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Photonics & Electromagnetics Research Symposium
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Modelling asymmetric two-port reciprocal microwave structures by means of compact equivalent circuits

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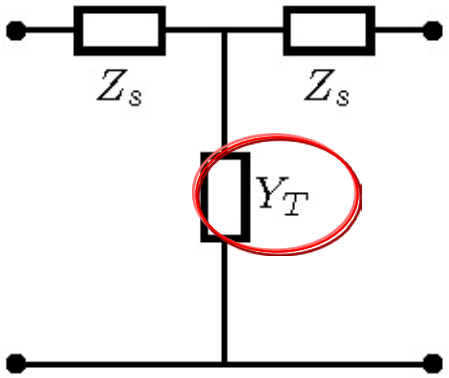
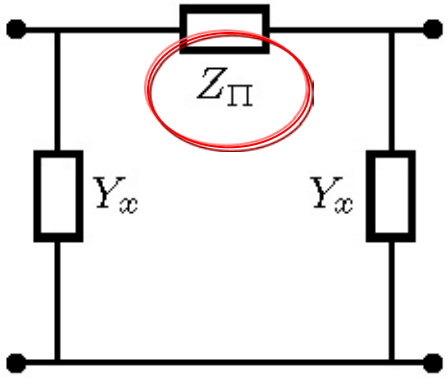
Overview

- Background:
  - Symmetric two-ports and lattice networks
  - Classic approach: Felsen-Oliner equivalent circuit
- Lattice-based non-symmetric equivalent circuits:
  - Transformer-lattice equivalent circuit (TEC)
  - Eigen-values based equivalent circuit (EEC)
  - Comparison between TEC and EEC
- Conclusions

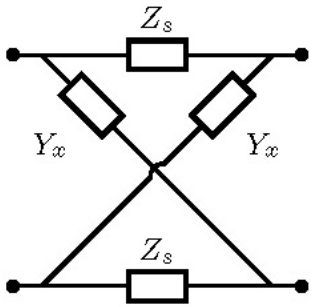
Symmetric two-ports (1): π and T networks

"In contrast, the π or T network equivalent of a complicated four-terminal network will sometimes require negative circuit elements in some of the arms, and hence be physically unrealizable"(1)





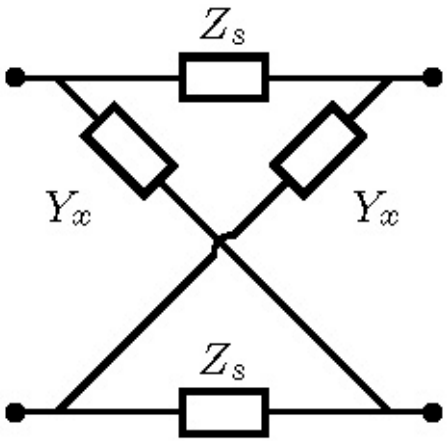
$$Y_T^{-1} = Y_x^{-1} - \frac{Z_s}{2}$$



(1) F.E. Terman, "Radio Engineers' Handbook", McGraw-Hill, 1943.

Symmetric two-ports (2): the lattice network

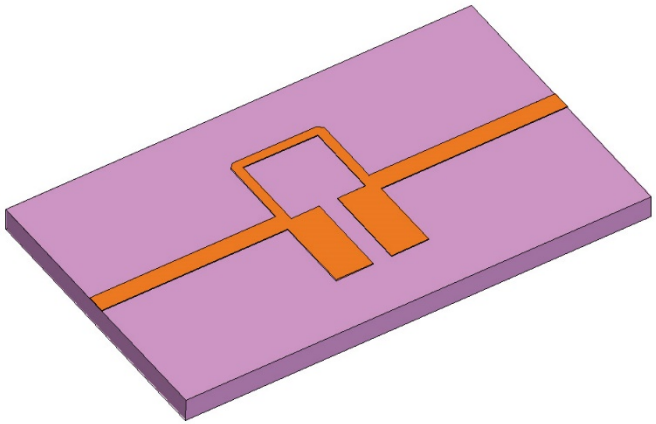
"It is possible to represent any symmetrical (reciprocal and lossy) four-terminal network by a lattice having physically realizable impedance arms"[1]



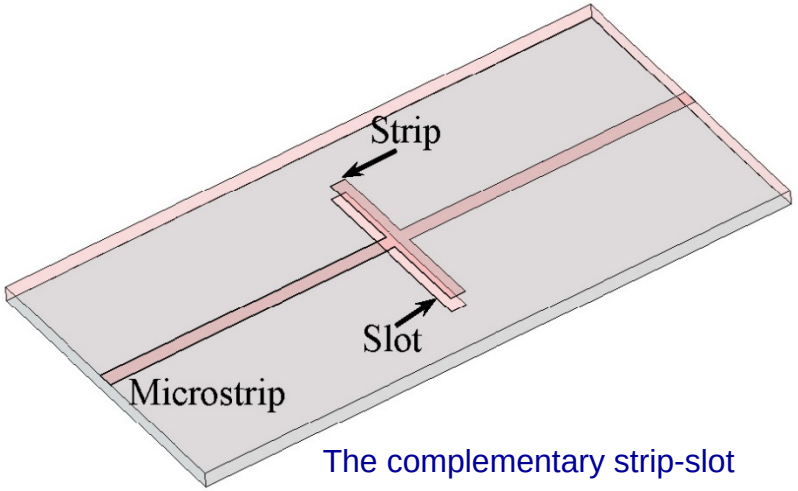
$$Z_s = Z_{11} - Z_{12}$$
$$Y_x = Y_{11} + Y_{12}$$

[1] F.E. Terman, "Radio Engineers' Handbook", McGraw-Hill, 1943.

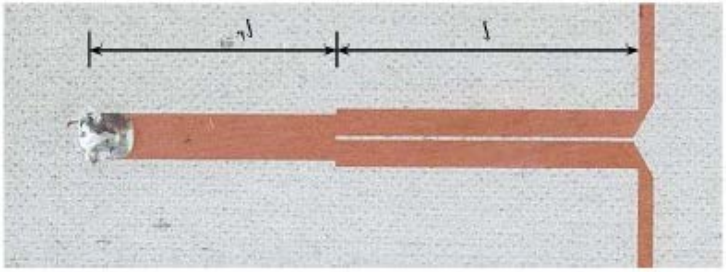
Symmetric two-ports (3): modelling examples[2]

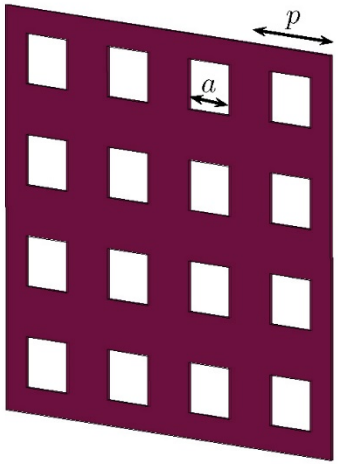


The stepped-impedance hair-pin resonator



The complementary strip-slot





Frequency-selective surface

[2] E. Abdo-Sánchez *et al.*, "Circuit Modelling of Electromagnetic Structures by Means of the Lattice Network," Proc. XI EIEC, 93-96, 2016.

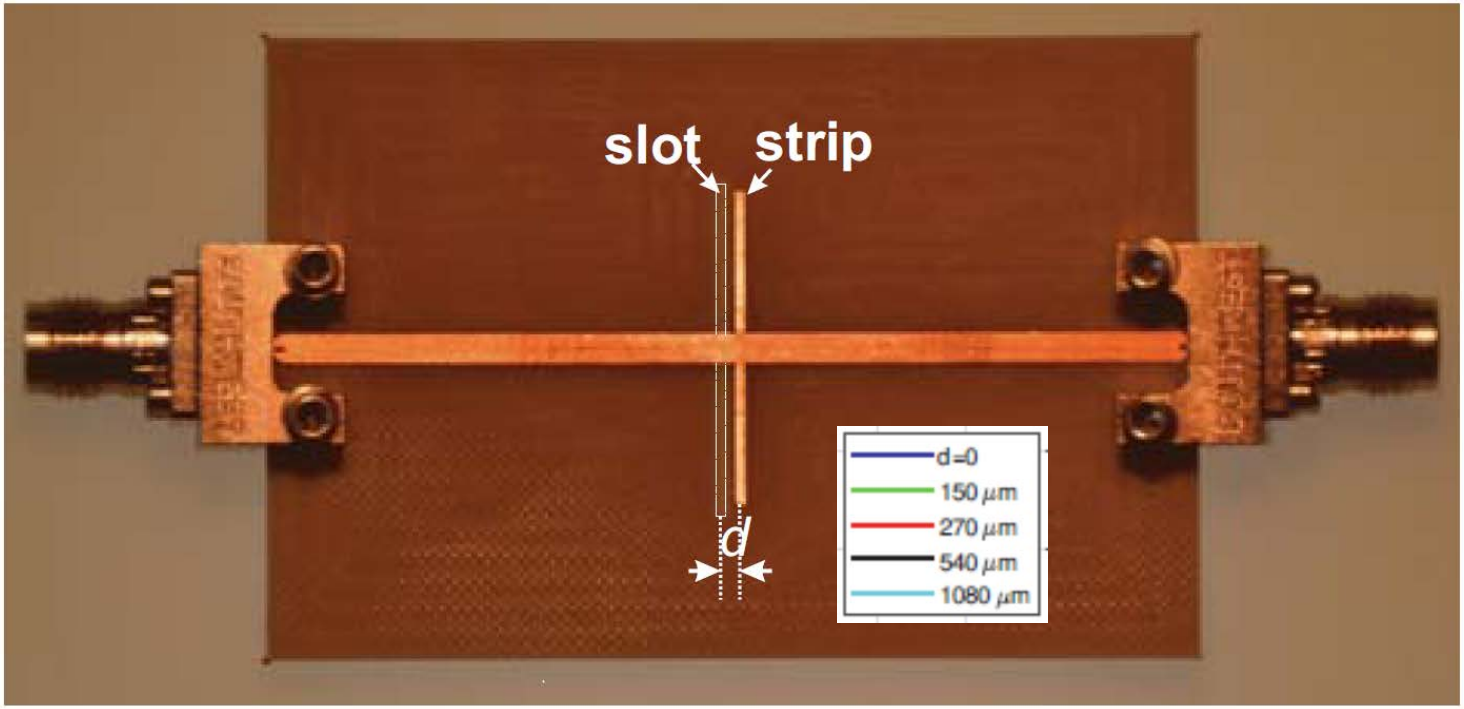
Symmetric two-ports (4): conclusion

- The lattice network provides equivalent circuits with realizable elements for symmetric and reciprocal lossy electromagnetic structures:
  - ✓Realizability
  - ✓Orthogonal-mode decomposition
  - ✓Deep physical insight

- Lattice network topology for non-symmetric reciprocal lossy electromagnetic structures?

Aim of this contribution

- To present a short description of three different approaches to the equivalent circuit modelling of non-symmetric reciprocal lossy electromagnetic structures and
- to compare their performances by modelling a misaligned complementary strip-slot element



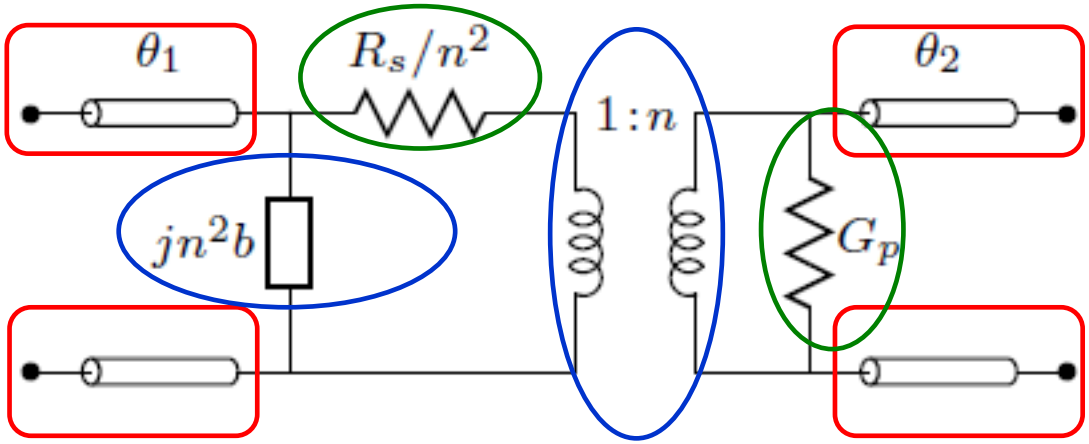
Classic apporach: Felsen-Oliner equivalent circuit (1)

Determination of Equivalent Circuit Parameters for Dissipative Microwave Structures*

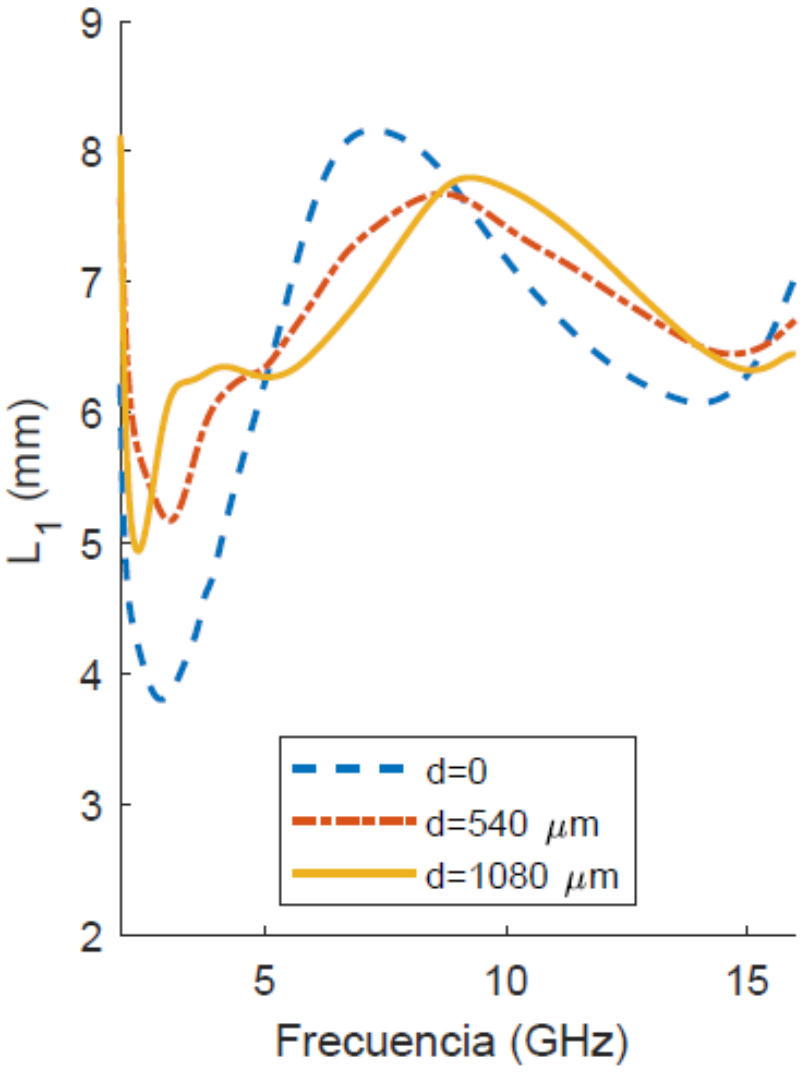
L. B. FELSEN†, ASSOCIATE, IRE, AND A. A. OLINER†, SENIOR MEMBER, IRE

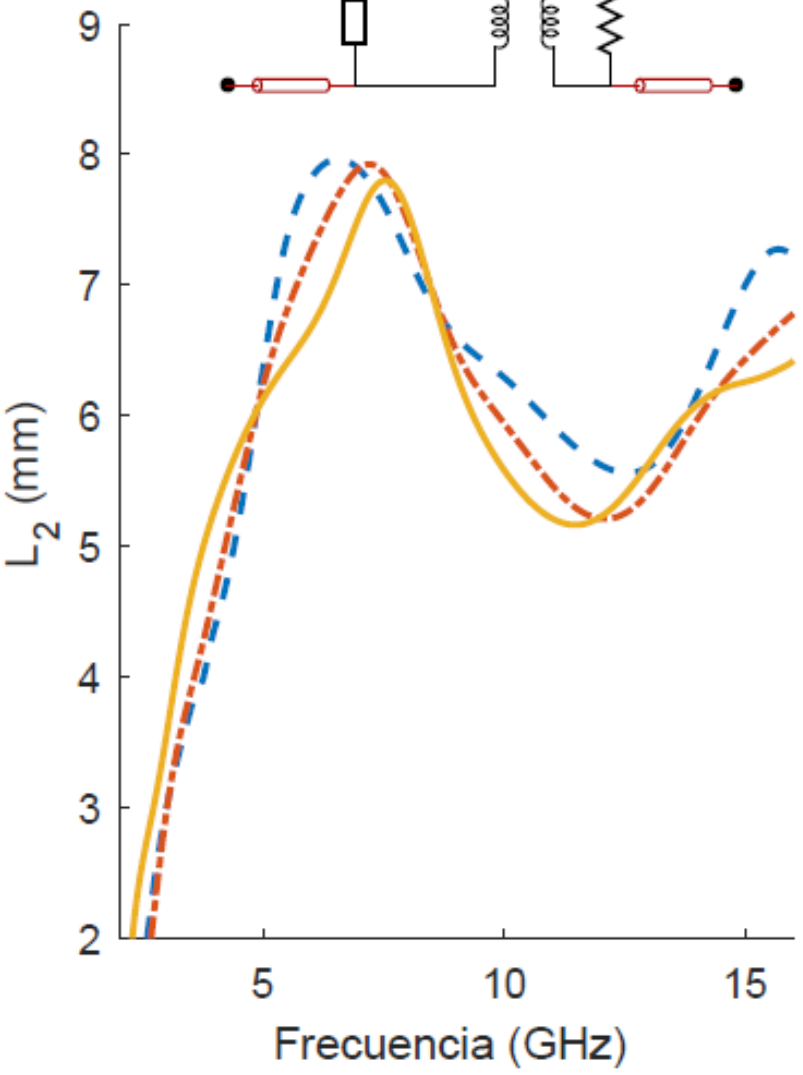
PROCEEDINGS OF THE I-R-E *February 1954*

- Procedure:
  - ✓ Reference plane shift
  - ✓ Extraction of positive resistance and conductance
  - ✓ Modelling of a lossless two-port

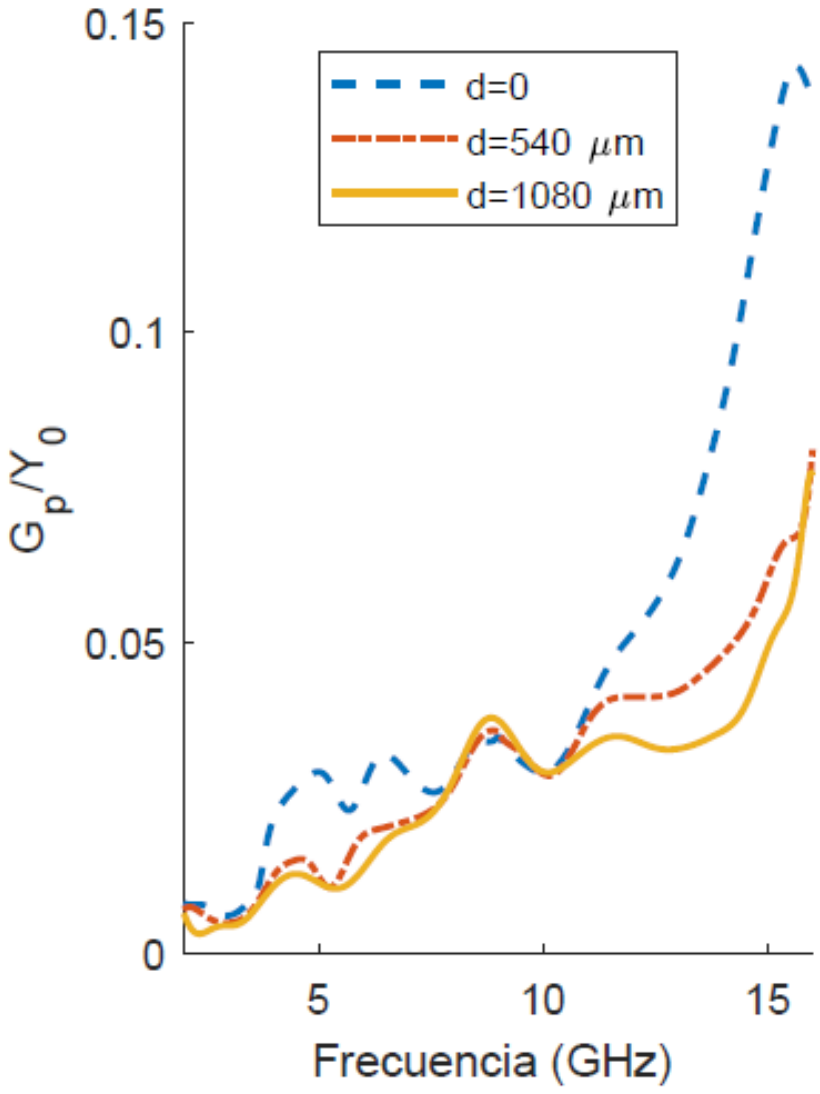


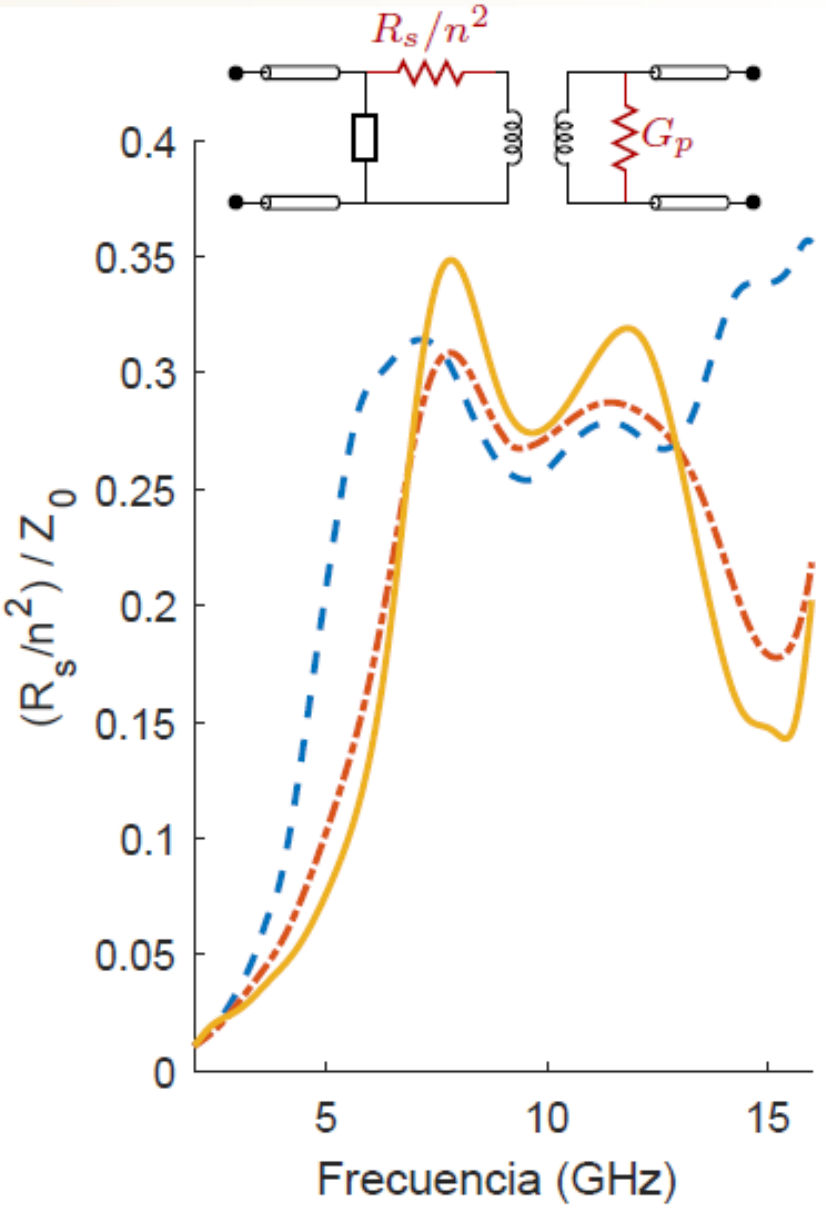
Classic apporach: Felsen-Oliner equivalent circuit (2)



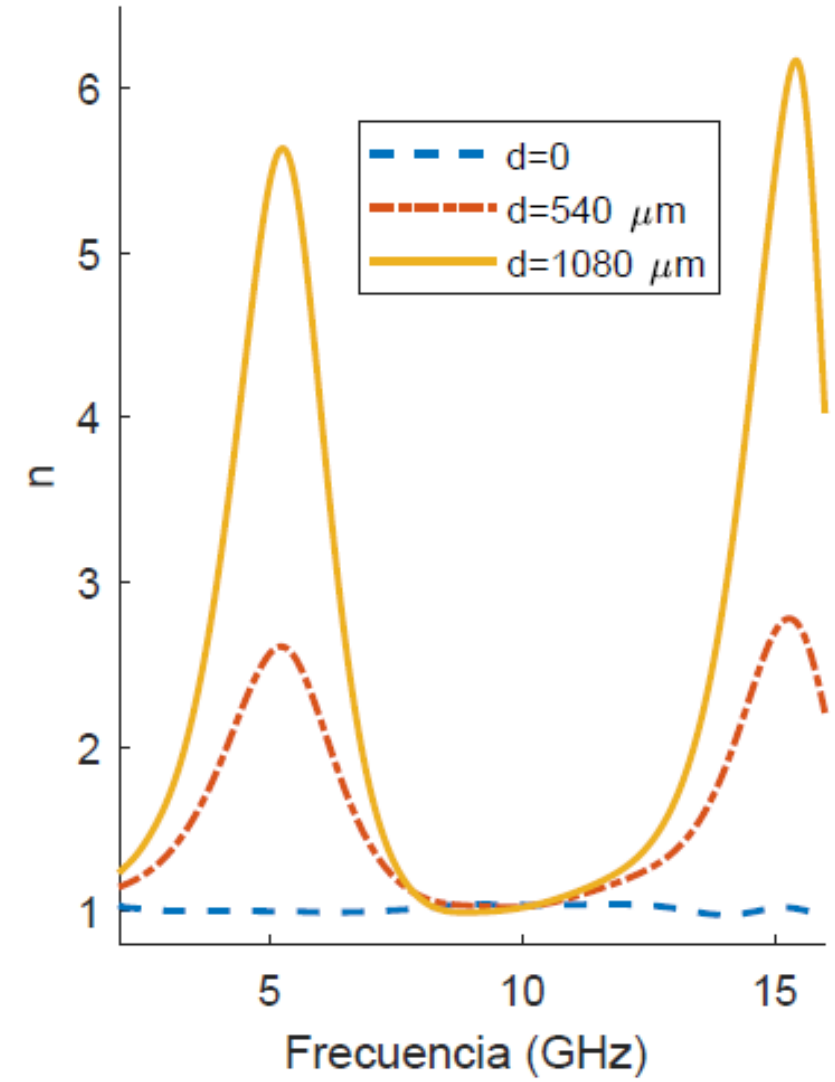


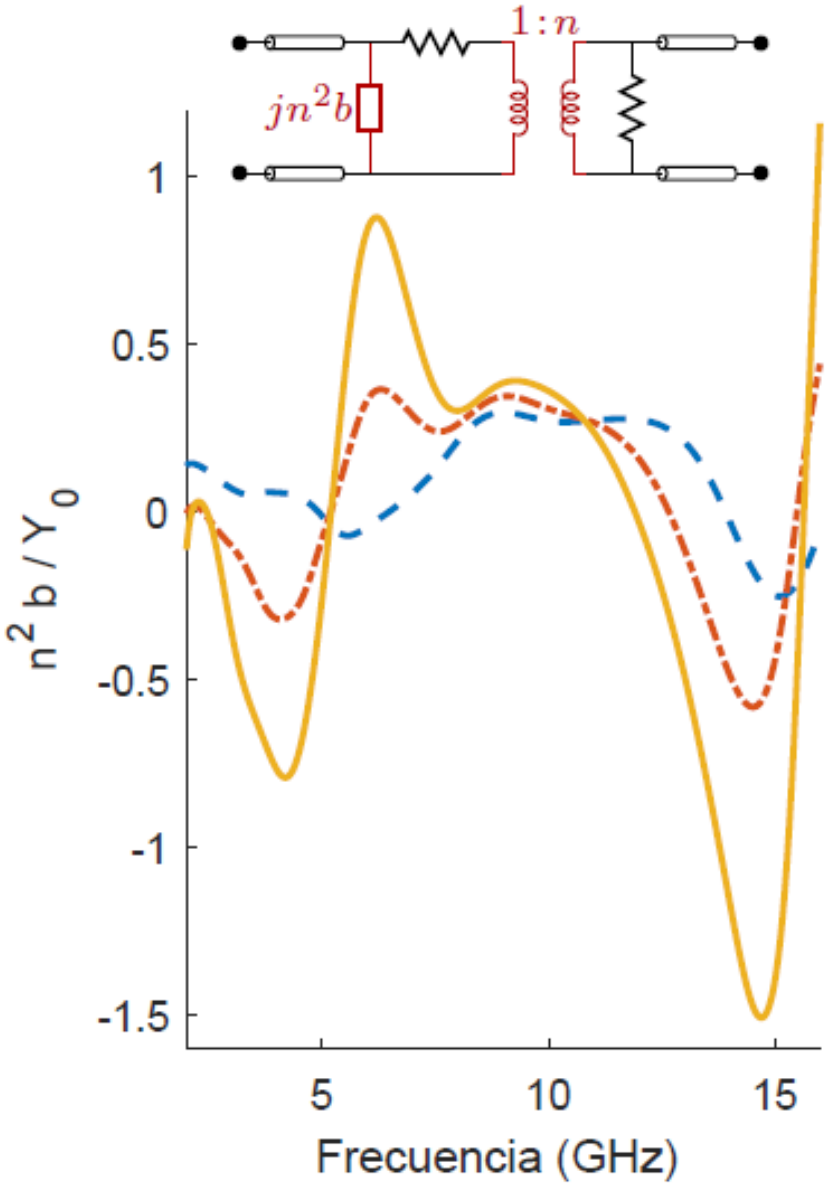
Classic apporach: Felsen-Oliner equivalent circuit (3)





Classic apporach: Felsen-Oliner equivalent circuit (4)





Felsen-Oliner equivalent circuit (5): conclusions

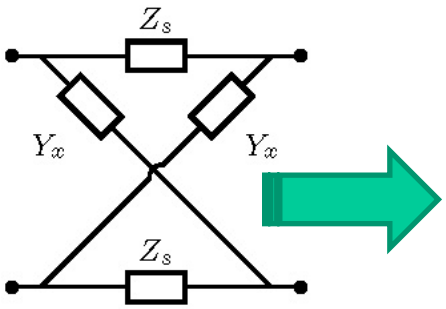
- Positive resistances and conductances with some physical meaning 
- Strong variation of the transformer ratio with the degree of asymmetry 
- Non-realizable susceptance 
- It does not converge to the lattice network in the symmetric case: realizability not guaranteed 

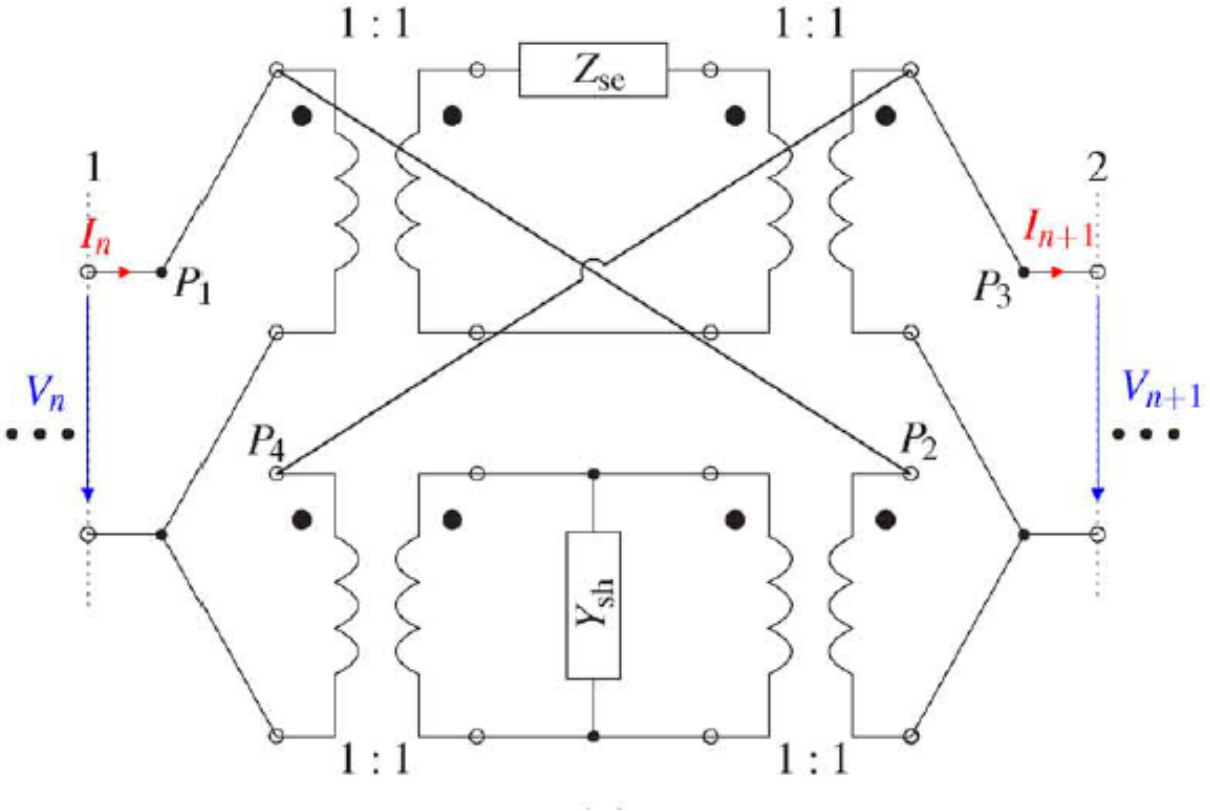
Transformer-lattice equivalent circuit. TEC (1)

Transversal Asymmetry in Periodic Leaky-Wave Antennas for Bloch Impedance and Radiation Efficiency Equalization Through Broadside

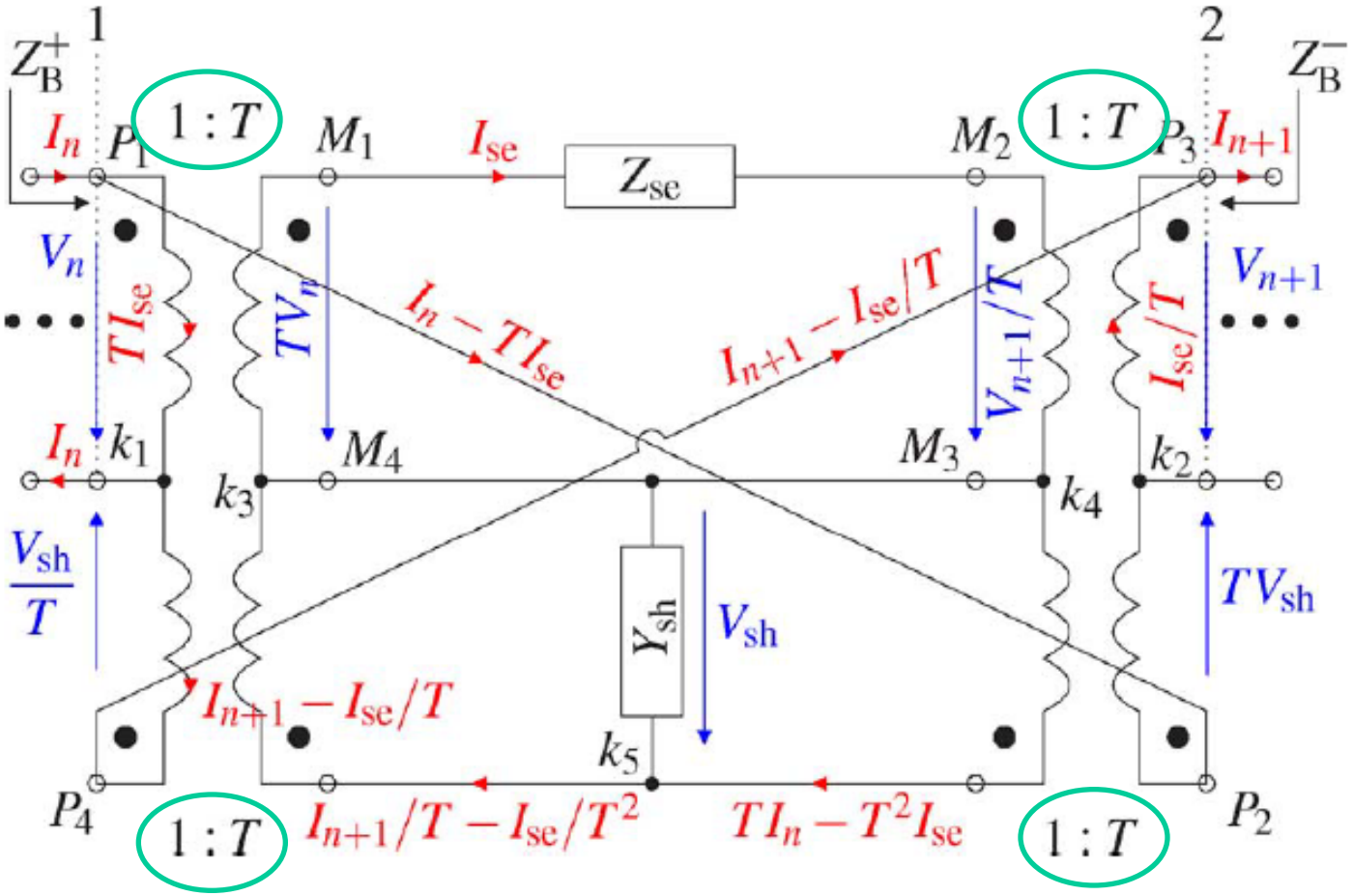
Simon Otto, *Member, IEEE*, Amar Al-Bassam, Andreas Rennings, *Member, IEEE*, Klaus Solbach, and Christophe Caloz, *Fellow, IEEE*

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 62, NO. 10, OCTOBER 2014





Transformer-lattice equivalent circuit. TEC (2)



$$T = \sqrt{\frac{y_{21} - y_{11}}{y_{21} - y_{22}}} = \sqrt{\frac{z_{21} + z_{11}}{z_{21} + z_{22}}}$$

$$Z_{se} = \frac{y_{11} + y_{22} - 2y_{21}}{(y_{21} - y_{11})(y_{21} - y_{22})}$$

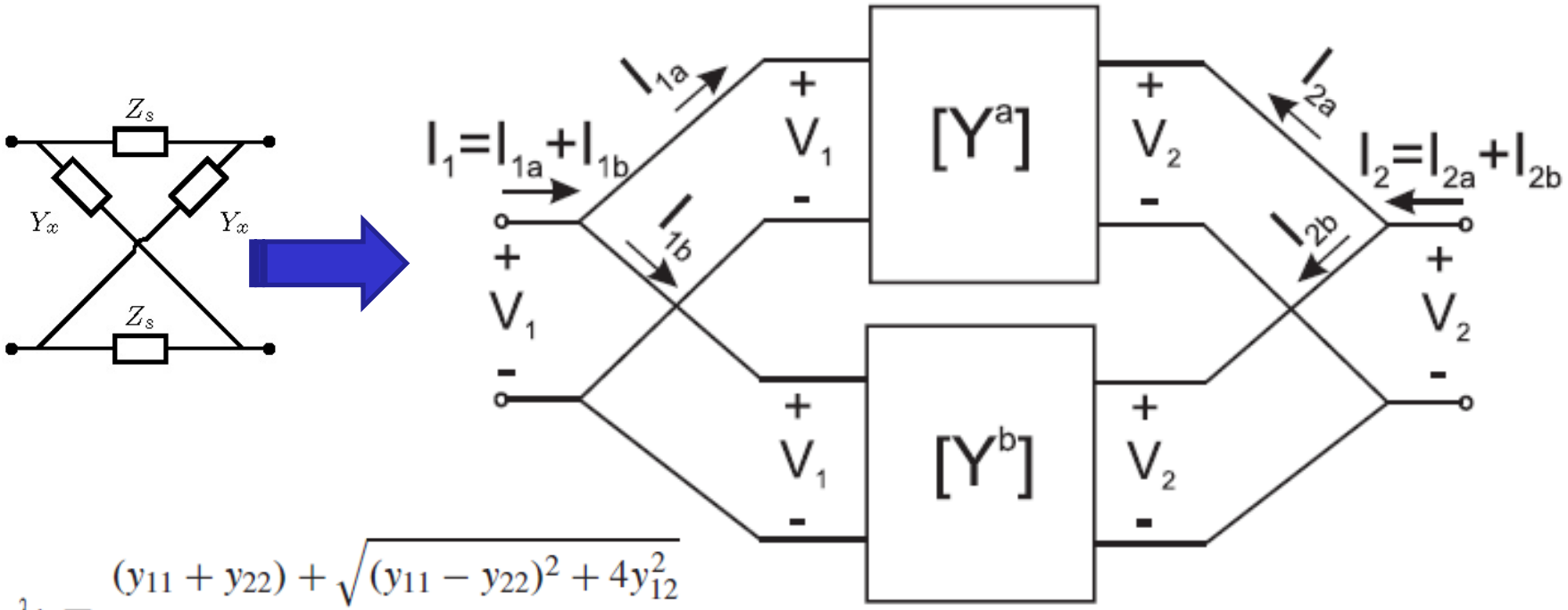
$$Y_{sh} = \frac{z_{11} + z_{22} + 2z_{21}}{(z_{21} + z_{11})(z_{21} + z_{22})}$$

Eigenstate lattice equivalent circuit EEC (1)

Equivalent Circuits for Nonsymmetric Reciprocal Two Ports Based on Eigenstate Formulation

Elena Abdo-Sánchez, *Member, IEEE*, Carlos Camacho-Peñalosa, *Senior Member, IEEE*,
Teresa M. Martín-Guerrero, and Jaime Esteban

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 65, NO. 12, DECEMBER 2017



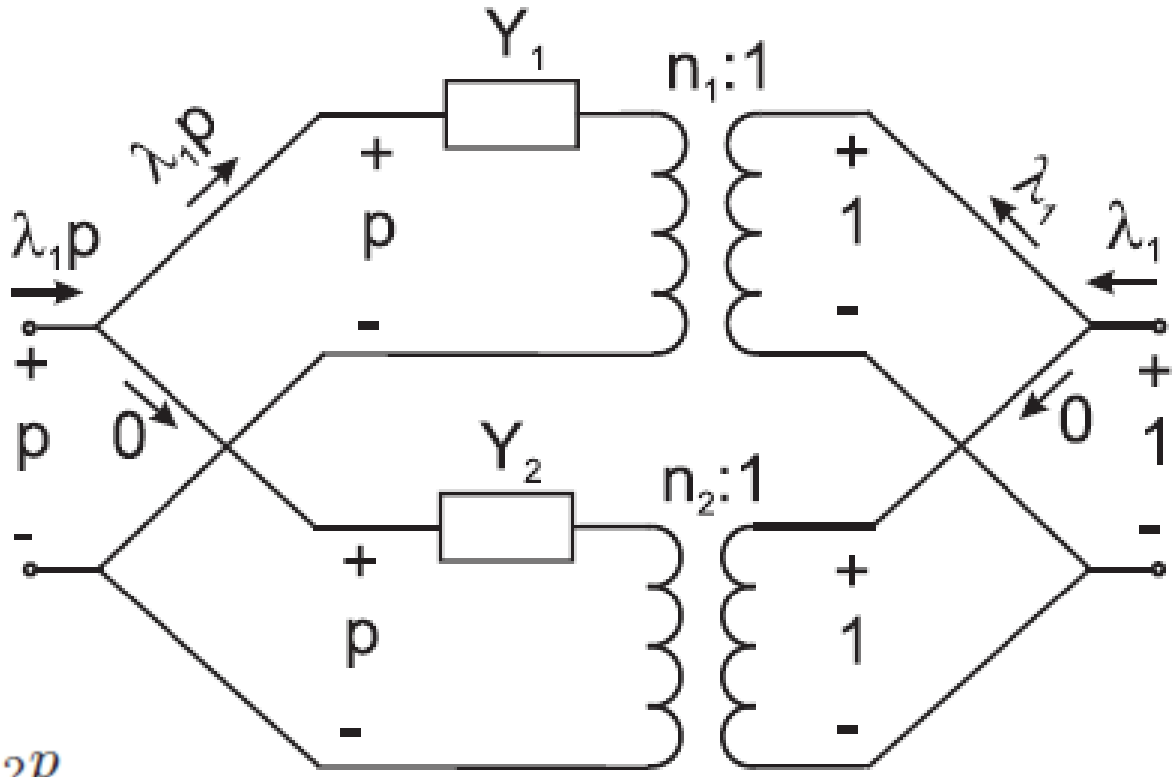
$$\lambda_1 = \frac{(y_{11}+y_{22}) + \sqrt{(y_{11}-y_{22})^2 + 4y_{12}^2}}{2}$$

$$\lambda_2 = \frac{(y_{11}+y_{22}) - \sqrt{(y_{11}-y_{22})^2 + 4y_{12}^2}}{2}$$

Eigenstate lattice equivalent circuit. EEC (2)

$$n_1 = \frac{-1}{p}$$

$$n_2 = p$$



$$Y_1 = p^2 \frac{y_{22} + y_{12}p}{1 + p^2}$$

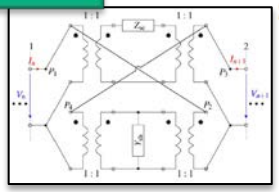
$$Y_2 = \frac{py_{22} - y_{12}}{p(1 + p^2)}$$

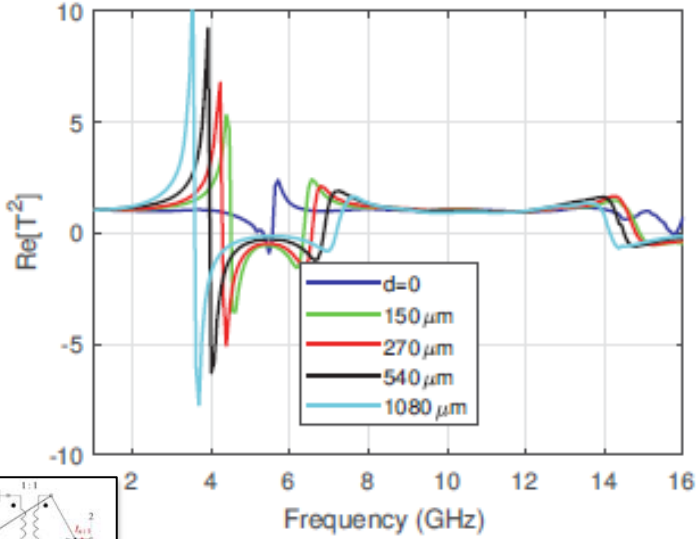
$$p = \frac{(y_{11} - y_{22}) + \sqrt{(y_{11} - y_{22})^2 + 4y_{12}^2}}{2y_{12}}$$

Reference plane shift → real transformer ratios and power orthogonality

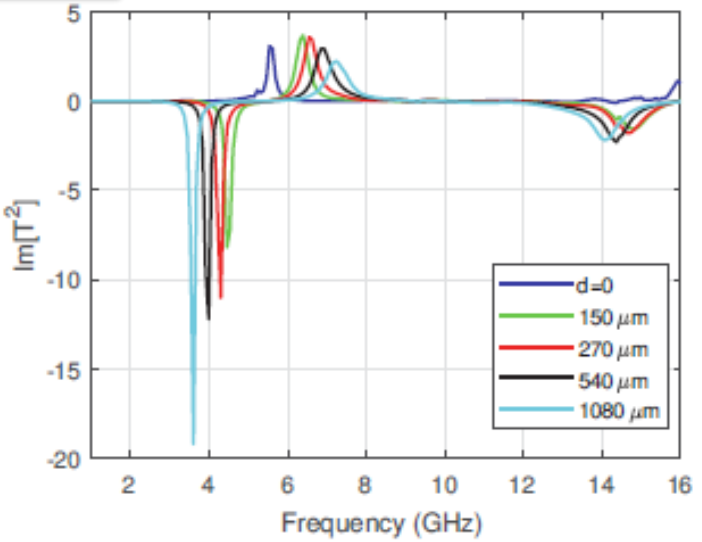
Lattice-inspired equivalent circuits: results (1)

TEC

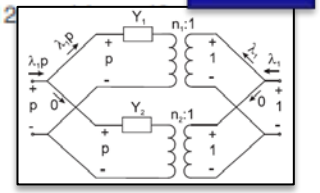


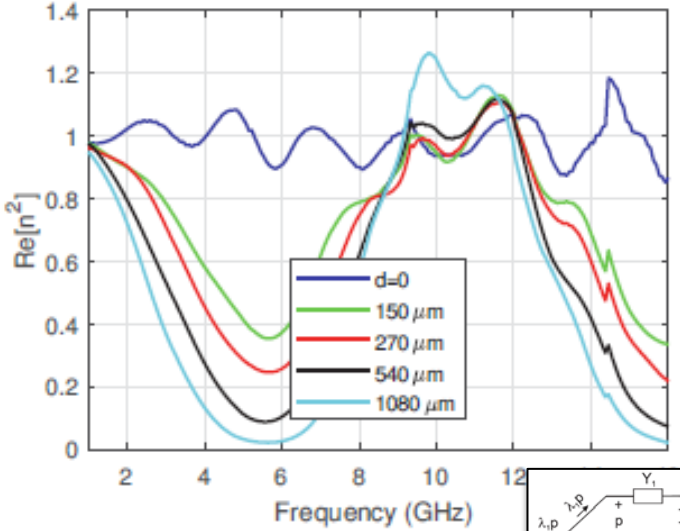


(a)

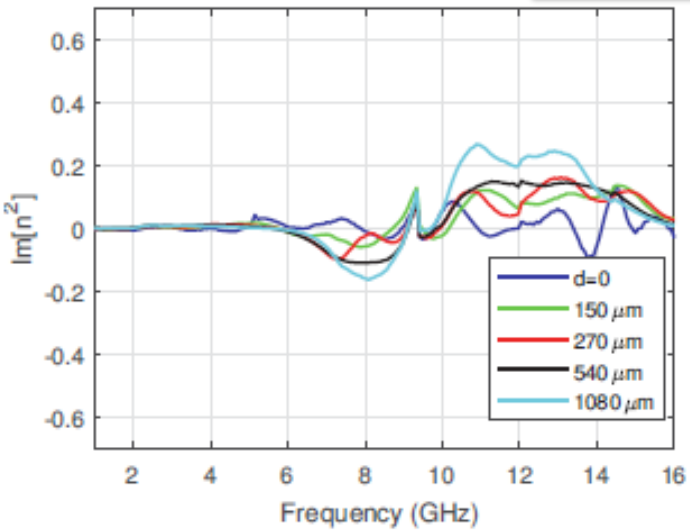


EEC



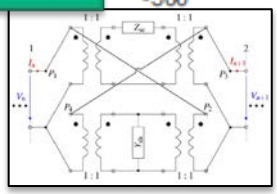


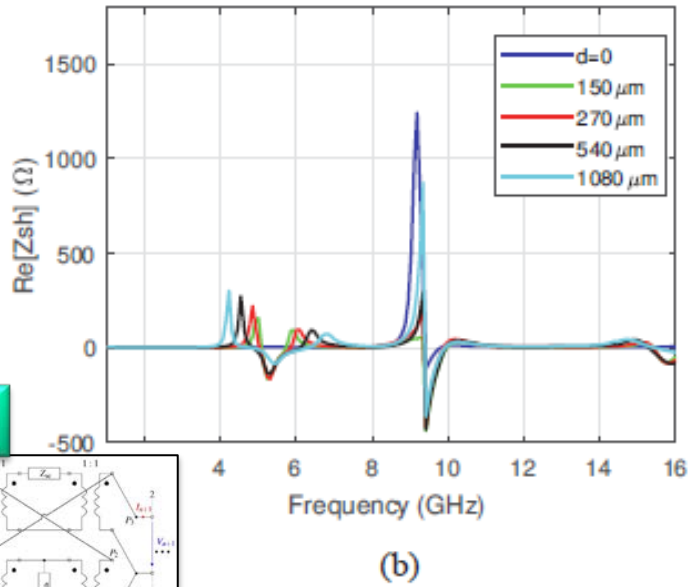
(a)



Lattice-inspired equivalent circuits: results (2)

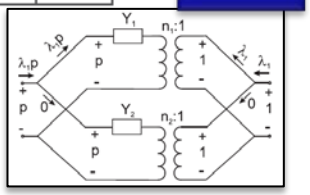
TEC

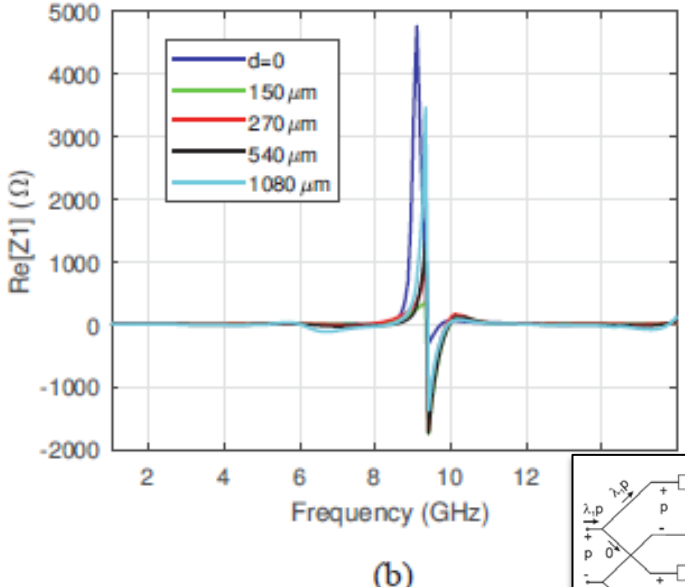




(b)

EEC





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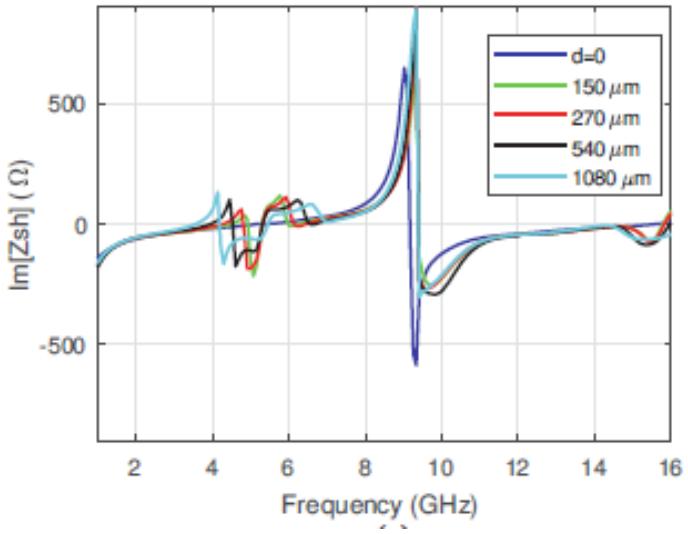
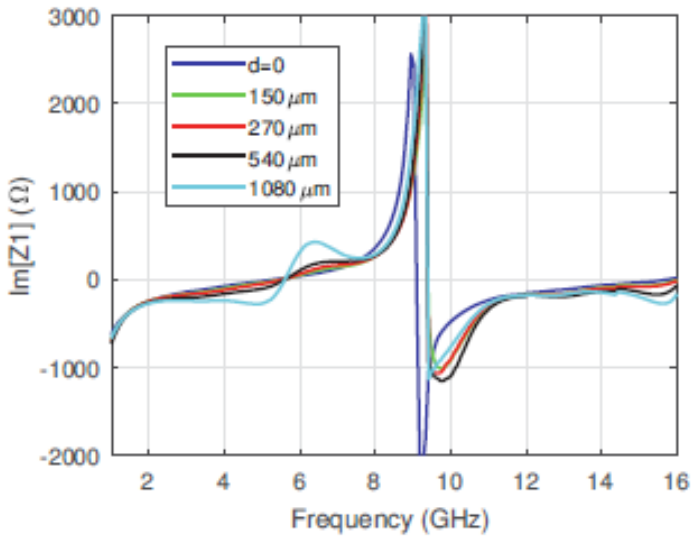
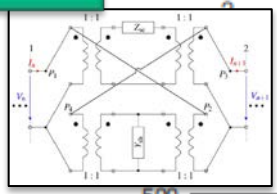
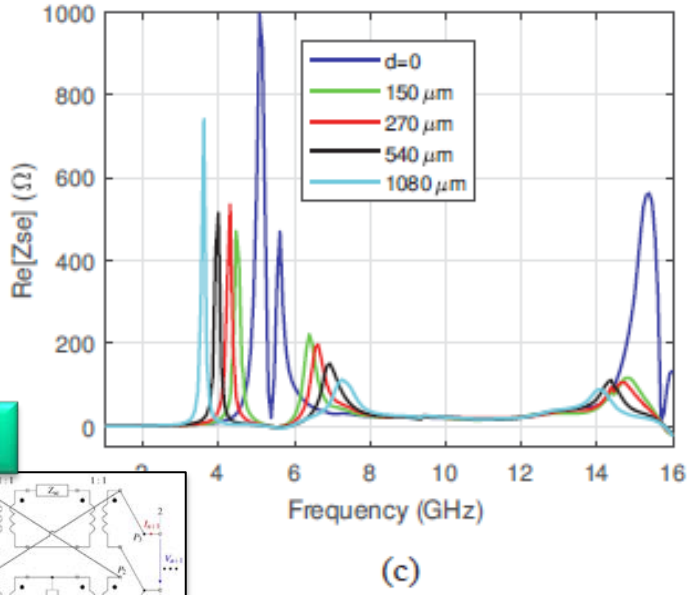


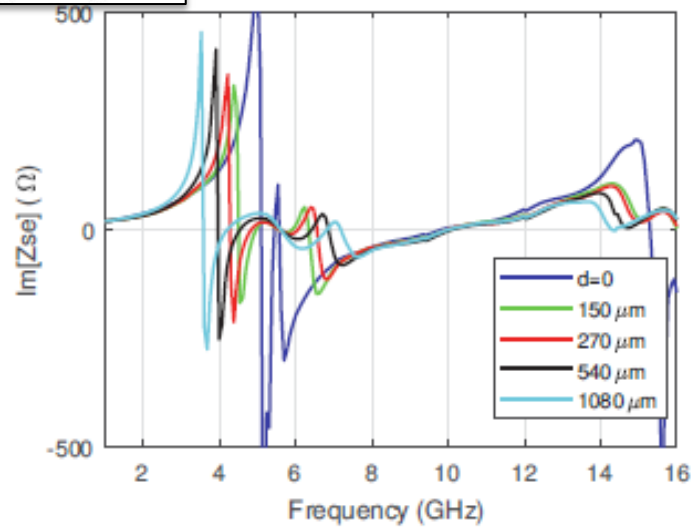


Lattice-inspired equivalent circuits: results (3)

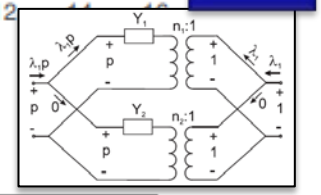
TEC

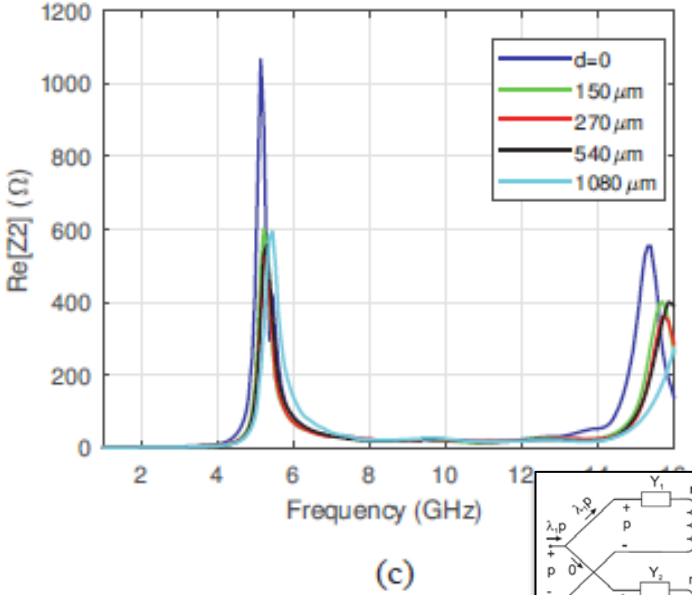


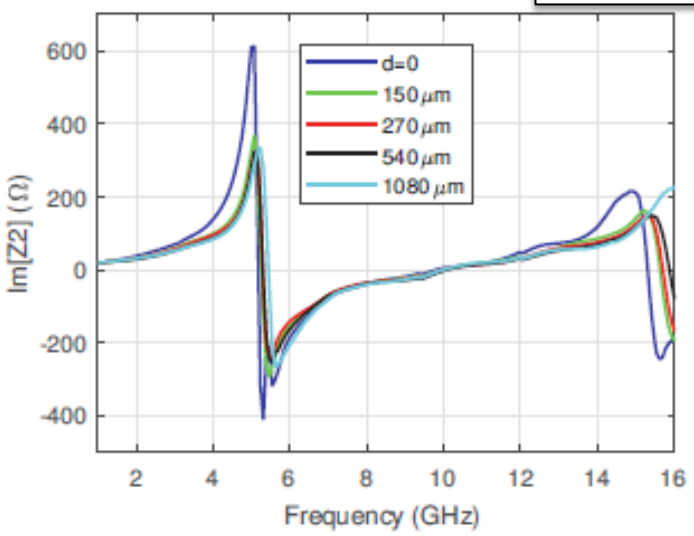




EEC







Lattice-inspired equivalent circuits: conclusions

- Both equivalent circuits converge to the lattice network in the symmetric case
- Better performance of the eigenstate-based network:
  - Asymmetry mainly absorbed by the transformer
  - Impedances practically the same as for the symmetric case
  - Better modelling of the underlying physics of the structure
- Further comparison using different structures

- Does a network topology exist that guarantees the realizability of the elements in the case of non-symmetric reciprocal lossy electromagnetic structures?

Acknowledgment

- European Union's Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Grant Agreement No. 706334

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THANK YOU FOR YOUR ATTENTION!