

TESTING SOLUTIONS FOR NEW FIBRE OPTICS

prepared and delivered
by



Optical Test and Calibration Ltd
FIA Breakfast Seminar
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9.15 - 10.30



TESTING SOLUTIONS FOR NEW FIBRE OPTICS


Optical Test and Calibration



Optical Test and Calibration Ltd
5 Campus Road
Listerhills Science Park
Bradford
BD7 1HR
Tel: +44 (0) 1274 393857
Fax: +44 (0) 1274 393336
Email: info@otc.co.uk
Web: www.otc.co.uk

- Fibre Optic Services
- Photometric/Radiometric Services
- Electrical/Electronic Calibration
- Maintenance & Repair Services
- Environmental Test Services
- Other Support Services


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Optical Test and Calibration Ltd
5 Campus Road
Listerhills Science Park
Bradford
BD7 1HR
Tel: +44 (0) 1274 393857
Fax: +44 (0) 1274 393336
Email: info@otc.co.uk
Web: www.otc.co.uk

Services Offered

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- Calibration Traceable or UKAS, service & repair
- Hire & Sales Cable testers etc


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- ILX Lightwave
- Noyes Fibre Optics
- STC/FTT/Biccotest Fibre Optic products
- Beale/BIT/First Fibre fusion splicers


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Agenda



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Section One

Section Two


Section Three

Fibre Optic Basics

Measurement Techniques


Understanding Measurements

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Agenda



Section One

Section Two

Section Three


Fibre Optic Basics

Measurement Techniques

Understanding Measurements


Multimode Optical Fibre
Singlemode Optical Fibre
Fibre Optic Sources
Coupling Losses
Typical Interconnections

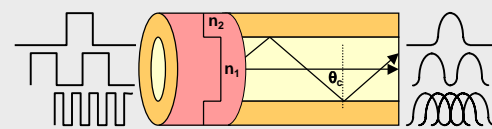
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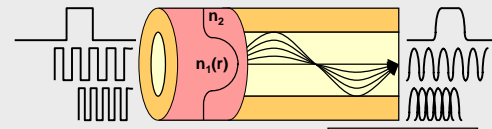
Multimode Optical Fibre





STEP INDEX (S.I.) MULTIMODE

- path lengths: maximum variation
- path times: maximum variation
- bandwidth: modal dispersion




GRADED INDEX (G.I.) MULTIMODE

- path lengths: significant variation
- path times: limited variation
- bandwidth:
 - 1st order: modal dispersion
 - 2nd order: chromatic dispersion

Typical Geometry	
d/D (µm)	NA
50/125	0.20
62.5/125	0.275
100/140	0.29
200/230	0.24

Slide courtesy of The Cabling Partnership


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Multimode Optical Fibre

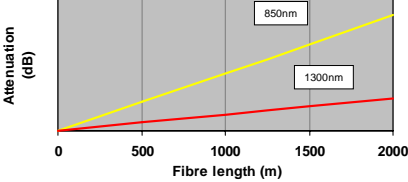


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Typical Optical Fibre Geometry			
	50/125	62.5/125	
Core diameter (m)	50 ± 3	62.5 ± 3	
Cladding diameter (µm)	125 ± 3	125 ± 3	
NA	0.20 ± 0.015	0.275 ± 0.015	

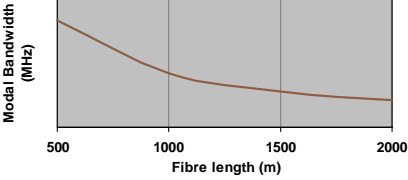
Typical Optical Fibre Performance Parameters*				
Fibre Type (µm)	Attenuation coefficient (dBkm ⁻¹ max)		Modal bandwidth (MHz.km min)	
	850nm	1300nm	850nm	1300nm
50/125	3.5	1.0	200	500
62.5/125	3.75	1.5	160	500
100/140	5.0	2.0	100	200
200/300	6.0	-	18	-

*Based on ISO/IEC11801 and EN50173 (1995)



Attenuation (dB)

Fibre length (m)




Modal Bandwidth (MHz)

Fibre length (m)

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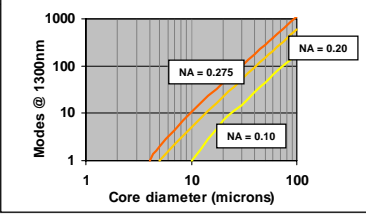
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Singlemode Optical Fibre

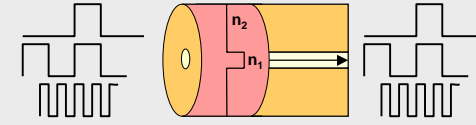


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Modes @ 1300nm

Core diameter (microns)



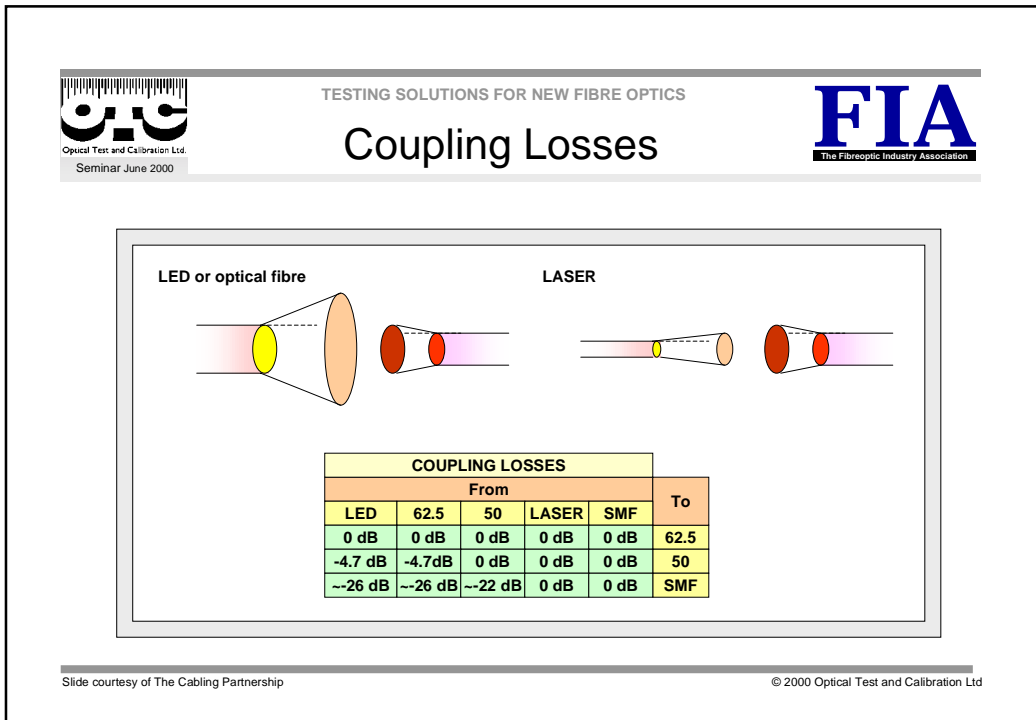
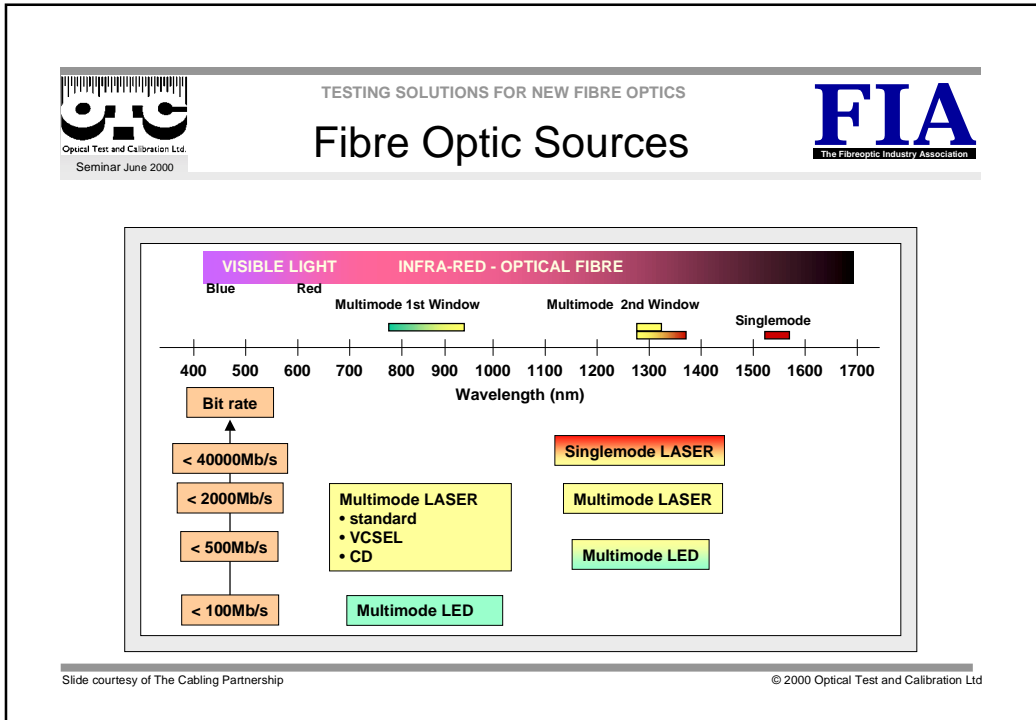
STEP INDEX (S.I.) SINGLEMODE


- path lengths: no variation
- path times: no variation
- bandwidth:
 - 1st order: chromatic dispersion
 - 2nd order: pulse shape dispersion

Typical Geometry	
d/D (µ0/)	NA
8-10/125	0.10

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Typical Interconnections




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SPLICED JOINTS		Insertion loss	Return loss
Multimode		<0.05 dB	N/A
Singlemode		<0.2 dB	N/A

DEMOUNTABLE CONNECTORS		Insertion loss	Return loss
Early Multimode	SMA905, SMA906, STC OFP101, AT&T Biconic, Stratos, etc	0.6 dB	N/A
Later Multimode	Diamond HFS-3, FC/FC, FC/PC, ST, ESCON, FDDI	0.3 dB	N/A
Singlemode	D4, FC/PC, Diamond HMS-0, HMS-10, DIN	0.2 dB	<-30 dB
Advanced Singlemode	HRL-10, FC/UPC, FC/APC, SC/APC, E2000, EC	0.25 dB	<-60 dB
Small Form Factor	LC, MT-RJ, SG (3M Volition™)	0.2 dB	-


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Agenda



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Section One

Section Two

Section Three


Fibre Optic Basics

Measurement Techniques

Understanding Measurements

Types of Tests
 Transmission Tests
 Field Testing
 Power Measurement
 Insertion Loss Measurement
 Reflectometry
 Specialist Measurements


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Types of Test




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Over its product life these measurements may be performed on a fibre optic cable:

- Mechanical tests Traction, Torsion, Bending, Thermal Cycling
- Geometrical tests Concentricity, Core Diameter, Cladding Diameter
- Optical tests Index Profile, Numerical Aperture, Spot Size
- Transmission tests Bandwidth, Optical Power, Optical Loss, Reflectometry

The first three measurements are normally only performed once, as part of a product qualification, as there is only minor variation of these parameters during the fibre's life. These are described in the FOTP (Fibre Optic Test Procedure) specifications of the EIA (Electronics Industries Association), as well as in the ITU-T G650 recommendations, EN188000 and other documents.


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Transmission Tests




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Measurements used to qualify optical systems for use for information transmission are:

- End-to-End optical link loss
- Attenuation per unit length
- Attenuation contribution of splices, connectors, couplers
- Length of fibre or distance to an event
- Linearity of fibre loss per unit length (attenuation discontinuities)
- Reflectance or Optical Return Loss

Specialist measurements such as bandwidth, polarisation mode dispersion or time of flight, may also be done, though the requirement has been rare to date. Some measurements may require access to both ends of the fibre, whereas others require only one end. These single ended test methods are of particular interest in field applications.


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Field Testing




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Installation, Maintenance and Restoration are the main themes for field tests:

- *Installation* testing to ensure quality of received cables (transit damage), damage during cable placement, cable splices, cable terminations (attenuation, location, reflectance), overall system characteristics (end-to-end loss, system optical return loss) and to provide completion documentation.
- *Maintenance* testing to assess periodic degradation of cable, splices and connections (cable attenuation, attenuation and reflection of splices and terminations). In high capacity and critical systems automated testing devices may be employed.
- *Restoration* usually begins with testing to ascertain the cause of a problem (system transmitter, system receiver, cable integrity, splice failures, connector faults). Once faults are identified and rectified, testing will then be used to assess the quality of the repaired system, similar to testing performed at the conclusion or hand-over of a cable installation.


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Power Measurement



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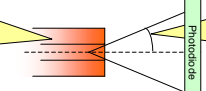
The power meter is the standard instrument for fibre testing and displays the incident power on the integral photodiode. Choice of the meter depends on the application and should have enough dynamic range to measure the transmitter output, but be sensitive enough to measure the received power at the remote end of the system.

Typical Dynamic Ranges for power meters are:

- +13 dBm to -70 dBm for telephony applications
- +24 dBm to -50 dBm for CATV applications
- -20 dBm to -60 dBm for LAN applications


Features on more sophisticated meters may include temperature stabilisation, ability to calibrate to different wavelengths, display power 'relative' to a 'reference' input, to introduce additional attenuation etc.

Optical Fibre under test. Normally terminated with an optical connector. Bare fibre adapters can be used for unterminated fibres, but accuracy and repeatability may be impaired.



Acceptance angle or NA (Numerical Aperture). Generally accepted that optimal power measurement made with 75% fill of the photodiode. Note that large area photodiodes will provide more repeatable results.


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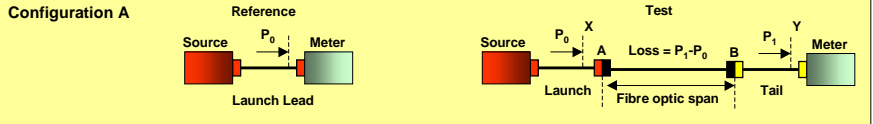
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Insertion Loss Measurement

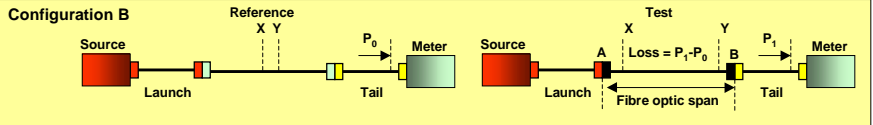


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Configuration A




Configuration B



Configuration C




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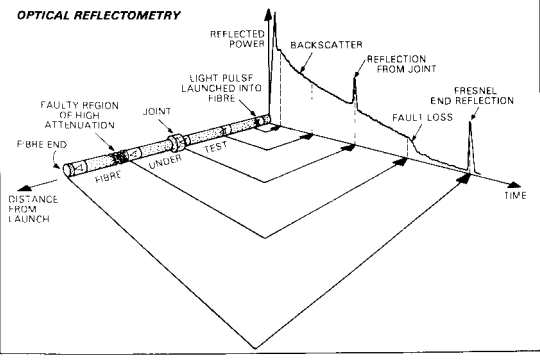
Reflectometry



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Optical Time Domain Reflectometer

- Dynamic Range:** This defines the maximum observable length of fibre and therefore the OTDR's suitability for analysing a particular network. The higher the dynamic range, the higher the signal to noise ratio, the cleaner the trace will be with better event detection. It is defined as the difference between the extrapolated point of the backscatter trace at its interception with the power axis and the upper level of the noise floor. IEC61746 & Bellcore define this limit as the point that contains $\leq 98\%$ of all the noise data points. The RMS definition takes the noise at an SNR=1 which gives a value 1.56dB bigger than IEC/Bellcore. Others include $N=0.1dB$, End Detection, 4% Fresnel and Peak Level Plus 0.3dB.



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Special Measurements

Return Loss
Measured using two methods:
• single ended with an OTDR and read direct from the display has the advantage of locating the reflection.
• single ended with a return loss test set, but needs access to the far end to dump and remove spurious reflections.

Bandwidth Measurement
Two possible methods:
• CW method which involves the direct measurement of the frequency response of the link
• The Pulse method which is indirect and measures pulse broadening in the time domain. These are then converted to the frequency domain using FFT techniques and a computer.
• Needed for measurement of 'legacy' systems.
• Requires access to both ends.
• Equipment is cumbersome.
• Developments are in hand.

Polarisation Mode Dispersion
This is becoming important in long haul singlemode EDFA systems and in DWDM systems. Single ended access is possible and many OTDR's now offer an optional plug-in module, but kit is expensive and measurement repeatability is poor due to environmental factors.

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Agenda

Section One Section Two Section Three

Fibre Optic Basics Measurement Techniques Understanding Measurements

Traceable Measurements
Sources of Error
Human Factors
Removing the Uncertainty


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Traceable Measurements



• Calibration
The comparison of a measurement or source device (UUT) of unverified uncertainty with a measurement or device of known or lesser uncertainty, and to report or correct errors.

• Random Error
This unpredictable error is the deviation of an individual reading from the long term mean of many such readings. The long term average of the random error is zero, but their amplitude can be expressed as a variance or standard deviation.

• Fibre Optic Calibration
• Optical Power
Absolute and relative values
• Spectral Characteristics
Centre wavelength, peak wavelength and spectral half-width


• Traceability
The ability to relate individual measurement results to defined national standards through an unbroken chain of comparisons

• Systematic Error
This is the deviation of the long term mean of the readings from what is believed to be the true value. In principle these errors can be corrected, but the uncertainty in the correction factor contributes to the final result.

• Optic Power Calibration
• Detectors
Silicon from 600 - 1000nm
Germanium from 800 - 1600nm
InGaAs from 750 - 1700nm
• Absolute Power
Transfer from NPL at -10dBm, -20dBm & -23dBm at 850, 1300, 1310 and 1550nm to $\pm 2\%$ for FC.
• Relative Responsivity
Response of a detector to an absolute power at a specific wavelength

• Uncertainty
The degree of doubt about a measurement. This parameter is associated with the measurement result and indicates the distribution of the values which could be assigned to it's true value.


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Sources of Error



• Wavelength
Experimentation with Time of Flight shows errors in length of up to 2m for a change in 20nm in peak wavelength!
Nominal 3km 50/125 multimode
812nm 3084.31m
834nm 3082.91m
851nm 3081.04m

• Decade Errors in Meters
Many calibration houses and some manufacturer's data only give calibration results at the decade points. Experience has shown errors up to 2dB in optical power measurement between these points due to log-amp non-linearities.

• Temperature Variations
These affect detector responsivity and source wavelength.

• Group Index
Many OTDR's now allow setting of Group Index to at least 4 decimals. Temperature fluctuations of only $\pm 1\text{C}$ around the fibre will affect the refractive index, and hence the Group Index, at the 3rd decimal place, giving length measurement errors of up to 4m.

• Saturation Effects
No true high power transfer standard exists for optical power in the fibre bandwidths. Results obtained will be subject to up to 10% uncertainty due to detector saturation and the as yet, unquantified, non-linear transmission effects at high power in passive devices

• Optical Reflections
Variations in power of several percent caused by reflections from fibre ends, lenses, detector windows etc. Coherence effects also cause instability by generation of an external laser cavity in the optical fibre.

• Source Characteristics
Mode structure of lasers, the laser drive current and localised laser chip heating effects all contribute to wavelength and optical power fluctuations.

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Human Factors

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- People**
 - Use personnel with direct practical experience of the work involved to conduct interviews with potential staff
 - Guard against any factors e.g. excessive time pressures which may adversely affect staff performance.
 - Invest in training to ensure staff have the skills and competency to fulfil their role.
- Tools**
 - Apply ergonomic as well as technical criteria when purchasing new equipment
 - Ensure that any software purchased for measurement or documentation is 'fit for purpose'.
 - Adopt a 'user-centred' approach when developing new systems.
- Process**
 - Involve staff in the design and review of jobs.
 - Design work processes to provide adequate variety and sufficient breaks.
 - Allow staff to concentrate when required and minimise sources of interruption.
 - Consider automating any parts of a process which may be prone to error.
 - Improve checking and audit strategies where possible.
 - Promote information exchange within the organisation.

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Remove the Uncertainty

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- Use the right people
- With the right equipment
- At the right time
- In the right way
- DON'T MAKE DO!**


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Fibre Standards



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International Standards

- IEC60793-1 and IEC60793-2: Optical Fibers.
- IEC60794-1, IEC60794-2 and IEC60794-3: Optical Fiber Cables.
- ITU-T G650: Definition and Test Methods for the relevant Parameters of Singlemode Fibers.
- ITU-T G651: Characteristics of 50/125µm Multimode Graded Index Optical Fiber.
- ITU-T G652: Characteristics of Singlemode Optical Fiber Cable.
- ITU-T G653: Characteristics of Dispersion Shifted Optical Fiber Cable
- ITU-T G654: Characteristics of 1550nm Loss Minimized Singlemode Optical Fiber Cable.

National Standards

- EN186000: Optical Fibre Connectors.
- EN187000: Optical Fibres.
- EN188000: Optical Fibre Cables.
- IEC62350: Power Meter Calibration
- IEC61746: OTDR Calibration.
- BS7718: Code of Practice for Installation of Fibre Optic Cabling.


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Glossary & Terms - 1




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Based on IEC50, chapter 731, EIA-440-B and other documents

<p>Absorption: in an optical fibre, loss of optical power resulting from the conversion of power into heat.</p> <p>Attenuation Dead Zone: region after an event where the trace deviates from the undisturbed backscatter trace by e.g. more than 0.1dB at a reflectance of -30dB (Bellcore definition). This dead zone depends on pulse width, reflectance, loss, displayed power level and location and indicates the minimum distance after an event where the backscatter trace can be measured.</p> <p>Attenuation: in optical fibres, loss of average optical power due to absorption, scattering and other radiation losses. Normally expressed as dB without the negative sign.</p> <p>Attenuation Coefficient: rate of optical power loss with respect to distance, usually expressed as dB/km. Attenuation for a fibre is normally specified over a temperature range of -60C to +85C.</p> <p>Backscattering: portion of scattered light returned in the opposite direction to that of propagation.</p> <p>Bandwidth: difference, expressed in Hertz (Hz), between the highest and lowest frequencies passed through a fibre. Often used to specify the bandwidth (MHz.km) of a multimode fibre.</p> <p>Bend Radius (minimum): The radius a fibre can bend before increased loss or mechanical damage occurs.</p> <p>Cut-off Wavelength: in a singlemode fibre, the shortest wavelength at which a single mode can be transmitted. Beyond this wavelength, several modes transmit simultaneously, and the fibre becomes multimode.</p>	<p>CW: abbreviation for continuous wave.</p> <p>Dense WDM: Dense Wavelength Division Multiplexing is used to transmit several signals on the same fibre within a narrow wavelength band.</p> <p>DFB: Distributed Feedback Laser, incorporates a Bragg reflection grating in the active region of the laser diode to enhance a single longitudinal mode.</p> <p>Dispersion: The cause of bandwidth limitation in fibre. The broadening of a light pulse as it propagates along a fibre: <i>Modal Dispersion</i> caused by differential optical path lengths in an optical fibre. <i>Chromatic Dispersion</i> caused by differential delay of various wavelengths of light passing through a fibre.</p> <p>Dynamic Range: The difference between the extrapolated point on the backscatter trace at the near end of the fibre (at the intersection with the power axis) and the upper level of the noise floor (see below). The dynamic range is expressed in dB. The value is measured after 180s usually with the largest OTDR pulse width. <i>IEC/Bellcore</i> defines this noise floor point as that containing at least 98% of all noise data points. <i>The RMS definition</i> defines the noise floor point for a Signal-to-Noise ratio = 1. (Typically gives a value ~1.56dB better than IEC)</p> <p>EDFA: Erbium Doped Fibre Amplifier. Amplifies optical signals without using O/E and E/O conversions.</p>
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Glossary & Terms - 2



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Event Dead Zone: Minimum distance on a trace, where two separate events can be distinguished. The distance to each event can be measured but the separate loss cannot be measured.

Reflective Event is the distance between two opposite points on a reflection that are 1.5dB down from the peak. Bellcore defines a reflectance of -30dB.

Non-Reflective Event is the distance between the points where the beginning and ending levels at a splice or feature (≤ 1 dB) are within ± 0.1 dB of their initial and final values.

Graded Index Fibre: The refractive index of the core gradually increases from the outside of the core towards a peak at the core centreline. This multimode fibre reduces the time difference between the arrival of different modes, minimising the modal dispersion and maximising bandwidth.

Group Index: The factor by which the speed of light in vacuum has to be divided to give a propagation velocity of light pulses in fibre.

Micro-bend: Small distortion of a fibre caused by external factors such as cabling. Particularly important in singlemode fibre systems at longer wavelengths, e.g. 1550nm.

Mode Field Diameter (MFD): A term that expresses the diameter (cross section) of the majority of the optical energy in a fibre. This is normally larger than the geometrical core diameter, so MFD effectively replaces core diameter.

Multimode Fibre: An optical fibre in which light travels in multiple modes.

Multiplex: Combining two or more signals into a single bit stream that can then be individually recovered.

Numerical Aperture: The number ratio that expresses the light gathering capacity of a fibre related to the acceptance angle. The sine of an angle representing 5% of the optical power (corresponds to -13dB) is used to measure the Numerical Aperture.

Optical Return Loss (ORL): The ratio, expressed in dB, of the reflected power to the incident power from a fibre optic system represented by the formula $ORL = -10 \log(P_r/P_i)$.

Reflectance: The ratio of reflected power to incident power of an event or connector, represented by $R = 10 \log(P_r/P_i)$.

Refractive Index: A property of light transmitting materials defined as the ratio of the velocity of light in a vacuum (c) to its velocity in a given transmission medium (v), i.e. $n=c/v$.

Scattering: A property that causes light to deflect out of the core area of the fibre, thereby contributing to attenuation.

Singlemode Fibre: An optical waveguide or fibre in which the signal travels in one mode.

Step Index Fibre: A fibre whose index of refraction changes sharply at the interfaces of its core and cladding.

WDM: Wavelength Division Multiplexer. Passive fibre optic components which combine optical channels on different wavelengths.


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Acknowledgements



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- "High BIT Rate Optical Fibre Networks" - FIA Breakfast Seminar by Mike Gilmore, The Cabling Partnership - 22nd March 2000
- "Manual of Fibre Optics Communication" - J.D.Archer, STC Components, Doc. 5191/2571E Ed.3 1983.
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