Prob. 1 (1999, Test 1-2)

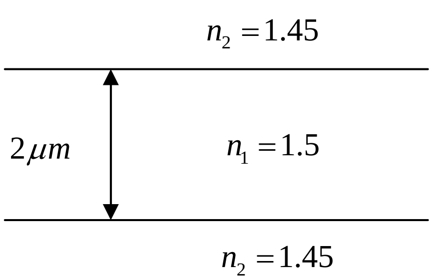
A symmetric three-layer waveguide is shown below. Consider only TE mode for this problem.

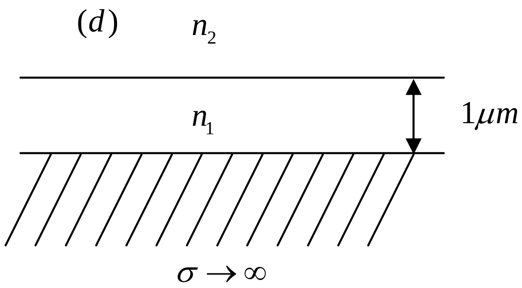
(a)(10) Determine how many modes the waveguide can support for λ=1.0μm.

(b)(10) Sketch the photon distribution function in the waveguide for each mode.

(c)(10) When λ is increased, the number of modes the waveguide can support may change. What is the largest wavelength for which the mode number remains the same as what was obtained in (a)?

(d)(10) Now the half of the waveguide is replaced with perfectly-conducting metal as shown below. Which modes among those determined in (a) can survive?



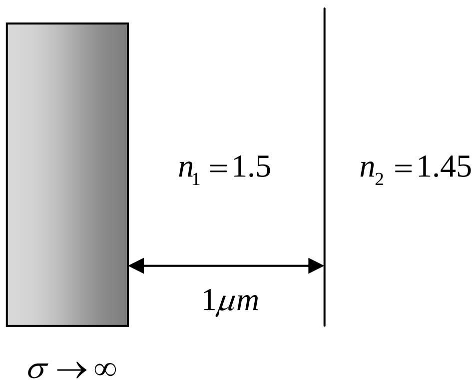


Prob. 2 (2000, Test Final-1)

(a)(10) A waveguide is formed by placing a sheet of perfectly conducting metal in parallel with the dielectric interface as shown below. How many guided TE modes are supported in this waveguide for λ=1μm? Give clear reasons for your answer.

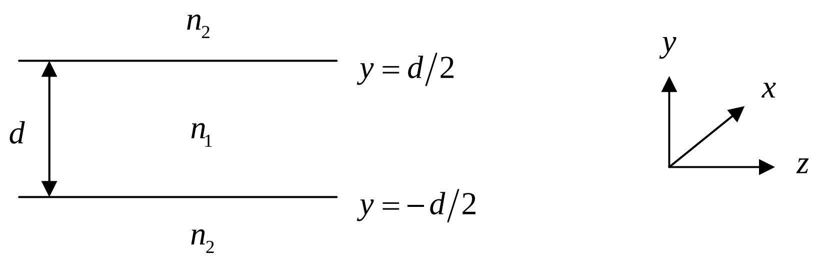
(b)(10) Sketch the photon distribution for the fundamental TE mode in the waveguide.

(c)(10) We would like to increase the number of guided TE modes by one by changing the waveguide width. Determine the range of waveguide width required.



Prob. 3 (2001, Test 1-2)

We derived solutions for TE guided modes in three-layer dielectric waveguide as shown below. In this problem, we would like to derive solutions for TM guided modes. For TM mode solutions, it is much easier to solve for H-fields than E-fields.



The wave equation to be solved is $\nabla^2 \underline{H} + k^2(y)\, \underline{H} = 0$. Assume the solution is in the form of $\underline{H} = \underline{x}\, H(y) \exp(i\beta z)$.

(a)(10) In each region of interest ($y>d/2$, $d/2 > y > -d/2$, $y< -d/2$), write down expressions for H(y). Make them as simple as possible. Define symbols that you introduce with symbols given in this problem and k_0, the wave number in the vacuum.

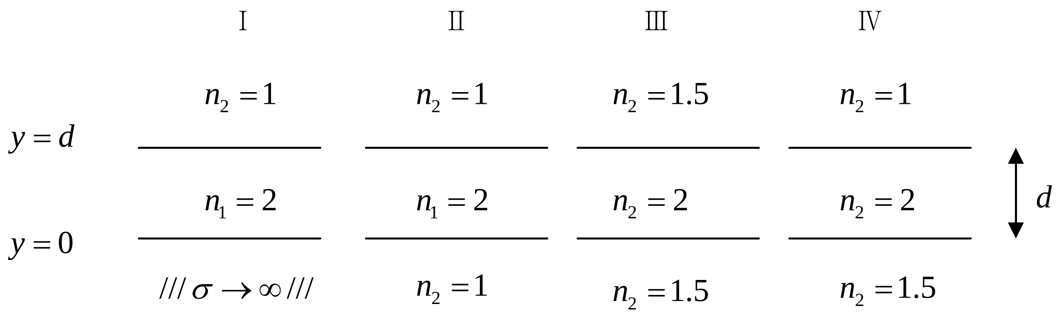
(b)(10) We know from the Maxwell's equations that the tangential components of E- and H-fields should be continuous at the lossless boundary. Based on this, determine two conditions that H(y) must obey at y=d/2.

(c)(10) Derive the relationship between α and k_y for even solutions, as has been done in the class for TE modes.

(d)(10) Between lowest-order TE and lowest-order TM modes, which has a larger value of effective index? Or are they the same? Explain why.

Prob. 4 (Test 1-3)

Several different types of waveguides having the same core material and thickness are shown below.



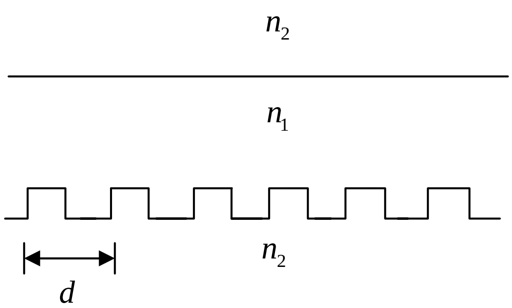
(a)(10) If we sketch the fundamental mode power distribution for each waveguide, which waveguide has the largest y value for the peak power position? Explain.

(b)(10) Among Type II, III, IV waveguides, which has the largest value for the fundamental mode effective index? Explain.

(c)(10) Among Type II, III, IV waveguides, which has the largest value for the fundamental mode confinement factor? Explain.

Prob. 5 (2002, Test 2-4)

Consider a single mode dielectric waveguide, a portion of which has a grating with period d formed by corrugated interface as shown below. Assume that the formation of the grating does not affect the effective index of the waveguide.



(a)(10) Show that light traveling in this waveguide can reverse its propagation direction if $\lambda = 2n_{eff}\,d$, where λ is the wavelength of the light in vacuum, n_{eff} is the effective index of the waveguide, and d is the grating period.

(b)(10) For certain λ's, the light can come out of the waveguide as shown below. What requirement does this λ should satisfy?

Prob. 6 (2002, Test 2-1)

Answer the following questions.

(a)(10) From the b-V diagram provided separately, determine the wavelength range within which the fiber is a single-mode waveguide. Use n_1

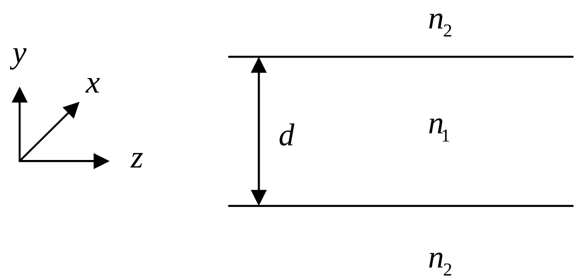
(core reflective index)= 1.458, n_2 = 1.452, and a (core radius) = 3.5 μm.

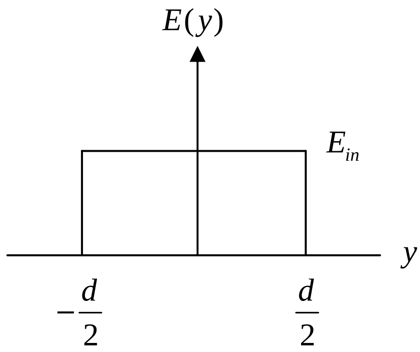
(b)(10) In a three-layer symmetric dielectric waveguide with n_1 (core reflective index)= 1.458, n_2 = 1.452, and d (core thickness) = 7 μm, what is the wavelength range within which the waveguide has a single TE mode?

(c)(10) A singe mode fiber has loss of 0.2 dB/km at λ= 1.5 μm. If 1 mW of 1.5 μm light is introduced at the input, what is the output power at the end of 100km long fiber?

Prob. 7 (2002, Test 2-2)

Assume that the symmetric three-layer dielectric waveguide shown below left supports 3 TE guided modes.





(a)(10) Estimate the propagation constants β for each guided mode. For the estimation, assume that the confinement factor for each mode is very close to one so that the evanescent fields in the cladding can be assumed zero.

(b)(10) An input field with TE polarization having the rectangular shape as shown above right is introduced to the waveguide at z=0. Among three guided modes traveling in z-direction, only two modes are excited.

Determine which mode is not excited and briefly explain why.

(c)(10) Two excited modes can experience interference as they travel along z-direction and, consequently, the detected power at the end of the waveguide can change as function of the waveguide length. Determine the condition on z for which the detected output power is maximized.

(d)(10) Determine how many percents of the input power is coupled to the fundamental mode.

Prob. 8 (2002, Test 2-3)

Determine whether each of the following statements is True or False. Briefly explain why. If your answer is False, you may give a counter example as an explanation. Without a clear and correct explanation, you will receive no credit even if your T/F answer is correct.

(a)(5) For a three-layer dielectric waveguide, the power peak of the fundamental mode is always at the middle of the core.

(b)(5) For guided modes in a three-layer dielectric waveguide, their confinement factors always decrease as the wavelength of the guided mode increases. (Assume for this problem that refractive indices are independent of wavelength.)

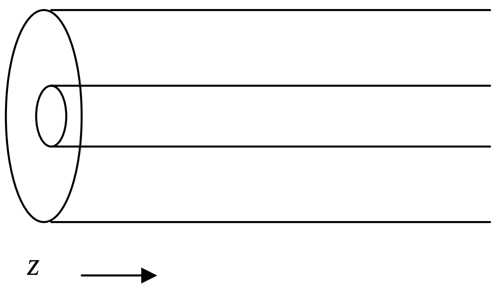
(c)(5) The loss in the fiber is lowest at 1.55um because both the Rayleigh scattering and lattice absorption are minimum at this wavelength.

(d)(5) In a standard optical fiber with D = 16 ps/nm-km at around 1.5um, light with longer wavelength travels faster than light with shorter wavelength.

(e)(5) If proper dispersion compensation is achieved, there is no limitation in how far optical signals in a fiber can be transmitted without significant detection error.

<u>Prob. 9 (2003, Test 2-1)</u>

A fiber has its core refractive index given as $n_1(z) = n_0 + \Delta n \sin[(2\pi/d) z)$ as shown below.



$n_2 = 1.497$

$n_1 = 1.5 + \Delta n \cdot \sin(\frac{2\pi}{d} Z)$, core radius: 5μm

(a)(10) Using the attached fiber b-V diagram, determine the approximate value of the effective index for the fundamental guided mode. Assume Δn = 0, the cladding layer is infinitely thick and λ=1.5μm.

(b)(10) With a very small amount of Δn so that the effective index of the guided mode does not change from the value obtained in (a), the fiber can reflect light having a specific wavelength of 1.5μm. Determine the numerical value d (with its unit) so that the reflection efficiency is highest.

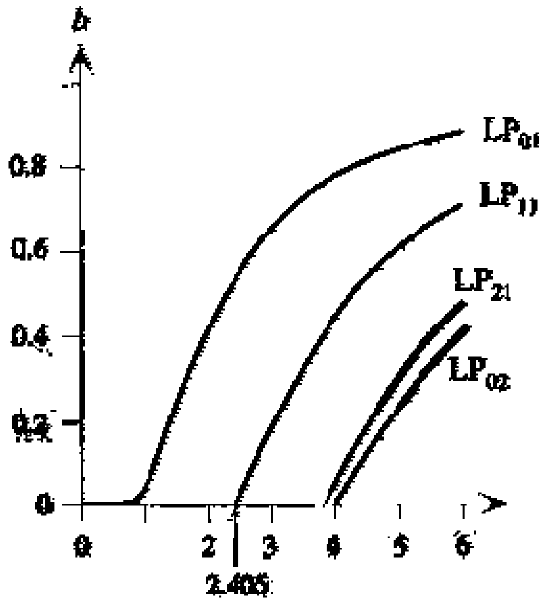
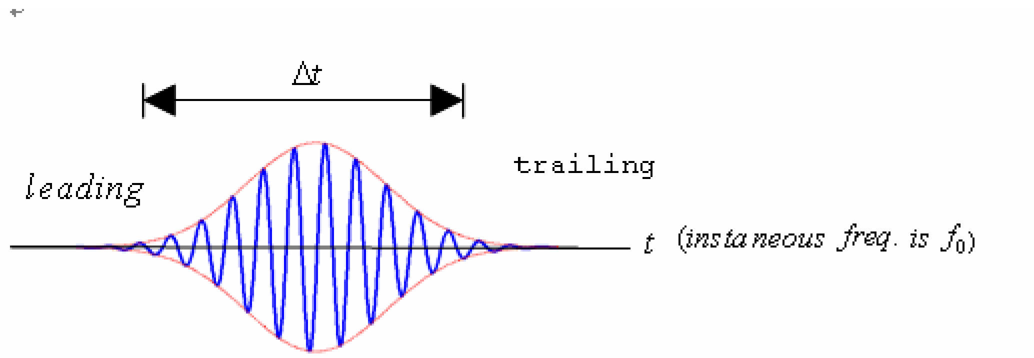


FIGURE 2.15 Normalized propagation constant b vs. V-number for a step index fiber for various LP modes.

Prob. 10 (2003, Test 2−2)

The time−domain profile of an E−field for an optical pulse is sketched below. Assume the carrier frequency is f_0 and the envelop has a Gaussian shape.



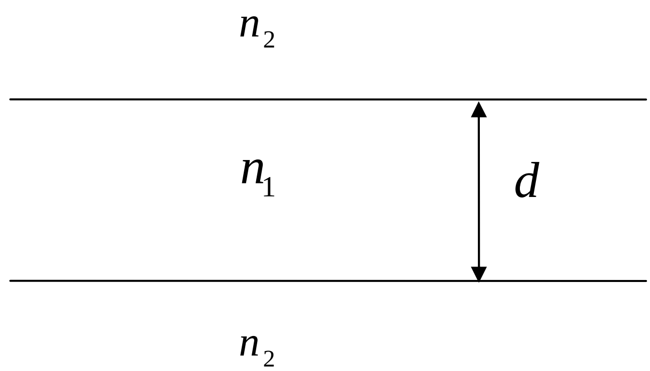
(a)(10) Sketch the frequency−domain spectrum (f>0 only) of the E−field pulse. Clearly indicate important features of your sketch.

(b)(10) The pulse has propagated in a fiber with a positive dispersion parameter (D>0). Sketch the resulting time−domain profile of the E−field pulse. Clearly indicate important features of your sketch.

(c)(10) It is possible for an optical pulse to get compressed (pulse width is reduced) while propagating in a dispersive fiber with D>0. For such a case, sketch how the time-dependent profile of the initial E-field pulse should be.

<u>Prob. 11 (2003, Test 2-3)</u>

The TE guided mode in a symmetric 3-layer dielectric waveguide shown below has to satisfy the following guidance condition: $k_y d - \phi = m\pi$, where m is an integer.



(a)(10) What is k_y? Express it as a function of n_1, n_2, N (effective index of the waveguide), and k_0 (wavenumber of input light in vacuum).
(b)(10) What is ϕ? Express it as a function of n_1, n_2, N (effective index of the waveguide), and k_0 (wavenumber of input light in vacuum).

(c)(10) The normalized frequency v is given as $v = k_0\, d\, \sqrt{n_1^2 - n_2^2}$. Determine the condition v has to satisfy when a given mode is at the cut-off condition.

(e)(10) For a given mode, how does the confinement factor change as v increases? Explain why.

(f)(10) The bottom cladding is replaced with a perfect metal. Determine the condition v has to satisfy when it is at the cut-off condition.

Prob. 12 (2005, Test 2-1)

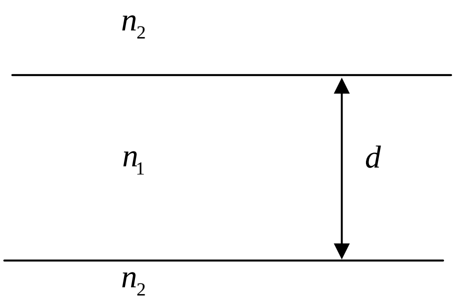
(a)(10) Assume one human eye can detect a single photon in one second. What is the power in W detected by the eye when the photon wavelength is 0.5μm?

(b)(10) The power of light propagating in z-direction in lossy fiber can be modeled as $P(z) = P_0 \exp(-\alpha z)$, where P_0 is the power at z=0. Given that fiber loss is 5dB/km, determine the numerical value of α in km^{-1}?

(c)(10) 1nW of light at 0.5μm is transmitted over fiber having 5dB/km loss. What is the maximum distance the light can travel and get detected by a human eye? Use the results obtained in (a) and (b).

Prob. 13 (2005, Test 2-2)

A three-layer dielectric waveguide shown below has both TE and TM guided modes. Answer the following questions. You must provide clear reasoning for your answers, otherwise you will not receive any credit even if your answer is correct.

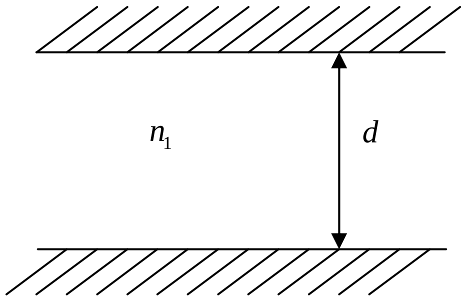


(a)(10) Which one (TE or TM) has the larger number of guided modes?

(b)(10) For lowest-order guided TE and TM modes, which one (TE or TM) has the larger effective index?

(c)(10) For lowest-order guided TE and TM modes, which one (TE or TM) has the larger confinement factor?

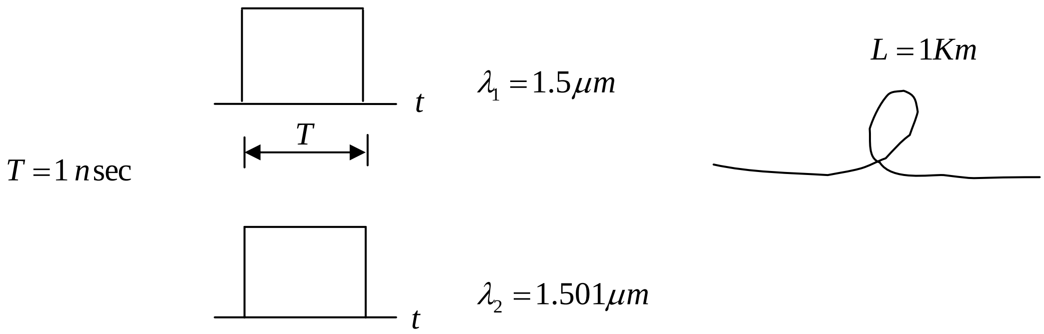
Now, a metallic waveguide is formed by replacing top and bottom cladding layers with perfectly conducting metals as shown below.



(d)(10) Comparing lowest-order TE modes in dielectric and metallic waveguides, which one (dielectric or metallic) has the larger propagation constant β?

<u>Prob. 14 (2005, Test 2-3)</u>

Two rectangular-shape light pulses having different wavelengths are sent over dispersive single-mode fiber as shown below. The fiber has D of 16 ps/(km nm) at 1.5μm.

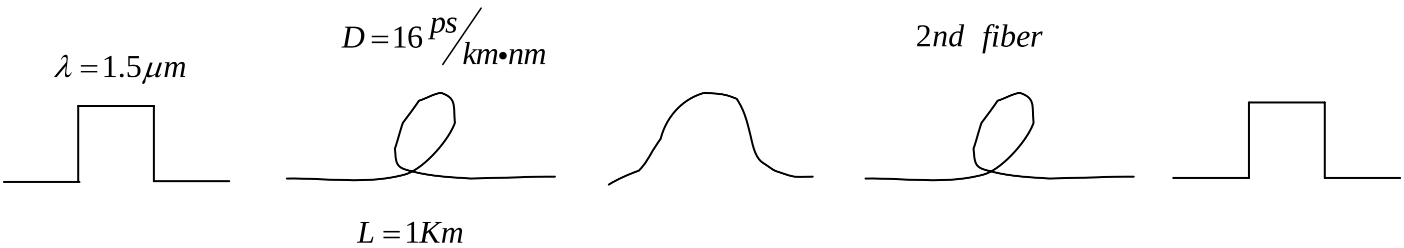


(a)(5) Which pulse (λ_1 or λ_2) will reach the receiver first? Why?

(b)(5) Estimate the arrival time difference.

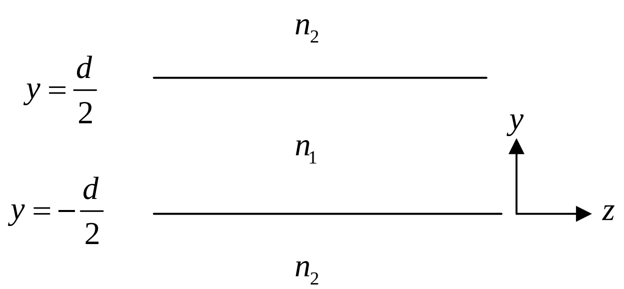
Now, a single short pulse at 1.5μm having rectangular shape is sent over the same fiber as shown below.

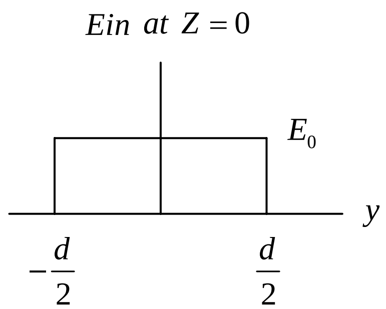
(c)(10) The short pulse will experience broadening due to dispersion in fiber. Estimate the pulse width when the pulse broadening is comparable to the arrival time difference determined in (b). For spectral width estimation of sync function, use the absolute value of the first null point.
(d)(10) It is possible to eliminate the pulse broadening effect by transmitting the received pulse over the second fiber as shown below. Give the required conditions for the second fiber.



Prob. 15 (2001, Test Final-2)

A three-layer dielectric waveguide shown below supports the TE modes. For this problem, do not consider any TM modes.





(a)(10) Sketch the field profile for each guided mode.

(b)(10) We would like to estimate the guided field profile by ignoring the evanescent field (in other words, assume the field goes to zero at the core-cladding boundaries). Obtain the estimation for each guided mode, $E_1(y)$, and $E_2(y)$. Use E_{10} or E_{20} for the proportion constant of each mode.

(c)(20) If an input field with a rectangular shape is introduced into the waveguide at z=0 as shown above, the input field becomes distributed among the guided modes. This process can be mathematically expressed as $E_{in}(y) = E_1(y) + E_2(y)$, where $E_{in}(y)$ is the input field and $E_1(y)$ and $E_2(y)$ represent the guided mode profiles approximately determined in (b). Determine expressions for E_{10} and E_{20} that best satisfy the above equation. Let $E_{in}(y) = E_0$ at $z = 0$ for $-d/2 < y < d/2$.

(d)(10) Using the results obtained in (c), how much of the input power is coupled into the waveguide?