Utilizing Active Circuit Elements for Dynamic Tuning and Electronic Scanning of CLL-Loaded Dipole Antenna Structure

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Metamaterials have gained considerable research interest within the engineering community for close to two decades. However, a recent push has been made to apply metamaterials to create useful real-world applications. Previous work (Hodge, Anthony, Zaghloul, IEEE AP-S Symposium, 2014) has introduced an antenna enhancing structure consisting of capacitively-loaded loop (CLL) metamaterial elements arranged radially around a conventional dipole antenna at an electrically small distance. As a result of this arrangement, the dipole antenna is easily transformed into a directive, mechanically scanned antenna with high realized gain. The desired directivity and gain can be tuned based on the number of radial CLL "fins" placed around the dipole. Interactions between the antenna and metamaterial elements result in enhancement of the maximum radiated field amplitude and front-to-back ratio of the resulting directive pattern. However, this resonant antenna structure is limited by bandwidth considerations for many real-world applications. The work reported in the above-mentioned reference was compared with the conventional Yagi-Uda array design and showed similar results. This paper seeks to use active circuit elements embedded in the CLLs surrounding the dipole antenna to dynamically change the operating frequency of the antenna or to scan the directive beam electronically. The paper builds on other works that demonstrated tunable nonlinear metamaterials operating at microwave frequencies by utilizing varactor diodes (Shadrivov, et al., Applied Physics Letters, 93(16), 2008). The varactor diodes are embedded into each resonator such that the magnetic resonance is tuned by varying the input power, hence changing the capacitance of each resonator. The paper demonstrates frequency tuning ability using HFSS full-wave simulation by modeling the varactor diodes as small capacitive sheets on each individual CLL. A parametric study is performed to vary the capacitance of the embedded sheets and observe changes in resonant frequency and realized gain of the antenna structure. Simulation results of return loss and realized gain of the antenna structure demonstrate that operating bandwidth can be changed dynamically by actively changing the capacitance of the CLLs.

In addition to demonstrating frequency agility of the CLL-enhanced dipole antenna, this paper also explores techniques to utilize tunable capacitance of the varactor diodes or electronic switches to electronically scan the antenna beam, for which a direction-finding antenna is a potential application. Beam scanning techniques can be performed by altering the capacitance of each CLL, in an addressable manner, to vary the relative phase response of each CLL element. This ability to dynamically scan the operating frequency of the antenna structure and electronically scan the antenna beam are functionalities that are not readily available in the Yagi-Uda antenna design.