EEEN 464 – DIGITAL COMMUNICATION

INTRODUCTION TO FIBRE OPTIC COMMUNICATION - STUDY GUIDE/REVISION

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1. FUNDAMENTAL CONCEPTS

1. Light Propagation Principle (Recap)

- Total Internal Reflection (TIR):
    - Occurs when light travels from higher to lower refractive index material
    - Critical angle: $\theta c=\sin^{-1}(n_2/n_1)$
    - Core (n_1) > Cladding (n_2)

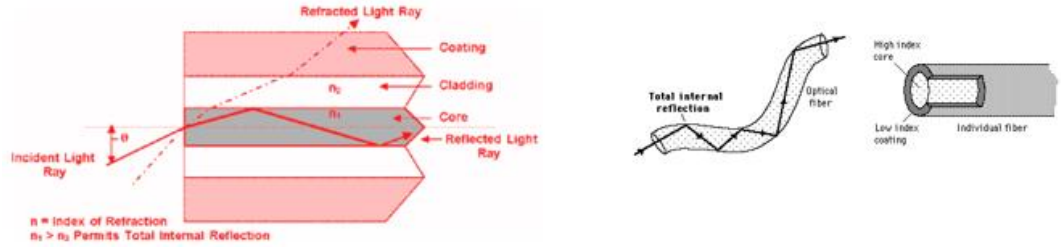

Figure 1. Fibre Optic Cable

2. Advantages over Copper

- Bandwidth: THz range vs MHz in copper
- Attenuation: 0.2 dB/km(fibre optic) vs 10 dB/km (coaxial)
- Immunity: EMI/RFI resistance
- Security: No signal tapping
- Size/Weight: 4x lighter than copper

3. Transmission Windows:

Band	Wavelength	Attenuation	Application
O-band	1260-1360 nm	0.4 dB/km	PONs
C-band	1530-1565 nm	0.2 dB/km	DWDM systems
L-band	1565-1625 nm	0.25 dB/km	Long-haul networks

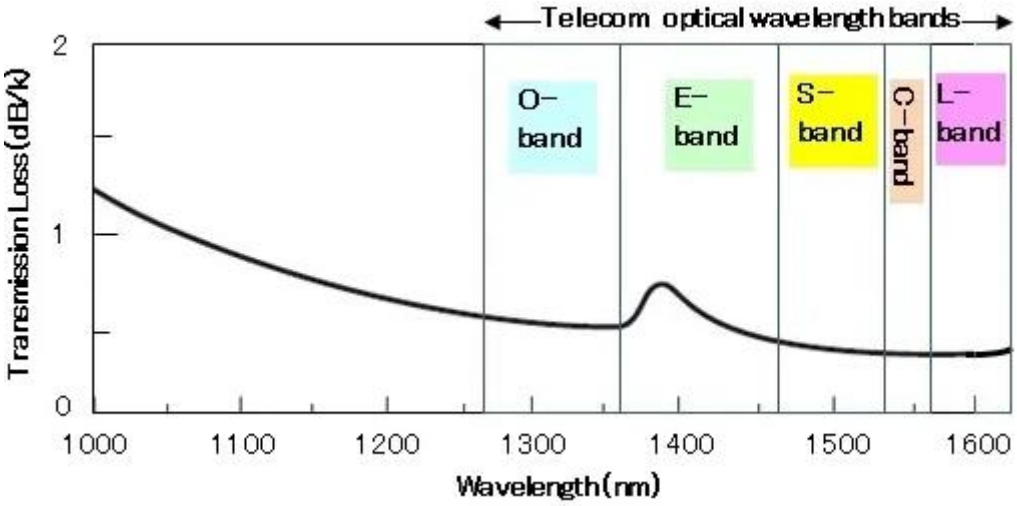

Figure 2 Telecommunication fibre optic optical wavelength bands

2. OPTICAL FIBRE TYPES

2.1 BASED ON REFRACTIVE INDEX PROFILE

1. **Step-Index Fiber**:
    - Sharp core-cladding interface
    - Used in multi-mode applications
2. **Graded-Index Fiber**:
    - Parabolic refractive index profile
    - Reduces modal dispersion

2.2 BASED ON MODES

Type	Core Diameter	Bandwidth	Distance	Application
Multi-Mode (MMF)	50-62.5 µm	100 MHz·km	≤2 km	LANs, Data Centres
Single-Mode (SMF)	8-10 µm	100 GHz·km	80-120 km	Telecom Backbone

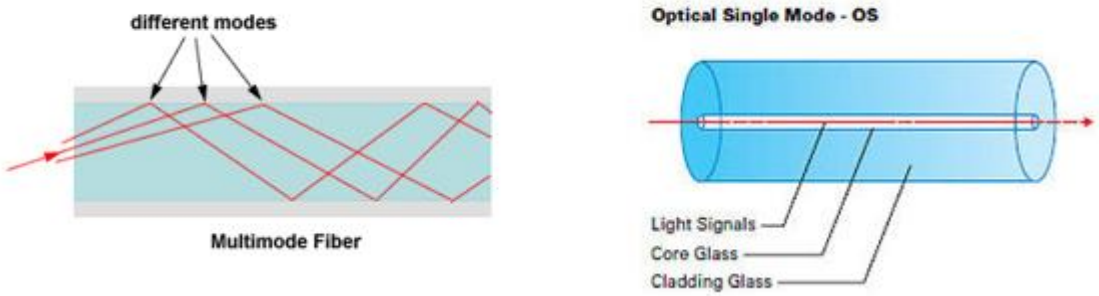

Figure 2. Single mode and multimode fibre optic propagation

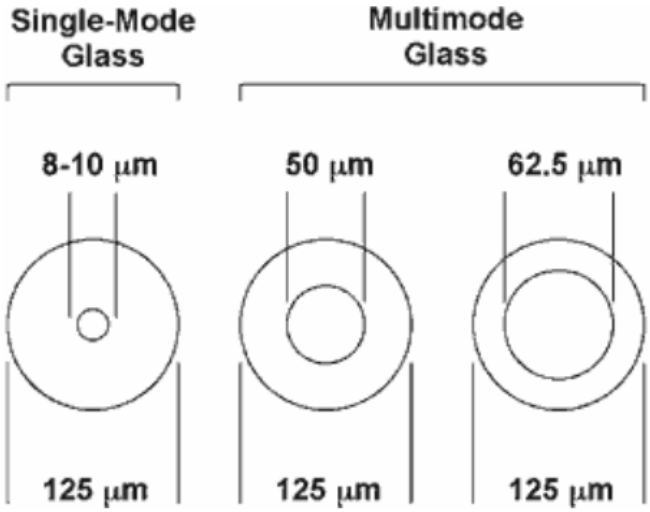

Figure 3. Single mode and multimode fibre sizes

2.3 SPECIALTY FIBERS

- Dispersion-Shifted Fiber (DSF): Zero dispersion at 1550 nm
- Erbium-Doped Fiber (EDF): Amplification medium
- Photonic Crystal Fiber: Microstructured cladding

3. KEY COMPONENTS

3.1 TRANSMITTERS

- **Lasers**: DFB (Distributed Feedback) for SMF, VCSEL (Vertical Cavity) for MMF
- **LEDs**: For short-range MMF
- **Modulation**: Direct (current) vs External (MZM)

3.2 RECEIVERS

- **Photodiodes**:
    - PIN: Low cost, <10 Gbps
    - APD: Internal gain, sensitive, >40 Gbps
- **Receiver Sensitivity**: Minimum power for BER=10^{-9}

3.3 OPTICAL AMPLIFIERS

- **EDFA**: C-band amplification (1530-1565 nm), Gain: 30-40 dB
- **Raman Amplifiers**: Distributed gain, lower noise

3.4 PASSIVE COMPONENTS

- Couplers/Splitters
- WDM Mux/Demux

- Isolators/Circulators
- Optical Switches

4. SIGNAL IMPAIRMENTS

4.1 ATTENUATION

- Causes: Absorption, Scattering (Rayleigh), Bending

$P_{out} = P_{in}e^{-\alpha L}$ (α = attenuation coefficient)

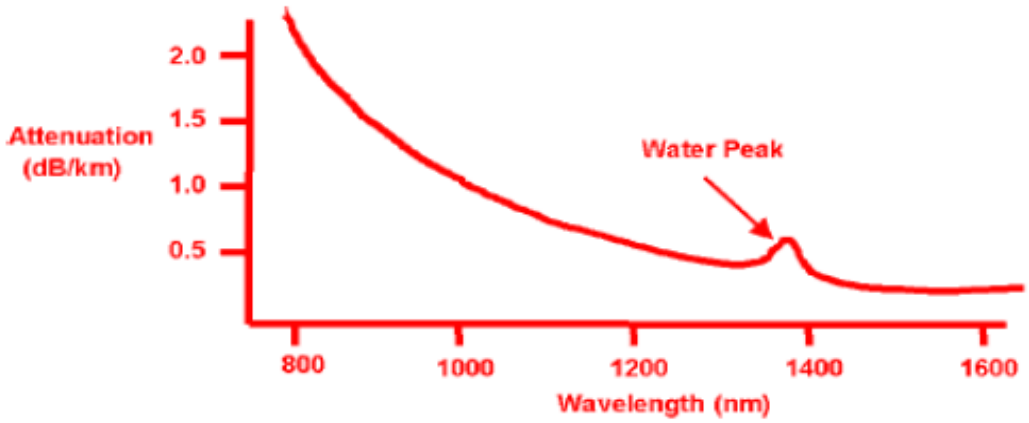

Figure x. Attenuation in Fibre Optic Cable

4.2 DISPERSION

1. **Chromatic Dispersion (CD)**:
    - Material + Waveguide dispersion
    - D=−λcd2ndλ2$D = -\frac{c\lambda}{d\lambda^2}\frac{d^2n}{}$ (ps/nm·km)
    - Compensation: DCF, FBG

Figure 4. Animation of dispersion in fibre optic cable

2. **Polarization Mode Dispersion (PMD)**:
    - Asymmetric core → Differential group delay
    - Critical at >40 Gbps

4.3 NONLINEAR EFFECTS:

- SRS (Stimulated Raman Scattering): Power transfer to longer λ
- SPM (Self-Phase Modulation): Intensity-dependent phase shift

- XPM (Cross-Phase Modulation): Inter-channel interference
- FWM (Four-Wave Mixing): New frequency generation

5. MODULATION & MULTIPLEXING

5.1 MODULATION FORMATS

- **Direct Detection**: OOK, PAM4
- **Coherent Detection**: QPSK, 16-QAM, 64-QAM
- **Advanced**: OFDM, Probabilistic Constellation Shaping

5.2 MULTIPLEXING TECHNIQUES

1. **Wave Division Multiplexing (WDM)**:
    - CWDM: 18 channels, 20 nm spacing (1270-1610 nm)
    - DWDM: 96+ channels, 0.8/0.4 nm spacing (C/L bands)
2. **Time Division Multiplexing (TDM)**: OTDM for >100 Gbps
3. **SDM**: Space Division Multiplexing (Multi-core fibers)

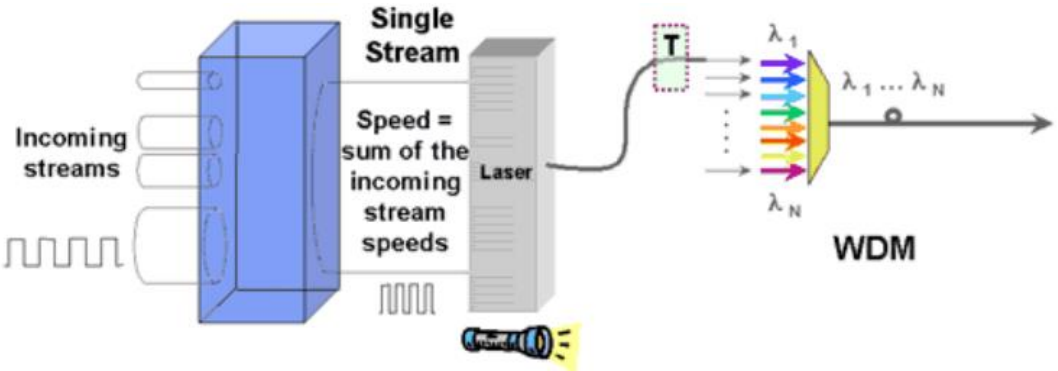

Figure 5 Operating principle of Wave Division Multiplexing (WDM)

6. MODERN APPLICATIONS

6.1 TELECOM NETWORKS

- FTTH: GPON (2.5G/1.25G), XGS-PON (10G symmetric)
- 5G Fronthaul: eCPRI, 25G/100G links

6.2 DATA CENTRES

- 400G-ZR: 80-120 km with coherent detection
- Multi-mode: OM5 for SWDM (850-950 nm)

6.3 UNDERSEA CABLES

- 200 Tbps capacity (C+L bands)
- Hybrid Raman-EDFA amplification

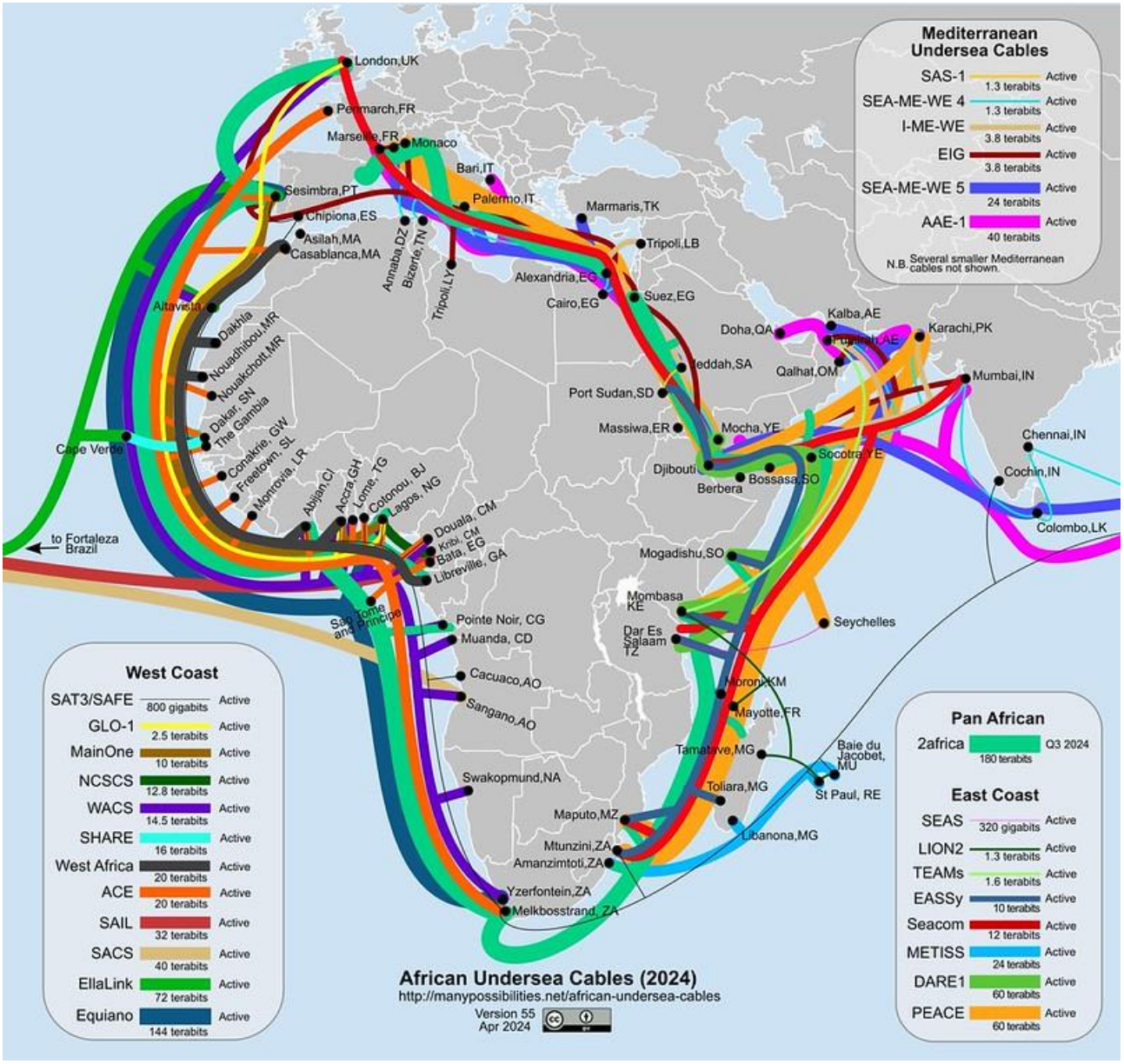

Figure: Undersea Fibre Optic Cable supplying Internet to African continent

6.4 EMERGING TECHNOLOGIES

- Quantum Key Distribution (QKD)
- Optical Computing
- LiFi (Light Fidelity)

7. MEASUREMENT & TESTING

7.1 KEY PARAMETERS

- **OTDR**: Fault location, loss measurement
- **OSA**: Optical spectrum analysis
- **BER Tester**: System performance
- **Chromatic Dispersion Analyzer**

7.2 STANDARD TESTS

- Insertion Loss
- Return Loss (>40 dB)
- Polarization Dependent Loss (<0.2 dB)