AFL Technology & Product Overview:

Wavelength Division Multiplexing
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)

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
● **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

Wavelength (nm)

1200 1300 1400 1500 1600 1700

1271 1291 1311 1331 1351 1371 1391 1411 1431 1451 1471 1491 1511 1531 1551 1571 1591 1611
**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

**G.652D Low Water Peak Fiber Attenuation (dB/km)**

- **O-Band** 1260-1360nm
- **E-Band** 1360-1460nm
- **S-Band** 1460-1530nm
- **C-Band** 1530-1565nm
- **L-Band** 1530-1625nm

**Wavelength (nm)**

1200 1300 1400 1500 1600 1700
Another distinguishing feature of CWDM devices is the signal profile.
Passband for a CWDM channel is +/- 6.5 nm center wavelength.
● CWDM Passband = Center Wavelength +/- 6.5 nm
  ▪ I.e: 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”
  ▪ I.e: 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
Typical Adjacent Channel Isolation for a CWDM Filter = ~30 dB or better
*More simplified and conservative definition of Adjacent Channel Isolation*
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

Pass-band Ripple

Power (dBm)

Wavelength (nm)
CWDM – Filter Technology

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

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

**Cons**

- Marginally higher IL
- Larger package size
Individual Thin Film Filters are spliced into a “cascade” in order to filter the appropriate wavelengths.

Wavelengths 1471, 1491, 1511, 1531, 1551, 1571, 1591, and 1611nm

1611nm

1591nm

1571nm

1551nm

All other wavelengths are passed through the “Express” Port.
CWDM – Free Space Filters

Pros
- Extremely High Uniformity
- Very Small Packages Possible

Cons
- Less Design Flexibility
- Longer Lead Times

Wavelength A, B, C
Single fiber input
Multiple λ Fiber Array

Lens
Grating
**Pros**

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

**Cons**

- High Cost (@ Low Ch Counts)
Directivity = Signal leakage into other input / output ports

Unwanted Output Light Leakage

Output Light
(all light should exit out this port)

Pass

Common

Reflect

Unwanted Output Light Leakage
Return Loss = the back reflectance along the incident optical path

Output Light (all light should exit out this port)

Unwanted Reflected Light

Input 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
● **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
A single CWDM Channel  
*CWDM Channel Spacing = 20 nm*

Multiple DWDM Channels  
*DWDM Channel Spacing = 0.8 nm*
16 DWDM Channels can fit within the passband of a single CWDM Channel!!!
The passband of a DWDM Ch is much narrower than the passband of a CWDM Ch.
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

- Channels A, B, C
- Channels D, E, F
- Channels G, H, I

Mux

- BWDM

Demux

- BWDM

- Channels A - I
- Channels A - I
- Channels A, B, C
- Channels D, E, F
- Channels G, H, I
Works well in MDU applications where “pockets” of customers exist.
WDM Applications

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

Coarse Wavelength Division Multiplexing (CWDM) Inside Plant Device
Dual Channel Optical Add/Drop Multiplexer (OADM)
Downstream or “transmit” traffic
Upstream or “receive” traffic
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.
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
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)
● 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
**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 – Rack Mount Panels
- **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
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?