(Invited) Planar Perodic Geometries: How to Reflect or Absorb Electromagnetic Energy in a Specific Manner


Published in:
Metamaterials Workshop

Document Version:
Other version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2017 QUB and © 2017 The Authors.
This work is made available online in accordance with the publisher's policies. Please refer to any applicable terms of use of the publisher.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Download date: 18. Mar. 2021
Planar Periodic Geometries: 
How to reflect or absorb electromagnetic waves in a specific manner

Dr Stylianos Assimonis and Prof Vincent Fusco
s.assimonis@qub.ac.uk, v.fusco@ecit.qub.ac.uk

Research Fellow, Centre for Wireless Innovation
ECIT Institute, Queen’s University Belfast, U.K.

Exeter Microwave Metamaterials Meeting, December 2017
Outline

- Introduction to electromagnetic periodic geometries
- Dispersing Electromagnetic Energy
- Absorbing Electromagnetic Energy
- Harvesting Electromagnetic Energy
Electromagnetic Periodic Geometries

- Problems
  - Mutual coupling reduction on MIMO antennas
  - Radar Cross Section reduction of an object
  - Design high-directivity planar antennas
  - Phase plates design
  - Electromagnetic energy absorption

- Why these geometries
  - They have unique properties mainly because of the periodicity and hence they efficiently solve all the above problems
  - Usually they are easily fabricated and have low cost

- Depending on electrical size, the operation mechanism and the application are categorized as
  - Frequency selective surfaces
  - Electromagnetic Band-Gaps
  - Metamaterials
  - Electromagnetic absorbers
  - Scatters
Dispersing Electromagnetic energy

\[ R = -1 \]

![PEC](image1)

\[ R = +1 \]

![PMC](image2)
Dispersing Electromagnetic energy

It is possible to disperse electromagnetic energy and thus to reduce RCS by properly placing pec and pmc plates.

Good news: the phase difference between the two reflection coefficients of the plates matters and not the absolute values.
Dispersing Electromagnetic energy

Unit-cells with size 10x10x3 mm: the basic geometry (left, unit cell 1) is rotated by 90 deg. right (right, unit-cell 2).

Magnitude of the cross-polarized reflection coefficient for the both unit-cells.

Phase and phase difference of the cross-polarized reflection coefficient for the both unit-cells.
Dispersing Electromagnetic energy

The finite planar periodic geometry, which consists of 2x2 lattices, which in turn consists of 4x4 unit-cells (left) and the RCS reduction (right) compared with a metallic plate with exactly the same size vs. frequency for normal incidence for both TE/TM polarization: reduction occurs from 10 to 25 GHz.

RCS for normal incidence at 15 GHz for the finite planar periodic geometry and for a metallic plate with exactly the same size: at (θ, φ) = (0, 0) point the reduction is about 20 dB (monostatic comparison), while in the general case (bistatic comparison) is about 3.5 dB.
Absorbing Electromagnetic energy

Absorbers use different mechanism than the diffusers

\[ \Gamma = \frac{Z_M - Z_0}{Z_M + Z_0} \]

Because of the ground plane the transmission is vanished. Hence, for perfect absorption

\[ \Gamma = 0 \rightarrow Z_M = Z_0 \rightarrow \mu_M = \varepsilon_M \]

From the effective medium theory and when the unit-cell is electrically small, the periodic geometry can be represented by the effective relative permittivity \( \varepsilon_M \) and the effective relative permeability \( \mu_M \), and thus

\[ Z_M = Z_0 \sqrt{\frac{\mu_M}{\varepsilon_M}} \quad \Gamma = 0 \rightarrow Z_M = Z_0 \rightarrow \mu_M = \varepsilon_M \]
Absorbing Electromagnetic energy

Unit cell with size of $a = 8$ mm, substrate (FR4) height of 1 mm, copper traces and surface current distribution at 10.31 GHz.

Absorption $A$, reflectance $R$, and transmittance $T$: the peak value for the absorption is found to be 95.81% at 10.31 GHz.

Absorption efficiency for obliquely incident waves for TE (a) and TM (b) polarization.

Absorbing Electromagnetic energy

Super cell of a triple-band absorber, consisting of nine properly scaled ERRs. The dimensions of the bigger, medium, and smaller ERRs are those of Fig. 1 scaled by $s_1 = 1$, $s_2 = 0.8$ and $s_3 = 0.7$, respectively.

Absorption efficiency of the triple-band absorber for obliquely incident waves in two different cases of polarization: TM ($\phi$ variation) and TE ($\theta$ variation).


Surface current distribution at 10.4, 13 and 15 GHz.
Absorbing Electromagnetic energy

Schematic of Hexagon FSS unit cell with \( p = 6.93 \text{ mm} \), substrate thickness of 3.13 mm, lossy traces with surface resistance of 27 ohm/sq and photograph of the fabricated, planar periodic structure consisting of 208 unit-cells. Y Shield HSF-74 electro conductive shielding paint was used to form the elements on the surface. Y Shield HSF-74 is a graphite and carbon black-based material, which is reinforced with long conductive fibers.

Simulated and measured reflectivity plots for normal (a) and 45 degrees (b) incidence. For the first case the bandwidth is 108%, while for the oblique incidence case is 16% for TE and TM polarization.

Absorbing Electromagnetic energy

The mechanism behind the absorbance: meta-surface (dielectric and metallic parts) acts like a resistor

losses on the volume $V_d$ of the dielectric parts

$$P_d = \pi f \tan \delta \varepsilon \varepsilon_0 \iiint_{V_d} |E|^2 \, dV$$

losses on the surface $S_m$ of the metallic parts

$$P_m = \frac{1}{2} \sqrt{\frac{\pi \mu f}{\sigma}} \iint_{S_m} |H|^2 \, dS$$

$f$: frequency, $\tan \delta$: loss tangent, $\varepsilon$: relative dielectric permittivity, $\mu$: relative magnetic permeability, $\sigma$: metals’ conductivity,

energy dissipates on dielectrics and metals

Losses on the dielectric and metallic parts to the total incident power for normal incidence for TE/TM (copper traces)

Losses on the dielectric and metallic parts to the total incident power for normal incidence for TE/TM (resistive traces)
Harvesting Electromagnetic Energy

Is it possible the captured energy to be delivered to a load?
Metamaterial RF Harvesters with conventional rectification system (i.e., diodes)

Metamaterial harvesters are like metamaterial absorbers BUT
• In metamaterial harvesters
  • RF power is mainly delivered to a properly placed load, representing the input impedance of a rectifier
• In metamaterial absorbers
  • RF power mainly dissipates on the metallic or dielectric parts of the structure

• Metamaterial harvesters usually outperform conventional harvesters because,
  • are inherit periodic geometries with unit-cell of dimension usually $\lambda/10$
  • each unit cell acts as a small battery
  • could form compact structures operating at low frequency bands (e.g., FM, TV) which usually carry more power
Harvesting Electromagnetic Energy

Triple-band (0.9 GHz, 1.8 GHz and 2.45 GHz) metamaterial absorber for RF Energy Harvesting

\[ \alpha \approx \frac{\lambda}{10} \]

Power efficiency: the power delivered to the rectification system (load) to the incident power

Surface current distributions at the three resonating frequencies at 0.9 GHz, 1.8 GHz and 2.45 GHz

Harvesting Electromagnetic Energy

A panel of 5x5 unit-cells (left) is formed. On the bottom a circuit grid of rectifiers transforms the captured RF energy to DC power.
Harvesting Electromagnetic Energy

Triple-band metamaterial absorber for RF Energy Harvesting

Assuming plane wave which impinges on the panel with power density

\[ S = 0.1 \text{ to } 100 \, \mu \text{W/cm}^2 \]

For each unit-cell

\[ A_i = (\lambda/10)^2 = 11.1 \, \text{cm}^2 \text{ and } P_{\text{in},i} = S A_i = -29.55 \text{ to } 0.45 \, \text{dBm} \]

For the whole \( 5 \times 5 \) panel with dimension \( \lambda/2 \times \lambda/2 \)

\[ A = (\lambda/2)^2 = 277.39 \, \text{cm}^2 \text{ and } P_{\text{in}} = S A = -15.57 \text{ to } 14.43 \, \text{dBm} \]

\[
\text{Efficiency} = \frac{P_{\text{out}}^{\text{dc}}}{P_{\text{in}}^{\text{RF}}} 
\]

It is possible to harvest above 20 mW for 100 \( \mu \text{W/cm}^2 \) from a metamaterial absorber panel with dimension \( \lambda/2 \times \lambda/2 \)
Thank you for your attention!