Equivalent Transverse Electromagnetic Modes and Effective medium inside Waveguide

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Waveguide is one of the important transmission lines, especially for high operating frequency ranges, e.g., millimeter wave or THz, with the merits of high shielding effect and low radiation loss. In the state-of-art techniques using waveguide, the propagating mode is usually utilized to design various building blocks and elements, such as filters, couplers, power dividers, and so on. Here, we move our attentions to the cutoff and evanescent modes, which are usually not used in the waveguide design, generating various interesting techniques based on the waveguide theory. And we name such modes as equivalent transverse electromagnetic (TEM) modes, as shown in Fig. 1(a), and with the effective relative permittivity controlled by the boundary conditions, as illustrated in Fig. 1(b).

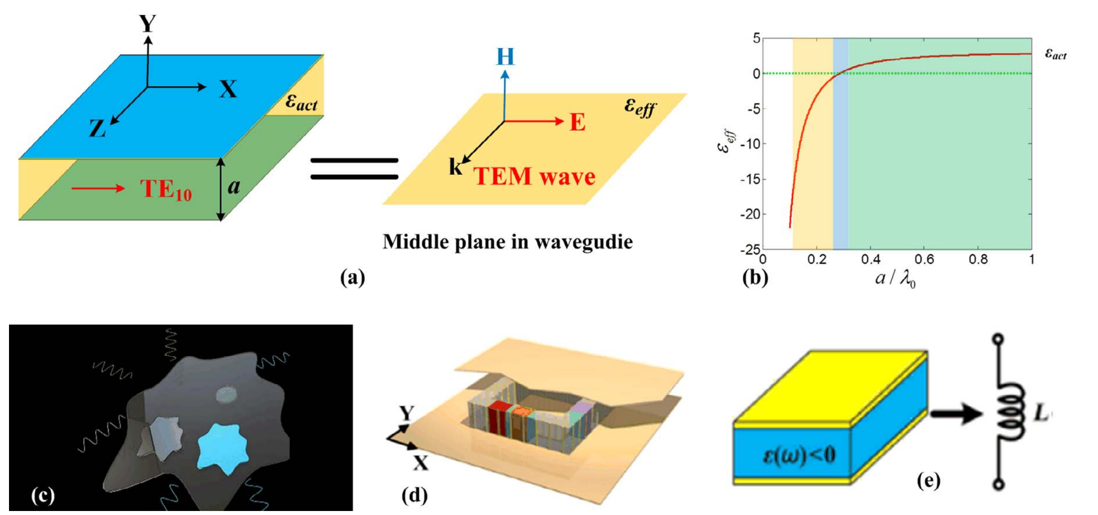

Figure 1. The general concept of Equivalent TEM modes inside waveguide: (a) TEM mode in the middle plane of waveguide, (b) Effective permittivity of the equivalent TEM mode in (a). Three applications: (c) photonic doping, (d) waveguide lumped circuits, and (e) capacitor-inspired inductor

In this talk, we introduce the equivalent TEM mode to analysis the TE_{10} mode inside waveguide. The equivalent TEM wave is in the middle plane of the waveguide, with the effective relative permittivity valuing at $\varepsilon_{eff} = \varepsilon_{act} - \left(\pi^2 c^2\right) / \left(a^2 \omega^2\right)$, indicating the different modes of the waveguide. Based on the cutoff mode with $\varepsilon_{eff} \approx 0$, a theory of microscopic doping is built with the assistant of epsilon-near-zero materials, tuning the effective permeability with different dopants, as indicating in Fig. 2(c). As another new technique shown in Fig. 2(d), the evanescent and propagating modes with $\varepsilon_{eff} < 0$ or $\varepsilon_{eff} > 0$ are adopted to build inductors and capacitors, which can be easily integrated with regular waveguides, coined the terminology of waveguide lumped circuits. The third application is to design inductors with the look of capacitors based on the effective negative medium inside the waveguide, as indicated in Fig. 1(e).