Field Displacement in a Traveling-wave Ring Resonator Meta-structure

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Abstract

Field displacement is demonstrated for the first-time in a non-molecular-scale structure, namely a meta-structure composed of rings equipped with an isolator. The structure is explained in terms of rotating magnetic dipole moments and demonstrated to produce typical gyrotropic field displacement.

1 Introduction

Gyrotropy and subsequent non-reciprocal effects generally require molecular-scale materials [2], such as ferrites or plasmas. This paper introduces a novel meta-structure composed of rings equipped with an isolator achieving gyrotropy from macroscopic "artificial spins," and demonstrates by full-wave simulation that this structure supports the field-displacement effect [1] following from this artificial gyrotropy.

2 Traveling-Wave Ring Resonator

Fig. 1 depicts the unit cell of the ring resonator meta-structure, whose isolator is typically realized with a FET transistor biased in its common source configuration featuring a phase shift of π.

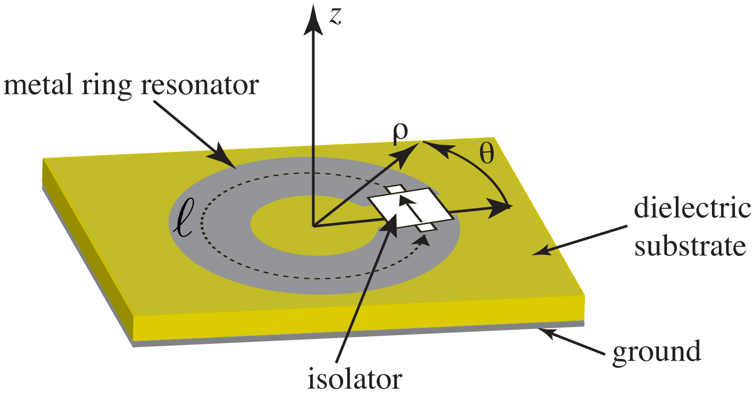

Figure 1: Unit cell of the proposed field-displacement traveling-wave ring resonator meta-structure

Fig. 2 represents the classical first resonance of a ring resonator without isolator, where the superposition of two waves azimuthally traveling in opposite directions gives rise to a standing wave. The insertion of an isolator in the ring, as in Fig. 1, suppresses one of the two waves, which leads to a traveling-wave regime, as illustrated in Figs. 3 and 4 at the first two resonances. Taking into account the π phase shift of the isolators, these two resonances correspond to circumferential lengths of $\ell = \lambda/2$ (Fig. 3) and $\ell = 3\lambda/2$ (Fig. 4), respectively.

3 Magnetic Dipole Moment and Gyrotropy

Figs. 5 and 6 show the field distributions along the ring at quarter-period spaced instants for the resonances of Figs. 3 and 4, respectively. They show that a rotating magnetic dipole moment $\mathbf{m}$ is generated in

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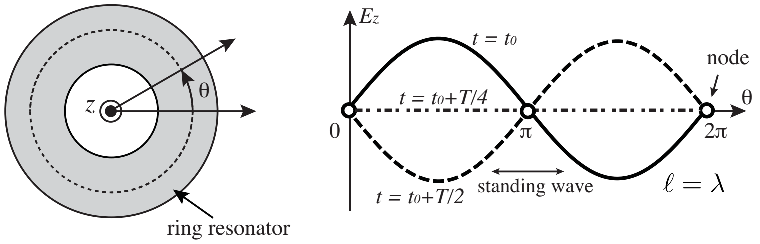


Figure 2: Conventional ring resonator, supporting a standing wave, and first resonance mode, $\ell = \lambda$.

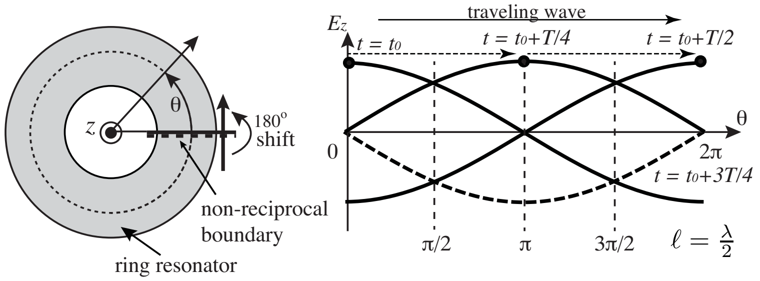


Figure 3: Proposed ring resonator with a localized isolator with π phase shift, supporting a traveling wave, and first resonant mode, $\ell = \lambda/2$.

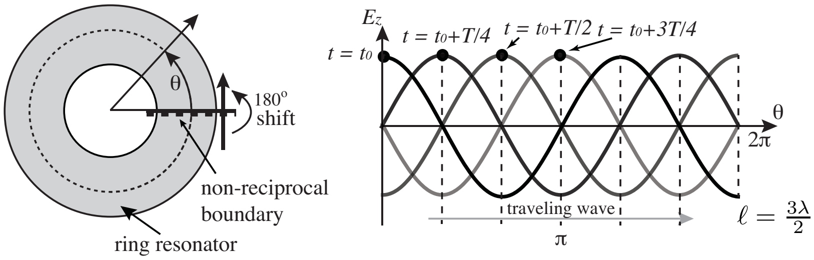
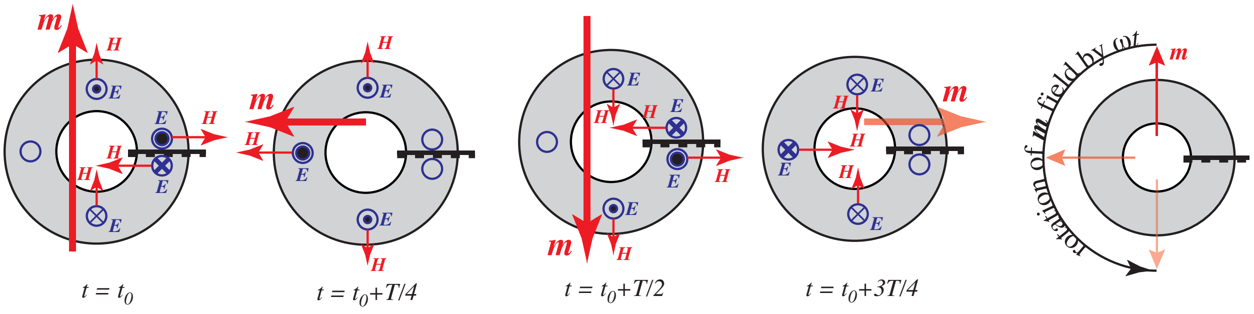


Figure 4: Proposed ring resonator as in Fig. 3 but excited in its second resonance, $\ell = 3\lambda/2$.

the ring as a result of the azimuthal unidirectionality of the wave propagation along it. As suggested by the figures, the variation of the magnitude of $\mathbf{m}$ is smaller at the second resonance, which is therefore expected to produce a stronger gyrotropic effect on the incident wave.



$t = t_0$ $t = t_0+T/4$ $t = t_0+T/2$ $t = t_0+3T/4$

Figure 5: Gyrotropy related to a rotating magnetic dipole moment $\mathbf{m}$ at the first resonance, $\ell = \lambda/2$ (case of Fig. 3)

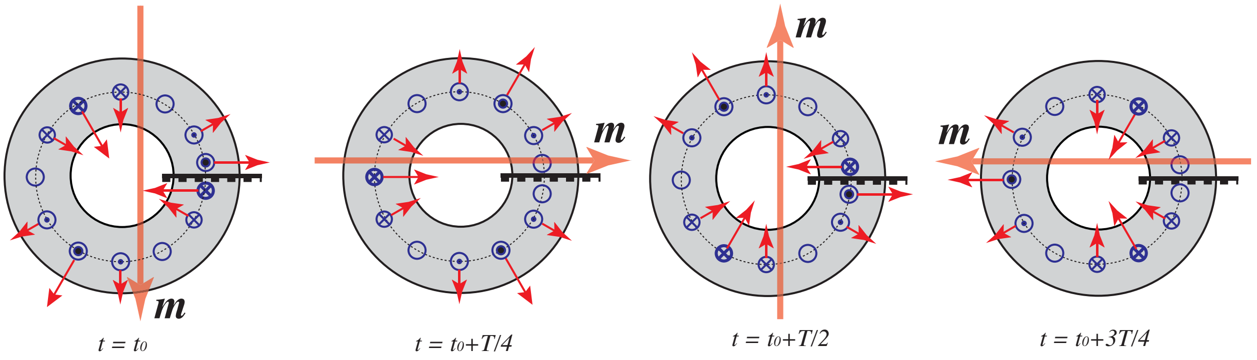
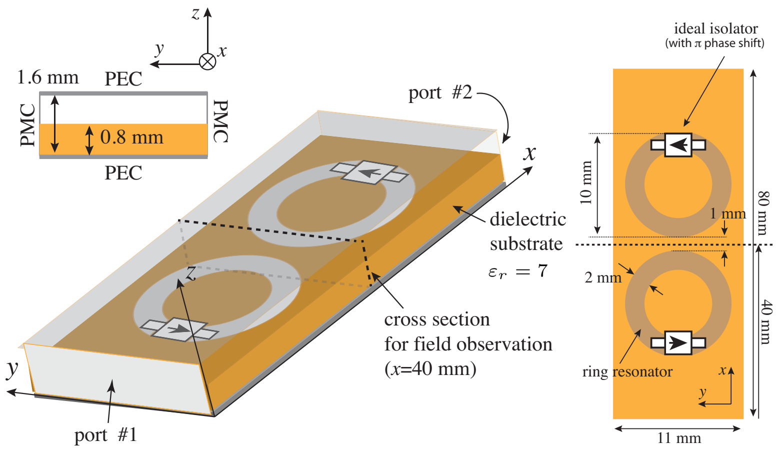


Figure 6: Gyrotropy related to a rotating magnetic dipole moment **m** at the second resonance, $\ell = 3\lambda/2$ (case of Fig. 4).

4 Field Displacement Result

Gyrotropy usually leads to the phenomenon of field displacement [1]. It is therefore expected that a meta-structure (not necessarily effective, i.e. not necessarily a meta-material) formed by a collection of rings equipped with an isolator will produce this effect. To verify this, the two-ring waveguide structure depicted in Fig. 7 is full-wave simulated, and the resulting transmission parameters and cross-sectional fields are plotted in Figs. 8 and 9, respectively. Fig. 8 shows the first three resonances ($\ell = \lambda/2, 3\lambda/2, 5\lambda/2$), while Fig. 9, showing power concentrations in opposite sides for the propagation in opposite directions, demonstrates the anticipated field-displacement phenomenon.



(a) (b)

Figure 7: Ring meta-surface in a parallel-plate waveguide for the demonstration of the field-displacement phenomenon (full-wave simulation set-up).

5 Conclusion

Field displacement has been demonstrated for the first-time in a non-molecular-scale structure, namely a meta-structure composed of rings equipped with an isolator. Many applications are anticipated due to the MMIC compatibility of the structure.

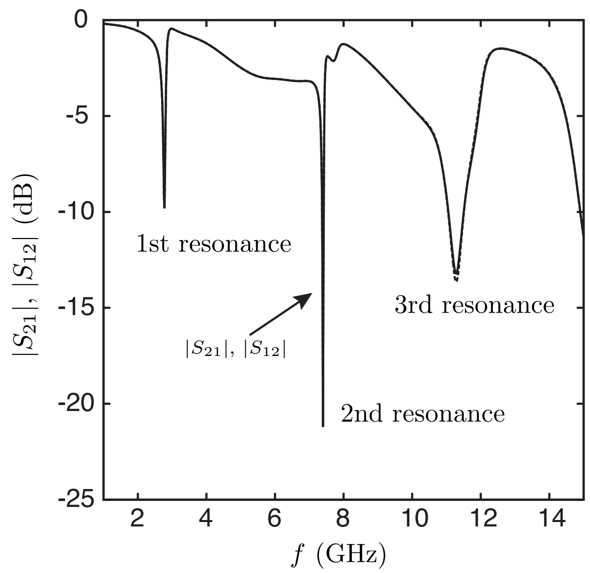


Figure 8: Transmission characteristics for the waveguide meta-structure of Fig. 7 (FIT CST Microwave Studio).

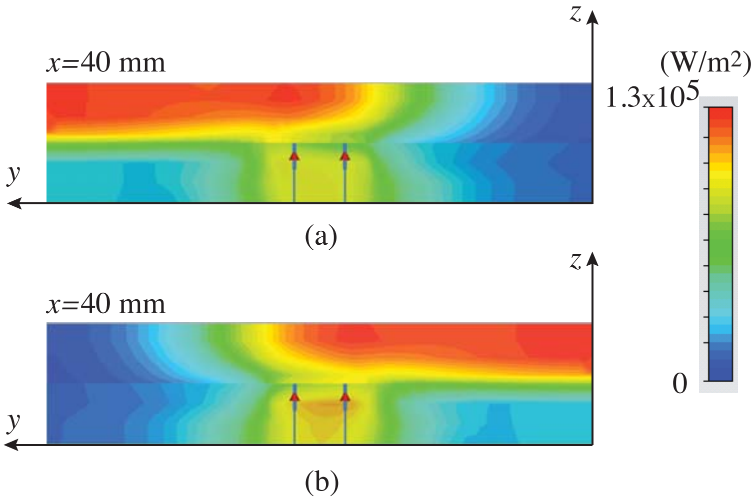


Figure 9: Cross-sectional magnitude of the Poynting vector at the position indicated in Fig. 7. (a) Port #1 excitation. (b) Port #2 excitation.

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