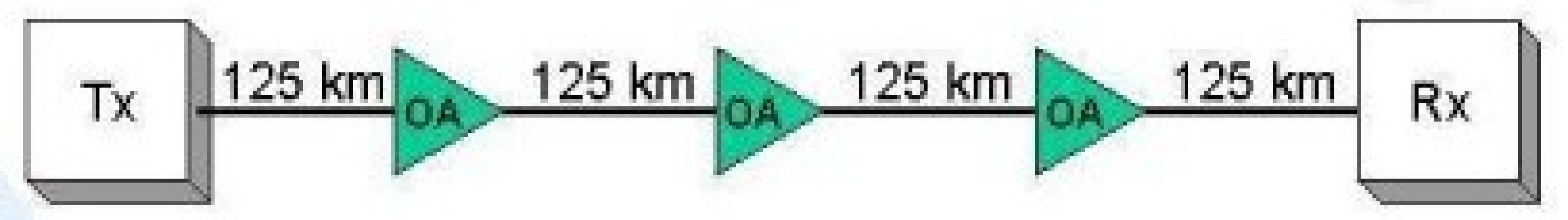
Amplificatori ottici per sistemi WDM

Sommario

- Introduzione;
- Amplificatori ottici a larga banda;
- **Erbium Doped Fiber Amplifiers;**
  - Componenti base di un EDFA;
  - “Architettura”;
  - Parametri di Design;
  - Esempio;
  - EDF;
  - Caratterizzazione sperimentale.

Amplificatori ottici: a cosa servono ?

- Il guadagno dell'OA compensa le perdite della tratta in fibra
  - Esempio:
    - 25 dB di perdita per ogni tratta
    - inseriti degli amplificatori ottici con 25 dB di guadagno

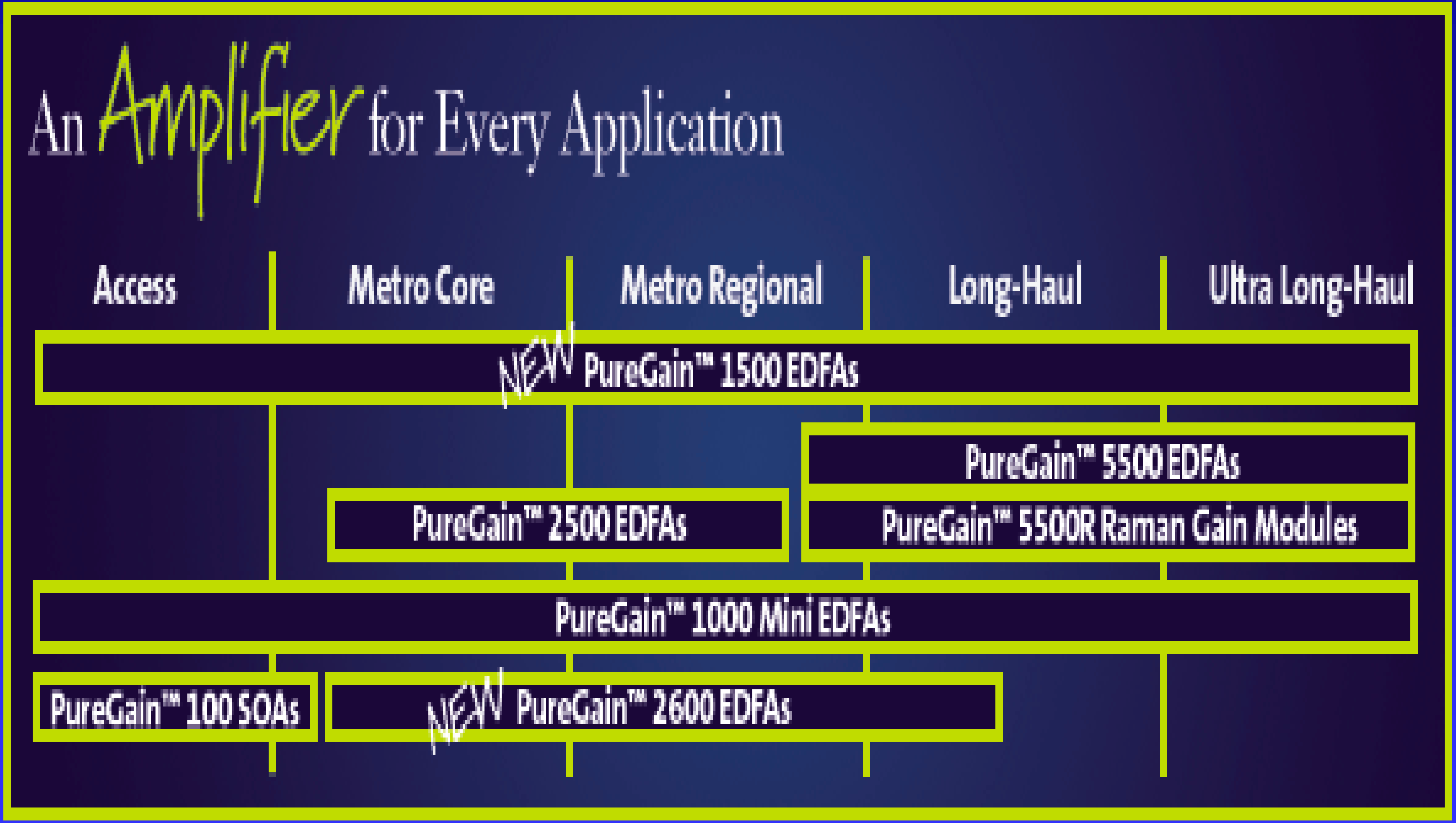

Tx
125 km
OA
125 km
OA
125 km
OA
125 km
Rx

Amplificatori ottici

- SOAs (Semiconductor Optical Amplifiers).
- FRAs (Fiber Raman Amplifiers).
- ReDFAs (Rare-earth Doped Fiber Amplifiers).
  - EDFAs (Erbium Doped Fiber Amplifiers).

- Amplets (SOA, FRA; ReDFA)

Lunghezza della tratta



An Amplifier for Every Application

Access | Metro Core | Metro Regional | Long-Haul | Ultra Long-Haul

NEW PureGain™ 1500 EDFAs

PureGain™ 5500 EDFAs

PureGain™ 2500 EDFAs

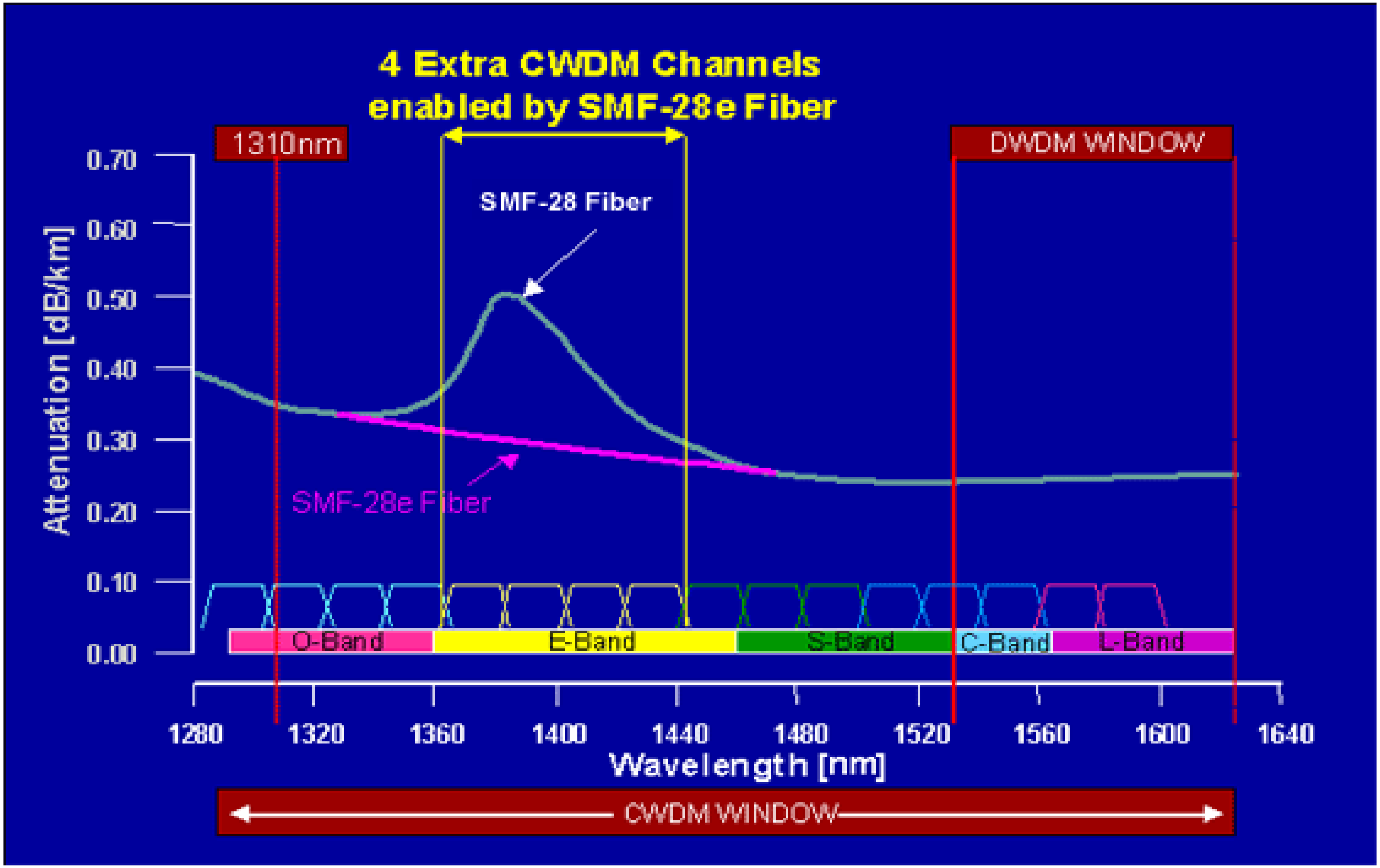
PureGain™ 5500R Raman Gain Modules

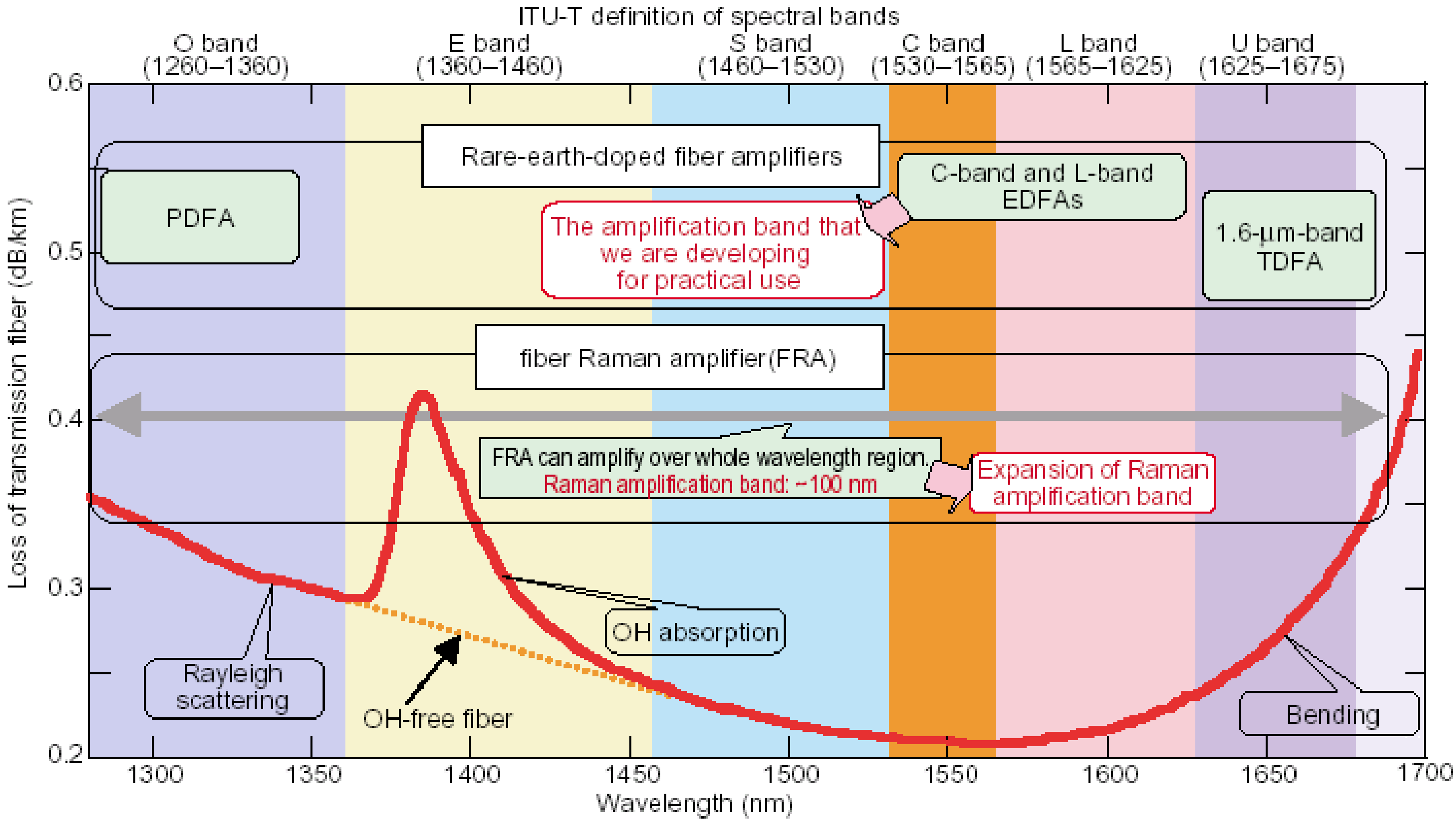
PureGain™ 1000 Mini EDFAs

PureGain™ 100 SOAs

NEW PureGain™ 2600 EDFAs

WDM, DWDM e CWDM





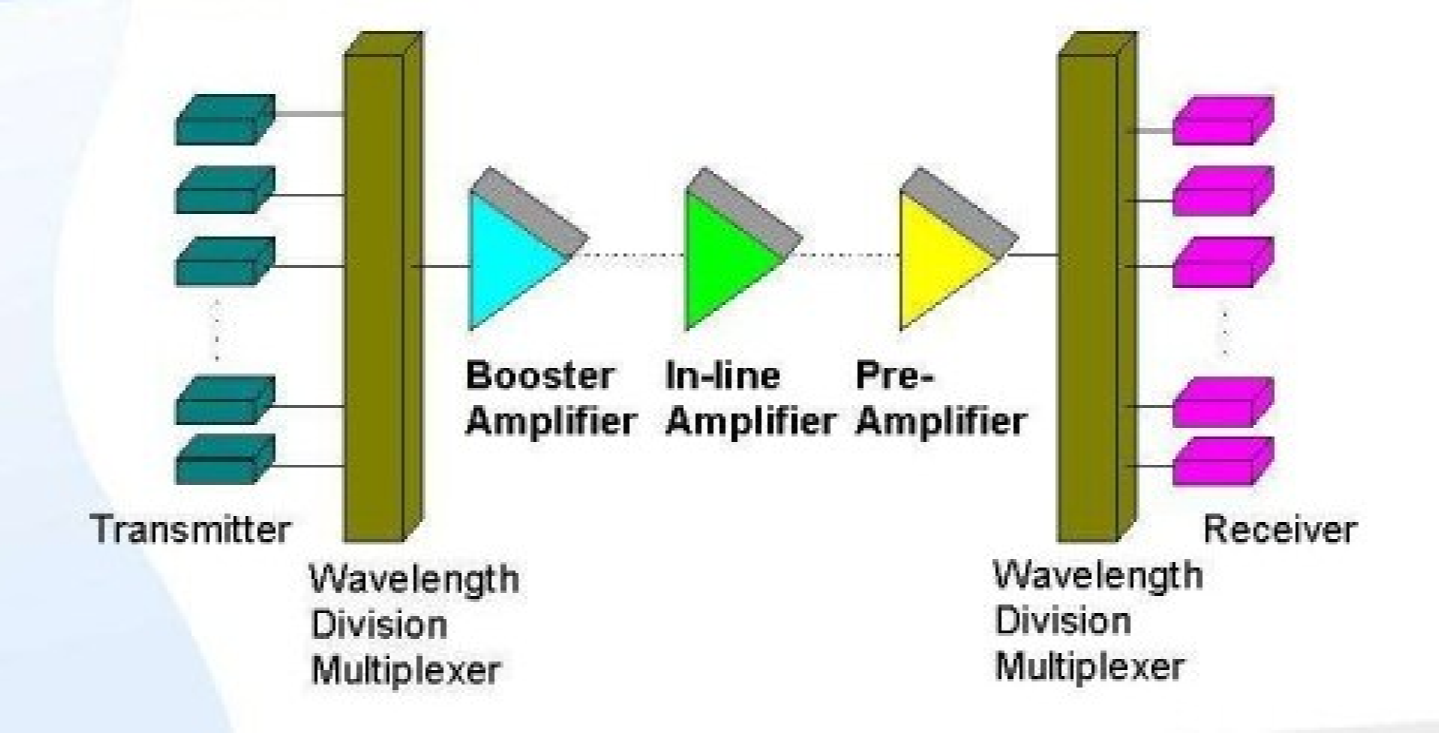
The amplification band that we are developing for practical use

FRA can amplify over whole wavelength region.
Raman amplification band: ~100 nm

Expansion of Raman amplification band

Fig. 1. Amplification bandwidth of each type of amplifier and loss spectrum of transmission fiber.

Locazione dell'OA lungo la linea


Booster Amplifier
In-line Amplifier
Pre-Amplifier
Transmitter
Wavelength Division Multiplexer
Receiver
Wavelength Division Multiplexer

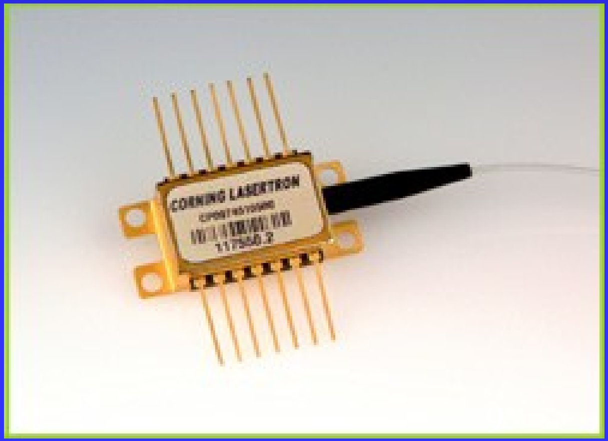
Componenti base di un EDFA (1/2)

JDS Uniphase
OA 500 SERIES

CORNING
March 2002

- Fibra drogata con Er^{3+}(EDF);

- Laser di pompa:
  980 oppure 1480nm.


CORNING LASERTRON

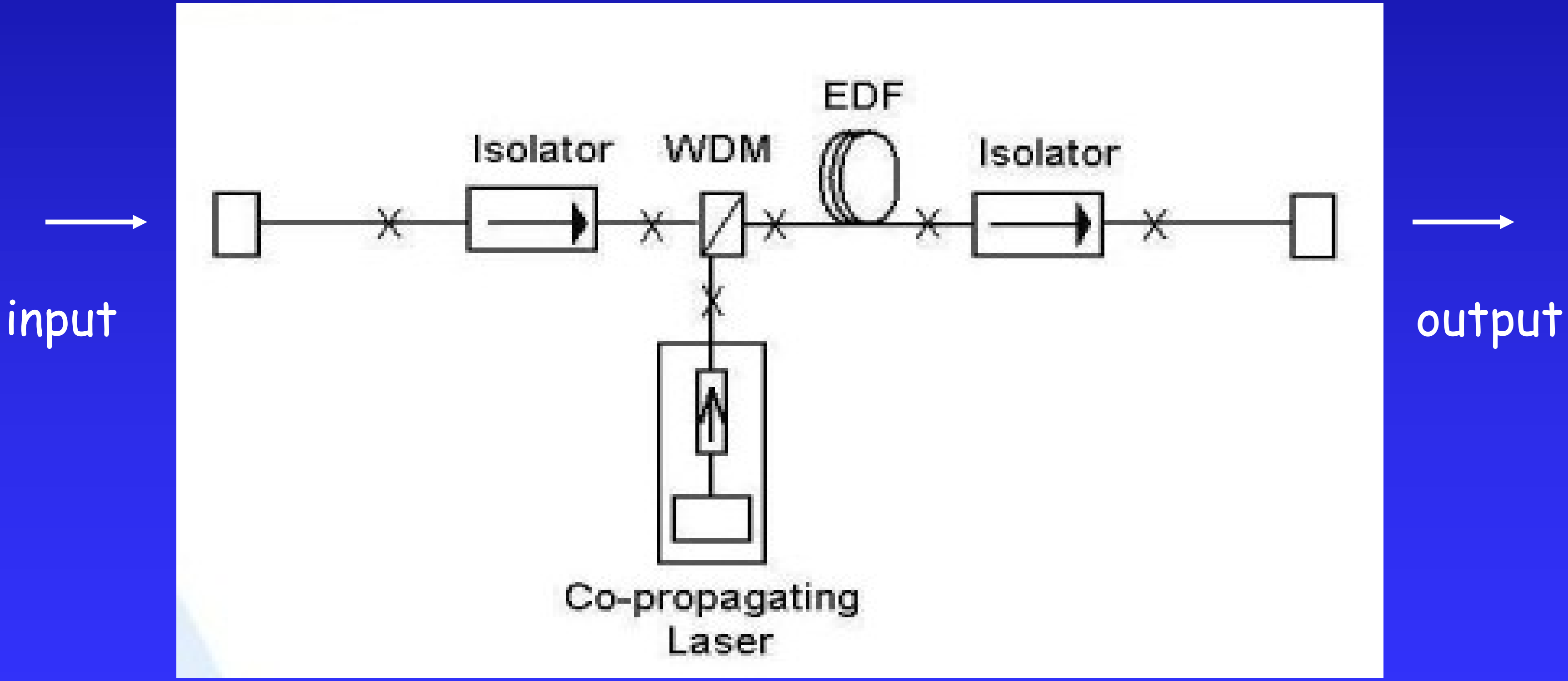
Componenti base di un EDFA (2/2)

- Componenti passivi:
  - WDM (wavelength division multiplexer);

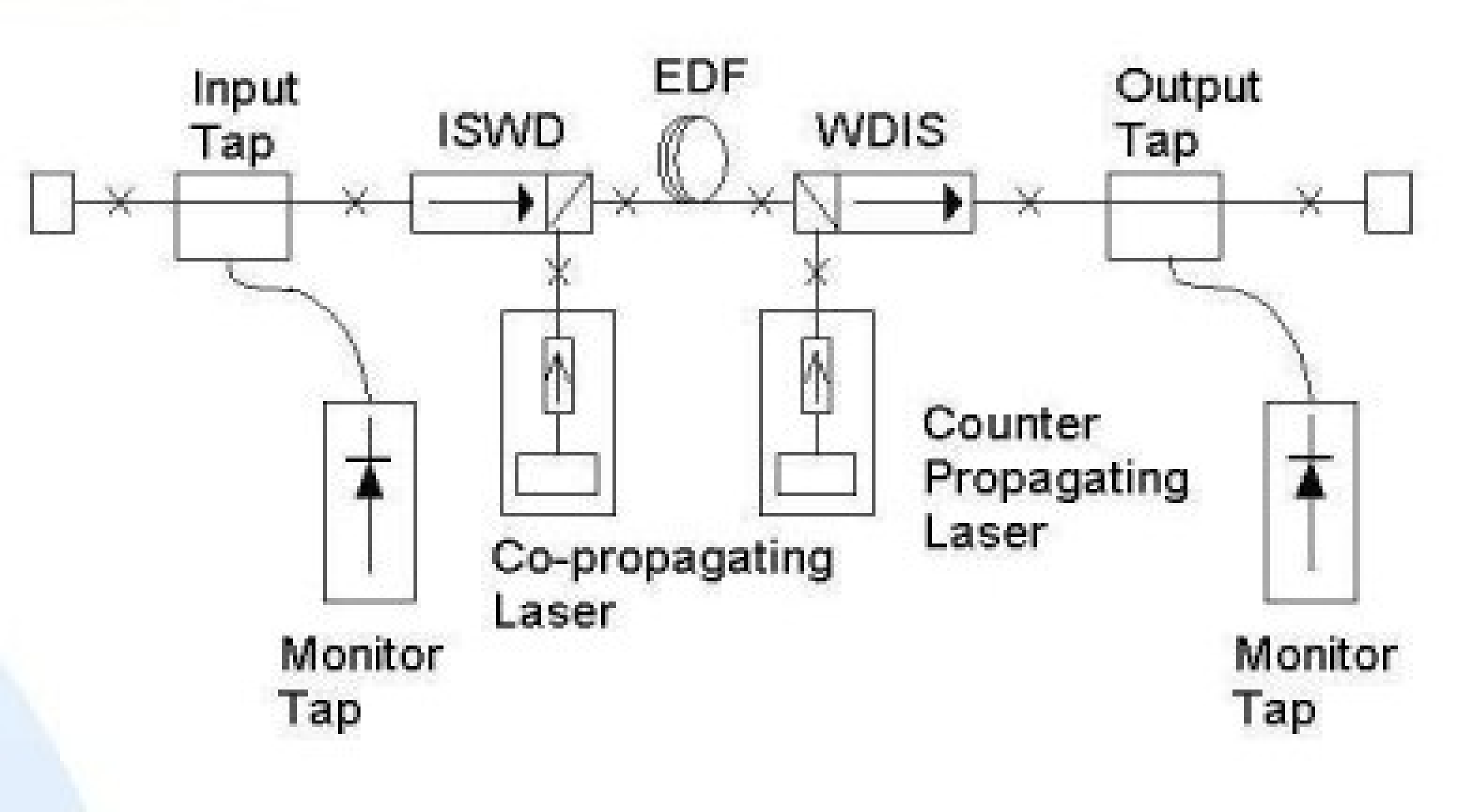
  - Isolatori ottici;

  - Gain Flattening Filter.

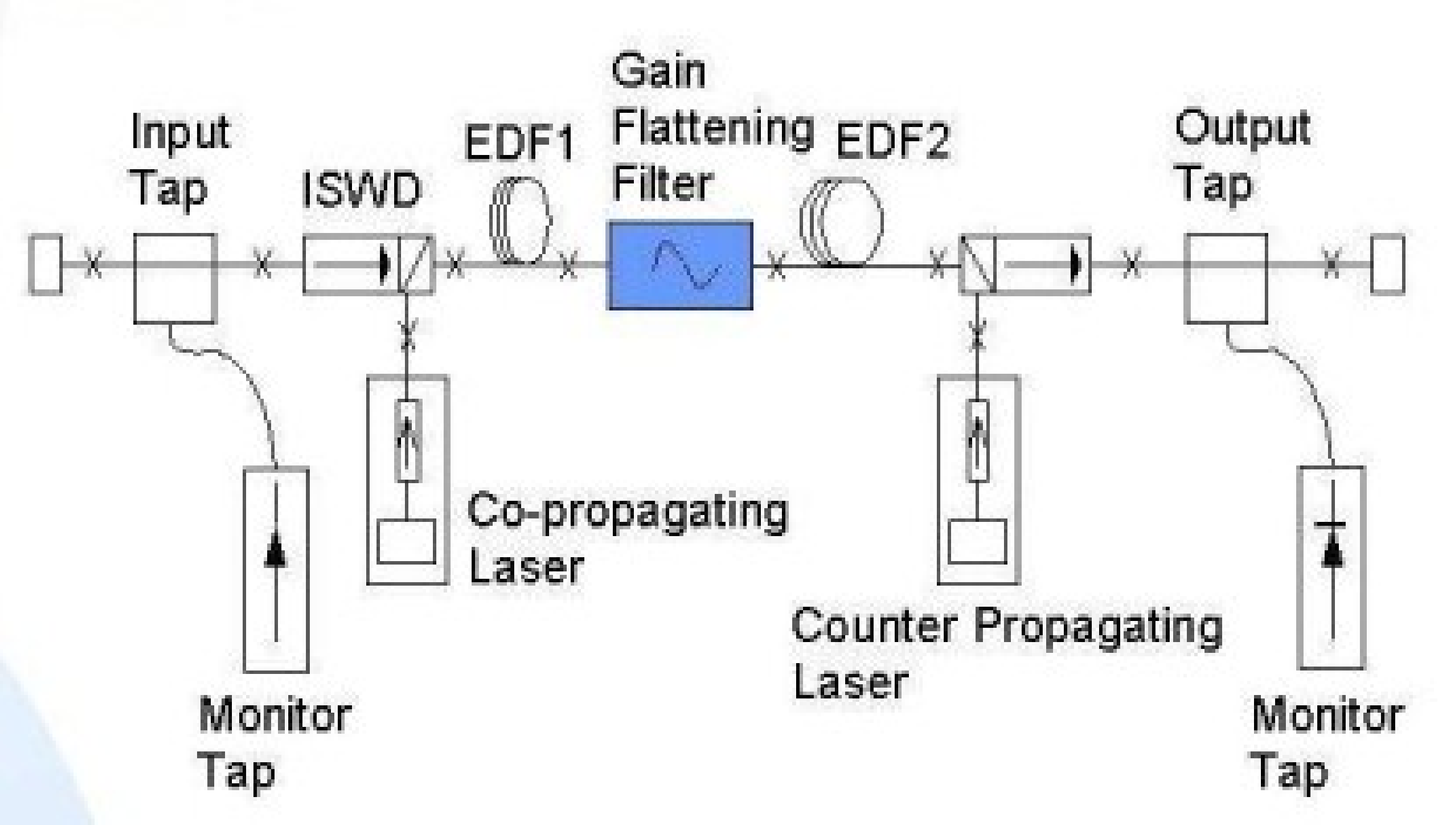
Architettura di un EDFA a singolo stadio (1/2)


input
Isolator
WDM
EDF
Isolator
output
Co-propagating Laser

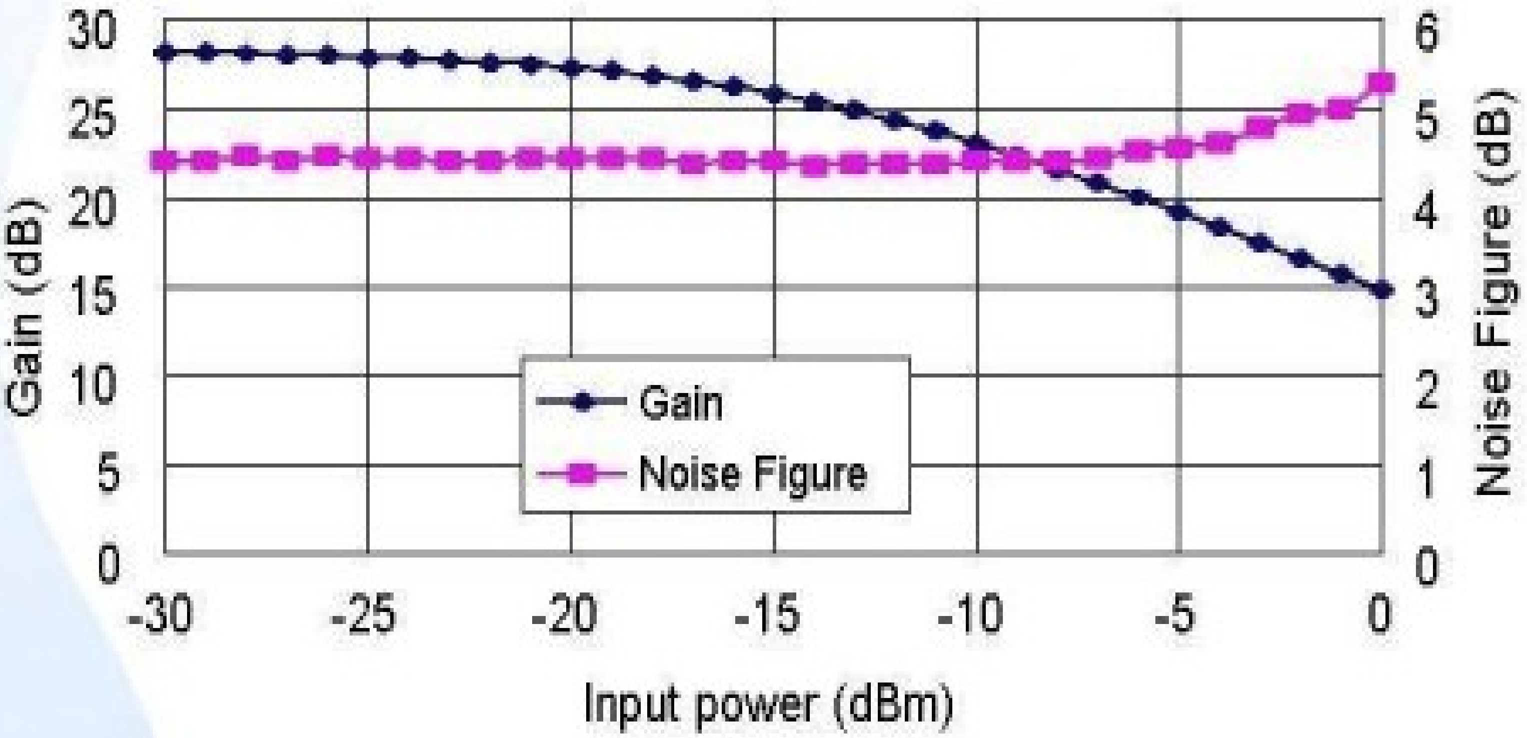
Architettura di un EDFA a singolo stadio (2/2)


Input Tap
ISWD
EDF
WDIS
Output Tap
Co-propagating Laser
Counter Propagating Laser
Monitor Tap
Monitor Tap

Architettura di un EDFA a doppio stadio


Input Tap
ISWD
EDF1
Gain Flattening Filter
EDF2
Output Tap
Co-propagating Laser
Counter Propagating Laser
Monitor Tap
Monitor Tap

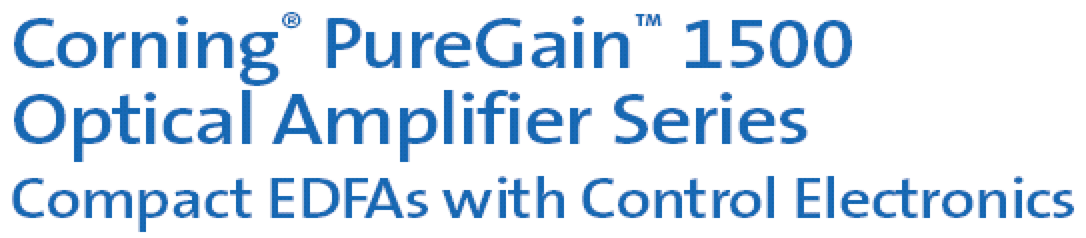
Guadagno


Gain (dB)
30
25
20
15
10
5
0
-30
-25
-20
-15
-10
-5
0
Input power (dBm)
6
5
4
3
2
1
0
Noise Figure (dB)
Gain
Noise Figure

Parametri di design

- Tipo di fibra drogata:
  - Apertura numerica;
  - Raggio del core e della zona drogata;
  - Profilo dell'indice di rifraz. e del drogante,
  - Concentrazione di drogante.
- Lunghezza della fibra drogata;
- Potenza di pompa;
- Filtro per equalizzzare il guadagno.

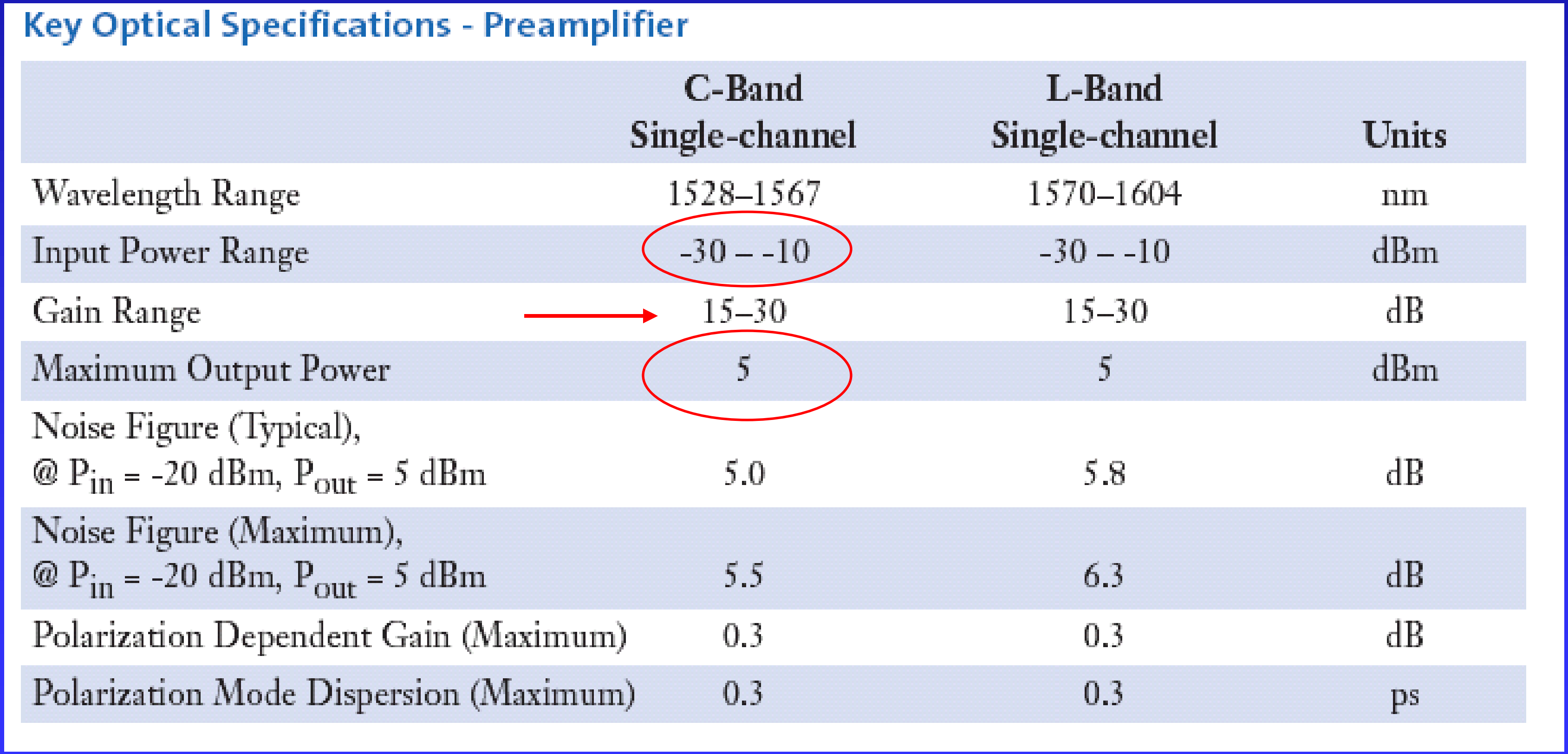
Esempio (1/3)



Corning® PureGain™ 1500 Optical Amplifier Series

Compact EDFAs with Control Electronics

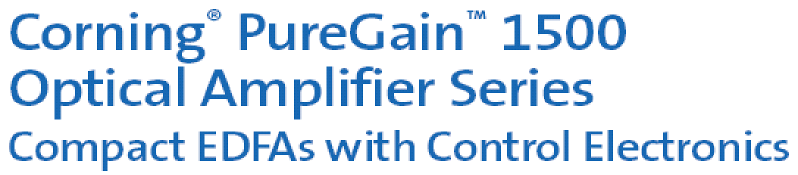
90 x 70 x 15 mm



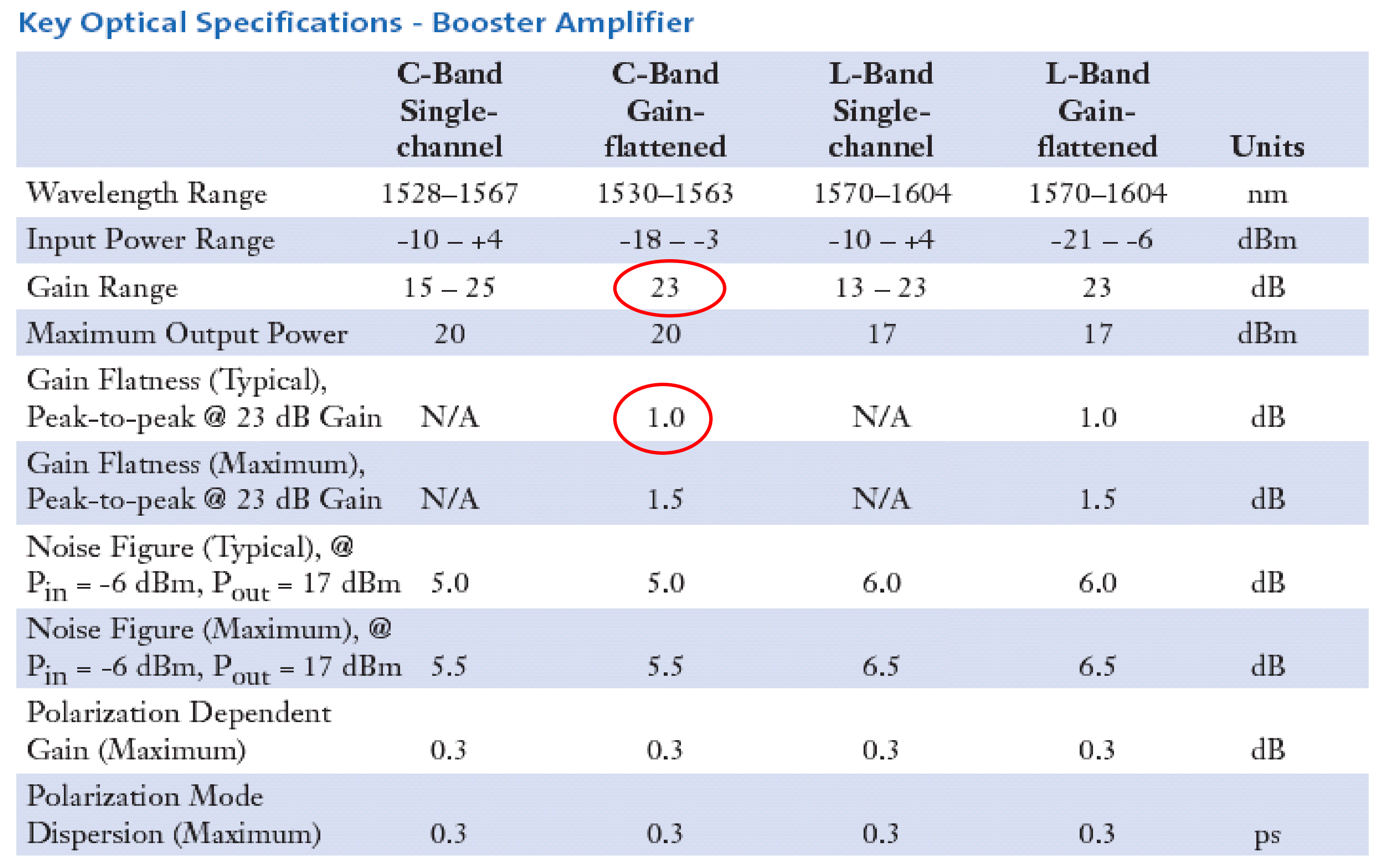
Key Optical Specifications - Preamplifier

	C-Band Single-channel	L-Band Single-channel	Units
Wavelength Range	1528–1567	1570–1604	nm
Input Power Range	-30 – -10	-30 – -10	dBm
Gain Range	15–30	15–30	dB
Maximum Output Power	5	5	dBm
Noise Figure (Typical), @ P_{in} = -20 dBm, P_{out} = 5 dBm	5.0	5.8	dB
Noise Figure (Maximum), @ P_{in} = -20 dBm, P_{out} = 5 dBm	5.5	6.3	dB
Polarization Dependent Gain (Maximum)	0.3	0.3	dB
Polarization Mode Dispersion (Maximum)	0.3	0.3	ps

Esempio (2/3)



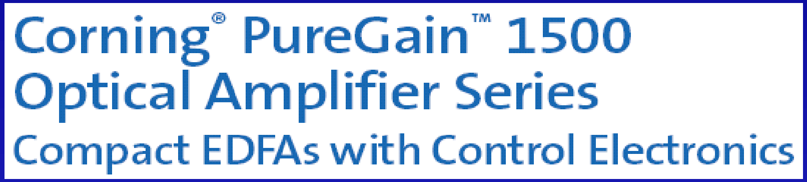
Corning® PureGain™ 1500
Optical Amplifier Series
Compact EDFAs with Control Electronics



Key Optical Specifications - Booster Amplifier

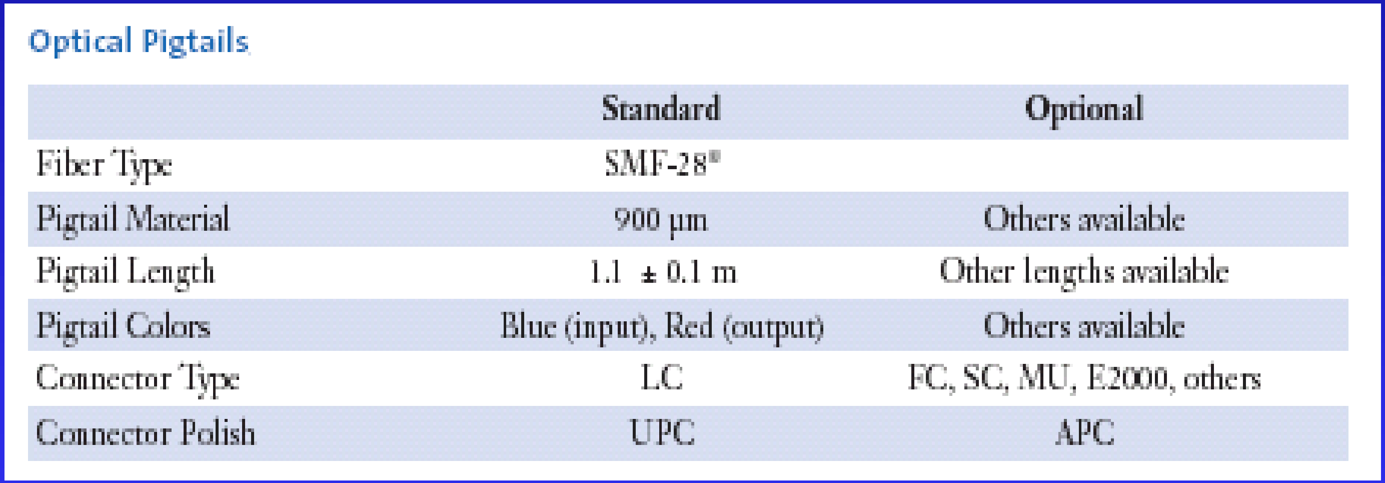
	C-Band Single-channel	C-Band Gain-flattened	L-Band Single-channel	L-Band Gain-flattened	Units
Wavelength Range	1528–1567	1530–1563	1570–1604	1570–1604	nm
Input Power Range	-10 – +4	-18 – -3	-10 – +4	-21 – -6	dBm
Gain Range	15 – 25	23	13 – 23	23	dB
Maximum Output Power	20	20	17	17	dBm
Gain Flatness (Typical), Peak-to-peak @ 23 dB Gain	N/A	1.0	N/A	1.0	dB
Gain Flatness (Maximum), Peak-to-peak @ 23 dB Gain	N/A	1.5	N/A	1.5	dB
Noise Figure (Typical), @ P_{in} = -6 dBm, P_{out} = 17 dBm	5.0	5.0	6.0	6.0	dB
Noise Figure (Maximum), @ P_{in} = -6 dBm, P_{out} = 17 dBm	5.5	5.5	6.5	6.5	dB
Polarization Dependent Gain (Maximum)	0.3	0.3	0.3	0.3	dB
Polarization Mode Dispersion (Maximum)	0.3	0.3	0.3	0.3	ps

Esempio (3/3)



Corning® PureGain™ 1500 Optical Amplifier Series

Compact EDFAs with Control Electronics



Optical Pigtails

	Standard	Optional
Fiber Type	SMF-28®	
Pigtail Material	900 µm	Others available
Pigtail Length	1.1 ± 0.1 m	Other lengths available
Pigtail Colors	Blue (input), Red (output)	Others available
Connector Type	LC	FC, SC, MU, E2000, others
Connector Polish	UPC	APC

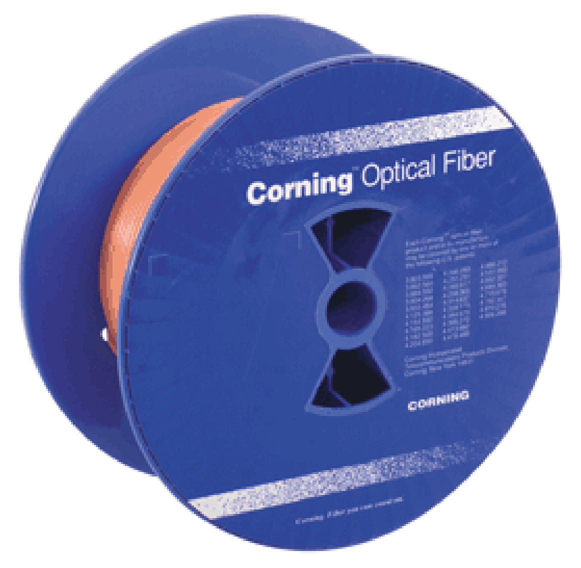
FC-FC/PC
ST-ST/SP
SC-SC/APC
SC2-SC2/APC
SMA
FDDI
BICONICO

Fibre per trasmissione vs fibre speciali

Facciamo un passo indietro….

Come è una fibra per trasmissione o fibra “standard” ?

SMF28



- 900μm Tight Buffer Outer Jacket
- Core Cladding Concentricity <0.8μm
- Core Diameter 8.3μm Typical
- Zero Dispersion Wavelength 1312nm Typical

Specifications:

- Operating Wavelength: 1260-1600nm
- Mode Field Dia. 1310nm/1550nm: 9.3μm /10.5μm
- Cladding ±1μm: 125mm
- Cut-Off Wavelength: <1260nm
- Attenuation @ 1310nm: <0.40dB/km
- Attenuation @ 1550nm: <0.30dB/km

NA: 0.13

Price: **$575.00** 1000m

Fibre speciali

- Fibre a mantenimento della polarizzazione.
- Fibre a singola polarizzazione.
- Fibre fotosensibili.
- Fibre per la compensazione della dispersione.
- Fibre ad alto salto di indice.
- Fibre drogate con erbio.

Erbium Doped Fiber

- Raggio del core;
- Profilo di indice di rifrazione;
- Apertura numerica;
- Concentrazione di erbio (ioni/m^3);
- Vetro ospite (Al-Ge-Er-doped silica);

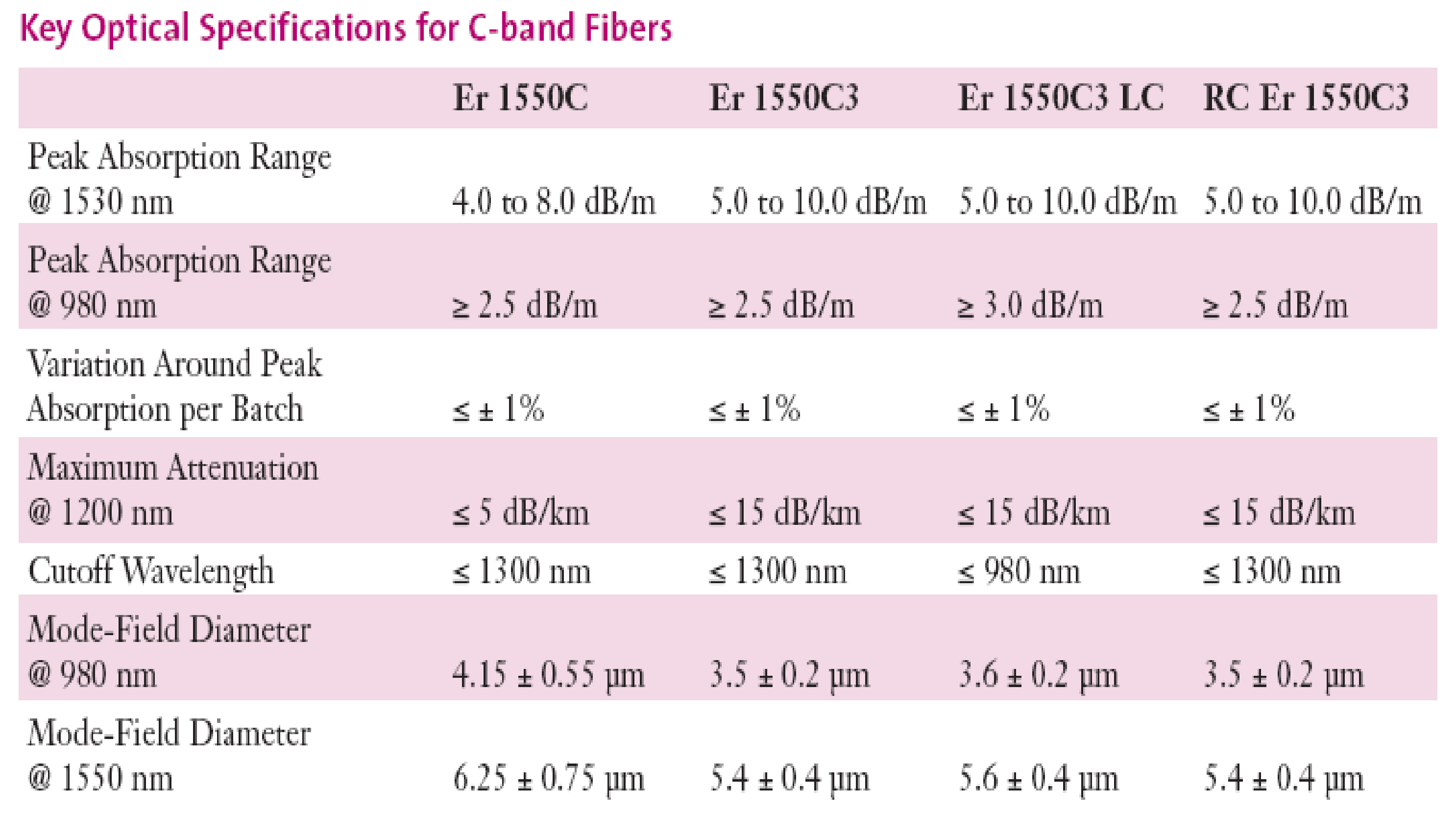
→ caratteristiche spettrali.

EDF555 - 1530-1560nm

- Single Mode For Pumping At 980 to 1480nm
- Core Concentricity <0.5mm
- Mode Field Diameter: 7.4μm @ 1550nm
- **Core diameter 4.7μm**, cladding 125μm,
- Jacket 250μm
- Cut-Off Wavelength: 910±50nm
- **Peak Absorption: 8.7dB/m @ 1530nm**
- **Core Material: $Er^{3+}Al_2O_3/GeO_2/SiO_2$**
- NA: 0.22
- **PRICE PER METER:**
  1 TO 9m: $67.50
  10 TO 49m: $50.00
  50 TO 249m: $43.50
  250 TO 999m: $36.43

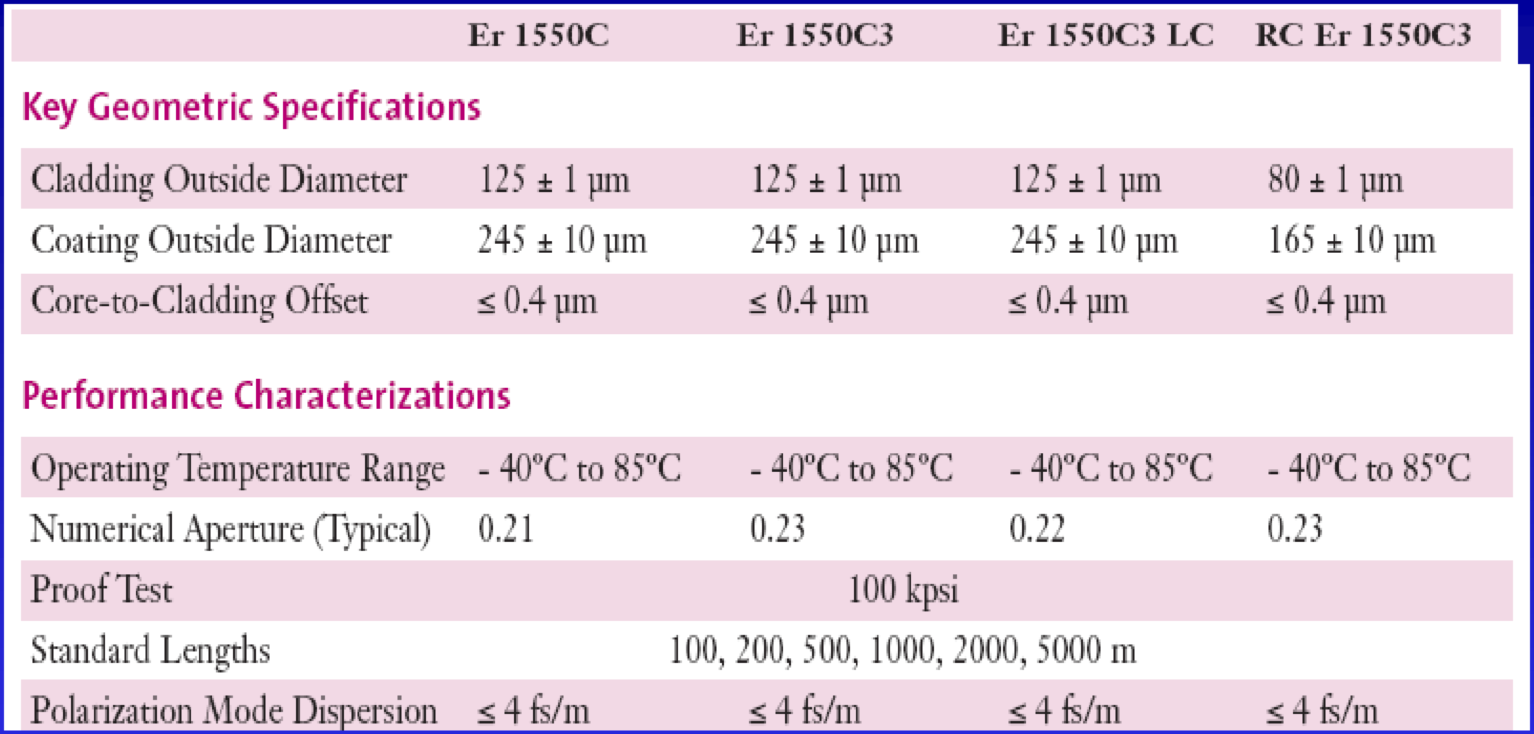
Corning® Er Specialty Fibers

Erbium-Doped Fibers for Use in Optical Amplifiers

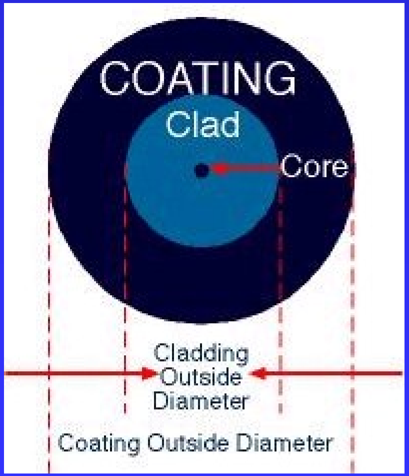


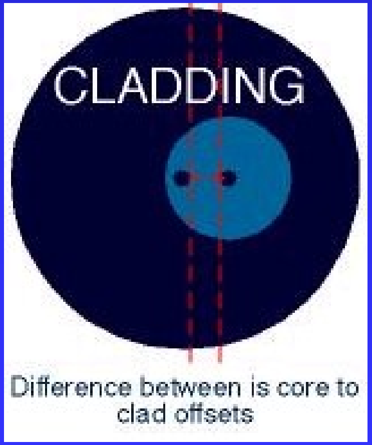
Key Optical Specifications for C-band Fibers

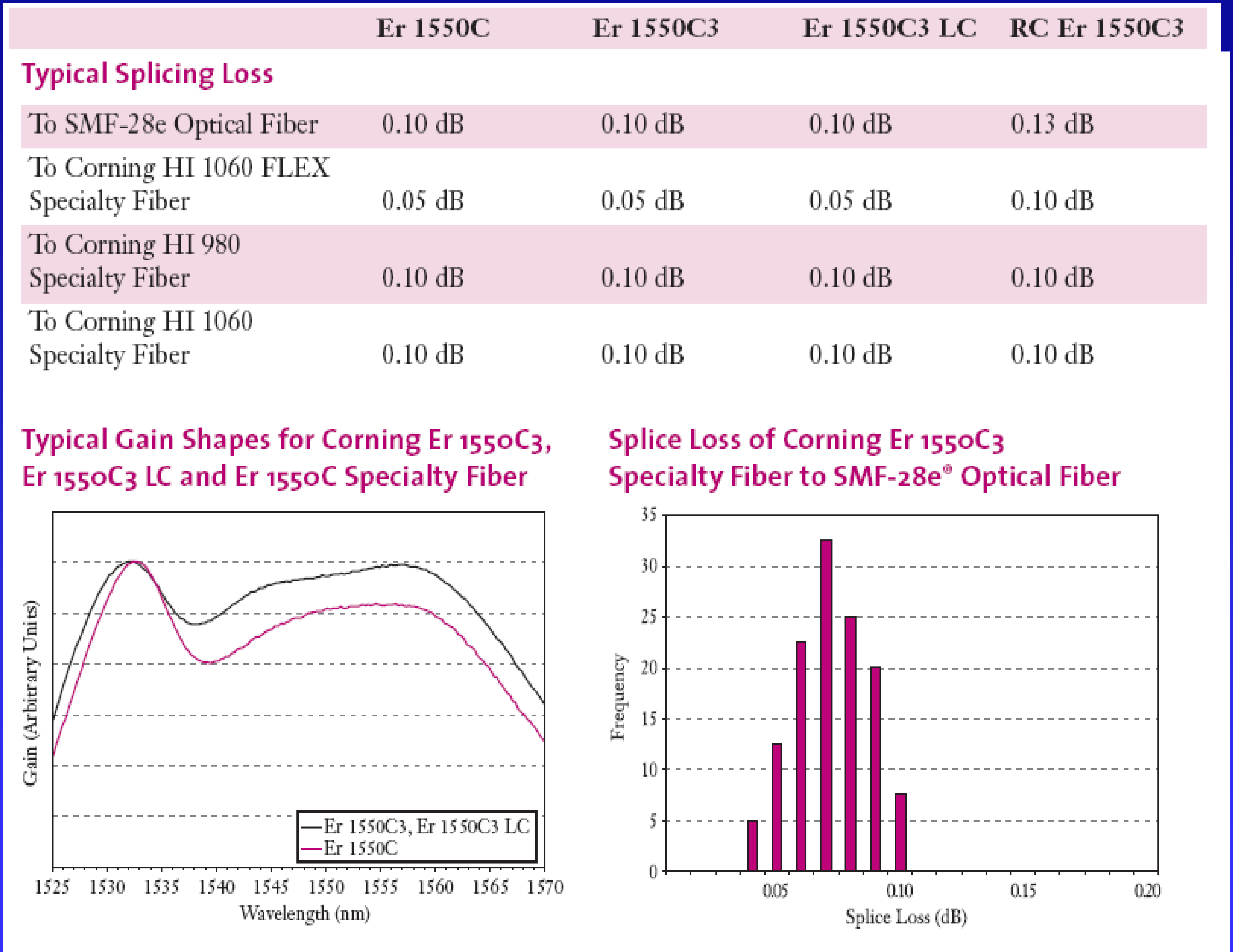
	Er 1550C	**Er 1550C3**	**Er 1550C3 LC**	**RC Er 1550C3**
Peak Absorption Range @ 1530 nm	4.0 to 8.0 dB/m	5.0 to 10.0 dB/m	5.0 to 10.0 dB/m	5.0 to 10.0 dB/m
Peak Absorption Range @ 980 nm	≥ 2.5 dB/m	≥ 2.5 dB/m	≥ 3.0 dB/m	≥ 2.5 dB/m
Variation Around Peak Absorption per Batch	≤ ± 1%	≤ ± 1%	≤ ± 1%	≤ ± 1%
Maximum Attenuation @ 1200 nm	≤ 5 dB/km	≤ 15 dB/km	≤ 15 dB/km	≤ 15 dB/km
Cutoff Wavelength	≤ 1300 nm	≤ 1300 nm	≤ 980 nm	≤ 1300 nm
Mode-Field Diameter @ 980 nm	4.15 ± 0.55 µm	3.5 ± 0.2 µm	3.6 ± 0.2 µm	3.5 ± 0.2 µm
Mode-Field Diameter @ 1550 nm	6.25 ± 0.75 µm	5.4 ± 0.4 µm	5.6 ± 0.4 µm	5.4 ± 0.4 µm



	Er 1550C	Er 1550C3	Er 1550C3 LC	RC Er 1550C3
Key Geometric Specifications				
Cladding Outside Diameter	125 ± 1 µm	125 ± 1 µm	125 ± 1 µm	80 ± 1 µm
Coating Outside Diameter	245 ± 10 µm	245 ± 10 µm	245 ± 10 µm	165 ± 10 µm
Core-to-Cladding Offset	≤ 0.4 µm	≤ 0.4 µm	≤ 0.4 µm	≤ 0.4 µm
Performance Characterizations				
Operating Temperature Range	- 40°C to 85°C	- 40°C to 85°C	- 40°C to 85°C	- 40°C to 85°C
Numerical Aperture (Typical)	0.21	0.23	0.22	0.23
Proof Test	100 kpsi			
Standard Lengths	100, 200, 500, 1000, 2000, 5000 m			
Polarization Mode Dispersion	≤ 4 fs/m	≤ 4 fs/m	≤ 4 fs/m	≤ 4 fs/m


COATING
Clad
Core
Cladding Outside Diameter
Coating Outside Diameter


CLADDING
Difference between is core to clad offsets



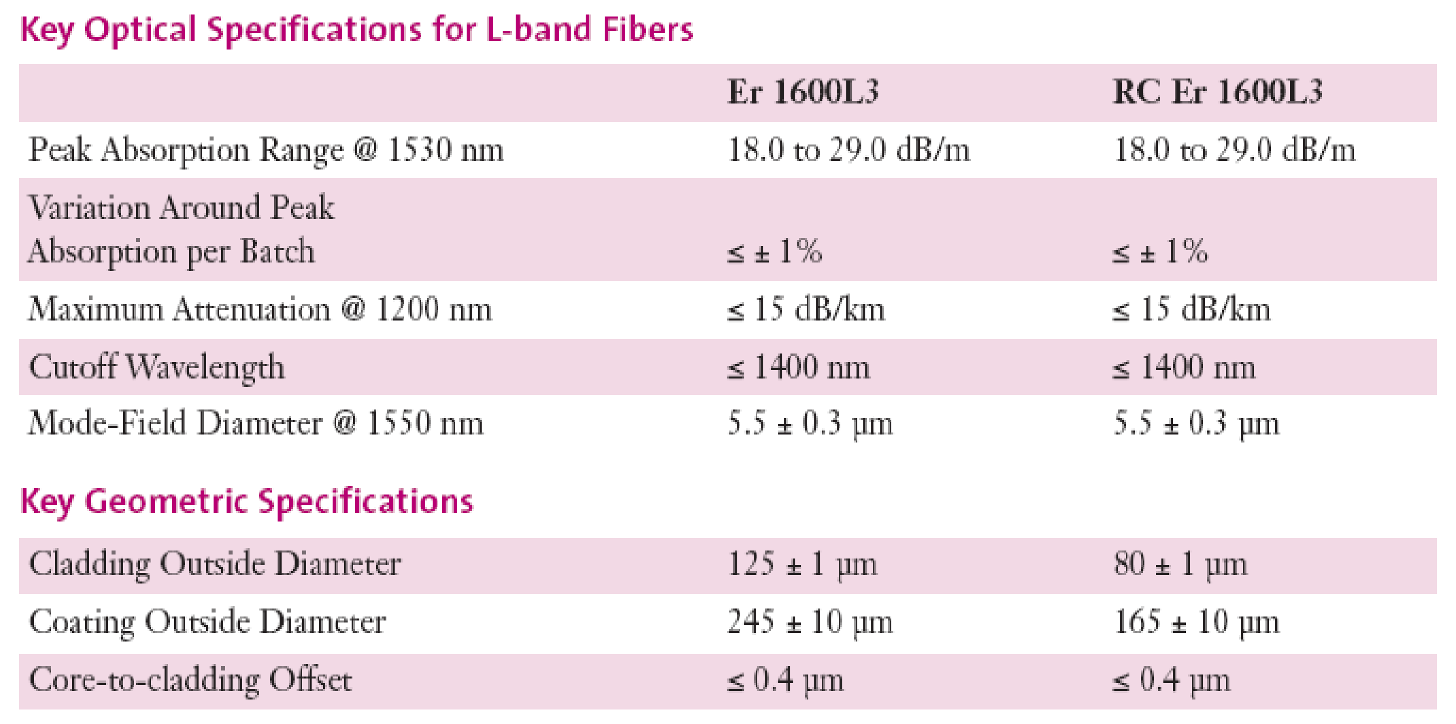
	Er 1550C	Er 1550C3	Er 1550C3 LC	RC Er 1550C3
Typical Splicing Loss				
To SMF-28e Optical Fiber	0.10 dB	0.10 dB	0.10 dB	0.13 dB
To Corning HI 1060 FLEX Specialty Fiber	0.05 dB	0.05 dB	0.05 dB	0.10 dB
To Corning HI 980 Specialty Fiber	0.10 dB	0.10 dB	0.10 dB	0.10 dB
To Corning HI 1060 Specialty Fiber	0.10 dB	0.10 dB	0.10 dB	0.10 dB

Typical Gain Shapes for Corning Er 1550C3, Er 1550C3 LC and Er 1550C Specialty Fiber

Gain (Arbitrary Units)
Wavelength (nm)
1525
1530
1535
1540
1545
1550
1555
1560
1565
1570
Er 1550C3, Er 1550C3 LC
Er 1550C

Splice Loss of Corning Er 1550C3 Specialty Fiber to SMF-28e® Optical Fiber

Frequency
0
5
10
15
20
25
30
35
Splice Loss (dB)
0.05
0.10
0.15
0.20



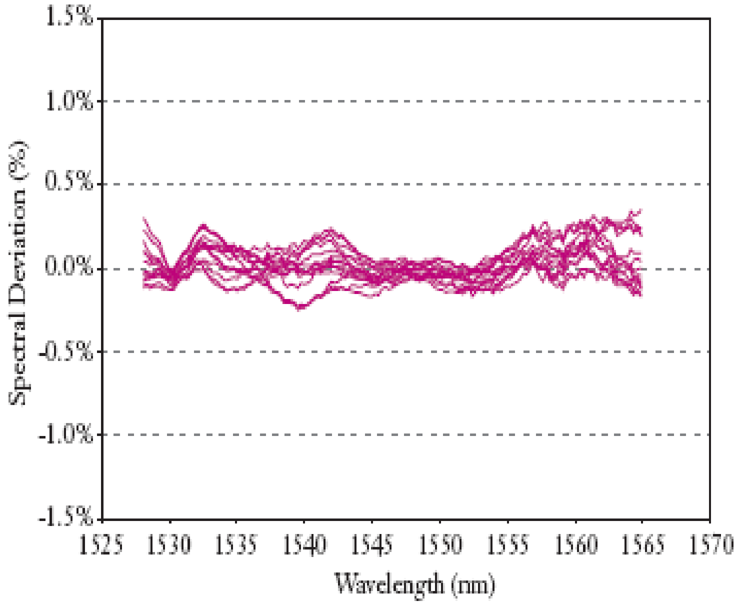
Key Optical Specifications for L-band Fibers

	Er 1600L3	RC Er 1600L3
Peak Absorption Range @ 1530 nm	18.0 to 29.0 dB/m	18.0 to 29.0 dB/m
Variation Around Peak Absorption per Batch	≤ ± 1%	≤ ± 1%
Maximum Attenuation @ 1200 nm	≤ 15 dB/km	≤ 15 dB/km
Cutoff Wavelength	≤ 1400 nm	≤ 1400 nm
Mode-Field Diameter @ 1550 nm	5.5 ± 0.3 µm	5.5 ± 0.3 µm

Key Geometric Specifications

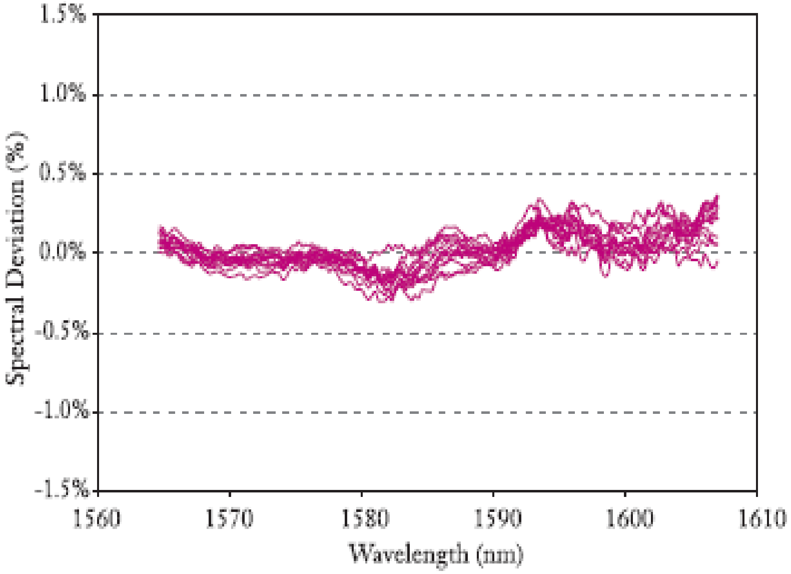
Cladding Outside Diameter	125 ± 1 µm	80 ± 1 µm
Coating Outside Diameter	245 ± 10 µm	165 ± 10 µm
Core-to-cladding Offset	≤ 0.4 µm	≤ 0.4 µm

Spectral Uniformity of Corning Er 1550C3 Specialty Fiber



Representative samples from multiple batches totaling more than 350 km.

Spectral Uniformity of Corning Er 1600L3 Specialty Fiber



Representative samples from multiple batches totaling more than 125 km.

Quali grandezze misurare ? (1/2)

- Sezioni d'urto di assorbimento e di emissione.

oppure

- Coefficienti di assorbimento, di guadagno e il parametro di saturazione intrinseca.

Quali grandezze misurare ? (2/2)

$$\alpha = \mathrm{N_T}\, \Gamma(\lambda)\ \ \sigma_\mathrm{a}(\lambda)$$

$$\mathrm{g} = \mathrm{N_T}\, \Gamma(\lambda)\ \ \sigma_\mathrm{e}(\lambda)$$

$$\xi = \mathrm{A_{eff}}\, \mathrm{N_T} / \tau$$

α , g e ξ sono direttamente misurabili

$\sigma_\mathrm{a}(\lambda)$, $\sigma_\mathrm{e}(\lambda)$ non sono direttamente misurabili ma possono essere ricavate.

Caratterizzazione sperimentale della EDF

Strumentazione base:

- Optical Spectrum Analyzer (OSA);
- Sorgente di luce bianca;
- Tunable Laser.

Optical Spectrum Analyzer (1/3)

Optical Spectrum Analyzer (2/3)

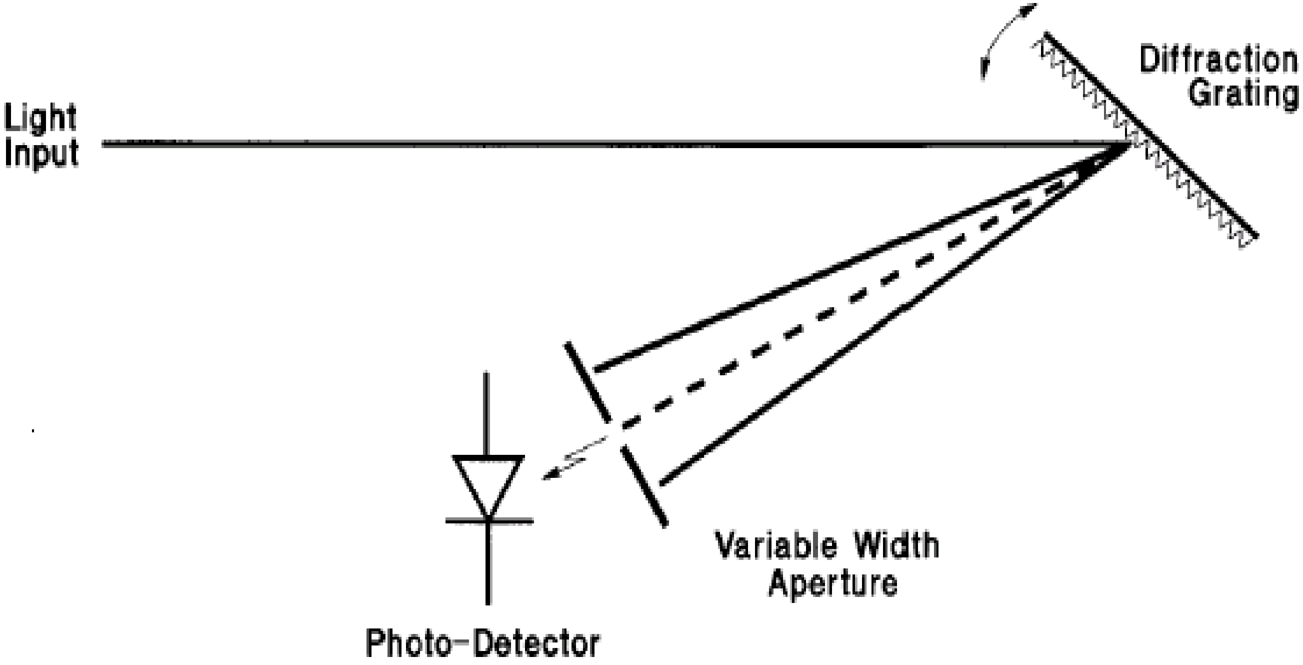
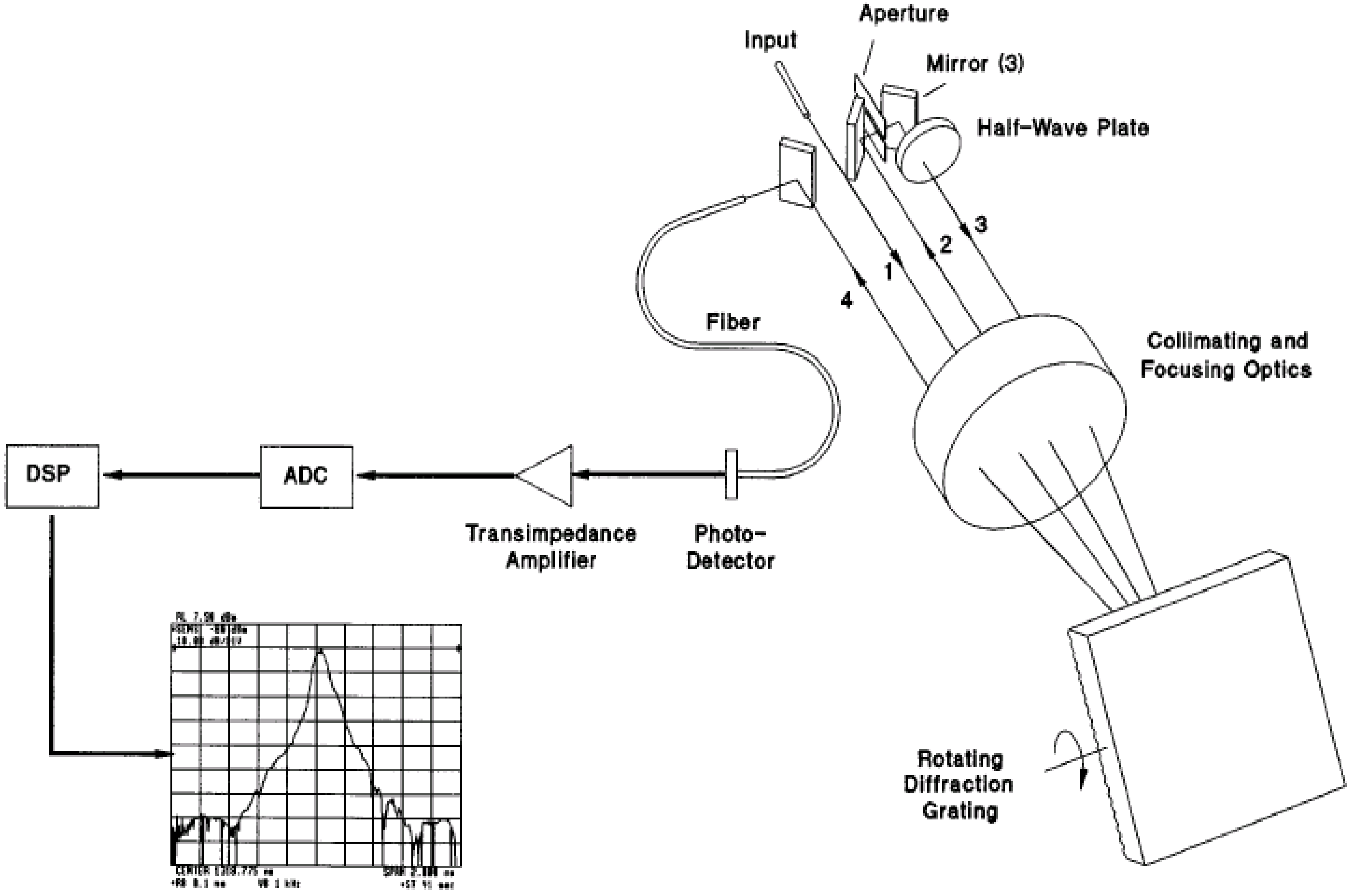
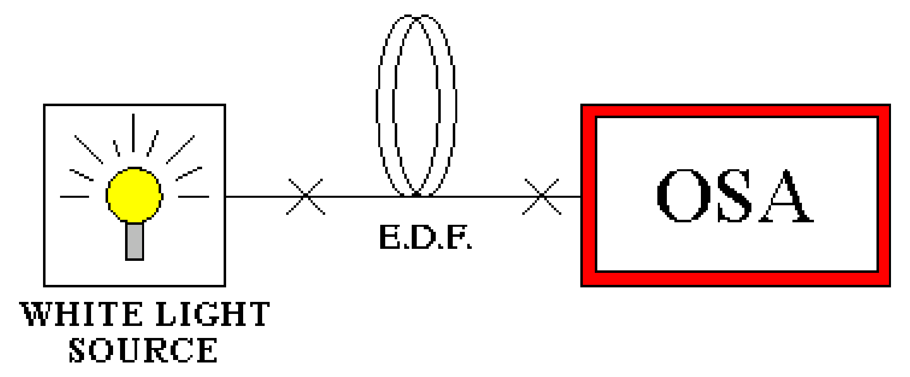

Diffraction Grating
Light Input
Variable Width Aperture
Photo-Detector

Figure 7.
Diffraction-grating-based
optical spectrum analyzer.

Optical Spectrum Analyzer (2/3)


Aperture
Input
Mirror (3)
Half-Wave Plate
3
2
1
4
Fiber
Collimating and
Focusing Optics
DSP
ADC
Transimpedance
Amplifier
Photo-
Detector
Rotating
Diffraction
Grating

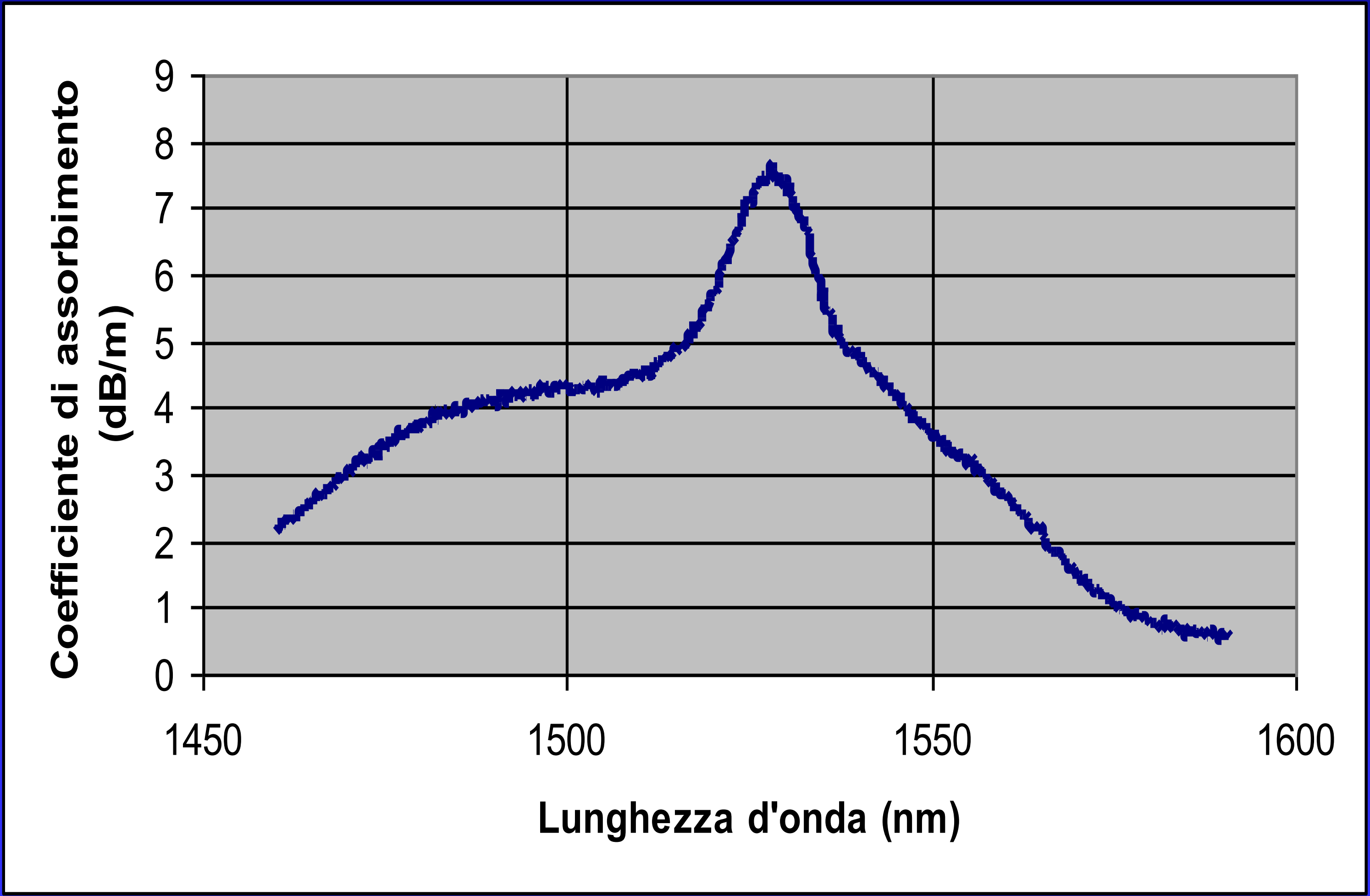
Misura di assorbimento (1/2)


WHITE LIGHT SOURCE
E.D.F.
OSA

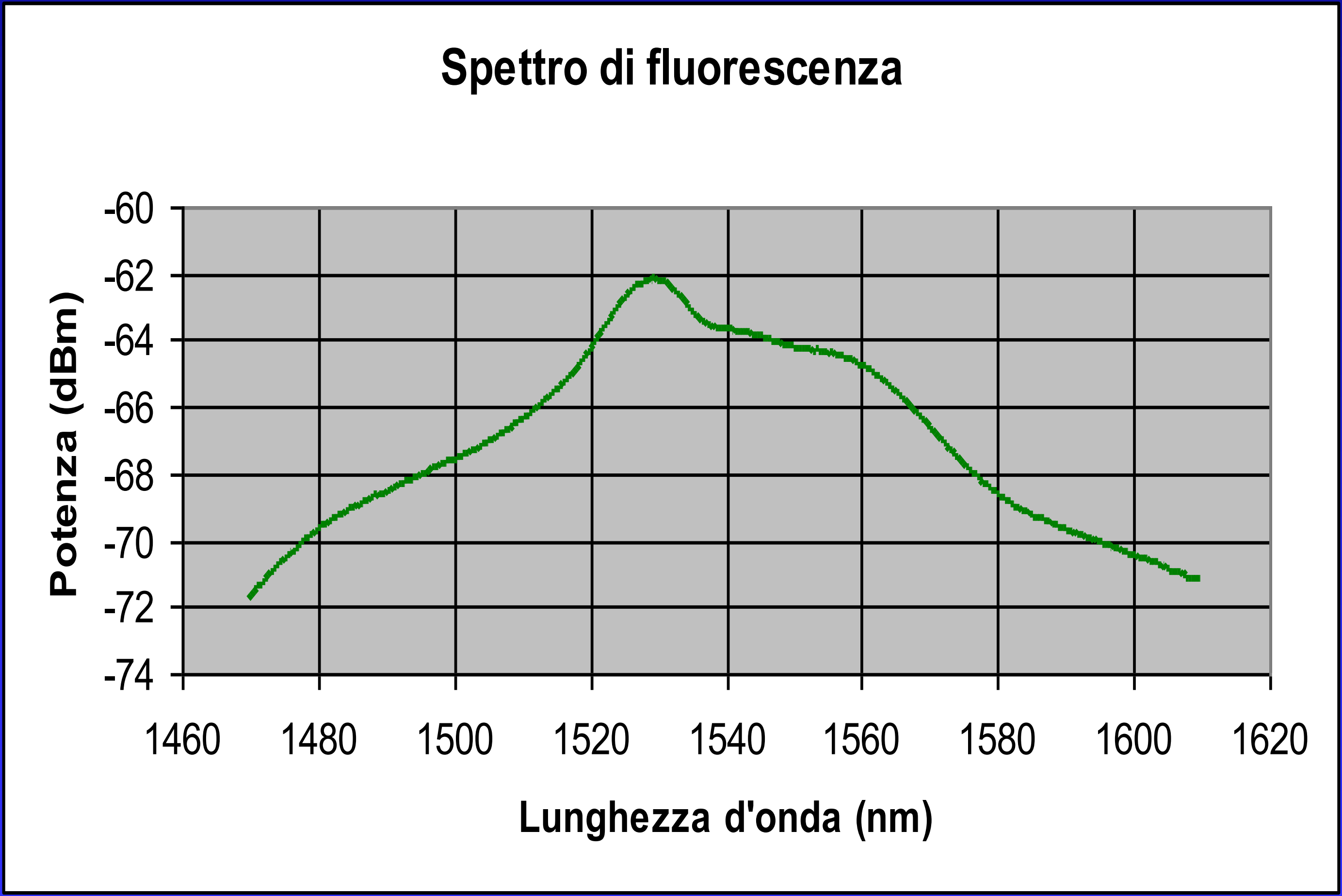
Tecnica del cut-back:

- $P^{out}(L_2)$ [dB]
- Taglio un pezzo di fibra $\Delta L = L_2 - L_1$
- $P^{out}(L_1)$ [dB]
- $A[dB/m] = (P^{out}(L_1) - P^{out}(L_2)) / \Delta L$

Misura di assorbimento (2/2)

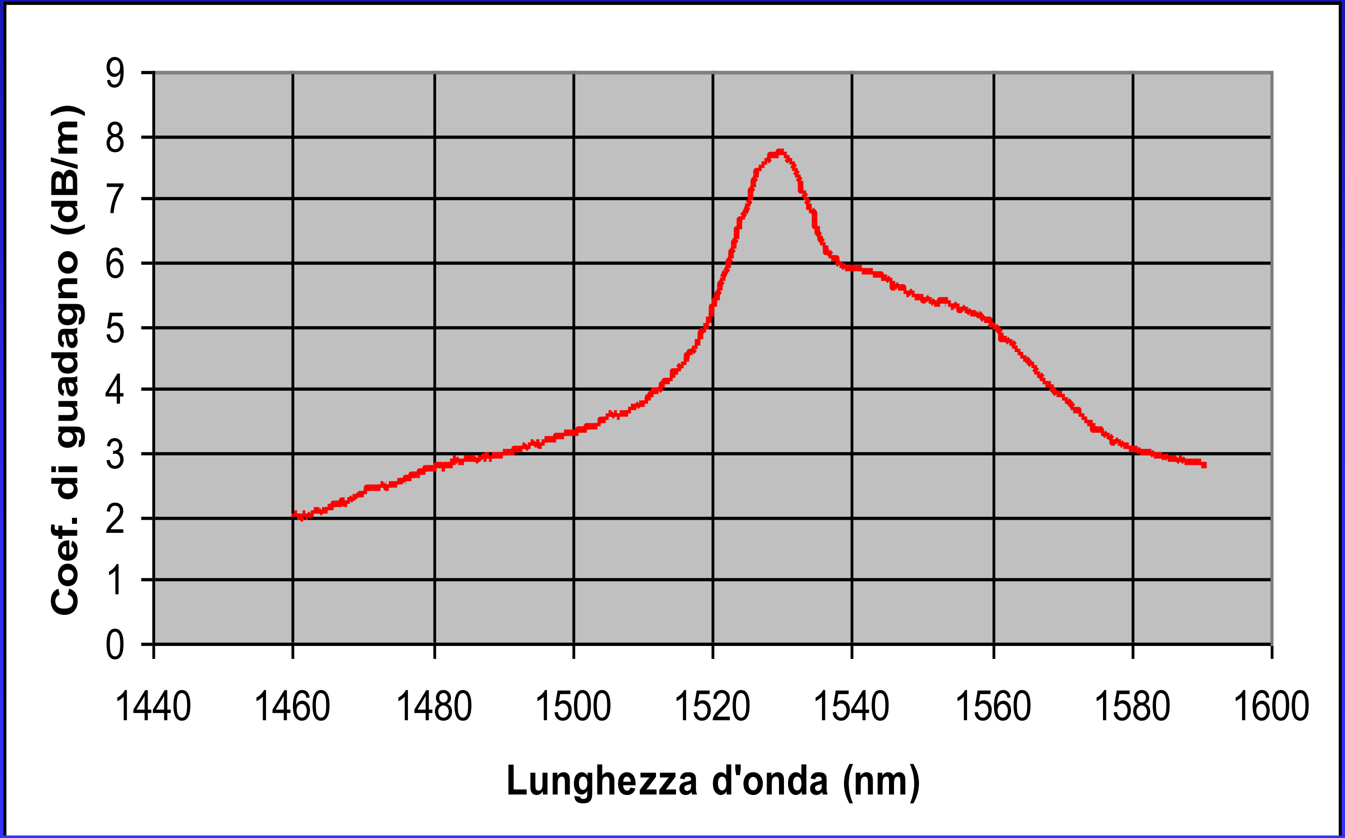


Misura di fluorescenza

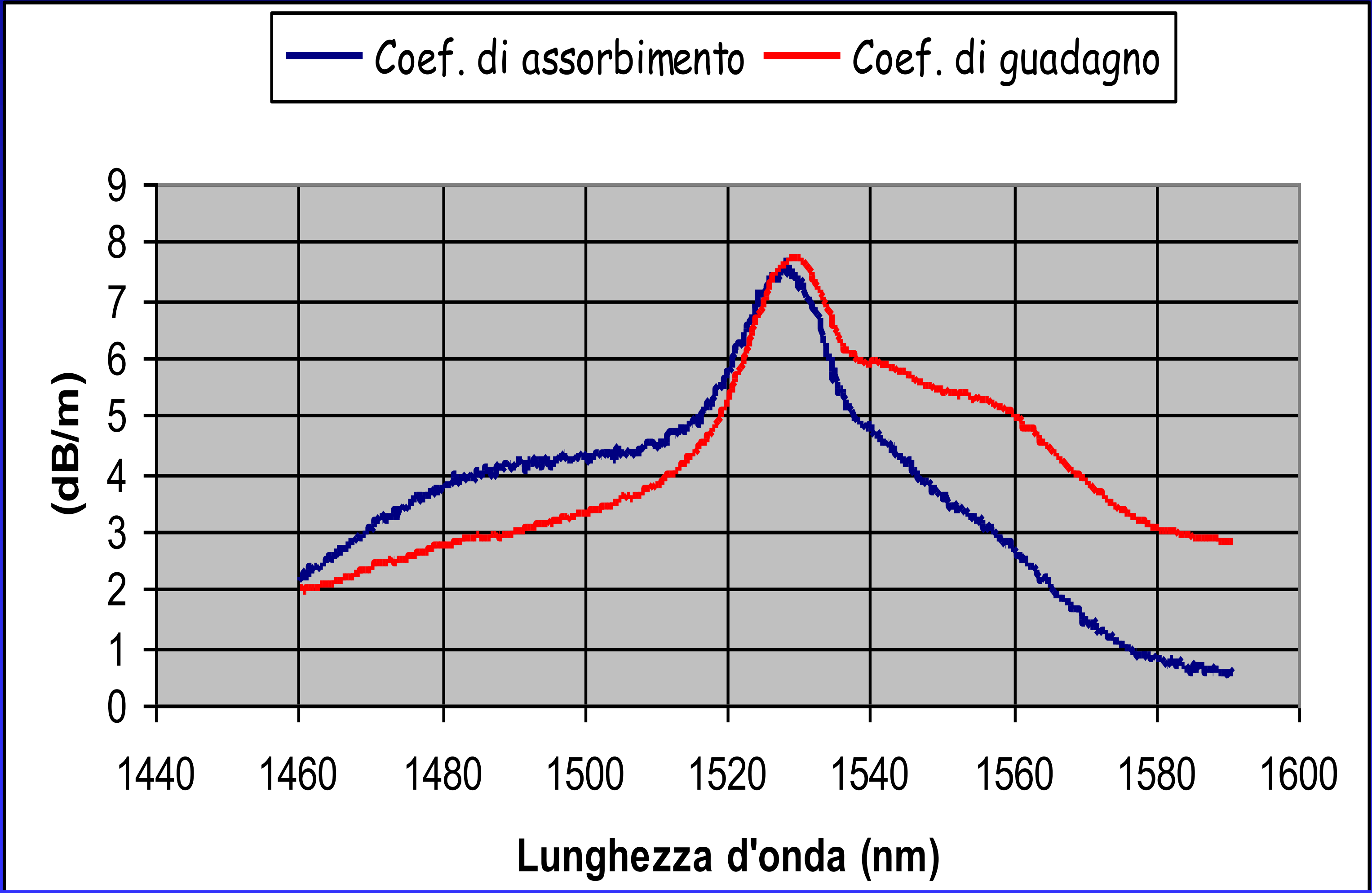


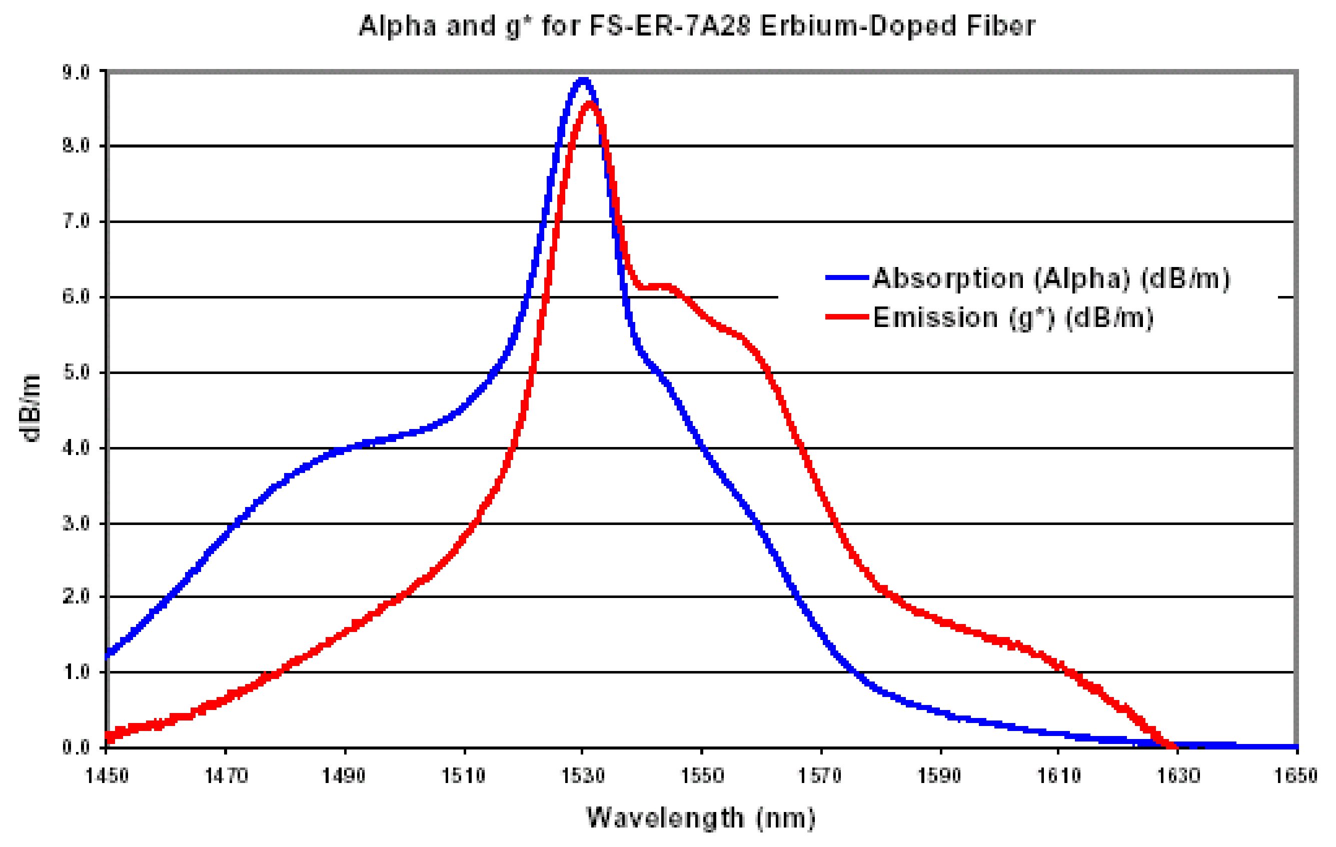
Misura di guadagno

$$g(\lambda)=[\Delta G(\lambda^*)/L - \alpha\ (\lambda^*)]F\ (\lambda)/F\ (\lambda^*)$$



Assorbimento e Guadagno



Fibra per banda C