



Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers



Plan

■ Principaux composants

- Connecteurs et épissures
- Atténuateurs
- coupleurs directifs
- Isolateurs
- circulateurs
- Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers



Fiber optic system components

- Directional couplers
- Lens couplers
- Attenuators
- Delays
- Polarization controllers
- Isolators
- Filters
- Modulators
- Amplifiers
- Connectors
- Detectors
- WDM couplers

www.ecse.rpi.edu/Homework/shivkuma/teaching/sp2003/bon2003-optical-components.ppt

165 pages

uspas.fnal.gov/materials/Timing_and_Synch/Components.ppt

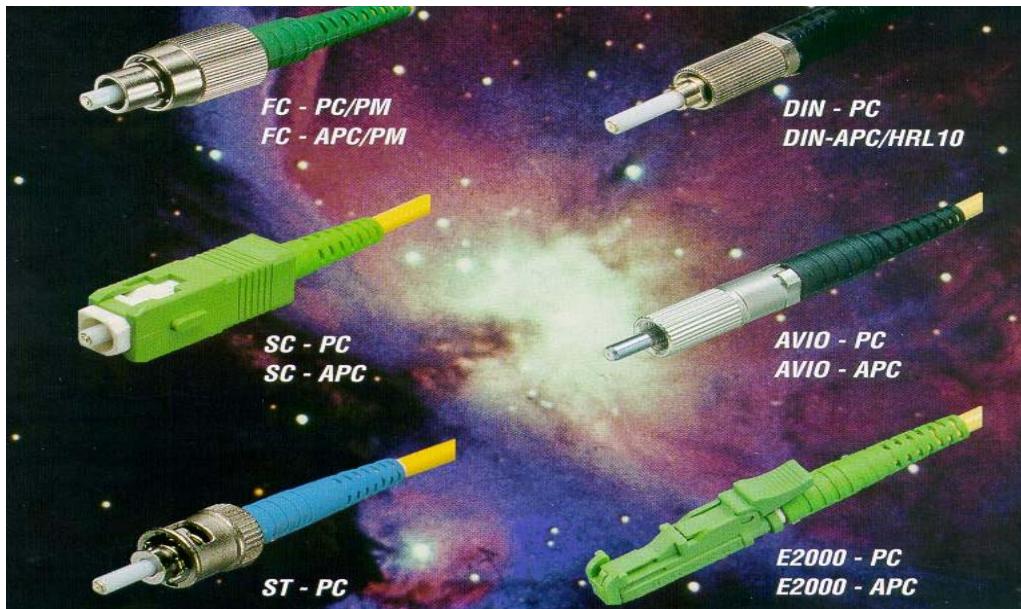


Plan

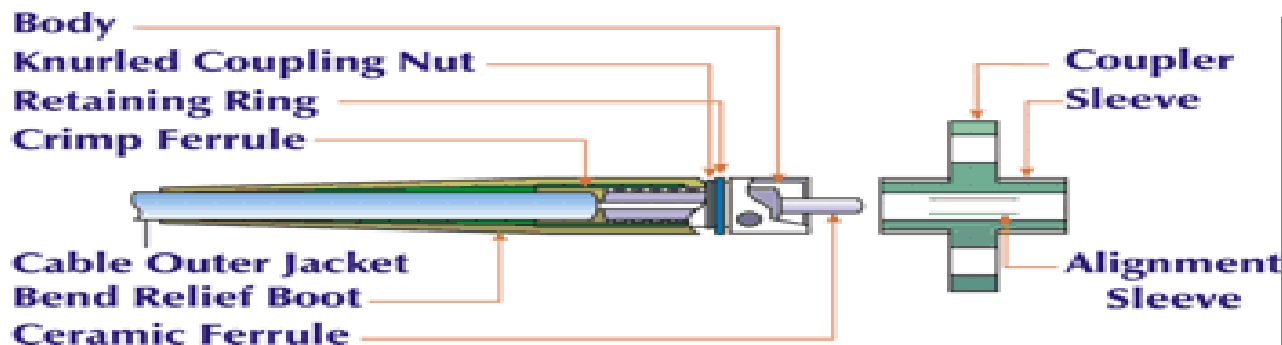
- **Principaux composants**
 - **connecteurs et épissures**
 - atténuateurs
 - coupleurs directifs
 - Isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers

Connecteurs Epissures


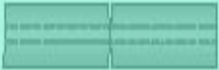

Connectors Splices

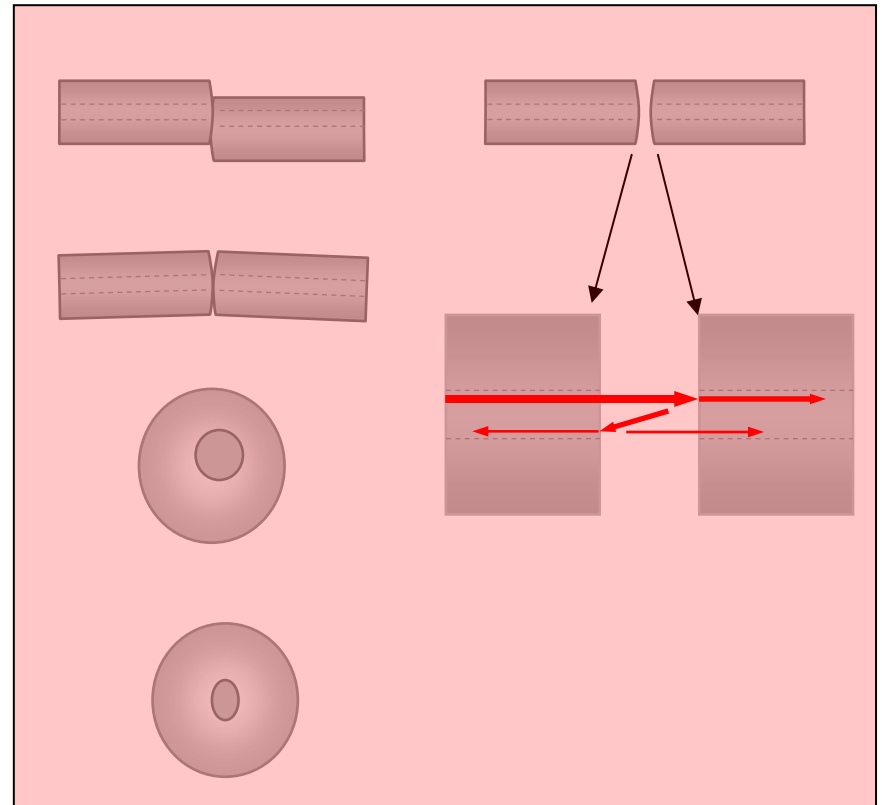


To avoid an air gap
Ferrule is polished flat, or
Rounded (**PC**—Physical Contact), or
Angled physical Contact (**APC**)
Polarization Maintaining (**PM**)



PC APC

Air Gap	Physical Contact (PC)	Angled Physical Contact (APC)
		
Medium insertion loss: typ. 0.5 dB	Lowest insertion loss: < 0.25 dB	Highest insertion loss: 0.4 to 0.9 dB
Worst return loss: < 14 dB (Fresnel)	Good return loss: > 40 dB	Best return loss: > 60 dB
Common multimode fiber connector	Common single-mode fiber connector	Cable TV, high performance systems

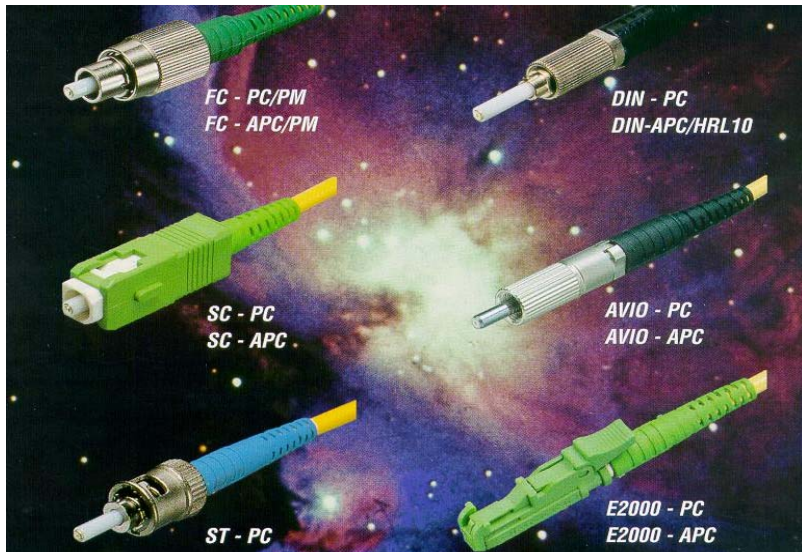


Atténuations (connecteurs, épissures)

source IBM

Table 2. Connector Characteristics

Connector Type	Insertion Loss (MM) Typical	Insertion Loss (SM) Typical	Return Loss Typical
ST	0.25 dB	0.2 dB	40 dB
SC	0.25 dB	0.2 dB	40 dB
SMA	1.5 dB		
FSD	0.6 dB		
FC	0.25 dB	0.2 dB	40 dB
D4	0.25 dB	0.2 dB	35 dB
DIN	0.25 dB	0.2 dB	40 dB
Biconic	0.6 dB	0.3 dB	30 dB

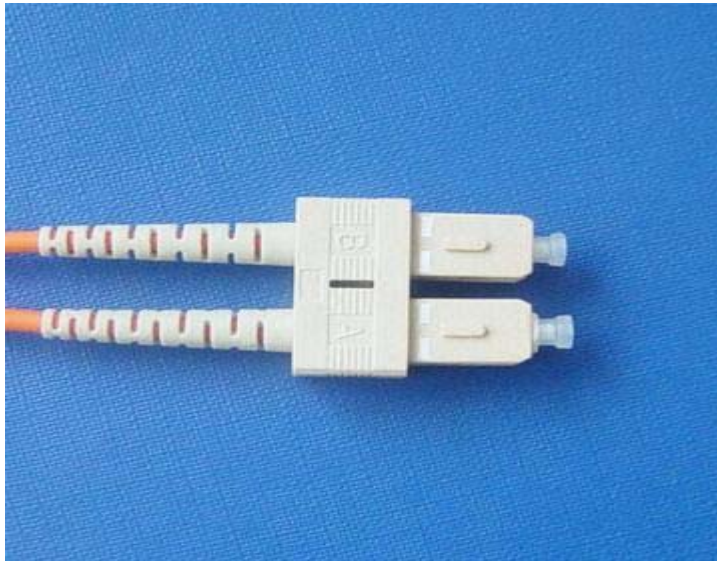


source Hayes

Fiber & Joint	Loss (max)	Reflectance (min)
SM splice	0.15 dB	50 dB
SM connector	1 dB	30 dB
MM splice	0.25 dB	50 dB
MM connector	0.75 dB	25 dB

Simplex-Duplex

LC



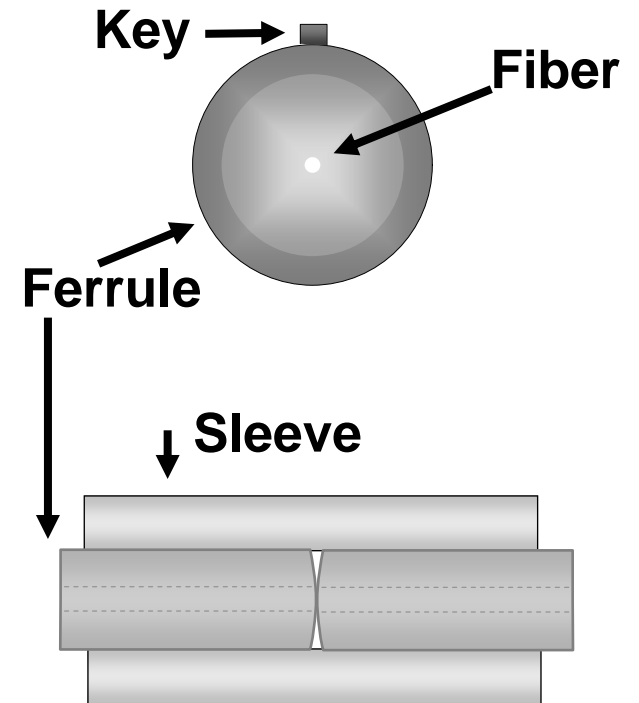
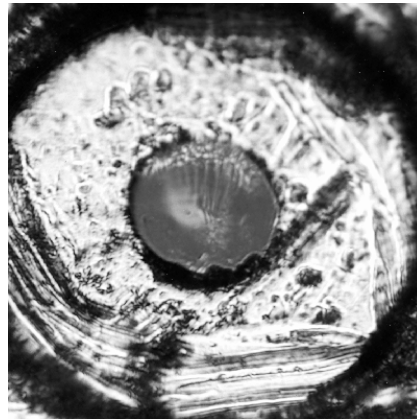
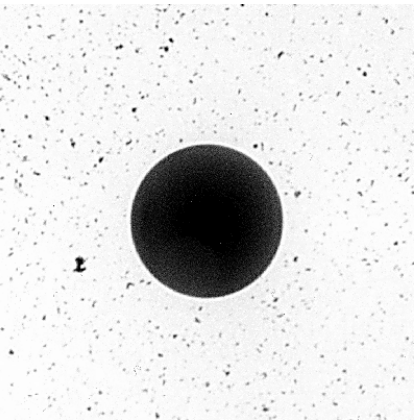
SC



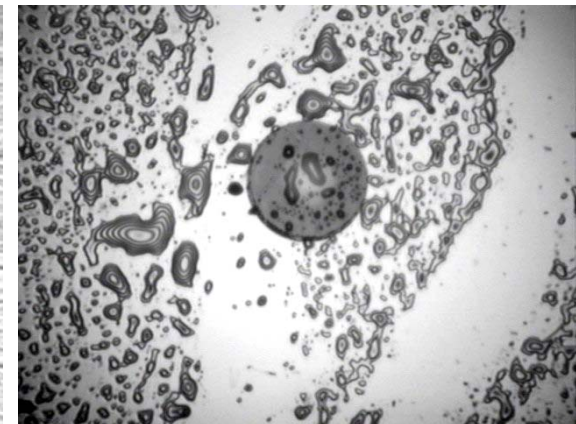
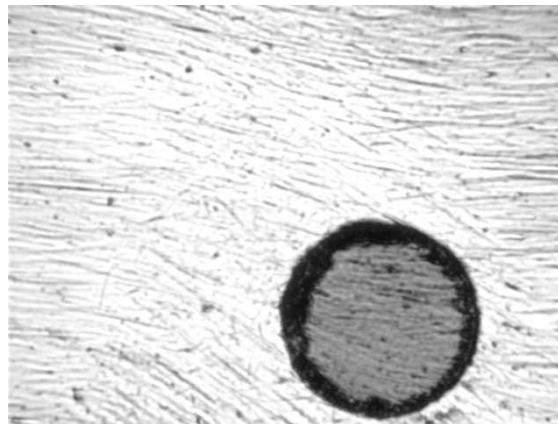
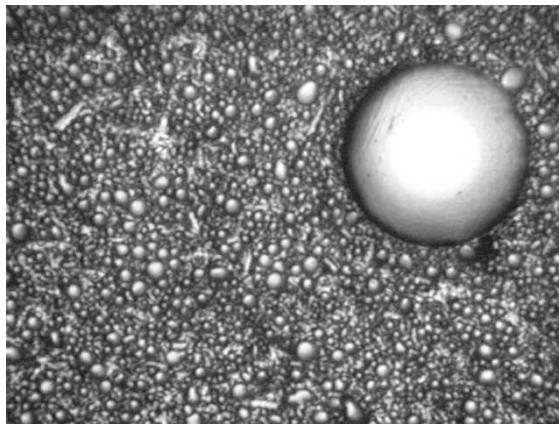
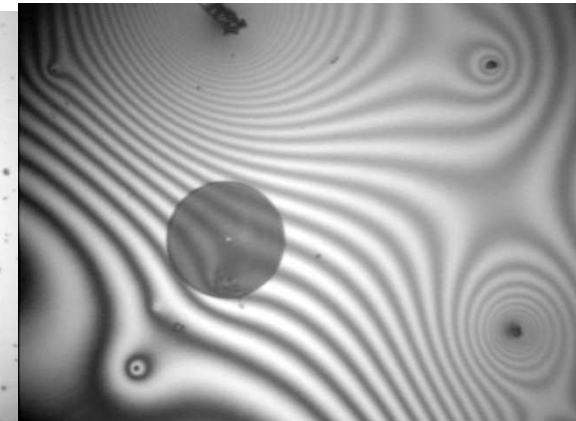
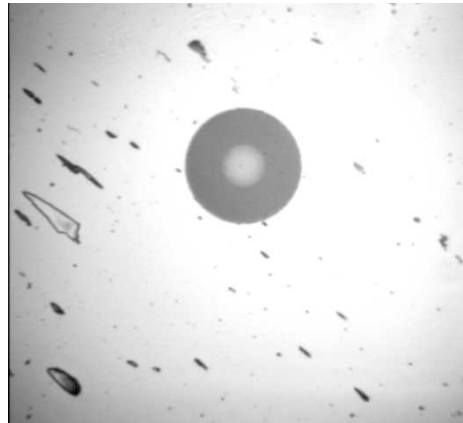
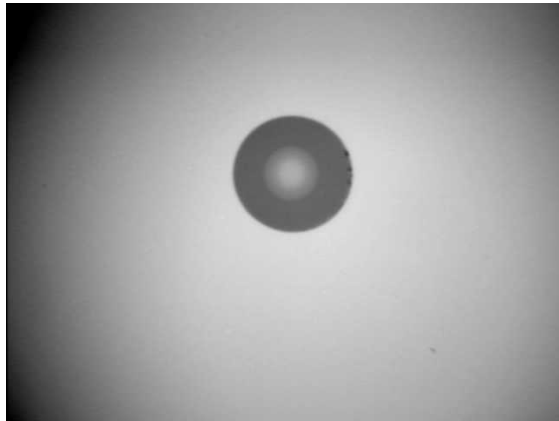
Connector Technology

Ultra-high precision

- Optical axis aligned to better than $\pm 1 \mu\text{m}$ (single-mode)
- Physical contact of the glass end surfaces necessary



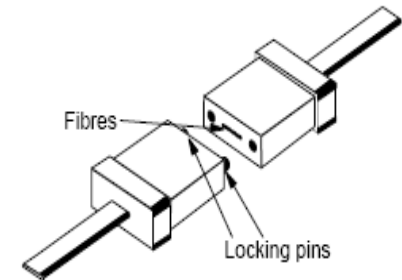
What does dirt look like



■ Dirt can migrate from a dirty to a clean connector

Technically Speaking: Fiber Connectors

- The ST® connector, which uses a bayonet locking system, is the most common connector.
- The SC connector features a molded body and a push-pull locking system.
- The FDDI connector comes with a 2.5-mm free-floating ferrule and a fixed shroud to minimize light loss.
- The MT-RJ connector, a small-form RJ-style connector, features a molded body and uses cleave-and-leave splicing.
- The LC connector, a small-form factor connector, features a ceramic ferrule and looks like a mini SC connector.
- The VF-45™ connector is another small-form factor connector. It uses a unique “V-groove” design.
- The FC connector is a threaded body connector. Secure it by screwing the connector body to the mating threads. Used in high-vibration environments.
- The MTO/MTP connector is a fiber connector that uses high-fiber-count ribbon cable. It's used in high-density fiber applications.
- The MU connector resembles the larger SC connector. It uses a simple push-pull latching connection and is well suited for high-density applications.



Epissures Splices

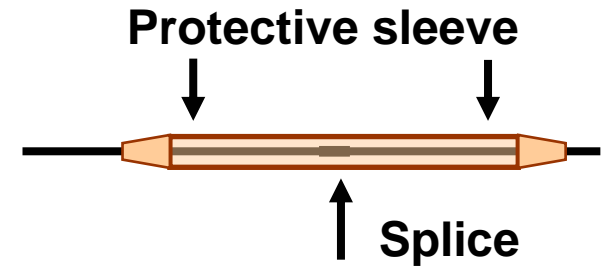
http://www.electronics.dit.ie/staff/tfreir/optical_2/splice_otdr_paper.pdf

■ Fusion Splices

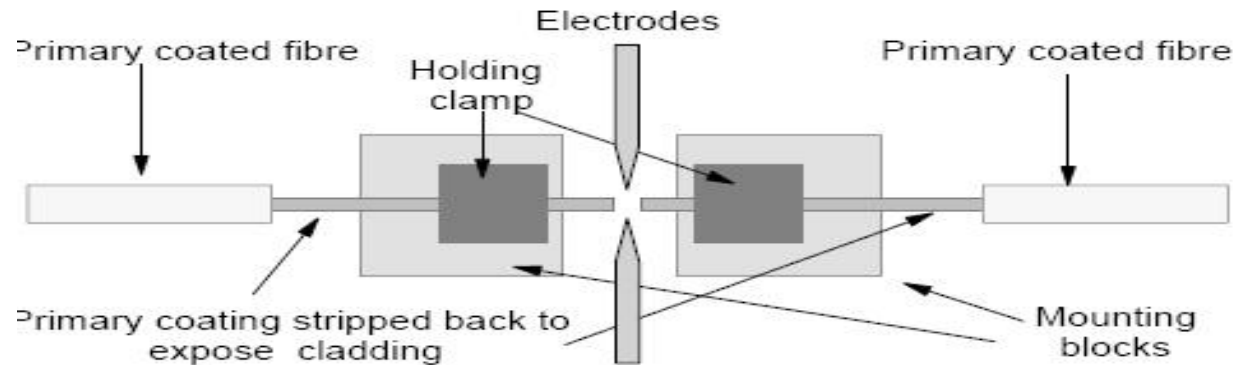
- Most common permanent fiber connection
- Very high performance and reliability
- Insertion loss 0.01 to 0.1 dB, no reflection
- Automated splicing tool costs \$10k to \$50k

■ Mechanical Splices

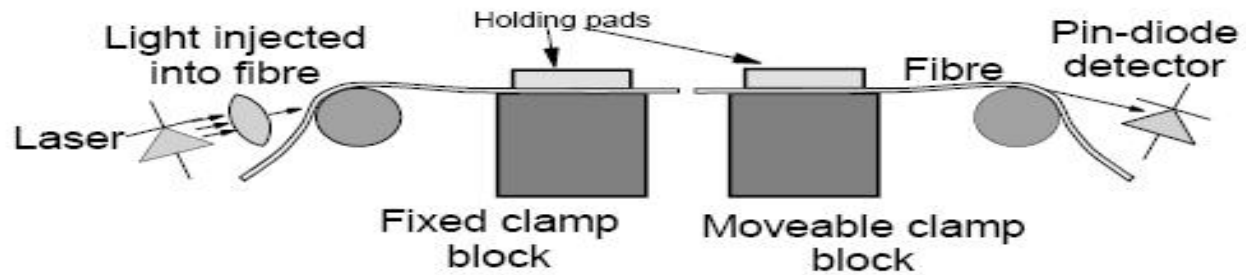
- Permanent and non-permanent types
- Insertion loss 0.1 to 0.5 dB
- Index-matching liquid used to minimize loss & reflections
- Epoxy or UV hardened elastomer based
- Less expensive tools (\$100 to \$1,000) required



Splicing



Fusion Splicing Schematic



Fibre Alignment Using Optical Feedback

hardware

Single Mode Connectors



Multimode Connectors



Reusable Splices / Termination



Furcation Tubing and Fiber Connector Caps



Termination Tools



Inspection Tools



Fiber Cleavers



Fiber Cleaning



Polishing Supplies



Epoxies & Supplies



UV Adhesives



UV Curing System



Fiber Connector Adapters



Mating Sleeves / Adapters



Single Mode Patch Cables



Multimode Patch Cables





Variety of cleaning methods in use today

Example:

Clean connector tips with
Isopropyl (96% medical alcohol)
using *adhesive free* cotton swabs

Immediately dry it with *dust-free*,
non residue compressed air



Filtered Air



Isopropyl Alcohol



Pure Cotton Swabs

<http://samsclass.info/211/ppt/ch1.ppt>

Ch 6

Fiber Optics Technician's Manual, 3rd. Ed

Jim Hayes

www.home.agilent.com/upload/cmc_upload/All/SLDPRE_basics

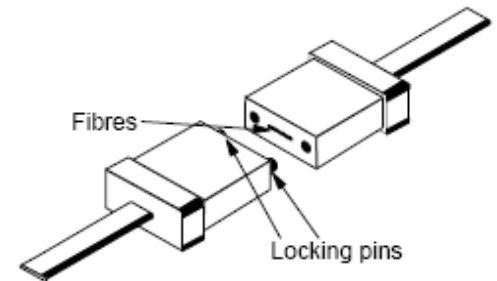
1.ppt

Elements of Lightwave Technology

Connectors

Technically Speaking: Fiber Connectors

- The ST® connector, which uses a bayonet locking system, is the most common connector.
- The SC connector features a molded body and a push-pull locking system.
- The FDDI connector comes with a 2.5-mm free-floating ferrule and a fixed shroud to minimize light loss.
- The MT-RJ connector, a small-form RJ-style connector, features a molded body and uses cleave-and-leave splicing.
- The LC connector, a small-form factor connector, features a ceramic ferrule and looks like a mini SC connector.
- The VF-45™ connector is another small-form factor connector. It uses a unique “V-groove” design.
- The FC connector is a threaded body connector. Secure it by screwing the connector body to the mating threads. Used in high-vibration environments.
- The MTO/MTP connector is a fiber connector that uses high-fiber-count ribbon cable. It's used in high-density fiber applications.
- The MU connector resembles the larger SC connector. It uses a simple push-pull latching connection and is well suited for high-density applications.





Plan

■ Principaux composants

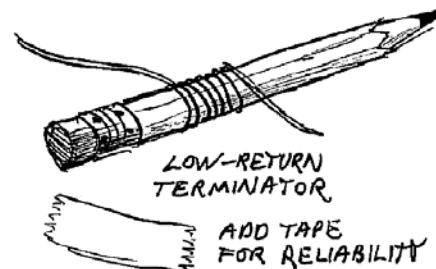
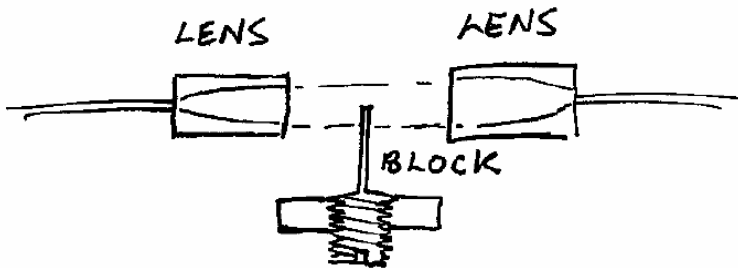
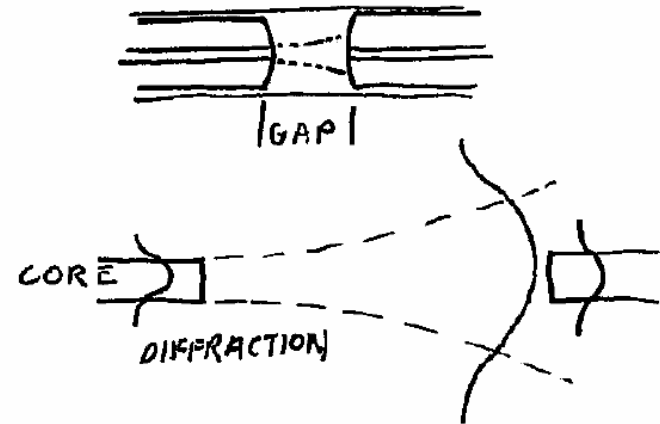
- connecteurs et épissures
- **atténuateurs**
- coupleurs directifs
- Isolateurs
- circulateurs
- Multiplexeurs-démultiplexeurs (en longueurs d'ondes)

- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CMT, 8b/10b,)
- Formation
- Biblio
- Divers

Atténuateurs

- Pulling connectors apart
 - Adjustable
 - Fixed ring
- Blocking free space beam
 - Digitally controlled versions
- Bend loss
 - Loops or s-curves
- Short sections of lossy fiber
 - Packaged like RF attenuators

GAP ATTENUATOR:



Atténuateurs

Types of attenuators

1. **Fixed attenuators:** 5dB, 10dB. etc
2. **Variable attenuator:** **VOA**(Variable optical attenuator)

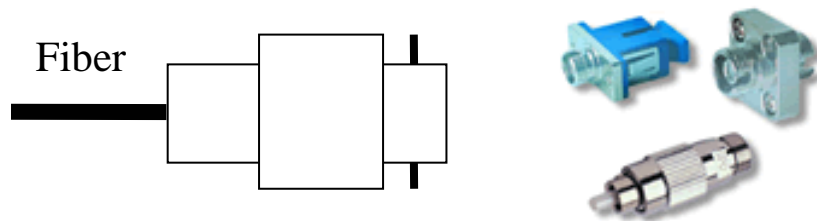
opto-mechanical devices with moving parts

without moving parts

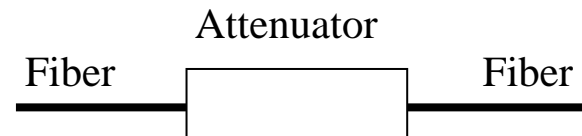
thermo-optical,

electro-optical

magneto-optical



A **plug-style attenuator** is employed as a connector where attenuation occurs.



An **in-line attenuator** is connected to a transmission fiber by splicing its two pigtails.

Atténuateurs

Characteristics and applications

Some of characteristics are included in the data sheets in all attenuators, such as: the range of operating wavelength, attenuation value, return loss, **PDL**, **PMD**, and temperature range.

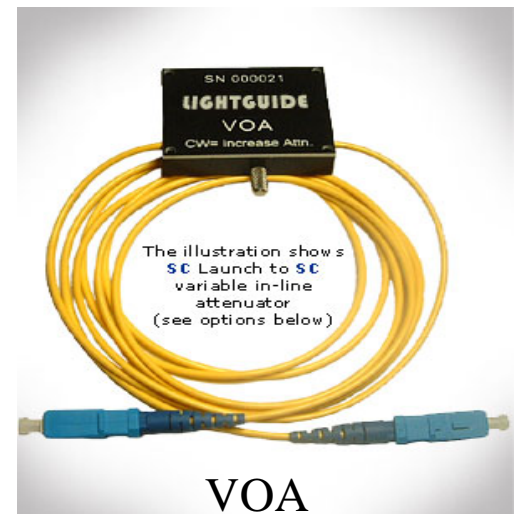
In addition, variable attenuators are characterized by the following parameters

1. Attenuation range: it is the specified range within which we can adjust to obtain attenuation.
2. Attenuation accuracy(resolution): it is the precision to which an attenuation value can be fine-tuned.

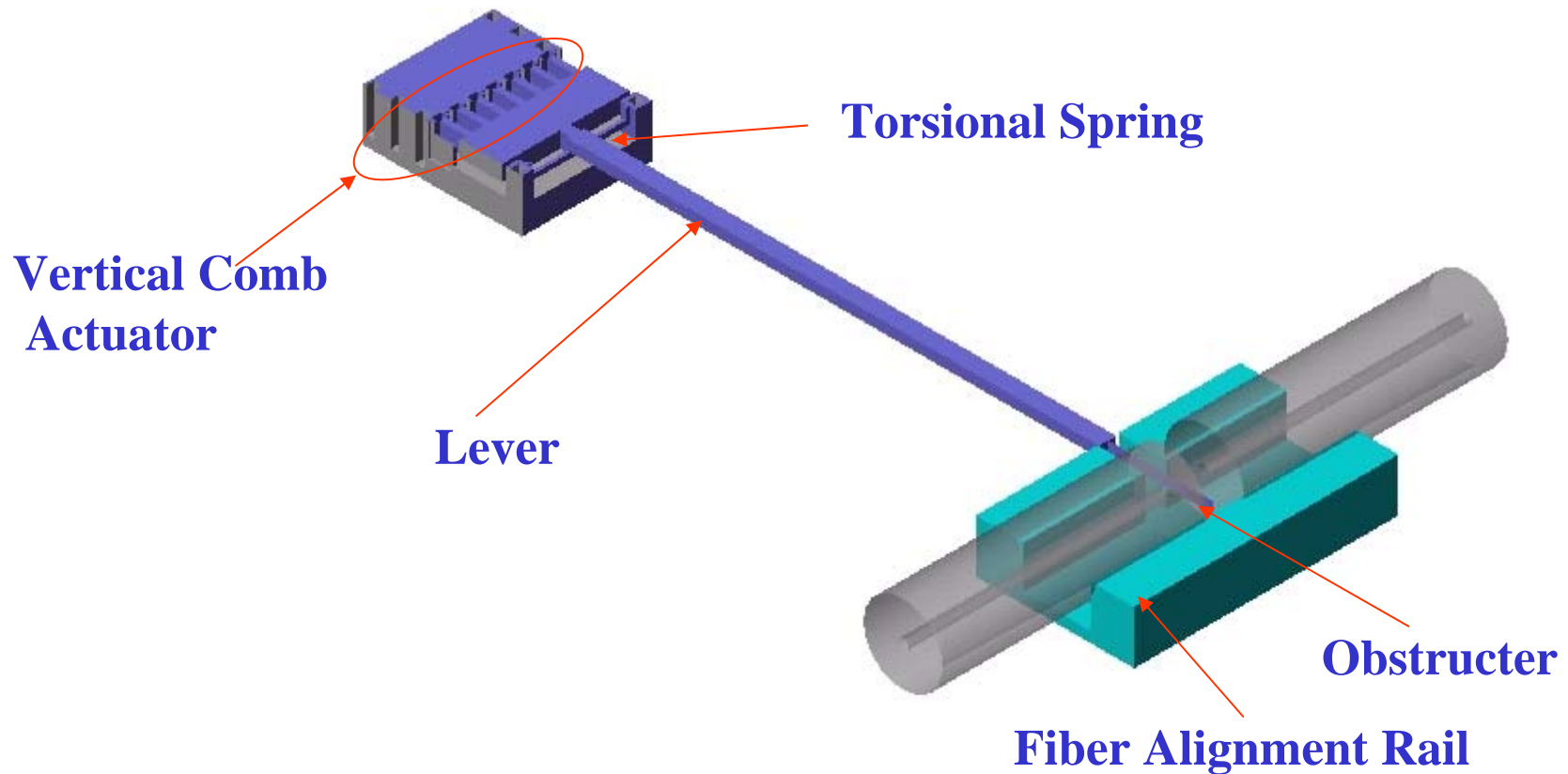
The most important applications for attenuator in fiber-optic networks include the following:

- 1) Preventing a receiver from reaching saturation
- 2) Wavelength balancing in **WDM** system
- 3) Equalizing power among the various nodes in distribution networks

PDL polarization dependent loss
Physical Medium Dependent (**PMD**)
WDM wavelength division multiplex



Variable Optical Attenuator (VOA)



Atténuateur



Electrical Connector Configurations

Pin number	Pin Usage	Specifications
1 and 2		
3 and 4	Control voltage input	0 ~ +5V

<http://www.agiltron.com/PDFs/Solid-state%20VOA.pdf>

Performance Specifications

SS Variable Optical Attenuator

Unit

Wavelength	C-band or L-band	nm
Insertion Loss ¹	<0.8(Typ), <1.0(Max)	dB
Wavelength Dependent Loss (WDL)	< 0.3 @15dB	dB
Temperature Dependent Loss (TDL)	< ± 0.6 @15dB	dB
Return Loss	> 45	dB
Polarization Dependent Loss (PDL)	< 0.4 @15dB	
Attenuation Range	> 25	dB
Response Time	< 150	s
Electrically Power consumption	< 0.1	W
Resolution	Continuous	dB
Operating Optical Power	< 500	mW
Operating Currant (0~5V)	<50	mA
Operating Temperature	-5 ~ 70	°C
Storage Temperature	-40 ~ 85	°C
Fiber Type	Corning SMF-28	
Package Dimension	(L)17.2x(W)9.0X(H)9.6	mm

Notes:

1. Excluding Connectors



Plan

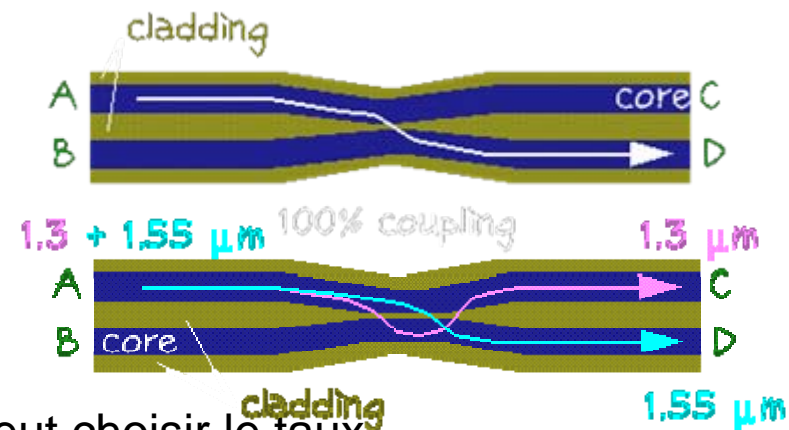
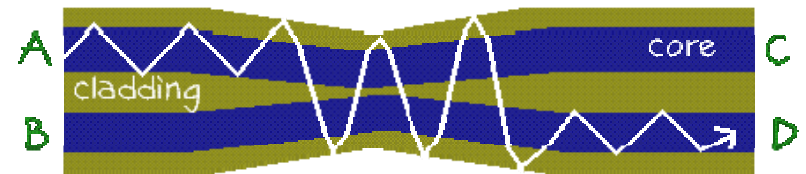
■ Principaux composants

- Connecteurs et épissures
- Atténuateurs
- **coupleurs directs**
- Isolateurs
- circulateurs
- Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers

Coupleur directif 1/5

En approchant les cœurs de deux fibres,
par usinage mécanique
ou par torsadage, chauffage et étirage,
on les couple par onde évanescente

100% de l'énergie passe de A vers D pour une
longueur L, dite longueur de couplage.
Au-delà elle recommence à repasser dans A,
complètement pour 2 L. La longueur de
couplage dépend de la longueur d'onde:
L de 1550nm > L de 1310nm.

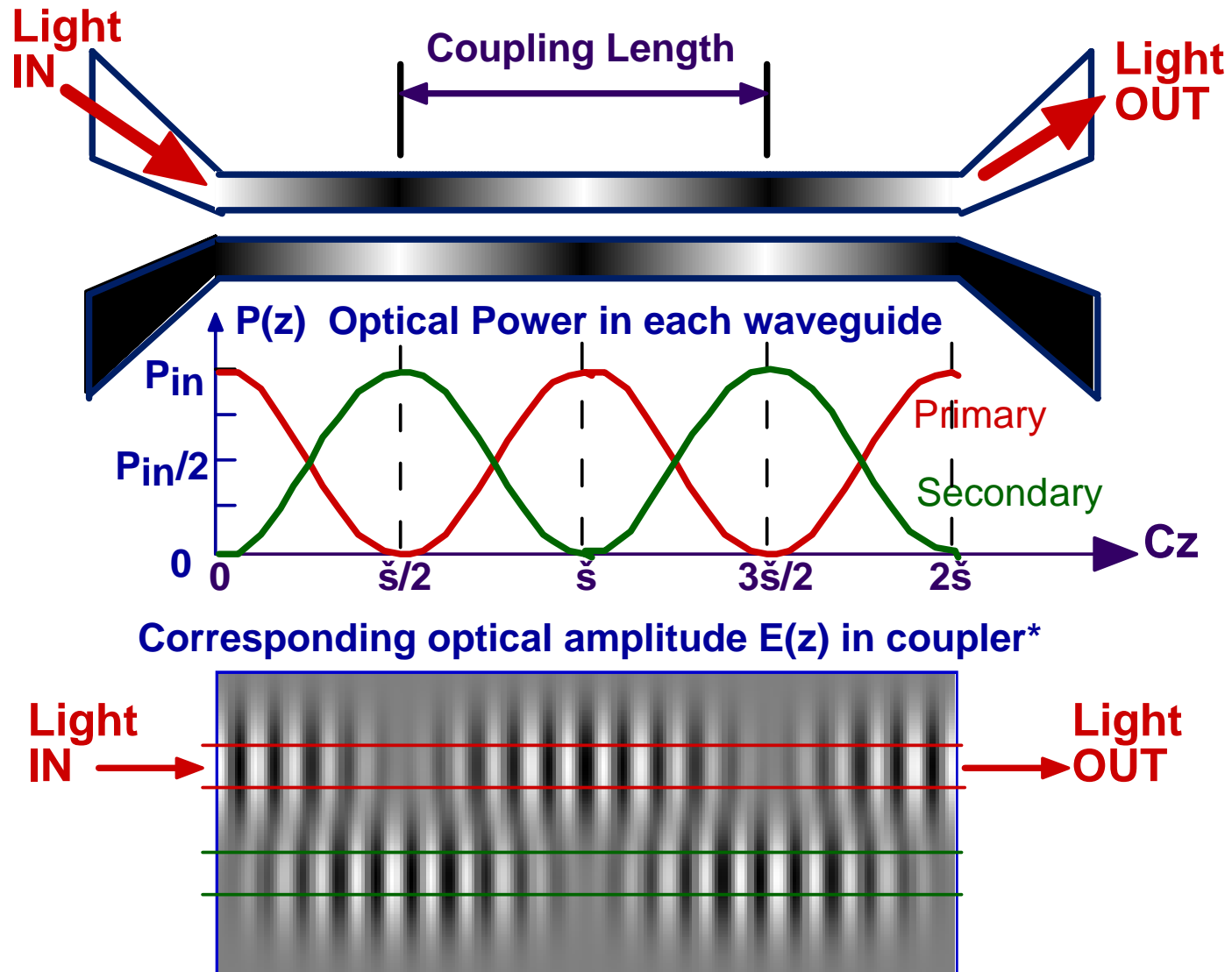


Il est directif (pas de couplage de A vers B). On peut choisir le taux
de partage entre C et D pour la puissance issue de A.

On peut séparer deux ondes issues de A vers C et D



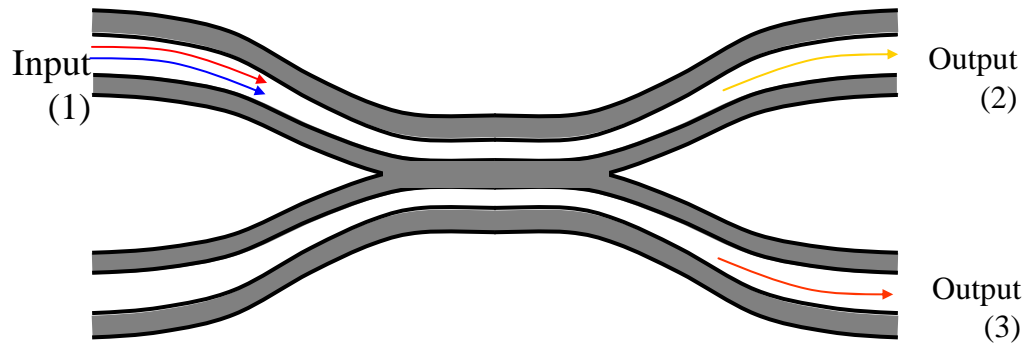
Photonic Devices - Couplers 2/5



Fibre Star Coupler 3/5

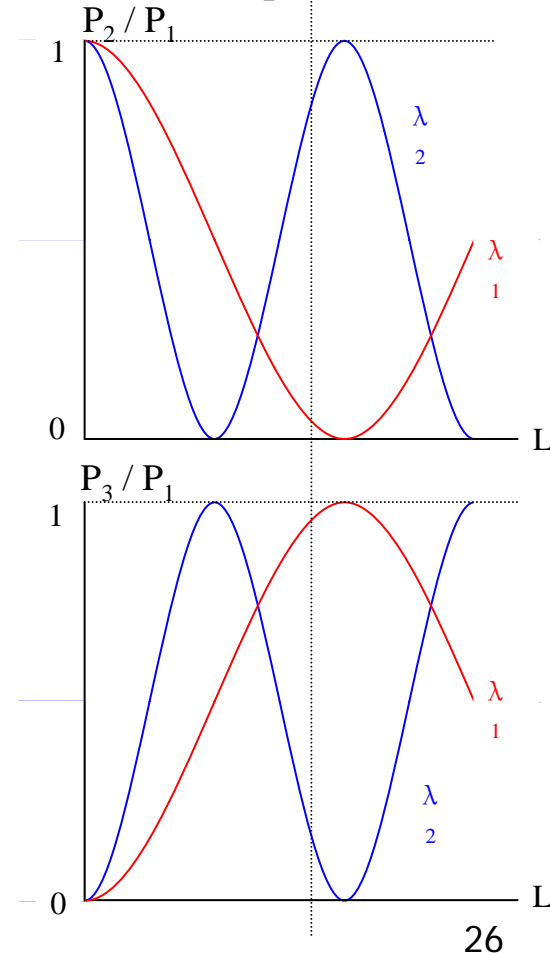
. Fused-fiber couplers are inherently sensitive to wavelength. Because the coupling coefficient $\Delta \beta$ varies with wavelength λ , coupling length L_c depends on λ . We can use this effect to separate wavelengths.

$$\frac{P_2}{P_1} = \cos^2(\Delta\beta(\lambda)L)$$



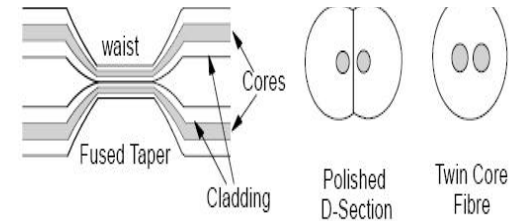
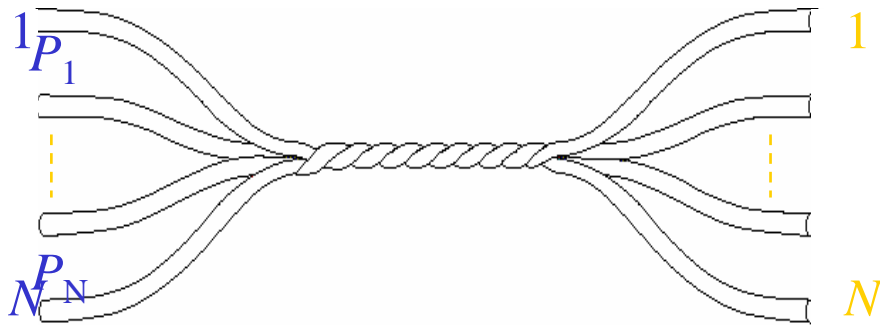
$$\frac{P_3}{P_1} = \sin^2(\Delta\beta(\lambda)L)$$

This WDM is essentially a FBT coupler, so it is also called WDM coupler. It can be used for broad WDM, such as 1310 and 1550nm.



Fibre Star Coupler 4/5

Combines power from N inputs and divided them between M outputs



Coupling ratio

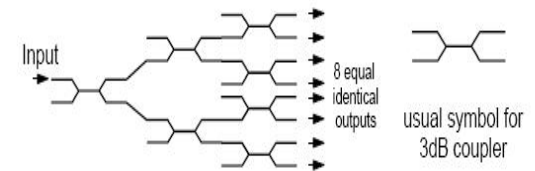
$$CR = -10\log_{10}\left(\frac{1}{N}\right) = 10\log_{10} N$$

Excess loss

$$L_e = 10\log_{10}\left(\frac{P_{in}}{\sum_i^N P_{out,i}}\right)$$

Power at any one output

$$P_{o,i} = \frac{1}{n}(P_1 + P_2 + \dots P_N)$$



8-way splitter using 3-dB couplers

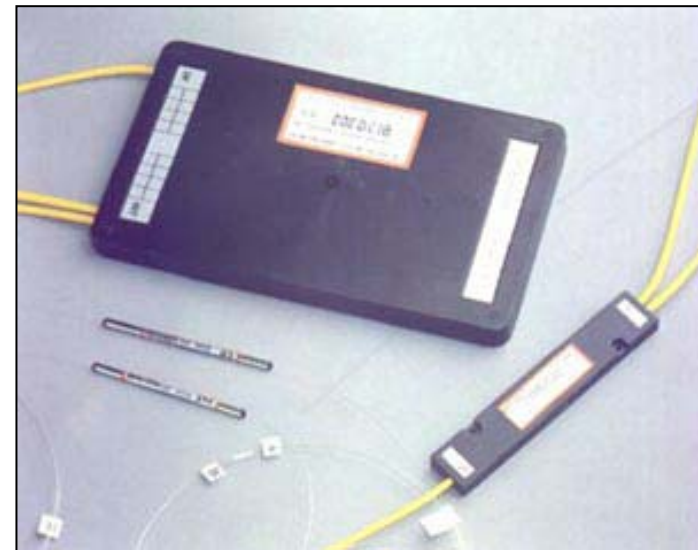
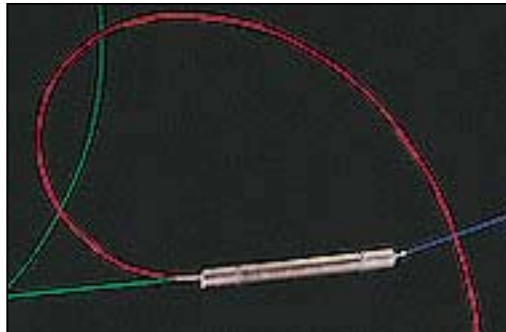
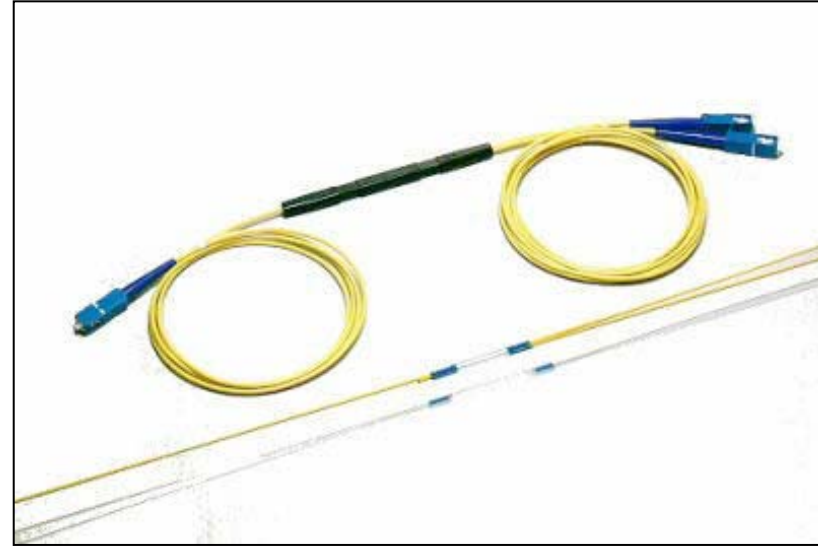


Photonic Devices - Couplers 5/5

Optical fibre couplers



A basic photonic device used to split or combine light to or from different fibres. A building block of “passive optical networks”.



Coupler Splitter datasheet

<http://www.agiltron.com/Fiber%20coupler,%20splitter,%20WDM.htm>

Performance Specifications

FC Series	Performance	Unit
Coupling Ratio	1/99 to 50/50	
Operation Wavelength	1440-1520	nm
Excess Loss	< 0.10	dB
Insertion Loss Split Ratio:50/50	< 3.4	dB
Split Ratio:40/60	< 4.4/2.5	dB
Split Ratio:30/70	< 5.7/1.8	dB
Split Ratio:20/80	< 7.8/1.1	dB
Split Ratio:10/90	< 11.0/0.60	dB
Split Ratio: 5/95	< 14.0/0.40	dB
Split Ratio: 1/99	< 19-21/0.2	dB
Uniformity (50/50)	< 0.5	dB
Polarization Dependent Loss	< 0.10	dB
Temperature Sensitivity	< 0.002	dB/°C
Directivity	> 55	dB
Return Loss	> 55	dB
Optical Power Handling	< 4	W
Operating Temperature	-10~70	°C
Storage Temperature	-40~85	°C
Fiber Type	Corning SMF-28	
Package Dimension *	250um&900um fiber: (φ)3.0x(L)54	mm
	Mini: (φ)3.0x(L)30 250um fiber only	
	3 mm Cable: (L)98x(W)14x(H)8.5	



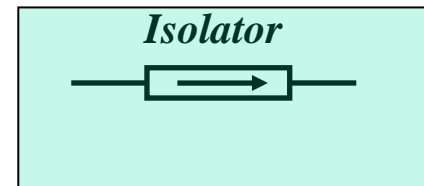
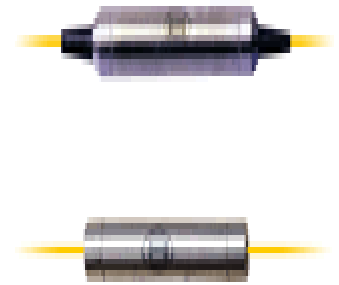
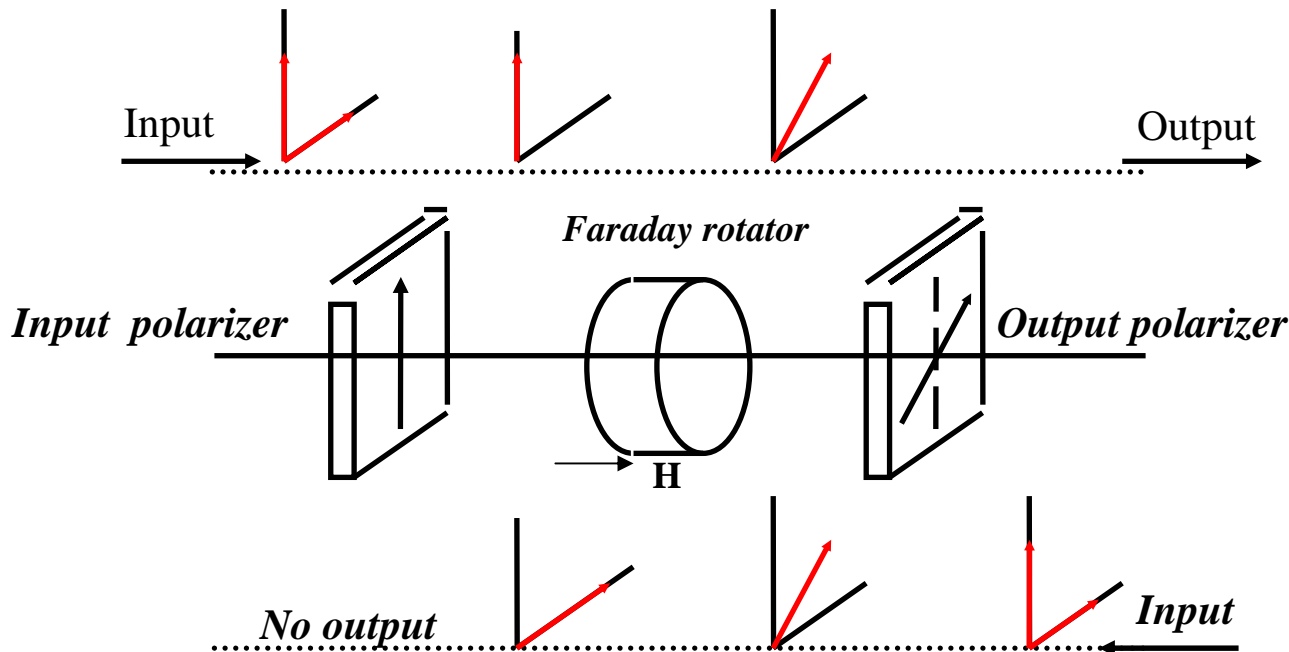
Plan

■ Principaux composants

- Connecteurs et épissures
- Atténuateurs
- coupleurs directifs
- **Isolateurs**
- circulateurs
- Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers

Fiber optical isolator 1/3

Optical isolators are devices that transmit light only in one direction. They play an important role in fiber-optic systems by stopping back-reflection and scattered light from reaching sensitive components, particularly, LDs.

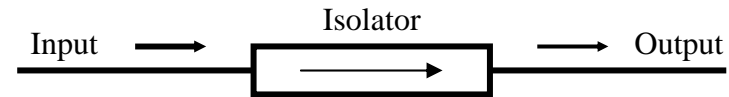


Fiber optical isolator 2/3

Main characteristics of isolator

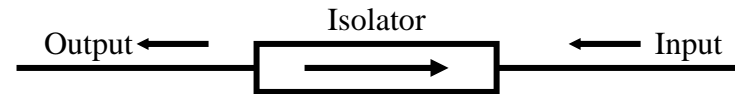
Insertion loss: give the transmission efficiency in the forward direction

$$L_{IL} = -10 \log \frac{P_o}{P_i}$$



Isolation: a measure of transmission efficiency when light travel in the reverse direction.

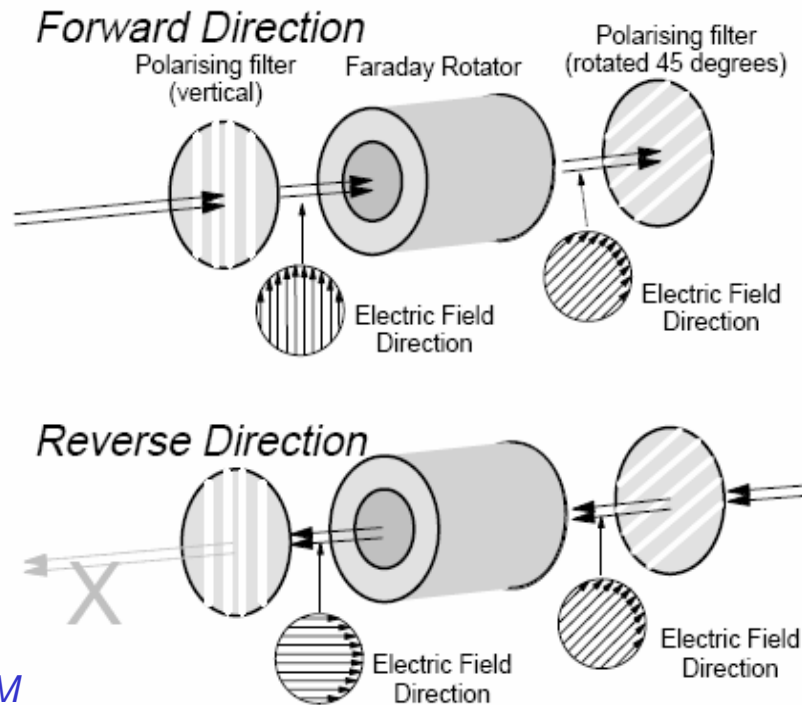
$$L_{IS} = -10 \log \frac{P_{o,r}}{P_{i,r}}$$



To increase isolation, manufacturer combine two units; in this case, the device is referred to as double(dual) stage. Now **insertion loss** of isolator could be as low as **0.15dB**, while **isolation** could be as high as **70dB**.

Other parameters for a isolator include: **return loss**, **polarization dependant loss(PDL)**, **polarization mode dispersion(PMD)**.

Fiber optical isolator 3/3



doc IBM

Figure 151. Isolator Operation

environ 2500 euros

10 W Polarization-Independent Fiber Isolators

IO-K-1064-CO

- ♦ **Wavelength Range:** 1054 - 1074 nm
- ♦ **Isolation:** 27 - 33 dB
- ♦ **Max Power:** 20 W
- ♦ **Insertion Loss:** 0.4 - 0.6 dB
- ♦ **Fiber:** HI1060



IO-K-1550

- ♦ **Wavelength Range:** 1535 - 1565 nm
- ♦ **Isolation:** 30 - 38 dB
- ♦ **Max Power:** 10 W
- ♦ **Insertion Loss:** 0.8 - 1.5 dB
- ♦ **Fiber:** SMF-28e



<http://www.thorlabs.com/Navigation.cfm>



Plan

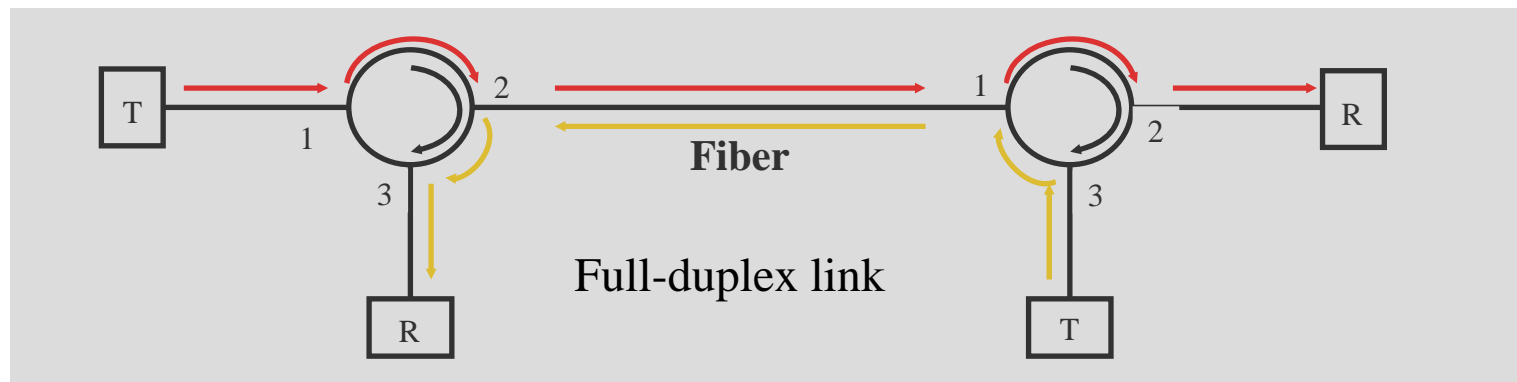
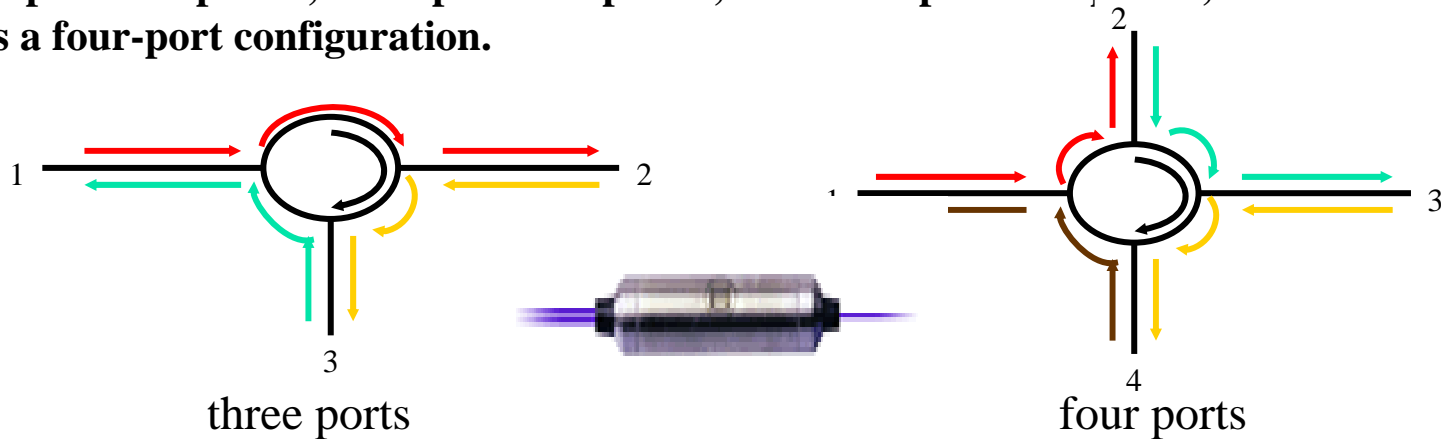
■ Principaux composants

- Connecteurs et épissures
- Atténuateurs
- coupleurs directifs
- Isolateurs
- **circulateurs**
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers

Circulator 1/2

Principle of operation

An optical circulator is a device which redirects the light sequentially **from one port to the next**. **Three-, four-, and six-port** circulators are commercially available. Three-port circulator redirect a light from port 1 to port 2, from port 2 to port 3, and from port 3 to port 1, as shown in fig.a. Fig.b illustrates a four-port configuration.



circulator 2/2

Product Description

The OC Series 1310/1550 Optical Circulators are non-reciprocal devices that redirect light at 1310/1550 nm from port-to-port in only one direction while minimizing back reflection and back scattering in the reverse directions for any state of polarization. Employing Agiltron's advanced micro optics design, it features low insertion loss, low polarization sensitivity, high isolation, compact structure, and high stability. The excellent characteristics of this product make it an ideal choice for application in fiber amplifier systems, pump laser diodes, and optical fiber sensors.

Performance Specifications

OC Series 1310/1550 Circulator		Specifications			Unit
Operating Wavelength	1310	1295 ~ 1325			nm
	C Band	1530 ~ 1570			
	L Band	1570 ~ 1610			
	C + L	1525 ~ 1610			
Type		3- Port		4-Port	nm
		1310	C, L	C +L	
Insertion Loss ¹	Typical	0.6		0.7	dB
	Maximum	0.9		1.0	
Isolation (2→1, 3→2, or 4→3) ²		36		30	36
Directivity (1→3 or 2→4)		> 50			dB
Polarization Dependent Loss		< 0.10		0.15	dB
Polarization Mode Dispersion		< 0.1			ps
Return Loss ¹		> 50			dB
Optical Power Handling		< 500			mW
Operating Temperature Range		0 ~ 70			°C
Storage Temperature		-40 ~ 85			°C
Fiber Type		Corning SMF-28			
Fiber Length		> 1			m
Package Dimension		Φ5.5× 58.0(L)		Φ5.5× 65.0(L)	mm

1. Excluding connectors

2. @λ_{op}, Top, SOP

<http://www.agiltron.com/PDFs/1310-1550%20circulator.pdf>



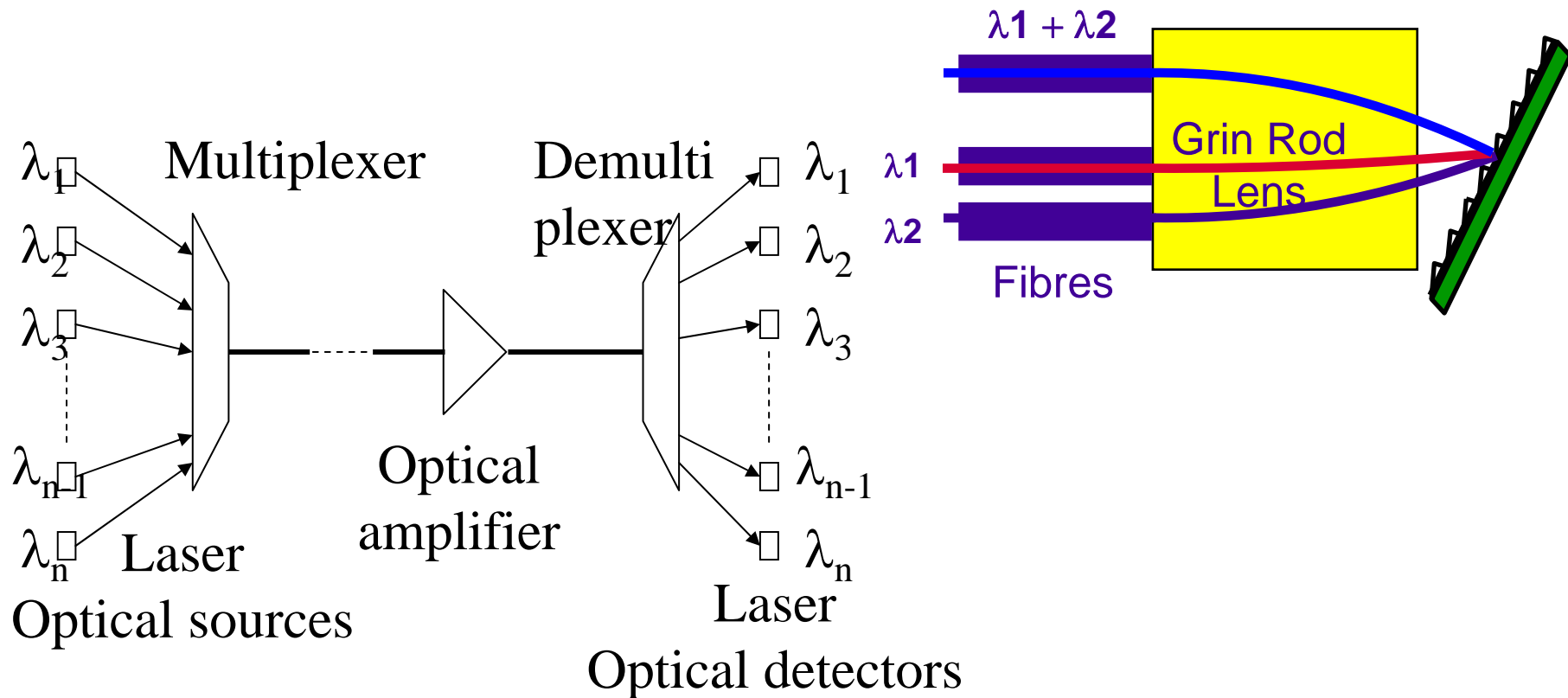
Plan

■ Principaux composants

- connecteurs et épissures
- atténuateurs
- coupleurs directifs
- isolateurs
- circulateurs
- **multiplexeurs-démultiplexeurs** (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CMT, 8b/10b,)
- Formation
- Biblio
- Divers

Wavelength-Division Multiplexing

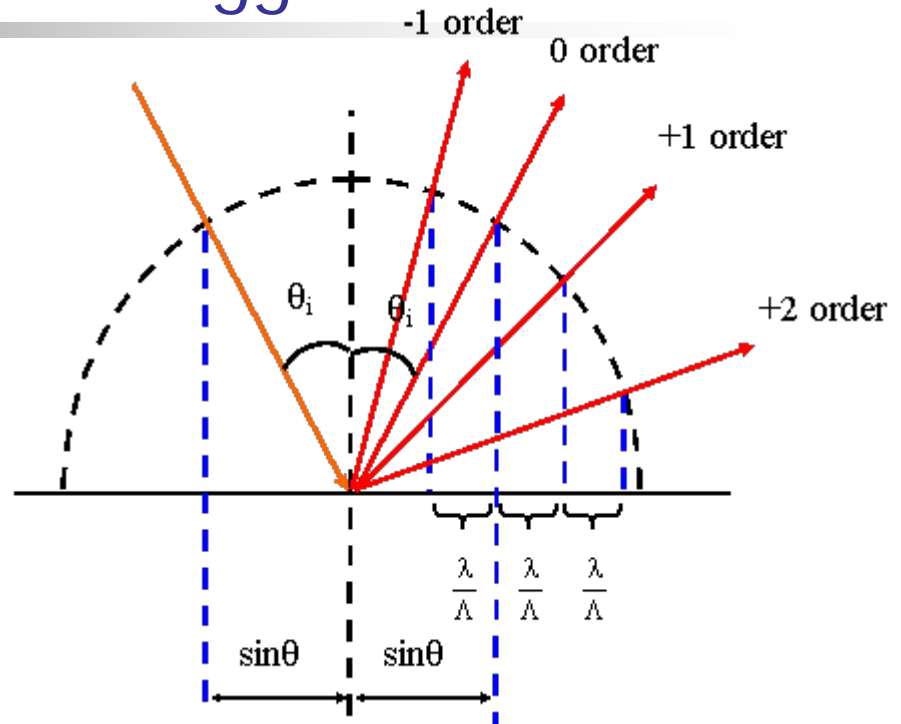
WDM sends information through a single optical Fiber using lights of different wavelengths simultaneously.



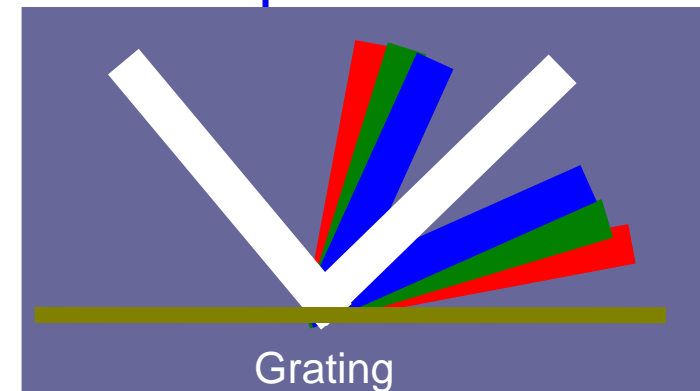
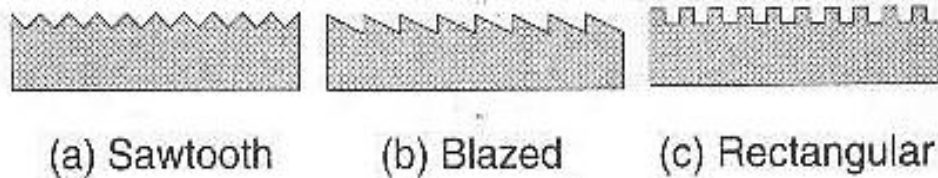
Réseau de Bragg

■ Grating Equation

$$\sin \theta_r = \sin \theta_i + m \frac{\lambda}{\Lambda}$$



■ Grating Profiles





Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- **Mesures (puissance, OTDR, ..)**
- BER, Jitter, Eye Diagram
- Codage caractère (CIMT, 8b/10b,)
- Formation
- Biblio
- Divers

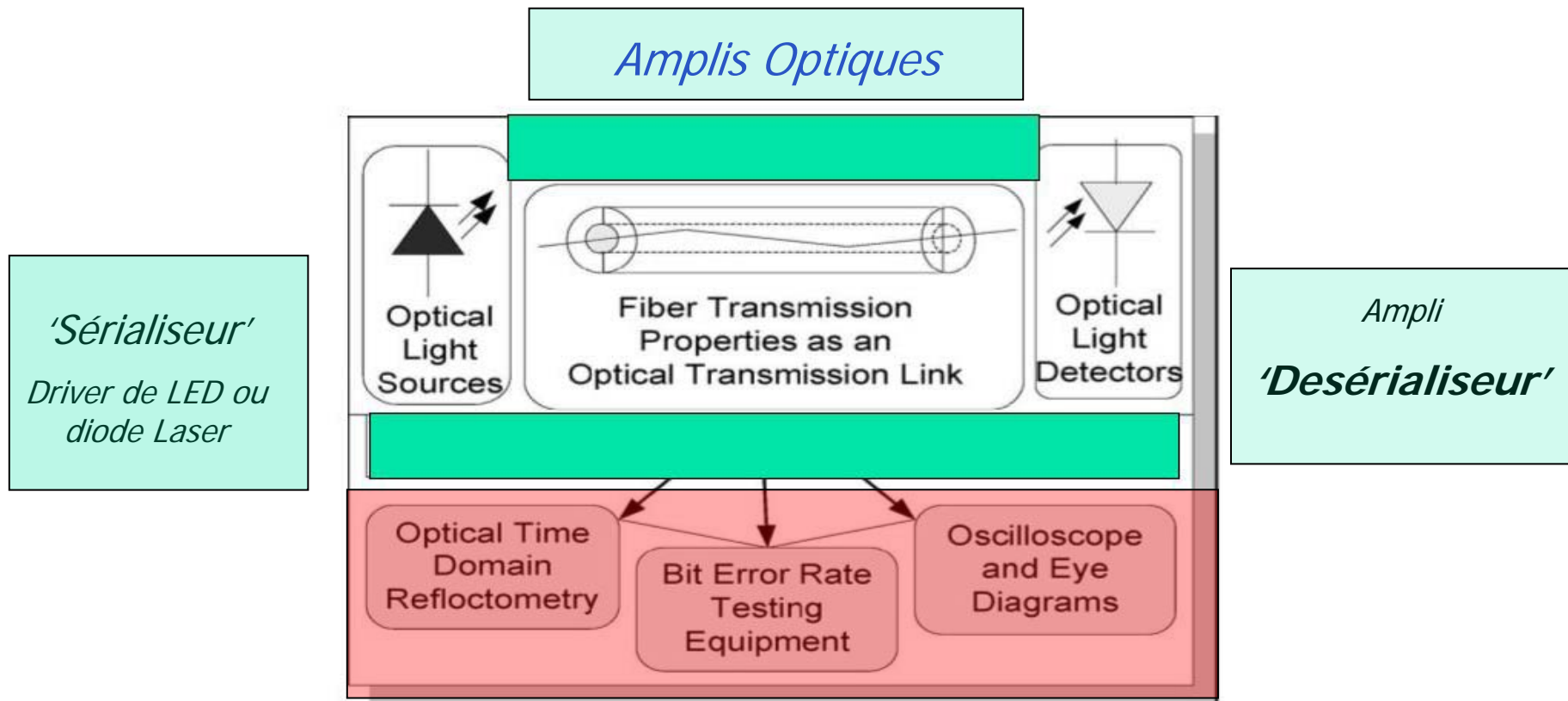


■ Mesures

- puissance
- OTDR: time domain reflectometry
-
-

Transmissions par Fibres optiques.

Composants optoélectroniques associés.





Optical Test and Measurement Equipment

Wide variety of equipment is in use.....

- **Optical source and power meter**
- **Optical test set (source and power meter combined)**
- **Optical Time Domain Reflectometer**
- **Optical spectrum analyser**
- **Optical waveform analyser/optical oscilloscope**
- **Dispersion analyser**
- **Polarization mode dispersion analyser**
- **Optical return loss test sets**
- **Fibre talk sets**
- **Connector inspection microscopes**

Fiber Optics Technician's Manual [Jim Hayes](#)

[**http://www.electronics.dit.ie/staff/tfreir/optical_2/**](http://www.electronics.dit.ie/staff/tfreir/optical_2/)

Instrumentation principles for optical time domain reflectometry P Healy
1986 J. Phys. E. Sci. Instrum. 19 334-341

Typical Portable Optical Sources



Output
connectors



Exfo FOS-120A series LED based
850 or 1310 or 1550 nm
Dual wavelength available (1310/1550 nm)
Output power -20 dBm into 50/125 micron fibre
Stable to within 0.08 dB over 1 hour

Exfo FOS-130A series Laser based
1310 or 1550 nm only
Dual wavelength available (1310/1550 nm)
Output power -7 dBm into all fibre types
Stable to within 0.08 dB over 1 hour

Typical Instrumentation for Attenuation Measurements

- Typical power meter and OTDR shown
- Measurements are wavelength specific
- OTDR is more accurate, gives more information and can be used to detect faults and other problems
- OTDR is more expensive and can be more difficult to use



OTDR



Power meter

Typical Portable Power Meter

Calibrated at 850 nm, 1300 nm and 1550 nm
Measurements in microwatts, dBm and dBm
Range +3dBm to -50 dBm (0.001 microwatts)
•Wide range of adapters including ST, FC/PC and SC

Silicon Photodiodes

Used from 400 nm to 1000 nm
Typical dynamic range from 1 pW to 1 mW
Typical area 1 cm squared

Germanium Photodiodes:

Used from 500 nm to 1800 nm
Typical dynamic range from 1 pW to 1 mW
Typical area 1 cm squared

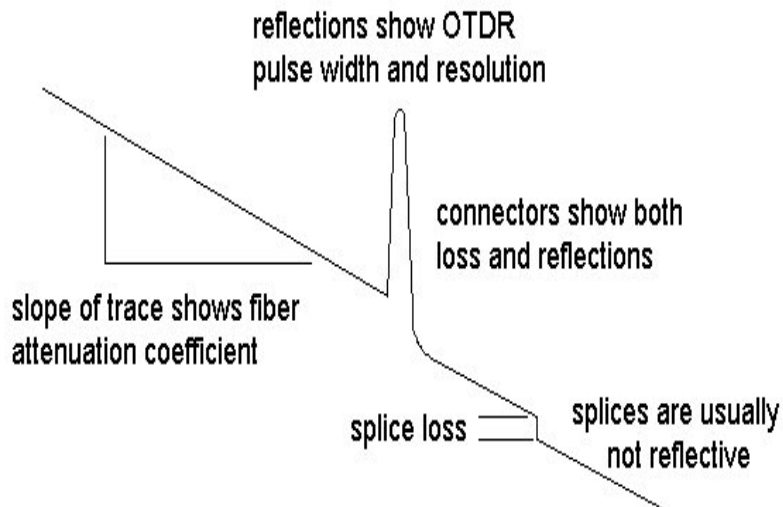
InGaAs Photodiodes:

Used from 1000 nm to 1600 nm
Higher cost
Typical area is small, 0.5 mm diameter, 0.007 cm squared



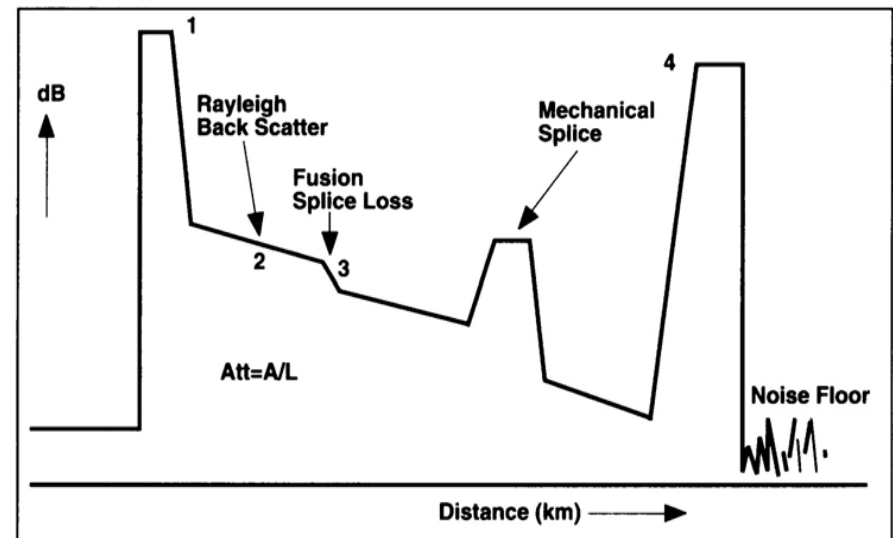
Understanding an OTDR Display

- Light is reflected back to the OTDR from along the fibre because of Rayleigh scattering in the fibre
- Much larger reflections occur at joints with small airgaps and at the fibre end or at a break
- Light reflected back from joints, breaks etc.. produces a spike on the display that looks like "gain". Indicates joints between fibres with different backscatters

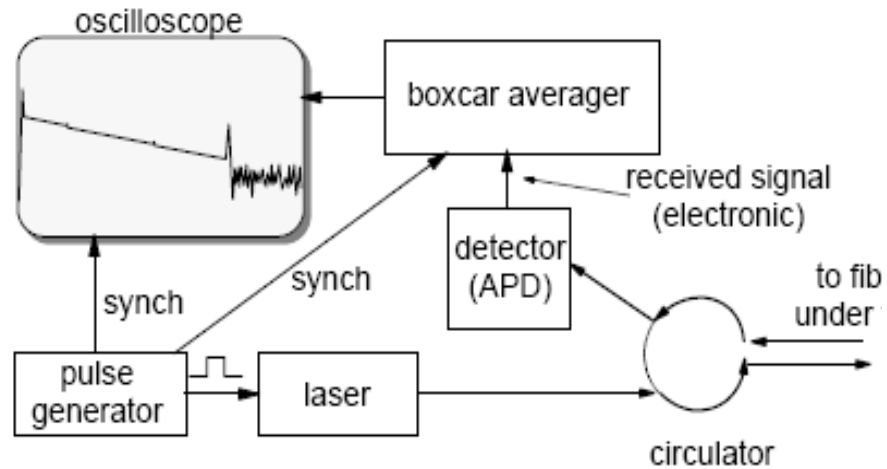


Key to diagram:

1. Fresnel reflection from first connector
2. Back scattered light from fibre
3. Increase in loss at fusion splice
4. Fresnel reflection from fibre end



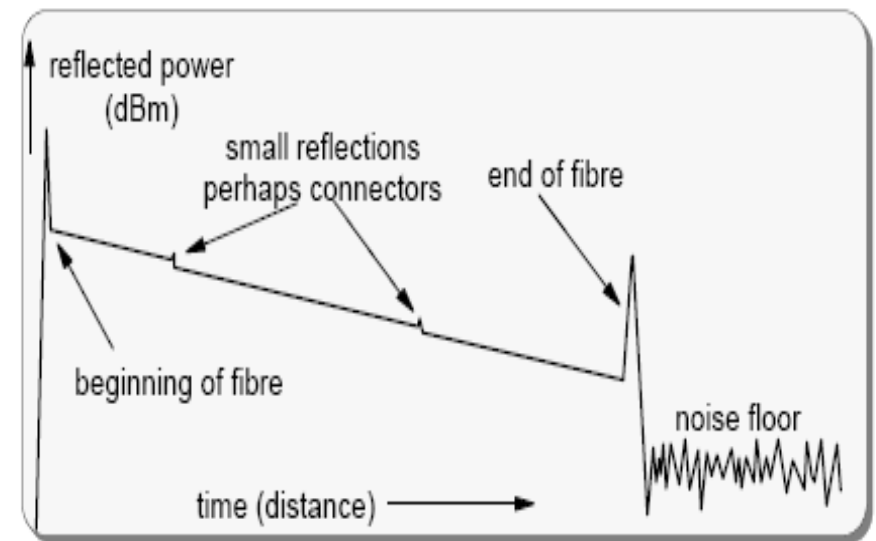
OTDR



OTDR Display - Schematic



OTDR Operational Logic





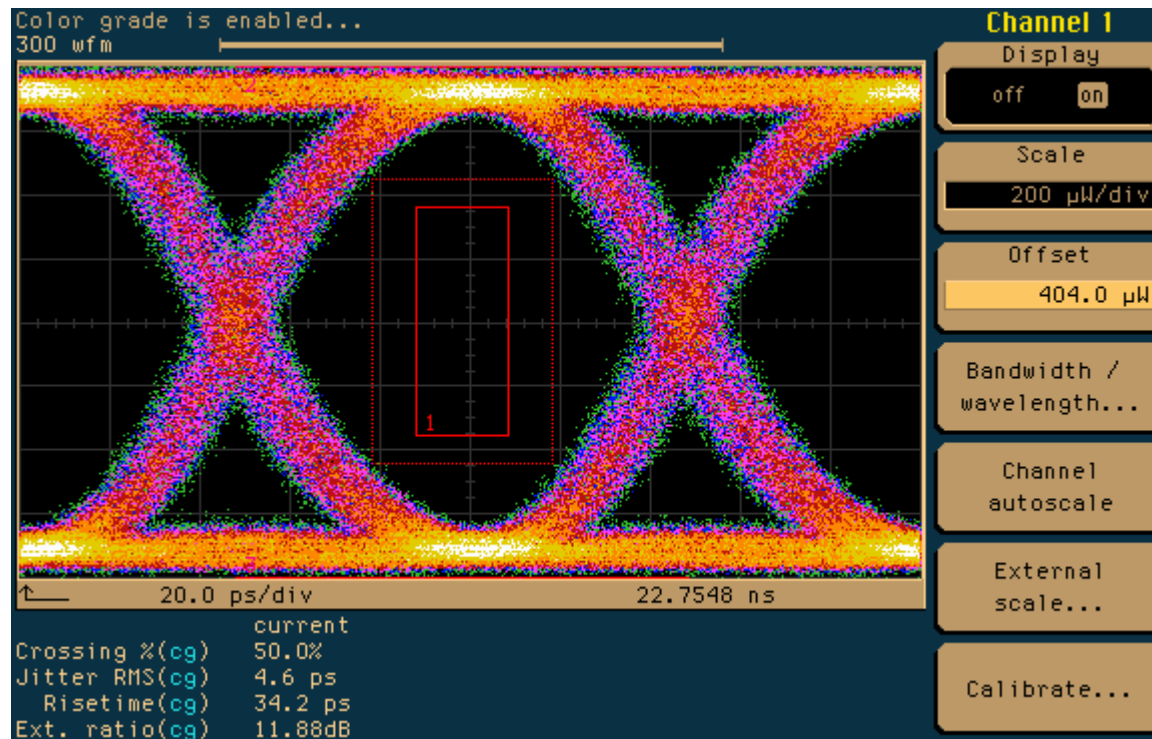
Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- **BER, Jitter, Eye Diagram**
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- Divers

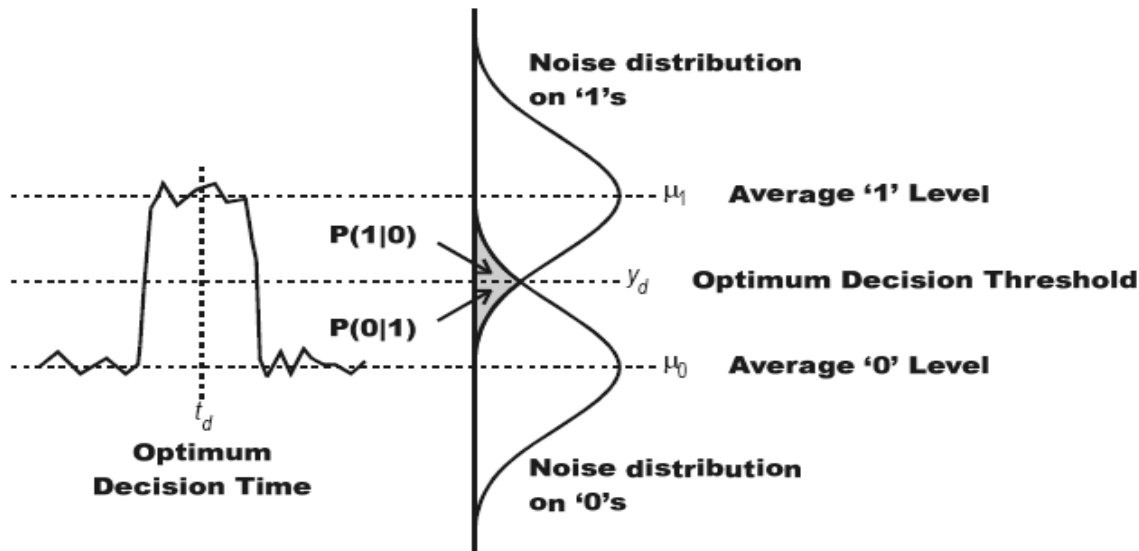
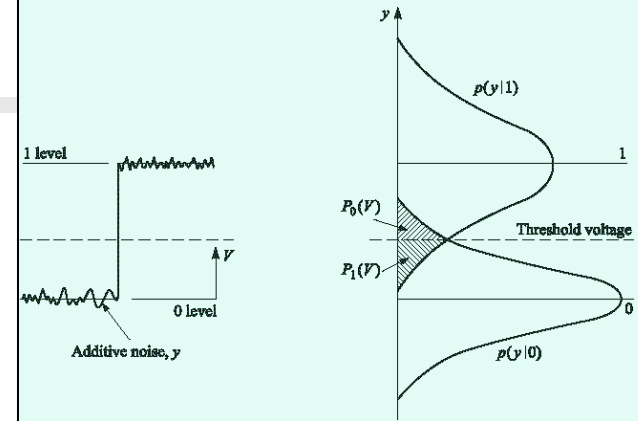
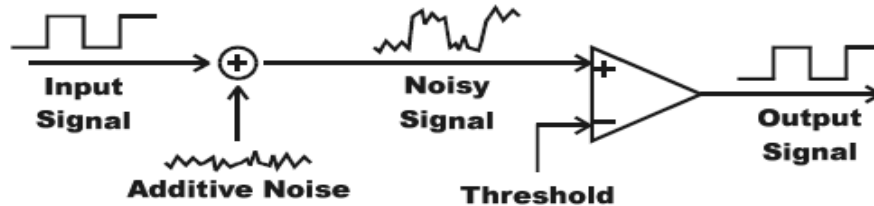
BER Jitter Diagramme de l'oeuil

Jitter is the short-term variation of the significant instants of a digital signal from their ideal positions in time.

www.ece.uci.edu/eceware/public/courses/294/Oct_06.ppt



BER *Bit Error Rate*



$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-x^2} dx$$

$$\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$$

$$\text{erfc}(x) = 1 - \text{erf}(x)$$

$$= \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-x^2} dx$$

BER and Q factor

Bit Error Rate

- The bit-error-rate (or bit-error-ratio) is

$$BER = p(1)P(0|1) + p(0)P(1|0)$$

- If the same number of '1's as '0's are sent

$$BER = \frac{1}{2} [P(0|1) + P(1|0)]$$

- For Gaussian noise

$$p_1(y) = \frac{1}{\sqrt{2\pi}\sigma_1} \exp\left(-\frac{(y_d - \mu_1)^2}{2\sigma_1^2}\right)$$

$$p_0(y) = \frac{1}{\sqrt{2\pi}\sigma_0} \exp\left(-\frac{(y_d - \mu_0)^2}{2\sigma_0^2}\right)$$

$$P(1|0) = P(y > y_d | y \sim p_0) = \frac{1}{2} \operatorname{erfc}\left(\frac{y_d - \mu_0}{\sqrt{2}\sigma_0}\right)$$

$$P(0|1) = P(y < y_d | y \sim p_1) = \frac{1}{2} \operatorname{erfc}\left(\frac{\mu_1 - y_d}{\sqrt{2}\sigma_1}\right)$$

Optimum Threshold and "Q"

- For Gaussian noise, the BER is given by

$$BER = \frac{1}{4} \left[\operatorname{erfc}\left(\frac{\mu_1 - y_d}{\sqrt{2}\sigma_1}\right) + \operatorname{erfc}\left(\frac{y_d - \mu_0}{\sqrt{2}\sigma_0}\right) \right]$$

- The optimum setting of y_d is that which gives minimum BER, i.e. when

$$p_1(y_d) = p_0(y_d)$$

◇ this equation must be solved numerically

◇ a common (and accurate) approximation is

$$P(1|0) = P(0|1) \Rightarrow y_d = \frac{\sigma_0\mu_1 + \sigma_1\mu_0}{\sigma_0 + \sigma_1}$$

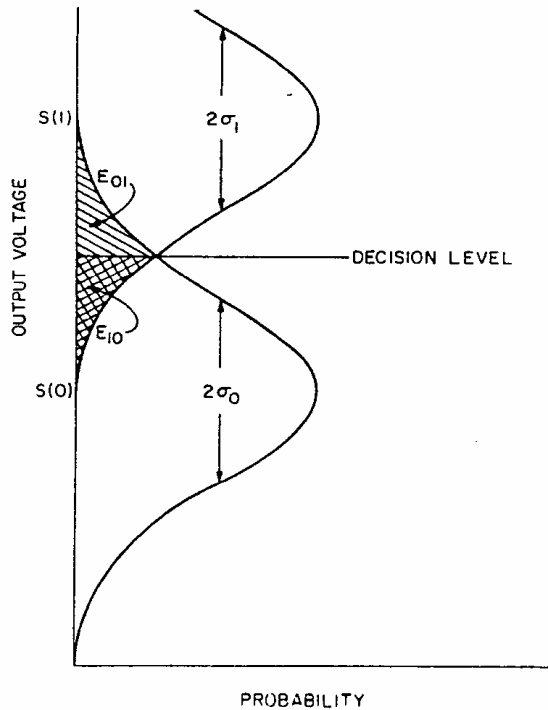
◇ for which the BER is

$$BER = \frac{1}{2} \operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{\sqrt{2\pi}Q} \exp\left(-\frac{Q^2}{2}\right)$$

◇ where $Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1}$

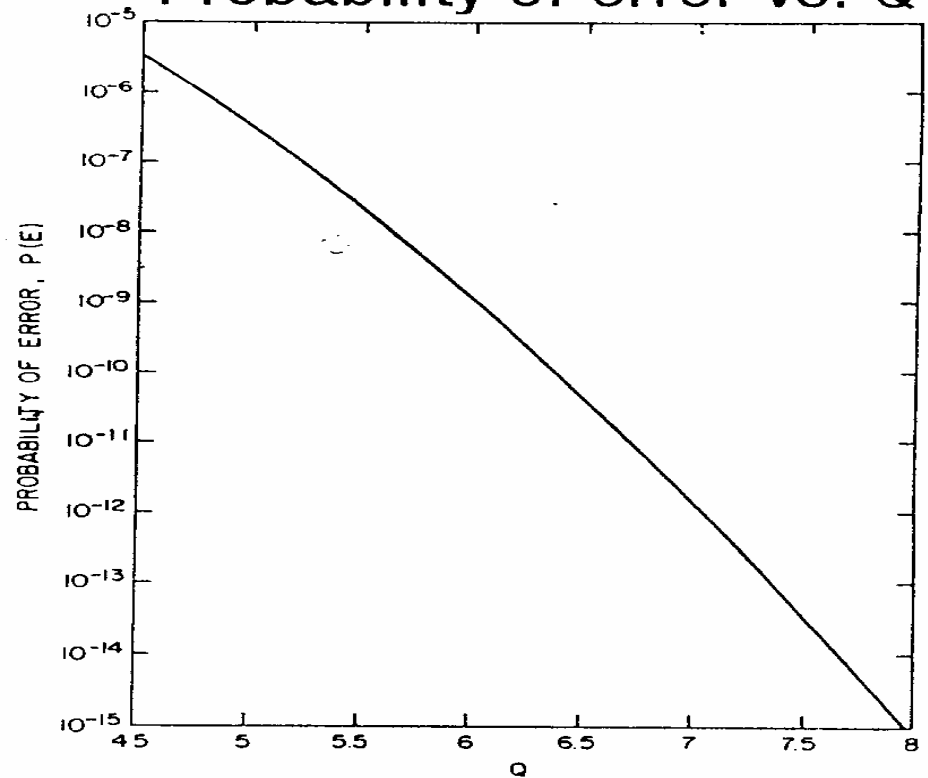
BER versus Q

Probability of error distribution function



$$Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1}$$

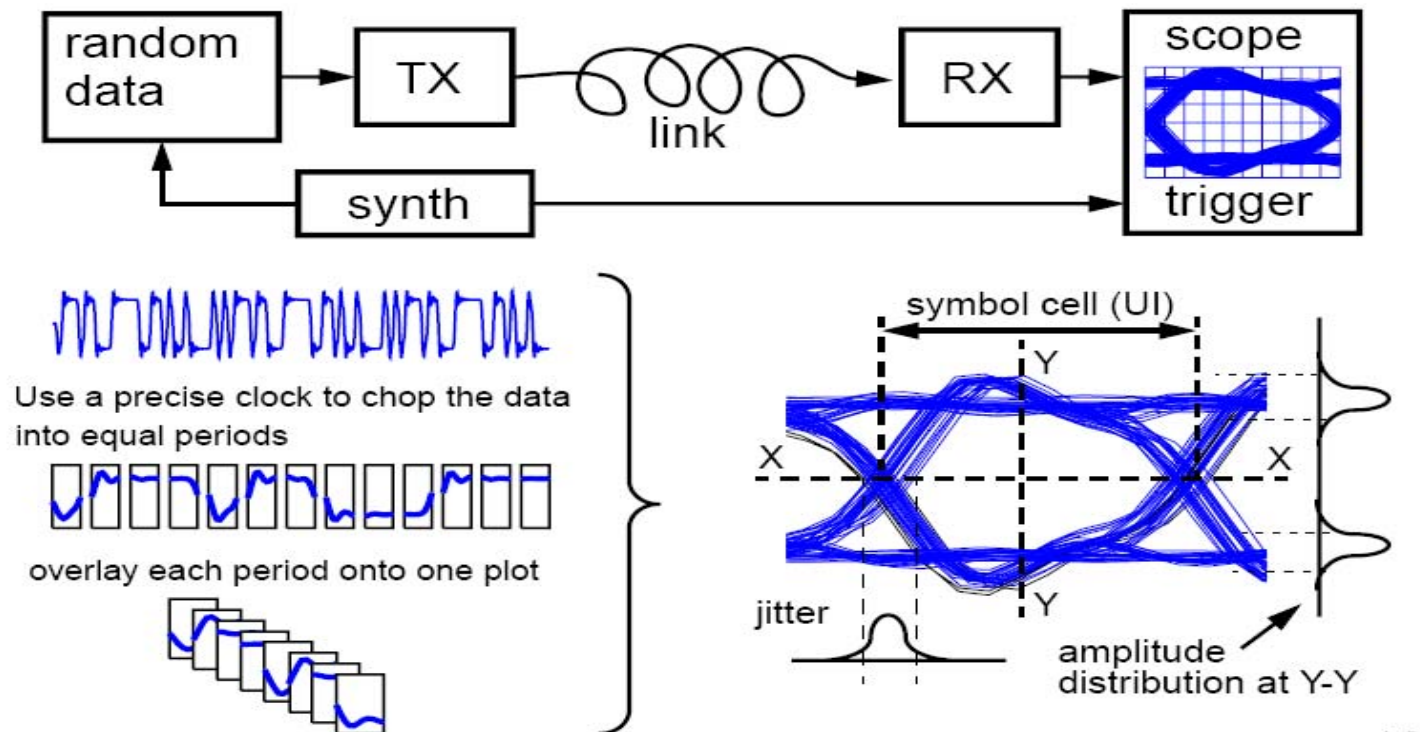
Probability of error vs. Q



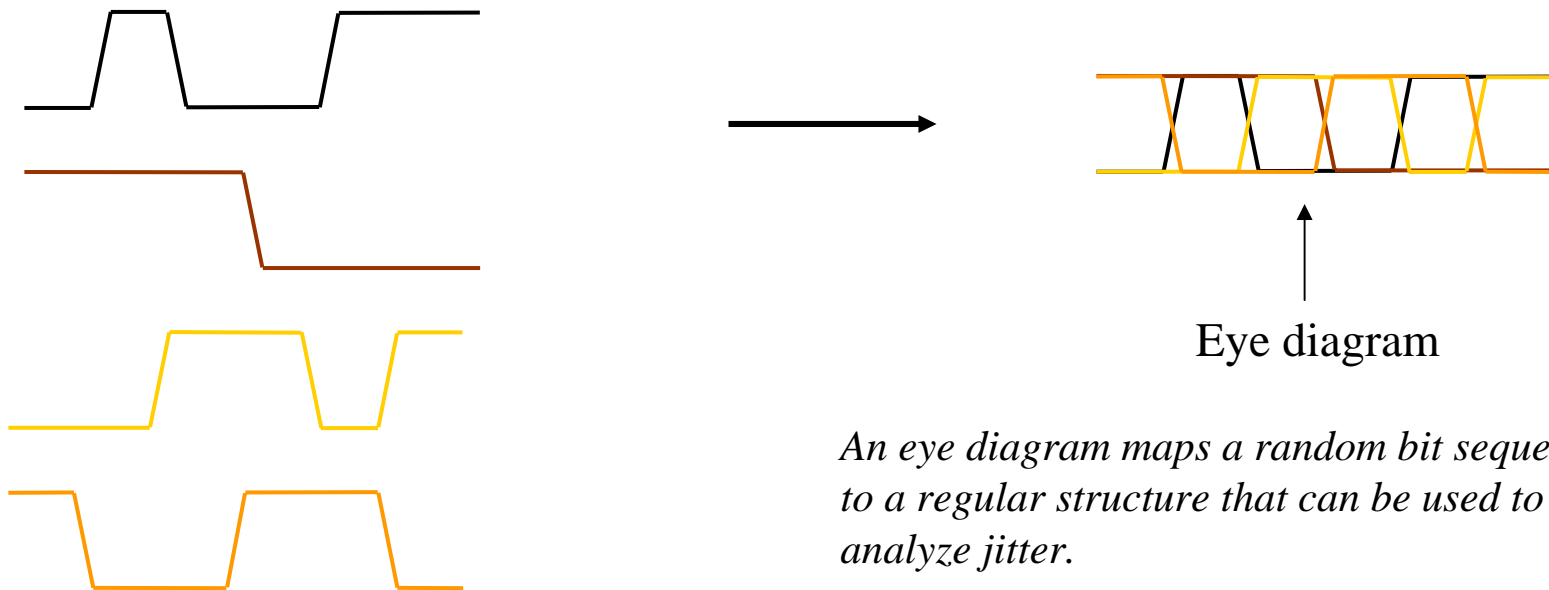
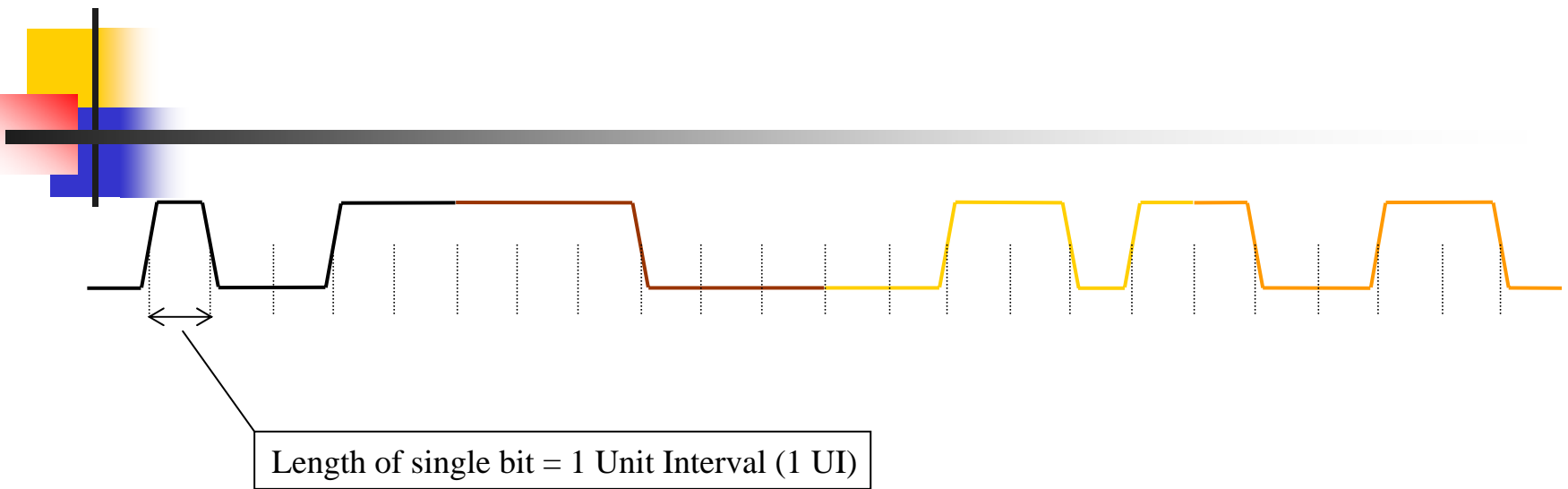
$$BER = \frac{1}{2} \operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{\sqrt{2\pi}Q} \exp\left(-\frac{Q^2}{2}\right)$$

Eye diagram

Eye diagram construction



10

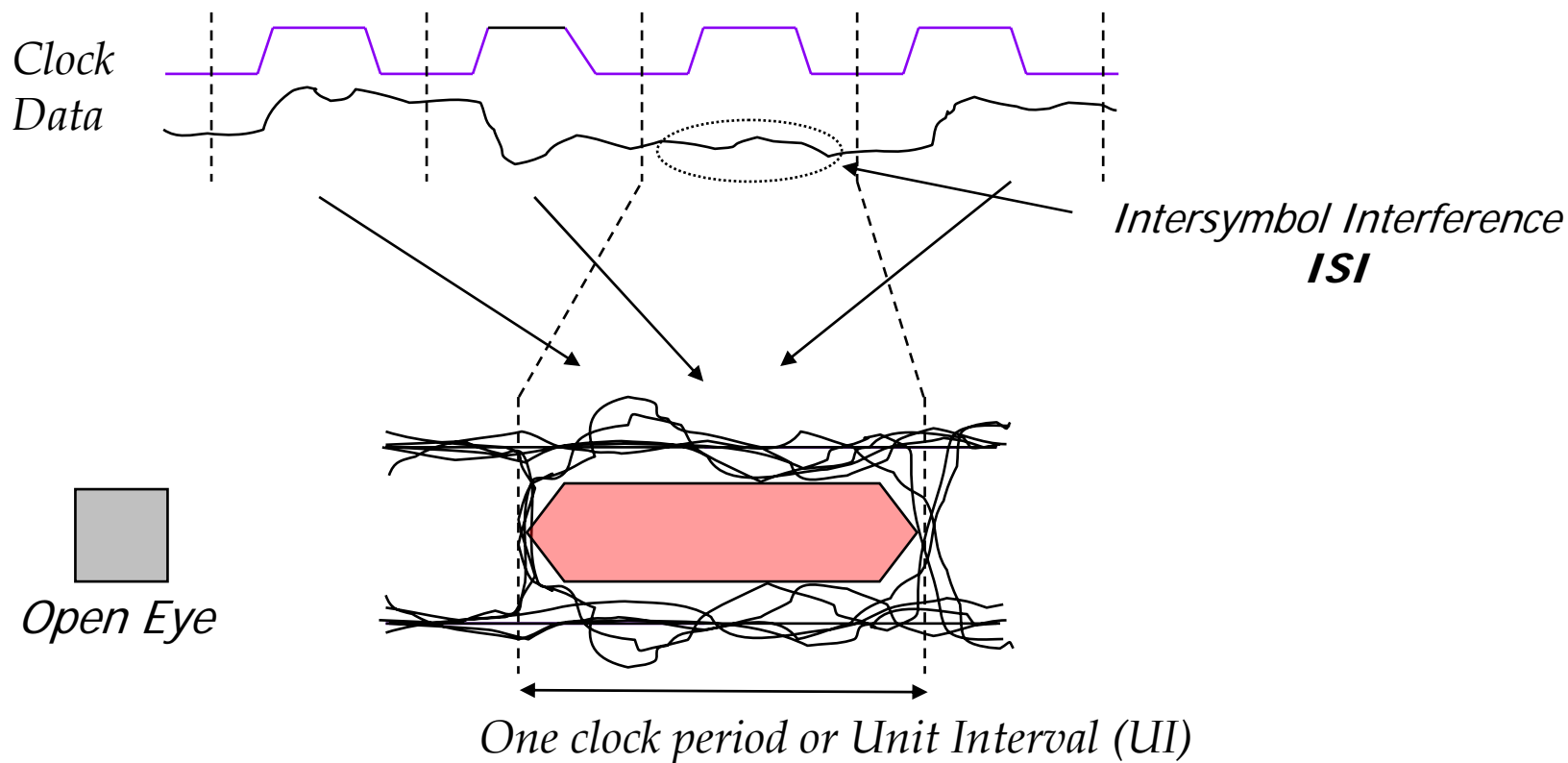


An eye diagram maps a random bit sequence to a regular structure that can be used to analyze jitter.

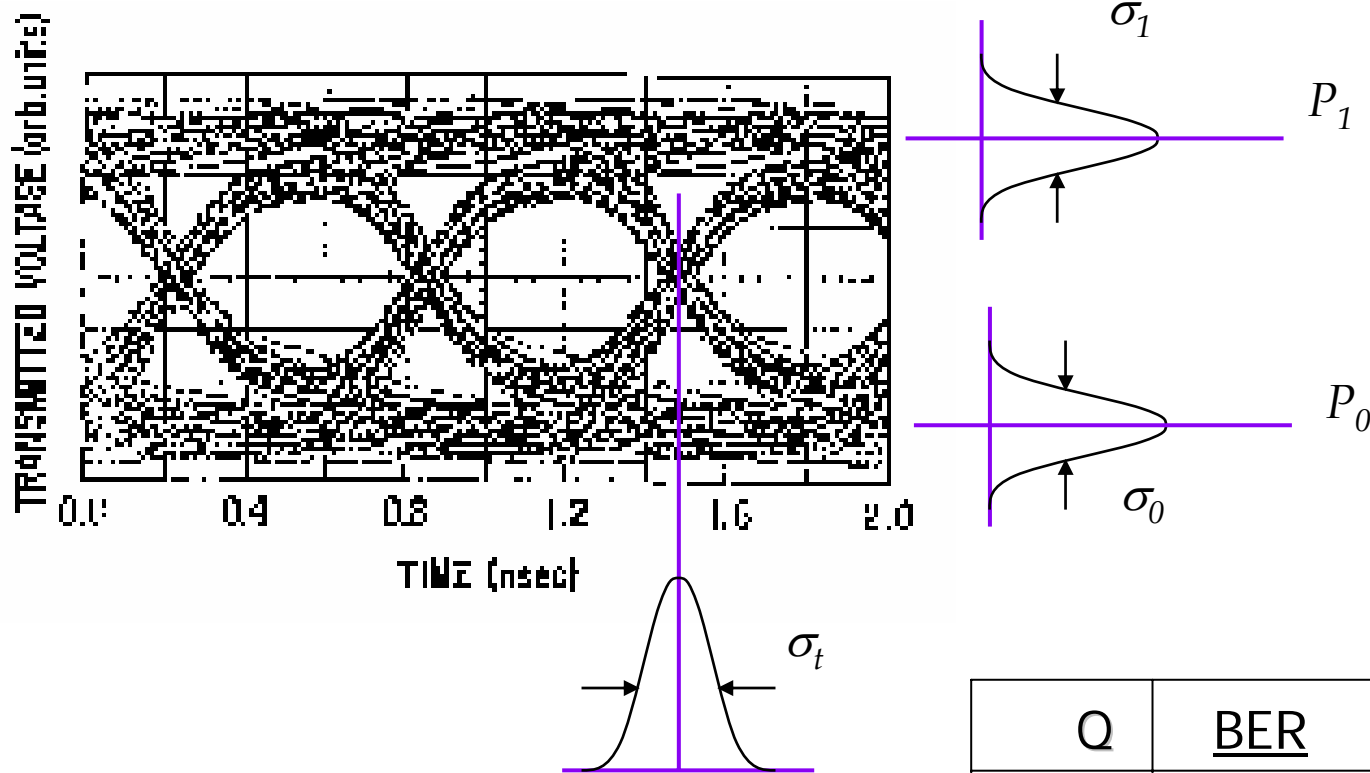
Eye Diagram

www.ece.ncsu.edu/asic/ece733/2008/docs/Signalling_clean.ppt

- *Send random data sequence down the channel*
- *Measure output waveform*
- *Superimpose all bit intervals on one Unit Interval (UI)*



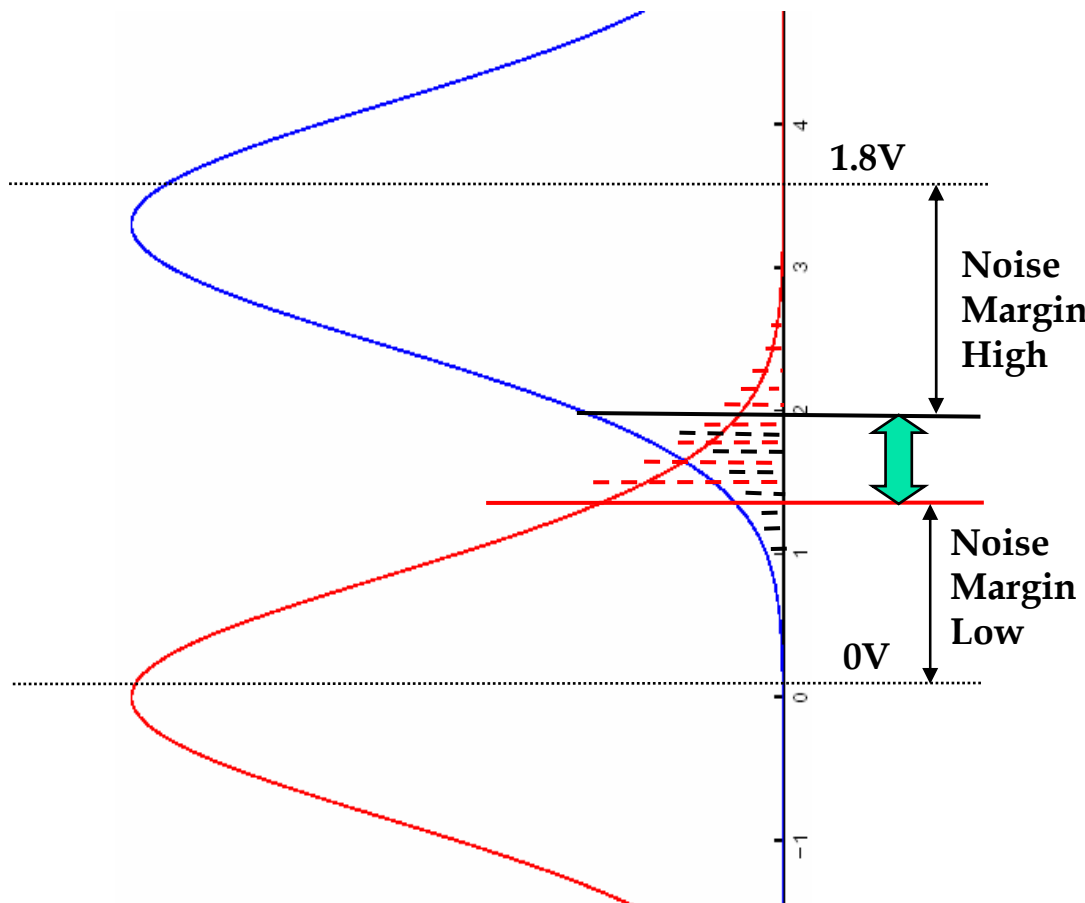
Eye Diagram Analysis



$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q}{\sqrt{2}} \right) \approx \frac{\exp(-Q^2/2)}{Q \sqrt{2\pi}}$$

Q	<u>BER</u>
6	10^{-9}
7	10^{-12}

Estimate BER from Eye Diagram




Note: Here we assume the signal is gauss distributed.

BER is expressed here by the shadow area:

Blue shadow for BER of '1'

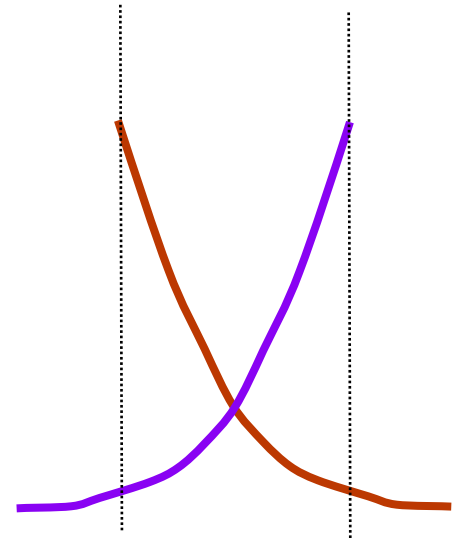
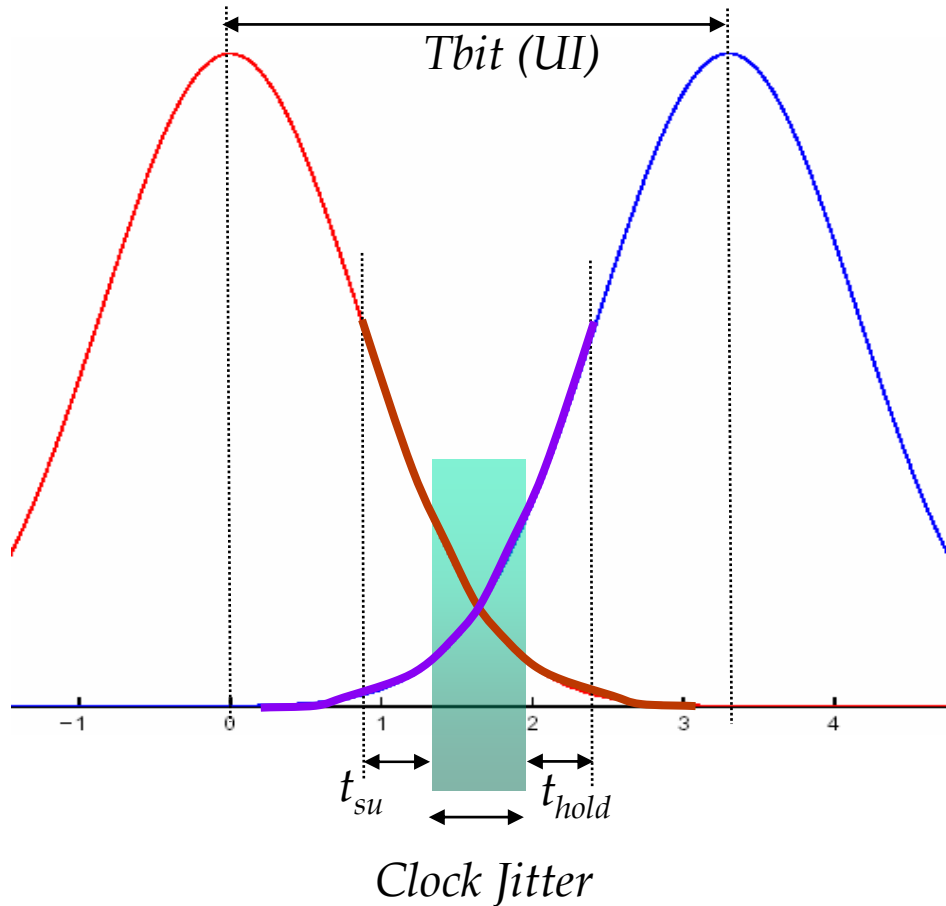
Red shadow for BER of '0'

BER=Integration of the shadow area

 *RX sensitivity + offset due to variations*

Time Domain Errors

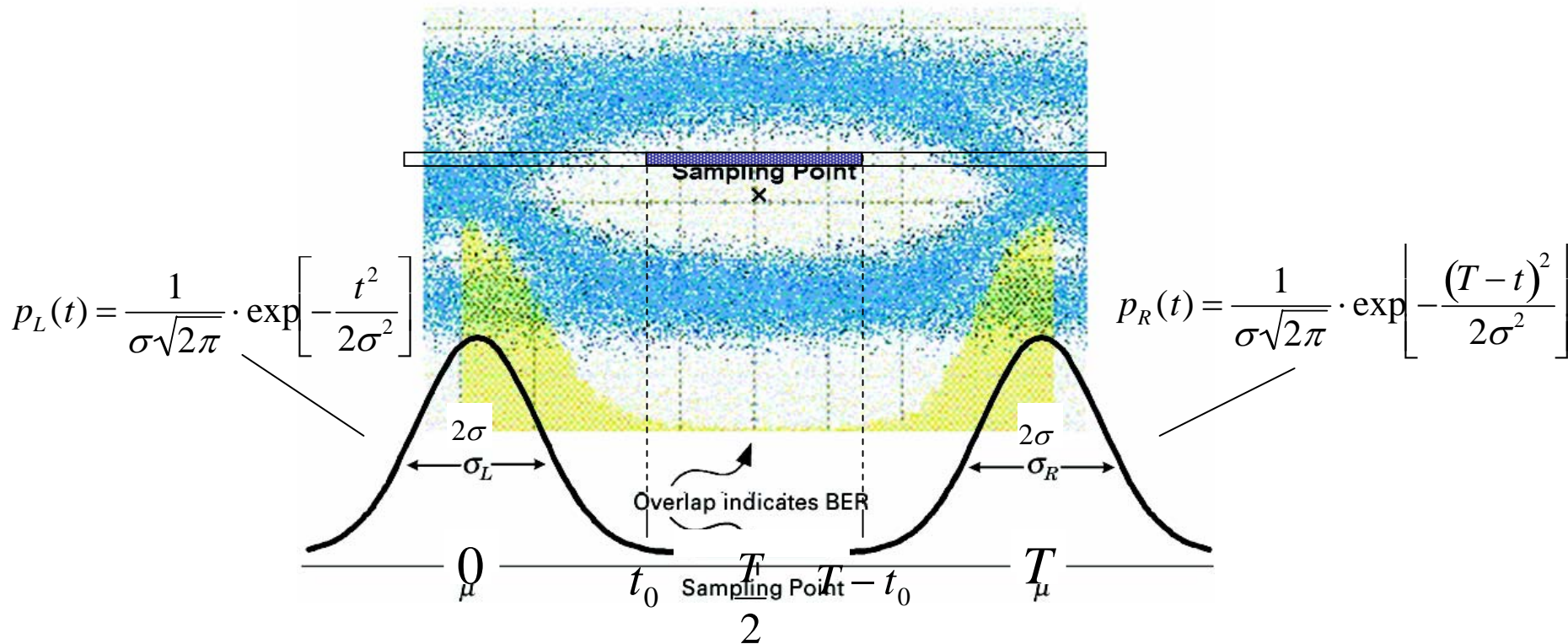
Signal Jitter captured in eye diagram



$P(\text{error}) = \text{area under these curves}$

Jitter and Bit Error Rate

www.ece.uci.edu/eceware/public/courses/294/Oct_06.ppt



Probability of sample at $t > t_0$ from left-hand transition:

$$P_L = \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{t_0}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx$$

Probability of sample at $t < t_0$ from right-hand transition:

$$P_R = \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{t_0}^{\infty} \exp\left[-\frac{(T-x)^2}{2\sigma^2}\right] dx$$



Jitter and Bit Error Rate

www.ece.uci.edu/eceware/public/courses/294/Oct_06.ppt

$$P_L = \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{t_0}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx$$

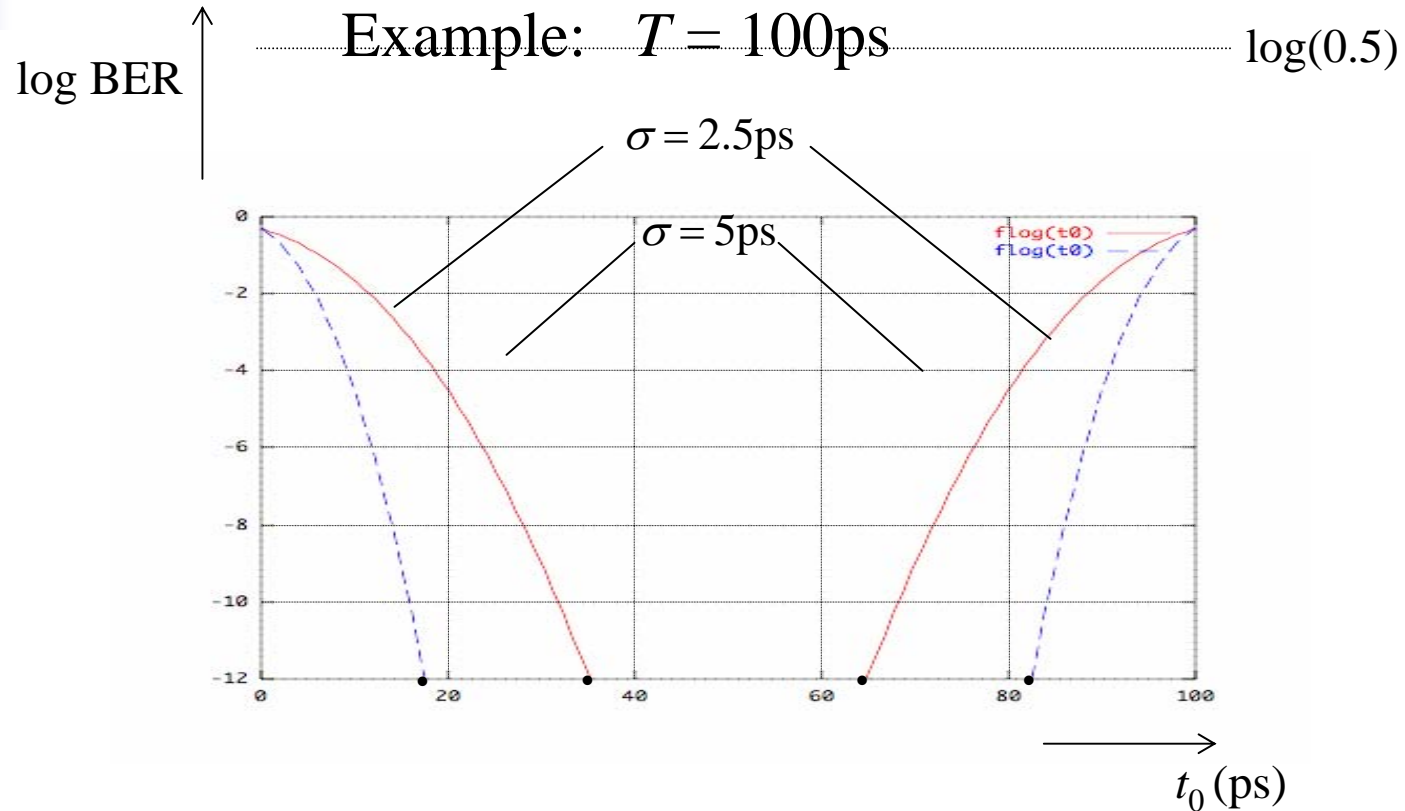
$$P_R = \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{t_0}^{\infty} \exp\left[-\frac{(T-x)^2}{2\sigma^2}\right] dx = \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{T-t_0}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx$$

Total Bit Error Rate (BER) given by:

$$\begin{aligned} BER = P_L + P_U &= \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{t_0}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx + \frac{1}{\sigma\sqrt{2\pi}} \cdot \int_{T-t_0}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx \\ &= \frac{1}{2} \left[\operatorname{erfc}\left(\frac{t_0}{\sqrt{2}\sigma}\right) + \operatorname{erfc}\left(\frac{T-t_0}{\sqrt{2}\sigma}\right) \right] \end{aligned}$$

$$\text{where } \operatorname{erfc}(t) \equiv \frac{2}{\sqrt{\pi}} \cdot \int_t^{\infty} \exp(-x^2) dx$$

Jitter and Bit Error Rate



$\sigma = 2.5\text{ps}$:

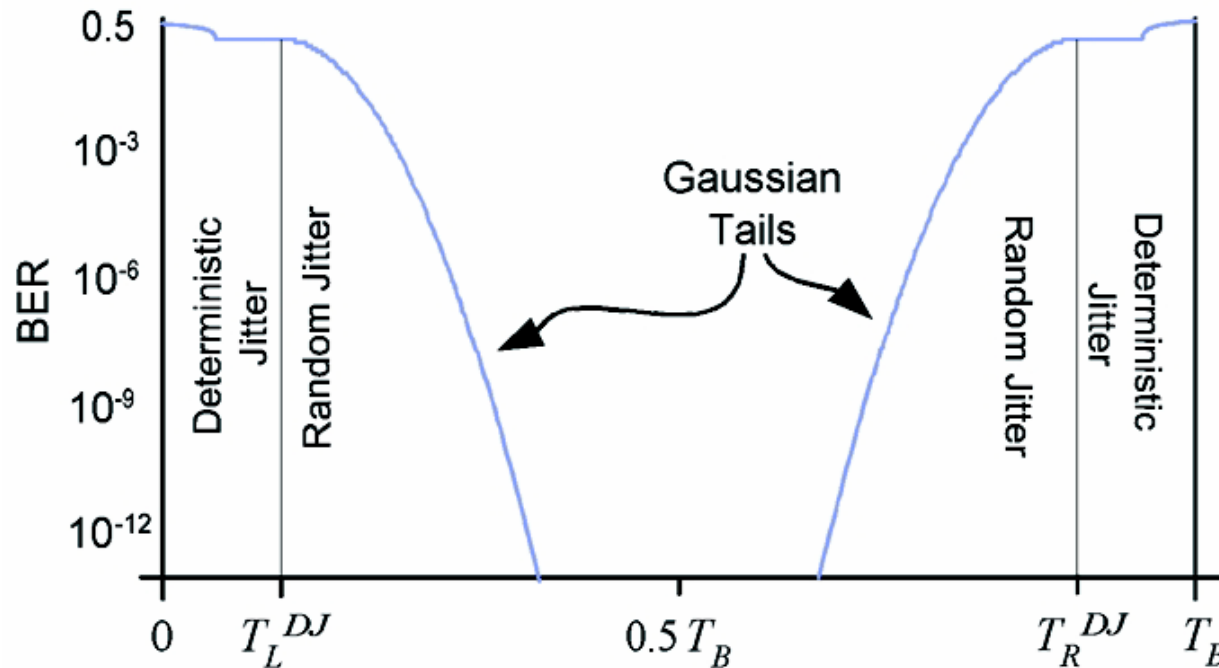
$\text{BER} \leq 10^{-12}$ for $t_0 \in [18\text{ps}, 82\text{ps}]$ (64ps eye opening)

$\sigma = 5\text{ps}$:

$\text{BER} \leq 10^{-12}$ for $t_0 \in [36\text{ps}, 64\text{ps}]$ (38ps eye opening)

Bathtub Curves

The bit error-rate vs. sampling time can be measured directly using a bit error-rate tester (BERT) at various sampling points.

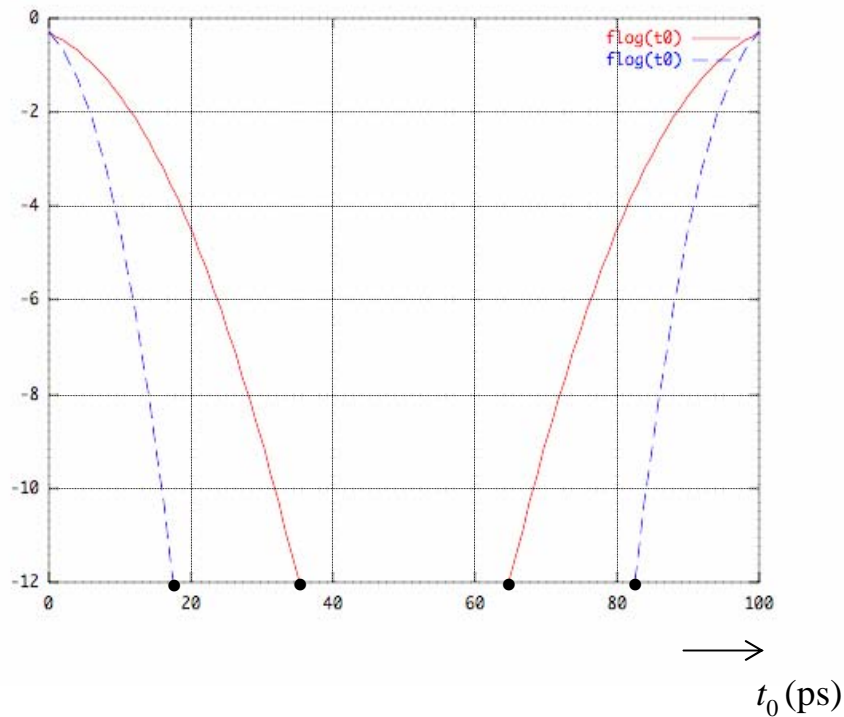


www.ece.uci.edu/eceware/public/courses/294/Oct_06.ppt

Benefits of Using Bathtub Curve Measurements

www.ece.uci.edu/eceware/public/courses/294/Oct_06.ppt

Curves can easily be numerically extrapolated to very low BERs (corresponding to random jitter), allowing much lower



Example:

10^{-12} BER with $T = 100$ ps is equivalent to an average of 1 error per 100s. To verify this over a sample of 100 errors would require almost 3 hours!

Bathtub curve

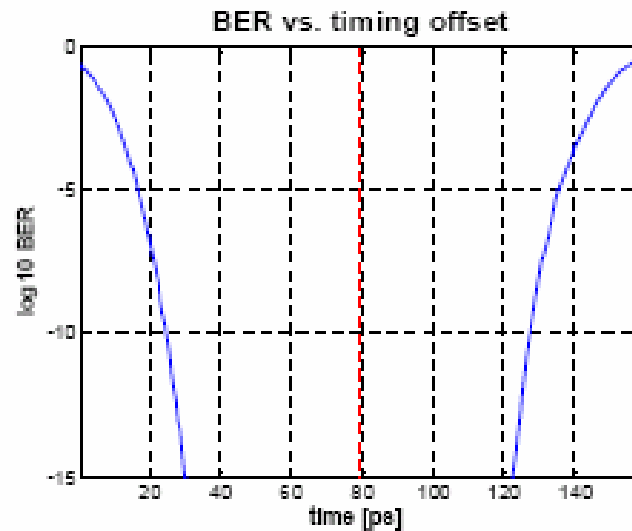


Figure 23. Timing bathtub curve

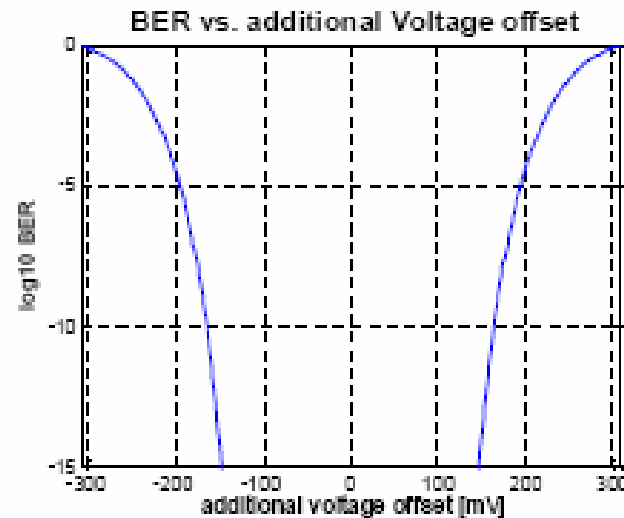


Figure 24. Voltage bathtub curve

DesignCon 2007

Accurate Method for Analyzing High-Speed I/O System Performance

Dan Oh, Rambus Inc.

[\[doh@rambus.com\]](mailto:doh@rambus.com)

Frank Lambrecht, Rambus Inc.

Sam Chang, Rambus Inc.

Qi Lin, Rambus Inc.

JiHong Ren, Rambus Inc.

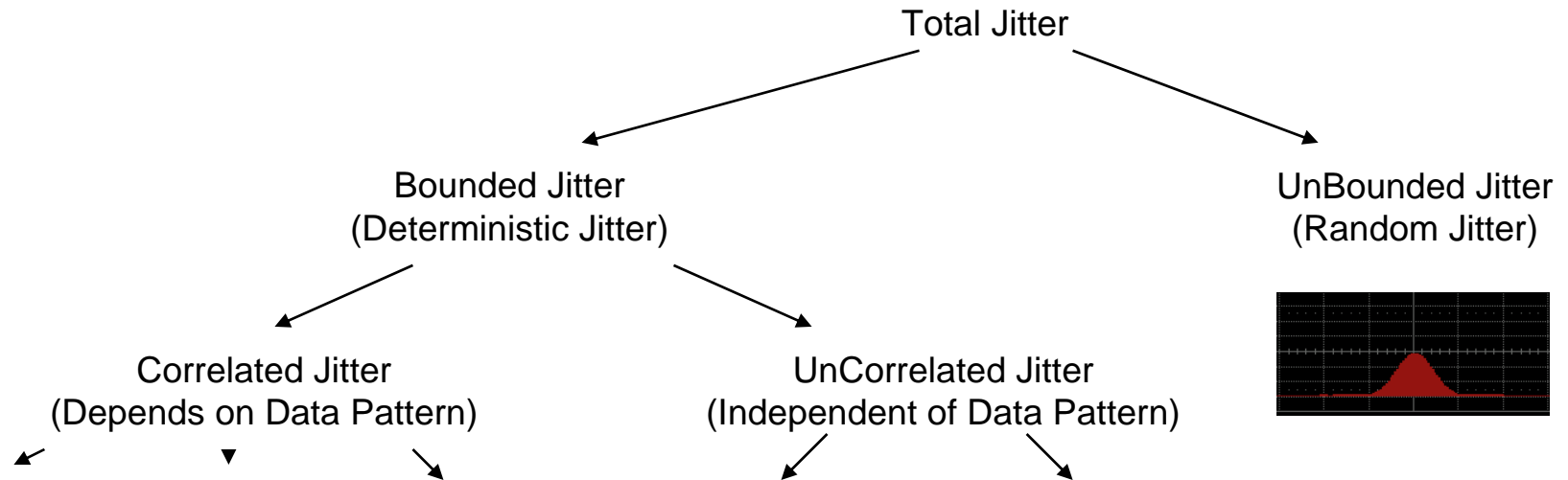
Jared Zerbe, Rambus Inc.

Chuck Yuan, Rambus Inc.

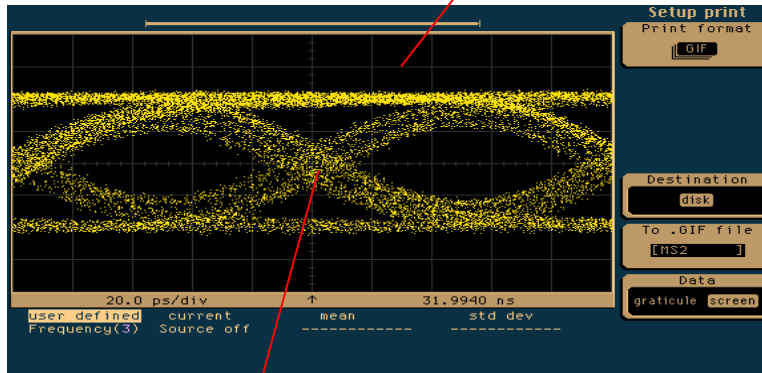
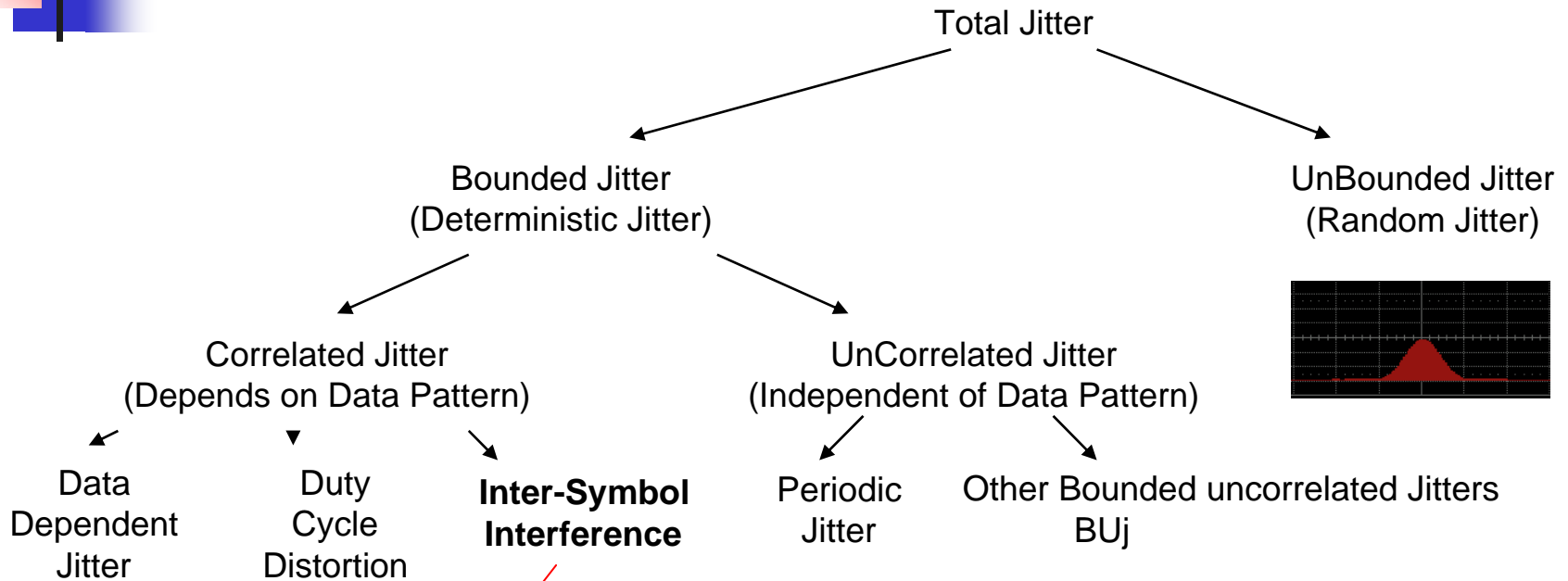
Chris Madden, Rambus Inc.

Vladimir Stojanovic, Massachusetts Institute of
Technology

Random jitter Deterministic jitter



Random jitter Deterministic jitter

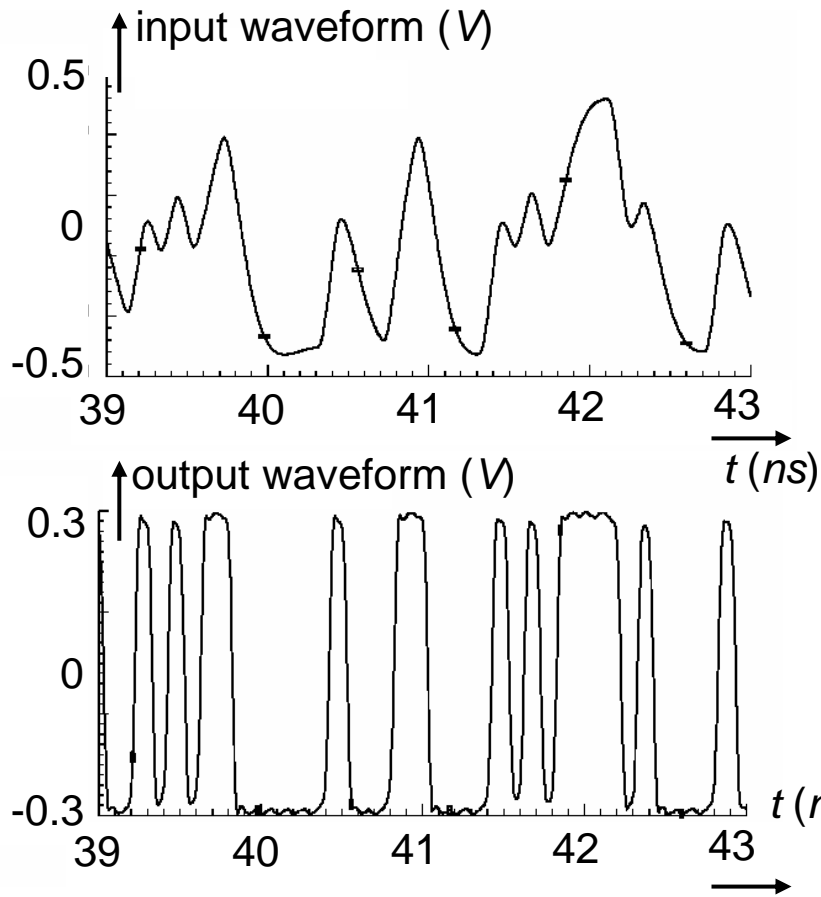


Double-edge

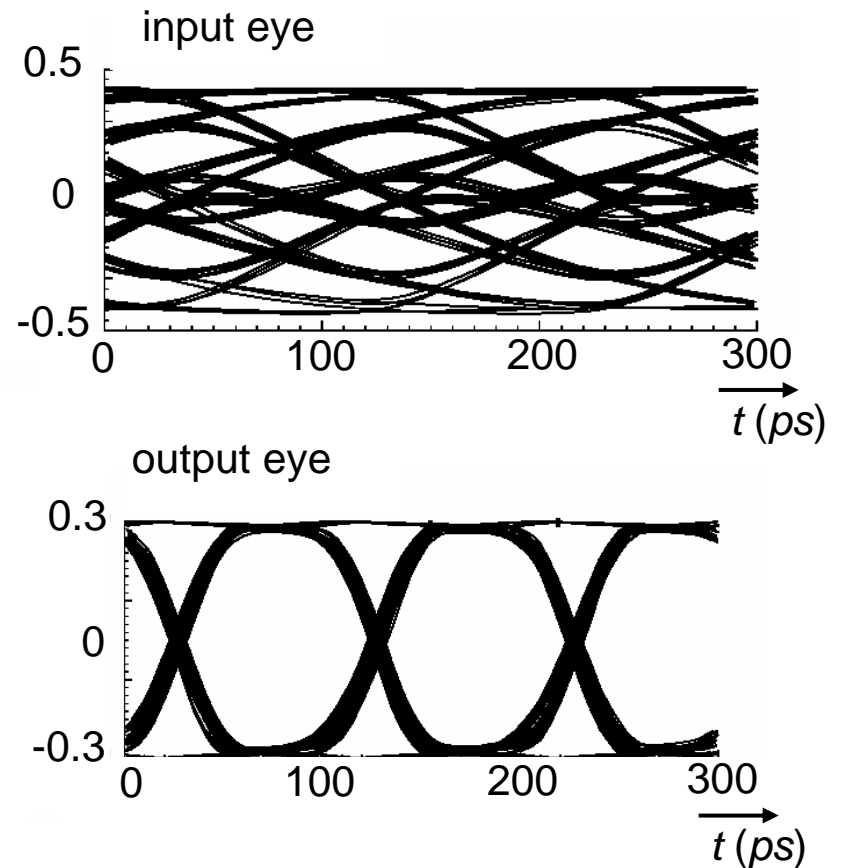
Equalization filter

ISI: Inter Symbol Interference

- Reduce ISI



- Improve receiver sensitivity





Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- **Codage caractère (CMT, 8b/10b,)**
- Formation
- Biblio
- Divers

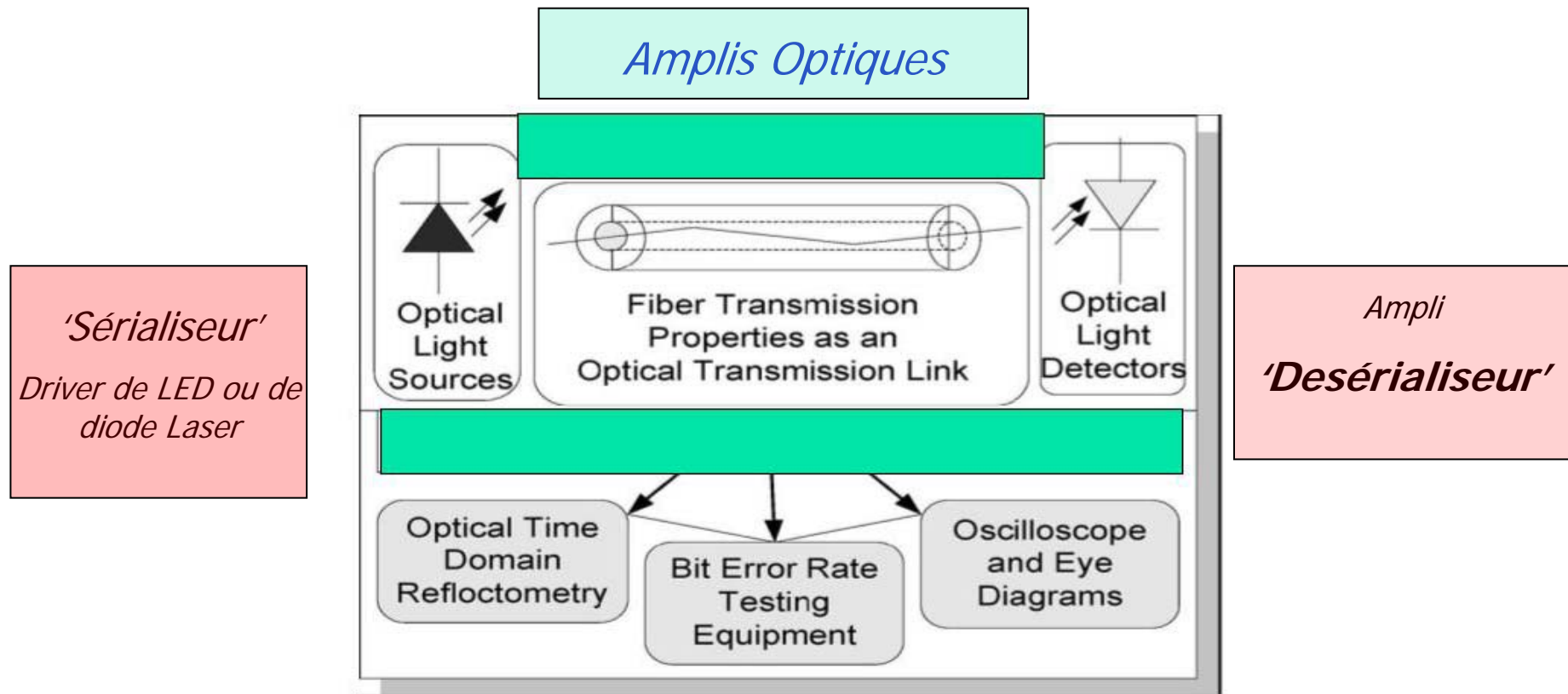


Codage caractère

+ traitements sous Matlab des BER, Jitter,...

Transmissions par Fibres optiques.

Composants optoélectroniques associés.

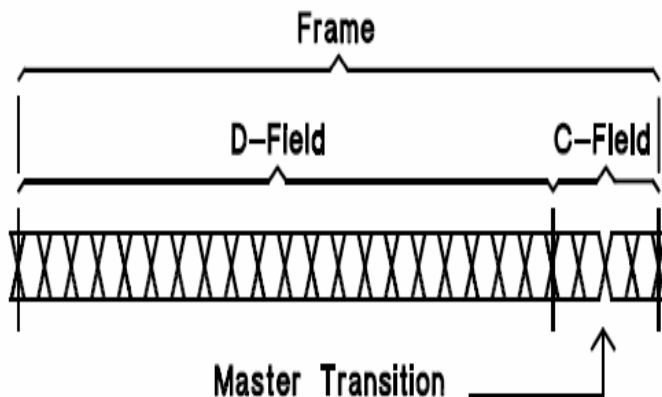


Codage caractère

CIMT

The “**C**onditional **I**nvert, **M**aster **T**ransition” Code (CIMT) used in this chipset transmits the parallel data words in either true or complement form, as needed, to maintain **DC-balance** on the line

The chipset is programmable to allow the transmission of either 16 or 20 bits of data to produce a 20 or 24 bit line code frame.



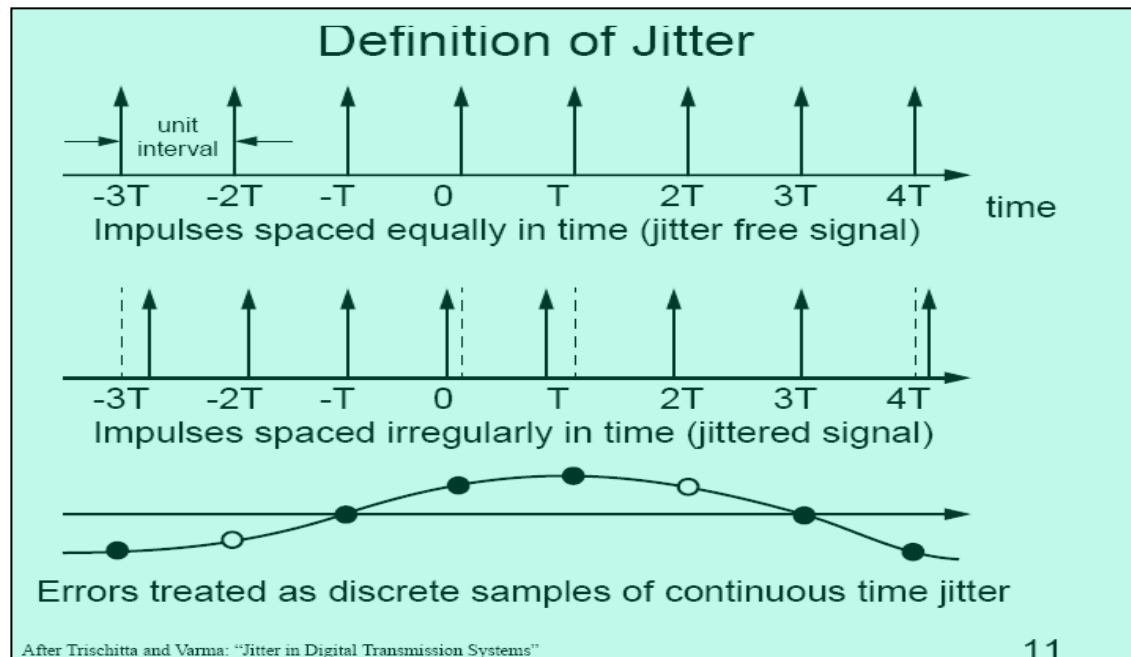
Structure of the CIMT Code

Table 3: 20 Bit CIMT Data Frame Definition

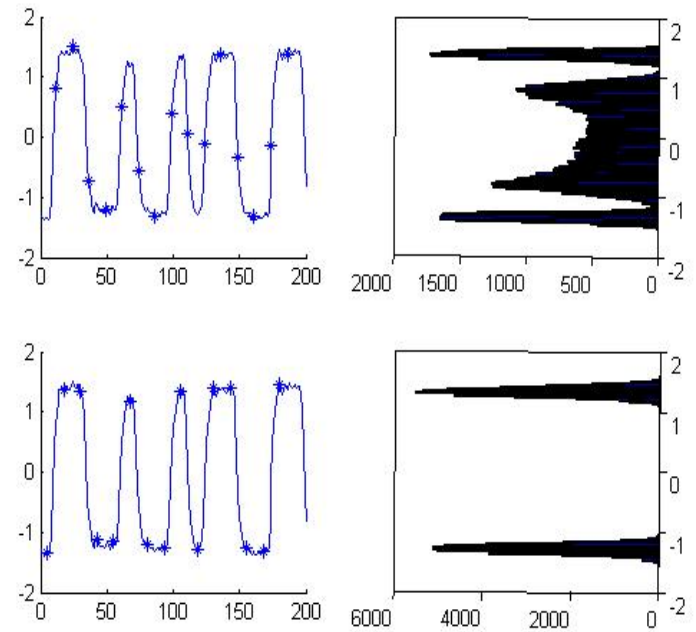
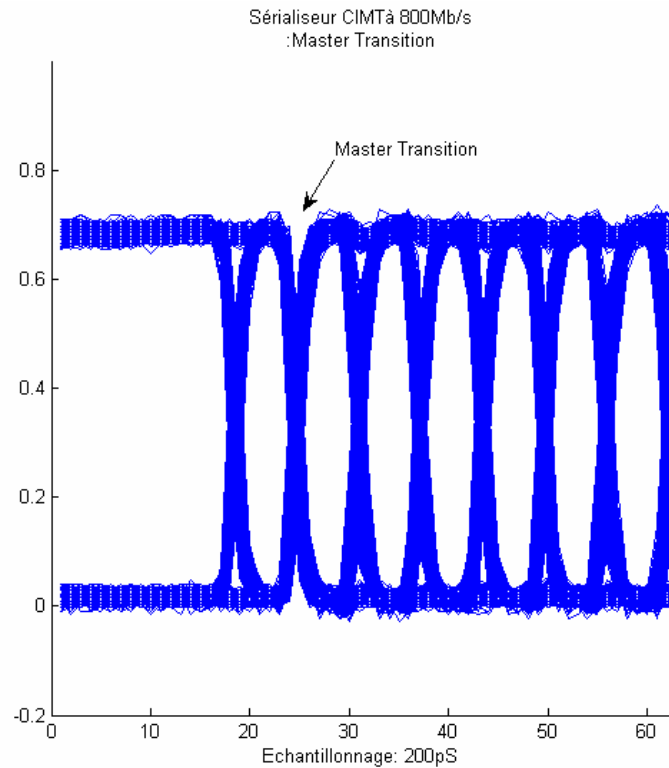
Data Status	FLAG bit	D-Field	C-Field
True	0	D1-D20	1 1 0 1
Inverted	0	$\overline{D1-D20}$	0 0 1 0
True	1	D1-D20	1 0 1 1
Inverted	1	$\overline{D1-D20}$	0 1 0 0

Oscillo 5 Ms/s $2 \cdot 10^6$ échantillons de signal

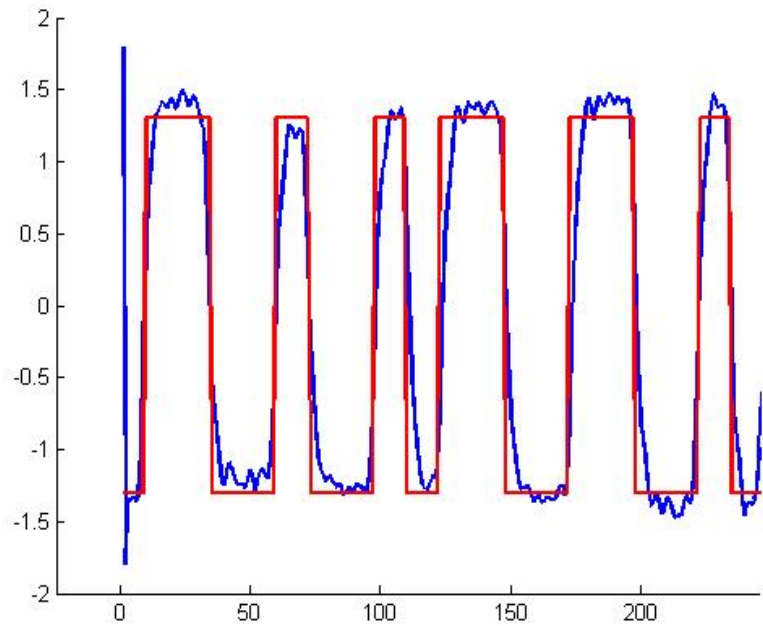
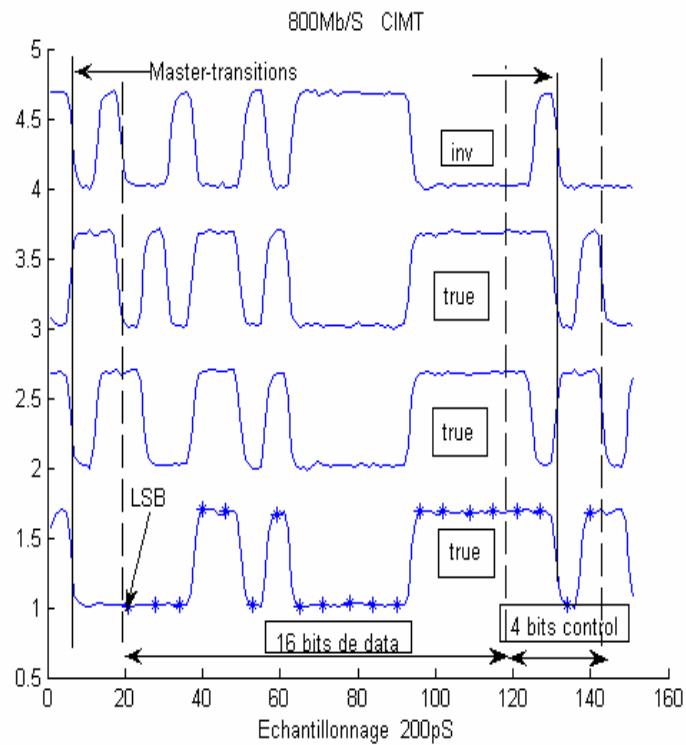
Sous Matlab ont été effectués les traitements suivants
récupération d'horloge
jitter et analyse de jitter (FFT etc..)
diagramme de l'oeuil
décodage série-parallèle



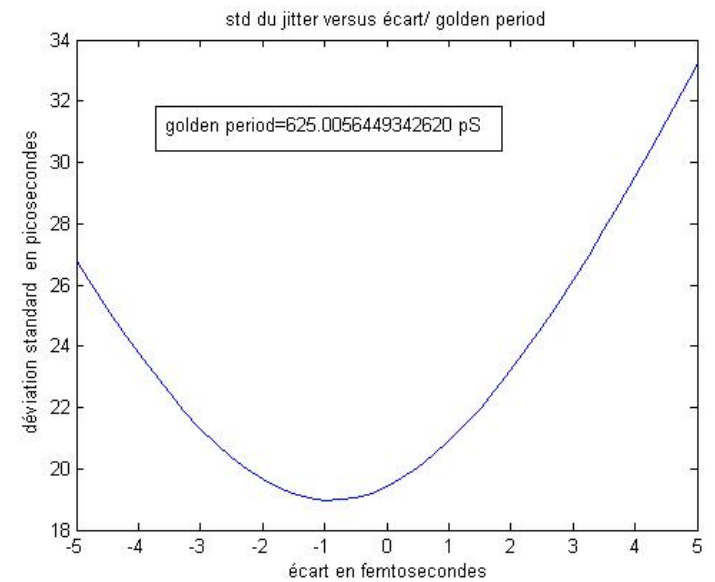
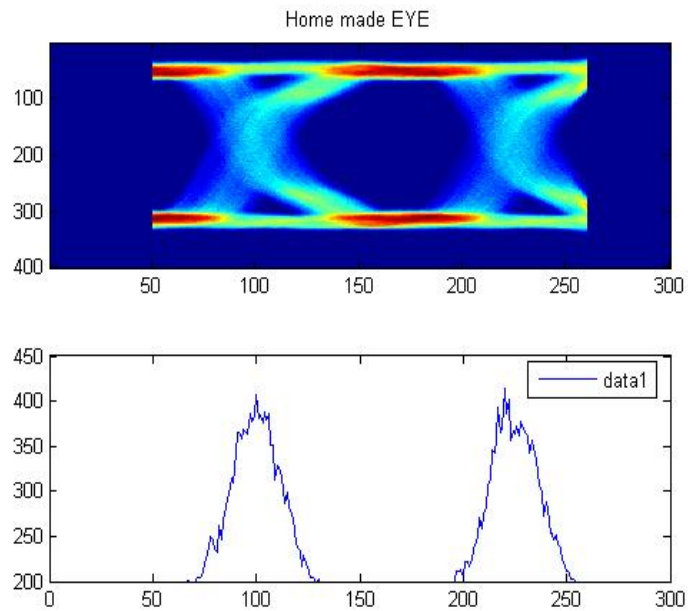
CIMT Matlab 2



CIMT Matlab 3



CIMT Matlab



Codage caractère 8b/10b

256 data characters

disparity

D27.7	111 11011	110110 0001	001001 1110
D28.7	111 11100	001110 1110	001110 0001
D29.7	111 11101	101110 0001	010001 1110
D30.7	111 11110	011110 0001	100001 1110
D31.7	111 11111	101011 0001	010100 1110

Table B-2: Valid Control Characters (K-Characters)

Special Code Name	Bits HGF EDCBA	Current RD – abcde1 fghj	Current RD + abcde1 fghj
K28.0	000 11100	001111 0100	110000 1011
K28.1	001 11100	001111 1001	110000 0110
K28.2	010 11100	001111 0101	110000 1010
K28.3	011 11100	001111 0011	110000 1100
K28.4	100 11100	001111 0010	110000 1101
K28.5	101 11100	001111 1010	110000 0101
K28.6	110 11100	001111 0110	110000 1001
K28.7 ⁽¹⁾	111 11100	001111 1000	110000 0111
K23.7	111 10111	111010 1000	000101 0111
K27.7	111 11011	110110 1000	001001 0111
K29.7	111 11101	101110 1000	010001 0111
K30.7	111 11110	011110 1000	100001 0111

Notes:

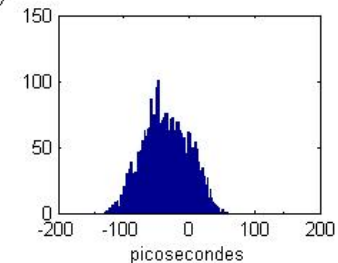
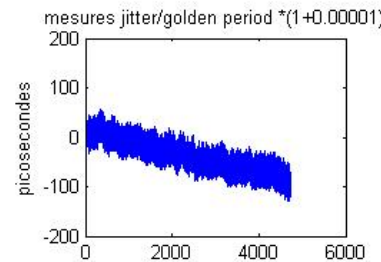
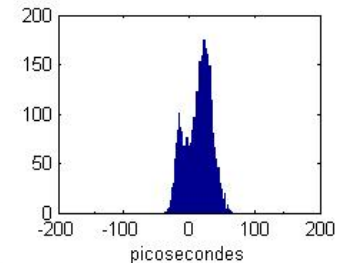
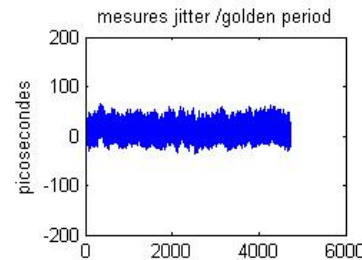
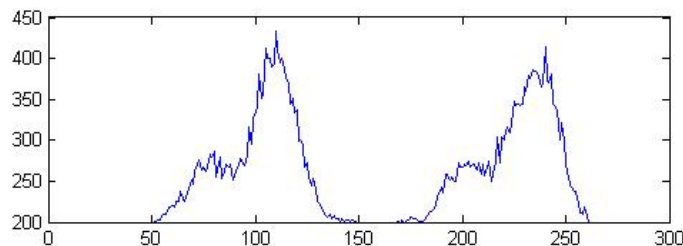
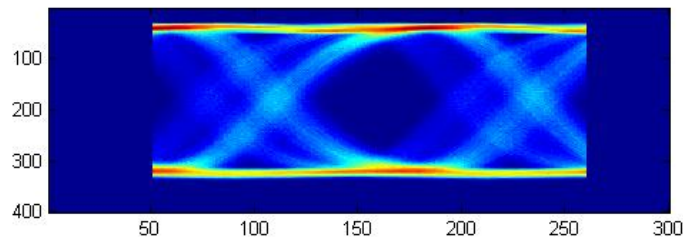
1. Used for testing and characterization only. Do not use in protocols.

http://www.xilinx.com/support/documentation/user_guides/ug024.pdf
<http://researchweb.watson.ibm.com/journal/rd/275/ibmrd2705D.pdf>

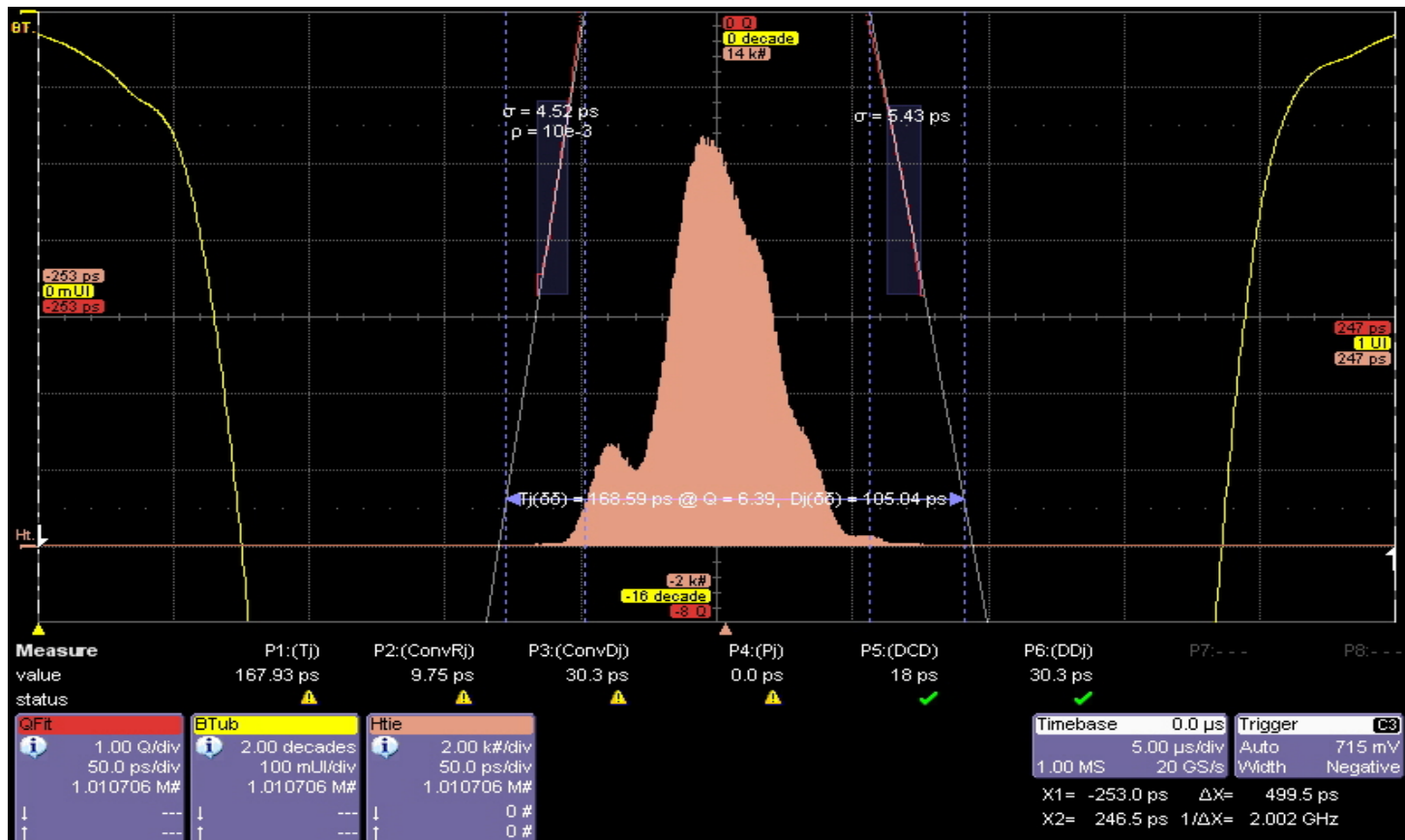
8b/10B Matlab

Oscillo 20 Gs/s $? \cdot 10^6$ échantillons de signal

Sous Matlab ont été effectués les traitements suivants
récupération d'horloge
jitter et analyse de jitter (FFT etc..)
diagramme de l'oeuil
décodage série-parallèle



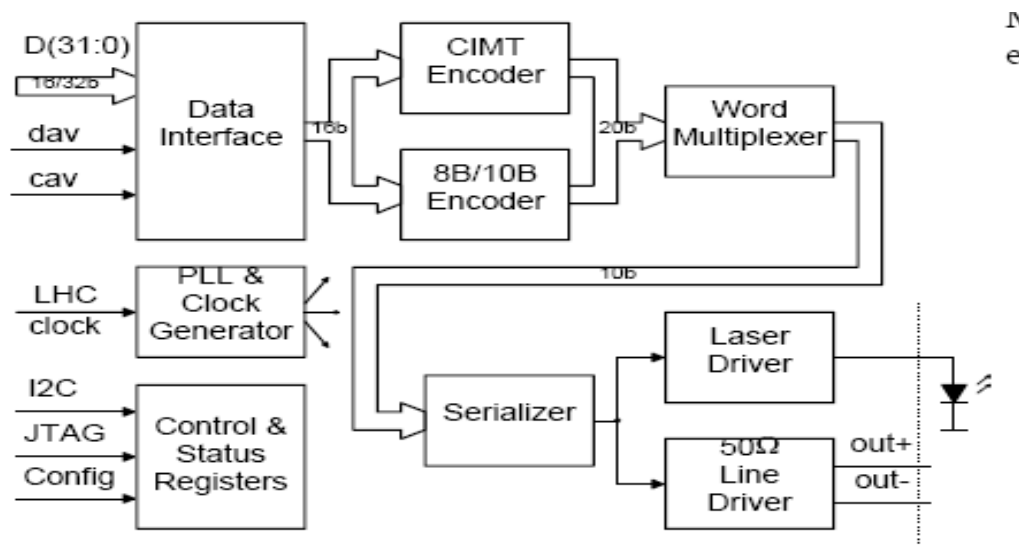
plus pro.... plus cher....



Le circuit 'séréaliseur' GOL

Gigabit OptoLink

http://ph-collectif-lecc-workshops.web.cern.ch/ph-collectif-lecc-workshops/LEB01_Book/opto/Moreira.pdf



A Radiation Tolerant Gigabit Serializer for LHC Data Transmission*

P. Moreira¹, G. Cervelli, J. Christiansen, F. Faccio, A. Kluge,
A. Marchioro and T. Toifl²

CERN, 1211 Geneva 23, Switzerland

J. P. Cachemiche and M. Menouni

CPPM, Marseille, France



sources

Circuit GOL

[http://ph-collectif-lecc-workshops.web.cern.ch/
ph-collectif-lecc-workshops/LEB01_Book/opto/Moreira.pdf](http://ph-collectif-lecc-workshops.web.cern.ch/ph-collectif-lecc-workshops/LEB01_Book/opto/Moreira.pdf)

CIMT

www.omnisterra.com/walker/pdfs.papers/Thesis.pdf

8b/10b

<http://researchweb.watson.ibm.com/journal/rd/275/ibmrd2705D.pdf>

**RocketIO™ Transceiver User Guide
UG024 (v2.5) December 9, 2004**

http://www.xilinx.com/support/documentation/user_guides/ug024.pdf



Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CMT, 8b/10b,)
- **Formation**
- Biblio
- Divers



Rechercher :



[Actualités](#) • [Accueil](#) • [Médiathèque](#) • [Annuaire](#) • [Liens](#) • [Contacts](#) • [FAQ](#) • [English](#) • [Intr@net](#) • [Entio](#)

[Qui sommes nous ?](#)

[Enseignement](#)

[Recherche](#)

[IOTech](#)

[Entreprises](#)

[International](#)

[Enseignement](#) > [Formation continue](#) > [Stages inter-entreprises](#) > [stage D](#) : [Imprimer](#)

[RETOUR](#)

Stage D6 : Les Fibres Optiques : Fonctionnement et Applications

Objectifs :

- Connaître le fonctionnement des fibres optiques monomodes et multimodes
- Comprendre leurs caractéristiques
- Savoir mettre en oeuvre un système à base de fibre optique

Public :

- Opérateur, technicien supérieur et ingénieur.

Thèmes abordés :

- Notions élémentaires d'optique guidée.
- Les fibres optiques multimodes, monomodes : principe de fonctionnement, caractéristiques.
- Technologie des fibres : fabrication, caractérisations et mesures, injection, connectique.
- Applications des fibres : transport de faisceau laser, transmission numérique sur fibre, amplificateur à fibre optique dopée Erbium, amplificateur à fibre Raman, capteurs à fibre optique, gyroscope à fibre.



Transmission numérique sur fibre multimode à gradient d'indice

[télécharger la fiche du stage](#)

Tous les sujets seront abordés par une approche simple et pragmatique. Cette formation articulée autour de cours et de travaux pratiques permet d'intégrer efficacement ces nouvelles compétences pour rapidement les mettre en oeuvre.

I. RAPPELS D'OPTIQUE : (3H00)

- A.1 La lumière : aspects corpusculaire et ondulatoire
- A.2 Notions élémentaires d'optique guidée
- A.3 Instruments de mesure

II. LES FIBRES OPTIQUES : (9H00)

- B.1 Structure générale
- B.2 Paramètres essentiels
- B.3 Fibres optiques multimodes
 - Propagation de rayons lumineux dans une fibre à saut d'indice
 - Caractéristiques : ouverture numérique, atténuation, dispersion intermodale
 - Fibre optique multimode à gradient d'indice : caractéristiques
- B.4 Fibres optiques monomodes
 - Paramètres typiques : diamètre de coeur, atténuation, longueur d'onde de coupure
 - Dispersion chromatique
 - Fibres à dispersion décalée et à compensation de dispersion, fibres à maintien de polarisation
 - Dispersion des modes de polarisation
- B.5 Technologie des fibres
 - Méthodes de fabrication des fibres optiques, clivage et polissage de l'extrémité d'une fibre
 - Raccords par épissure et connecteurs, pertes par raccordement
 - Normes
 - Caractérisations et mesures

III. APPLICATIONS DES FIBRES OPTIQUES : (9H00)

C.1 Transport de faisceau laser

- Couplage efficace dans une fibre optique
- Exemples de systèmes optiques d'injection
- Application : diode laser fibrée

C.2 Transmission numérique sur fibres optiques

- Rappels sur les bruits de photodétection
- Règles de conception élémentaires : budgets en puissance et en temps
- Taux d'erreurs d'une liaison numérique
- Diagramme de l'oeil
- Illustrations sur des exemples concrets

C.3 Amplificateur à fibre optique dopée

- Principe et intérêts de l'amplification optique
- Amplificateur à fibre dopée Erbium : principe de fonctionnement, architectures typiques, principales caractéristiques
- Source large bande

C.4 Fibre optique non-linéaire

- Introduction à l'optique non-linéaire
- Amplificateur à fibre optique Raman : principe de fonctionnement, architecture et caractéristiques typiques
- Propagation en régime soliton : effet Kerr optique, solitons temporels et spatial
- Source très large bande

C.5 Laser à fibre optique

- Laser à fibre optique dopée
- Laser à fibre Raman

C.6 Capteurs à fibre optique

- Principes
- Mesures de contrainte, température, pression, accélération
- Montages interférométriques

IV. TRAVAUX PRATIQUES : (9H00)

- Amplification optique et laser sur fibre optique dopée Erbium
- Mesure d'atténuation sur fibre par réflectométrie
- Mesure de dispersion de fibre optique monomode
- Effet Raman dans une fibre en silice
- Gyroscope à fibre optique



Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CMT, 8b/10b,)
- Formation
- **Biblio**
- Divers



Bibliographie

"If you steal from one author, it's plagiarism;
if you steal from many, it's research"
-- *Wilson Mizner*, 1953.

ECE 477 <http://www.ece.uwaterloo.ca/~ece477/Lectures/>
EE230 <http://www.cse.ucsc.edu/classes/ee230/Spring04/>
Photonics Glossary Of Terms
<http://www.aapn.mcgill.ca/eng/resources/PhotonicsGlossary.pdf>

TDR (*Time Domaine Reflectometry*)
<http://cp.literature.agilent.com/litweb/pdf/5966-4855E.pdf>

Sans doute la meilleure référence:
Understanding Optical Communications:
<http://www.redbooks.ibm.com/redbooks/pdfs/sg245230.pdf>
et aussi
http://www.electronics.dit.ie/staff/tfreir/optical_2/
http://www.home.agilent.com/upload/cmc_upload/All/SLDPRE_basics1.ppt

Livres:
Télécoms par fibres optiques. Pierre Lecoy Hermes
Optical Fiber communications Gerd Keiser McGraw Hill 3ed
Fiber Optics Technician's Manual [Jim Hayes](#)

Site CNAM:
www.cnam.fr/elau/publi/hincelin/index.html



Plan

- Principaux composants
 - connecteurs et épissures
 - atténuateurs
 - coupleurs directifs
 - isolateurs
 - circulateurs
 - Multiplexeurs-démultiplexeurs (en longueurs d'ondes)
- Mesures (puissance, OTDR, ..)
- BER, Jitter, Eye Diagram
- Codage caractère (CIMA, 8b/10b,)
- Formation
- Biblio
- **Divers**



Divers

- TDM WDM
- Optical switching
- Autres modulations
- Détection hétérodyne

- Solitons

TDM WDM DWDM Principes

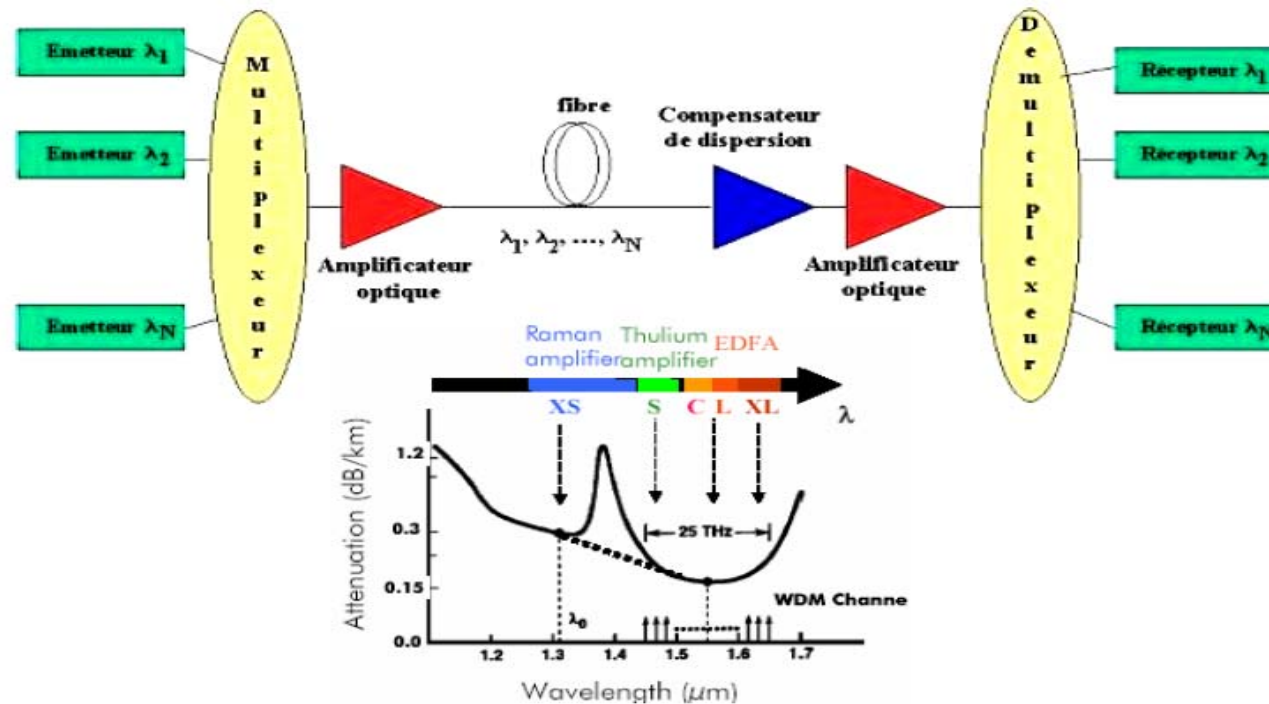


figure extraite de : Communications optiques à très haut débit. J. Laurent
CNAM Probatoire 2004

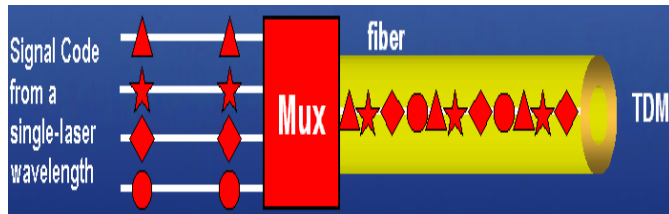
http://www.electronics.dit.ie/staff/tfreir/optical_2/

www.cnam.fr/elau/publi/hincelin/index.html

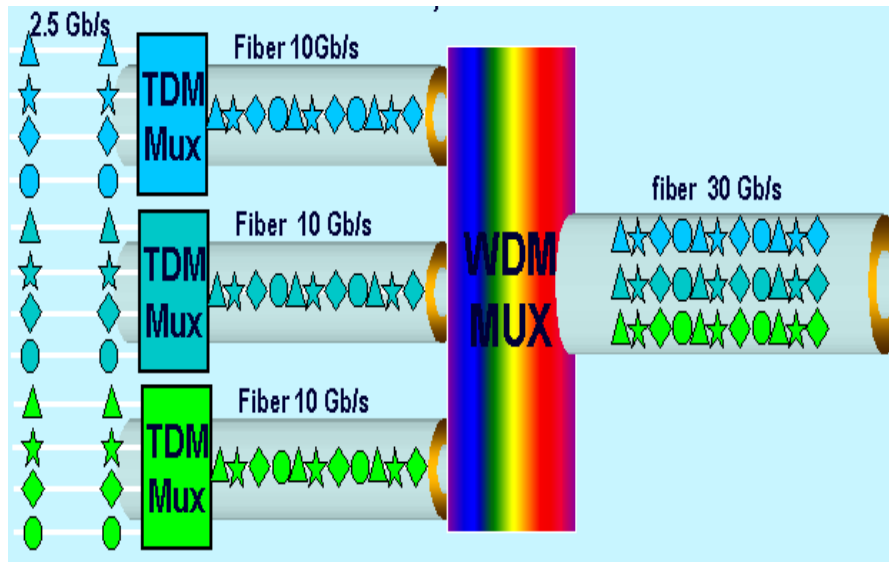
kpp.nsysu.edu.tw/2004kpprcprep/seminer/20041208_Introduction%20to%20Optical%20Network.ppt

TDM WDM DWDM Principles

Time Division Multiplexing(TDM)



Wavelength Division Multiplexing(WDM)



number of wavelength channels >16
Dense WDM → DWDM

Année	Nom	Pas entre répéteurs	Débit	Nombre voies eq. téléphone	Technologie
1956	TAT-1	70 km	Analogique	36	Coaxial Liaison Electrique.
1970	TAT-7	12 km	Analogique	4 000	Coaxial Liaison Electrique.
1988	TAT-8	40 km	280Mbit/s	4 375	Fibre 1.3 µm Liaison Opto-Elec.
1991	TAT-9	120 km	560Mbit/s	8 750	Fibre 1.5 µm Liaison Opto-Elec.
1995	TAT-12/13	45 km	5Gbit/s	78 125	Ampli. optique liaison optique
2000	TAT-14	50 km	160Gbit/s	2 500 000	WDM liaison optique

SDH is the standardized TDM based hierarchial model where the following transmission rates are defined:
STM-1: 155 Mbps
STM-4: 622 Mbps
STM-16: 2.5 Gbps
STM-64: 10 Gbps
STM-256: 40 Gbps
Gigabit Ethernet: 1 Gbps, 10 Gbps

WDM ITU-T NOMINAL CENTER FREQUENCIES

central frequencies(wavelengths) for 100 GHz spacing

$$f_c = 193.1 \pm m \times 0.1 \text{ THz}$$

$$\lambda_c = 1552.52 \text{ nm} \pm m \times 0.8 \text{ nm}$$

central frequencies(wavelengths) for 50 GHz spacing

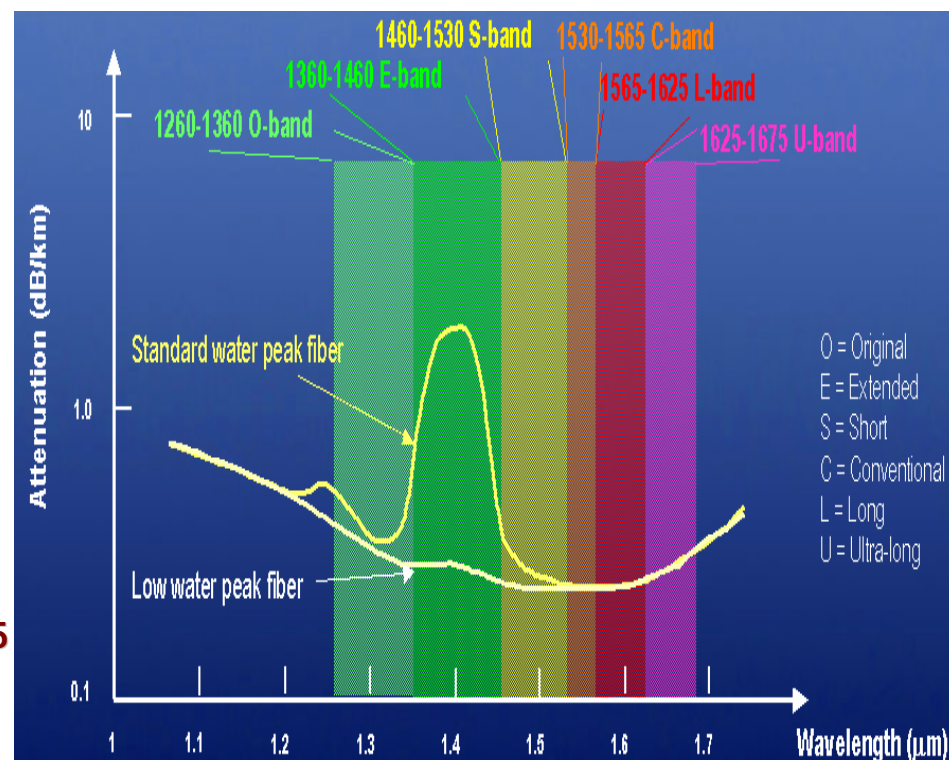
$$f_c = 193.1 \pm m \times 0.05 \text{ THz}$$

$$\lambda_c = 1552.52 \text{ nm} \pm m \times 0.4 \text{ nm}$$

Channel Spacing(GHz): 400, 200, 100, 50, 25, 12.5

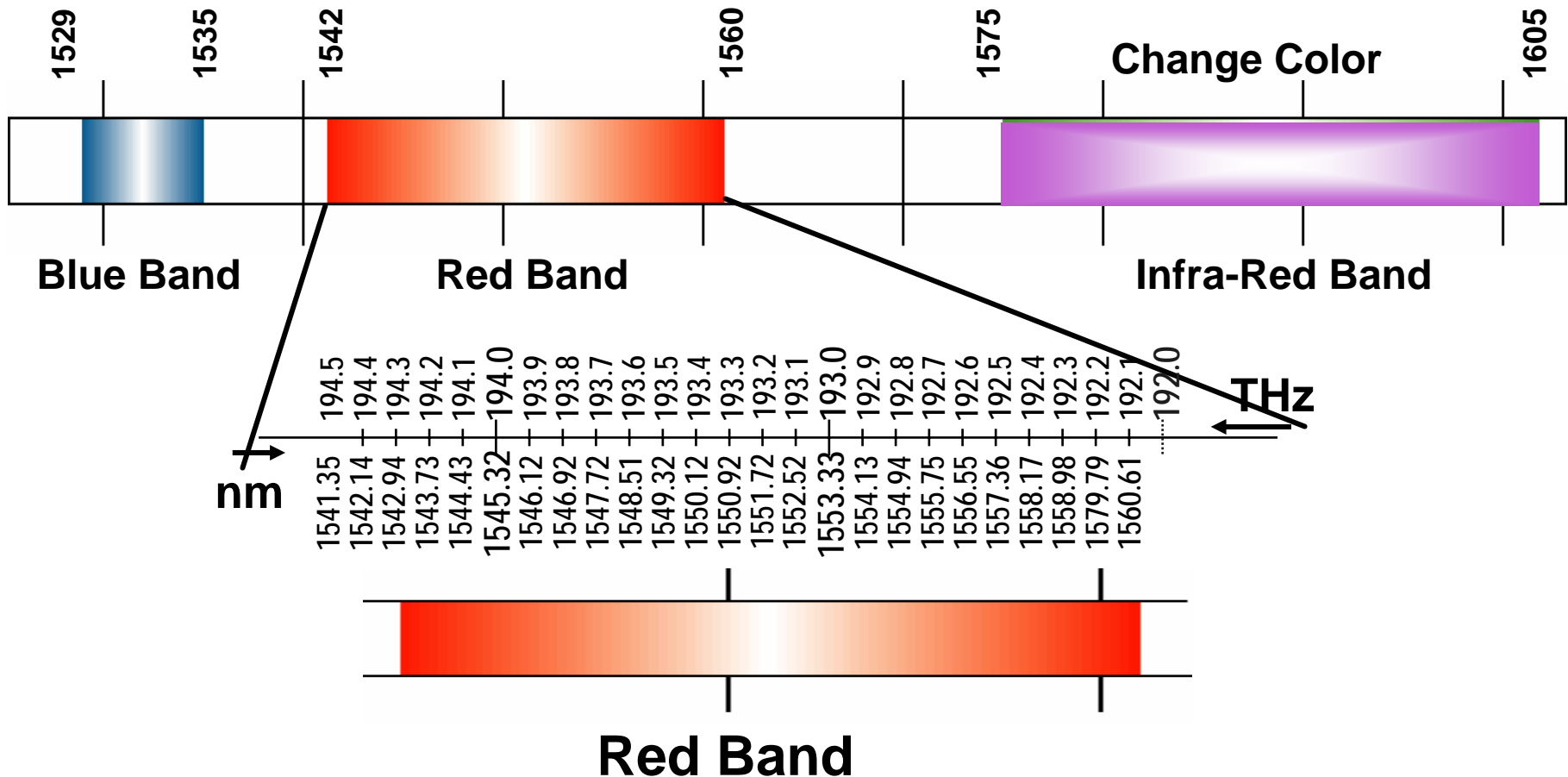
Channel Number: 4, 8, 16, 32, 64, 128, 256, 512

**G. 692 standard: 81 channel
in C band (1530-1565 nm)
Channel spacing= 50 GHz(0.4 nm)**



eri.ict.gov.ir/video/seminar84_10_28.ppt

DWDM Operating Wavelengths

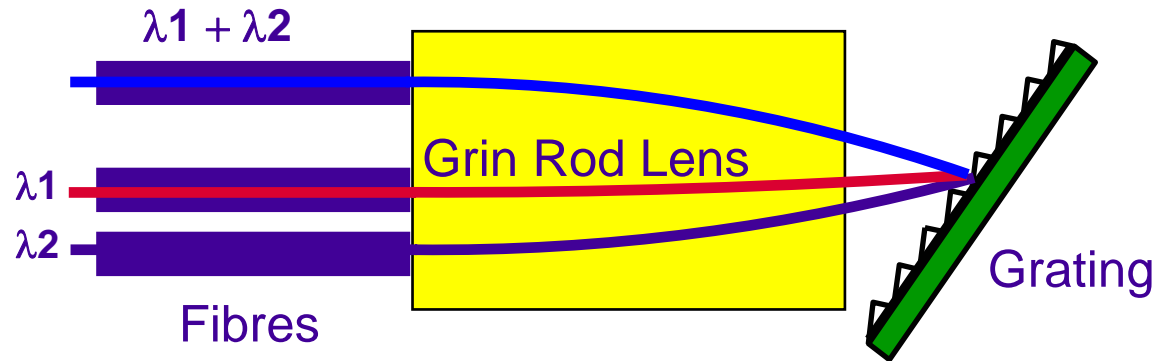


In Red Band: 24 Channels @ 100GHz Spacing; 48 Channels @ 50GHz Spacing
 In C (Red+Blue) Band: 40 Channel @ 100GHz Spacing; 80 Channel @ 50GHz Spacing

WDM Multiplexers/Demultiplexers

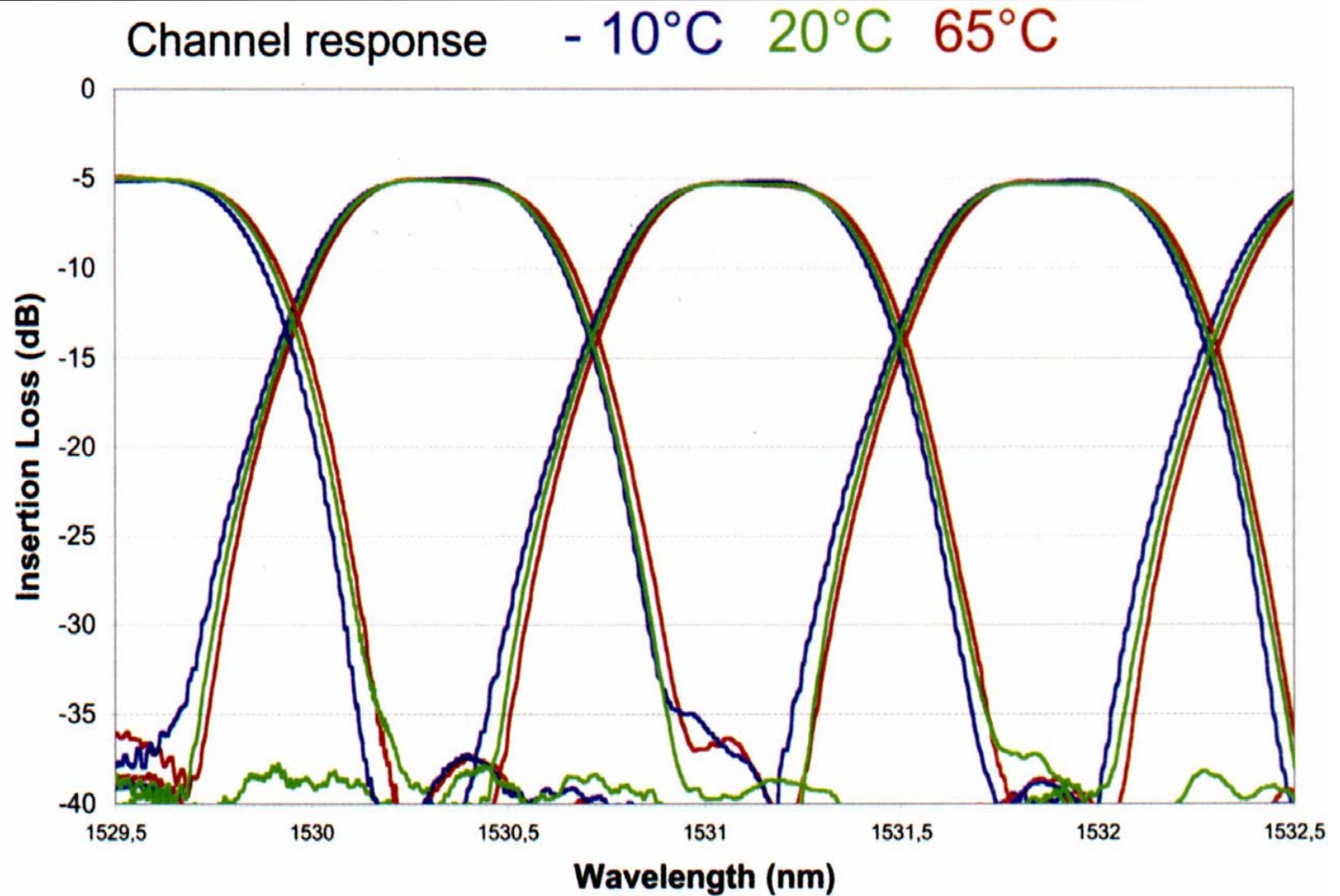
- Wavelength multiplexer types include:
 - Fibre couplers
 - **Grating multiplexers**
- Wavelength demultiplexer types include:

- Single mode fused taper couplers
- **Grating demultiplexers**
- Tunable filters



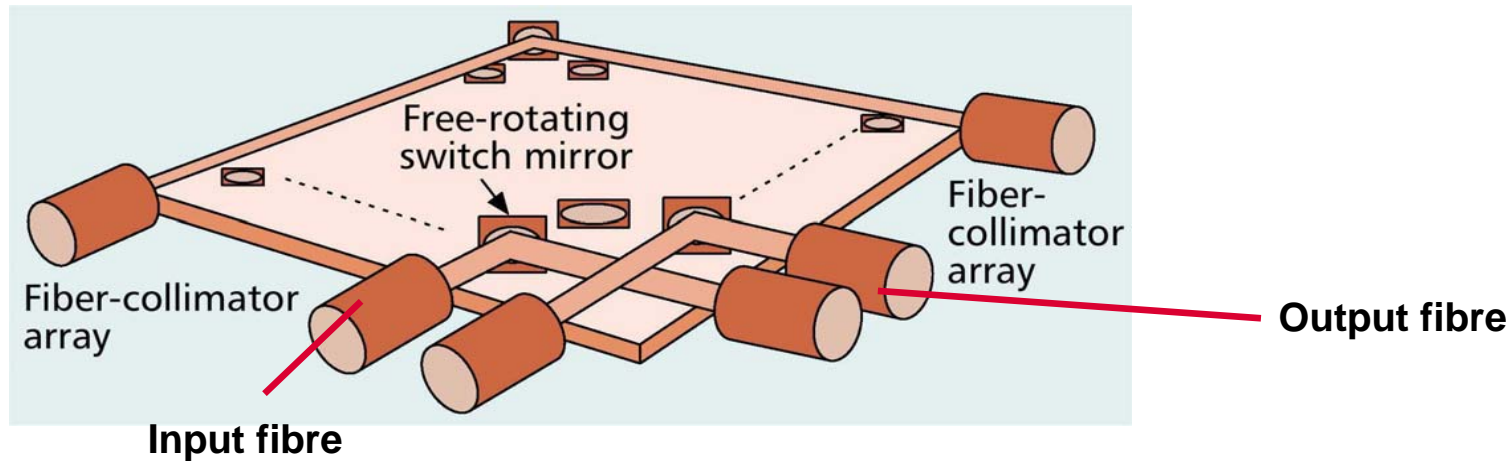
[http://www.electronics.dit.ie/staff/tfreir/optical_2/
unit_4.ppt](http://www.electronics.dit.ie/staff/tfreir/optical_2/unit_4.ppt)

Demux temperature dependence

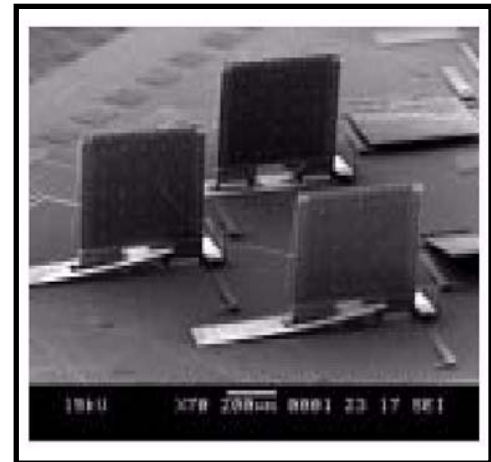


optical switching

2D MEMS based Optical Switch Matrix

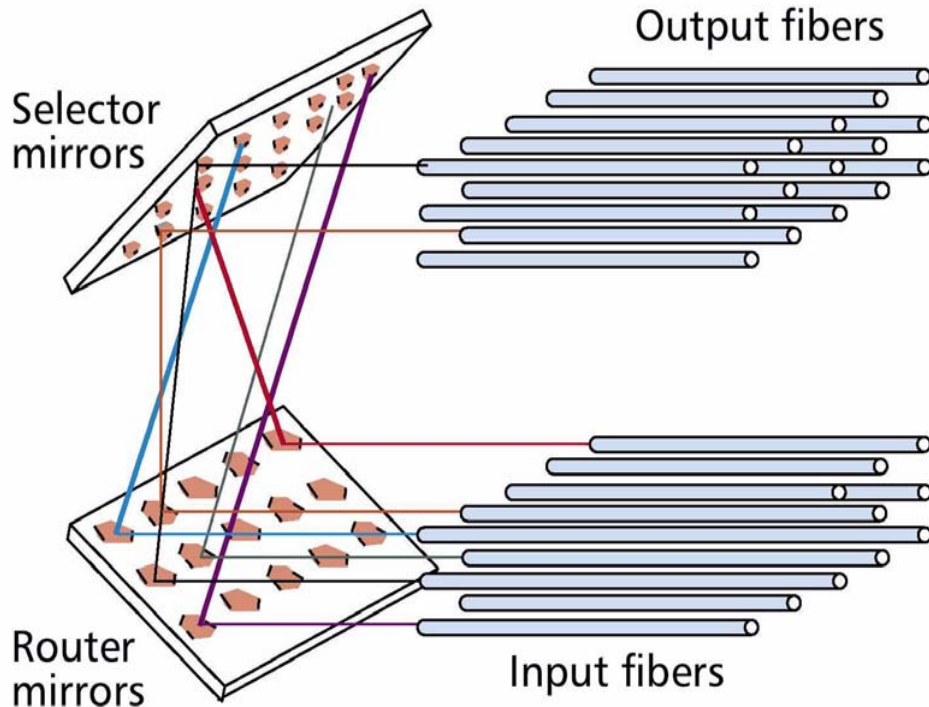


- Mirrors have only two possible positions
- Light is routed in a 2D plane
- For N inputs and N outputs we need N^2 mirrors
- Loss increases rapidly with N



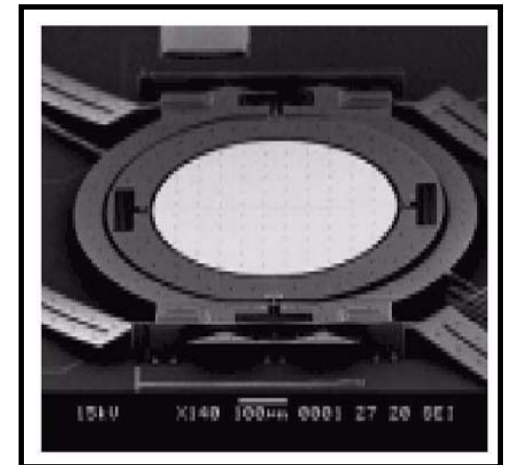
SEM photo of 2D MEMS mirrors

optical switching



3D MEMS based Optical Switch Matrix

- Mirrors require complex closed-loop analog control
- But loss increases only as a function of $N^{1/2}$
- Higher port counts possible



SEM photo of 3D MEMS mirrors

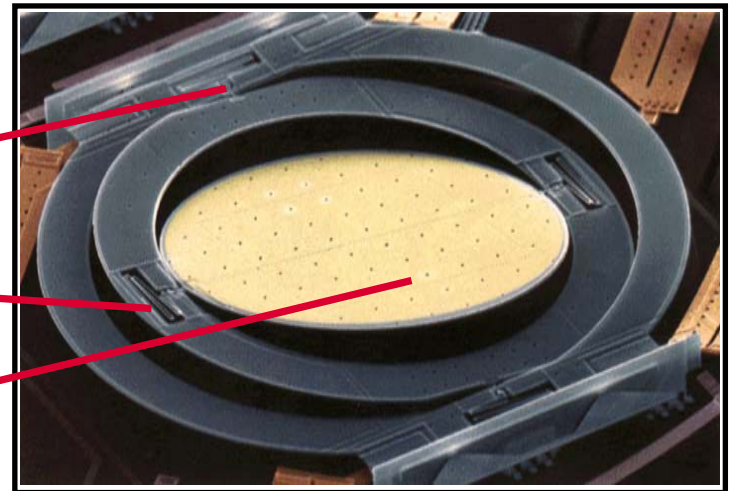
optical switching

- Based on microscopic mirrors (see photo)
- Uses MEMS (Micro-ElectroMechanical Systems) technology
- Routes signals from fibre-to-fibre in a space division switching matrix
- Matrix with up to 256 mirrors is currently possible
- 256 mirror matrix occupies less than 7 sq. cm of space
- Does not include DWDM Mux/Demux, this is carried out elsewhere
- Supports bit rates up to 40 Gb/s and beyond

Lucent LambdaRouter Optical Switch

Two axis motion

Micro mirror





Contenu du CD