COARSE WAVE DIVISION MULTIPLEXING (CWDM)

Introduction

Fiber optic technology has been instrumental in extending the distance over which signals can be transmitted. Broadcast and production applications, particularly with digital signals, have significantly benefited from this advancement. As SDI bit rates have escalated from 270 Mb/s to 1.5 Gb/s, 3 Gb/s, and now 12 Gb/s, the maximum transmission distance of coaxial cable has diminished. Currently, 12 Gb/s signals can only travel less than 100 meters via coax, imposing substantial limitations on system design for facilities and events.

Fiber optics offer a solution to these constraints by enabling longer transmission distances. This capability is crucial for a range of scenarios, including large brick-and-mortar facilities, campuses, live event venues, and even interfacility applications using leased dark fibers. While this discussion substantially focuses on Serial Digital Interface (SDI), fiber optics facilitate the transmission of virtually all signal types used in broadcast and production. This includes other digital signals, such as serial or Ethernet data, and even analog signals like reference or satellite L-Band.

Beyond distance, fiber optics provide several key advantages due to their use of light instead of electrical signals:

- **Electrical Isolation:** Fiber optics are immune to electrical surges or disturbances and complications arising from disparate grounding planes.
- **Electrical Noise Immunity:** Fiber is not susceptible to electromagnetic interference.
- **Smaller Diameter and Lighter Weight:** Notably advantageous in scenarios where size and weight are critical, such as in OB vans, deployable flight cases, or even facilities where overcrowded raceways and conduits can no longer accommodate additional coaxial cables.

Furthermore, Coarse Wavelength Division Multiplexing (CWDM) dramatically increases the number of signals that can be transmitted over a single fiber. This capability enhances system design flexibility and efficiency, making CWDM a valuable technology in modern broadcast and production environments.

What is CWDM?

Coarse Wavelength Division Multiplexing (CWDM) is a technology that combines multiple optical signals on a single fiber optic cable. CWDM utilizes specially designed lasers that transmit light at different wavelengths, effectively different colors of light. These wavelengths are often referred to as "lambdas," denoted by the symbol λ.

Optical devices known as CWDM multiplexers and demultiplexers are used to combine and separate these multiple wavelengths of light on a single fiber. Multiplexers and demultiplexers contain a series of optical filters, each capable of adding or extracting light of a specific wavelength from a fiber carrying multiple wavelengths.

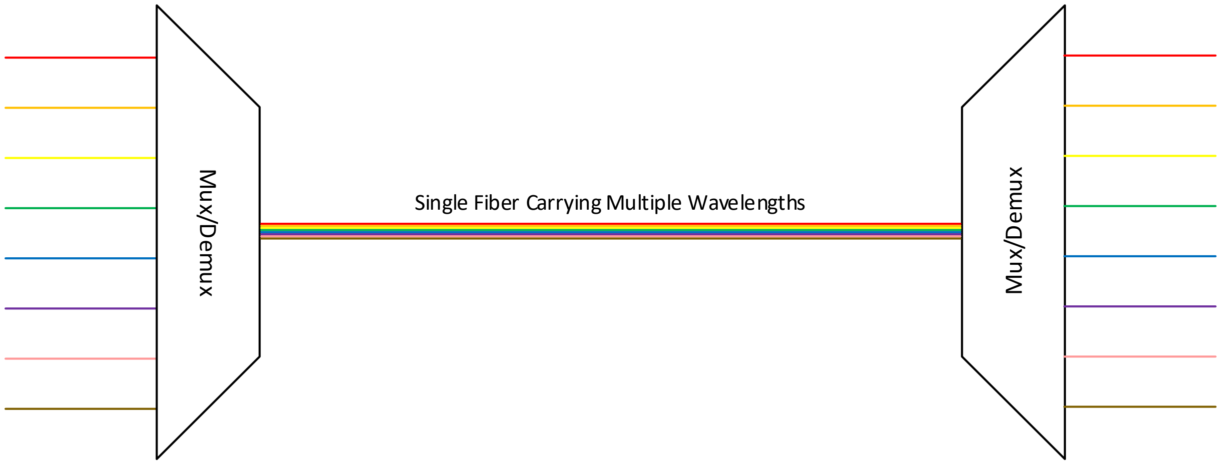

Figure 1 - CWDM Multiplexer/Demultiplexer Concept

While the terms multiplexer and demultiplexer suggest one-way transmission, CWDM is actually bi-directional, allowing signals to travel in both directions on a single fiber.

It's important to note that CWDM, particularly in the context of Ross products, requires the use of single-mode fiber. Additionally, CWDM systems must utilize optics with specific CWDM lasers, characterized by the spectral precision needed to interface with CWDM multiplexer and demultiplexer filters. While each CWDM laser operates at a designated wavelength, the optical receivers in CWDM systems are designed to be wideband. These receivers are capable of accepting the full CWDM spectrum, and it is the CWDM multiplexer/demultiplexer that filters individual wavelengths, delivering single signals to the receivers.

CWDM Multiplexers and Demultiplexers

CWDM lasers operate in a portion of the optical spectrum that is invisible to humans. This spectrum, defined by the ITU standard ITU-T G.694.2, spans from 1270 nm to 1610 nm. Each "channel" in CWDM occupies a 20 nm segment within this spectrum, allowing for a total of 18 potential channels.

Although 18 channels fit into the spectrum, CWDM multiplexers and demultiplexers often offer a maximum of 16 channels due to a phenomenon known as the fiber optic "water peak." The water peak occurs at the 1390 nm and 1410 nm channels, where older single-mode fibers exhibit high attenuation, significantly impacting the attainable distance. While modern fibers show balanced loss across the full CWDM spectrum, avoiding these wavelengths and limiting the maximum number of channels to 16 ensures full compatibility and reliability with existing fibers of any age.

CWDM multiplexers and demultiplexers are typically available to accommodate 4, 8, or 16 individual wavelengths. They feature ports for individual wavelengths and a common port for the combined spectrum.

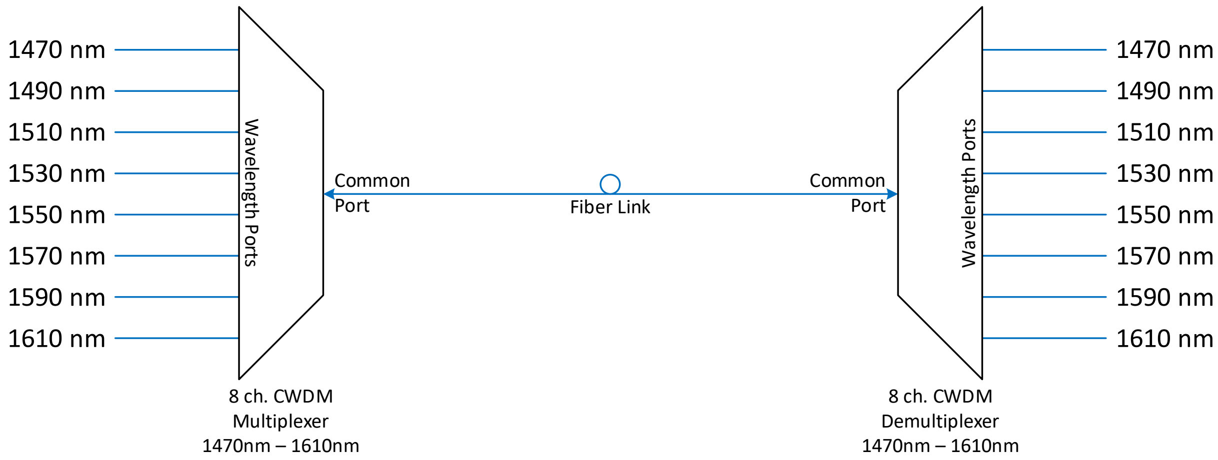

Figure 2 - 8-Channel CWDM Multiplexer/Demultipler Block Diagram

Additionally, 4 and 8-channel multiplexers may include "expansion" ports, allowing another multiplexer/demultiplexer with an alternate set of wavelengths to be connected in a cascade fashion, utilizing the same single fiber.

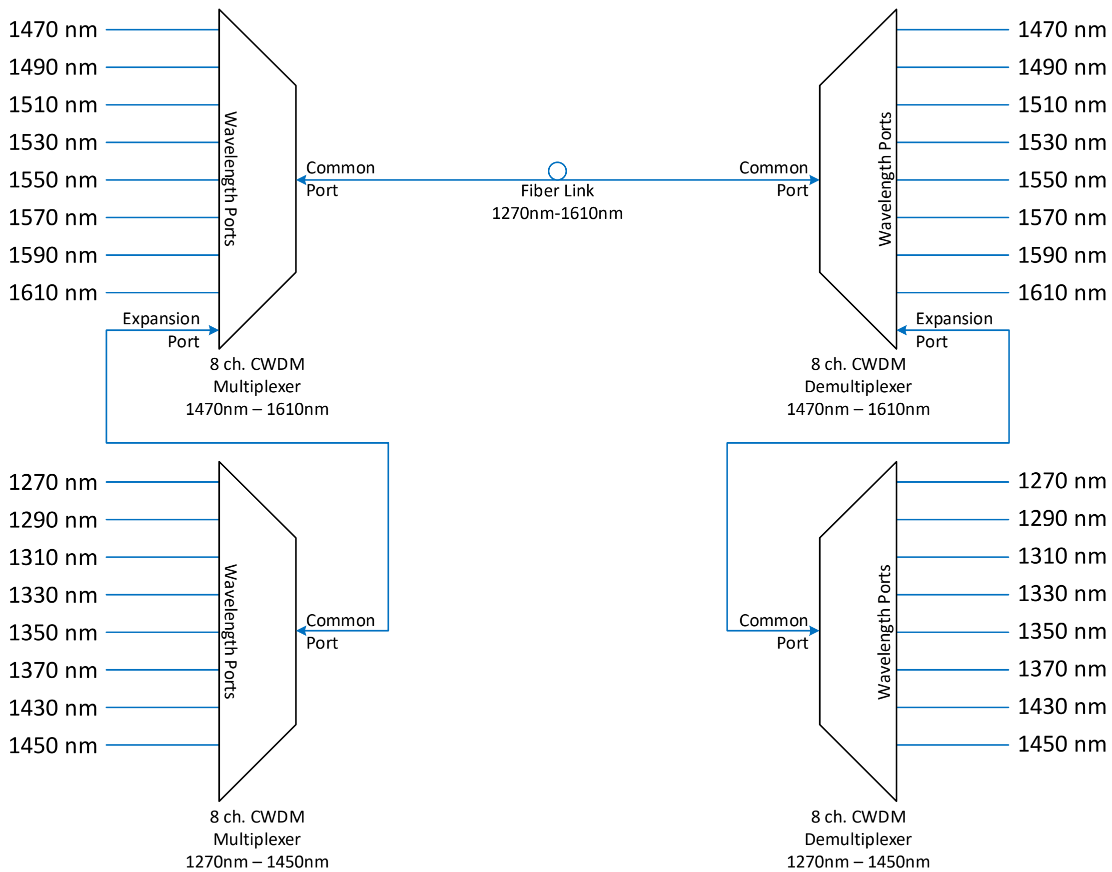

Figure 3 - 16-Channel (8+8 Cascaded) CWDM Multiplexer/Demultipler Block Diagram

Multiplexer and Demultiplexer Terminology Explained

As mentioned, the term multiplexer or demultiplexer implies directionality, but CWDM technology allows bi-directional traffic on one fiber. So, why use this seemingly misleading terminology? The individual wavelength filters within a multiplexer or demultiplexer are connected in a series formation, where each filter imparts optical attenuation, which is cumulative. By the time the first signal reaches the last filter in the series, the wavelength associated with the first filter will have passed through multiple filters and incurred the most attenuation. For example, in Figure 4 - 4-Channel CWDM Multiplexer/Demultiplexer Internal Filter Series StructureFigure 4, note how λ1 and λ4 both pass through four filters each.

To balance this attenuation, the multiplexer arranges the filters in one order, while the demultiplexer reverses that order to ensure balanced attenuation across all wavelengths. Thus, the terms multiplexer and demultiplexer denote the order of filters, allowing the system designer to specify one of each type at either end of a fiber link.

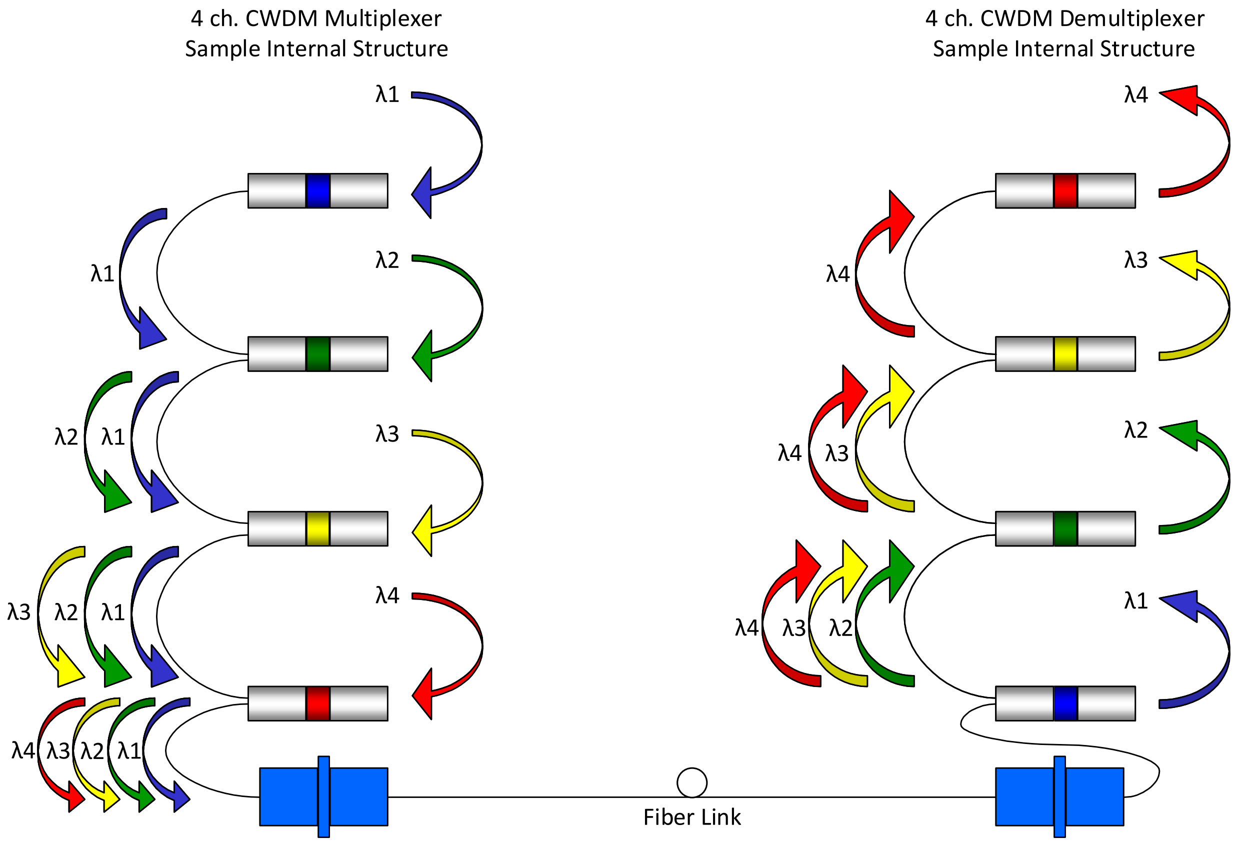

Figure 4 - 4-Channel CWDM Multiplexer/Demultiplexer Internal Filter Series Structure

Formfactors

Ross offers two formfactors of CWDM multiplexer and demultiplexer products. The first is a selection of six different openGear modules:

Figure 5 - openGear CWDM Multiplexer/Demultiplexer

- FCM-6844: 4 Channel Optical Multiplexer with Expansion Port (1350nm-1450nm)
- FCD-6845: 4 Channel Optical Deultiplexer with Expansion Port (1350nm-1450nm)
- FCM-6846: 8 Channel Optical Multiplexer (1270nm-1450nm)
- FCD-6847: 8 Channel Optical Demultiplexer (1270nm-1450nm)
- FCM-6848: 8 Channel Optical Multiplexer with Expansion Port (1470nm-1610nm)
- FCD-6849: 8 Channel Optical Deultiplexer with Expansion Port (1470nm-1610nm)

Pros: Compact, neat integration with openGear products.
Cons: High link-loss with cascaded configurations (using expansion ports).

Ross also offers 16-channel multiplexer and demultiplexer modules that mount in a 1RU mounting frame:

Figure 6 - 1RU Modular CWDM Multiplexer/Demultiplxer

Figure 7 - Demultiplexer Module - Removed from Mounting Frame

- FCM-9941-16: 16 Channel Optical Multiplexer (1270nm-1610nm)
- FCD-9942-16: 16 Channel Optical Demultiplexer (1270nm-1610nm)
- RM-9940: 1RU mounting frame to accommodate up to 3 FCM-9941-16 and/or FCD-9942-16 modules

Pros: Economical, low link-loss
Cons: Requires its own 1RU of rack space

Ross Products with CWDM Optics

Ross offers CWDM SFP options for the SHC-6901 openGear cards and the Ultrix media processing platform.

SFC-6901 openGear Card

The SFC-6901 is a quad-channel fiber converter card for ASI, SDI, HD-SDI, 3 Gb/s SDI and 12 Gb/s SDI. This openGear card has 4 HDBNC ports, each configurable as an input or an output. It also has two SFP slots, each of which will accommodate dual transmitter or dual receiver SFP modules. Optical transmit or receive functionality is dependent on the SFP installed. An internal crosspoint allows the connection between optical and electrical ports to be defined by the user, allowing flexible optical or electrical distribution or automatic failover scenarios to be defined. Onboard 2si gearbox functionality allows for the management of quad-link UHD signals, or can be used as a means of conserving fiber by electrically multiplexing four co-timed HD or 3G SDI signals to/from a single 12 Gb/s stream.

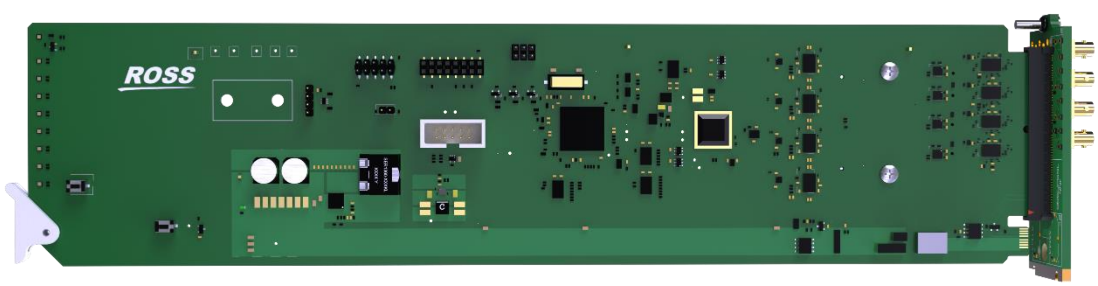

Figure 8 - SFC-6901 openGear Quad-Channel Fiber Card

16 wavelengths of 12G-capable CWDM transmitter SFPs are available for the SFC-6901, along with a high-sensitivity, wide-spectral-bandwidth, dual-channel SFP receiver.

Ultrix

The ULTRIX-MODX I/O card accommodates the installation of up to four sub-modules with various I/O capabilities. One of these sub-modules, the ULTRIX-MOD-SFP, accommodates the installation of up to four 12G-capable transceiver SFPs for SDI.

Figure 9 - ULTRIX-MODX-IO I/O Card

16 wavelengths of 12G-capable CWDM transceiver SFPs are available for the for the ULTRIX-MOD-SFP.

CWDM System Design

The two main effects that limit the distance that an optical signal can travel over a fiber are attenuation and dispersion:

Attenuation: Attenuation refers to the gradual loss of signal strength as it travels through the fiber. This effect is largely independent of the signal's frequency and is caused by factors such as absorption, scattering, and bending losses in the fiber.

Dispersion: Dispersion causes the spreading of a signal over time as it travels through the fiber, leading to signal distortion and potential data errors. This effect becomes more pronounced at higher signal frequencies, resulting in higher-frequency signals experiencing dispersion effects earlier and limiting the maximum distance they can travel without degradation.

CWDM multiplexers and demultiplexers are passive devices and therefore impart attenuation to a fiber optic system. This is a trade-off of CWDM technology—while it increases the efficiency of fiber usage, it also reduces the distance that can be traversed without regenerating the optical signals. Attenuation is the dominant source of loss in a CWDM system, allowing dispersion to be ignored in typical system designs.

Calculating the link budget of a CWDM system is similar to the process used for a simple point-to-point link, but the extra loss incurred by the multiplexer and demultiplexer, plus additional connection points, must be accounted for. It should also be noted that while typical CWDM laser launch powers are similar regardless of the data rate of the applied signal (up to 12 Gb/s SDI), receiver sensitivity does not follow this rule and should be carefully taken into account. For example, the receiver sensitivity for the Ross SFP-FIBER-12G-xx series of CWDM SFPs offered for the Ultrix is -10 dBm at 12 Gb/s and -14 dBm at 3 Gb/s. This means the extra sensitivity at 3 Gb/s can achieve a longer fiber link, while the 12 Gb/s requirement must be considered for designs utilizing 12 Gb/s SDI at deployment or potentially in the future.

Cost Considerations of CWDM

CWDM technology introduces additional costs for fiber optic system designs, as the optics used for CWDM are generally more expensive than those used for discrete point-to-point applications, plus the cost of CWDM multiplexers and demultiplexers. However, there are two key scenarios where the extra cost of CWDM is justified:

Limited Existing Fiber Infrastructure: When the available fiber infrastructure is limited and spare fibers are scarce, the cost of adding additional fiber strands can exceed that of CWDM products. In such cases, CWDM provides a cost-effective solution by maximizing the utilization of existing fibers.

Deployable Systems: For deployable systems, such as flight cases connecting to a central production center, CWDM allows multiple signals to be connected very quickly by combining them onto a single fiber. This capability significantly reduces setup time and complexity, making CWDM ideal for temporary or portable applications where rapid deployment is essential.

Ross SHC-6901 openGear CWDM Example

For a simple calculation example, we will consider 16 channels of 12 Gb/s SDI traveling bi-directionally using Ross SHC-6901 openGear cards equipped with CWDM lasers and high-sensitivity CWDM receivers. The multiplexer and demultiplexer will be the Ross openGear FCM-6846, FCM-6848, FCD-6847, and FCD-6849 configured for a 16-channel CWDM system.

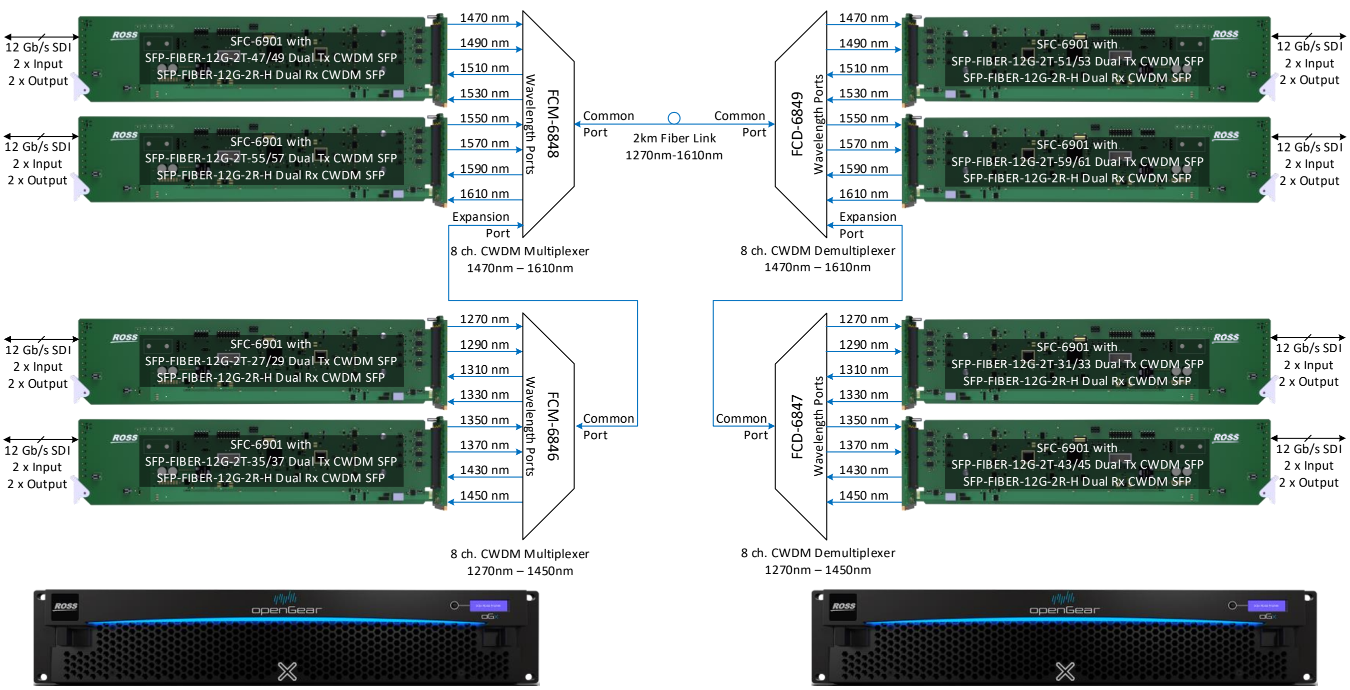

Figure 10 - 16 Channel 12G SDI CWDM System – SHC-6901

Parameters:

- Laser launch power: -3 to +1 dBm (worst case: -3 dBm)
- Receiver sensitivity: -18 dBm @ 12 Gb/s
- CWDM multiplexer/demultiplexer link loss: 10.1 dB (end-to-end)
- Fiber length: 2 km

We must also account for the loss incurred by fiber connectors, of which this system comprises 6. While the loss across an LC connector that is new, clean and in good condition could be as low as 0.1 dB, a safe value to use is 0.25 dB per connector to account for variation and imperfection.

Additionally, we must account for fiber attenuation loss. While short patch cables may be ignored, impactful loss will be incurred over the 2 km link. The loss value to be used for single-mode fiber depends on the wavelength under consideration:

- 1270 nm - 1450 nm: 0.35 dB/km
- 1470 nm - 1610 nm: 0.25 dB/km

Since the system design utilizes the full CWDM spectrum, we'll use the worst-case figure of 0.35 dB/km.

Total Link Budget:

- Receiver Sensitivity - Laser launch power: -18 dBm - (-3 dBm) = 15 dB

Therefore, if the loss is greater than 15 dB total, the system may not work error-free.

Total Loss:

- Connector loss + multiplexer/demultiplexer link loss + fiber loss
- (8 x 0.25 dB) + 10.1 dB + (2 x 0.35 dB) = 12.8 dB

Margin:

- 15 dB – 12.8 dB = 2.2 dB

This system is therefore attainable, with a margin of 2.2 dB.

Ultrix CWDM Example

Depending on the technology used by the optics, the receive sensitivity can vary. For example, the receive sensitivity of the optics offered for use with the Ultrix is -10 dBm at 12 Gb/s, which might seem to limit the ability to design a 16-channel CWDM system. However, different technologies are also employed by CWDM multiplexers and demultiplexers. Ross also offers the FCM-9941-16 and

FCD-9942-16 multiplexer/demultiplexer pair. These modules mount in a 1RU mounting frame (RM-9940) and exhibit a very low link loss of only 4.6 dB, end-to-end. Let's calculate an example of a 16-channel, bi-directional Ultrix-to-Ultrix 12 Gb/s SDI link.

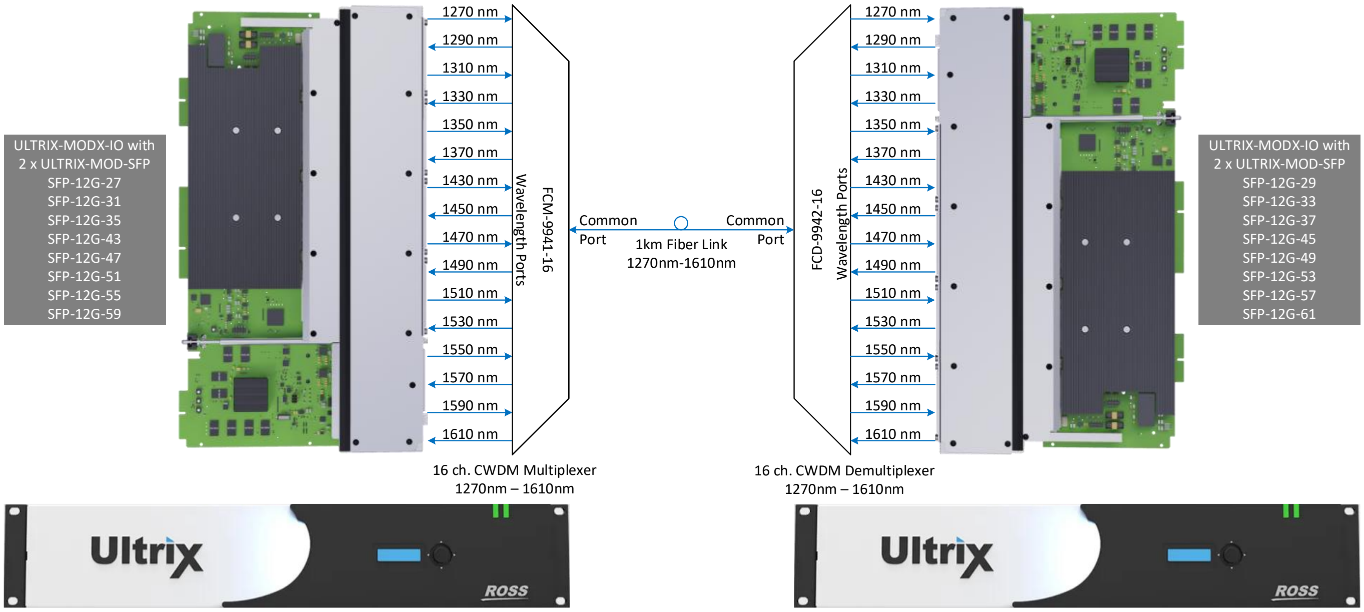

Figure 11 - 16 Channel 12G SDI CWDM System – Ultrix

Parameters:

- Laser launch power: -2 to +3 dBm (worst case: -2 dBm)
- Receiver sensitivity: -10 dBm at 12 Gb/s
- CWDM multiplexer/demultiplexer link loss: 4.6 dB (end-to-end)
- Fiber length: 1000 m

Total Link Budget:

- Receiver Sensitivity - Laser launch power: -10 dBm - (-2 dBm) = 8 dB

Total Loss:

- Connector loss = 6 x 0.25 dB = 1.5 dB
- Fiber loss = 1 x 0.35 dB = 0.35 dB
- Multiplexer/demultiplexer link loss = 4.6 dB
- Total = 1.5 dB + 0.35 dB + 4.6 dB = 6.45 dB

Margin:

- 8 dB - 6.45 dB = 1.55 dB

In this example, we started with a tight link budget of 8 dB, much of which was used by connector loss and CWDM mux/demux loss, leaving a final calculated margin of 1.55 dB. Although a 2 dB margin is typically recommended, a margin of 1.55 dB can still be sufficient for reliable operation, especially in controlled environments, such as intrafacility or campus links. Here's why this link remains attainable:

Controlled Fiber Infrastructure:

Unlike longer-distance links leased from a third-party, the owner has full control over the fiber, ensuring optimal conditions, such as clean connectors, properly executed splices, and adherence to proper bend radii. This level of control helps reduce unexpected losses and maximizes reliability.

Quality Components and Practices:

Using new patch cables with low-loss connectors and maintaining strict cleanliness standards significantly minimizes insertion loss. High-quality connectors and fibers further contribute to reducing any potential margin erosion. Fiber management best practices, including loose securing with Velcro instead of tight zip ties, help prevent fiber damage and microbending losses, which are common sources of additional loss in poorly managed installations.

Conservative Power Calculations:

The power budget calculations were based on worst-case launch power. Since there is a 5 dB range in the launch power specification, you could have as much as 5 dB more available power, effectively increasing the margin. This adds flexibility and safety to the system, mitigating the concern of a tight calculated margin.

While industry guidelines typically recommend a margin of 2 dB or more, a smaller margin (like 1.55 dB) can still work in environments where conditions are well-controlled and the components are of high quality. Properly maintaining the cleanliness of connectors, ensuring proper handling, and regular inspection can further ensure that this link will perform reliably.

Additional Application Examples

In the previous section, we discussed two simple application examples using openGear SFC-6901 cards and Ultrix systems directly connected via CWDM. There are other possibilities that offer further efficiencies in fiber utilization.

Ultrix ↔ SHC-6901 Interoperation

When converted to an optical signal, SDI follows the SMPTE 297-2006 standard. This ensures that Ultrix and SFC-6901 cards can interoperate seamlessly, including over CWDM links. This interoperability is particularly useful in applications where a core Ultrix router needs to move SDI over fiber to/from openGear SFC-6901 cards at edge locations.

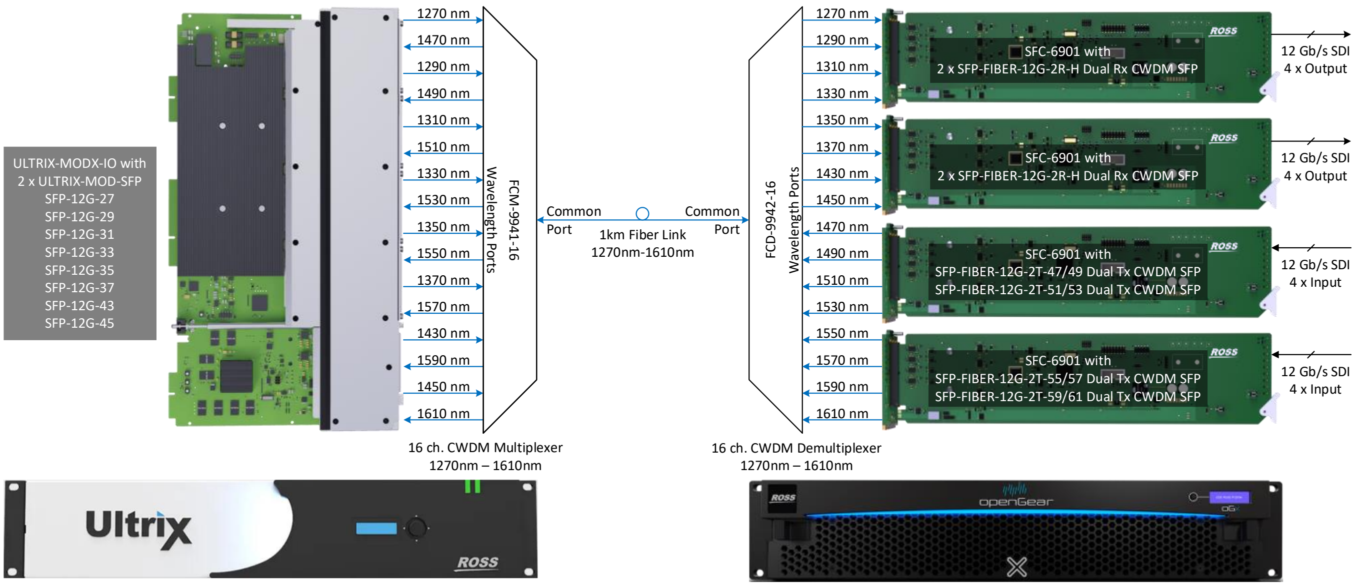

Figure 12 - 16 Channel 12G SDI CWDM System – Ultrix & SHC-6901

SFC-6901 Onboard Gearbox

The SFC-6901 card features an onboard 2SI gearbox. In addition to general quad-link signal management, this gearbox can be used to multiplex up to four HD or 3G signals into one 12G stream. The applied signals do not need to form a quad-link group comprising one UHD signal; they can be any four HD or 3G signals as long as they are synchronous and of the same standard. Combining the gearbox functionality with CWDM allows up to 64 HD/3G signals to be transmitted on a single fiber.

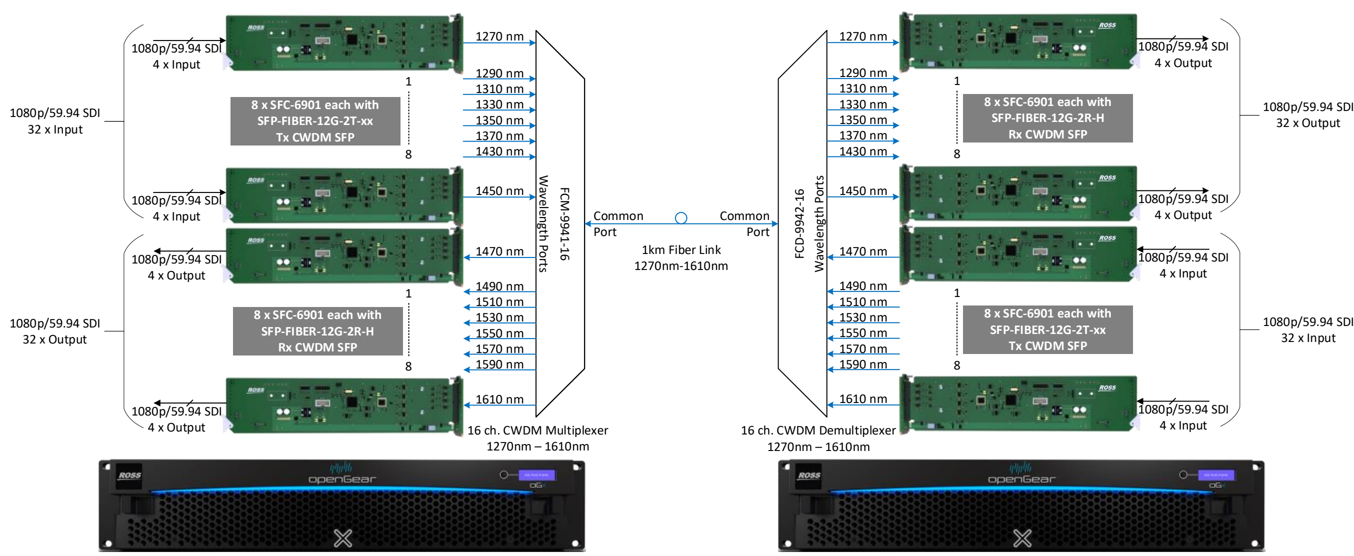

Figure 13 - 64 Channel 12G SDI CWDM System – SHC-6901 Gearbox

This example demonstrates 64 channels of 1080p/59.94 SDI signals running bi-directionally. However, any combination of inputs and outputs can be accommodated at 4 signals per SHC-6901 card, provided the signals applied to a single card are synchronous and of the same standard. The supported standards include 720p, 1080i, or 1080p.

Signals Beyond SDI

As mentioned in the introduction, fiber optics can convey various signals beyond SDI. CWDM systems can transmit multiple signal types and data rates over a single fiber. As long as transmitter and receiver products are available to convert specific electrical signals to an optical CWDM wavelength, they can share the same CWDM multiplexer and demultiplexer, and thus the same common fiber link. This efficiency maximizes the utilization of fiber.

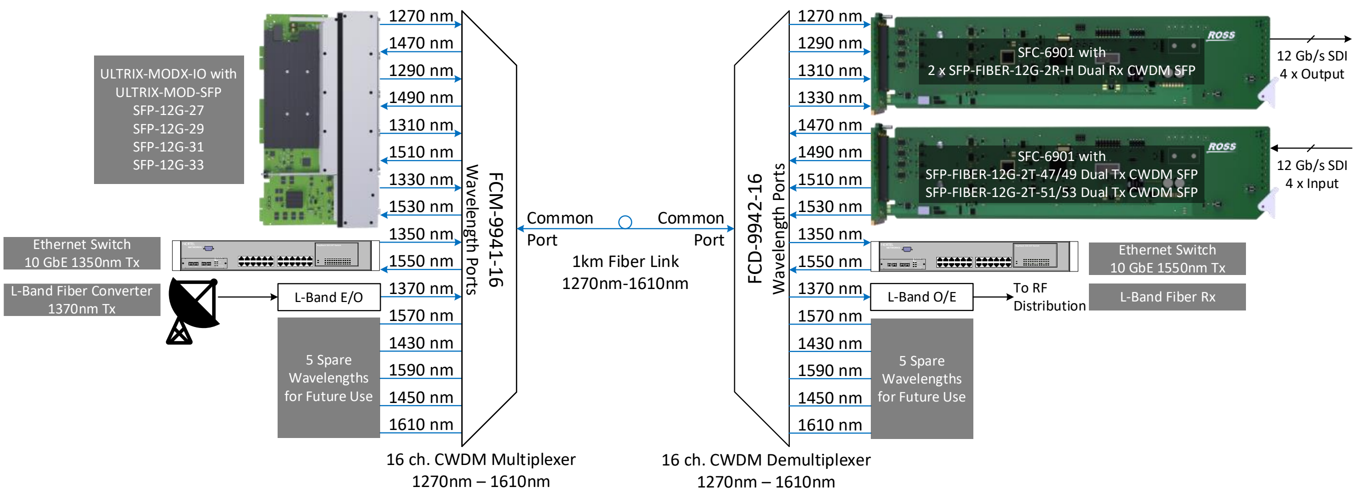

Figure 14 - Multiple Signal Formats Over CWDM

In this example we have 4 bi-directional 12 Gb/s SDI between and Ultrix and SFC-6901 cards, a 10 GbE link between two switches with CWDM optics installed, and one L-Band analog satellite link utilizing CWDM-capable L-Band fiber converters.

When considering a system design like this, it is crucial at the outset to ensure that all equipment supports CWDM optics. For example, while 10 GbE SFP+ modules for Ethernet are available in the upper 8 CWDM wavelengths, higher data rate Ethernet connections such as 100 Gb/s use internal multi-lane modulation and optical multiplexing techniques that are not compatible with discrete CWDM multiplexers/demultiplexers, and therefore require their own dedicated fibers.

CWDM System Installation and Operation

The installation of CWDM-based equipment is similar to that of single-wavelength systems, but a few additional steps will ensure reliable operation and easier commissioning.

As previously mentioned, since the filters in CWDM multiplexer and demultiplexer devices are wavelength-dependent, it is crucial to follow the intended signal path for each wavelength. The laser wavelengths must be correctly matched with their corresponding ports on the multiplexer, demultiplexer, and receiver. Proper labeling and documentation during installation can help prevent errors and simplify troubleshooting. A variety of fiber management products are available and should be used to keep fibers neat, secure, and within the proper bending radius. When securing fibers, it is important to do so carefully and loosely using products like Velcro. Tight bundling with zip ties (ty-wraps) can lead to fractures and micro-bending losses.

The CWDM multiplexer and demultiplexer devices introduce additional fiber connectors into the system. As with any fiber optic installation, it is essential that all connectors are perfectly clean to ensure minimal optical attenuation and prevent back-reflections. Ross recommends the use of dry, reel-type cleaners, which are available in models for cleaning fiber end faces and within the LC receptacles on SFPs and multiplexer/demultiplexer ports. Be sure to follow the manufacturer's instructions when using these cleaners. In addition to cleanliness, connectors should be fully seated to ensure proper optical coupling.

Once clean and properly seated, fiber connectors generally maintain their condition as long as they are not disturbed. Therefore, unnecessary plugging and unplugging should be avoided. If fibers need to be disconnected, the end faces should be capped to prevent contamination or damage, and receptacles should have dust plugs inserted. Before reconnecting, it is recommended to clean the connectors again to ensure optimal performance.

As passive devices, CWDM multiplexer and demultiplexer modules consume no power, generate no heat, and require virtually no maintenance. This makes them extremely reliable and not prone to failure. The use of LC connectors with locking mechanisms and strain relief also contributes to the robustness of these systems in mobile applications. However, mobile installations present additional challenges, such as movement, vibration, dust, potential fiber pulling or pinching, and temperature fluctuations. In such cases, it is advisable to take extra precautions in fiber management and securing, protection, and to perform periodic system inspections.

Conclusion

CWDM technology offers a powerful and efficient solution for modern broadcast and production environments, addressing the limitations of traditional coaxial cables and enhancing the capabilities of fiber optic systems. By combining multiple optical signals on a single fiber, CWDM maximizes fiber utilization and supports a wide range of signal types and data rates, including UHD video.

While CWDM introduces additional costs due to the specialized optics required, the benefits in terms of increased capacity, reduced infrastructure costs, and simplified deployment often outweigh these expenses. This is particularly true in scenarios where fiber availability is limited and the costs of installing additional strands is prohibitive.

Through careful system design and following best practices for fiber optic network management, CWDM can be effectively implemented to achieve reliable and high-performance signal transmission over distances that exceed the capabilities of copper cables. The ability to seamlessly integrate with existing infrastructure and support bi-directional traffic further enhances its appeal for a wide range of applications.

In summary, CWDM is a versatile and cost-effective technology that significantly enhances the efficiency and capability of fiber optic systems in broadcast and production settings. It is an invaluable tool in the Ross product line, enabling end-to-end workflows and maximizing the capabilities of existing infrastructure to support modern media workflows.