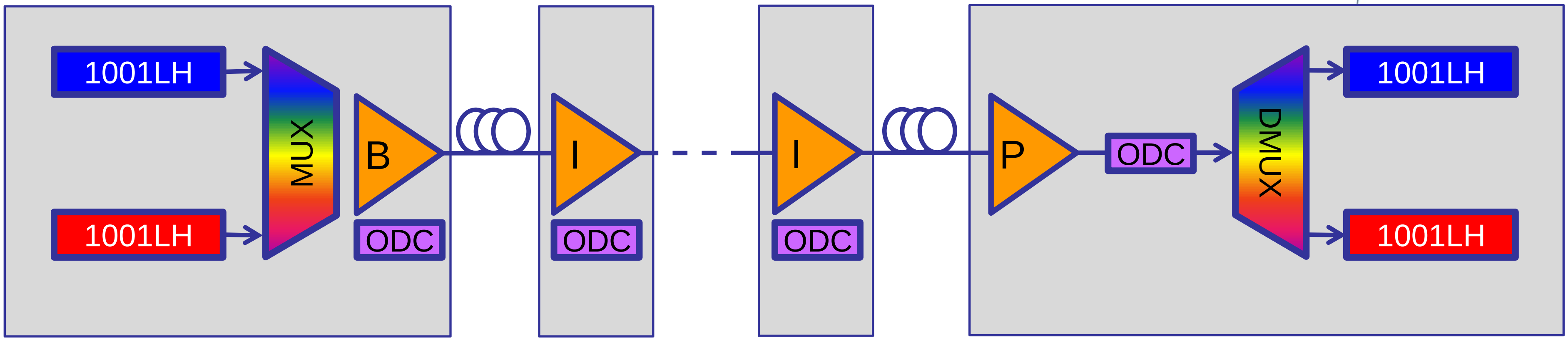
DWDM Basics

DWDM Basics

- **DWDM Network Components**
  - ⇨ Line Fiber
  - ⇨ Multiplexers and OADMs
  - ⇨ Optical Amplifiers
  - ⇨ Chromatic Dispersion Compensators
  - ⇨ Service Cards (10G, 2G5,...)

- **Main parameters of a DWDM design**
  - ⇨ Attenuation (fiber,...)
  - ⇨ Receivers Sensitivity (10G)
  - ⇨ Optical Signal to Noise Ratio (OSNR)
  - ⇨ Forward Error Correction (FEC)
  - ⇨ Non Linear Effects
  - ⇨ DWDM Line Examples

DWDM Network Components



- Line Fiber
- Optical MUX / DMUX
- OADM / ROADM
- Optical Amplifiers
- Optical Dispersion Compensators
- Service cards

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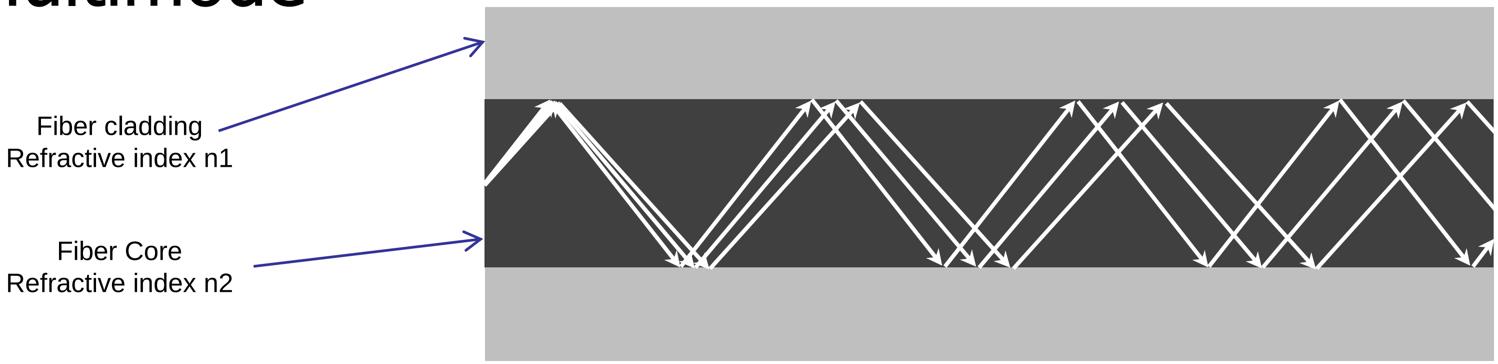
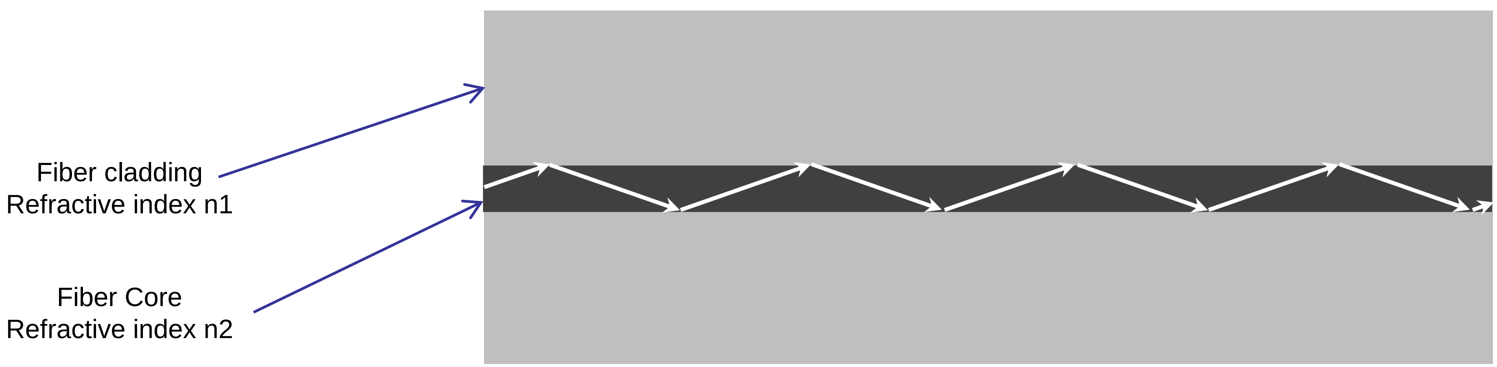
Light propagation

- Multimode

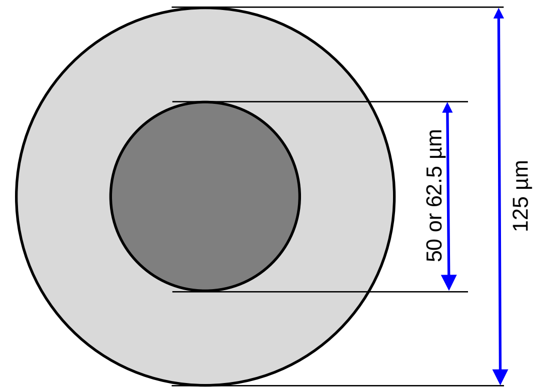


- Single Mode

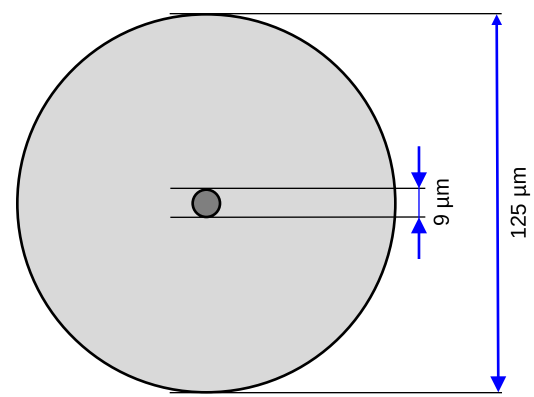


Line Fiber – MM vs SM

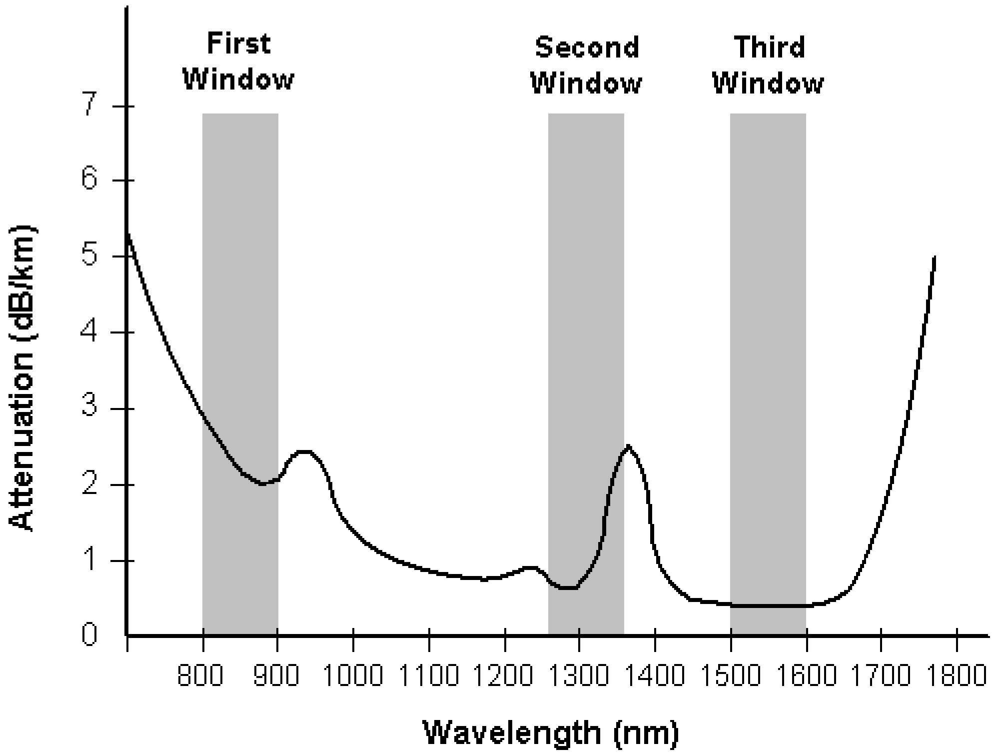
- Multi Mode Fiber
  - Large core
  - Multiple Light path transmitted
  - Short distance



- Single Mode Fiber
  - Thin core
  - One Light path transmitted
  - Long distance

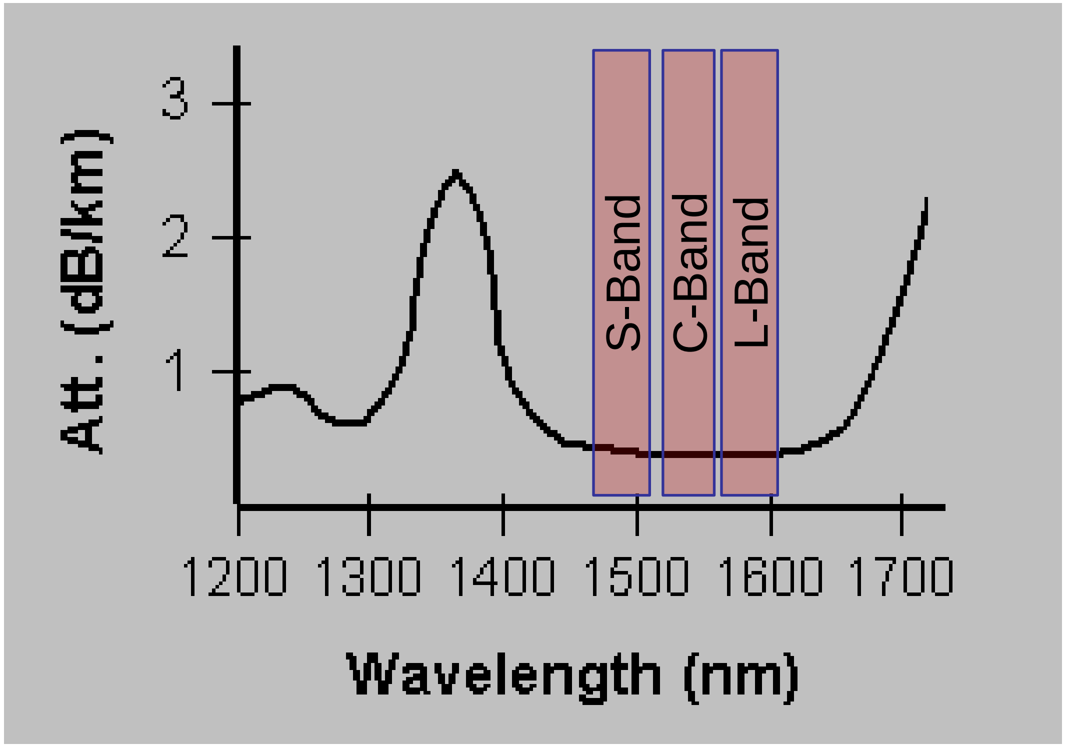


Line Fiber – Transmission windows



- First Window: 850 nm Multi Mode
- Second Window: 1310 nm Single Mode, Single Wavelength
- Third Window: 1550 nm Single Mode, Single Wavelength or WDM

Line Fiber – DWDM Bands



- S-Band: 1470 to 1530 nm
- C-Band: 1530 to 1565 nm
- L-Band: 1565 to 1625 nm

Line Fiber – Attenuation

- Expressed in dB/km
- 1310 nm band:
  - ⇨ 0.3 to 0.35 dB/km
- 1550 nm Band
  - ⇨ 0.22 to 0.25 dB/km

Line Fiber – Chromatic Dispersion

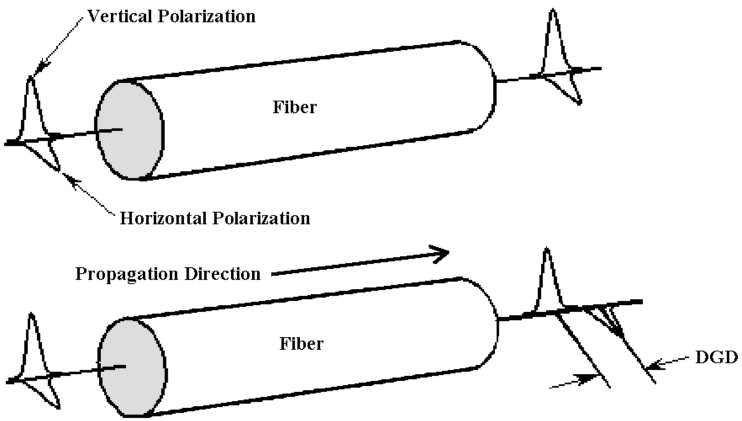
- wavelength do not travel the same speed in fiber
  - Expressed in ps/nm

- Propagation in the fiber broadens the transmitted pulse

- Each Fiber type has a "zero dispersion wavelength"
- Each Fiber type has a chromatic dispersion slope
  - Expressed in ps/nm2/km

Line Fiber – Polarization Mode Dispersion

- Ligth transmistted on two principal state of polarization in fiber:
  - ⇨ Horizontal
  - ⇨ Vertical



- Light do not travel the same speed on both axis
  - ⇨ DGD : Differential Group Delay
  - ⇨ Varies with time and wavelength
- Broadens transmitted pulse
- PMD is a mean value of DGD
  - ⇨ Expressed in picoseconds

Line Fiber – Fiber Types

Fiber Type	Att. @1550 nm (dB/km)	Chromatic Dispersion (ps/nm/km)	Applications
G652 SMF Single Mode Fiber	0.22 - 0.25	0 @ 1310 nm 17 @ 1550 nm	• Metro and Long-Haul • Most Commonly Deployed • Well suited for DWDM

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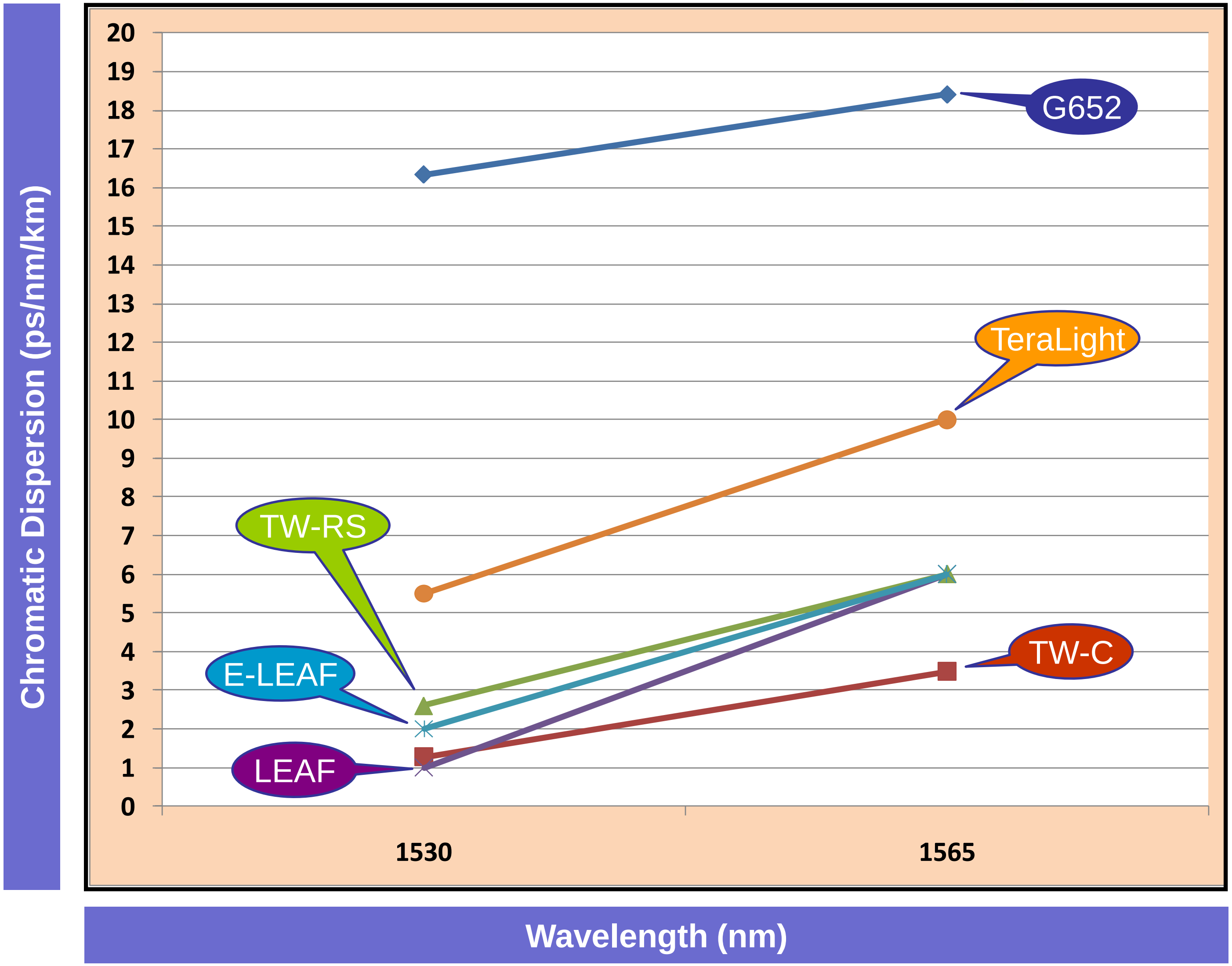
G655 NZDSF Non Zero Dispersion Shifted Fiber	0.22	2 to 6 @ 1550 nm	• Long Haul • Designed for DWDM Networks

Line Fiber – Fiber CD



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  - ⇨ DWDM Spectrum

DWDM Grid

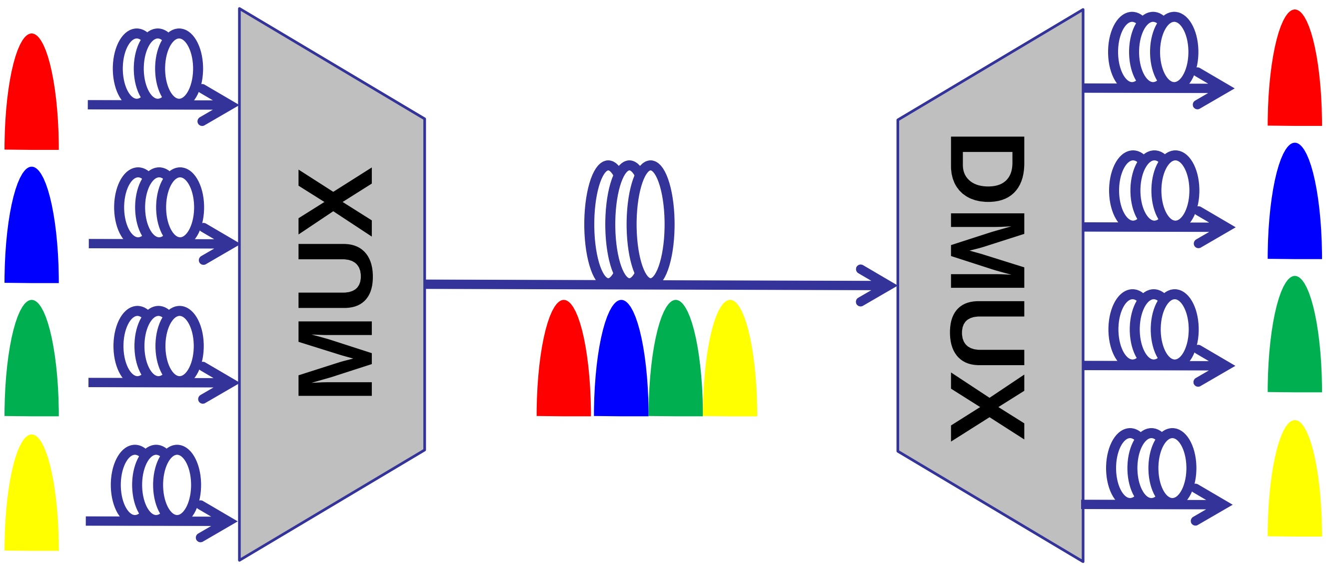
- Defines spacing between DWDM optical channels
- Expressed in GHz
- Defined in G694.1

- 100 GHz grid
  - ⇨ ~0.8 nm between channels
- 50 GHz grid
  - ⇨ ~0.4 nm between channels
- 25 GHz grid
  - ⇨ ~0.2 nm between channels

Channel Frequency (THz)			**Wavelength (nm)**
25 GHz Grid	50 GHz Grid	100 GHz Grid	
193.100	193.10	193.1	1552.52
193.075	-	-	1552.73
193.050	193.05	-	1552.93
193.025	-	-	1553.13
193.000	193.00	193.0	1553.33

Optical MUX and DMUX

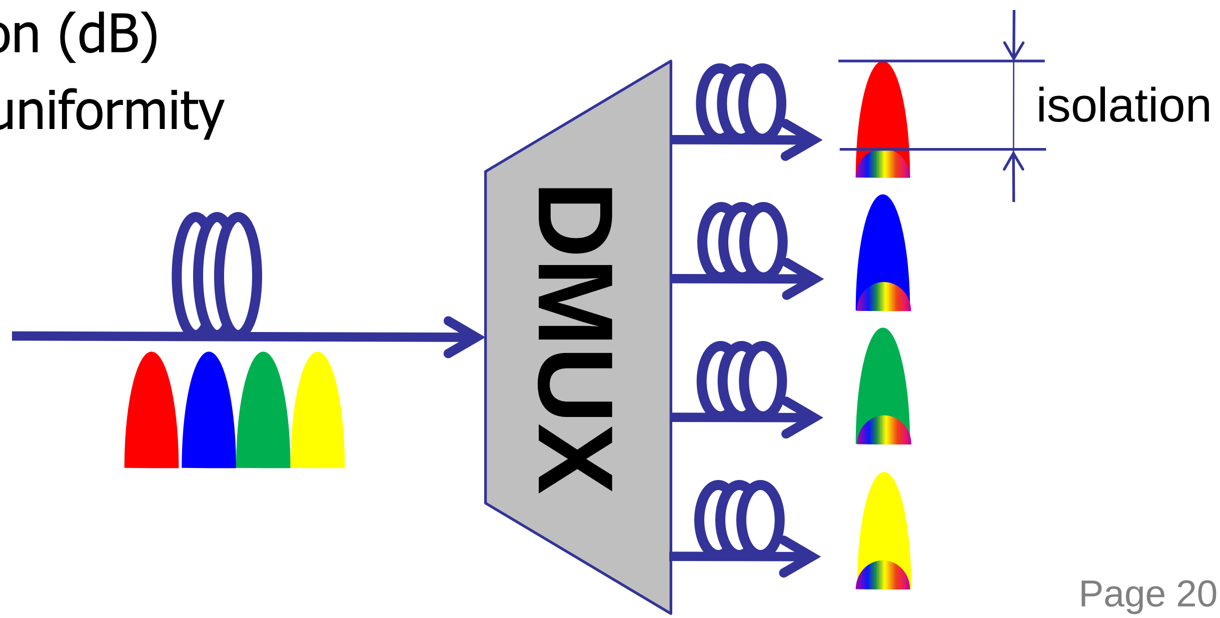
- Transmit side:
  - ⇨ Combines wavelengths from different transmitters on a single fiber
- Receive side:
  - ⇨ Separates several wavelengths from a single fiber to individual receivers



Optical MUX and DMUX

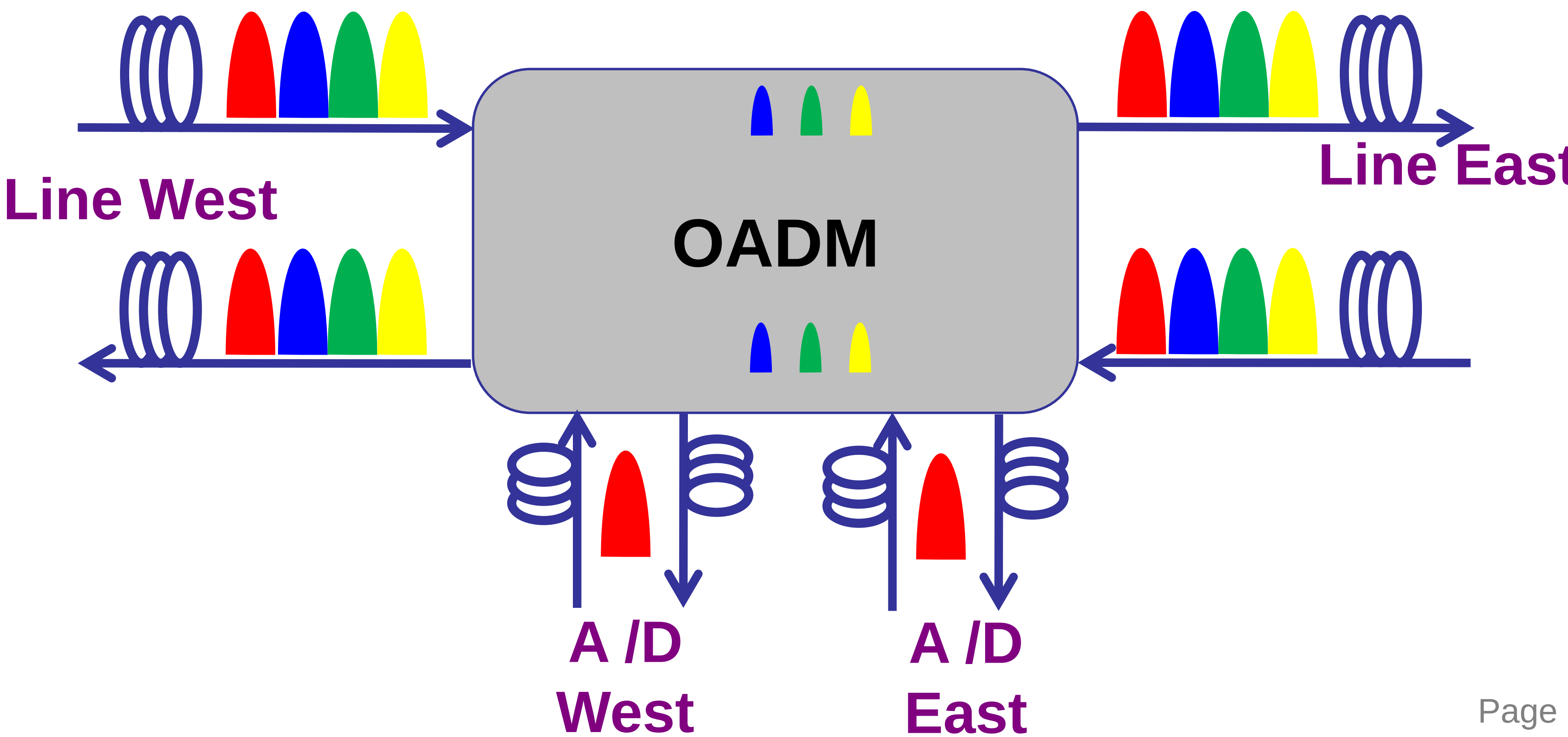
- Mux important parameter
  - ⇨ Insertion loss (dB)
  - ⇨ Insertion Loss uniformity

- D-MUX important parameters
  - ⇨ Insertion Loss (dB)
  - ⇨ Channel isolation (dB)
  - ⇨ Insertion Loss uniformity



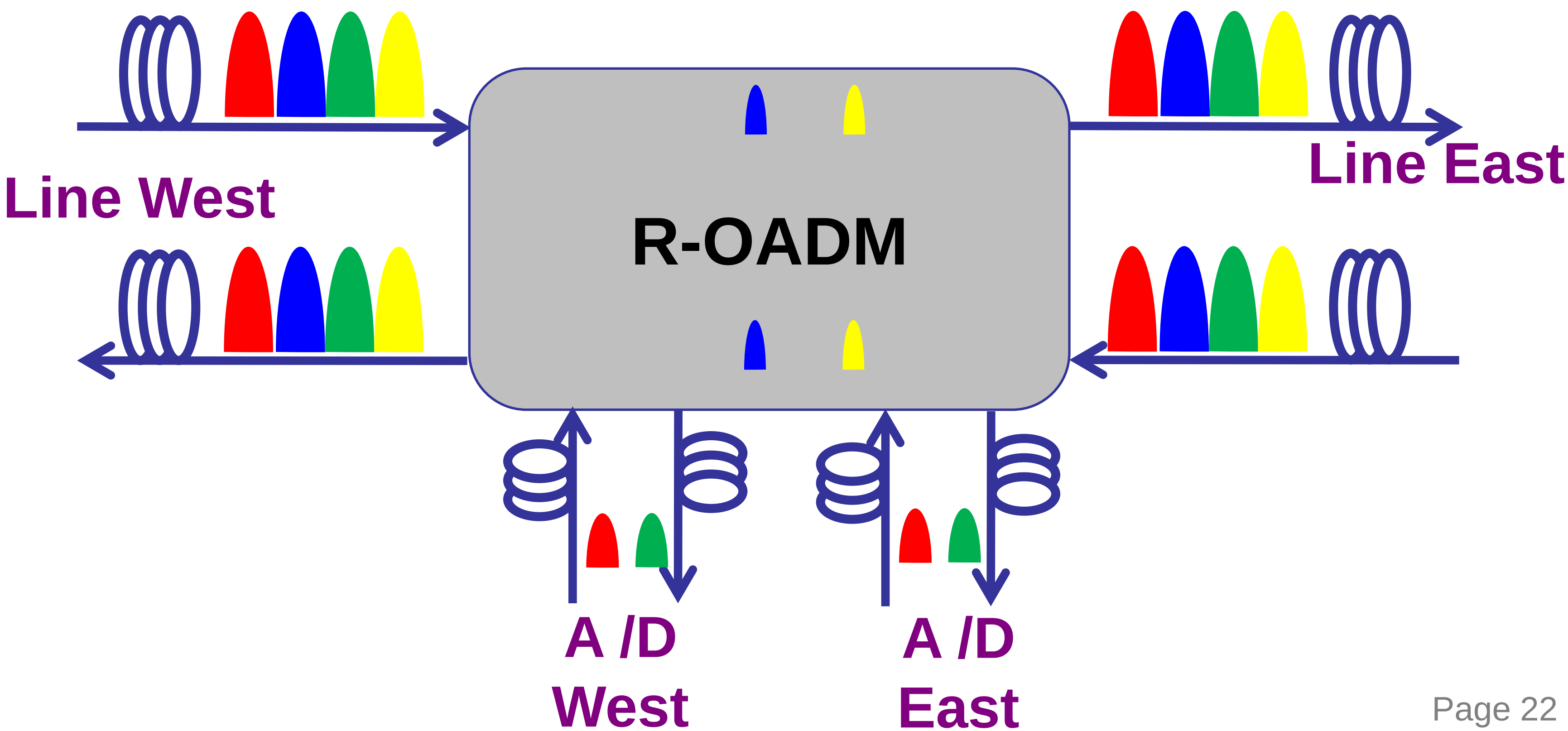
OADM (Optical Add/Drop Mux)

- Drop and Add Optical channels from / to a DWDM multiplex
- Add /drop one or several pre-determined channels



ROADM (Reconfigurable-OADM)

- Drop and Add Optical one or several channels from / to a DWDM multiplex
- Channels to be add/drop is configured by SW
- Active Device



OADM / R-OADM important parameters

- Insertion Loss
  - ⇨Line port to drop port
  - ⇨Add port to Line port
  - ⇨Line port to Line port

- Isolation
  - ⇨Line port to drop port
  - ⇨Add port to Line port
  - ⇨Line Port to Line Port

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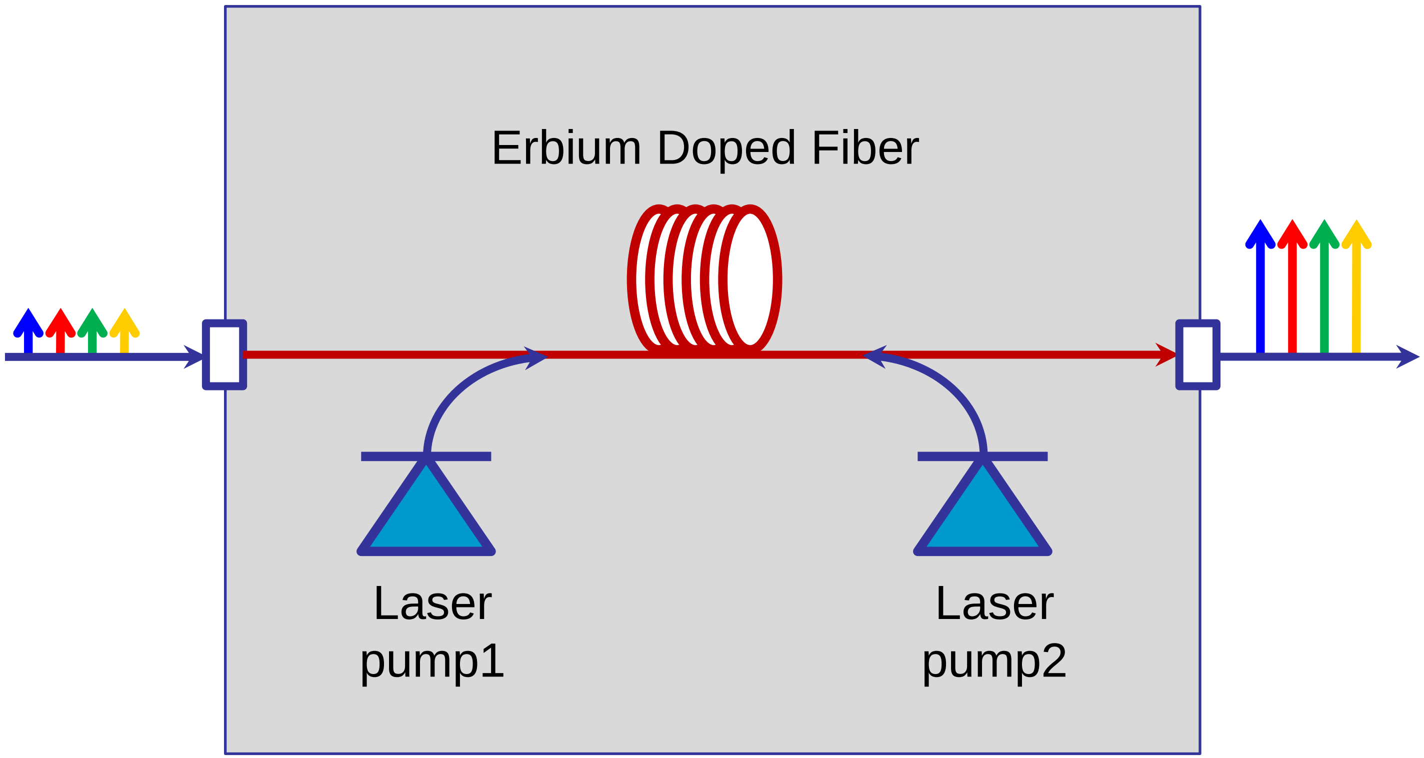
Optical Amplifiers

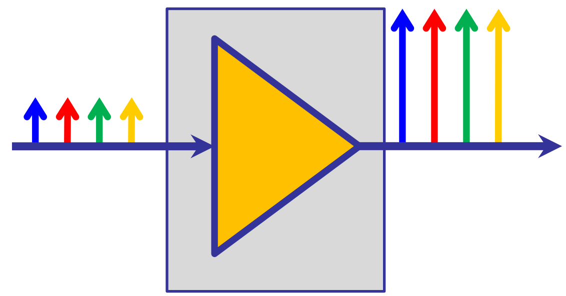
- Two main types
  - ⇨ EDFAs: Erbium Doped Fiber Amplifiers
    - Standalone Device
    - Booster type
    - In-Line Type
    - Pre-Amp type
  - ⇨ RAMAN
    - Utilizes line fiber as amplification medium

EDFA Optical Amplifiers

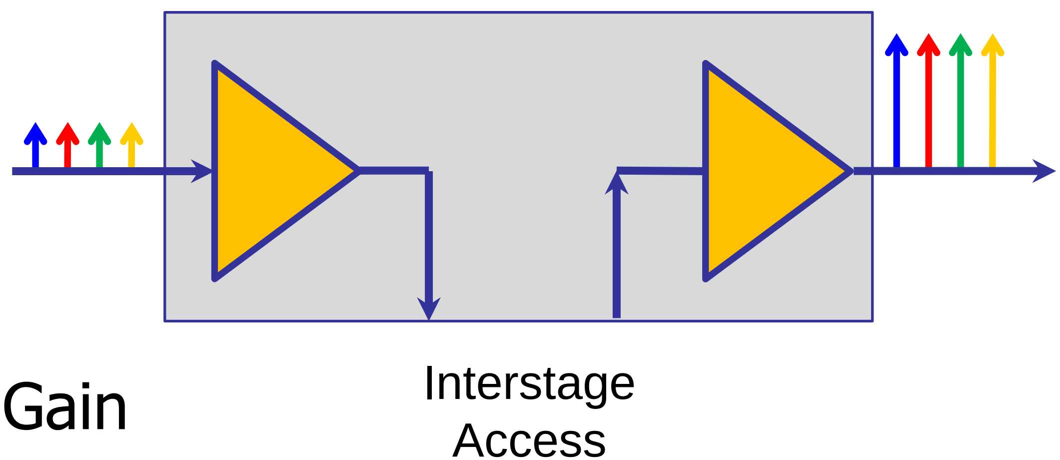


EDFA Optical Amplifiers

- Single Stage
  - ⇨ Booster
  - ⇨ In-Line
  - ⇨ Pre-Amp
  - ⇨ Usually Fixed Gain

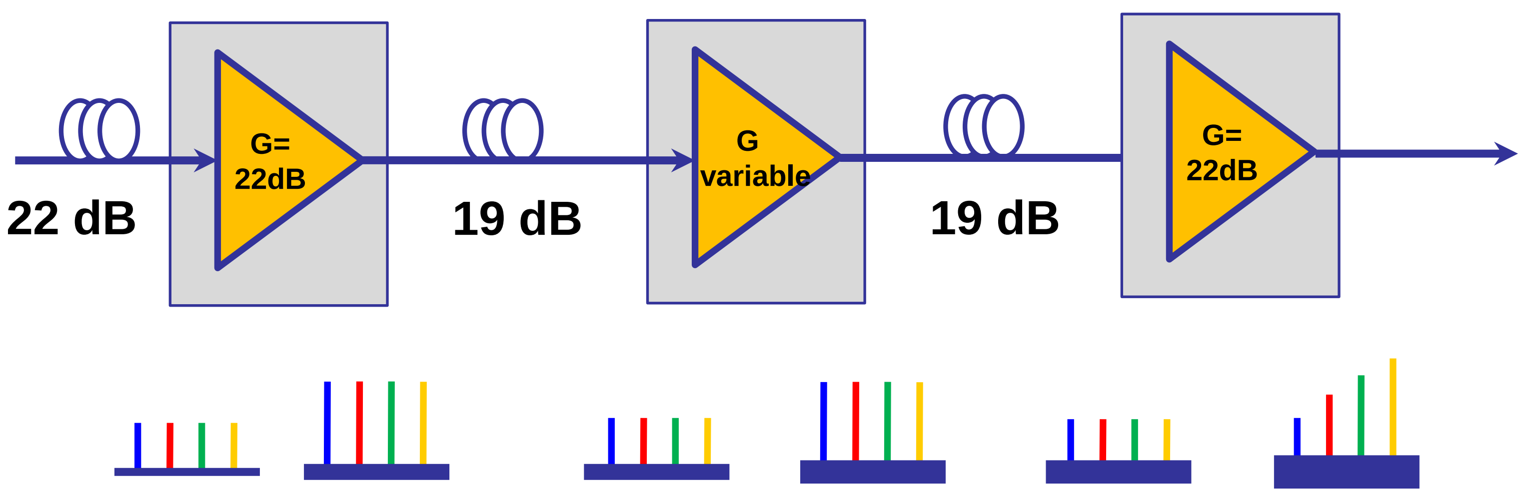


- Dual Stage
  - ⇨ Booster
  - ⇨ In-Line
  - ⇨ Pre-Amp
  - ⇨ Fixed or Variable Gain



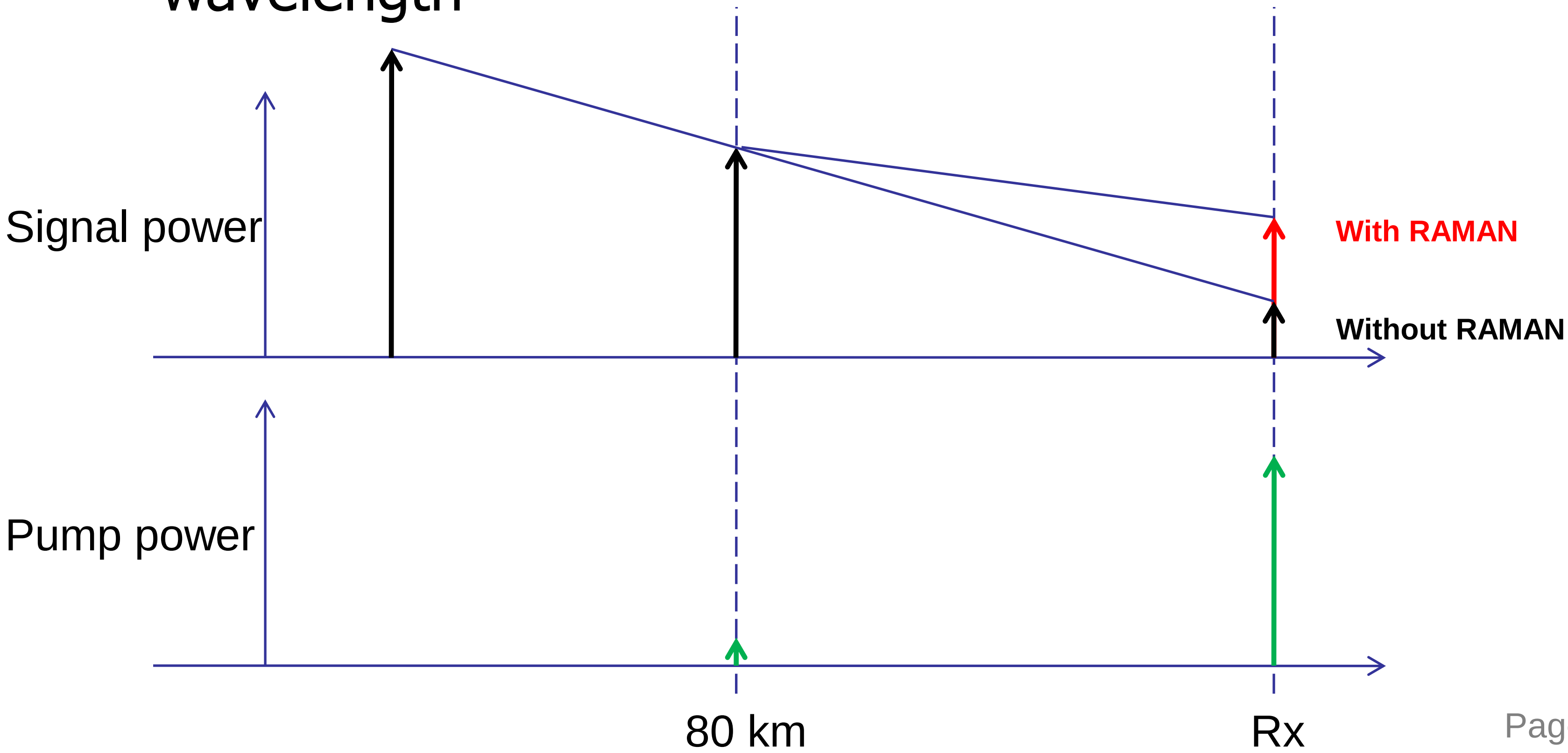
EDFA Optical Amplifiers

- Important Parameters
  - ⇨Gain
  - ⇨Noise Figure
    - Determines the level of noise amplifier adds to Signal

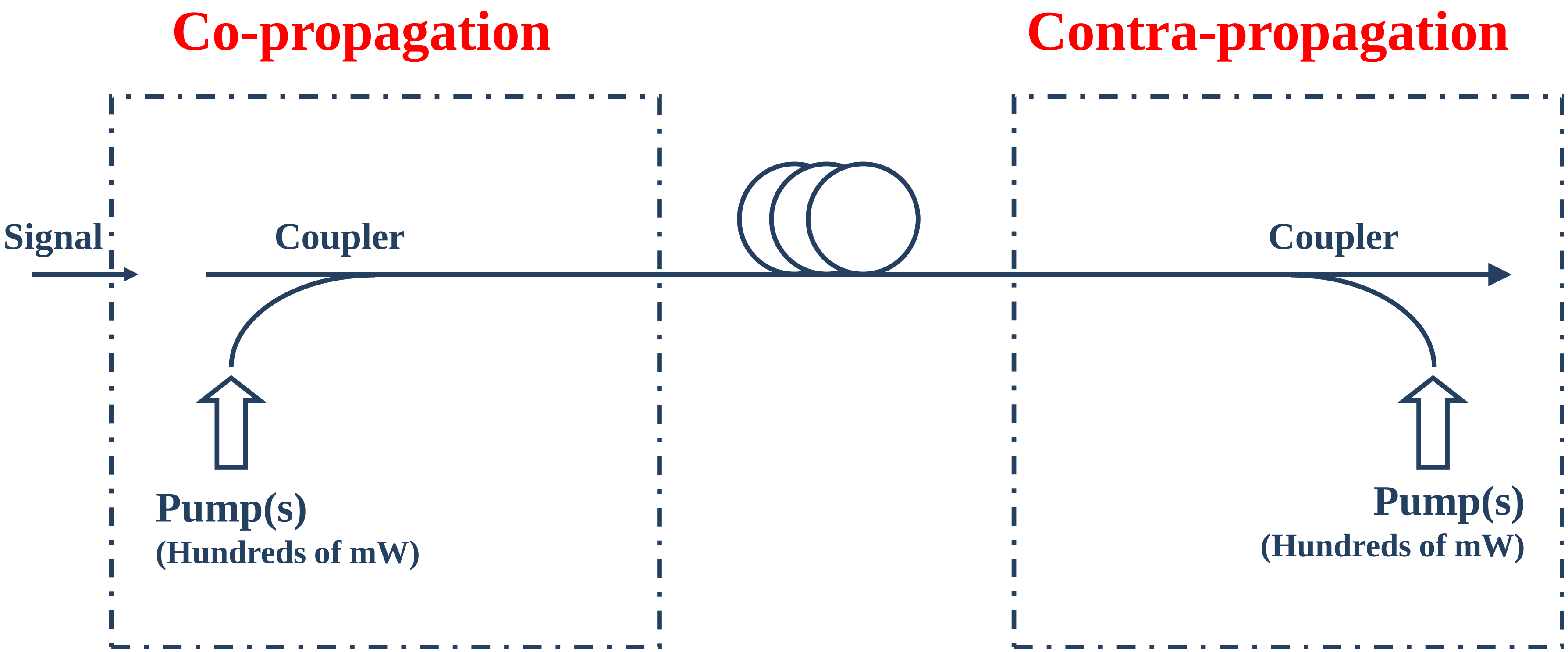


RAMAN Optical Amplifiers

- Two wavelenght propagated in the fiber
  - ⇨ Separated by 13 THz
  - ⇨ Energy transfer from lower wavelength to higher wavelength



RAMAN Location on a system



RAMAN Optical Amplifiers

- Associated to EDFA amplifiers
- Important Parameters
  - ⇨ Line Fiber as clean as possible
    - Lowest attenuation possible
    - No optical reflections
  - ⇨ Raman output has to be spliced on Line Fiber

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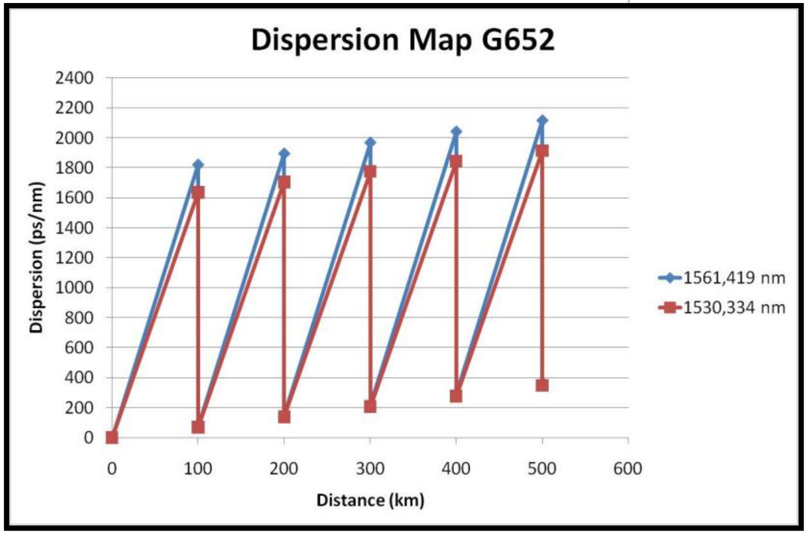
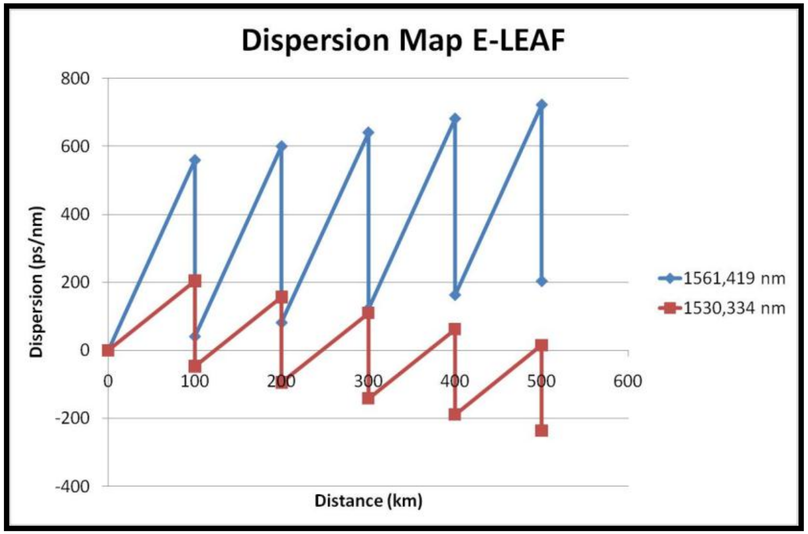
Chromatic Dispersion Compensators

- Compensate for Fiber Chromatic Dispersion
- One type per fiber type
  - ⇨ G652
  - ⇨ G655
- Compensate for slope and distance
- Two main technologies:
  - ⇨ Fiber based
    - Length of compensation = ~20% of fiber length
    - Insertion Loss depends on fiber length to be compensated
  - ⇨ Fiber Bragg Grating Based
    - Constant insertion Loss whatever the length to be compensated for
    - DWDM grid dependent for some suppliers

Chromatic Dispersion Compensators

- 500 kms of fiber
  - ⇨ Each span compensated
- Effets of
  - ⇨ Dispersion Compensation
  - ⇨ Dispersion compensation slope





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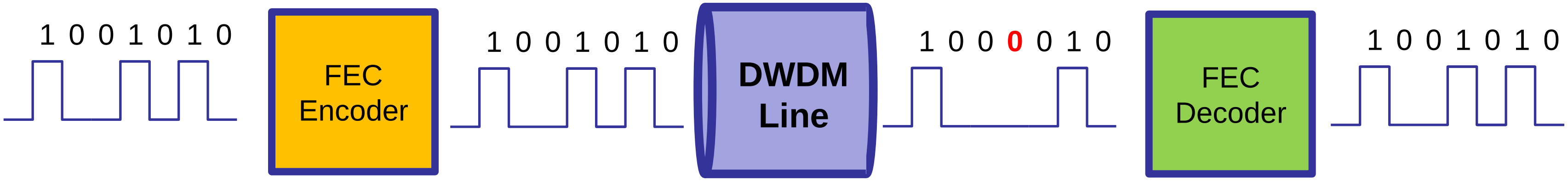
Client Signals on a service card

- Aggregation
  - ⇨ n client signals on a line signal
  - ⇨ Exemple: 8xGbE on 10G
- Transponder
  - ⇨ 1 client signal on a line signal
  - ⇨ Exemple: 1x10GbE on 10G
- Optical interfacing:
  - ⇨ SFP based for data rate <4 Gb/s
  - ⇨ XFP based for data rates of 10 Gb/s

Line Signals on a service card

- Transport
  - ⇨ Transmitter: generates a modulated wavelength compatible with DWDM transmission
  - ⇨ Receiver: detects a modulated wavelength from a DWDM transmission

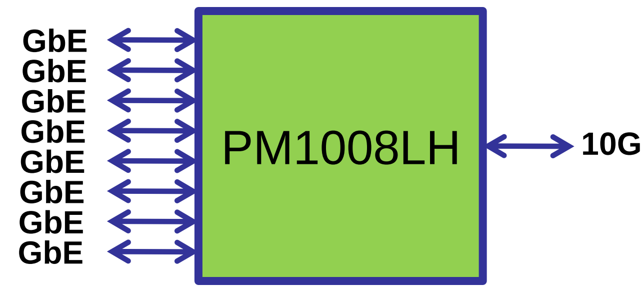
- Forward Error Correction (FEC)
  - ⇨ Digital algorithm correcting bit errors from the transmission line



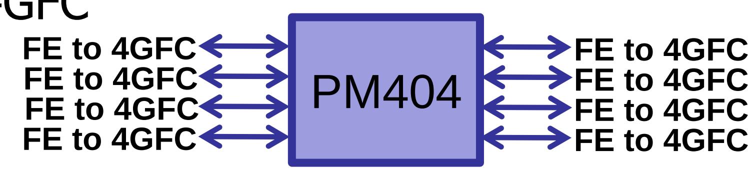
Service card examples

- PM1001LH
  - ⇨ 10GbE transport into 10G

- PM1008LH
  - ⇨ 8x GbE transport in 10G
  - ⇨ FEC capable



- PM404
  - ⇨ Quadruple transponder any rate up to 4GFC
  - ⇨ No FEC



- PM253
  - ⇨ 2xGbE transport in 2G5
  - ⇨ No FEC

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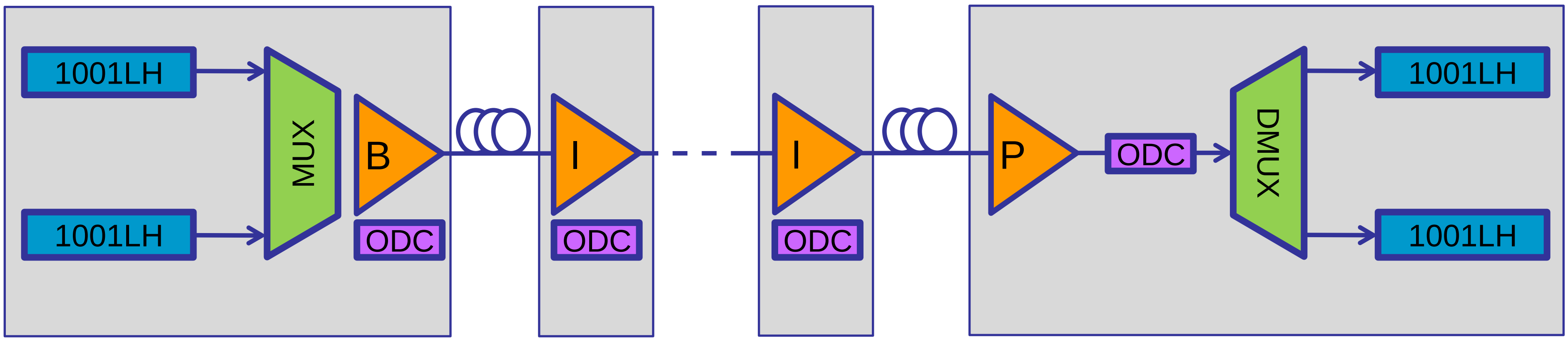
DWDM Line architecture



Fiber

- Fiber Type
  - ⇨ Defines chromatic Dispersion on the line
- Fiber Spans
  - ⇨ BOL (Beginning Of Life) Attenuation
  - ⇨ EOL (End Of Life) Attenuation
- Number of spans
  - ⇨ Defines where locate amplifiers

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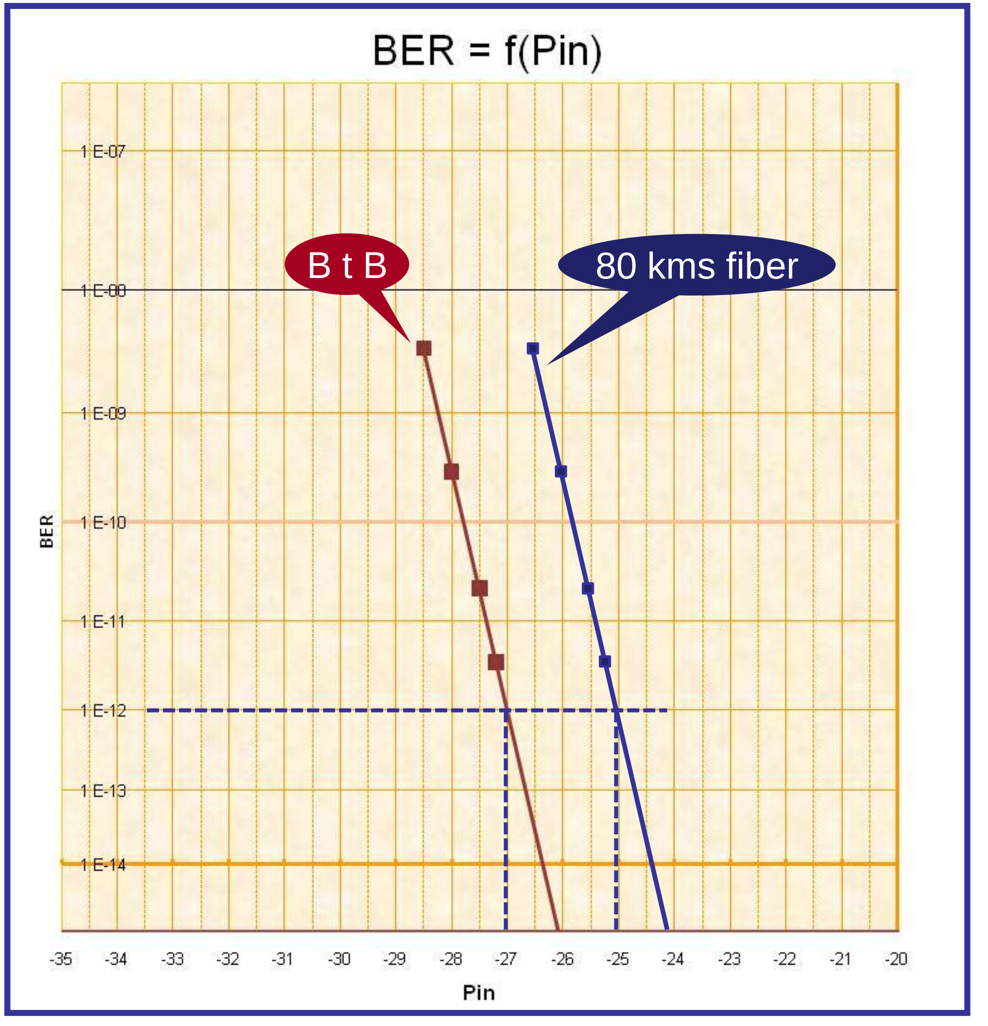
Receiver Input Power Sensitivity

- Sensitivity Range
  - For a given BER
  - Usually 10^{-12}

- Chromatic Dispersion
  - Range:
    - 40 kms: 0 to 800 ps/nm
    - 80 kms: 0 to 1600 ps/nm
  - Power penalty: usually 2 dB

- OTX-TLH60
  - Overload: 0 dBm
  - Sensitivity BtB: -20 dBm
  - Sensitivity 80 kms: -18 dBm

- OTX-TLH80
  - Overload: -9 dBm
  - Sensitivity BtB: -26 dBm
  - Sensitivity 80 kms: -24 dBm



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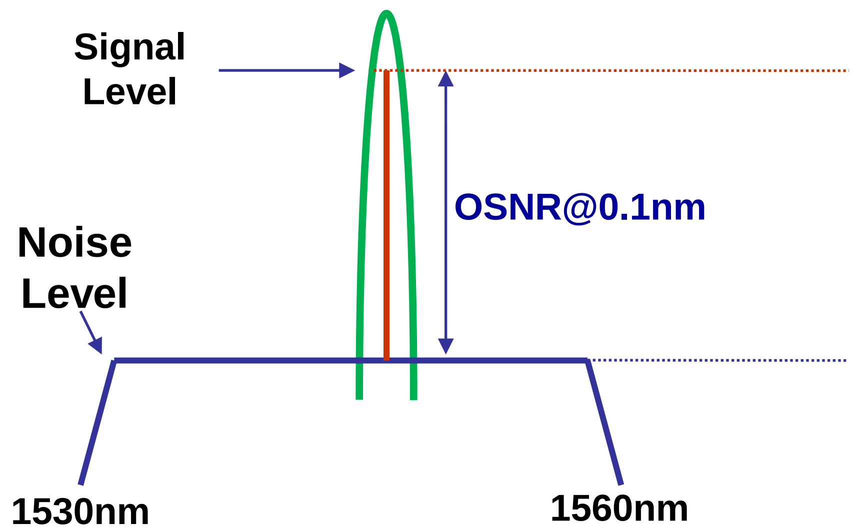
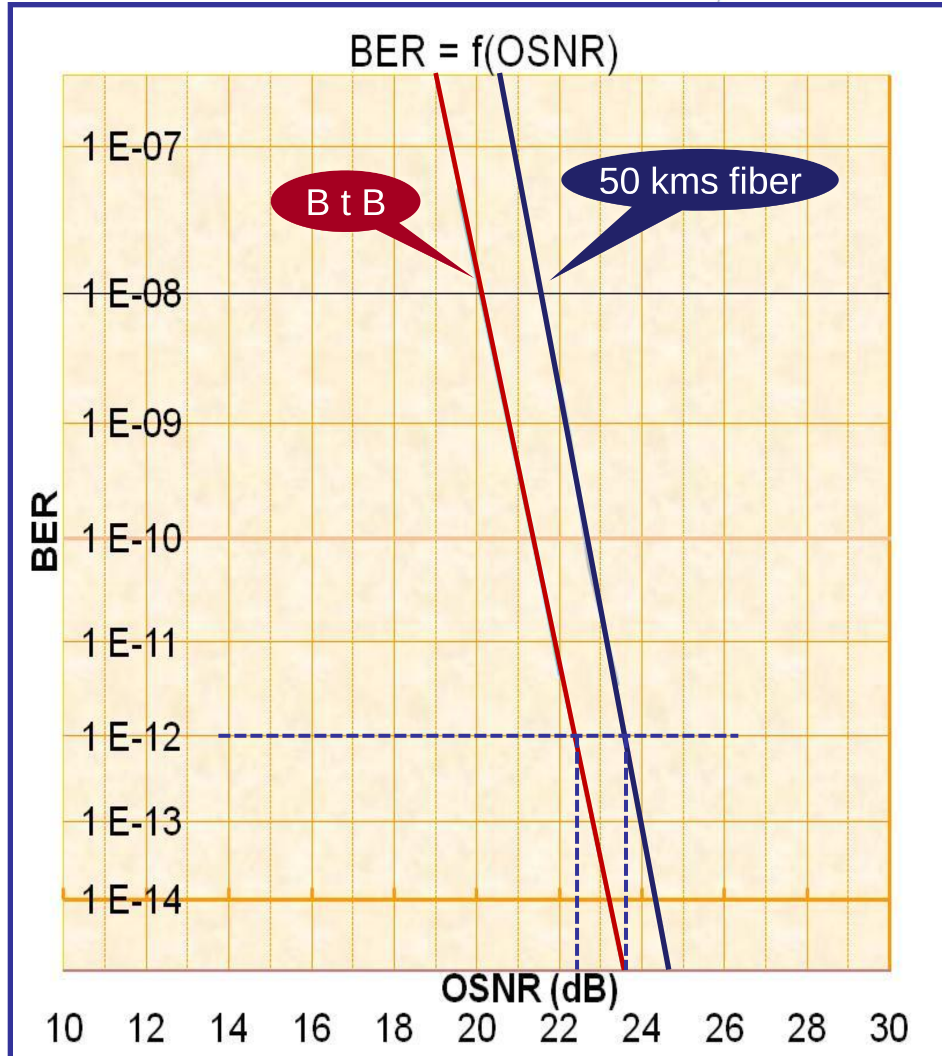
OSNR

- Optical Signal to Noise Ratio
- Expressed in dB
- Noise measured in a 0.1 nm bandwidth



Receiver OSNR Sensitivity

- OSNR sensitivity
  - ⇨ For a given BER
  - ⇨ Usually 10^{-12}
- Chromatic Dispersion
  - ⇨ Range:
    - 40 kms: 0 to 800 ps/nm
    - 80 kms: 0 to 1600 ps/nm
  - ⇨ OSNR penalty: usually 2 dB
- OTX-TLH60 / OTX-TLH80
  - ⇨ OSNR Sensitivity BtB: 22 dB
  - ⇨ OSNR Sensitivity 50 kms: 24 dB



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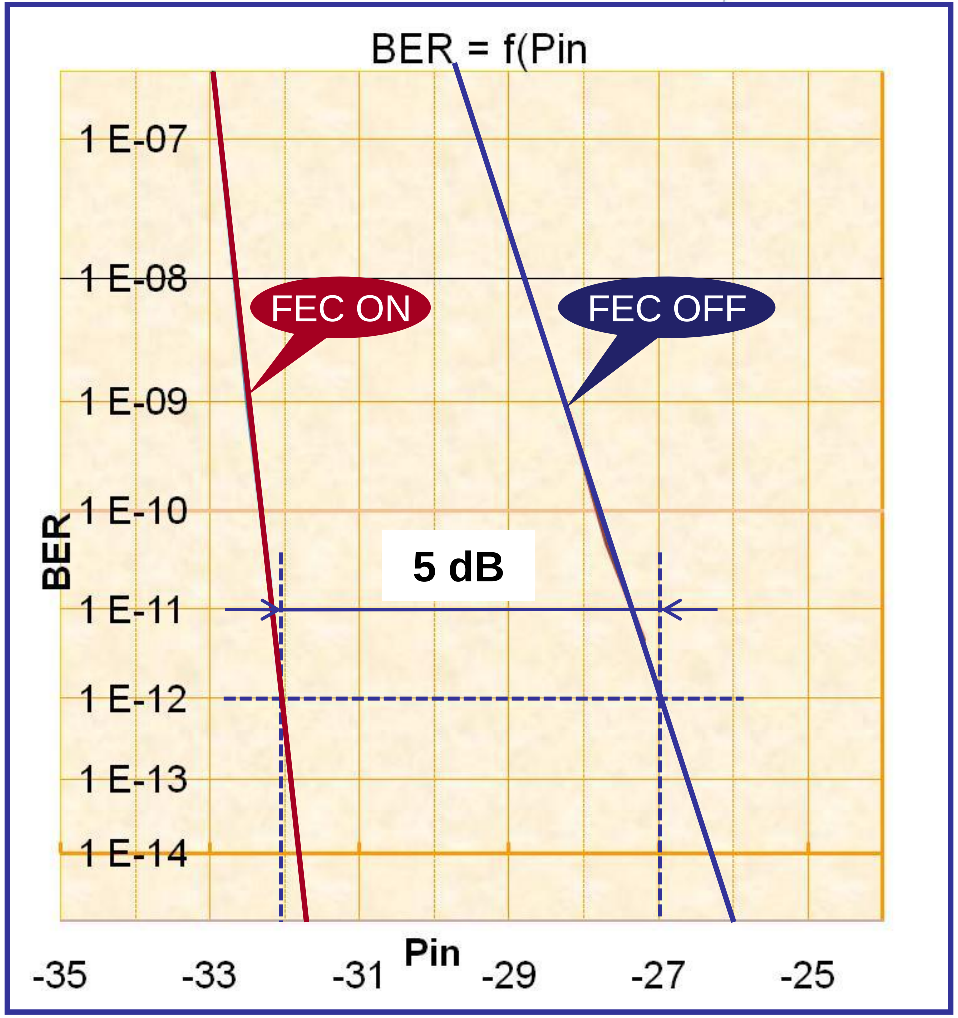
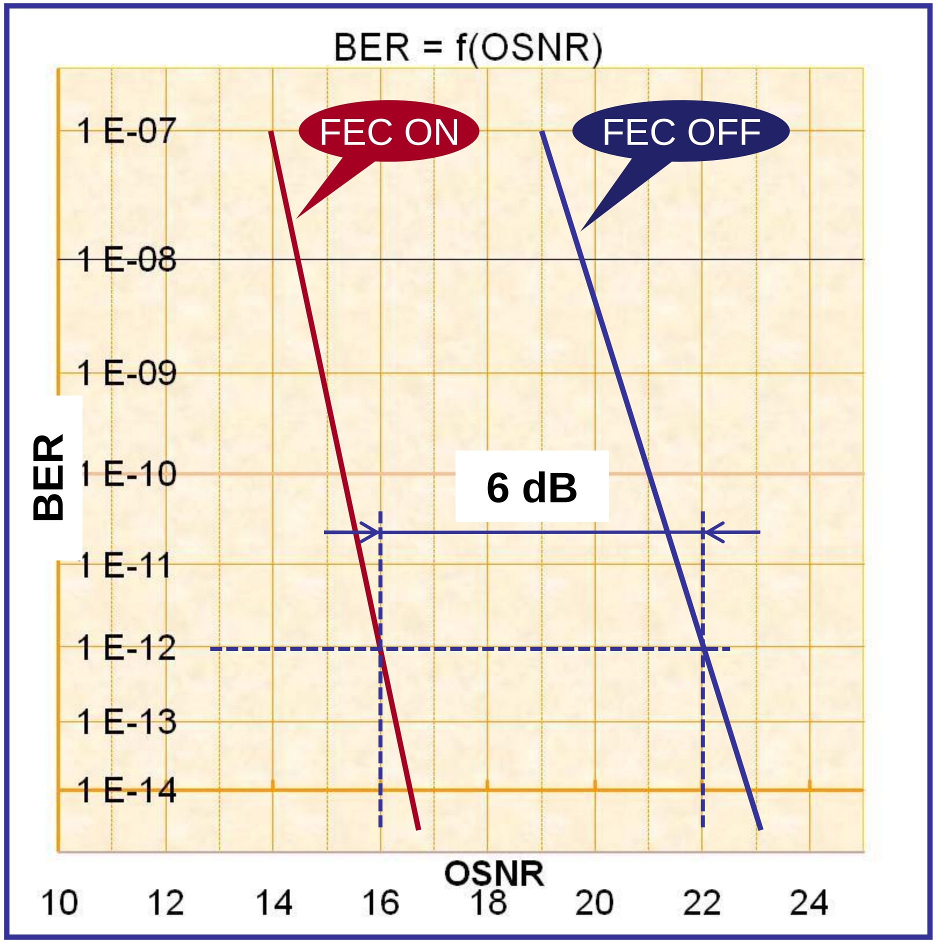
FEC effects on input power sensitivity

- Improves input power Sensitivity
- Characterized in gain expressed in dB
- 5 dB gain is 20 kms more distance on a single span



FEC effect on OSNR

- Improves OSNR Sensitivity
- Characterized in gain expressed in dB
- 6 dB gain allows quadruple the number of spans on a DWDM line



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Optimizing Optical Networks

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  - ⇨ Non Linear Effects
  - ⇨ DWDM Line Examples

Transmission Non Linear Effects

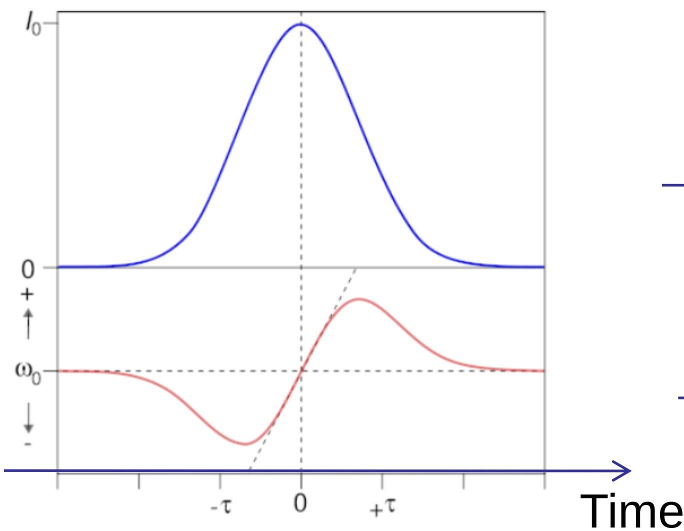
- Fiber Refractive index depending on power per wavelength in the fiber

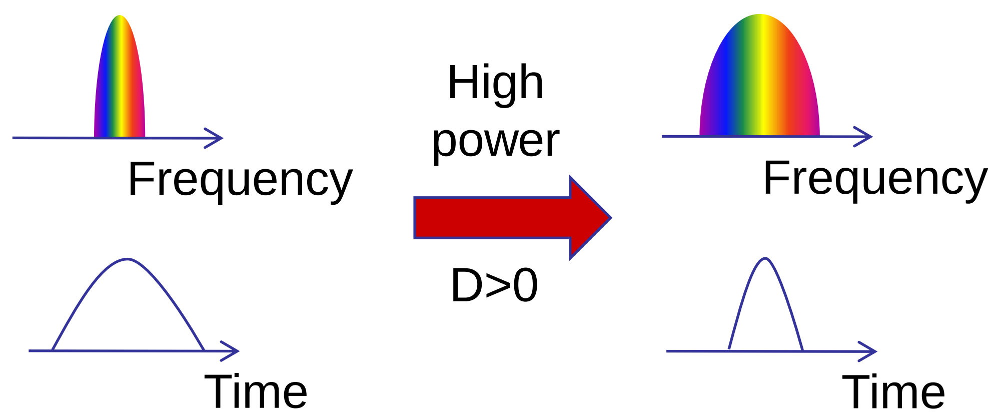
- Kerr effects
  - ⇨ SPM: Self Phase Modulation
  - ⇨ XPM: Cross Phase Modulation
  - ⇨ FWM: Four Wave Mixing

- SRS: Stimulated Raman Scattering
- SBS: Stimulated Brilloin Scattering

SPM

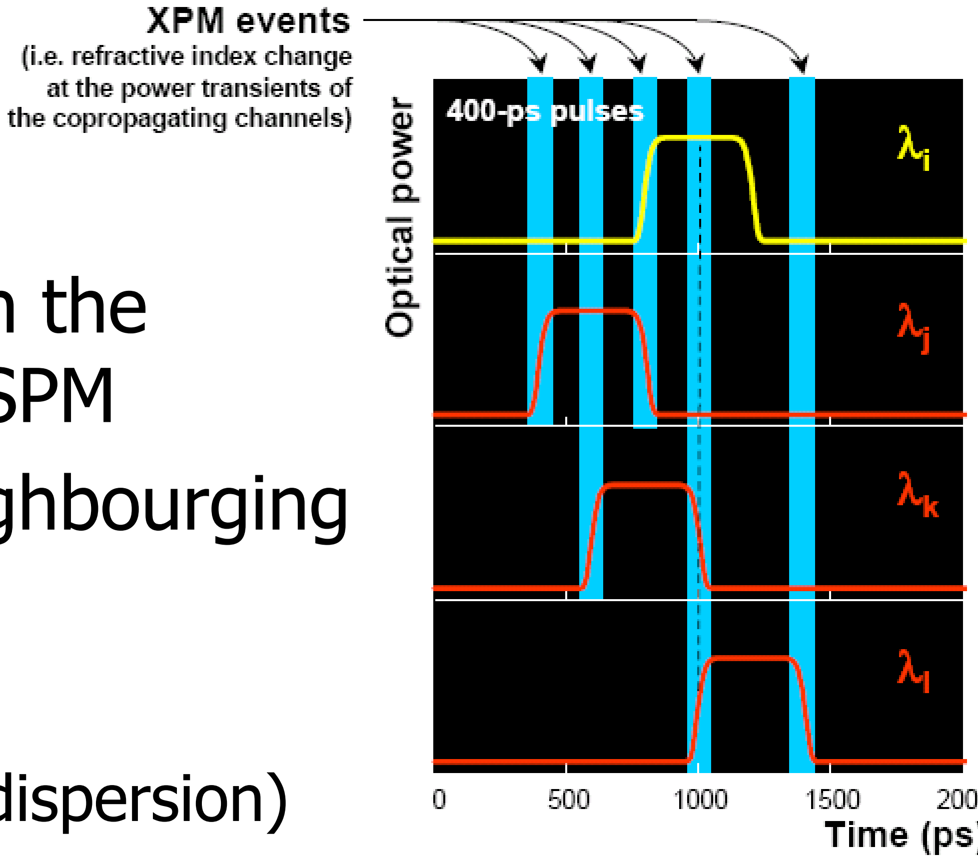
- Single channel effect
- Fiber refractive index depends on optical power
- Optical Spectrum broadening
- Induce temporal pulse compression with the fiber positive chromatic dispersion (ps/nm.km)





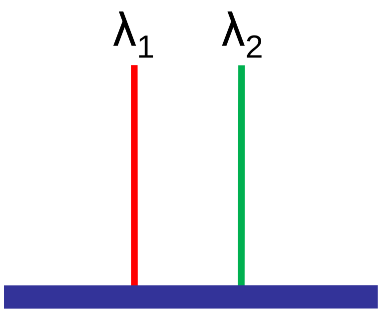
XPM

- Multichannel effect
- Same kind of effect on the refractive index than SPM
- Induce non-linear neighbourging channels X-talk
- Depends on
  - ⇨ Fiber type (chromatic dispersion)
  - ⇨ Per wavelength launched power in the fiber
  - ⇨ DWDM grid

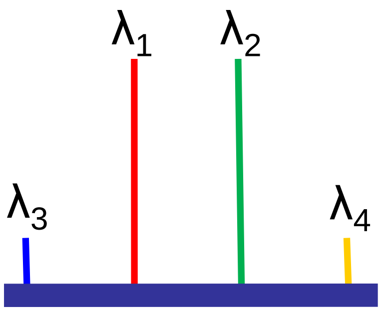


FWM

- Multichannel effect
- Depending on
  - ⇨ Fiber type (chromatic dispersion)
  - ⇨ Power per wavelength launched power in the fiber
  - ⇨ DWDM grid
- Without FWM



- With FWM

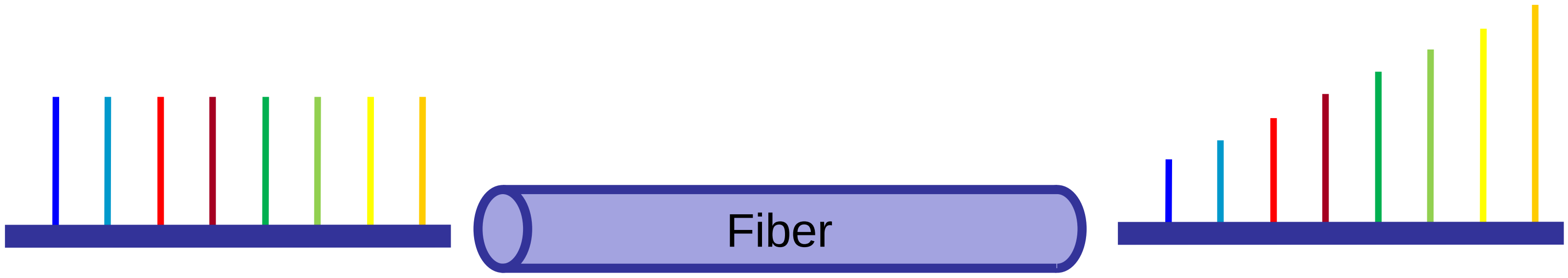


SBS

- Single channel effect
- Depends on channel power launched in fiber
- Part of launched power is back reflected
- Limit can be pushed further by low frequency modulation of the 10G transmitted signal
  - ⇨ Called SBS supression tone

SRS

- Multi channel effect
- Depends on power per channel
- Short wavelength pumps long wavelengths



NLE Thresholds examples

- Single Span transmission

Fiber	Grid	FWM	SBS	SPM
G652	200 GHz	NA	17 dBm	14 dBm
	100 GHz	NA		
	50 GHz	12 dBm		
G655	200 GHz	12 dBm	14 dBm	12 dBm
	100 GHz	10 dBm		
	50 GHz	8 dBm		

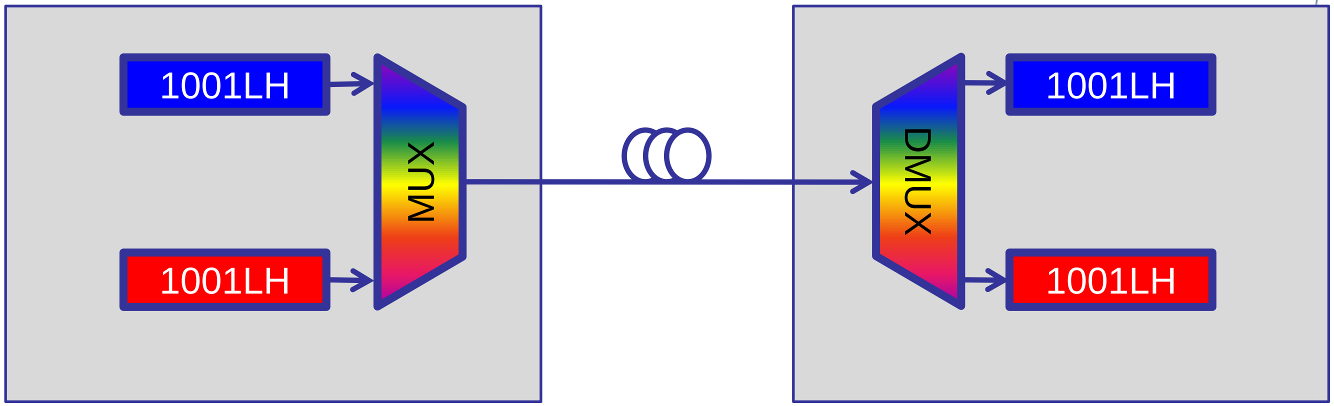
- Threshold lowers with number of spans

DWDM Basics

- DWDM Network Components
  - ⇨ Line Fiber
  - ⇨ Multiplexers and OADMs
  - ⇨ Optical Amplifiers
  - ⇨ Chromatic Dispersion Compensators
  - ⇨ Service Cards (10G, 2G5,...)

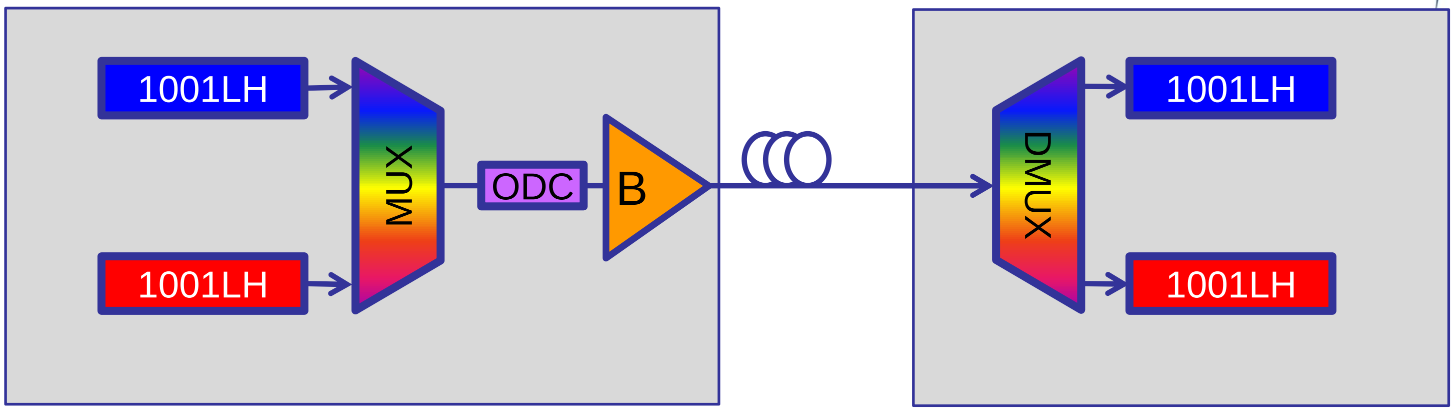
- Main parameters of a DWDM design
  - ⇨ Fiber (attenuation, chromatic dispersion)
  - ⇨ Receivers Sensitivity (10G)
  - ⇨ Optical Signal to Noise Ratio (OSNR)
  - ⇨ Forward Error Correction (FEC)
  - ⇨ Non Linear Effects
  - ⇨ DWDM Line Examples

DWDM Line 1



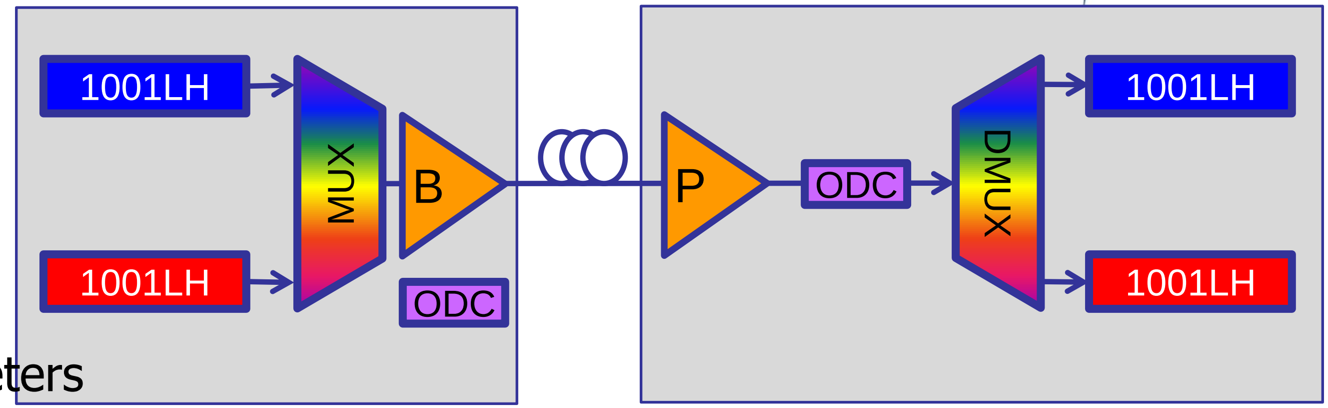
- Important Parameters
  - ⇨ 10G transmit power
  - ⇨ Attenuation
    - MUX
    - Line Fiber
    - DMUX
  - ⇨ 10 receiver
    - input power sensitivity
    - Residual chromatic dispersion

DWDM Line 2



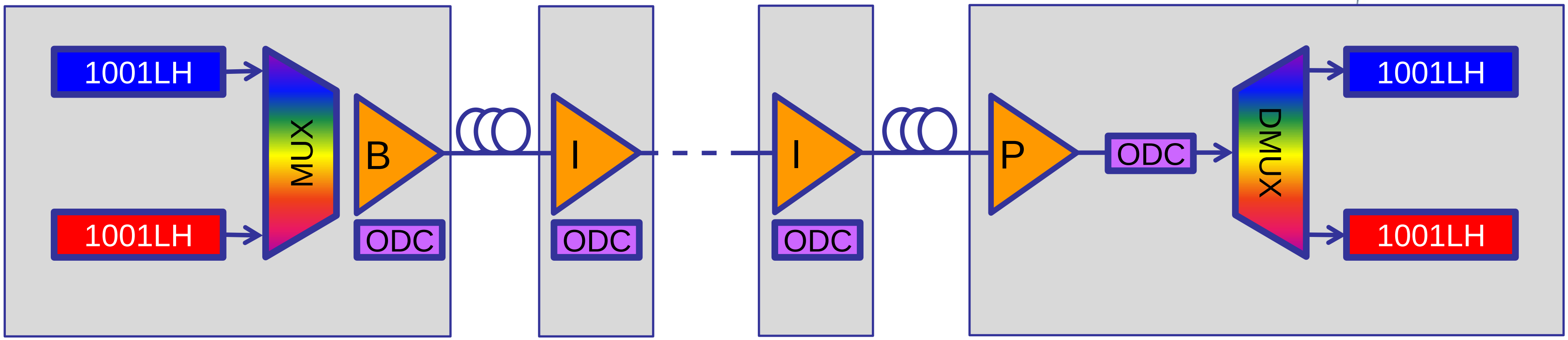
- Important Parameters
  - ⇨ Booster
    - output power
    - gain
    - 10G transmit power per channel on booster output
  - ⇨ Attenuation
    - MUX
    - Line Fiber
    - DMUX
  - ⇨ Chromatic Dispersion
  - ⇨ 10G receiver
    - input power sensitivity
    - Residual chromatic dispersion

DWDM Line 3



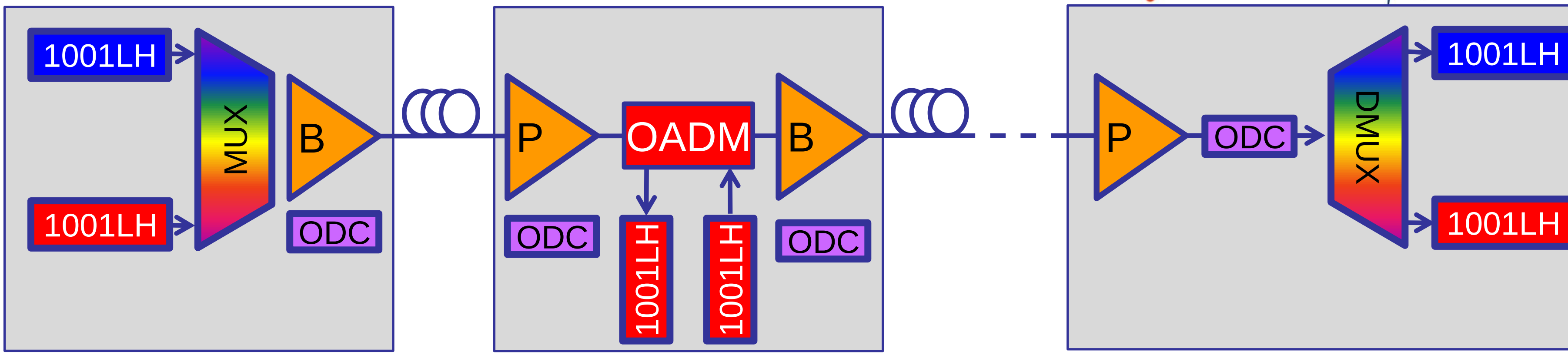
- Important Parameters
  - Booster
    - output power
    - gain
    - 10G transmit power per channel on booster output
  - Line Fiber
    - Attenuation
    - Chromatic Dispersion
  - Pre-Amp
    - Gain
    - OSNR per 10G channel
  - 10G receiver
    - OSNR sensitivity
    - Residual Chromatic dispersion

DWDM Line 4



- Important Parameters
  - Booster / In-Line
    - gain
    - 10G transmit power per channel on booster output
  - Line Fiber
    - Attenuation
    - Chromatic Dispersion
  - Pre-Amp
    - Gain
    - OSNR per 10G channel
  - 10G receiver
    - OSNR sensitivity
    - Residual chromatic Dispersion

DWDM Line 5



- Important Parameters
  - ⇨ Booster
    - gain
    - 10G transmit power per channel on booster output
  - ⇨ Line Fiber
    - Attenuation
    - Chromatic Dispersion
  - ⇨ Pre-Amp
    - Gain
    - OSNR per 10G channel
  - ⇨ 10G receiver
    - OSNR sensitivity
    - Residual chromatic Dispersion