Optical Fiber Communications

Chapter 14

Performance Measurement and Monitoring

ITU-T Recommendations

- International Telecommunication Union - Telecommunication Standardization Sector

Series	Description
A	Organization of the work of ITU-T
B	Means of expression: definitions, symbols, classification
C	General telecommunication statistics
D	General tariff principles
E	Overall network operation, telephone service, service operation and human factors
F	Non-telephone telecommunication services
G	Transmission systems and media, digital systems and networks
H	Audiovisual and multimedia systems
I	Integrated services digital network
J	Cable networks and transmission of television, sound programme and other multimedia signals
K	Protection against interference
L	Construction, installation and protection of cables and other elements of outside plant
M	Telecommunication management, including TMN and network maintenance
N	Maintenance: international sound programme and television transmission circuits
O	Specifications of measuring equipment

ITU-T Recommendations

Series	Description
Q	Switching and signalling
R	Telegraph transmission
S	Telegraph services terminal equipment
T	Terminals for telematic services
U	Telegraph switching
V	Data communication over the telephone network
X	Data networks, open system communications and security
Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Z	Languages and general software aspects for telecommunication systems

ITU-T Recommendations

- G series : Transmission systems and media, digital systems and networks

Specification Range	Specification Type
G.100 - G.199	International Telephone Connections and Circuits
G.200 - G.299	General Characteristics Common to all Analogue Carrier Transmission Systems
G.300 - G.399	Individual Characteristics of International Carrier Telephone Systems on Metallic Lines
G.400 - G.449	General Characteristics of International Carrier Telephone Systems on Radio-Relay or Satellite Link
G.450 - G.499	Coordination of Radiotelephony and Line Telephony
G.600 - G.699	Transmission Media and Optical Systems Characteristics
G.700 - G.799	Digital Terminal Equipments
G.800 - G.899	Digital Networks
G.900 - G.999	Digital Sections and Digital Line System
G.1000 - G.1999	Quality of Service and Performance – Generic and User-Related Aspects
G.6000 - G.6999	Transmission Media Characteristics
G.7000 - G.7999	Data Over Transport – Generic Aspects
G.8000 - G.8999	Packet over Transport Aspects
G.8000 - G.8099	Ethernet over Transport aspects
G.8100 - G.8199	MPLS over Transport aspects
G.8200 - G.8299	Quality and availability targets
G.8600 - G.8699	Service Management
G.9000 - G.9999	Access Networks

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ITU-T Recommendations

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  - G.100-G.199: International telephone connections and circuits
    - G.100-G.109: Transmission planning and the E-model
    - G.110-G.119: General Recommendations on the transmission quality for an entire international telephone
    - G.120-G.129: General characteristics of national systems forming part of international connections
    - G.130-G.139: General characteristics of the 4-wire chain formed by the international circuits and national
    - G.140-G.149: General characteristics of the 4-wire chain of international circuits; international transit
    - G.150-G.159: General characteristics of international telephone circuits and national extension circuits [E
    - G.160-G.169: Apparatus associated with long-distance telephone circuits
    - G.170-G.179: Transmission plan aspects of special circuits and connections using the international teleph
    - G.180-G.189: Protection and restoration of transmission systems

ITU-T Recommendations

- For Optical Communication Systems

  - G.600-G.699: Transmission media and optical systems characteristics
    - G.600-G.609: General
    - G.610-G.619: Symmetric cable pairs
    - G.620-G.629: Land coaxial cable pairs
    - G.630-G.639: Submarine cables
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    - G.650-G.659: Optical fibre cables
    - G.660-G.679: Characteristics of optical components and subsystems
    - G.680-G.699: Characteristics of optical systems

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G.652 **G.652 : Characteristics of a single-mode optical fibre and cab**

Recommendation G.652 (11/09)

Approved in 2009-11

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ITU-T Recommendations

- For Optical Communication Systems

G.652: Characteristics of a single-mode optical fibre and cable

International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.652
(11/2009)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

ITU-T Recommendations

- For Optical Communication Systems

G.652: Characteristics of a single-mode optical fibre and cable

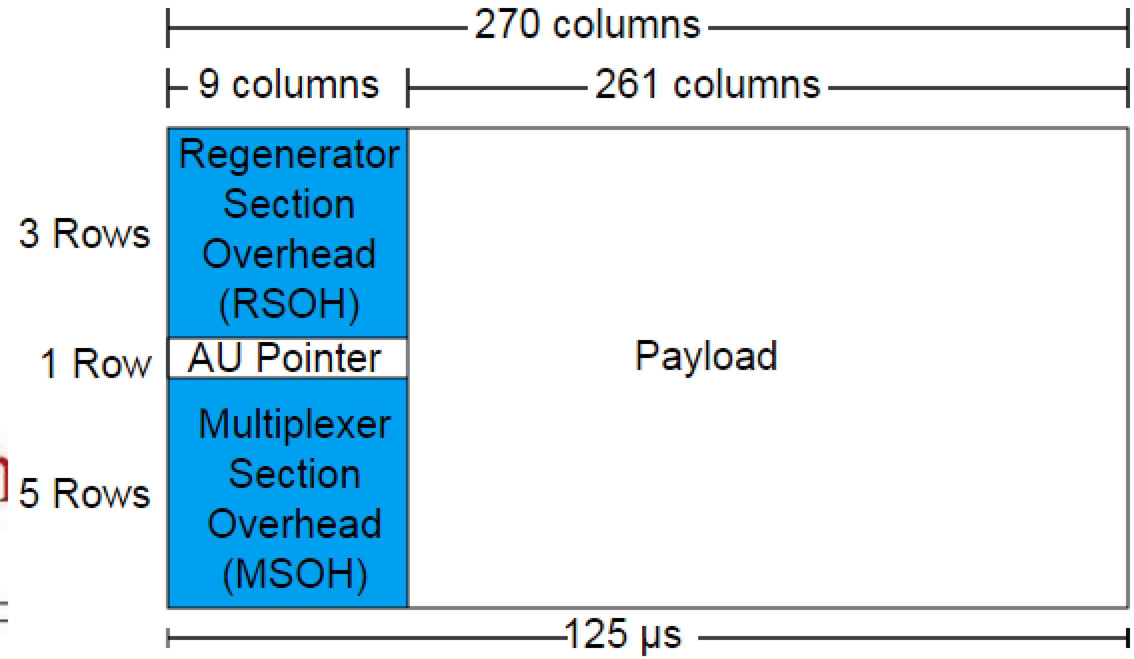
CONTENTS

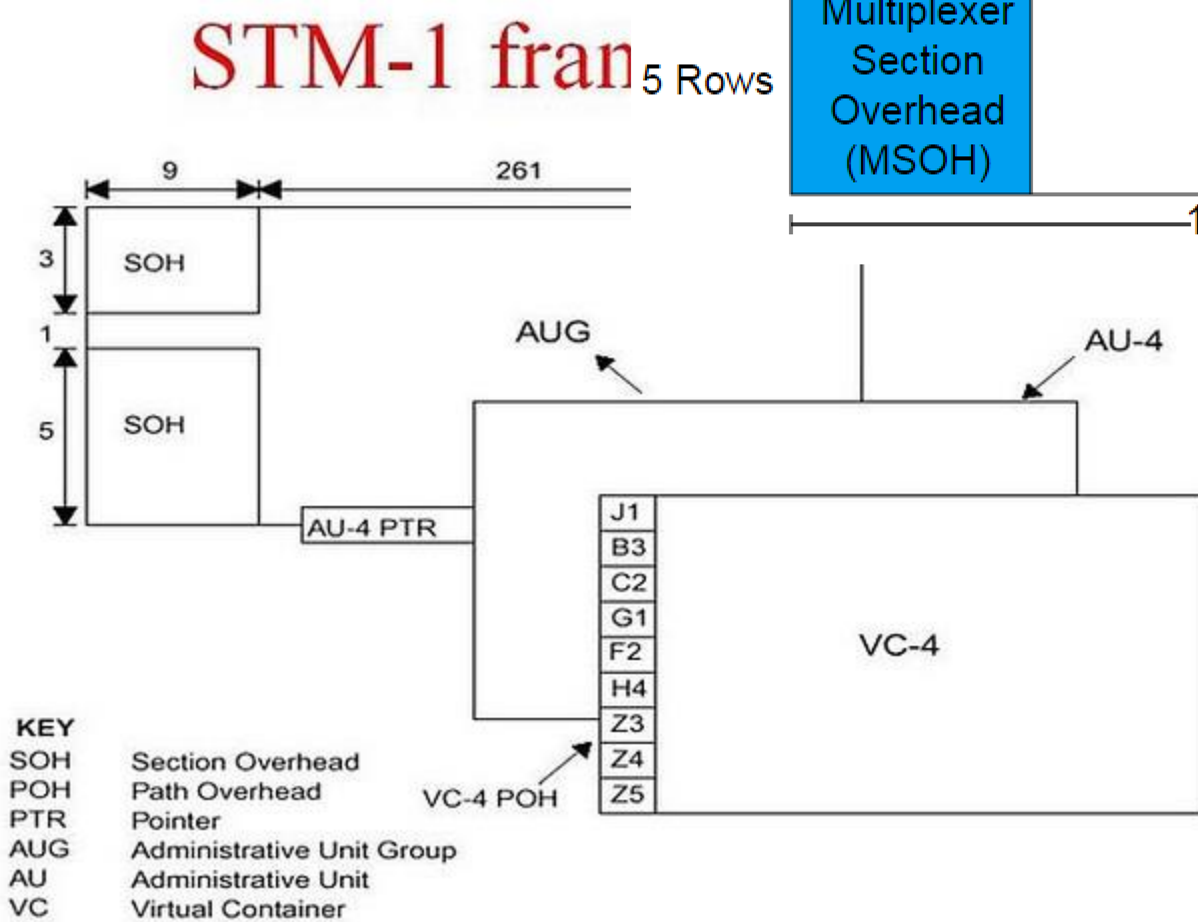
SONET/SDH

- Synchronous Digital Hierarchy
- The SDH standard was originally defined by the European Telecommunications Standards Institute (ETSI), and is formalized as International Telecommunication Union (ITU) standards G.707, G.783, G.784, and G.803.

- Synchronous Optical Networking
- The SONET standard was defined by Telcordia and American National Standards Institute (ANSI) standard T1.105.

SONET/SDH


270 columns
9 columns
261 columns
3 Rows
1 Row
5 Rows
Regenerator Section Overhead (RSOH)
AU Pointer
Multiplexer Section Overhead (MSOH)
Payload
125 µs


STM-1 fran
9
261
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SOH
SOH
AU-4 PTR
AUG
AU-4
J1
B3
C2
G1
F2
H4
Z3
Z4
Z5
VC-4
VC-4 POH
KEY
SOH Section Overhead
POH Path Overhead
PTR Pointer
AUG Administrative Unit Group
AU Administrative Unit
VC Virtual Container

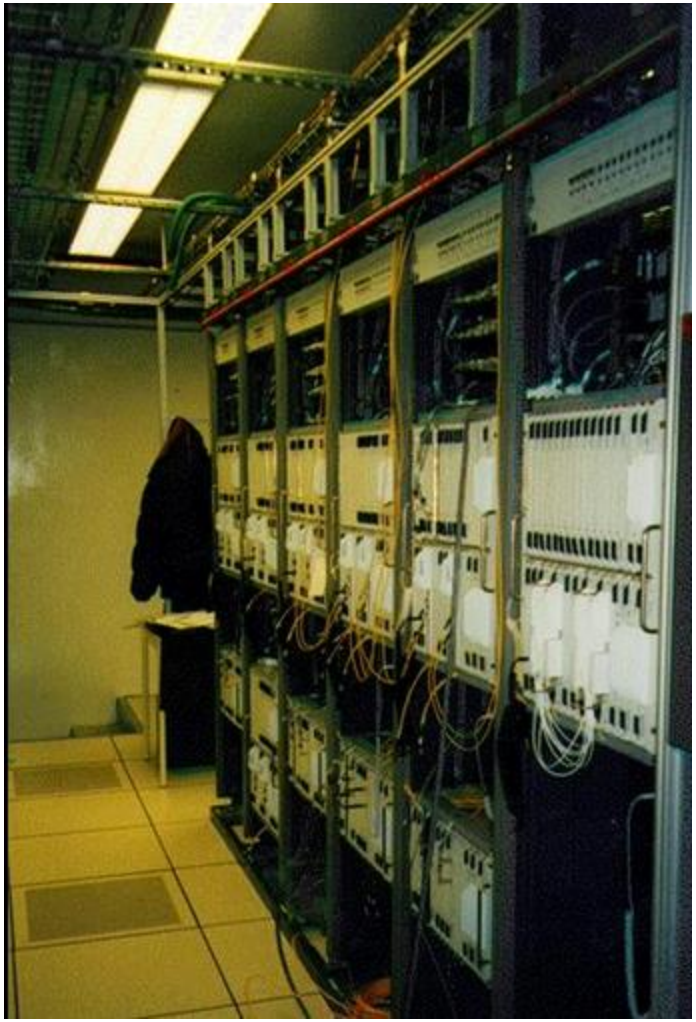
SONET/SDH

SONET/SDH data rates [edit]

SONET/SDH Designations and bandwidths

SONET Optical Carrier level	SONET frame format	SDH level and frame format	Payload bandwidth[nb 3] (kbit/s)	Line rate (kbit/s)
OC-1	STS-1	STM-0	50,112	51,840
OC-3	STS-3	STM-1	150,336	155,520
OC-12	STS-12	STM-4	601,344	622,080
OC-24	STS-24	–	1,202,688	1,244,160
OC-48	STS-48	STM-16	2,405,376	2,488,320
OC-192	STS-192	STM-64	9,621,504	9,953,280
OC-768	STS-768	STM-256	38,486,016	39,813,120

SONET/SDH



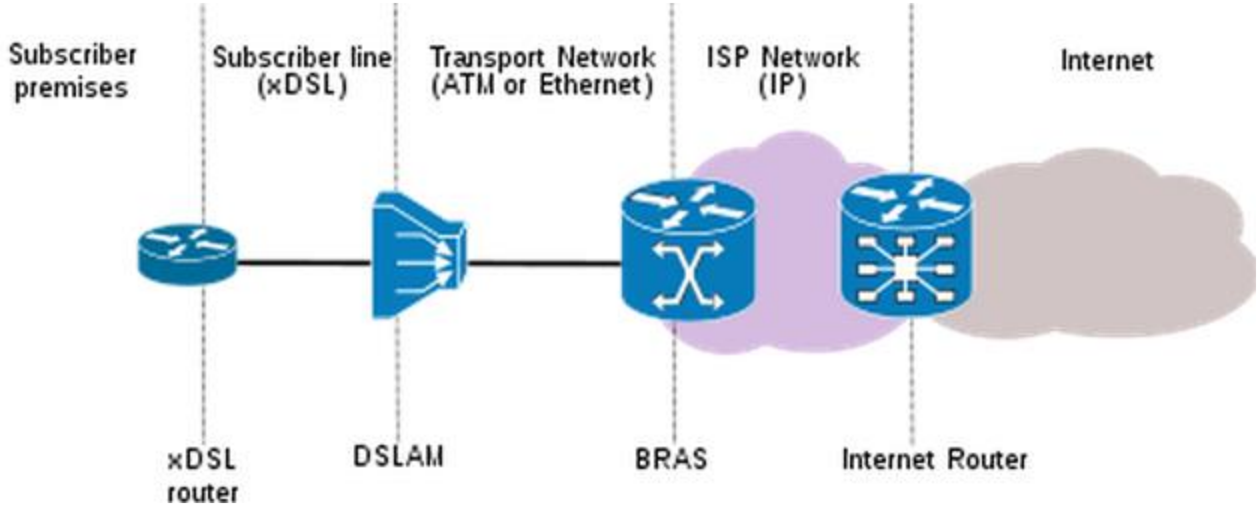
Ref : Racks of Alcatel STM-16 SDH add-drop multiplexers

http://en.wikipedia.org/wiki/Synchronous_optical_networking

DSLAM (xDSL Add Drop Multiplexer)

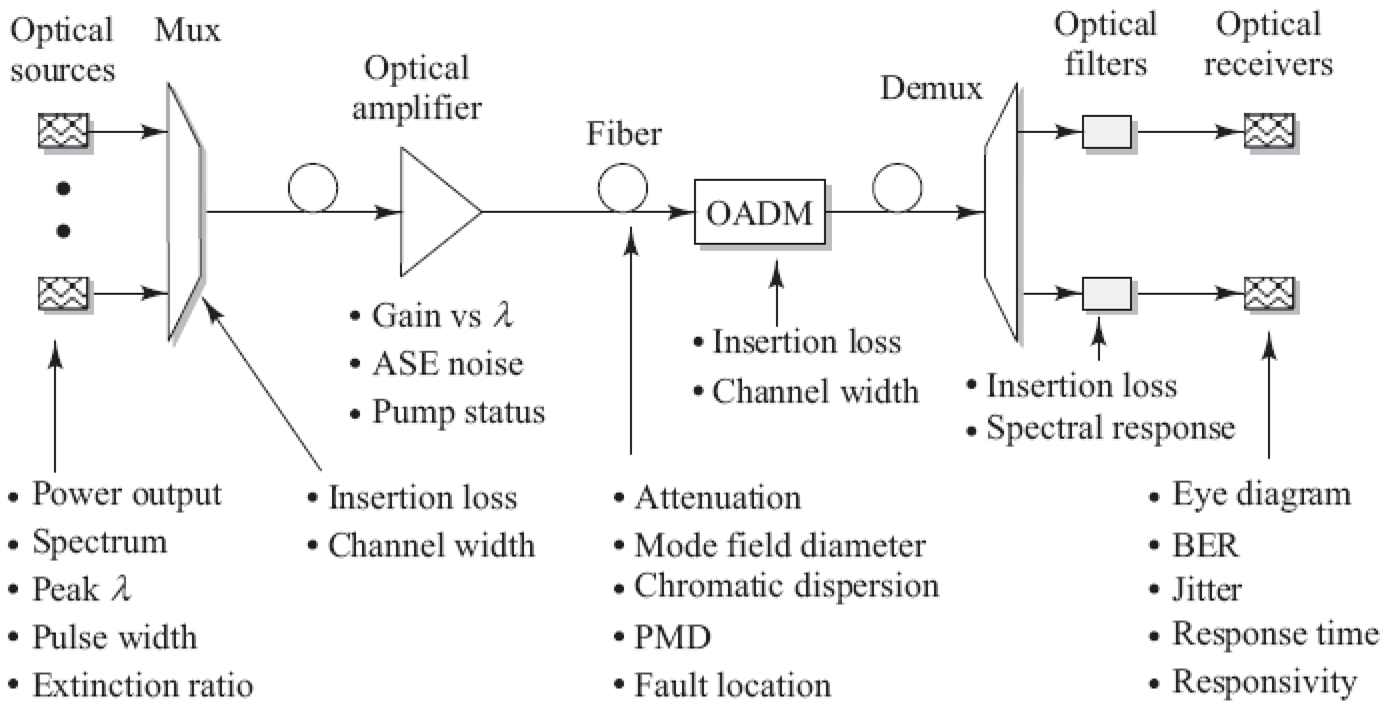
Ref : Racks of Siemens DSLAM

http://en.wikipedia.org/wiki/Synchronous_optical_networking



Cf) BRAS (Broadband Remote Access Server)

Performance Measurement Parameters



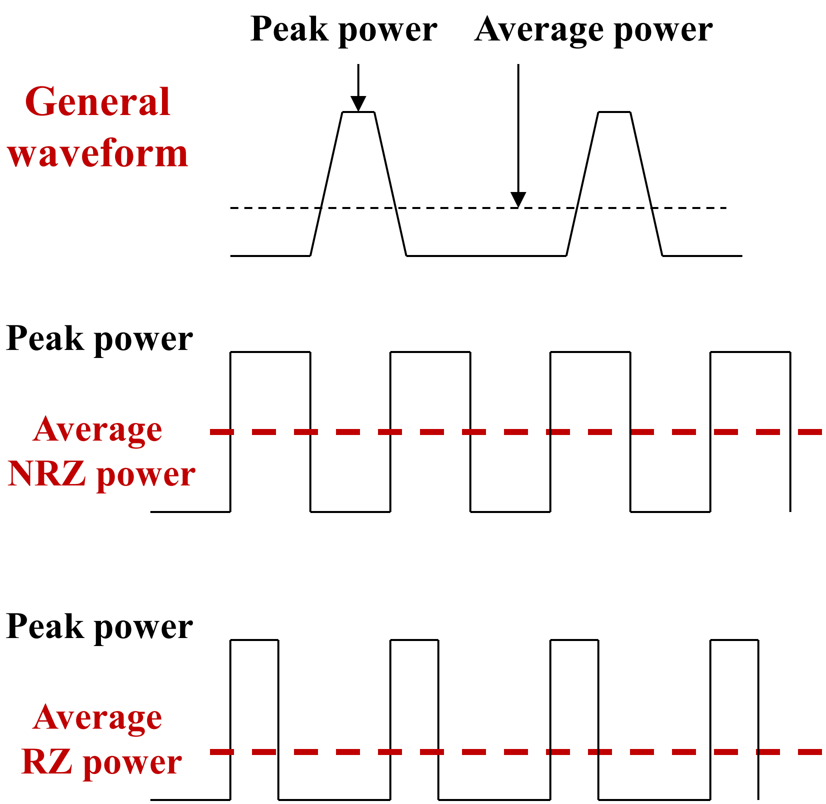
Components of a typical WDM link and some performance-measurement parameters of user interest

Basic Test Equipment

Table 14.3 *Some widely used optical system test instruments and their functions*

Test instrument	*Function*
Test-support lasers (multiple-wavelength or broadband)	Assist in tests that measure the wavelength-dependent response of an optical component or link
Optical spectrum analyzer	Measures optical power as a function of wavelength
Multifunction optical test system	Factory or field instruments with exchangeable modules for performing a variety of measurements
Optical power attenuator	Reduces power level to prevent instrument damage or to avoid overload distortion in the measurements
Conformance analyzer	Measures optical receiver performance in accordance with standards-based specifications
Visual fault indicator	Uses visible light to give a quick indication of a break in an optical fiber
Optical power meter	Measures optical power over a selected wavelength band
BER test equipment	Uses standard eye-pattern masks to evaluate the data-handling ability of an optical link
OTDR (field instrument)	Measures attenuation, length, connector/splice losses, and reflectance levels; helps locate fiber breaks
Optical return loss tester	Measures total reverse power in relation to total forward power at a particular point

Optical Power Definition



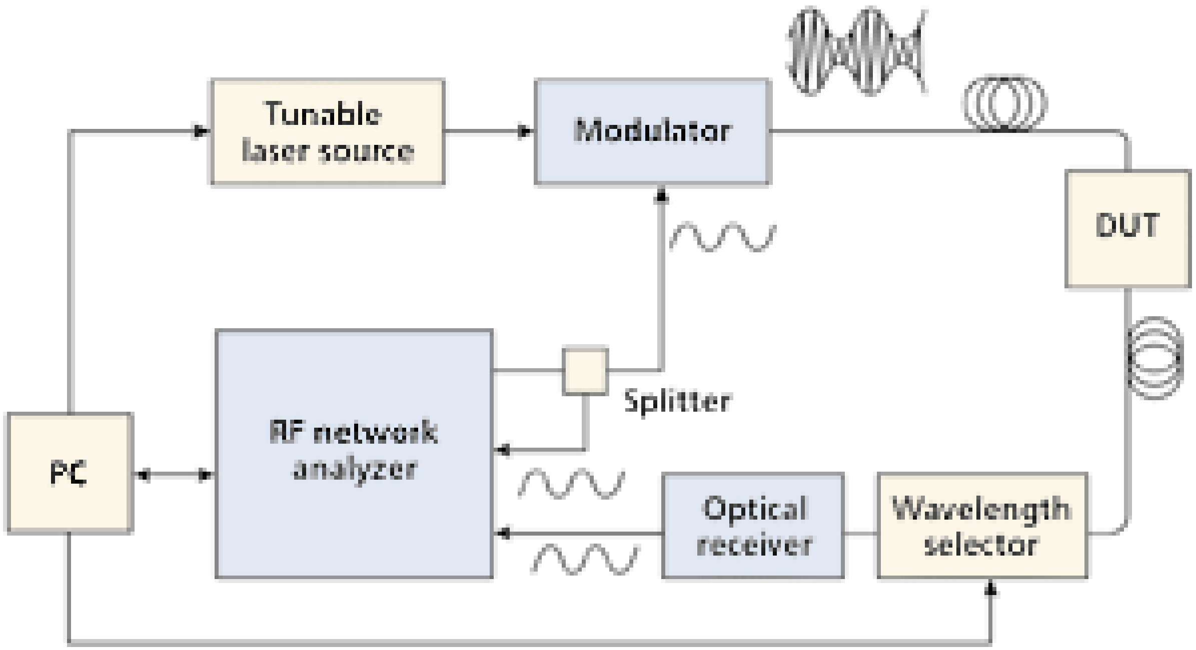
Optical power measurement is the most basic function in fiber optic metrology.

- **Peak power:** the maximum power level in a pulse
- **Average power:** a measure of the power level averaged over a relatively long time period compared to the duration of an individual pulse

Optical Power Meters

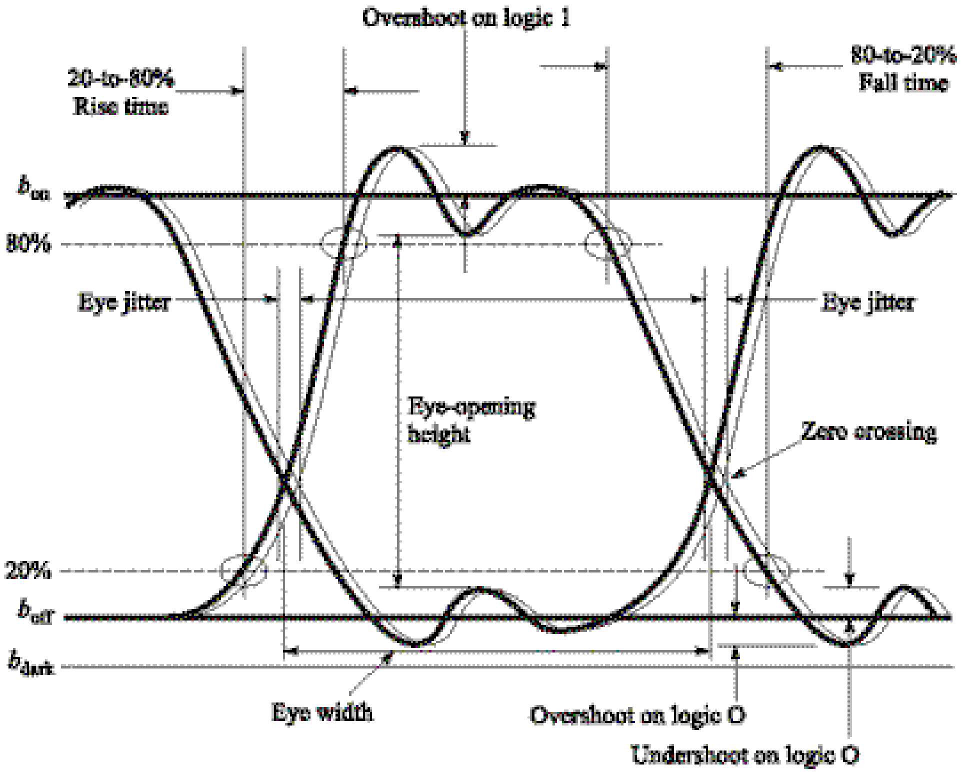
- The function of an *optical power meter* is to measure total power over a selected wavelength band.
- Some form of optical power detection is in almost every piece of lightwave test equipment.
- *Multiwavelength optical power meters* using several photodetectors are the most common instrument for measuring optical signal power levels.
- Usually the *meter outputs* are given in dBm (where 0 dBm = 1 mW) or dBμ (where 0 dB μ = l μ W).
- Examples: (a) EXFO FOT920; (b) Yokogawa AQ2160; (c) Kingfisher 9600

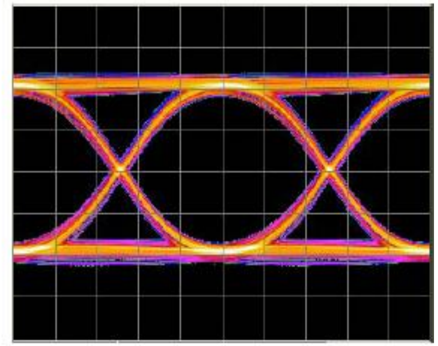
Dispersion Measurement



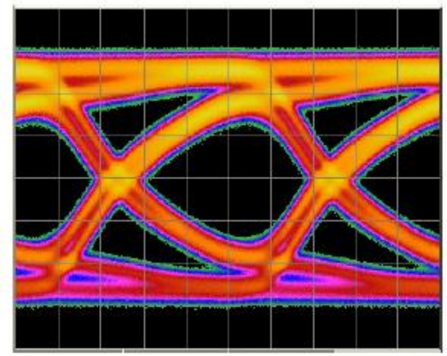
- **Ref :** http://tmworld.com/design/design-and-prototyping/4386390/Two-methods-measure-chromatic-dispersion
- **Ref :** http://cp.literature.agilent.com/litweb/pdf/5988-5318EN.pdf
- **Ref :** http://cp.literature.agilent.com/litweb/pdf/86037-90024.pdf

NRZ-Generated Eye Diagram





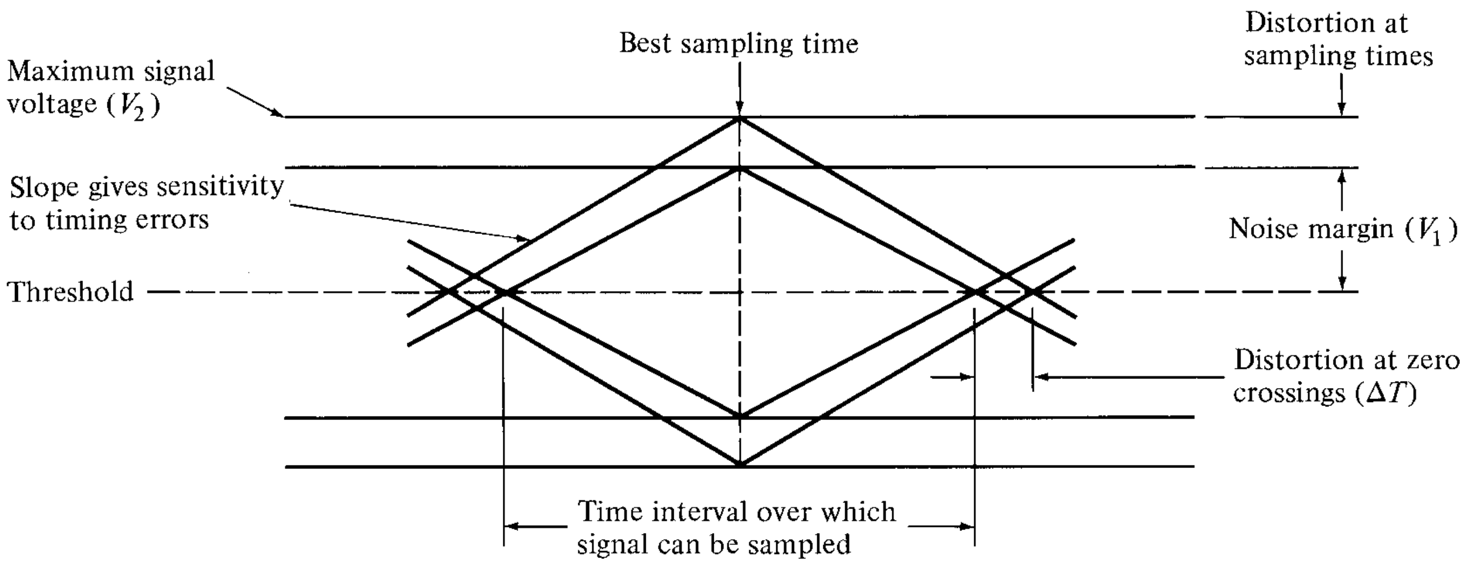
Eye diagram of a clean signal



Eye diagram of a distorted signal

- The eye-pattern technique is a simple but powerful measurement method for assessing the performance of a digital transmission link.
- It is formed by a pseudorandom bit sequence (PRBS) of length 2^{N-1}, where typical values of N are 7, 10, 15, 20, 23, and 31.

Simplified NRZ Eye Diagram

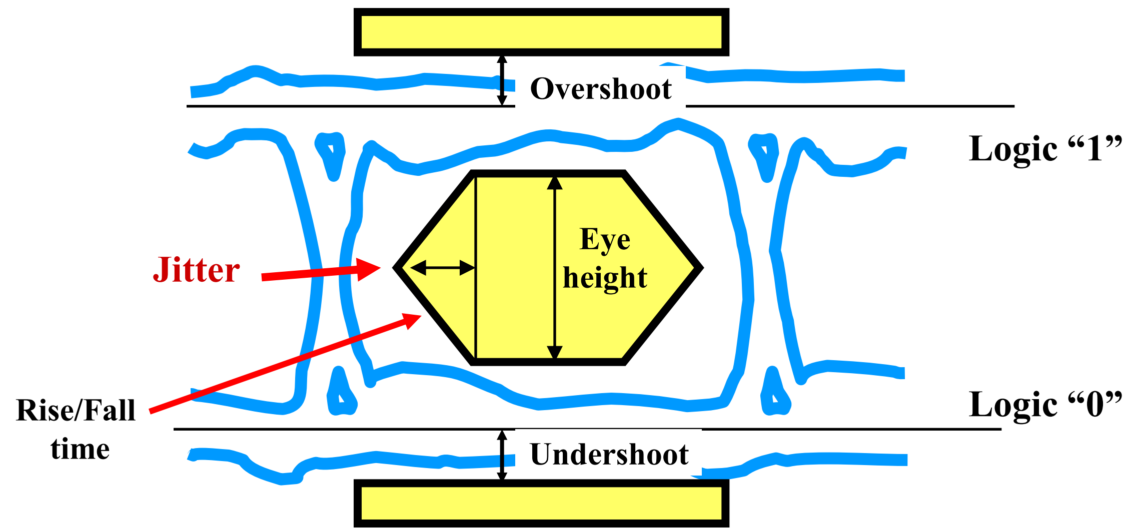


Performance measures derived from an NRZ eye diagram:

- **Eye width** defines the time interval over which a signal can be sampled
- **Largest opening of the eye** gives the **best sampling time**
- **Slopes of eye sides** determine the **sensitivity to timing errors**
- **Eye height** at sampling time shows that **noise margin** = $V_1/V_2 \times 100\%$
- **Rise & fall times** = time intervals between 10 and 90% points

Channel nonlinearities will create an asymmetric eye pattern

NRZ Eye Mask Parameters

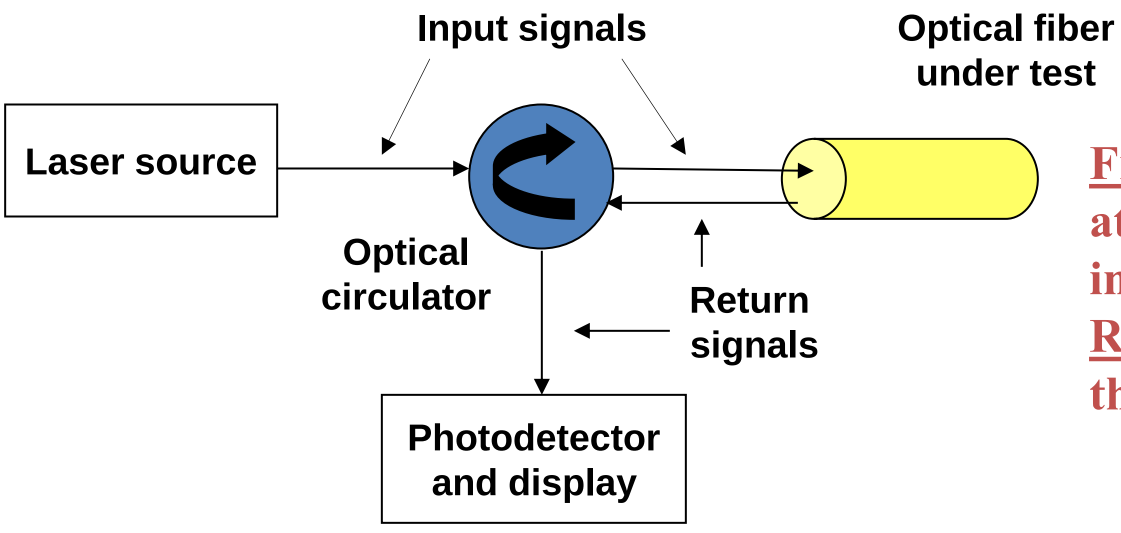


Definitions of mask parameters for NRZ eye diagrams

- **Eye height parameter**: minimum separation needed between logic "1" and "0" levels
- **Rise/fall time parameter**: half of maximum allowable 10-90% rise/fall time
- **Jitter parameter**: half of peak-to-peak jitter tolerance associated with the signal
- **Overshoot & undershoot parameters**: bound the amplitudes in terms of the logic levels

Protocol	Jitter	Rise time	Eye height	Overshoot	Undershoot
OC1/3	0.15	0.200	0.60	0.20	0.20
OC12	0.25	0.150	0.60	0.20	0.20
OC48/192	0.40	0.000	0.50	0.25	0.25
GigE	0.22	0.155	0.60	0.30	0.20
FibreCh	0.15	0.200	0.60	0.30	0.20

Optical Time-Domain Reflectometer



Fresnel reflection points are at fiber ends, at imperfections, or at splices. Rayleigh scattering occurs throughout the fiber length.

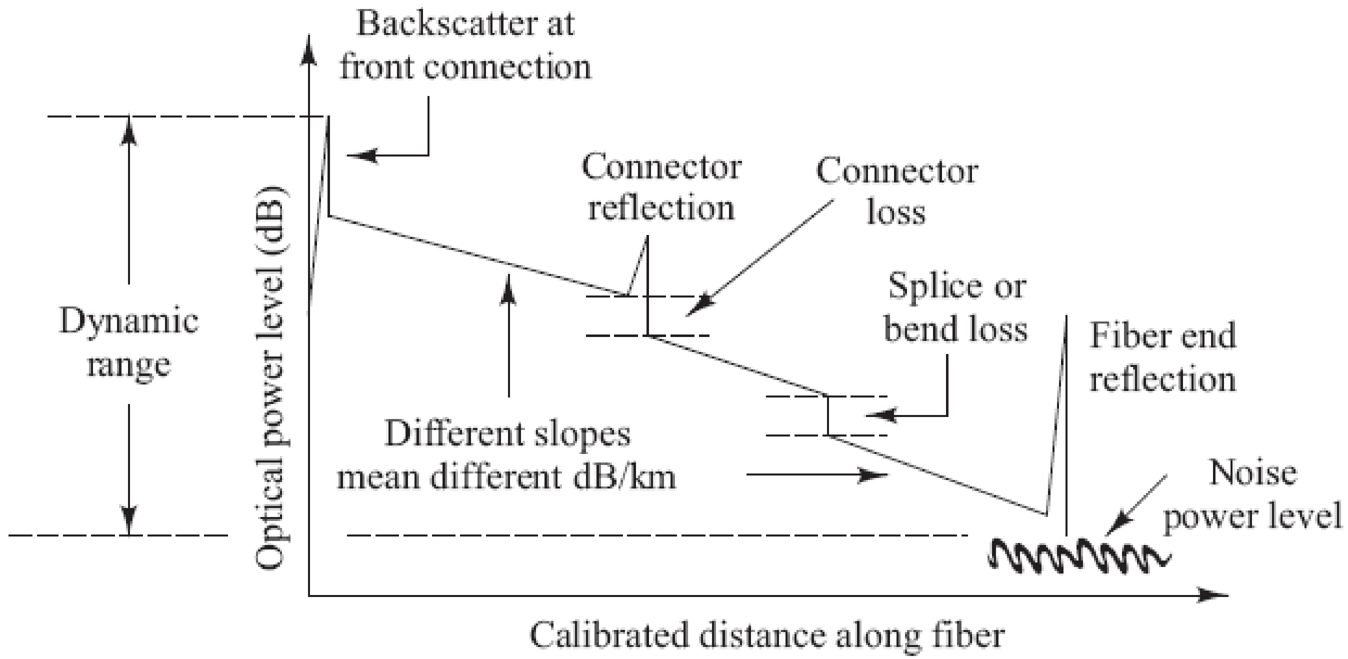
Operates on measuring back-scattered and back-reflected light

- **Measures attenuation and splice losses**
- **Helps locate faults in a fiber link**
- **Usually configured as a portable instrument for field use**

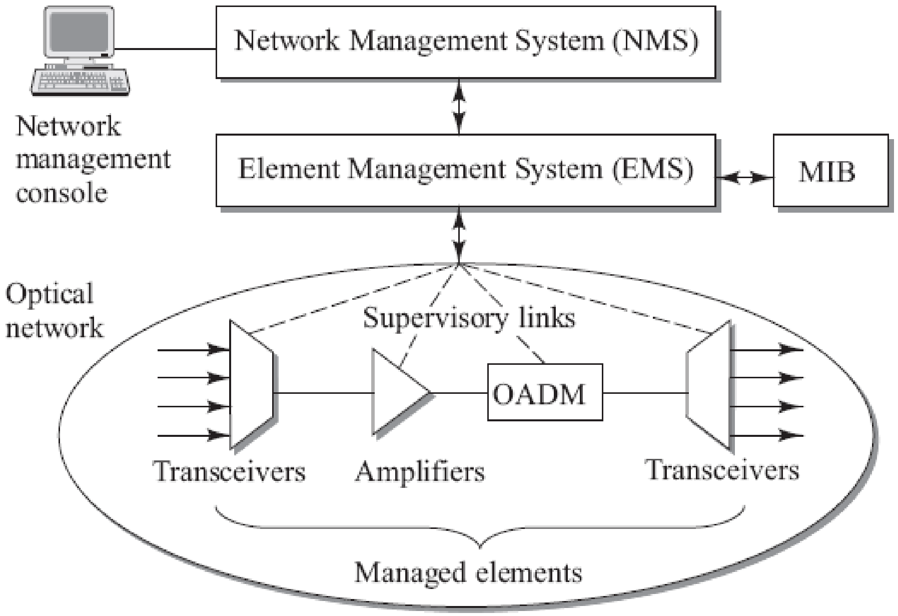
Typical OTDR Trace

- A commercial OTDR will show a trace on a display screen
- Vertical markers can be set to automatically measure and display the attenuation between the two selected points

<u>Note</u>: points where there are connectors, splices, fiber breaks, or other physical changes in the link are called "events"



OPM System Components



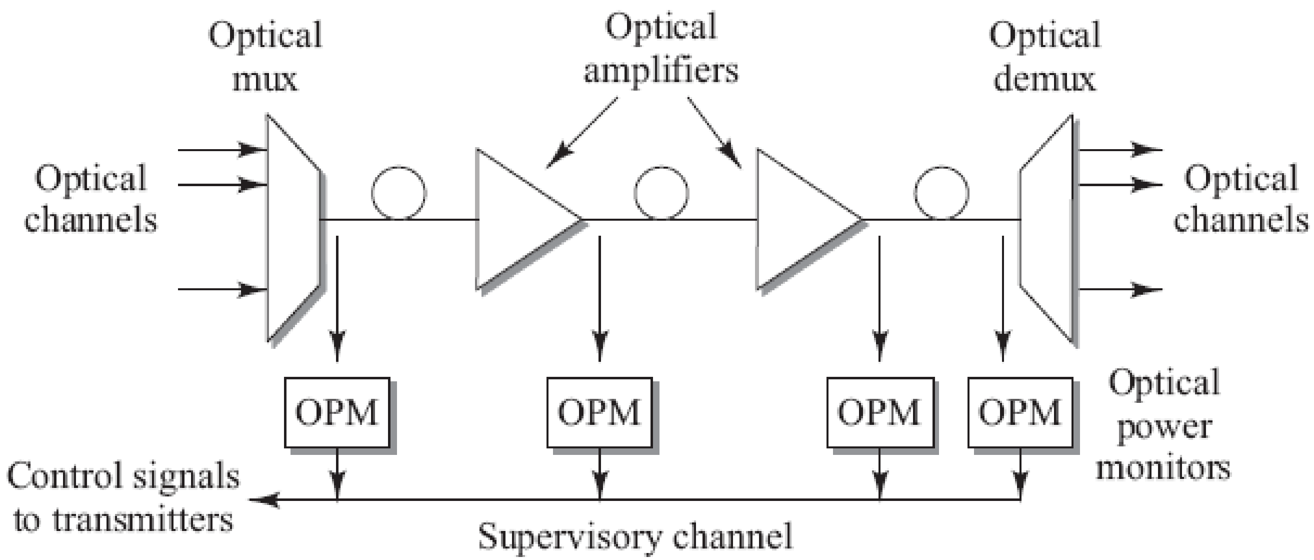
- The ***network management console*** **is the interface for the human network manager.**
- **The** ***managed devices*** **are network components.**
- **An** ***element management system*** **monitors and controls each device.**
- ***Agents*** **are management software modules that continuously gather and compile status and performance information on the managed devices.**

Network Management Functions

Table 14.6 *The purposes of five basic network management functions*

Management function	*Purpose*
Performance management	Monitor and control parameters that are essential to the proper operation of a network in order to guarantee a specific quality of service to network users.
Configuration management	Monitor network setup information and network device configurations to track and manage the effects on network operation of the various hardware and software elements.
Accounting management	Measure network-utilization parameters so that individuals or groups of users on the network can be regulated and billed for services appropriately.
Fault management	Detect fault or degradation symptoms, determine the origin and possible cause of faults, issue instructions on how to resolve the fault.
Security management	Develop security policies, set up a network security architecture, implement firewall and virus-protection software, establish access-authentication procedures.

Network Maintenance

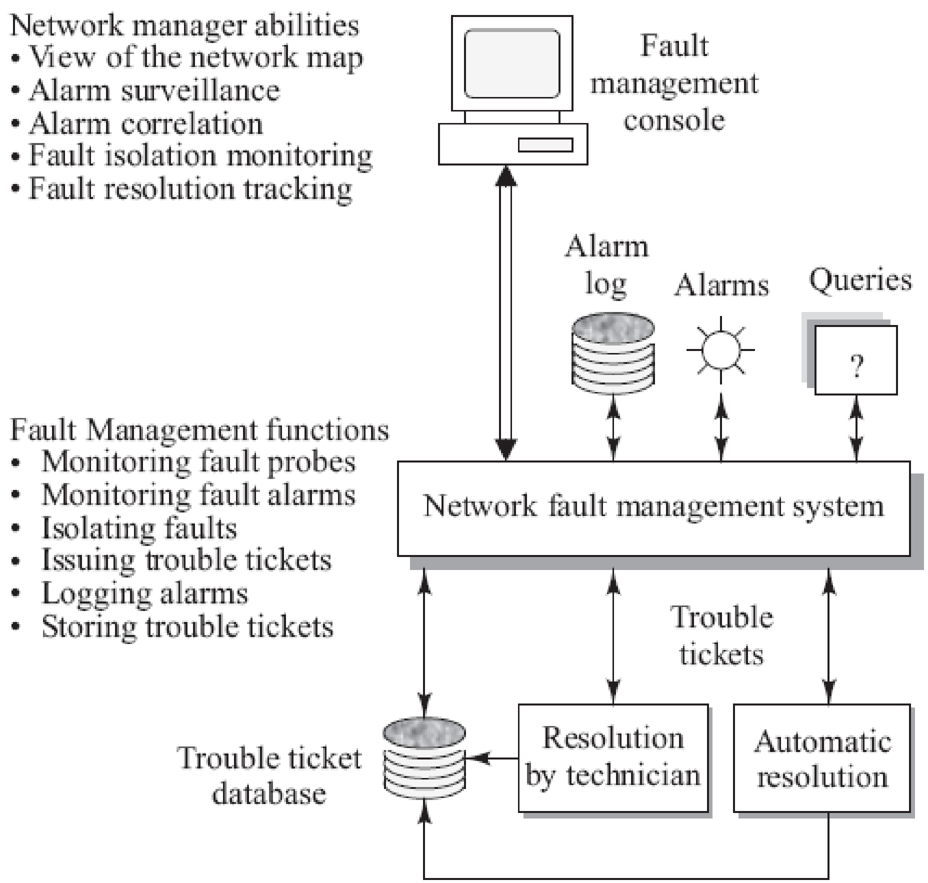


DWDM networks might use an automated OPM to measure the light level of each wavelength at various network points and to adjust the individual laser outputs at the transmitter.

Fault Management

Fault management involves:

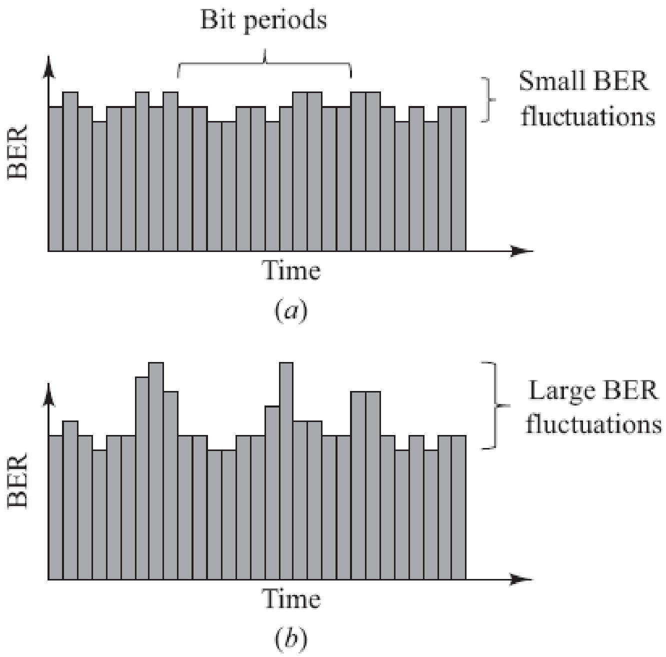
- **Detecting fault or degradation symptoms**
- **Determining the origin and possible cause of faults**
- **Issuing trouble tickets that indicate what the problem is and possible means of how to resolve the fault**
- **Once the problem has been fixed, the repair is operationally tested on all major subsystems**



Bit-Error Rate Testing

- **BER is *a statistical parameter* that depends on the measurement time and on the factors that cause the errors, such as signal dispersion, accumulated excess noise, and timing jitter.**
- **In BER measurements both the number of misinterpreted bits N_e and the total number of received bits are counted in a specific time window ΔT called the *gating time*.**

$$\mathrm{BER} = \frac{N_e}{B\,\Delta T}$$



Sequence of bit periods with

(a) relatively stable BER and

(b) bursty BER

Optical Signal-to-Noise Ratio (OSNR) Estimation

- **In multispan optically amplified DWDM networks, the system performance is limited by the *optical signal-to-noise ratio* (OSNR)**
- **The OSNR is given by** $$\text{OSNR} = \frac{P_{\text{ave}}}{P_{\text{ASE}}}$$

or in decibels $$\text{OSNR(dB)} = 10 \log \frac{P_{\text{ave}}}{P_{\text{ASE}}}$$

Example 14.8 Consider an optical signal level of –15 dBm (32 μW) arriving at a *pin* optical receiver in a 10-Gb/s link. If the noise power density is –34.5 dBm (0.35 μW), what is the OSNR?

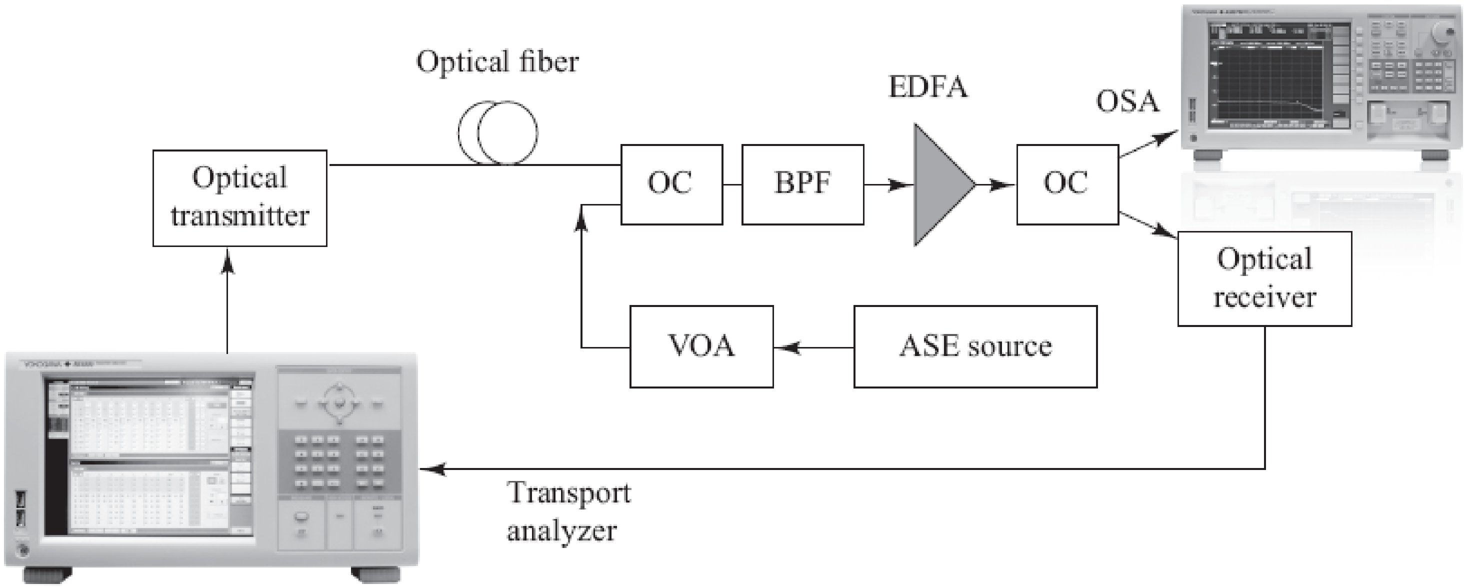
Solution: From Eq. (14.28) we obtain

$$\text{OSNR} = 32/0.35 = 91$$

or, in decibels,

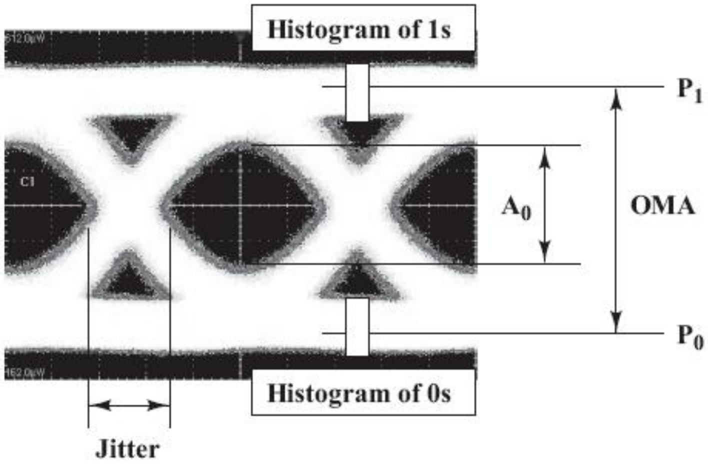
$$\text{OSNR(dB)} = 10 \log 91 = 19.6 \text{ dB}$$

Q Factor Estimation



- **An experimental setup that gives a correlation between the OSNR and the Q factor of the system.**
- ***Transport Analyzer and Optical Spectrum Analyzer photos courtesy of Yokogawa***

Optical Modulation Amplitude (OMA) Measurement



- The ***optical modulation amplitude*** **is the difference between the high and low power levels: OMA = $P_1 - P_0$**
- **To measure the OMA, a transmitter puts out a repetitive square-wave pattern of typically five 1s and five 0s (…11111000001111100000…).**

Timing Jitter Measurement

- ***Timing jitter*** **is an instantaneous unintentional deviation in the ideal timing between binary symbols.**
- **Jitter occurs when the transition from one symbol state to the next state occurs earlier or later than the exact end of the bit time interval.**
- ***Random jitter*** **is caused by thermal and shot noises in the receiver, and from ASE noise accumulated throughout the transmission link.**
- ***Deterministic jitter*** **arises from pattern distorting effects due to chromatic dispersion, self-phase modulation, and interchannel crosstalk.**
- **For a bit sequence with a data rate *B, a jittered waveform* can be expressed as**

$$P_{jitter}(t) = P\left[t + \frac{\Delta\varphi(t)}{2\pi B}\right] = P[t + \Delta t(t)]$$

- **Here Δϕ(t) is the phase variation introduced by time jitter and P(t) is the waveform in the absence of time jitter**