Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

# Designing Directional Antenna with Magnetic Artificial Materials

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# Abstract

We introduce the application of magnetic artificial materials in the design of directional antenna. Two ways to use magnetic materials to enhance the directional radiation of sources are demonstrated. One way is the left-handed materials (LHMs) and the other is electromagnetic bandgap (EBG) structures. In both cases, the radiation of the antenna exhibits good radiation performance but the underlying mechanisms are different. The special advantage of the antenna designed by LHM is its lower radar cross section, whereas the one by magnetic EBG structures is the frequency tunability.

*Keywords— diretiional antenna, radar cross-section, tunable operation frequency.*

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**Rui-xin Wu** graduated from Nanjing University, Nanjing, China, and received the M. Sc and Ph. D degrees in Nanjing University in 1993 and 1996, respectively, all major in the radio physics.

Since 1996, he has been on the faculty of the Nanjing University. He is the Full Professor in the school of electronic science and engineering since 2004.

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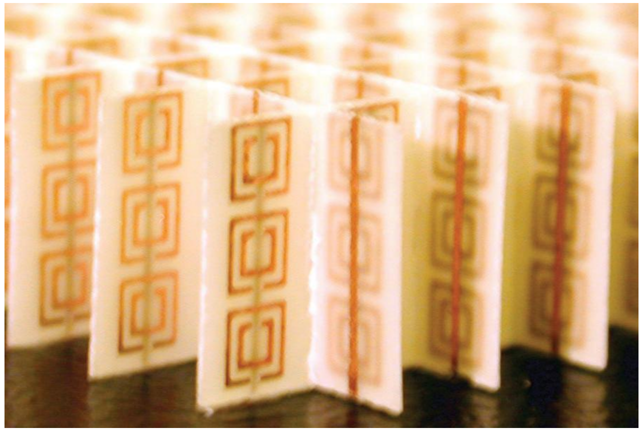
# Outline

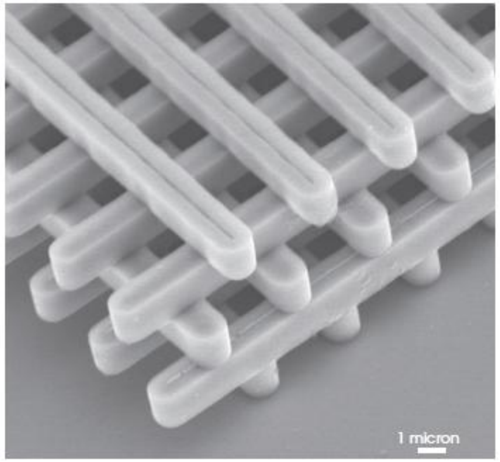
- Background and motivation
- Antenna by magnetic left-handed metamaterial
- Antenna by magnetic photonic crystal
- Summary

# Background and Motivation

- Two kind of artificial materials are of great interests, one is the metamaterial and the other is the electromagnetic bandgap (EBG) structures.



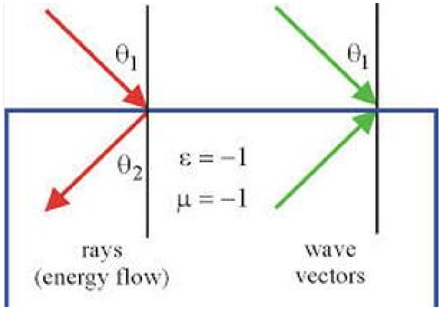
*Metamaterials of which the feature size is much smaller than  wavelength*

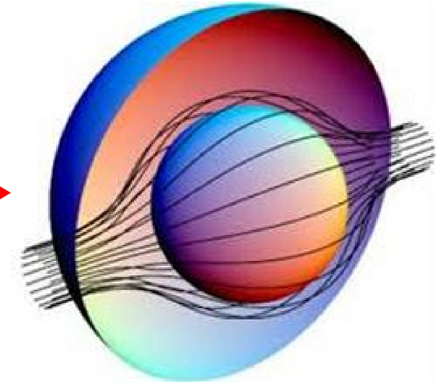


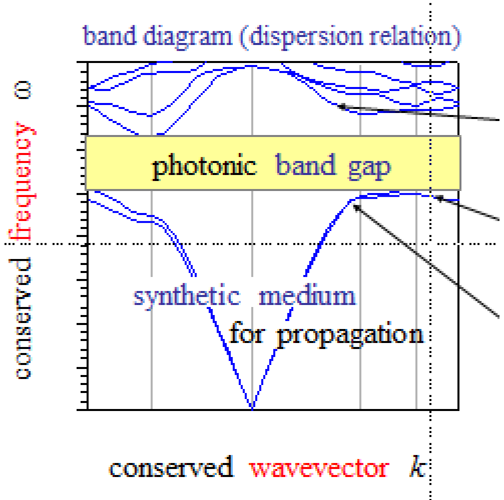

*EBGs structure of which the feature size is the same order of  wavelength*

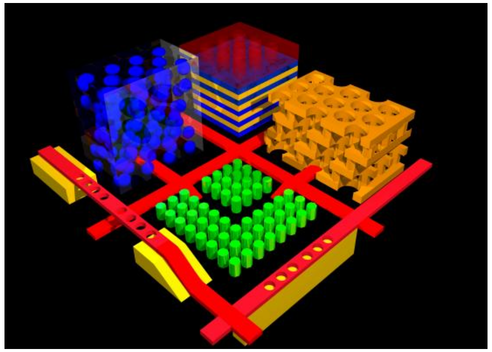
- The two types of artificial materials have some special properties that have important applications

*The negative index metamaterials lead to the application of cloaking*





*The bandgap and special features of energy band lead to the application of all optical system*

**They are also used in antenna designs**

- **Benefits of magnetic artificial materials**

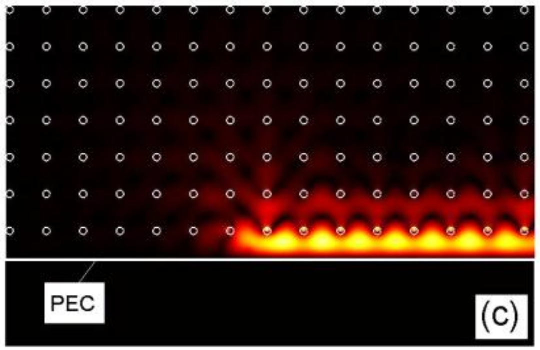
In applied DC magnetic field, magnetic materials is gyro-magnetic ; its magnetic permeability is a tensor for which the elements are the function of applied magnetic field and frequency.

$$\bar{\bar{\mu}}_r = \begin{pmatrix} \mu & j\kappa & 0 \\ -j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

*Apply to build magnetic metamaterials with frequency and polarization tunability*

*Apply to build magnetic metamaterials EBG structures with frequency tunability.*

*New phenomena such as edge state*




*One-way transmission associated with edge state*

- **Motivations**

  Explore the ways how to use magnetic artificial materials to realized direction radiation

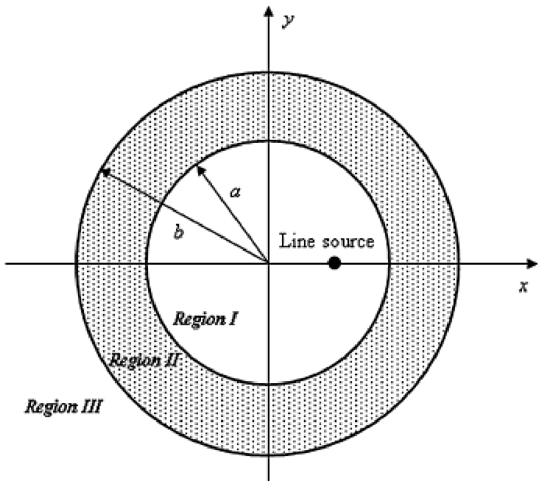
  The performance of the antenna designed by different usages of magnetic artificial materials and the underline mechanism.

  The advantages of the antenna by magnetic artificial materials

# Antenna by Magnetic Left-handed Metamaterial

- **Configuration**

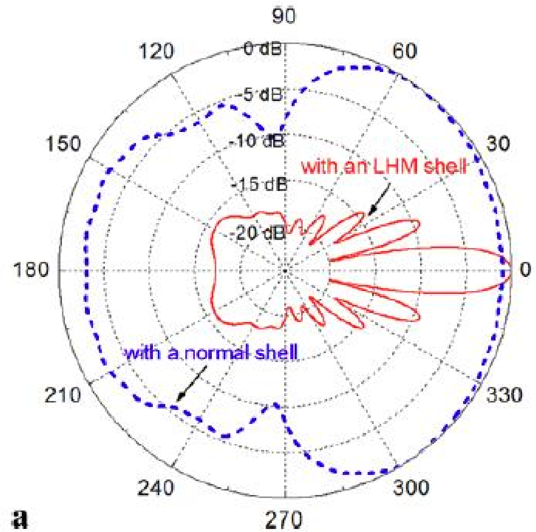
  The antenna consists of a line source and shell of left-handed metamaterial




- **Radiation Pattern**

  The shell has ε=μ=-1 under certain bias magnetic field intensity.

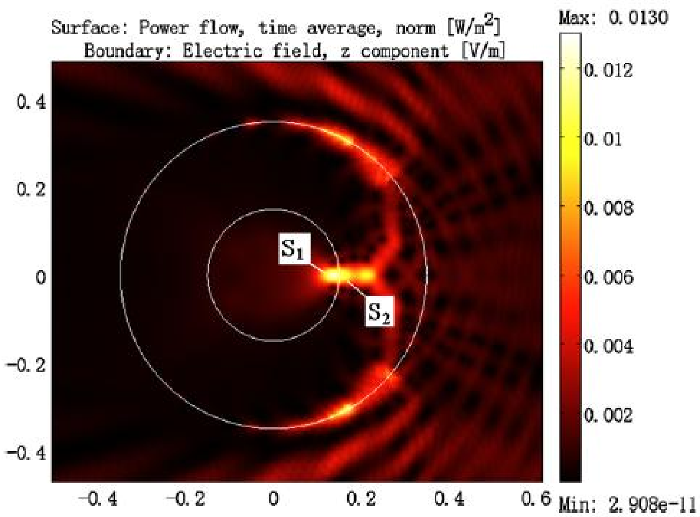
  The antenna shows a clear directional radiation



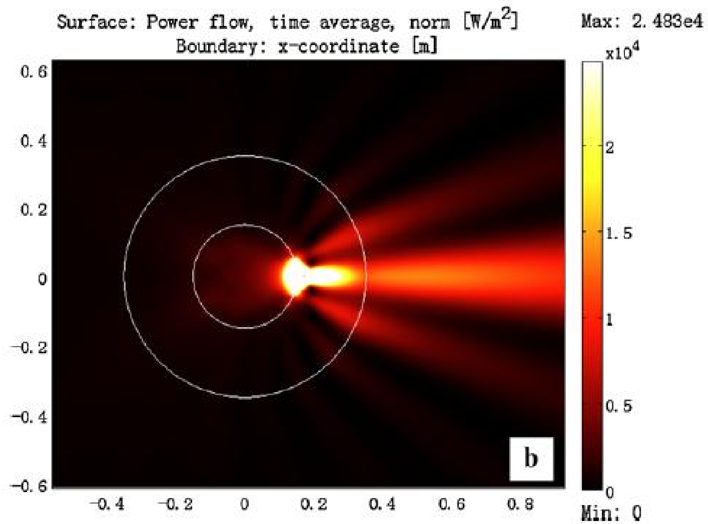
- **Mechanism**

  The negative refraction occurring at the outer edge of LHM shell forms the light spots S2, which is very close to the inner edge

  The image process of S2 at inner edge of LHM creates the light spot S1



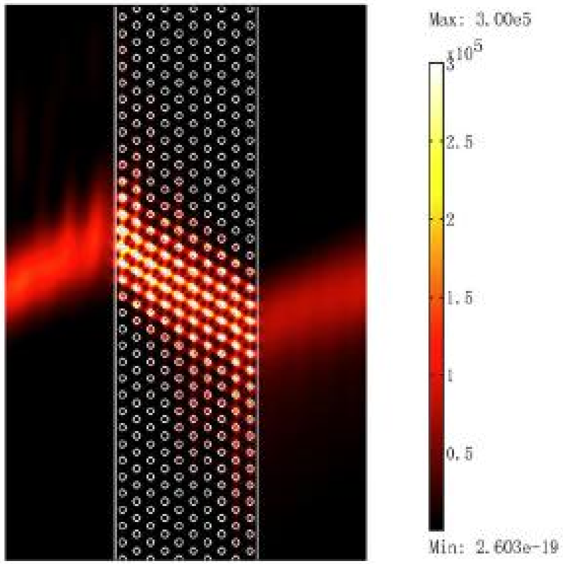

*Power flow distribution for the LHM shell illuminated by a plane wave incident from right-hand side.*

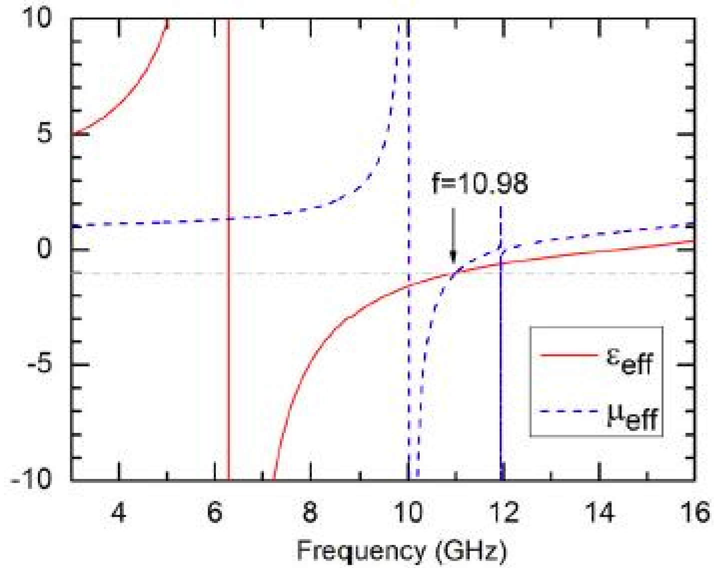



*Power flow distribution for the line source at S1*

- **Implementation of LHM by magnetic material**

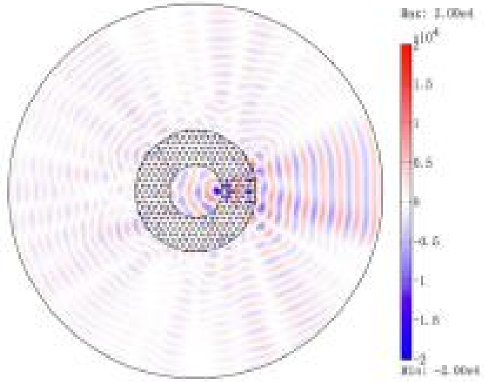
Realization of LHM by ferrite rod array (MPC)
biased by applied magnetic field

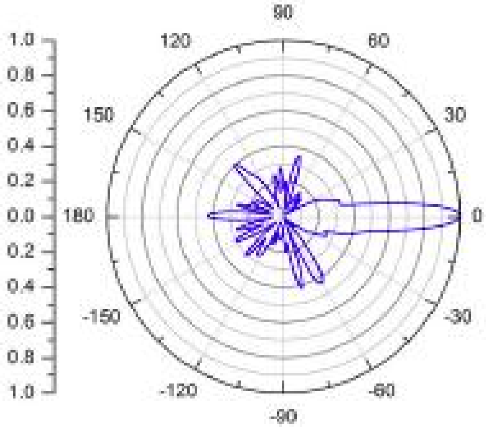


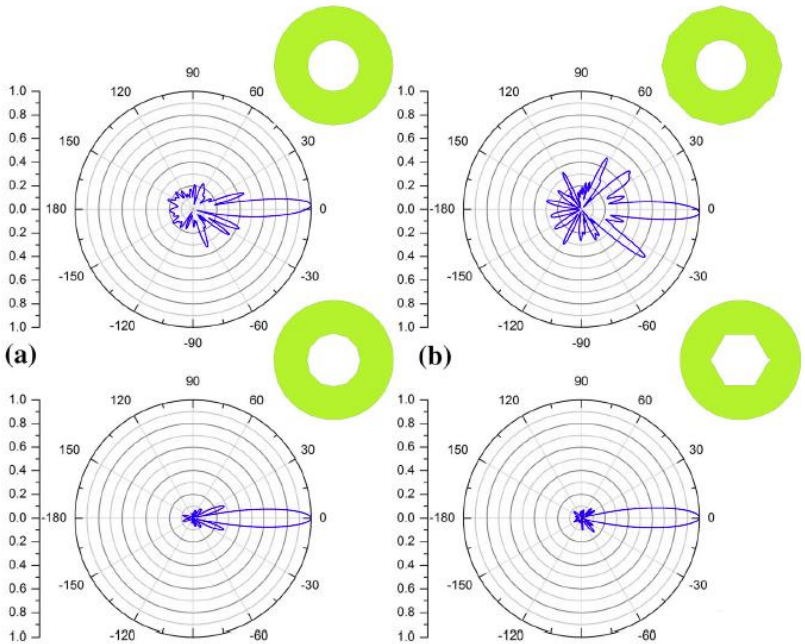




*A beam of Gaussian wave incidences obliquely on the boundary of MPC of hexagonal lattice. It refracts negatively on both sides of the MPC at 10.9 GHz The retrieved effective permittivity and effective permeability are both -1*

The symmetry of the magnetic array leads to the boundaries of LHM shell  in form of polygon , which affects the radiation pattern of the source



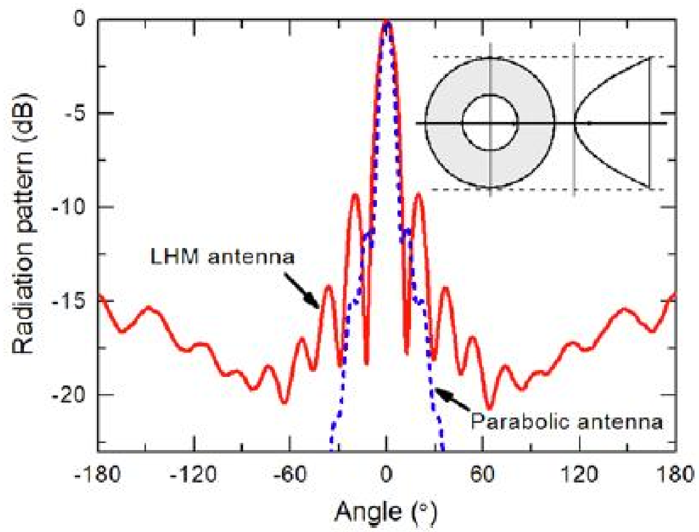



With the rod array, we designed the LHM-antenna which achieves the directivity and HPBW about 12.2 and 12° , respectively.

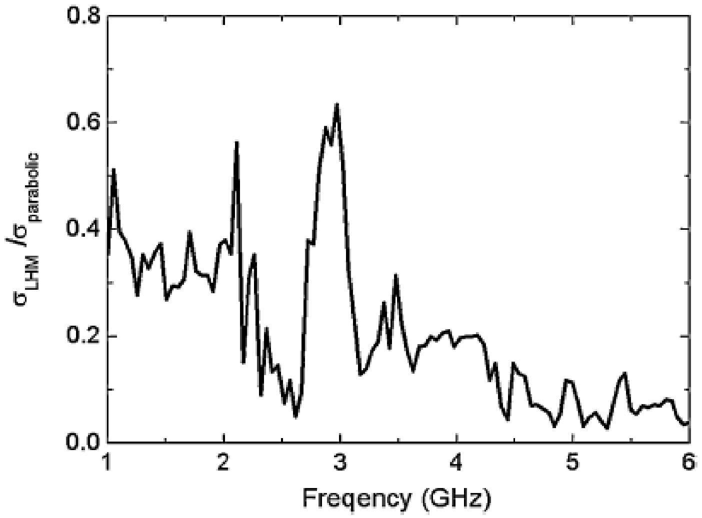
- **Advantage of the LHM antenna**

The main beam of the LHM antenna is the same that of parabolic antenna with same feature size.




*Suppose the shell is with inner radius a = 1.5λ0 and outer radius b = 3.5λ0, where λ0 is the wavelength in free space at the working frequency. The line source is located near the inner wall at ρ0 = 1.35λ0*

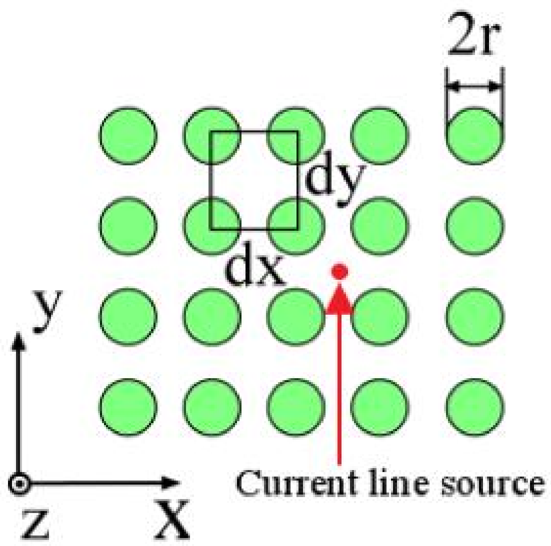
The RCS ratio of the LHM-antenna to the reflector antenna is less than 0.5 in most frequencies. This could be useful for the stealth antenna designs.



# Antenna by magnetic photonic crystal

- Different from the LHM-antenna, the directional radiation of EBG-antennas is due to the band structure of EBG structures.

- **Antenna Configuration**



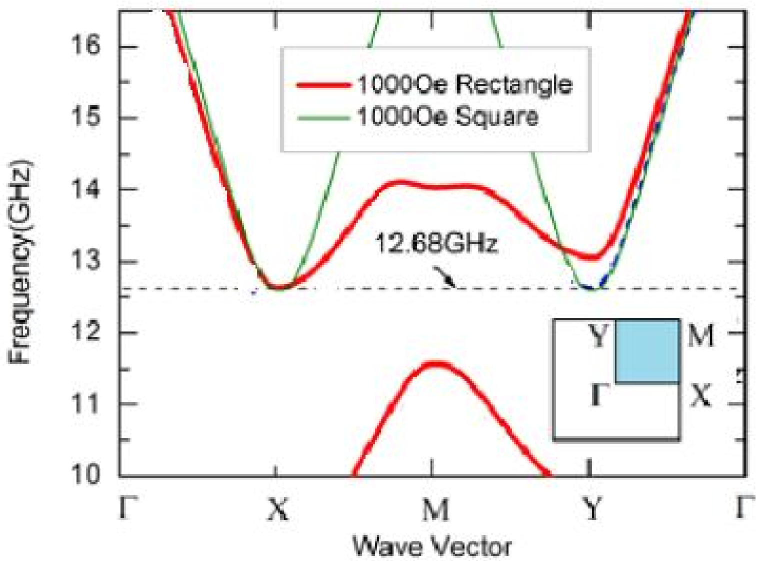

*The antenna consists of magnetic rods and a line current line source embedded in. The rods are in diameter of 4 mm and made of ferrite YIG with saturation magnetization 4πMs =2200 Ga and permittivity εr =12.2(1-j 0.006)*

- **Band structure of magnetic EBG structure**

The directional radiation of the current line source presents at the band edge of the EBG and is closely related to the type of EBG.

*If EBG is in square lattice the allowed electromagnetic states at the band edge are along ΓX and ΓY directions as shown in green line.*

*If EBG is in rectangular lattice, the allowed states only along ΓX as illustrated in red line, though the band edge is not changed.*

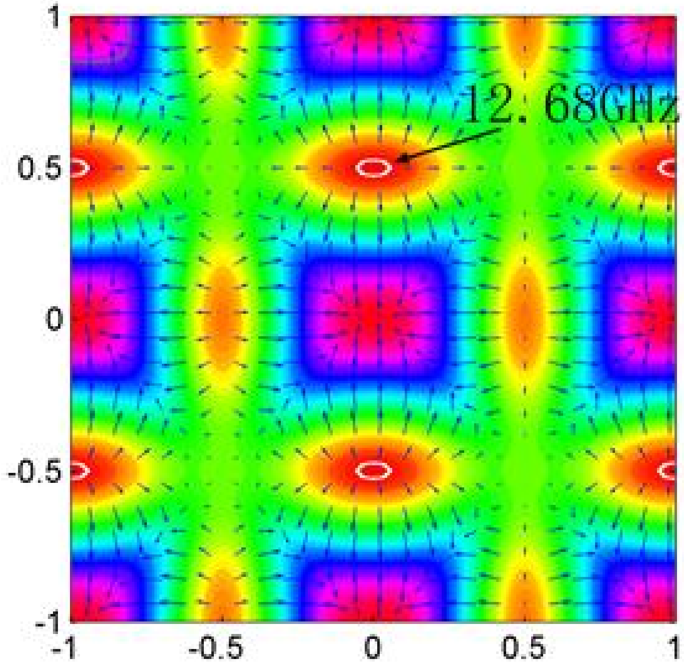



*Mg-Mn ferrite rods is in radius 2 mm. The ferrite has relative permittivity $\varepsilon_r$=12.2(1-j0.006) and saturation magnetization $4\pi M_s$ =2200 Ga.*

The contour lines for frequency 12.68GHz are only appear at about Y point on the Bloch boundary in k-space

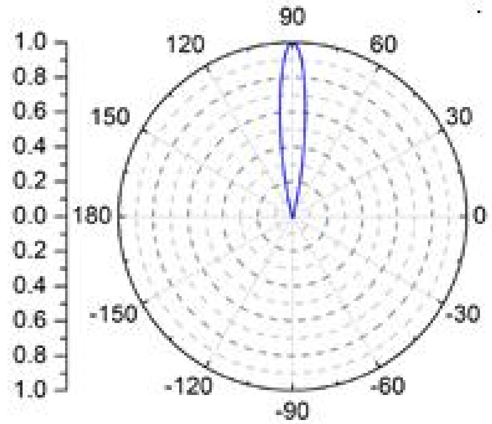
The small contour indicates electromagnetic energy can only spread in a small angle along y-direction but suppressed along the other directions..

The arrows, which illustrate the group velocity of the FMPC, around the contour of 12.68GHz mainly point to y-direction, which indicate a good plane wave front along y-direction



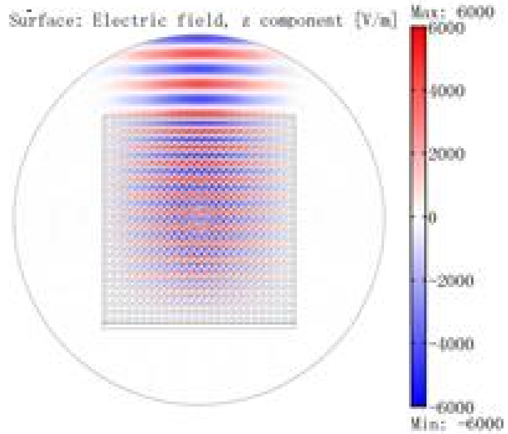
- **Radiation Performance**

EBG-antenna in size 26×48 rods could reach the directivity D=56 and HPBW 5.6º.




The size of EBG-antenna affects the directional radiation performances.

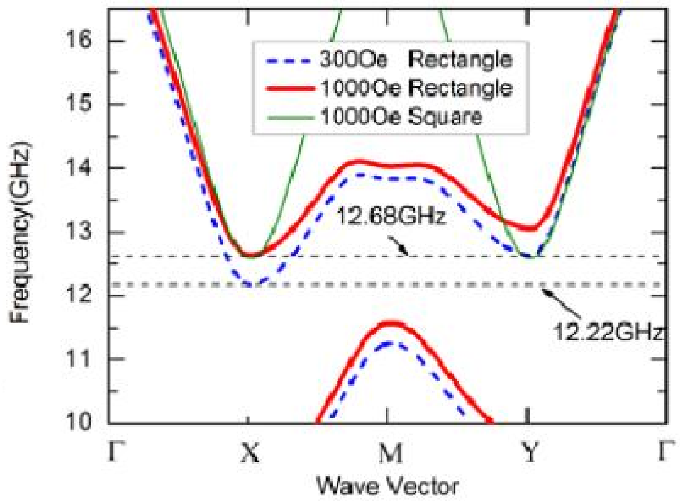
Our studies indicates suppressing the leaky wave in other directions is more important to improve the directive radiations of the EBG antenna.

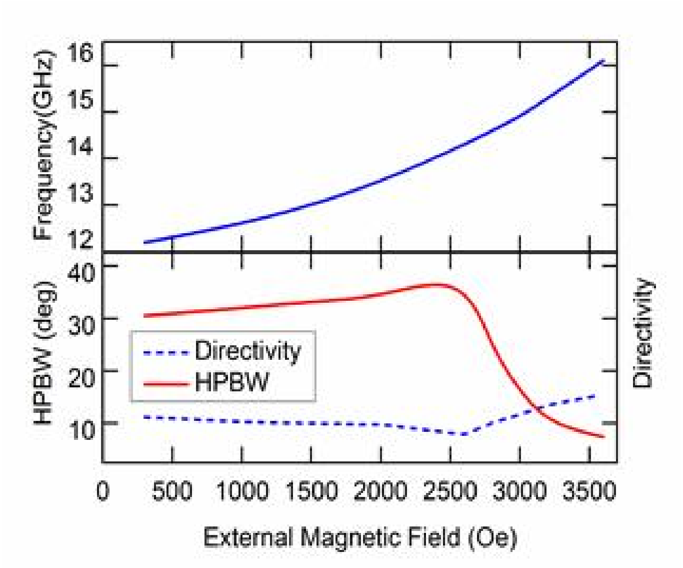


- **Advantage of the magnetic EBG antenna**

  It can be used to realize the frequency tunable antenna

When bias magnetic field increases from 300 to 1000 Oe, the band edge moves from 12.22 to 12.68 GHz.




The operating frequency moves from 12.2 to 14.3 GHz (about 2 GHz) when bias field changes from 300 to 2600 Oe. The average directivity in the tunable range is about 32.

# Summary

- There are two ways to use magnetic artificial materials to realize directional antennas, the magnetic EBG structures and the magnetic left-handed metamaterials.
- For the both ways, the antennas exhibit good directional radiation performance, but the underlying mechanism are totally different.
- The antennas have some unusual properties in radiation performance, which are preferred in the modern antenna designing