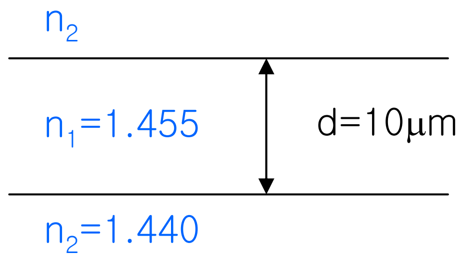
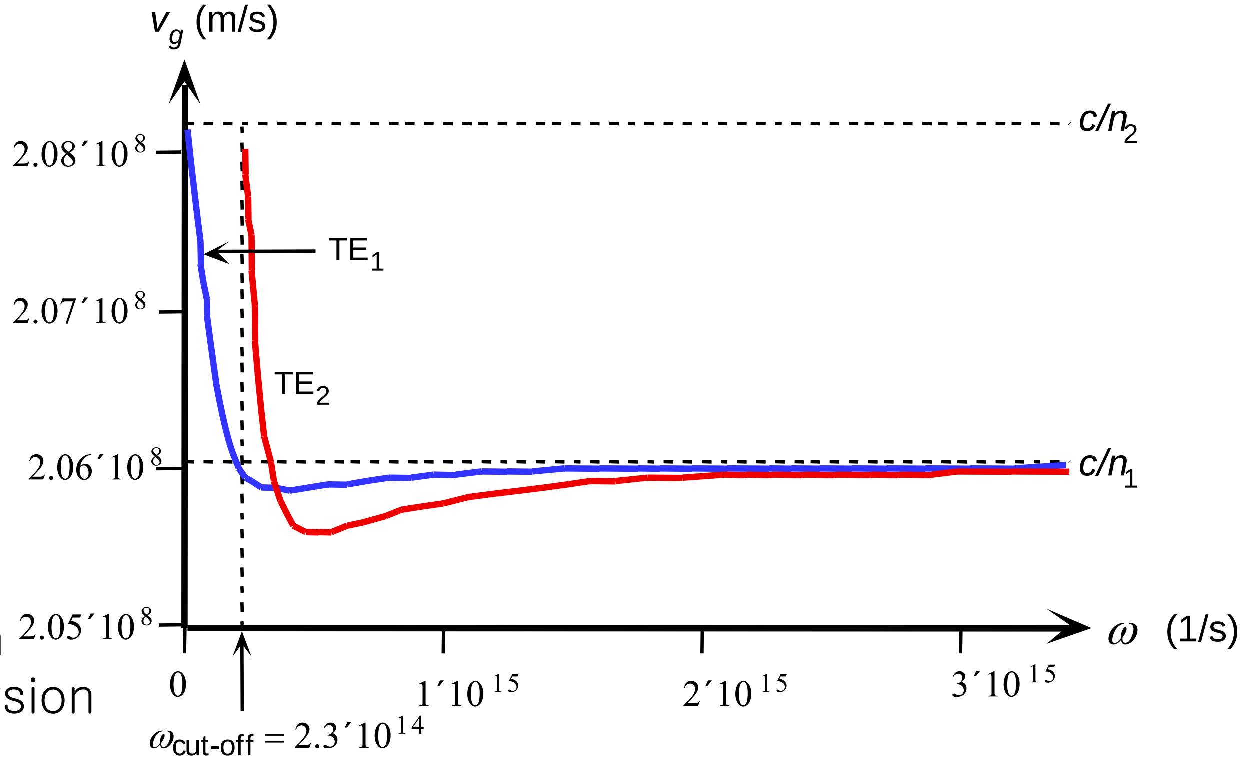
Lect. 14: Dispersion in Optical Fiber



Modal (or intermodal) dispersion:

Waveguide can support several modes having different values of v_g

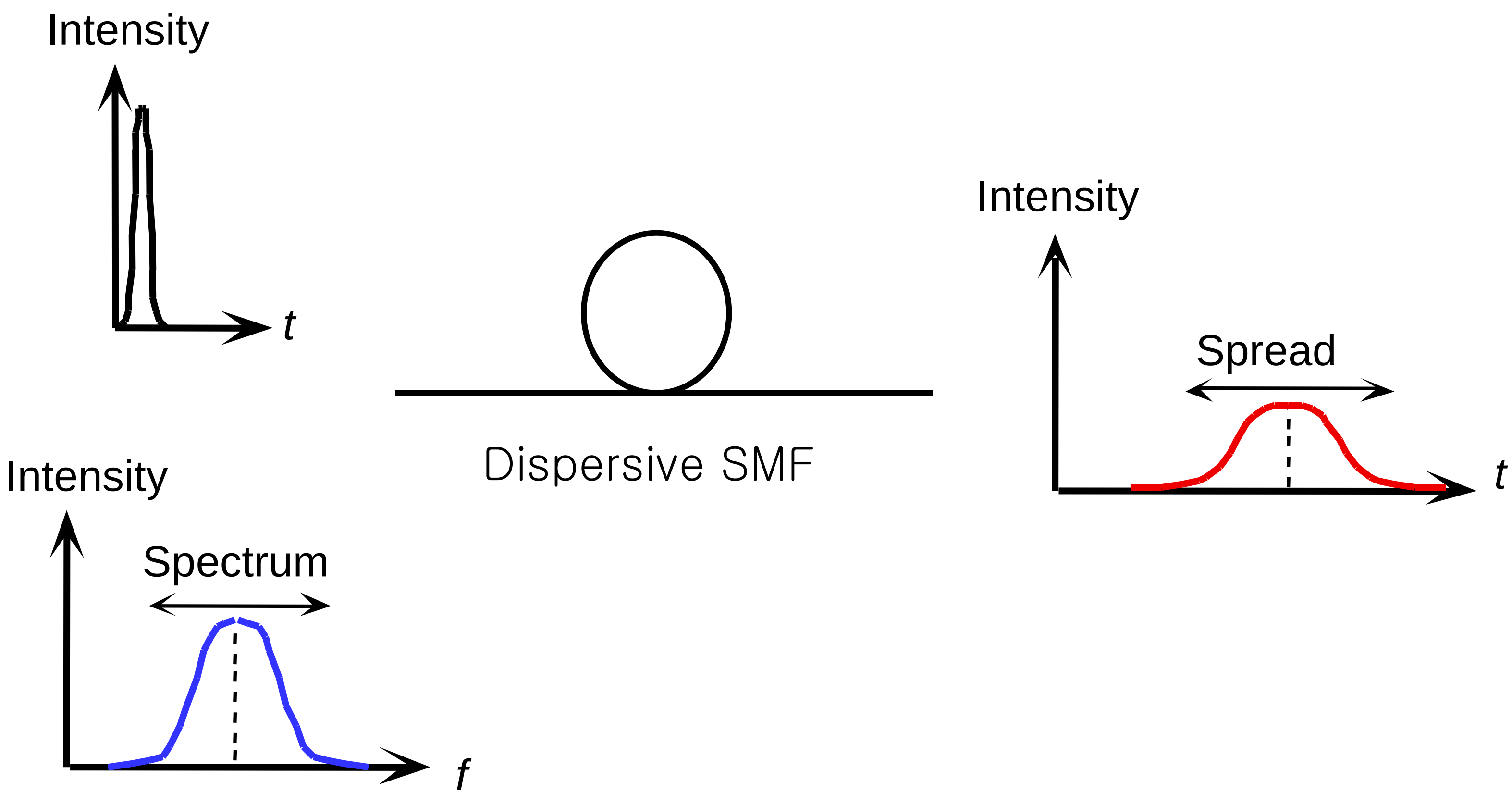
➔Solution: Use single mode waveguide



➔Group velocity depends on Frequency: intramodal dispersion

Lect. 14: Dispersion in Optical Fiber

Dispersion in single-mode waveguide:
Group velocity depends on frequency.
Limitation on data rate and transmission distance.



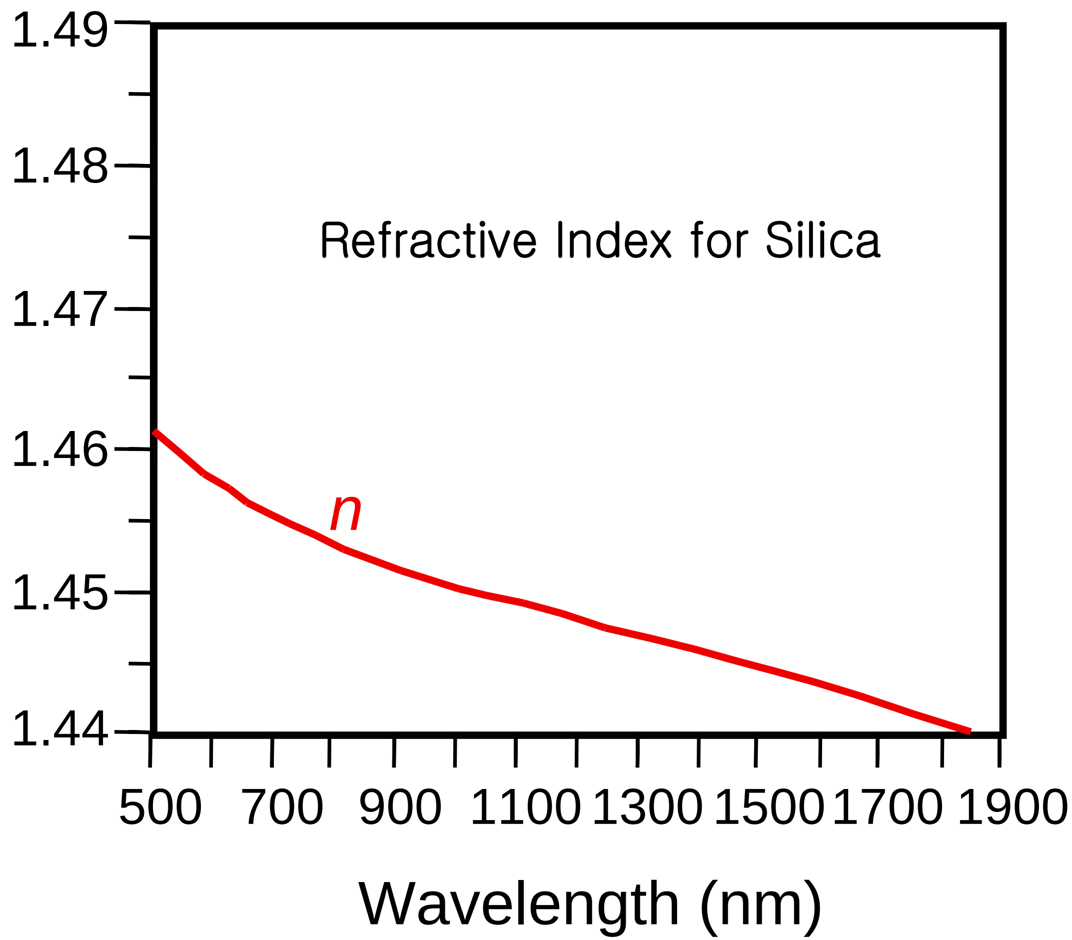
Lect. 14: Dispersion in Optical Fiber

Why does single mode waveguide have dispersion?

– Material (or chromatic) dispersion

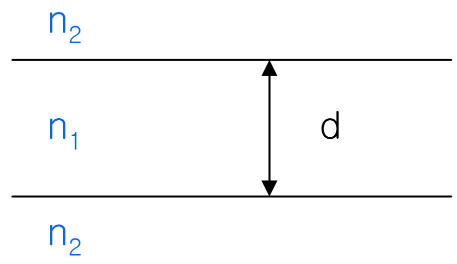
Refractive index of any material depends on frequency (wavelength)

➔ v_g depends on frequency (wavelength)



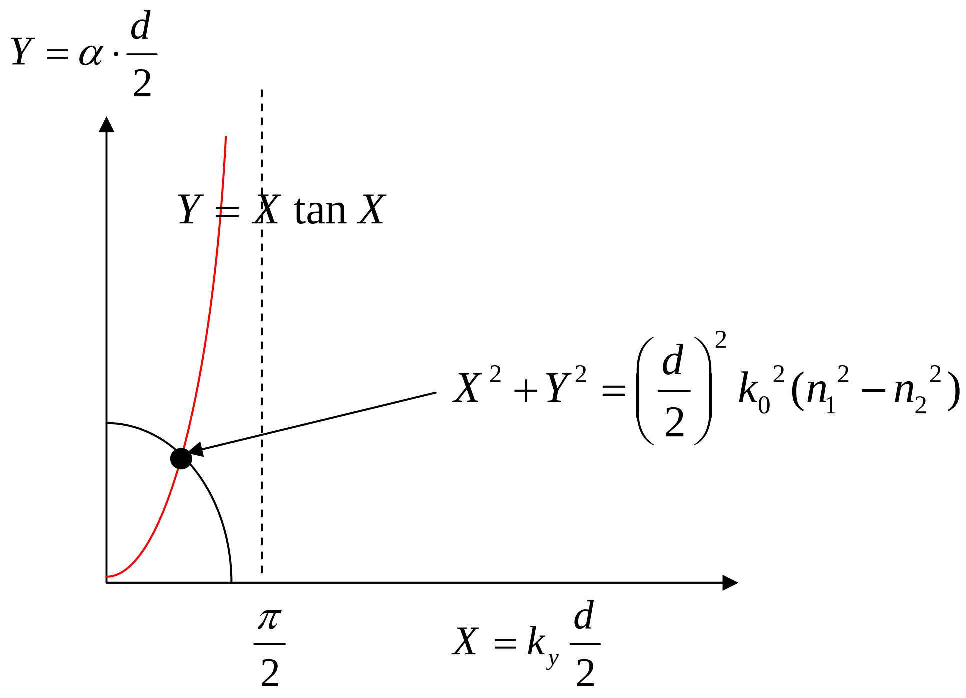
Lect. 14: Dispersion in Optical Fiber

Why does single mode waveguide have dispersion?



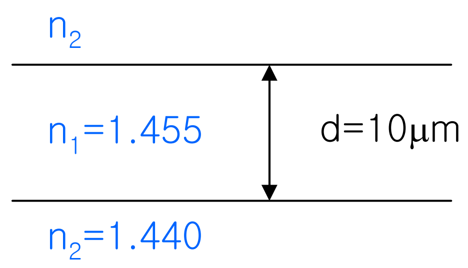
Waveguide dispersion

Even if refractive index does not change, v_g depends on frequency (wavelength)



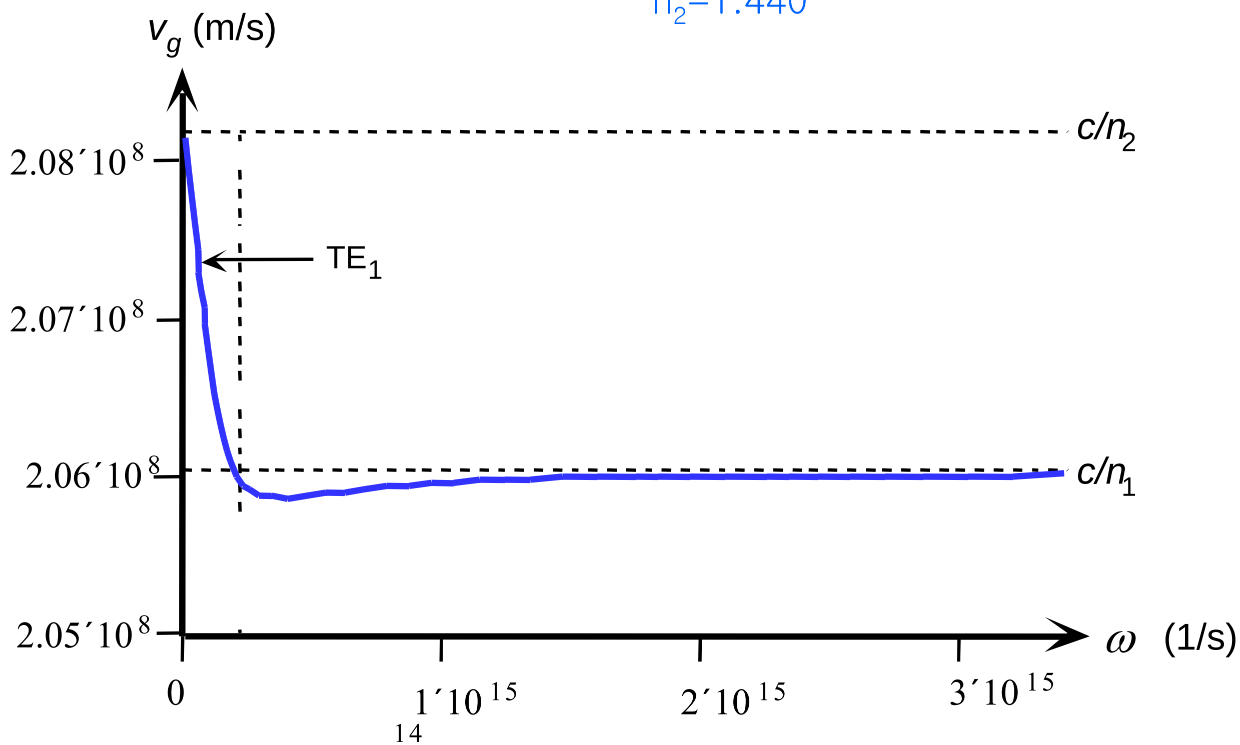
Lect. 14: Dispersion in Optical Fiber

Why does single mode waveguide have dispersion?



Waveguide dispersion

Even if refractive index does not change, v_g depends on frequency (wavelength)



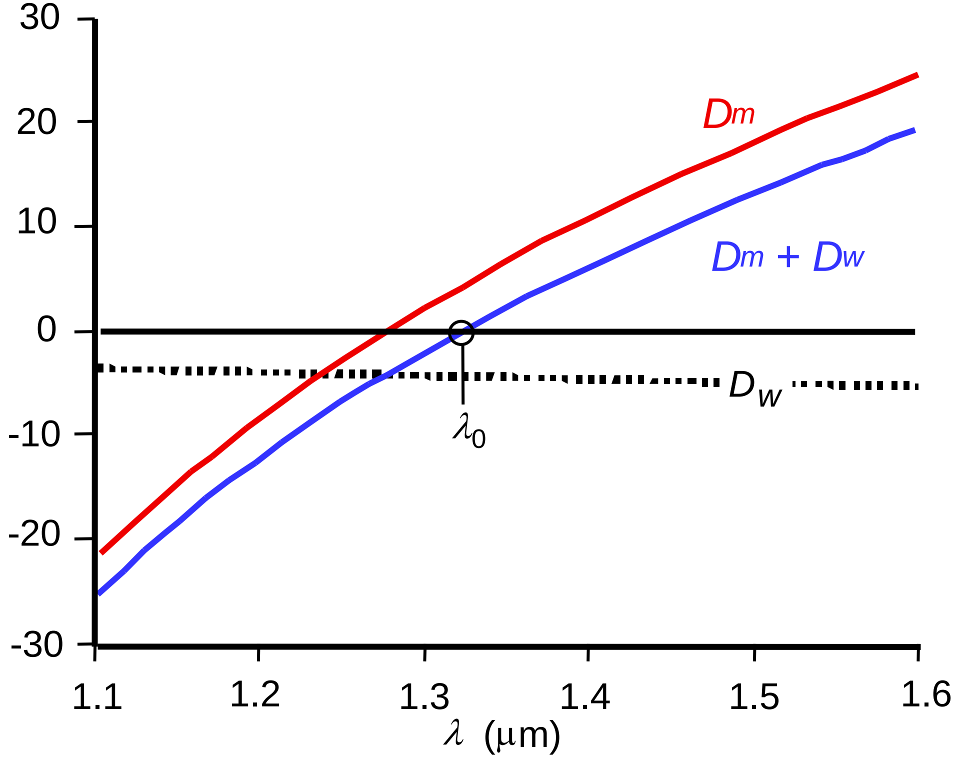
Lect. 14: Dispersion in Optical Fiber

Dispersion coefficient, D, for silica fiber with a=4.2μm

D_m: material (chromatic) dispersion only

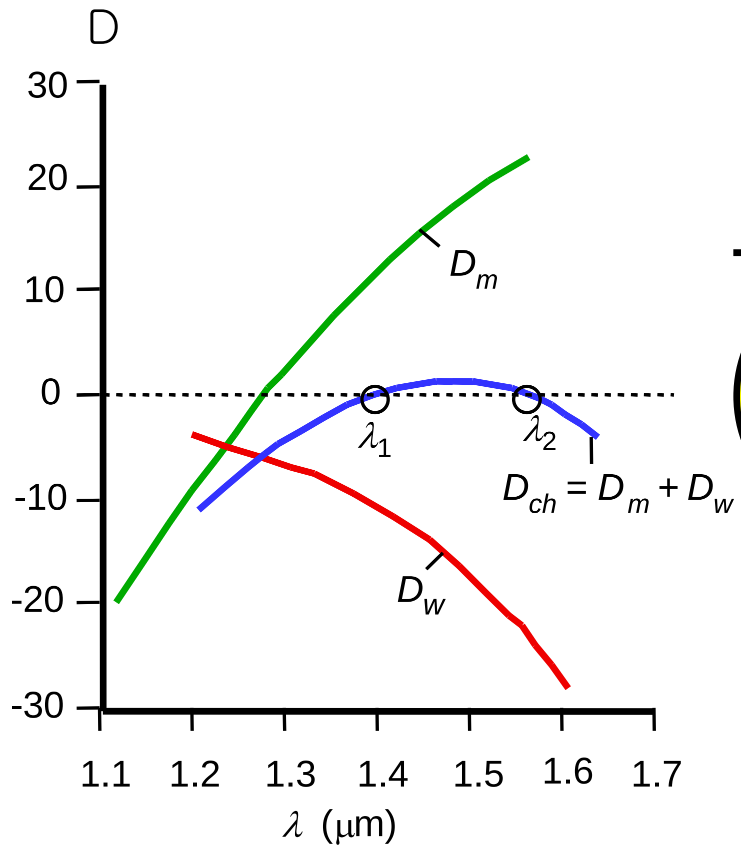
D_w: waveguide dispersion only

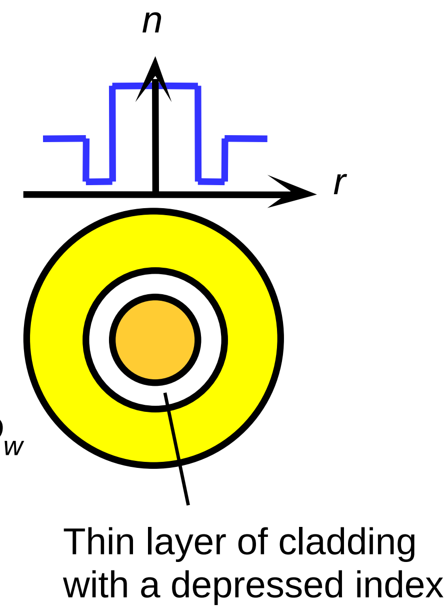
D_m+D_w: total dispersion



Lect. 14: Dispersion in Optical Fiber

It is possible to control D by changing waveguide structure
(Dispersion Flattened Fiber)





Lect. 14: Dispersion in Optical Fiber

How do we model dispersion

$$\beta(\omega_0+\omega)=\beta(\omega_0)+\left.\frac{\partial\beta}{\partial\omega}\right|_{\omega_0}\bullet\omega+\frac{1}{2}\left.\frac{\partial^2\beta}{\partial\omega^2}\right|_{\omega_0}\bullet\omega^2+\bullet\bullet\bullet$$

$$\simeq\beta(\omega_0)+\beta_1(\omega_0)\bullet\omega+\frac{1}{2}\beta_2(\omega_0)\bullet\omega^2$$

$$=\beta(\omega_0)+\frac{1}{v_g(\omega_0)}\bullet\omega+\frac{1}{2}\frac{\partial}{\partial\omega}\left.\left(\frac{1}{v_g}\right)\right|_{\omega_0}\bullet\omega^2$$

==> Dispersion exists if β is not not linear with ω

In Silica fiber, β_2 ~ –20 ps^2/km at λ=1.5μm

(With $\beta_2<0$, v_g increases as ω increases)

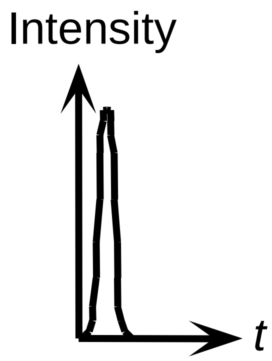
Lect. 14: Dispersion in Optical Fiber

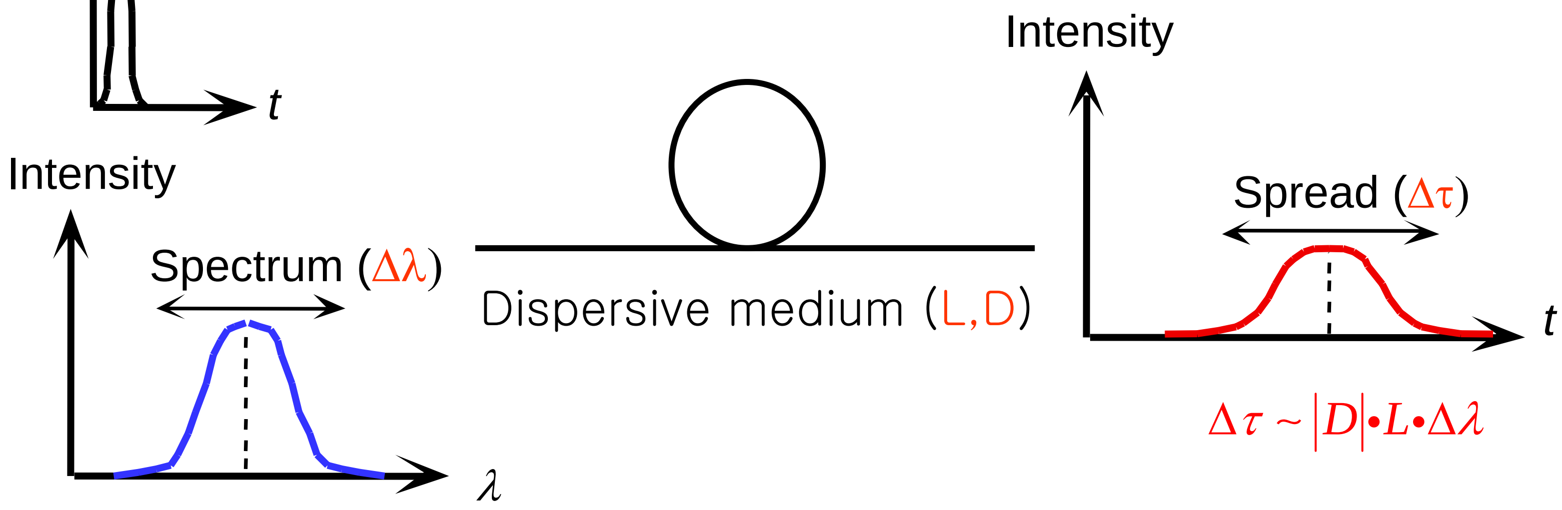
Often, dispersion parameter D is used.

$$D \triangleq \frac{\partial \beta_1}{\partial \lambda} = \frac{\partial \omega}{\partial \lambda}\frac{\partial \beta_1}{\partial \omega} = \frac{\partial \omega}{\partial \lambda}\beta_2$$

$$\text{Since } \omega = kc = \frac{2\pi}{\lambda}c, \ \ \frac{\partial \omega}{\partial \lambda} = -\frac{2\pi}{\lambda^2}c$$

$$\therefore D = -\frac{2\pi}{\lambda^2}c\beta_2 \ \left(\text{at } \lambda = 1.5\mu m, \ \text{D} \sim 16 \ \text{ps}/\text{km}\cdot\text{nm}\right)$$





$$\Delta\tau \sim |D| \cdot L \cdot \Delta\lambda$$

For λ_1 and λ_2 ($\Delta\lambda = \lambda_1$-$\lambda_2$),

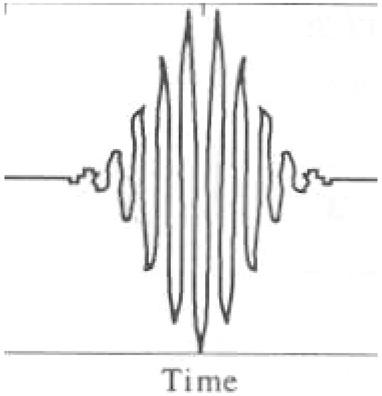
$$\tau_1 = \frac{L}{v_{g1}}, \ \ \tau_2 = \frac{L}{v_{g2}}$$

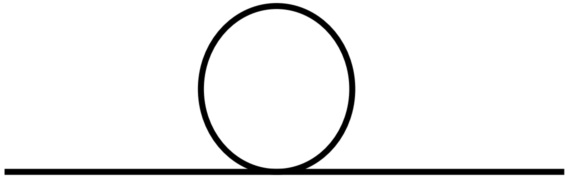
$$\therefore \Delta\tau (= \tau_1 - \tau_2) = L\left(\frac{1}{v_{g1}} - \frac{1}{v_{g2}}\right) = L\Delta\beta_1 = L\frac{\partial\beta_1}{\partial\lambda}\Delta\lambda = LD\Delta\lambda$$

Lect. 14: Dispersion in Optical Fiber

What happens to a short pulse in a dispersive medium?

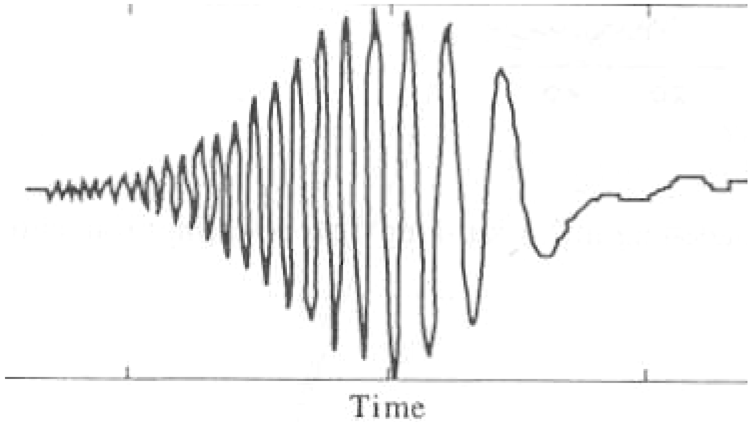
Gaussian input pulse





Dispersive medium
(D>0)

Dispersed pulse



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Exercises:

Prob. 8, 9, 10, 14