A Review of Active Metamaterials Incorporating Gain Device / Medium

Qi Tang, Adnan Kantemur, and Hao Xin *
Department of Electrical and Computer Engineering, University of Arizona,
Tucson, AZ 85721, USA

In the last one and half decade, metamaterials intrigued many exciting applications, such as cloaking, lens, electrically small antennas, etc., ranging from microwave to optical spectrum. The intrinsic loss and narrow bandwidth associated with existing passive metamaterials are still two main problems preventing many interesting applications from becoming reality. In recent years, the discussions of incorporating active devices or media into conventional passive metamaterial structures have been attracting more and more interests for loss compensation as well as dispersion control both in microwave and optical regime. The added design degree of freedom may enable new and rich physical phenomena and insights may be discovered in active metamaterials.

This work reviews the important theoretical and experimental progress in the whole realm of active, gain-assisted metamaterials in recent years. A study on the causality issues and physical bounds on the relationship between the strong dispersion and loss for passive metamaterials are firstly reviewed. Our recent experimental efforts in transmission-line (T. Jiang, K. Chang, L. Si, L. Ran, and H. Xin, *Phys. Rev. Lett.*, 107, 20, 205503, Nov. 2011) and volumetric metamaterials (D. Ye, K. Chang, L. Ran and H. Xin, *Nature Comm.*, 5, 5841, Dec. 2014) with net gain at the microwave frequencies are presented. Equivalent circuit analysis, simulations and experimental measurements show that traditional metamaterials with microwave active devices embedded exhibits a band-limited negative refraction index with an over-compensated loss (gain). Some recent works of utilizing “non-Foster” active devices to reduce the strong dispersion and obtain broadband metamaterials are also discussed. Finally, some unique and interesting problems associated with active metamaterials, such as the sign determination and stability issues, and potential methods to analyze the stability are discussed.