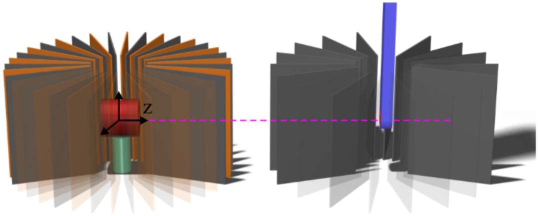
Magnetic Concentrators for more Efficient Wireless Charging

Donovan Webb
D. Wildman (project partner), S. Bending (Supervisor)

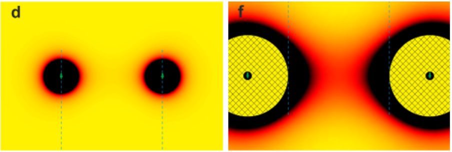
University of Bath



(Image: Jordi Prat Camps 2015)

Motivation

Aim: Create a device to concentrate magnetic fields



www.wonderfulengineering.com/38-high-def-wind-turbine-pictures-from-around-the-world/
www.fujitsu.com/global/about/resources/news/press-releases/2006/0830-01.html

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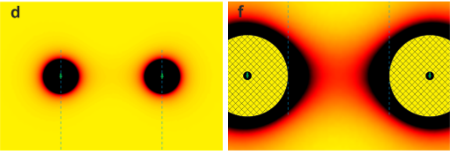

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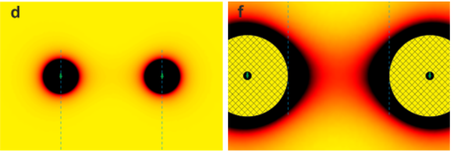

R eplicate
O ptimise
E xtend

PRL **109**, 263903 (2012) PHYSICAL REVIEW LETTERS week ending 28 DECEMBER 2012

Magnetic Energy Harvesting and Concentration at a Distance by Transformation Optics

Carles Navau, Jordi Prat-Camps, and Alvaro Sanchez*
Grup d'Electromagnetisme, Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, Spain
(Received 21 August 2012; published 28 December 2012)

Based on transformation optics, we introduce a magnetic shell with which one can harvest magnetic energy and distribute it as desired in space with unprecedented efficiency at an arbitrary scale. It allows a very large concentration of magnetic energy in a free space region, which can be used for increasing the sensitivity of magnetic sensors, and the transfer of magnetic energy from a source to a given distant point separated by empty space, with possible applications in wireless transmission of energy.

DOI: 10.1103/PhysRevLett.109.263903 PACS numbers: 41.20.−q, 75.90.+w, 85.25.−j, 85.75.Ss

APPLIED PHYSICS LETTERS **105**, 234101 (2014)

Experimental realization of magnetic energy concentration and transmission at a distance by metamaterials

Jordi Prat-Camps, Carles Navau, and Alvaro Sanchez
Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, Spain

(Received 16 October 2014; accepted 28 November 2014; published online 9 December 2014)

Concentrating magnetic energy in a desired volume is an important requirement for many technologies. Here, we experimentally realize a superconductor-ferromagnetic metamaterial that allows to concentrate the magnetostatic energy in its interior and in other situations to amplify the energy in its exterior. We show that surrounding two distant current loops with two such metamaterials enhance the magnetostatic coupling between them. We also demonstrate that a ferromagnetic-only metamaterial, without superconducting parts, achieves these properties with only a slight decrease in performance. Results may be applied to increase the sensitivity of magnetic sensors or for enhancing wireless power transmission, where efficiency depends critically on the magnetic coupling strength between source and receiver. © *2014 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4903867]

Metamaterials have opened new possibilities to control electromagnetic fields,[1–5] in particular, for concentrating energy at different scales and wavelengths. Examples range from electromagnetic energy concentration by plasmonics at the nanoscale[6,7] to thermal energy concentration at larger scale.[8,9] Metamaterials have also provided new ways of controlling static magnetic fields, often by applying the ideas of transformation optics to the static dc case.[10–14] For example, magnetic cloaks have been proposed and experimentally realized using superconductors combined with magnetic

We build a metamaterial cylindrical shell made of 36 rectangular prisms of alternated SC and FM materials (see supplemental material Sec. A and Fig. S1 for details[25]). The FM and SC pieces are made of commercial high-permeability metallic alloy (mu-metal) and coated conductor, respectively. The pieces are radially distributed and fixed in a non-magnetic 3D-printed support (Figs. S1(b) and S1(c)).

We first experimentally study the magnetic concentration properties of our metamaterial shell. Two Helmholtz

www.wonderfulengineering.com/38-high-def-wind-turbine-pictures-from-around-the-world/
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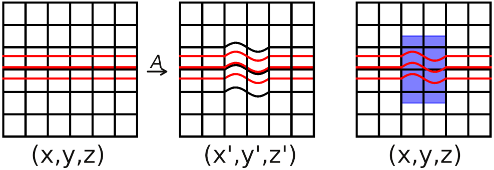
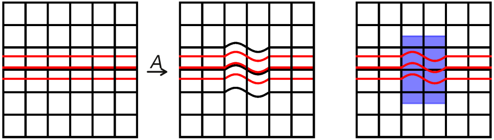
Transformation Optics and Metamaterials



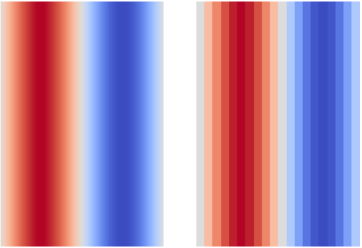
$$\mu' = \frac{A\mu_0 A^T}{|A|} \quad \text{and} \quad \epsilon' = \frac{A\epsilon_0 A^T}{|A|}$$

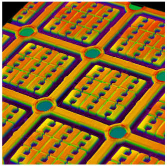
Transformation Optics and Metamaterials



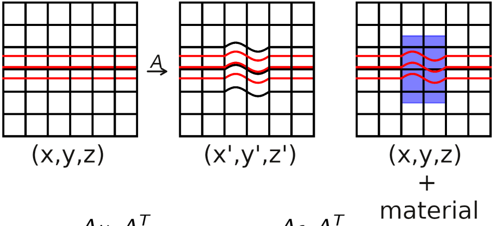
(x,y,z) (x',y',z') (x,y,z) + material

$$\mu' = \frac{A\mu_0 A^T}{|A|} \quad \text{and} \quad \epsilon' = \frac{A\epsilon_0 A^T}{|A|}$$





Transformation Optics and Metamaterials



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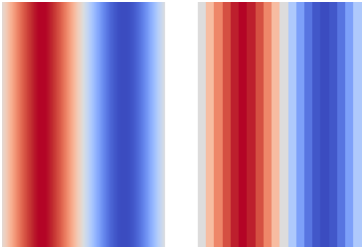
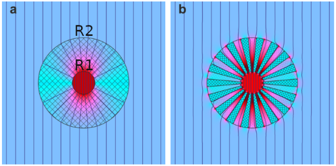
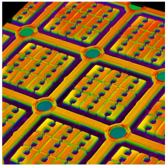




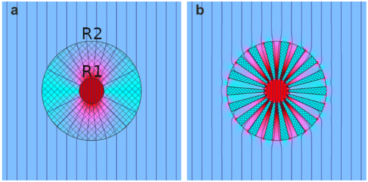


Navau, C. et. al. (2012).https://doi.org/10.1103/PhysRevLett.109.263903
https://physics.anu.edu.au/nonlinear/research/metamaterials/

Magnetic Concentrator

$$\mu_\rho \to \infty, \ \ \mu_\theta \to 0$$

External→Internal

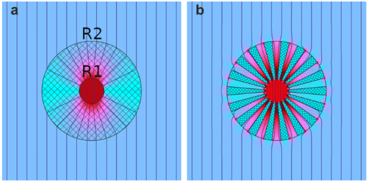


$$\frac{R_2}{R_1}$$

Magnetic Concentrator

$$\mu_\rho \to \infty, \ \ \mu_\theta \to 0$$

External→Internal



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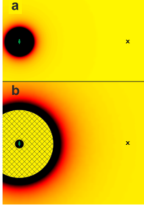

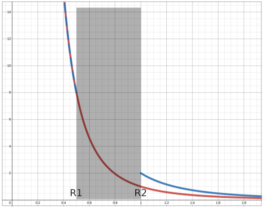

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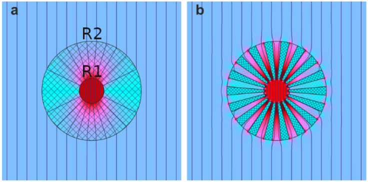

$\frac{R_2}{R_1}$

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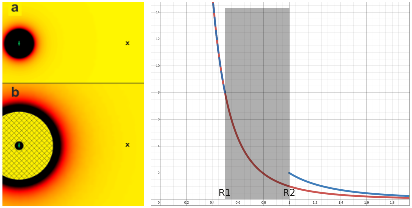
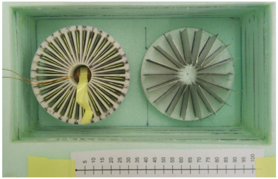


Superconductor $\mu = 0$
Ferromagnet $\mu >> 0$



Prat-Camps, J., et. al. https://doi.org/10.1063/1.4903867

Magnetic Concentrator

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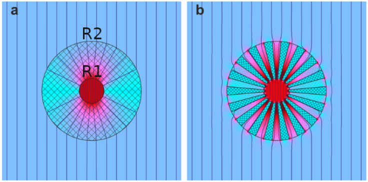
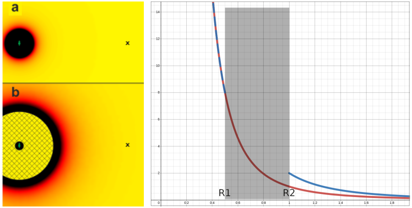
External→Internal



$$\frac{R_2}{R_1}$$

Internal→External



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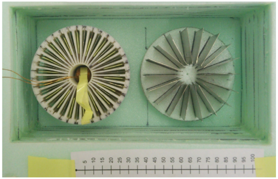

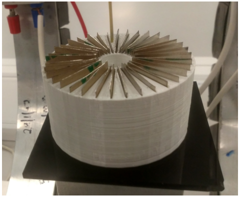

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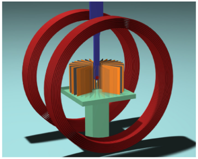
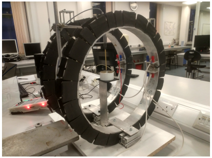
DC Experiments

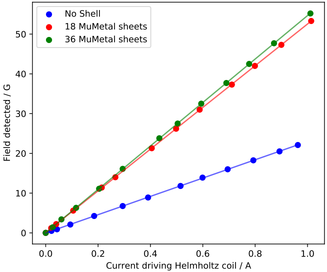
R





$$\frac{R_2}{R_1} = 4$$

$$\text{Measured} = 2.38$$



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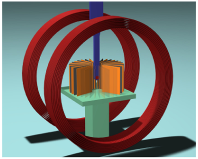

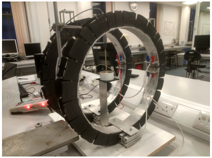

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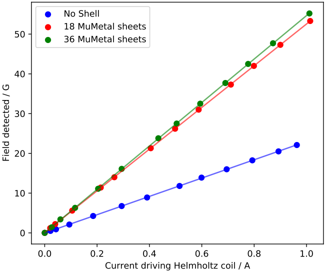

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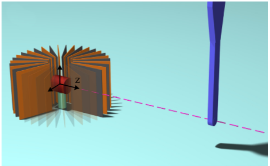

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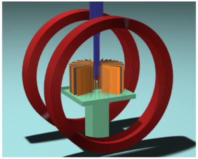

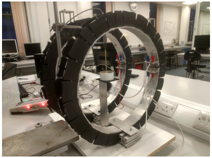

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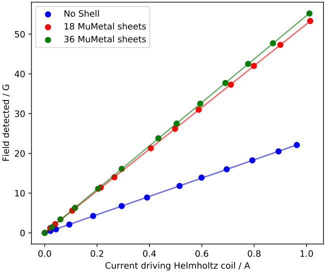

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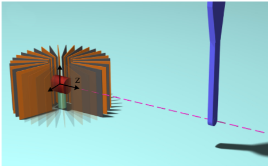

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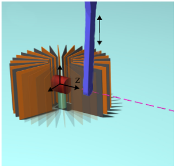

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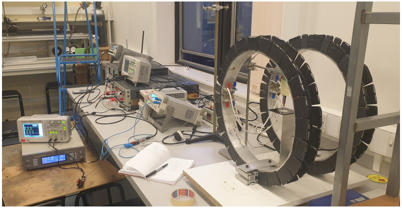
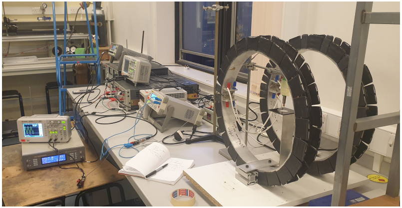
AC Experiments

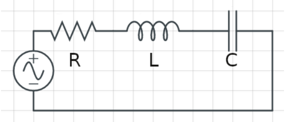
E



AC Experiments

E



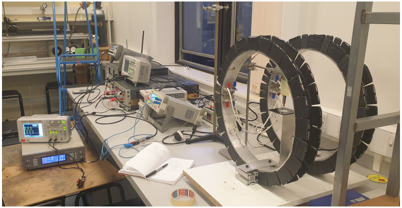


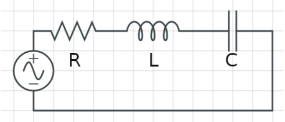
Problems encountered:

- Impedance of Helmholtz coils

AC Experiments

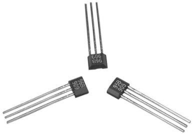
E





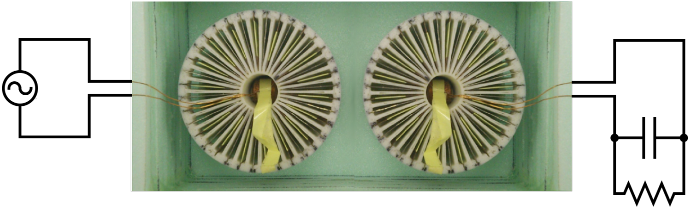
Problems encountered:

- Impedance of Helmholtz coils
- pick up
- noisy V_H



Other proposed Work

E Power transfer



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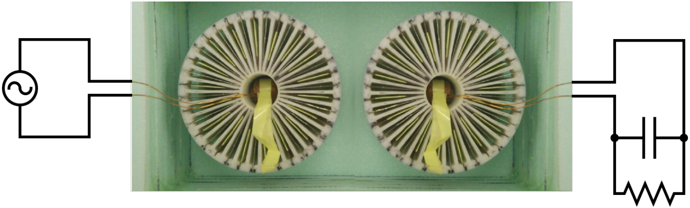

O Modelling

COMSOL

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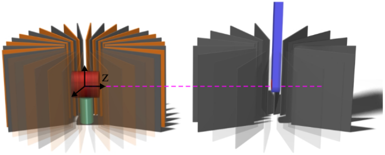
Conclusion



- An introduction to Transformation Optics.
- DC concentrating shell created.
- Dipole exploration.
- AC exploration.

- More efficient wireless power transfer.