

# How do we define Metamaterials?

Is it a material with negative  $\epsilon$  and  $\mu$ ?

Is it a medium with periodic structures?

Is it an EBG structure?

Is it a DNG structure?

Is a non-foster circuit structure?

Is it based on the equivalent circuit of the propagation mode?

Is it a material with negative phase velocity?

Is it a material with near zero velocity?

Definition from Oct 2011

IEEE Proceedings issue (Eleftheriades)

## Metamaterials

Artificially Engineered Materials with Electromagnetic Properties [is the subject of] topics on prescribing material parameters to obtain exotic new functions, physically implementing metamaterials, and applying them in the microwave and optical domains.

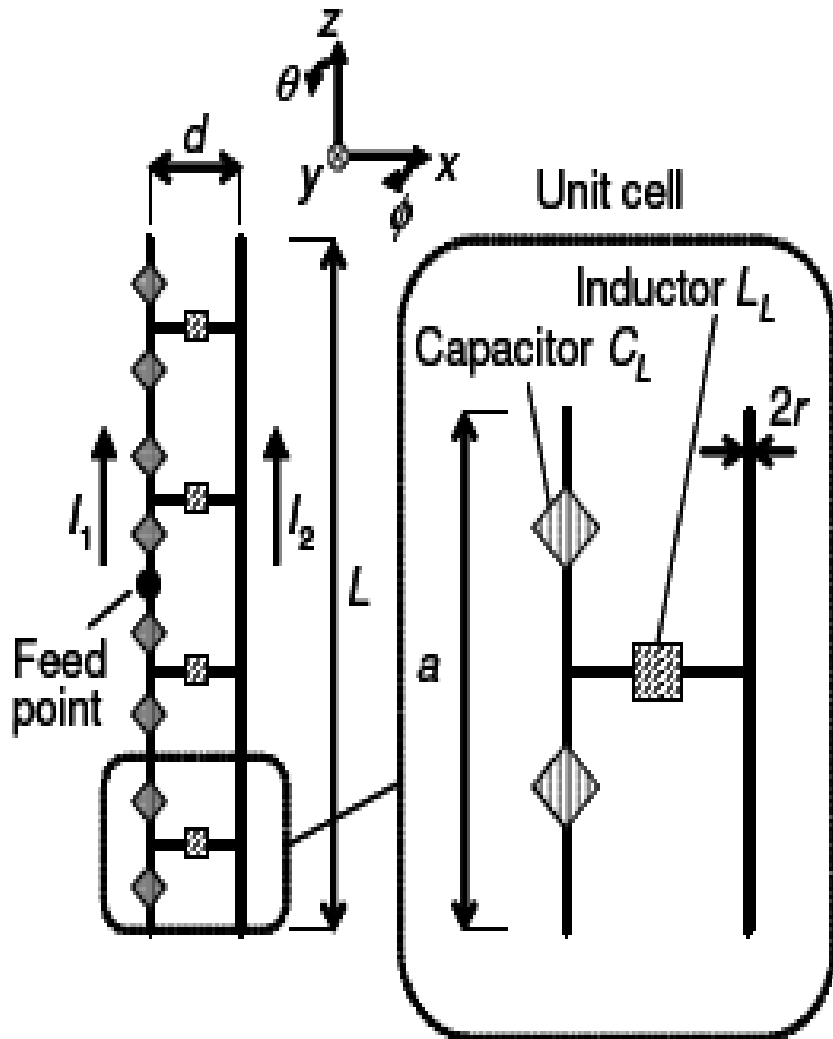
Interpretation: any structure that is man-made (artificial) and leads to new phenomena can be called metamaterials.

This covers a very large set of materials.

# Example-1

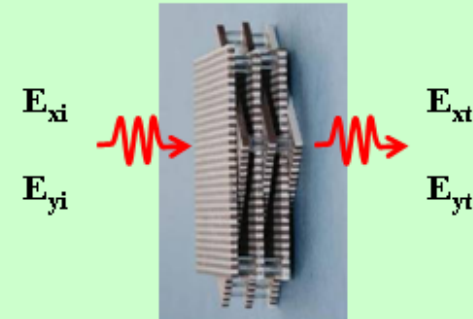
Negative Metamaterial Circuit

From Izuka & Hall, *IEEE Trans Ant and Prop.* May 2007



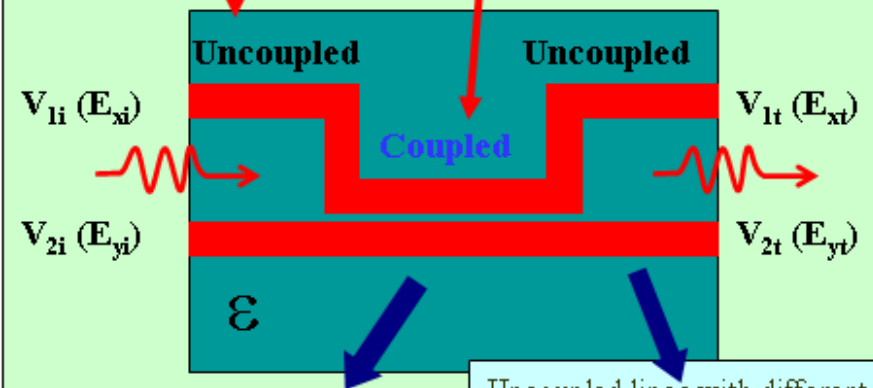
Sertel/Volakis, 2005/2006

DBE Structure – 1D volumetric crystals



Emulating Anisotropy with Coupled Lines

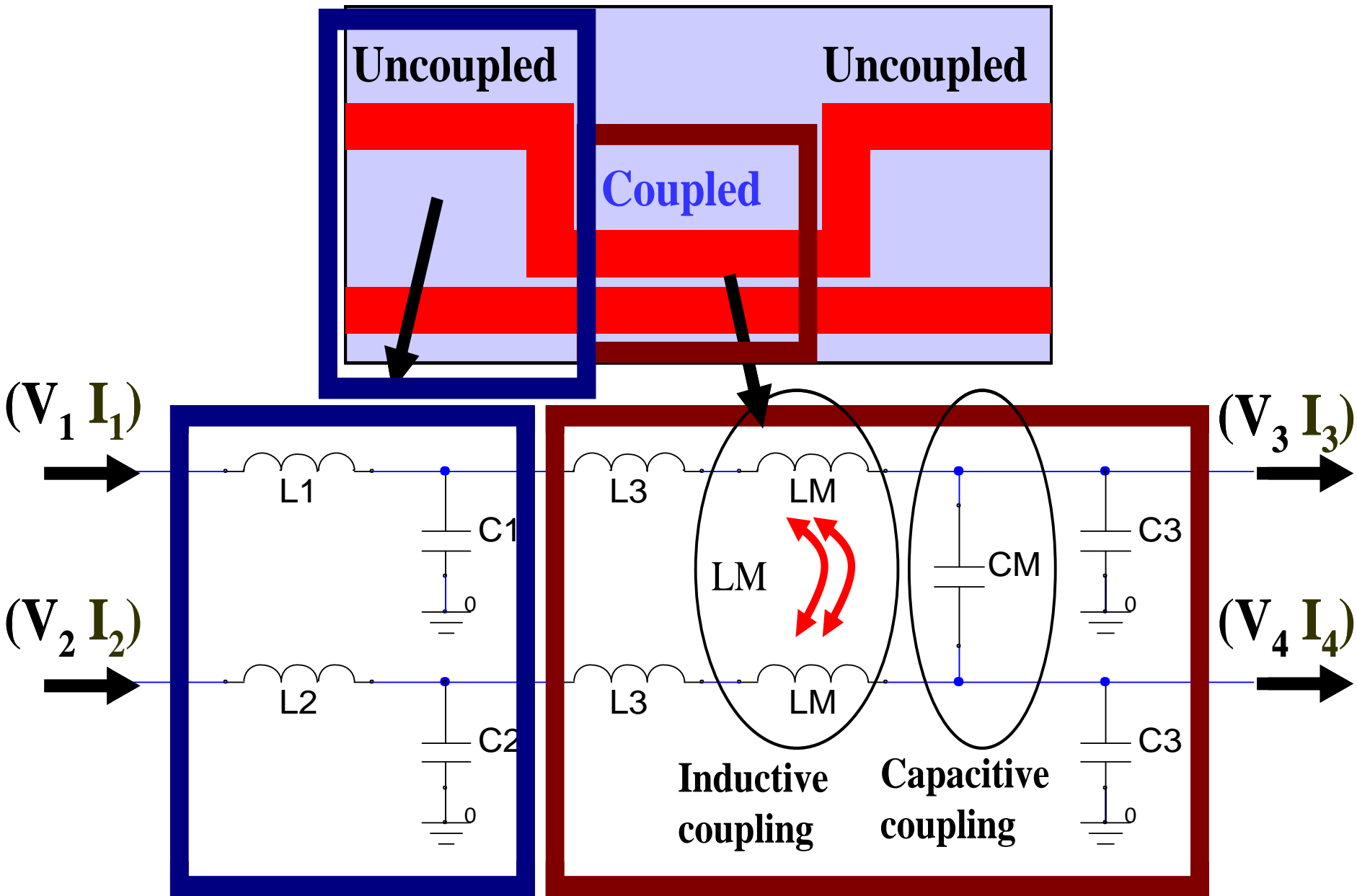
$$\bar{\epsilon}_{eq}(0) = \begin{bmatrix} 45 & 0 & 0 \\ 0 & 17.78 & 0 \\ 0 & 0 & 45 \end{bmatrix} \quad \bar{\epsilon}_{eq}(\varphi) = \begin{bmatrix} 38.1944 & 11.7876 & 0 \\ 11.7876 & 24.5833 & 0 \\ 0 & 0 & 45 \end{bmatrix}$$



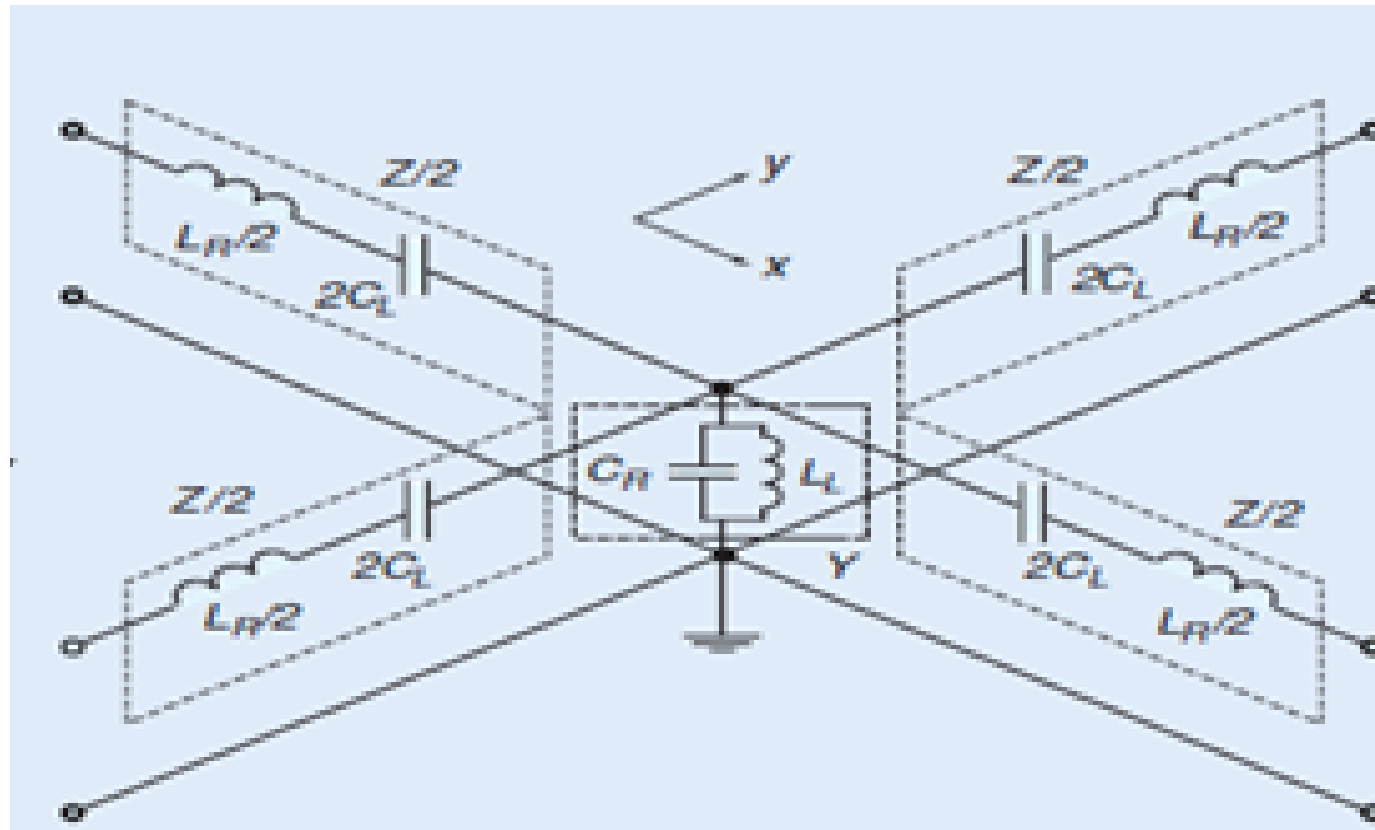
Coupled lines (even mode odd mode impedances) emulate rotation of anisotropic  $\epsilon$  tensor

Uncoupled lines with different lengths emulate anisotropic  $\epsilon$  tensor (phase shift difference between two lines)

# Coupled Transmission Lines



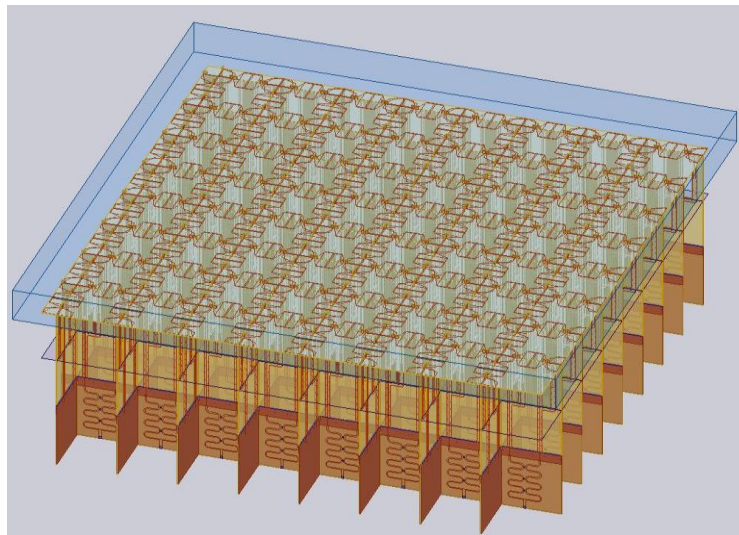
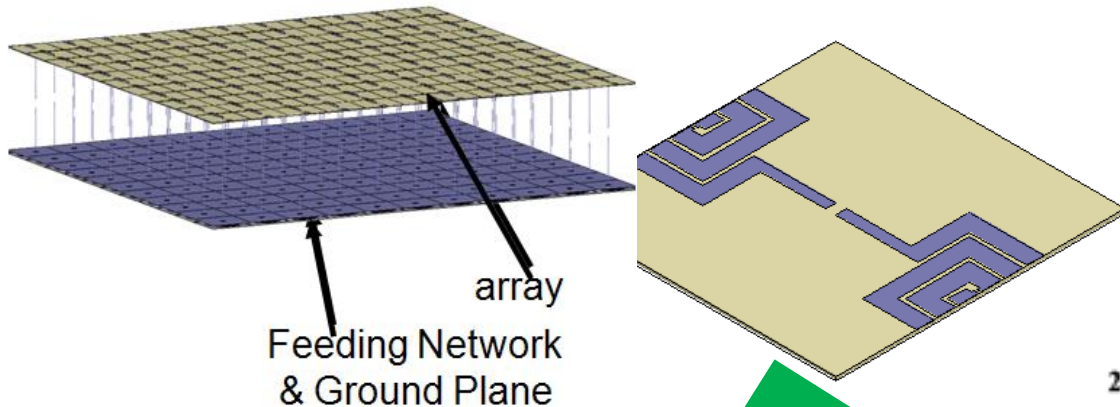
## Example 2: General Metamaterial Propagation Circuit



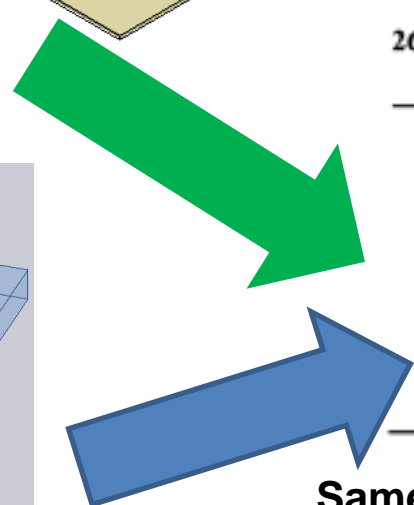
Metamaterial Circuit (from book by Coloz & Itoh, Wiley 2006)

# Conformal Periodic Arrays

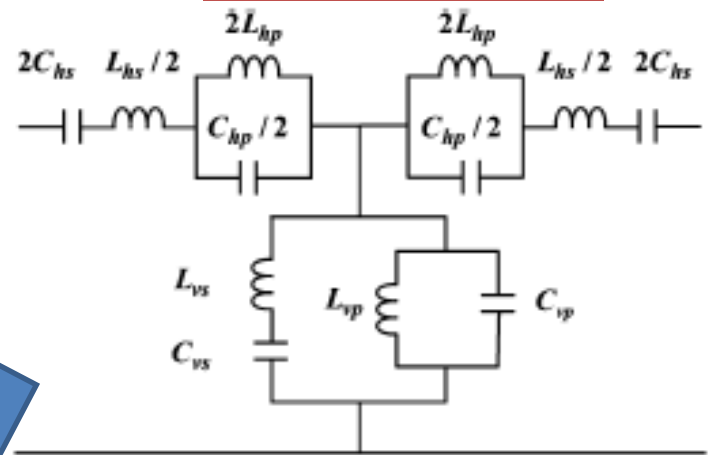
Doane, Sertel & Volakis, *IEEE Trans. Antenna Propagat.*, Sept. 2013  
 Moulder, Sertel, & Volakis, *IEEE Trans. Antennas and Propagat.*, Nov. 2013.



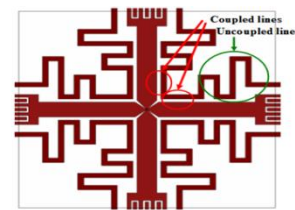
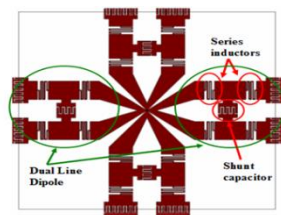
Novak, Papantonis & Volakis  
 Overlapping Dipole Array with 14:1 BW



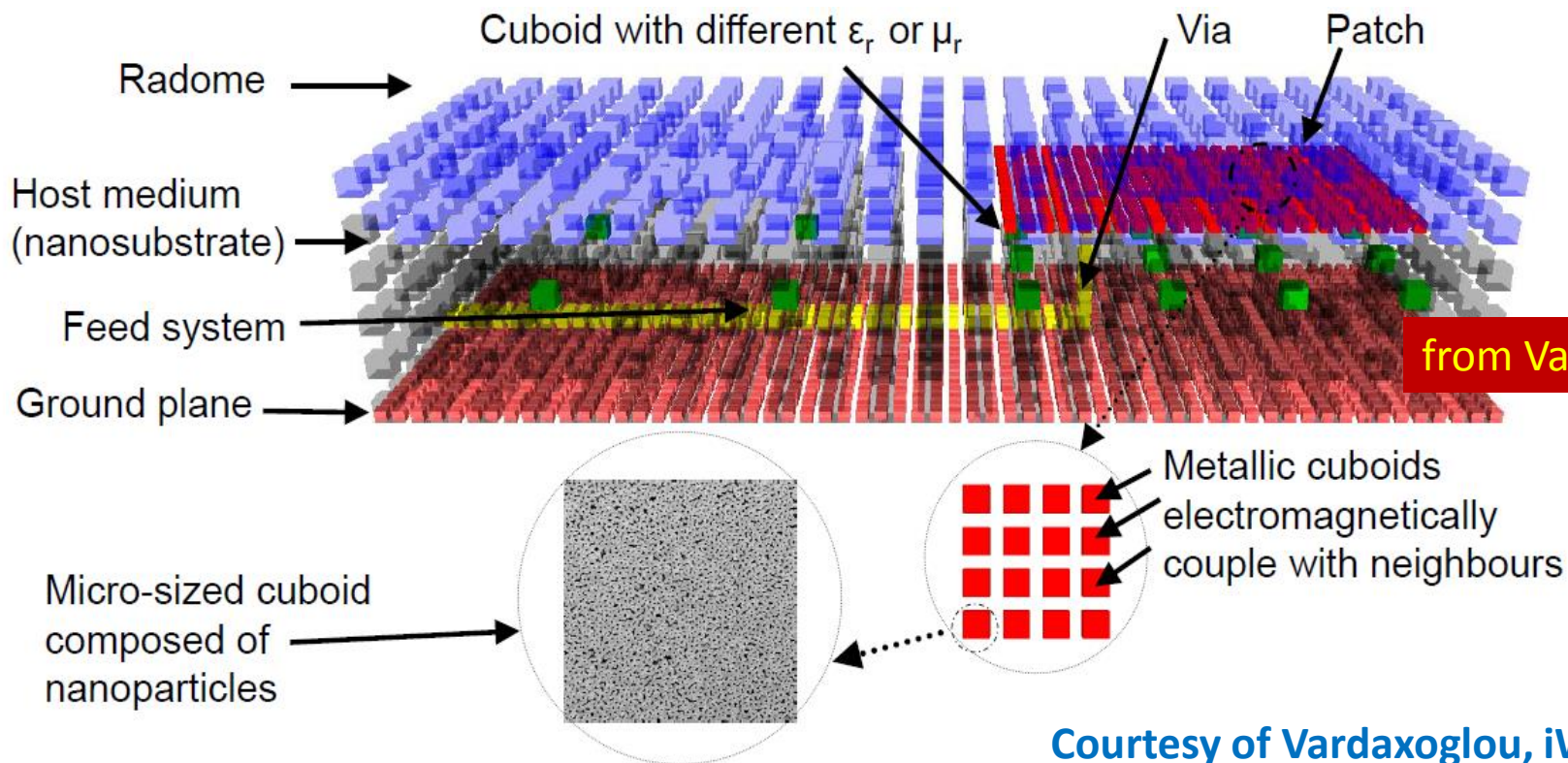
## Equivalent Circuit



Same as that by Eleftheriades. et.al.



If we realize these composites, we will not need the word *Metamaterial* to impress. Instead, the exotic phenomena themselves will be impressive and exotic



Courtesy of Vardaxoglou, iWAT 2014)