HIGH BIT RATE OPTICAL FIBRE NETWORKS

-

optical fibre selection and implementation

prepared and delivered

by

φ The Cabling Partnership

19th January 2000

The Cabling Partnership

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- **Training**
- **Design and specification**
- **Cabling and IT cost management**
- **Project management**
- **Audits and arbitration**

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- Training
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- Standards

UK
- Fibreoptic Industry Association, Technical Director
- BSI, Chairman, TCT7/-/1: IT Cabling

PD1001: "EMC and structured cabling"
BS 7718: CoP "Installation of Fibre optic Cabling"

Europe
- CENELEC, Convenor, TC215 WG1: IT Cabling

EN 50098-1: "ISDN Basic Access"
EN 50098-2: "ISDN Primary Rate"
EN 50173: "Generic - Design"
prEN 50174: "Installation"
prEN 50xxx: "Testing of Installed Cabling"

International
- ISO/IEC, Member, JTC1 SC25 WG3: Generic Cabling

ISO/IEC 11801: "Generic - Design"
ISO/IEC 14763-1: "Administration"
ISO/IEC TR14763-2: "Planning and Installation"
ISO/IEC TR14763-3: "Testing optical cabling"
and via IEC SC46A WG2
IEC 61935: " Testing copper cabling"

Agenda

Session One

Designing attenuation-limited networks

Attenuation-limited LAN systems

Break

Session Two

Designing bandwidth-limited networks

Bandwidth-limited LAN systems

Session Three

Multi-Gigabit applications

Practical implementation issues

End

Agenda

Session One

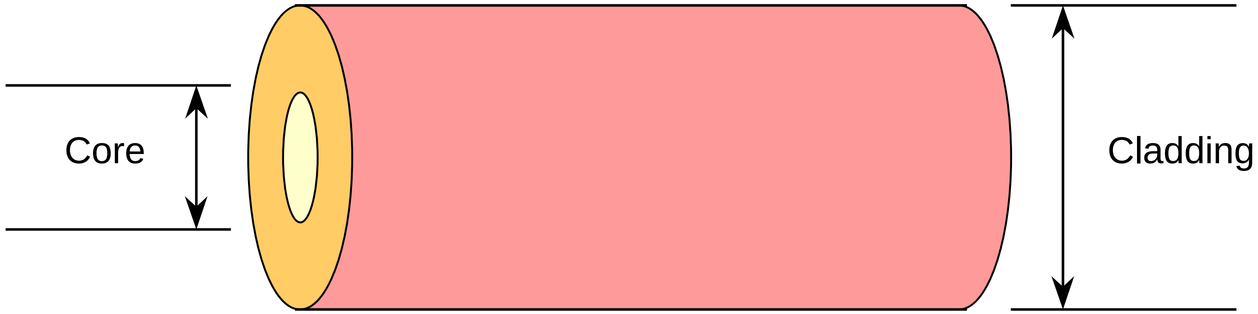
Designing attenuation-limited networks

Attenuation-limited LAN systems

Break

- optical fibre transmission
  - multimode, singlemode
- optical fibre attenuation
- transmission wavelengths/windows
- optical fibre components
  - optical fibre
  - connecting hardware
- optical power budget
- optical loss budget

Optical fibre construction

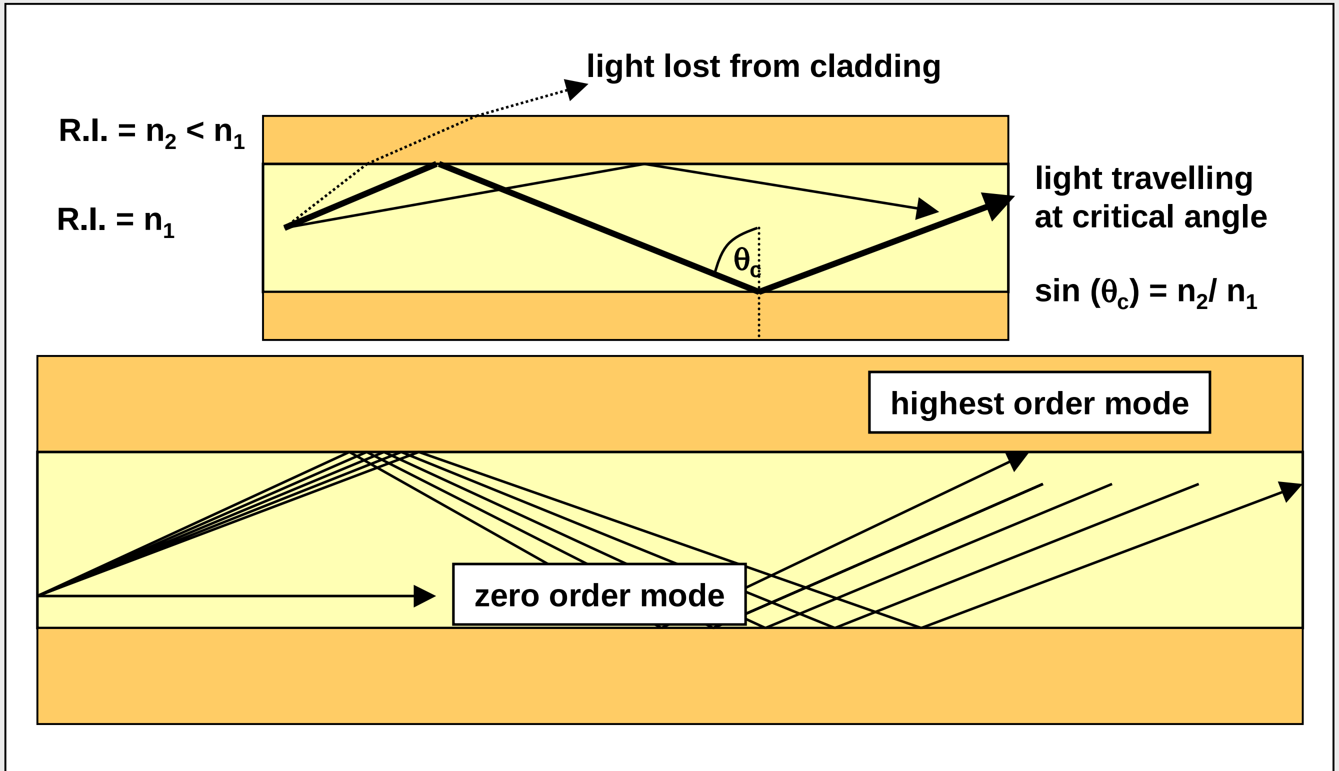


Core and cladding have different optical properties

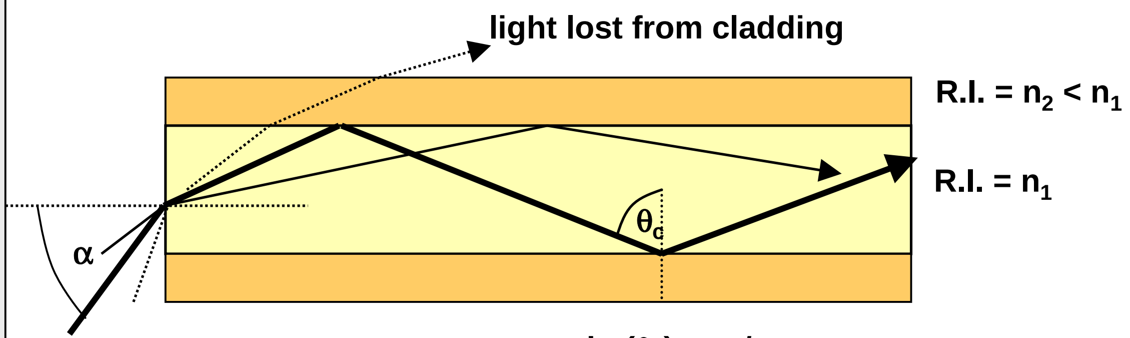
Refractive index (R.I.) $n_x = c/v_x$
c = speed of light in a vacuum
v_x = speed of light in material x

Light is transmitted in the core when $n_{core} > n_{cladding}$

Total internal reflection



Acceptance angle: N.A.

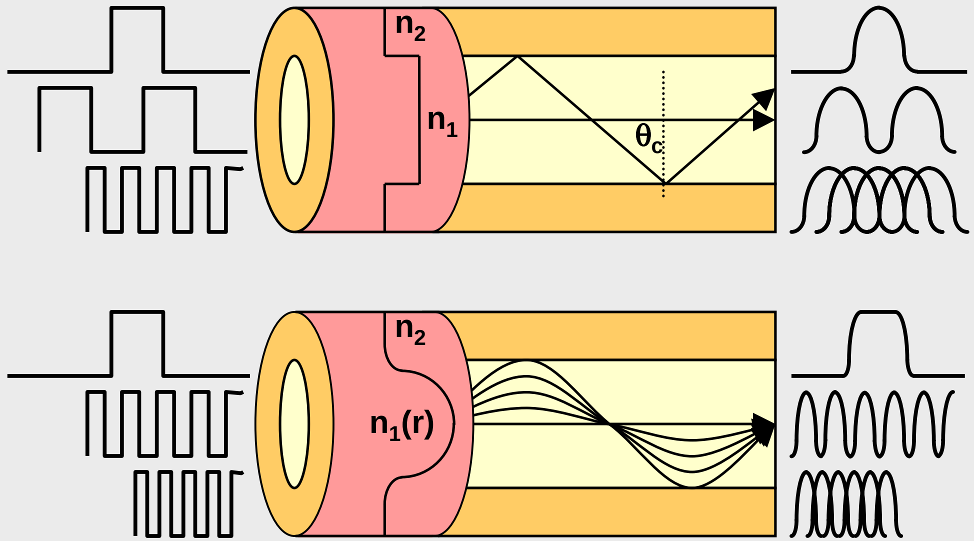


$\sin(\theta_c) = n_2 / n_1$

$\sin(\alpha) = \{n_1^2 - n_2^2\}^{0.5}$ = NA (numerical aperture)

Light injected into optical fibre
= “coupled power”
= f (core diameter^2)
= f (NA^2)

MMF: Multimode optical fibre



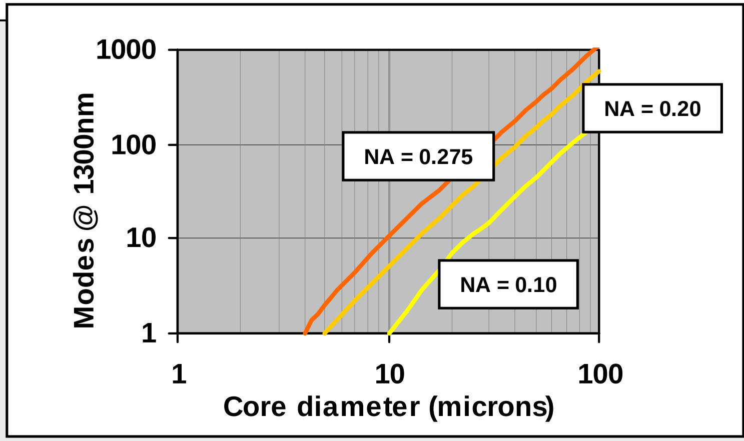
STEP(PED) INDEX (S.I.) MMF
- path lengths: maximum variation
- path times: maximum variation
- bandwidth: modal dispersion

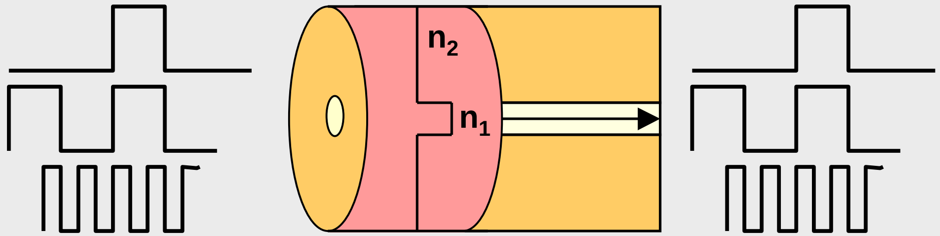
GRADED INDEX (G.I.) MMF
- path lengths: significant variation
- path times: limited variation
- bandwidth:
  - 1st order: modal dispersion
  - 2nd order: chromatic dispersion

Geometry options

d/D	NA
50/125	0.20
62.5/125	0.275

SMF: Singlemode optical fibre





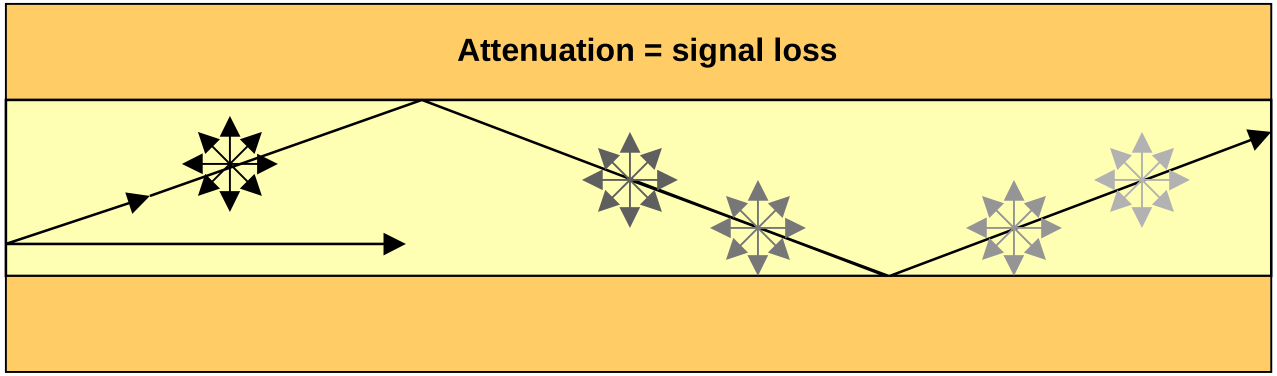
STEP(PED) INDEX (S.I.) SMF

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

Geometry

d/D	NA
8-10/125	*0.10*

Attenuation in optical fibre



INTRINSIC ATTENUATION
- scattering
  - due to variations in structure
  - wavelength dependent
- material absorption
  - impurities (necessary)
  - impurities (unavoidable)
  - wavelength dependent
- path length dependent

EXTRINSIC ATTENUATION
- microbending
  - deformation of the CCI
    - CCI = core-cladding interface
- macrobending
  - deformation of the optical fibre

Attenuation coefficient

Transmitted power

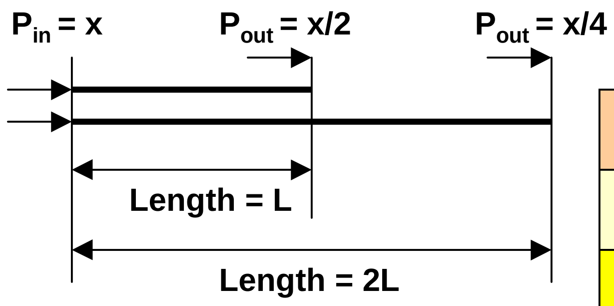
- **linear**

  transmission = P_{out} / P_{in} (%)

- **logarithmic**

  attenuation = $-10 \log_{10}(P_{out}/P_{in})$ (dB)

Transmission (%)	Attenuation (dB)
90	0.45
75	1.25
50	3.01
25	6.02
10	10.0

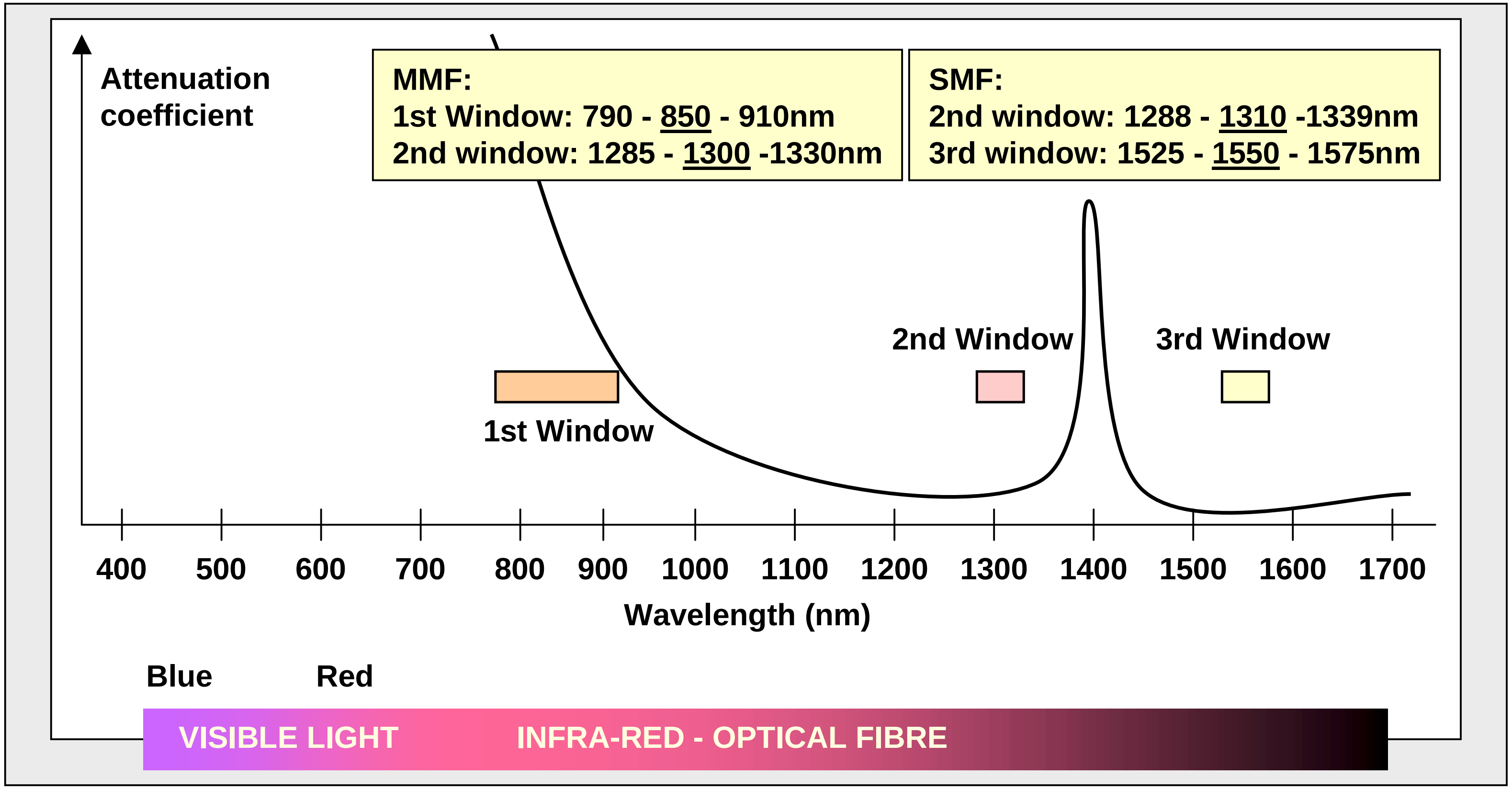


Length (km)	Attenuation (dB)
L	3.01
2L	6.02

Attenuation coefficient

α = x $dBkm^{-1}$

Transmission wavelengths/windows



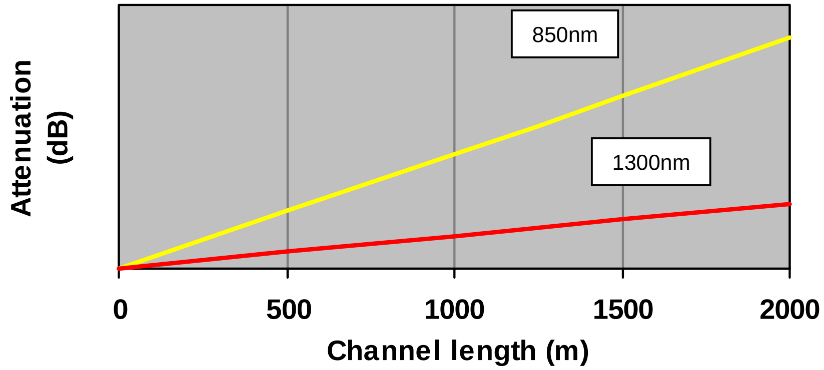
MM optical fibre

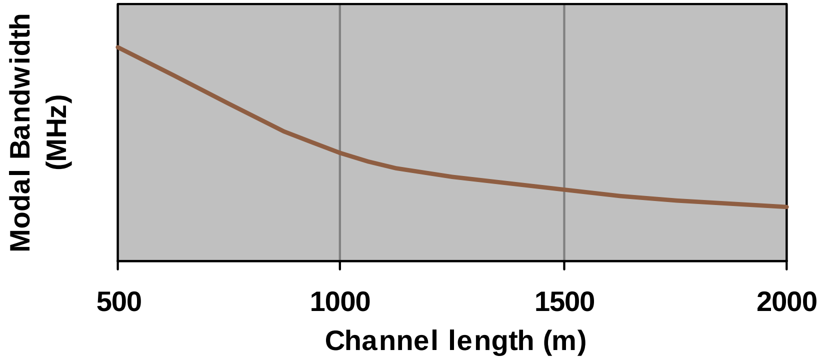
Optical fibre geometry (standardized)

	50/125	62.5/125
Core diameter (µm)	50 ± 3	62.5 ± 3
Cladding diameter (µm)	125 ± 3	125 ± 3
NA	0.20 ± 0.015	0.275 ± 0.015

Optical fibre performance parameters (options)

Attenuation coefficient dBkm^{-1} max.		Modal bandwidth MHz.km min.	
850nm	1300nm	850nm	1300nm
?	?	?	?





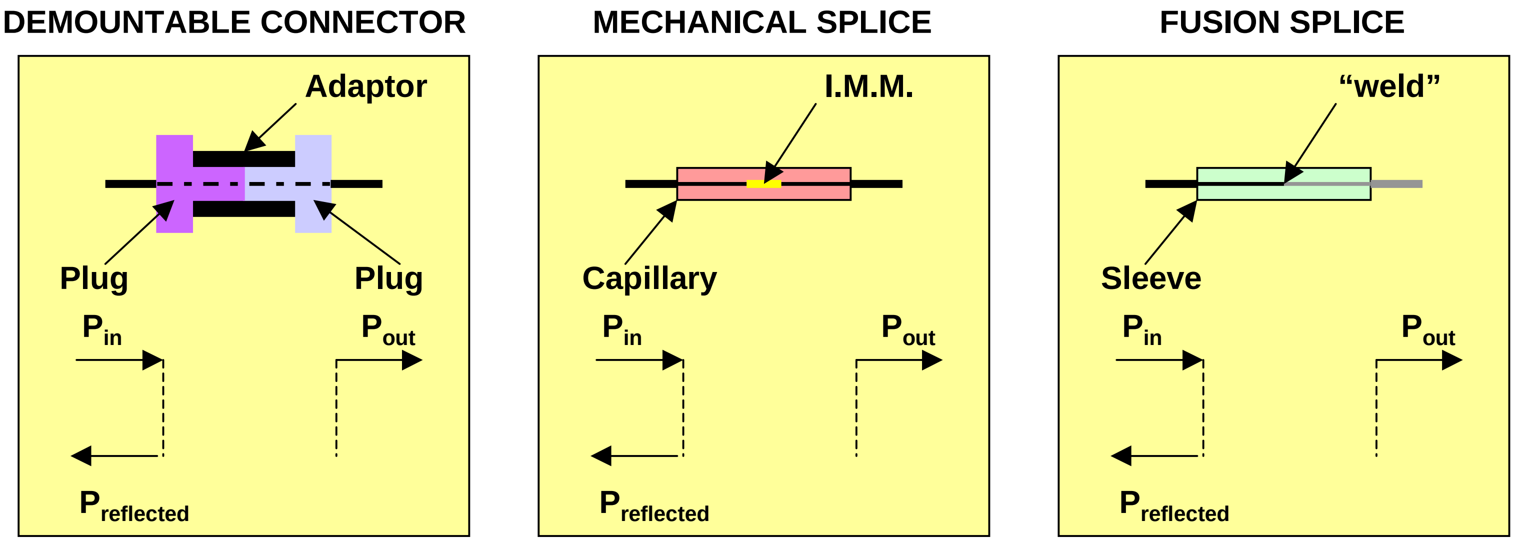
MMF performance options

	Attenuation coefficient dBkm^{-1} max.		Modal bandwidth MHz.km min.		
	850nm	1300nm	850nm	1300nm	
50/125 and 62.5/125	3.5	1.0	200	500	ISO/IEC 11801 and EN 50173 (1995)
62.5/125	3.75	1.5	160	500	ANSI/TIA/EIA 568A (1995)
50/125	3.5	1.5	500	500	ISO/IEC 11801 and EN 50173 (2001)
62.5/125	3.5	1.5	200	500	ISO/IEC 11801 and EN 50173 (2001)

	Attenuation coefficient dBkm^{-1} max.	
	850nm	1300nm
50/125	2.4	0.6
	2.5	0.8
	2.7	1.0
62.5/125	3.0	0.7
	3.2	0.9

	Modal bandwidth MHz.km min.				
	850nm	1300nm	850nm	1300nm	
50/125	400	400	200	400	50/125 and 62.5/125
	400	600	200	600	
	400	800	160	200	62.5/125
	400	1000	200	200	
	400	1200	250	1000	
	400	1500	300	800	
	600	1000			

Connecting hardware



Attenuation
- Insertion loss (dB) = $-10 \log_{10}(P_{out} / P_{in})$

Reflection
- Return loss (dB) = $-10 \log_{10}(P_{reflected} / P_{in})$

Modal bandwidth and delay
- no effect

Connecting hardware options

SPLICES		Insertion loss (max.)	Return loss	
		Singlemode/multimode	Singlemode	Multimode
ISO/IEC 11801 and EN 50173 (1995/2001)		100% < 0.30 dB	-	-

DEMOUNTABLE CONNECTING HARDWARE: INTEROPERABILITY STANDARDS		Insertion loss (max.)	Return loss	
TO in ISO/IEC 11801 and EN 50173 (1995)		Singlemode/multimode	Singlemode	Multimode
ST (BFOC2,5): MMF	IEC 60874-10	100% < 0.75 dB	26dB	20dB
SC-D (duplex): MMF	IEC 60874-19-1			
TO in ISO/IEC 11801 and EN 50173 (2001)				
SC-D (duplex): MMF	IEC 60874-19-1	95% < 0.5 dB, 100% < 0.75 dB	35dB	20dB

DEMOUNTABLE CONNECTING HARDWARE: ALTERNATIVE INTERFACE STANDARDS

Interoperability not guaranteed by standards

F-SMA, CF-03, CF-04, BAM, LSA, FC, D, OF-2, OCCA-PC, OCCA-BU, CF-08, SC, DS, F-05, MU, MPO

SFF types in preparation: LC, SG (Volition), MT-RJ

Optical power budget (OPB) - I

$P_{TX}(dBm) = 10 \log_{10} P_{TX}(mW)$

$P_{RX}(dBm) = 10 \log_{10} P_{RX}(mW)$

Input power P_{TX}

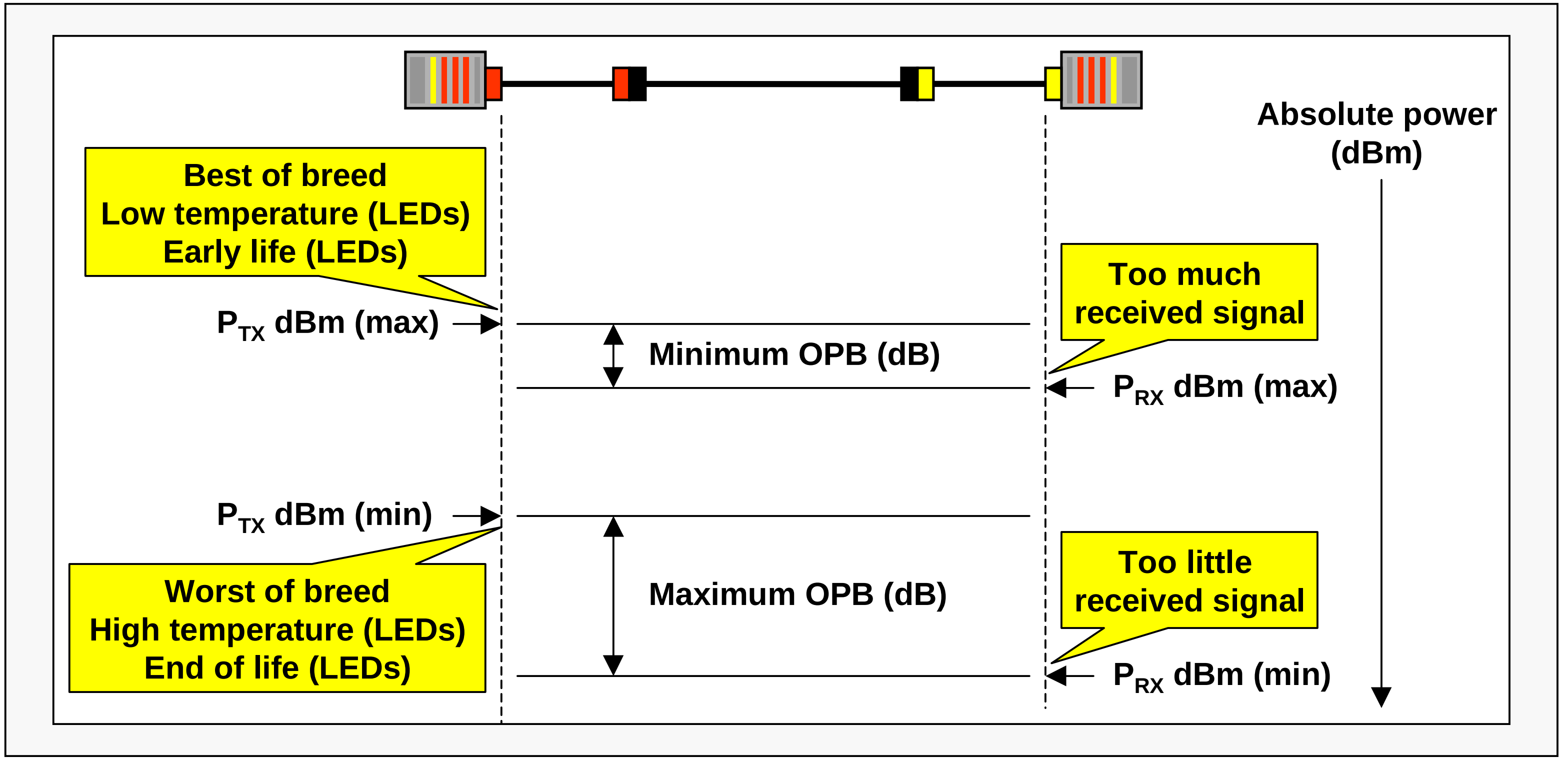
- **milliwatts (mW)**
  - **1W = 1000mW**
  - **1mW = 1000µW**
- **dBm**
  - **referenced to 1mW**

Received power P_{RX}

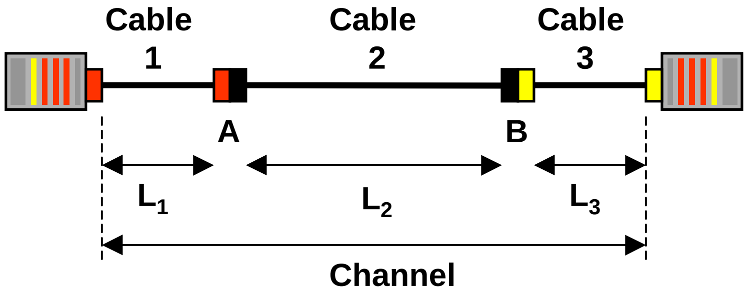
- **milliwatts (mW)**
  - **1W = 1000mW**
  - **1mW = 1000µW**
- **dBm**
  - **referenced to 1mW**

1mW =	0 dBm
0.5mW =	-3 dBm
0.1mW =	-10 dBm
0.05mW =	-13 dBm

Optical power budget (OPB) - II



Optical loss budget (OLB)



Optical loss budget: limits of calculated channel attenuation

In the example:

$OLB_{min} = L_1 * \alpha_{(Cable\ 1)} + L_2 * \alpha_{(Cable\ 2)} + L_3 * \alpha_{(Cable\ 3)} + loss_A + loss_B$ (dB) using min. values

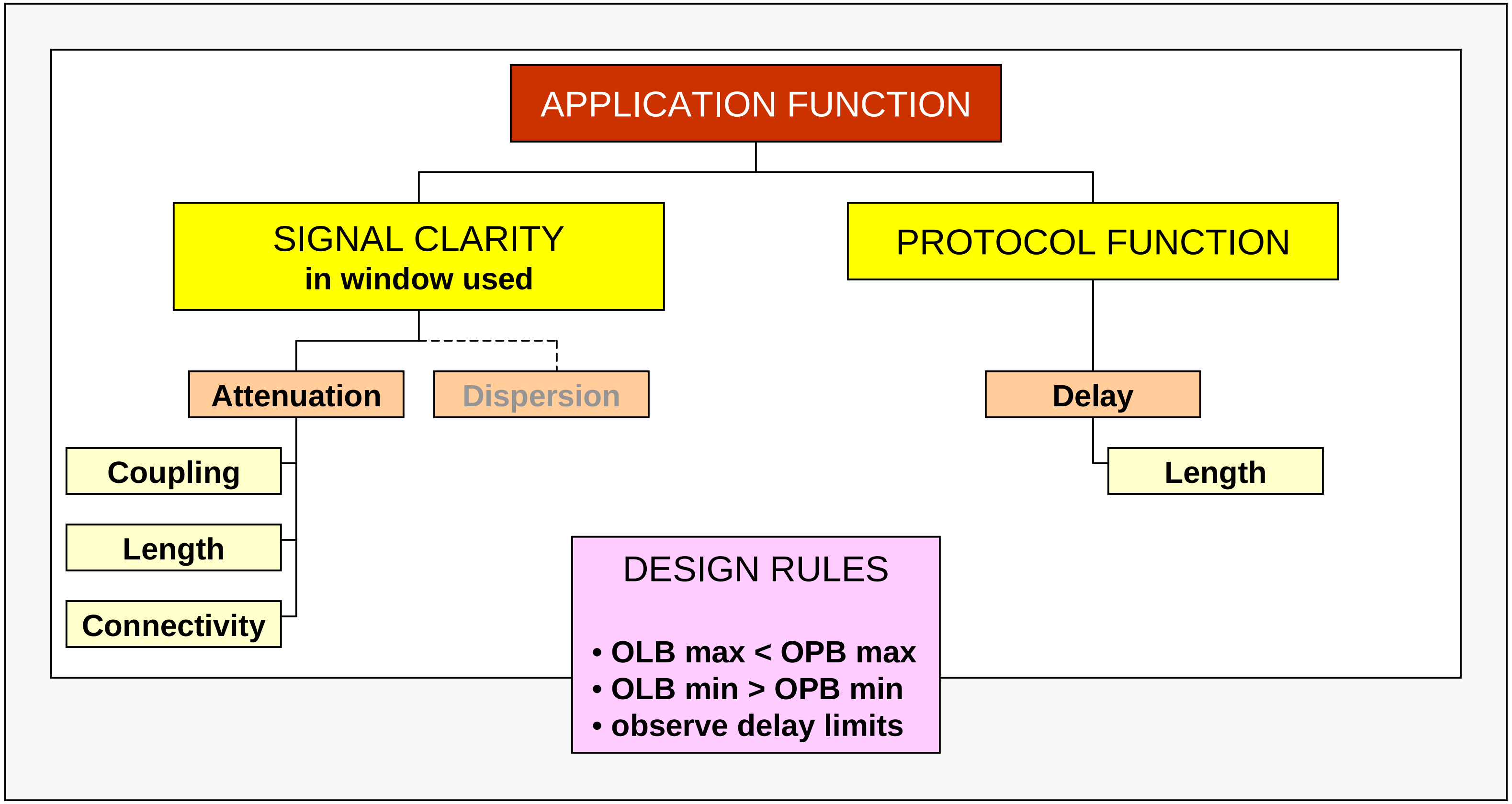
$OLB_{max} = L_1 * \alpha_{(Cable\ 1)} + L_2 * \alpha_{(Cable\ 2)} + L_3 * \alpha_{(Cable\ 3)} + loss_A + loss_B$ (dB) using max. values

In general:

$OLB_{min} = \Sigma \alpha_{(Cable\ i)} \times L_i + \Sigma$connectors/splices (dB) using minimum values

$OLB_{max} = \Sigma \alpha_{(Cable\ i)} \times L_i + \Sigma$connectors/splices (dB) using maximum values

Designing attenuation-limited systems



Agenda

Session One

Designing attenuation-limited networks

Attenuation-limited LAN systems

- attenuation-limited LAN standards
- MMF Light injection devices
- coupling losses
- OPB-based cabling design
- channel length equations

Break

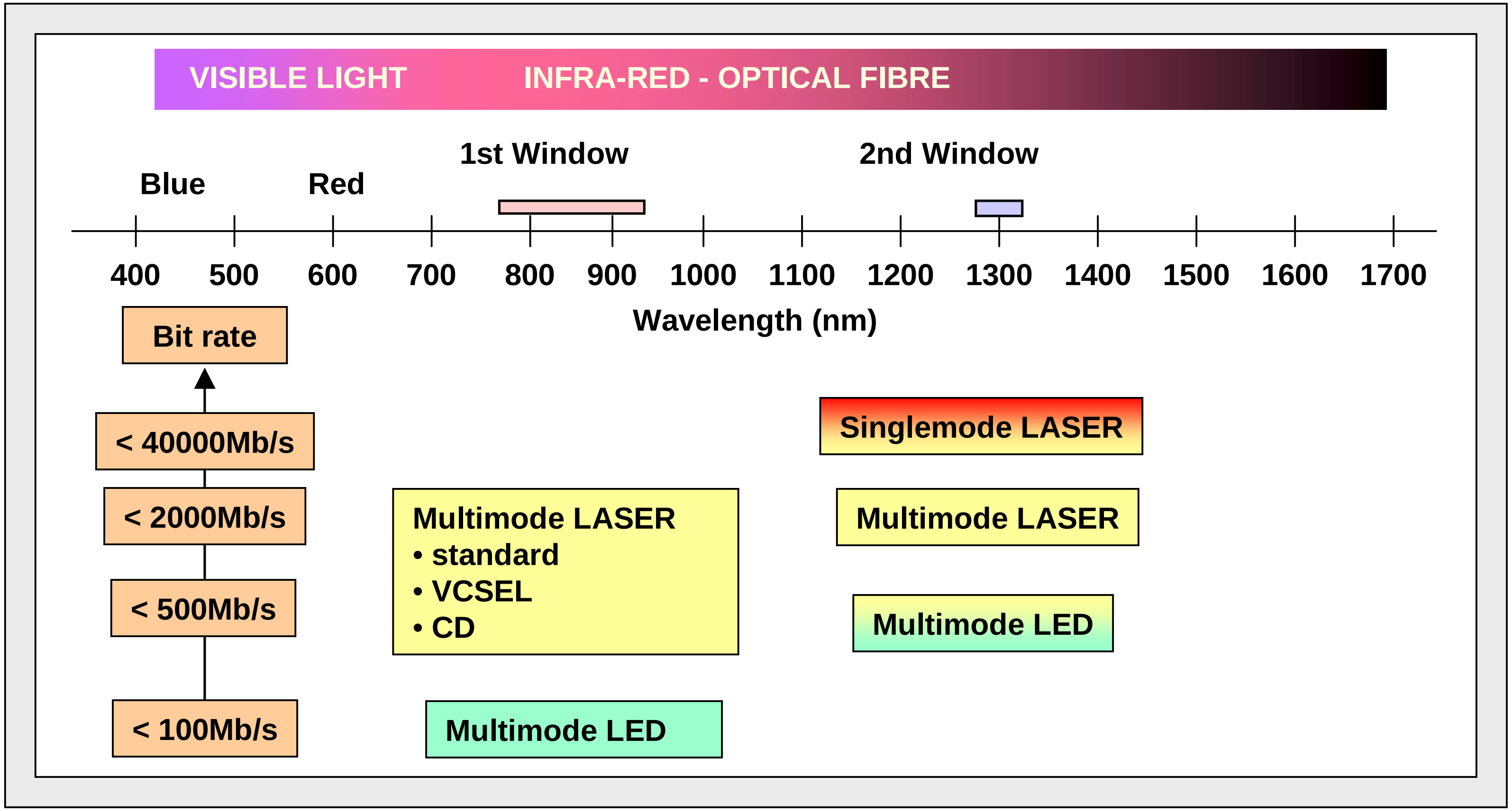
Attenuation-limited LAN standards

		50/125		62.5/125		
		Max. length (m)	OPB max. (dB)	Max. length (m)	OPB max. (dB)	OPB Δ (dB)
850 nm	ISO/IEC 8802-3: FOIRL	514[1]	3.3	1000	9.0	5.7
	ISO/IEC 8802-3: 10BASE-FL/FB	1514[1]	6.8	2000	12.5	5.7
	ISO/IEC TR 11802-4: 4 & 16 Mb/s Token Ring	1857[1]	8.0	2000	13.0	5.0
	IEEE 802.12: Demand priority	371[1]	2.8	500	7.5	4.7
1300 nm	ISO/IEC 9314-3: FDDI PMD	2000	6.0	2000	11.0	5.0
	ISO/IEC 8802-3: 100BASE-FX	2000	6.0	2000	11.0	5.0
	IEEE 802.12: Demand priority	533[1]	2.3	2000	7.0	4.7
	ATM @ 52 Mb/s	2000	5.3	2000	10.0	4.7
	ATM @ 155 Mb/s	2000	5.3	2000	10.0	4.7

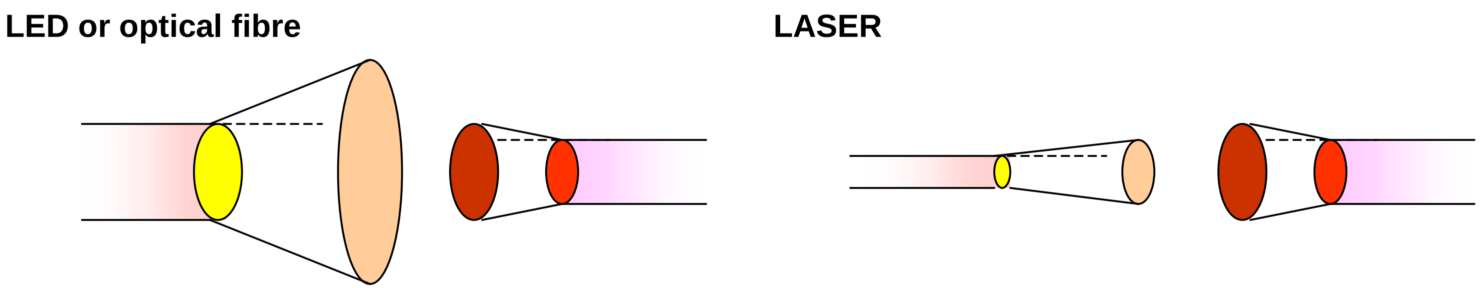
[1] Calculated values using 1.5dB of connecting hardware losses

62.5/125 seems to offer advantages

MMF light injection devices

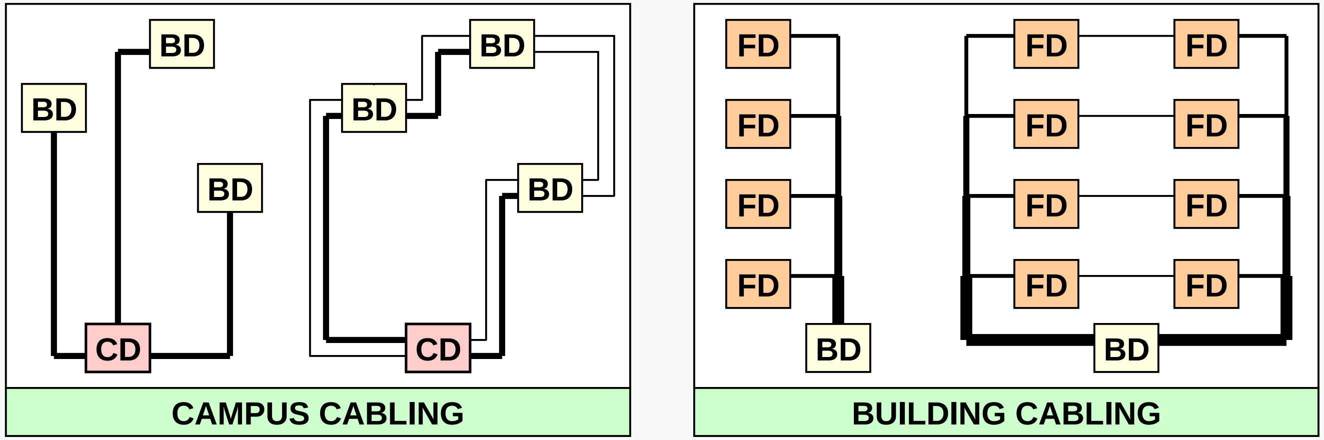


Coupling losses



COUPLING LOSSES					
From					To
LED	62.5	50	LASER	SMF	
0 dB	0 dB	0 dB	0 dB	0 dB	62.5
-4.7 dB	-4.7dB	0 dB	0 dB	0 dB	50
~-26 dB	~-26 dB	~-22 dB	0 dB	0 dB	SMF

OPB-based cabling design



Maximum channel length = (OPB - total connection loss)/cable attenuation

Channel length equations

		50/125		62.5/125	
		CAP	Channel length (m)	CAP	Channel length (m)
850 nm	ISO/IEC 8802-3: FOIRL	-	940 - 142x - 85y	1000	2570 - 142x - 85y
	ISO/IEC 8802-3: 10BASE-FL/FB	-	1940 - 142x - 85y	2000	3570 - 142x - 85y
	ISO/IEC TR 11802-4: 4 & 16 Mb/s Token Ring	2000	2285 - 142x - 85y	2000	3710 - 142x - 85y
	IEEE 802.12: Demand priority	500	800 - 142x - 85y	500	2140 - 142x - 85y
1300 nm	ISO/IEC 9314-3: FDDI PMD	2000	4000 - 333x - 200y	2000	7330 - 333x - 200y
	ISO/IEC 8802-3: 100BASE-FX	2000	4000 - 333x - 200y	2000	7330 - 333x - 200y
	IEEE 802.12: Demand priority	800	1530 - 333x - 200y	2000	4665 - 333x - 200y
	ATM @ 52 Mb/s	2000	3530 - 333x - 200y	2000	6665 - 333x - 200y
	ATM @ 155 Mb/s	2000	3530 - 333x - 200y	2000	6665 - 333x - 200y
		x = no. of mated connectors @ 0.5dB			
		y = no. of splices @ 0.3dB			

Agenda

Session One

Designing attenuation-limited networks

Attenuation-limited LAN systems

Break

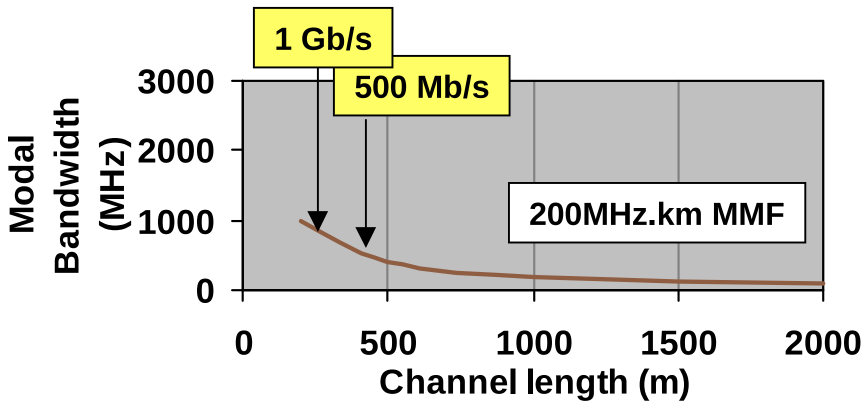
Session Two

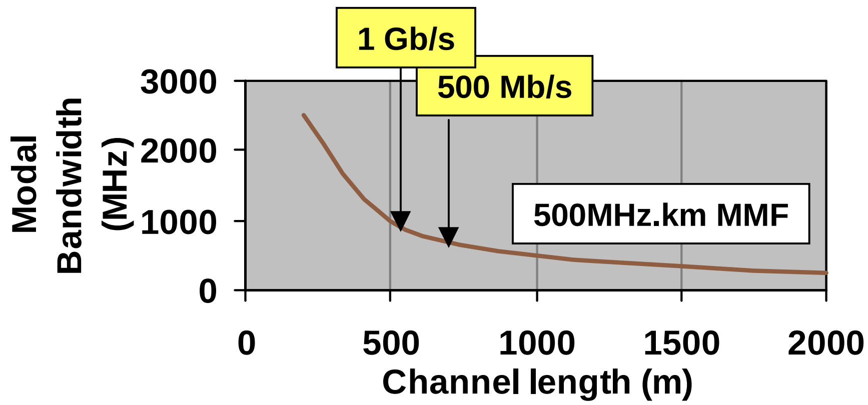
Designing bandwidth-limited networks

Bandwidth-limited LAN systems

- **modal bandwidth**
- **bandwidth-limited technology**

Modal bandwidth





	Attenuation coefficient dBkm^{-1} max.		Modal bandwidth MHz.km min.		
	850nm	1300nm	850nm	1300nm	
50/125 and 62.5/125	3.5	1.0	200	500	ISO/IEC 11801 and EN 50173 (1995)
62.5/125	3.75	1.5	160	500	ANSI/TIA/EIA 568A (1995)
50/125	3.5	1.5	500	500	ISO/IEC 11801 and EN 50173 (2001)
62.5/125	3.5	1.5	200	500	ISO/IEC 11801 and EN 50173 (2001)

Bandwidth-limited technology

Historic applications have channel lengths defined by OPB
• OPB > calculated bandwidth for distances supported

New applications use data rates for which bandwidth requirements define channel lengths
• longer lengths cannot be guaranteed even if low attenuation channels are used

Modal bandwidths have rarely been specified by users/installers

Modal bandwidth difficult/impossible to measure on-site
• bandwidth-limited applications are installed with higher risk

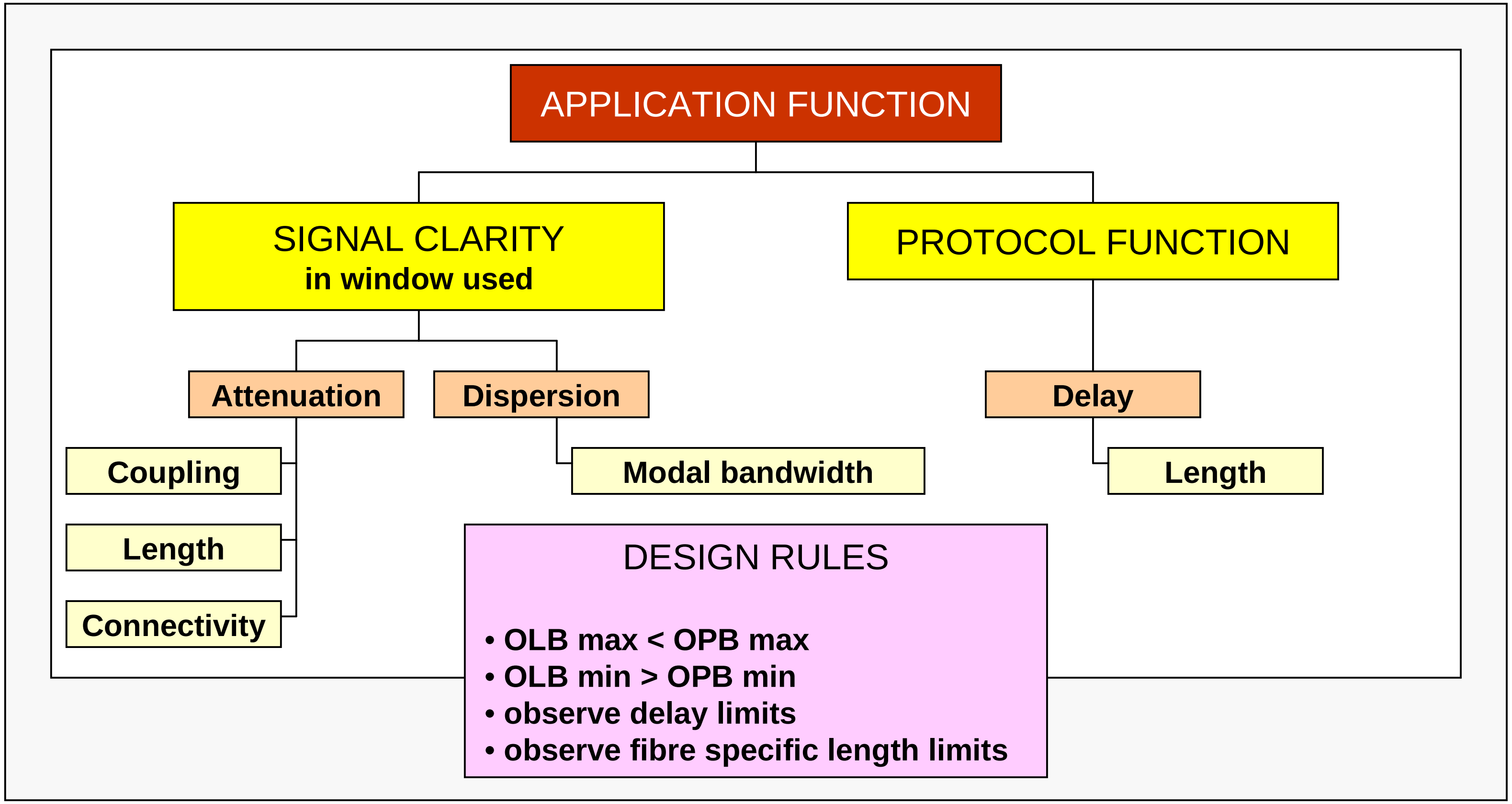
Higher data rates utilise LASER technologies
• CD LASERS, VCSELs and standard LASERs

• reductions in OPBs due to restricted power input/channel lengths

Optical fibre modal bandwidth measured using LED launch conditions
• LASER sources should provide improved bandwidth
• some problems found with RI profiles

OPTICAL FIBRE SELECTION AND CONFIGURATION IMPACTED

Designing bandwidth-limited systems



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Session One

Designing attenuation-limited networks

Attenuation-limited LAN systems

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Session Two

Designing bandwidth-limited networks

Bandwidth-limited LAN systems

- bandwidth-limited LAN standards
- channel length equations
- resilient networks

Bandwidth-limited LAN standards

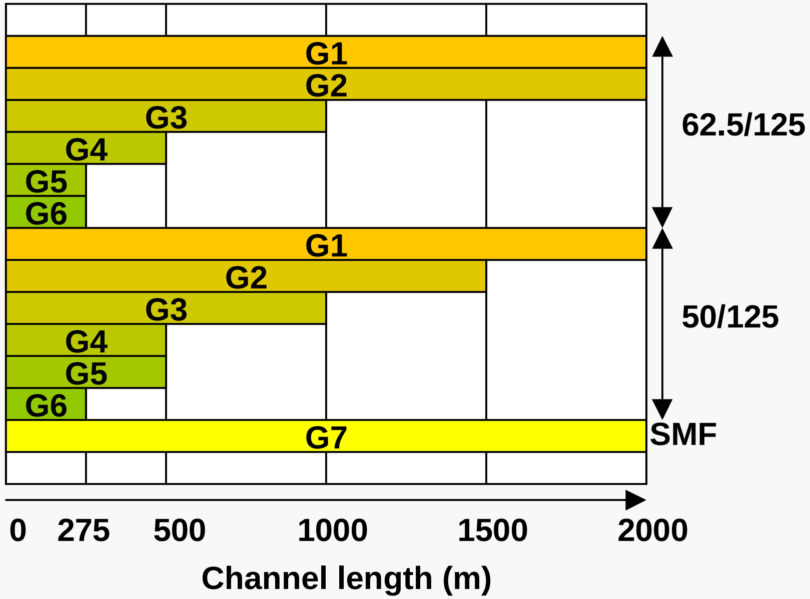
		50/125 500/500MHz.km		62.5/125 200/500MHz.km		
		Max. length (m)	OPB max. (dB)	Max. length (m)	OPB max. (dB)	OPB Δ (dB)
850 nm	ATM @ 155 Mb/s	1000	7.2	1000	7.2	0.0
850 nm	CD 14165: FibreChannel @ 266 Mb/s	2000	12.0	700	12.0	0.0
850 nm	CD 14165: FibreChannel @ 531 Mb/s	1000	8.0	350	8.0	0.0
850 nm	ATM @ 622 Mb/s	300	4.0	300	4.0	0.0
850 nm	IEEE 802.3: 1000BASE-SX: Gigabit Ethernet	550	3.56	275	2.6	- 0.96
850 nm	CD 14165: FibreChannel @ 1062 Mb/s	500	4.0	300	4.0	0.0
1300 nm	CD 14165: FibreChannel @ 133 Mb/s	371[1]	1.3	1500	6.0	4.7
1300 nm	CD 14165: FibreChannel @ 266 Mb/s	2000	5.5	1500	6.0	0.5
1300 nm	ATM @ 622 Mb/s	330	2.0	500	6.0	4.0
1300 nm	IEEE 802.3: 1000BASE-LX: Gigabit Ethernet	>550	2.35	550	2.35	0.0

[1] Assuming no connecting hardware loss

50/125 seems to offer advantages

OF Application Grading

	MMF	SMF	
G1	Token Ring 100BASE-FX FDDI ATM52 (1300) ATM155 (1300	FDDI ATM52 (1310) ATM155 (1310)	G7
G2	10BASE-FL 10BASE-FB		
G3	ATM155 (850)		
G4	1000BASE-LX ATM622 (1300)*	1000BASE-LX ATM622 (1310)	
G5	1000BASE-SX		
G6	ATM622 (850)		

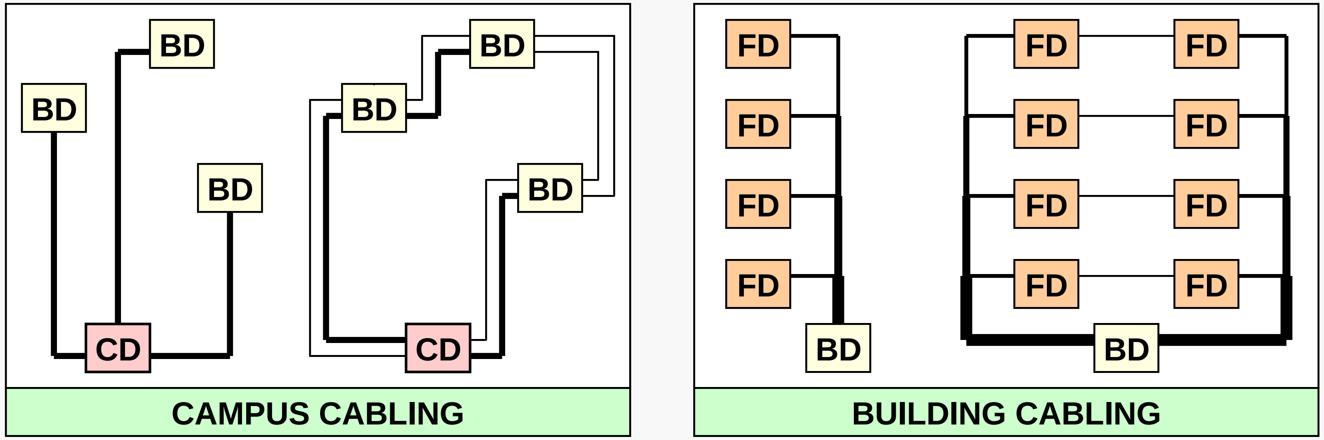


KEY FEATURES
- lengths shown assume 1.5dB connecting hardware loss
- G2 applications limited on 50/125
- G5 applications limited on 62.5/125
- not all applications supported on singlemode

Channel length equations

		50/125 500/500MHz.km		62.5/125 200/500MHz.km	
		CAP	Channel length (m)	CAP	Channel length (m)
850 nm	ATM @ 155 Mb/s	2000	2085 - 142x - 85y	1000	2085 - 142x - 85y
	CD 14165: FibreChannel @ 266 Mb/s	2000	3425 - 142x - 85y	700	3425 - 142x - 85y
	CD 14165: FibreChannel @ 531 Mb/s	2000	2285 - 142x - 85y	350	2285 - 142x - 85y
	ATM @ 622 Mb/s	300	1140 - 142x - 85y	300	1140 - 142x - 85y
	IEEE 802.3: 1000BASE-SX: Gigabit Ethernet	550	1015 - 142x - 85y	275	740 - 142x - 85y
	CD 14165: FibreChannel @ 1062 Mb/s	500	1140 - 142x - 85y	300	1140 - 142x - 85y
1300 nm	CD 14165: FibreChannel @ 133 Mb/s	-	865 - 333x - 200y	1500	4000 - 333x - 200y
	CD 14165: FibreChannel @ 266 Mb/s	2000	3665 - 333x - 200y	1500	4000 - 333x - 200y
	ATM @ 622 Mb/s	300	1465 - 333x - 200y	500	4000 - 333x - 200y
	IEEE 802.3: 1000BASE-LX: Gigabit Ethernet	550	1565 - 333x - 200y	550	1565 - 333x - 200y
		x = no. of mated connectors @ 0.5dB			
		y = no. of splices @ 0.3dB			

Bandwidth-based cabling design



Maximum channel length = (OPB - total connection loss)/cable attenuation

Optical fibre selection <1Gb/s

	Max. OLB (dB)		Optical fibre choices	
	850 nm	1300 nm		
< 200 metres	2.3	1.3	Either 50/125[1] or 62.5/125[2]	
< 500 metres	3.3	2.3	50/125[1]	SMF > 1Gb/s
< 1500 metres	6.8	6.0	50/125	SMF > 200Mb/s
	12.0	10.0	62.5/125[3]	
< 2000 metres	6.8	6.0	50/125	
	12.0	10.0	62.5/125[3]	

[1] 50/125:	3.5/1.5$dBkm^{-1}$, 500/500MHz.km
[2] 62.5/125:	3.5/1.5$dBkm^{-1}$, 200/500MHz.km preferred
[3] 62.5/125:	3.5/1.5$dBkm^{-1}$, 200/500MHz.km adequate

Agenda

Sessi

- **10 Gb/s Ethernet**
  - **objectives**
  - **proposals**
- **optical fibre developments**

Attenuation-limited LAN systems

Break

Bandwidth-limited LAN systems

Session Three

Multi-Gigabit applications

Practical implementation issues

End

10 Gb/s Ethernet: 802.3ae (03/02)

OBJECTIVES

- switched operation only
- star topology
- support link aggregation
- support 10GB/s Ethernet and 9.584640GB/s SONET
- 2000 m, 10000 m and 40000 m over SMF
- 100 m over existing MMF
- 300 m over “new” optical fibre @ 850nm

PROPOSALS

- legacy MMF
  - 850nm VCSELs: ~ 65 m
  - 850nm 4 x parallel optics: 300 m
  - 850nm PAM-5 coding: >100 m
  - 1300nm FP LASERs: > 100 m
  - 1300nm 4 x WWDM: 300 m
- enhanced MMF
  - 850nm VCSELs: 300 m
- legacy SMF
  - 1300nm LASERs: 300 m to 10000 m
  - 1550nm LASERs: 40000 m

Optical fibre developments

PROPOSALS UNDERWAY

50/125µm: 3.5/1.5dBkm^{-1}, 2200/500MHz.km

Bandwidth measurement made using LASER launch conditions

Agenda

Session One

Session Two

- channel configuration
- SFF connections
- testing the link
- testing the channel
- maintenance

Session Three

Multi-Gigabit applications

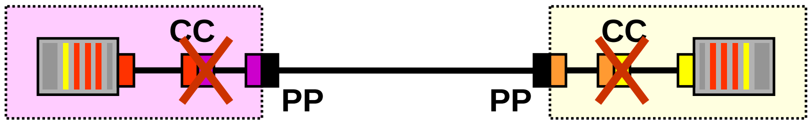
Practical implementation issues

End

Channel configuration

Reduce loss to a minimum for a given length

• do not use unnecessary connections



remember:

1 mated connection	= 142 metres (@ 850 nm in MMF)
	= 333 metres (@ 1300 nm in MMF)
1 splice	= 85 metres (@ 850 nm in MMF)
	= 200 metres (@ 1300 nm in MMF)

Consider splicing of pre-manufactured tails

Lower overall loss than field terminations

Adopt cleaning procedures to minimise contamination losses

SFF connections

Differ dramatically from conventional connectors

- ~~performance~~
- ~~cost~~
- ~~size~~
- duplex nature
- plug/socket configuration rather than plug/adaptor/plug
  - good for the inexpert user
  - bad for testing
  - bad for cleaning

ANSI/TIA/EIA 568B.3 (2000?)

- proposal exists to remove specific selection of connector
- currently SC-D
- this allows the use of SFF options “let the market decide”

Considerable range of options

- no definition of SFF
- some undergoing IEC interface standardiazation
  - LC, MT-RJ and SG (Volition)
  - interface standards do not guarantee interoperability
    - all items are proprietary
    - joint set consistency is required

Testing the link - conventional

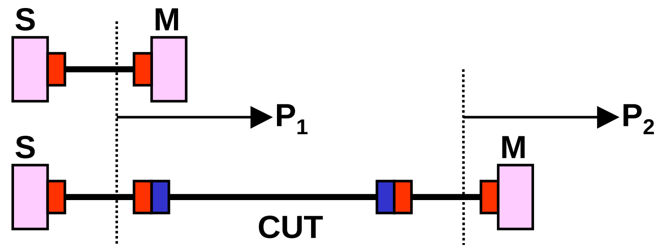
CONVENTIONAL METHOD

Source (S) and Meter (M)
- correct transmission window
  - wavelength correction (850 nm)
- fitted with correct adaptors
- stable
- calibrated

Test leads
- BS 7718 (IEC 61280-4)

Measurement error
- up to 0.75dB
- hides localised faults
  - small incremental losses
  - stress-induced
  - cause of breaks later

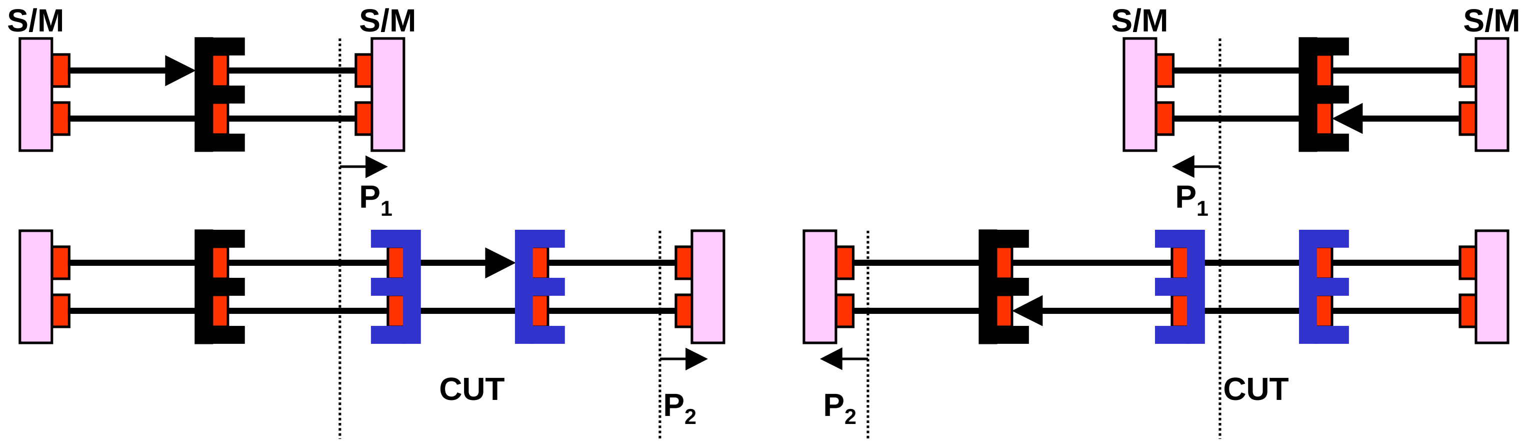
No evidence of test



Loss = CUT result - reference result
$= P_2 - P_1$

This test configuration is suitable for "patch panel - patch panel" installations on both multimode and single mode. Refer to BS 7718 or IEC 61280-4-1 and -2 for alternative configurations

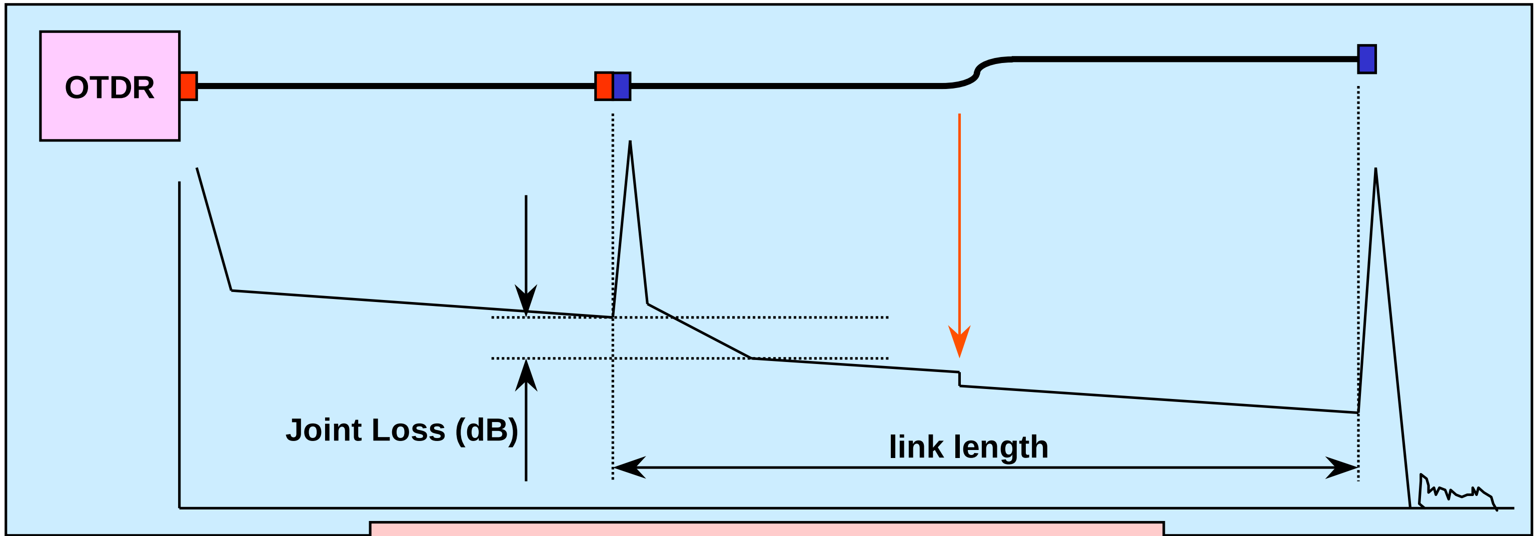
Testing the link - SFF



Loss = CUT result - reference result
$= P_2 - P_1$

Courtesy of
3M Innovation

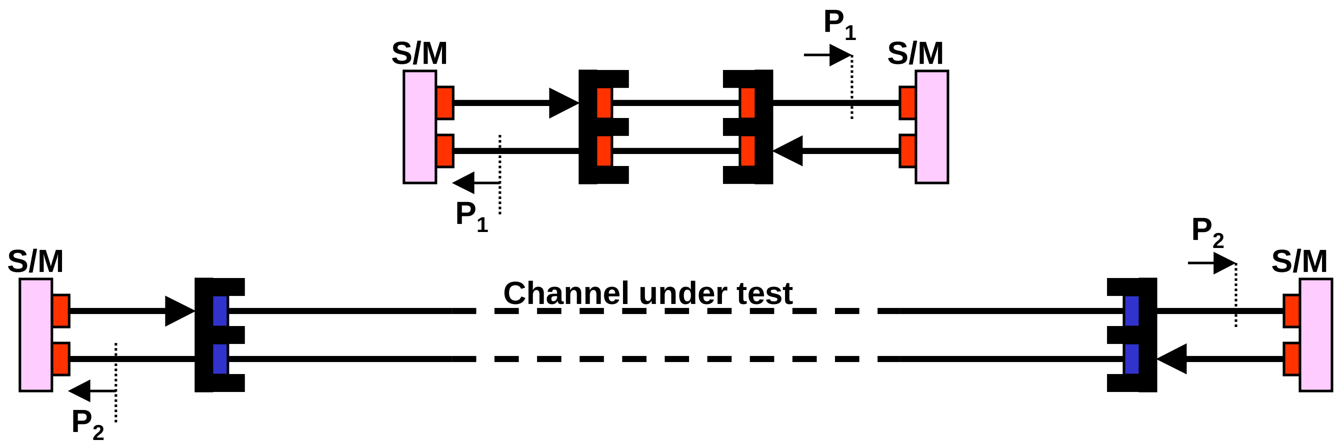
Testing the installation - OTDR



Optical Time Domain Reflectometer
- operating in correct transmission window
- calibrated

Test (launch) lead
- in accordance with BS7718 (IEC 1280-4)

Testing the channel - SFF



Channel loss = CUT result - reference result
= $P_2 - P_1$

Maintenance

CLEANLINESS IS NEXT TO

~~**GODLINESS**~~

WORKING GIGABIT NETWORKS

SFF connectors are proprietary
- **adopt cleaning regime recommended**

The End

- full colour copy of this presentation including explanatory notes
- www.it-cabling.com/gendocs/gsf.pdf

- the next MELTING POT seminars are on
  - 23rd March 2000
  - 28th March 2000