Gyrotropic metamaterials with tailored magnetization

Nazar Pyvovar[1], Sadi Ayhan[1], Carl Pfeiffer[2], Igor Anisimov[2], Ilya Vitebskiy[2], Andrey A. Chabanov[1]

[1] Department of Physics and Astronomy, University of Texas at San Antonio, San Antonio, TX, USA.
[2] Sensors Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH, USA.

Abstract: Magnetic materials play a crucial role in nonreciprocal electromagnetic devices, such as Faraday rotators, isolators, circulators, and nonreciprocal phase shifters. However, their use is often limited by the need for a uniform bias magnetic field and nonuniform demagnetizing fields. This results in the restricted aperture of free-space devices, poor temperature stability, and incompatibility with magnetic field-sensitive applications. Alternative methods have been developed to achieve nonreciprocity using active, nonlinear, and time-varying metamaterials, each with its own advantages and limitations. Here, we present a new approach[1] based on self-biased gyrotropic metamaterials composed of magnetically hard magnets embedded in a magnetically soft ferrite matrix. In this configuration, the hard magnets provide the magnetic bias for the soft ferrite matrix, which produces a nonreciprocal response. This gyrotropic metamaterial can exhibit zero net magnetization (ZNM) while producing strong and uniform Faraday rotation over a broad temperature range. Without bias and demagnetizing fields, the aperture of this Faraday rotator can be virtually unlimited. Using this method, we demonstrate uniform 45-degree Faraday rotation and effective isolation across the microwave X-band.

Figure 1 presents the magnetic and MW properties of a gyrotropic metamaterial featuring ZNM. This ZNM metamaterial consists of a hexagonal array of NdFeB micromagnets embedded in a planar YIG matrix. The ferrite's thickness is tuned to achieve a 45-degree Faraday rotation at 10 GHz. Figure 1a shows the z-component of the magnetic field $\boldsymbol{H}_\mathrm{e}$ produced by the NdFeB micromagnets without the ferrite. The field $\boldsymbol{H}_\mathrm{e}$ is highly uniform throughout the array and strong enough to magnetize the ferrite matrix to its saturation point. As expected for ZNM metamaterials, the internal field $\boldsymbol{H}_0$ is zero both inside and outside the composite, except near the poles of the micromagnets (Fig. 1b). When the ZNM metamaterial is sandwiched between two impedance-matching layers, it produces a 45-degree Faraday rotation and a slight ellipticity, as demonstrated in Fig. 1c. This Faraday rotator achieves isolation exceeding 40 dB and insertion loss below 0.5 dB within the frequency range of 9 to 11.5 GHz (Fig. 1d).

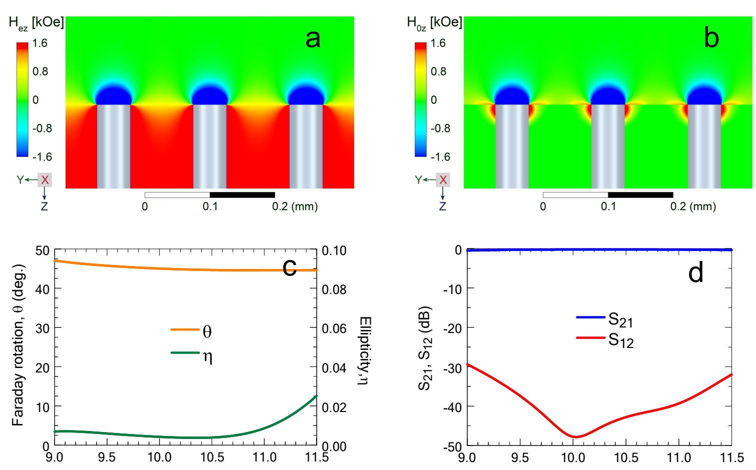

Figure 1. A 45-degree Faraday rotator based on a gyrotropic metamaterial with zero net magnetization. (**a**) The z-component of the field $\boldsymbol{H}_\mathrm{e}$ produced by a hexagonal array of NdFeB micromagnets in the absence of the ferrite matrix. (**b**) The z-component of the field $\boldsymbol{H}_0$ within and outside the ferrite matrix. (**c**) The Faraday rotation and the ellipticity of the transmitted microwaves and (**d**) the microwave isolation function.

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