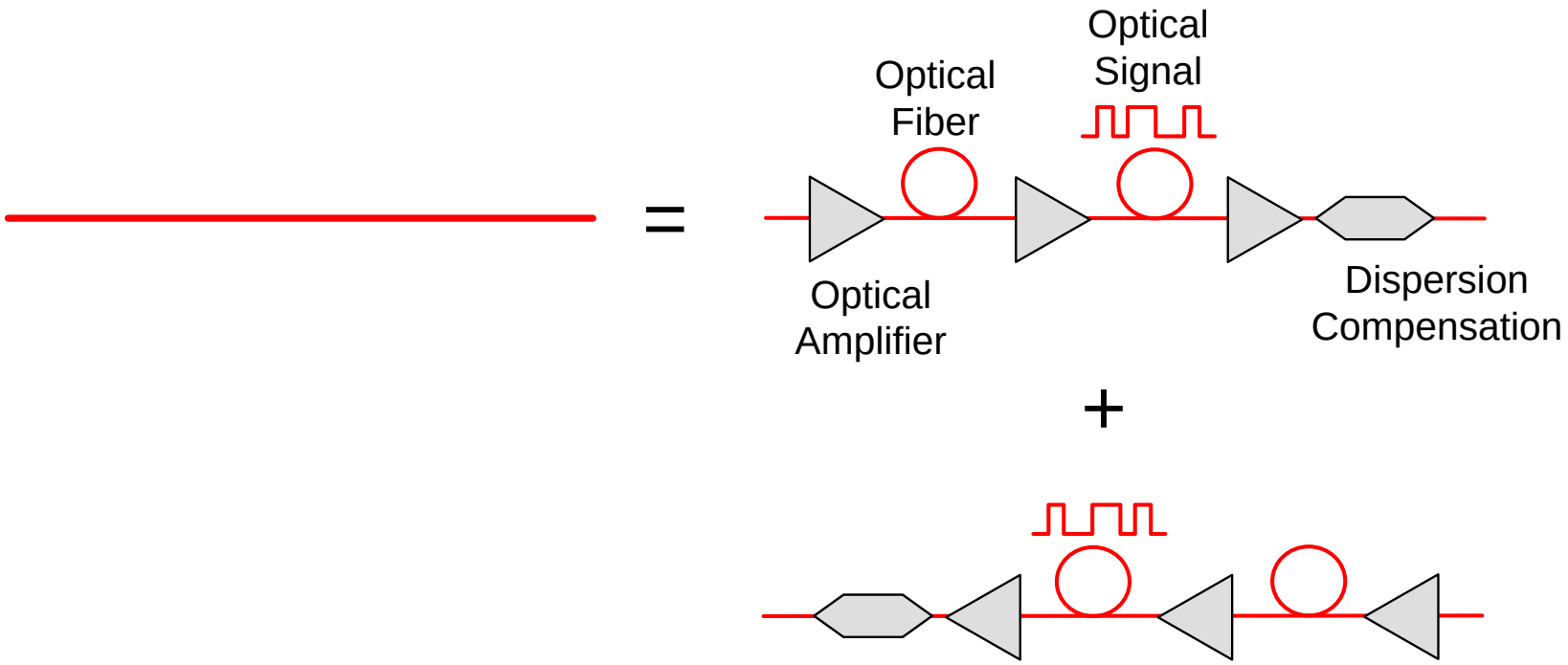


- Networks with mesh topology are robust

# Network Hierarchy

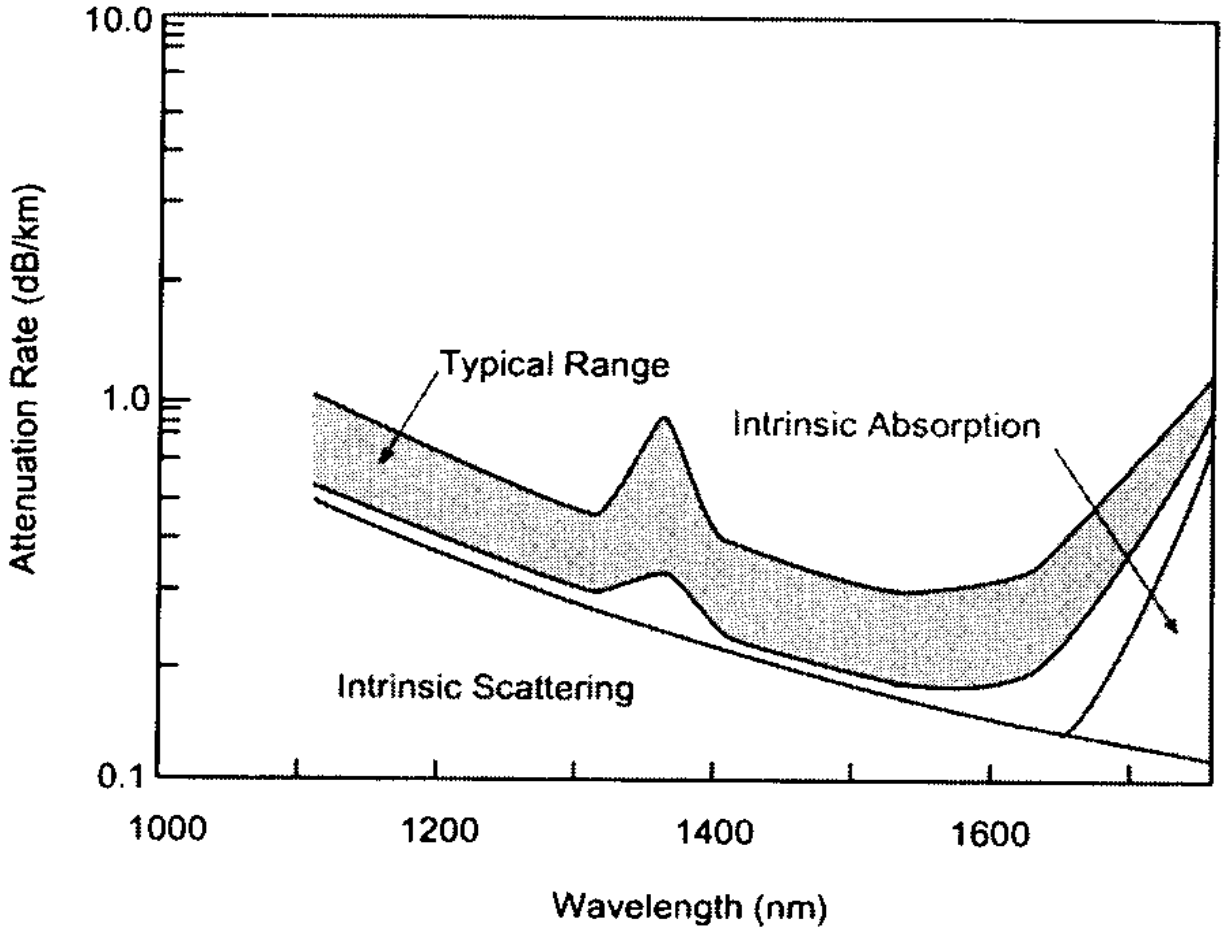


# Optical Network Links

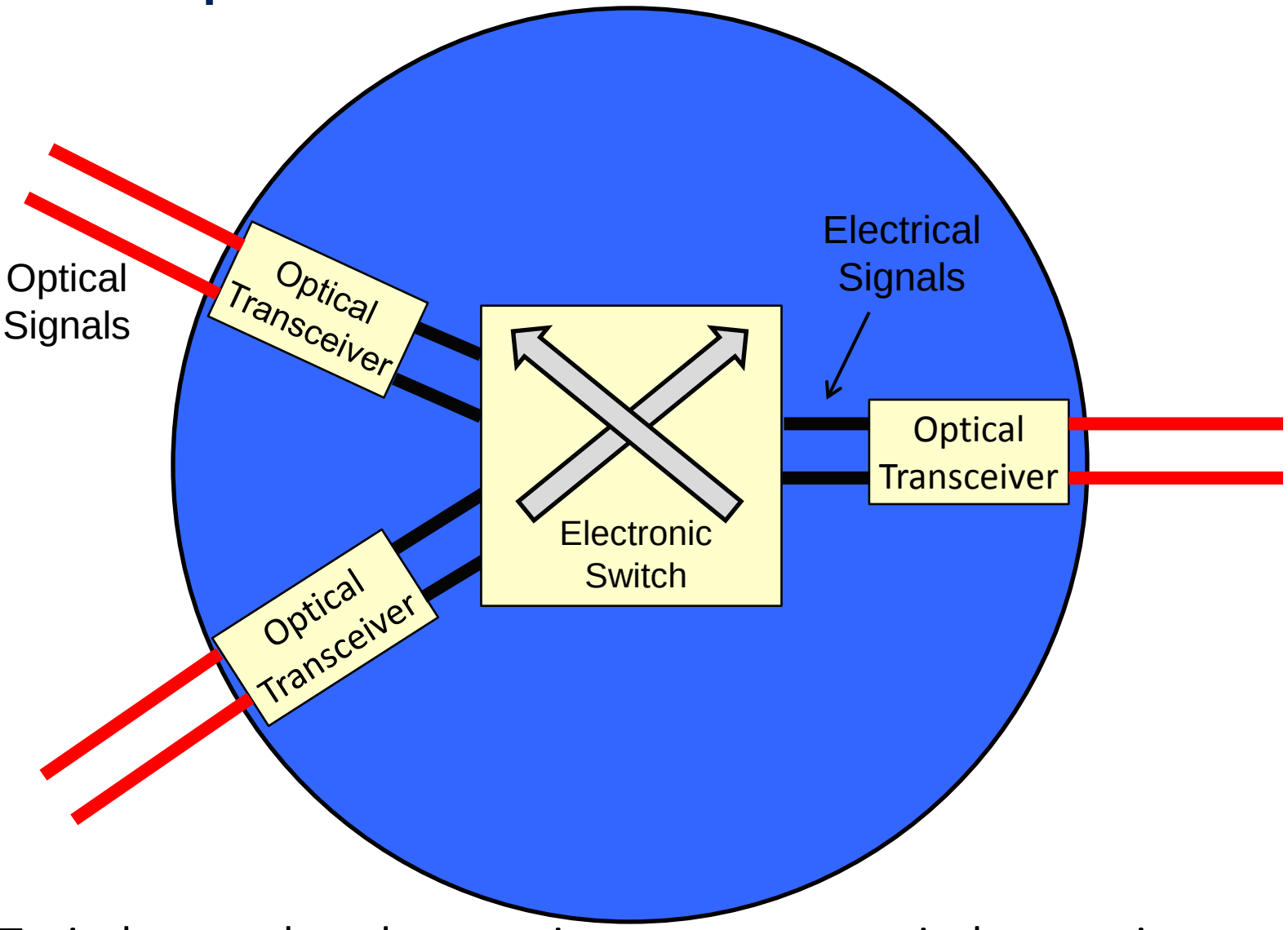



- Transmission links are lengths of optical fiber (or free-space beam paths) that may have components inserted that condition the optical signal. The links may include multiple fibers that enable bi-directional communication and/or increase capacity.

# Optical Fibers

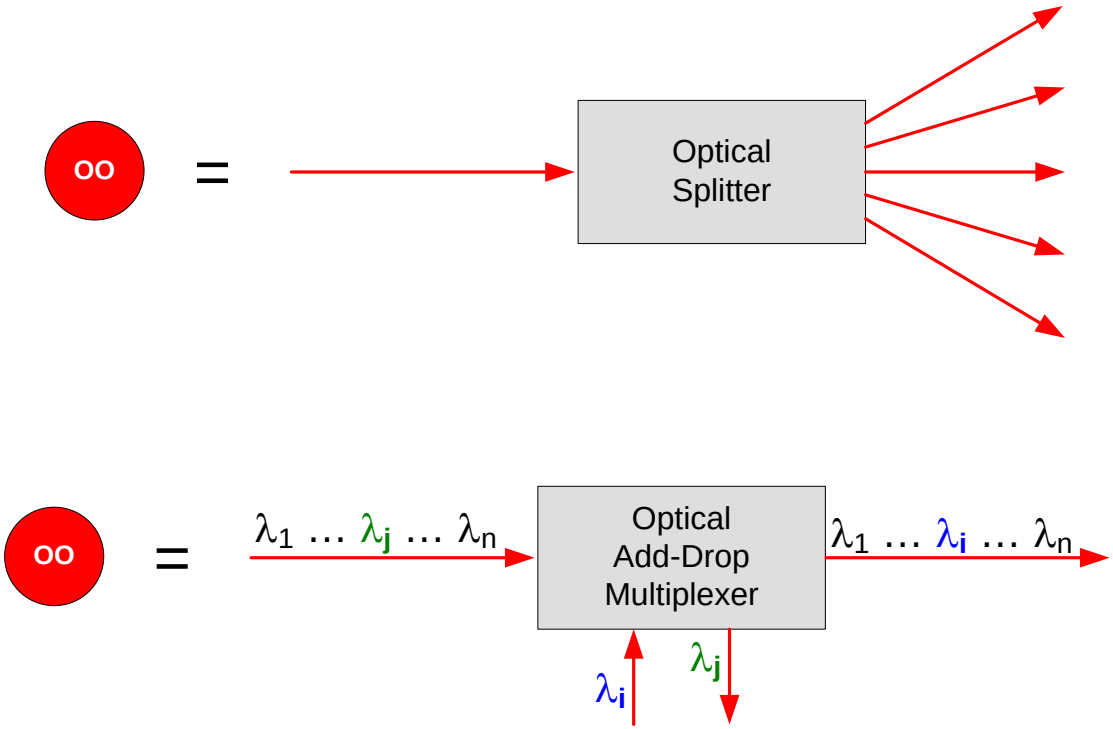


# Optical Network Nodes



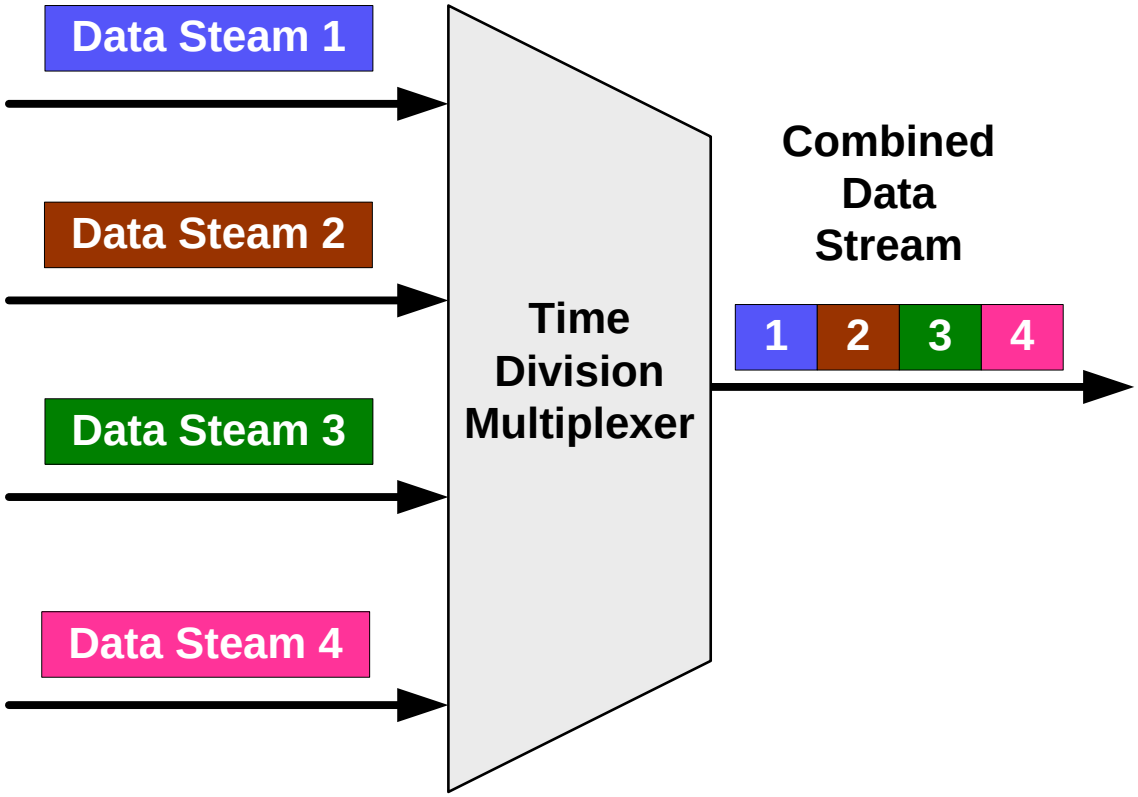

- Typical network nodes contain one or more optical transceivers and optical-to-electrical-optical (OEO) conversion.

# “O-O” Optical Network Nodes



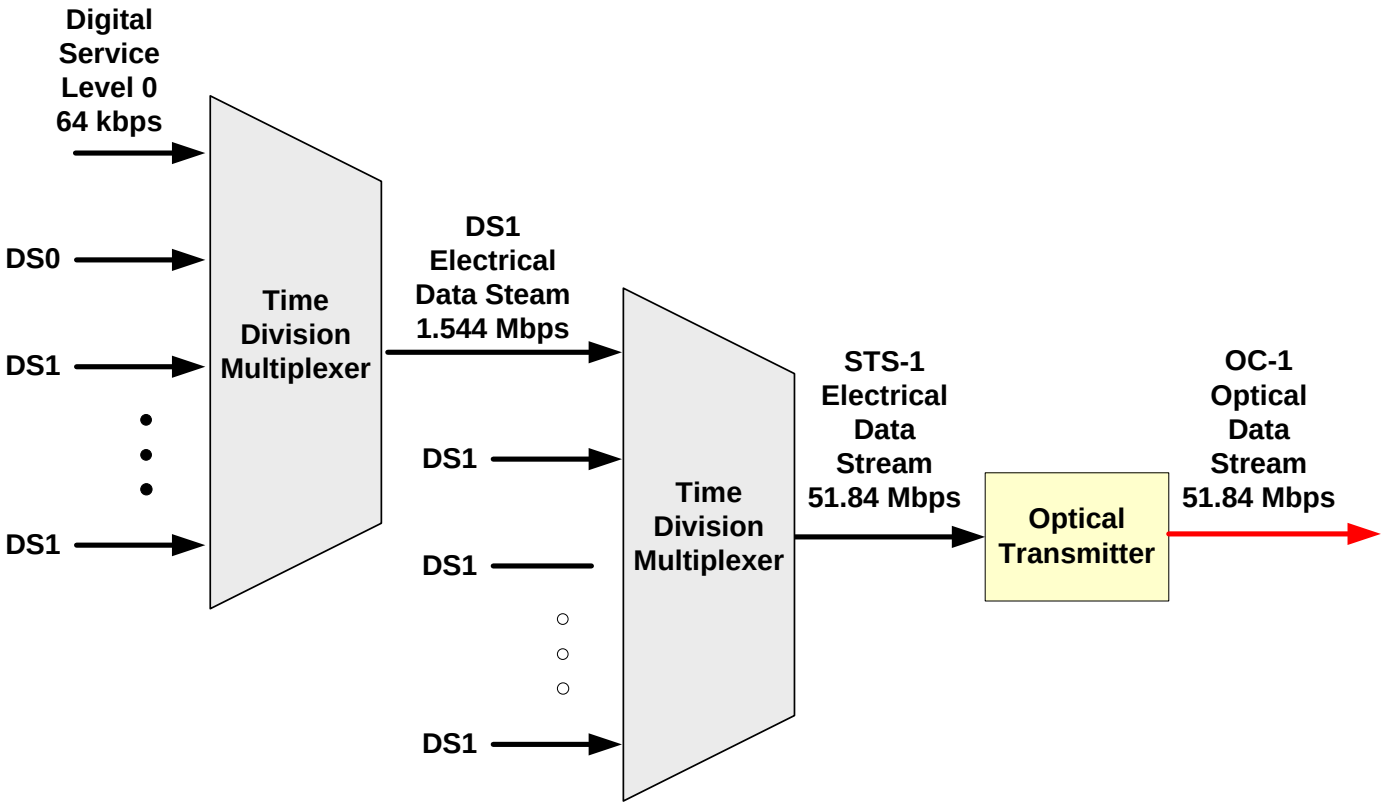

- “Transparent” optical-to-optical nodes are becoming more common.

# Time Division Multiplexing




- Time Division Multiplexing (TDM) combines lower data rate signals into higher data rate signals

# Time Division Multiplexing

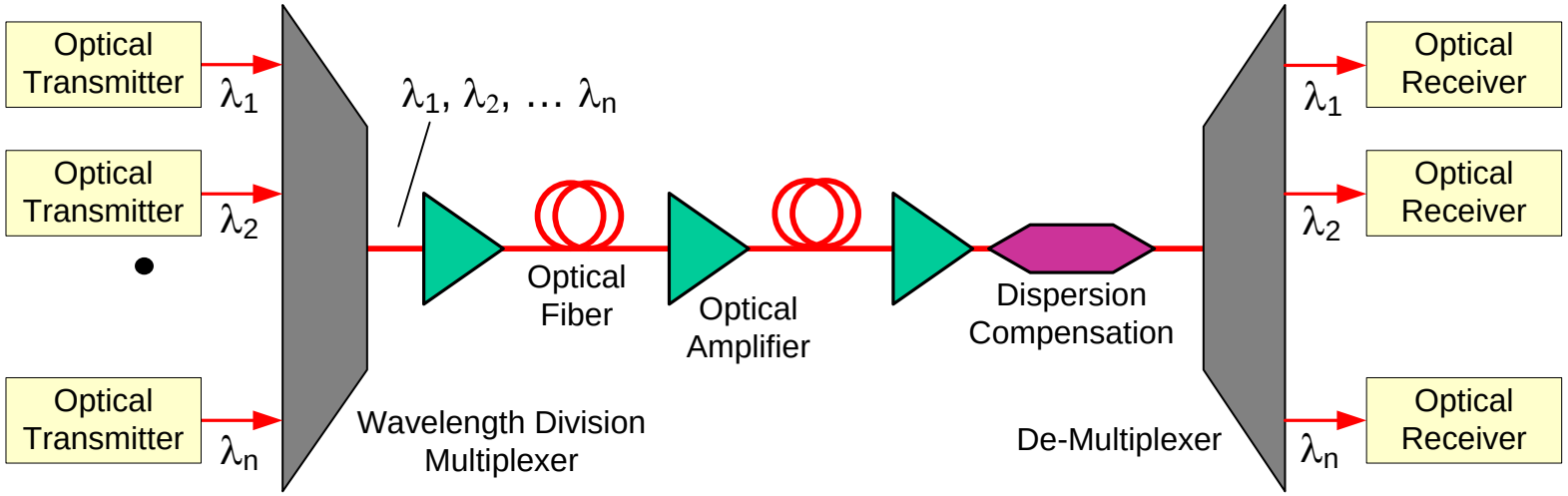



- Many individual phone calls carried by Digital Service Level 0 (DS0) links can be multiplexed for transmission over long distances.
- An OC-1 (Optical Carrier 1) carries 672 phone calls.

# The Synchronous Optical Network (SONET) Hierarchy

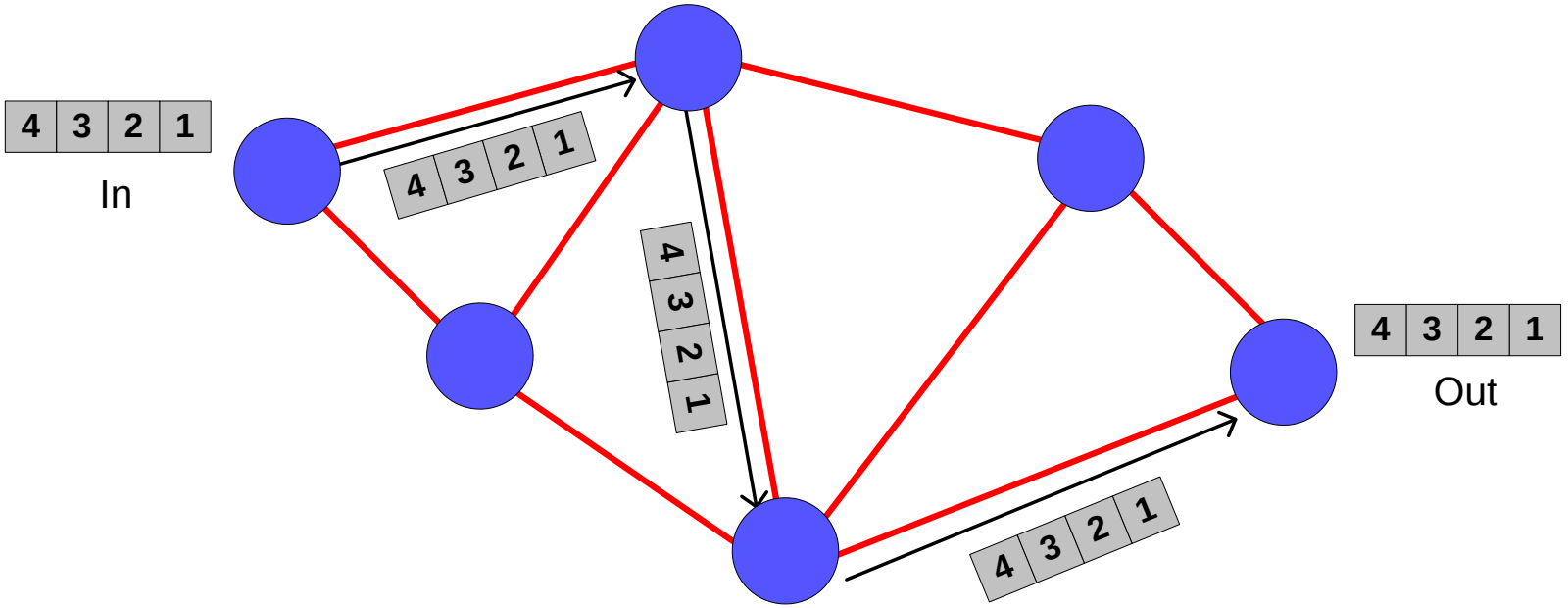
| Signal Designation | Data Rate (Mbps) | Phone Call Capacity |
|---|---|---|
| OC-1 | 51.84 | 672 |
| OC-3 | 155.82 | 2016 |
| OC-12 | 622.08 | 8064 |
| OC-48 | 2488.32 | 32256 |
| OC-192 | 9953.28 | 129024 |
| OC-768 | 39,813.12 | 516096 |

# Wavelength Division Multiplexing



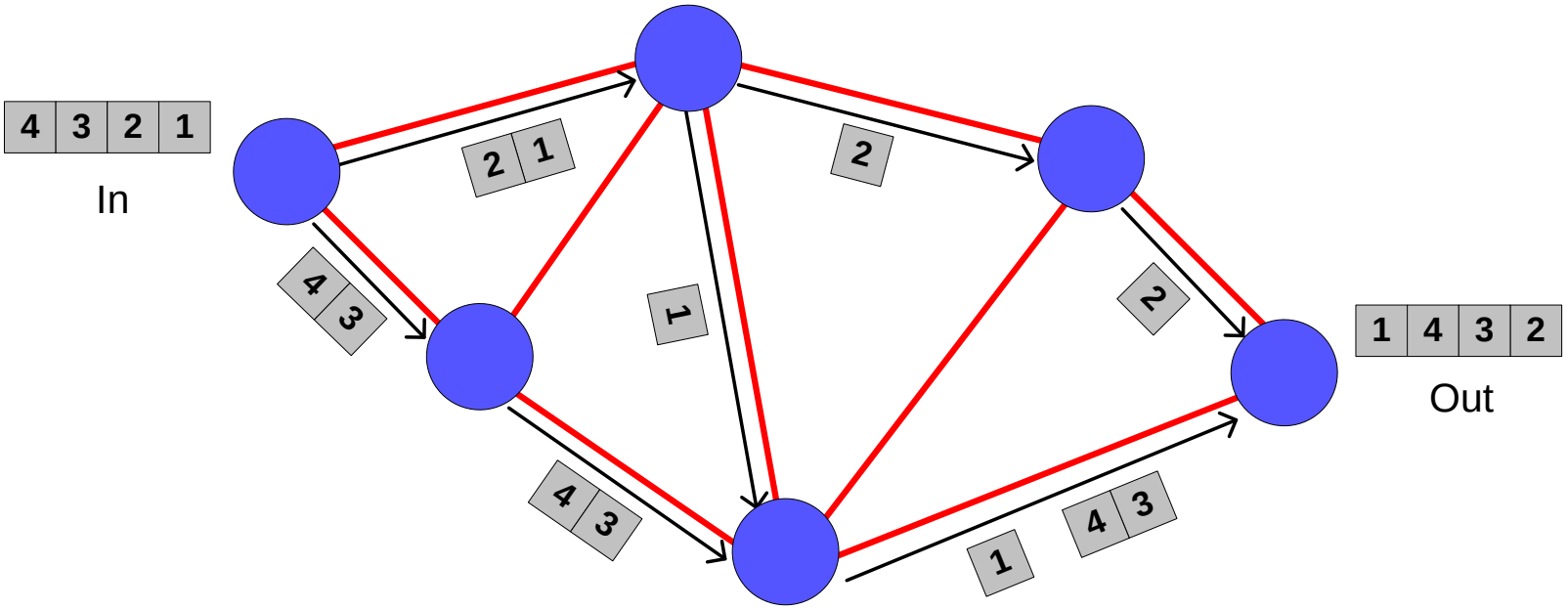

- A wavelength division multiplexed (WDM) link with 80 OC-192 wavelength channels operates at close to 1 Terabit per second and carries just over 10,000,000 simultaneous phone calls

# Circuit Switching (Telecom Networks)



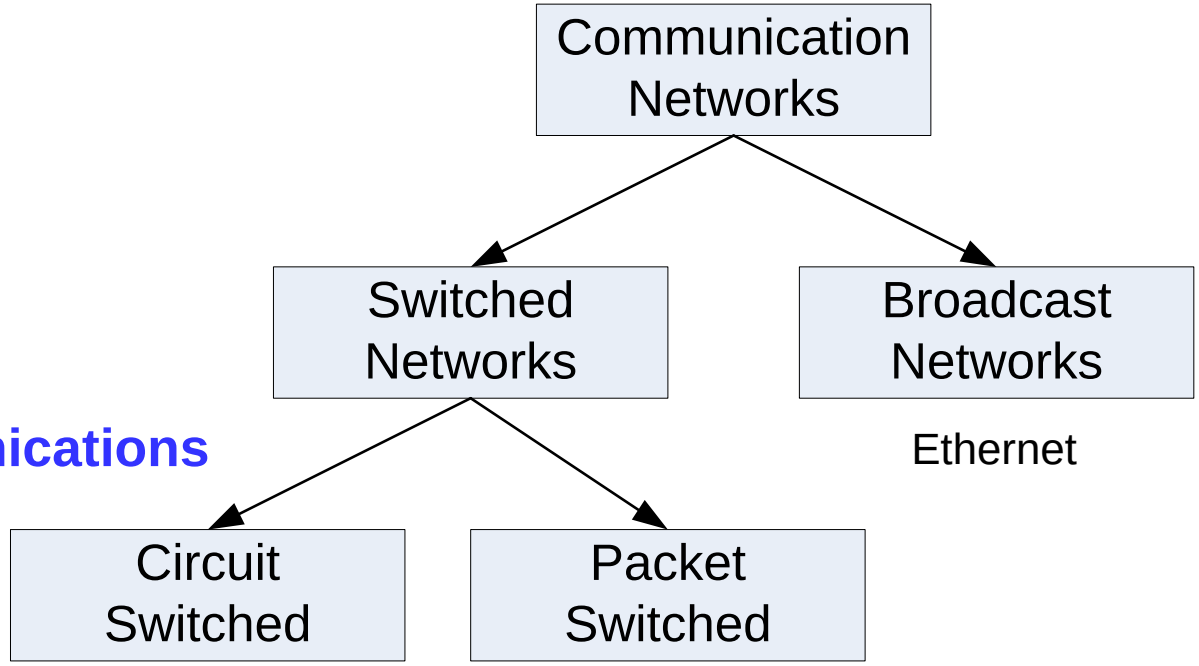

- When data is “circuit switched” a fixed path is established for the duration of the transfer

# Packet Switching



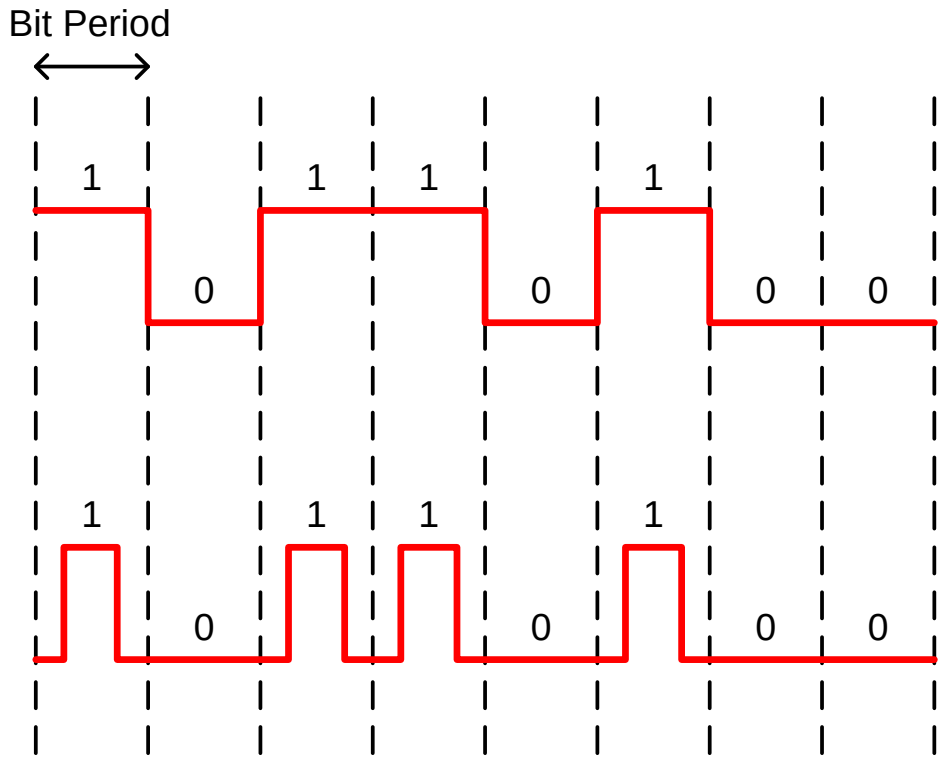

- When data is switched packet by packet, individual packets (or frames) can follow separate paths

# Network Classification by Switching Type




- There is no switching in broadcast networks
- Ethernet networks often contain broadcast regions connected by packet switches

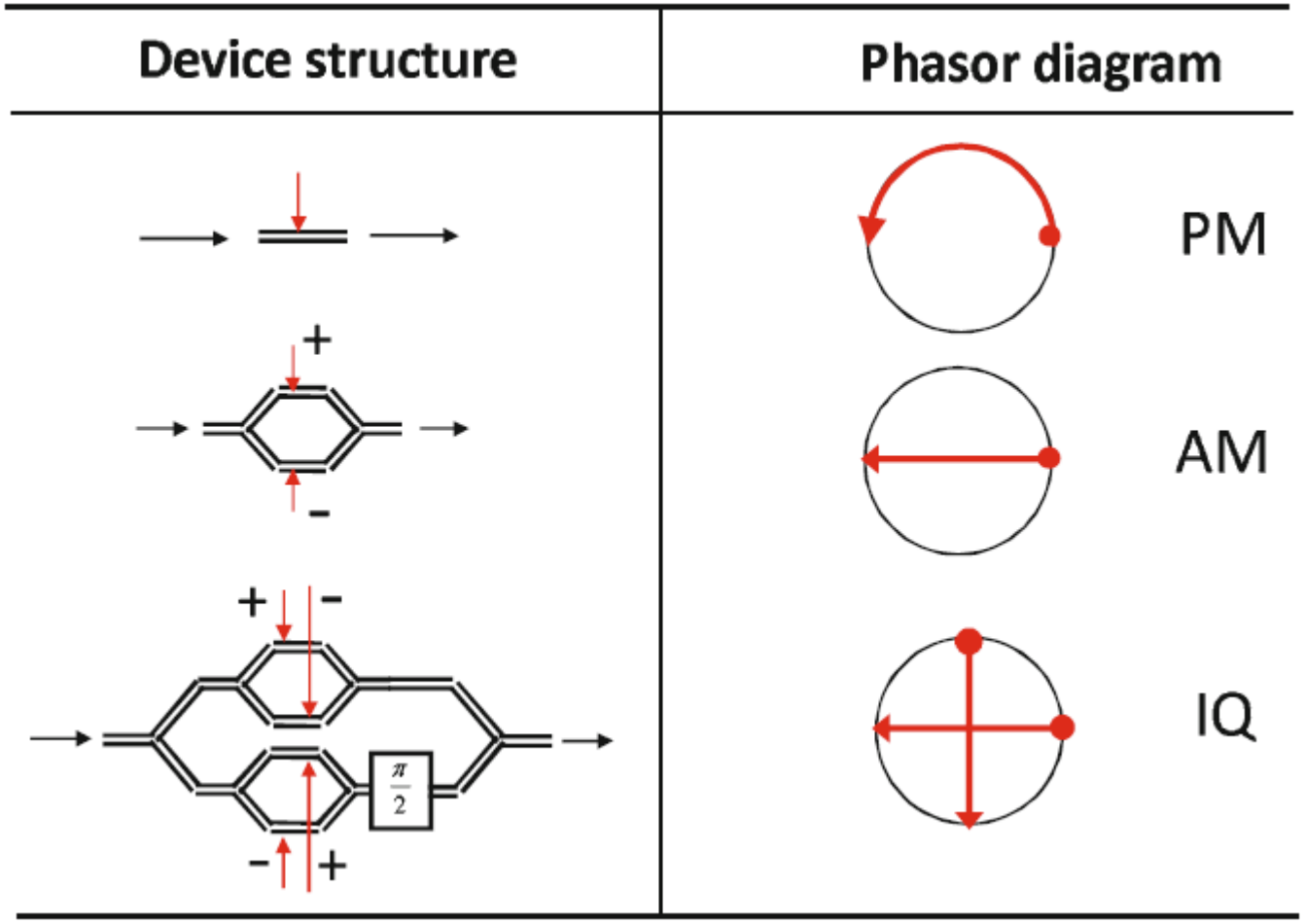
# SONET Uses Binary, Amplitude Modulated, Non-Return-to-Zero Coding




Non-Return-to-Zero (NRZ) Coding

Return-to-Zero (RZ) Coding

# Phase, Amplitude, and In-Phase and Quadrature Modulation

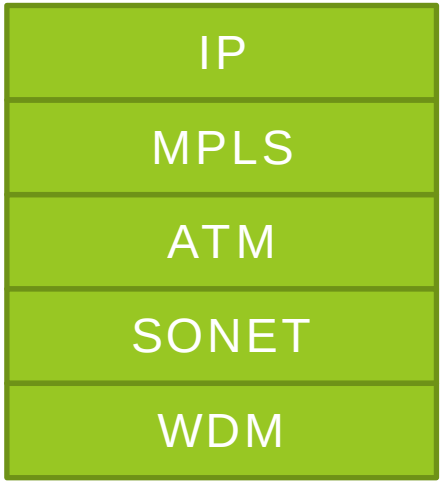



"Coherent Optical Communications: Historical Perspectives and Future Directions", Kazuro Kikuchi, in *High Spectral Density Optical Communication Technologies* (Springer Verlag, 2010)

# Network Convergence

- Network convergence refers to the use of both datacom and telecom protocols and hardware in the same network.
- The motivation is to share resources and to combine the flexibility of datacom networks with the high capacity and Quality of Service assurance of telecom networks

# A More Fully Converged Network

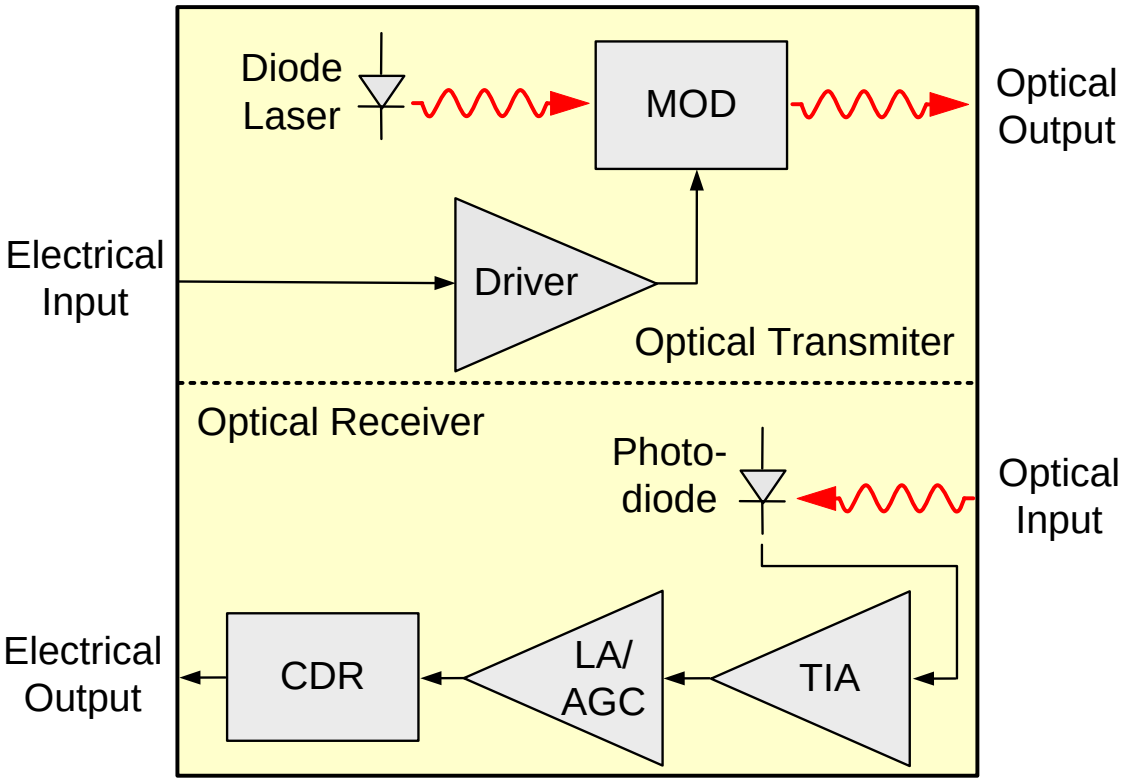



- The communication infrastructure has evolved so that complicated convergence schemes like this are widely used today
- People agree that simplification would be a good thing

# “IP over WDM”


- IP is here to stay
- So is WDM
- The question is how to most efficiently build networks that use both
- Real world solutions must take into account the current network infrastructure

# An Optical Transceiver




MOD = Optical Modulator

TIA = Transimpedance Amplifier
LA = Limiting Amplifier
AGC = Automatic Gain Control
CDR = Clock and Data Recovery

# Why go to the trouble of using an external modulator?

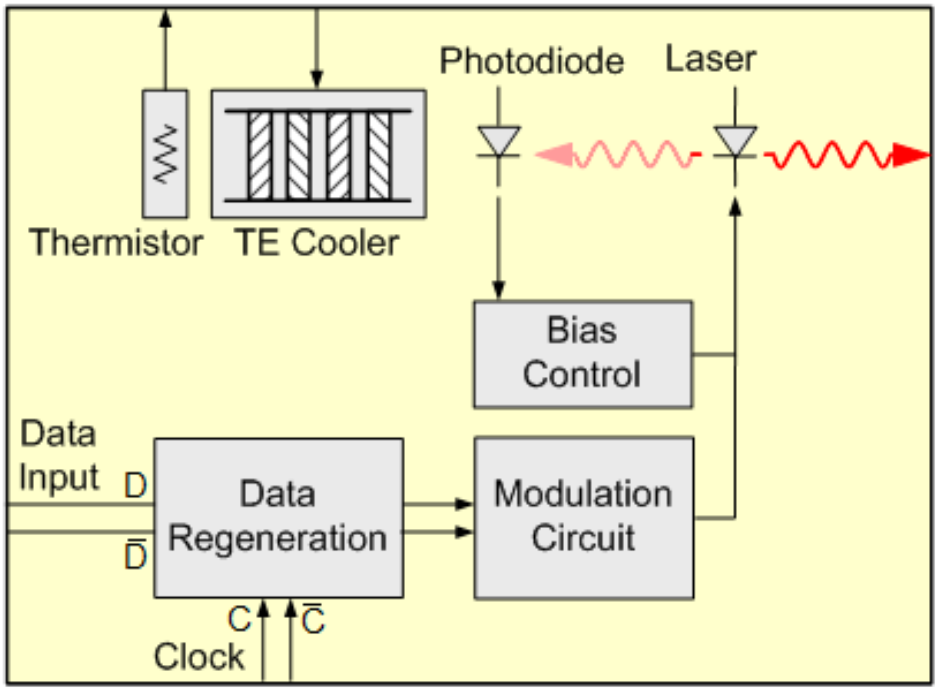
***Table 7.1*** Maximum (unrepeatered) transmission distances over an SMF at 1.55 $\mu$m for various transmitter types based on Eqs. (7.19), (7.18), and (7.16) with $D = 17\,\text{ps/(nm} \cdot \text{km)}$.

| Transmitter Type | 2.5 Gb/s | 10 Gb/s |
|---|---|---|
| Fabry-Perot laser ($\Delta\lambda = 3$ nm) | 4 km | 1 km |
| Distributed feedback laser ($\alpha = 4$) | 230 km | 15 km |
| External modulator ($\alpha = 0$) | 960 km | 60 km |

From Broadband circuits for optical fiber communication, Eduard Säckinger, Wiley 2005

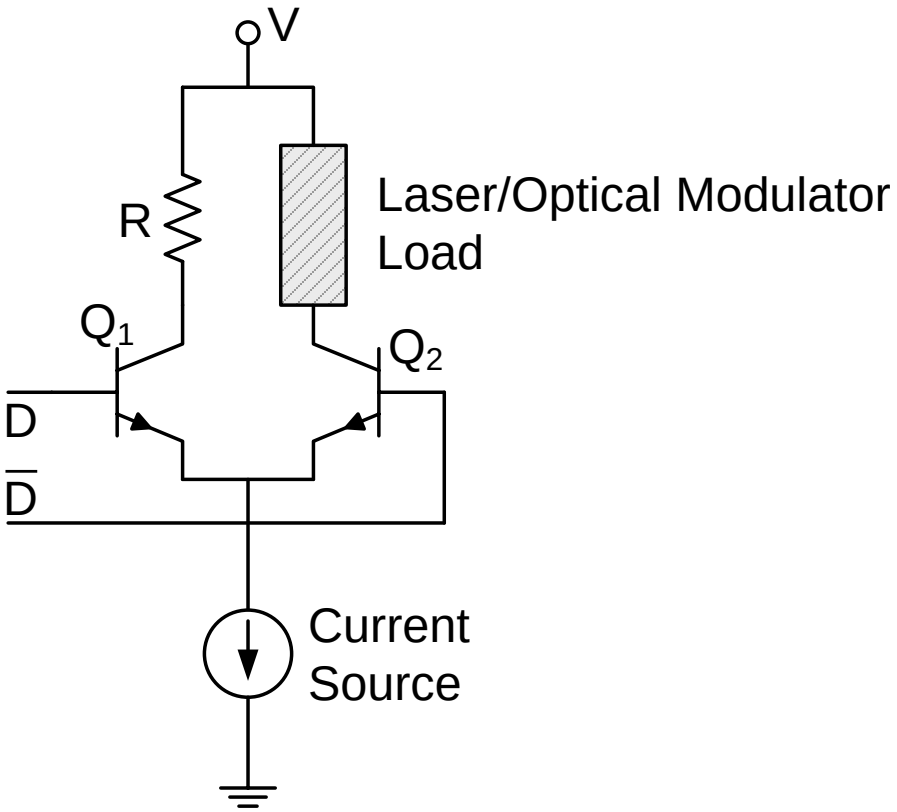
- An external modulator offers extended transmission distance

# The Inside of an Optical Transmitter

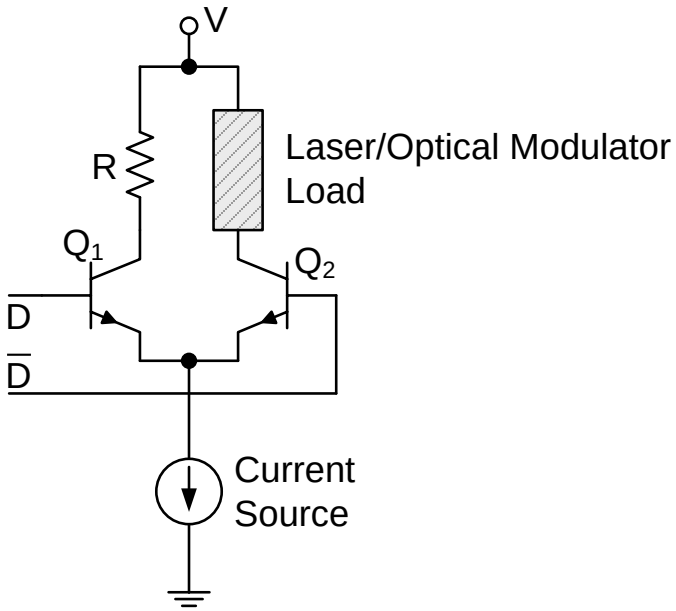



- The transmitter includes components for control of temperature and average power
- A transmitter may contain circuitry for re-shaping and re-timing data

# Basic Laser/Modulator Drive Circuitry

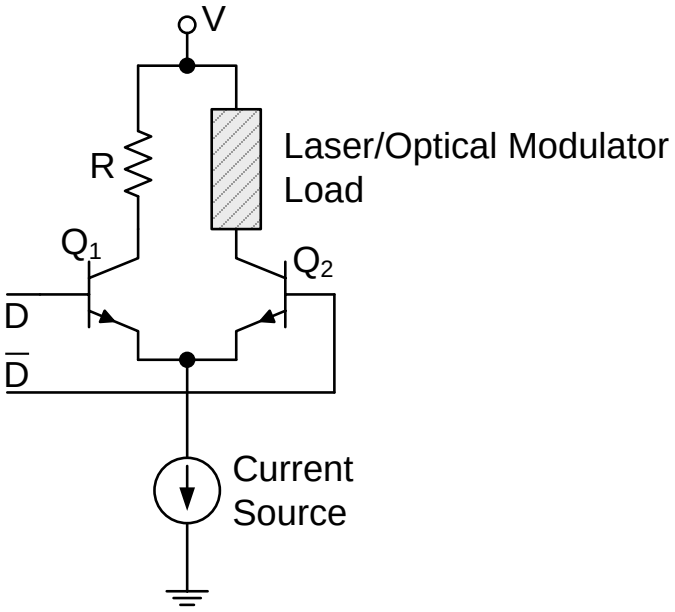


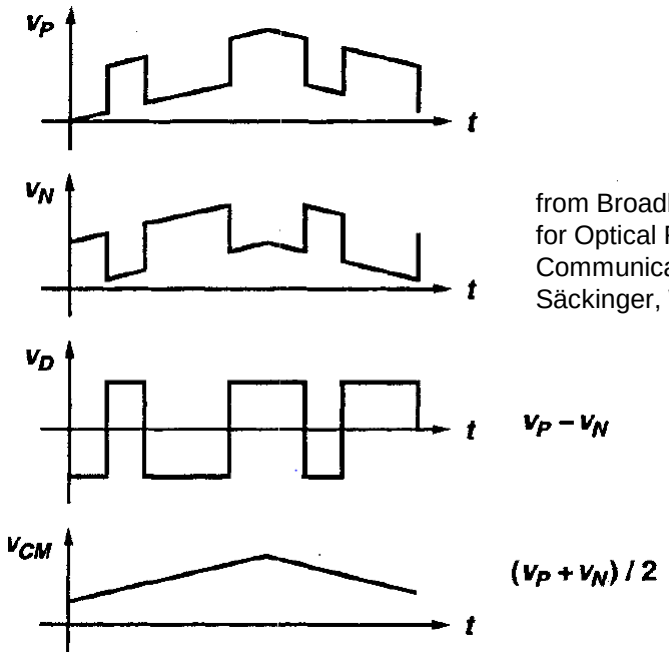
# Why do we use current steering?




- A constant current to the ground through the current source avoids current transients due to parasitic capacitances and inductances

# Why do we use differential input?

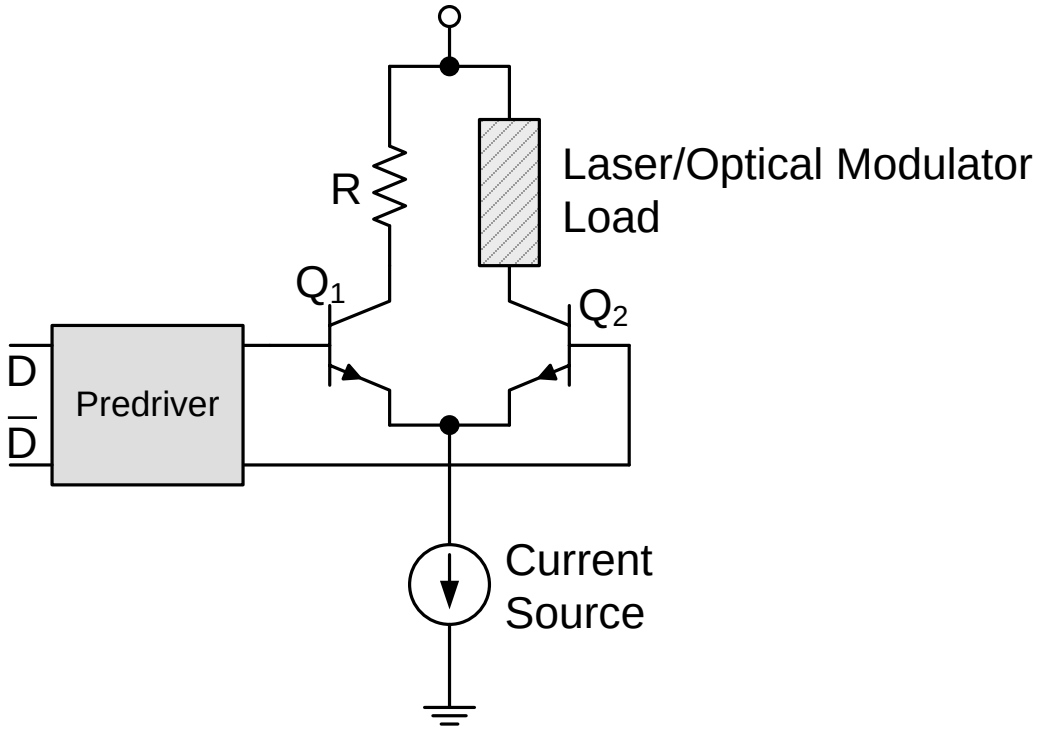



from Broadband Circuits for Optical Fiber Communication, Eduard Säckinger, Wiley 2005

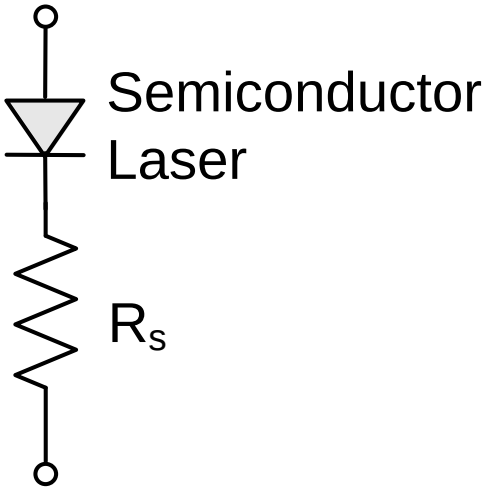
- The differential design is insensitive to common-mode noise and avoids the need for an input reference voltage

# Drive Circuitry with an Additional Predriver



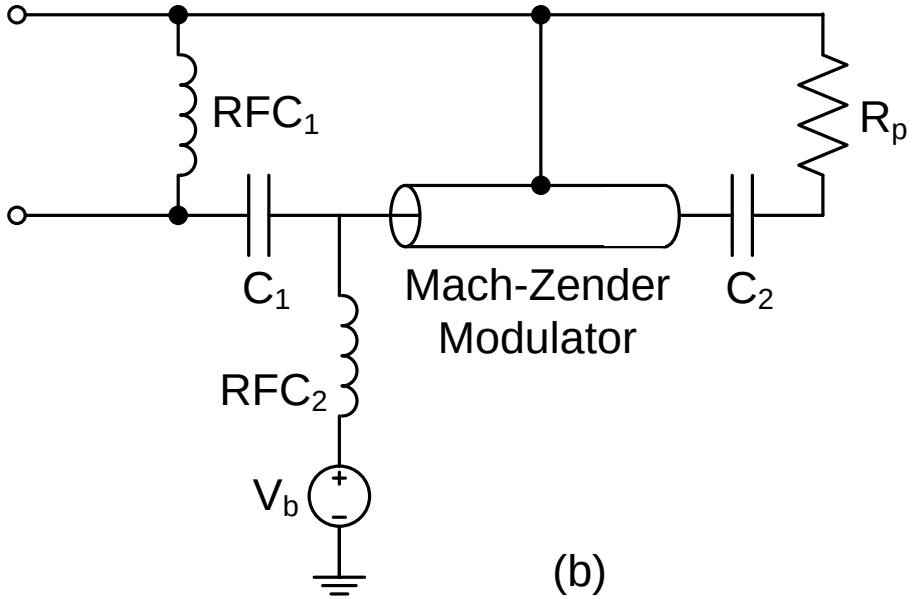

- The predriver conditions the signals for input to transistors $Q_1$ and $Q_2$

# Laser Load for the Drive Circuitry



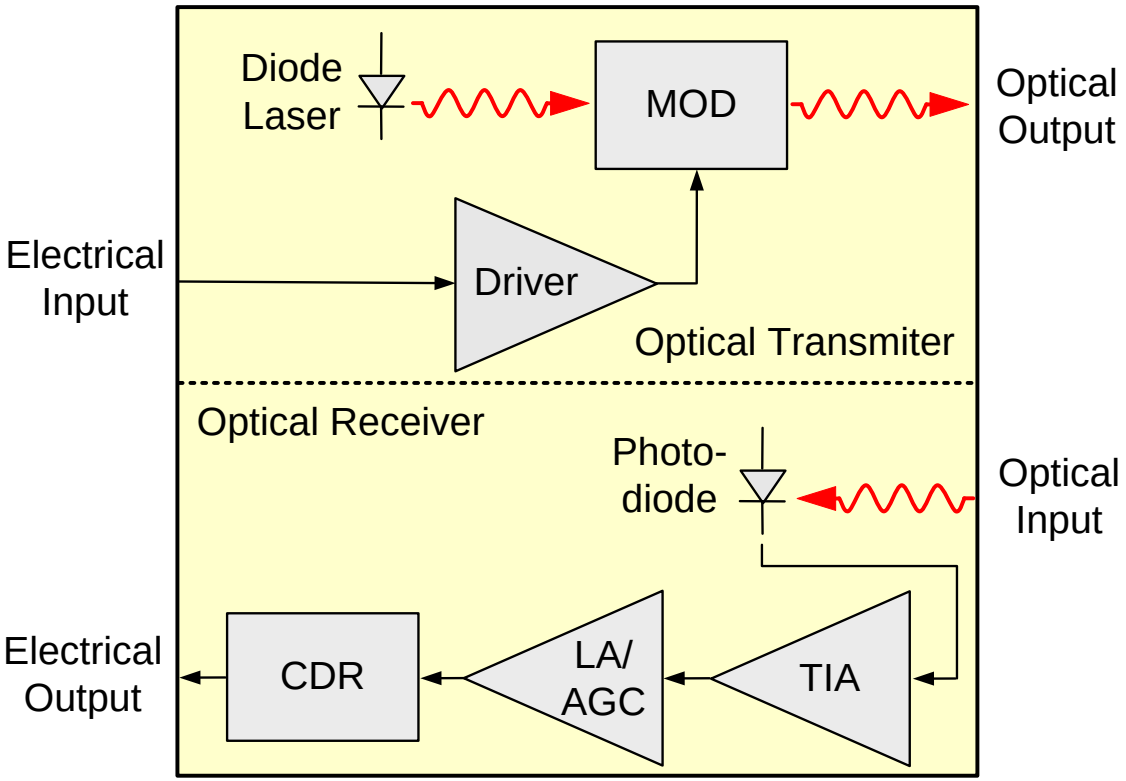

- The resistor $R_s$, dampens current oscillations due to parasitic inductances in the circuitry

# Optical Modulator for the Drive Circuitry




- Load is a transmission line
- Modulator is AC coupled to the drive circuitry by inductor $RFC_1$ (RF Choke 1) and capacitor C1 (the combination is know as a “Bias T”)
- A Bias voltage $V_b$ is DC coupled to the modulator by $RFC_2$
- The resistor $R_p$ generates the voltage signal on the modulator
- The capacitor $C_2$ blocks DC current through the modulator

# An Optical Transceiver




MOD = Optical Modulator

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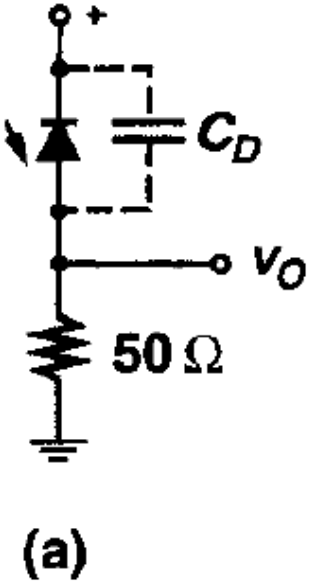
# Simple Pre-Amplifiers for Optical Receivers

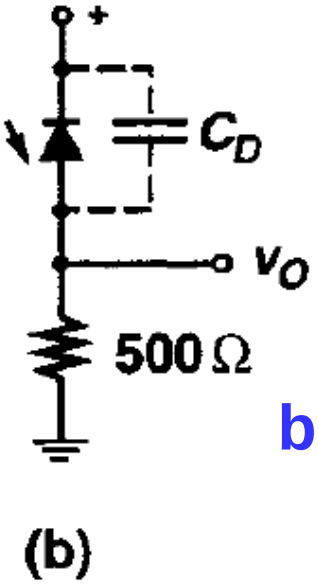
**Noisy but Fast**

$$V_{signal} = RI_{signal}$$

$$I_{noise} = \sqrt{\frac{4kT}{R}}$$

$$\tau = RC$$




**Quiet but Slow**

***Fig. 5.5*** (a) Low-impedance and (b) high-impedance front-end.

from Broadband Circuits for Optical Fiber Communication, Eduard Säckinger, Wiley 2005

# Transimpedance Amplifers

**Quiet and Fast**

$$V_{signal} = R_F I_{signal}$$

$$I_{noise} = \sqrt{\frac{4kT}{R_F}}$$

$$\tau \sim \frac{R_F}{A+1} C$$

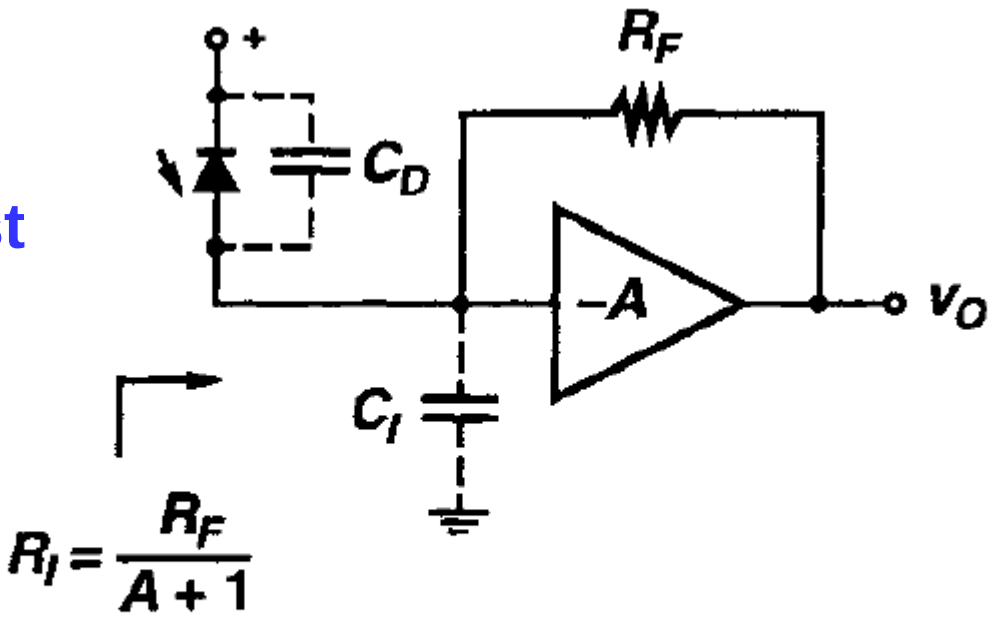
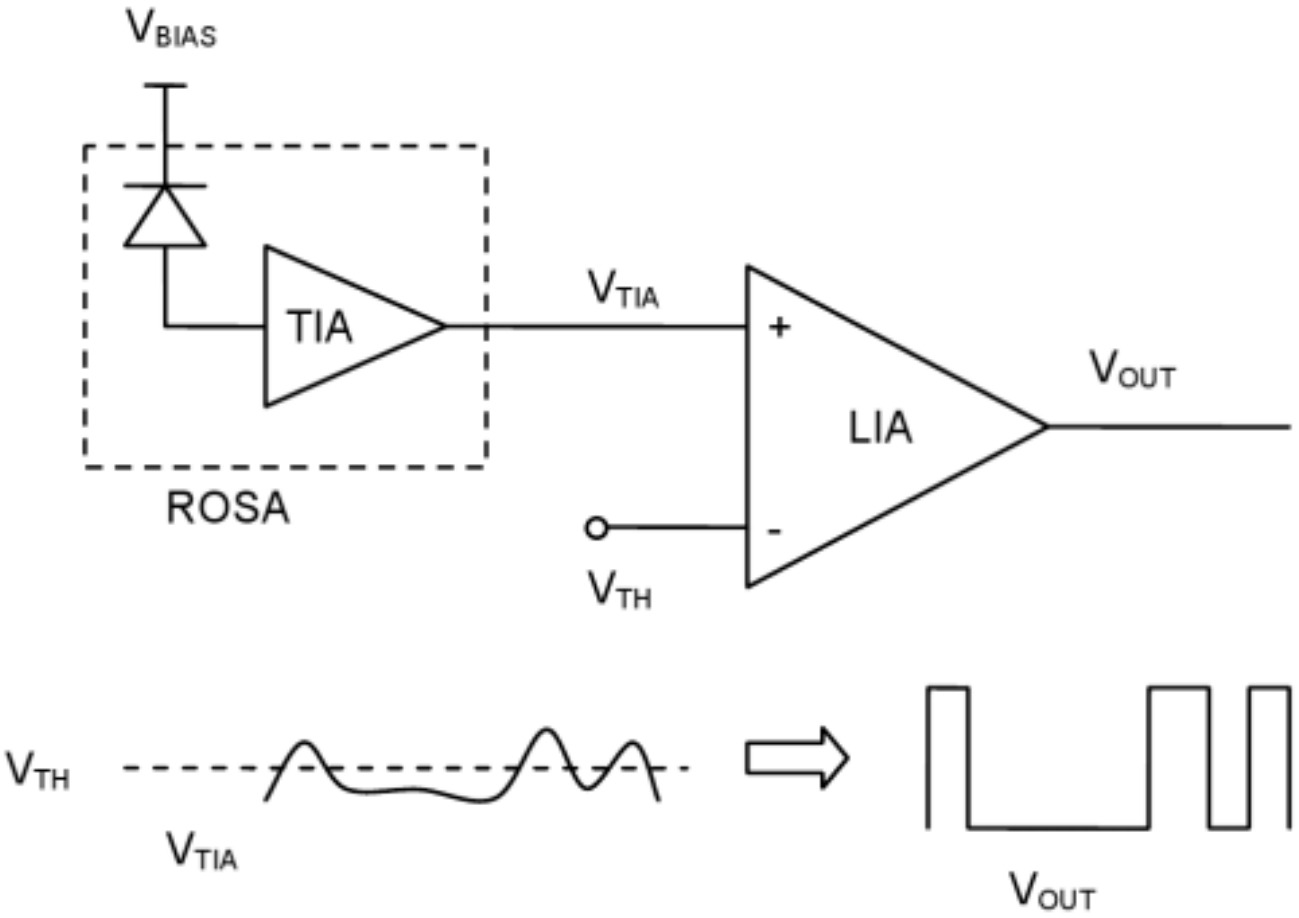


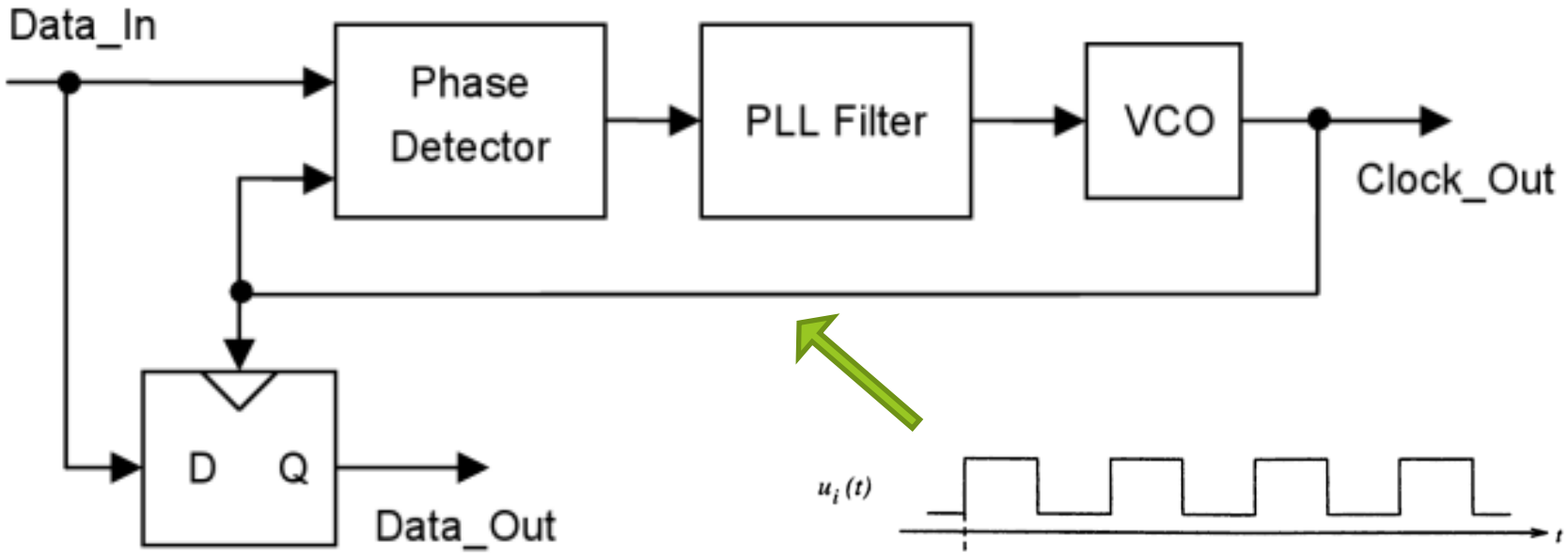

**Fig. 5.6** Basic shunt-feedback transimpedance amplifier.

# Limiting Amplifiers




From Fiber Optics Engineering, by Mohammad Azade, Springer Verlag, 2009

# Clock and Data Recovery

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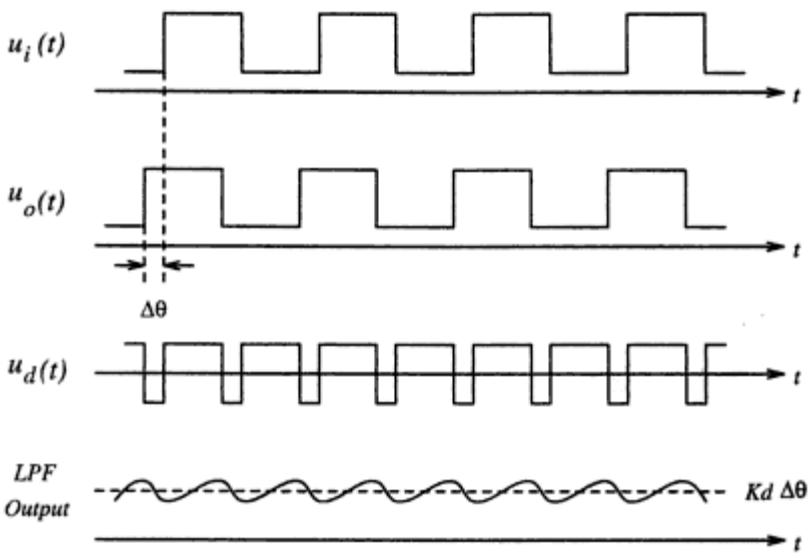
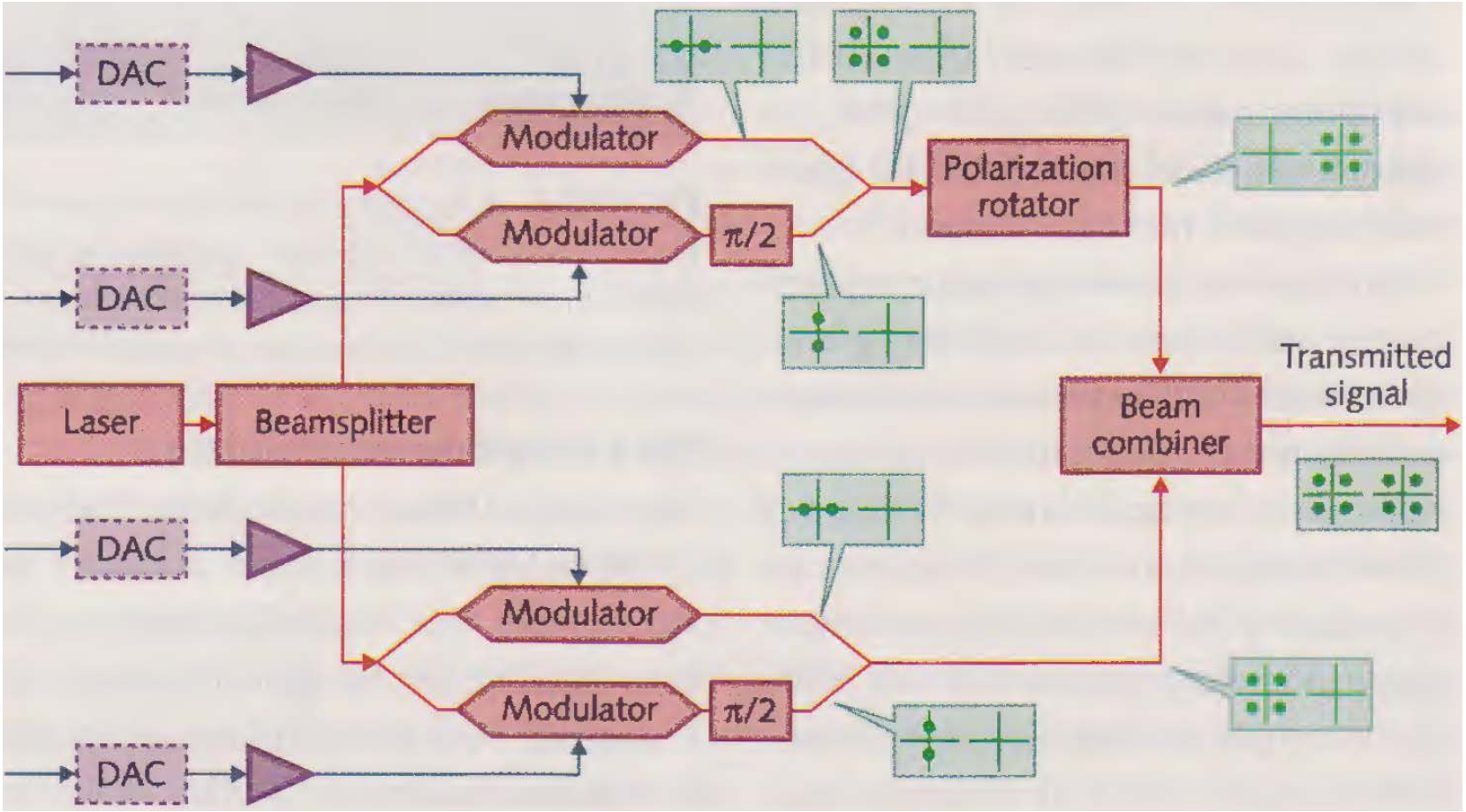



The Circuits and Filters Handbook, Third Edition . edited by Wai-Kai Chen, Section 59, 2003

# A DP-QPSK Transmitter




From "Multilevel Modulation Formats Push Capacities Beyond 100 Gbits/sec," Shubhashish, Data, and Crawford, In Laser Focus World, February, 2012, pp. 58-63.

# DP-QPSK Receiver