



# **Negative Refractive Index Metamaterials (NRIM)**

**Rakhesh Singh Kshetrimayum**

Title: Metamaterials Extending Materials Properties  
Speaker: Rakhesh Singh Kshetrimayum



## Presentation in a nutshell

### Properties:

- ✓ Negative refractive index
- ✓ Negative epsilon &  $\mu$
- ✓ Left handed rule of electromagnetism
- ✓ Reversed Doppler effect
- ✓ Backward wave

### Applications:

- ✓ Perfect flat lens focusing light to a geometric point
- ✓ Smart antennas with back-fire to end-fire scanning
- ✓ Performance enhanced RF circuits

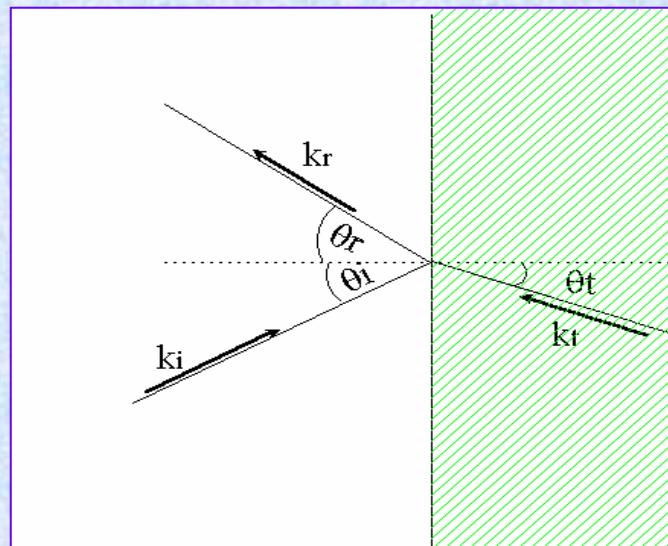
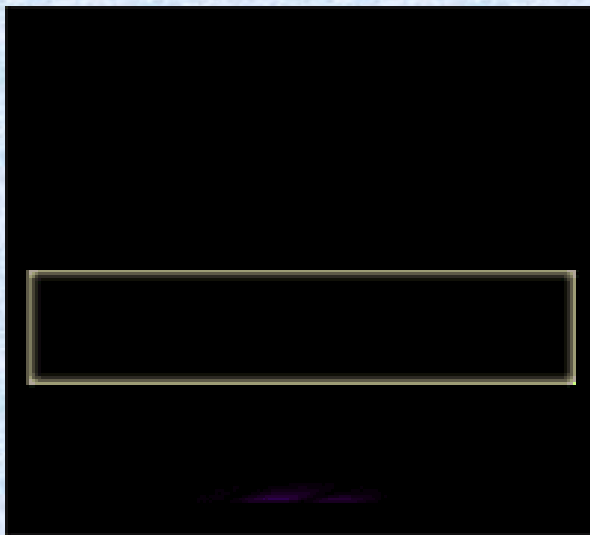
- ✓ Problems with existing metamaterials
  - ✓ Bulky 3D, distributed and unit cells not connected
  - ✓ A novel waveguide based metamaterials has been proposed

Title: Metamaterials Extending Materials Properties  
Speaker: Rakhesh Singh Kshetrimayum



## Negative refractive index

$$n = -\sqrt{\epsilon\mu}$$



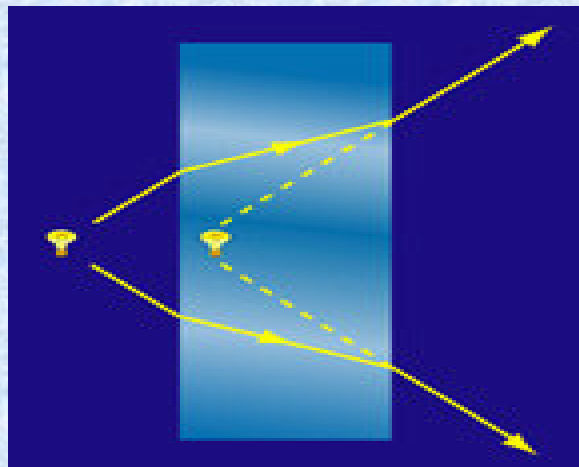
$$\sin(\theta_i)/\sin(\theta_t) = n$$

Light bends the “wrong way” when it enters metamaterial from vacuum

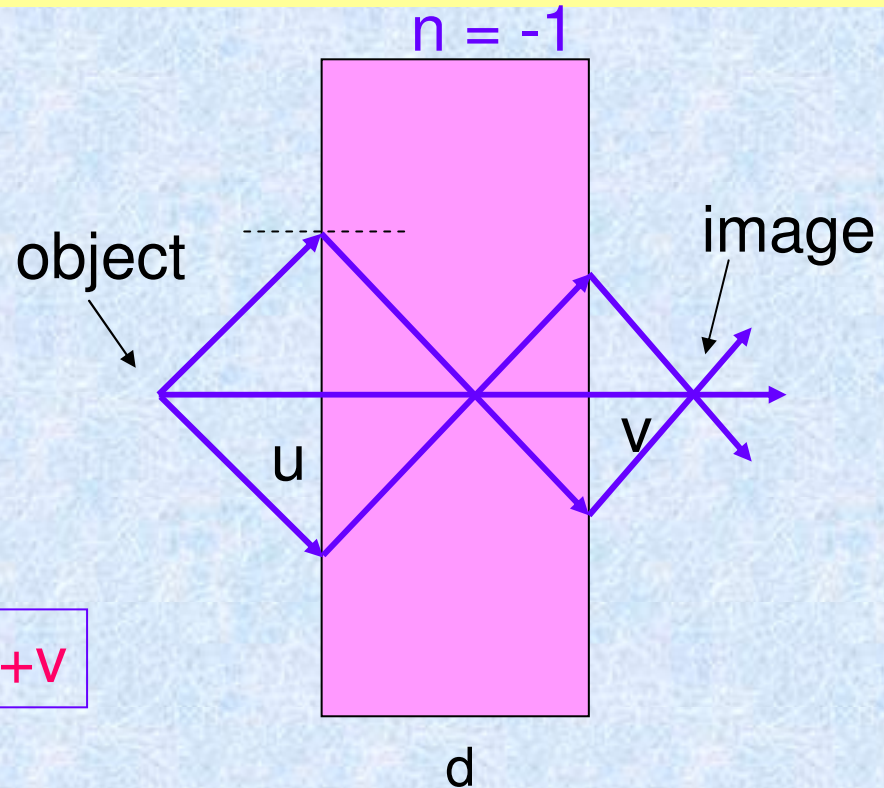
Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



## Perfect flat super lens



$$d = u + v$$

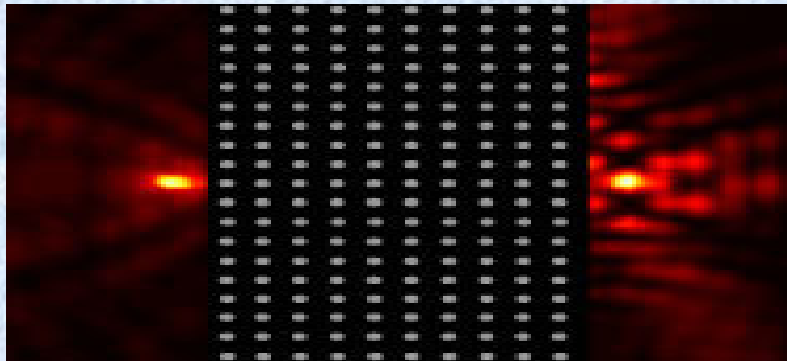


For normal flat lens light diverges (Left Figure) whereas a metamaterial based perfect flat lens focuses light to a geometric point (Right Figure).

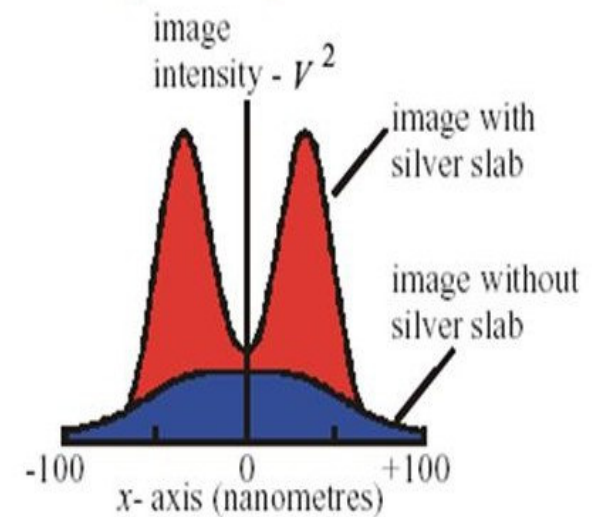
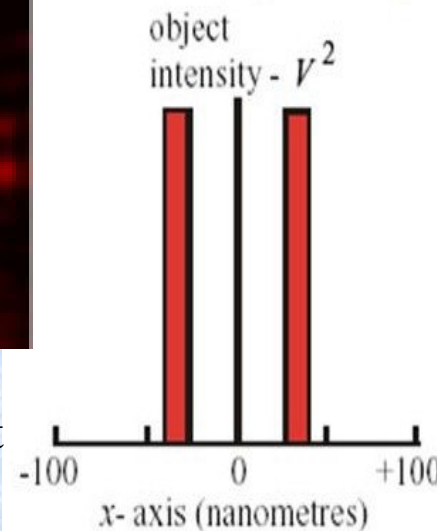
Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



## Beating the Diffraction Limit



Limitation of conventional lens: cannot focus light onto an area smaller than a square wavelength.



Ref.: J. B. Pendry, “Negative refraction makes a perfect lens”, Phys. Rev. Lett., 2000

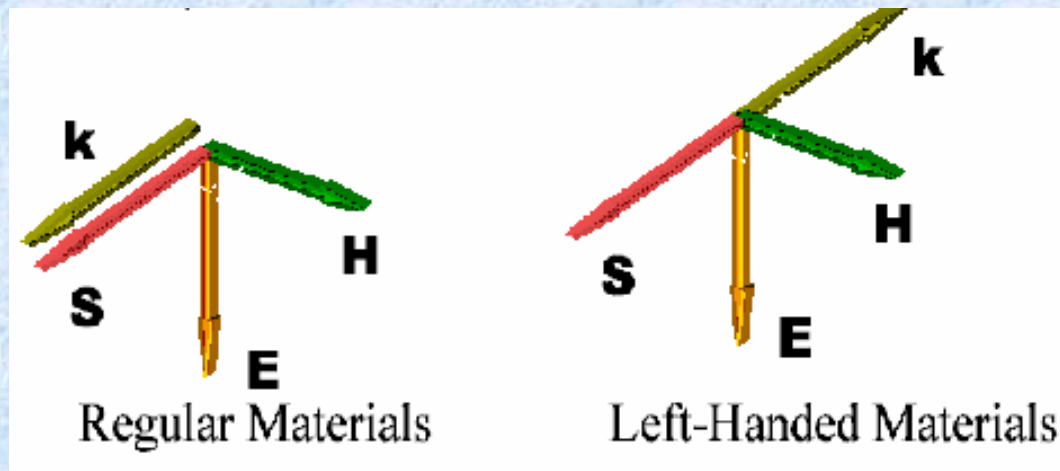
Sub-wavelength focusing is possible for these new super lens.

Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



## Negative epsilon and mu: left handed rule of electromagnetism

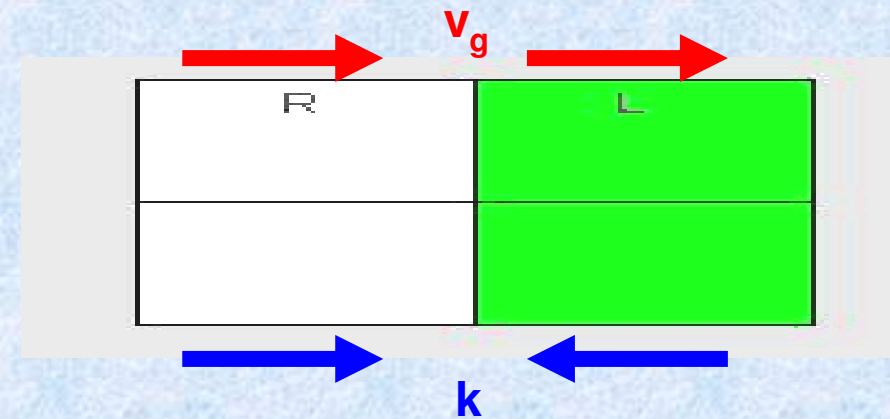
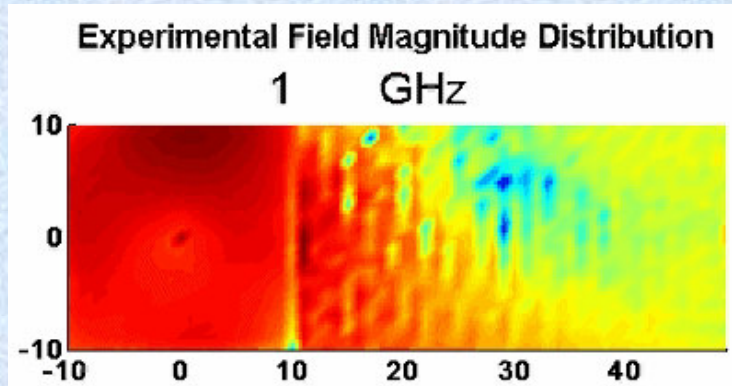
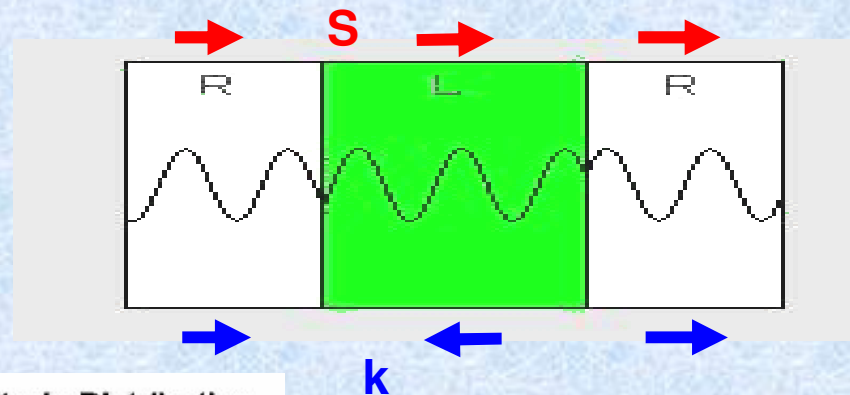
Epsilon and mu are the main determinants of a materials response to EM waves.



By inserting negative epsilon and mu in the four Maxwell's equations we get a left-handed triplet. Ref: V. G. Veselago, "Electrodynamics of substances with simultaneously negative electrical and magnetic permeabilities", Sov. Phys. Usp., 1968

Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum

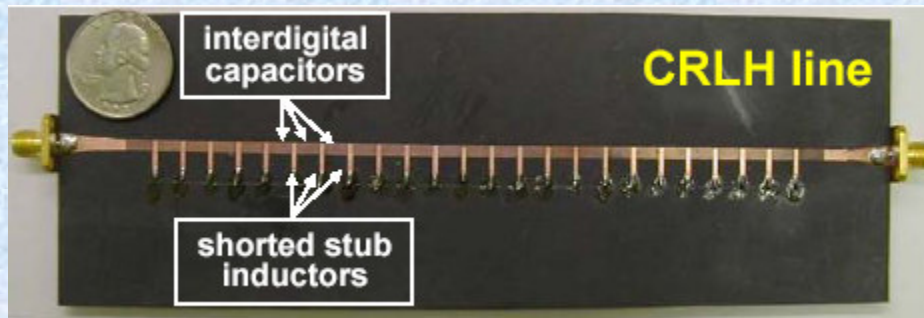
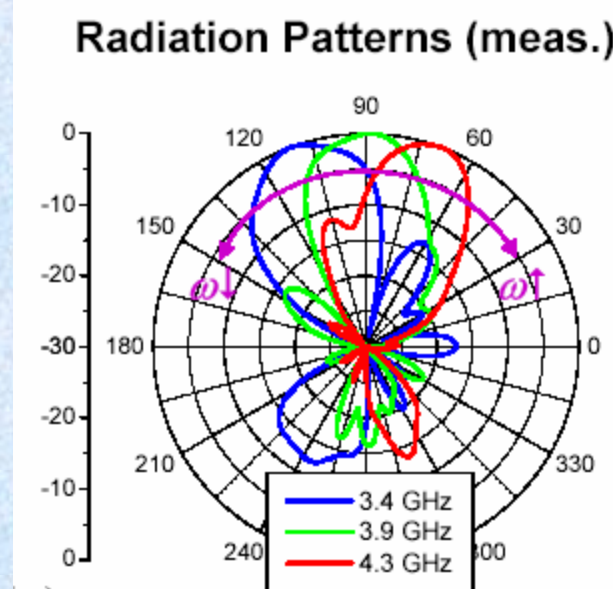
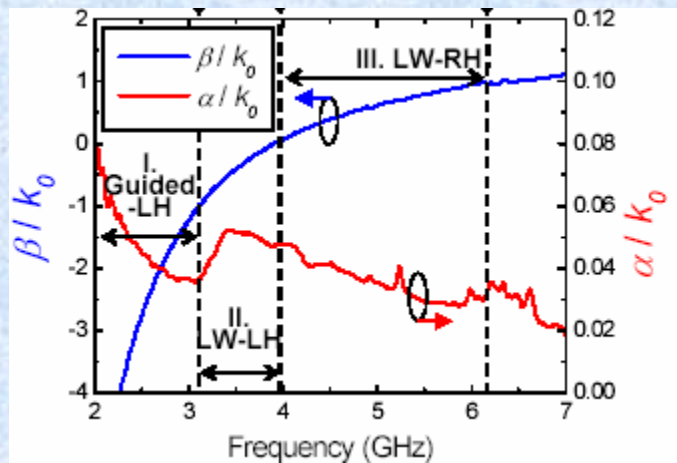
## Backward wave



Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



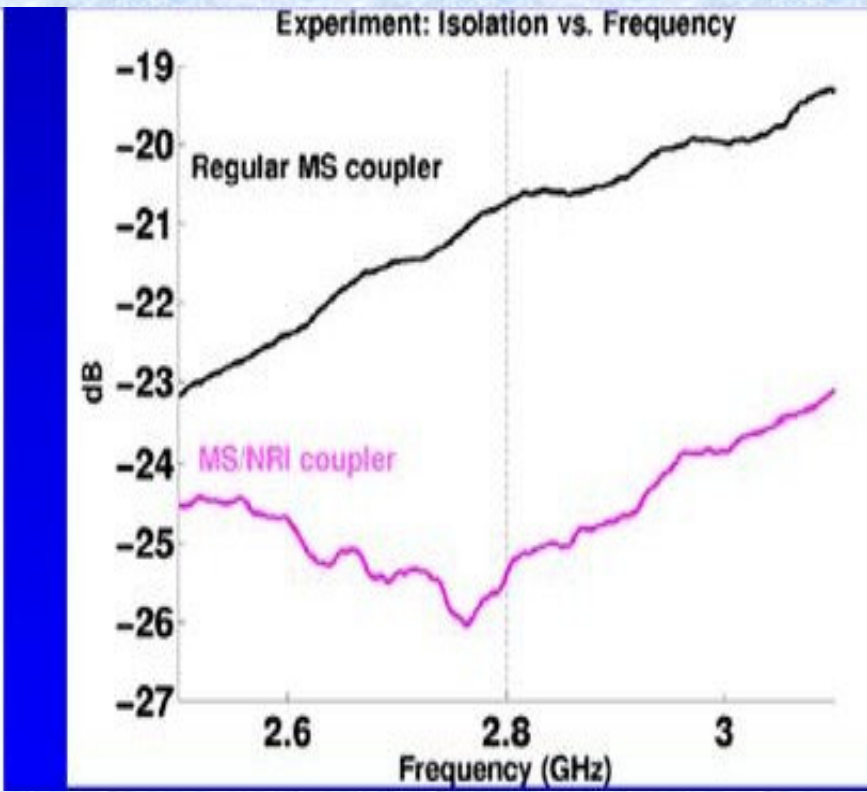
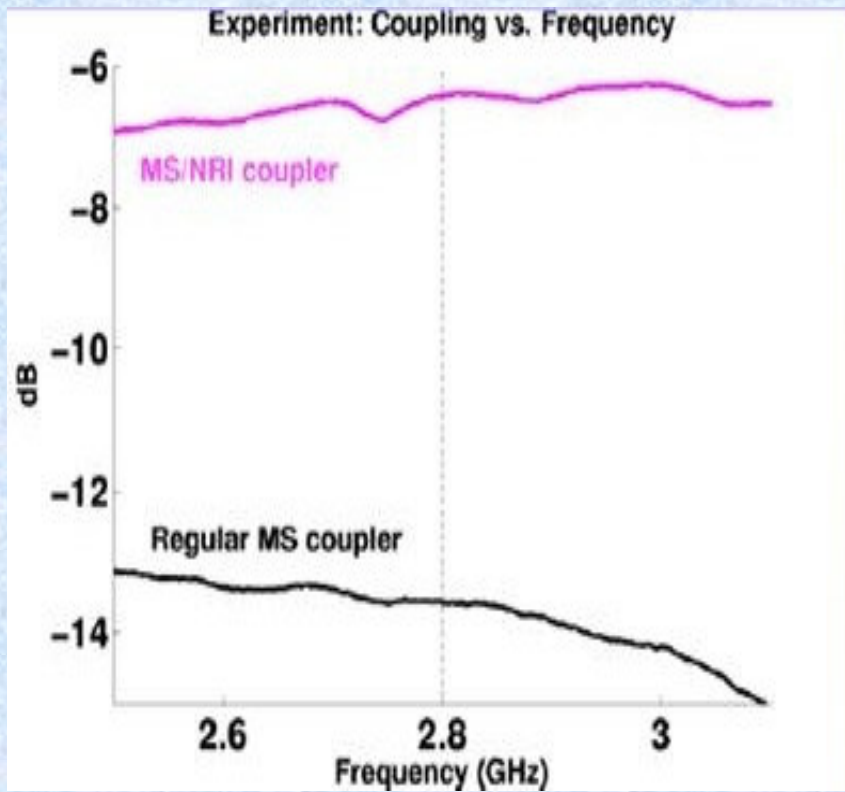
End-fire to Back-fire Antenna



Itoh et al., “Dominant mode leaky-wave antenna with backfire-to-endfire scanning capability,” Electron. Letter 2002

Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum

Performance enhanced RF circuits

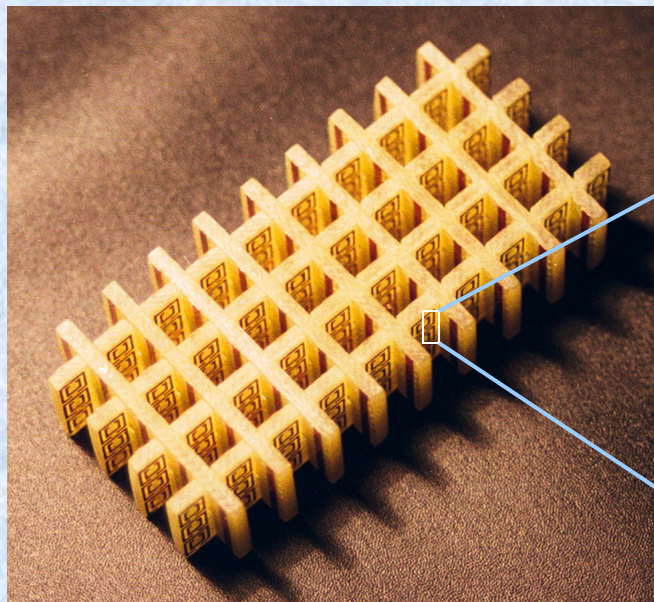


Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



## Construction

Periodic structures composed of pairs of elements, in which one element array produces negative epsilon and the other element array produces negative mu. Ref.: R. A. Shelby, D. R. Smith, and S. Schultz, “Experimental verifications of a negative refractive index of refraction”, *Science*, 2001

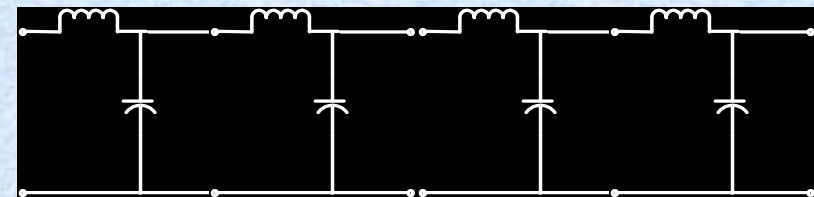
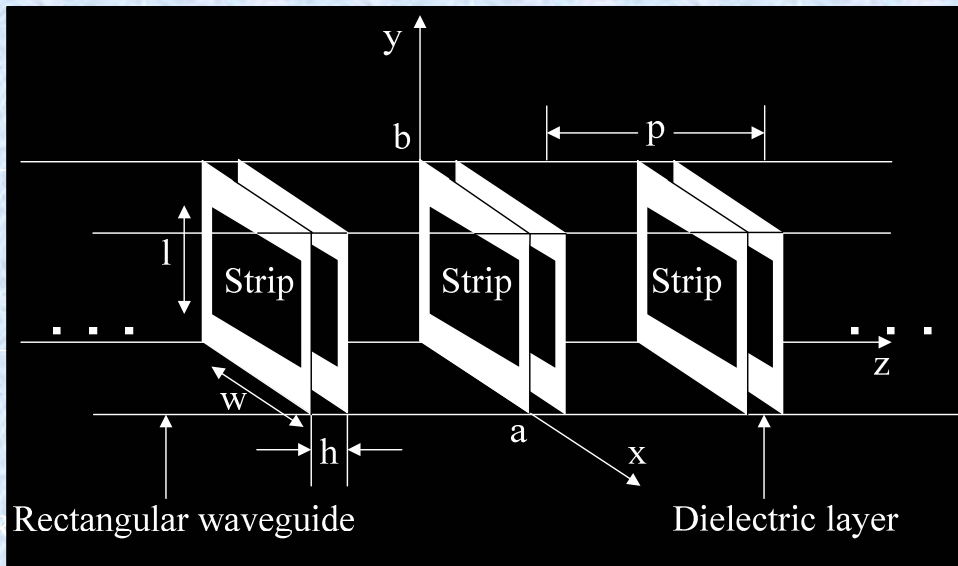


Title: Metamaterials Extending Materials Properties

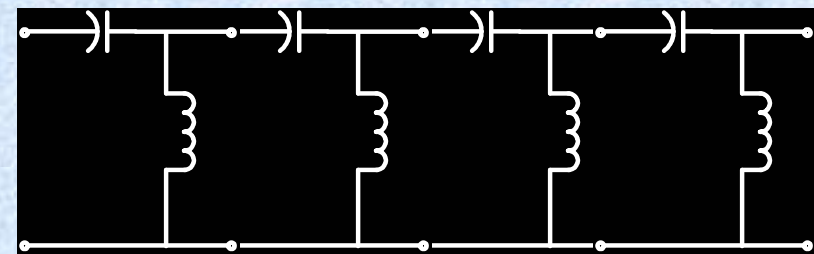
Speaker: Rakesh Singh Kshetrimayum



Novel Waveguide Based Metamaterials



Rectangular waveguide without any loading (equivalent circuit)

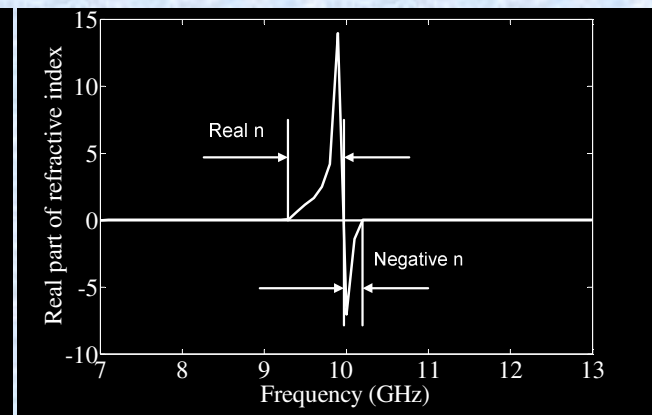
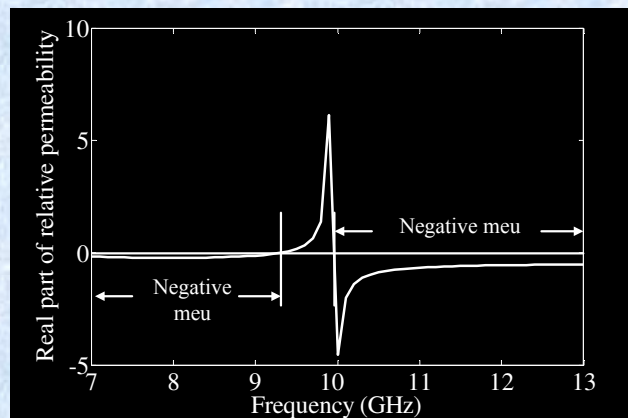
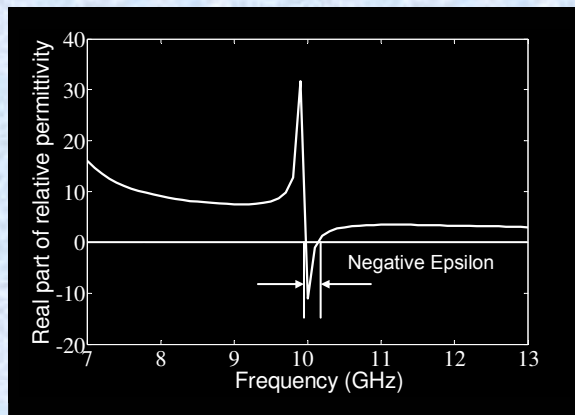


Rectangular waveguide loaded with closely spaced strips printed on dielectric layer (equivalent circuit)

Title: Metamaterials Extending Materials Properties  
Speaker: Rakhesh Singh Kshetrimayum



## Negative epsilon, mu and refractive index



This novel waveguide based periodic structure with closely spaced strip layers behaves as metamaterial in the frequency regions where  $n$  is negative. For  $w=10$ .mm,  $l=7.00$ mm,  $h=1$ mm,  $p=2.8$ mm,  $\epsilon_r=3.78$ , this frequency region is 9.97-10.15GHz.

Title: Metamaterials Extending Materials Properties  
Speaker: Rakesh Singh Kshetrimayum



Any questions please?

Have a nice day!

The End

Title: Metamaterials Extending Materials Properties

Speaker: Rakesh Singh Kshetrimayum