COMSOL ® Design Tool:

Lecture 6: S Parameters

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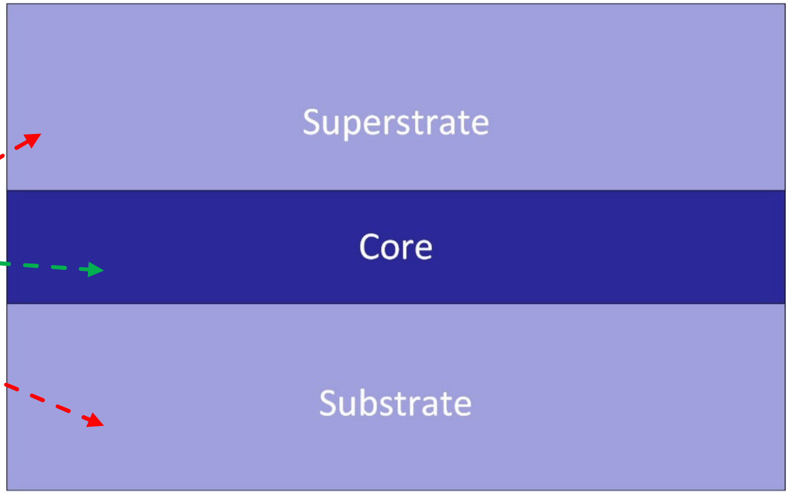
Content

- **Revision wave propagation**
  - Waveguide
  - Confinement
  - Modes
- **S-parameters**
  - Theory

Revision Wave Propagation

- Dielectric slab waveguide
- What we want
  - Propagation in core
  - Decay (exponential) in sub/superstrate
  - High confinement
- What we don't want
  - Propagation in sub/superstrate
  - Low confinement (except in certain application - e.g. couplers)



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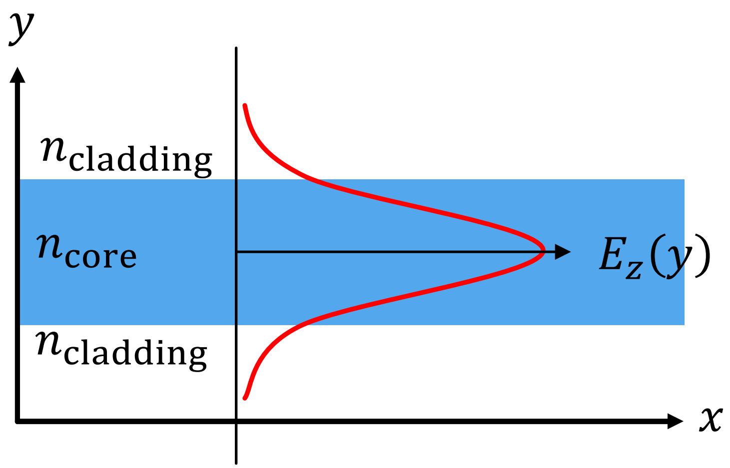
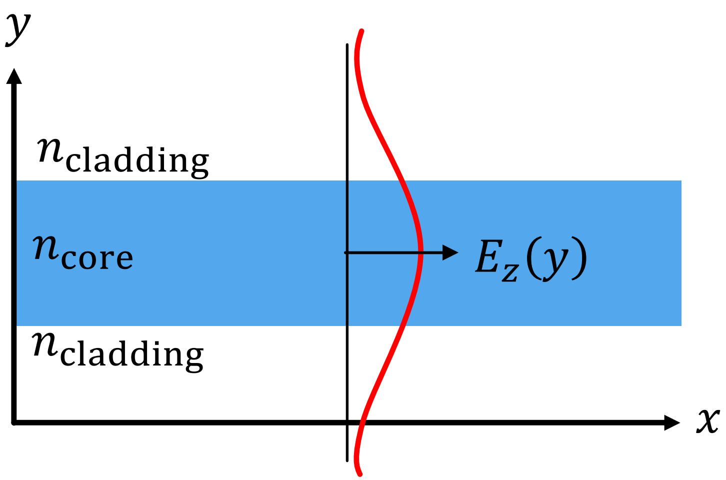
Revision Wave Propagation

- Confinement



Strongly confined
Wave mostly in the core



Weakly confined
Wave leaks into cladding

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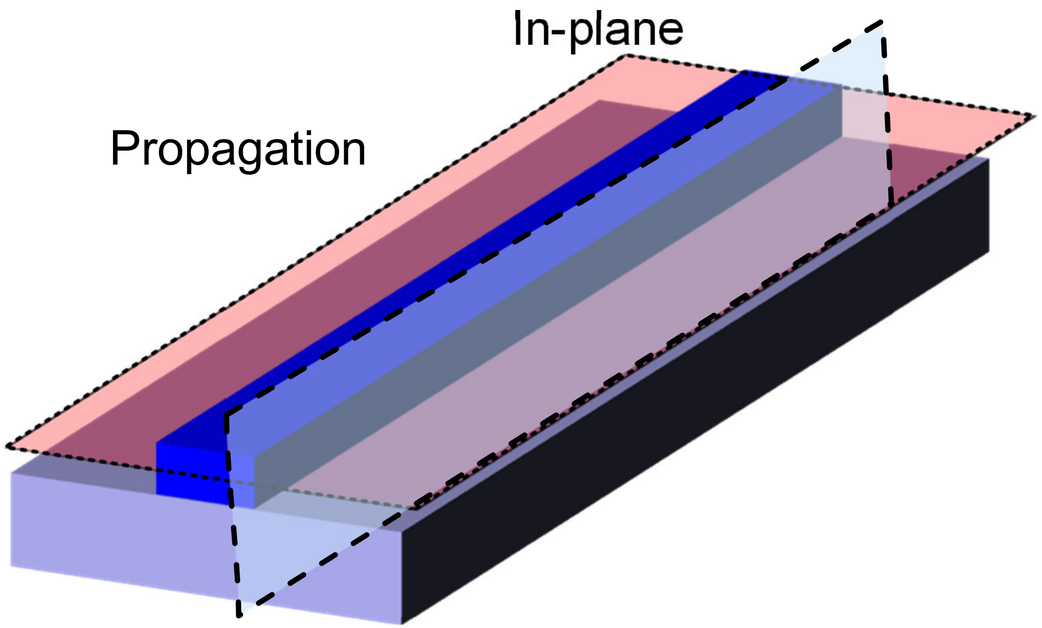
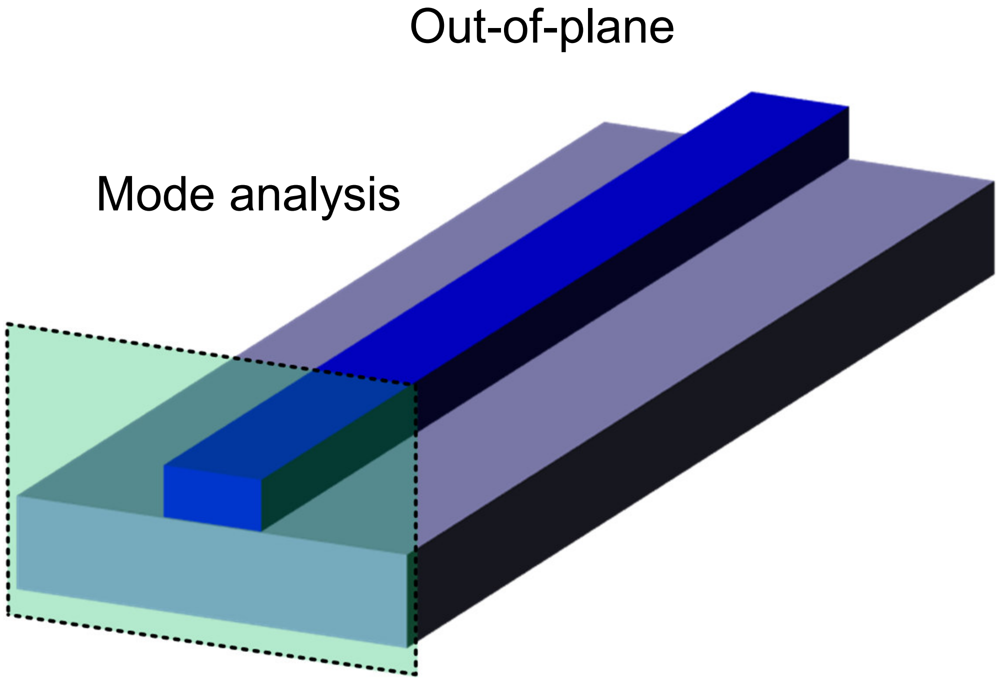
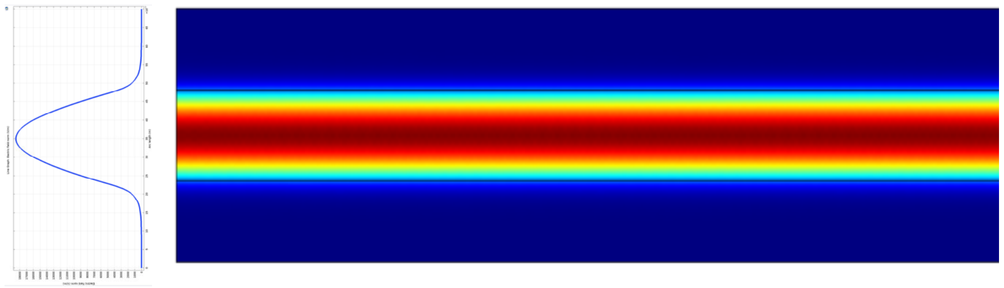
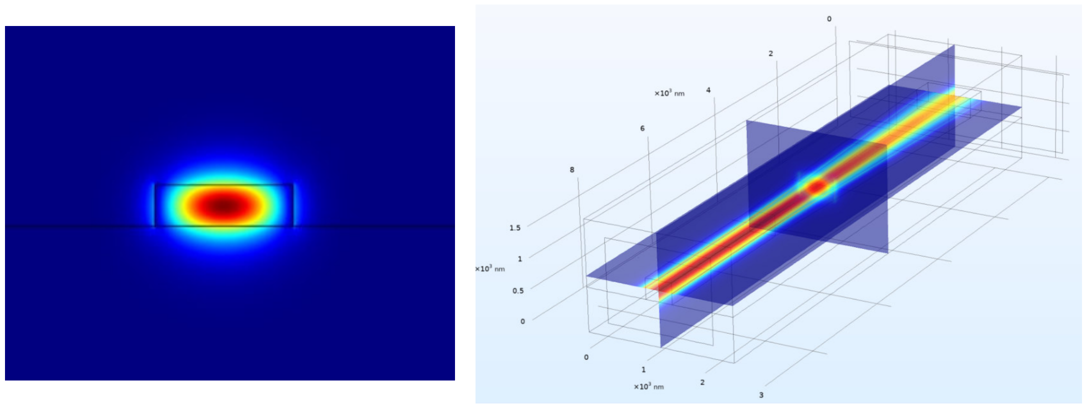
Revision Wave Propagation









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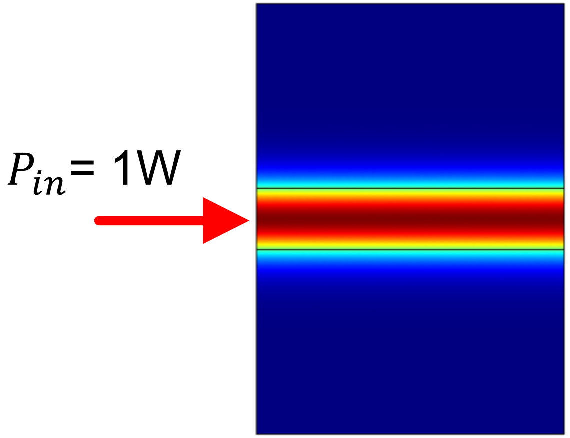
Revision Wave Propagation: Quiz

- We have 1W at the input of our waveguide
- It's straight
- We have lossless material



- Now, the output P_{out} will be
  a) 0.333… W
  b) 0.5 W
  c) 1 W
  d) Impossible to calculate

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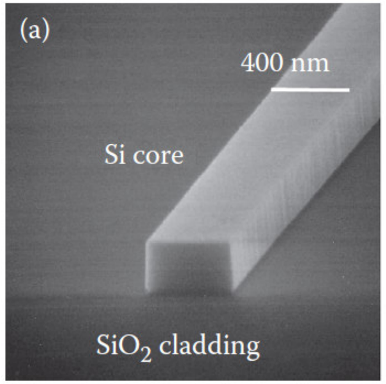
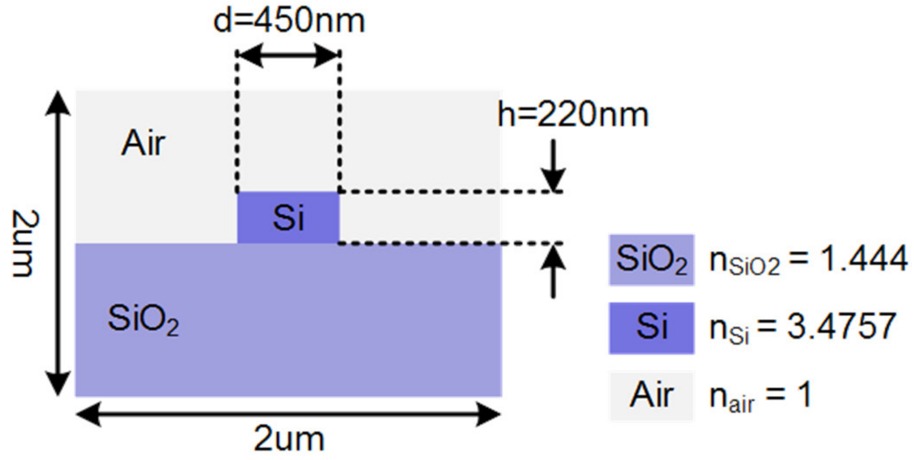
Revision Wave Propagation: Ridge Waveguide

- Multimode silicon ridge waveguide





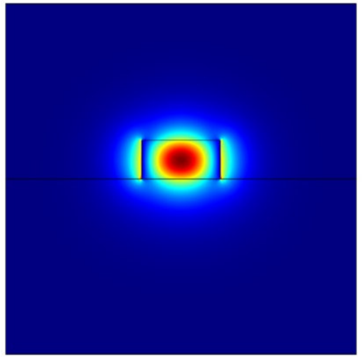
Given:
- $\lambda = 1550$ nm
- $n_{\text{Si}} = 3.47$
- $\text{Si}_{\text{Height}} = 220$ nm
- $\text{Si}_{\text{Width}} = [350,1000]$ nm

Output:
- E-field (guided modes)
- Effective refractive index n_{eff}

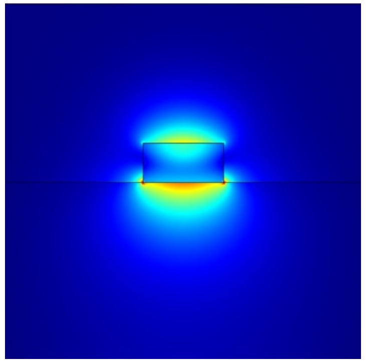
Revision Wave Propagation: Ridge Waveguide

$n_{Si} = 3.4757$
$n_{SiO_2} = 1.44$
$n_{air} = 1$

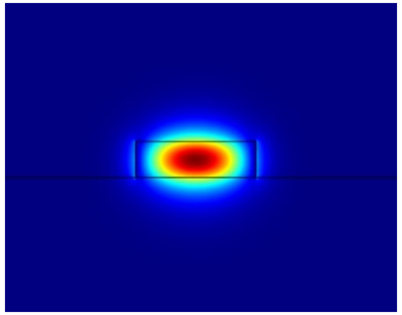
- Single-mode ridge
  - Solution 1: $n_{eff} = 2.2719$



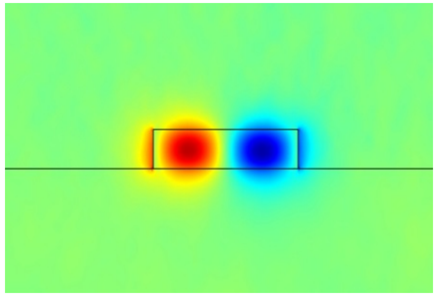
  - Solution 2: $n_{eff} = 1.5422$



- Multi-mode ridge (increased geometry)
  - Fundamental mode



  - Higher order mode



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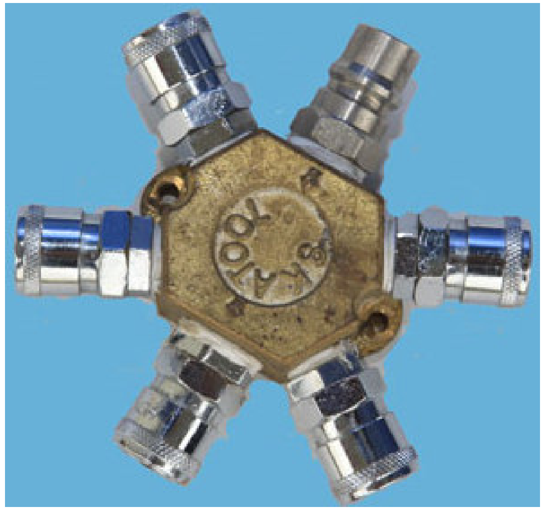
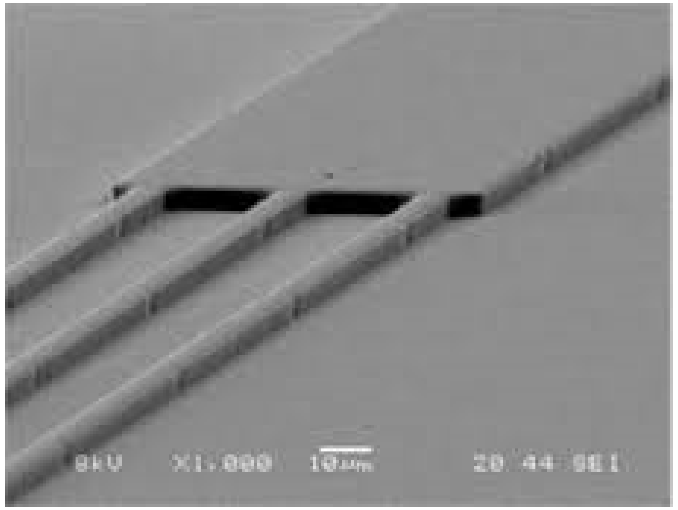
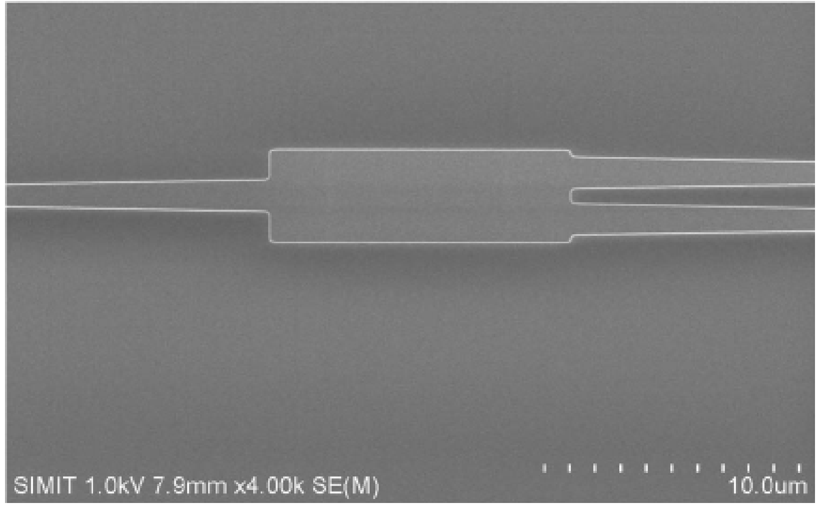
S-Parameters: Motivation

- What happens with systems for multiple inputs and multiple outputs (MIMO)?
- How can it be described mathematically?



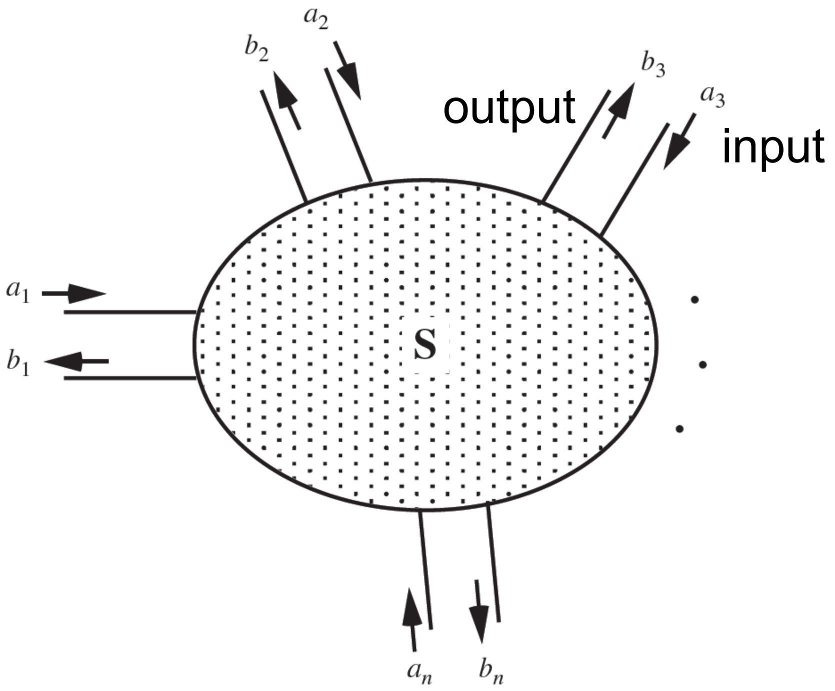




- → We use the S-matrix

S-Parameters for Photonics

- How to characterize our photonics system as whole?
  - Scattering matrix (so called S-matrix)
    - Unitary in lossless systems
    - Diagonal S_{ii} terms are complex valued amplitude reflection coefficients



Superposition:

$$b_i = \sum_{j=1..n} S_{ij} a_j$$

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$$

S-Parameters for Photonics

- How to characterize our photonics system as whole?
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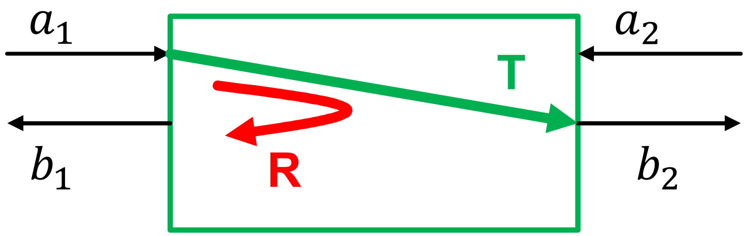
Two input/output ports:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$\boldsymbol{T} =$$

$$\boldsymbol{R} =$$



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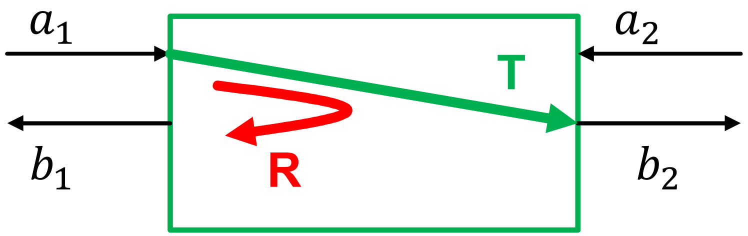
$$\boldsymbol{T} = |S_{21}|^2$$
$$\boldsymbol{R} = |S_{11}|^2$$



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These are the ports we define in COMSOL!

Two input/output ports:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$T = |S_{21}|^2$$
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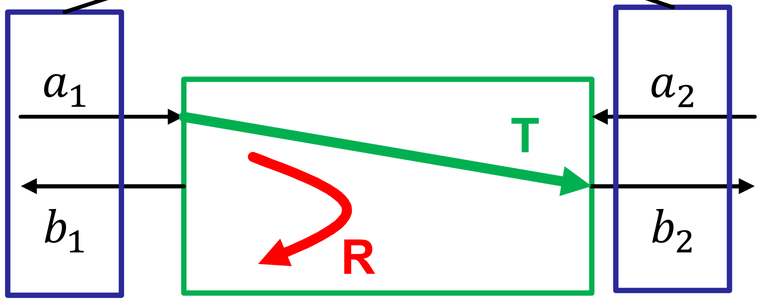

COMSOL calculates this matrix!

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