OPTICAL FIBRE COMMUNICATIONS & MEASUREMENTS

Wien Schall GesmbH. Seit 1906.
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HISTORY + DEVELOPMENT 1/2

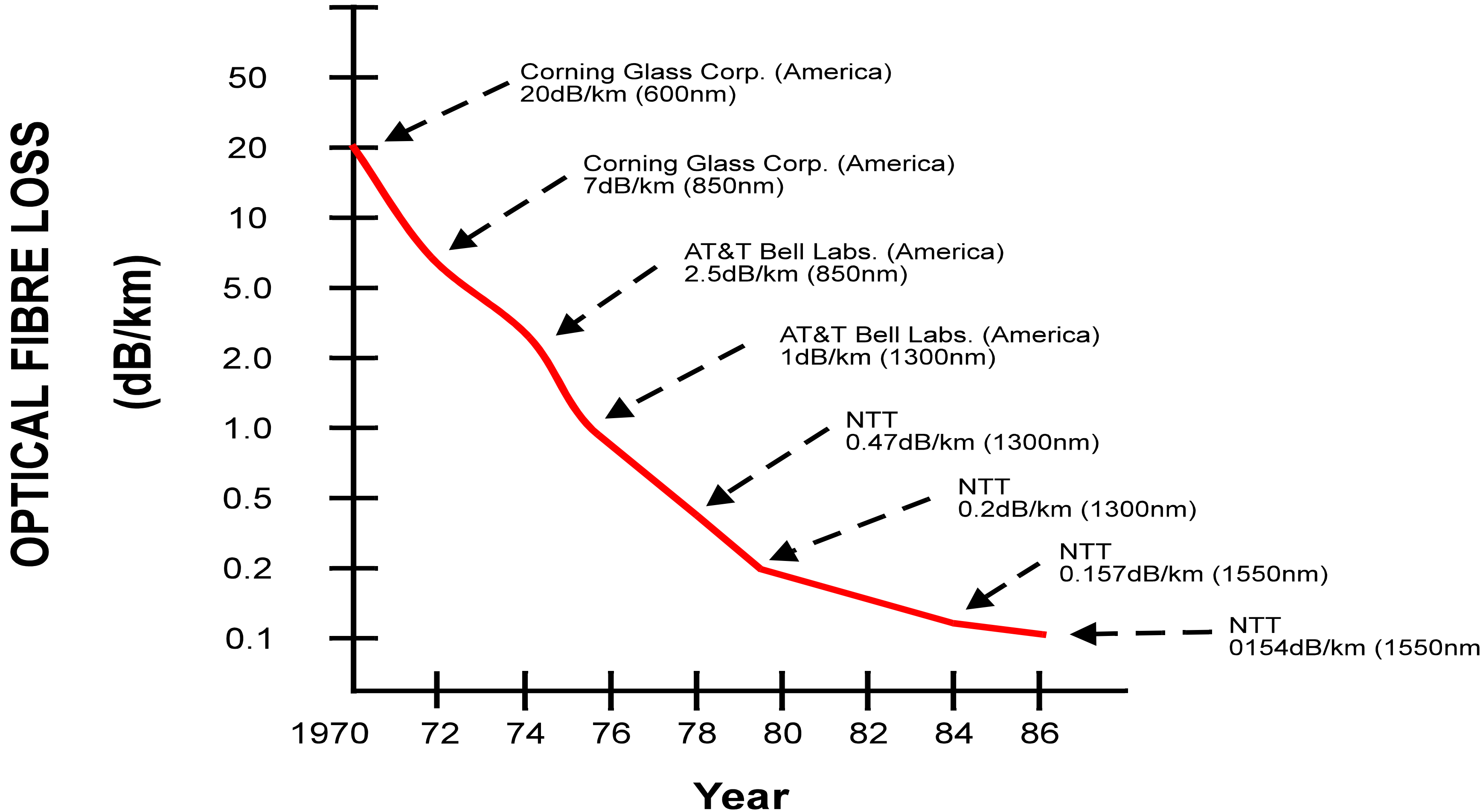
- **1870 John Tyndall showed light will follow curved jets of water issuing from a container.**
- **Later J.L.Baird & others worked on transmission of light in glass rods, Patents filed.**
- **1950s Brian O'Brian - American Optical Company + Narinder S. Kapany, Imperial College, worked on image transmitting fibres for medical applications etc.**

HISTORY + DEVELOPMENT 2/2

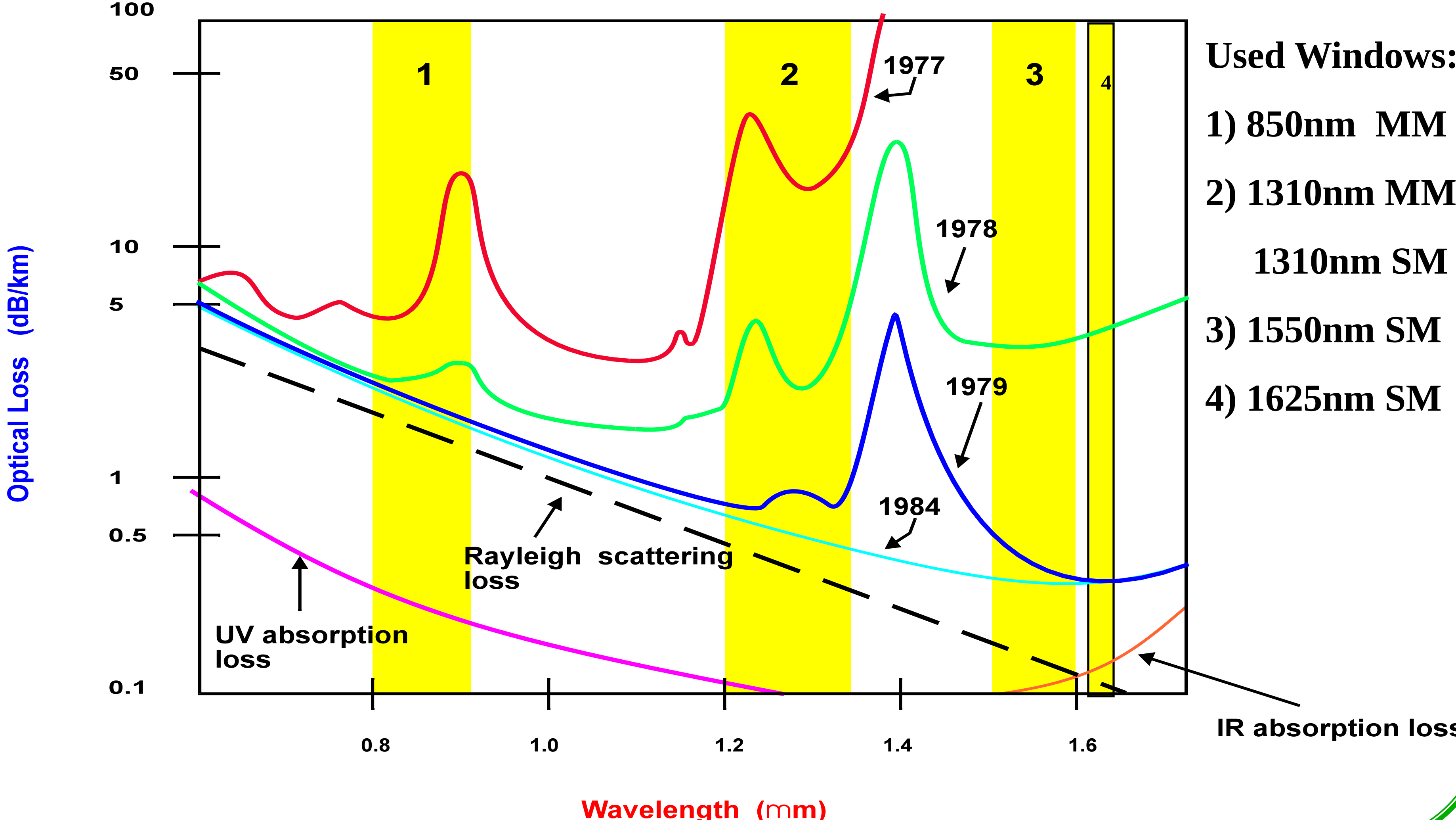
- 1960 Theodore Maiman of Hughes Labs demonstrated first ruby laser
- 1962 Lasing in s/c chip first observed
- 1966 Kao & Hockham STL proposed transmission of information via transparent dielectric medium would require reduction of losses from 1000 to 20dB/km
- 1970 Corning achieve 20dB/km

- Similar advances in sources, detectors, connectors and other related areas.

HISTORY OF LOSS REDUCTION



SPECTRAL LOSS REDUCTION



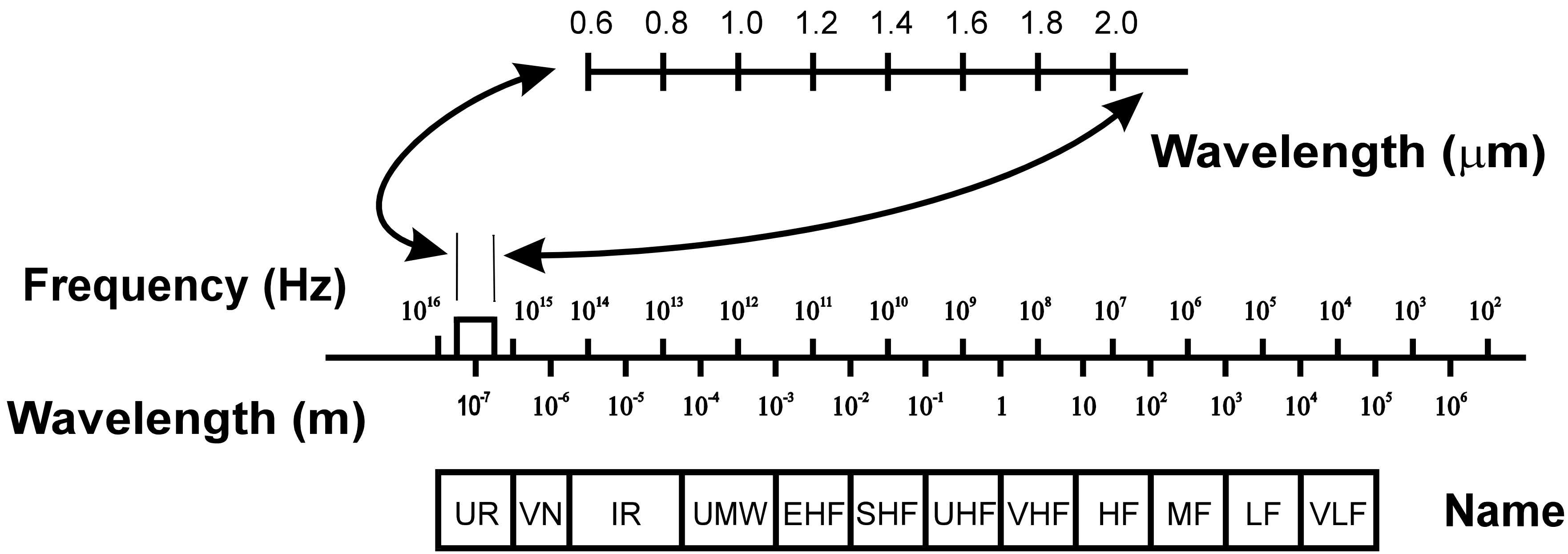
Used Windows:

1) 850nm MM
2) 1310nm MM
   1310nm SM
3) 1550nm SM
4) 1625nm SM

WHY OPTICAL FIBRE?

- Low Loss
- High Bandwidth
- EMI Immunity
- Lightweight/small size
- Negligible Cross-Talk
- Safe in Explosive Environments
- Difficult to Tap
- No Scrap Value

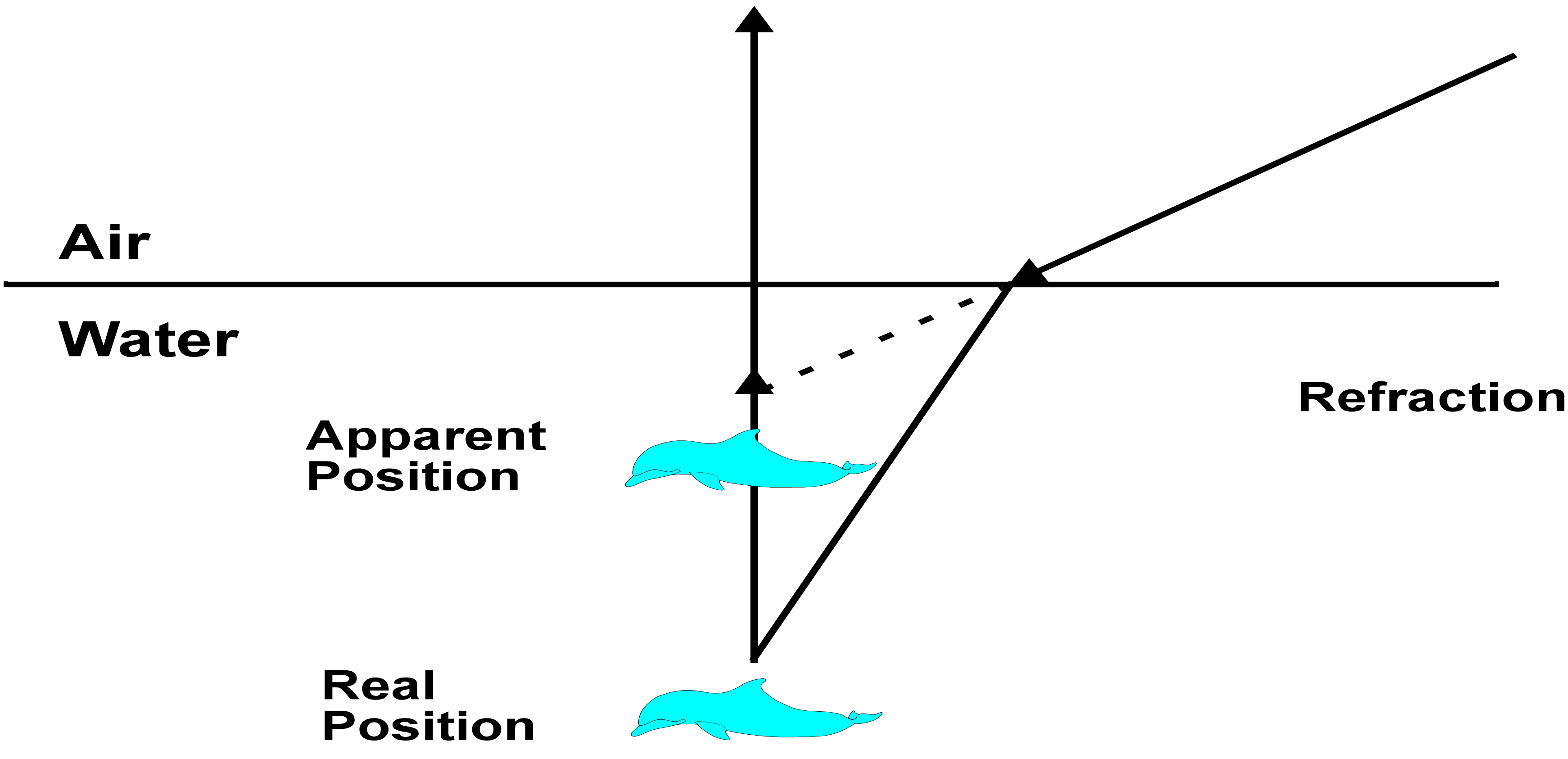
EM SPECTRUM



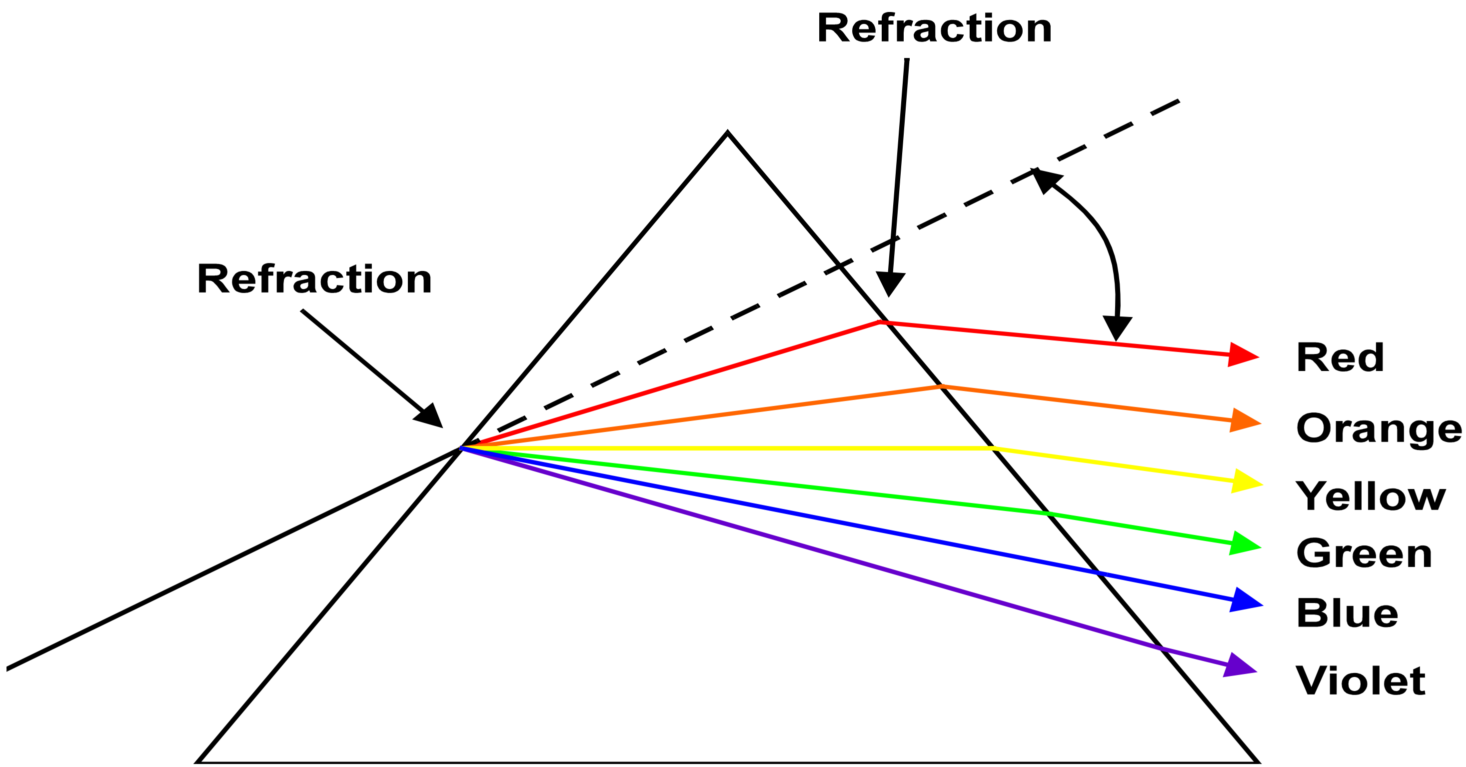
Includes visible red for POF !

LIGHT RAYS & GEOMETRICAL OPTICS

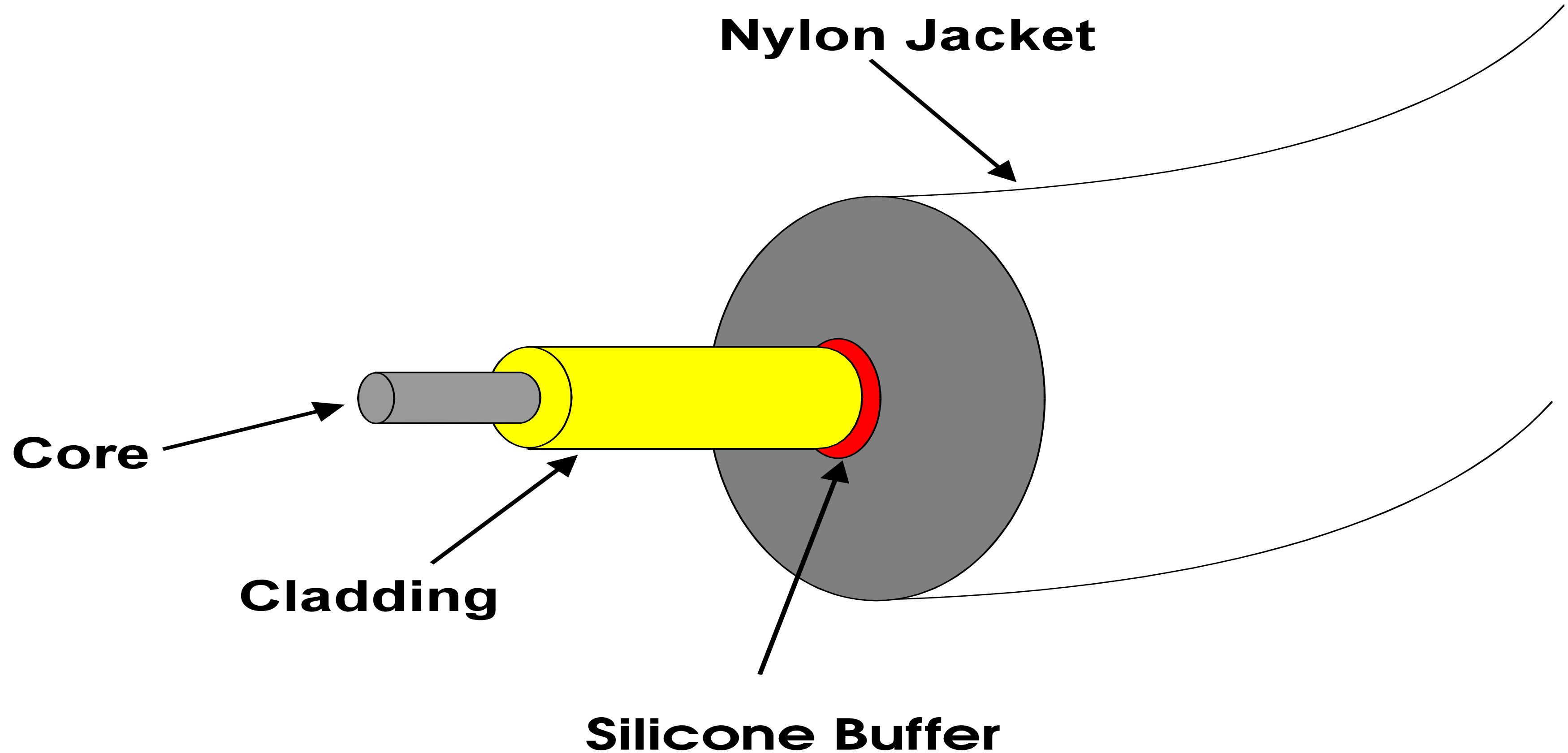
Reflection & Refraction (1/3)



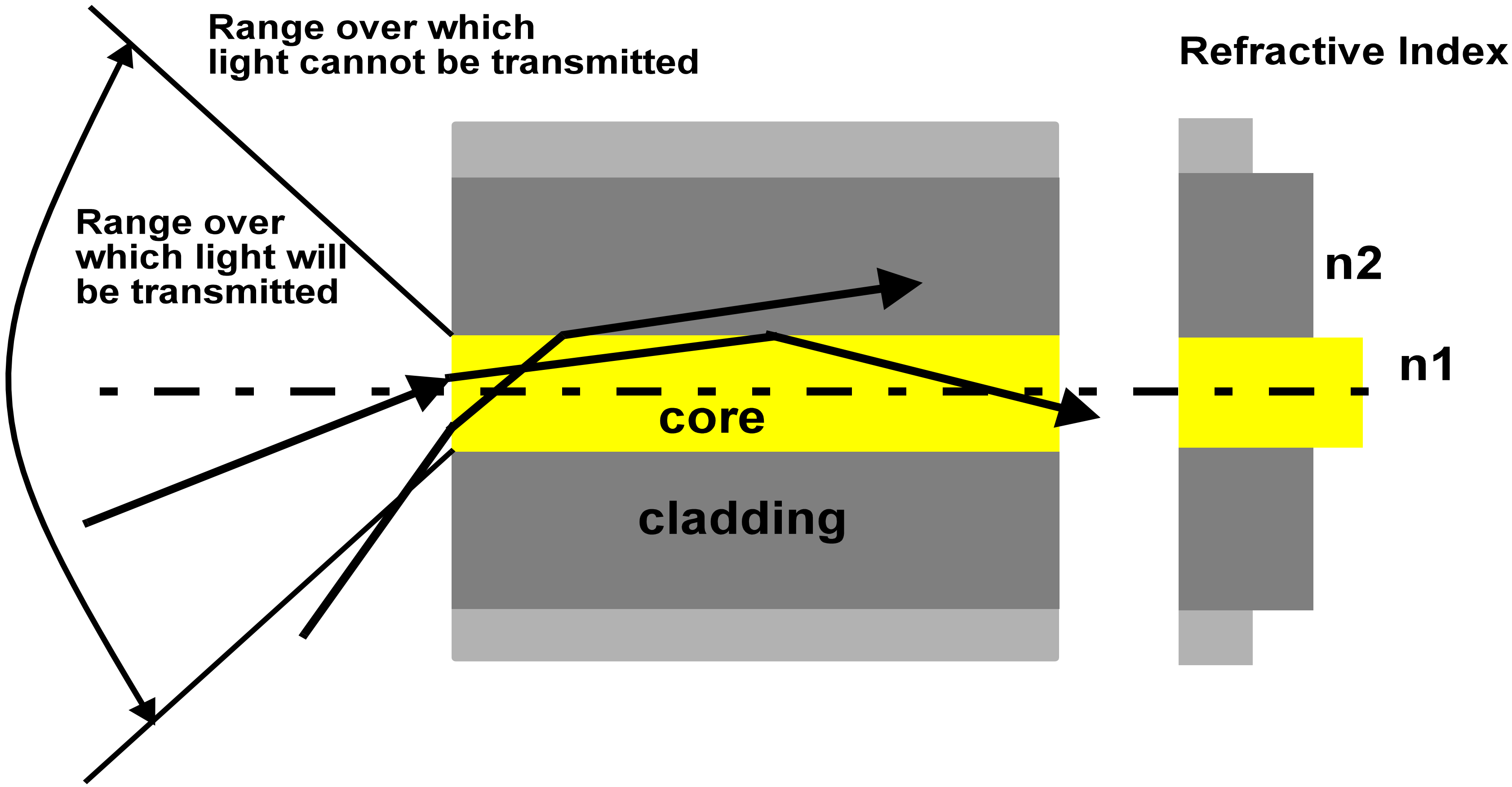
REFLECTION & REFRACTION (2/3)



OPICAL CABLE CONSTRUCTION



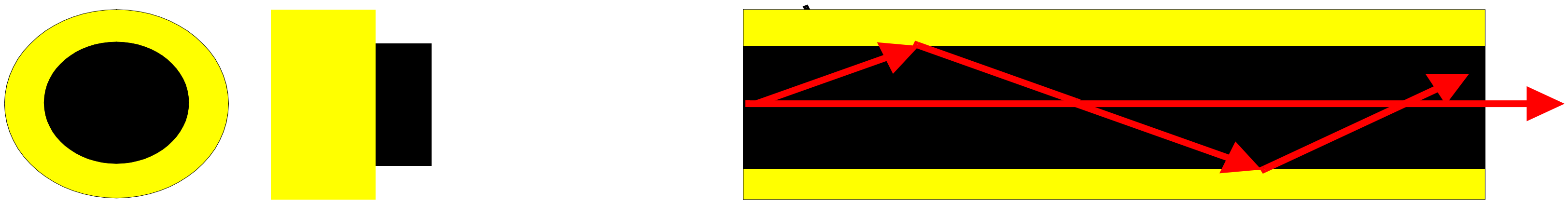
NUMERICAL APERTURE



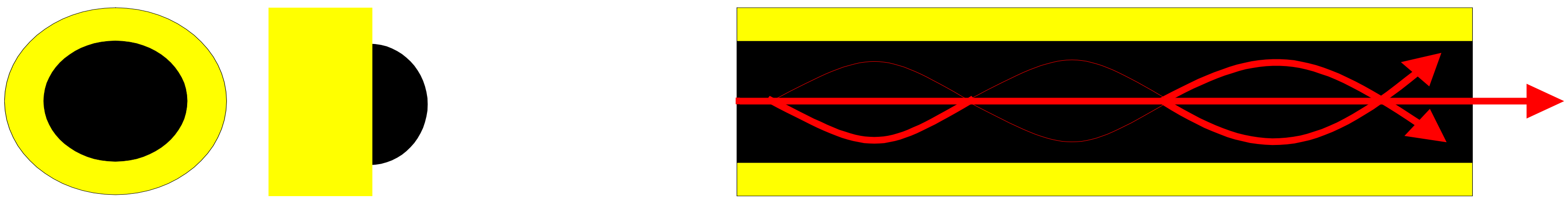
NA = sin(θ max)

TRANSMISSION IN VARIOUS FIBRES

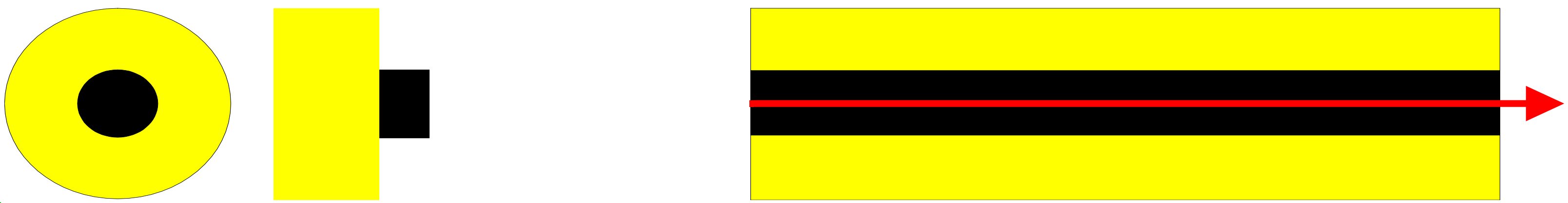
Propagation in Step Index Multimode Fibre



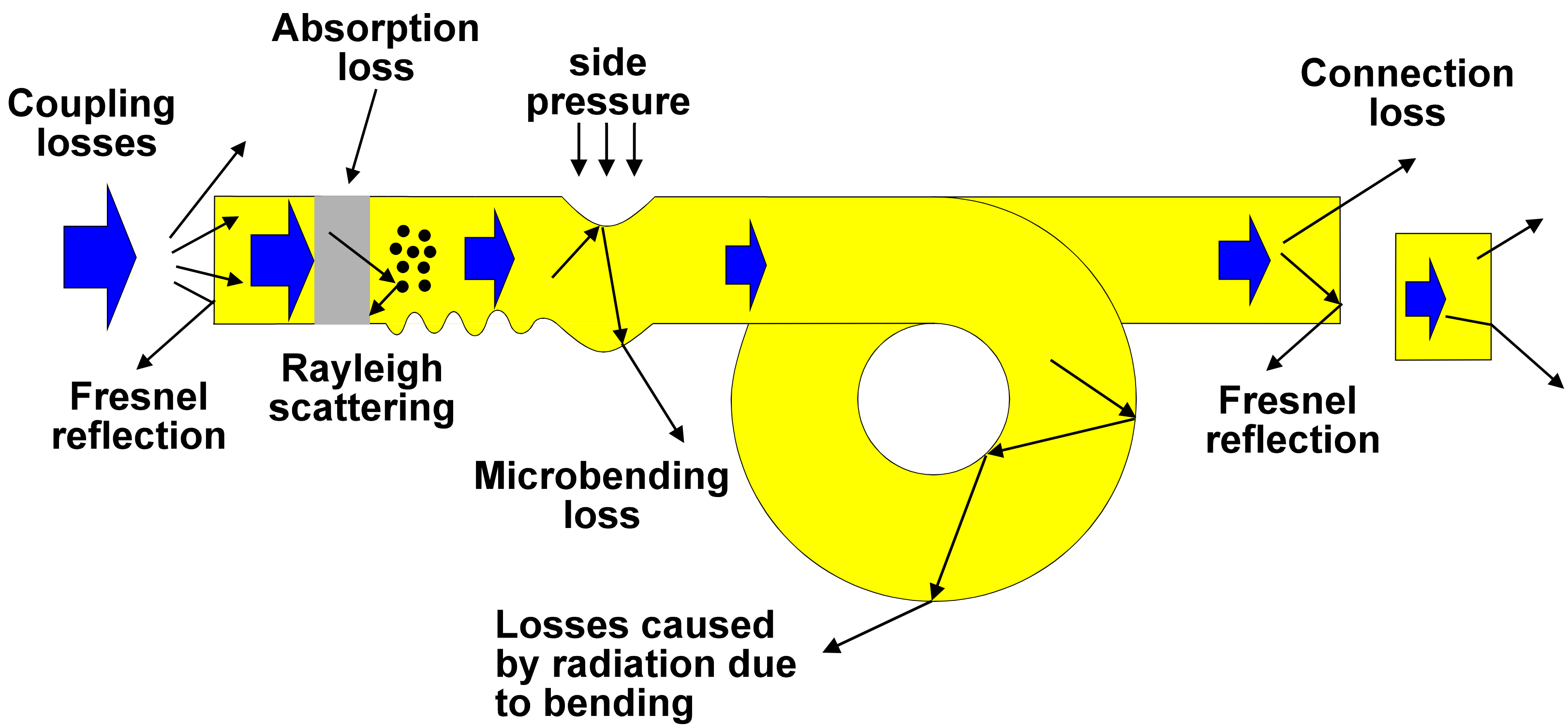
Propagation in Graded Index Multimode Fibre



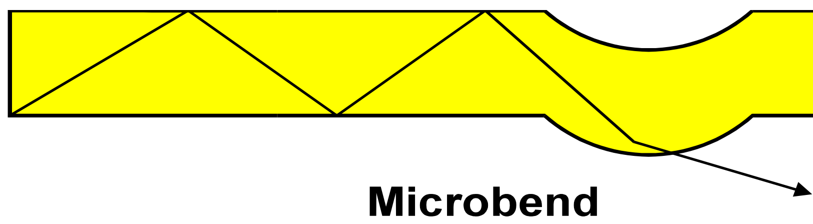
Propagation in Single Mode Fibre

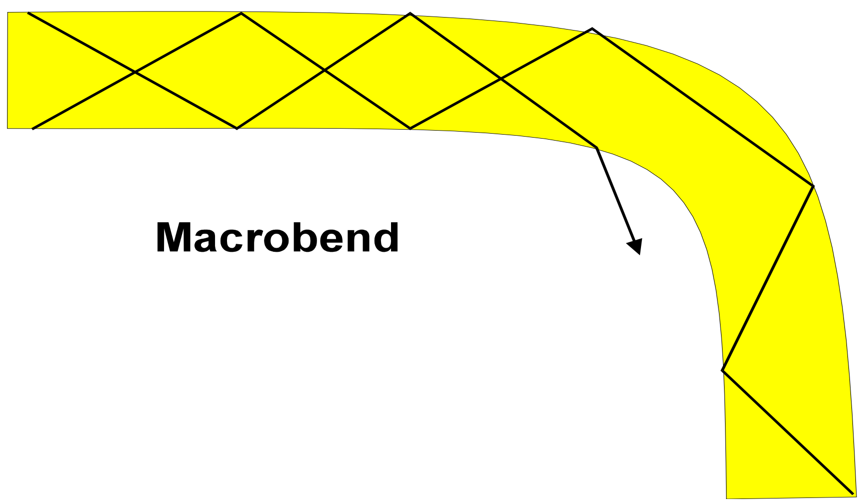


CAUSES OF LOSS



BENDS MICRO & MACRO





EQUILIBRIUM MODE DISTRIBUTION

(MULTIMODE FIBRES)

- **Not all modes carry equal energy**
- **Not all modes carry energy efficiently**
- **Energy can transfer between modes**
- **Launch condition**
  - **underfilled**
  - **overfilled**
- **Mode scramblers/filters**

CONNECTORS, SPLICES, SPLITTERS & COUPLERS

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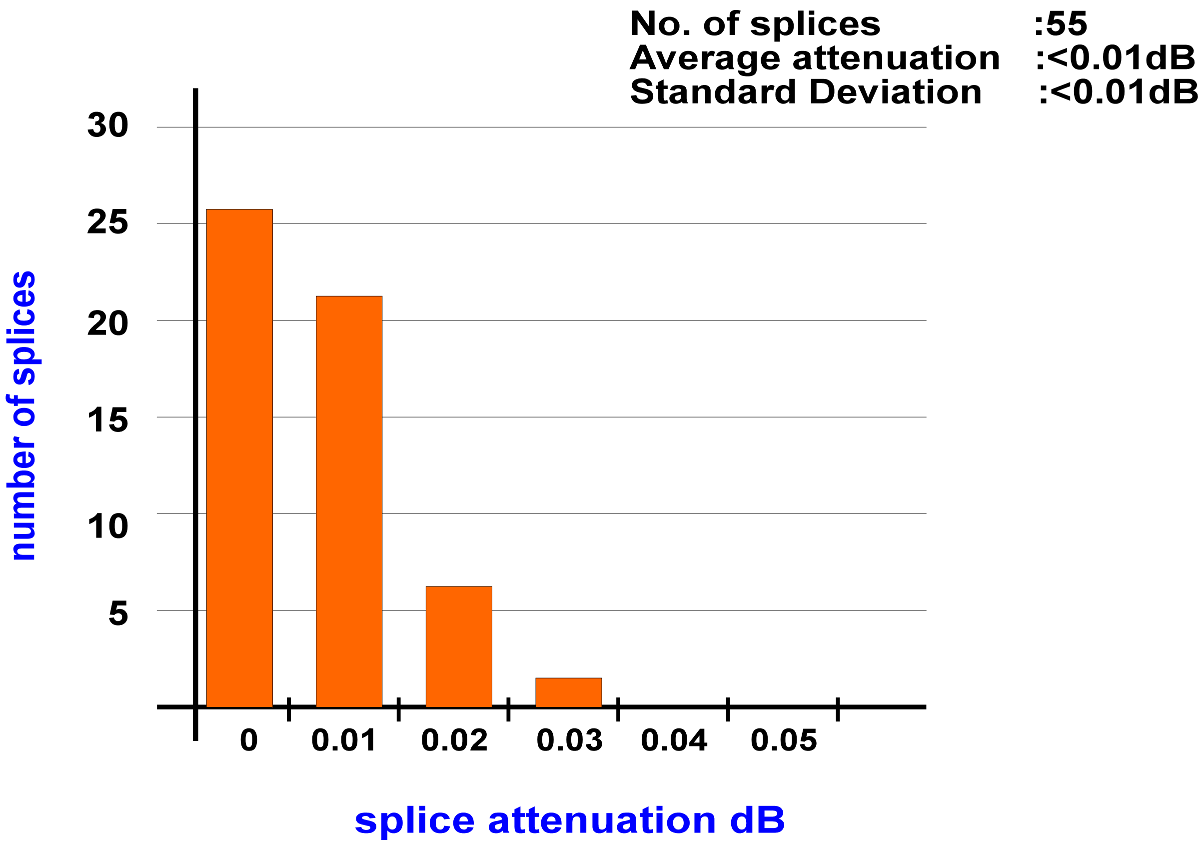
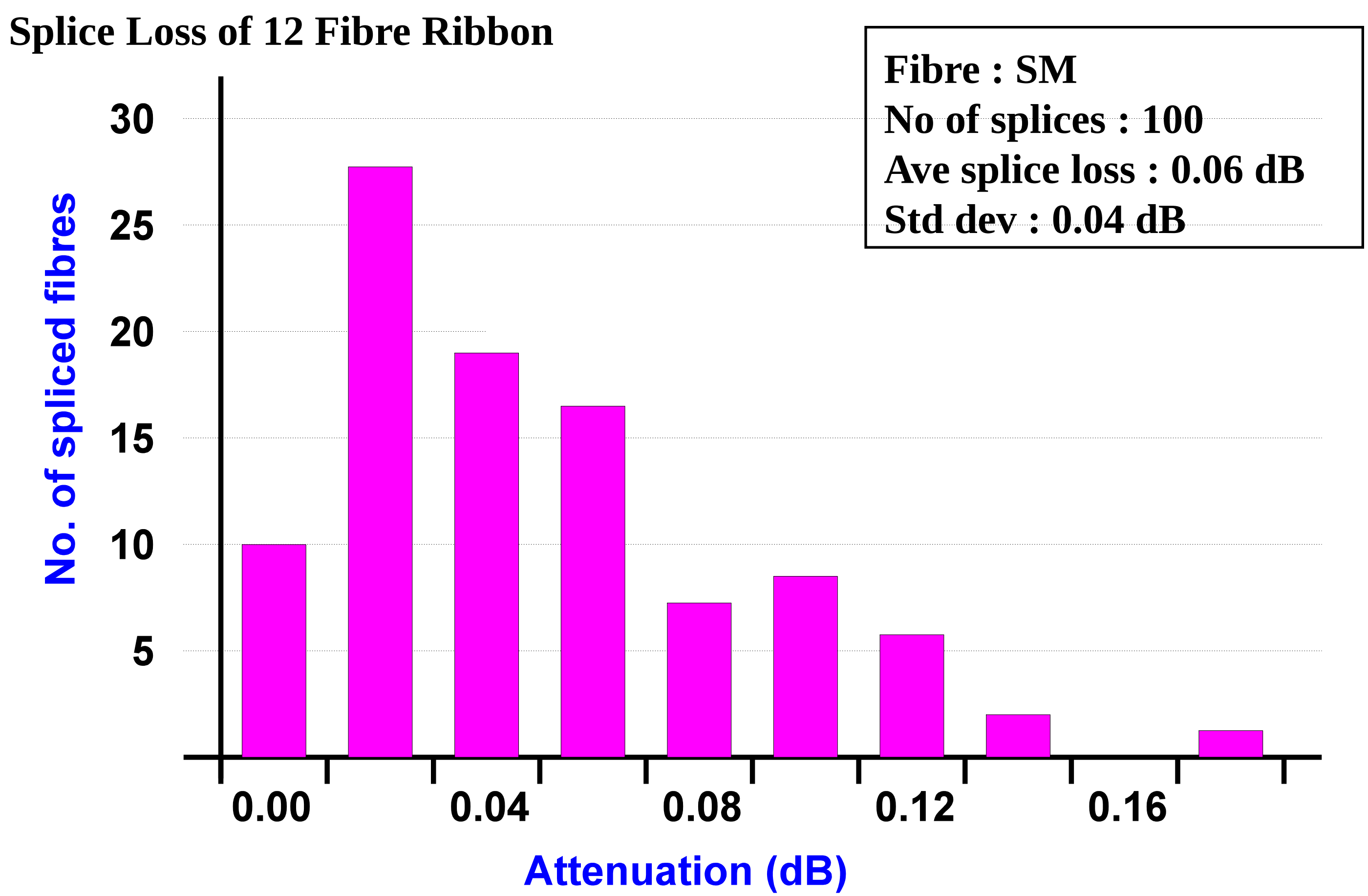
SPLICE LOSS DISTRIBUTION

- **Automatic Fusion Splicer, Identical Fibres**

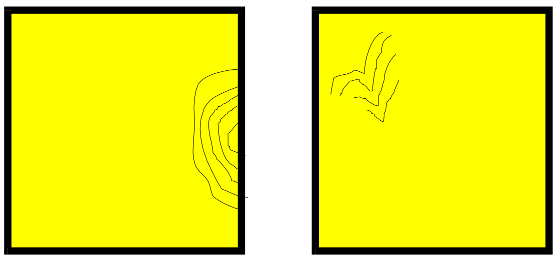


RIBBON SPLICERS

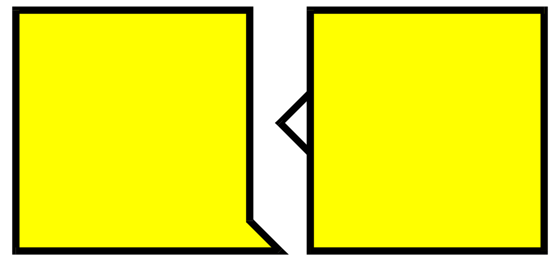


BAD CLEAVE EXAMPLES

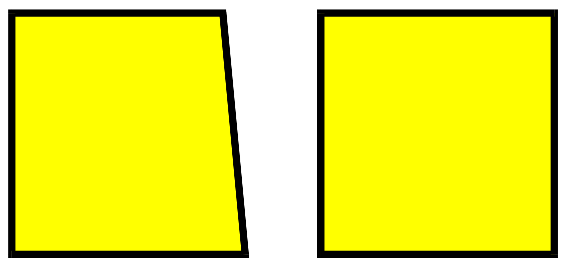
Crack



Lip

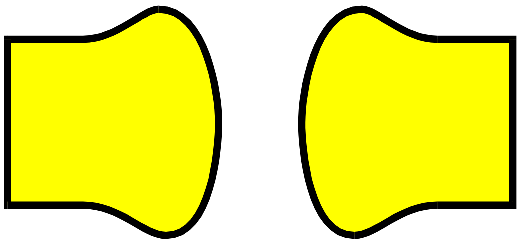


Incline

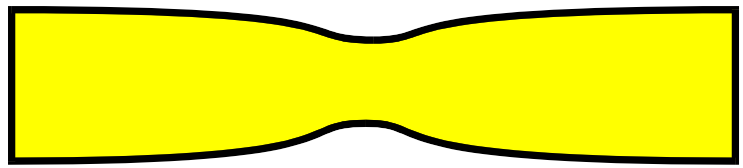


BAD SPLICE EXAMPLES

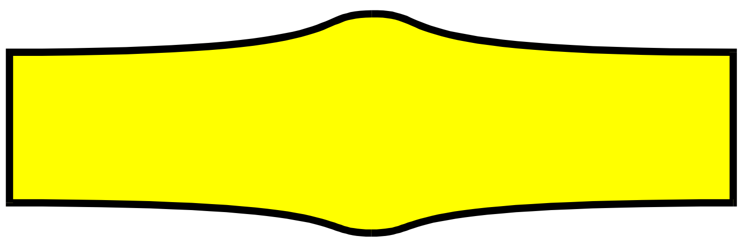
Separation



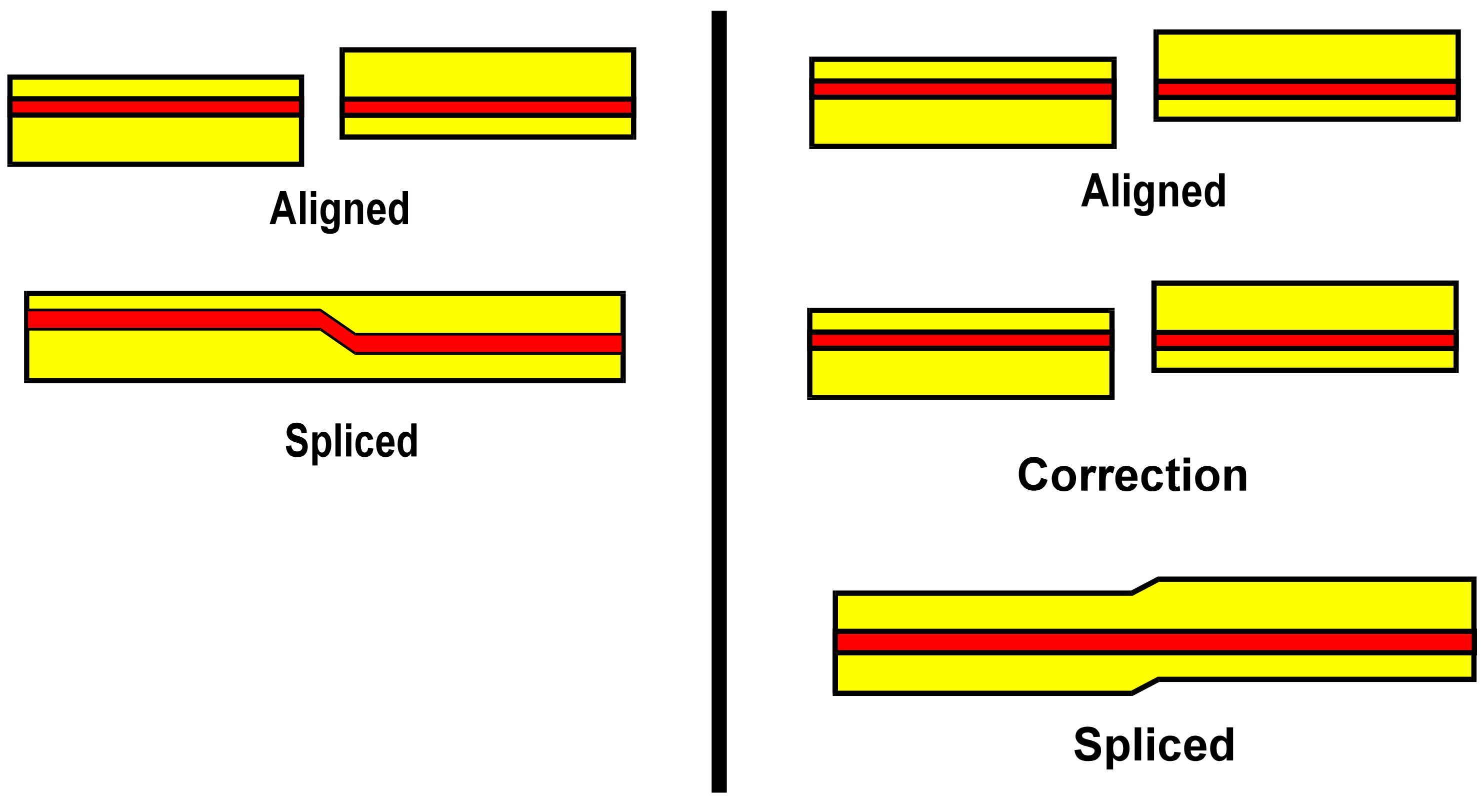
Too thin



Too thick



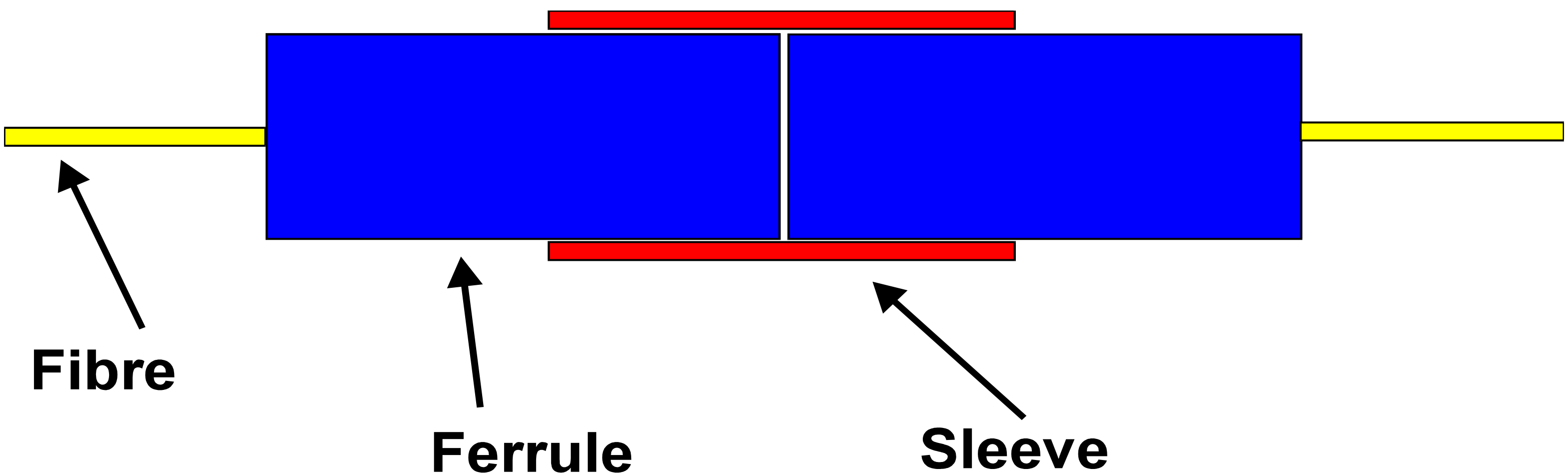
SURFACE TENSION EFFECT



CONNECTOR REQUIREMENTS

- Low loss
  - <0.2dB for T'comms / Long Haul
  - ~0.3-1dB for LANs etc.
  - 1-3dB for v. short / v. cost dominated installations
- Easy Installation
  - Quick to fit, easy to learn how
- Repeatability
- Consistency
- Economical

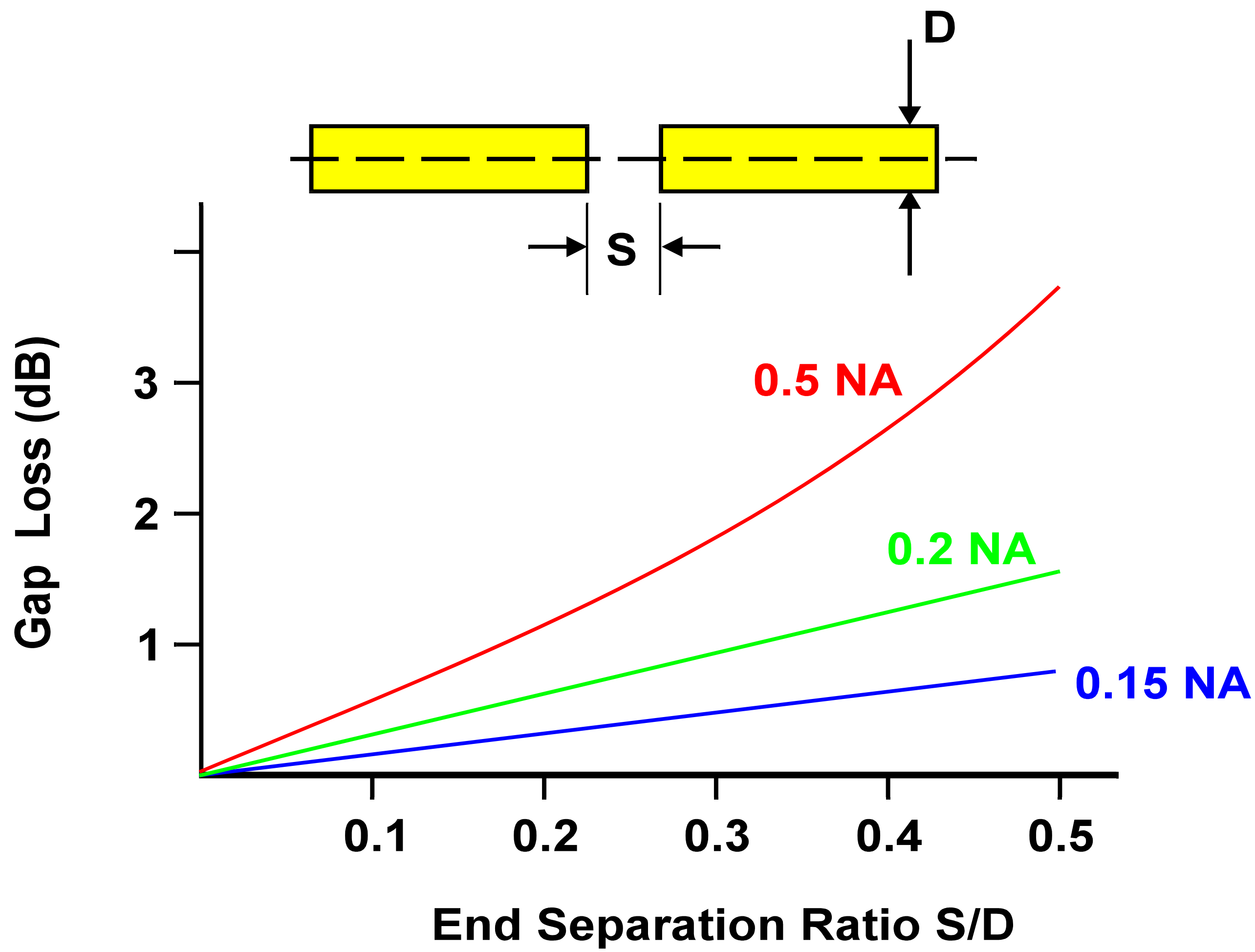
BASIC CONNECTOR



CAUSES OF LOSS AT A JOINT

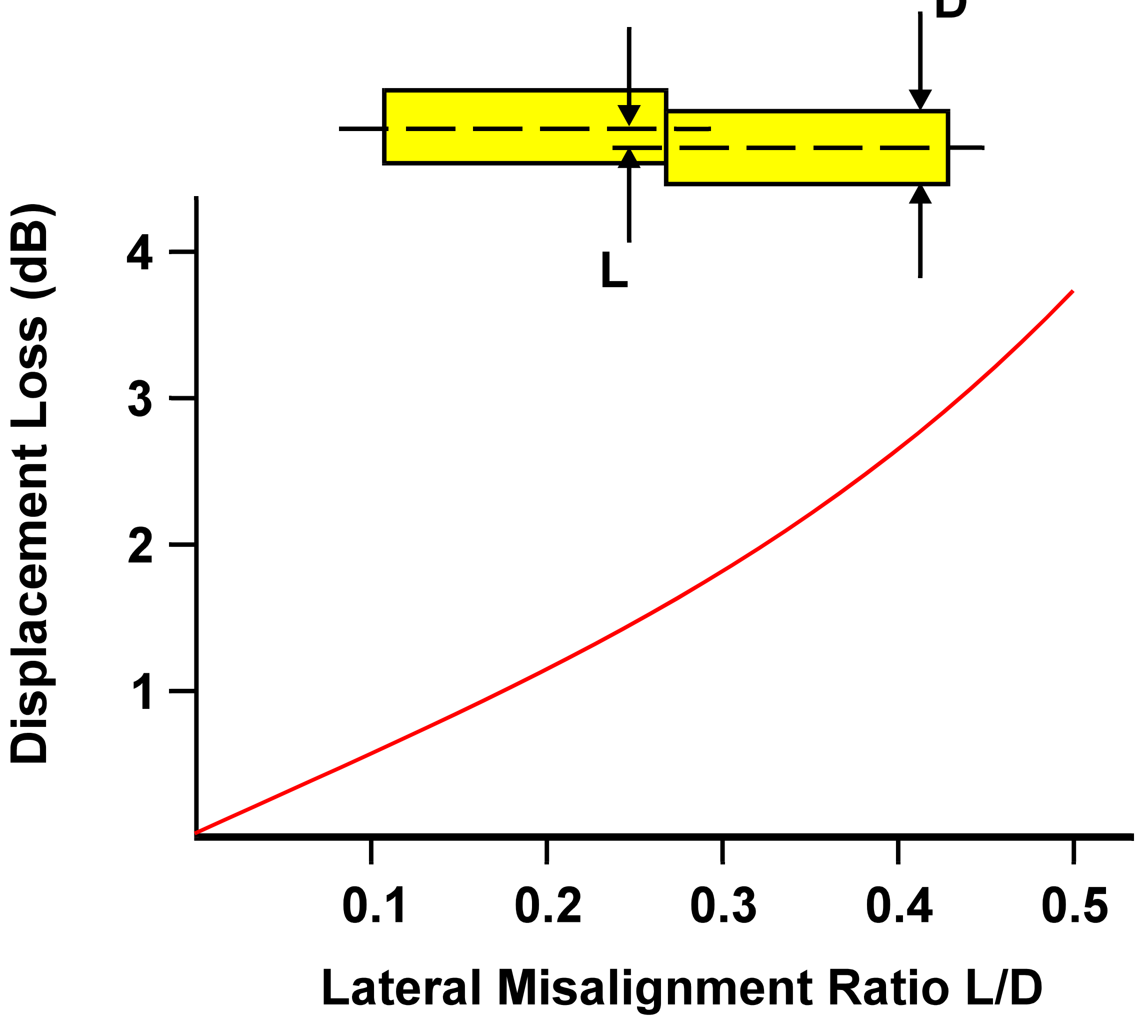
- **Fibre Mismatch**
  - **Core Diameter**
  - **Cladding Diameter**
  - **NA**
  - **Concentricity**
  - **Ellipticity**
  - **Mode Field Diameter (Spot Size) (Singlemode)**
- **Non-Perfect Cleave/Fibre End Surface**
- **Fibre End Separation (Air Gap)**
- **Lateral Displacement**
- **Angular Misalignment**
- **Mode Distribution (Multimode)**

SEPARATION

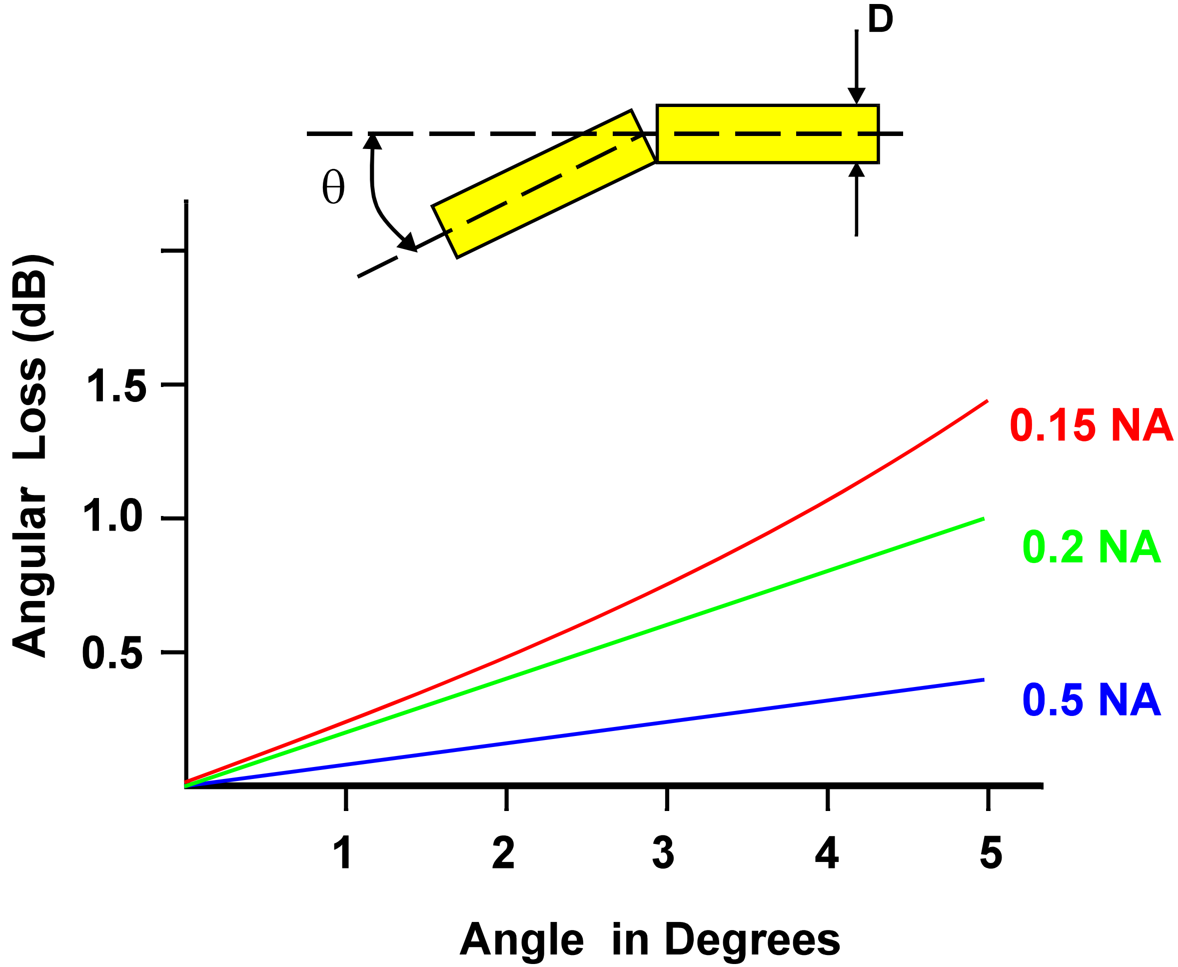


D
S
Gap Loss (dB)
3
2
1
0.5 NA
0.2 NA
0.15 NA
0.1
0.2
0.3
0.4
0.5
End Separation Ratio S/D

LATERAL


D
L
Displacement Loss (dB)
4
3
2
1
0.1
0.2
0.3
0.4
0.5
Lateral Misalignment Ratio L/D

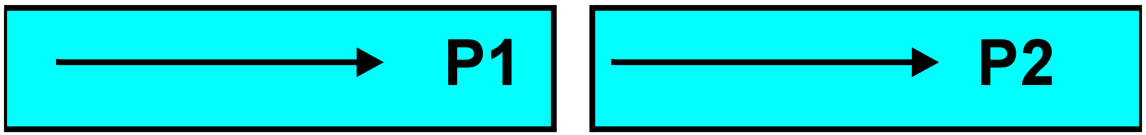
ANGULAR



D
θ
Angular Loss (dB)
1.5
1.0
0.5
0.15 NA
0.2 NA
0.5 NA
1
2
3
4
5
Angle in Degrees

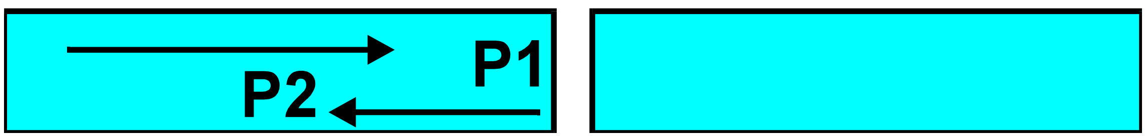
RETURN LOSS / INSERTION LOSS

Insertion Loss



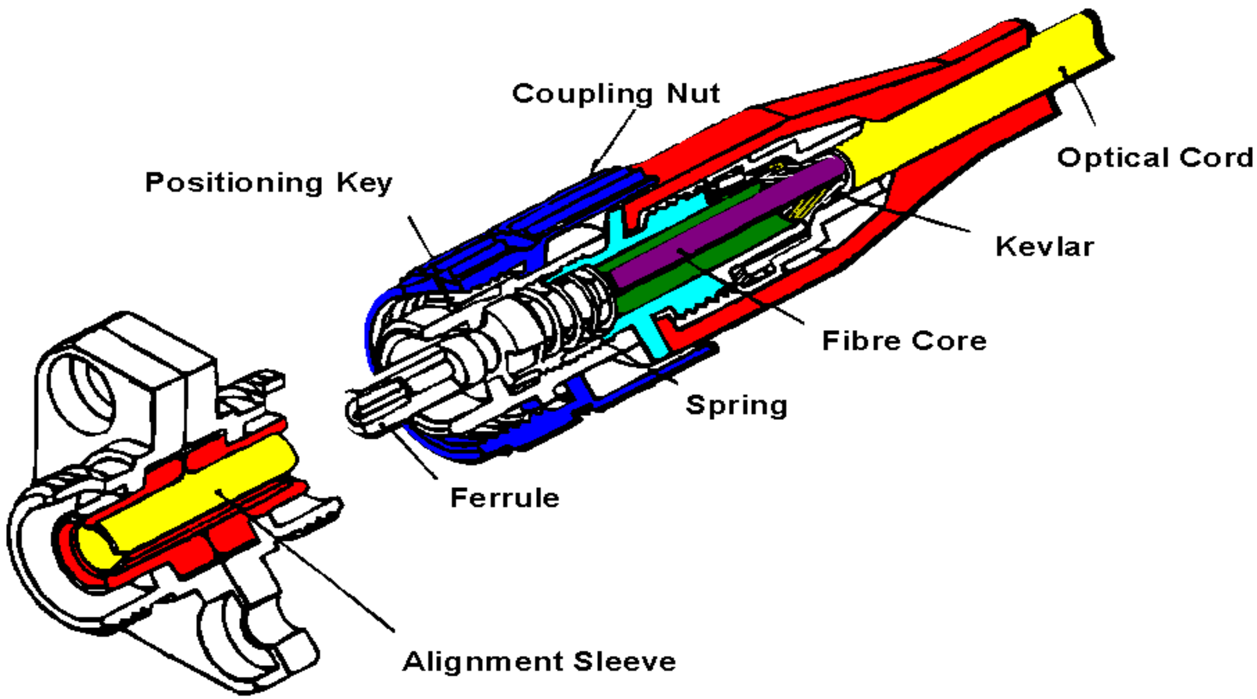
P1-P2 (dB)

Return Loss



P1-P2 (dB)

FC CONNECTOR



Seiko Instruments

OTHER CONNECTORS

- **Diamond E2000**
- **SC**
- **DIN**
- **D4**
- **ST**
- **MT/MPO**
- **SMA**
  - **905, 906**
- **FDDI**

LC

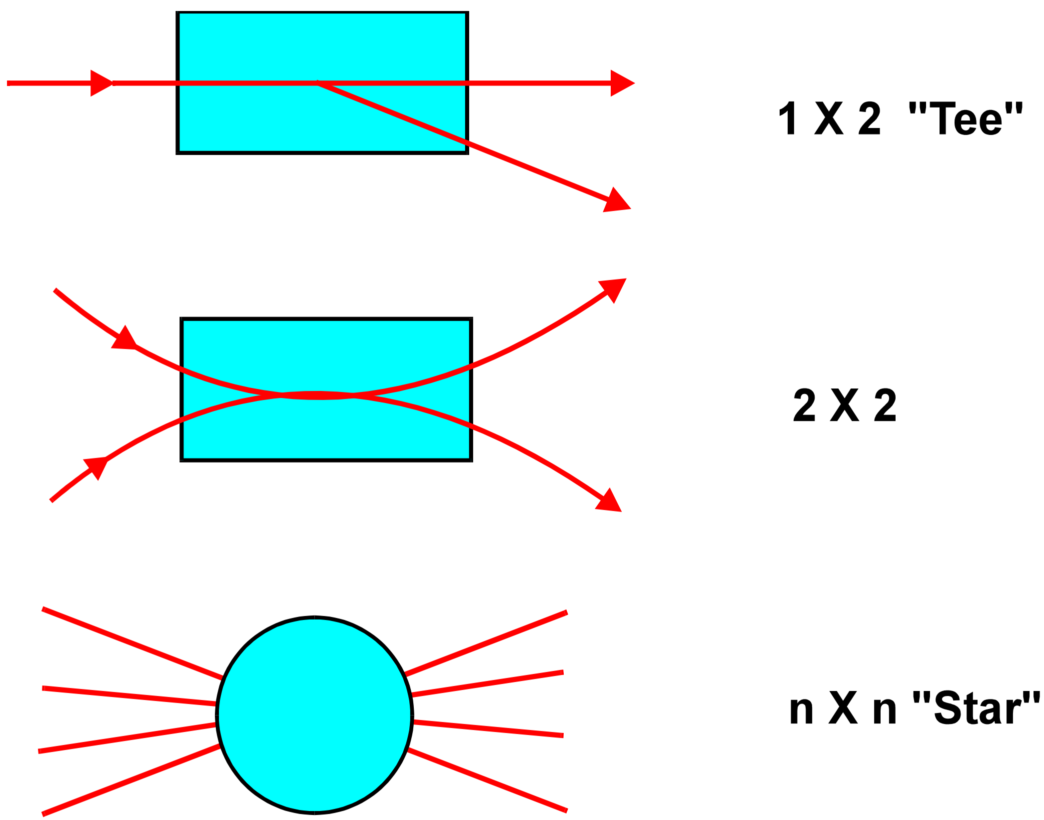
MU

MTRJ

Angular Versions (8°)

SPLITTERS & COUPLERS

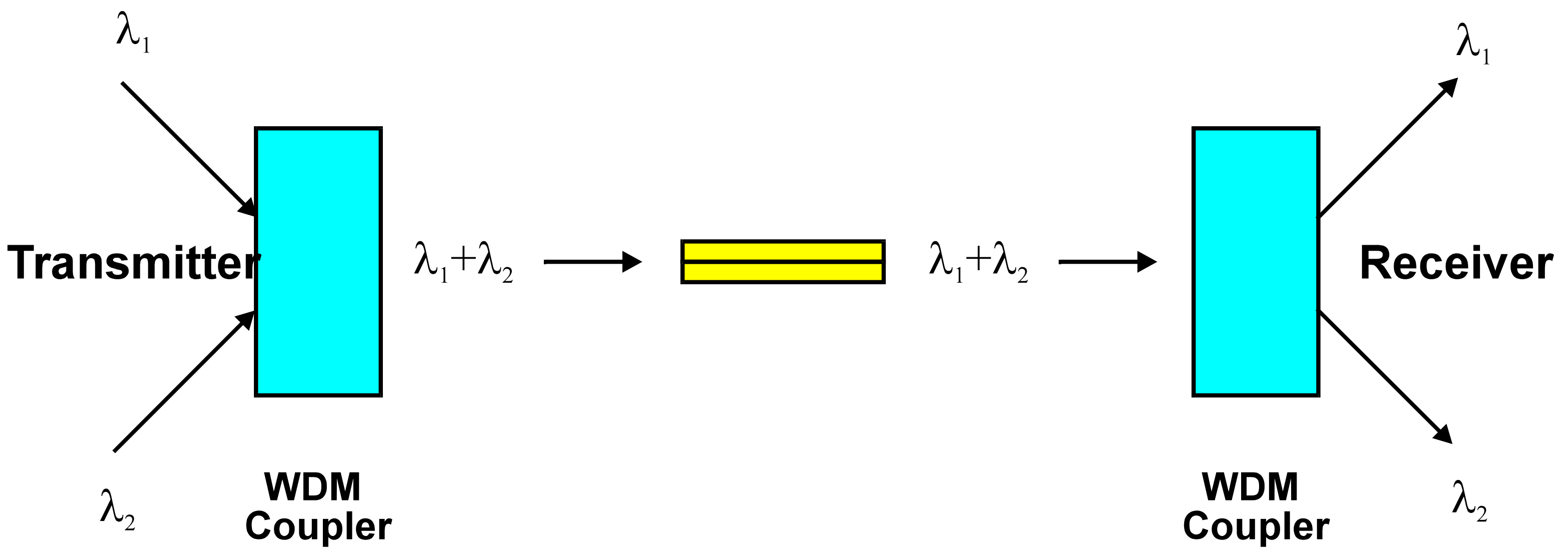
- **Combine and Split the Light Paths, enabling Point to Multi-Point Transmission**



WAVELENGTH DIVISION MULTIPLEXING & DEMULTIPLEXING

- **Different wavelengths in the same fibre do not interfere, so if they can be separated at the receiver end, capacity can be increased**
- **Separation achieved by:**
  - **Diffraction Gratings**
  - **Interference Filters**
  - **External Mirrors (CSR technology)**

WDM

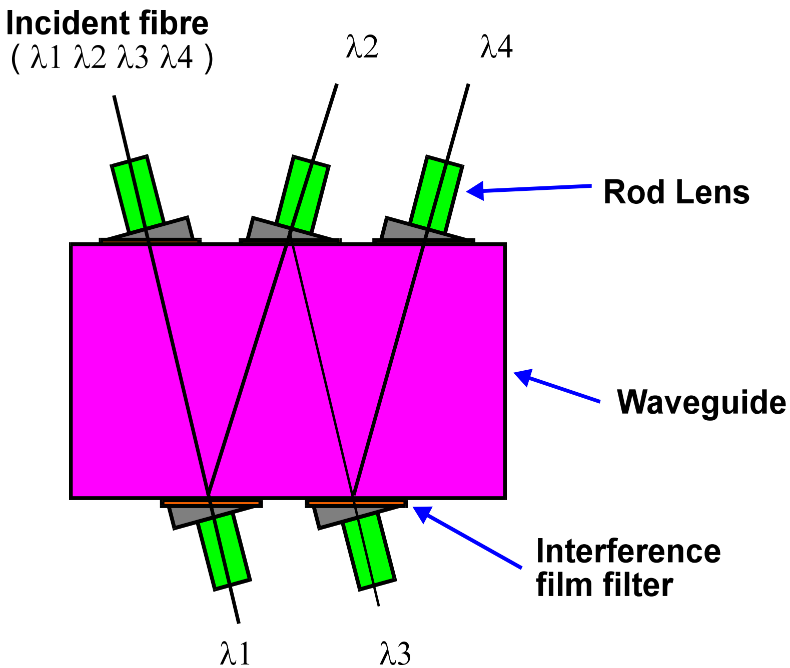


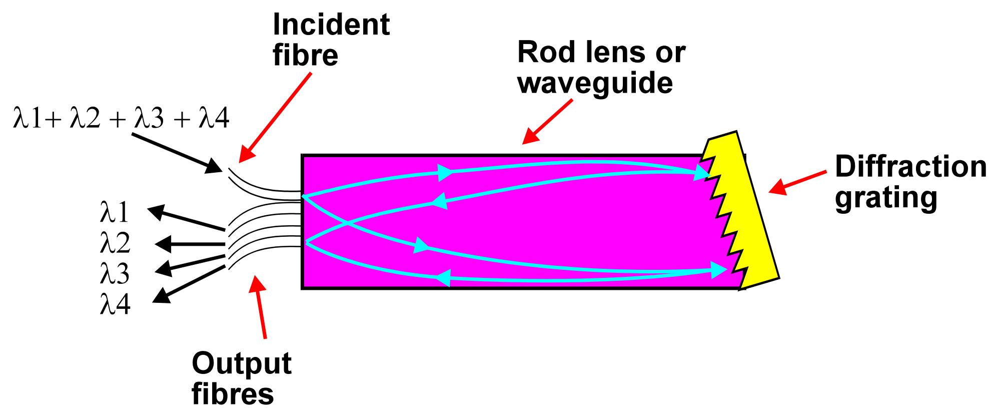
Coarse WDM : 1310/1550/1625nm

Dense WDM : Grid standarized by ITU, Channel spacing 100GHz and 50GHz

50GHz spacing $\Delta\lambda\sim0{,}4$nm at 1550nm

DEMULTIPLEXER EXAMPLES





OPTICAL FIBRE COMMUNICATIONS & MEASUREMENTS SEMINAR

Part 2: Introduction to Measurements

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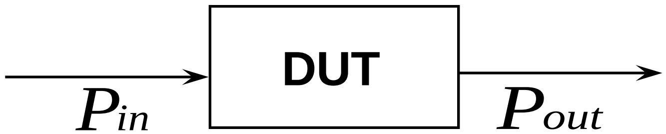
OPTICAL POWER

- **Relative**
  - **(%), usually dB**
  - **Requires good linearity**
- **Absolute**
  - **mW, μW, dBm (Relative to 1mW)**
  - **Requires good accuracy & traceability**

THE OPTICAL dB

- **Relative unit**

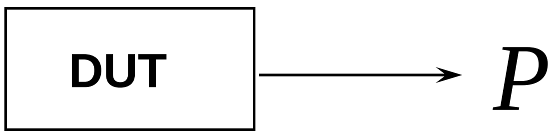


$$\mathrm{dB} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

-3dB = 50% power lost
-10dB = 90% loss, ie. P_{out} **is 10% of** P_{in}
-20dB = 99% loss, ie. P_{out} **is 1% of** P_{in}
-30dB = 99.9% loss, ie. P_{out} **is 0.1% of** P_{in}

The dBm

- **Absolute power - expressed relative to 1mW**



$$\mathrm{dBm} = 10\log_{10}\left(\frac{P}{1mW}\right)$$

+10dBm = 10mW	**-13dBm = 50µW**
0dBm = 1mW	**-20dBm = 10µW**
-3dBm = 500µW	**-30dBm = 1µW**
-10dBm = 100µW	**-60dBm = 1nW**

WAVELENGTH

$$\boxed{\lambda = \frac{c}{f}}$$

- **Absolute**
  - **Centre/RMS Wavelength**
    - **System Source Wavelength**
    - **Test Equipment Wavelength**
- **Relative**
  - **Spectral Widths (FWHM)**
    - **System Source**
    - **Test Equipment**

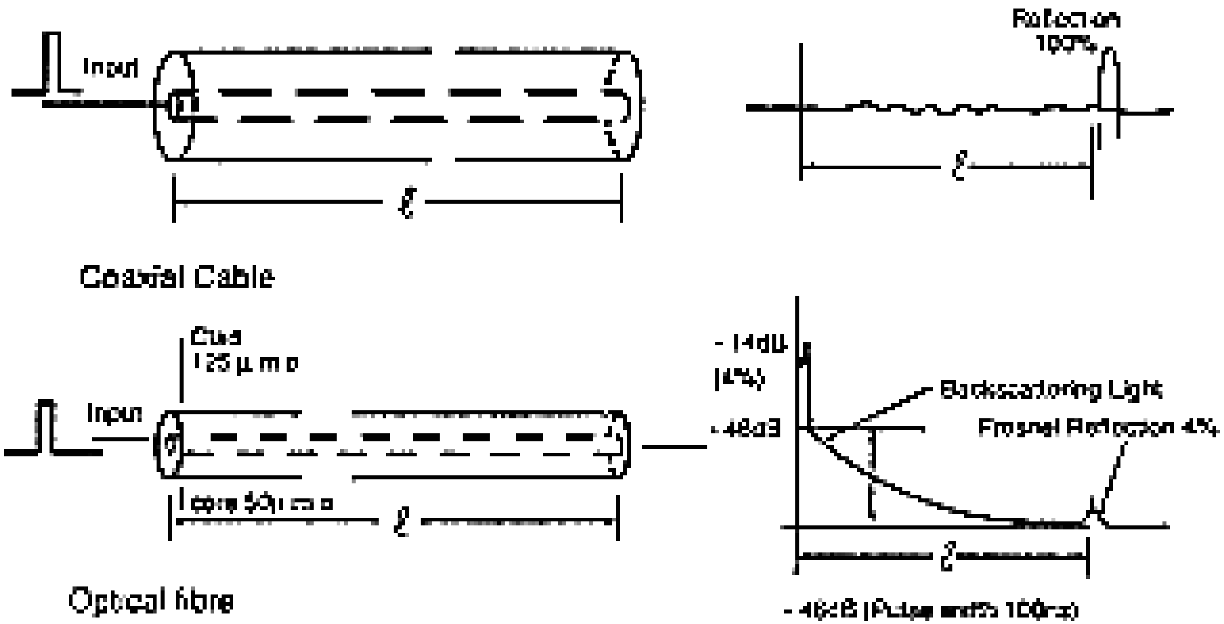
STANDARDS

- **Optical Power (Absolute)**
  - **NPL, National Standards**
  - **Transfer Optical Power Meter to NAMAS Accredited Calibration Site**
  - **NAMAS Lab calibrates users' Working Standards/Field Power Meters**
- **Wavelength**
  - **Gas Discharge Tubes, Physical Constants**
    - **Ar, Kr, Ne, Hg, He-Ne**
    - **Emit Spectral Lines across a Range of Wavelengths**

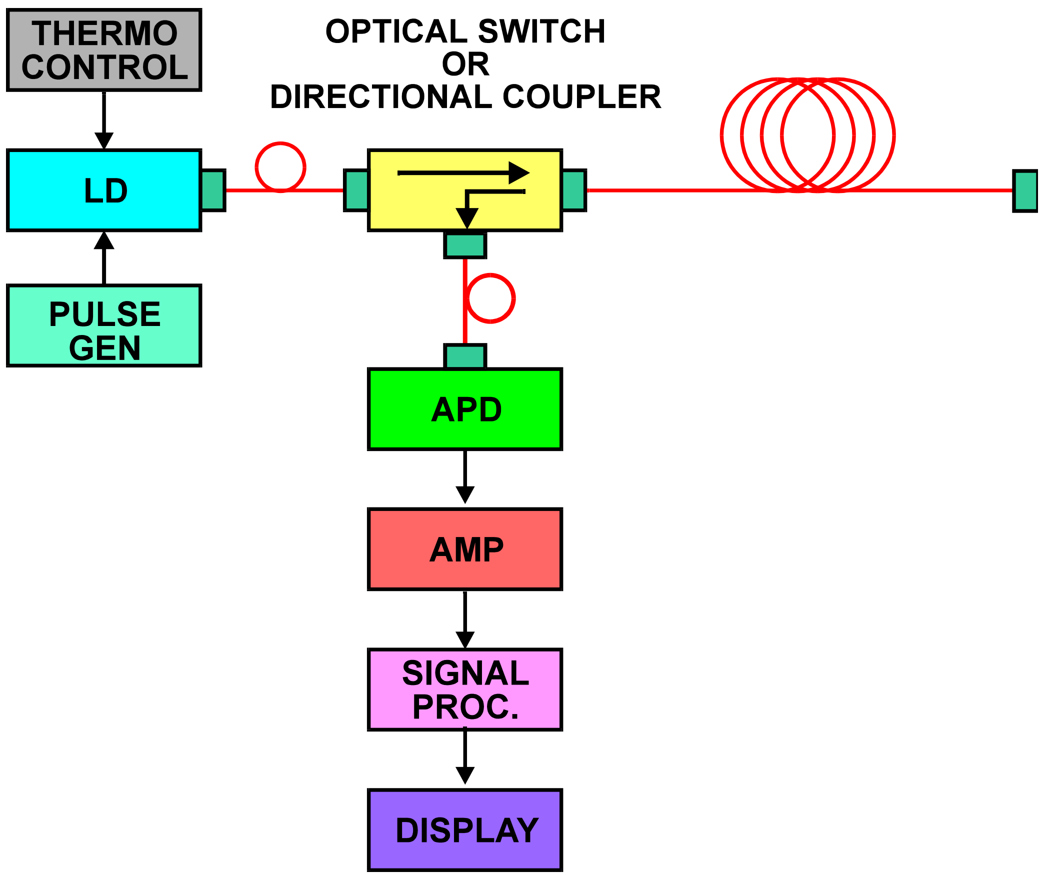
OTDR FUNCTIONS

- **Distance / Length Measurement**
  - **km, m, ft**
- **Fibre Loss Measurement**
  - **dB, dB/km**
- **Connector / Splice Loss Measurement**
  - **dB Loss**
  - **Return Loss**

TDR (Copper) vs OTDR (Fibre)

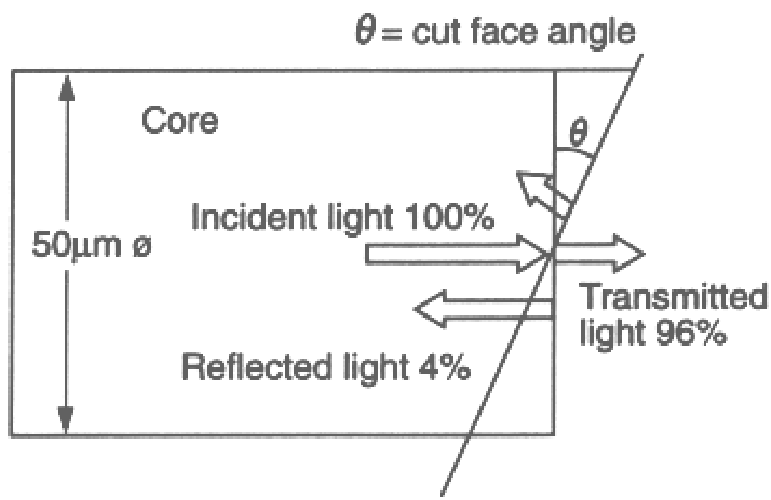


OTDR BLOCK DIAGRAM

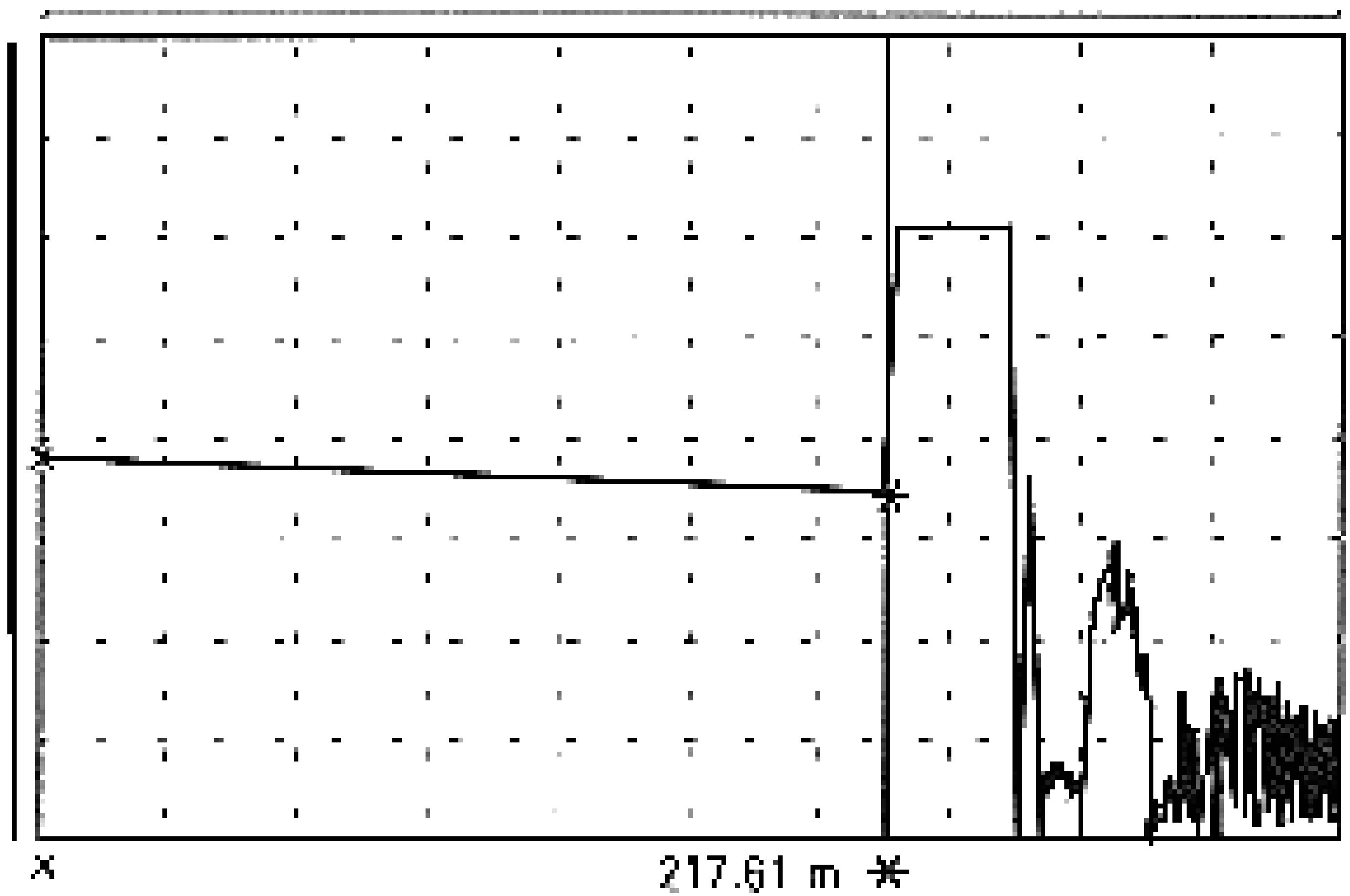


FRESNEL REFLECTION

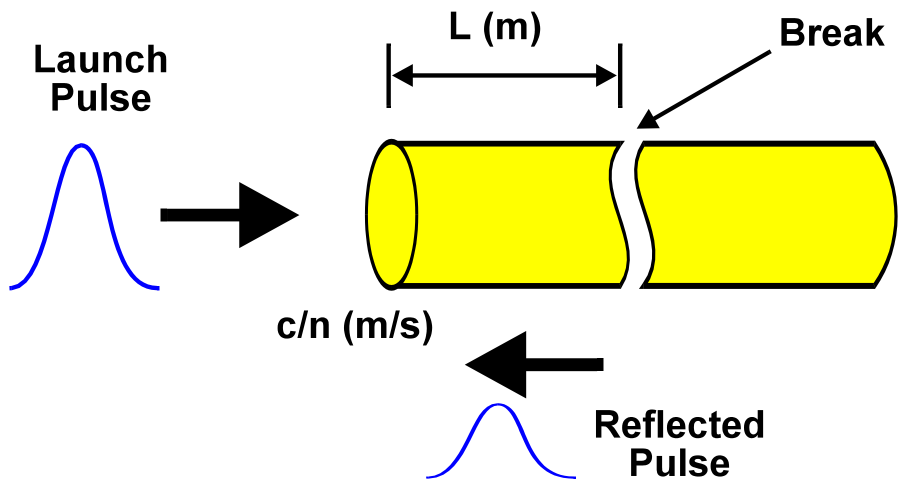
- **Perfectly cleaved fibre / air interface gives 4% (-14dB) reflection (Fresnel Reflection)**
- **If end angle > 5.5º, virtually no Fresnel Reflection occurs at all**



BREAK LOCATION



DISTANCE MEASUREMENT BY OTDR



$$2 \times L = c/n \times T \text{ (s)}$$

$$L = c/n \times T/2 \text{ (m)}$$

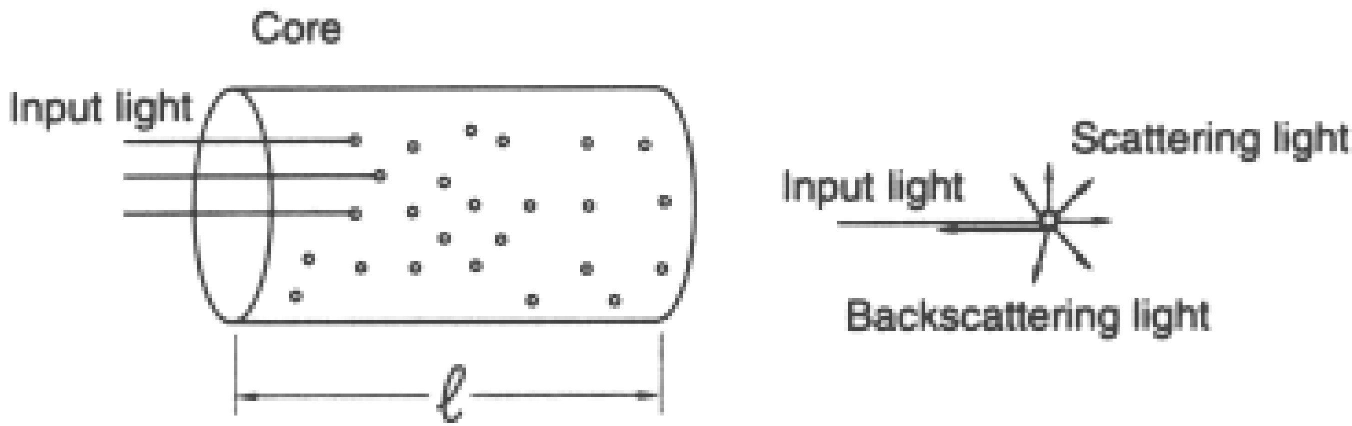
n: Effective index of refraction : IOR

c: Velocity of light in a vacuum

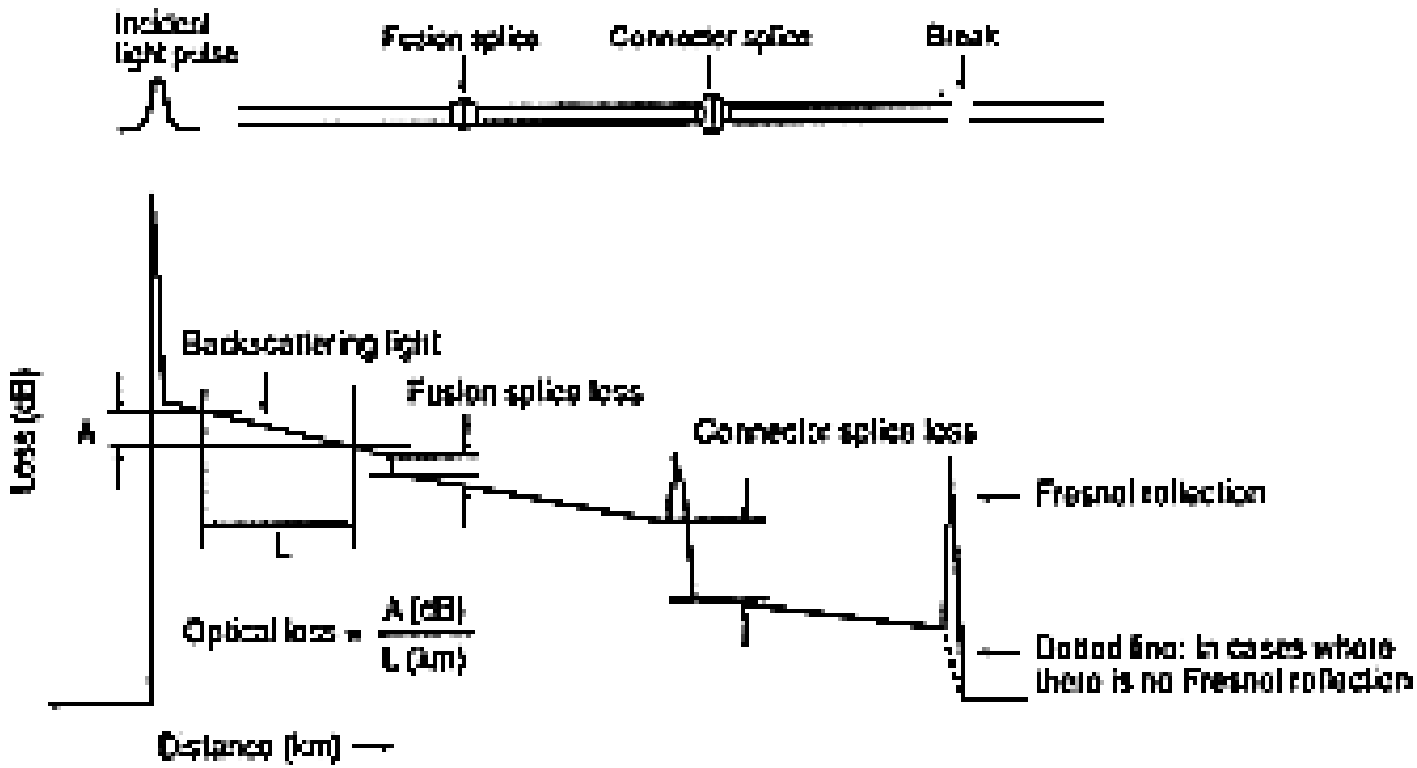
EFFECTIVE REFRACTIVE INDEX

Fibre Type	EIOR @ 850nm	EIOR @ 1300nm	EIOR @ 1550nm
SMF-21		1.468	1.468
SMF-28		1.470	1.470
SMF-D2		1.476	1.476
50/125	1.4837	1.4856	
62.5/125	1.5014	1.4966	
100/140	1.5080	1.5016	

BACKSCATTER

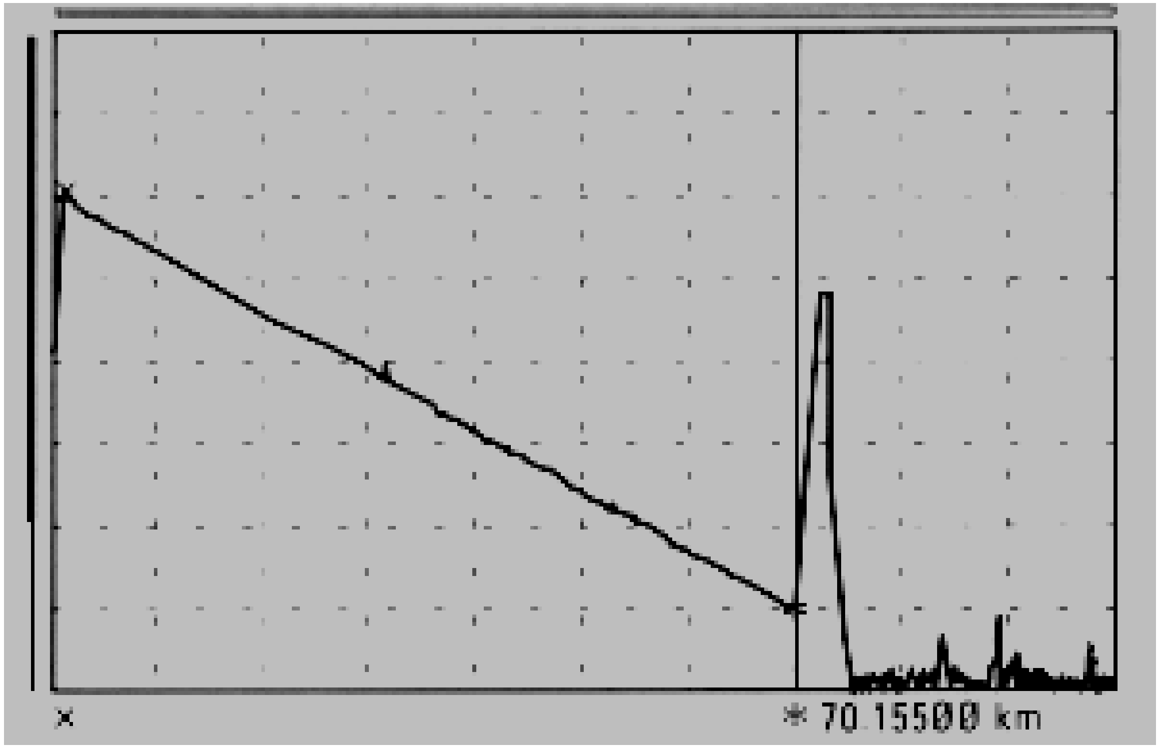


TYPICAL OTDR TRACE



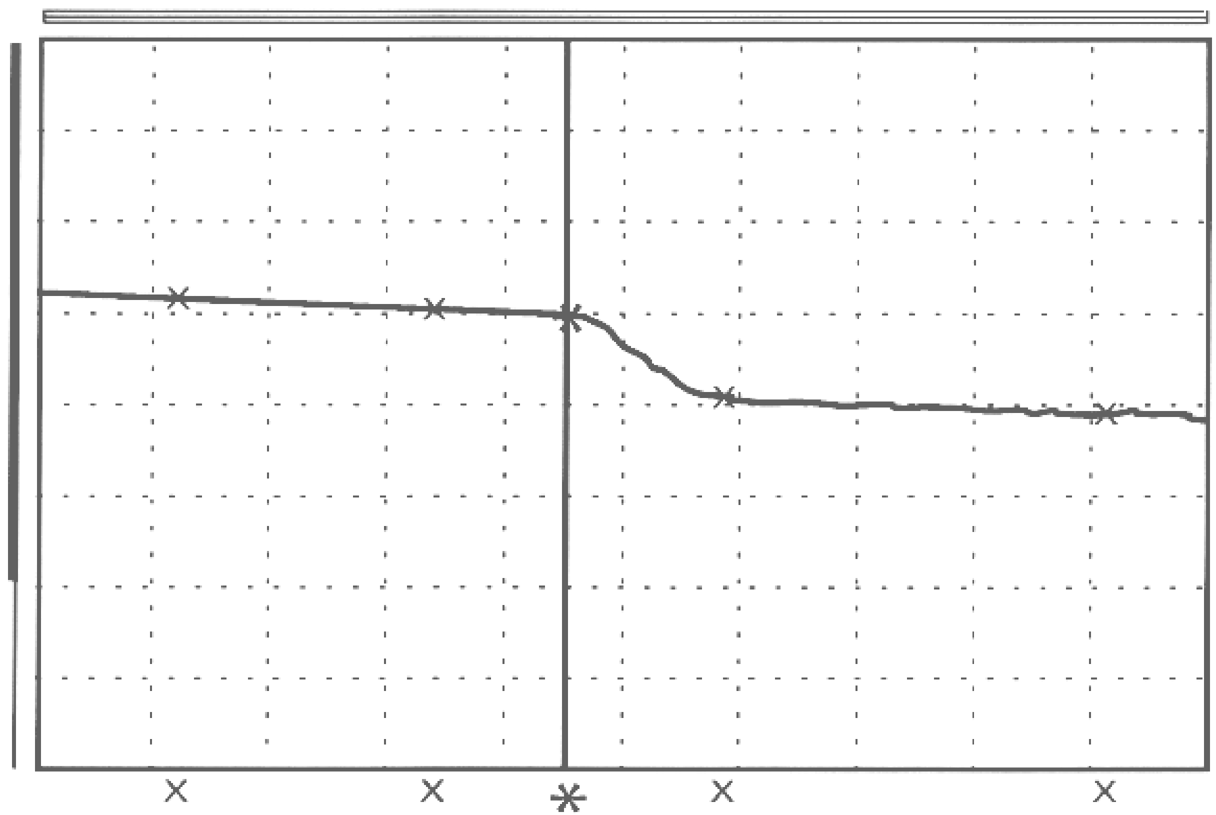
FIBRE LOSS

- **2PA = Two Point Approximation**
- **LSA = Least Squares Approximation**

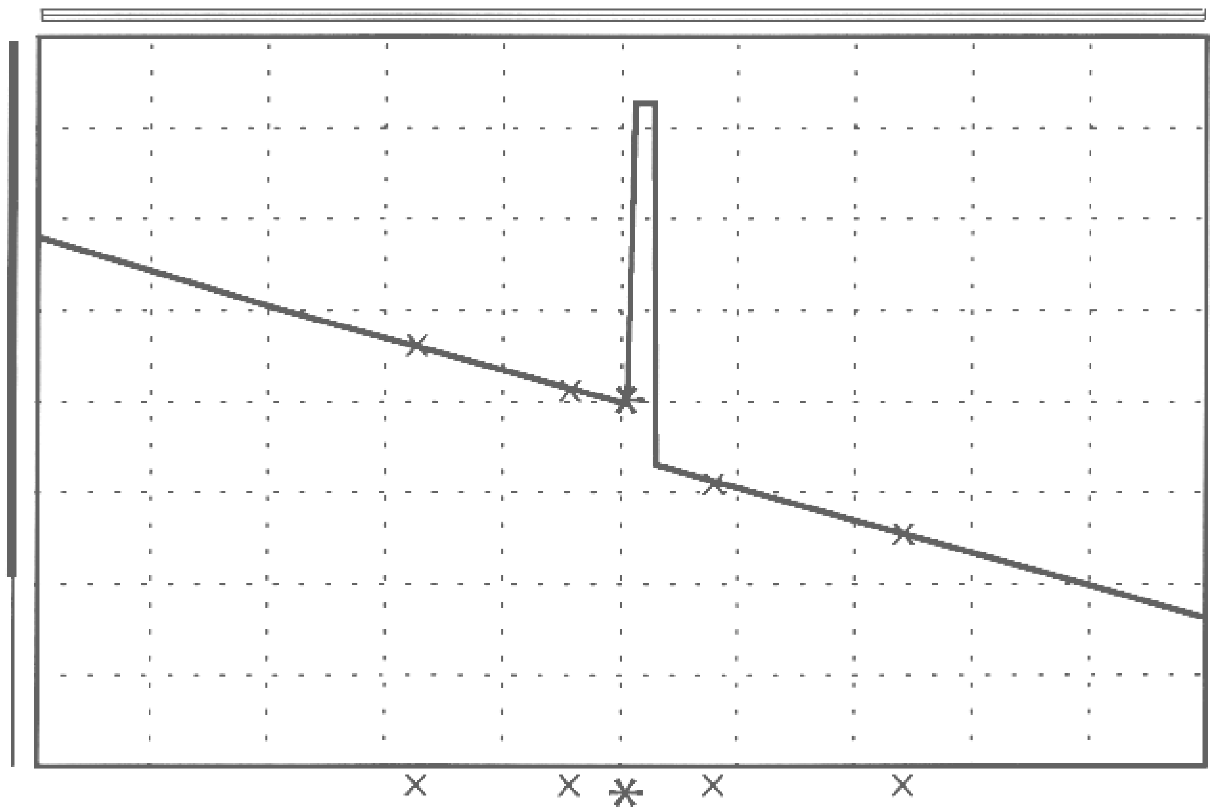


SPLICE LOSS

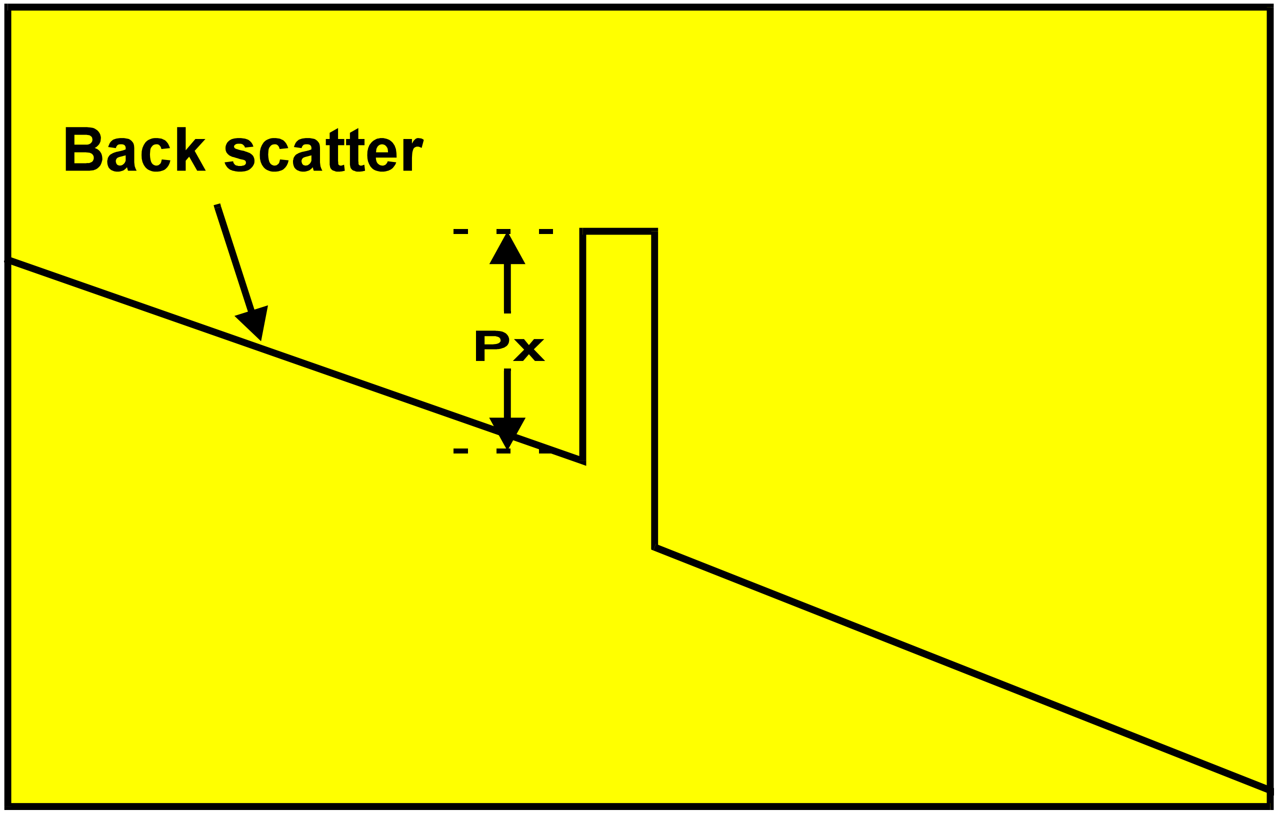
- **2PA = Two Point Approximation**
- **LSA = Least Squares Approximation**



CONNECTOR LOSS



RETURN LOSS



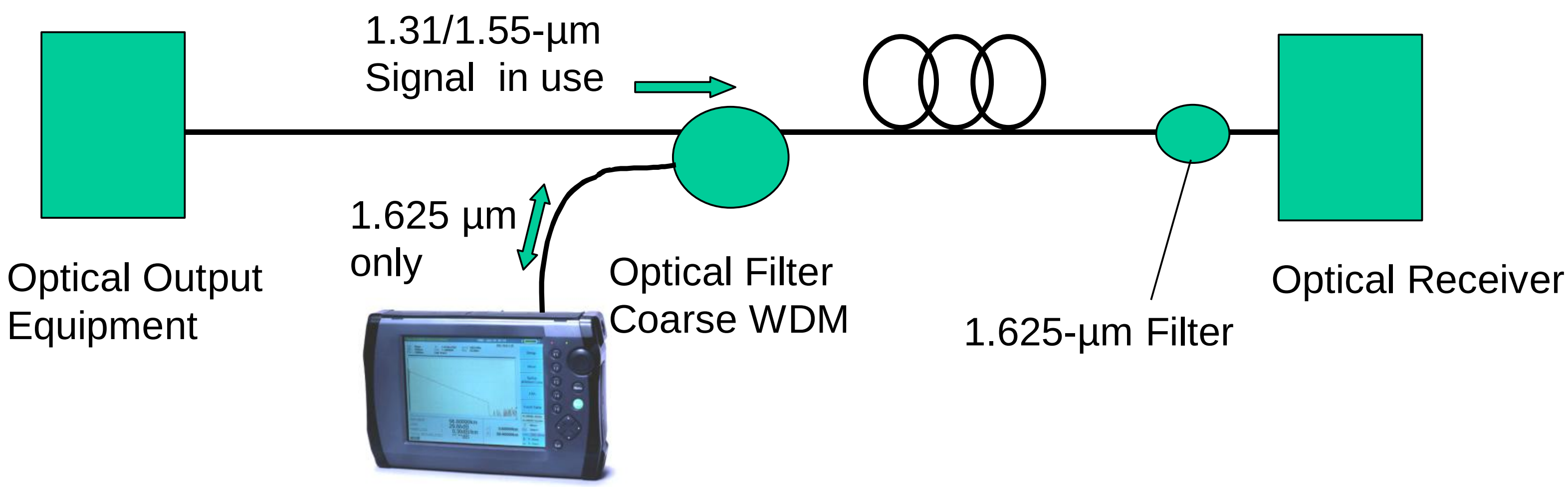
Maintenance

Requirement

• Active circuit monitoring and maintenance

Required Instrument

In addition to 1.31/1.55 µm, the MW9076C has the 1.625-µm wavelength, which is useful for measuring active circuits.



To measure circuits in use, the OTDR signal requires control using an optical filter, etc., so that it does not have any effect on the signal in use.

OTDR TERMINOLOGY(1/4)

- Fresnel Reflection
- Rayleigh Backscatter
- Plug-ins, Fibre Type
- Laser Wavelength
- Dynamic Range Definitions
- Distance Range ($\neq$Measurement Range)
- Pulse Widths
- Resolution
  - Read out, Horizontal + Vertical
  - Spatial, Reflective
  - Spatial, Non-Reflective

OTDR TERMINOLOGY(2/4)

- **LSA/2PA; What difference does it make?**
- **Accuracy / Linearity**
- **Calibration**
- **IOR/EIOR**
- **Dead Zone**
- **Dead Zone Loss Extrapolation**
- **Sampling Rate**
- **Display Data / Measurement Data**
- **Masks**
  - **Variable Width, Near End Mask**

OTDR TERMINOLOGY(3/4)

- **Ghosts**
- **Noise and Averaging**
- **Smoothing**
- **Splice Gains and Two-Way Measurements**
- **Receiver Saturation**
- **Manual / Auto Attenuation**
- **“Full Trace” Display**
- **Laser Output Power Variation**
- **Launch Level**

OTDR TERMINOLOGY(4/4)

- **Trace Comparison**
- **Event Tables, Splice Thresholds and Auto Search**
- **Procedure / “Macro” Functions**
- **Macro/Micro Bends**
- **Data Storage Media**
- **Emulation Software**

RETURN LOSS

- **Typical Figures (Approx.)**
  - **Perfect (90º)Cleave ,Glass/Air Interface..-14dB**
  - **SMA Connector (Mated pair)..................-12dB**
  - **ST Connector (")...........-12~-35dB (-65dB, Angled, SM)**
  - **FC Connector (")....................-14dB**
  - **PC Connector (").............-25~-35dB**
  - **SPC Connector (").............-40~-45dB**
  - **UPC Connector (").............-50~-55dB**
  - **APC Connector (")....................-65dB**
- **Higher value figure = Lower reflectance loss = Better connector**

IMPORTANCE OF RETURN LOSS

-Effects of Excess Reflection (1/2)

- **Transmitter**
  - **Laser Mode Hopping**
  - **Laser Output Power Fluctuations**
  - **Increase in Laser Linewidth (Spectral Width)**
  - **Degraded Freqency Response**
- **Receiver**
  - **Multiple Path Interference (MPI)**
    - **Multiple reflections add to the original signal , effectively increasing the noise**

IMPORTANCE OF RETURN LOSS

-Effects of Excess Reflection (2/2)

- **System**
  - **Erratic System Performance**
  - **Increased BER in High Speed Digital Signals**
  - **Degraded SNR in High Bandwidth Analogue Systems**
  - **Distortion in Analogue Systems caused by Non-Linearity**

IMPORTANCE OF RETURN LOSS

-Effects Depend Upon:

- **Magnitude of Individual Reflections**
- **Source Wavelength**
- **Source Coherence Length**
- **Distance between Reflections**
  - **If separation > source coherence length then the return loss will be constant**

BANDWIDTH-LENGTH PRODUCT

- **Multimode Fibres**
- **'Figure of Merit' eg. 600MHz.km**
  - ***NOT* per km**
  - **BW x Length =< 600**
  - **ie. 600MHz signal can be transmitted for 1km**
  - **Lower freqency can go further,or**
  - **Higher frequency over shorter distance**

CHROMATIC DISPERSION

- **Unit = ps/nm/km or ps/nm.km (equivalent)**
- **ie. propagation time difference for each nm of source spectral width per fibre km**
- **Approximate Bandwidth is given by**

$$BW = \frac{0.187}{(Disp)(S.Width)(Length)}$$

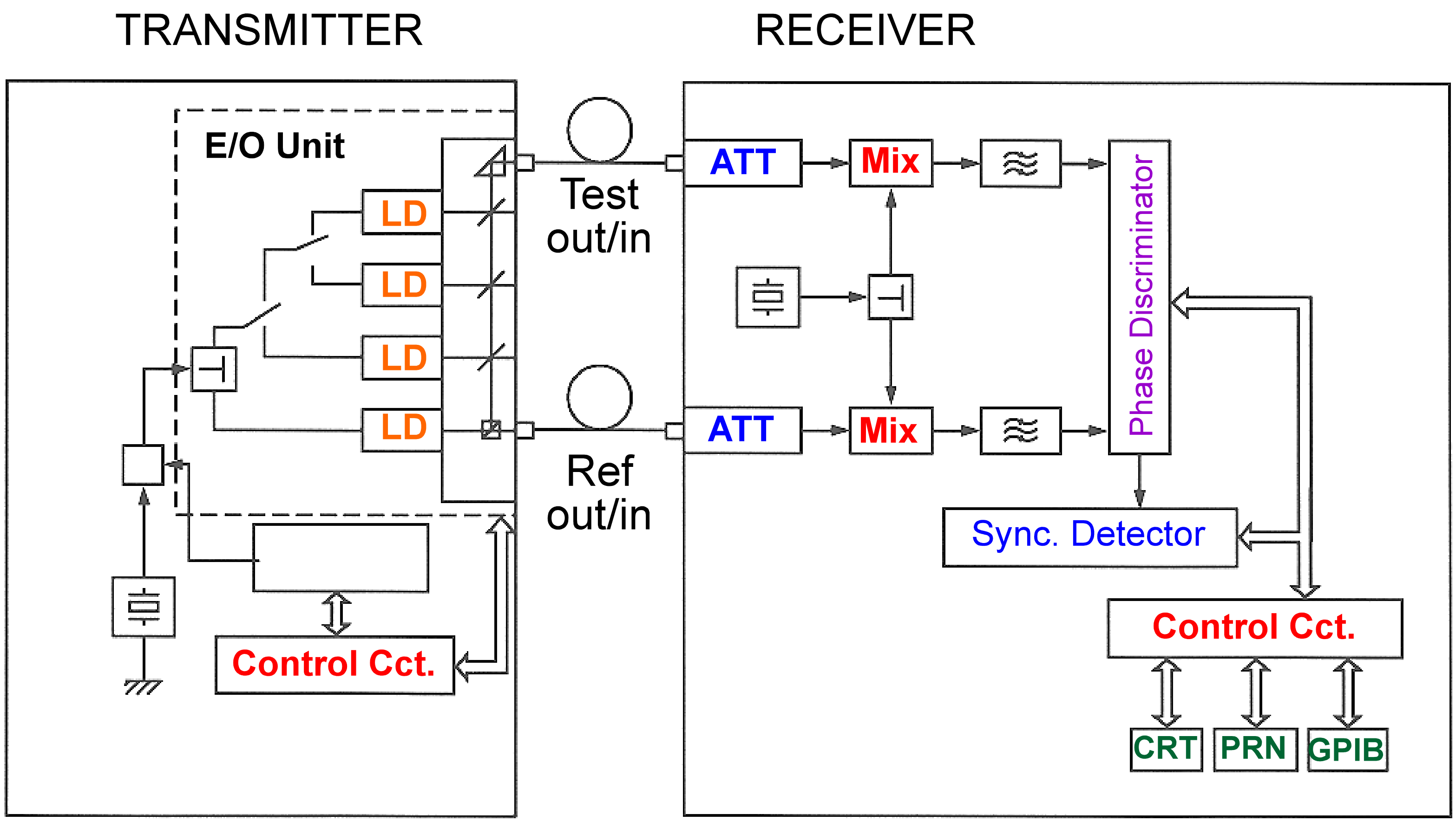
with Dispersion in seconds/nm/km,

Spec Width in nm, Length in km

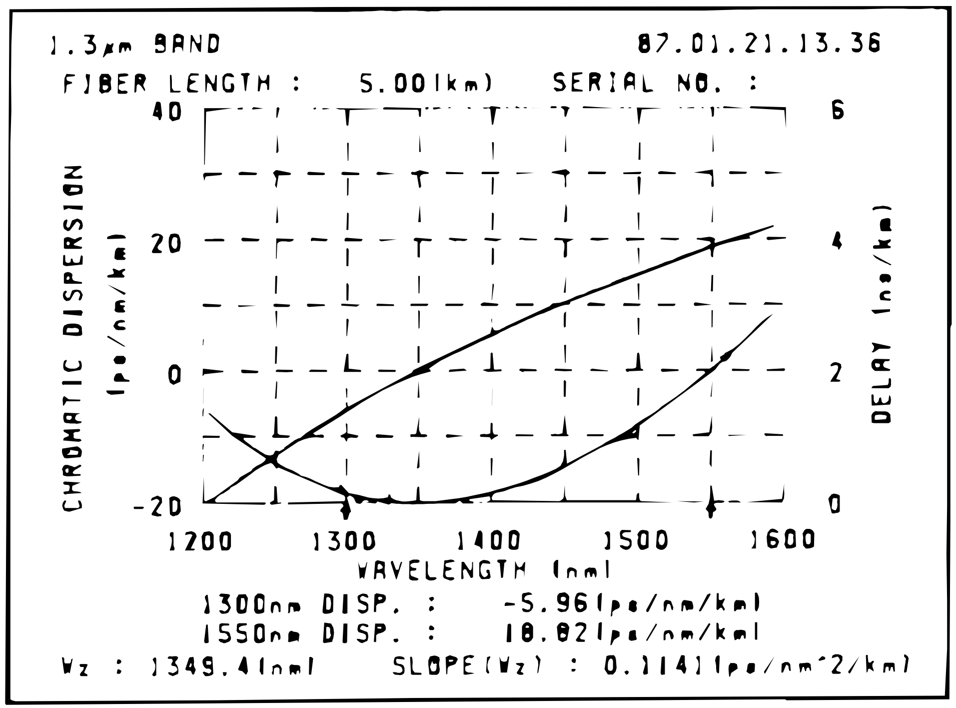
CHROMATIC DISPERSION Measurement (1/4)

- **Methods**
  - **Fibre Raman Laser + Spectroscope , Measure Delay and Differentiate**
  - **Multiple LEDS, Baseband Phase Comparison**
  - **Multiple LDs, Baseband Phase Comparison**
  - **Interference Method**

CHROMATIC DISPERSION Measurement (2/4)

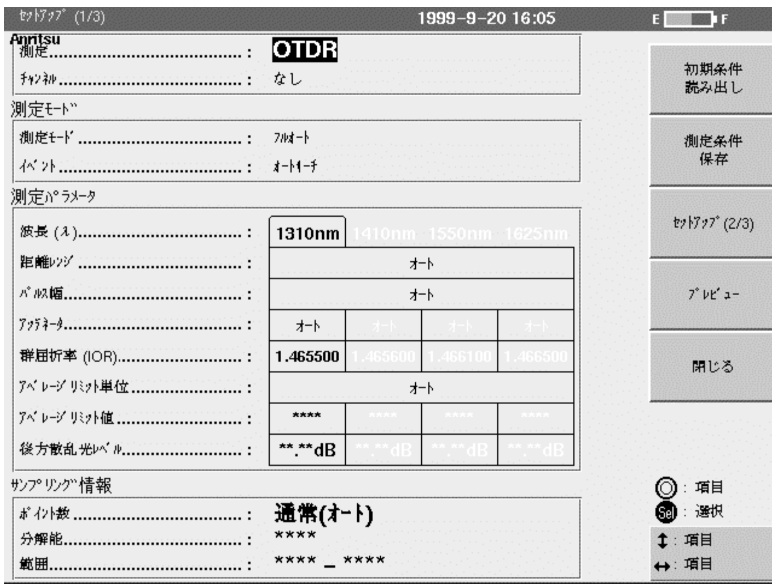


CHROMATIC DISPERSION Measurement (4/4)

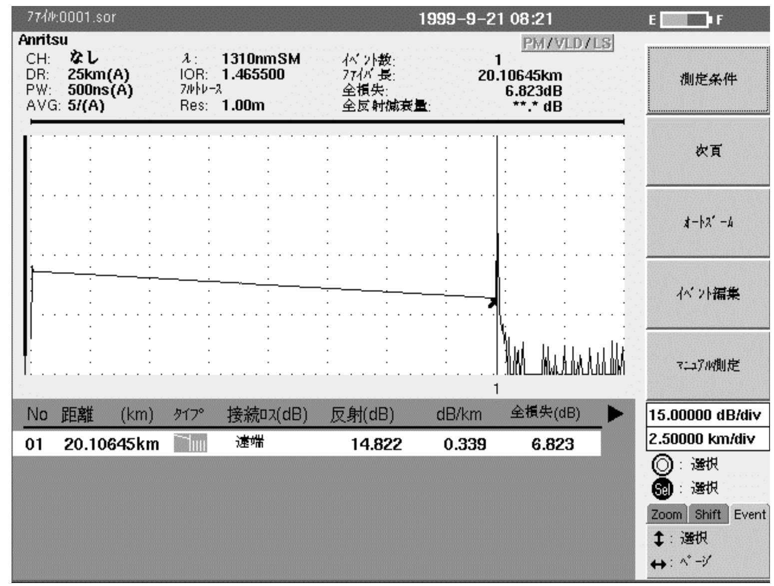


CD measurement procedure

1. Measurement in OTDR mode (Full Auto)
   to find the fiber length (I.e. DR)



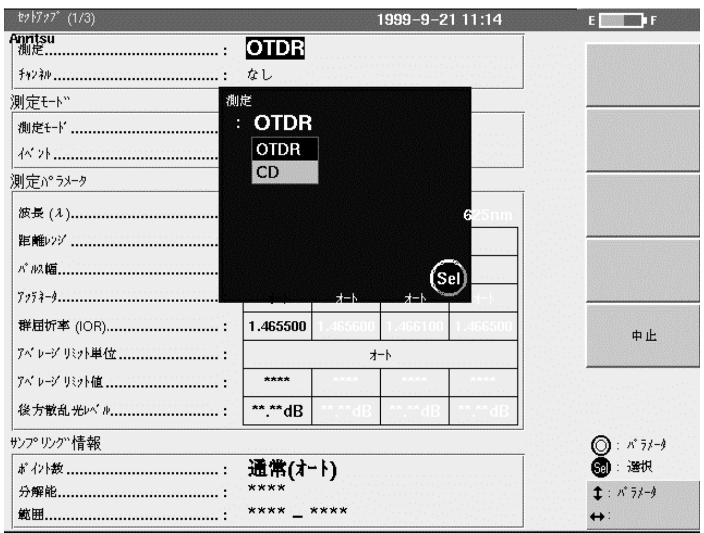
Set-up screen



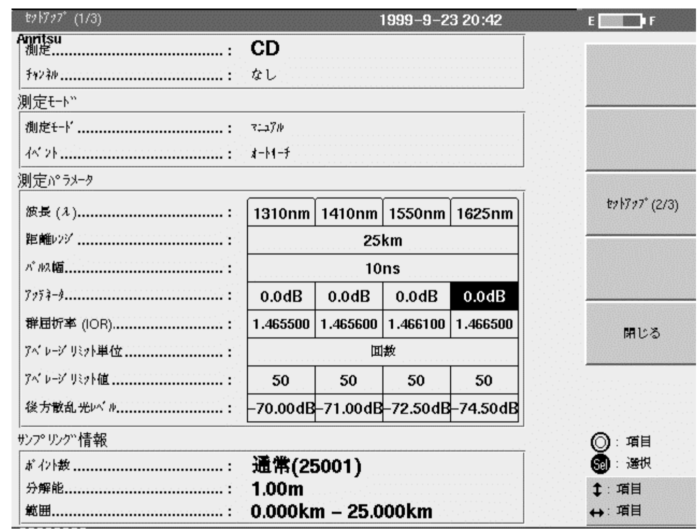
Measurement screen

2. Measurement in CD mode

Change the mode to CD, and set the DR to the appropriate value and PW to 10ns, ATT to 0dB. Then press Start key. Or use full Auto Mode (Firmw.3.1)



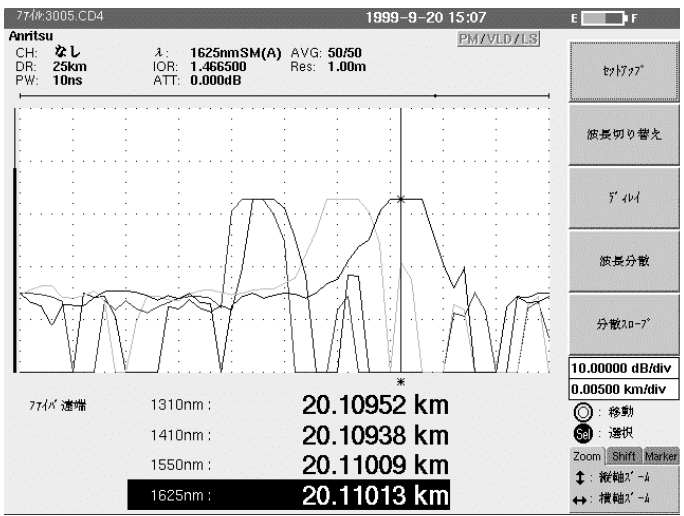
Change the mode to CD



Set-up screen

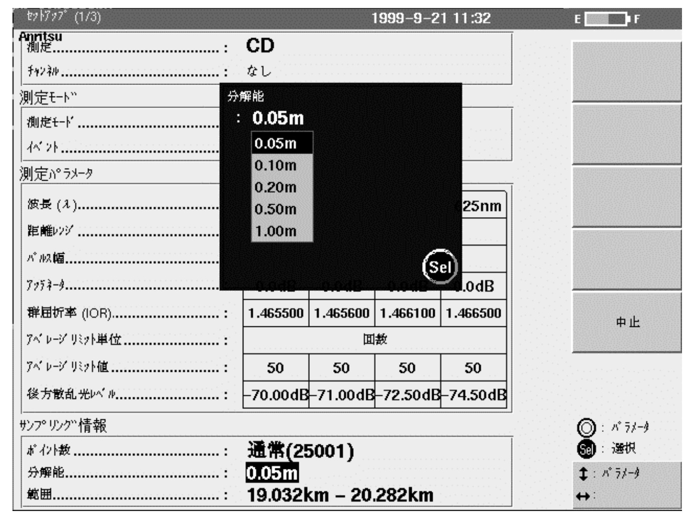
Note: In full Auto Mode all is done automatically !!!

3. H-Zoom arround the end reflection



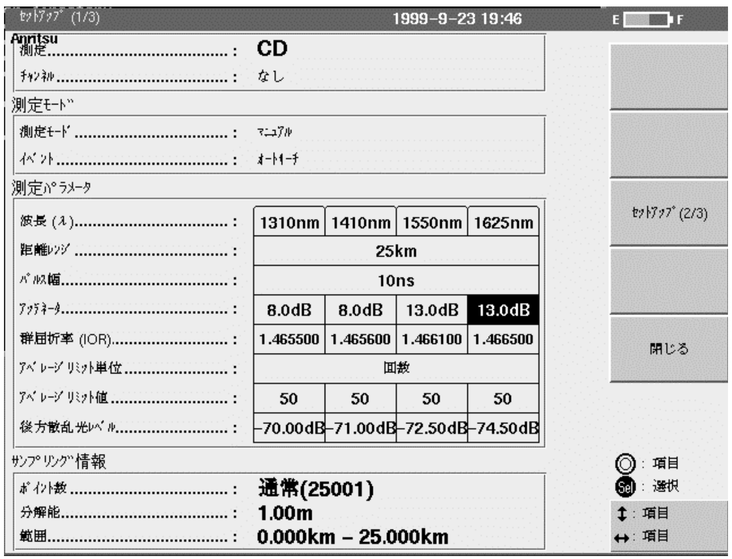
H-zoom

4. Return to set-up screen And set the resolution to 0.05m then press start key

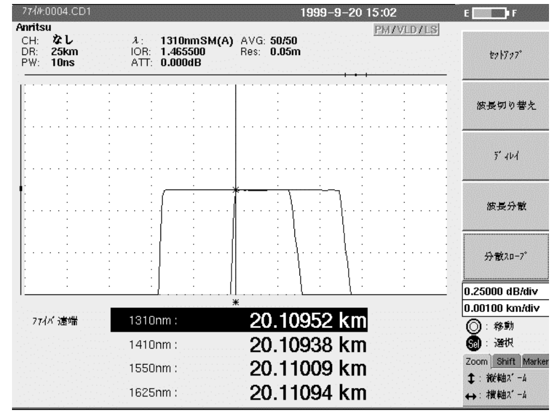


Setting to 0.05m

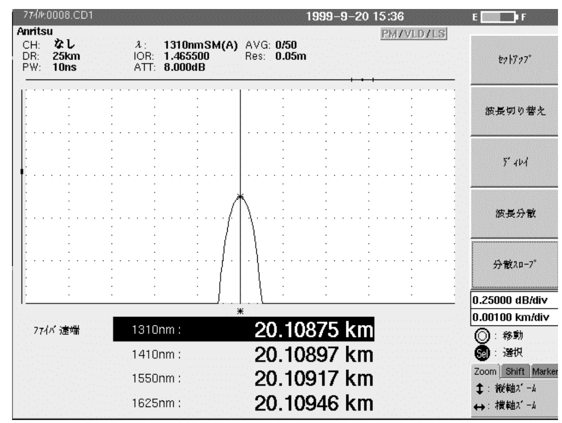
5. ATT setting



ATT setting

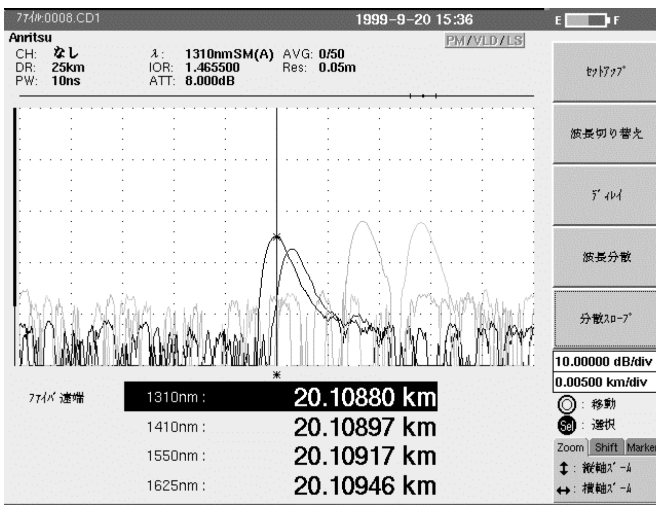


Wrong example（saturation）

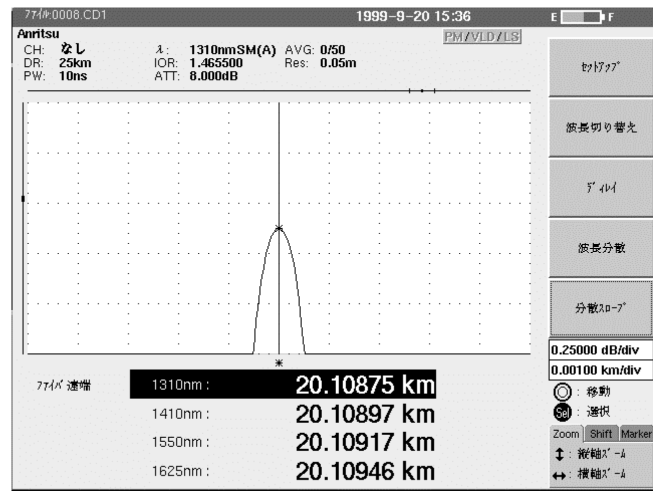


Good example

6. Marker setting at each reflections



OTDR wave



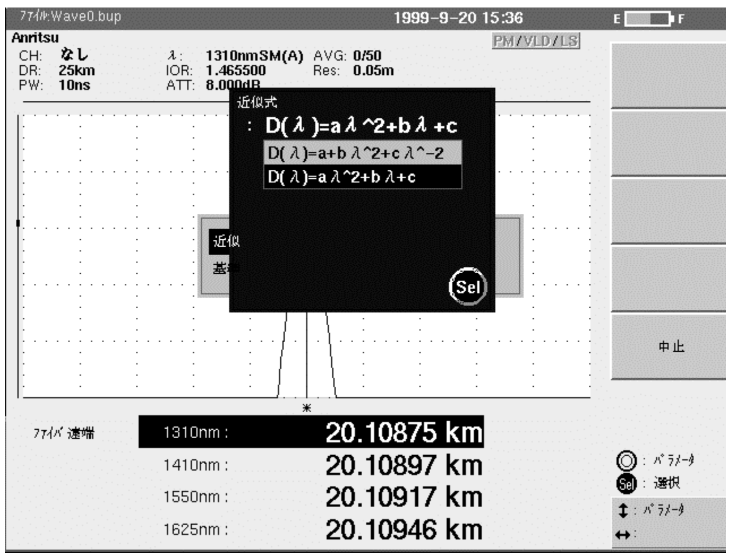
Set the marker at
The weighted center

7. analysis

Select approximation formula

$A\lambda^{2+}b\lambda+c$・ ・ ・ DSF

$A+b\lambda^{2}+c\lambda^{-2}$・ ・ SMF



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