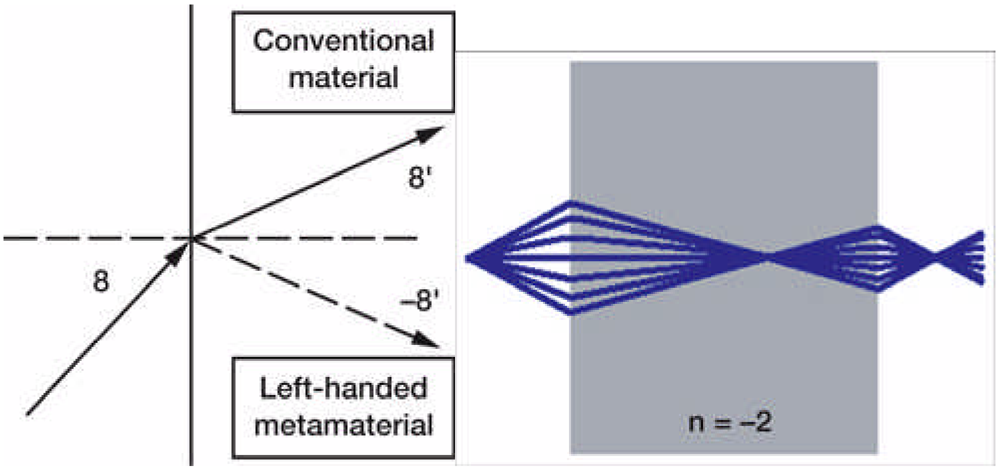
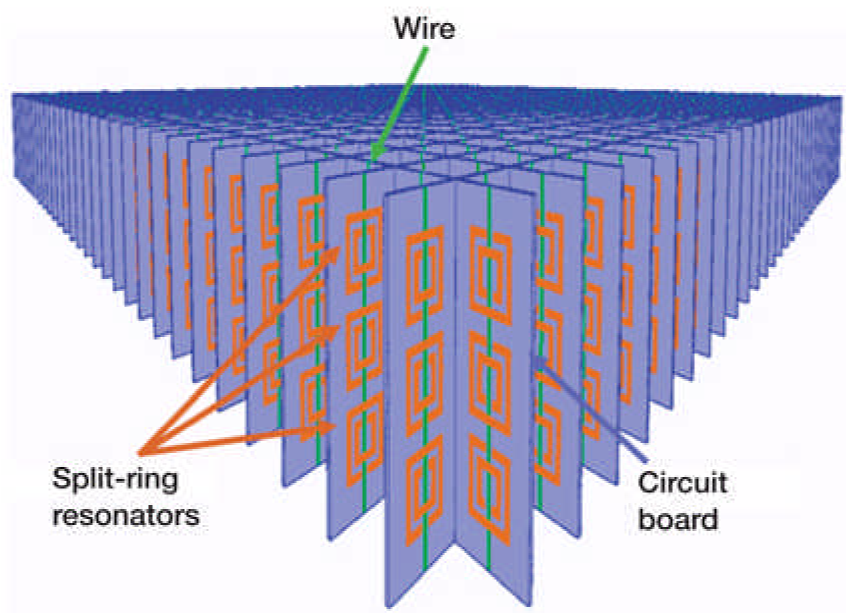
# Flat Lens Focusing Demonstrated With Left-Handed Metamaterial




*Left: An incident electromagnetic wave from free space entering a material at the boundary indicated by the lower left arrow refracts as shown by the solid upper right arrow when entering a conventional material and as shown by the dashed lower right arrow when entering a left-handed metamaterial.* An incident electromagnetic wave traveling to the right with an upward angle continues to travel to the right but with a different upward angle upon entering a conventional material. When an identical incident wave enters a left-handed material it still continues to the right but with a downward angle. *Right: Electromagnetic radiation is focused by a flat slab of left-handed metamaterial (n, index of refraction).* : Electromagnetic radiation is focused by a flat slab of left-handed metamaterial. Diverging radiation entering a flat slab of left-handed metamaterial refracts toward the center and crosses over so that it is diverging again as it leaves the slab. At the second boundary, the radiation refracts again toward the center to a focal point.

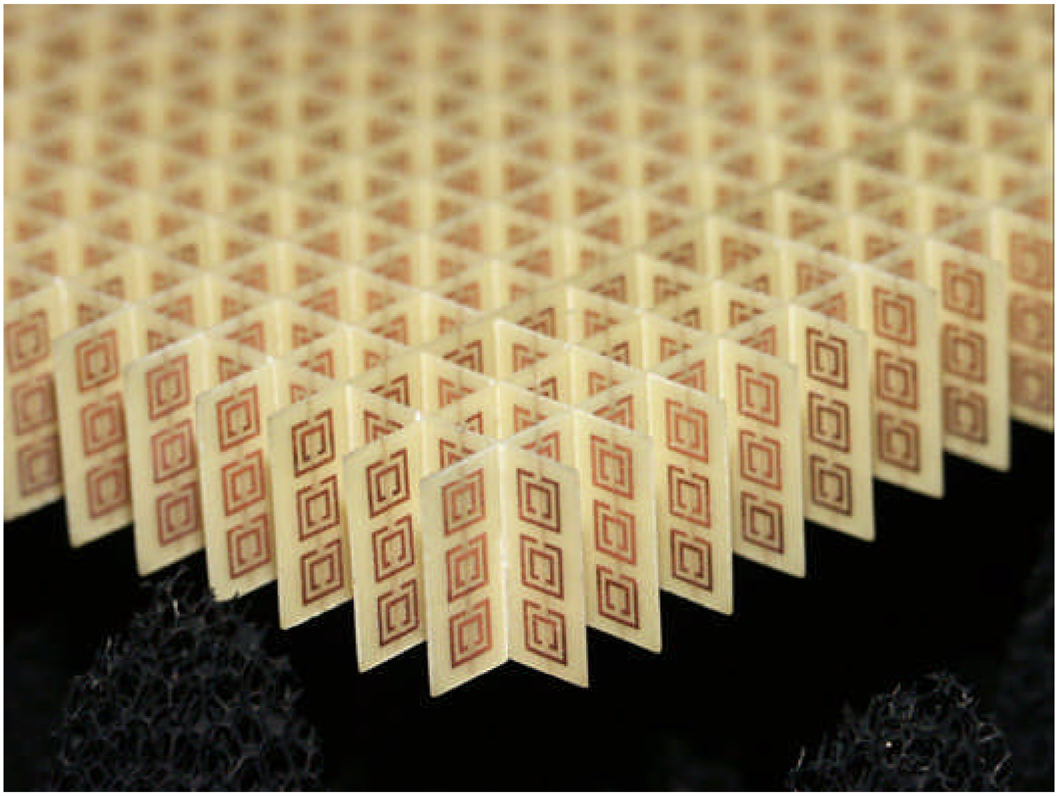
Left-handed metamaterials (LHM's) are a new media engineered to possess an effective negative index of refraction over a selected frequency range. This characteristic enables LHMs to exhibit physical properties never before observed. In particular, a negative index of refraction should cause electromagnetic radiation to refract or bend at a negative angle when entering an LHM, as shown in the figure above on the left. The figure on the right shows that this property could be used to bring radiation to a focus with a flat LHM lens. The advantage of a flat lens in comparison to a conventional curved lens is that the focal length could be varied simply by adjusting the distance between the lens and the electromagnetic wave source. In this in-house work, researchers at the NASA Glenn Research Center developed a computational model for LHMs with the three-dimensional electromagnetic commercial code Microwave Studio, constructed an LHM flat lens, and used it to experimentally demonstrate the reversed refraction and flat lens focusing of microwave radiation.

The LHM configuration is a periodic array of metallic rings and wires based on work by researchers at the University of California at San Diego (refs. 1 and 2). A schematic representation of an array is shown in the left side of the following figure, and a photograph of the flat lens array of LHM cells that we have constructed is shown on the right. For microwave radiation at wavelengths about 10 times a cell length, this configuration provides negative effective values of electric permittivity and magnetic permeability, resulting in a negative value for the index of refraction. Preliminary testing has demonstrated a reversed refraction effect with focusing of the microwave radiation. Finite element models are being developed and an optics ray tracing code is being used to create new lens designs. We plan to create, design, and test other LHM configurations that are more amenable for operation at higher frequencies and investigate applications of a flat lens for biomedical imaging and detection and other applications.




*Left-handed metamaterial array configuration consisting of copper split-ring resonators and wires mounted on interlocking sheets of fiberglass circuit board.*

Left-handed metamaterial array configuration consisting of copper split-ring resonators and wires mounted on interlocking sheets of fiberglass circuit board. A split-ring resonator consists of an inner square with a split on one side embedded in an outer square with a split on the other side. The split-ring resonators are on the front and right surfaces of the square grid and the single vertical wires are on the back and left surfaces.



*Left-handed metamaterial flat lens consisting of an array of 3 by 20 by 20 unit cells. With a unit cell width of 5 mm, this geometry shows reversed refraction and left-handed focusing properties at microwave frequencies between 10 and 11 GHz.*

# References


1. Smith, D.R., et al.: Composite Medium With Simultaneously Negative Permeability and Permittivity. Phys. Rev. Lett., vol. 84, no. 18, 2000, pp. 4184-4187.

2. Shelby, R.A., et al.: Microwave Transmission Through a Two-Dimensional, Isotropic, Left-Handed Metamaterial. Appl. Phys. Lett., vol. 78, no. 4, 2001, pp. 489-491.


**Find out more about this research:** http://microgravity.grc.nasa.gov/grcbio/SRF.html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