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Multiphysics Modeling of Electro-Optic Devices

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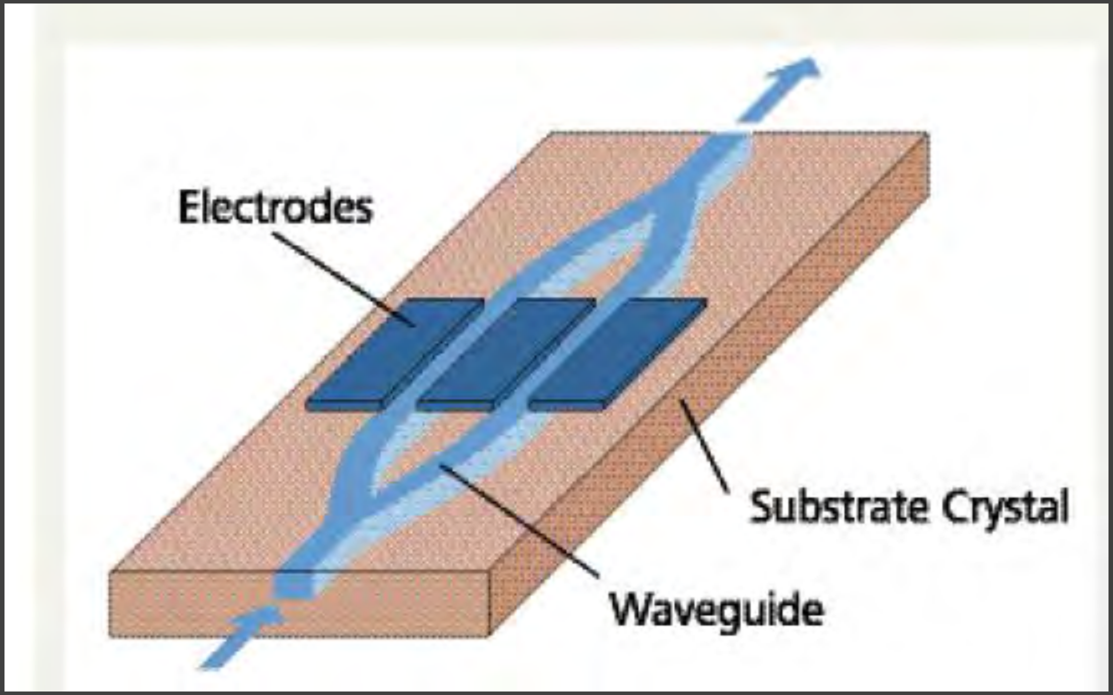
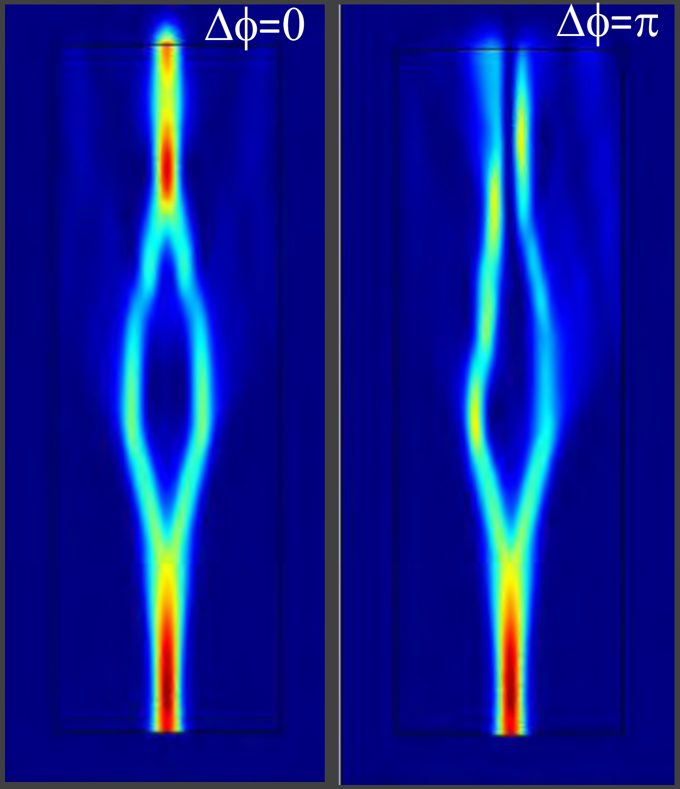
Outline

- Combined RF-Optical mode analysis
  - RF waveguide mode
  - Optical waveguide modes
  - Electro-optic interaction
- Combined wave propagation
  - Paraxial optical propagation
  - DC modulation
  - Time-dependent RF modulation

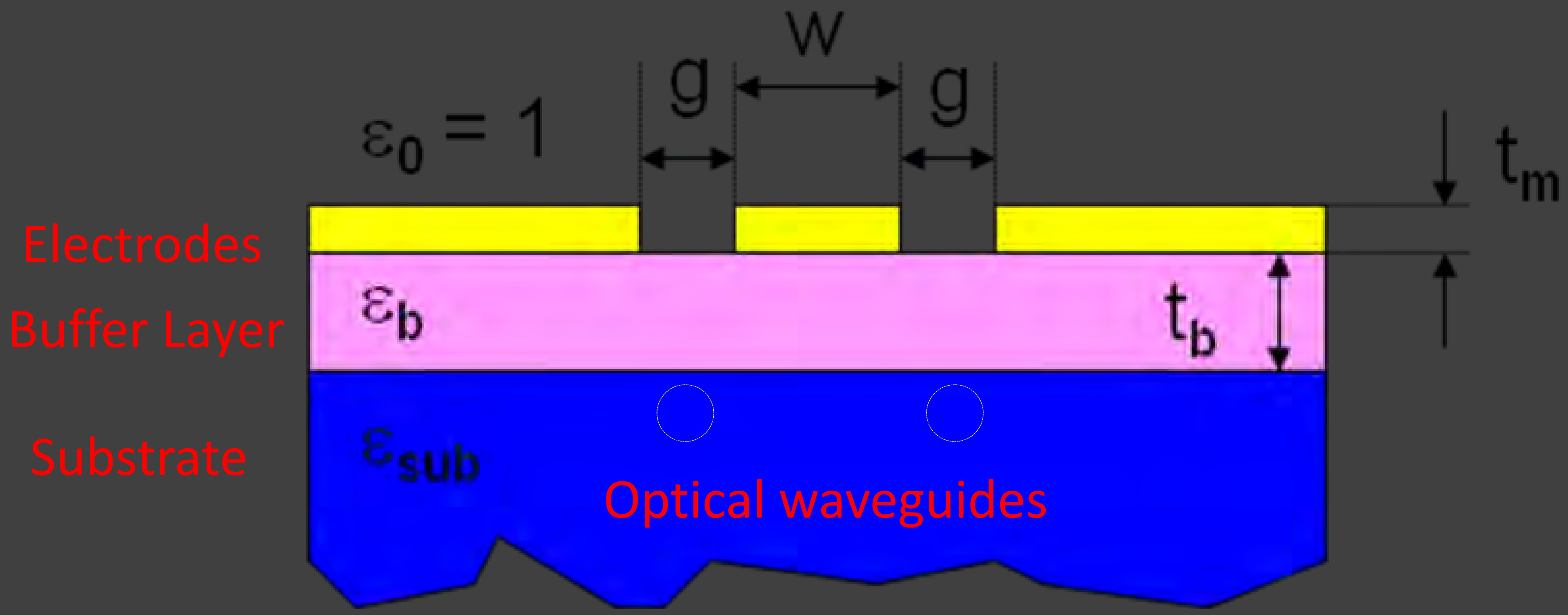
The Workhorse Electro-Optic Device: Mach-Zehnder Interferometer



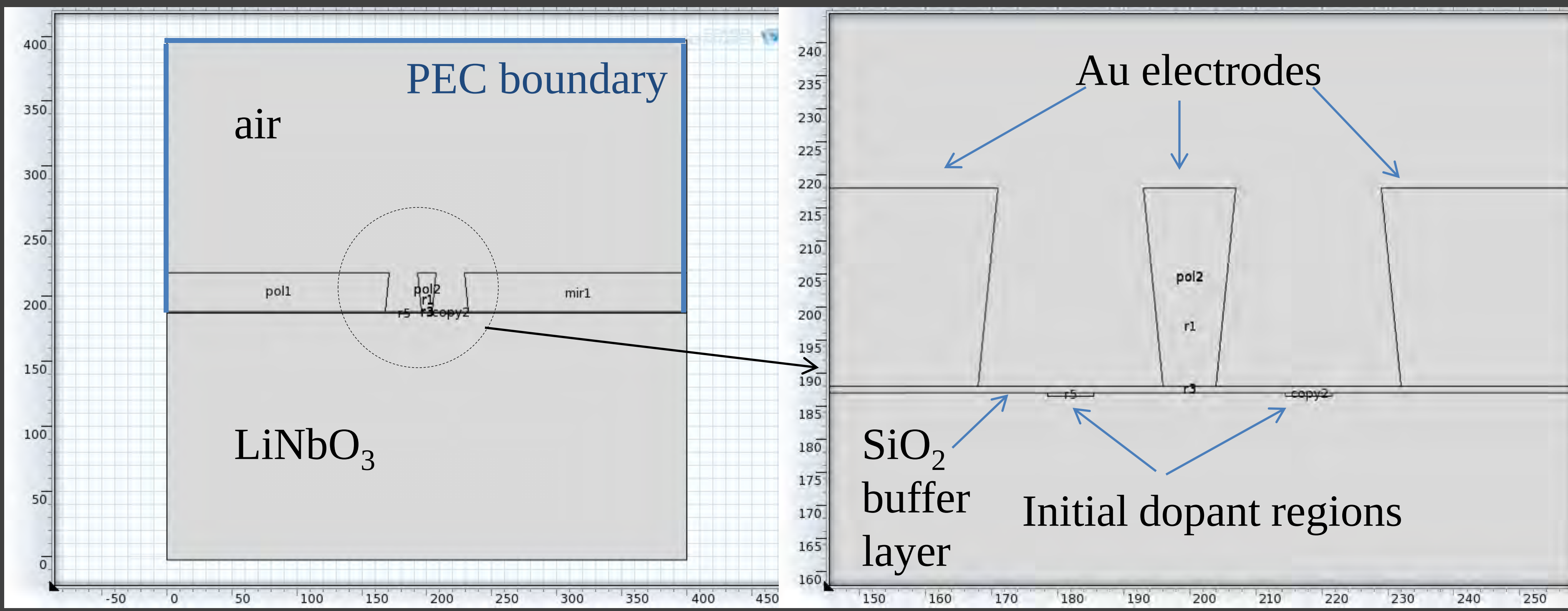
$$P_{out} = \frac{P_{in}}{2}\left[1 + \cos\frac{\pi\left(V_{DC} + V_{RF}\right)}{V_{\pi}}\right]$$



Coplanar Waveguide Structure



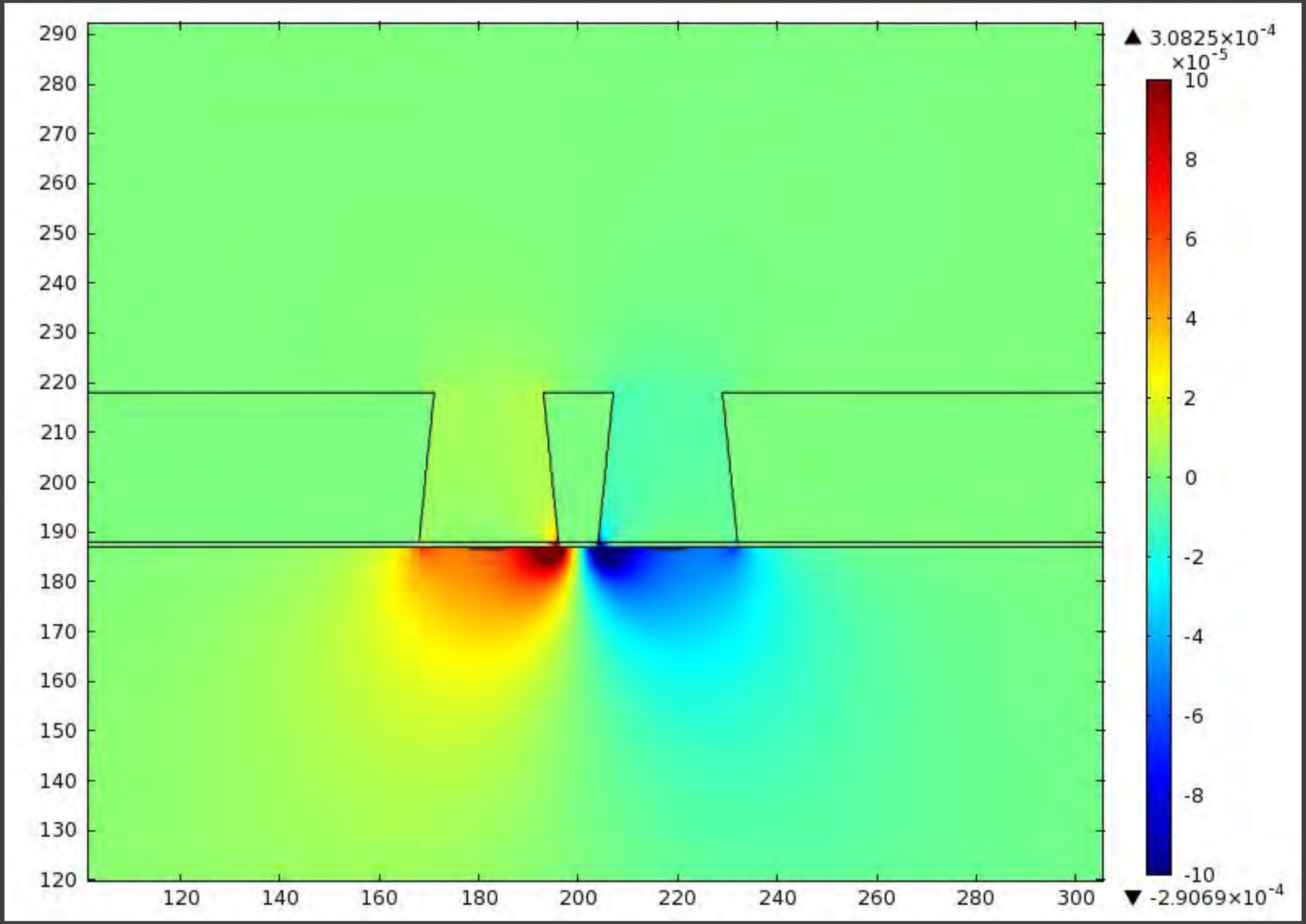
Geometry for RF and Optical Mode Solving in Comsol



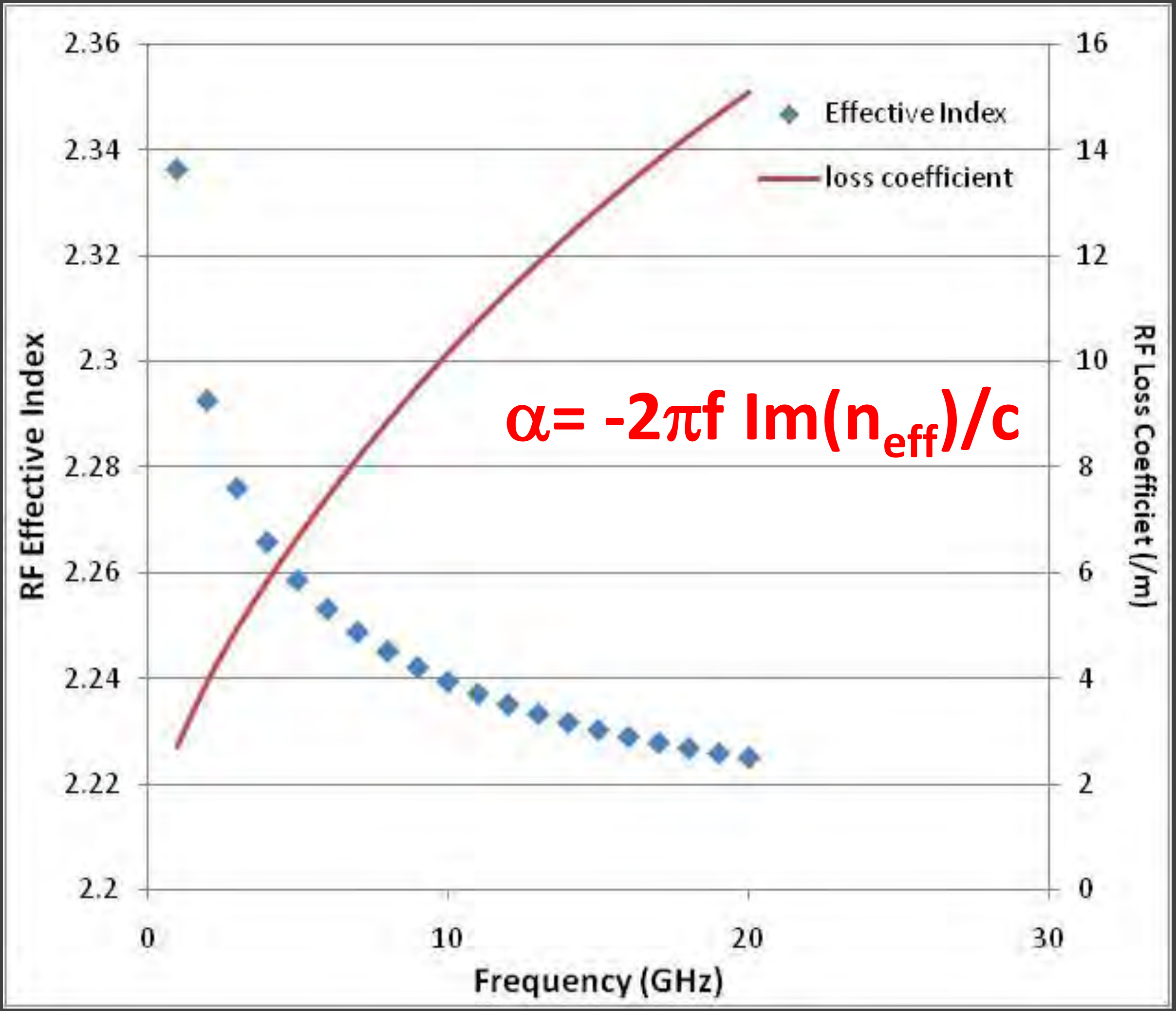
$w = 8\ \mu m$, $g = 28\ \mu m$, $t_m = 30\ \mu m$, $t_b = 1\ \mu m$, $\varepsilon_b = 3.8$, $\varepsilon_{sub} = [28,44,44]$

Optical waveguide profile is defined by diffusion equation

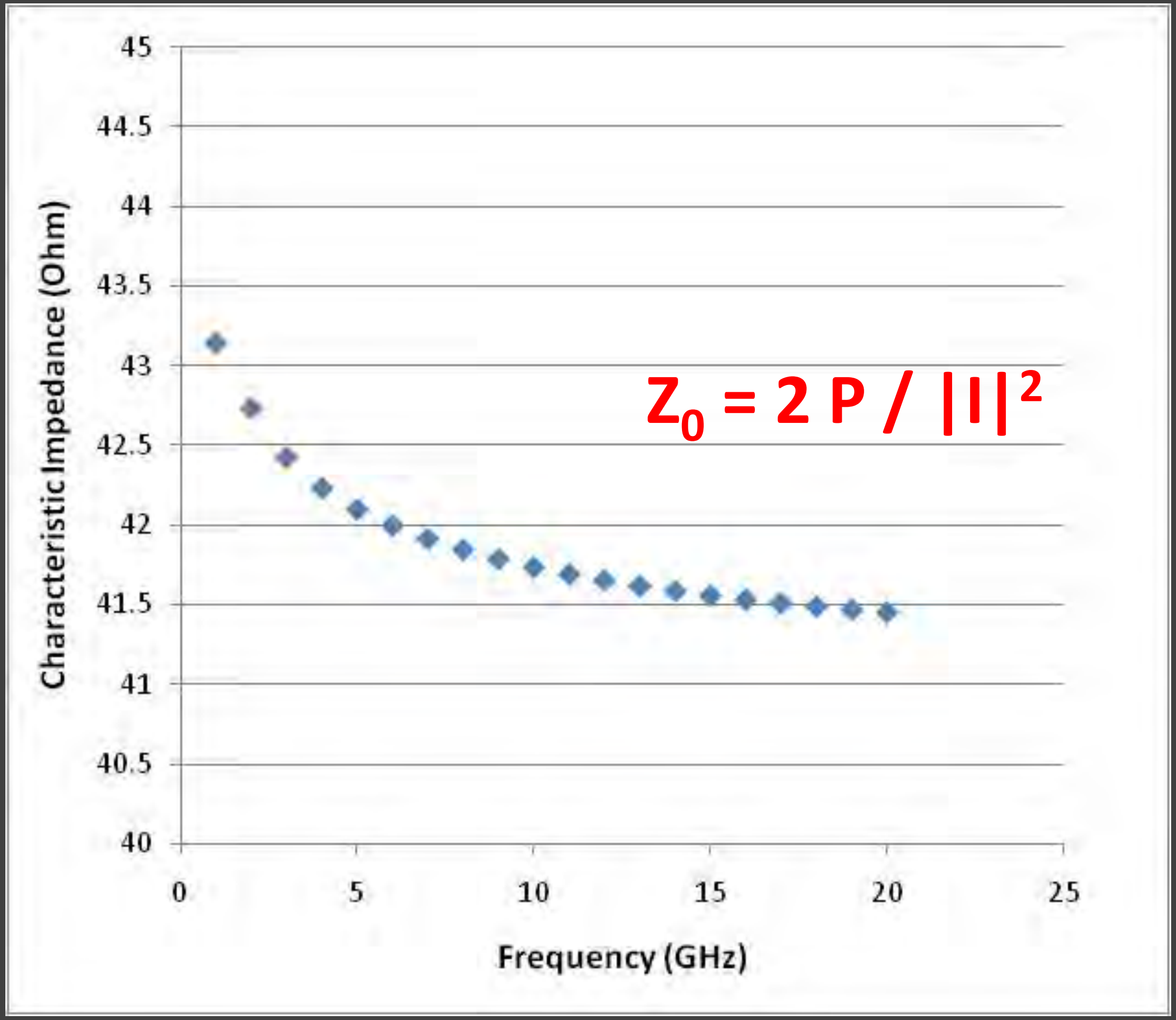
Electric Displacement Field (D_x) of RF Mode



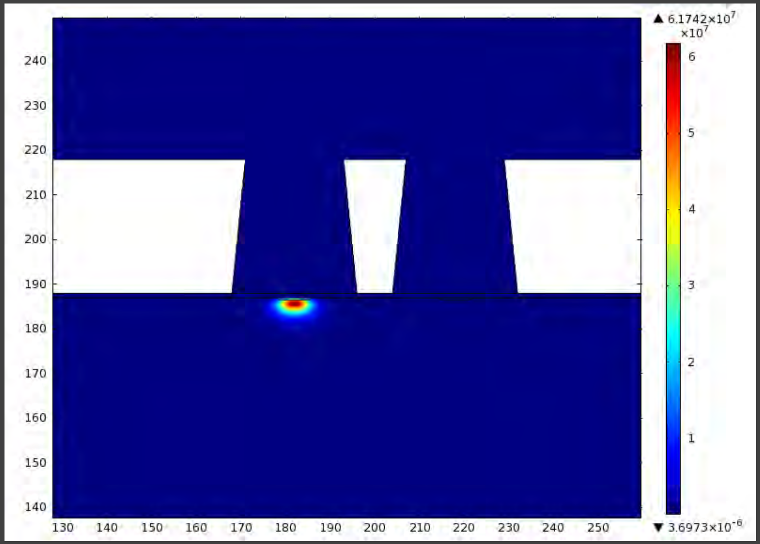
RF Mode Effective Index and Loss vs. Frequency

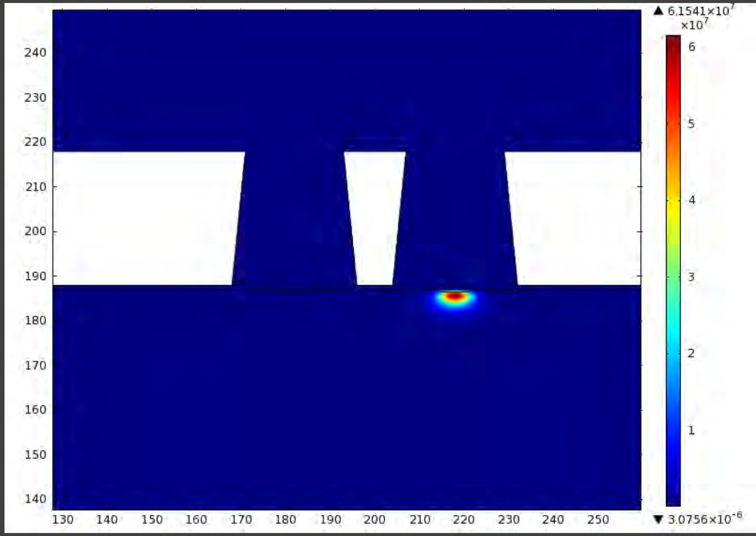


Characteristic Impedance vs. Frequency

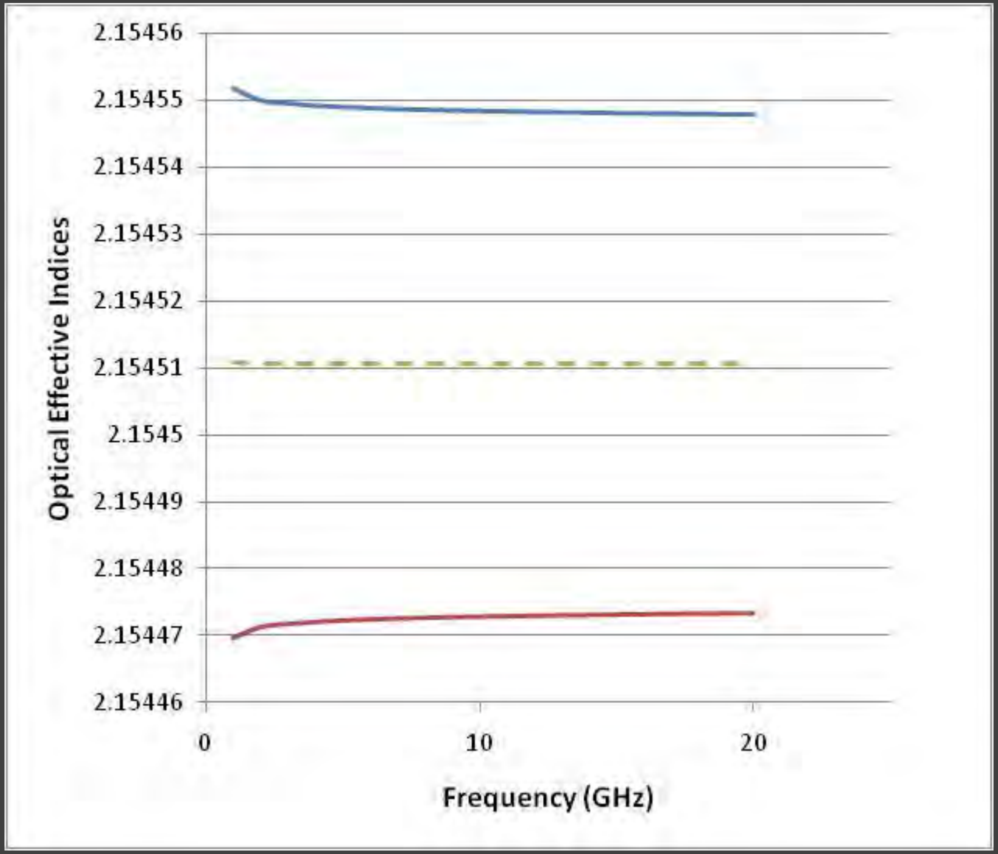


Optical Waveguide Mode Splitting with Applied E-Field

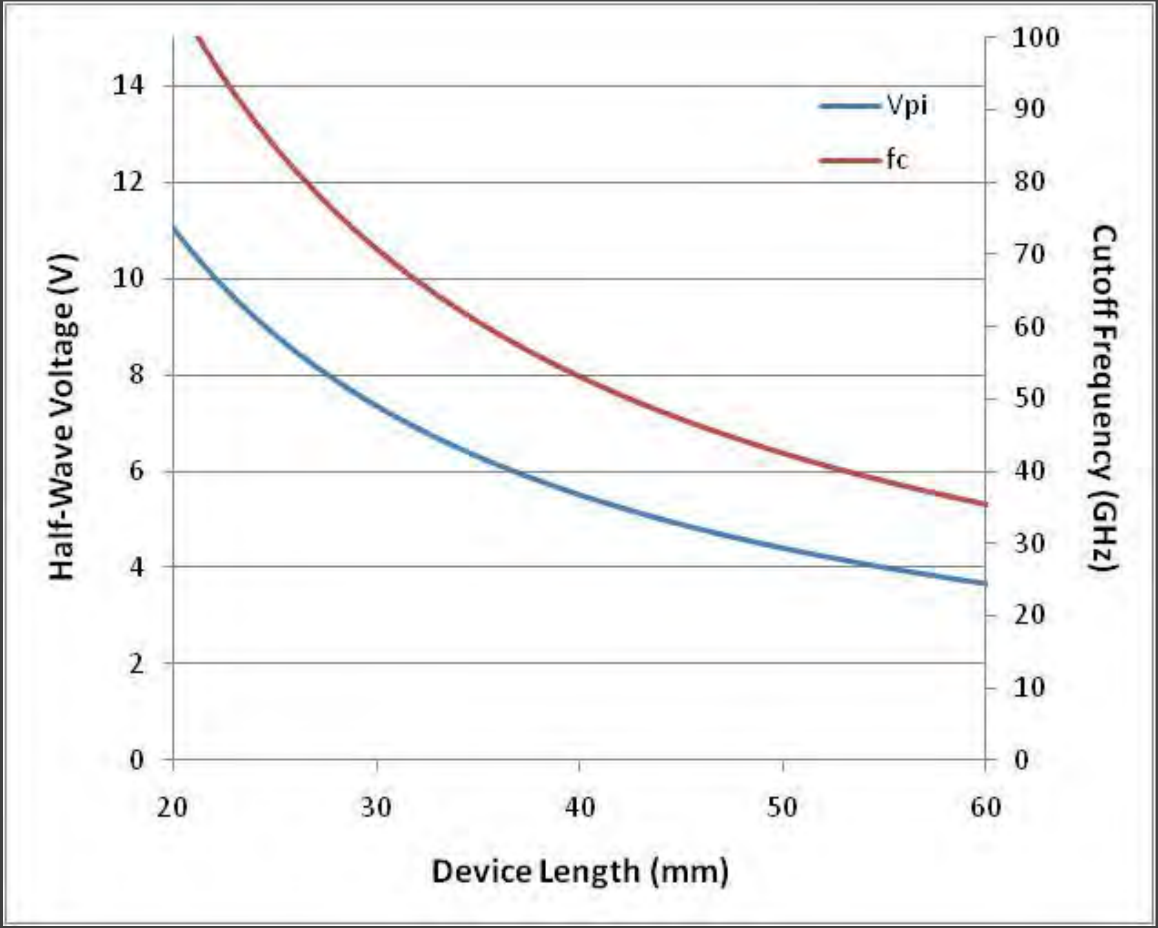




$$\Delta n_{o/e} = -\tfrac{1}{2}\, n_{o/e}^{3} r_{i3}\, E_x$$



Velocity Matching Bandwidth and Half-Wave Voltage vs. Device Length



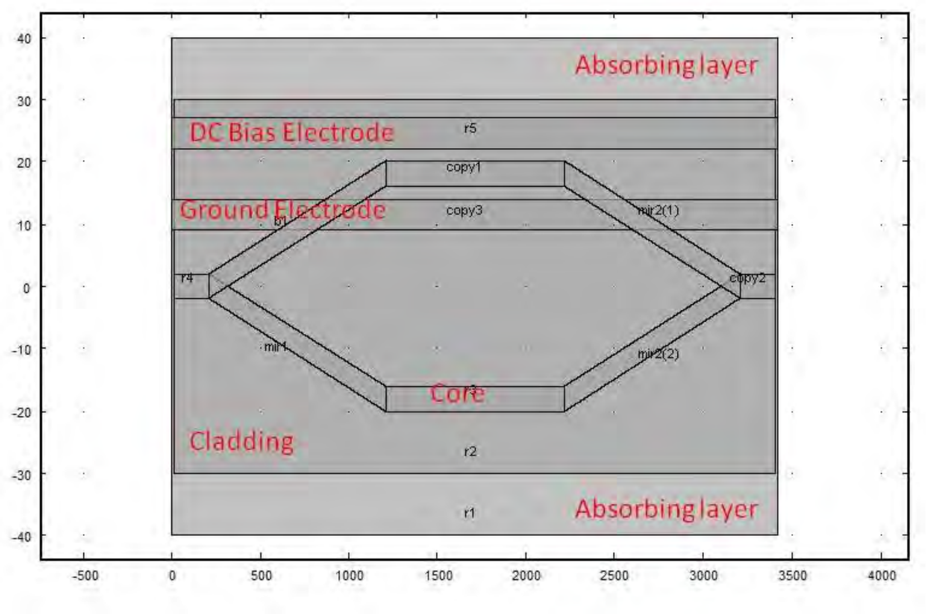
$f_c = c / (2\ n_m\ L\ \delta)$

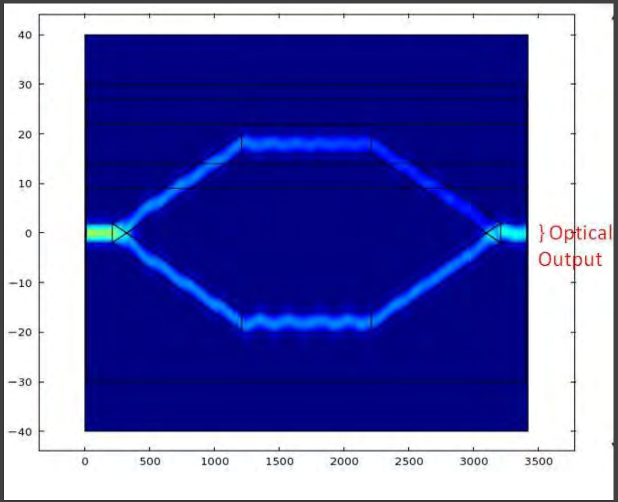
$\delta = 1 - (n_o/n_m)$

$V_\pi = \lambda / [2\ (\Delta n/V)\ L]$

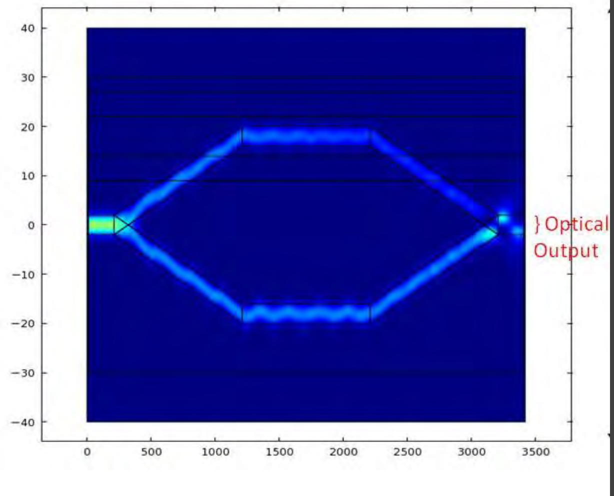
[does not incorporate electrode losses]

Simplified 2D MZI Model with DC Electrodes





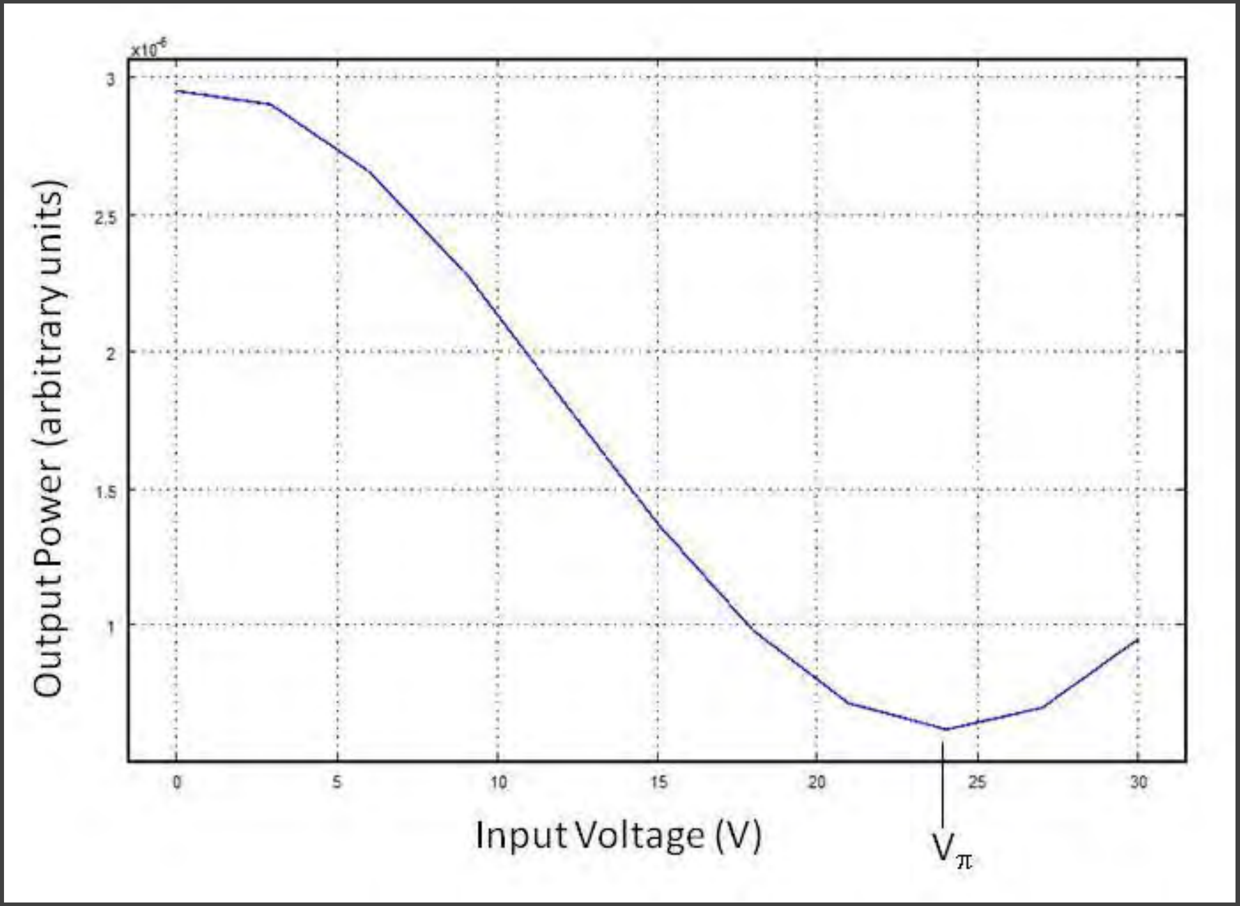
V=0



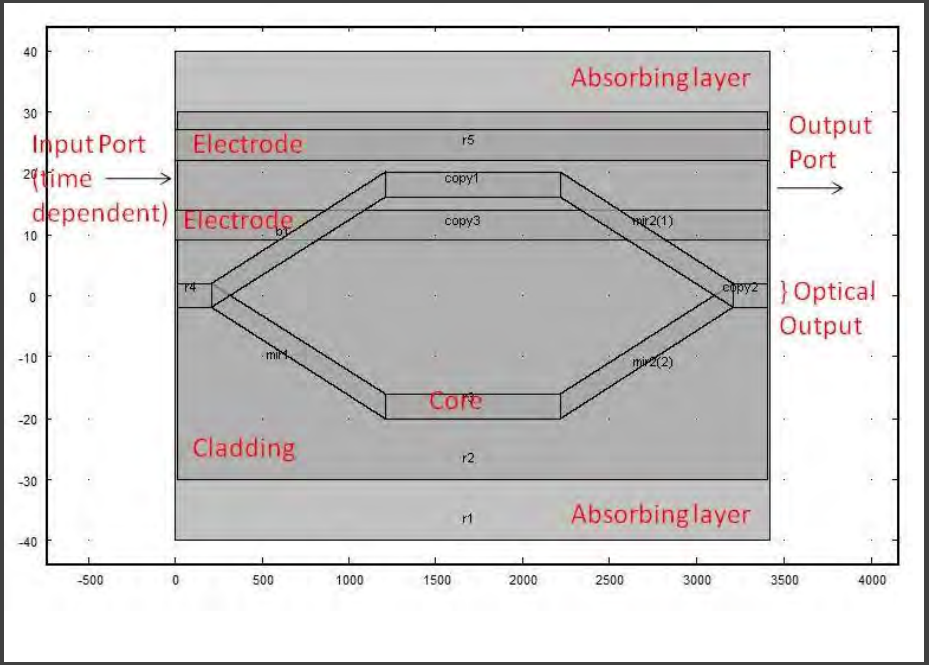
V=24 V

- Scalar Paraxial Wave Equation for Optics
- Electrostatics
- Stationary Solution

Transmission of 2D MZI Model vs. DC Voltage

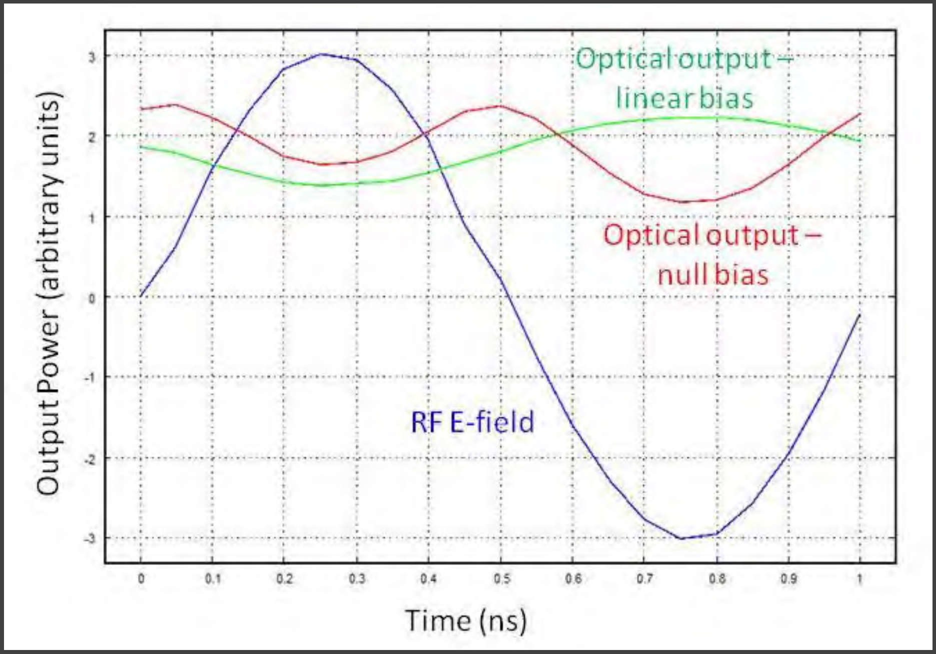


Simplified 2D MZI Model with RF Electrodes



- Time-Dependent EM Wave Propagation for RF
- Scalar Paraxial Wave for Optics (stationary solution at each time step)

Input/Output Waveforms @f_{in} = 1 GHz



Conclusions

- Comsol Multiphysics provides complete capabilities for modeling of electro-optic devices
- With adequate computational resources, 3D EO propagation models are possible