

Transmission line analysis of optical metamaterials

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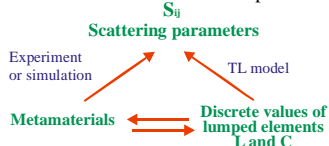
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Motivation

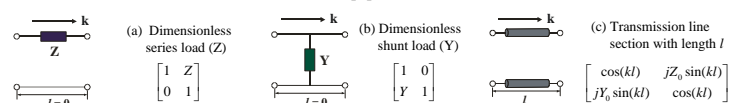
- Apply transmission line (TL) theory to metamaterials at optical frequencies
- Study optical responses of three TL circuits and their effective material parameters
- Construct TL models for cut wires, cut-wire pairs, metallic mesh and mesh pairs based on the simulated results and the features of the material parameters of the TL circuits

Introduction

- Relationship of TL circuit with simulation and experiments: S-parameters

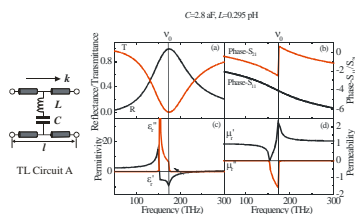


- TL Elements and their ABCD matrices [1]



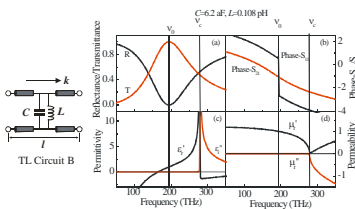
- ABCD matrix \rightarrow S-parameters \rightarrow effective μ_r and ϵ_r [2]

Optical responses of typical TL equivalent circuits



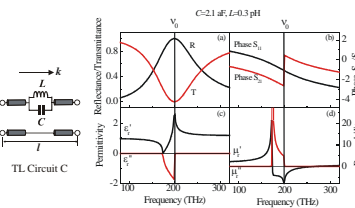
Circuit A: a dimensionless admittance composed of a series combination of C and L loading a TL section.

Stopband element exhibiting a band-rejection resonant behavior and a π -jump on phase- S_{21} at ν_0 . In addition, ϵ_r' displays a resonant behavior, and μ_r' displays an antiresonant behavior [3]. Frequency ν_0 corresponds to a minimum and maximum on ϵ_r' and μ_r' , respectively.



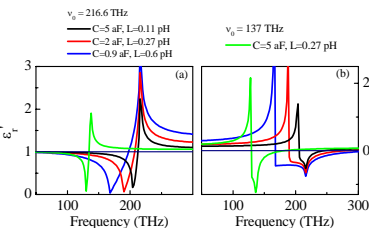
Circuit B: a dimensionless admittance composed of a parallel combination of C and L shunt loading a TL section.

Passband element exhibiting a band-rejection resonant behavior and a π -jump on phase- S_{11} at ν_0 . In addition, ϵ_r' displays a resonant behavior, and μ_r' displays an antiresonant behavior. Frequency ν_0 corresponds to a minimum and maximum on ϵ_r' and μ_r' , respectively.

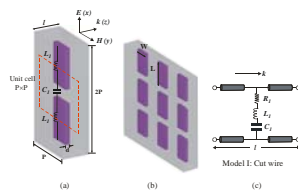


Circuit C: a dimensionless impedance composed of a parallel combination of C and L loading a TL section.

Stopband element exhibiting a band-rejection resonant behavior and also a π -jump on phase- S_{21} at ν_0 . In contrast to Circuit A, ϵ_r' displays an antiresonant behavior, and μ_r' displays a resonant behavior. Frequency ν_0 corresponds to a maximum and minimum on ϵ_r' and μ_r' , respectively.

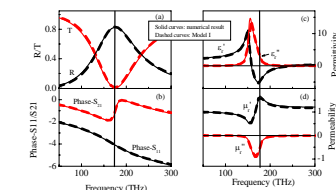


TL model for cut wires



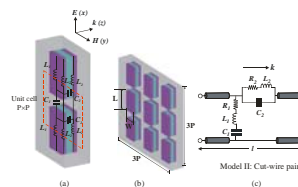
Schematic of Ag cut wires. (a) Two unit cells and (b) the overall structure; (c) TL model for the cut wires [4]

\rightarrow The TL Model I represents the cut wires well



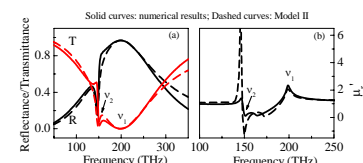
(a-b) R/T-spectra from the TL model and CST simulator, respectively; (c-d) Effective material parameters retrieved from the TL model and the CST MWS, respectively

TL model for cut-wire pairs



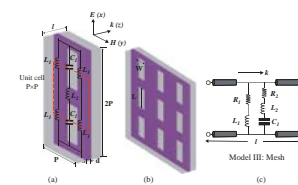
Schematic of Ag cut-wire pairs. (a) Two unit cells and (b) the overall structure; (c) TL model for the cut-wire pairs

\rightarrow The TL II model represents the cut-wire pairs well



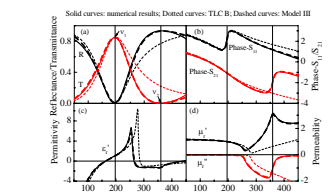
(a) R/T-spectra from the TL model and CST MWS, respectively; (b) Effective permeability retrieved from the TL model and the CST MWS, respectively

TL model for metallic Mesh



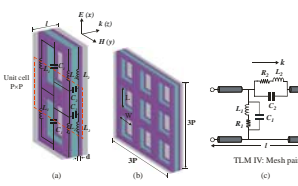
Schematic of Ag mesh. (a) Two unit cells and (b) the overall structure; (c) TL model for the Ag mesh

\rightarrow TL Model III represents the mesh structure very well



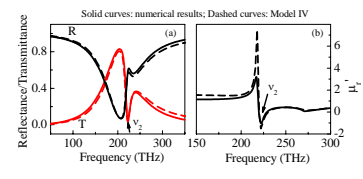
(a-b) R/T-spectra from the TL model and CST MWS, respectively; (c-d) Effective material parameters retrieved from the TL model and the CST MW simulator, respectively

TL model for mesh pairs



Schematic of Ag mesh pair structure. (a) Two unit cells and (b) the overall structure; (c) TL model for the mesh pair

\rightarrow TL Model IV can represent the metallic mesh pair well.



(a) R/T-spectra from the TL model and CST MWS, respectively; (b) Effective permeability retrieved from the TL model and the CST MW simulator, respectively

Circuit parameters for calculating the EM response of the TL models

	L_1 (pH)	C_1 (aF)	R_1 (Ω)	L_2 (pH)	C_2 (aF)	R_2 (Ω)
Model I	0.295	2.8	18			
Model II	0.169	3.8	2.5	0.021	55	0.5
Model III	0.148	3.12	8.0	0.063		7.0
Model IV	0.055	11.0	1.1	0.0245	21	0.5

Conclusion

- TL theory is a powerful analysis tool for metamaterial at optical frequencies
- Constructed TL models for cut wires, cut-wire pairs, metallic mesh and mesh pairs can represent the structures very well
- Physical insight into the structures are gained respect to the resonant behaviour of the effective μ and ϵ , the bandwidth and the amplitude of the negative μ .

Acknowledgement

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References

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