# Plasmonic Waveguides as Transmission Lines

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**Abstract:** We show that simple transmission line models can describe mode propagation in plasmonic waveguides. Despite different metal behavior at near-infrared compared to microwaves, our simulation results agree very well with our impedance model predictions.

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The newly emerging field of plasmonics is seen as a candidate that can solve the size mismatch between nanometer scale electronics and micrometer scale photonics [1]. Metallic waveguides will play a crucial role, and two-conductor guides may be able to confine to dimensions on the scale of 10's of nanometers. We already in the microwave region [2] know how to represent wave guiding regions by transmission lines of given impedances and waveguide discontinuities by lumped circuit elements. Metals behave quite differently in the optical domain, however, and so far design of such guides typically requires computationally expensive techniques such as finite difference time domain (FDTD) approaches. Here, we show that transmission line models can be used for plasmonic waveguides operating in the telecommunication wavelength range by use of a new approach to the concept of impedance of such structures, thus restoring a simple conceptual model for such waveguides at optical frequencies

To test the validity of impedance models [3] for plasmonic waveguides, we numerically [4] simulated mode propagation through two different waveguide geometries: the 2D metal-insulator-metal (MIM) waveguide [5], and the 3D slot waveguide [6]. Each different section of the waveguide is modeled as a transmission line with a characteristic impedance $Z=k/(\omega\varepsilon_d)$ where $k$ is the mode propagation vector, $\omega$ is the angular frequency and $\varepsilon_d$ is the permittivity of the dielectric region. Transmission through the structure is calculated by considering a series connection of transmission lines with different characteristic impedances.

Comparison of the numerical results with the impedance model show very good agreement. The impedance model calculations are orders of magnitude faster than the numerical simulations, and can be used to predict the transmission and reflection of modes without the use of extensive numerical calculations.

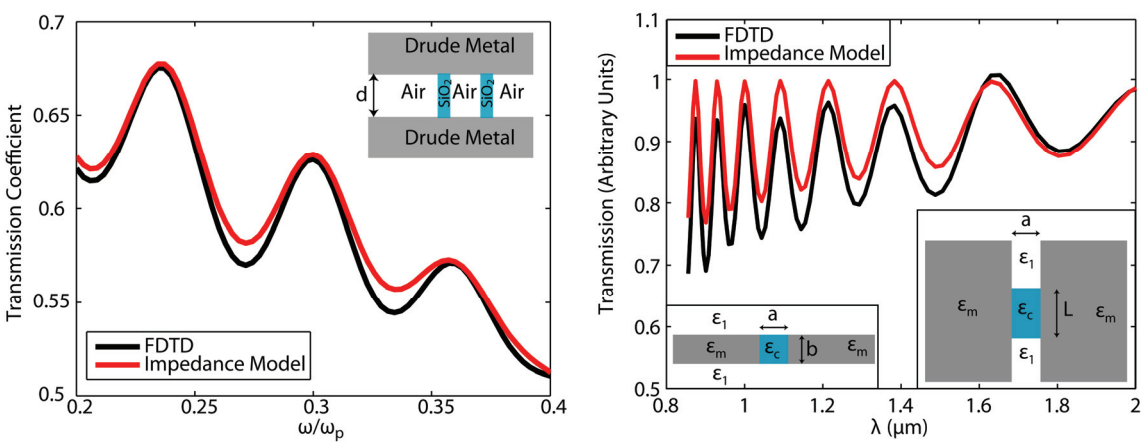


Fig. 1. Comparison of numerical results with the predictions of the impedance model for the 2D MIM waveguide (left) and the 3D slot waveguide (right). For the left figure, a lossy single pole Drude model was used for the metal region, $\omega$ denotes angular frequency, $\omega_p$ denotes plasmon frequency, $\varepsilon_{air}$=1.0, $\varepsilon_{oxide}$=2.0736, $d = 0.5\lambda_p$ where $\lambda_p$ is the plasmon wavelength. For the figure on the right, a lossless single pole Drude model was used for Au with $\omega_p$=1.2x10$^{16}$ rad/sec, $a$=50nm, $b$=80nm, $L$=800nm, $\varepsilon_1$=4, $\varepsilon_c$=12.25. The insets show the cross sections of the waveguides.

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