



Contribution ID: 600  
compétition)

Type: Oral (Student, In Competition) / Orale (Étudiant(e), inscrit à la

## Generalized Waveguide Theory including Electromagnetic Duality

*Wednesday, June 17, 2015 2:30 PM (15 minutes)*

We introduce a general theory for describing modes and characteristics of linear, homogeneous, isotropic waveguide materials and metamaterials with slab and cylindrical geometries.

Our theory accommodates exotic media such as double-negative-index and near-zero-index metamaterials as special cases, and we demonstrate that our general theory exhibits electromagnetic duality that would arise if we were to incorporate magnetic monopoles into the media.

To ensure manifest electromagnetic duality, we construct generic electromagnetic susceptibilities for the constituent materials using a generalized Lorentz-Drude model that manifests this duality, and our model reduces to standard cases in appropriate limits.

Using our theory, we present and explain intriguing modes arising in waveguides that exploit such exotic materials and metamaterials.

In particular, we show that, in slab and cylindrical hollow-core metamaterial waveguides, exchanging electric and magnetic material properties leads to the exchange of transverse magnetic and transverse electric modes, which suggests a good test of the potential duality of waveguides.

We appreciate financial support from the NSERC and AITF.

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**Session Classification:** W2-10 Spectroscopy and Optics (DAMOPOC) / Spectroscopie et optique (DPAMPC)

**Track Classification:** Division of Atomic, Molecular and Optical Physics, Canada / Division de la physique atomique, moléculaire et photonique, Canada (DAMOPOC-DPAMPC)