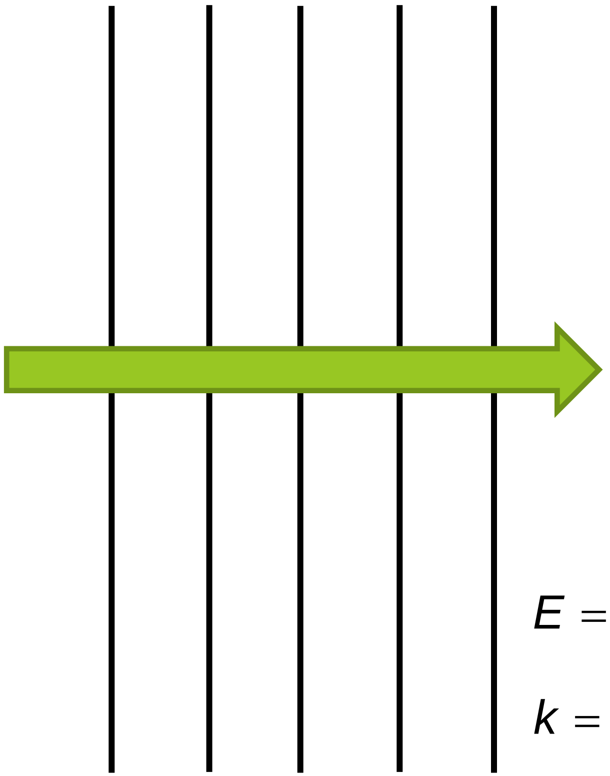
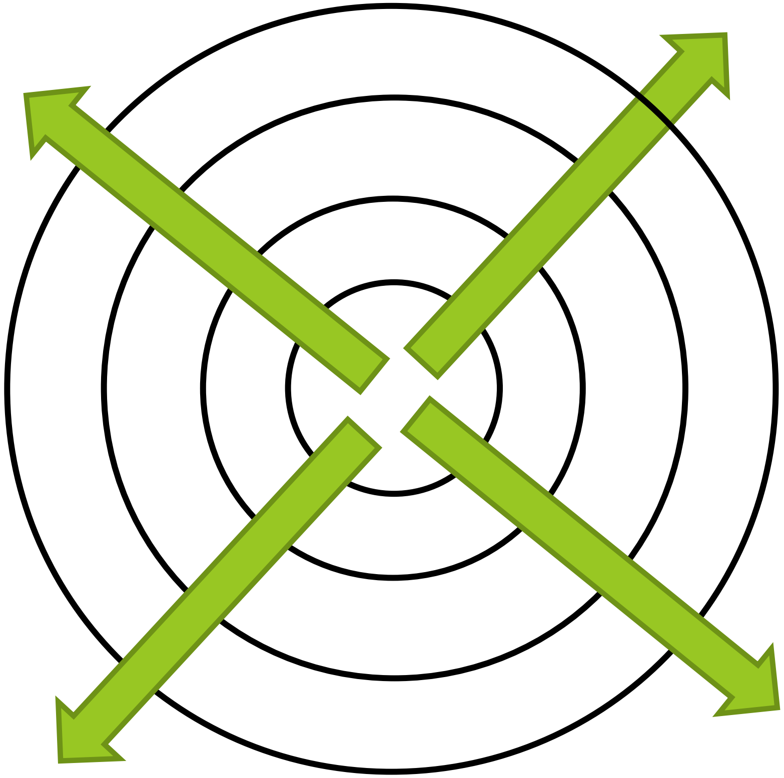
Waves in Free Space



$$E = E_0 e^{i(\omega t - kz)}$$

$$k = \frac{2\pi}{\lambda_0} n$$

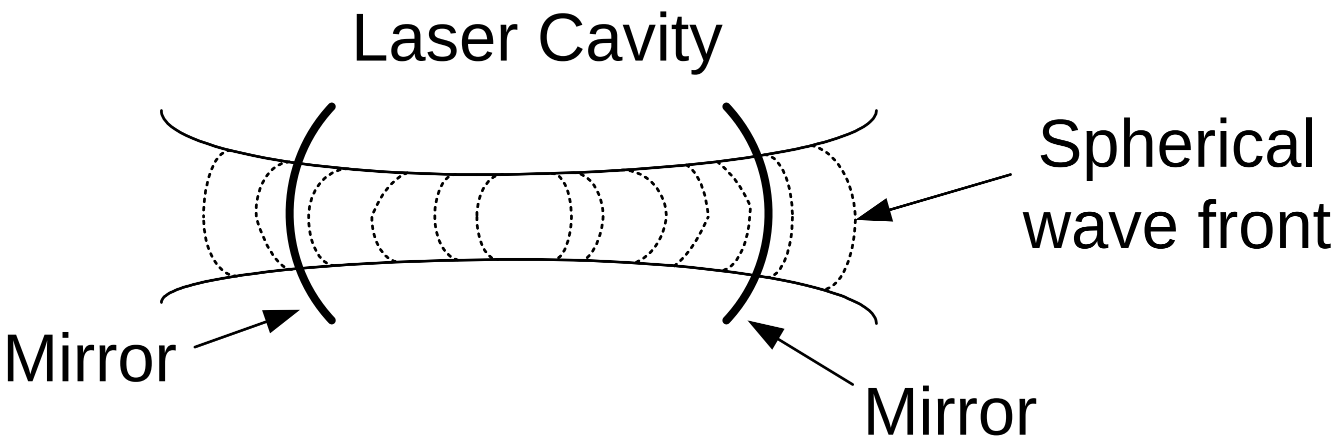
Plane Wave



Spherical Wave

$$E = E_0 \frac{e^{i(\omega t - kr)}}{r}$$

Gaussian Beams



$$E(r,z,t) = E_0 \frac{w_0}{w} e^{-r^2/w^2} e^{-jk(z+\frac{r^2}{2R})} e^{j\phi} e^{j\omega t}$$

$$w(z)^2 = w_0{}^2 \left[1 + \left(\frac{z}{z_R} \right)^2 \right]$$

Spot Size

$$R(z) = z \left[1 + \left(\frac{z_R}{z} \right)^2 \right]$$

Radius of Curvature

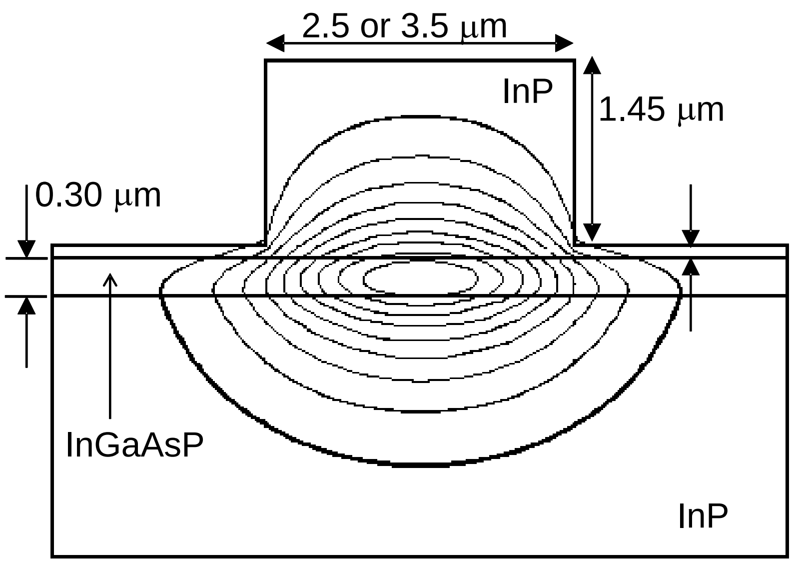
$$\phi(z) = \tan^{-1}(z / z_R)$$

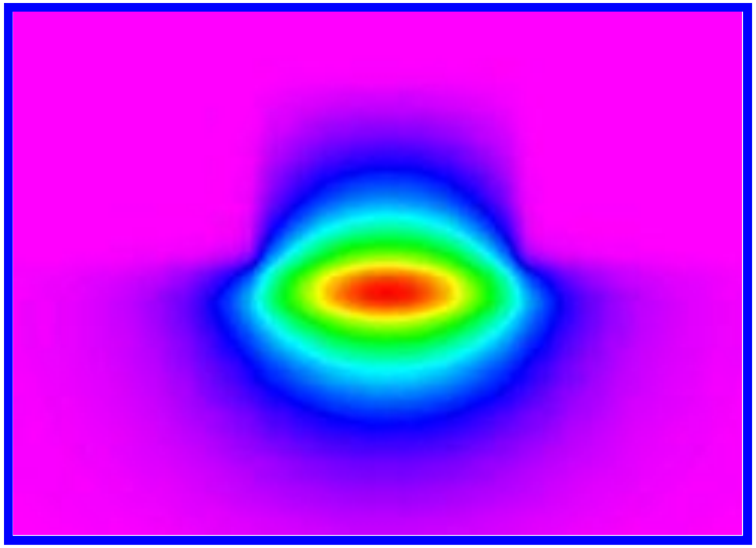
Extra Phase Factor

$$z_R = \frac{\pi w_0{}^2}{\lambda}$$

Rayleigh Range

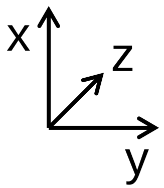
Guided Waves



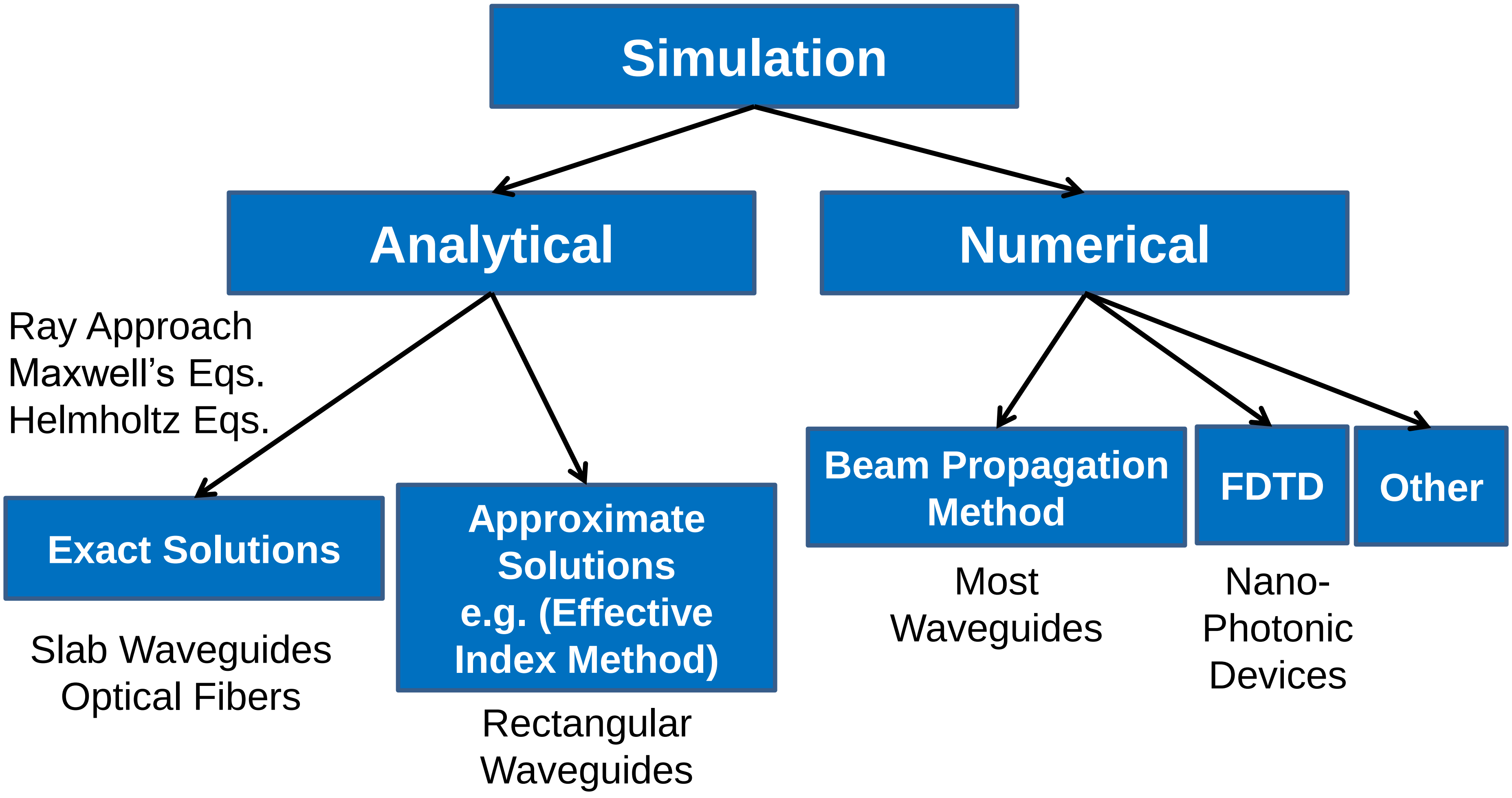


$$\vec{E}(x,y),\vec{H}(x,y) \qquad \vec{E}(x,y),\vec{H}(x,y)$$

$$e^{i\frac{2\pi}{n_{eff}}z} = e^{i\beta z}$$

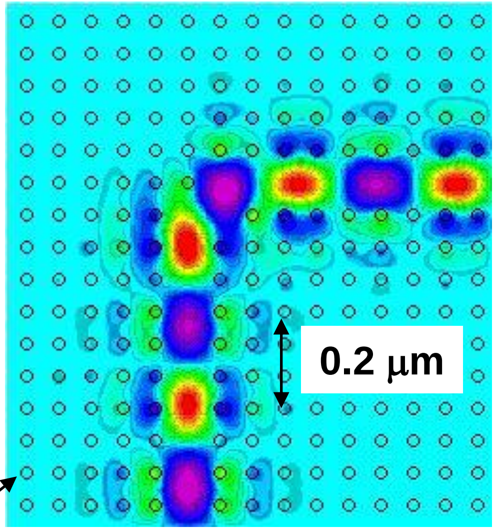


Analysis of Guided Waves



An Simulation for Which FDTD is Particularly Well-Suited

A Photonic Crystal

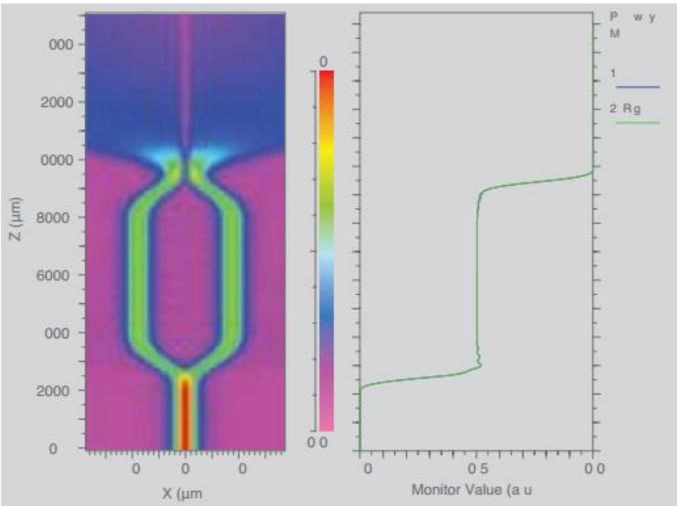


Optical Field

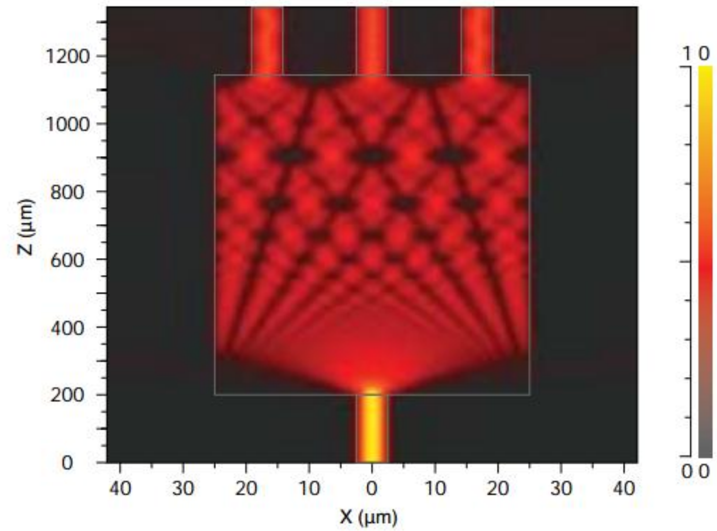
Simulated Results

Dielectric Post

Beam Propagation Method



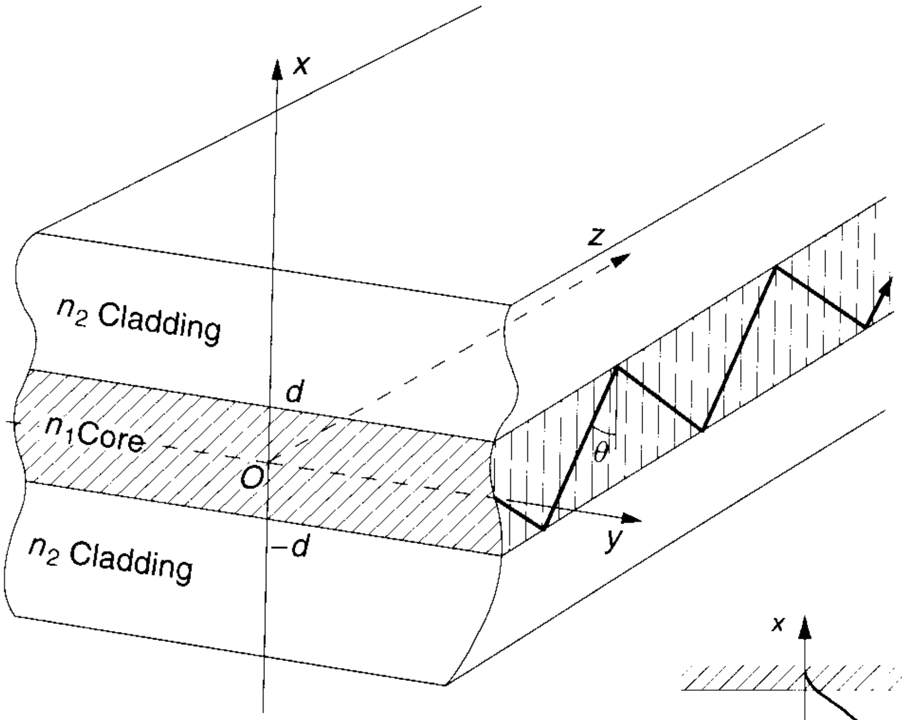
BeamPROP simulation of a Mach-Zehnder modulator operating completely out of phase. The power in each arm is shown on the right.



BeamPROP simulation of a multi-mode interference device (MMI) operating as a 1 to 3 optical aplitter

- Approximate, but can be used to simulate waves in a wide variety of photonic devices.

Slab Waveguides



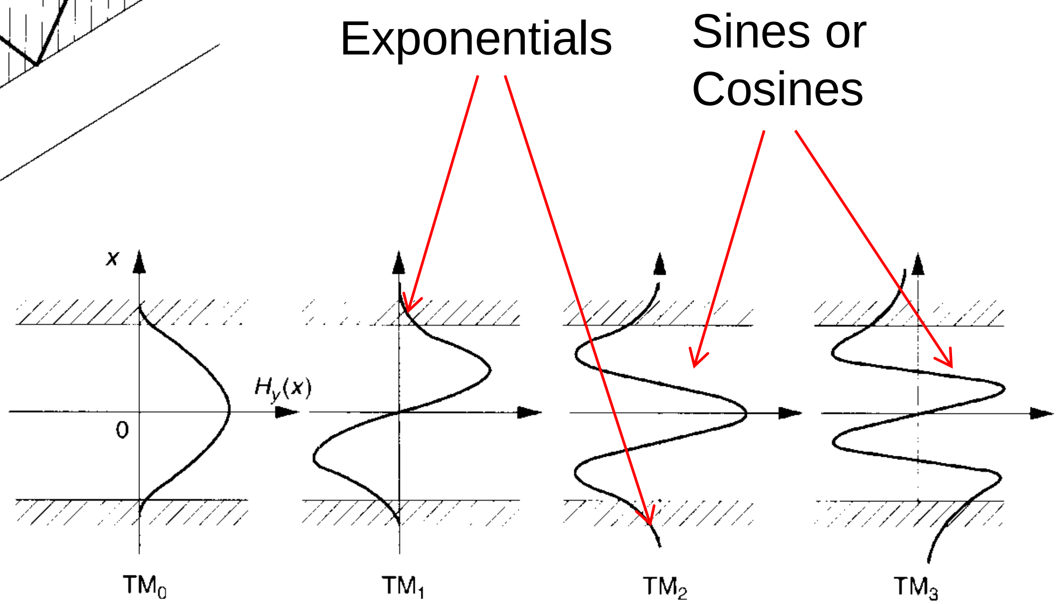
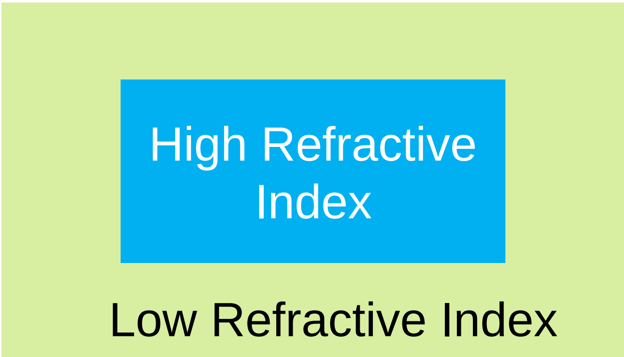


Figure 9.3 Distribution of the H_y field in the slab optical guide. The field distributions correspond to the modes in Fig. 9.2.

Question

What functions could be used to describe the cross-sectional profile for a guided optical wave in waveguide with a rectangular cross-section?



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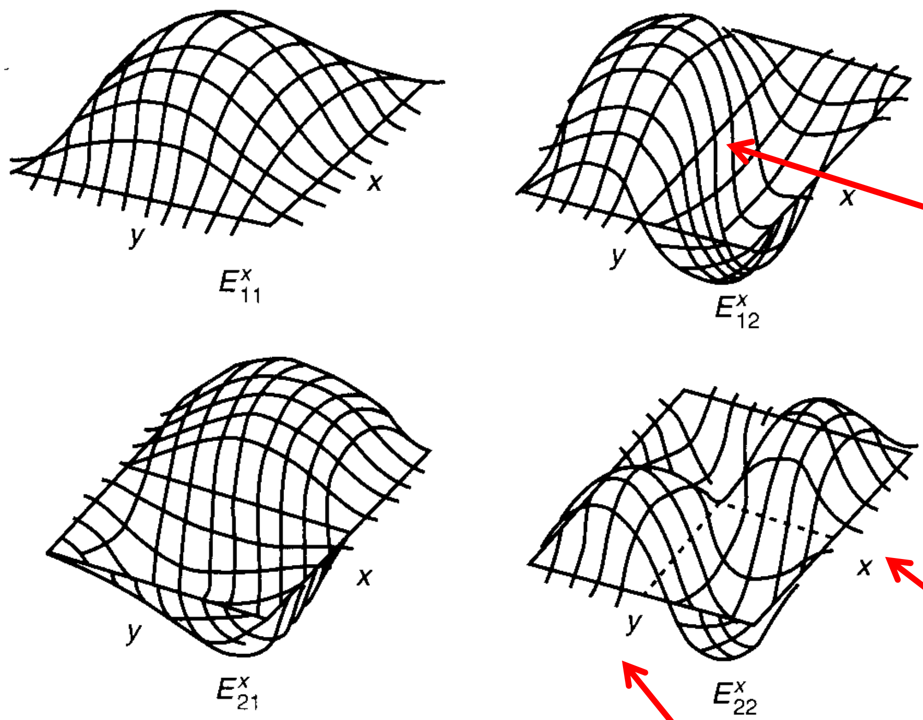
Field Profiles in Rectangular Waveguides

Commonly used approximation

$$E(x,y) = E(x)E(y)$$



we use a sine or cosine function for E(x) and E(y) in the core (high index region) of the guide

We use an exponential function for E(y) out here

We use an exponential function for E(x) out here

Question

What functions are used to describe the cross-sectional profiles for optical waves in optical fibers?

Hint: Optical fibers have cylindrical Symmetry

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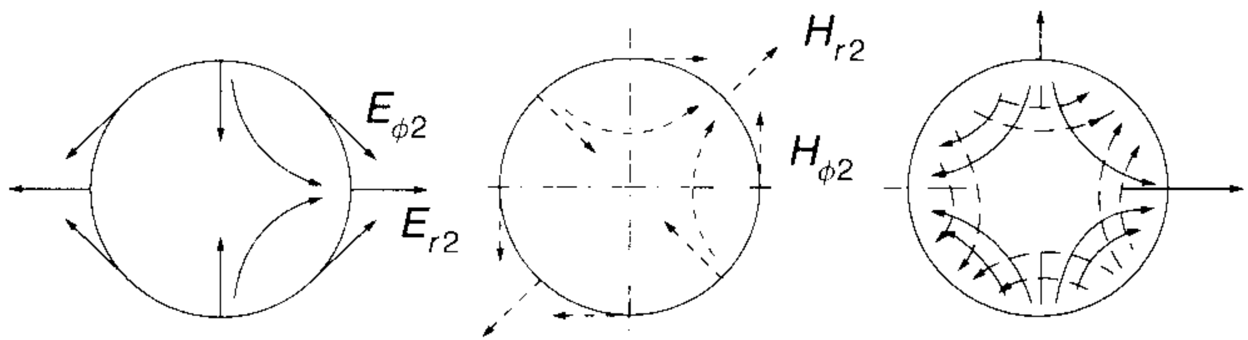
Field Distributions in Optical Fibers

$EH_{\nu\mu}$ Modes:

$$
\begin{aligned}
E_r &\propto -J_{\nu+1}\left(\kappa_{\nu\mu} r\right)\cos\nu\phi \\
E_\phi &\propto -J_{\nu+1}\left(\kappa_{\nu\mu} r\right)\sin\nu\phi \\
H_r &\propto J_{\nu+1}\left(\kappa_{\nu\mu} r\right)\sin\nu\phi \\
H_\phi &\propto -J_{\nu+1}\left(\kappa_{\nu\mu} r\right)\cos\nu\phi
\end{aligned}
$$

$HE_{\nu\mu}$ Modes:

$$
\begin{aligned}
E_r &\propto J_{\nu-1}\left(\kappa_{\nu\mu} r\right)\cos\nu\phi \\
E_\phi &\propto -J_{\nu-1}\left(\kappa_{\nu\mu} r\right)\sin\nu\phi \\
H_r &\propto J_{\nu-1}\left(\kappa_{\nu\mu} r\right)\sin\nu\phi \\
H_\phi &\propto J_{\nu-1}\left(\kappa_{\nu\mu} r\right)\cos\nu\phi
\end{aligned}
$$



E_2 field $\quad$ H_2 field $\quad$ HE_{21} mode