

Saturation of magnetic response of split-ring resonators at optical frequencies

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We investigate numerically the limits of the resonant magnetic response with negative effective permeability, μ_{eff} , for single-ring multi-cut SRR designs up to optical frequencies. We find the breakdown of linear scaling due to the free electron kinetic energy for frequencies above ~ 100 THz. Above the linear scaling regime the resonance frequency saturates while the amplitude of the resonant permeability decreases, ultimately ceasing to reach negative value. The highest resonance frequency at which $\mu_{\text{eff}} < 0$ increases with the number of cuts in the SRR. A LC circuit model provides explanation of the numerical data.

PACS numbers:

1. INTRODUCTION

In the last few years left-handed meta-materials (LHMs) of the split-ring resonator[1] (SRR) plus continuous wire[2] type have been intensely studied throughout a wide window of operating frequencies, from radio and microwaves[3, 4] up to the THz region[5–8]. In some narrow frequency band the key components, SRR and wire, simultaneously provide a negative effective permeability, μ_{eff} (due to a resonance of circular currents around the SRR) and a negative effective permittivity, ϵ_{eff} , with plasma frequency, ω'_p , greatly reduced compared to that of bulk metal, ω_p , as a result mainly of the magnetic field energy dominating the kinetic energy of the current carrying electrons (for frequencies much lower than 100 THz). The anti-parallel Poynting and wave-vector exhibited by LHMs enables a range of interesting possible applications, like negative refraction, superlensing[?], etc.

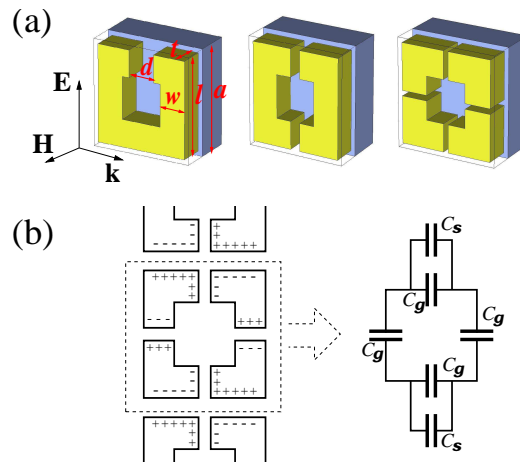


FIG. 1: (a): The geometries of the 1, 2 and 4-cut single-ring SRR are shown; the unit cell has the dimensions $a \times a$ in the SRR plane and $0.614a$ perpendicular to it. The SRR is made of aluminum, simulated using a Drude-model permittivity ($f_p = \omega_p/2\pi = 3570$ THz, $f_\tau = \omega_\tau/2\pi = 19.4$ THz), separated from the $0.343a$ thick substrate (glass, $\epsilon = 2.14$) by an $0.014a$ thin ITO layer ($\epsilon = 7$). The parameters of the SRR are: side length $l = 0.914a$, width and thickness $w = t = 0.257a$ and cut-width (d) $0.2a$, $0.1a$ and $0.05a$ for the 1, 2 and 4-cut SRR, respectively. (b): The left panel shows the charge accumulation in a 4-cut SRR, as a result of the periodic boundary conditions in the \vec{E} (and \vec{H}) direction. The right panel shows the equivalent LC circuit describing this SRR. C_g is the gap capacitance and C_s the side capacitance resulting from the interaction with the neighboring SRR.

2. SUBJECT 1

There is a sustained effort[5–9] in the community to push the operating frequency of the metamaterials deeper and deeper into the THz region to reach ultimately optical frequencies. This is so important because there are no natural materials that would still have magnetic properties at such high frequencies.

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3. SUBJECT 2

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