Wrocław University of Technology

Design of tunable metamaterial operating near 90 GHz

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Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan

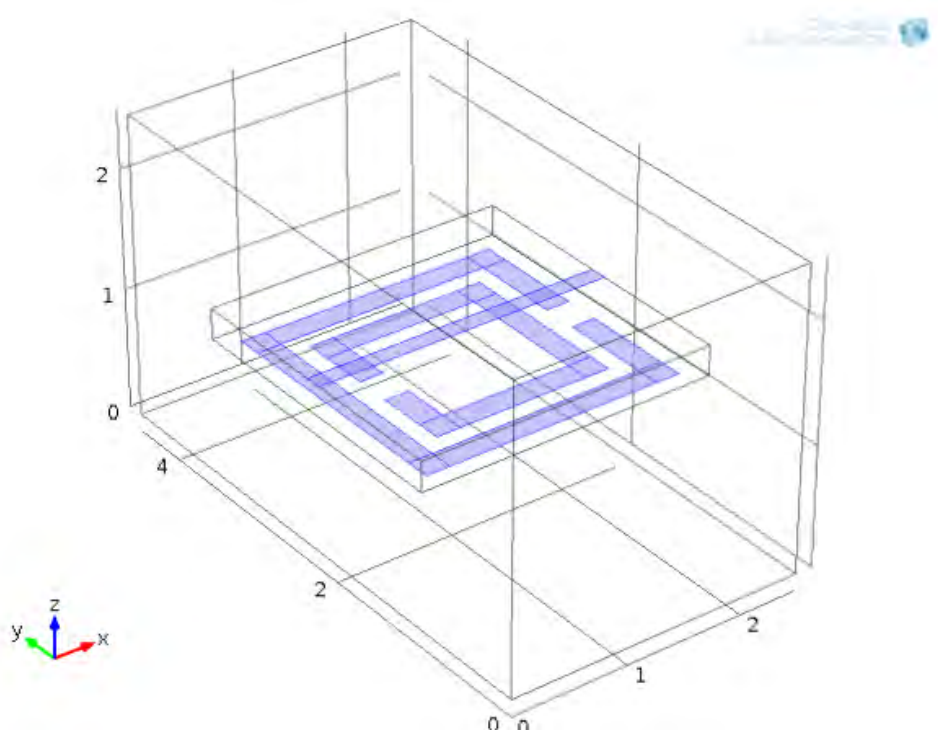
Outline

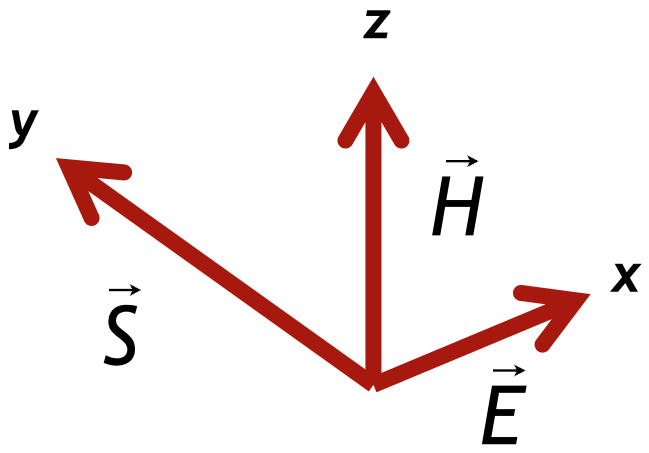
- Purpose
- Initial design and test of numerical procedure based on FEM
- Road to fulfil requirements
- Final design
- Summary

Purpose

- Tunable metamaterial cell
- Nematic liquid crystal
- Operation in 90 GHz range

Initial design





[1] R. Liu, T. J. Cui, D. Huang, B. Zhao, D. R. Smith, „Description and explanation of electromagnetic behaviors in artificial metamaterials based on effective medium theory", *Physical Review E*, vol. 76, 026606 (2007)

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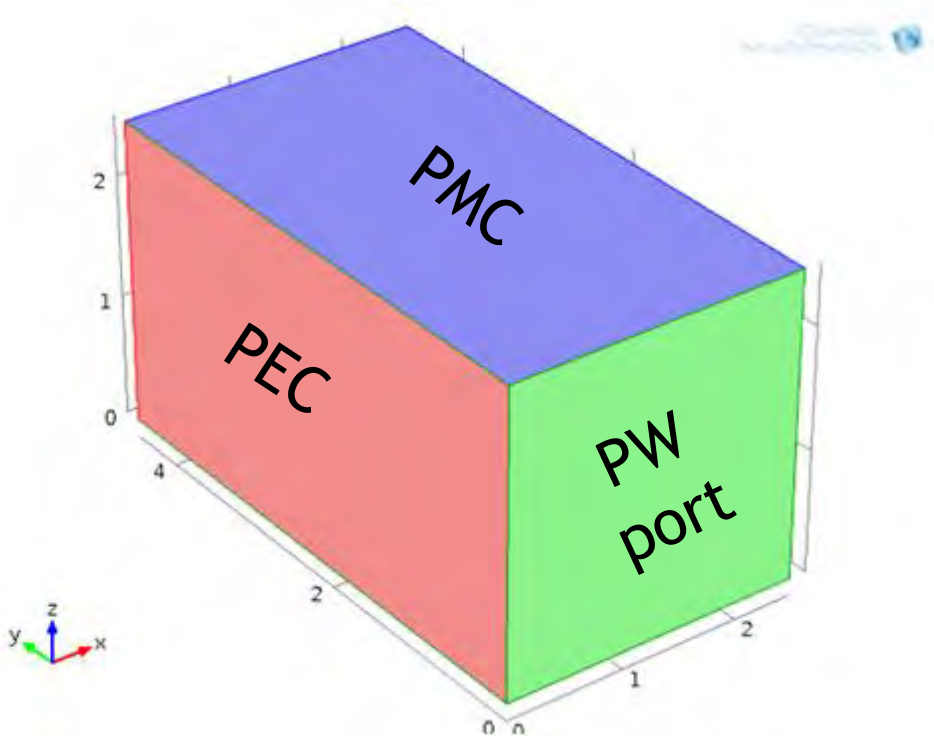
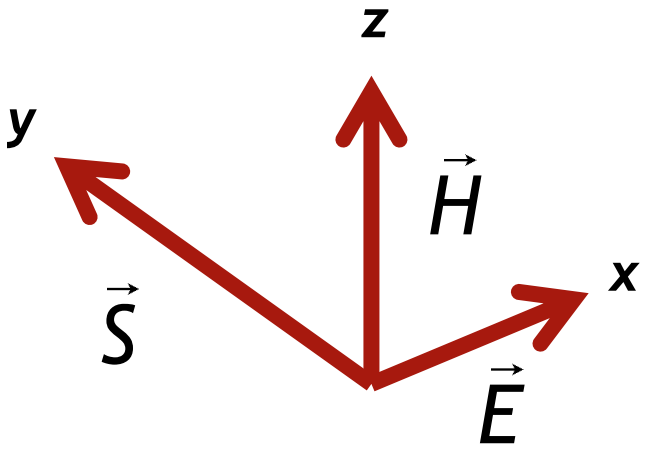
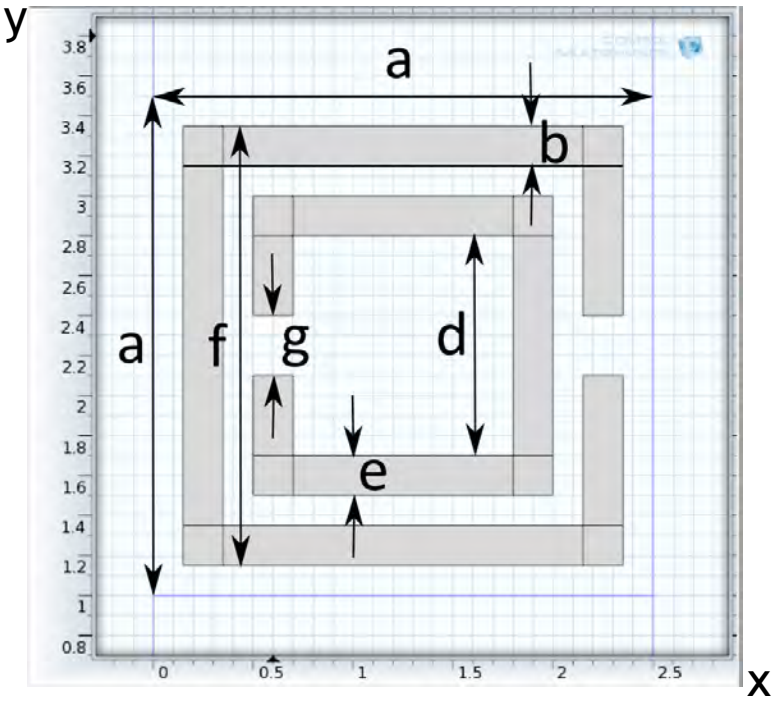
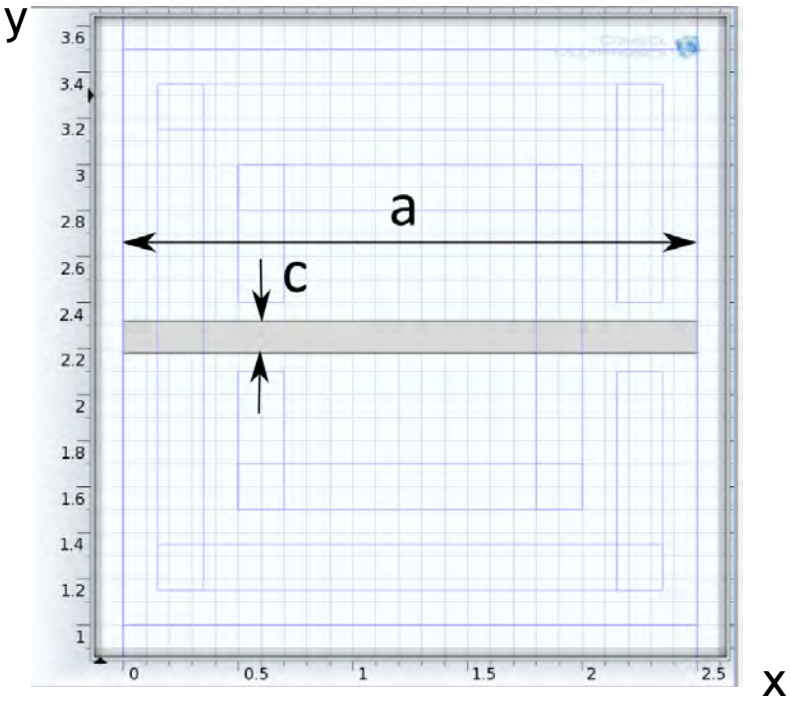
Initial design





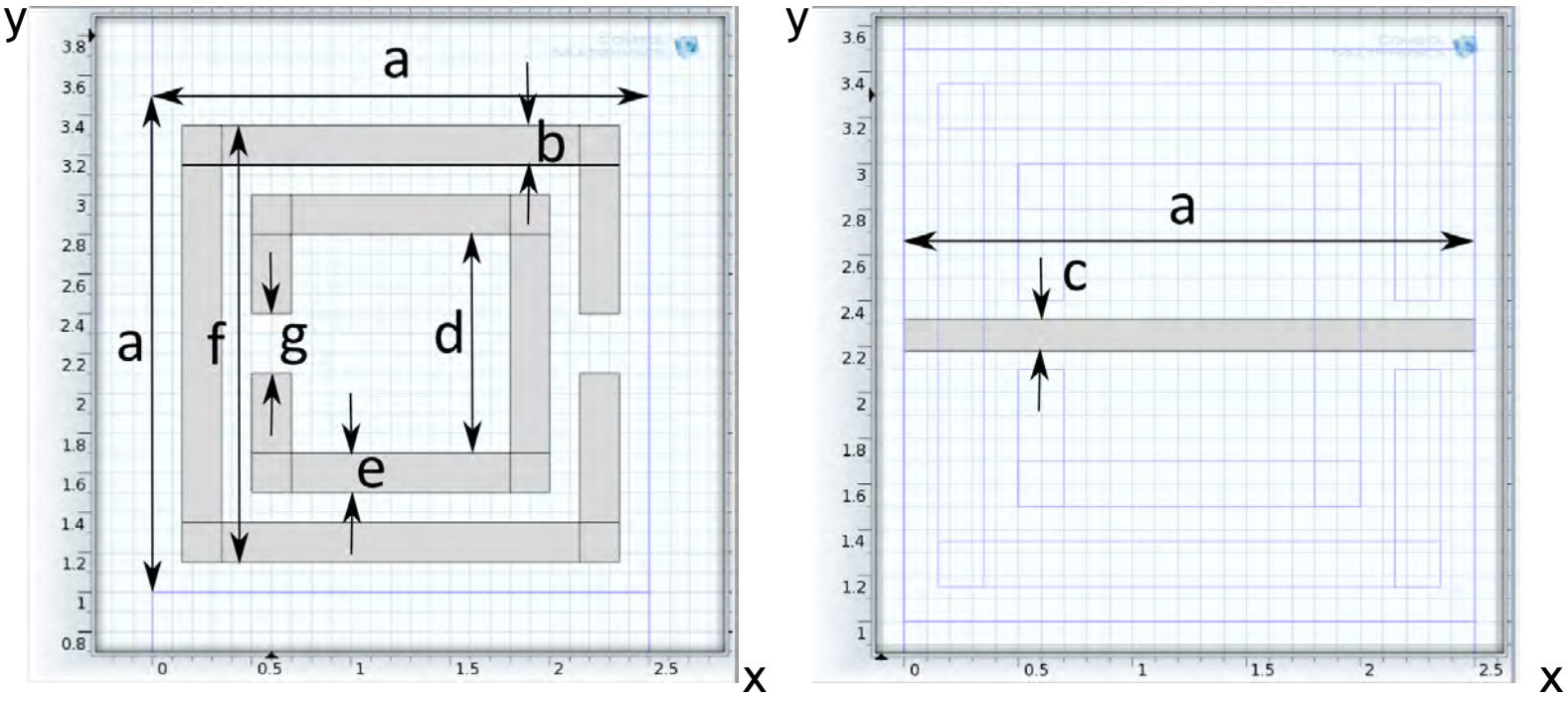
Initial design





- SRR placed on a bottom surface
- TW placed on a top surface
- a = 2.5 mm, b = e = 0.2 mm, c = 0.14 mm, d = 1.1 mm, f = 2.2 mm, g = 0.3 mm

Initial design



- metallic elements were modelled as PEC placed on bottom and top surfaces of dielectric plate
- plate thickness 0.25 mm
- plate permittivity $\varepsilon = 4.4 - 0.001i$

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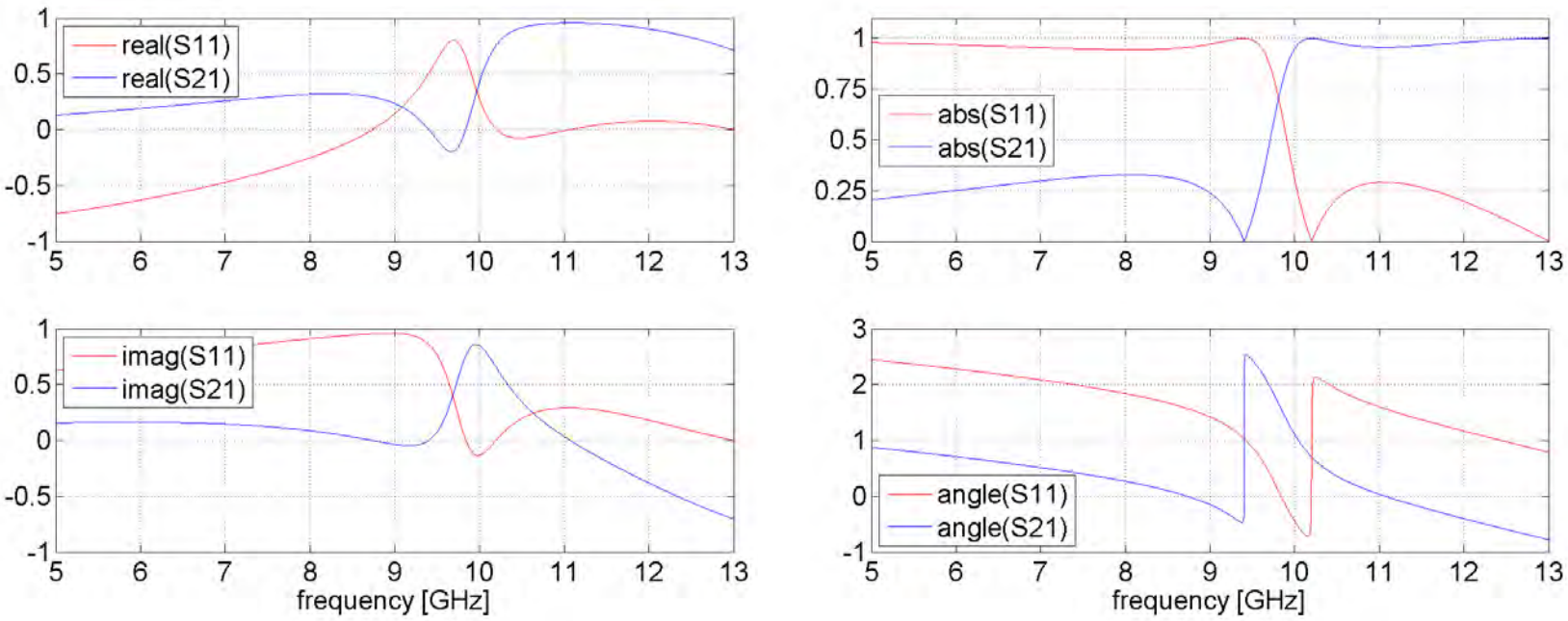
Initial design - results



Transmission and reflection coefficients (S_{21}, S_{11}) calculated with Comsol Multiphysics represented in Cartesian and polar coordinate systems

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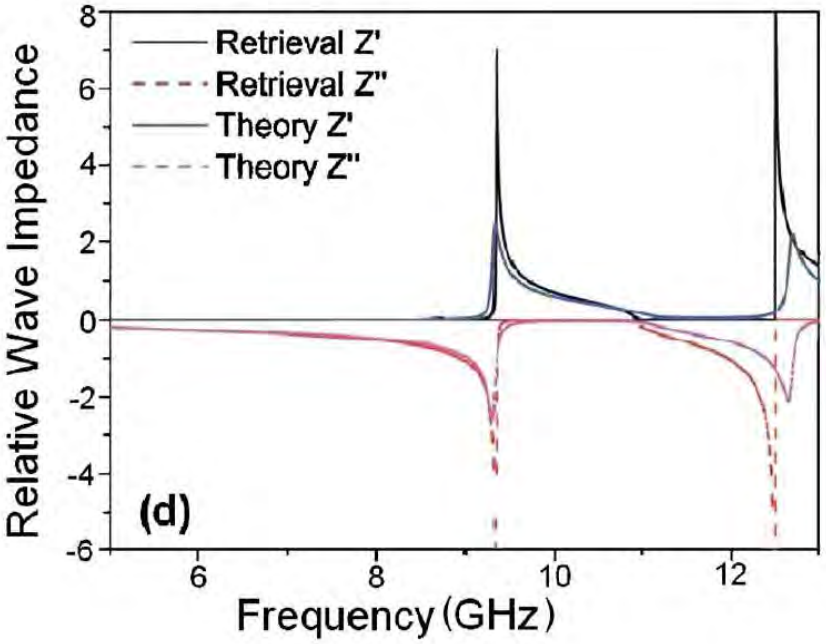
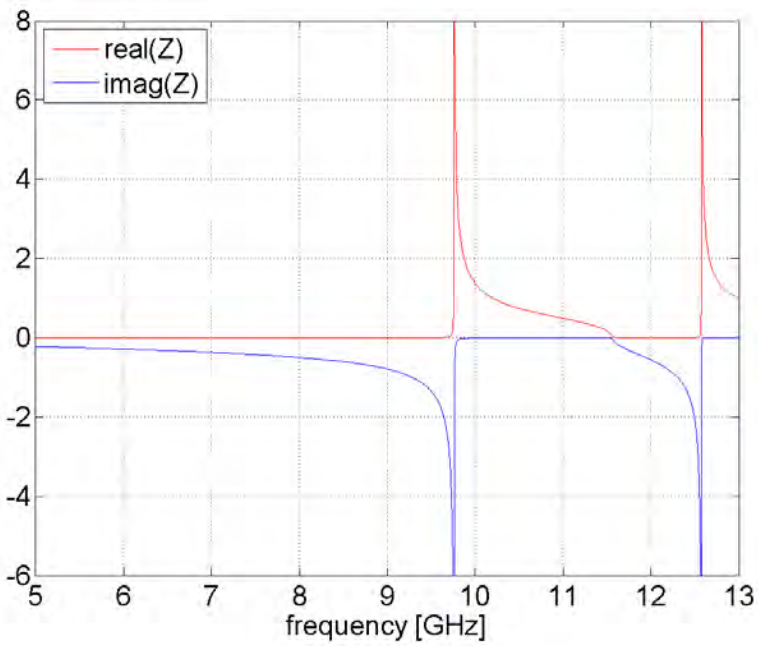
Initial design - results

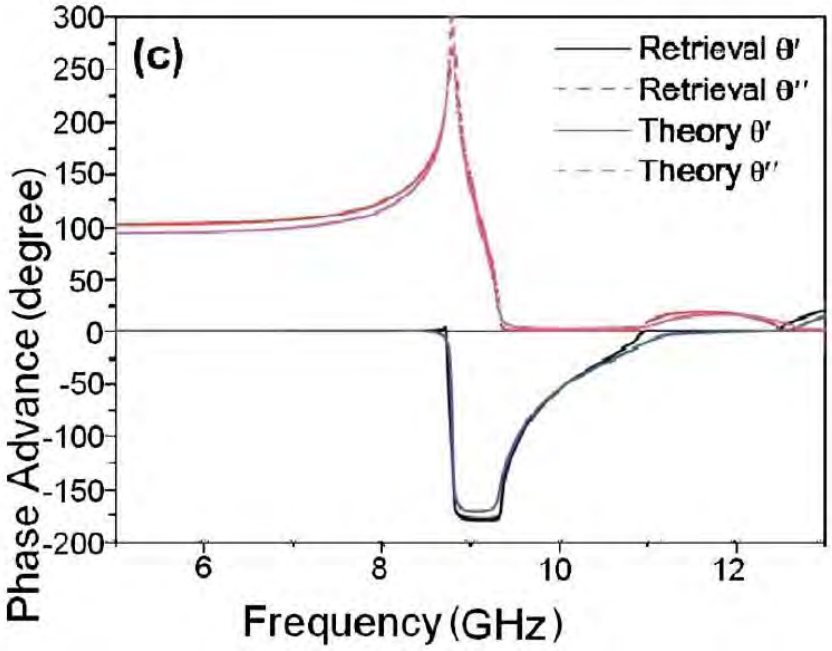


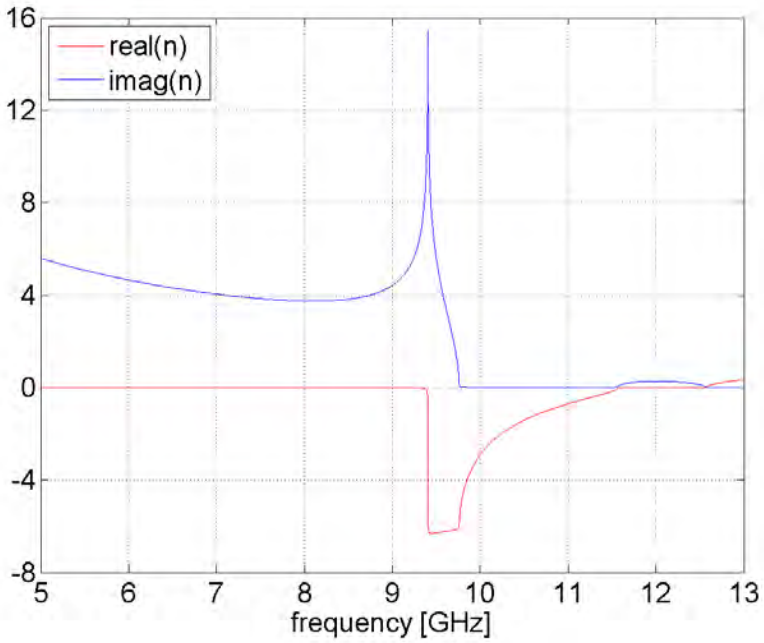


Comparison of impedances presented in [1] (left hand side) and retrived (right hand side)

[2] X. Chen, T. M. Grzegorczyk, B.-I. Wu, J. Pacheco, J. A. Kong, „Robust method to retrieve the constitutive effective parameters of metamaterials", *Physical Review E*, vol. 70, 016608 (2004)

Initial design - results





Comparison of phase advance presented in [1] (left hand side) and retrived (right hand side)

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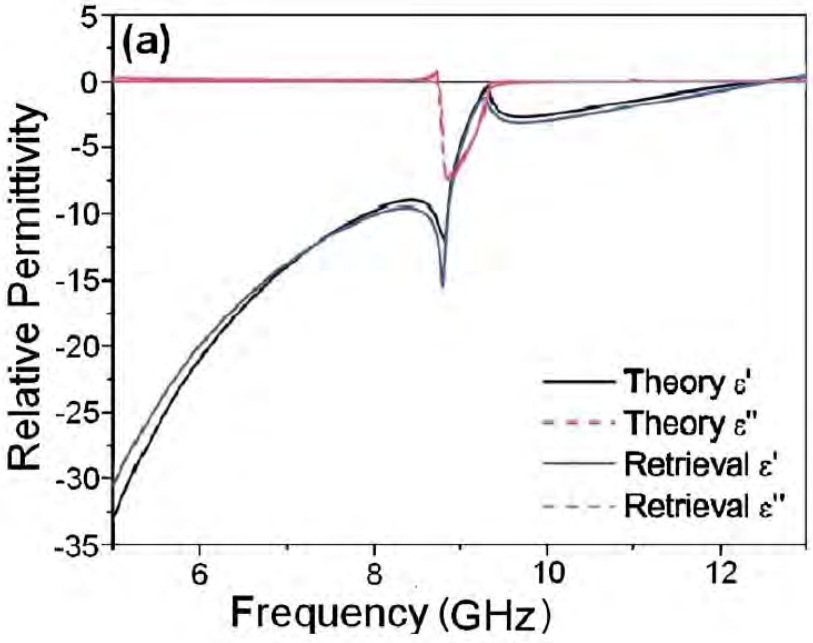
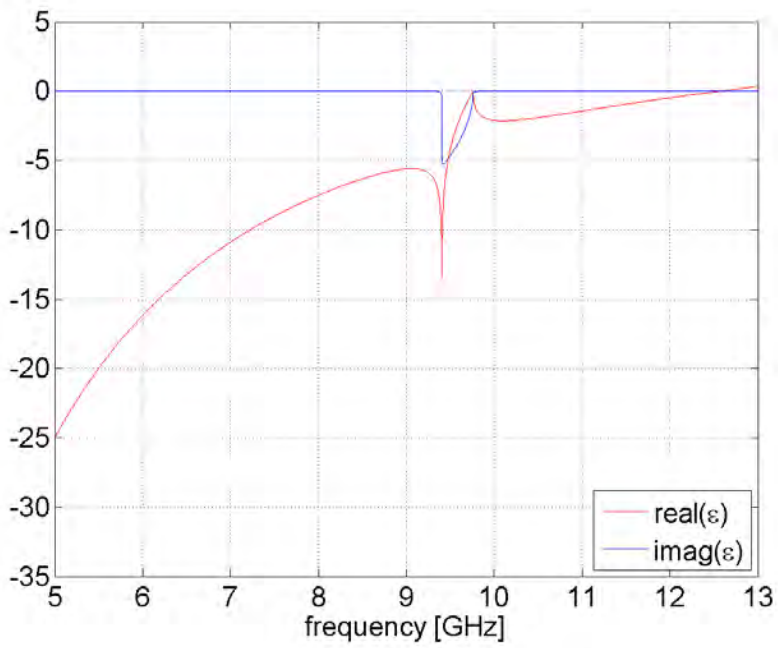
Initial design - results





Comparison of permittivity presented in [1] (left hand side) and retrived (right hand side)

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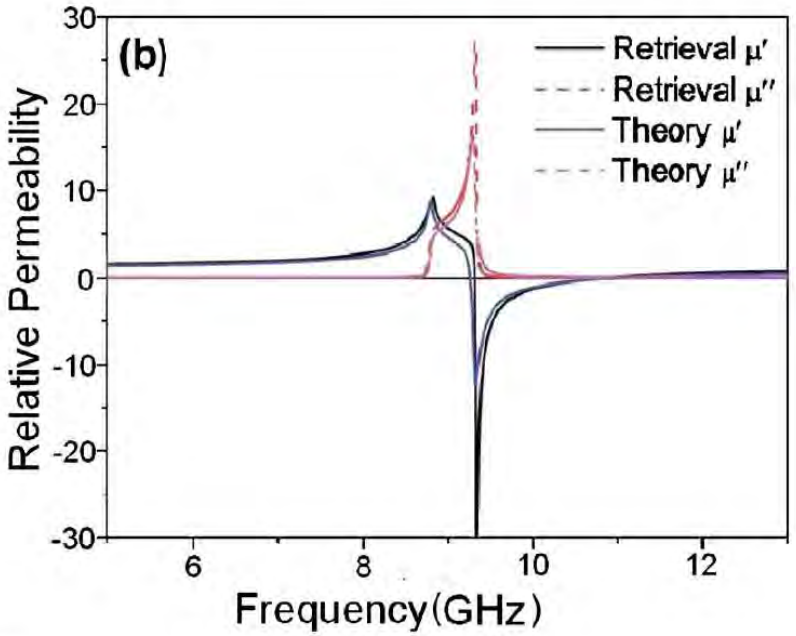
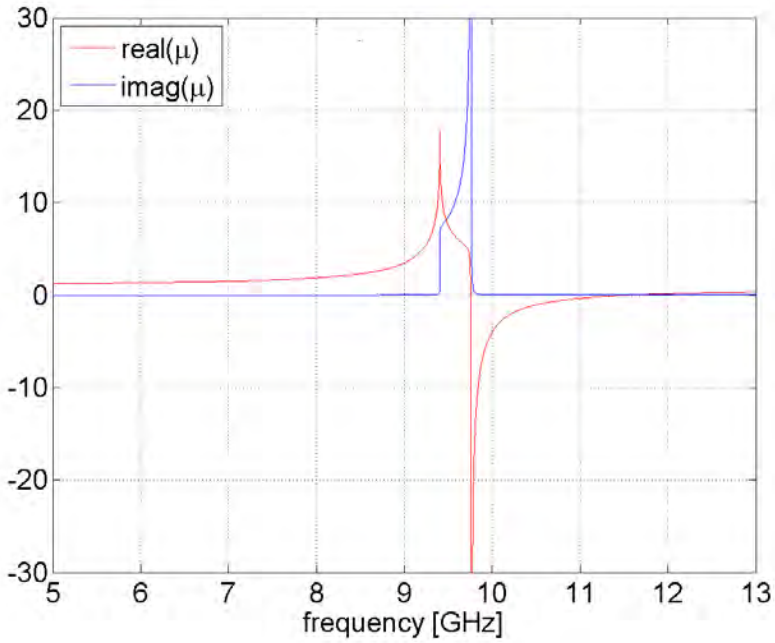
Initial design - results





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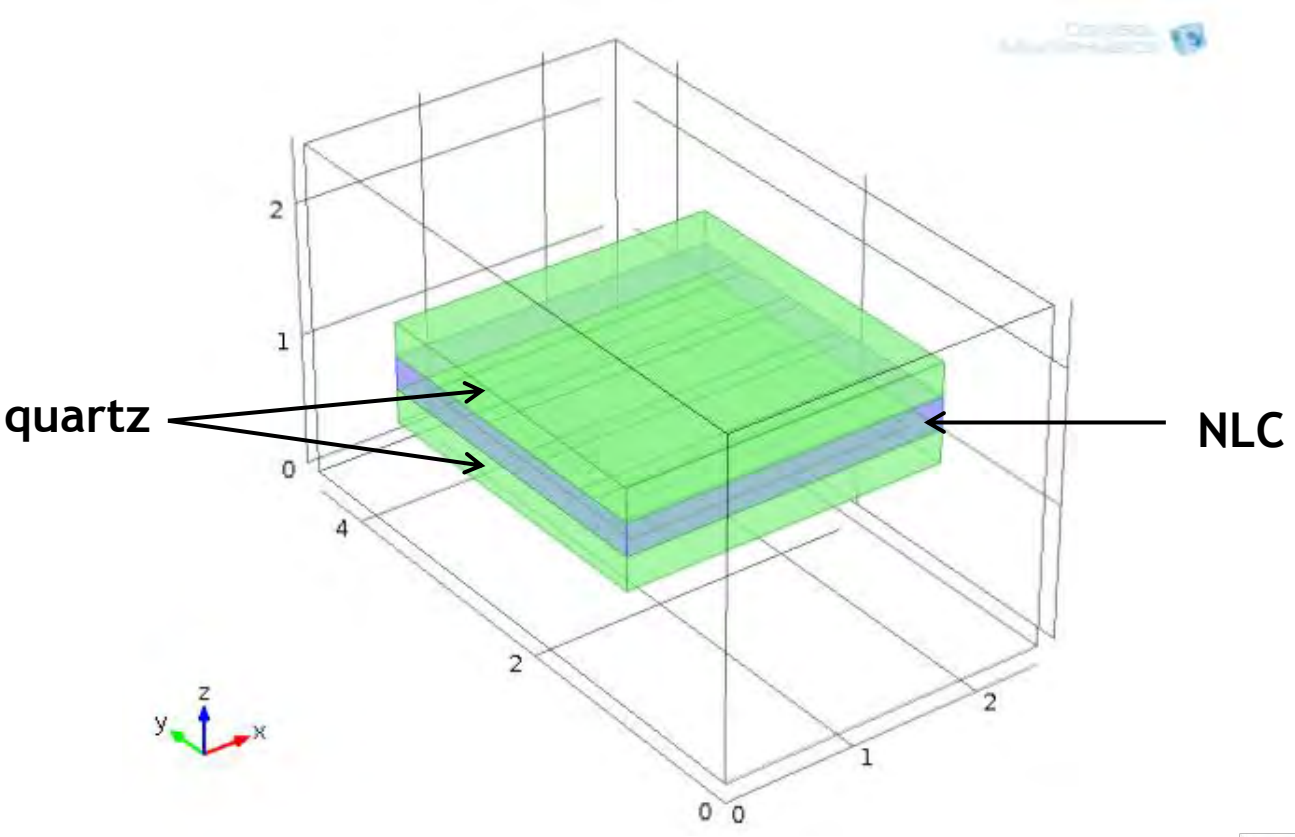
Introduction of nematic liquid crystal



Nematic liquid crystal placed between two quartz plates

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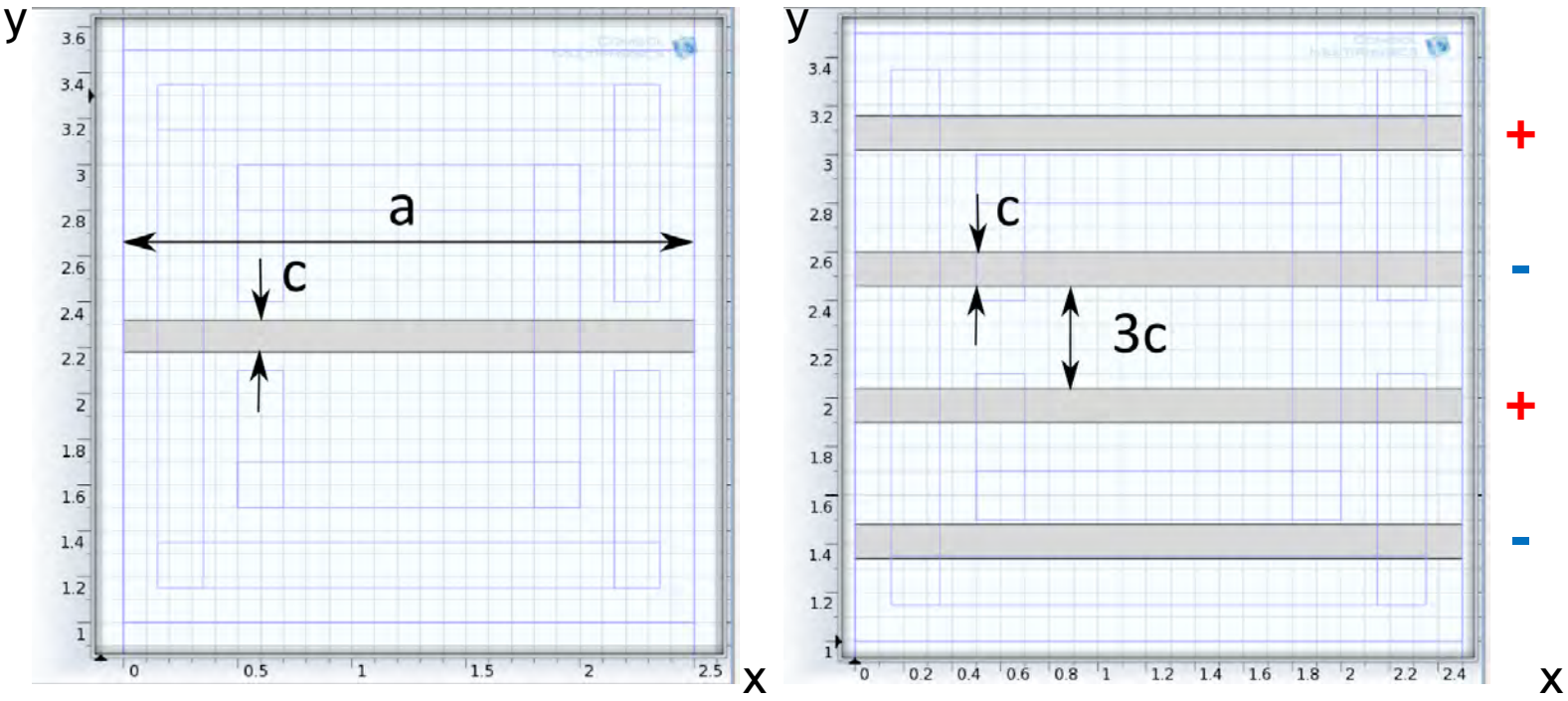
Additional TW



Additional thin wires introduced for IPS (in-plane switching)

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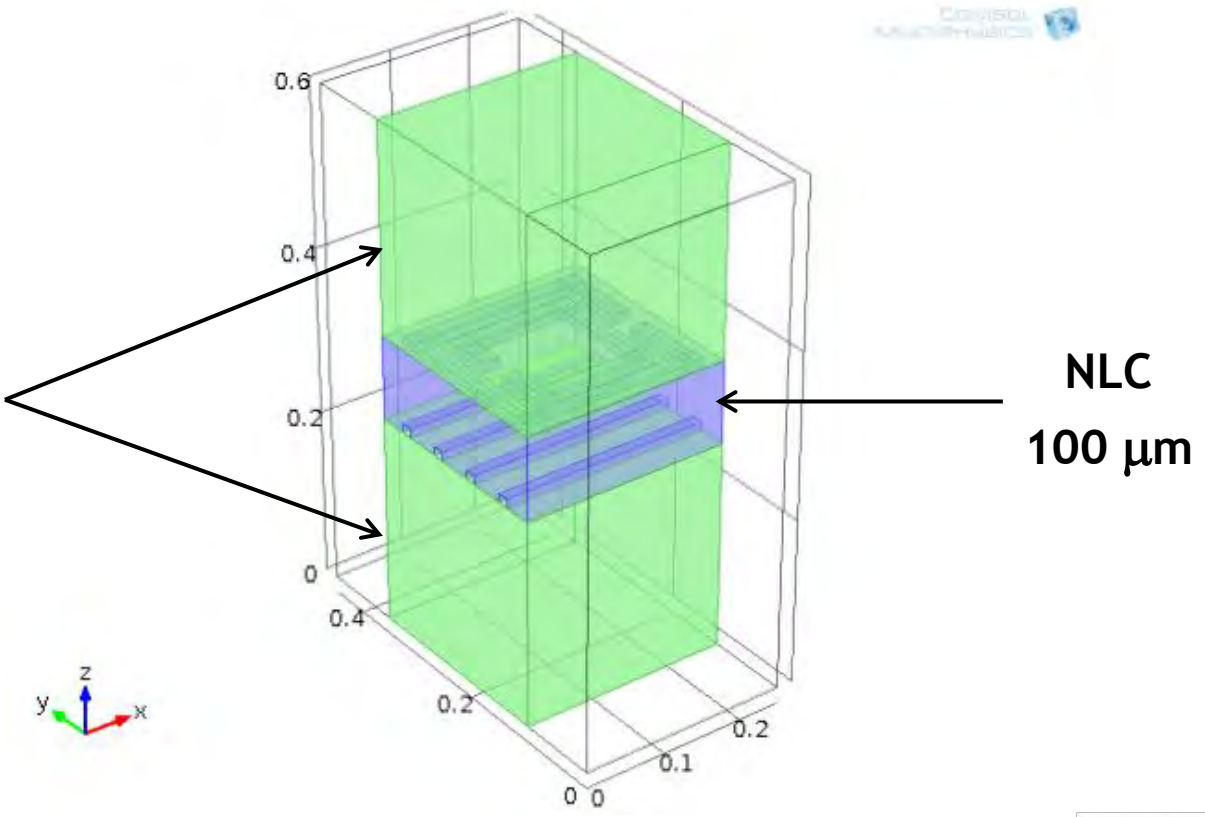
Subsequent changes

- Scaling in Z-direction to fulfil technological requirements
- Scaling in XY-plane to shift resonance to desired spectral range
- Accounting losses in metallic elements
- Different NLC parameters

Final design



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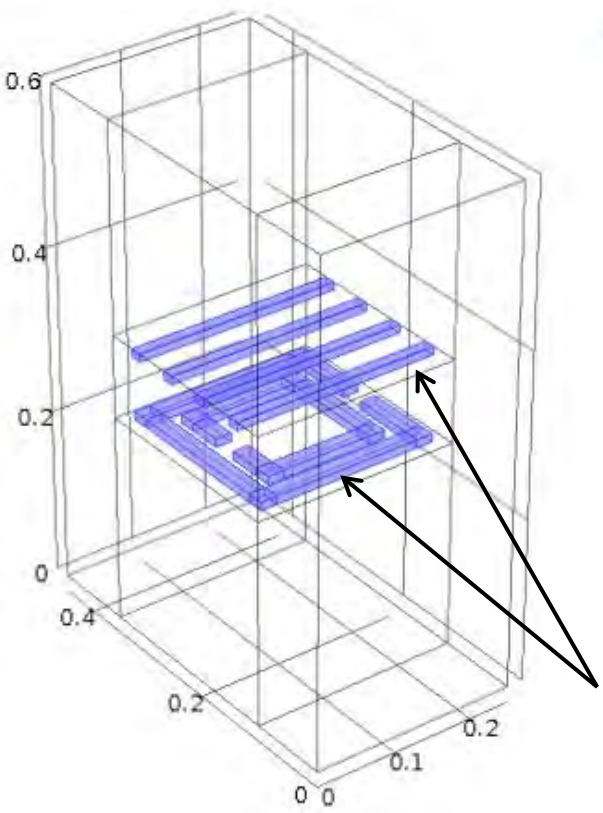
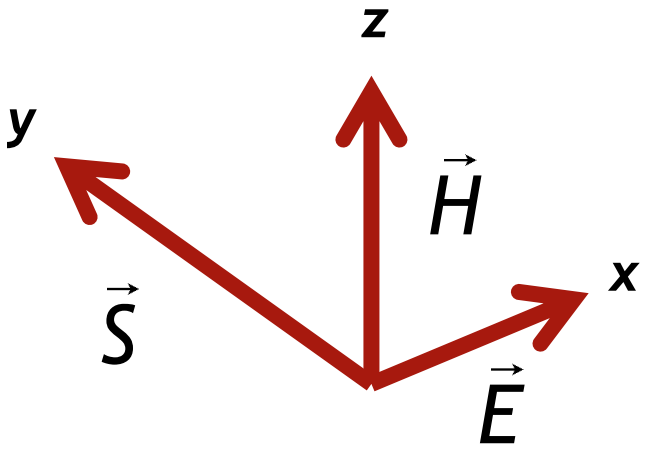


gold

10 μm



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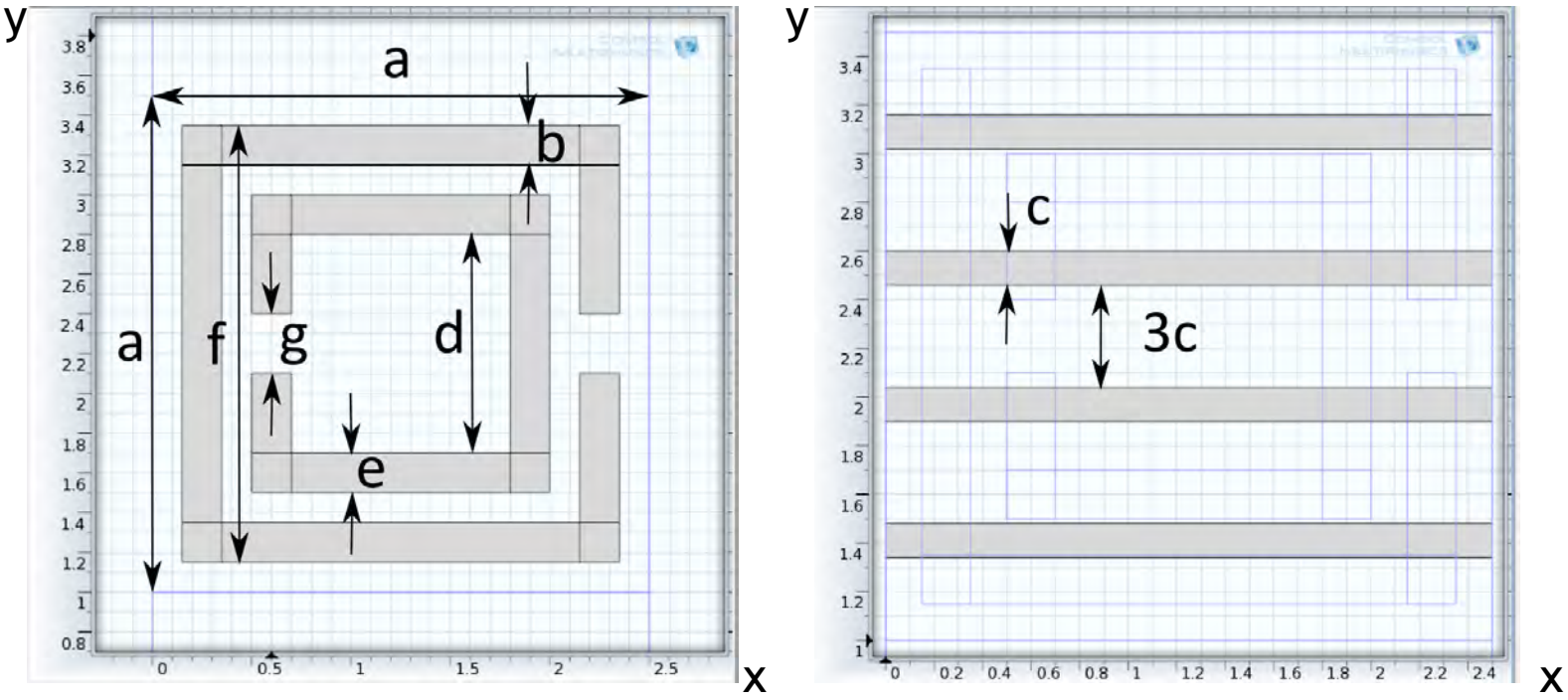
Final design



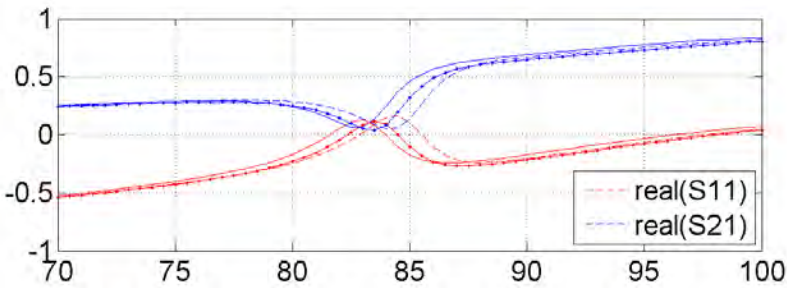
- **dimensions: a = 250 μm, b = e = 20 μm, c = 14 μm, d = 110 μm, f = 220 μm, g = 30 μm**

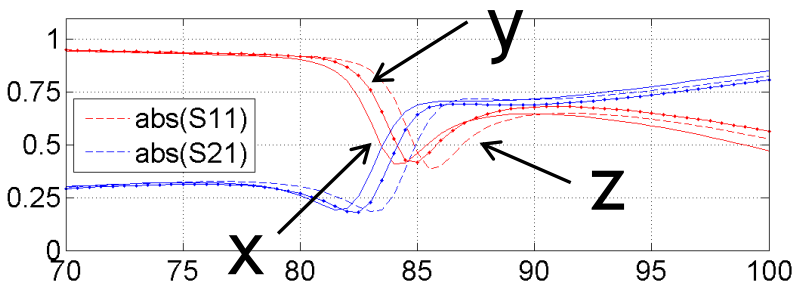
Final design

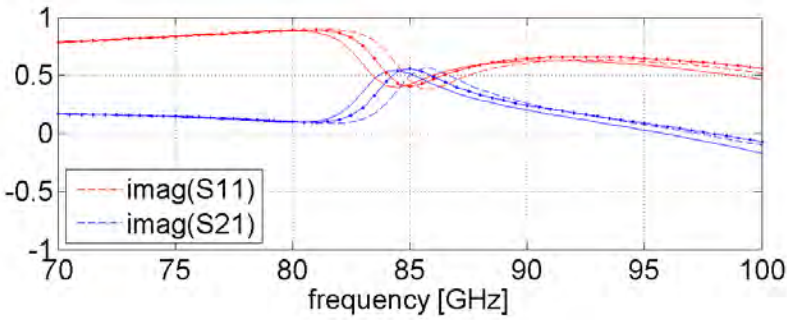
- Nematic liquid crystal permittivity:
  - $\varepsilon_{||} = 4.004336 \cdot (1 - 4.44 \cdot 10^{-2} i)$,
  - $\varepsilon_{\perp} = 2.566052 \cdot (1 - 2.65 \cdot 10^{-2} i)$.

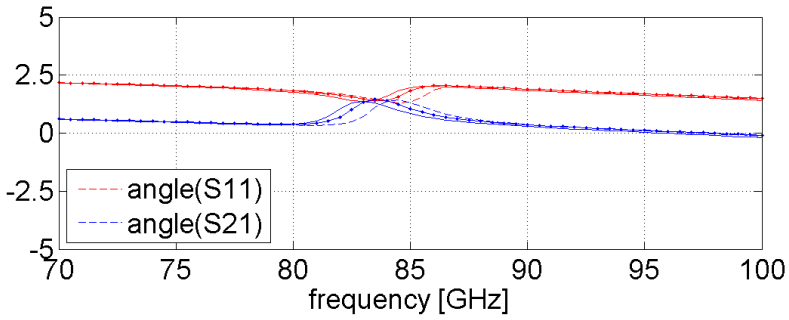
- Possible orientations:
  - along X-axis ($\varepsilon_x = \varepsilon_{||}$, $\varepsilon_y = \varepsilon_{\perp}$, $\varepsilon_z = \varepsilon_{\perp}$),
  - along Y-axis ($\varepsilon_x = \varepsilon_{\perp}$, $\varepsilon_y = \varepsilon_{||}$, $\varepsilon_z = \varepsilon_{\perp}$),
  - along Z-axis ($\varepsilon_x = \varepsilon_{\perp}$, $\varepsilon_y = \varepsilon_{\perp}$, $\varepsilon_z = \varepsilon_{||}$)

Final design - results









Transmission and reflection coefficients (S_{21}, S_{11}) calculated with Comsol Multiphysics represented in Cartesian and polar coordinate systems

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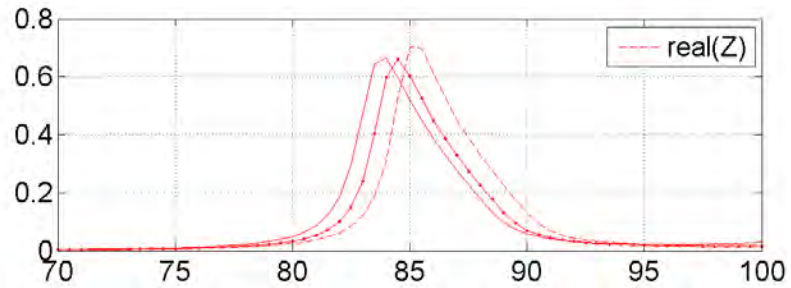
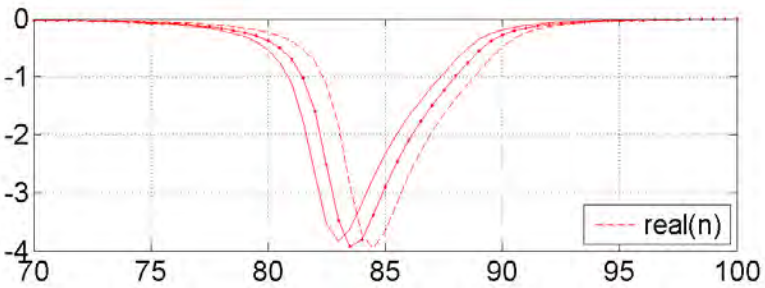
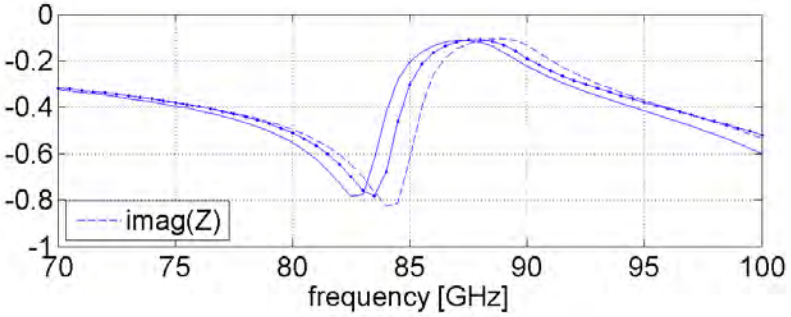
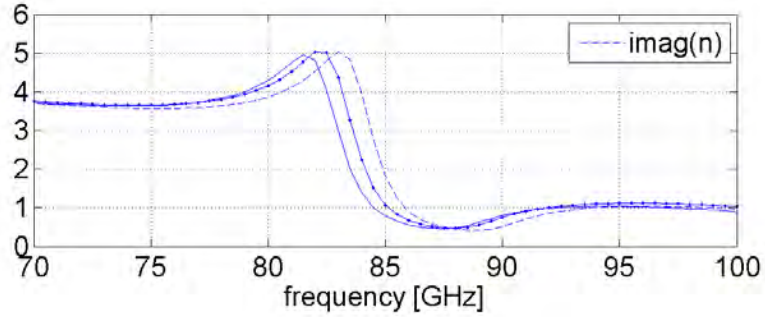
Final design - results









Effective refractive index and impedance retrived from S_{21}, S_{11}.

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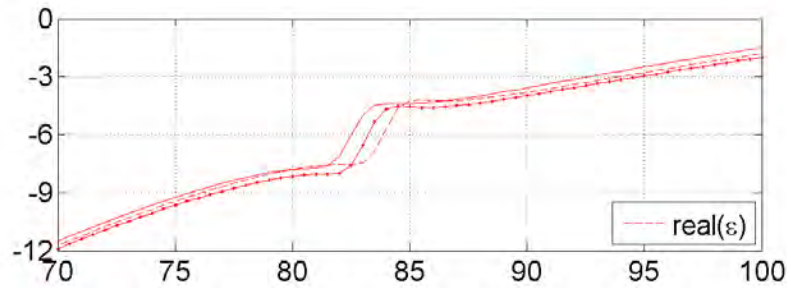
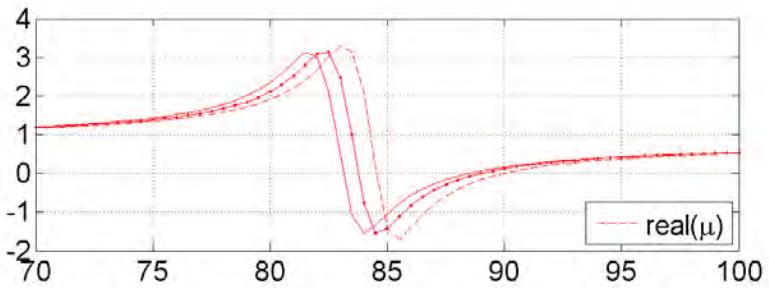
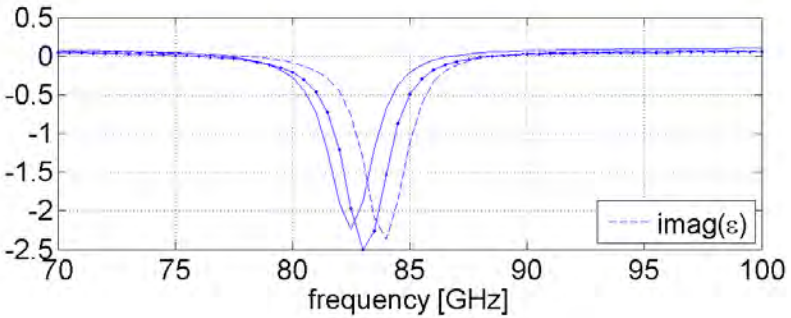
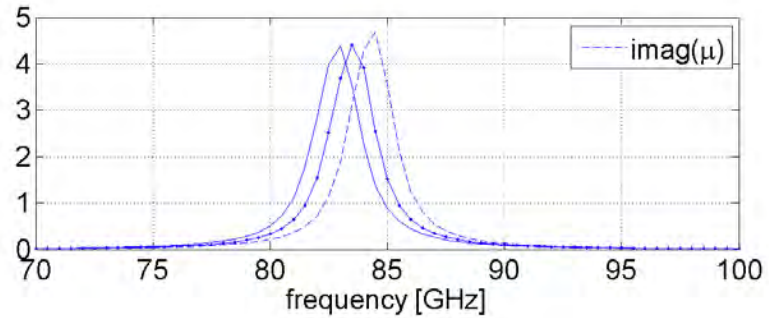
Final design - results









Effective permittivity and permeability retrived from S_{21}, S_{11}.

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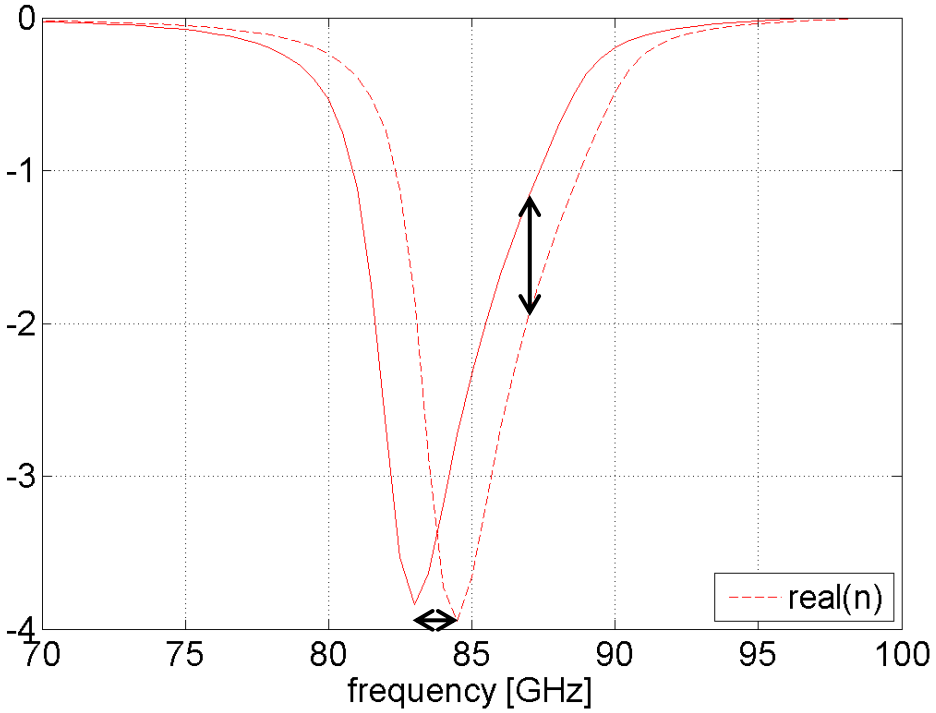
Final design - results



$$\frac{1{,}937-1{,}162}{1{,}162}\approx 67\%$$

$$\frac{84{,}5-83{,}0}{83{,}0}\approx 1{,}8\%$$

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Summary

- Initial design and test of numerical procedure based on FEM
- Road to fulfil requirements
- Final design

Acknowledgments

- Colaborators:
  - J. Parka, P. Nyga, R. Kowerdziej (Military University of Technology, Warsaw)
  - B. Salski, M. Olszewska (Warsaw Technical University, Warsaw)

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  - Polish Ministry of Science and Higher Education, grant no. O R00 0144 12

Thank you for your attention