光纖光柵原理與應用

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光纖與光纜
Classification of optical fibers

一、依折射率在 core 横截面上的分佈形状：
- 级射率光纖 (step index fiber)
- 斜射率光纖 (graded index fiber)

二、依光纖中傳輸模態的多少分類：
- single-mode fiber
- multimode fiber

三、依製造光纖所使用的材料來分類：
- 石英系列 (All-glass)
- 塑膠外殼石英核心
- 全塑膠光纖 (All-plastic)
Classification of optical fibers

(a) Single Mode Fiber

Core diameter ~ 8µm

(b) Multimode Fiber

Core diameter > 50µm

(c) Graded Index Multimode Fiber
(a) Single Mode Fiber

Core diameter ~ 8um
Classification of optical fibers

(b) Multimode Fiber

Core diameter > 50um

Intensity

Spread, Δτ

dispersion
Classification of optical fibers

(c) Graded Index Multimode Fiber

Core diameter > 50um
\[ \frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \]

- \(\Delta \lambda\): linewidth or spectral width
- \(\lambda\): central wavelength
- \(f\): central frequency
- \(\Delta f\): the range of frequencies radiated

The smaller the linewidth, the more coherent the source. If it has **zero linewidth** and is **perfectly monochromatic**.

**Typical Source Spectral Widths**

<table>
<thead>
<tr>
<th>Source</th>
<th>Linewidth (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-emitting diode</td>
<td>20-100</td>
</tr>
<tr>
<td>Laser diode</td>
<td>1-5</td>
</tr>
<tr>
<td>Nd:YAG laser</td>
<td>0.1</td>
</tr>
<tr>
<td>HeNe laser</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Fig. **Pulse spreading** caused by propagation through a dispersive material. The complete pulse contains wavelengths $\lambda_1$, $\lambda_2$, and $\lambda_3$, each traveling at a different speed.
Dispersion in Single Mode Fibers

Fig. Dispersion causes loss in amplitude of an analog signal.

Dispersion does not change the average power or the modulation frequencies, but it does lower the signal variation.
Dispersion in Single Mode Fibers

For $\lambda < 1.3 \mu m$, $\lambda \uparrow$, $V \uparrow$

For $\lambda > 1.3 \mu m$, $\lambda \uparrow$, $V \downarrow$

Fig. Using chirped-fiber Bragg grating for dispersion compensation
Total dispersion for conventional, dispersion-flattened and dispersion-shifted fibers.
光纖之損失來由
The losses occurring in glass fibers can be classified as **absorption**, **scattering**, and **geometric effect**.

**Absorption**: intrinsic absorption (UV absorption and IR absorption) → owing to strong electronic and molecular transition bands. **Impurities’ absorption**: OH ions and transition-metal ions, such as Fe, Cu, V, Co, Ni, Mn, and Cr etc.
Fig. **Rayleigh scattering**, showing attenuation of an incident stream of photons owing to localized variations in refractive index.

The Rayleigh scattering loss can be approximated by the expression:

\[ L = 1.7\left(\frac{0.85}{\lambda}\right)^4 \]

**Rayleigh scattering \(\rightarrow\) Elastic scattering**

In Fig, a trapped ray proceeds through an SI fiber, striking the core-cladding interface at an angle \(\theta_1 > \theta_c\), so that total reflection occurs. This same ray enters the bend and strikes the interface at an angle \(\theta_2\), which is clearly less than \(\theta_1\) and which may be less than critical angle. The angle \(\theta_2\) diminishes as the bend radius decreases.
光纖通訊簡介
光纖的各項優點:

- 低色散
- 低損失
- 高頻寬
- 不受電磁干擾
- 保密性高
- 無串音
- 耐惡劣環境
- 可撓性高
- 徑細、質輕
- 原料豐富
台灣光纖通信系統

1. 西部第一幹線光纖通信系統：
   沿省道鋪設，台北-高雄，全長434Km，24芯單模光纜。

2. 中山高光纖通信系統，沿高速公路鋪設，台北-高雄，48芯單模光纜。

3. 東部光纖通信系統：台北-基隆-蘇澳-…-高雄，全長624Km，其中北迴鐵路鋪設24芯單模光纜，南迴鐵路鋪設48芯單模光纜。

4. 外島離島海底光纜系統：
   (1)台南-澎湖，8芯單模光纜。
   (2)澎湖-金門，12芯單模光纜。
   (3)台灣-馬祖，12芯單模光纜。
Some conducting transmission lines and their bandwidth:
1. Twist paired line: 200MHz
2. Coaxial cable: 1.2 ~ 2 GHz → 0.5" 750MHz loss ~7dB/100m
3. Optical fiber: ~10,000GHz → loss 1.55um ~0.25dB/Km
A generalized fiber optic communications system

Message Origin → Modulator → Carrier Source → Channel Coupler

Carrier Source

Repeater or Optical Amplifier

Detector → Amplifier → Processing → Message Output

Receiver
The Electromagnetic Spectrum

The Optical Spectrum

Radio  Microwaves  Visible Light  Ultraviolet  Infrared  X Rays  Gamma Rays

Frequency (Hz)

Photon Energy (ev)

Wavelength (m)
Optical Transmission Windows

» O-Band - 1260nm to 1310nm
» E-Band - 1360nm to 1460nm
» S-Band - 1460nm to 1530nm
» C-Band - 1530nm to 1565nm
» L-Band - 1565nm to 1625nm
» U-Band - 1625nm to 1675 nm
nm 與 GHz 之換算

1nm \equiv 125 \text{ GHz} @ \lambda = 1550\text{nm}

\[ C = \lambda \times f \]
\[ \therefore f = \frac{C}{\lambda} \]
\[ \Rightarrow \left| \Delta f \right| = \left| \frac{C}{\lambda^2} \times \Delta \lambda \right| \]

\[ \therefore 1\text{nm} @ 1550\text{nm} = \frac{3 \times 10^8}{(1550 \times 10^{-9})^2} \times (1 \times 10^{-9}) \]

\[ \equiv 125 \text{ GHz} \]

Similarly, 1nm @ 1310nm \equiv 175 \text{ GHz}
Application of Fiber-Optic Communications

光纖網路應用主要有兩大類:

一、Telephone System

在單模光纖1300nm和1550nm光波長範圍內，兩穿透視窗的頻寬各大約為100nm，換算為頻率領域將近30,000GHz。(在高達數GHz載波頻率之電子系統中，頻寬也不過數GHz罷了)

二、Cable Television

CATV網路架構以光纜為主幹線，而在用戶迴路採用同軸纜線，即光纖同軸混合網路系統(Hybrid Fiber/Coaxial Cable, HFC)
Subcarrier Multiplexing; SCM

如何利用有限頻寬的電子技術去善用光纖的巨大頻寬？

目前解決的方法，如 Optical time division multiplexing-OTDM，Wavelength division multiplexing-WDM 等等。

其中最經濟簡單的方法是類比的次載波多工法（SCM）- 即 光波 和 射頻載波 分別作二次調變 (Modulation)的載子 (Carrier)。示意圖如下：
## SONET Transmission Rates

**SONET** - Synchronous Optical **NET**work

The basic SONET transmission rate is **OC-1** (Optical Carrier at level 1). The electrical equivalent is **STS-1** (Synchronous transport signal at level 1).

<table>
<thead>
<tr>
<th>Transmission (Electrical)</th>
<th>Designation (Optical)</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>51.84</td>
</tr>
<tr>
<td>STS-3C</td>
<td>OC-3</td>
<td>155.52</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>622.08</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>1244.16</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>2488.32</td>
</tr>
<tr>
<td><strong>STS-192</strong></td>
<td><strong>OC-192</strong></td>
<td>10 Gbps</td>
</tr>
<tr>
<td><strong>STS-768</strong></td>
<td><strong>OC-768</strong></td>
<td>40 Gbps</td>
</tr>
</tbody>
</table>

**STM-16** refers to 2.5Gbps and **STM-64** refers to 10 Gbps.
**Wavelength Division Multiplexing (WDM)**

**Multiplexer**

\[ \lambda_1 \text{ Signal} \rightarrow \text{Single fiber} \]
\[ \lambda_2 \text{ Signal} \rightarrow \text{Single fiber} \]
\[ \lambda_n \text{ Signal} \rightarrow \text{Single fiber} \]

**Demultiplexer**

\[ \lambda_1 \text{ Signal} \rightarrow \lambda_1 \text{ Signal} \]
\[ \lambda_2 \text{ Signal} \rightarrow \lambda_2 \text{ Signal} \]
\[ \lambda_n \text{ Signal} \rightarrow \lambda_n \text{ Signal} \]

**WDM** is accomplished using a multiplexer to combine wavelengths traveling on separate fibers into a single fiber. At the receiver end of the link, a demultiplexer separates the wavelengths and routes them into different fibers.
Uncooled coarse WDM lasers drift in wavelength at the rate of approximately 0.08nm/centigrade. The filter passband and laser channel spacing must be wide enough to accommodate this temperature dependent wavelength drift, plus any manufacturing variations.
**Difference Between DWDM and CWDM**

**DWDM = Dense WDM**
- 64 to 128 λ for 1Tbps+
- Utilize 0.8nm spacing
- Expensive laser & optical module
- Temperature control
- 500 to 5000 km with optical amplifiers
- Long haul, between metro

**CWDM = Coarse WDM**
- 4 to 16 λ for 8 to 32 Gbps
- Utilize 20 nm spacing
- Low cost laser & optical module
- Need less Temperature control
- 10 to 80 km without optical amplifiers
- Metro back bone, Metro Access
Differences in Application

<table>
<thead>
<tr>
<th>距離</th>
<th>傳輸技術</th>
</tr>
</thead>
<tbody>
<tr>
<td>x00 - x000Km</td>
<td>DWDM</td>
</tr>
<tr>
<td>&gt;100Km</td>
<td>DWDM</td>
</tr>
<tr>
<td>60–100Km</td>
<td>DWDM/CWDM</td>
</tr>
<tr>
<td>10–50Km</td>
<td>CWDM</td>
</tr>
<tr>
<td>1–5Km</td>
<td>FTTH, xDSL, GbE…</td>
</tr>
</tbody>
</table>

海纜網路
長途網路
都會核心網路
都會區域網路
用戶接取網路
光通訊常見儀器及元件

(图片展示了一台光纤切割器，型号为Fujikura HIGH PRECISION FIBER CLEAVER)
Optical Spectrum Analyzer - OSA
Power Meter
Operation Principle of Power meter and OSA

InGaAs

Responsivity

λ (nm)

750

1750

OSA工作原理

繞射光柵

狹縫
Typical OTDR Trace
Fiber Splicing Machines 2/2

Principle of fusion splicing

Dirt in the V-grooves
Optimal fiber position in the V-groove

Endface quality
Poor position of fibers in V-groove due to dirt particles
Applications -

- DWDM OADM
- Pump laser stabilization
- EDFA gain flattening
- Dispersion compensation (chirped)
Fiber Bragg Grating, FBG 2/2

\[ \lambda = 2n_{\text{eff}} \Lambda \]

Incident UV Beam

Reflection Spectrum of Fiber Bragg Grating

T.C.Liang
Chirped Bragg grating

Dispersion compensation with a chirped Bragg grating

Wideband chirped grating (left) and narrowband (for 50 GHz channel spaced DWDM applications) linear grating (right) fiber Bragg gratings.
Long-Period Fiber Grating (LPG)

$\lambda$ 滿足 period 散射到 cladding

$\lambda = 2 \Delta n_{eff} \Lambda$
Isolators/ Circulators

Isolator - commercial product
Principle of Isolator
Optical Add Drop Multiplexer, OADM

Signal input

\( \lambda_1 \), \( \lambda_i \)

Circulator

\( \lambda_i \) FBG

Dropped signal

\( \lambda_i \)

Conventional OADM

Added signal

\( \lambda_i \)

Signal output
Optical Add Drop Multiplexer, OADM

Multi-port optical circulator: MOC
Multi-port optical circulator OADM