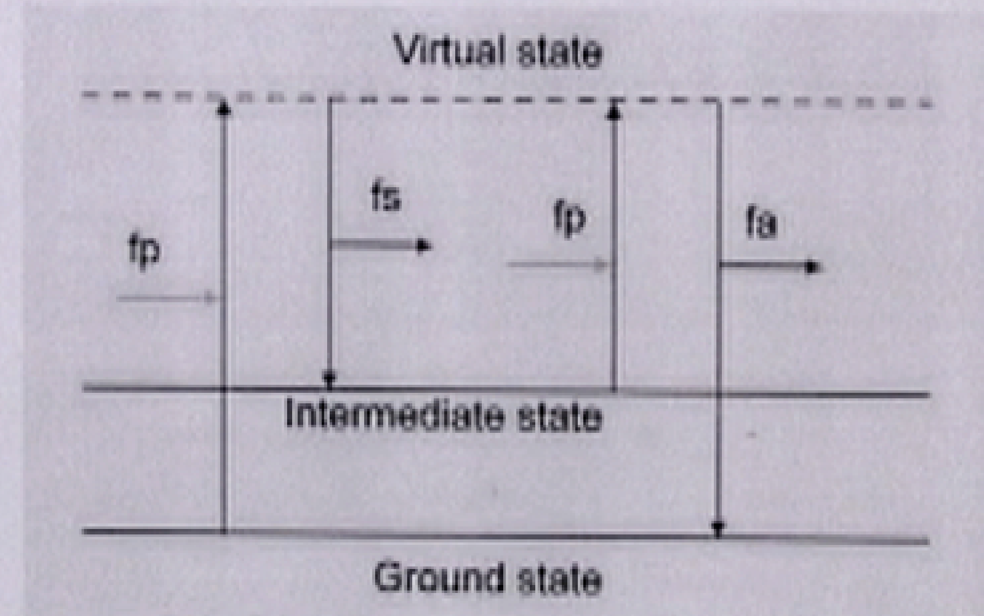
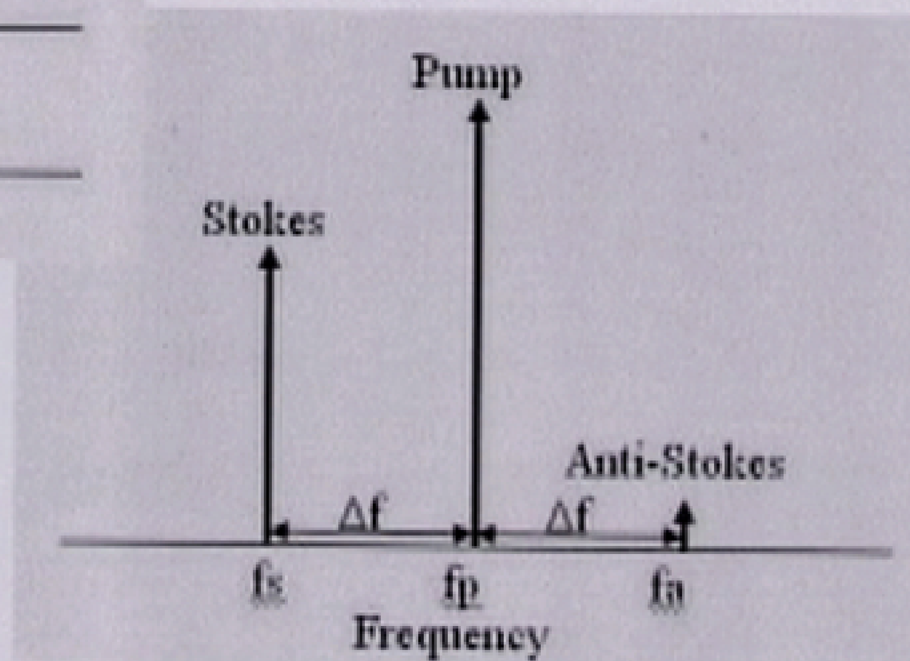
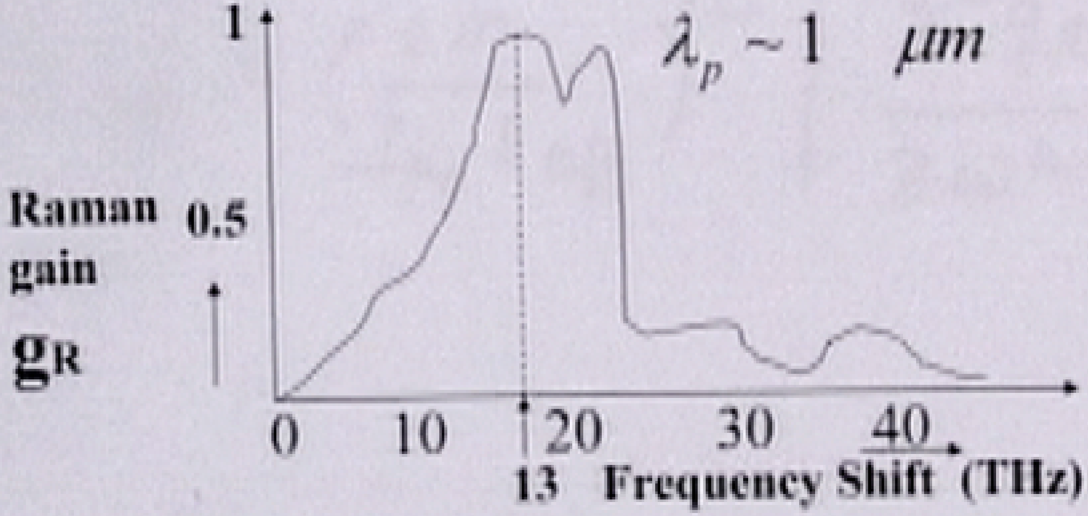
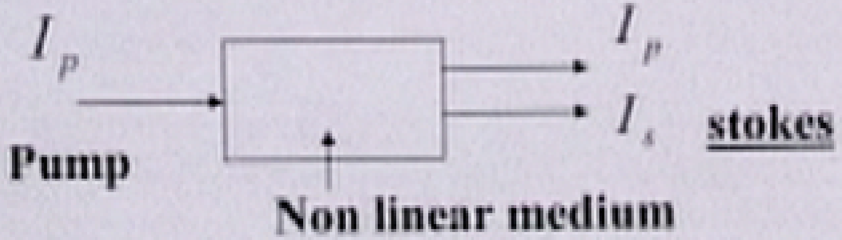
# Raman Scattering



# Raman Gain Profile



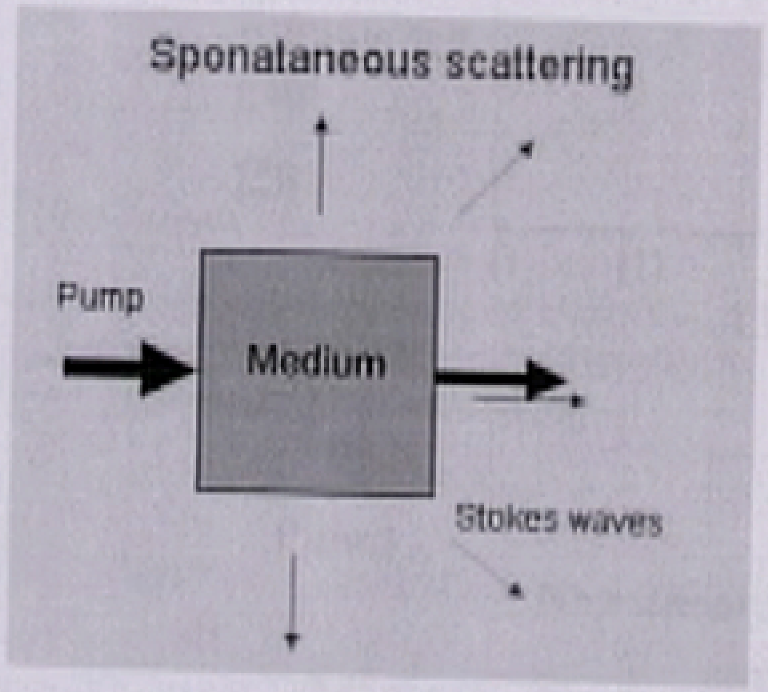



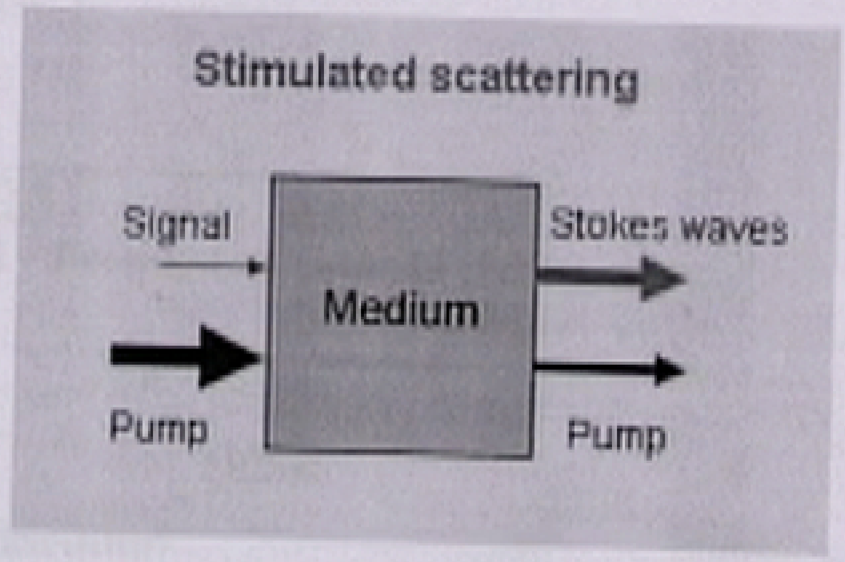

$$\frac{dI_s}{dz} = g_R I_p I_s$$

$I_s$ grows exponentially

- **Fiber Raman Laser**
- **Fiber Raman Amplifier**

# Spontaneous and Stimulated Scattering



Pump : $I_p$ , $\omega_p$ — Loss $\alpha_p$

Signal : $I_s$ , $\omega_s$ — $\alpha_s$

$$\frac{dI_s}{dz} = g_R I_p I_s - \alpha_s I_s$$

$$\frac{dI_p}{dz} = -\underbrace{\frac{\omega_p}{\omega_s}}_{\text{conservation of photons}} g_R I_p I_s - \alpha_s I_p$$

$$\frac{d}{dz}\left\{ \frac{I_p}{\omega_p} + \frac{I_s}{\omega_s} \right\} = 0$$

Pump depletion is neglected

$$I_p(z) = I_{p0}\, e^{-\alpha_p z}$$

<u>Signal</u>: $$\frac{dI_s}{dz} = g_R I_{p0} e^{-\alpha_p z} I_s - \alpha_s I_s$$

$$I_s(z) = I_s(0) \exp\{ g_R I_{p0} L_{eff} - \alpha_s z \}$$

where $L_{eff} = (1 - e^{-\alpha_p z})/\alpha_p$.

Total Stoke's power

$$P_s(z) = \int_{-\infty}^{\infty} \hbar\omega \{ g_R(\Omega) I_{p0} L_{eff} - \alpha_s z \} d\omega$$

↑ Relative freq $(\omega_p - \omega)$

Effective Bandwidth

$$B_{eff} = \left(\frac{2\pi}{I_{p_0} L_{eff}}\right)^{1/2} \left| \frac{\partial^2 g_R}{\partial \omega^2} \right|^{1/2}_{\omega = \omega_0}$$

Input power $P_{s0} = \hbar \omega_s \cdot B_{eff}$

Output power

$$P_s(z) = P_{s0} \exp\left\{ g_R(\Omega) I_{p_0} L_{eff} - \alpha_s z \right\}$$

Raman Threshold :

$$P_s(z) = P_p(z) = P_{p0} e^{-\alpha_p z}$$

$P_{p0} \leftarrow I_{p0} \cdot A_{eff}$ Eff. fiber area.

Assume that $\alpha_p \approx \alpha_s$

$$P_{s0} \exp\{ g_R(-\Omega) P_{p0} L_{eff}/A_{eff} \} = P_{p0}$$

$$\frac{g_R P_{p0}^{th} L_{eff}}{A_{eff}} \approx 16$$

$L_{eff} \approx \frac{1}{\alpha_p} \longrightarrow 20\ Km$

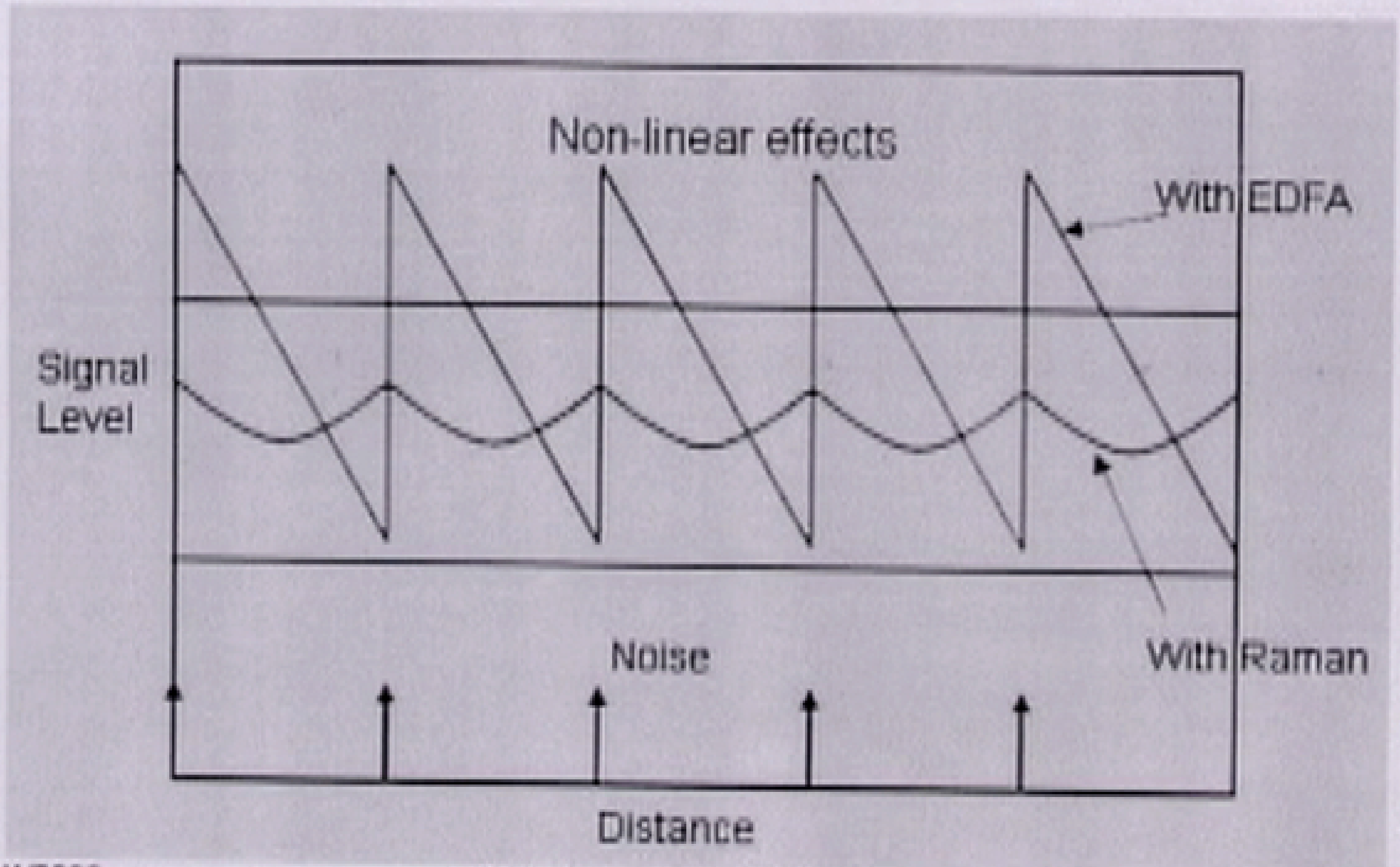
$\alpha_p \leftarrow 0.2\ dB/km$

$g_R \sim 10^{-13}$ at $\lambda_p = 1\ \mu m$

$A_{eff} \approx 50\ \mu m^2$

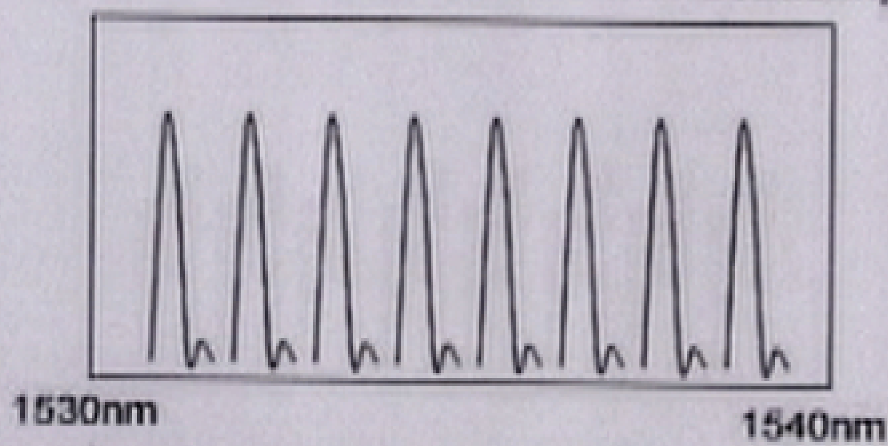
$\Rightarrow \quad P_{p0}^{th} \approx 600\ mW.$

# Signal Levels on a Long Haul Link With EDFA and SRA

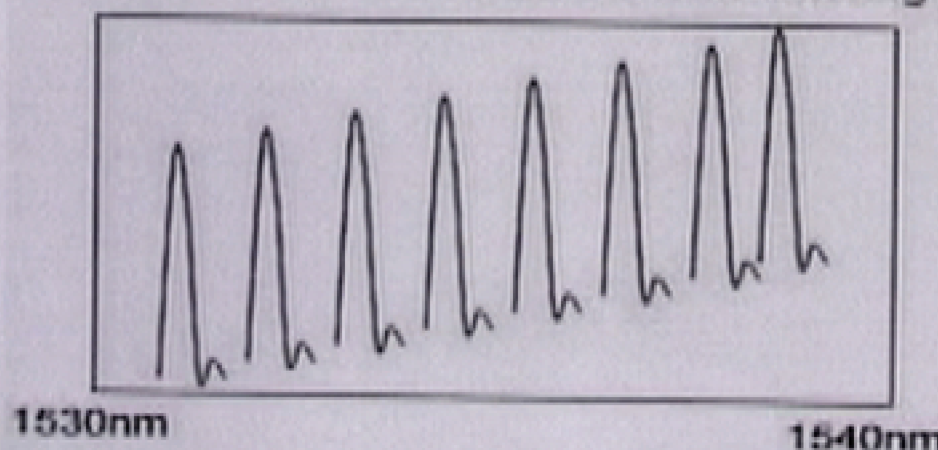


# Cross-Talk in SRA

WDM Channels with out Raman Scattering




WDM Channels with Raman Scattering



# Power Penalty Due to SRS

N: Number of equally spaced DWDM channels

$\Delta\lambda$: Spectral separation between DWDM channels = 0.8 nm

$\Delta\lambda_R$: Raman gain BW ~ 125 nm

$g_R$: Raman gain coefficient = $6 \times 10^{-14}$ m/W

Power Coupled from 0th to ith channel

$$P_o(i) = g_R \frac{i\Delta\lambda}{\Delta\lambda_R} \frac{PL_{eff}}{2A_{eff}}$$

Total Power Reduction in 0th channel

$$P_o = \sum_{1}^{N-1} P_o(i) = g_R \frac{i\Delta\lambda}{\Delta\lambda_R} \frac{PL_{eff}}{2A_{eff}} \frac{N(N-1)}{2}$$

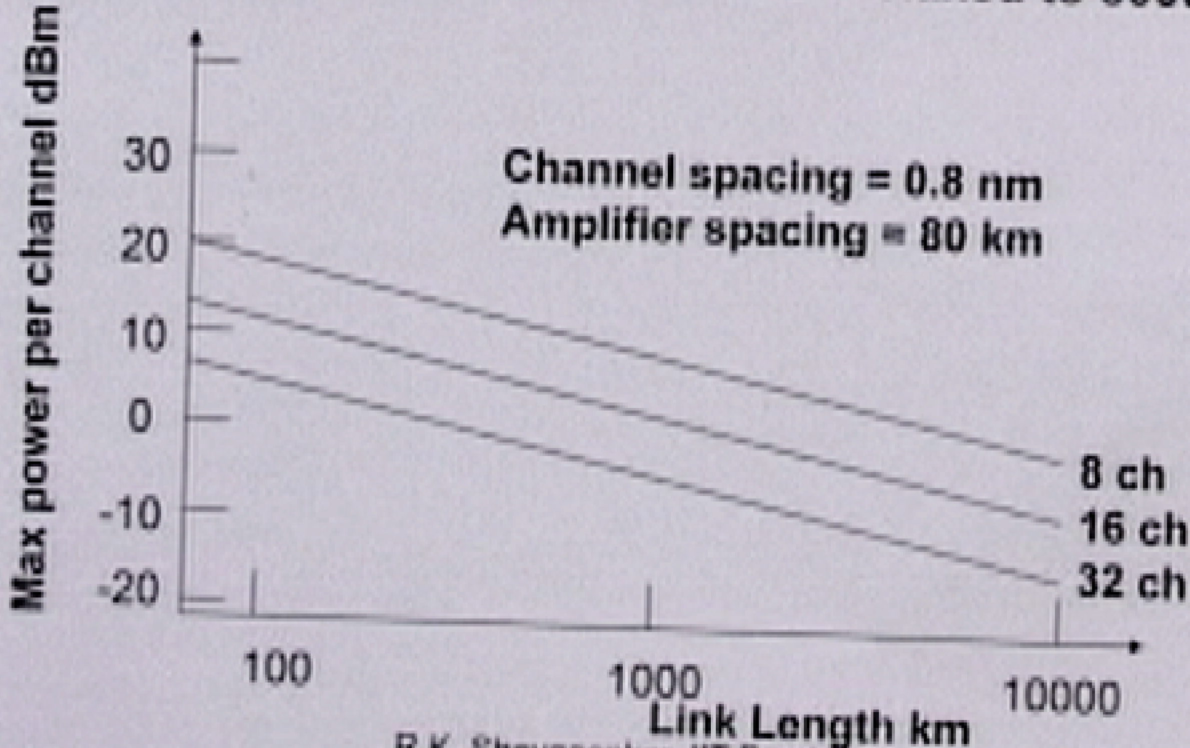
Power Penalty $\delta = -10 \log(1 - P_o)$

# Contd.

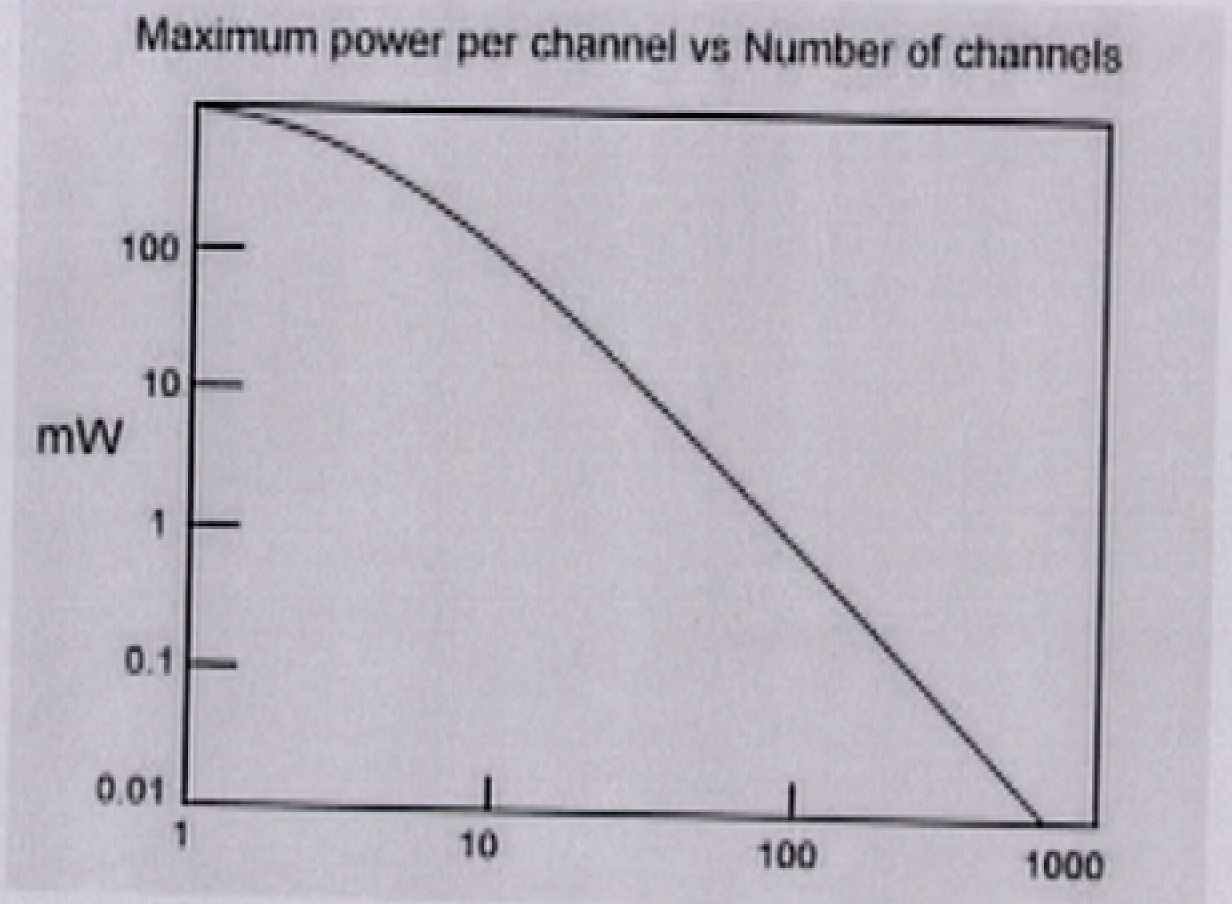
For $\delta < 0.5$ dB, $P_\Omega < 0.1$ i.e.,

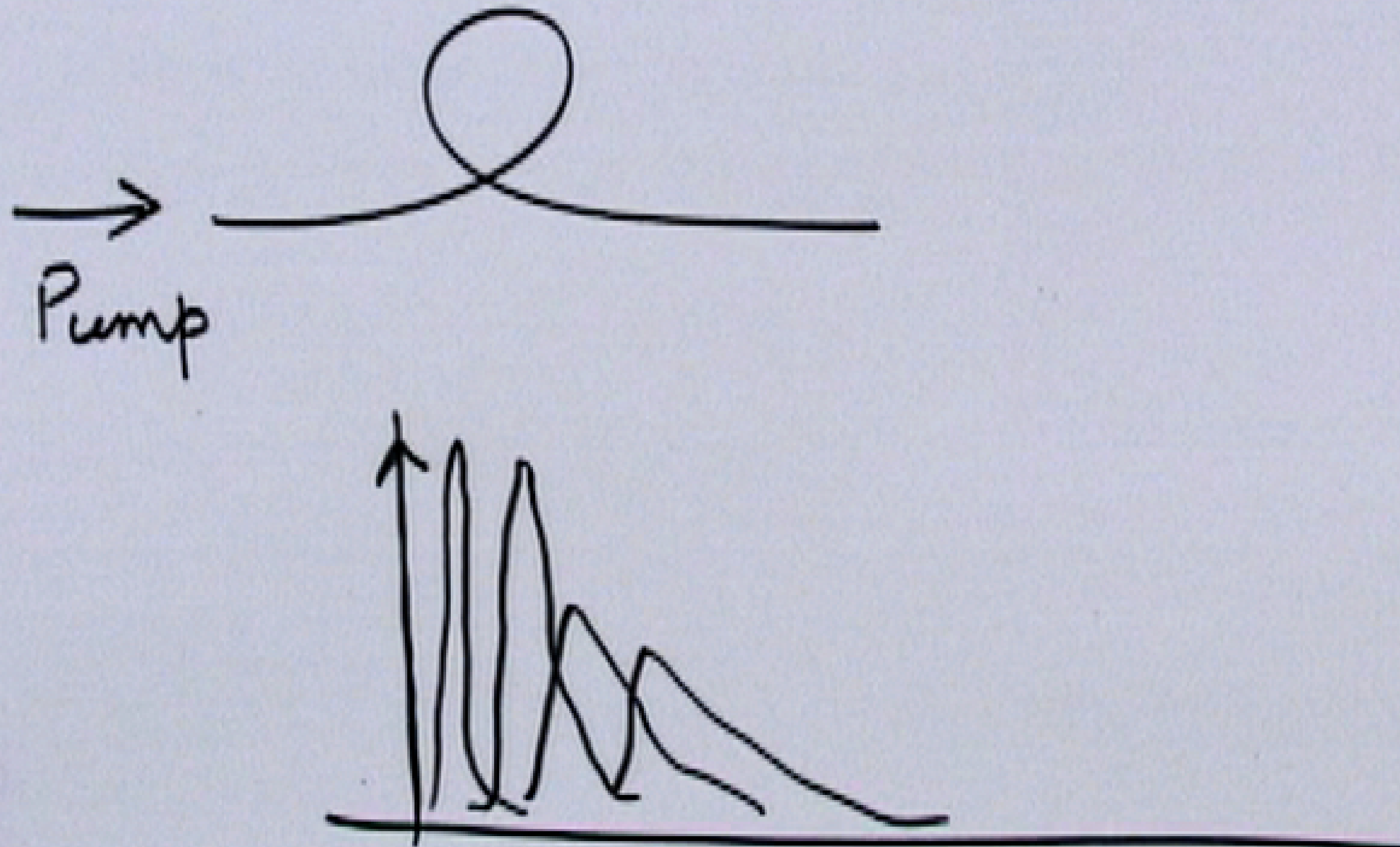
$$N\,P\,(N-1)\,\Delta\lambda\,L_{eff} \;<\; 40000 \text{ mW-nm-km}$$

**With chromatic dispersion present, it can be relaxed to 80000 mW-nm-km**



# Power vs Number of Channels




Pump