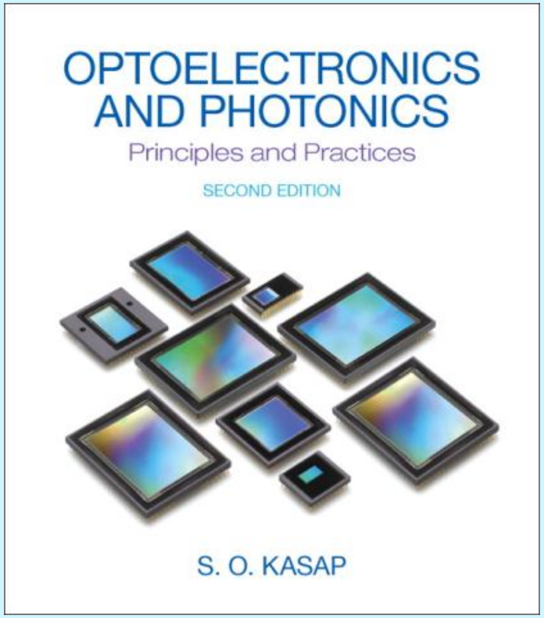
Student Supplement for *Optoelectronics and Photonics: Principles and Practices* Second Edition

A Complete Course in Power Point

Chapter 2



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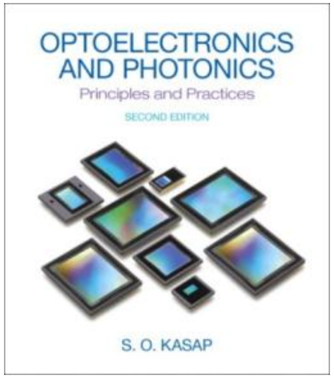

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Waveguide Condition

$$\left[\frac{2\pi n_1(2a)}{\lambda}\right]\cos\theta_m - \phi_m = m\pi$$

***m* = integer, n_1 = core refractive index, θ_m is the incidence angle, 2*a* is the core thickness. ϕ_m is the phase change upon TIR at the n_1/n_2 boundary**

Minimum θ_m and maximum *m* must still satisfy TIR

There are only a finite number of modes

Propagation along the guide for a mode *m* is

$$\beta_m = k_1\sin\theta_m = \left(\frac{2\pi n_1}{\lambda}\right)\sin\theta_m$$

Modes in a Planar Waveguide: Summary

$$\left[\frac{2\pi n_1(2a)}{\lambda}\right]\cos\theta_m - \phi_m = m\pi$$

Phase change upon TIR at n_1/n_2, and depends on θ_m

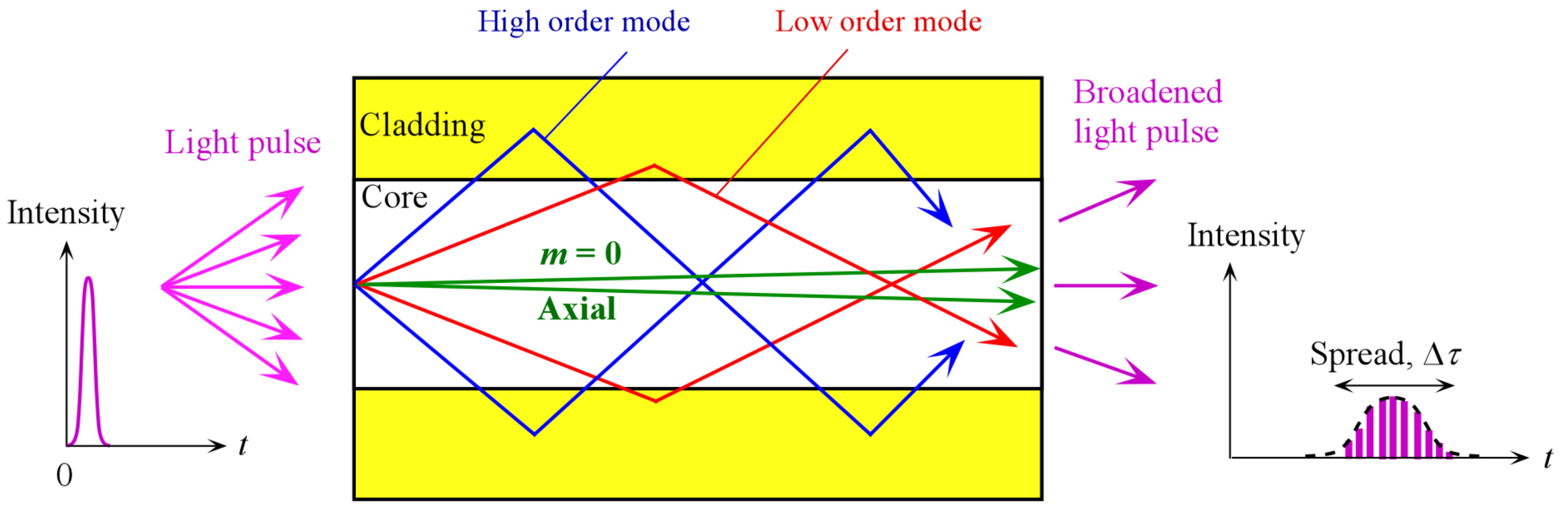
$$\beta_m = k_1 \sin\theta_m = \left(\frac{2\pi n_1}{\lambda}\right)\sin\theta_m$$

$$E(y,z,t) = E_m(y)\cos(\omega t - \beta_m z)$$

Traveling wave along z

Field pattern along y

Intermode (Intermodal or Modal) Dispersion



Schematic illustration of light propagation in a slab dielectric waveguide. Light pulse entering the waveguide breaks up into various modes which then propagate at different group velocities down the guide. At the end of the guide, the modes combine to constitute the output light pulse which is broader than the input light pulse.

Example on Waveguide Modes

Consider a planar dielectric guide with a core thickness 20 μm, n_1 = 1.455, n_2 = 1.440, light wavelength of 900 nm. Find the modes

TIR phase change ϕ_m for TE mode

$$\tan\left(\tfrac{1}{2}\phi_m\right) = \frac{\left[\sin^2\theta_m - \left(\dfrac{n_2}{n_1}\right)^2\right]^{1/2}}{\cos\theta_m}$$

TE mode

Waveguide condition

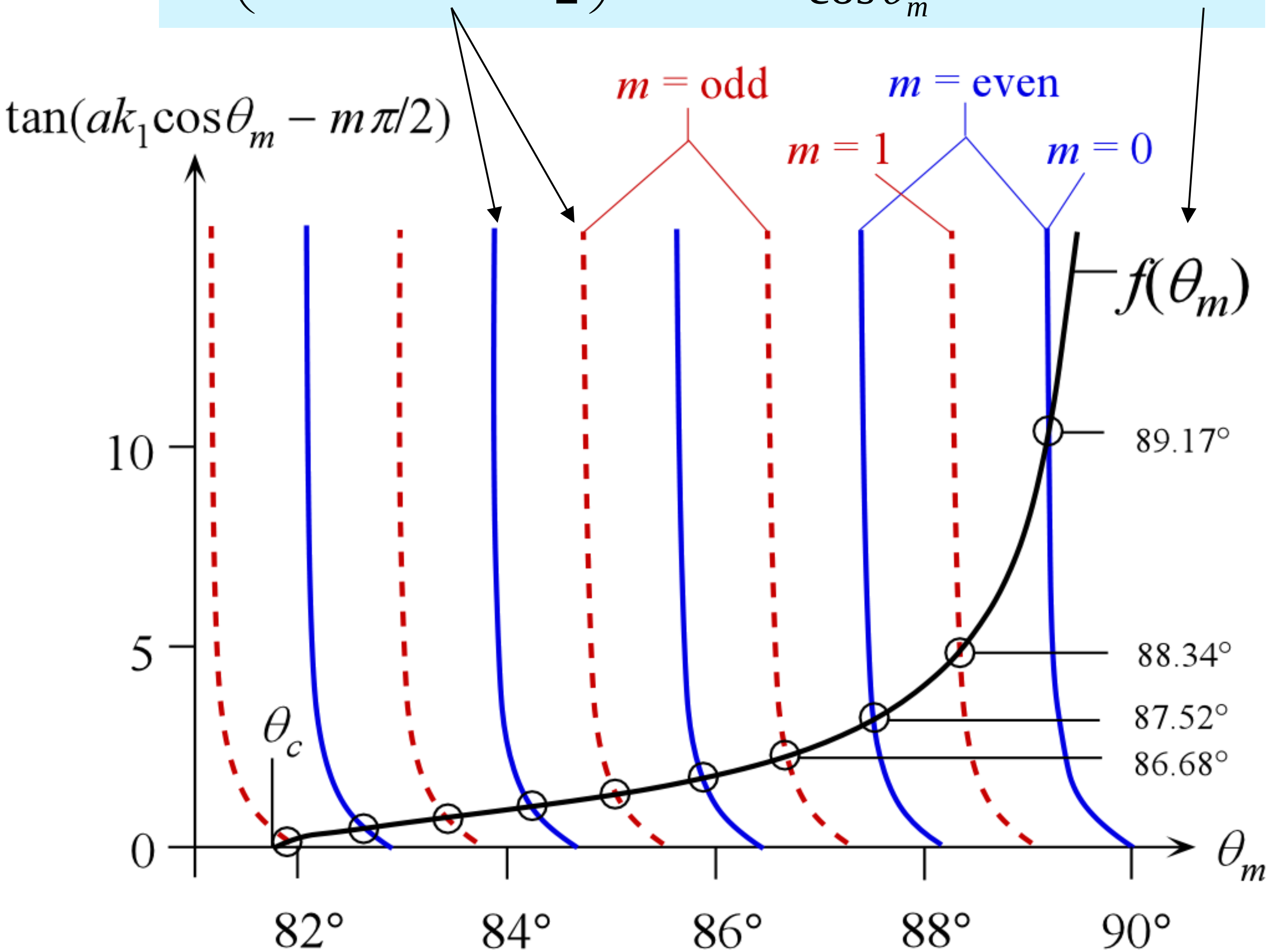
$$\left[\frac{2\pi n_1(2a)}{\lambda}\right]\cos\theta_m - \phi_m = m\pi$$

Waveguide condition

$$\phi_m = 2ak_1\cos\theta_m - m\pi$$

$$\tan\left(ak_1\cos\theta_m - m\frac{\pi}{2}\right) = \frac{\left[\sin^2\theta_m - \left(\frac{n_2}{n_1}\right)^2\right]^{1/2}}{\cos\theta_m} = f(\theta_m)$$

TE mode



$$\frac{1}{\delta_m} = \alpha_m = \frac{2\pi n_2 \left[\left(\frac{n_1}{n_2} \right)^2 \sin^2 \theta_m - 1 \right]^{1/2}}{\lambda}$$

Mode m, incidence angle θ_m and penetration δ_m for a planar dielectric waveguide with $d = 2a = 20$ μm, $n_1 = 1.455$, $n_2 = 1.440$

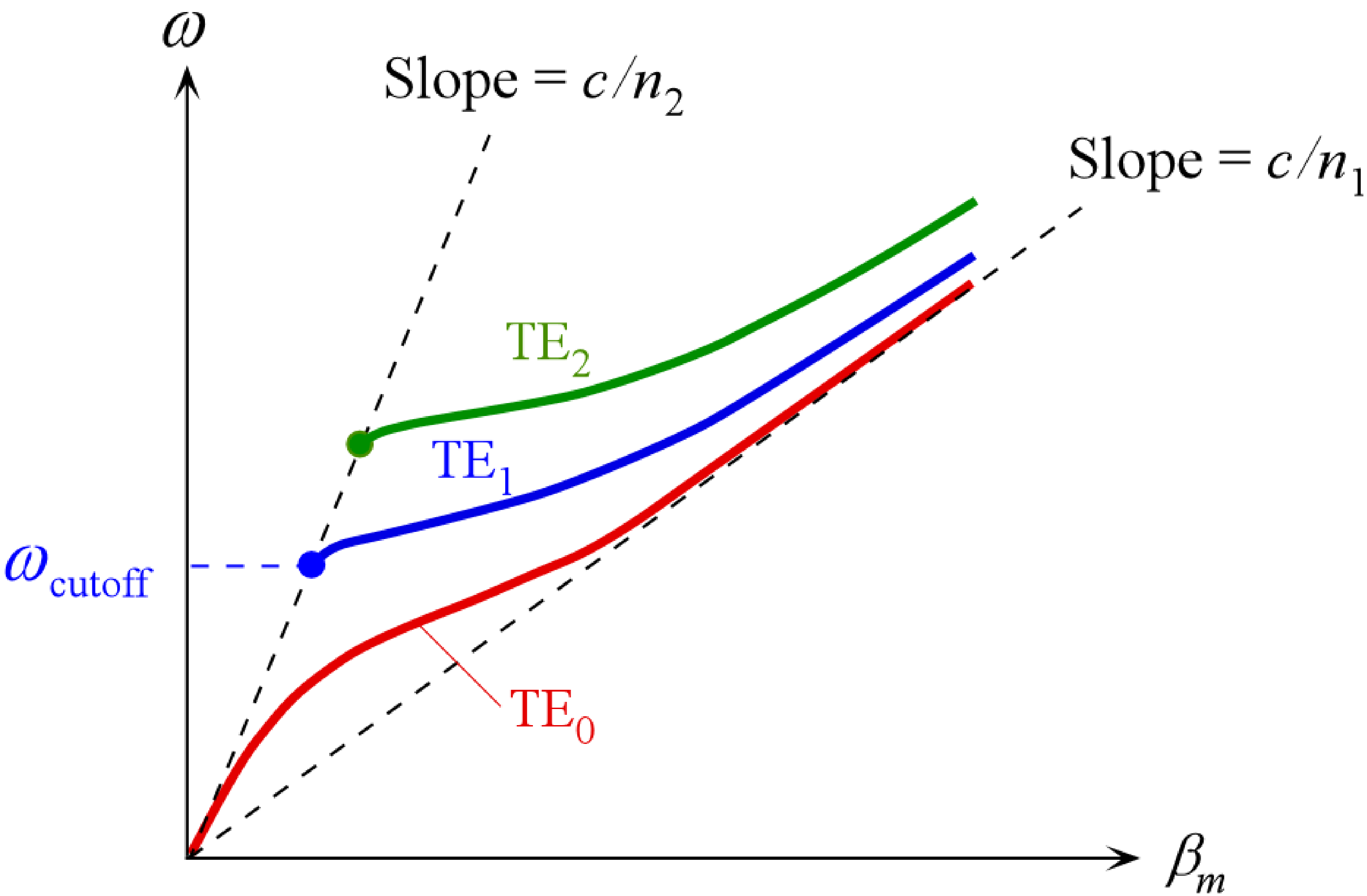
m	0	1	2	3	4	5	6	7	8	9
θ_m	89.2°	88.3°	87.5°	86.7°	85.9°	85.0°	84.2°	83.4°	82.6°	81.9°
δ_m (μm)	0.691	0.702	0.722	0.751	0.793	0.866	0.970	1.15	1.57	3.83

$m = 0$ Fundamental mode

Highest mode

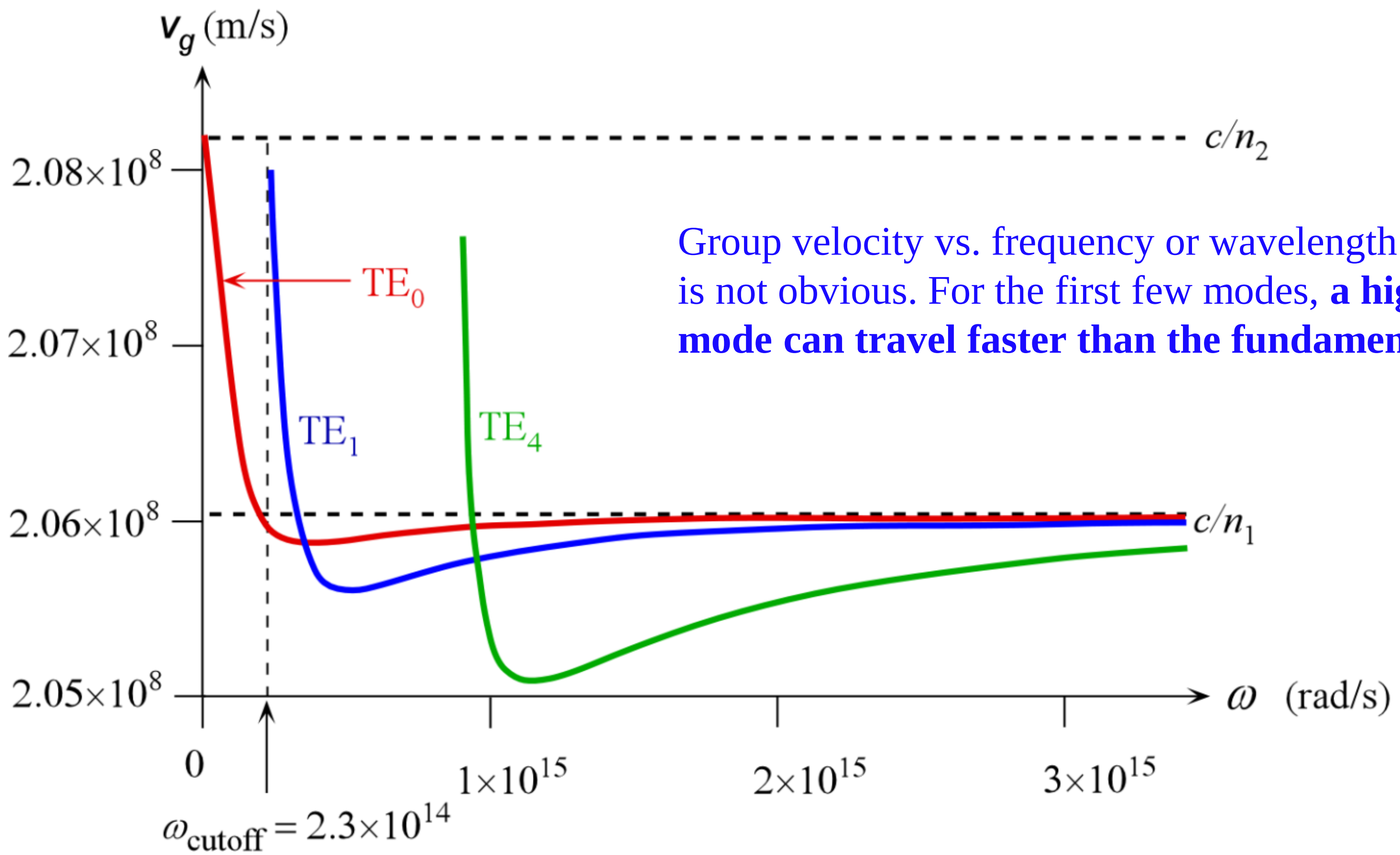
Critical angle $\theta_c = \arcsin(n_2/n_1) = 81.77°$

Waveguide Dispersion Curve



The slope of ω vs. β is the group velocity v_g

Mode Group Velocities from Dispersion Diagram

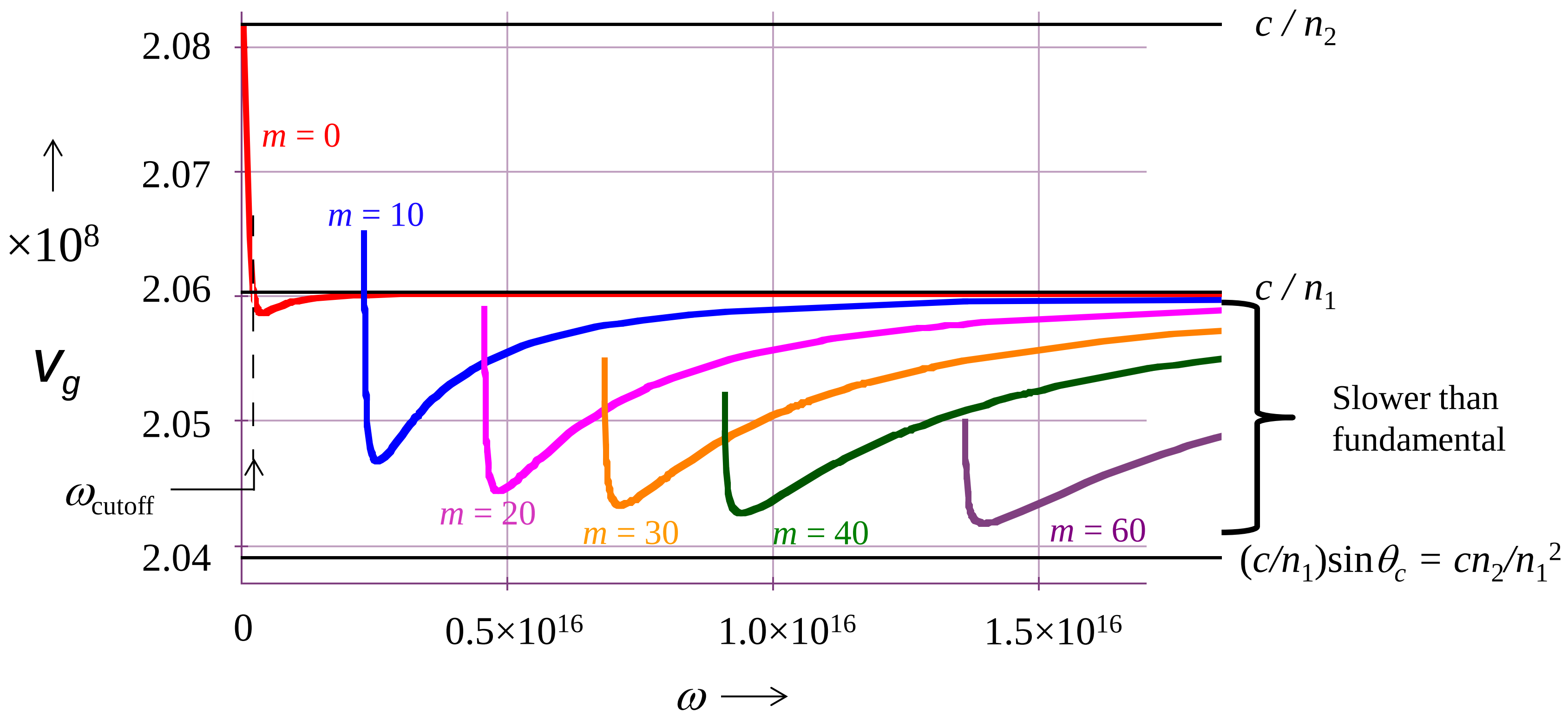


Group velocity vs. frequency or wavelength behavior is not obvious. For the first few modes, **a higher mode can travel faster than the fundamental**.

The group velocity v_g vs. ω for a planar dielectric guide with a core thickness ($2a$) = 20 μm, n_1 = 1.455, n_2 = 1.440. TE_0, TE_1 and TE_4

Not in the textbook

A Planar Dielectric Waveguide with Many Modes



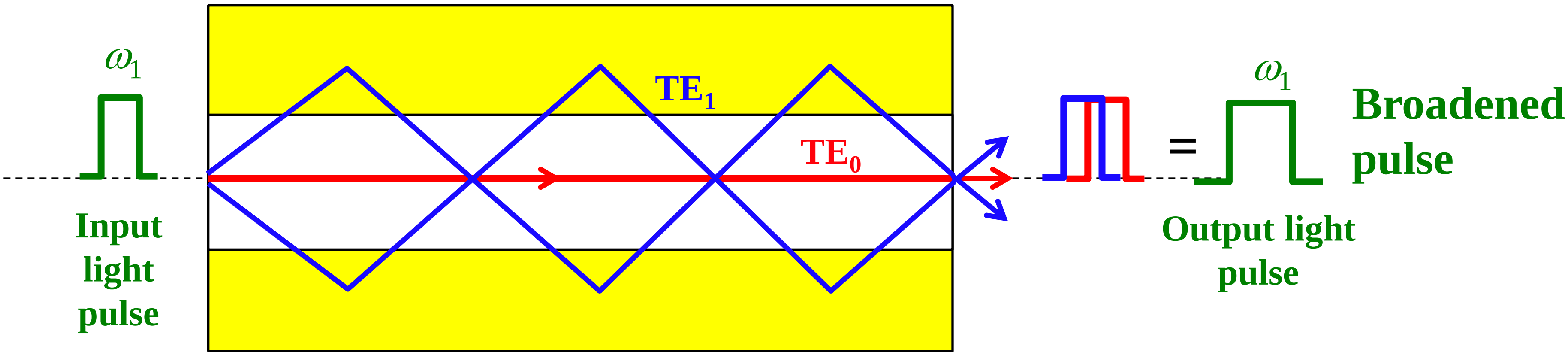
The group velocity v_g vs. ω for a planar dielectric guide

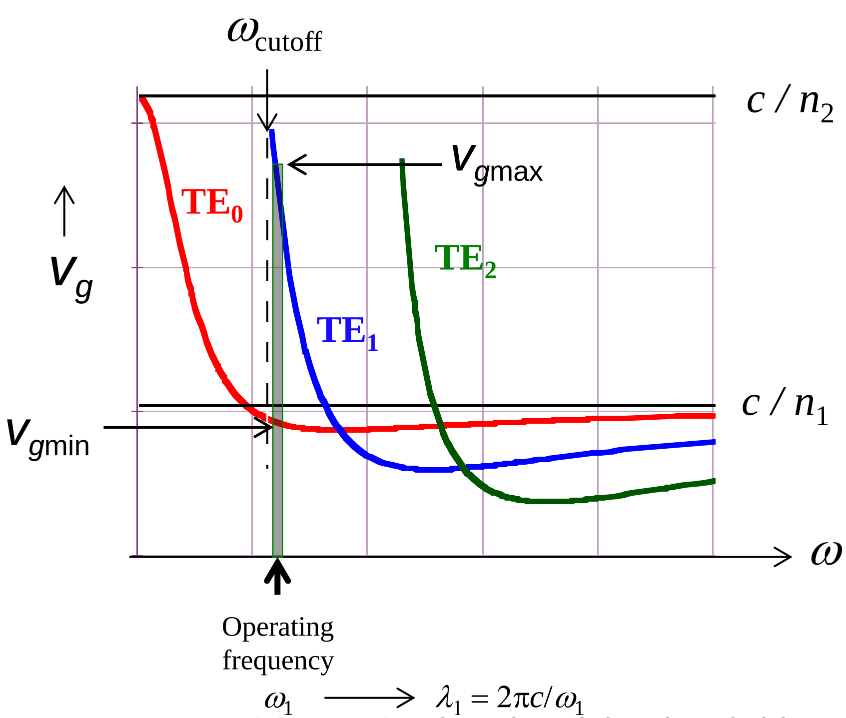
Core thickness ($2a$) = 20 μm, n_1 = 1.455, n_2 = 1.440

[Calculations by the author]

Not in the textbook

Dispersion in the Planar Dielectric Waveguide with TE_0 and TE_1 (Near cut-off)





$$v_{g\max} \approx c/n_2$$

$$v_{g\min} \approx c/n_1$$

$$\Delta\tau = \frac{L}{v_{g\min}} - \frac{L}{v_{g\max}}$$

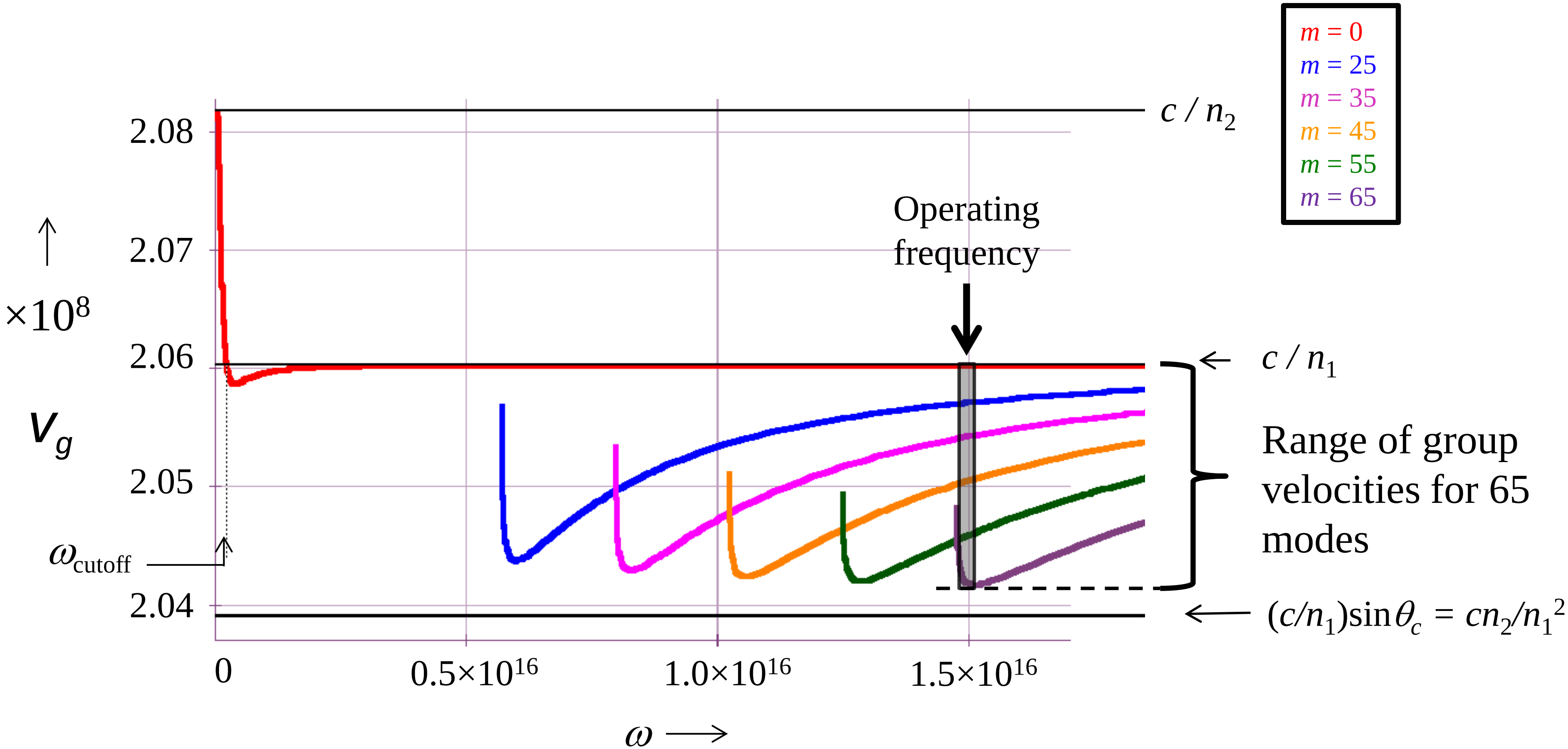
Spread in arrival times

$$\frac{\Delta\tau}{L} \approx \frac{n_1 - n_2}{c}$$

Dispersion

Not in the textbook

A Planar Dielectric Waveguide with Many Modes



Multimode operation in which many modes propagate with different group velocities

v_g vs. ω for a planar dielectric guide with a core thickness $(2a) = 20$ μm, $n_1 = 1.455$, $n_2 = 1.440$
[Calculations by the author]

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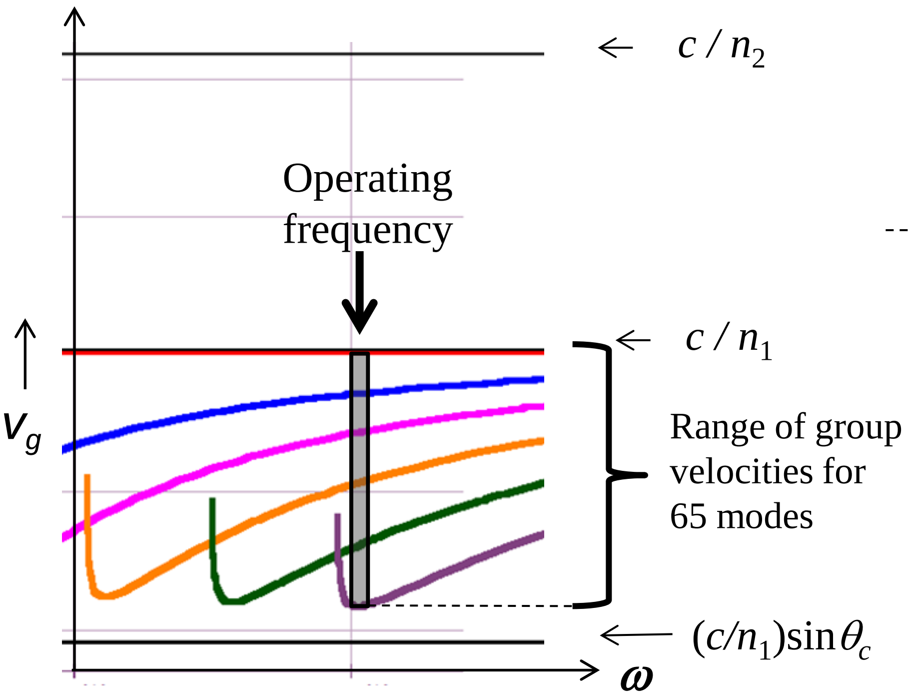
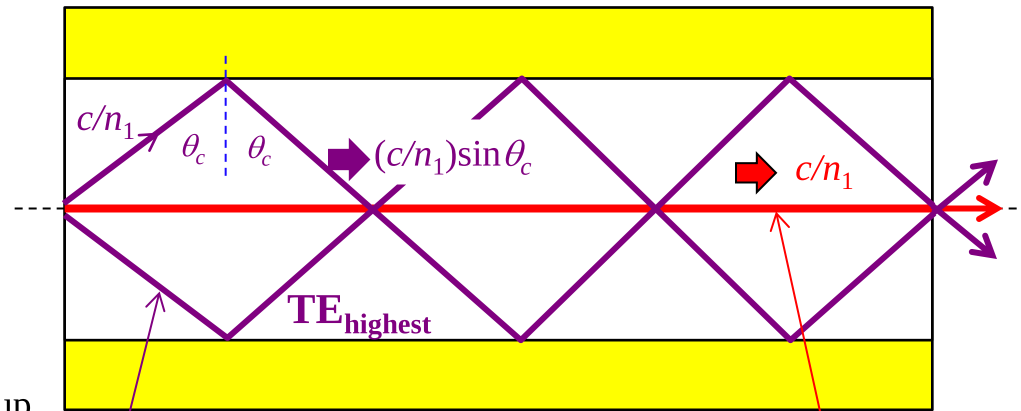
Dispersion in the Planar Dielectric Waveguide with Many Modes Far from Cutoff





$$v_{g\min} \approx \frac{c}{n_1}\sin\theta_c = \frac{c}{n_1}\left(\frac{n_2}{n_1}\right)$$

$$v_{g\max} \approx \frac{c}{n_1}$$

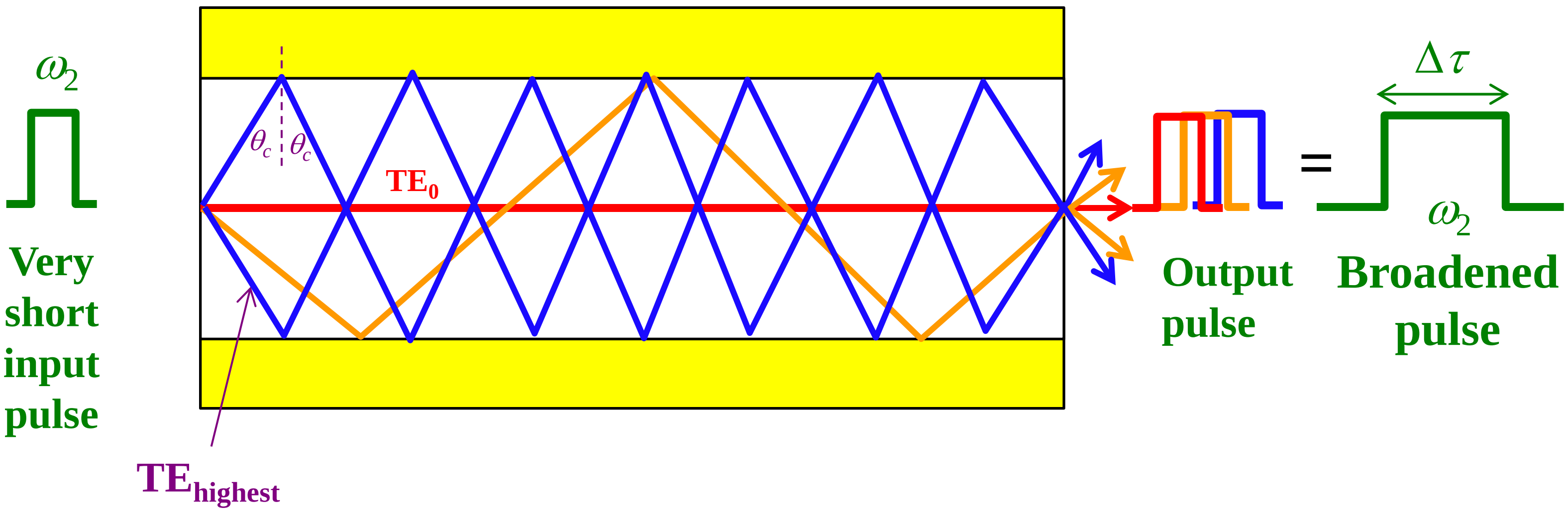
$$\frac{\Delta\tau}{L} = \frac{1}{v_{g\min}} - \frac{1}{v_{g\max}} \Rightarrow \frac{\Delta\tau}{L} = \frac{n_1^2}{cn_2} - \frac{n_1}{c} = \frac{1}{c}\left[\frac{(n_1-n_2)n_1}{n_2}\right] \approx \frac{(n_1-n_2)}{c}$$

$$\frac{\Delta\tau}{L} \approx \frac{n_1-n_2}{c}$$

(Since n_1 and n_2 are only slightly different.)

Not in the textbook

Dispersion in the Planar Dielectric Waveguide
Many Modes



$$\frac{\Delta\tau}{L} = \frac{1}{v_{g\min}} - \frac{1}{v_{g\max}}$$

$$\frac{\Delta\tau}{L} \approx \frac{(n_1 - n_2)}{c}\left(\frac{n_1}{n_2}\right)$$

$$\frac{\Delta\tau}{L} \approx \frac{n_1 - n_2}{c}$$

(Since $n_1/n_2 \approx 1$)

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Class Demonstrations

Class Problems

Check author's website http://optoelectronics.usask.ca

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