Optical Primer

HKNOG 2016

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Topics to Cover

- What is WDM?
- Optical Transmission Challenges
- Grey and Colored Optics
- Receive Power
- Dispersion
- Multiple Wavelengths
- Amplifiers
- ROADMs
- Transponders and Muxponders
- Modulation Formats
- Disaggregated vs. Integrated Optics

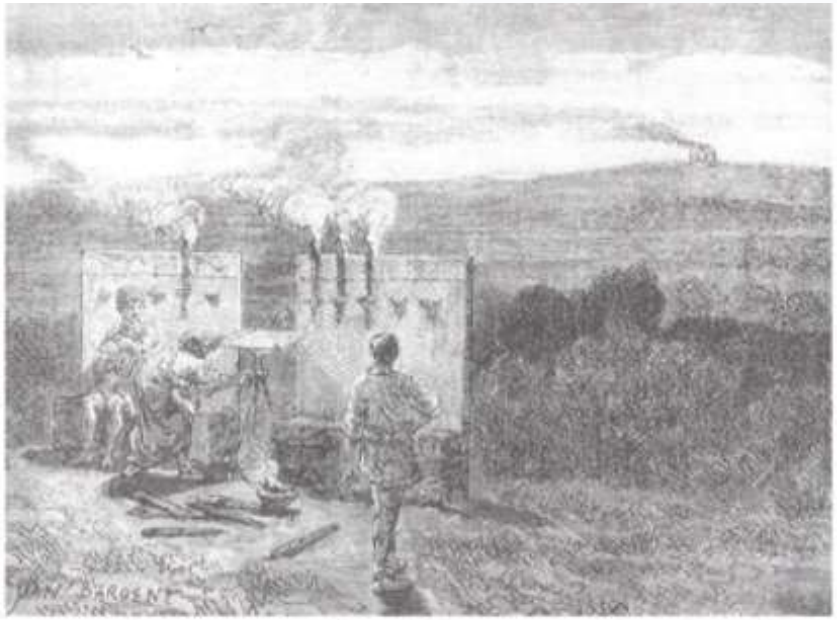
The History of Bandwidth Limited Channels

- The signaling system of Aenius
- Its capacity is limited by the speed of the slave's arm

350 B.C.

Gerard J. Holzmann & Bjorn Pehrson,
The Early History of Data Networks,
IEEE Computer Soc. Press, 1995
Coll. Musee de la Poste, Paris

… And how we overcame them



150 B.C.

ibid.

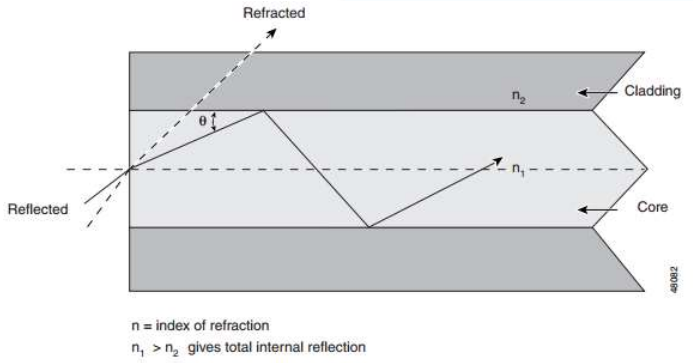
- The signaling system of Polybius multiplies the effectiveness of the channel by transmitting multiple bits simultaneously

What is WDM?

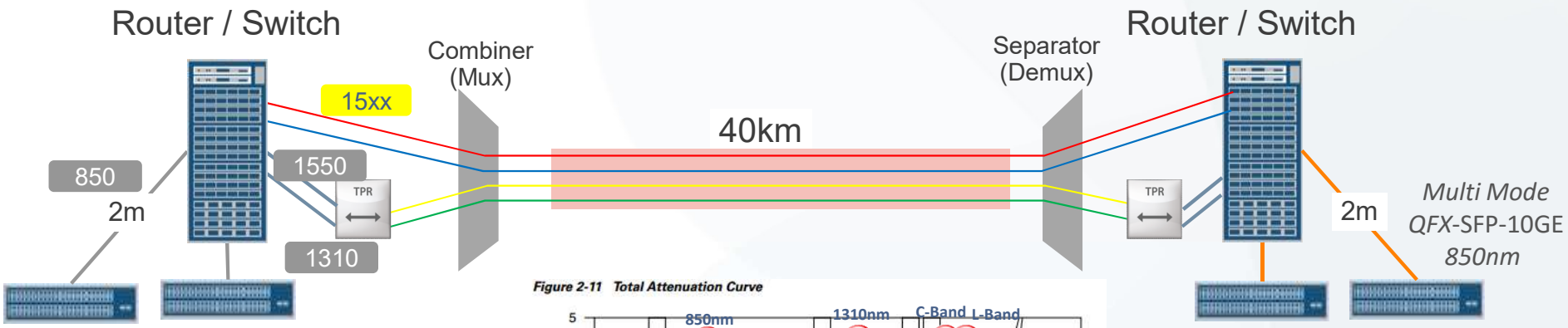
- With Wavelength division multiplexing (WDM) technology, several wavelengths, or light colors, can be simultaneously multiplexed over a strand of fiber.
- No need to lay new fiber, the effective capacity of existing fiber plant can be increased by a factor 40, 96, and 128
- The term wavelength is used instead of the term frequency to avoid confusion with other uses of frequency. Wavelength is often used interchangeably with lambda and channel

Optical Transmission Challenges

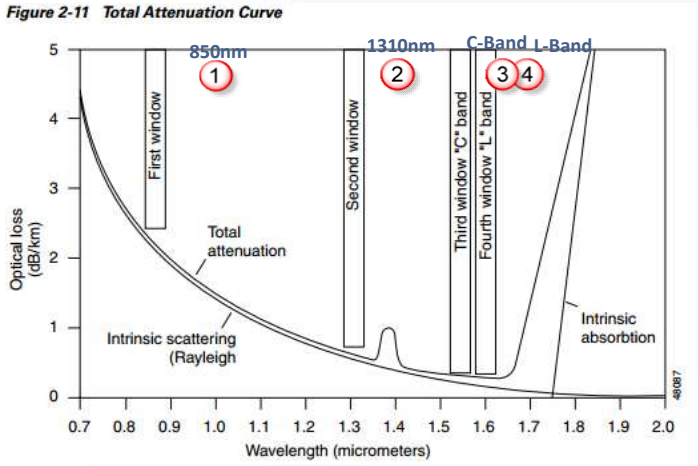
- Attenuation
  - decay of signal strength, or loss of light power, as the signal propagates through the fiber
- Chromatic dispersion
  - spreading of light pulses as they travel down the fiber
- Nonlinearities
  - cumulative effects from the interaction of light with the material through which it travels, resulting in changes in the lightwave and interactions between lightwaves



Gray and Colored Optics…



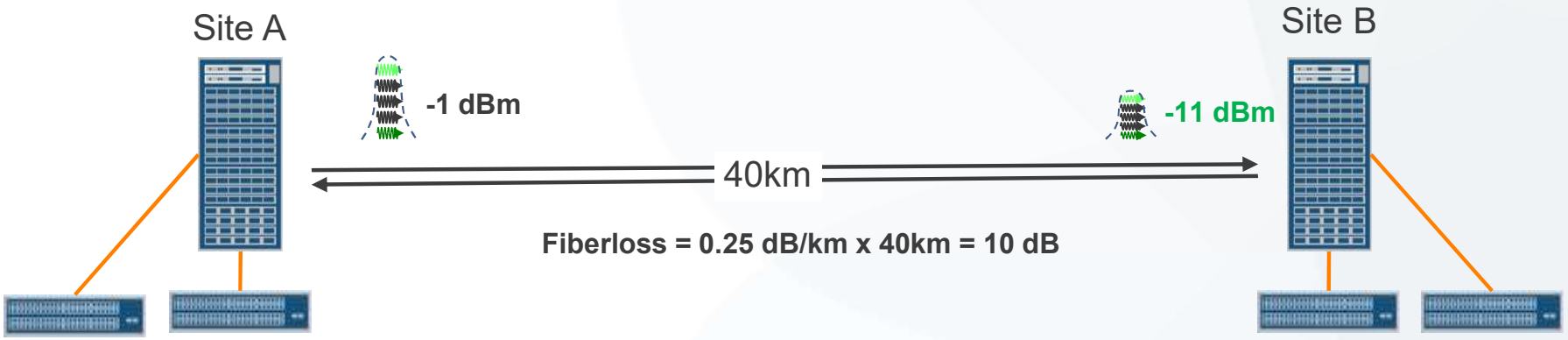
- Gray (850nm/1310nm/1550nm)
- Colored Optics (WDM: 15xx nm)



1. 850nm – ~2dB/km
2. 1310nm – ~0.5dB/km
3. C-Band ~0.25dB/km 1530–1565 nm
4. L-Band ~0.25dB/km 1565–1625 nm

DWDM

Receive Power

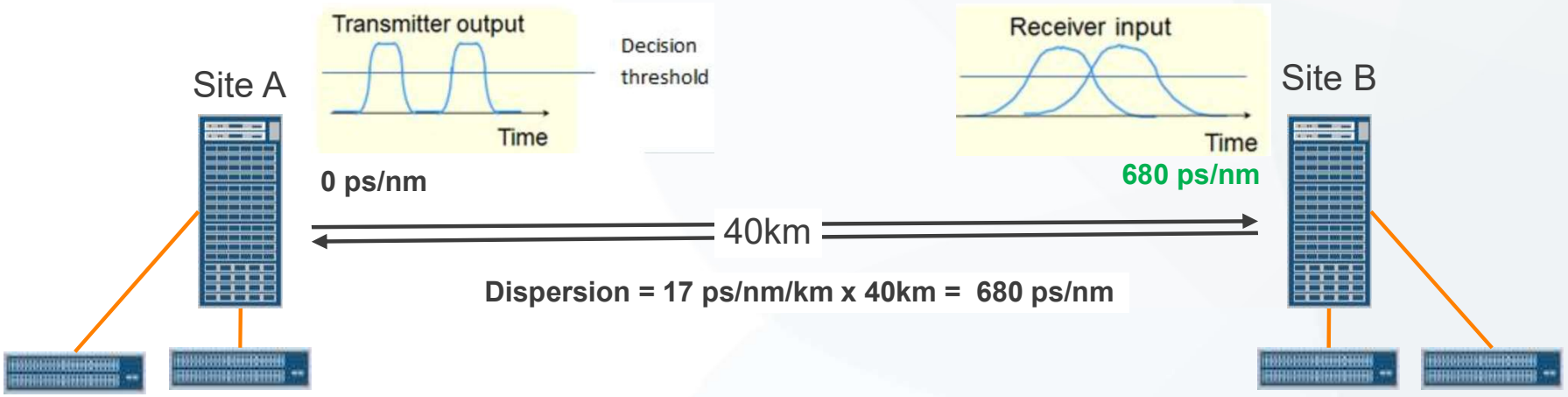


- Receiver needs to be able to distinguish 1 from 0
- 3 key parameters have to be within the tolerance of the receiver
- Rx Power, Dispersion, and Optical Signal to Noise Ratio (OSNR)
- dB : relative measurement
- dBm : an absolute value

Sample SFP Tx/Rx Spec

Tx Power	-1 to 2 dBm
Rx Power	-22 dBm
Dispersion Tolerance	1600 ps/nm
OSNR	20dB

Dispersion

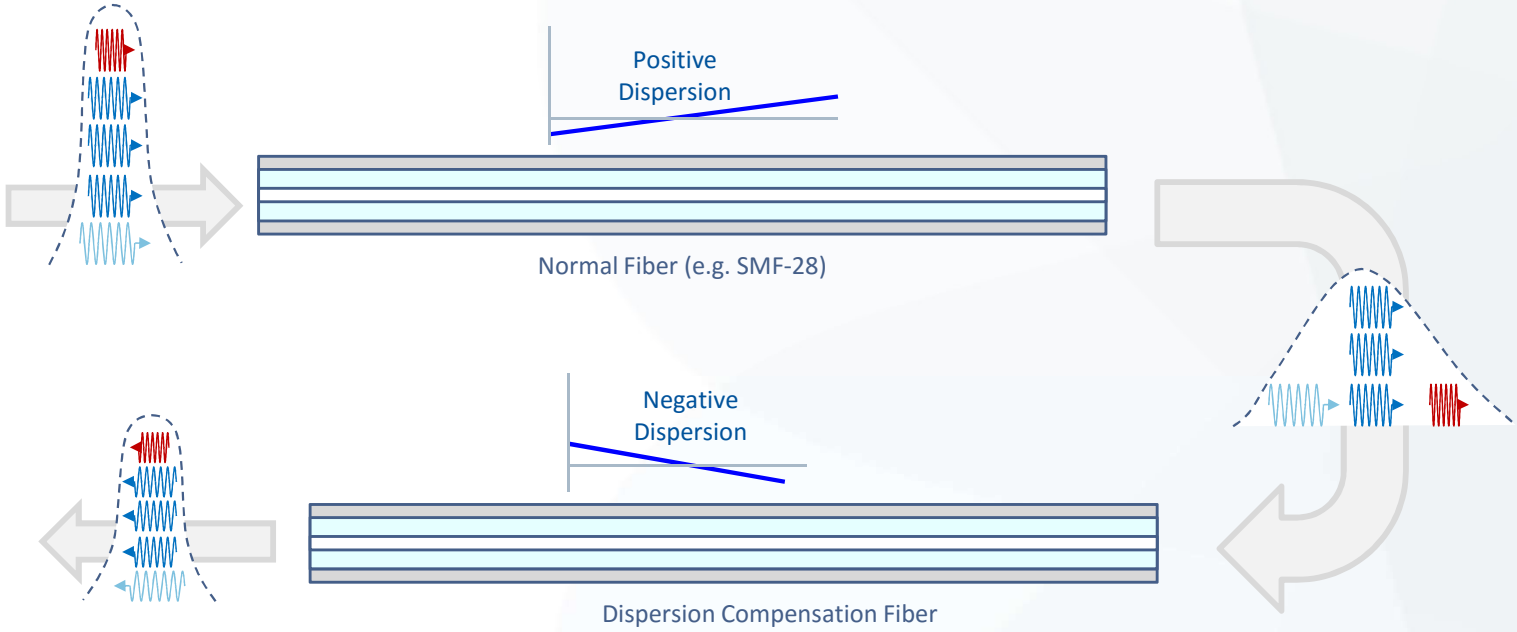


- Different wavelengths will travel at a different rate through fiber
- Causes pulse broadening which makes it difficult to discriminate 1 from 0 pulses
- Not an issue for Coherent Systems

Sample SFP Tx/Rx Spec

Tx Power -1 to 2 dBm
Rx Power -22 dBm
Dispersion Tolerance 1600 ps/nm
OSNR 20dB

Dispersion Compensating Fiber (DCF)

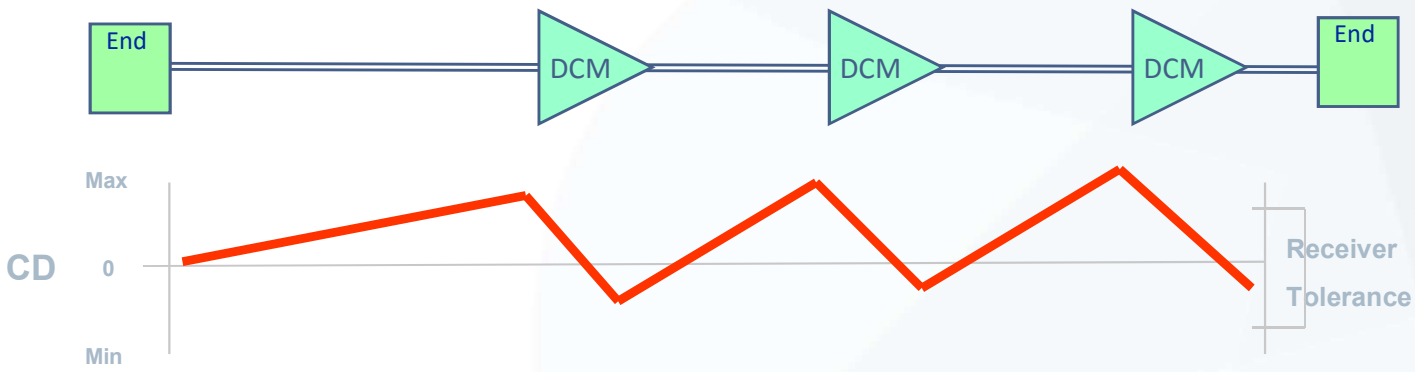


- A normal fiber with positive-slope dispersion makes different wavelengths travel at different speeds from point A to Z
- By passing the wavelengths through a “negative-sloped” dispersion fiber reverses the effects of dispersion or the spread
- *Side Effect: DCF adds extra losses and latency to the transmission*

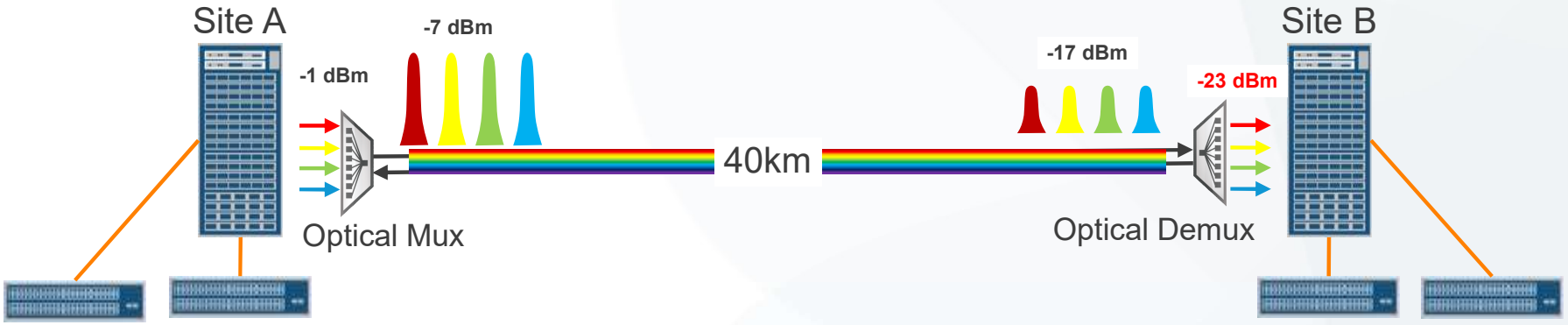
Dispersion Compensation Over Multi-span Route

Span-by-Span CD Compensation for 10G/40G transmission

Simply match fiber distance to DCM type (e.g. Use 60km DCM for ~60km link)



Multiple Wavelengths



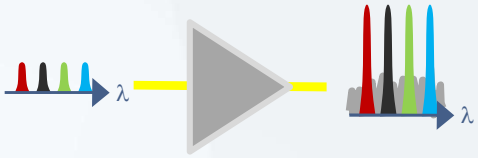
- C-Band or L-Band is where we transport multiple wavelengths
- Wavelengths are combined using Optical Mux/Demux Modules
  - 8-32ch, 40ch, 96ch
- Spacing of the wavelengths or channels is usually **100GHz** or **50GHz**
- Mux/Demux have insertion loss
  - i.e. 96ch Mux/Demux pair has 12 dB loss
- For discussion purpose we will assume loss is the same for Mux and Demux and uniform across – however this is usually not the case

Sample SFP Tx/Rx Spec

Tx Power	-1 to 2 dBm
Rx Power	-22 dBm
Dispersion Tolerance	1600 ps/nm
OSNR	20dB

Amplifiers

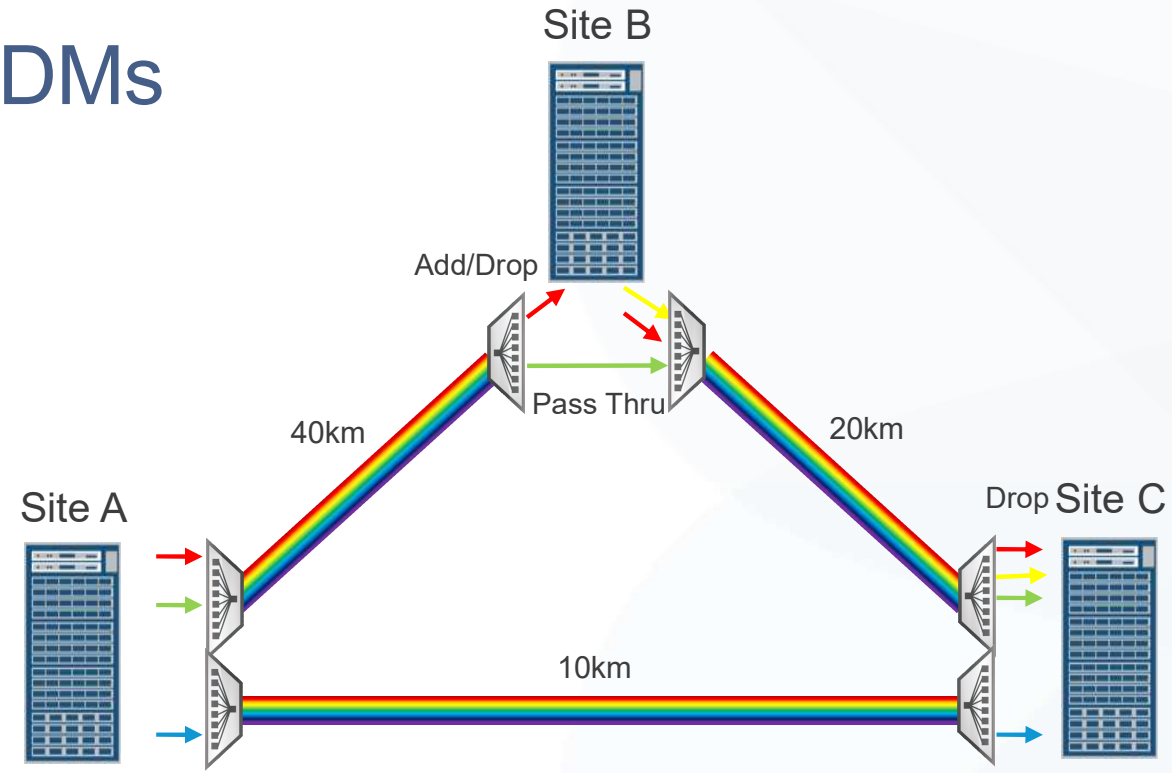
- Amplifiers or EDFAs work in the C & L Bands, not the whole CWDM spectrum
- Typically 3-types of Amplifiers
  - Post-Amp (Booster) – Lower gain with best output power
  - Pre-Amp – High gain with best receiver sensitivity
  - Line-Amp – Multi-stage combining Pre & Post amplifiers
- EDFAs are not 100% efficient; amplify both the signal and the noise
- If you go thru a series of amplifiers the OSNR will degrade to the point where your only choice is to regenerate (OEO)
- 3R re-shape, re-time, re-amplify



EDFA

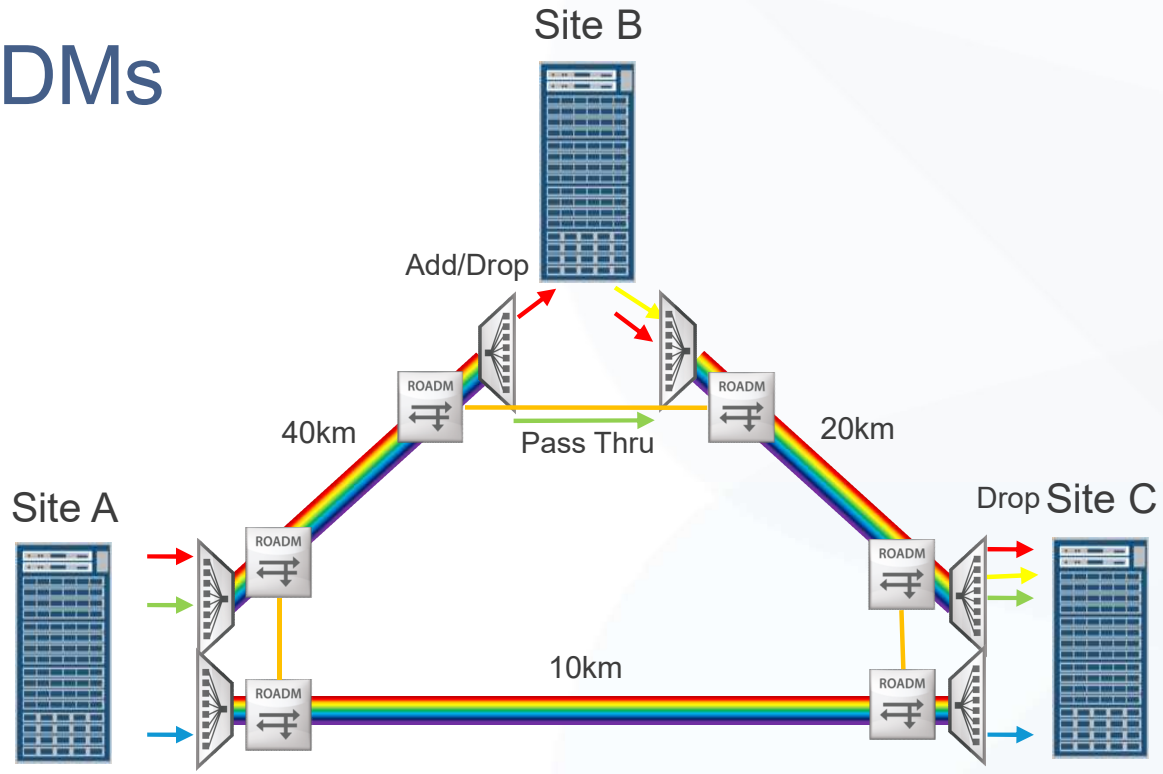
The signal is amplified but Amplified Spontaneous Emissions (ASE) noise is also added.
Amplifiers also introduce additional noise

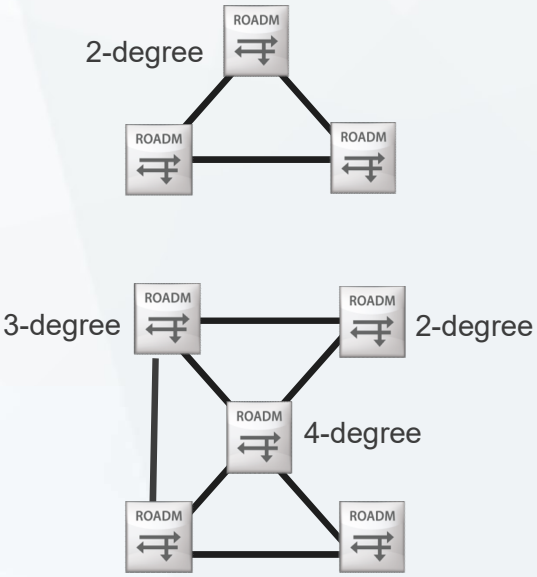
FOADMs



- FOADM : Fixed Optical Add/Drop Multiplexor
- Required manually patching at transit site
- Manual adjust optical power is required

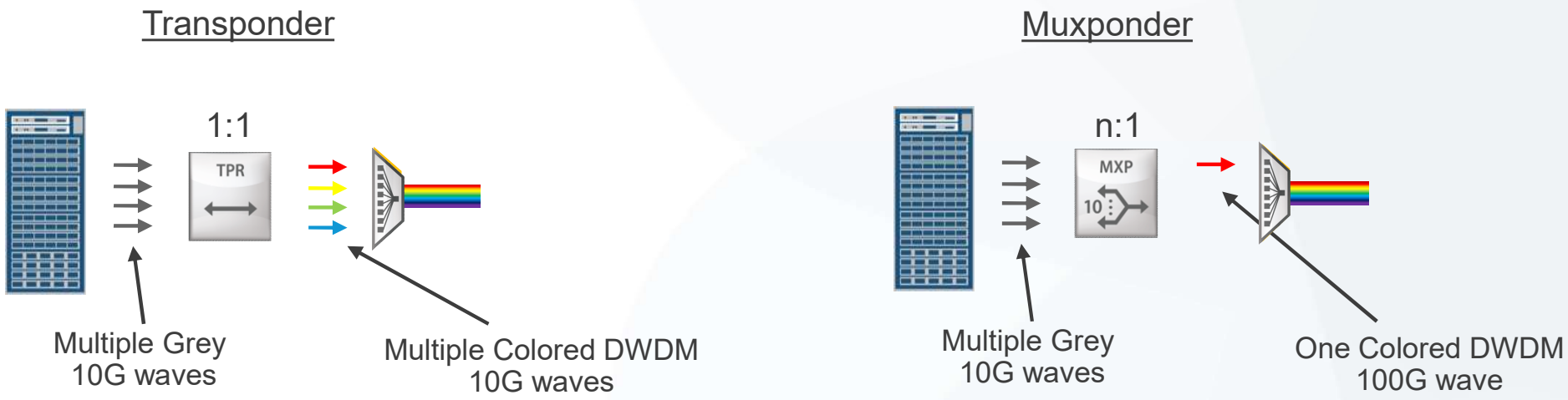
ROADMs





- ROADM : Reconfigurable Optical Add/Drop Multiplexer
- Allows one to control which channels are add/dropped and which channels are passed thru
- Power management and balancing to avoid non-linear effects

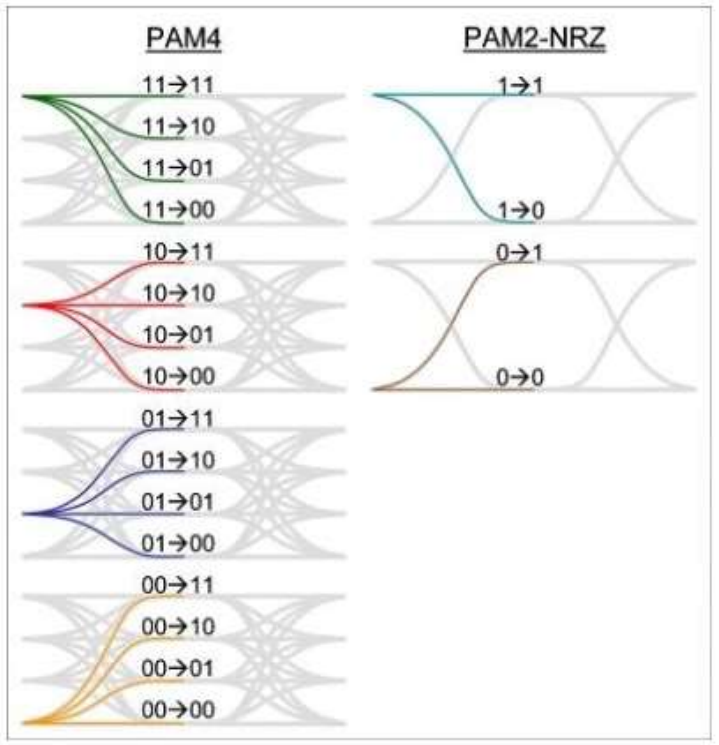
Transponders and Muxponders



Modulation Techniques

Direct Detect

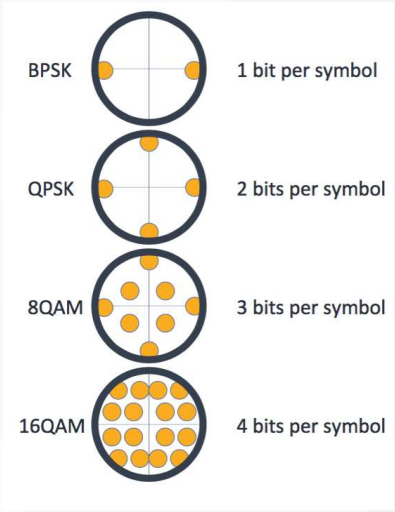
- On/Off Keying has been used for decades, but is susceptible to impairments at speeds over 10Gb/s
- Most plugs 10G and below use direct detect technology
- Encodes a single bit in each symbol (or 2 for PAM4)
- Simple to implement, with few optical components.
- New offerings of 100G Direct Detect using PAM4.

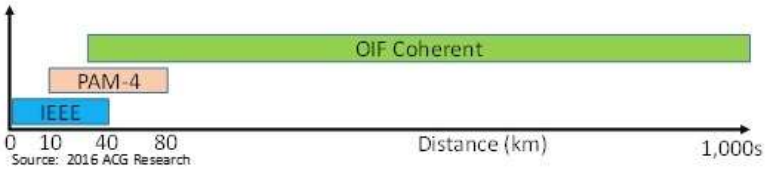


Modulation Techniques

Coherent Detection

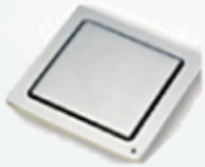
- First employed in wireless communications, optical deployment started in 2010.
- Local reference laser is used to “tune” the receiver, resulting in improved sensitivity and noise immunity.
- Linear impairments can be corrected using DSP techniques.
- Lower network latency because DCMs are not required.
- SW Programmable!!





Baud Rate	34 Gbaud	45 Gbaud	34 Gbaud	64 Gbaud	64 Gbaud	64 Gbaud
Modulation	DP QPSK	8QAM	16 QAM	16 QAM	32 QAM	64 QAM
Ch capacity	100G	200G	200G	400G	500G	600G
Normalized Reach	3000 km	1500 km	700 km	700 km	300 km	150 km

Evolution of Coherent



2015 PRESENT
- 28 nm
- 19W/100Gb*
- 32 GBd

2017 PLANNED
- 16 nm
- 8W/100Gb/s
- 60GBd

>2019 FORESEEN
- 7nm
- 4W/100Gb/s
- 80 GBd

CAPACITY PER λ	CAPACITY PER λ	CAPACITY PER λ
4 bit/sym 100 Gb/s (Metro)	4/8 bit/sym 200/400 Gb/s (Metro)	6/8 bit/sym 400/600 Gb/s (Metro)
8 bit/sym 200 Gb/s (DCI)	12 bit/sym 400/600 Gb/s (DCI)	12 bit/sym 800 Gb/s (DCI)

Coherent Transponder Integration

- Integrated Coherent Transponder = Simplified Operation
- Management Choice

- Larger footprint, power & cost
- Optimized for scalability and high-end cases


Thank you

Direct Detect PAM4

Low-Cost P2P DCI applications

- Operates in the C-band, using fixed wavelengths
- Two carriers @ 50G
- Fewer components, lower cost
- 60-80km span lengths, over “special” OLS
- Limited channels (40), total 4T
- High OSNR demands
- DCMs are required

Vs.