EEEN 464 – DIGITAL COMMUNICATION

DENSE WAVE DIVISION MULTIPLEXING (DWDM) - STUDY GUIDE/REVISION

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1. INTRODUCTION TO DENSE WAVE DIVISIOM MULTIPLEXING (DWDM)

- ### Definitions

Wavelength Division Multiplexing (WDM) allows different data streams to be sent simultaneously over a single optical fibre network. The two key WDM technologies are Coarse Wavelength Division Multiplexing, CWDM and Dense Wavelength Division Multiplexing, DWDM.

Coarse Wavelength Division Multiplexing (CWDM) uses a wider spacing of optical wavelengths compared to DWDM (Dense WDM) to transmit multiple data streams over a single fiber. Specifically, CWDM employs 18 channels with 20 nm spacing between 1271 nm and 1611 nm. This wider spacing allows for the use of less expensive components, but it also limits the maximum transmission distance due to the lack of efficient wideband optical amplifiers.

Dense Wavelength Division Multiplexing (DWDM) is a technology that enables high-capacity data transmission over optical fibre by using multiple light wavelengths to carry different data streams simultaneously.

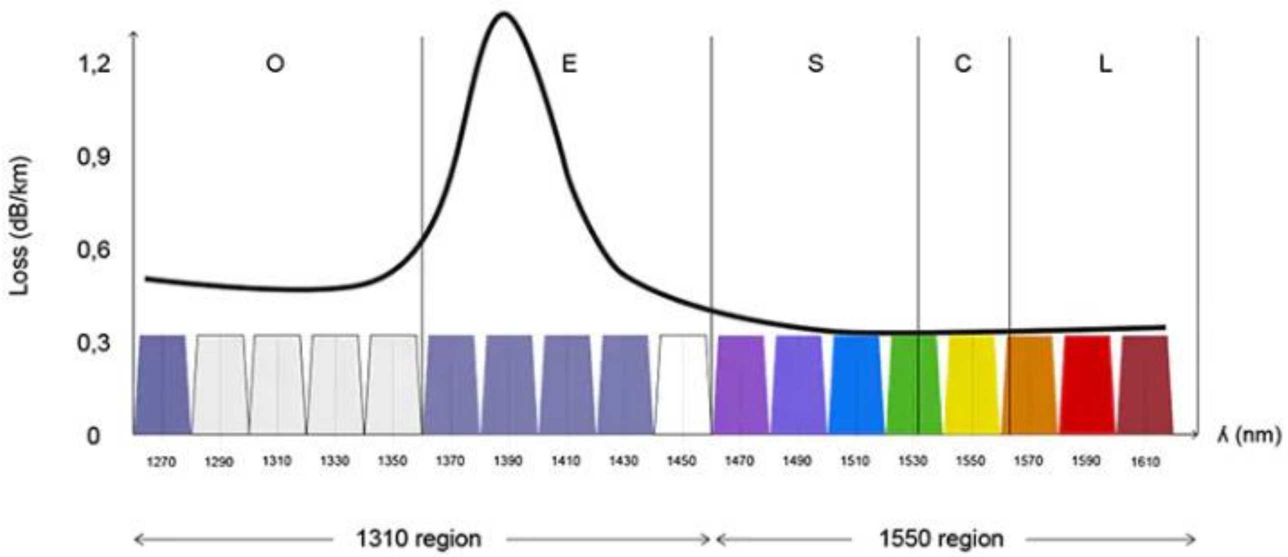

Figure 1. Attenuation in various WDM bands

- **Purpose**

The main reasons for sing DWDM are:

1. **High Capacity:** By using closely spaced wavelengths within a specific optical window (like the C-band), DWDM allows for a large number of channels, potentially 80 or more, to be transmitted simultaneously.
2. **Increased Bandwidth:** A single fibre can carry a massive amount of data using DWDM, significantly increasing the capacity of existing fibre optic networks without the need for installing new cables.
3. **Flexibility:** DWDM systems can be configured to drop or add individual channels along a route, allowing for flexible network management and service provisioning.
4. **Cost-Effectiveness:** DWDM is a cost-effective solution for expanding network capacity as it leverages existing fibre infrastructure.

- **Key Features**

1. High data rates (up to terabits per second).
2. Long-distance transmission with minimal signal loss.
3. Compatibility with existing fibre infrastructure.

2. BASIC CONCEPTS

2.1 Wavelength Division Multiplexing (WDM) vs. DWDM

- **WDM**: Combines a few wavelengths (coarse spacing, e.g., 20 nm).
- **DWDM**: Dense spacing (e.g., 0.8 nm or 100 GHz), allowing more channels (40, 80, or 160+).

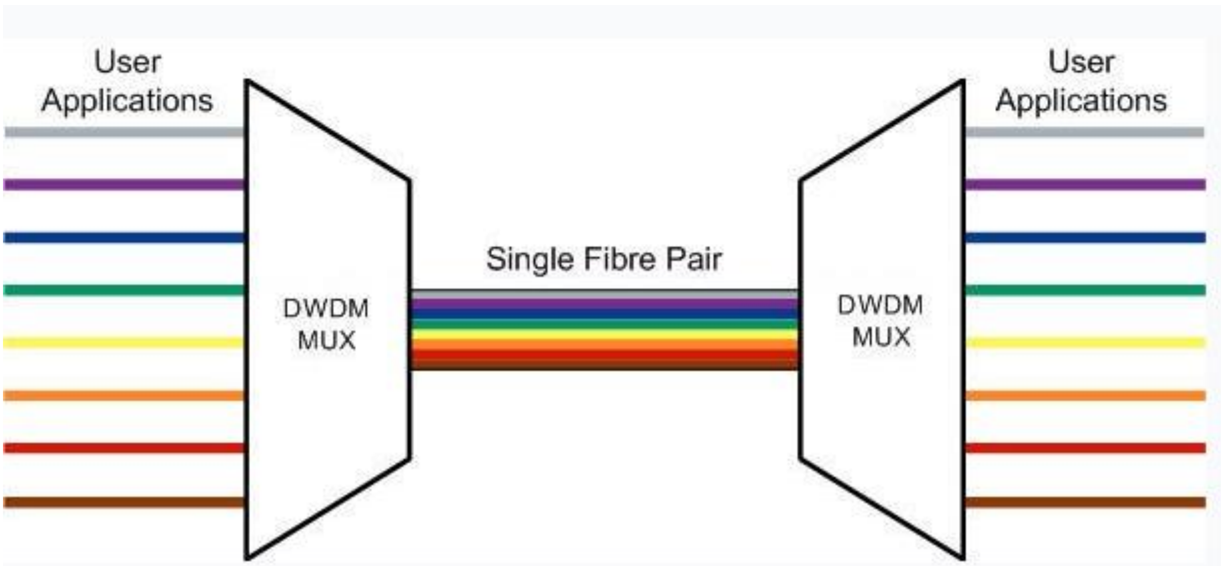

Figure 2. Block diagram of WDM system

Further Reading:

[FOA Tech Topics: DWDM, Dense Wavelenght Division Multiplexing]

2.2 Optical Spectrum in DWDM

DWDM utilizes the optical spectrum to transmit multiple signals over a single fibre by using different wavelengths of light which yields increased bandwidth capacity in optical networks. DWDM systems typically operate within the C-band (1530nm to 1565nm) and sometimes include the L-band (1565nm to 1625nm).

- **C-band (Conventional Band)**: 1530–1565 nm (most commonly used).
- **L-band (Long Band)**: 1565–1625 nm (used for extended reach).
- **Channel Spacing**: Typically 0.8 nm (100 GHz) or 0.4 nm (50 GHz).

Typical channel spacing being 0.8nm or 0.4nm.

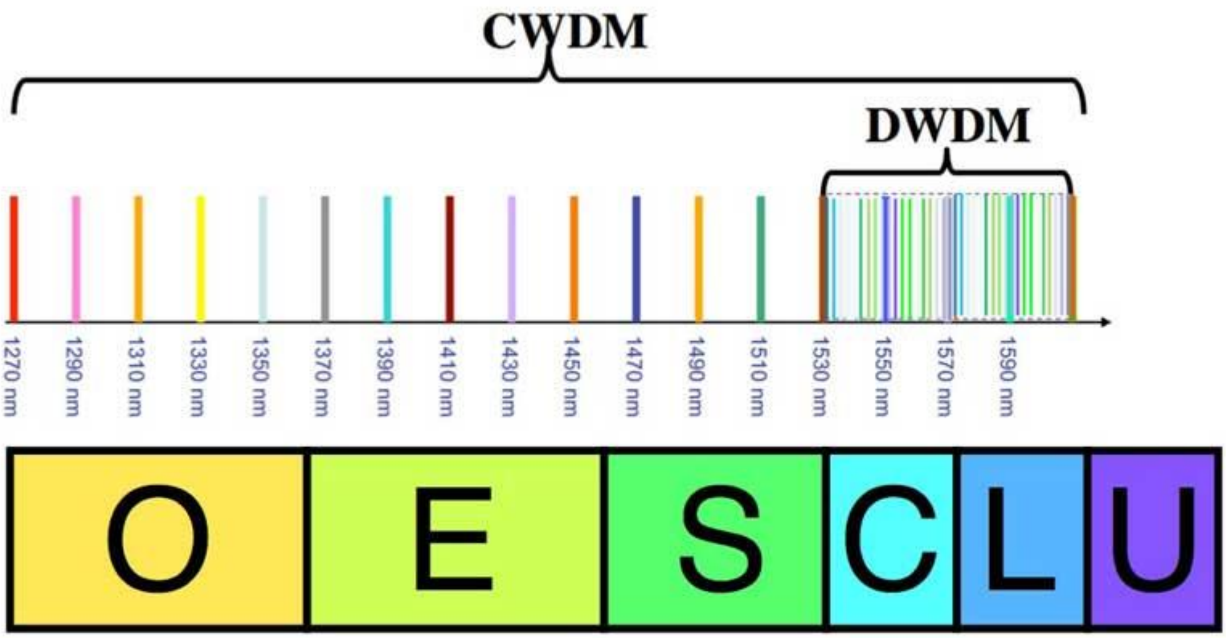

Figure 3. CWDM and DWDM spectrum

2.3 Key Components of a DWDM System

1. **Transmitters (Lasers)**: Generate precise wavelengths (λ).
2. **Multiplexers (MUX)**: Combine multiple wavelengths into a single fiber.
3. **Optical Amplifiers (EDFA)**: Boost signals without O-E-O conversion.

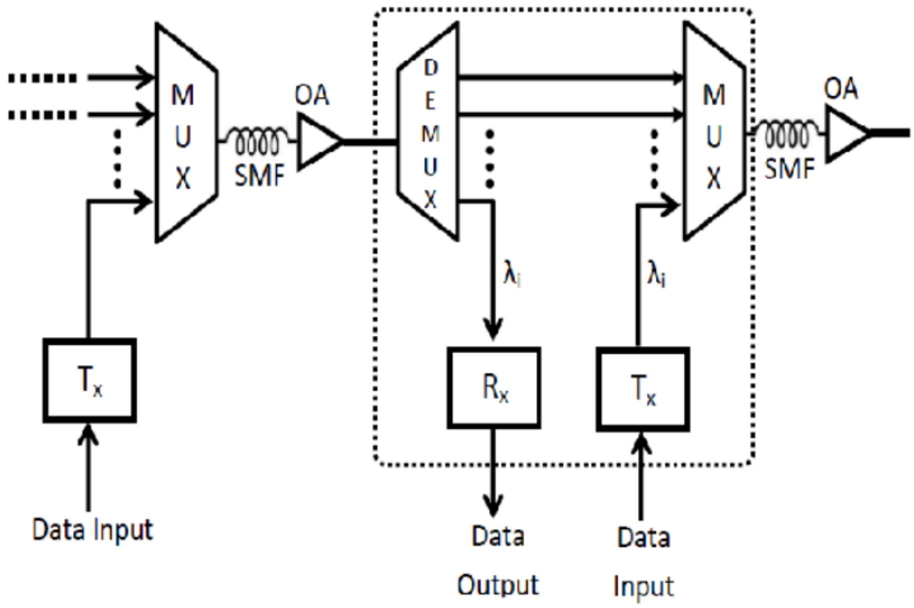

Figure 4. Block diagram of Optical Add Drop Multiplex (ADM)

4. **Demultiplexers (DEMUX)**: Separate wavelengths at the receiving end.
5. **Optical Add-Drop Multiplexers (OADM)**: Add/drop specific wavelengths.
6. **Receivers (Photodiodes)**: Convert optical signals back to electrical.

3. DWDM ARCHITECTURE & NETWORK DESIGN

3.1 Point-to-Point DWDM

- Simple link between two endpoints.
- Used in long-haul and submarine networks.

3.2 Ring-based DWDM

- Used in metro networks for redundancy.
- Supports bidirectional traffic (East-West rings).

3.3 Mesh Networks

- Highly flexible, dynamic wavelength routing.
- Uses **Reconfigurable OADMs (ROADMs)** for automated provisioning.

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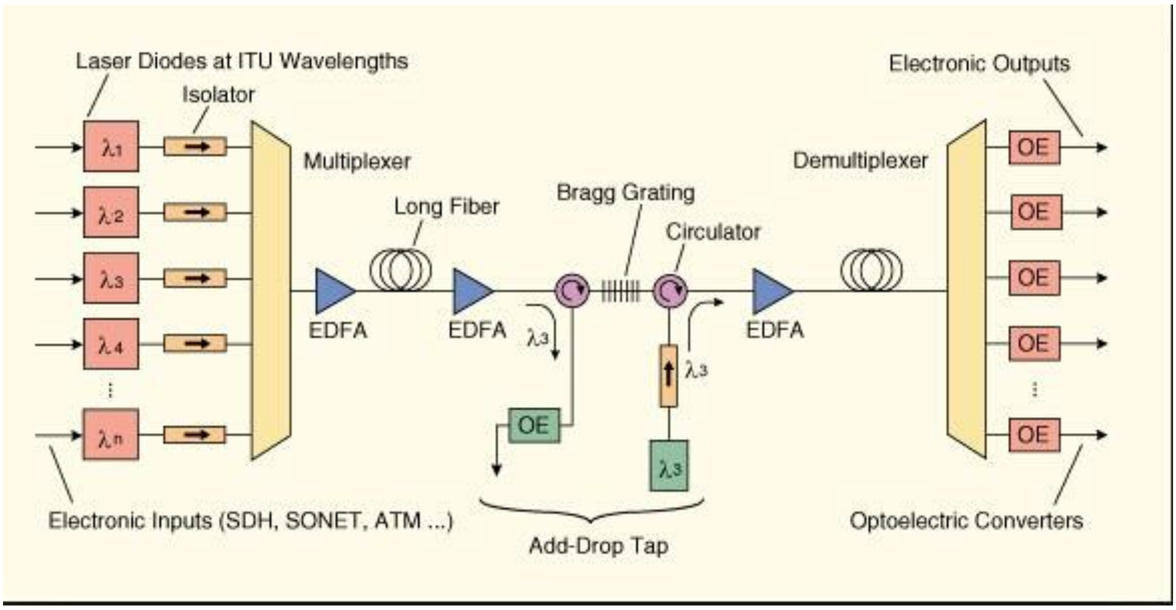

- **Figure 5.** Key components of DWDM system

4. DWDM TRANSMISSION CHALLENGES & SOLUTIONS

4.1 Signal Degradation Issues

- **Attenuation**: Loss of signal strength over distance → **Solution**: Optical amplifiers (EDFA).
- **Dispersion**: Pulse spreading → **Solution**: Dispersion-compensating fibers (DCF).
- **Nonlinear Effects**: Cross-phase modulation, four-wave mixing → **Solution**: Proper channel spacing and power management.

4.2 Power Management & Optical SNR

- **OSNR (Optical Signal-to-Noise Ratio)**: Critical for signal quality.
- **Forward Error Correction (FEC)**: Improves error tolerance.

4. TYPES OF DWDM

Passive DWDM: Uses passive filters to multiplex and demultiplex wavelengths, offering a cost-effective solution for shorter distances and lower-bandwidth requirements.

Active DWDM: Employs active components like amplifiers and tunable lasers to achieve higher capacity and longer distances, often used in metro and long-haul DCI applications.

Coherent DWDM: Utilizes advanced modulation techniques to increase the capacity and reach of DWDM systems, enabling higher data rates and longer distances.

6. DWDM STANDARDS & TECHNOLOGIES

- **ITU-T G.694.1**: Defines DWDM wavelength grid.

- **ITU-T G.709 (OTN)**: Optical Transport Network framing.
- **Coherent DWDM**: Uses advanced modulation (QPSK, 16-QAM) for higher capacity.

7. APPLICATIONS OF DWDM

- **Telecom Backbone Networks** (Long-haul, Metro).
- **Data Centre Interconnects (DCI)**: DWDM enables multiple data channels to be transmitted over a single fibre, effectively multiplying the available bandwidth and allowing for efficient and scalable data transfer between data centres.
- **Submarine Cable Systems**.
- **5G Transport Networks**.

8. FUTURE TRENDS IN DWDM

- **Flexible Grid DWDM**: Variable channel spacing.
- **Space Division Multiplexing (SDM)**: Multi-core fibres.
- **Integration with SDN/NFV**: Software-defined control of optical networks.
- **Hands-on Practice**:
    - Simulators like OptiSystem, GNS3 with DWDM plugins.

9. KEY TAKEAWAYS FOR EXAMS/INTERVIEWS

- Understand the difference between WDM and DWDM.
- Know the ITU-T wavelength grid and channel spacing.
- Be familiar with DWDM components (MUX, DEMUX, OADM, EDFA).
- Identify key challenges (attenuation, dispersion, nonlinearities).
- Recognize applications in telecom, Data Centre Interconnects (DCI), and 5G.