Design and Measurement of Frequency Tunable Metamaterials

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Metamaterials are artificial structures designed to exhibit unusual responses to electromagnetic radiation, and most research in this field has examined passive linear particles with fixed responses that cannot change for a given design. To enable real-time control of the achievable electromagnetic parameters, we discuss our work on frequency tunable magnetic metamaterials by capacitive loading of split ring resonators (SRRs) with tunable elements. To achieve better control of the response of magnetic metamaterials, we examine a dual-state SRR in which the self-resonant frequency is turned on and off using an RF microelectromechanical (MEMS) switch with an external bias. We show how the placement of this switch on the ring affects the self-resonant frequency of the particle and completely dictates responses the ring can excite. Transmission and loss characteristics of MEMS-loaded rings were measured for different switch configurations so that the parasitics of the switch (and hence the achievable response of the ring) could be deduced.

We also discuss design and measurements of ferroelectric frequency tunable SRRs loaded with barium strontium titanate (BST), a ferroelectric thin film dielectric with a tunable effective permittivity. S-Parameter measurements of the BST-SRR medium show that the resonant frequency is voltage tunable across a 140 MHz band centered at 1.75 GHz. The retrieved effective magnetic permeability of the medium is strong and has a roughly Lorentzian shape with a real part that reached minimum values between -2 and -3 throughout the range of applied bias (0-5 V). The ability of the slab to tune between positive and negative values of magnetic permeability makes it useful in applications requiring real-time control of the magnetic permeability state.

Finally, we discuss design and measurement of a tunable magnetic medium using SRRs loaded with varactor diodes. The wide tolerance of the varactor diodes causes a significant variance in the resonant property of each unit cell, making the design of such a medium at a specific resonant frequency very difficult. To eliminate the undesirable effect of diode variance, the diodes loading the SRRs were integrated with a network of digital potentiometers. The potentiometers were used in a voltage divider circuit so that the bias across each diode could be controlled independently. Comparison between the addressable and non-addressable SRR media responses show that the uncontrolled medium tunes over 150 MHz (15% bandwidth) centered at approximately 1 GHz. However, since the resonant frequency of each ring is slightly different, the resulting transmission is split among several resonances. This results in a weak material response with a rather large loss tangent. The controlled medium possesses a single strong resonance with magnetic permeability that tunes over 95 MHz (9.5 % bandwidth), with a loss tangent that is significantly reduced from the uncontrolled medium throughout the tunable range. These results suggest that tight control of metamaterial responses through external cell addressing help to enhance the overall material response and reduce effective losses.