

Claims

What is claimed is:

1. A metamaterial split ring resonator, comprising:

a first split ring comprising a first split at a first edge of the first split ring and a second split at a second edge of the first split ring, the first edge being opposite to the second edge; and

a second split ring inside the first split ring and concentric with the first split ring, the second split ring comprising a third split at a first edge of the second split ring adjacent to the first edge of the first split ring;

wherein the first split ring comprises a first pair of stubs extending inwardly from the first split, and the second split ring comprises a second pair of stubs extending inwardly from the third split.
2. The metamaterial split ring resonator according to claim 1,

wherein the first split ring and the second split ring are in the same shape.
3. The metamaterial split ring resonator according to claim 1 or 2,

wherein the first split ring and the second split ring are hexagonal rings.
4. The metamaterial split ring resonator according to any one of claims 1 to 3,

wherein the first pair of stubs and the second pair of stubs are at least substantially parallel to each other, and are at least substantially perpendicular to the first edge of the first split ring and the first edge of the second split ring.
5. The metamaterial split ring resonator according to any one of claims 1 to 4,

wherein lengths of the first pair of stubs and the second pair of stubs are determined based on a desired resonant frequency of the metamaterial split ring resonator.

6. The metamaterial split ring resonator according to any one of claims 1 to 4,
wherein lengths of the first pair of stubs and the second pair of stubs are adjustable to fine tune a resonant frequency of the metamaterial split ring resonator.
7. The metamaterial split ring resonator according to any one of claims 1 to 6,
wherein the first pair of stubs and the second pair of stubs have lengths in a range between 0.5mm to 1.1mm.
8. The metamaterial split ring resonator according to any one of claims 1 to 7,
wherein the metamaterial split ring resonator is an electrically small antenna.
9. The metamaterial split ring resonator according to any one of claims 1 to 8,
wherein the metamaterial split ring resonator has a maximum dimension substantially equal to or less than 0.1λ , wherein λ represents a wavelength of a resonant frequency of the metamaterial split ring resonator.
10. The metamaterial split ring resonator according to any one of claims 1 to 9,
wherein the second split forms feed points configured to connect with a diode.
11. A metamaterial split ring resonator array, comprising:
a plurality of metamaterial split ring resonators arranged adjacent to each other in an array, wherein each metamaterial split ring resonator comprises:

a first split ring comprising a first split at a first edge of the first split ring and a second split at a second edge of the first split ring, the first edge being opposite to the second edge; and

a second split ring inside the first split ring and concentric with the first split ring, the second split ring comprising a third split at a first edge of the second split ring adjacent to the first edge of the first split ring;

wherein the first split ring comprises a first pair of stubs extending inwardly from the first split, and the second split ring comprises a second pair of stubs extending inwardly from the third split.

12. The metamaterial split ring resonator array according to claim 11,
wherein the plurality of metamaterial split ring resonators are tessellated.
13. The metamaterial split ring resonator array according to claim 11,
wherein the plurality of metamaterial split ring resonators are arranged with a gap between adjacent metamaterial split ring resonators.
14. The metamaterial split ring resonator array according to any one of claims 11 to 13,
wherein the plurality of metamaterial split ring resonators are arranged in the same orientation.
15. The metamaterial split ring resonator array according to any one of claims 11 to 14,
wherein the plurality of metamaterial split ring resonators are arranged on a first surface of a substrate,
wherein the plurality of metamaterial split ring resonators are connected to direct current lines on a second surface of the substrate via the respective second splits, the second surface being opposite to the first surface.

16. The metamaterial split ring resonator array according to any one of claims 11 to 15,
wherein the first split ring and the second split ring of each metamaterial split ring resonator are in the same shape.
17. The metamaterial split ring resonator array according to any one of claims 11 to 16,
wherein the first split ring and the second split ring of each metamaterial split ring resonator are hexagonal rings.
18. The metamaterial split ring resonator array according to any one of claims 11 to 17,
wherein the first pair of stubs and the second pair of stubs in each metamaterial split ring resonator are at least substantially parallel to each other, and are at least substantially perpendicular to the first edge of the first split ring and the first edge of the second split ring.
19. The metamaterial split ring resonator array according to any one of claims 11 to 18,
wherein lengths of the first pair of stubs and the second pair of stubs in each metamaterial split ring resonator are determined based on a desired resonant frequency of the respective metamaterial split ring resonator.
20. The metamaterial split ring resonator array according to any one of claims 11 to 18,
wherein lengths of the first pair of stubs and the second pair of stubs in each metamaterial split ring resonator are adjustable to fine tune a resonant frequency of the respective metamaterial split ring resonator.

21. The metamaterial split ring resonator array according to any one of claims 11 to 20,
wherein the first pair of stubs and the second pair of stubs in each metamaterial split ring resonator have lengths in a range between 0.5mm to 1.1mm.
22. The metamaterial split ring resonator array according to any one of claims 11 to 21,
wherein the respective metamaterial split ring resonator is an electrically small antenna.
23. The metamaterial split ring resonator array according to any one of claims 11 to 22,
wherein the respective metamaterial split ring resonator has a maximum dimension substantially equal to or less than 0.1λ , wherein λ represents a wavelength of a resonant frequency of the metamaterial split ring resonator.
24. The metamaterial split ring resonator array according to any one of claims 11 to 23,
wherein the second split of each metamaterial split ring resonator forms feed points configured to connect with a respective diode.
25. An energy harvesting apparatus, comprising:
a plurality of metamaterial split ring resonators arranged adjacent to each other in an array, wherein each metamaterial split ring resonator comprises:
a first split ring comprising a first split at a first edge of the first split ring and a second split at a second edge of the first split ring, the first edge being opposite to the second edge; and

a second split ring inside the first split ring and concentric with the first split ring, the second split ring comprising a third split at a first edge of the second split ring adjacent to the first edge of the first split ring;

wherein the first split ring comprises a first pair of stubs extending inwardly from the first split, and the second split ring comprises a second pair of stubs extending inwardly from the third split;

a plurality of rectifiers, each being coupled to the respective metamaterial split ring resonator and configured to convert energy harvested by the metamaterial split ring resonator to a respective direct current; and

a direct current combining circuit coupled to the plurality of rectifiers, and configured to combine the direct currents produced by the plurality of rectifiers.

26. The energy harvesting apparatus according to claim 25, further comprising:
a load coupled to the direct current combining circuit.
27. The energy harvesting apparatus according to claim 25 or 26,
wherein each rectifier comprises a diode connected with the second split of the respective metamaterial split ring resonator.
28. The energy harvesting apparatus according to any one of claims 25 to 27, being configured to be applied to at least one of a façade, interior partitions, walls, ceilings or floors of a building, for energy harvesting and shielding of electromagnetic waves.