Waveguide-Based Metatronics

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Plasmonic phenomena, such as surface plasmon polariton (SPP) and the local surface plasmon resonance (LSPR), occur in structures that involve materials with negative permittivity (i.e., epsilon-negative (ENG) media). In the infrared and visible regions of the electromagnetic spectrum, materials with ENG properties are available. The examples include noble metals such as Ag and Au, transparent conducting oxides (TCO) such as indium tin oxide (ITO), and silicon carbide (SiC). However, in the low frequency regimes such as radio frequency (RF) and microwaves metals behave effectively as very good (and approximately perfect) conductors. Therefore, effects related to the plasmonic optics may not be naturally observable in the RF and microwave domains. Nevertheless, it is possible to engineer microwave metamaterials with plasmonic properties. One of the methods is the use of structural dispersion in the guided-wave structures [C. Della Giovampaola and N. Engheta, "Waveguide Metamaterials", presented at the 7th International Congress on Advanced Electromagnetic Materials in Microwave and Optics (Metamaterials 2013), Bordeaux, France, September 16-21, 2013). Using this technique, in our earlier work we showed how one could achieve some of the plasmonic features, e.g., SPP, cloaking, ENZ, and related effects using materials all with positive permittivity functions.

In the present work, we utilize the methodology of waveguide metamaterials to develop the concept of metatronics using all positive-permittivity materials. The field of metatronics deals with optical lumped nanocircuit paradigm, in which nanostructures with different materials, when selected properly and arranged next to one another judiciously, behave as lumped circuit elements such as optical capacitors, optical inductors and optical resistors. However, in such assembly of nanoparticles, materials with negative permittivity would be needed if one needed to have a metatronic inductor. In our current work, we have extended the notion of metatronics to waveguide metamaterials, showing that using the waveguide dispersion we can achieve effective lumped capacitors, lumped inductors, lumped resistors, and ENZ insulators all using materials with positive permittivity. We have utilized extensive numerical simulations to demonstrate the various functionalities of metatronics in the waveguide environment. We have also explored how the material loss affects some of the wave features in waveguide metamaterials and metatronics. In this talk, we will present some of our most recent results on this ongoing effort, and will discuss their physical insights.