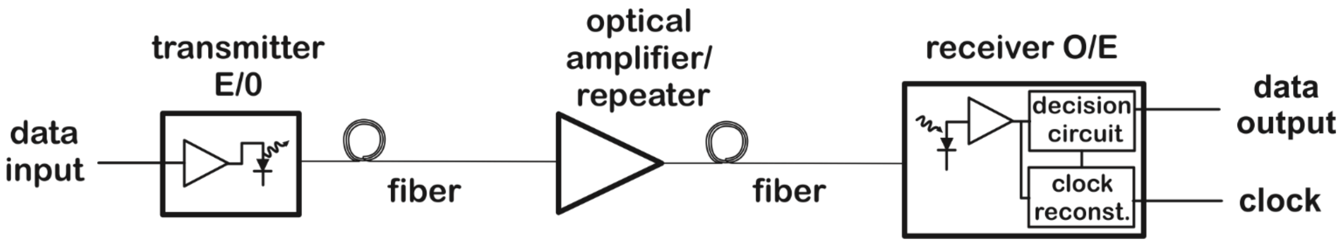
Introduction to fiber optic systems and measurements



- basic components of a fiber optic link:
  - transmitter: it acts as an electrical-to-optical (E/O) converter
  - fiber optic: it is the physical medium used for the transmission
  - fiber devices: filters, optical insulators, optical amplifiers, …
  - receiver: it acts as an optical-to-electrical (O/E) converter
- for the very first applications of the fiber links the measuring requirements were limited to:
  - measuring of power losses along the fiber link: carried out by a testing source and a power meter
  - locating a break of the fiber: time-domain reflectometry

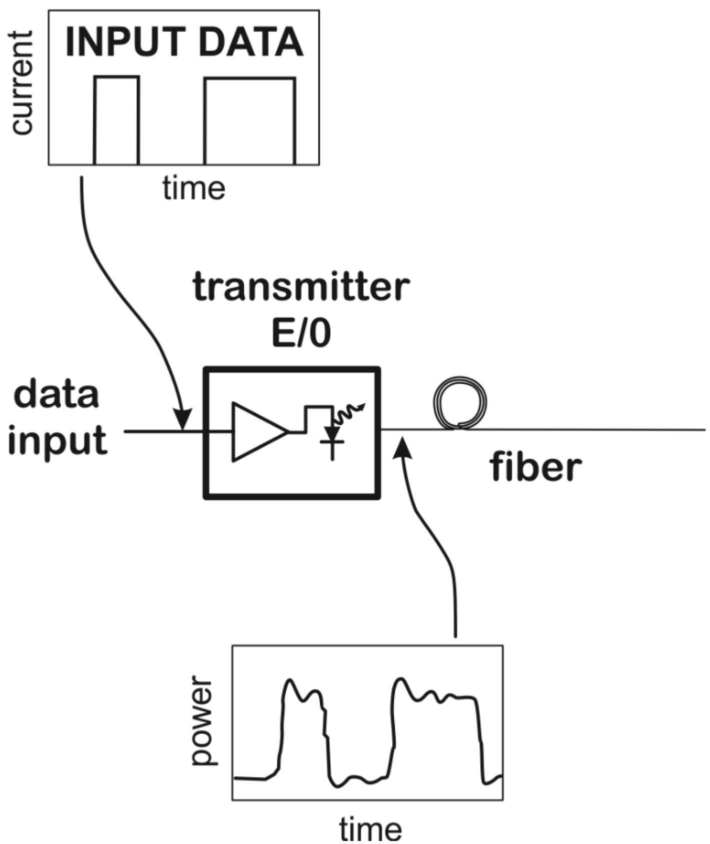
Evolution of the modern fiber links

- introduction of multiple channels on the same fiber: multiple wavelength (Wavelength Division Multiplexed or WDM) channels: they require instruments for measuring the optical power, the S/N ratio, and of the optical wavelength for each channel
- very high transmission rates: commercial systems having bit rates up to tens of Gb/s per channel. It is necessary to monitor the emission spectrum of the transmitting lasers and the chromatic dispersion of the fibers. The bandwidth of the transmitters and of the receivers must be optimized
- use of optical amplifier: they make it possible the insertion in the fiber link of lossy components such as optical MUX and DEMUX. To characterize these components we need optical network analyzers.

cont.

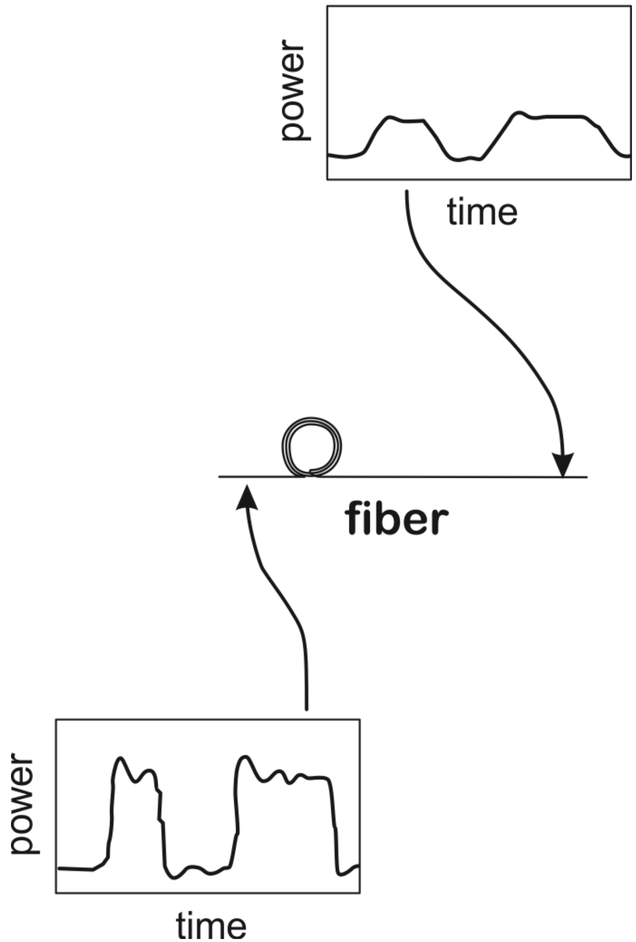
- **short range links:** fibers start to be competitive also for short range applications. The number of installation could exponentially increase, there is a need for low-cost testing equipment
- **increasing complexity:** the availability of optical switches and their application to multiple wavelength systems make it possible to design optical networks more and more complex. The instrumentation must follow the evolution of the new systems.

Transmitter



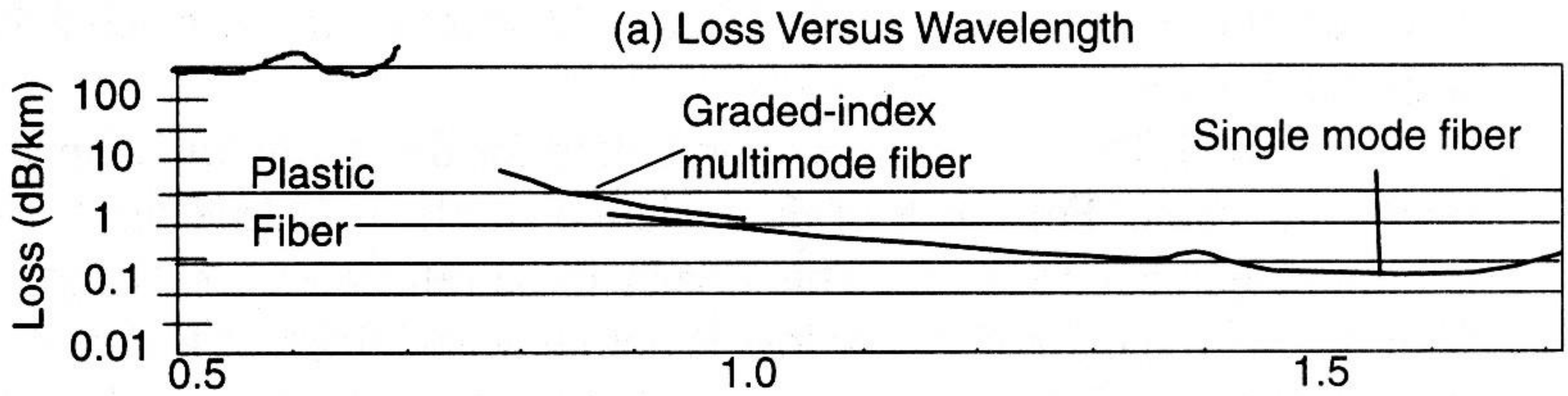
- the transmitter is basically a (electrical) current-to-(optical) power converter:
  - long range transmissions: laser source
  - short range transmissions: LED source
- the need is to measure the output signal of the transmitter to verify its performance and efficiency

Optical fiber



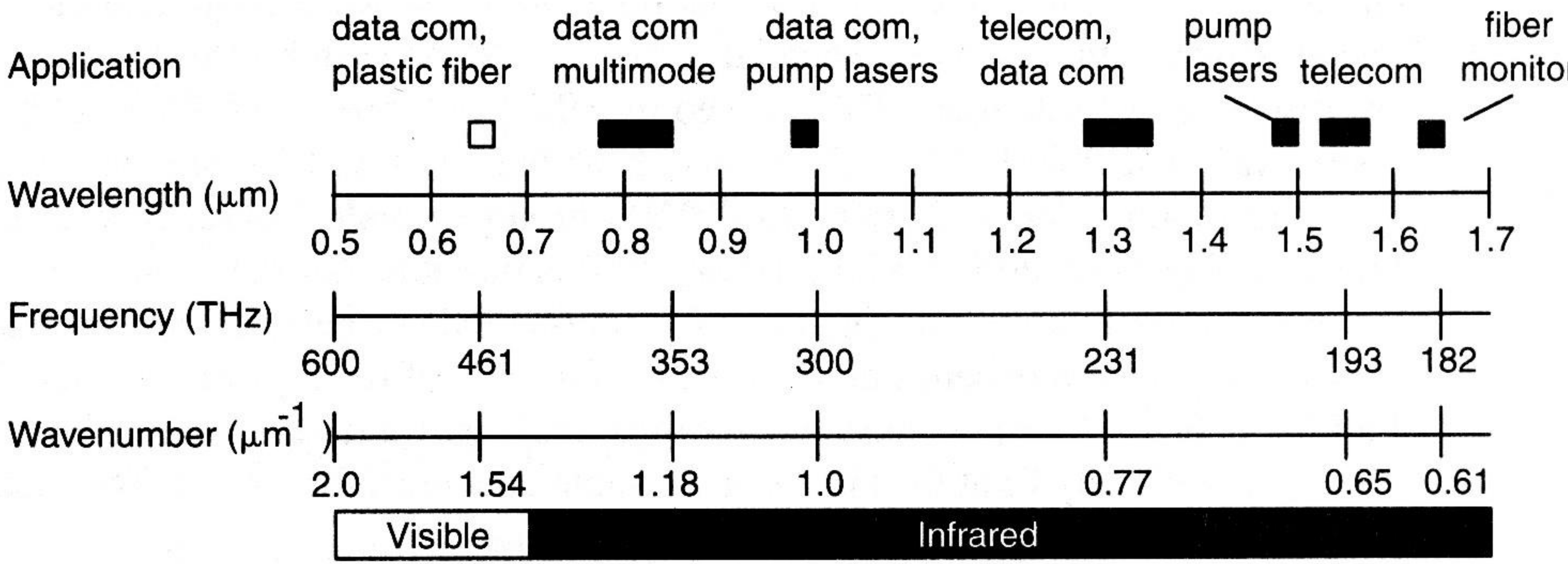
- the signal undergoes degradation while propagating along the optical fiber:
  - attenuation
  - chromatic dispersion
    - laser spectral width
    - laser chirp
- we need optical instruments to characterize the fibers

Fiber losses



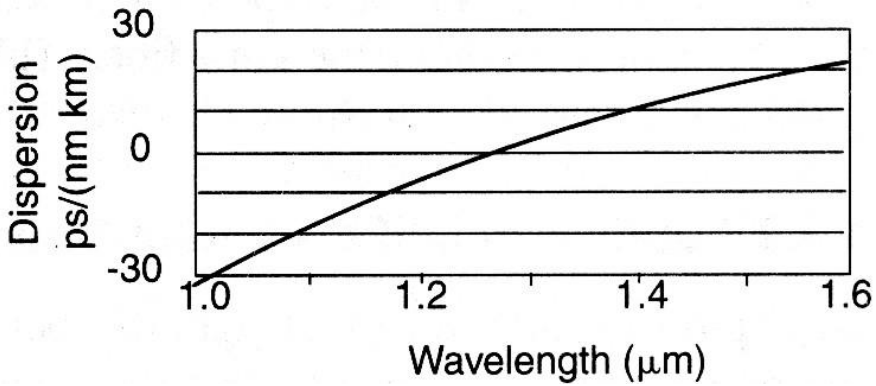
- single mode fibers have a loss minimum (of 0.2 dB/Km) in the region around 1550 nm
  - as a reference, for a link operating at 2.5 Gb/s it is accepted a loss of 25dB --> we can have a section of 125 Km without any signal regeneration

Optical fiber applications



- 1300, 1550 nm: long distance data comm. (low losses)
- 980, 1480 nm: pump lasers for optical amplifiers
- 1650 nm: measuring channels for operating fibers
- 780->850, 980->1300: short distance data comm.
- 650 nm: plastic fibers, short range, low bitrate

Single mode fibers chromatic dispersion



- the propagation velocity inside the fiber depends on the optical wavelength

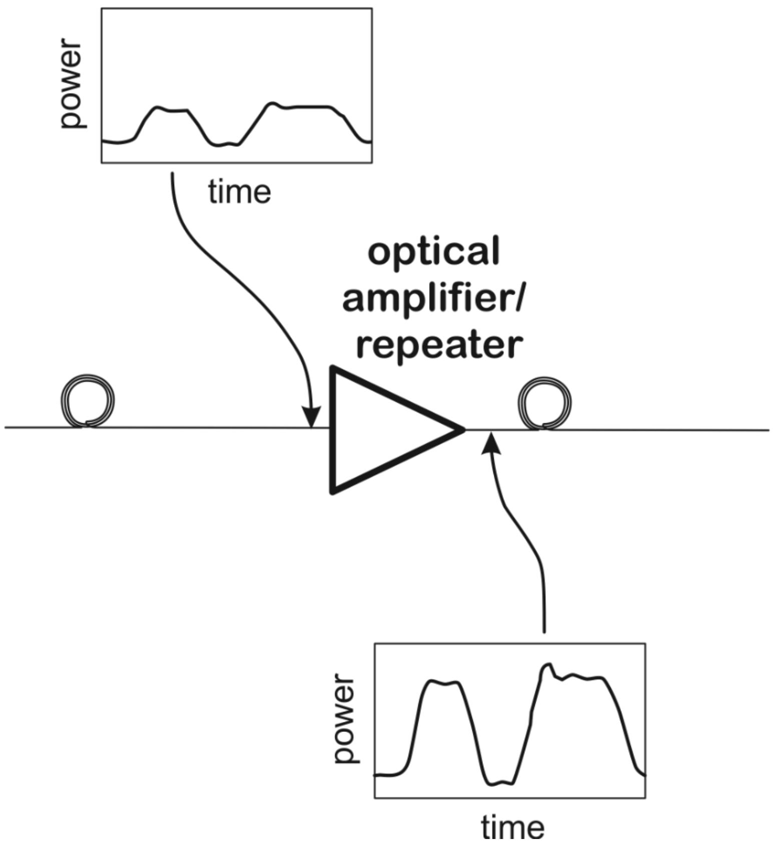
Polarization dispersion

- the propagation velocity inside the fiber depends on the optical polarization state

Modal dispersion in multiple mode fibers

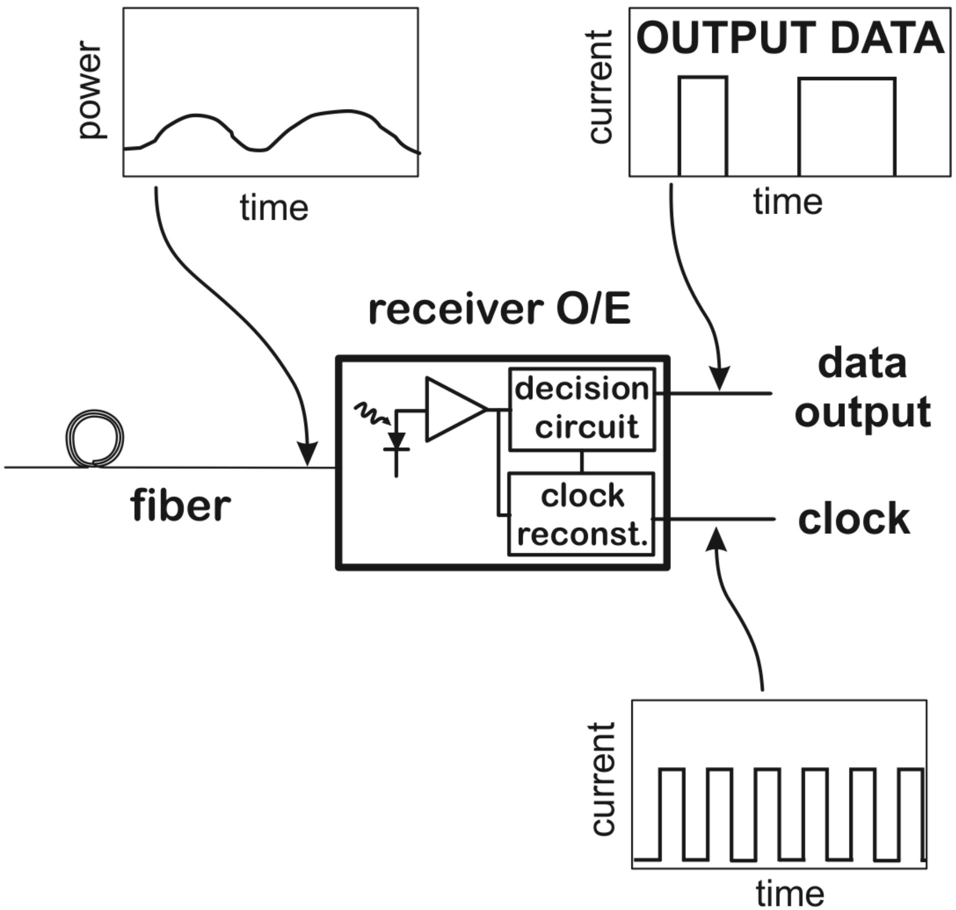
- inter-symbol interference problems

Optical amplifier/ repeaters



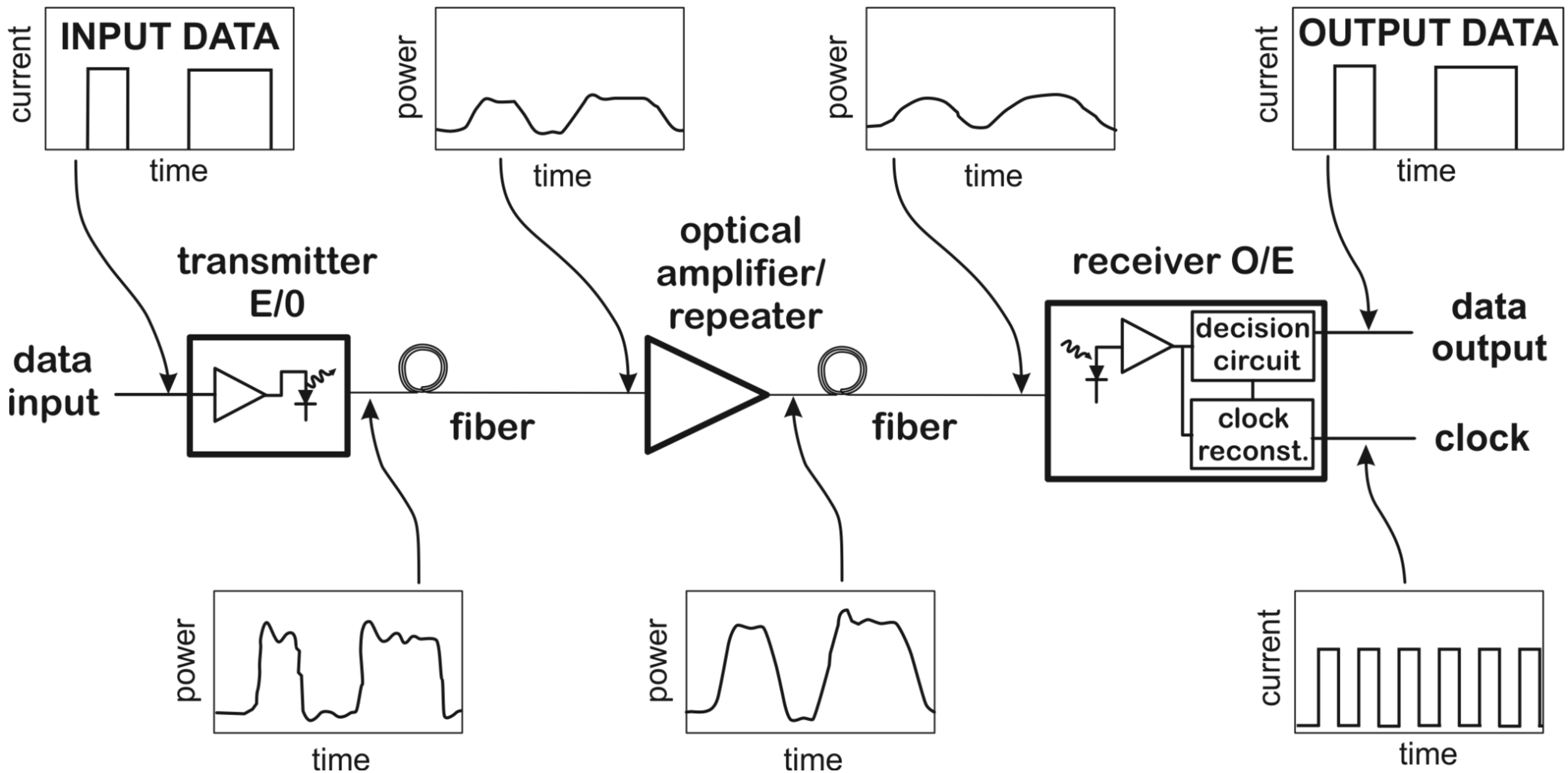
- optical amplifier
  - losses compensation
  - little worsening of the S/N ratio
  - addition of some signal distortion
  - high output power
- repeater
  - the optical signal is first converted into an electrical signal, it is reshaped and then retransmitted
  - very complex system
- optical amplifier and repeaters must be characterized with suitable optical/electrical instruments

Receiver

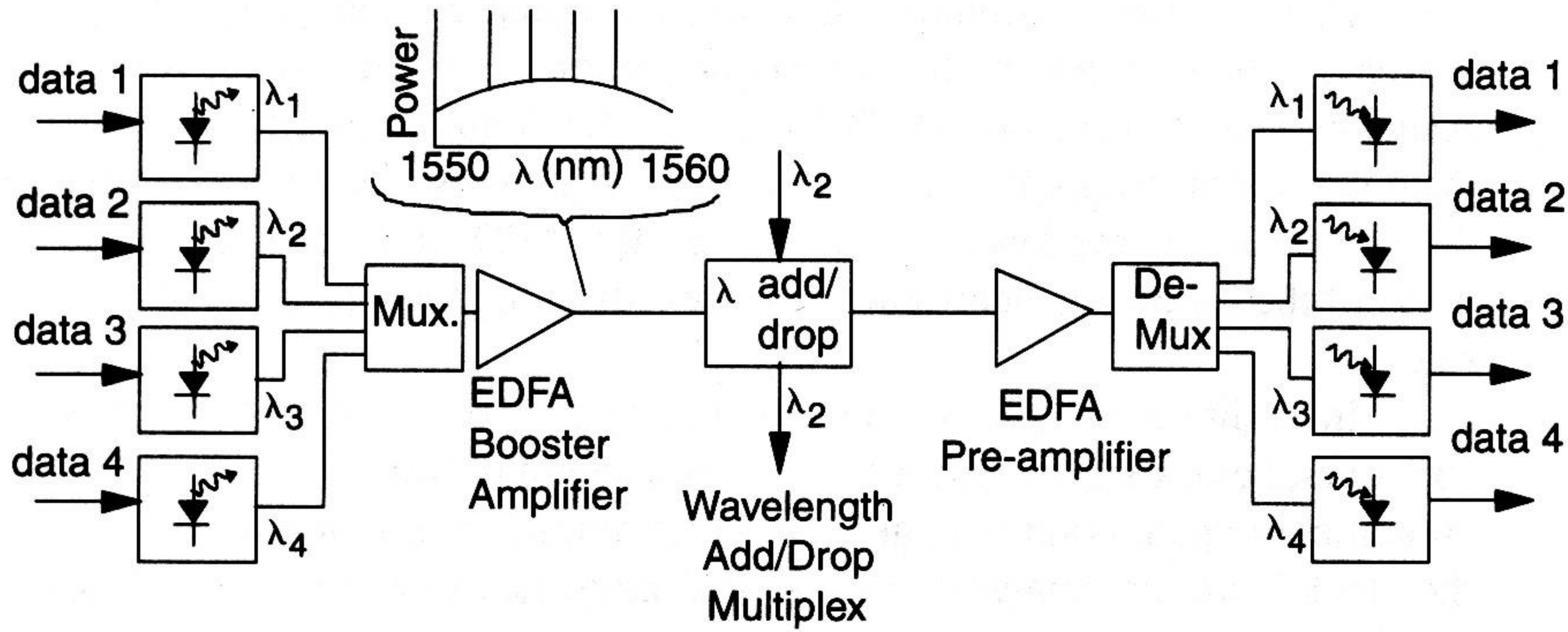


- it is a (optical) power-to-(electrical) current converter
- it is based on the use of optoelectronic detectors: PIN diode or APD (avalanche photo-detectors)
- Automatic gain control circuits are required to compensate for the power fluctuations of the received signal.
- clock reconstruction
- high velocity electronic instruments

Digital transmission over a fiber link



Multiple wavelength systems or WDM

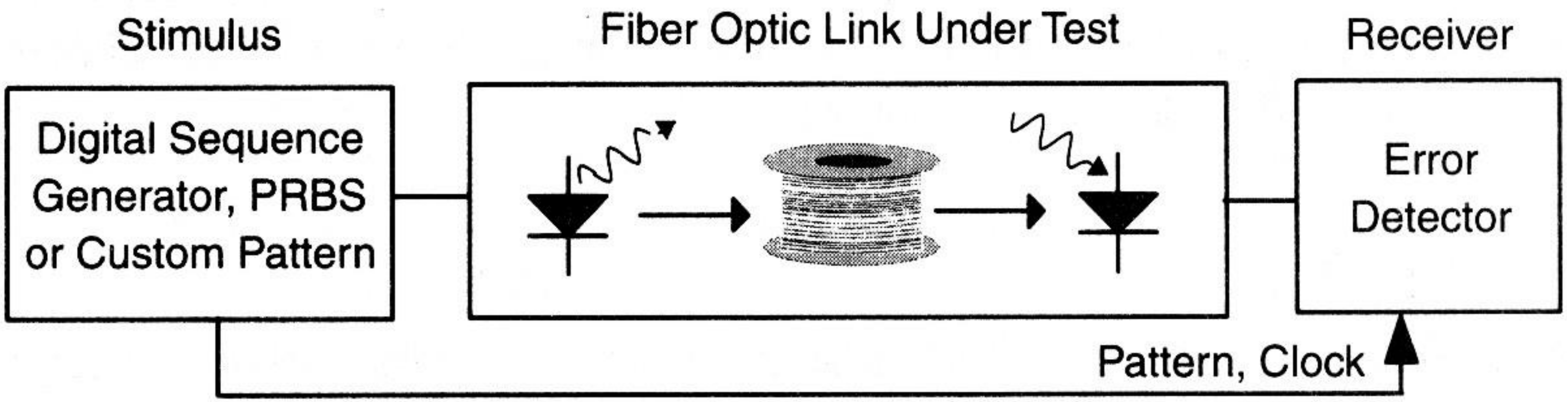


- The insertion of Erbium Doped Fiber Amplifier (EDFA) implies to operate in the spectral region 1530-1565 nm
- DWDM standard: 100 GHz wavelength spacing

Measurements specific to WDM systems

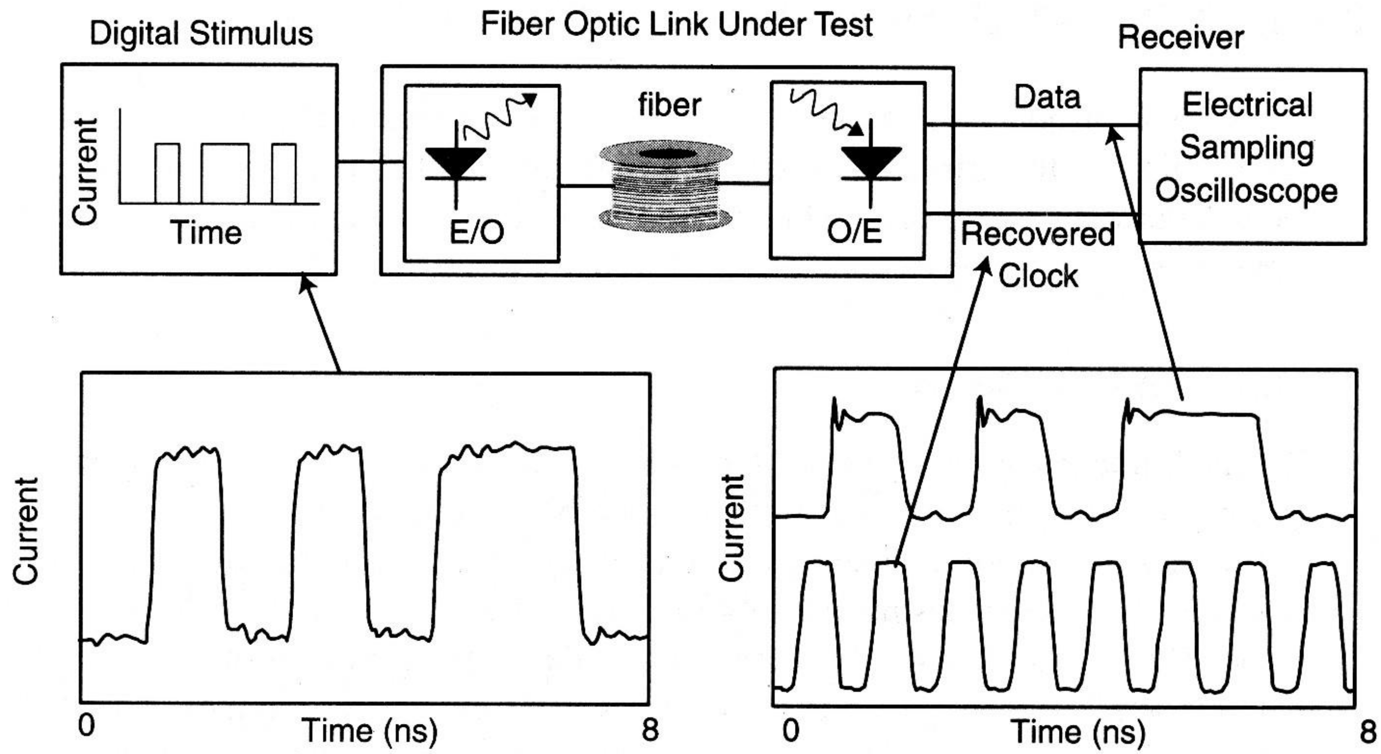
- absolute measurement of the optical wavelength with an accuracy better than 0.01 nm
- measurement of the laser-source wavelength-stability over short and long time period with a resolution better than 0,001 nm
- loss measurement in optical components as a function of the wavelength
- monitoring of the wavelength, optical power, and S/N for each channel of the WDM system

Characterization of an optical fiber digital link



- Pseudo Random Binary Sequence: typical length 2^{23}-1
- The receiver records the symbol errors and computes the Bit Error Rate (BER)
- typical values BER: from 10^{-9} to 10^{-13}
- it is usual to measure the BER as a function of the fiber loss

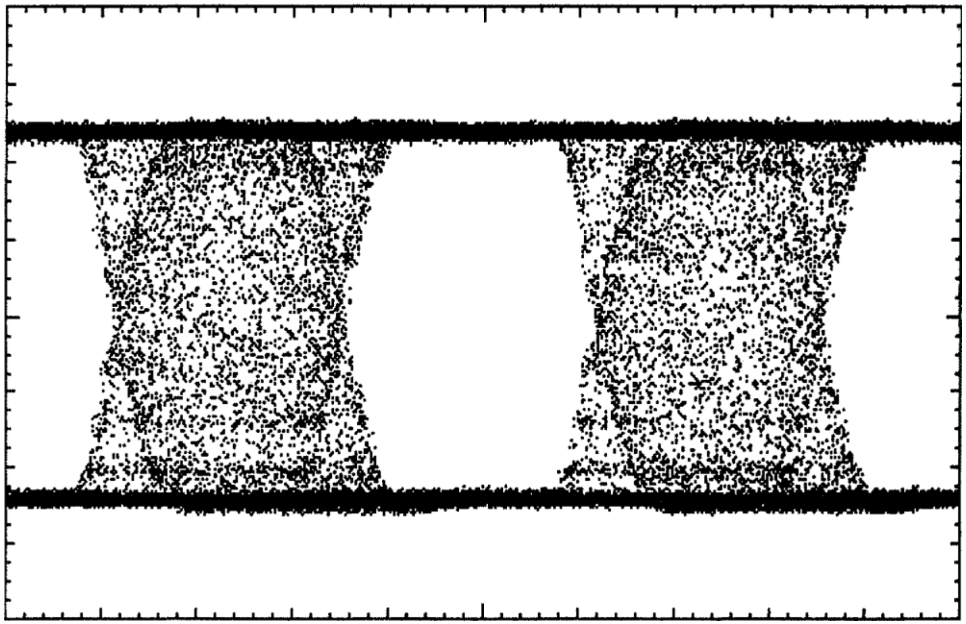
Waveform analysis



- ❑ **diagnosis of the origin of a high BER**
- ❑ **evaluation of the performance margin**

Clock jitter measurements

- jitter represents the variability of the time unit of the digital channel, that is the variability of the period of the clock
- Jitter causes bit errors: at the receiver, the digital signal is not always sampled at the optimum instant in time

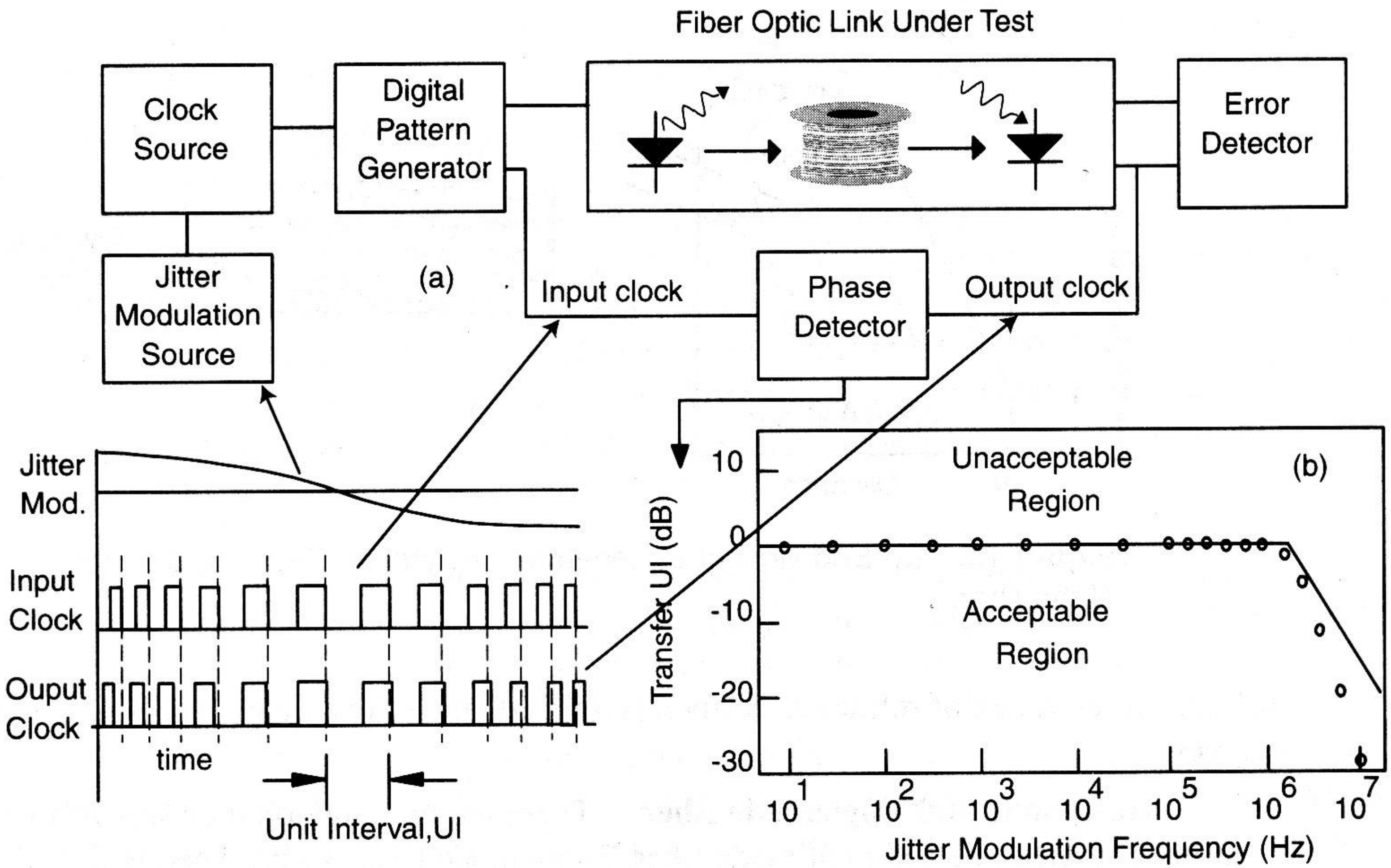


- jitter control is important to avoid time related errors in cascaded links

Clock jitter measurements

- **jitter tolerance** defines how well the receiver can tolerate a jittered incoming signal
  - it is estimated the maximum level of input jitter that can be tolerated at the receiver input for a given BER
- **jitter generation**: a jitter-free test signal is applied to the input of the digital channel and the output jitter is measured. The jitter added by the channel is evaluated.
- **jitter transfer** evaluates how much of the input jitter is transferred to the output of a signal regenerator

cont.



Fiber Optic Link Under Test
Clock Source
Digital Pattern Generator
Error Detector
Jitter Modulation Source
(a)
Input clock
Phase Detector
Output clock
Jitter Mod.
Input Clock
Ouput Clock
time
Unit Interval,UI
Unacceptable Region
Acceptable Region
(b)
Transfer UI (dB)
10
0
-10
-20
-30
10^1 10^2 10^3 10^4 10^5 10^6 10^7
Jitter Modulation Frequency (Hz)