Raman Effect in Multi-Wavelength Optical Communication Systems

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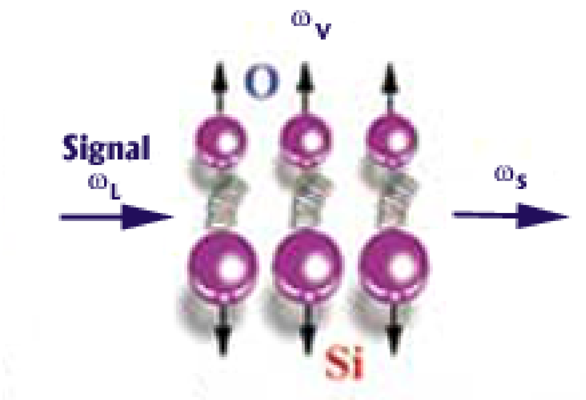
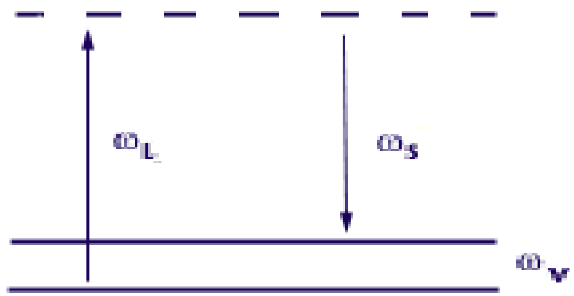
Spontaneous Raman Scattering





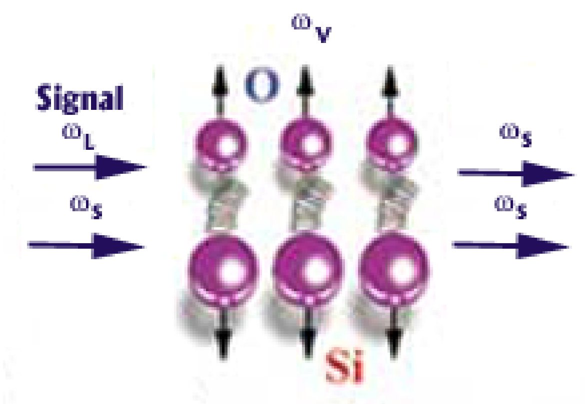
- Absorbs a energy photon

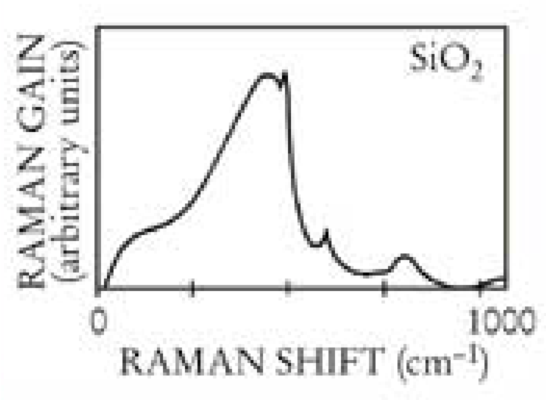
- suffers a transition to a intermediate state

- A lower energy photon is emitted.

Stimulated Raman Scattering

•The incident field is subject to a scattering process and is partially deflected to a lower frequency, leading to optical gain

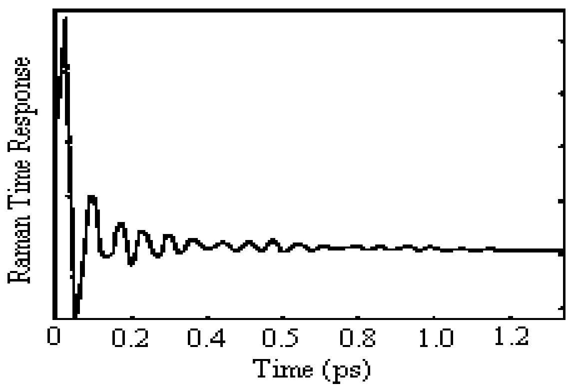




$$h_R(t) = \frac{\tau_1^2 + \tau_2^2}{\tau_1 \cdot \tau_2^2} \cdot \exp(-t/\tau_2) \cdot \sin(t/\tau_1)$$

$$\tau_1 = 12.2\ \text{fs} \quad \text{and} \quad \tau_2 = 32\ \text{fs}$$

G. Agrawal, Nonlinear Fiber Optics



Temporal variation of the Raman response function

Raman Effect in WDM Systems

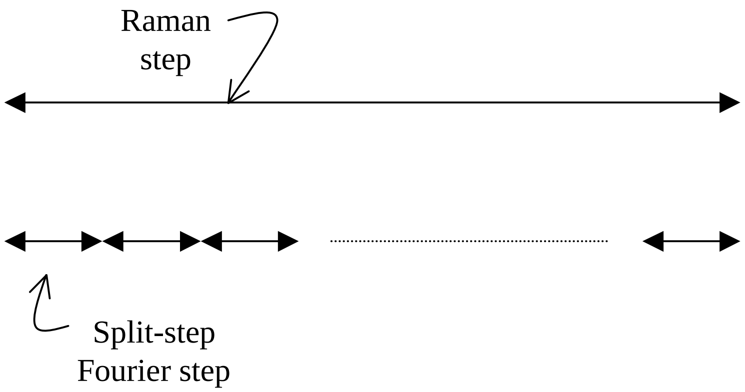
- Channel with lowest wavelength pumps channel with higher one
- Allows optical amplification
- Can limit the performance of a WDM system since it induces inter-channel modulation

$$\frac{d\tilde{A}_i}{dz} = -\frac{\alpha_i}{2}\tilde{A}_i - \frac{1}{2}\sum_{m\neq i}\tilde{A}_i\left|\tilde{A}_m\right|^2 g(f_i, f_m) \qquad \text{where} \qquad g(f_i, f_k) = 2f_r\gamma\,\mathrm{Im}(H(f_i - f_k))$$

$$\frac{\partial A_k}{\partial z} = -\frac{i}{2}\beta_2\frac{\partial^2 A_k}{\partial t^2} - \frac{\alpha}{2}A_k + i\gamma\left|A_k\right|^2 A_k$$

Raman Effect in WDM Systems

Split-step Fourier and 4th order Runge-kutta



$$\frac{d\tilde{A}_i}{dz} = -\frac{\alpha_i}{2}\tilde{A}_i - \frac{1}{2}\sum_{m\neq i}\tilde{A}_i\left|\tilde{A}_m\right|^2 g(f_i, f_m)$$

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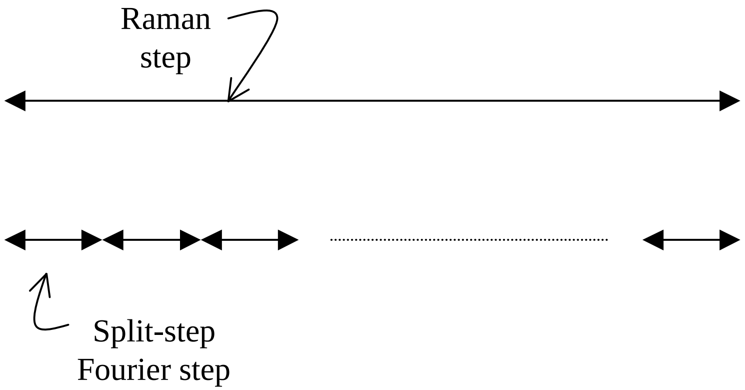
- One channel in time domain
- N channels in frequency domain

Raman Effect in WDM Systems

Split-step Fourier and 4th order Runge-kutta



$$\frac{d\tilde{A}_i}{dz} = -\frac{\alpha_i}{2}\tilde{A}_i - \frac{1}{2}\sum_{m \neq i}\tilde{A}_i\left|\tilde{A}_m\right|^2 g(f_i, f_m)$$

$$\frac{\partial A_k}{\partial z} = -\frac{i}{2}\beta_2\frac{\partial^2 A_k}{\partial t^2} - \frac{\alpha}{2}A_k + i\gamma\left|A_k\right|^2 A_k$$

$$\Downarrow$$

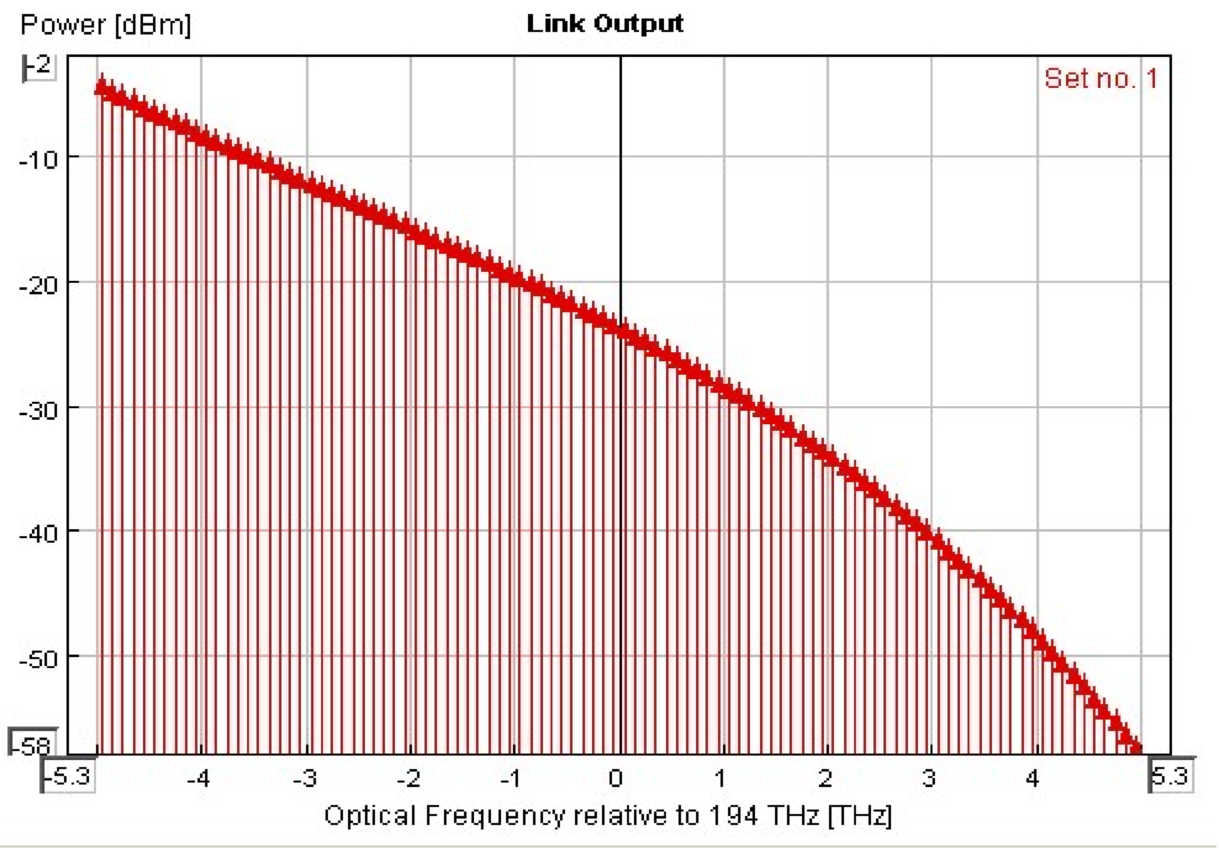
$$\frac{\partial A_k}{\partial z} = -\frac{i}{2}\beta_2\frac{\partial^2 A_k}{\partial t^2} - \left(\frac{\alpha}{2} + C\right)A_k + i\gamma\left|A_k\right|^2 A_k$$

$$C = f_r\gamma\sum_{m \neq k}\tilde{A}_k\left|\tilde{A}_m\right|^2 \operatorname{Im}\left(H(f_k - f_m)\right)$$

- Allows an analysis of the Raman effect in time domain
- Speeds simulation

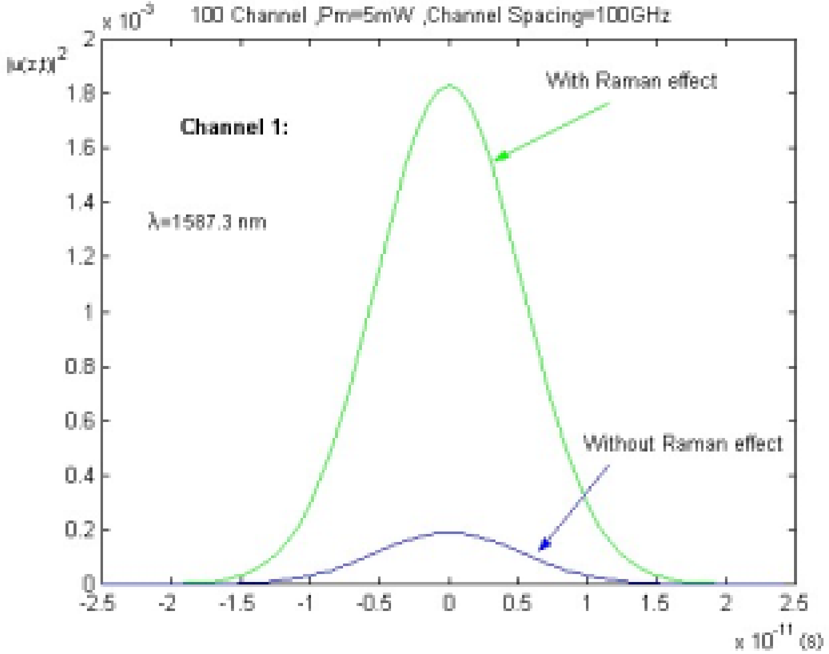
Raman Effect in WDM Systems: Results

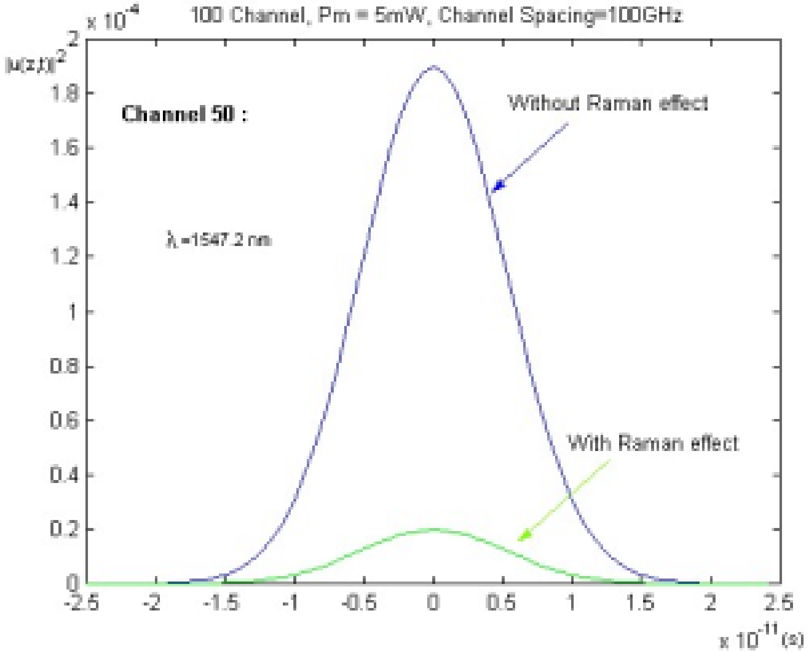
- **Inter-Channel**



Raman Effect in WDM Systems: Results

D=16 ps/nm/km





Conclusions

- **The Raman effect induces power fluctuation in WDM systems, which depends on**
    - Frequency spacing
    - Optical Power
    - Number of channels
- **This numerical algorithm allows the study of the Raman effect in hundred of channels DWDM systems**

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Thank You