宽带与光纤

一、Optical Fiber Fundamentals and Transmission Properties.

Photon Energy Equation : $\boxed{E(eV) = \frac{1.24}{\lambda(\mu m)}}$

Critical Angle : $\boxed{\sin\phi_c = \frac{n_2}{n_1}}$

Step-Index (SI)

1) $\boxed{NA = n_0 \sin(\theta_a) = \sqrt{n_1^2 - n_2^2}}$, θ_a为最大可接受角.

2) Relative refractive index difference $\boxed{\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}}$.

3) Normalised-Frequency $\boxed{V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}}$, a为 core radius

存在 Cutoff V-number, $V_c = 2.405$, 小于V_c, 单模.

Number of modes $\boxed{M = \frac{V^2}{2}}$.

4) Dispersion 带来 broaden $\Delta T = \frac{n_1^2\Delta}{c n_2} \cdot L$

modal delay per length $= \frac{\Delta T}{L} = \frac{n_1^2 \Delta}{c n_2}$

若T的变化在一个区间,为r.v., 则 rms 为 $\sigma_s = \frac{L n_1 \Delta}{2\sqrt{3} c}$.

为了无ISI, 要求 $\Delta T < T_B = \frac{1}{B}$, 有 $BL < \frac{n_2}{n_1^2}\frac{c}{\Delta}$

Graded-Index (GI).

1) $NA = \sqrt{n_1^2 - n_2^2}$, $\boxed{NA(r) = \begin{cases} NA\sqrt{1-(\frac{r}{a})^2}, & r \le a \\ 0, & r > a \end{cases}}$

2) $V = \frac{2\pi a}{\lambda} NA$, $V_c = 2.405\sqrt{\frac{2+\alpha}{\alpha}}$

Number of modes $\boxed{M = \frac{\alpha}{\alpha+2}\frac{V^2}{2}}$. α为GI参数.

3) $\Delta T = \frac{n_1^2 \Delta^2 L}{8c}$, $\sigma_g = \frac{L n_1 \Delta^2}{20\sqrt{3} c}$, $BL < \frac{8c}{n_1^2 \Delta^2}$ $(\alpha = 2)$

Attenuation.

$\boxed{\alpha_{total} = 10 \log_{10} \frac{P_{in}}{P_{out}}}$

每km衰减 $\alpha = \frac{1}{L}\alpha_{total} = \frac{1}{L} \cdot 10\log_{10}\frac{P_{in}}{P_{out}}$.

二、Optical Fiber Communication Systems.

1. Bandgap Energy 确定释放出什么样的波长光. $E(eV) = \frac{1.24}{\lambda(\mu m)}$

2. Fabry-Perot Cavity

往返光路长度为波长整数倍才可运行: $\boxed{2nL = m\lambda}$, n为超参.

Frequency spacing or longitudinal model space : $\boxed{\Delta f = \frac{c}{2nL}}$

光速/阈增益

minimum gain required for laser oscillation :

$\boxed{g = \alpha_{init} + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)}$

常数

photon lifetime $\boxed{\tau_p = \frac{n}{c \cdot g}}$

3. PIN photodiodes.

响应性 Responsivity $R = \eta\frac{q}{h\nu} = \eta\frac{q}{h}\frac{\lambda}{c}$

Photocurrent $i_p = R \cdot P_{in}$

4. Avalanche Photodiodes (APD) 可放大微弱信号(电)

unmulitiplied photocurrent $\boxed{i_p = R \cdot P_{in}}$

倍增因子 Multiplication factor $\boxed{M = \frac{i_m}{i_p}}$, i_m为放大后电流.

同样,可定义. $R_{APD} = R \cdot M$, $i_m = R_{APD} \cdot P_{in}$.

5. EDFAs 光纤放大器(光).

需要调整 signal input 和 pump input 的强度. (两种光)

$$\boxed{G = \frac{P_{s,out}}{P_{s,in}} \le 1 + \frac{\lambda_p}{\lambda_s}\frac{P_{p,in}}{P_{s,in}}}$$

三. Optical Networks (Synchronous Optical Network, SONET)

1. 帧结构 (STS-1).

$\boxed{9\times 90}$ 的 Byte 矩阵, 前3列为 Transport Overhead.

第4列为 Path Overhead, 剩下列中有两列固定 Byte

所以 SPE (Synchronous Payload Envelope) = 87列

其中 Effective payload of SPE 为 87-3 = 84列.

STS-1 的传输时间是固定的, 125 μs.

$N\times STS\text{-}1 \Rightarrow STS\text{-}N \longrightarrow OC\text{-}N$.

2. 虚拟支流 Virtual Tributaries (VTs).

目的 Efficiently aggregate lower-speed signals, such as DS1 and E1, into a higher-capacity SONET frame.

种类 $VT_{1.5}$, VT2, VT3, VT6, (VT_n 占 n×2 列).

Effective SPE payload (84 columns) is divided into T-equal-size (~~12 columns~~ 共12个VTG) groups (VTGs).

对应关系 DS1 - $VT_{1.5}$, E1 - VT2, DS1C - VT3, DS2 - VT6.

3. Pointer Justification. 解决时钟不对应导致的问题.

主要是对 Pointer Bytes H1, H2, H3 的调整. (Internal Buffer)

1) Negative Byte-Stuffing, 时钟过快, 一个 Byte 被挤进 H3. [H1, H2] 的指针减1.

2) Positive Byte-Stuffing, 时钟过慢, 在H3后插入空字节, [H1, H2] 指针加1.

每4帧只能有一次 Pointer Justification.

目的 Let the Network absorb frequency misalignment.

4. Pointer Justification 的界限.

所有的计算都是以4帧为准则.

正常传输速率: $\dfrac{783\times 8\times 4}{125\mu\times 4}$

Positive byte-stuffing: $\dfrac{(783\times 4-1)\times 8}{125\mu\times 4}$

Negative byte-stuffing: $\dfrac{(783\times 4+1)\times 8}{125\mu\times 4}$.

可计算 Positive 和 Negative 的 normalised 偏差 = $\dfrac{\text{偏差速率}}{\text{正常速率}}$

则 Total frequency misalignment the network can absorb

$= |\Delta N_p(\text{norm})| + |\Delta N_N(\text{norm})|$

5. High-order SONET

STS-N: STS-1 的拼接, 每个STS-1 有独立的 POH.

STS-Nc: STS-1 的级联, 组合成大块, 共享一个 POH.

Rate of STS-N = N × Rate of STS-1.

四. Optical Access Networks and key Technologies.

1. Topologies for Optical Access Networks

1) 点对点, 2) Active Tree 3) PON Tree.

2. Passive Optical Networks (PONs).

TDM / WDM / Hybrid WDM/TDM / TWDM-PON.

重点介绍 TDM-PON.

① Downstream: broadcast

② Upstream: Multiple Access, Time Division Multiple Access (TDMA) and DBA

3. DBA

定义 DBA Dynamic Bandwidth Allocation, DBA adapts to changing traffic conditions by dynamically adjusting time slot allocations, optimising network performance and efficiency in response to fluctuating traffic loads.

Type { Standard Polling，单线程 (threaded)
Interleaved Polling，多线程.

注意是 OLT 轮询 ONUs.

4. Optical Fiber Coupler

Coupler {
- Three- and four-port couplers
- Star couplers (~~input~~ single input, multiple output) 均分功率.
- WDM devices {
  - Arrayed Waveguide Grating (AWG)
  - Optical Add/Drop Multiplexer (OADM)
    ↓ +光交换技术
  - Reconfigurable OADM (ROADM)
    ↓ 大规模
  - Optical Crossconnects (OXC).

Fiber Bragg Grating & Optical Circulators

1) 损耗.

四端口：

$$\boxed{\begin{aligned}\text{Excess loss} &= 10\log_{10}\frac{P_1}{P_3+P_4}\\ \text{Insertion loss} &= 10\log_{10}\frac{P_{in}}{P_{out}}\end{aligned}}$$

(根据测量的两个端口)

Star couplers：

$$\boxed{\begin{aligned}\text{Insertion loss} &= \text{splitting loss} + \text{excess loss}\\ \text{Splitting loss} &= 10\log_{10}N\end{aligned}}$$

$$\text{Excess loss} = 10\log_{10}\frac{P_{in}}{P_{out}} = 10\log_{10}\frac{P_{in}}{\sum_{i=1}^{N} P_{i,out}}$$

Splice loss：熔接损耗.

2) 控制光路

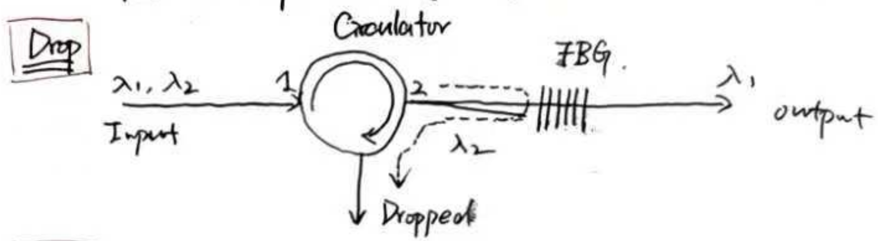
① Fiber Bragg Grating (FBG)：反射固定频率的光

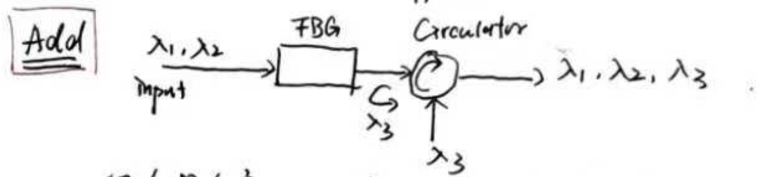
② Optical Isolator：光二极管.

③ Optical Circulators：specific sequence.

3) OADM 原理.

Add or Drop wavelengths from a multi-wavelength optical signal.





组合或分离 N个波长的光，需要 (N-1)个 FBG 和 Circulators.

4) Reconfigurable OADM.

光交换技术 {
- Electroptic switch
- Liquid crystal switch
- $\boxed{\text{MEMS} \\ \text{WSS}}$

Reconfigurable OADM 可依赖于 MEMS, WSS.