Towards Addressable and Reconfigurable Metasurfaces: Utilizing Active and Passive Variants of the Capacitive-Loaded Loop (CLL) Element for the Design of Modulated Metasurface Antennas

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In the push to realize practical real-world applications using metamaterial innovations, a considerable amount of metamaterial research in recent years has focused on the development of metasurfaces (MTSs) due to their subwavelength thickness, planar nature, and reduced dimensionality. MTSs are the 2-D equivalent of traditional 3-D metamaterials and generally function to modify wavefronts arbitrarily using a spatially-varying (modulated) surface distribution of electrically small scatterers. MTSs can be engineered to control electromagnetic waves through modified boundary conditions. The application of modulated MTSs has been generalized into three major areas: aperture antennas, control of surface-wave (SW) wavefronts, and lenses for the control of field transmission (Minatti *et al.*, IEEE AP-S Trans, 2015). One of the main limitations of most MTS designs is that they are inherently narrowband and have a fixed behavior or beam pattern once fabricated. Many practical applications require antennas that are either broader in bandwidth or reconfigurable. To overcome these limitations, this work explores the practicality of embedding active Capacitively-Loaded Loop (CLL) elements into spatially-varying MTSs.

Previous work by this author introduced an antenna enhancing structure consisting of CLL metamaterial elements arranged radially around a conventional dipole antenna at an electrically small distance to create a directive antenna with high realized gain (Hodge, Anthony, Zaghloul, IEEE AP-S Symp, 2014). Also, this author previously presented the concept of using active circuit elements embedded in the CLL-loaded dipole antenna for dynamic frequency tuning and electronic beam scanning (Hodge *et al.*, USNC-URSI Meeting, 2015) as well as using passive CLLs for negative index applications (Hodge *et al.*, USNC-URSI NRSM, 2014).

This paper explores how the CLL element with embedded active circuit elements can be characterized and used as a building blocks to realize active MTSs for modulated SW antennas and advanced wavefront engineering. First, the passive CLL element's surface impedance was characterized using two established methods: a HFSS Eigenmode simulation method and a HFSS driven-mode simulation method for comparison. Once characterized, the CLL element is used to realize and simulate a passive Sinusoidally-Modulated Reactance Surface (SMRS) (Patel and Grbic, IEEE AP-S Trans, 2010) and a Holographic Artificial Impedance Surface (HAIS) (Fong *et al.*, IEEE AP-S Trans, 2010). Next, active CLL elements are characterized for their tunable surface impedance using the same techniques. Finally, the author attempts to implement the same SMRS and HAIS radiating surfaces by electronically tuning the capacitance of the CLL elements rather than modulating the impedance by element size. Electronic tunability and addressing have been demonstrated for similar scattering elements using technologies including varactor diodes, RF-MEMS, ferroelectric thin-films, and liquid crystals. The CLL element demonstrates anisotropic behavior given its non-symmetrical structure, which can be tuned and utilized to design anisotropic MTSs.

This work is a building block towards designing and demonstrating a practical digitally addressable MTS antenna demonstrating tunable, switchable, and reconfigurable functionality. The goal is to provide electronic scanning, frequency agility, and reconfigurable aperture antennas as an alternative to traditional active phased-array antennas. The type of tunable CLL-based MTS technology explored in this work is also relevant to the design of reconfigurable reflectarray antennas. Future work will attempt to fabricate and develop a prototype of CLL-based MTSs demonstrated through simulation in this work to achieve a measured to modeled comparison.