AFL Technology & Product Overview:

Wavelength Division Multiplexing

We connect.

Overview

- What is WDM?
- Why use WDM?
- WDM Technology
- Applications
- Common Product Configurations
- Testing/Troubleshooting

What is WDM?

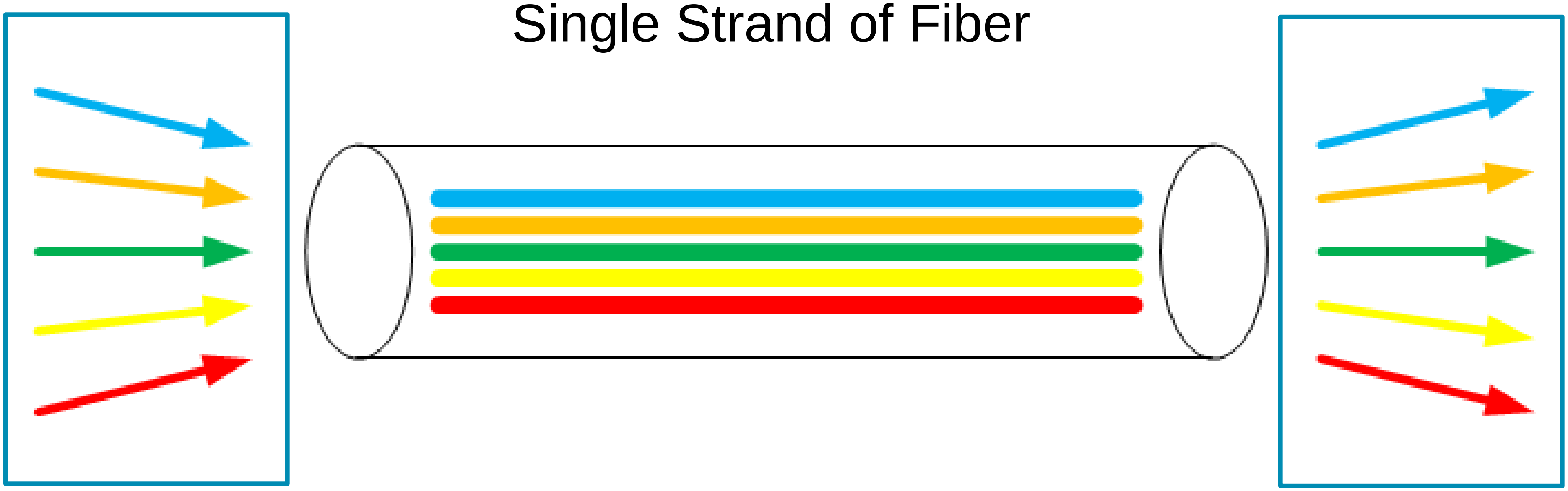
- WDM stands for “Wavelength Division Multiplexing”
- Wavelength Division Multiplexing is a method of combining/separating multiple wavelengths of light into/out of a single strand of fiber
- Each wavelength of light “carries” a different signal
- This can be accomplished using a variety of different passive optical filters (CWDM, DWDM, BWDM, etc.)

What is WDM? (Cont'd)

WDM Filter

WDM Filter

Single Strand of Fiber



Different wavelengths of light combined or multiplexed ("mux'd") into fiber

Different wavelengths of light separated or de-multiplexed ("demux'd") out of fiber

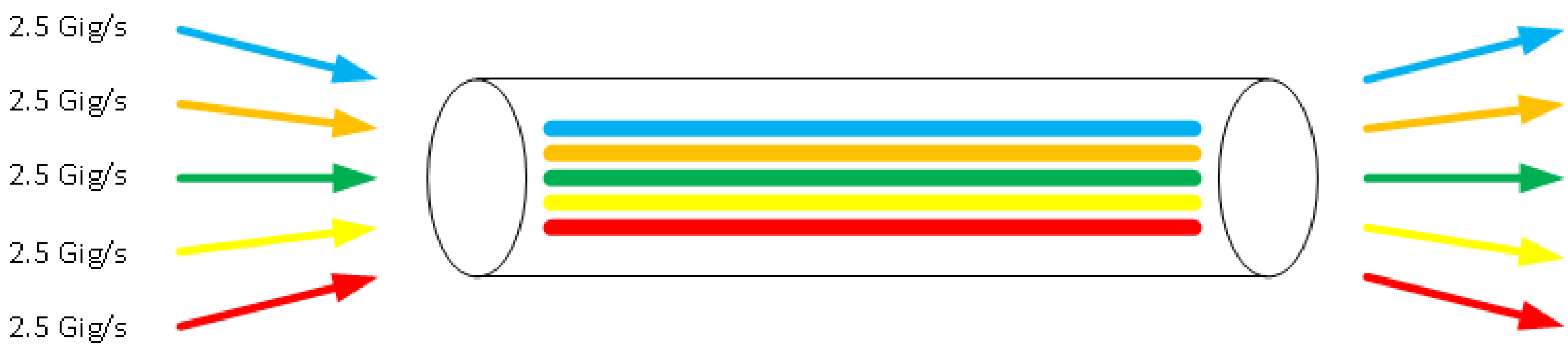
Why use WDM?

- WDMs increase the data-carrying capacity of fiber optic cable
- How is this done?
  - Each wavelength of light acts as an independent data-carrying "pathway"
  - WDM filters allow multiple wavelengths of light to be added to a single fiber
  - Increasing the number of wavelengths on a fiber increases the number of data-carrying "pathways," which in turn increases the overall data-carrying capacity of the fiber

Why use WDM? (Cont'd)

Data Transfer Rate with 1 Wavelength per Fiber = 2.5 Gig/s

Data Transfer Rate with Multiple Wavelengths per Fiber = (2.5 Gig/s) x (# of Wavelengths) = **Larger Capacity**

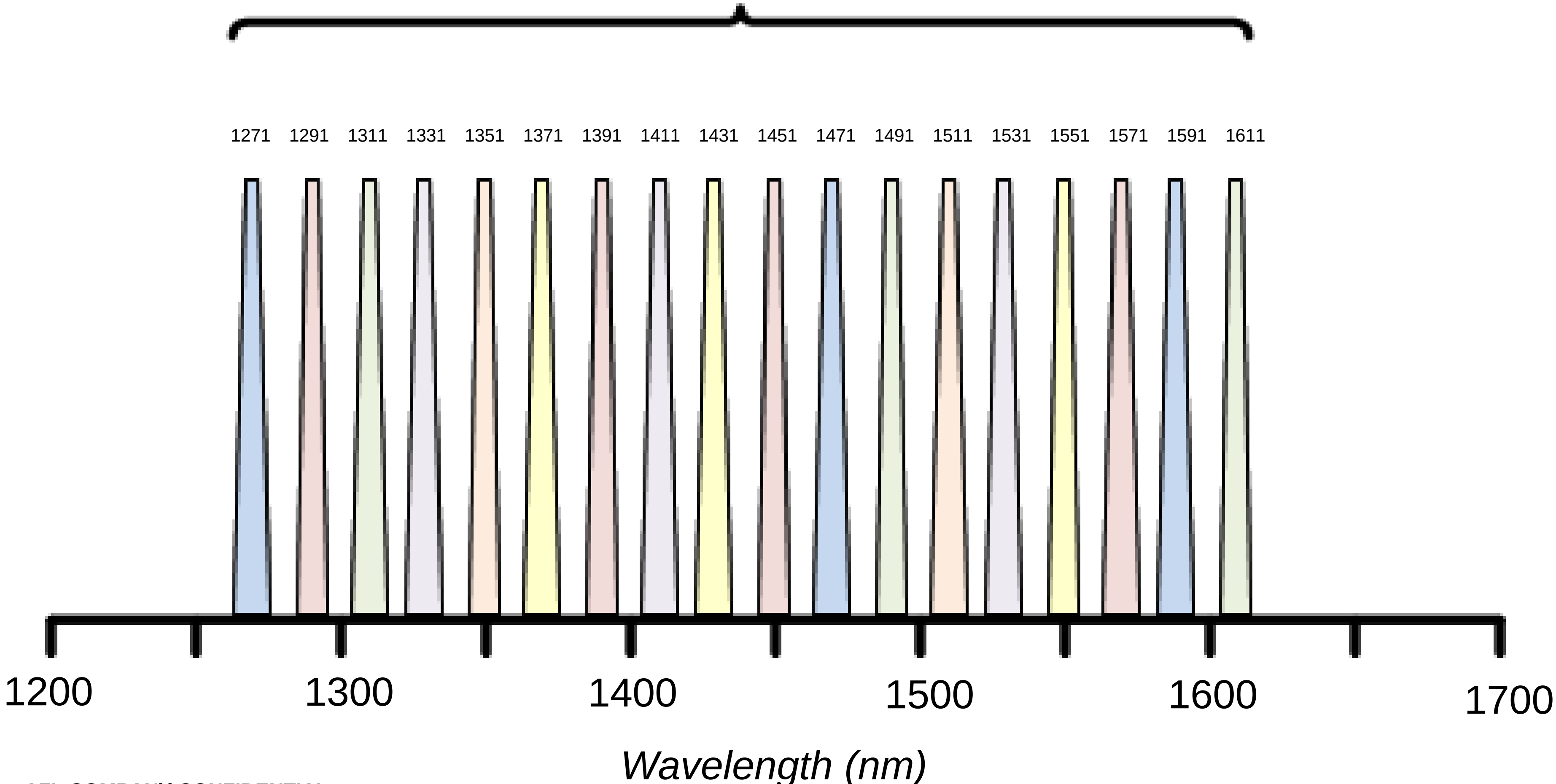


WDM Technology - CWDM

- **CWDM** stands for "*Coarse*" Wavelength Division Multiplexer
- One of the most distinguishing features of this type of WDM device is the spacing between the wavelengths
- Per ITU-T Standard G.694.2 the channel spacing between CWDM wavelengths is 20 nm

CWDM - Wavelengths

CWDM – 18 Available Wavelengths/Channels

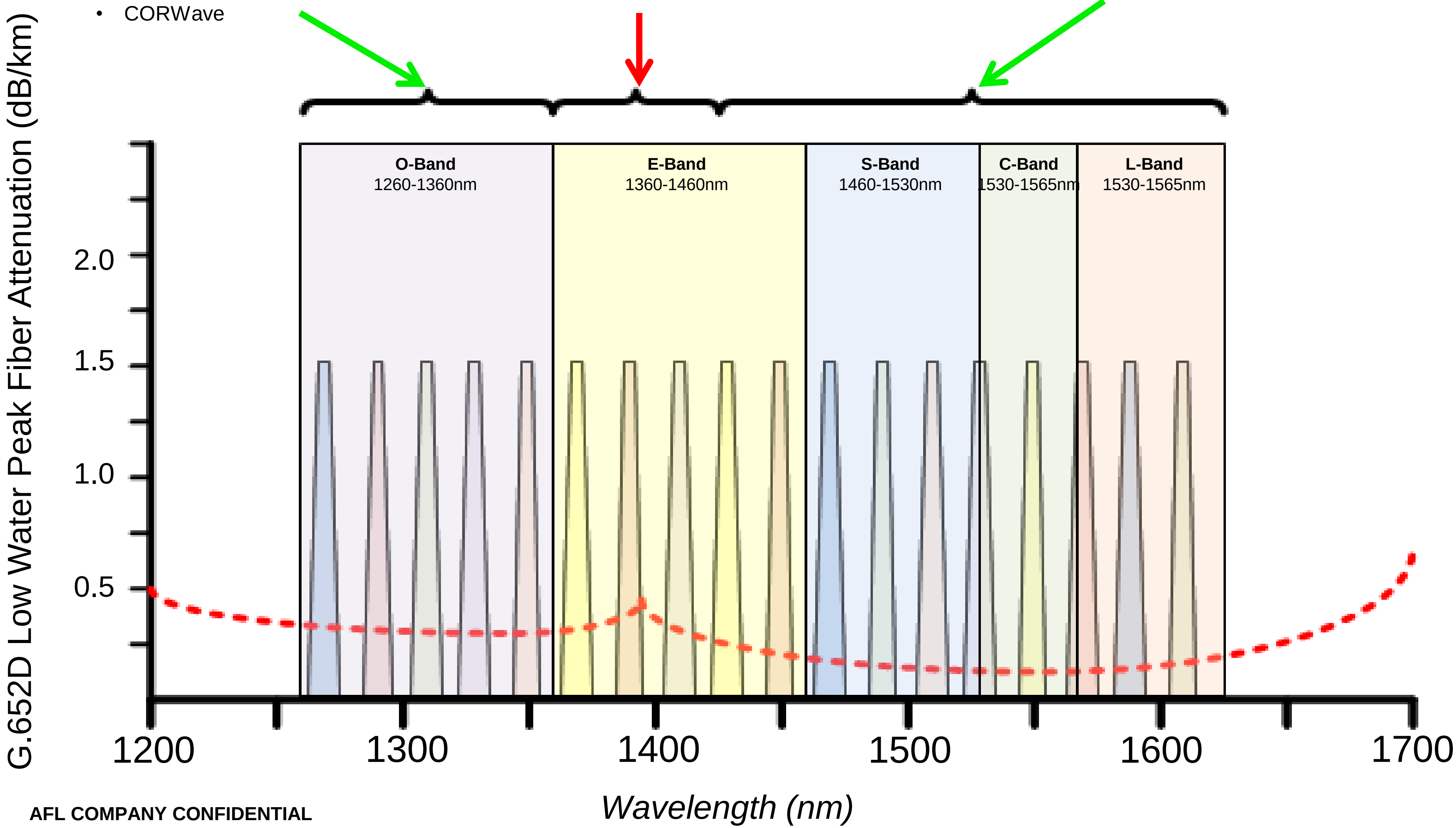


CWDM – Spectrum Bands and Applications

Region 1 (1260 - 1360nm)
- Legacy Node Traffic
- Upstream PON
- CORWave

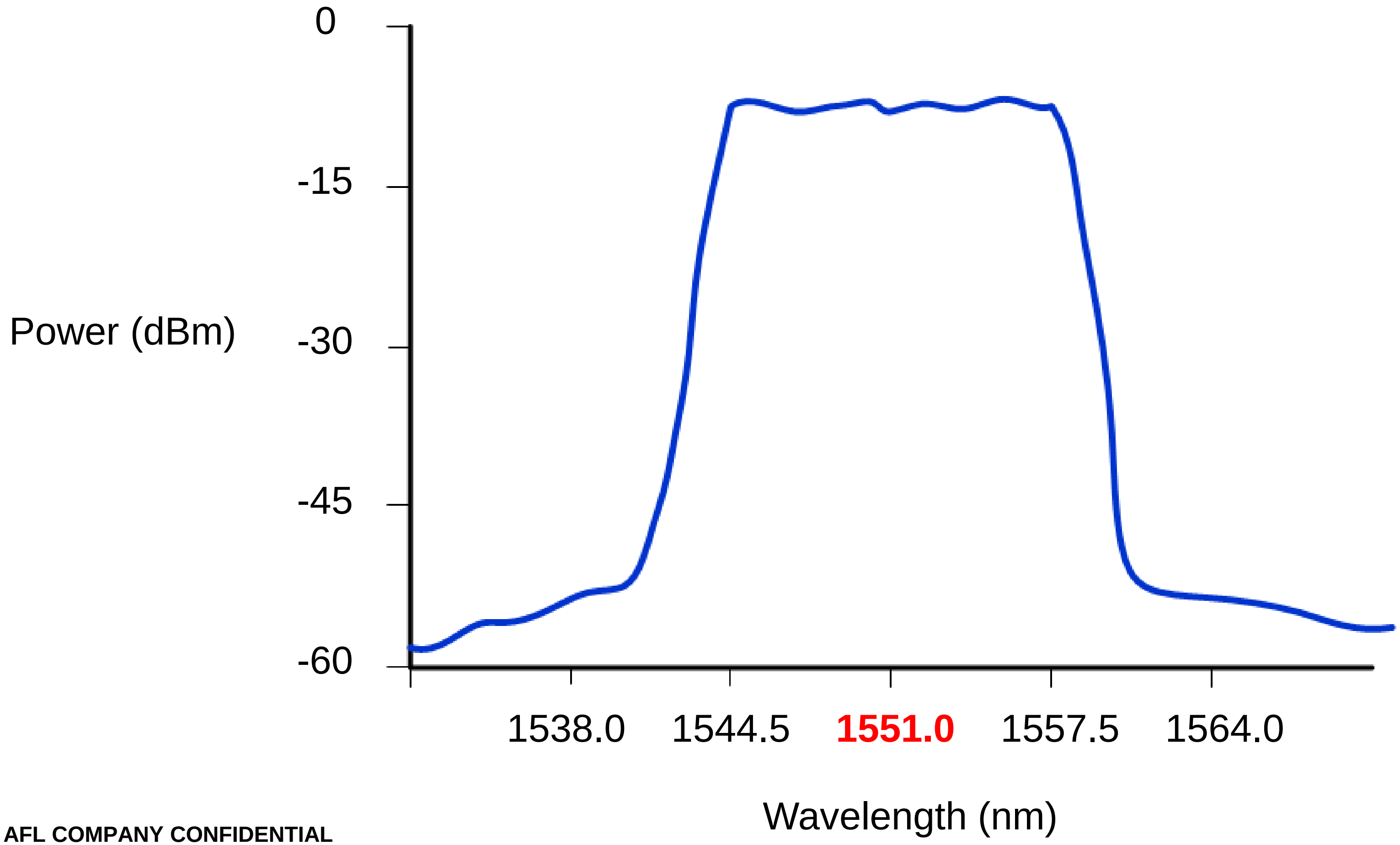
Region 2 (1360 - 1420nm)
- Typically not occupied (due to water peak)
- G.652D can be used (low water peak)

Region 3 (1420 - 1625nm)
- Most common CWDM wavelengths



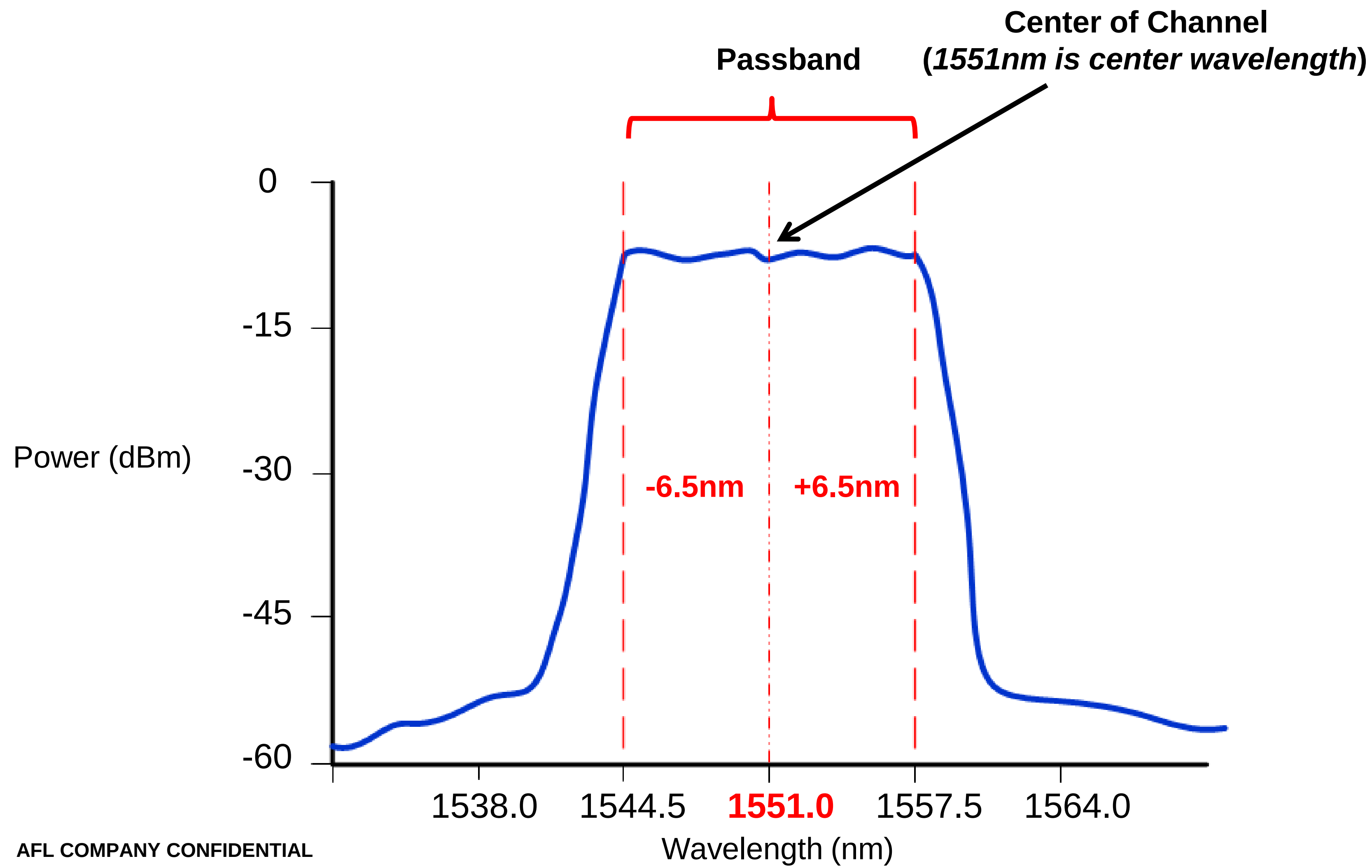
CWDM – Signal Profile

- Another distinguishing feature of CWDM devices is the signal profile



CWDM – Signal Profile (Passband)

Passband for a CWDM channel is +/- 6.5 nm center wavelength

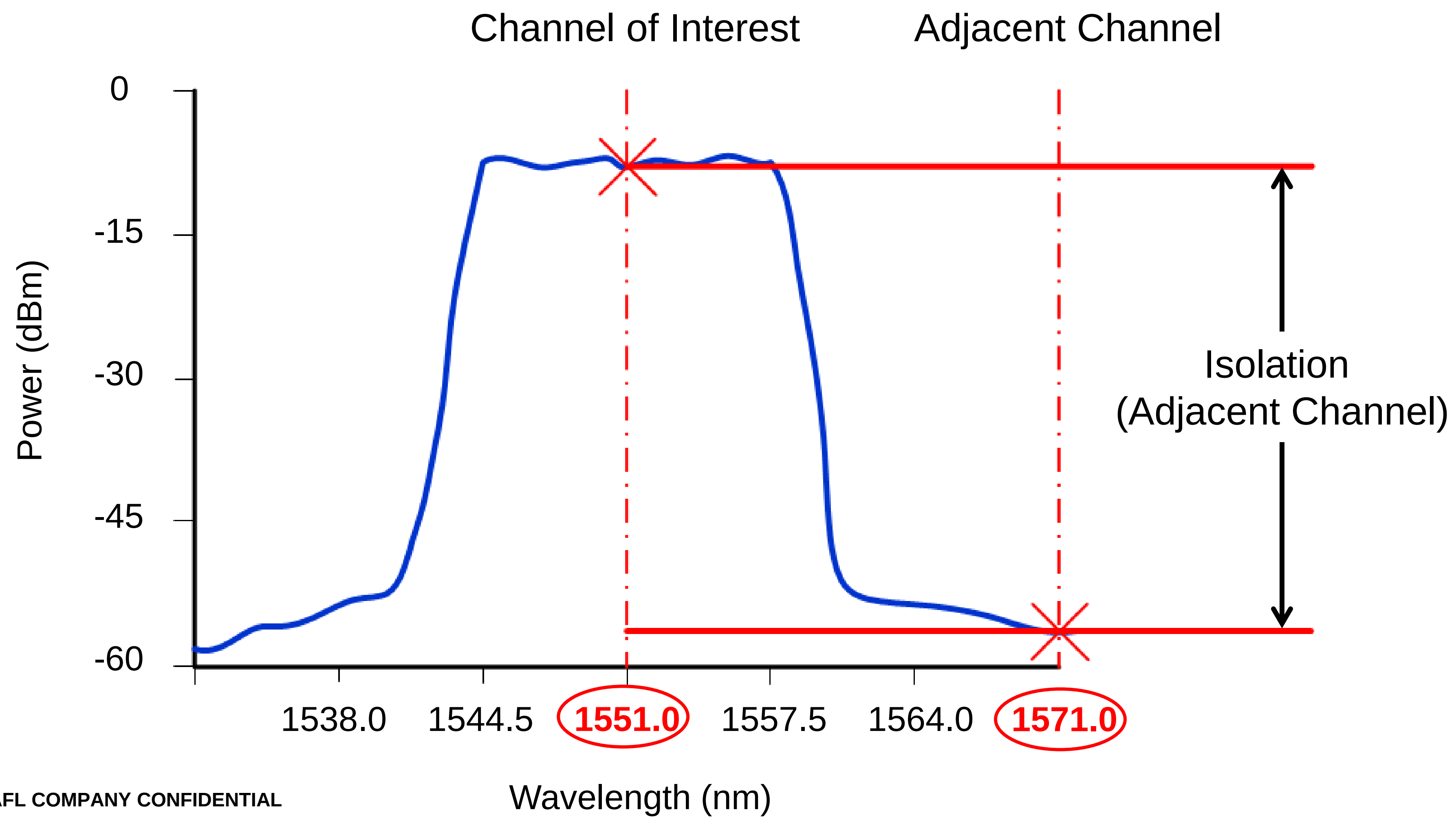


CWDM – Signal Profile (Passband take-aways)

- CWDM Passband = Center Wavelength +/- 6.5 nm
  - Ie: The passband of 1551 is 1544.5 – 1557.5 nm
- Per ITU-T standards, the center wavelength is defined on the “1”, not the “0”
  - Ie: 1551 is correct, 1550 is incorrect
- Since CWDM technology utilizes filters with large passbands (relative to DWDM), the channel spacing must also be large (20 nm) and in turn the amount of wavelength spectrum consumed is significant

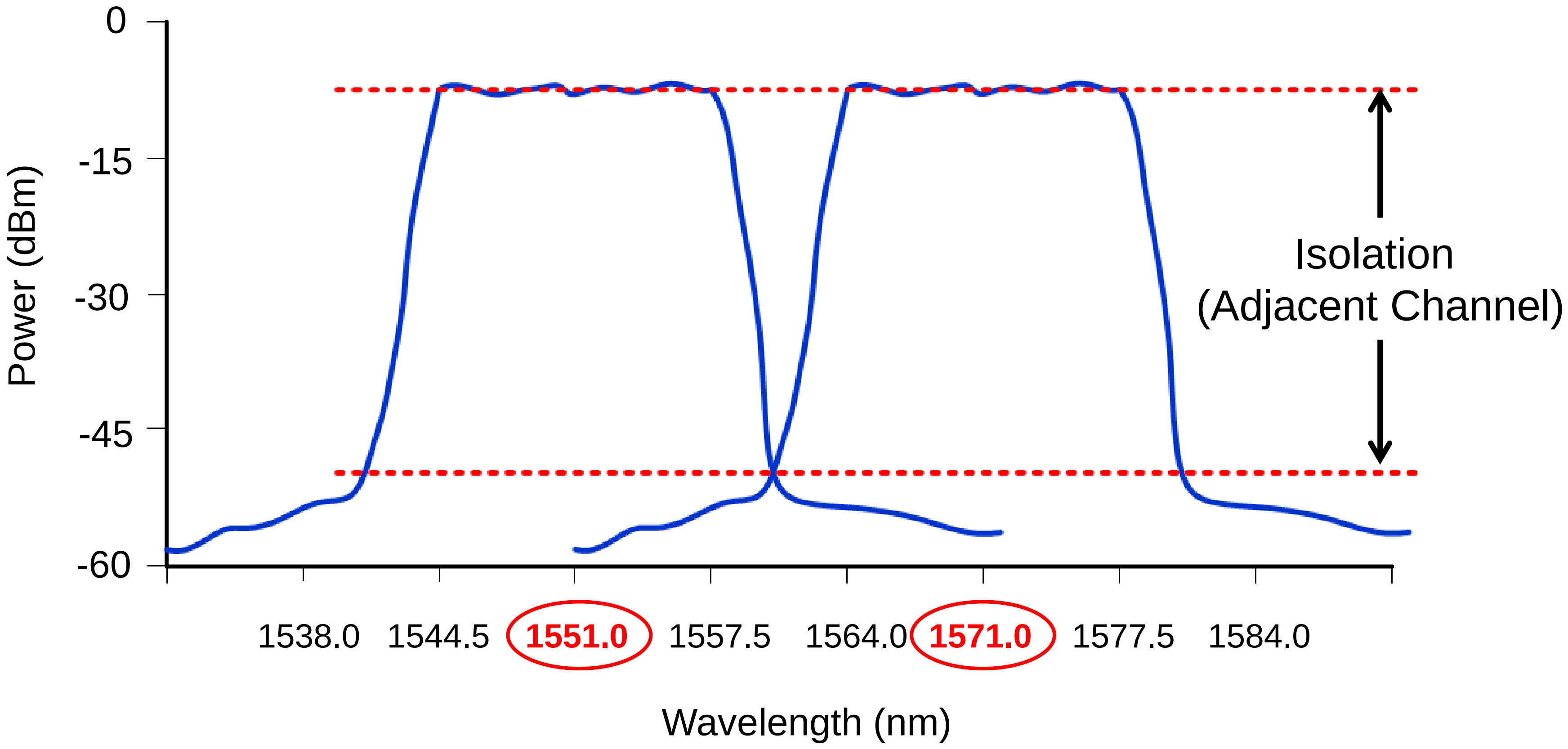
CWDM – Signal Profile (Isolation)

Typical Adjacent Channel Isolation for a CWDM Filter = ~30 dB or better



CWDM – Signal Profile (Isolation)

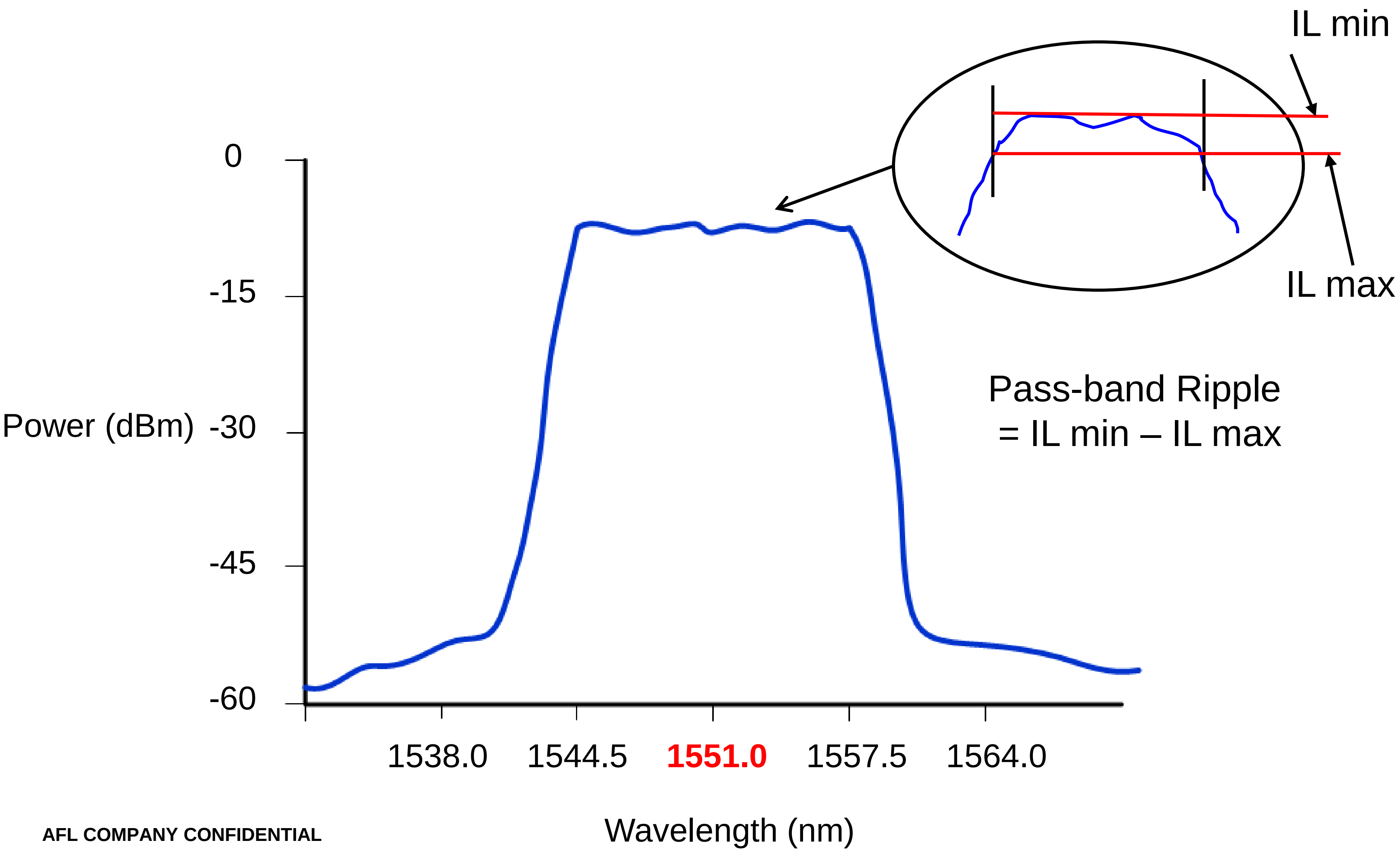
More simplified and <u>conservative</u> definition of Adjacent Channel Isolation



CWDM – Signal Profile (Isolation take-aways)

- When the active equipment interprets an optical signal, it is important that the signal possesses tall, well-defined peaks for each channel. This trait allows the individual signal peaks to be easily distinguishable from one another.
- A high isolation filter makes this possible by attenuating signal immediately outside of the channel passband (sharp drop-off).
- Additionally, a variety of environmental factors such as temperature can cause these peaks to alter shape and even “drift” (although more common with DWDM, cross-talk can occur when adjacent channels drift toward one another)

CWDM – Signal Profile (Ripple)

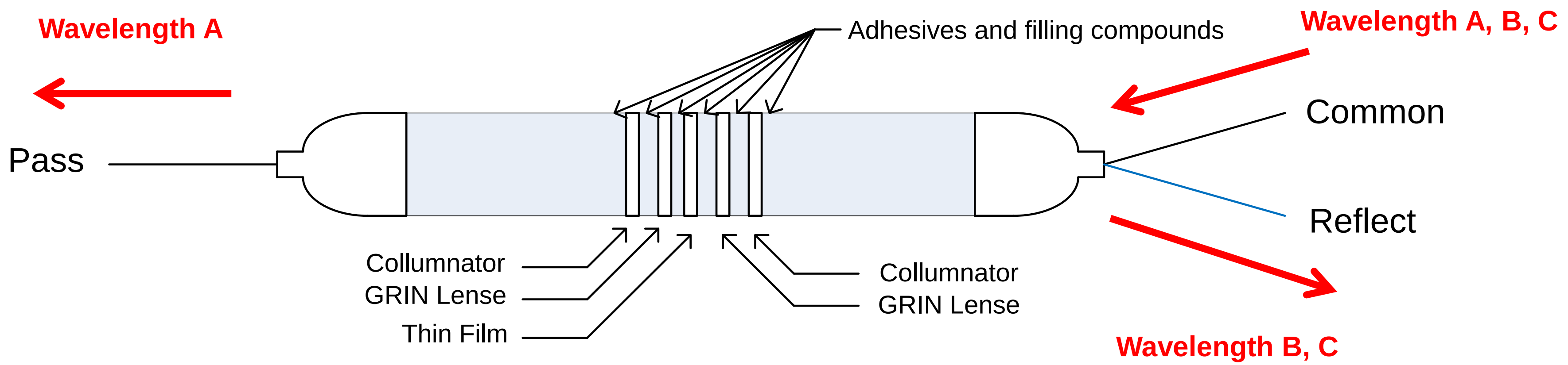


Pass-band Ripple
= IL min – IL max

CWDM – Filter Technology

- Thin Film Filter
- Free Space Filter
- AWG (Arrayed Waveguide Grating) Filter

CWDM – Filter Technology (Thin Film Filter)



Pros

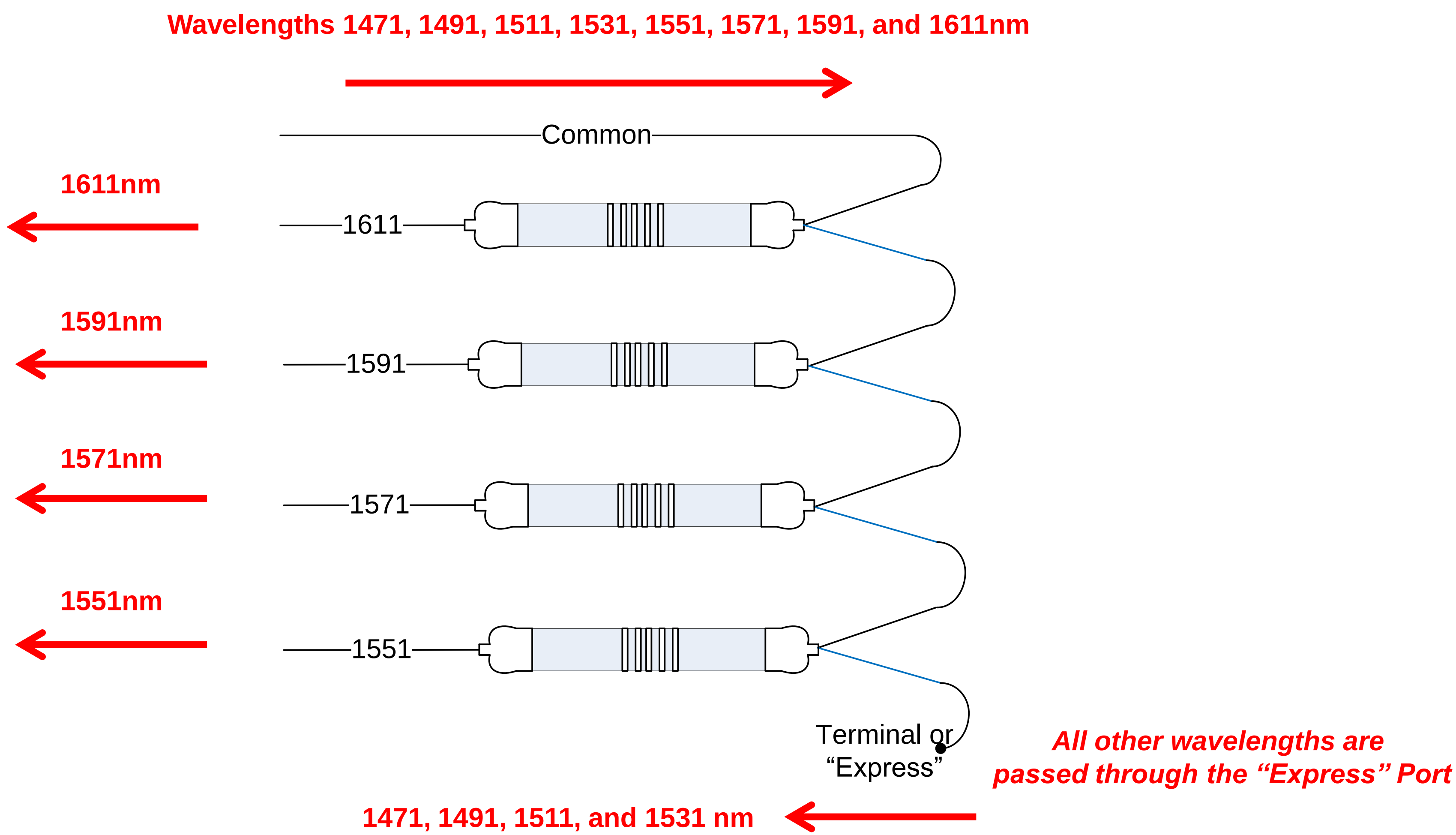
- Allows for highly customized device configurations
- Economical
- Faster Lead Time

Cons

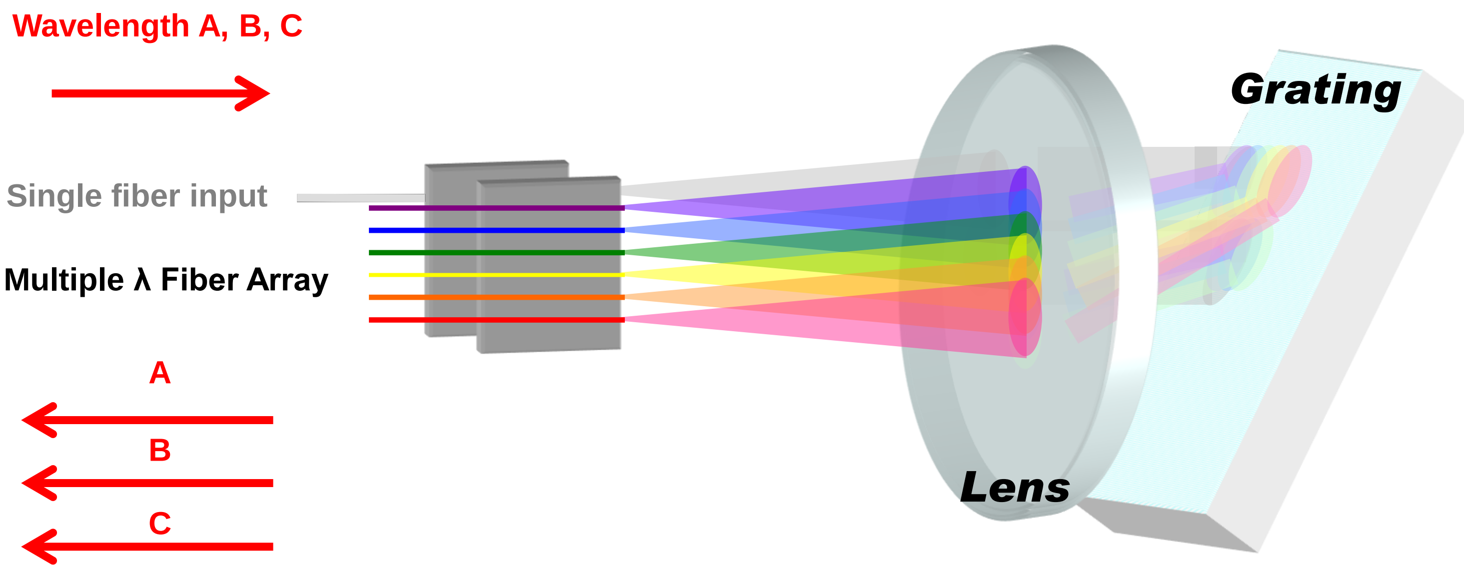
- Marginally higher IL
- Larger package size

CWDM – Filter Technology (Thin Film Filter Cont'd)

Individual Thin Film Filters are spliced into a "cascade" in order to filter the appropriate wavelengths



CWDM – Free Space Filters



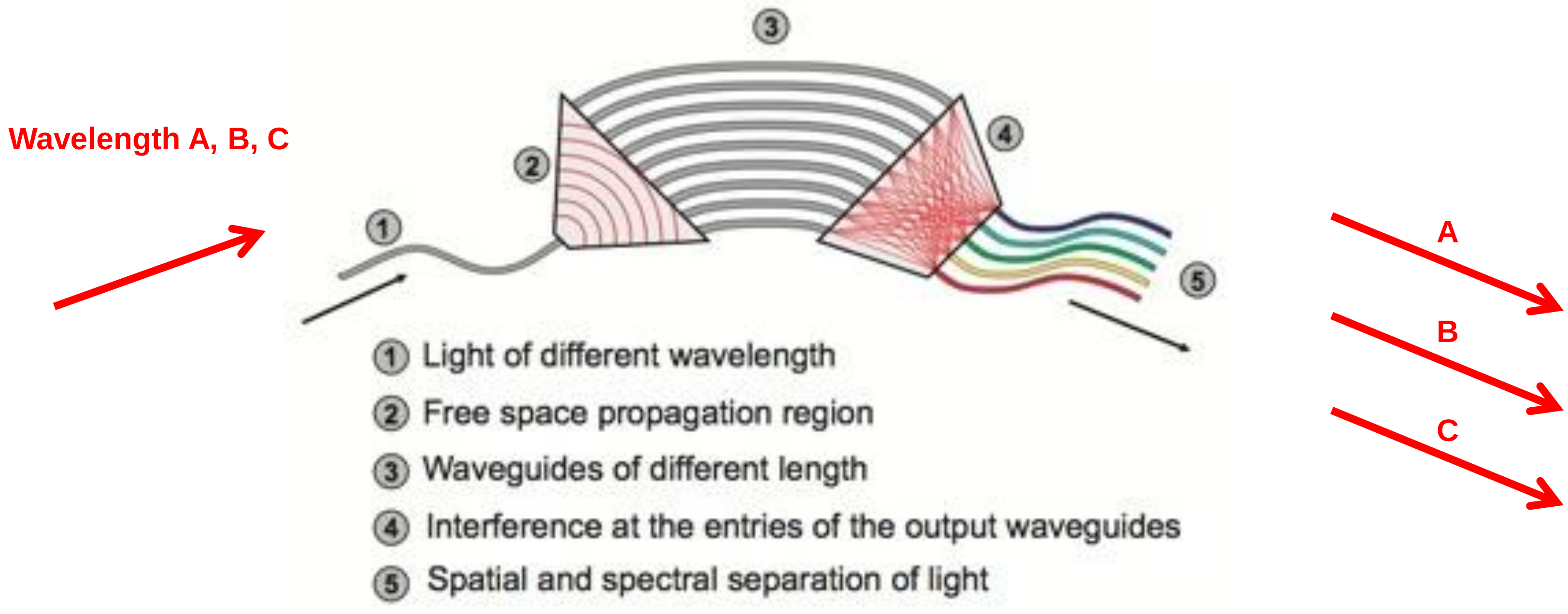
Pros

- Extremely High Uniformity
- Very Small Packages Possible

Cons

- Less Design Flexibility
- Longer Lead Times

CWDM – AWG Filters



Pros

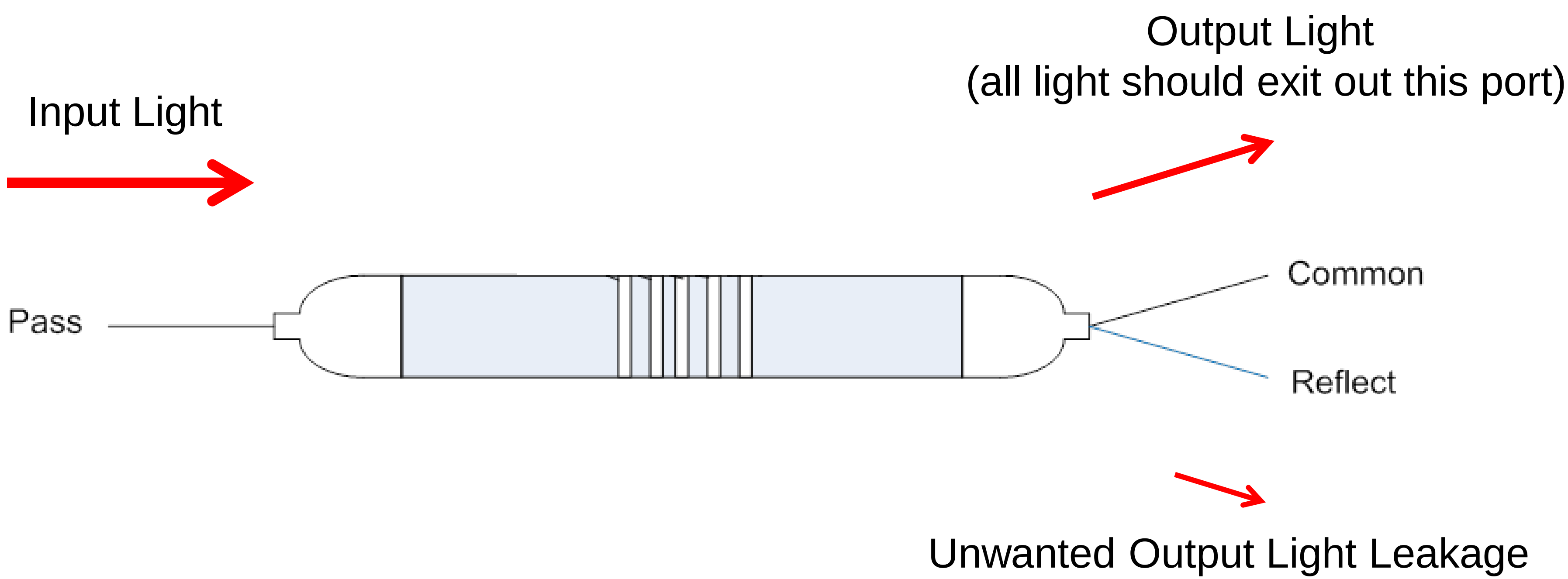
- Large Channel Count/Density Possible
- Low Cost (@ High Ch Counts)
- Temperature Insensitive (Athermal)

Cons

- High Cost (@ Low Ch Counts)

CWDM – Additional Terms and Definitions

- Directivity = Signal leakage into other input / output ports



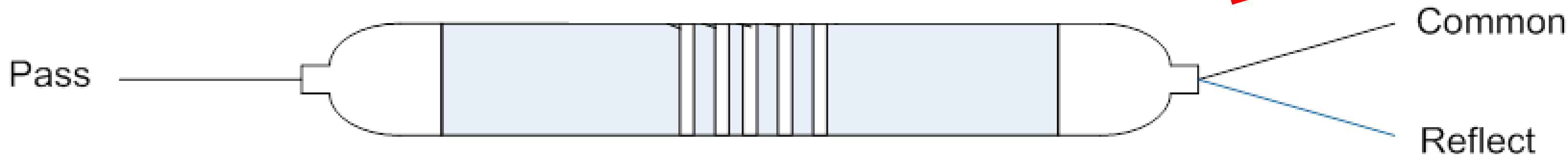
CWDM – Additional Terms and Definitions

- Return Loss = the back reflectance along the incident optical path

Input Light

Output Light
(all light should exit out this port)

Unwanted Reflected Light



WDM Technology – DWDM

- Concepts and terms that also apply to DWDM technology
  - Passband
  - Isolation
  - Ripple
  - Directivity
  - Return Loss

- Filters also found in DWDM devices
  - Thin Film Filters
  - Free Space Filters
  - AWG Filters

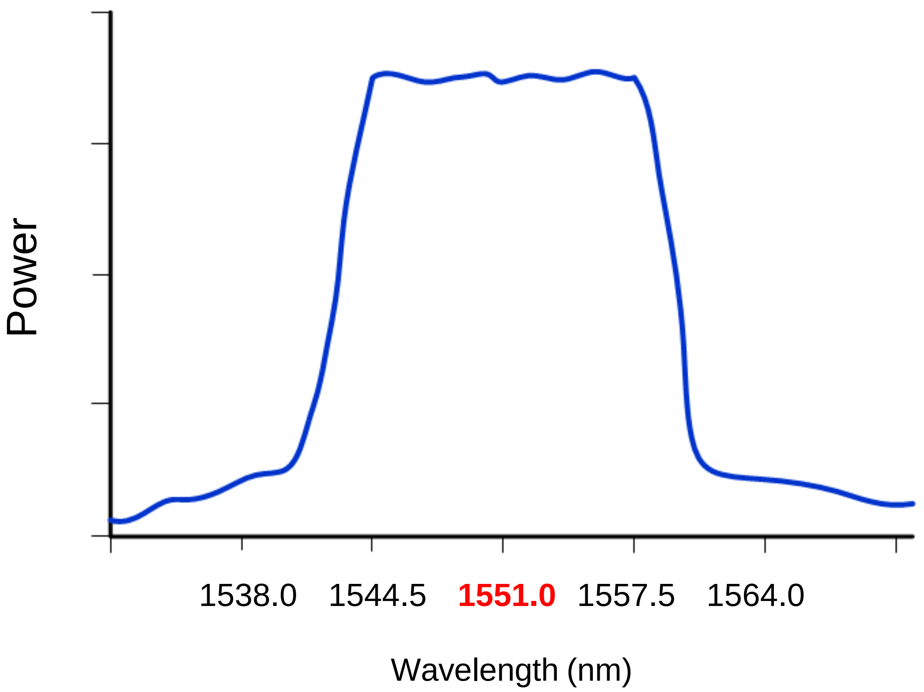
DWDM – Differences as compared to CWDM

- Channel/Wavelength Spacing
  - DWDM Channels are spaced closer together
- Passband
  - DWDM passband is narrower
- Smaller region of occupation on the Wavelength Spectrum
  - Since DWDM Channels are spaced closer together and the passband is narrower than the amount of wavelength spectrum occupied is less than that of CWDM devices

DWDM – Channel/Wavelength Spacing

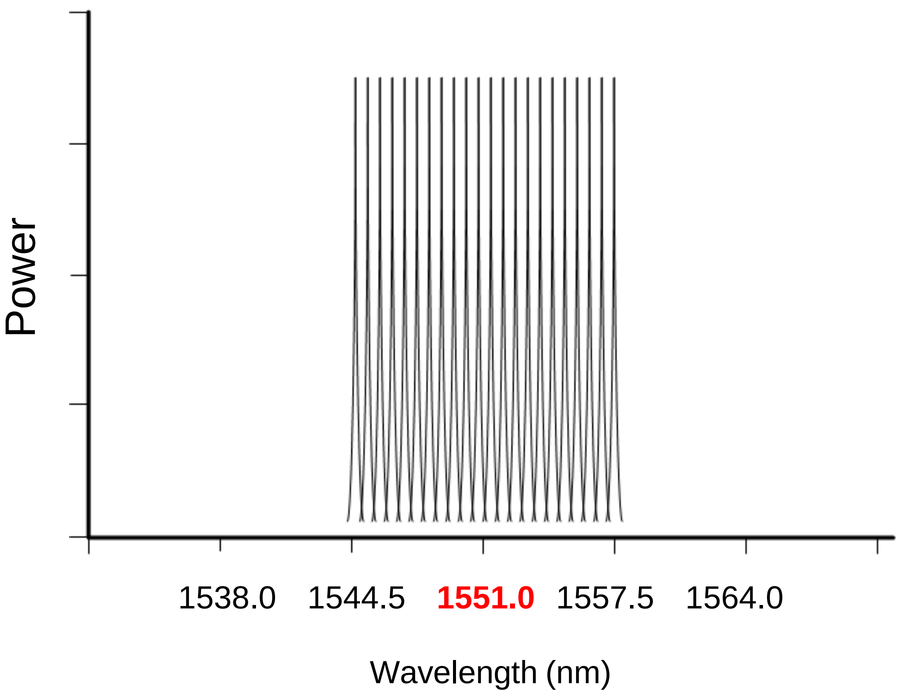
A single CWDM Channel

CWDM Channel Spacing = 20 nm



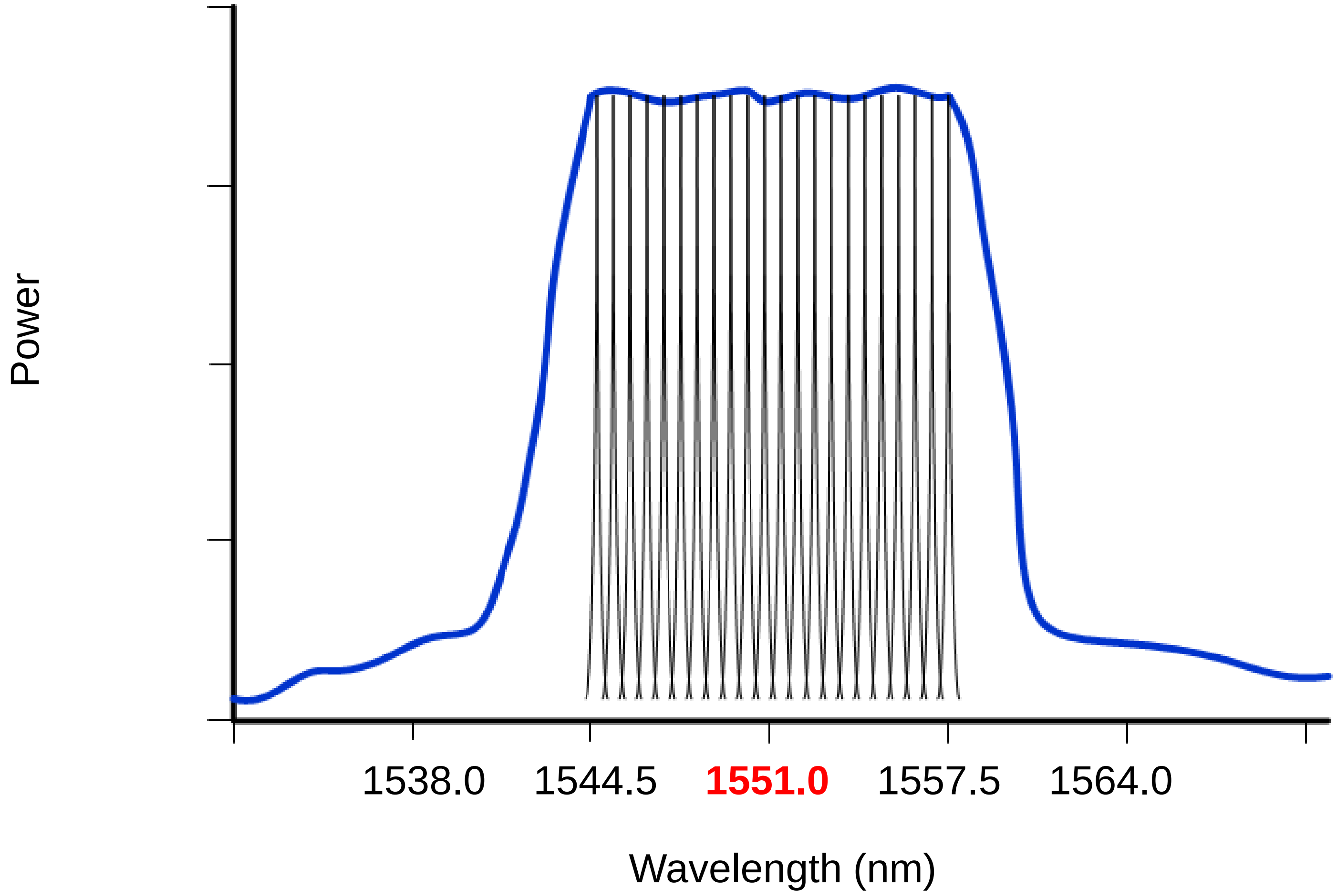
Multiple DWDM Channels

DWDM Channel Spacing = 0.8 nm



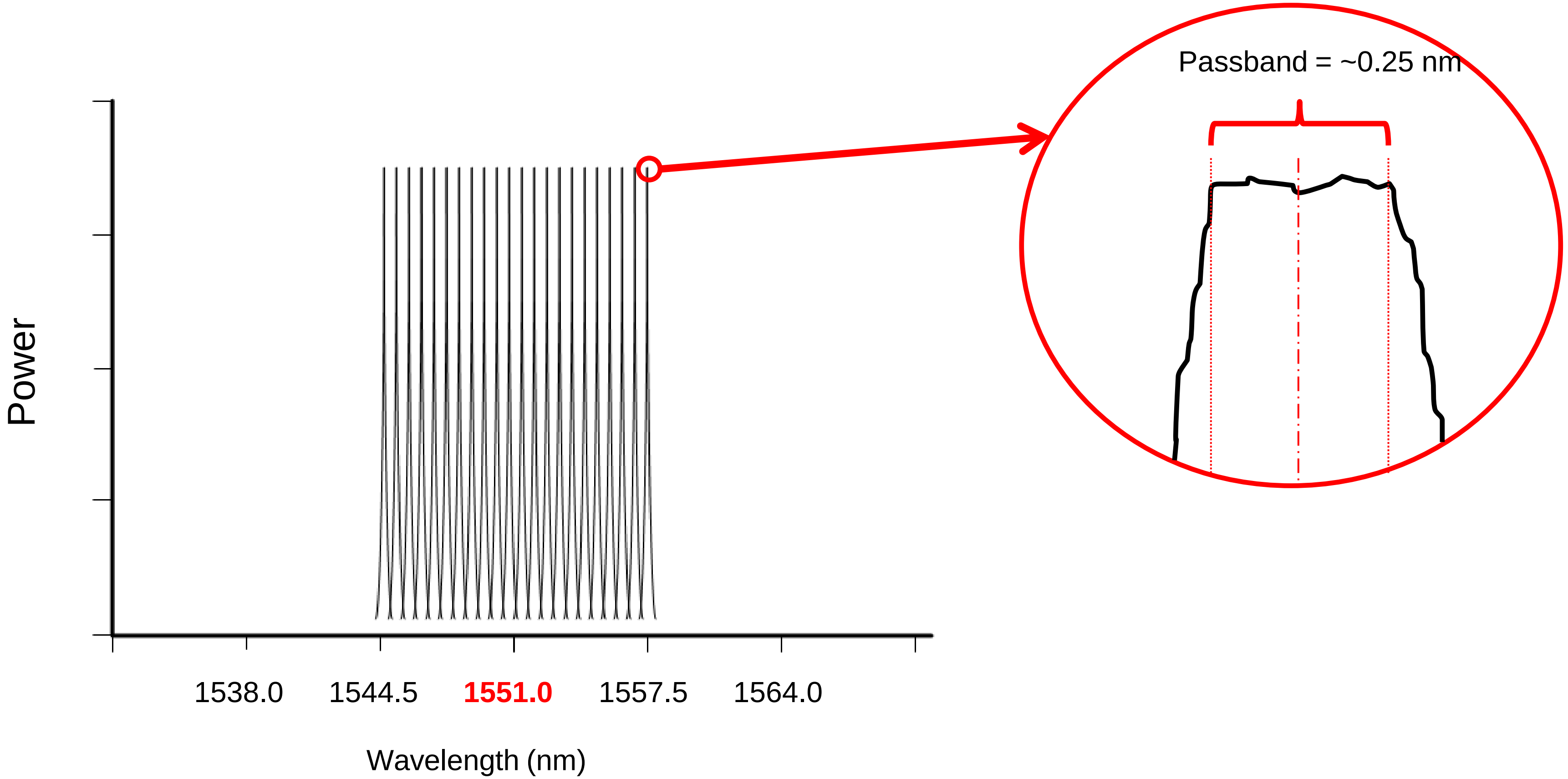
DWDM – Channel/Wavelength Spacing

16 DWDM Channels can fit within the passband of a single CWDM Channel!!!



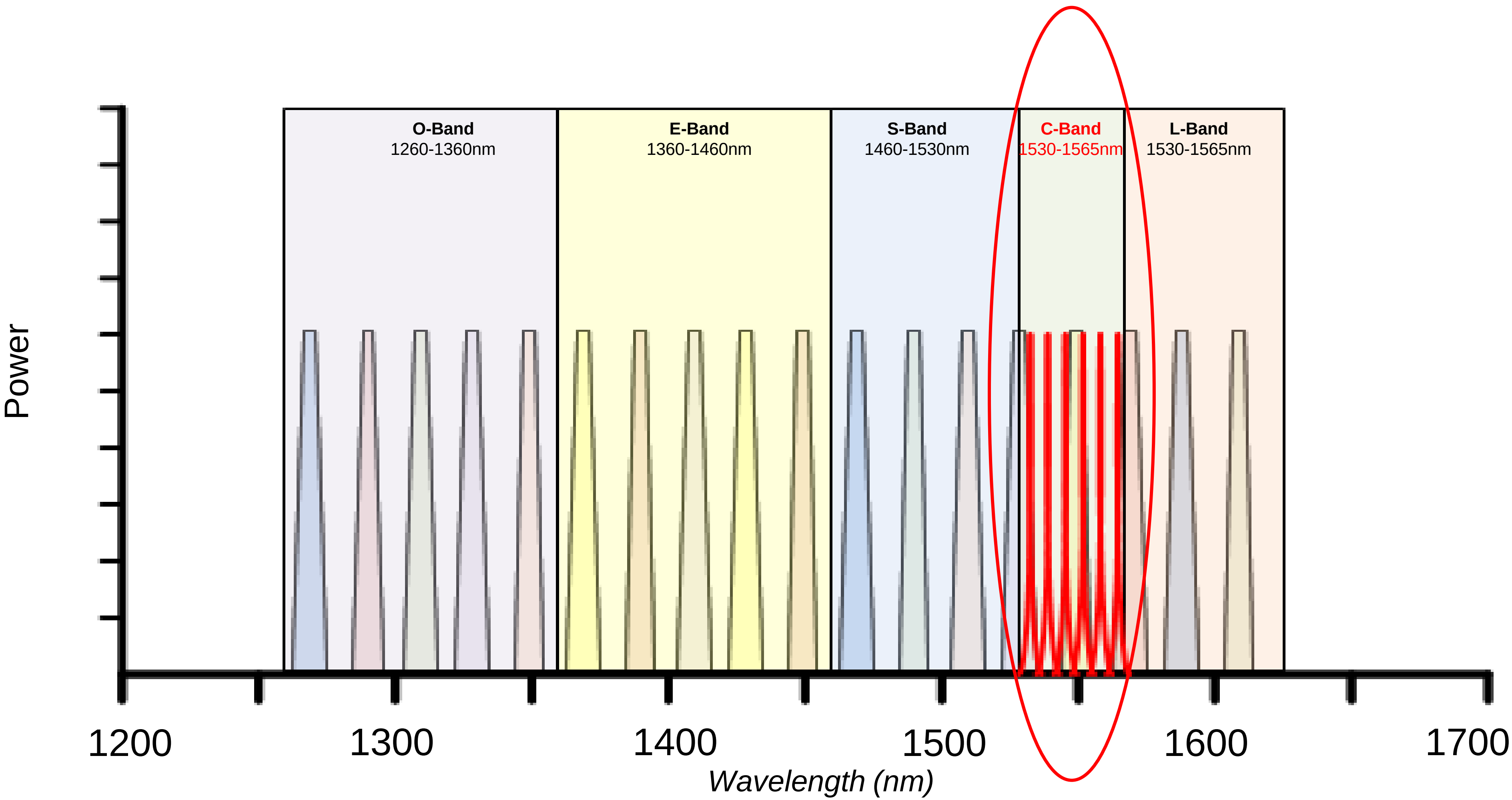
DWDM – Passband

The passband of a DWDM Ch is much narrower than the passband of a CWDM Ch



DWDM – Location on the Wavelength Spectrum

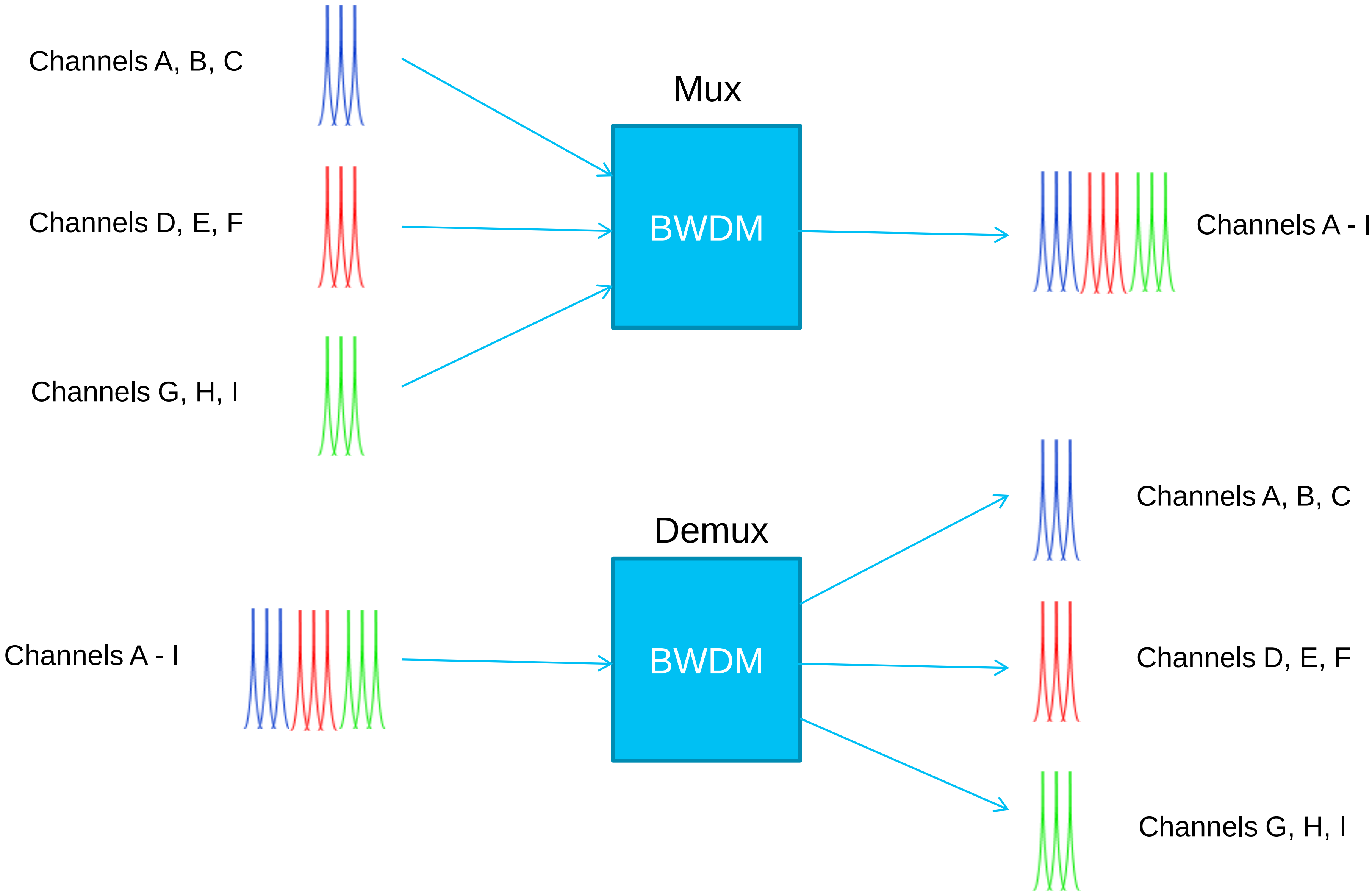
Most Commercial DWDM Channels are found within the C-band



So now what is a BWDM?

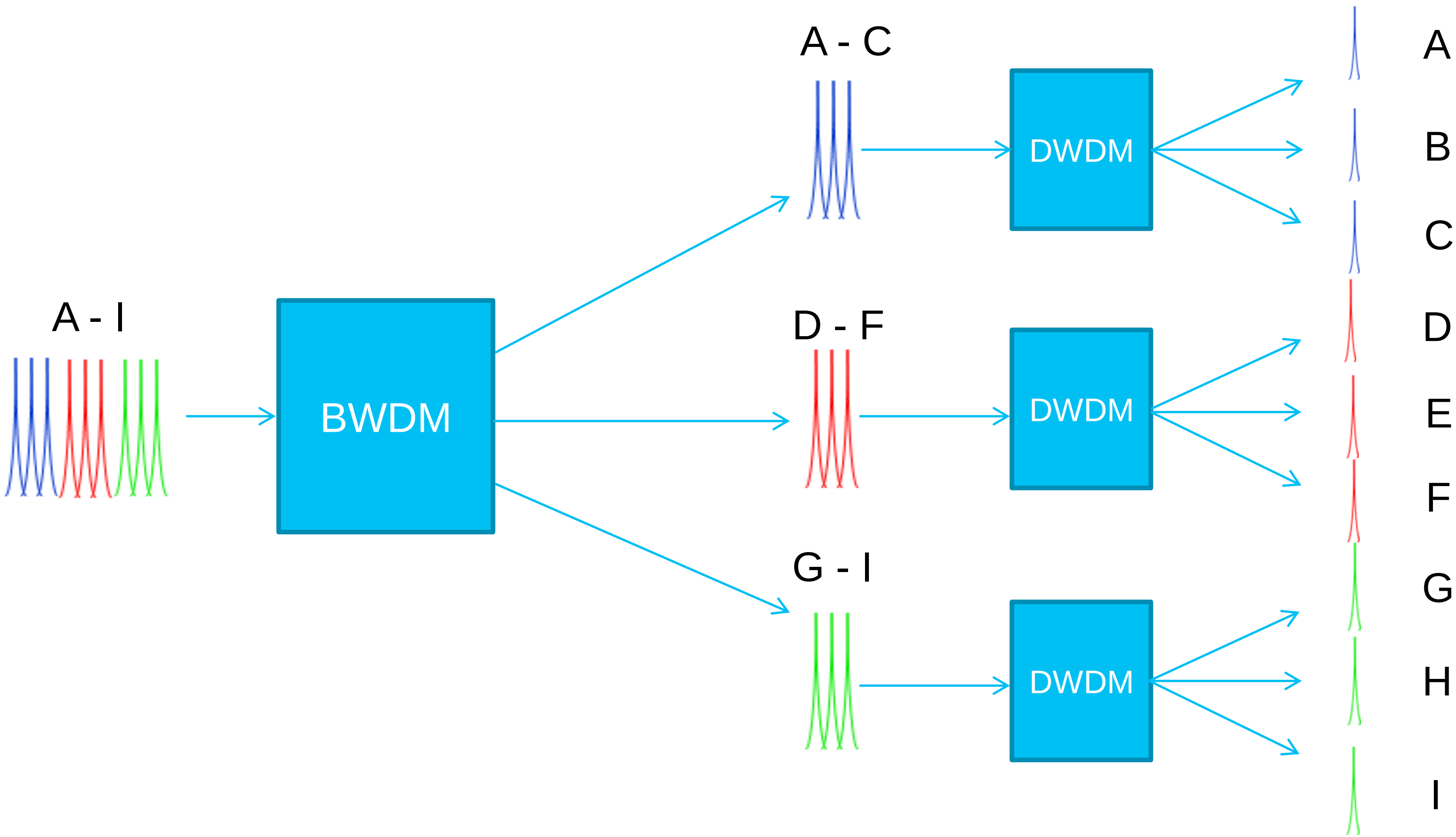
- BWDM stands for “Band” Wavelength Division Multiplexer
- Instead of filtering individual channels, a BWDM will filter a group of channels
- Although “BWDM” is a generic term that can be applied to any filter device, it is most often used when addressing DWDM channels

BWDM – Example Diagram



BWDM – Example (Cont'd)

Works well in MDU applications where "pockets" of customers exist

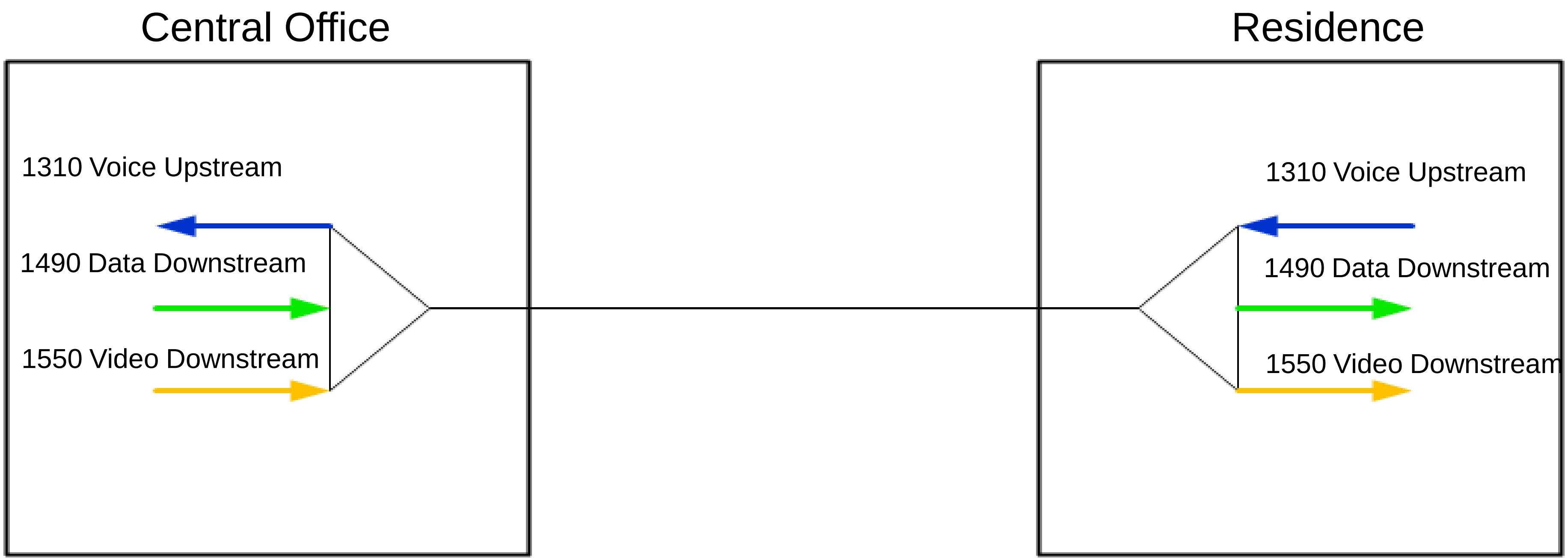


WDM Applications

- PON
- WDM-PON
- Metro Ethernet
- Cell Tower Backhaul
- Long Haul

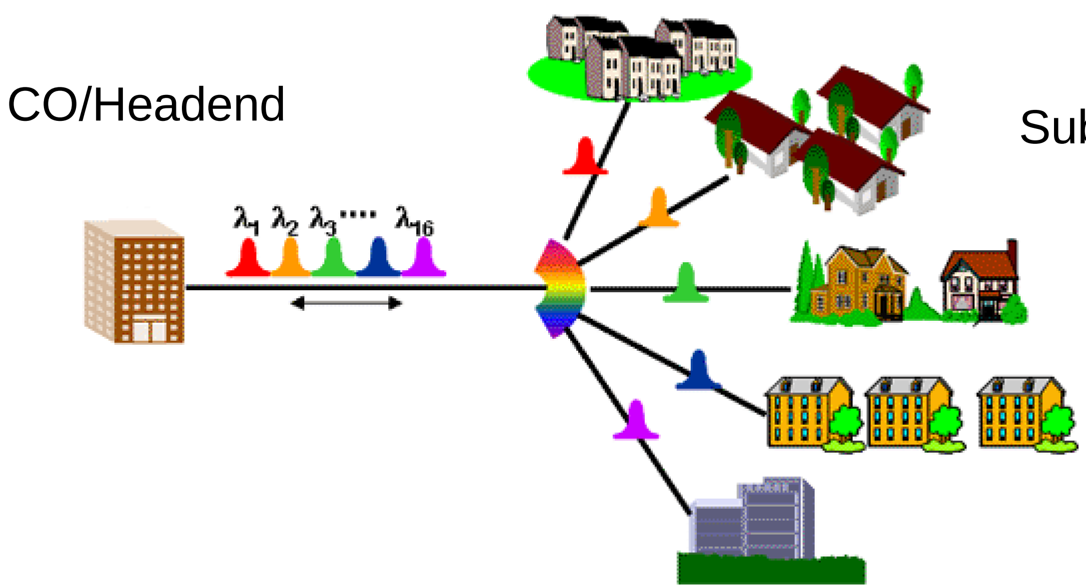
WDM Applications – PON Architectures

- PON
  - Residential Applications
  - Typically only a few different wavelengths/channels are used (1310, 1490 and 1550 nm)
  - 1G systems widely deployed; 10G gaining popularity



WDM Applications – PON Architectures

- WDM-PON
  - Multiple (32 channels+) Transmit/Receive Channels used to provide service to a variety of customers
  - 10G+ service possible (Higher speeds compared to PON alternatives)
  - Leverages existing PON infrastructure
  - SOA (Semiconductor Optical Amplifiers) are key to WDM-PON systems

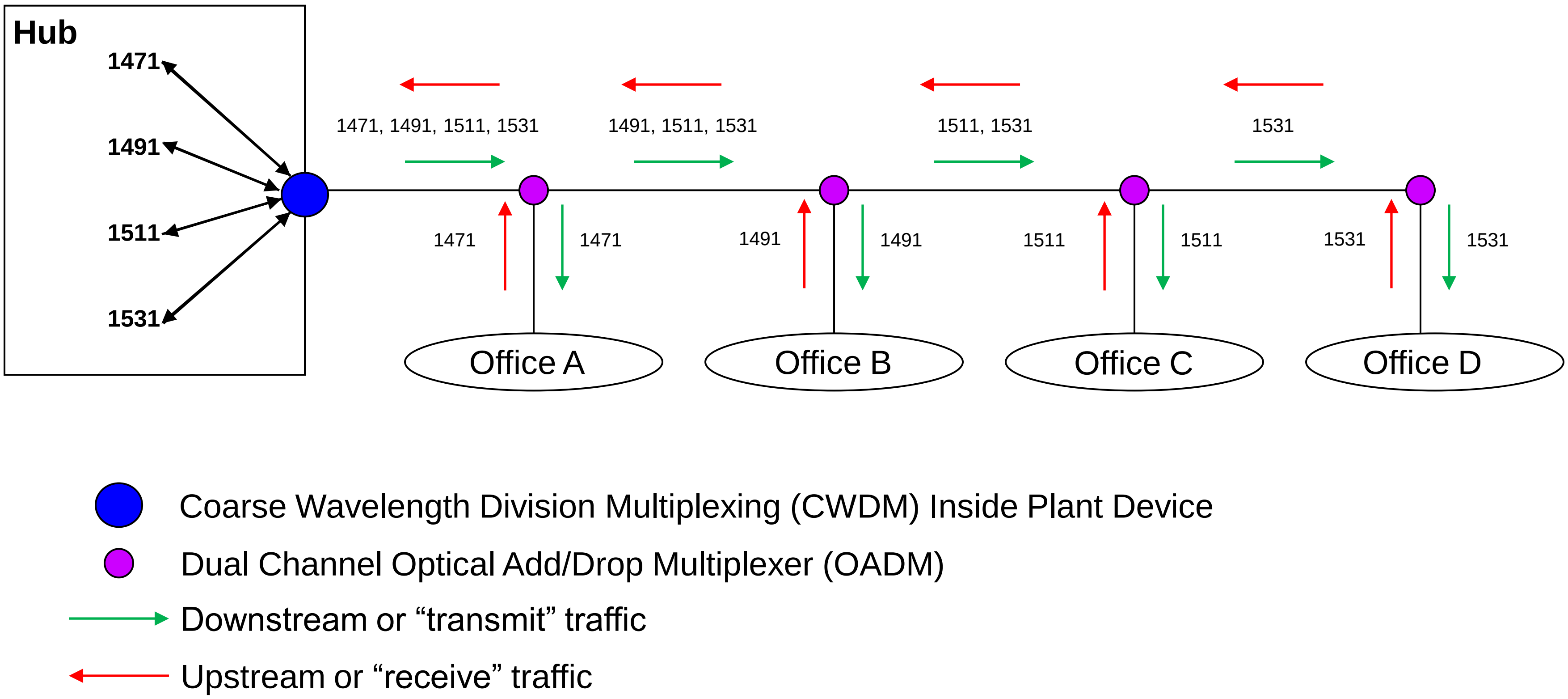


WDM Applications – Metro Ethernet

- Metro E
  - Metro Area Network based on Ethernet standard
    - Connects WANs to LANs
  - Commercial customers in need of demanding data speeds
    - As demand for capacity increases, the Metro Network becomes the bottleneck to the system (need to improve data-carrying capacity)
  - Economies of scale/relative technical simplicity have made Ethernet protocol alternatives more effective than pre-existing Frame Relay (FR) and Asynchronous Transfer Mode (ATM) formats
  - Increased data-carrying capacity of WDM technology (CWDM, DWDM and BWDM) has offered Metro Ethernet networks an effective means of addressing these challenges

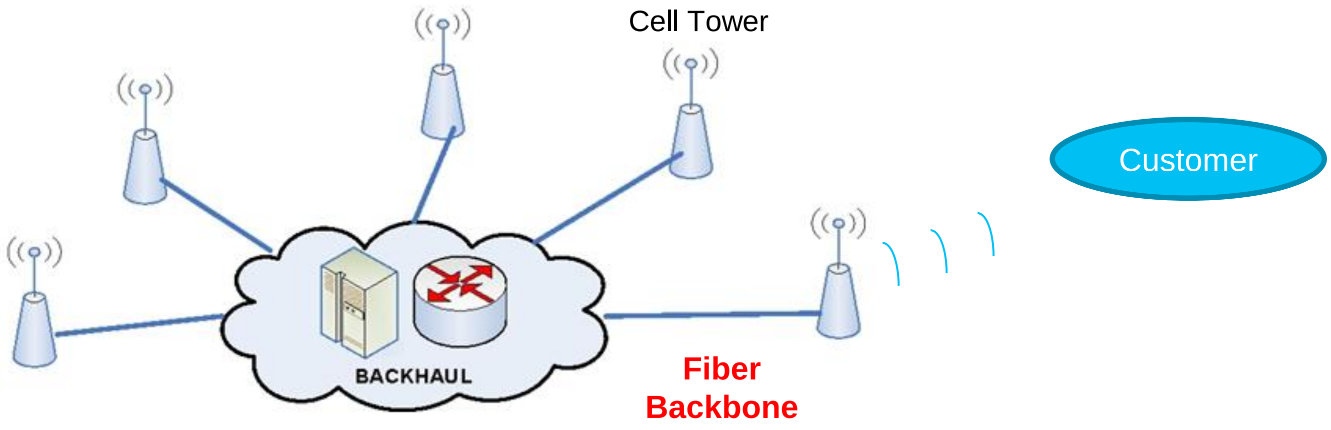
WDM Applications – Metro Ethernet (Example)

- Two-fiber system utilizing single wavelength CWDM optical add/drop filters
- One fiber dedicated to downstream traffic while a second fiber is dedicated to upstream traffic



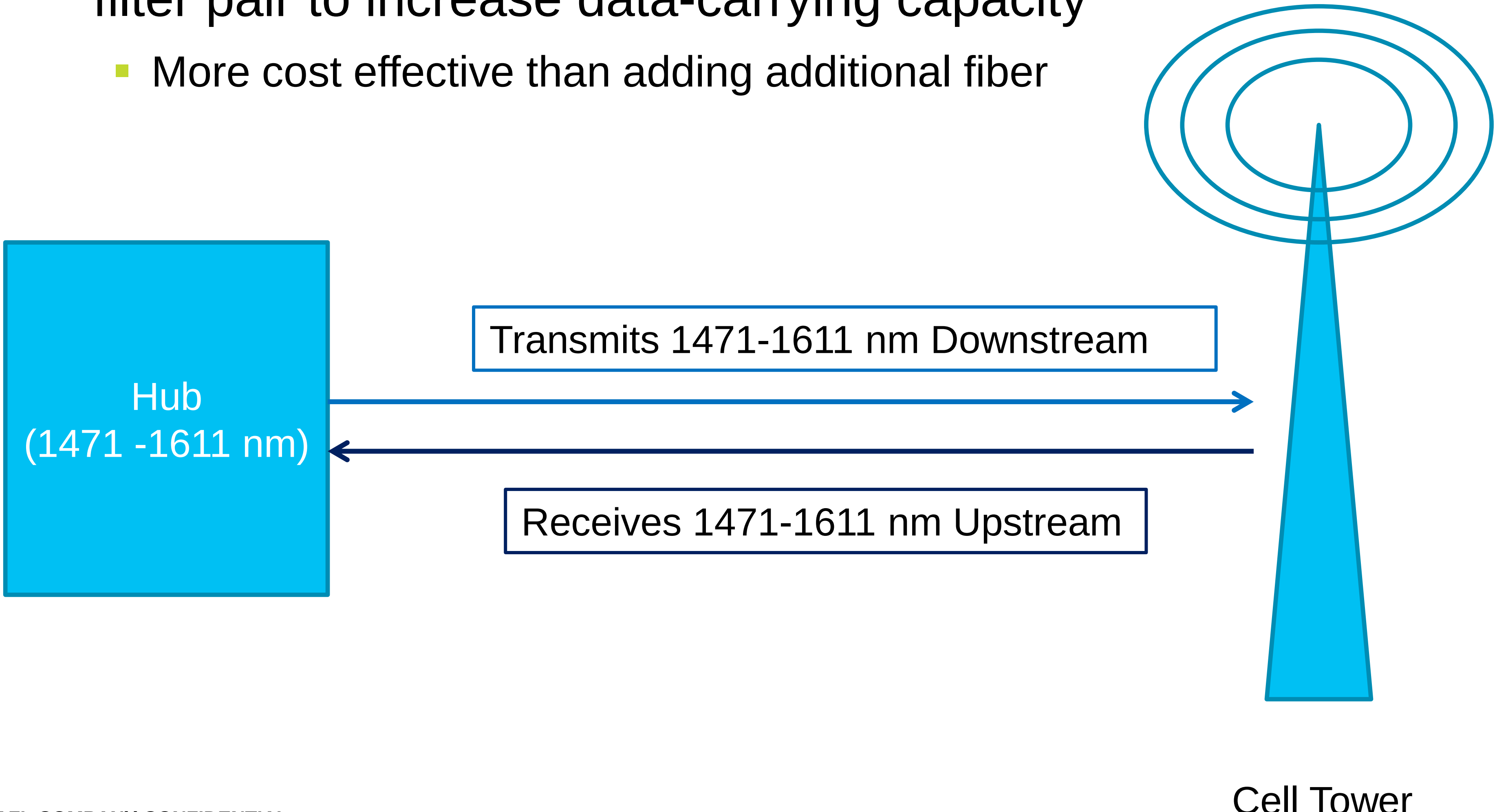
WDM Applications – Cell Tower Backhaul

- Cell Tower Backhaul
  - Smart Phones have caused a significant increase in data capacity requirements for mobile networks
  - The number of cell tower sites in addition to the bandwidth requirements of pre-existing sites has increased exponentially over the past 3-5 years
  - WDM technology offers a cost-effective means of **increasing fiber backbone data-carrying capacity**



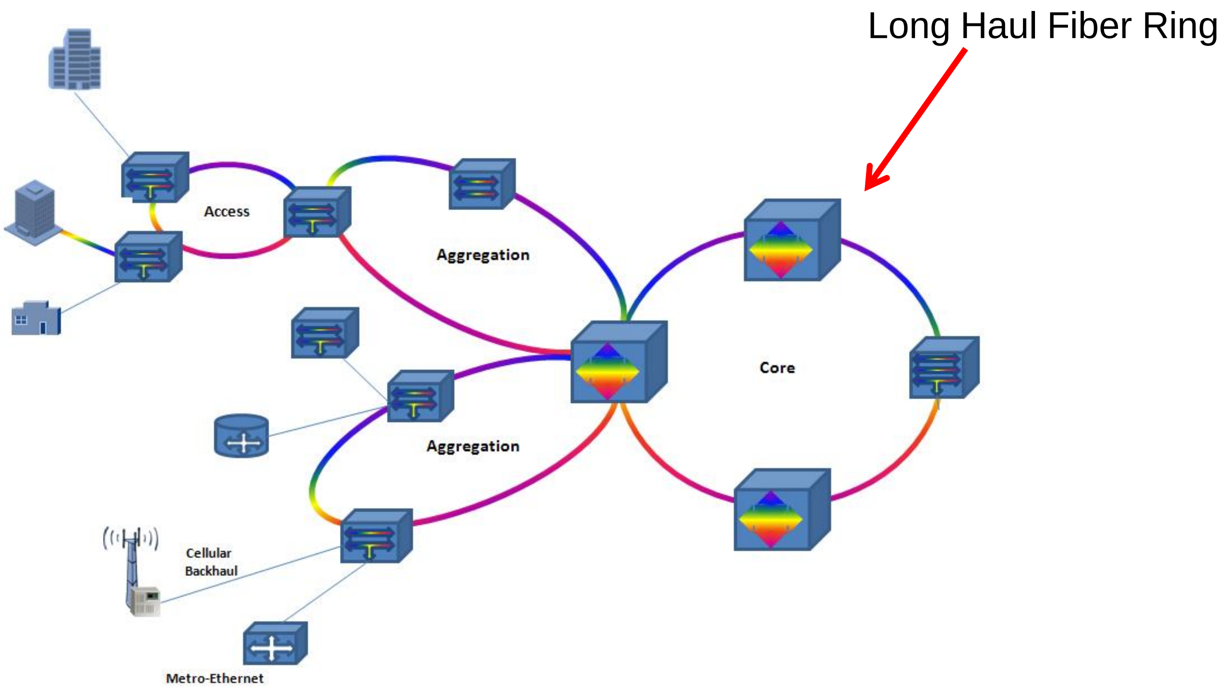
WDM Applications – Cell Tower Backhaul (Example)

- The below “two-fiber” example shows a cell tower fiber backbone outfitted with a common 8-channel CWDM filter pair to increase data-carrying capacity
  - More cost effective than adding additional fiber



WDM Applications – Cell Tower Backhaul

- Long Haul
  - DWDM technology is effective in providing a convenient solution for long haul fiber deployments
    - DWDM offers high data capacity solution (large # of DWDM channels)
    - Can transmit over long distances due to commercially available fiber amplifiers (EDFA's can operate over the C-band for use with DWDM devices)



Product Configurations: ISP Devices – LGX Modules

- **CWDM LGX configuration shown**
  - 8-Channel (1471 – 1611 nm)
  - LC/APC
  - Single-wide module
  - In/Out Test Ports
  - 1310 Upgrade Port

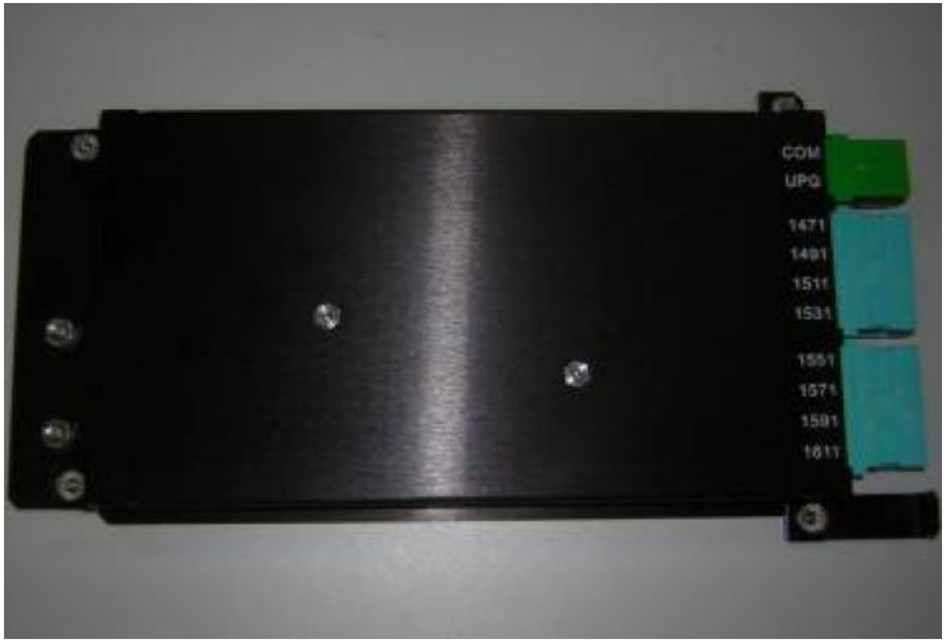
- **LGX Module Advantages**
  - Industry accepted format
  - Wide variety of configurations available
  - Optically robust

Product Configurations: ISP Devices – Rack Mount Panels

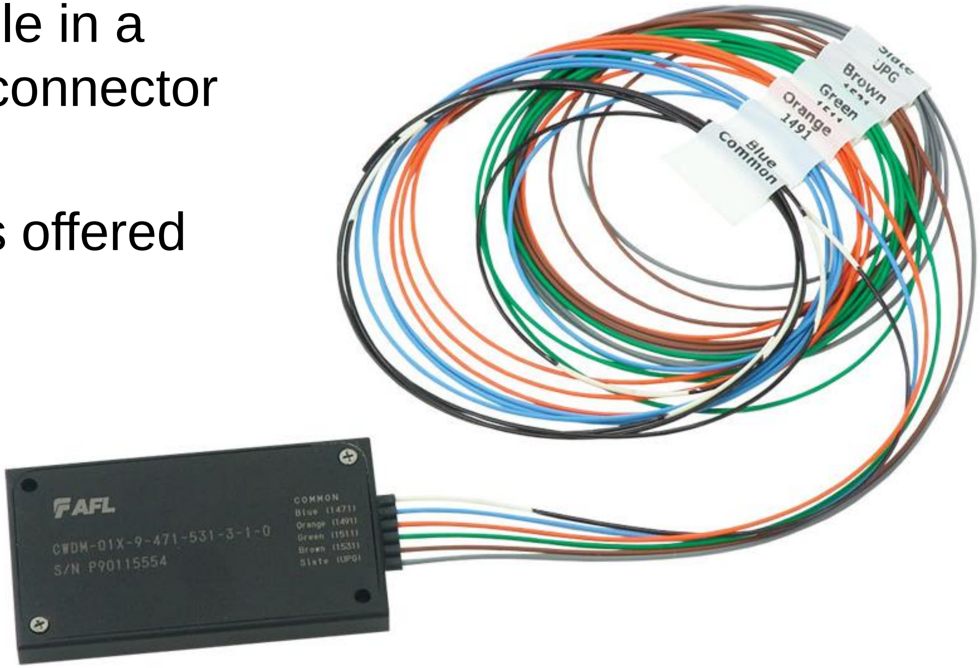
- **DWDM Rack-Mount Panel configuration**
  - 40+ DWDM Channels possible
  - SC/APC, SC/UPC, LC/APC or LC/UPC
  - In/Out Test Ports
  - Express Ports
  - Upgrade Ports
  - High capacity/density

Product Configurations: ISP Devices – High Density

- **Small Form Factor ISP Alternatives**
  - High Density Module
  - Hundreds of channels can be added to a rack-mount panel
  - Space efficient



- **Cassette configuration**
  - Can accommodate 40+ channels
  - Fiber leads are available in a variety of lengths and connector configurations
  - Variable package sizes offered



- **Single Channel Filters**
  - 250 µm or 900 µm fiber leads
  - 5.5 mm diameter x 39 mm length package common
  - Available for both CWDM and DWDM
  - Compact size allows for mounting in splice chips

Product Configurations: OSP Devices – Pre-configured Closure Assemblies

- **Closure Assemblies Preconfigured with Filters**
  - Sealed Closure w/ dual CWDM Cassettes
  - Offered in a variety of configurations (both 4 and 8 Ch CWDM most common)
  - Cassette fiber leads are pre-routed into splice tray

Questions?