Superconducting Metamaterials

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The most exciting new physics of negative index of refraction metamaterials that will enable new technologies is their predicted ability to amplify evanescent waves. Evanescent wave amplification has been predicted under the ideal condition that the index of refraction, $n = -1 + i\,0$ precisely, but is difficult to observe in practice because current metamaterials suffer from substantial losses. We present experimental results on a metamaterial that employs superconducting Nb metals and low-loss dielectric materials (Michael Ricci, Nathan Orloff, and Steven M. Anlage, "Superconducting Metamaterials," Appl. Phys. Lett. **87**, 034102 (2005)). Results include transmission data on a wire, split-ring resonator, and a combination medium at temperatures between 4.2 K and 297 K. Evidence of negative effective permittivity, permeability, and a negative effective index passband are seen in the superconducting state between 50 MHz and 18 GHz. We find a dielectric loss of $\varepsilon_{eff,\,2} = 2.6 \times 10^{-3}$ in a superconducting wire array at 10.75 GHz.

We also investigate the properties of a single superconducting thin film split-ring resonator (SRR). The experiments were performed in an all-Nb waveguide, with Nb wires and Nb SRRs. Transmission data showed a deep notch for a single Nb SRR ($Q = 4.5\times10^4$ at 4.2 K) below T_c, and no notch for a Cu resonator, and closed Nb loops, of similar dimensions (Michael Ricci, and Steven M. Anlage, "Single Superconducting Split-Ring Resonator Electrodynamics," submitted to Appl. Phys. Lett., http://ArXiv.org/cond-mat/0512515). Adding SRRs increased the bandwidth, but decreased the insertion loss of the notches. Placing the Nb SRR into the array of wires produced a single, elementary negative-index passband ($Q = 2.26\times10^4$ at 4.2 K). Changes in features due to the superconducting kinetic inductance were observed. Models for the SRR permeability, and the wire dielectric response, were used to fit the data.

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