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XXXIII Cycle

Anisotropic metasurface for scattering field manipulation

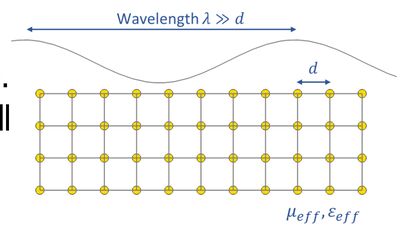
Barbara Cappello

Supervisor: Prof. Ladislau Matekovits

Research context and motivation

Metamaterials characteristics:

- Artificial periodic structure (arrangement of basic unit cells).
- Homogenisation of the material parameters (if unit cell dimensions << wavelength of the incident EM wave).
- Global properties that natural materials do not possess.



Acting on the geometrical shape of the unit cell it is possible to properly control the path of the incident electromagnetic wave in the proximity of the object.

Metasurfaces applications: Polarization converters, absorbers, leaky wave antenna, artificial magnetism, **Cloaking**.

Cloaking applications: Reducing field distortions from antenna struts, lowering the mutual coupling between nearby antennas, sensors cloaking. Not only in electromagnetics, but also multiphysics applications (acoustic, mechanical or thermal cloaking).

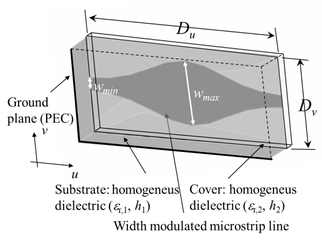
Addressed research questions/problems

1) Investigation of the **mantle cloaking of a metallic cylinder**.

- **Goal**: reducing the field scattered by the target object by using a thin metasurface which can be described in terms of an equivalent value of surface impedance Z_S.
- **Method**: by opportunely tuning the surface impedance, surface waves can be excited on the object boundary, bounding the electromagnetic energy and reducing the scattering.

Challenges:

- **Narrowband:** due to their resonant behaviour, passive cloaking devices are intrinsically of narrowband.
- **Electrically large objects:** a larger number of harmonics contributes to the scattered field.



Possible solutions:

- Width **modulated** microstrip line unit cell → modulated value of surface impedance.
- Using both **capacitive and inductive** surface impedances.

2) Study of the connection between mantle cloaking and manifestation of a non radiating **anapole mode**.

Adopted methodologies

- Analysis of the scattered field harmonics and of the surface impedance effect, following a theoretical approach based on Mie theory.
- Characterization of the proposed metasurface in terms cloaking performances.
- Multipole analysis of the scattering from a cloaked structure.

List of attended classes

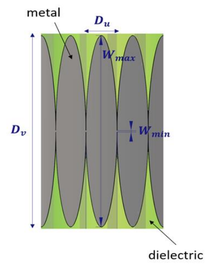
- 01SIVRO – Analysis of Mechanical Metamaterials. A short course (18/06/2018, 3 CFU)
- 01SIIRV – Introduction to Phased Array Antennas (15/03/2018, 2 CFU)
- 01QCTKG – Intro. formulazione hamiltoniana di sistemi classici e quantistici (26/06/2018, 4 CFU)
- 01SGRRV – Magnetic materials for electrical energy (23/11/2017, 4 CFU)
- 01QUWRV – Mathematical-physical aspects of electromagnetism (15/06/2018, 3 CFU)
- 01SFVRV – Metamaterials: Theory and multiphysics applications (01/03/2018, 4 CFU)
- 01RGBRV – Optimization methods for engineering problems (13/06/2018, 6 CFU)
- 01QCNKG – Proprietà elettroniche del grafene (26/03/2018, 4 CFU)
- 02NQUBG – Radio Planning (28/06/2018, 6 CFU)
- 01SHCRV – Unsupervised neural networks (09/04/2018, 6 CFU)
- 02LWHRV – Communication (19/03/2018, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (17/10/2018, 1 CFU)
- 08IXTRV – Project management (15/06/2018, 1 CFU)
- 01RISRV – Public speaking (14/05/2018, 1 CFU)
- 01RNCRV – Public Speaking II (03/05/2019, 2 CFU)
- 01SYBRV – Research integrity (08/02/2019, 1 CFU)
- 01SWQRV – Responsible research and innovation (25/02/2019, 1 CFU)
- 02RHORV – The new Internet Society (14/05/2018, 1 CFU)
- 01SWPRV – Time management (06/12/2018, 1 CFU)
- 01TGRRV – Uso degli strumenti per un efficace uso del tempo (22/03/2019, 1 CFU)
- 01QORRV – Writing Scientific Papers in English (18/04/2019, 3 CFU)
- External course – EUPROMETA XXXV Doctoral School on Metamaterials (18/12/2017)
- External course – PhD School Extreme Electromagnetic Matter Interactions (19/11/2018)
- External course – Summer School on Topological Photonics (08/07/2019)

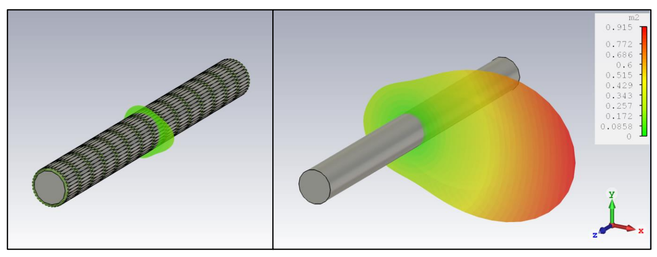
Novel contributions

Innovative unit cell: width modulated microstrip line

- Metasurface unit cell: sinusoidally modulated profile.
- Analysis of geometrical parameters on frequency of operation and bandwidth.

→ Reduction of the scattered field and restoration of the incident wave.



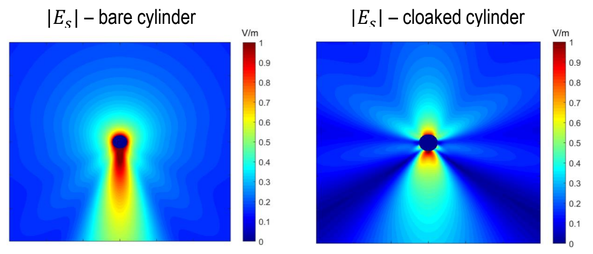


Cloaking of electrically large objects

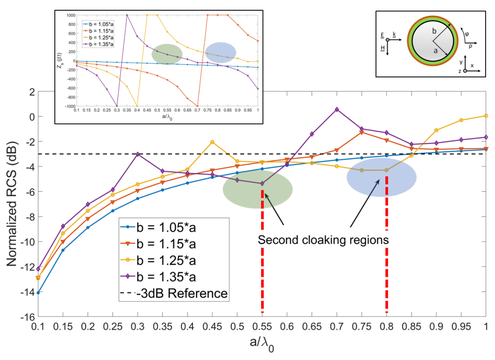
- Theoretical and numerical analysis of the scattered field beyond quasi static regime.

→ By opportunely setting the dielectric layer thickness and permittivity it is possible to achieve a "second cloaking region".

→ Inductive surface reactance.



$a = 0.8\lambda \quad b = 1.25a \quad X_s = 110j\Omega$

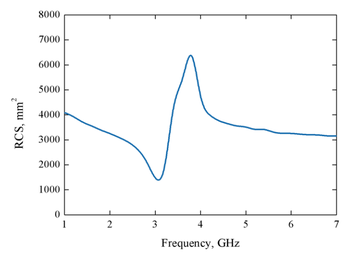


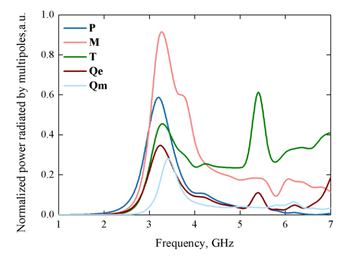
Correspondence between cloaking and anapole mode

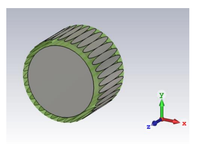
- Multipole decomposition of the internal field [7,8].

→ At the cloaking frequency, the anapole mode condition is fulfilled.

→ Strong response in terms of magnetic dipole.







Future work

- Connection between the geometrical parameters of the modulated metasurface to its characteristics in terms of effective dielectric constant and surface impedance.
- Further investigation on the link between cloaking phenomenon and the existence of an anapole mode.
- Introduction of higher order symmetries (such as glide symmetry) and study of their effects on the dispersion characteristics of the metasurface.

Submitted and published works

[1] Cappello, B., Labate, G., and Matekovits, L., "A Surface Impedance Model for a Microstrip-line based Metasurface", International Conference on Electromagnetics in Advanced Applications (ICEAA), Verona, Italy, 2017, pp. 429-432 **(Published)**.

[2] Labate, G., Cappello, B., and Matekovits, L., "A Radial Transmission Line Model for Mantle Cloaking with Impedance Metasurfaces", European Conference on Antennas and Propagation (EuCAP), London, UK, 2018 **(Published)**.

[3] Cappello, B., and Matekovits, L., "Effect of Geometrical Parameters of a Width Modulated Microstrip Line based Mantle-Cloak", IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Boston, USA, 2018, pp. 1859-1860 **(Published)**.

[4] Cappello, B., and Matekovits, L., "Spectral Composition of the Scattered Field from a Large Metallic Cloaked Cylinder", International Conference on Electromagnetics in Advanced Applications (ICEAA), Cartagena de Indias, Colombia, 2018, pp. 240-243 **(Published)**.

[5] Cappello, B., Matekovits, L., and Naishadham, K., "Preliminary Study of a Cylindrical Microstrip Metasurface Using the State Space Method", IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Atlanta, USA, 2019 **(Published)**.

[6] Cappello, B., Shestopalov, Y., and Matekovits, L., "Analysis of the Surface Impedance of a Sinusoidally Modulated Metasurface", International Conference on Electromagnetics in Advanced Applications (ICEAA), Granada, Spain, 2019 **(Published)**.

[7] Cappello, B., Ospanova, A., Basharin, A., and Matekovits, L., "Ideal Magnetic Dipole: Scattering and Mantle Cloaking Effects", International Conference on Electromagnetics in Advanced Applications (ICEAA), Granada, Spain, 2019 **(Published)**.

[8] Cappello, B., Ospanova, A., Matekovits, L., and Basharin, A., "Mantle cloaking due to ideal magnetic dipole scattering", Scientific Reports, 2019 **(Submitted)**.

[9] Olekhno, N.A., Kretov, E.I., Stepanenko, A.A., Filonov, D.S., Cappello, B., Matekovits, L., and Gorlach, M.A, "Topological edge states of interacting photon pairs realized in a topolectrical circuit", Nature Communications, 2019 **(Submitted)**.

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