UNIVERSITY OF CAMBRIDGE

IIA project – Simulations of Mode Coupling

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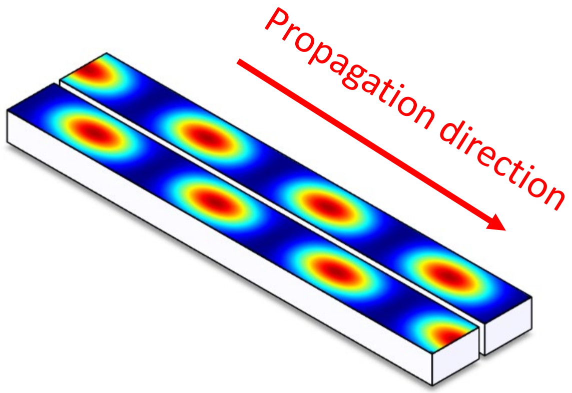
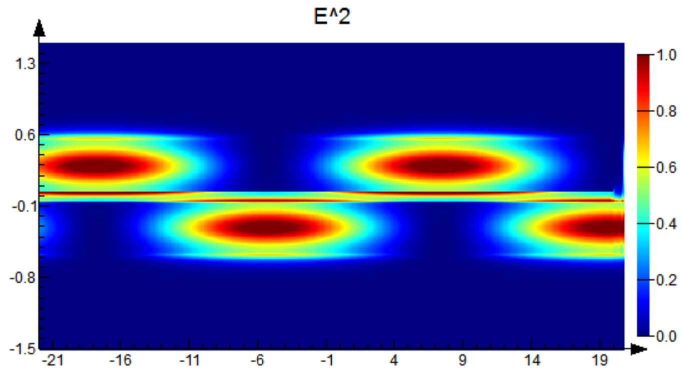
Basics of Mode Coupling

When two waveguides are brought close to each other, a phenomenon called **mode coupling** occurs, which means that optical energy periodically transfers between the two waveguides.

This happens because:

- The **evanescent fields** of the two waveguides extend into the surrounding space, and when placed close enough, **they overlap and interact**.
- This interaction enables **periodic energy transfer** between the two waveguides, where energy oscillates back and forth between the waveguides (like beating)





Basics of Mode Coupling

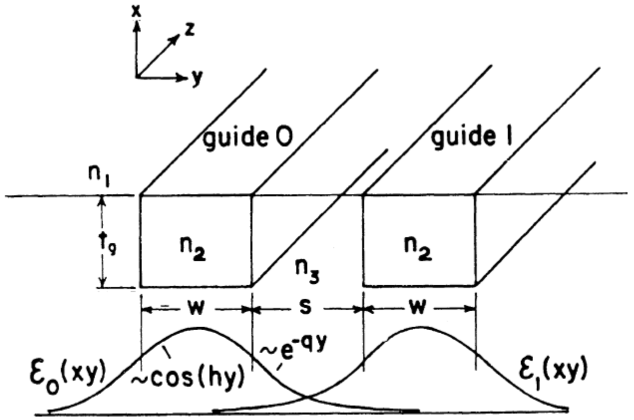
Coupled-Mode Theory of Synchronous Coupling

Coupling between two identical lossless waveguides ($\beta = \beta_0 = \beta_1$), and the field of the propagating mode is denoted, as:

$$\bar{E}(x,y,z) = A(z)\bar{E}(x,y)$$

where $A(z)$ is the complex amplitude of the field, such that the mode power equals

$$P(z) = |A(z)|^2 = A(z)A^*(z)$$



The mode coupling can be described by the general **coupled mode equations** for the amplitudes of the two modes:

$$\begin{cases} \dfrac{dA_0(z)}{dz} = -i\beta A_0(z) - i\kappa A_1(z) \\ \dfrac{dA_1(z)}{dz} = -i\beta A_1(z) - i\kappa A_0(z) \end{cases} \quad (1.11)$$

where β_0 and β_1 are the mode propagation constants, and κ is the **coupling coefficient** between modes, which quantifies the strength of interaction between the two waveguides: the larger κ, the faster the energy transfer between them.

Basics of Mode Coupling

Assume that the light is all within Waveguide *0* at the position *z=0*, we have:

$$A_0(0) = 1 \quad \text{and} \quad A_1(0) = 0$$

Thus, the solutions of the coupled mode equations are:

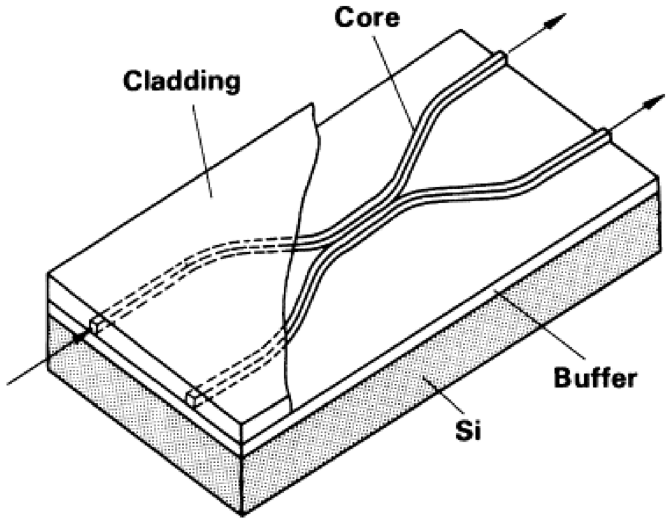
power flow in waveguides

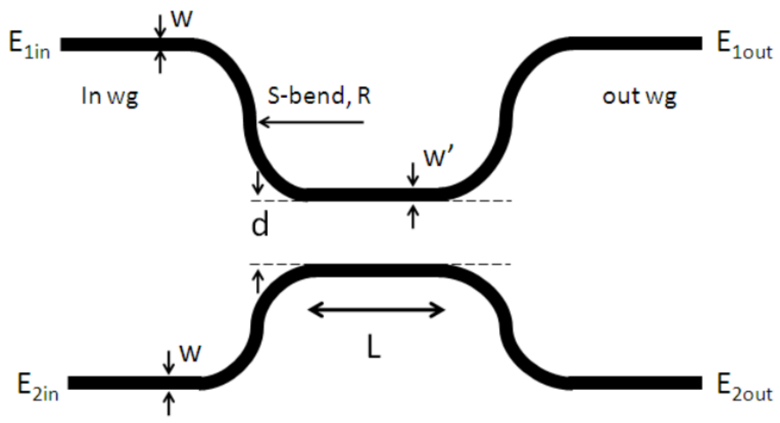
$$\begin{cases} \dfrac{dA_0(z)}{dz} = -i\beta A_0(z) - i\kappa A_1(z) \\ \dfrac{dA_1(z)}{dz} = -i\beta A_1(z) - i\kappa A_0(z) \end{cases} \Rightarrow \begin{cases} A_0(z) = \cos(\kappa z)e^{-i\beta z} \\ A_1(z) = -i\sin(\kappa z)e^{-i\beta z} \end{cases} \Rightarrow \begin{cases} P_0(z) = A_0(z)A_0^*(z) = \cos^2(\kappa z) \\ P_1(z) = A_1(z)A_1^*(z) = \sin^2(\kappa z) \end{cases}$$

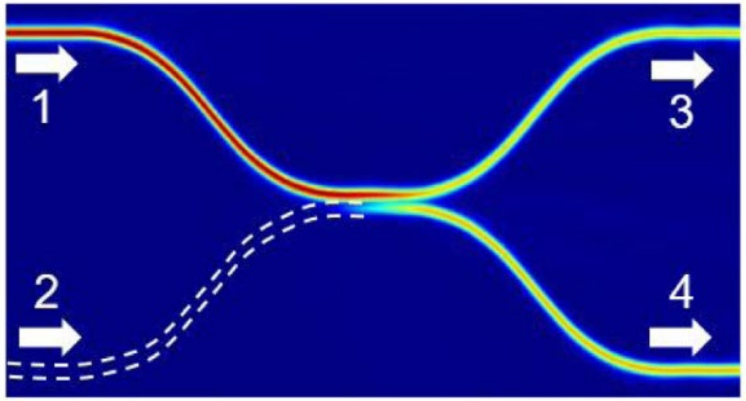
It can be seen that the **coupling length** *L* necessary for complete transfer of power from one guide to the other is given by:

$$L = \frac{\pi}{2\kappa} + \frac{m\pi}{\kappa} \qquad \text{where } m = 0,1,2,3 \ldots$$

Directional Coupler







By adjusting the waveguide width, coupling region length, gap, and other geometrical parameters, directional couplers can be engineered to achieve various power-splitting ratios.

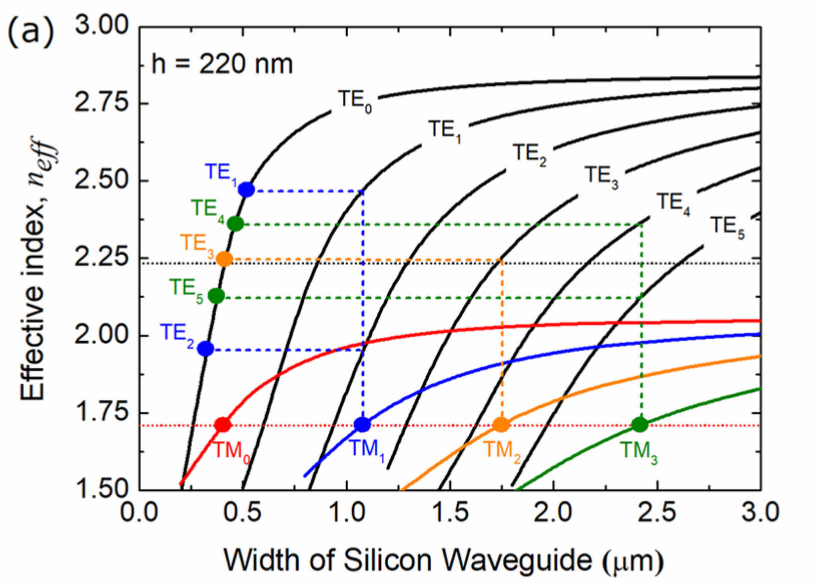
Coupling between asymmetrical waveguides

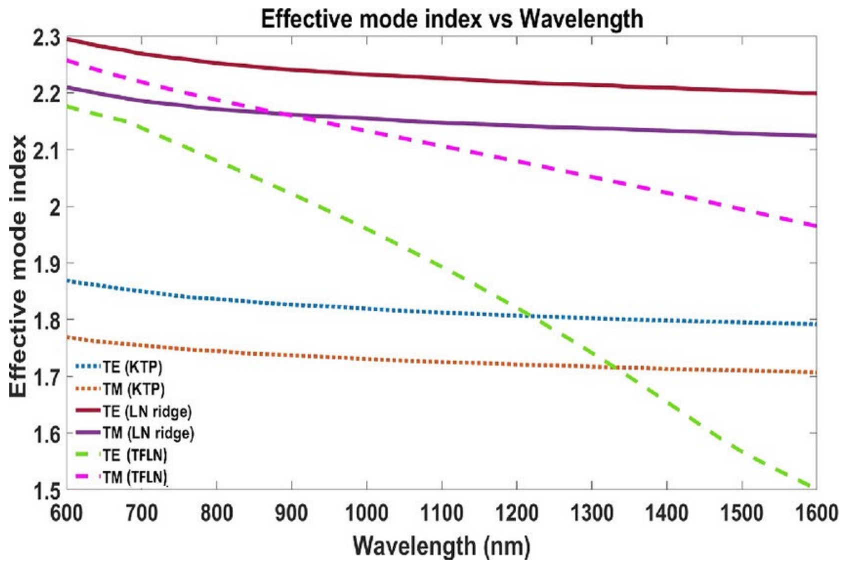
Mode Effective Index

$$\begin{cases} \dfrac{dA_0(z)}{dz} = -i\beta A_0(z) - i\kappa A_1(z) \\ \dfrac{dA_1(z)}{dz} = -i\beta A_1(z) - i\kappa A_0(z) \end{cases}$$

***Effective refractive index** experienced by the guided mode*

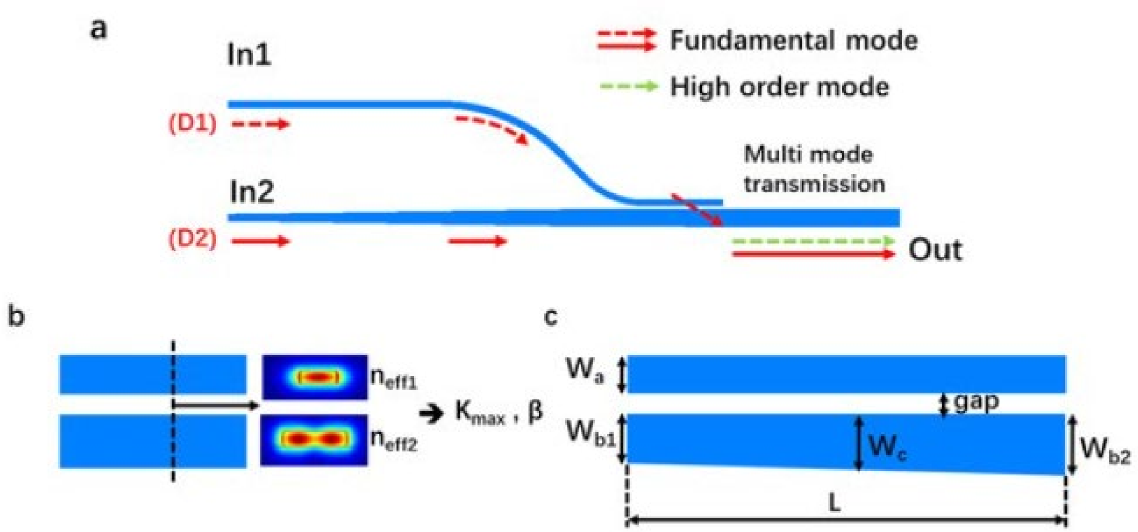
where β is the propagation constant, $\beta = kn_{eff} = \omega n_{eff}/c$

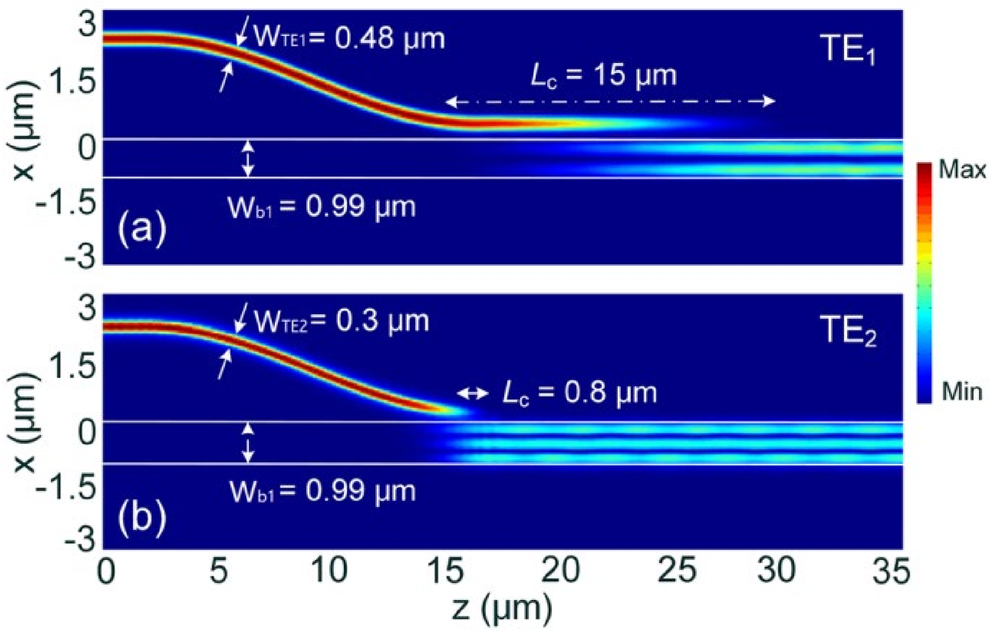




Varies over Mode Order, Waveguide geometry, Wavelength, etc…

Coupling between asymmetrical waveguides





By tuning the waveguide width, the effective indices of different mode orders can be matched, enabling the structure to function as a **mode order converter**, facilitating transitions between guided modes (e.g., $TE_0 \rightarrow TE_1$).

For remote control

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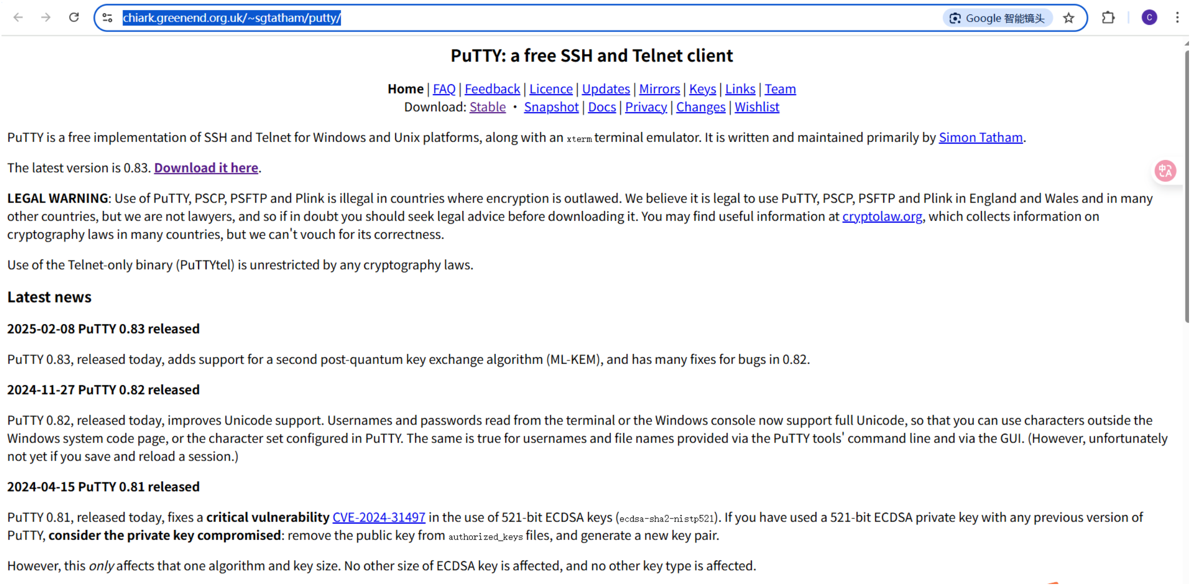
Download Putty



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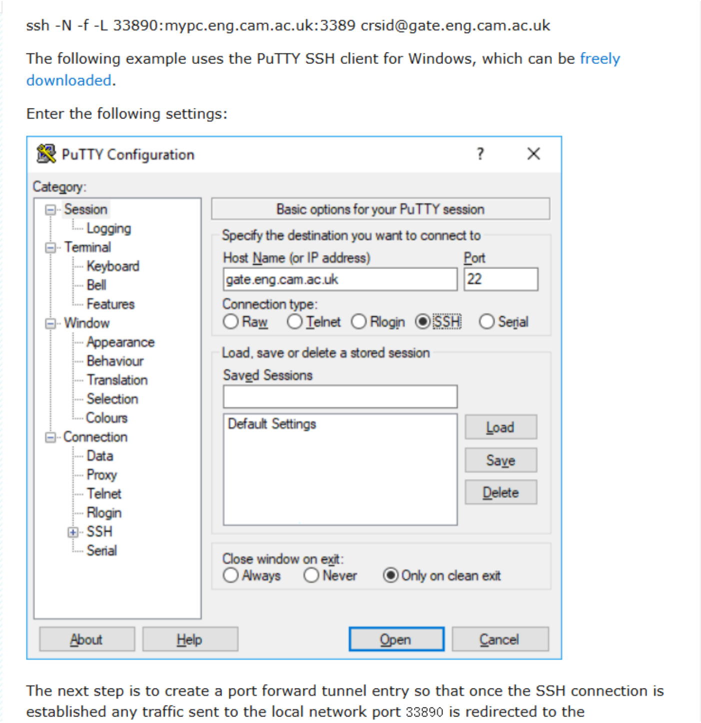

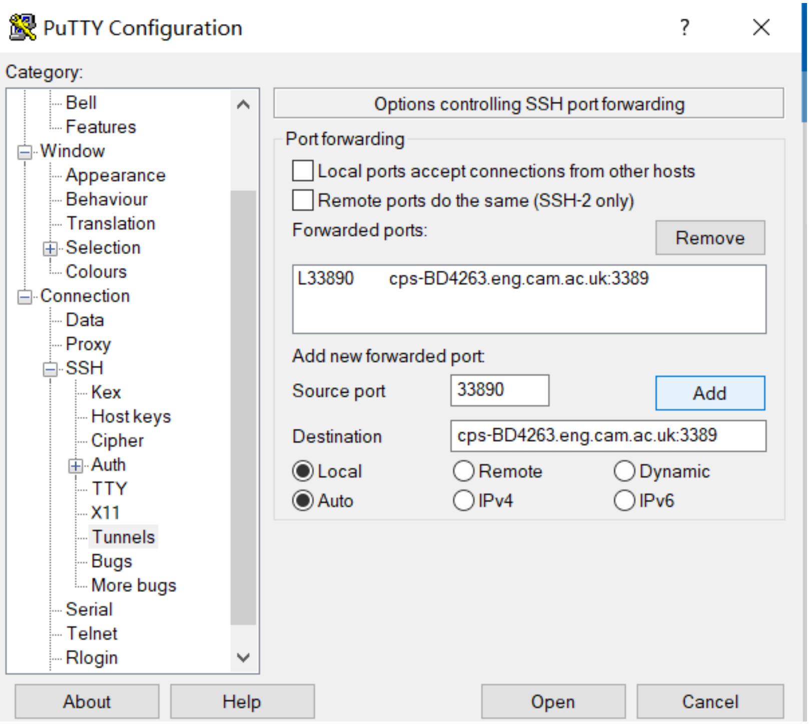

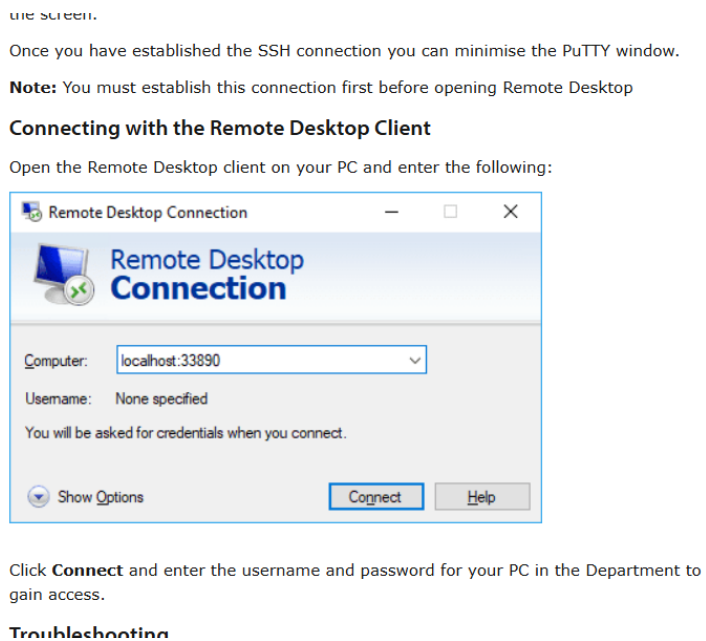

For remote control

Current Workstations address:

- cps-BD3977
- cps-BD4263
- cps-BD4682

Five/Six more to be ready….

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