A simulation study on the property of micro-arrayed negative refractive index material for the energy transfer

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ABSTRACT

In this paper we discuss in building a micro-arrayed negative refractive index material which enhances the energy transfer between a wireless transmitter and a receiver. We simulate and study the effects of introduction of negative index refractive materials of micro-array configuration between the transmitter and the receiver. The size, structure and physical parameters play an important role in efficiency and quantum of energy transfer. They have a significant effect on the transfer coefficient. These properties and feature can be studied before optimizing the structure and physical nature of the system. Further the degree of anisotropy of the system has been discussed. The simulations are done using a finite element simulation tool. Some interesting results evolved as we introduce the negative refractive index material in the environment are discussed.

Keywords: Micro-array, Negative Refractive Index medium, Magnetic flux density.

1 INTRODUCTION

Non contact charging of electronic equipment from mobiles to electric vehicle has created immense interest among researchers. There are various groups working on both radiative and non-radiative energy transfer. The idea based on strongly coupled magnetic resonances is of interest because of the increased distance of energy transfer.[3-4] This technology is based on resonant magnetic coupling with the introduction of negative refractive index materials in the environment is also novel and exciting.[1-2] Negative refractive index material introduces immense possibility of improved and enhanced wireless power transfer. To improve the efficiency of wireless power transfer for low as well as high power applications it is important to understand the enhancement of magnetic flux density when the characteristics of the medium in which the power is transferred is changed. In this paper change of magnetic flux density with and without the negative refractive material is analyzed. The enhancement of magnetic flux density by introducing micro-arrays and anisotropy in the array influences the power transfer efficiency. These features have been presented in this paper.

2 THEORY

A circular coil carrying a current I is related to the current density as follows:

$$I = \iint J.ds$$

ds is the vector component perpendicular to the cross section of the circular coil. The current density of the coil is given by

$$J = \frac{\sigma V}{2\pi r}$$

σ is the conductivity of the copper, V is the applied potential and r is the radius of the circular coil.

The magnetic flux density created by the current carrying coil denote the presence of a magnetic field in a given region of space related to the magnetic field intensity by

$$\vec{B} = \mu \vec{H}$$

where B is the magnetic flux density in Tesla, H is the magnetic field intensity in A/m and μ is the permeability of the medium H/m.

The magnetic field H at any point in space to the steady current I that generates H is given by Biot-Savart law

$$d\vec{H} = \frac{I d\vec{l} \times \hat{R}}{4\pi R^2} \text{ A/m}$$

where $\vec{R} = \hat{R}R$ is the distance vector between dl and the observation point P.

To understand the behavior of Negative Refractive Index (NRI) material in a uniform magnetic field we aimed at simulating the medium based on the FDTD (Finite Difference Time Domain) or the FEM (Finite Element Method). In both cases, the Maxwell equations are solved for each element subject to the boundary conditions by dividing the structure into a finite number of elements. To solve using FEM each element is governed by the following equations which is derived from the maxwell's equation.

$$\nabla \times \mu^{-1} B - \sigma v \times B = J_e$$

The vector potential is related to the magnetic flux density as shown below

$$B = \nabla \times A$$

and the constitutive relationship between B and H is

$$B = \mu H$$

where $\mu=\mu_r\mu_0$ and $\mu_0=4\pi\times10^{-7}$ H/m

3 SIMULATION

3.1 Model

The model is created in COMSOL a Finite Element Analysis simulation software. A circular coil of radius 100mm excited with a current of 1A is considered as the source. The coil is made of copper of radius 1mm. A micro-array of 32 x 32 elements is introduced in the medium where each element size is 500µm × 500 µm. Since the structure is symmetry in nature a 2D axisymmetry model is chosen for simulation as shown in fig. 1. The micro-array is a negative refractive index material having the relative permeability and permittivity of -1, as shown in fig. 2.

3.2 Simulation Results

The magnetic flux density without any micro-array, with micro-array of Double Positive Side(DPS) medium and NRI medium are shown in figure 3. When a NRI is introduced in the medium next to the coil, the magnetic flux density increases in the region of microarray is clearly seen. This enhancement in the magnetic flux density is due to introduction of the NRI. Next the position of the micro-array is optimized by moving the micro-array from the coil from 4mm to 14mm in steps of 5mm as shown in figure 4. From the figure it is observed that at a distance of 9mm from the coil the flux density is more. Then the spacing between the array is optimized by varying the space from 500 µm to 1500 µm in steps of 500 µm. And it is seen from figure 5 that enhancement in flux density occurs when the spacing between the micro-array is 500 µm. Finally the degree of anisotrophy is introduced in the microarray. The relative permittivity and permeability in x, y and z direction are varied as (-0.25,-1,-0.25), (-0.25,-0.25,-1), (-1,-0.25,-0.25) (we consider the diagonal of the 3 x 3 matrix) And it is found that at (-1,-0.25,-0.25) the flux density increases to the left of the micro-array.

4 CONCLUSION

The simulation result shows that the magnetic field can be focused on a particular region by introducing the NRI, changing the distance between the NRI and the source, varying the space between the micro-array and varying the degree of anisotropy of the micro-array. All these parameters play a vital role in enhancing the magnetic flux density at specific regions in the space field. This increase in the field gives rise to increase in induced voltage if the coil is excited with an AC voltage. Further, to enhance the range, resonators can be used as transmitter and receiver instead of coil. The analysis can be done by increasing the number of elements which acts as a relay between the transmitter and receiver to enhance the range.

5 REFERENCES

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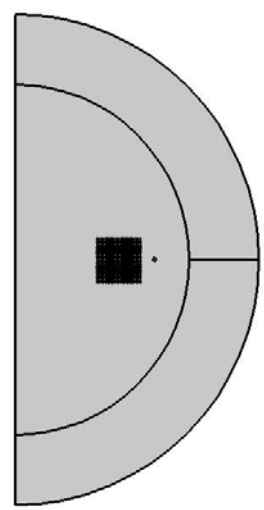

Fig. 1 Geometry of source with micro-array in 2D axisymmetry

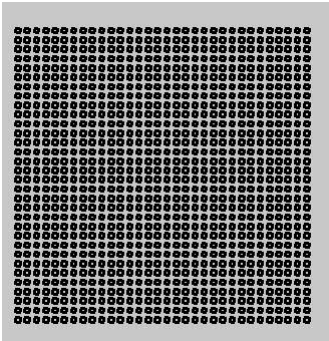

Fig. 2 Micro-array

Fig. 3 Magnetic flux density with source, source and DPS and source and NRI (Units –Tesla)

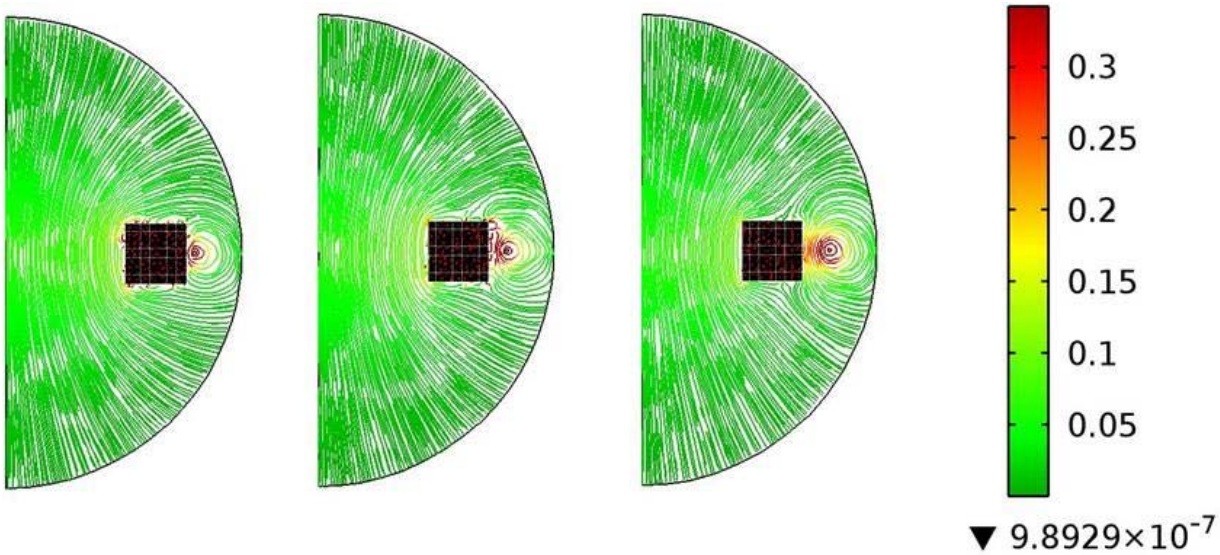

Fig. 4. Distance between source and NRI varied from 4mm to 14mm in steps of 5mm (Units –Tesla)

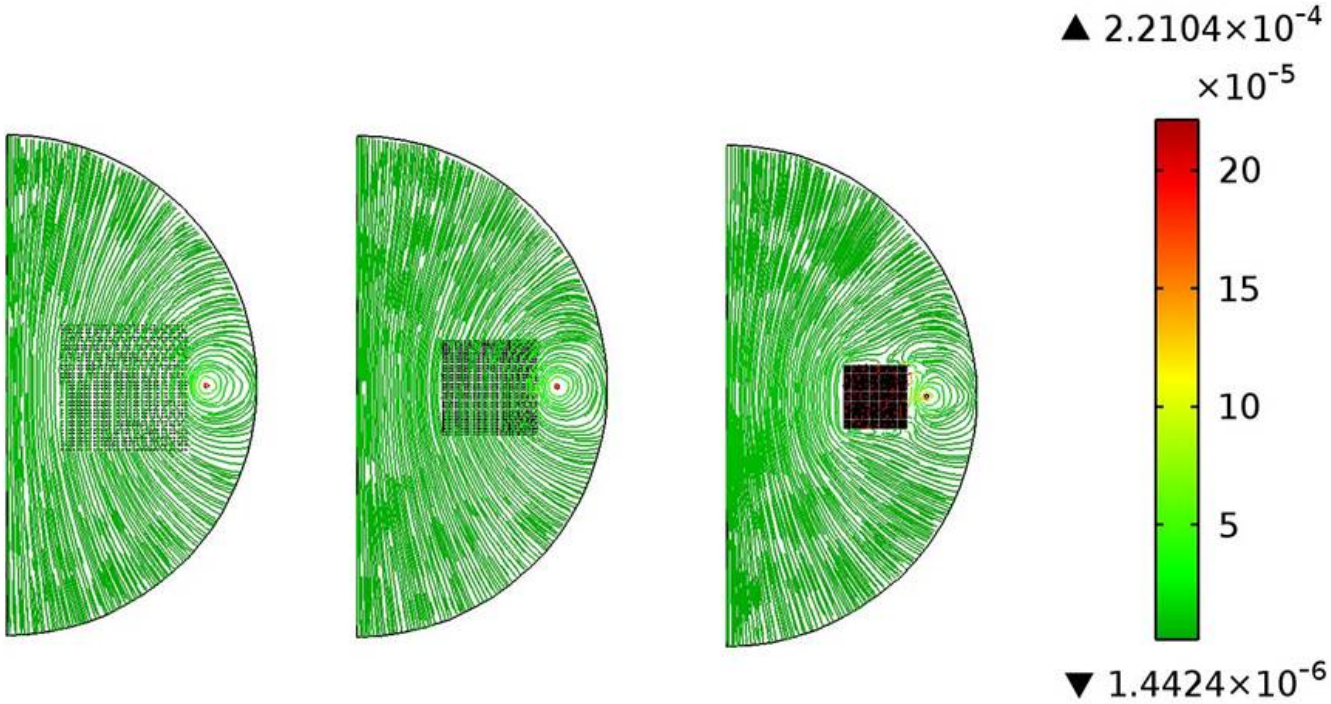

Fig. 5. Micro-array spacing from 1500µm to 500 µm in steps of 500 µm

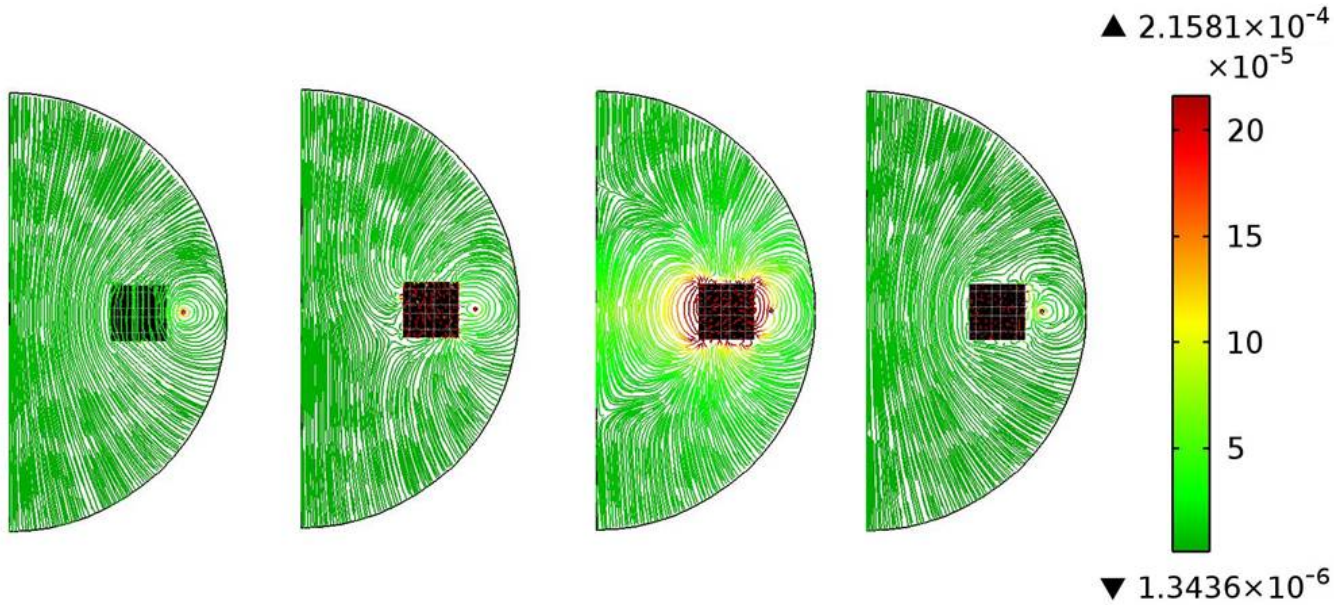

Fig. 6. Degree of anisotropy changed as (-0.25,-1,-0.25), (-0.25,-0.25,-1), (-1,-0.25,-0.25), (-1,-1,-1)