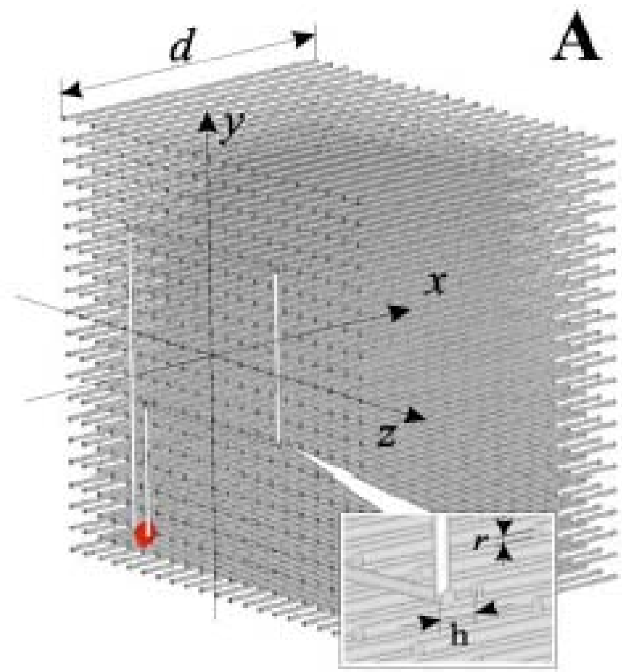
Effective Parameter Definitions & Physical Meanings

Yang Hao

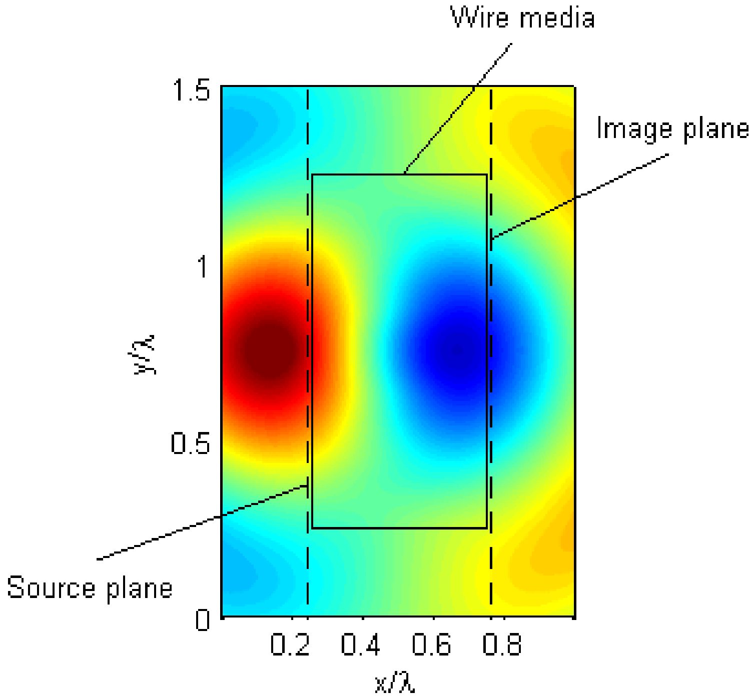
Queen Mary
University of London

Finite-Difference Time-Domain Method

- Modelling Different Structures in FDTD



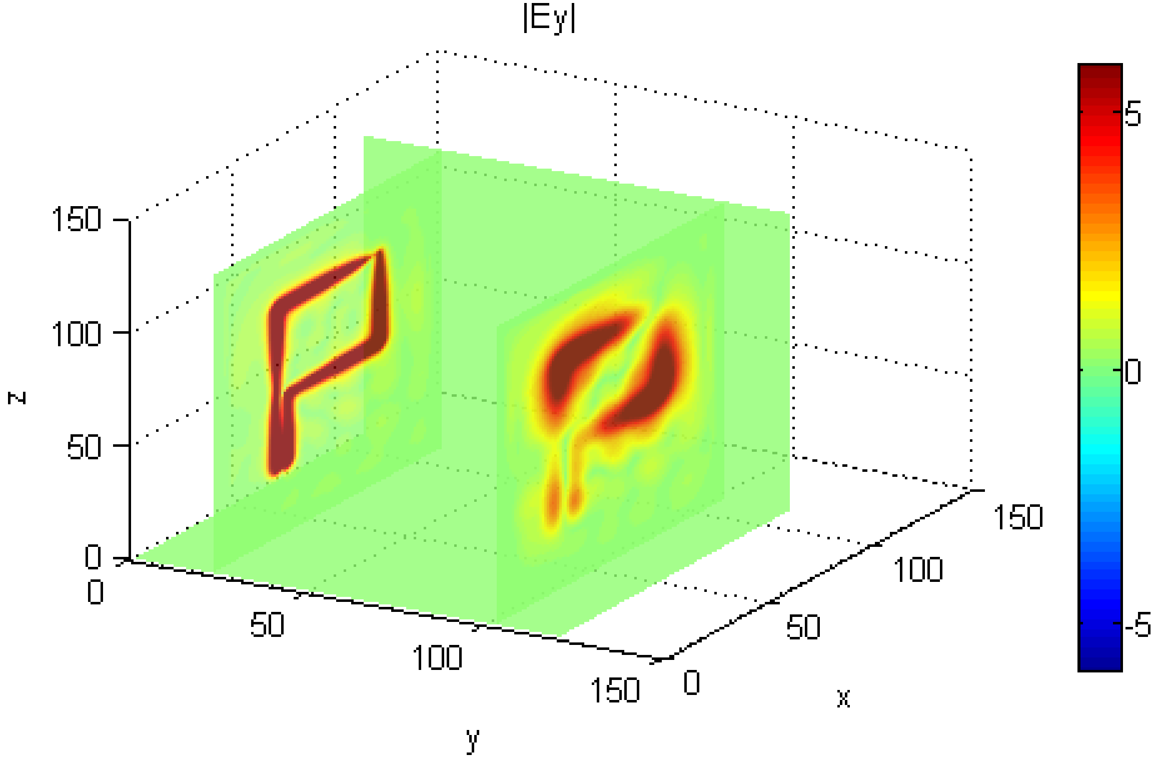
Modelling actual structure



Effect medium approximation (if dimension « λ)

FDTD Modelling of Wire Medium

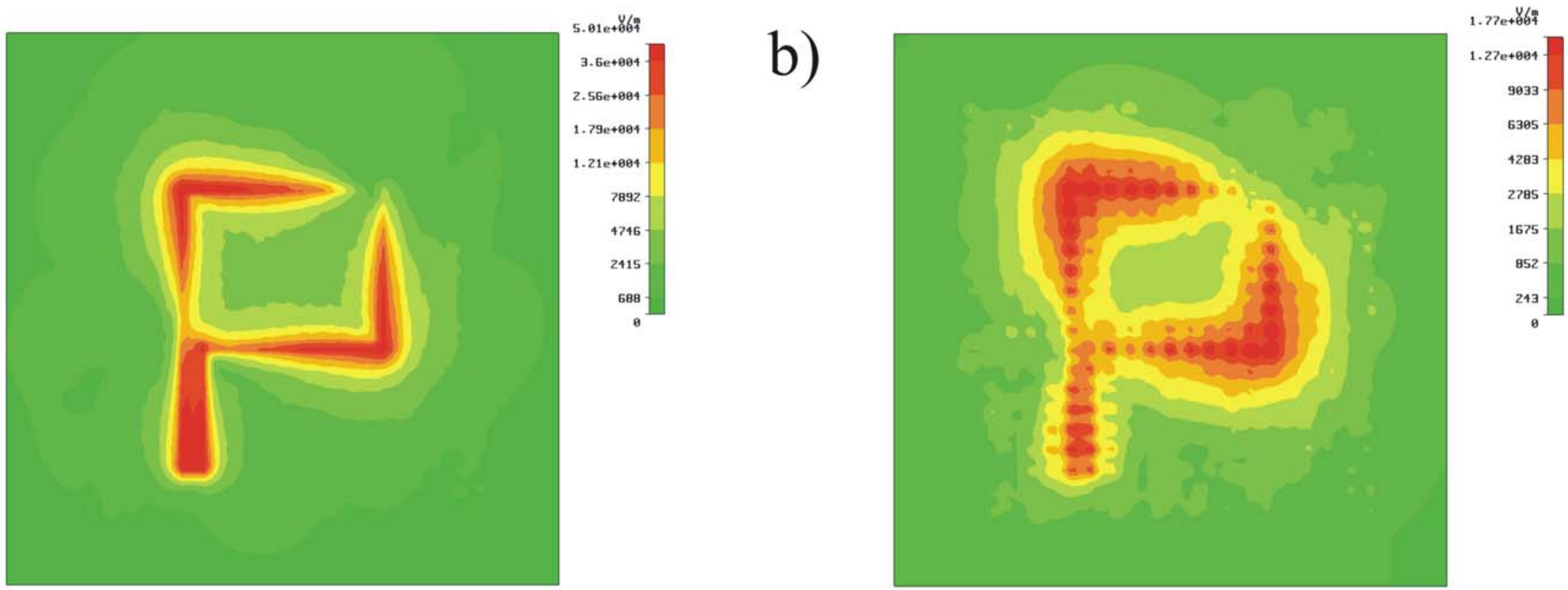
- 3-D Simulation



Frequency = 1.0 GHz, Wire Media Length = λ, Thickness = λ/2, FDTD cell size = λ/150

Intensity distribution

a) b)

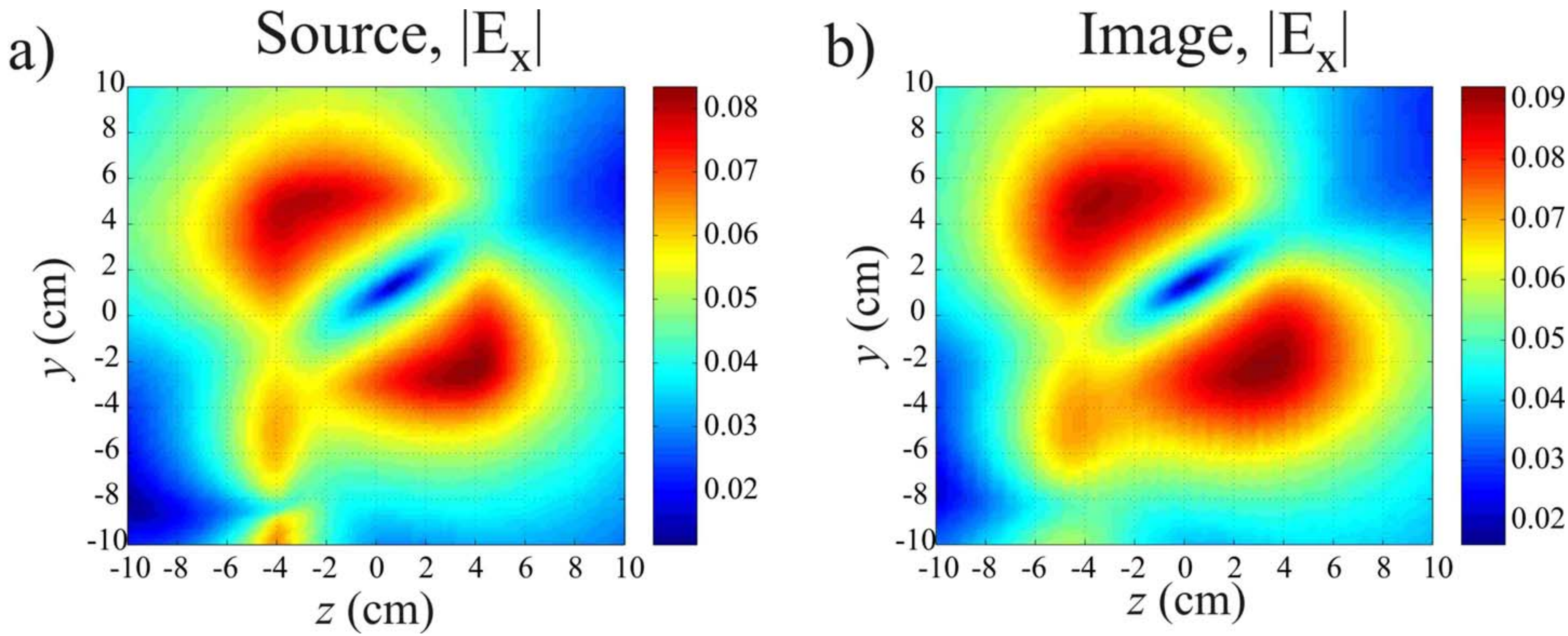


a) near the front interface b) near the back interface

Resolution is $\lambda/15$!

P.A. Belov, Y. Hao, S. Sudhakaran, "Subwavelength microwave imaging using an array of parallel conducting wires as a lens", Phys. Rev. B, vol. 73, 033108, 2006.

Near field scan results



Distribution of electrical field at the source and image planes.
Confirmation of λ/15 resolution and 18% bandwidth reported!

P.A. Belov, Y. Hao, S. Sudhakaran, "Subwavelength microwave imaging using an array of parallel conducting wires as a lens", Phys. Rev. B, vol. 73, 033108, 2006.

Spatial Dispersion in Wire Media

- Dispersive FDTD Formulations

$$\varepsilon_r = 1 - \frac{k_0^2}{k^2 - q_z^2} \qquad (\ q_z \text{ - Spatial dispersion})$$

- With relations between **D** and **E**

$$D_z = \varepsilon \cdot E_z = \varepsilon_0 \cdot \left(1 - \frac{k_0^2}{k^2 - q_z^2}\right) \cdot E_z \qquad \Rightarrow \qquad \left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial z^2}\right)(D_z - \varepsilon_0 E_z) = \varepsilon_0 k_0^2 E_z$$

- Using central difference approximations

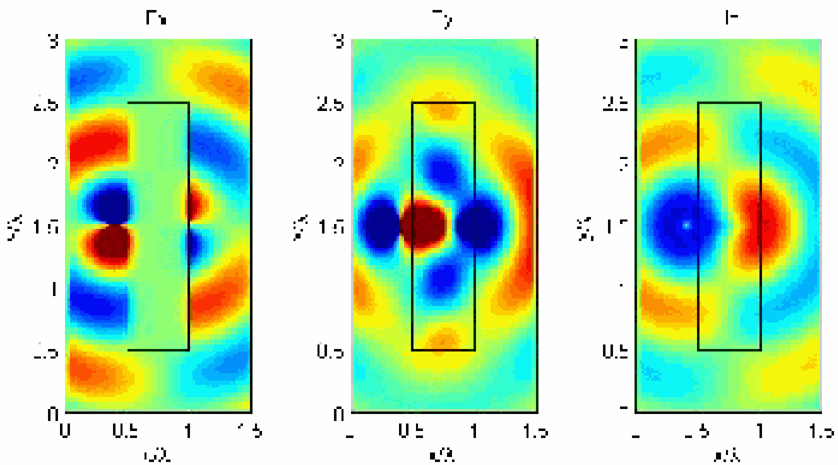
$$\begin{cases} \dfrac{\partial^2 D_z}{\partial t^2} = \dfrac{D_z^{n+1} - 2D_z^n + D_z^{n-1}}{dt^2}, \dfrac{\partial^2 D_z^n}{\partial z^2} = \dfrac{D_{z+1}^n - 2D_z^n + D_{z-1}^n}{dz^2} \\ \dfrac{\partial^2 E_z}{\partial t^2} = \dfrac{E_z^{n+1} - 2E_z^n + E_z^{n-1}}{dt^2}, \dfrac{\partial^2 E_z^n}{\partial z^2} = \dfrac{E_{z+1}^n - 2E_z^n + E_{z-1}^n}{dz^2} \end{cases}$$

$$\Rightarrow \begin{aligned} &-\frac{1}{c^2 dt^2}\left(D_z^{n+1} - 2D_z^n + D_z^{n-1}\right) + \frac{1}{dz^2}\left(D_{z+1}^n - 2D_z^n + D_{z-1}^n\right) \\ &= -\frac{\varepsilon_0}{c^2 dt^2}\left(E_z^{n+1} - 2E_z^n + E_z^{n-1}\right) + \frac{\varepsilon_0}{dz^2}\left(E_{z+1}^n - 2E_z^n + E_{z-1}^n\right) - \varepsilon_0 k_0^2 \frac{E_z^{n+1} + E_z^n}{2} \end{aligned}$$

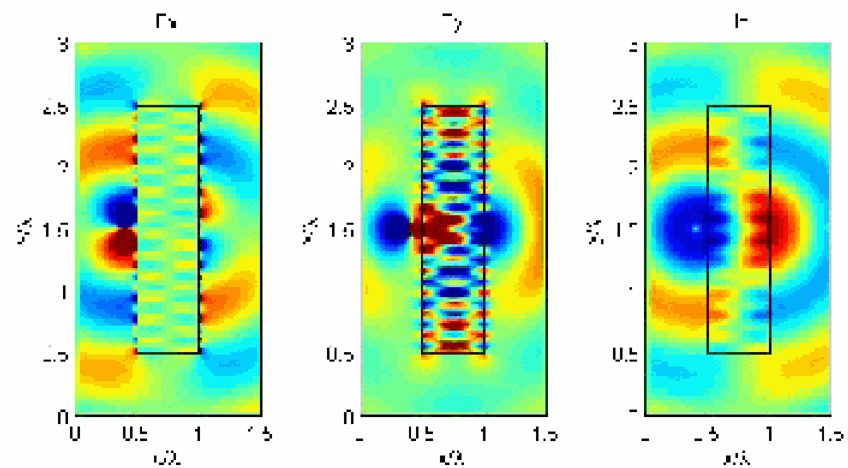
- in FDTD code

FDTD Modelling of Wire Medium

- The Effect of Spatial Dispersion

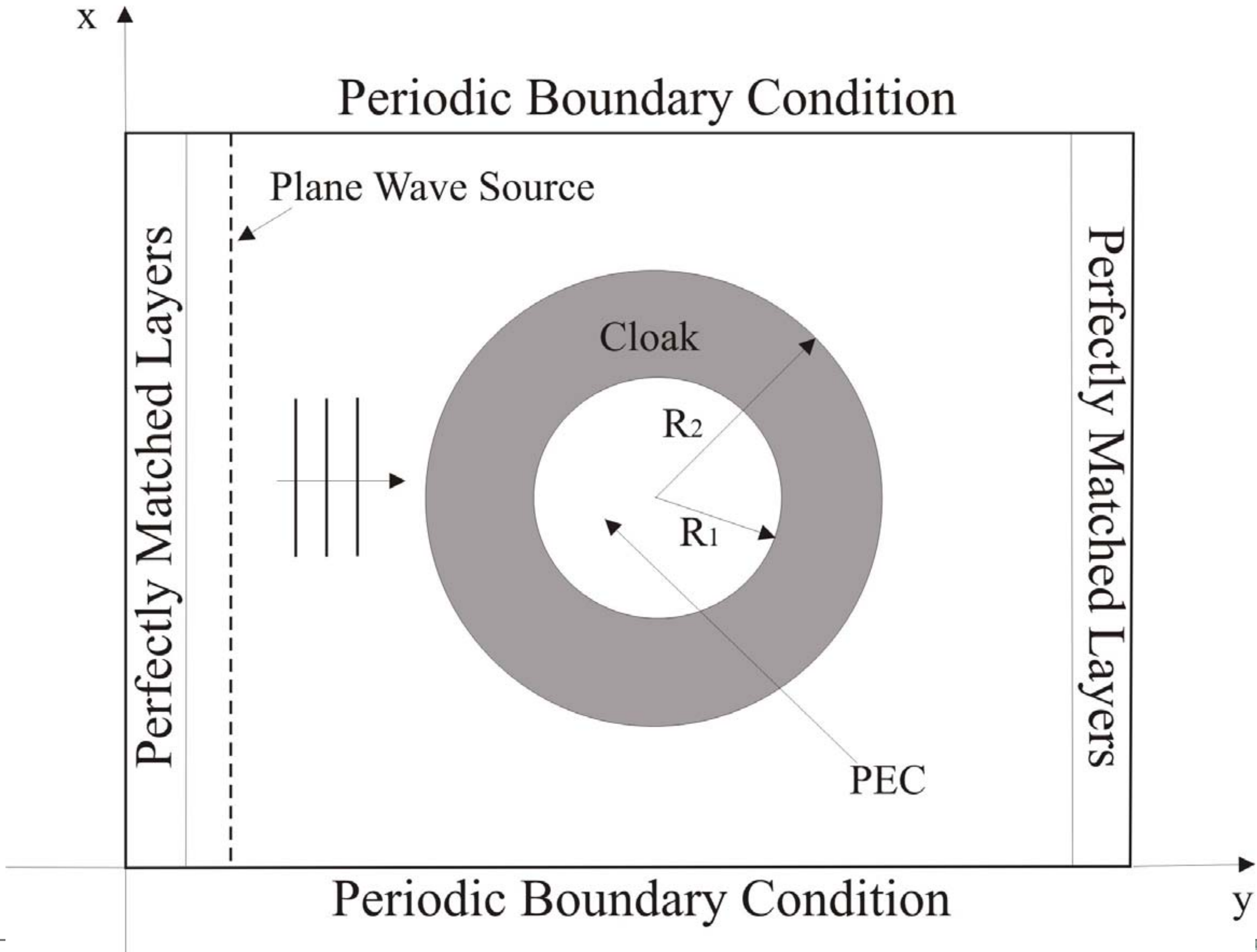


Only Frequency Dispersion



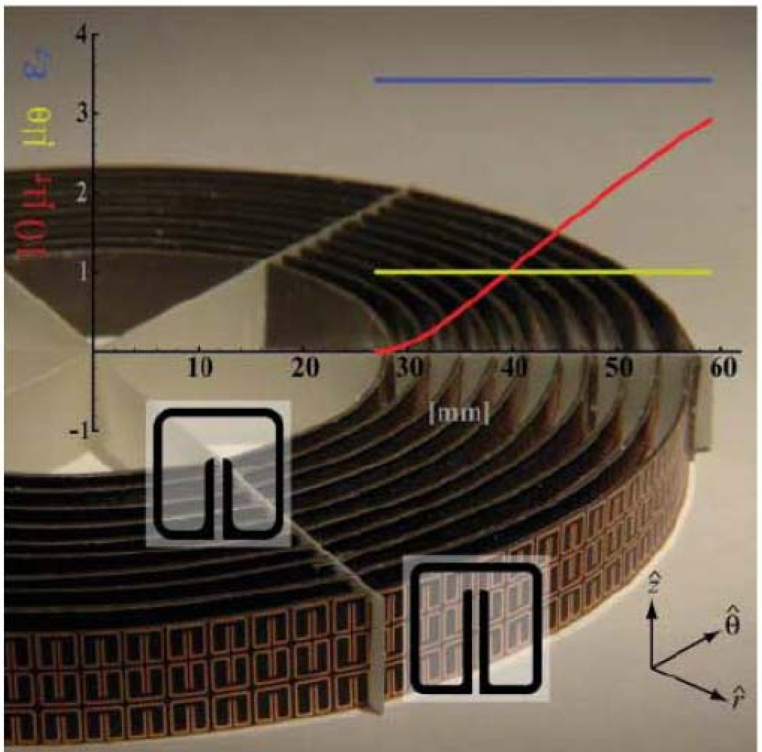
Frequency + Spatial Dispersions

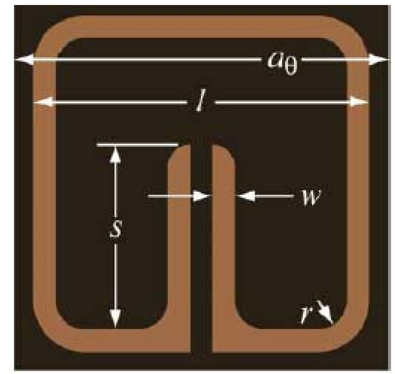
The FDTD computational domain is:



Cloaking device has been constructed for TM polarization (Hx, Hy, Ez) and it is working only in microwave frequencies.

$$\mu_r = \left(\frac{r - R_1}{r}\right)^2, \mu_\phi = 1, \varepsilon_z = \left(\frac{R_2}{R_2 - R_1}\right)^2$$

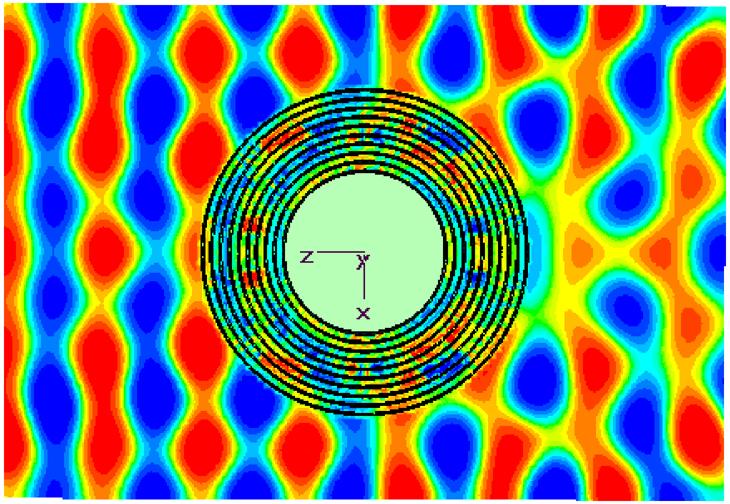


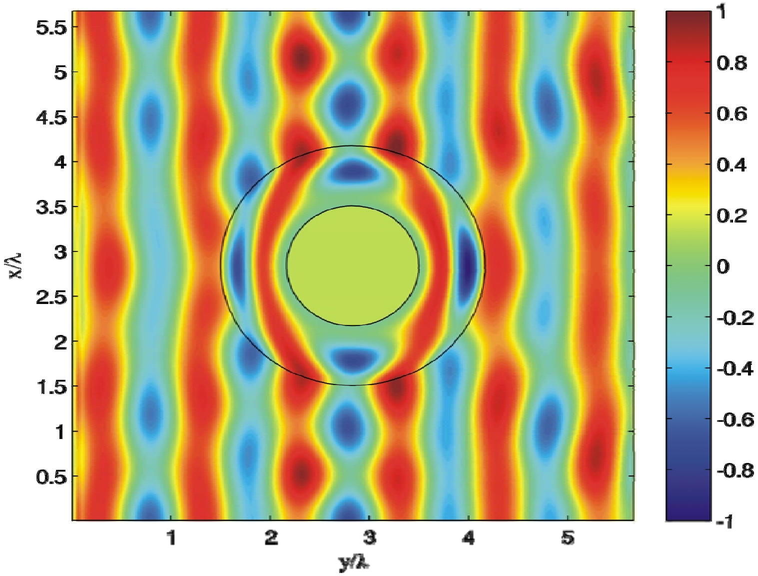


cyl.	r	s	μr
1	0.260	1.654	0.003
2	0.254	1.677	0.023
3	0.245	1.718	0.052
4	0.230	1.771	0.085
5	0.208	1.825	0.120
6	0.190	1.886	0.154
7	0.173	1.951	0.188
8	0.148	2.027	0.220
9	0.129	2.110	0.250
10	0.116	2.199	0.279

Schurig et al., Science, 2006

Effective Medium Models vs Physical Structures





a) Physical Structure

b) Effective Medium

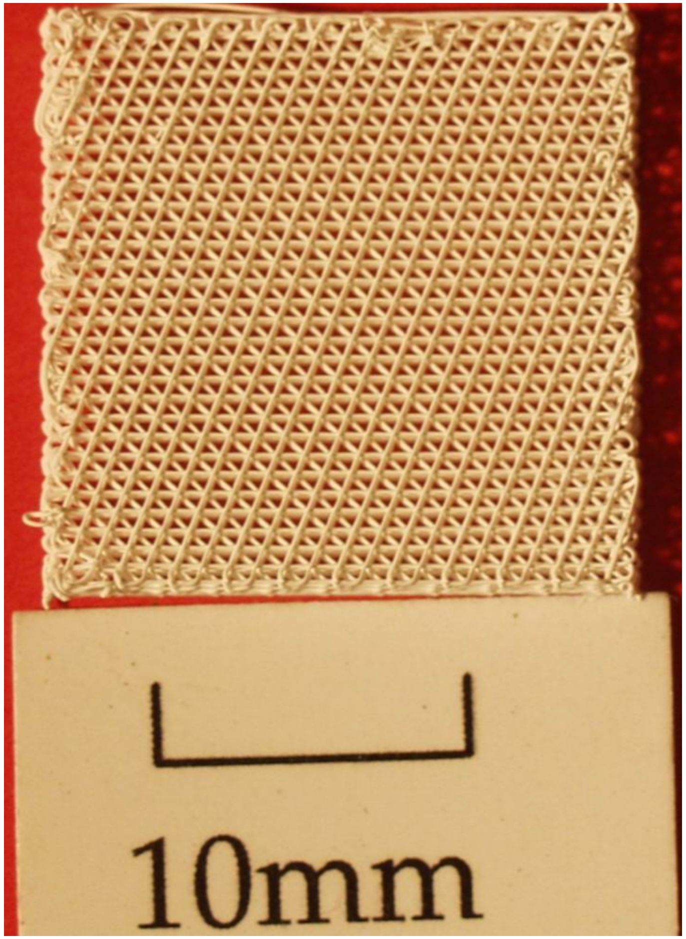
The Department of ELECTRONIC ENGINEERING

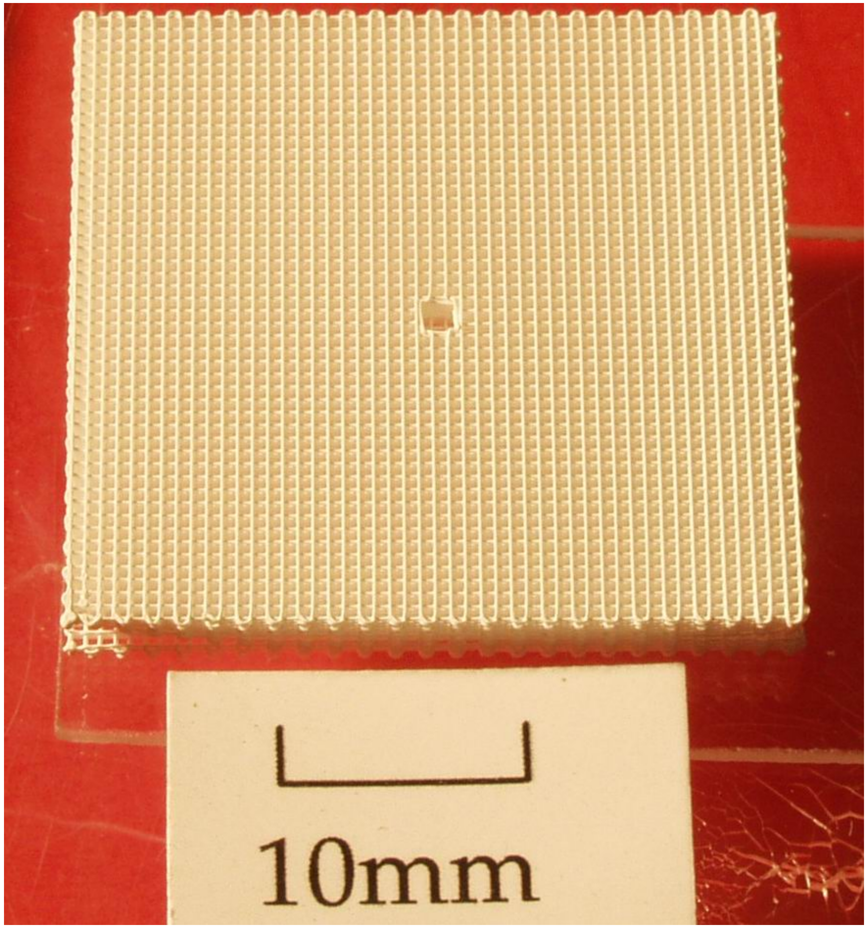
Applications to Antennas, Scattering, Imaging and Cloaking Devices

Yang Hao

Queen Mary
University of London

THz Woodpile Metamaterials



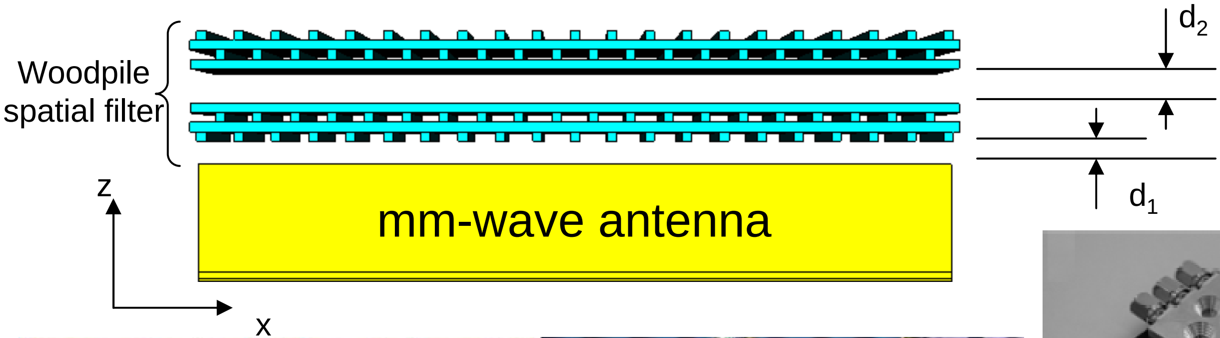


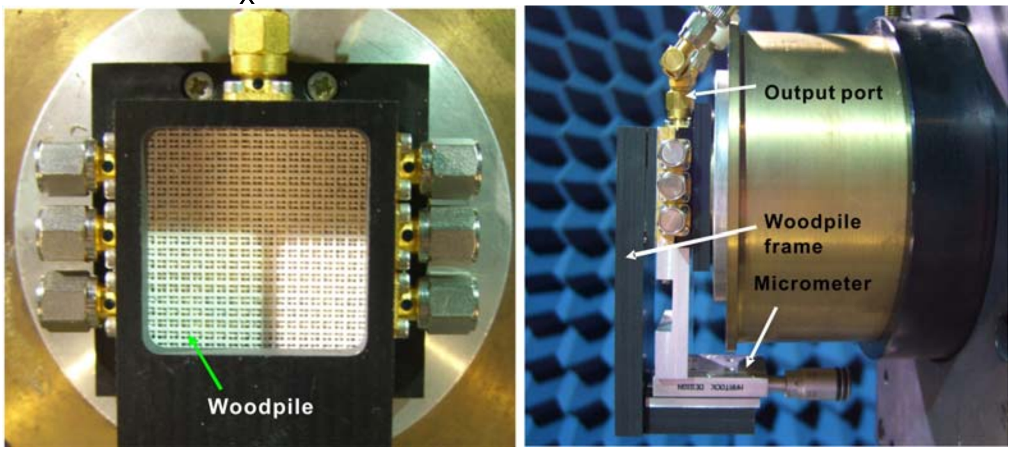
Woodpile spatial angular filter for beam shaping of conical horn array

- Dual-layer woodpile cavity provides very sensitive angular discrimination for off-normal transmission through the structure.

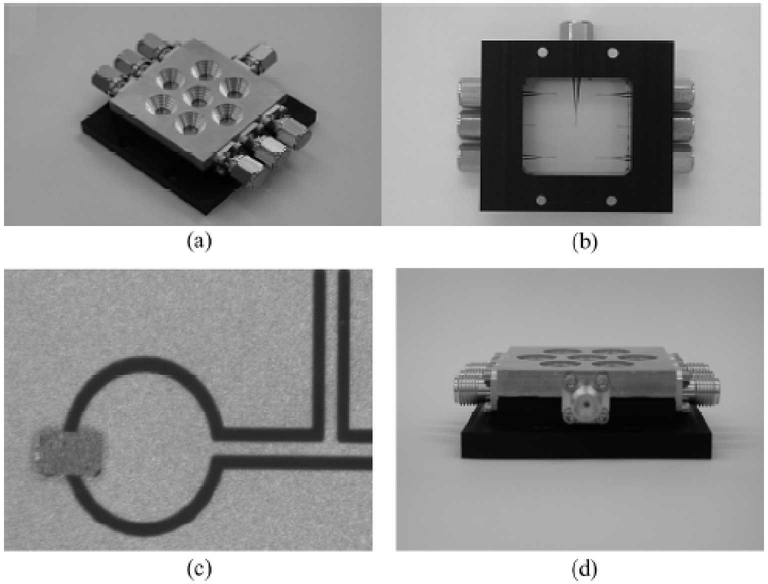
d_1 = 1mm

d_2 = 1.4 -1.7mm





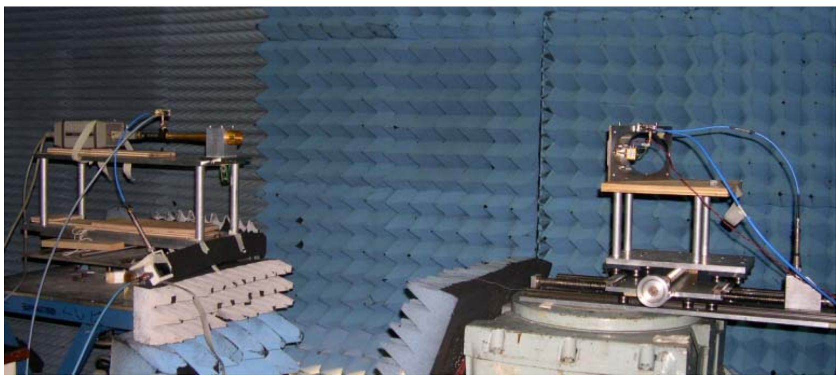
woodpile spatial angular filter

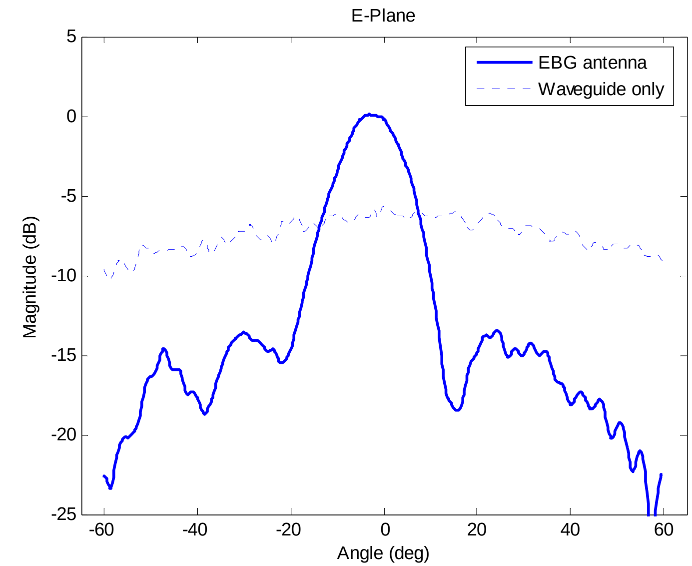


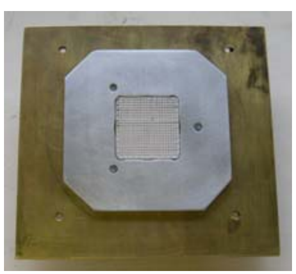
V. Douvalis, et al., IEEE TAP, 54(5), 1393 (2006)

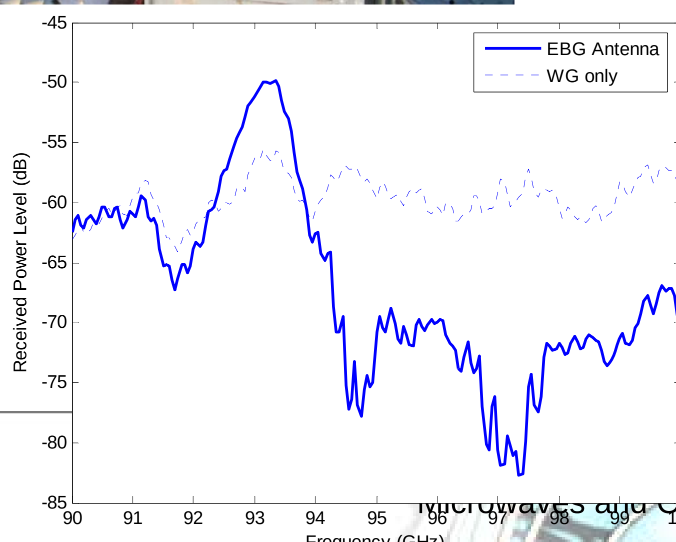
MMW EBG antenna fabrication and measurement

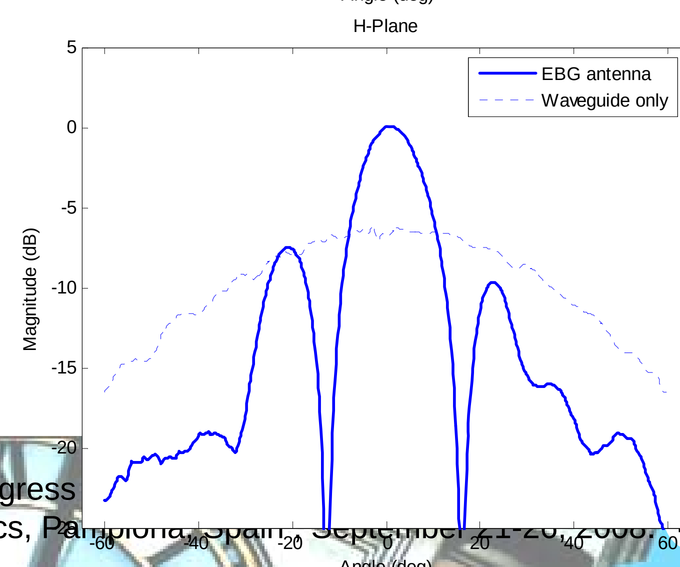
HPBW: Waveguide: 110° (E-pl.), 68 ° (H-pl.)
EBG antenna: 14° (E-pl.), 10° (H-pl.)
Gain=13dBi (7dB broadside gain improvement)



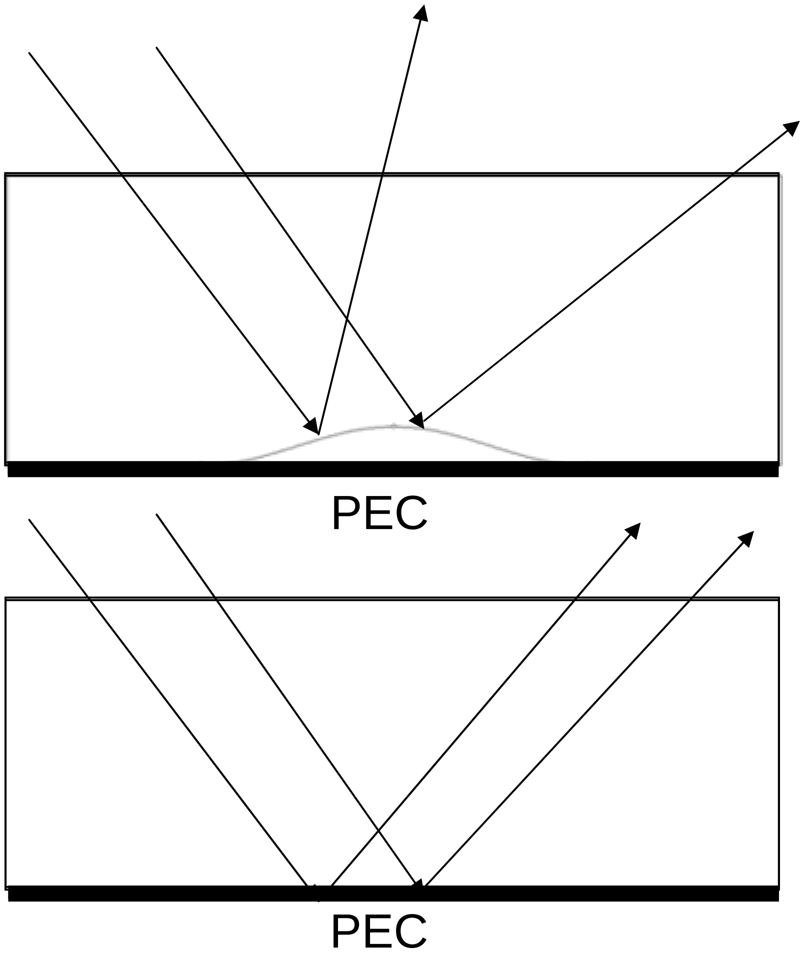


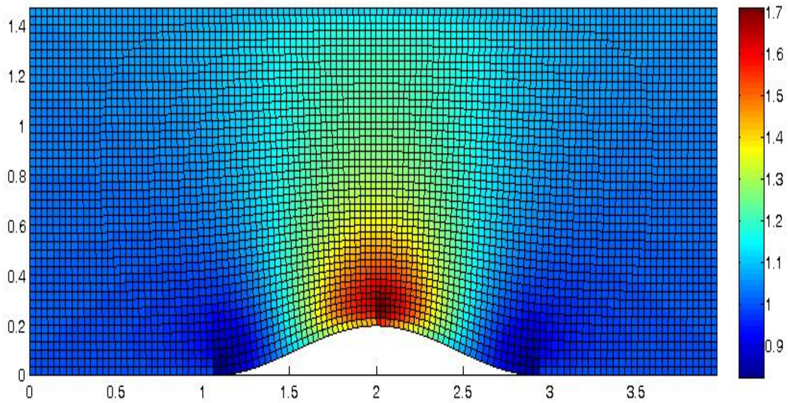






Other Means of Cloaking?





Hiding Under the Carpet: a New Strategy for Cloaking. Authors: Jensen Li, J. B. Pendry. arxiv.org/abs/0806.4396v1

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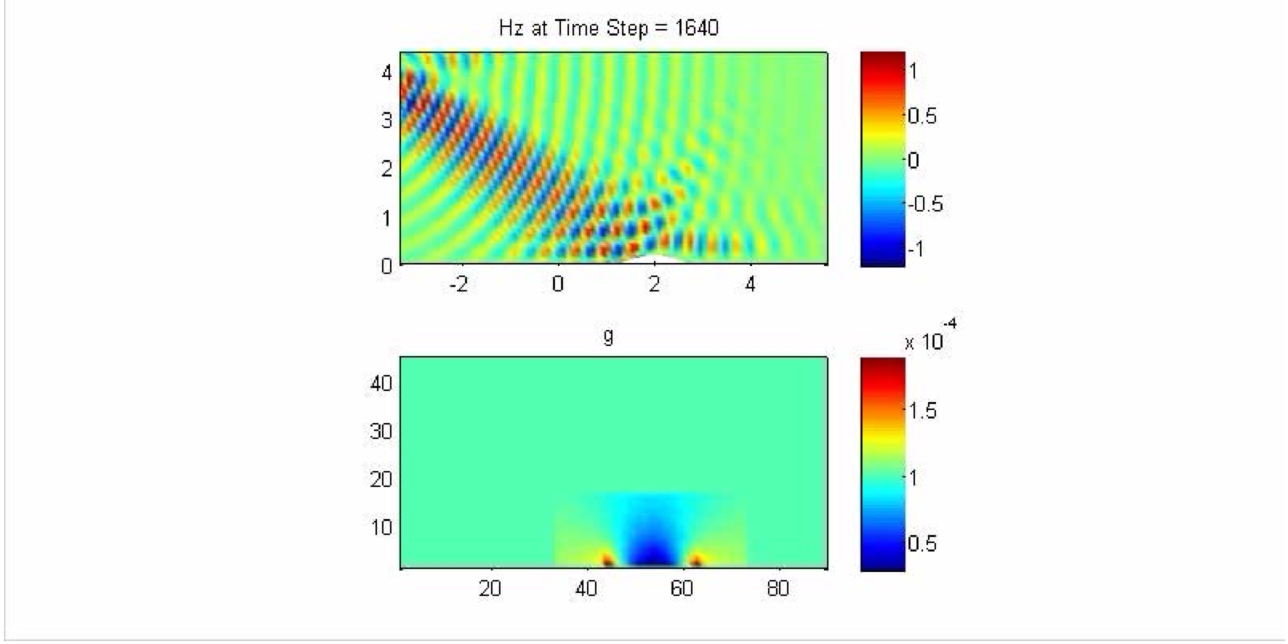

Other Means of Cloaking?