Reti in fibra ottica – Formulario

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Lightwave Basics

Physical Constants

Description	Value	Symbol
Velocity of Light	2.9979 x 10 ^{8} m/s	c
Electron Charge	1.602 x 10^{-19} C	q
Planck Constant	6.626 x 10^{-34} J·s	h
Boltzman Constant	1.38 x 10^{-23} J/K	k

Conversion formulae between frequency and wavelength

Absolute frequency/wavelength: $f = \frac{c}{l}$

Frequency/wavelength intervals: $\Delta f = -\frac{c}{l^2}\Delta l$

Optical power: $\begin{cases} P_{dBm} = 10\log_{10}\left(P_{mW}\right) \\ P_{mW} = 10^{P_{dBm}/10} \end{cases}$

Propagation of light in optical fibers

Velocity of light in dielectric of index n : $v = \frac{c}{n}$

Dispersion limits in step index multimode fibers

Normalized Frequency Parameter V: $V = k_0 a\left(n_1^2 - n_2^2\right)^{1/2} = \left(\frac{2p}{l_0}\right) a n_1 \sqrt{2\Delta}$

In order to have a Single Mode Fiber: V ≤ 2.405

In order to have a Multi Mode Fiber: V > 2.405

Amount of pulse broadening in a step index multimode fiber: $dT = L \cdot \frac{n_1^2}{n_2} \cdot \frac{\Delta}{c}$

Bit Rate Limit: $dT < \frac{1}{2B}$, $BL < \frac{n_2 c}{2 n_1^2 \Delta}$

Dispersion limit in graded index multimode fibers

Amount of pulse broadening in a step index multimode fiber: $dT = \frac{L n_1}{8c} \Delta^2$

Bit Rate Limit: $dT < \frac{1}{2B}$, $BL < \frac{4c}{n_1 \Delta^2}$

Transmission Systems Design

Single-Span Without Amplifiers

Available Power Budget: $\overline{P}_{TX_{dBm}} - \overline{P}_{sens_{dBm}}$

System degradation: $a_{dB} \cdot L + a_{spl} + a_{conn} + a_{bends} + a_{path} + m$

Maximum distance: $L_{\max, pract} = \dfrac{\overline{P}_{TX_{dBm}} - \overline{P}_{sens_{dBm}} - a_{spl} - a_{conn} - a_{bends} - a_{path} - m}{a_{dB}}$

Quantum limit: $BER = \dfrac{1}{2} e^{-2\overline{N}_{RX}}$, $\overline{N}_{RX} = \dfrac{\overline{P}_{RX}}{h\nu \cdot R_B} = \dfrac{\overline{P}_{RX} \cdot T}{h\nu}$ =number of average photons per bit

Single-Span with RX Optical Amplifier

The Optical Signal-to-Noise Ratio over a bandwidth R_B:

$$OSNR \equiv \frac{\overline{P}_{signal}^{out}}{(G-1) \cdot F \cdot h\nu \cdot R_B}, \quad OSNR\big|_{dB} \cong \overline{P}_{signal}^{out}\big|_{dBm} - G\big|_{dB} - F_{EDFA}\big|_{dB} - P_{base}\big|_{dBm}$$

$$P_{base}\big|_{dBm} = 10 \cdot \log_{10}(h\nu \cdot R_b \cdot 10^3), \; h = 6.6261 \cdot 10^{-34} \text{ J} \cdot \text{s}, \; \nu = 193.41 \; THz \; (@ \; 1550 \; nm)$$

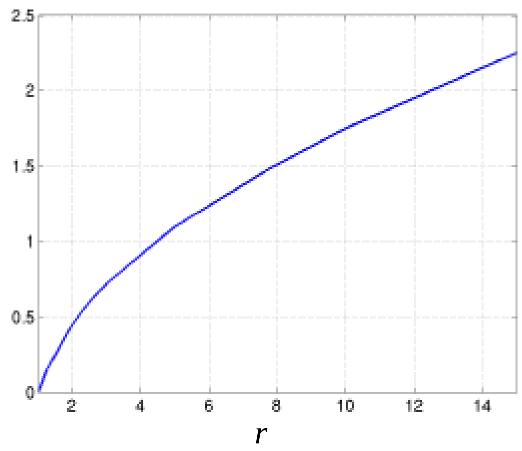
Tables of typical values of P_{base} at 1550 nm for different bandwidths

Bandwidth over which P_{base} is defined	P_{base} *(dBm)*
2.5 GHz	-54.9 dBm
10 GHz	-48.9 dBm
40 GHz	-42.9 dBm
0.1 nm	-47.9 dBm
0.5 nm	-40.9 dBm

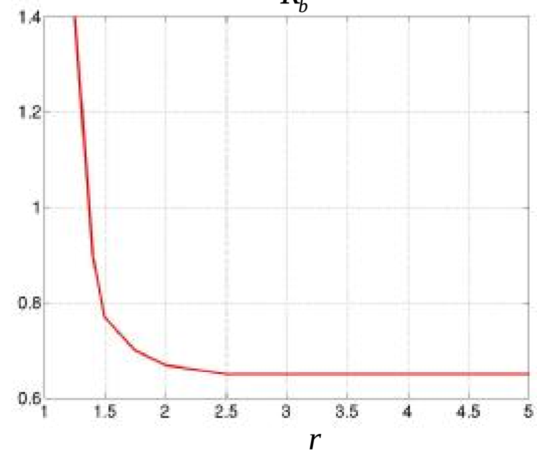
The Bit Error Rate: $P(e) \cong \dfrac{1}{2} \mathrm{e}^{-0.98 \cdot OSNR}$ (ideal matched optical filter+photodiode, the *OSNR* is defined over a bandwidth equal to the bit rate)

Ratio between the optical – 3dB filter bandwidth and the bit-rate: $r = \frac{B_{opt}}{R_B}$

OSNR penalty [dB]



$\frac{B_{elt,opt}}{R_b}$



Multi-Span, with In-line Optical Amplifiers

The Optical Signal-to-Noise Ratio OSNR, defined over a bandwidth equal to the bit rate:

$$OSNR = \frac{\bar{P}_{TX}}{2N_{span} \cdot N_0 \cdot R_B}, \quad OSNR\big|_{dB} \cong \bar{P}^{out}_{signal}\Big|_{dBm} - a_{span} - 10\log_{10} N_{span} - F_{EDFA}\big|_{dB} - P_{base}\big|_{dBm}$$

Propagation in Optical Fibers

Group delay: $t_g = \frac{L}{n_g}$; Group velocity: $n_g = \frac{c}{n_g}$, $n_g = 1.5$

The dispersion parameter D: $D \hat{=} \frac{d}{dl}\left(t_g\right)\Big|_{over\,1Km}$ $\left[\frac{\text{ps}}{\text{nm}\cdot\text{km}}\right]$

Relative delay: $\Delta_{delay} = D \cdot L \cdot \Delta l$

Accumulated delay over different pieces of fibers:

$$\Delta_{delay,tot} = \Delta_{delay,1} + \Delta_{delay,2} \quad = \left(D_1 \cdot L_1 + D_2 \cdot L_2\right) \cdot \Delta l$$

The dispersion parameter β2: $b_2 = \frac{d}{dw}\left(t_g\right)\Big|_{over\,1Km}$ $\left[\frac{\text{ps}^2}{\text{km}}\right]$

Relative delay: $\Delta_{delay} = L \cdot \left|b_2\right| \cdot \Delta w = L \cdot \left|b_2\right| \cdot 2p \cdot \Delta f$

Dispersion parameters β2 and D: $D = -\frac{2p\,c}{l^2} b_2$

Higher Order Dispersion: $S = \frac{dD}{dl}$ $\left[\frac{\text{ps}}{\text{nm}^2\cdot\text{km}}\right]$, $b_3 = \frac{db_2}{dw}$ $\left[\frac{\text{ps}^3}{\text{km}}\right]$

Dispersion limits

Case #1: large spectrum optical sources, D≠0

$$\left(B_r \cdot L\right)_{\max} \le \frac{1}{2\left|D\right|\Delta l_{opt}}$$

Case #2: large spectrum optical sources, D=0

$$\left(B_r \cdot L\right)_{\max} \le \frac{1}{\left|S\right|(\Delta l_{opt})^2\sqrt{8}}$$

Case #3: external modulation, D≠0

$$\left(B_r^2 L\right)_{\max} \le \frac{1}{8\left|b_2\right|}$$

Case #4: external modulation, D=0

$$\left(B_r^3 L\right)_{\max} \le \frac{\left(0.324\right)^3}{\left|b_3\right|}$$