Commutated Multipath Networks: Miniaturized Non-Reciprocal Delay Lines with Broad Bandwidth and Giant Phase Velocity

Mykhailo Tymchenko, Dimitrios Sounas, and Andrea Alù
Department of Electrical and Computer Engineering,
The University of Texas at Austin, Austin, TX 78712, USA

Spatiotemporal modulation is a peculiar type of modulation able to break parity-time (PT) symmetry and, thus, reciprocity, by varying spatial and temporal properties of a system synchronously. Spatiotemporal modulation is a key to achieve magnetic-free non-reciprocal devices, such as isolators, circulators, gyrators, and phase shifters.

In this work, we study a special class of spatiotemporally modulated systems – commutated switched capacitor networks. We show that under specific conditions such networks can operate as nearly ideal broadband reciprocal or non-reciprocal phase shifters, exhibiting little insertion and return loss, and linear phase velocity dispersion. We prove that their phase shift depends solely on the reconfigurable delay between the input and output sets of switches. We show that such networks can replace large inductances and transmission line segments that are usually very challenging to implement on-chip at gigahertz frequencies and below. We rigorously study an infinite cascade of such networks and show that they possess a giant effective refractive index, which is theoretically unbounded. Importantly, commutated networks bear an important advantage over systems employing traveling-wave-like spatiotemporal modulation which requires accurate and coherent control of properties of spatially distinct elements. Instead, in periodic commutated multipath networks spatiotemporal modulation is applied locally to each cell. Additionally, commutated networks employ only two states of switches, ON and OFF, with practically infinite contrast of resistances between the two states, leading to significantly enhanced linearity to the amplitude of the input signal. We also emphasize that commutated networks presented here possess very low group velocity dispersion over extremely wide frequency range, which is a remarkably different behavior from that of conventional waveguides or arrays of coupled resonators which always comprise a trade-off between the group delay and bandwidth.

Using these findings, we also demonstrate a novel topology of a 1GHz 3-port fully integrable circulator which employs commutated networks instead of large inductances to replace quarter-wavelength transmission line segments. A successful realization of such a complex device is a compelling evidence that commutated multipath networks offer unprecedented opportunities for truly miniaturized non-reciprocal electronic components. The results presented here also lay the groundwork for application of the commutated multipath network concept at higher frequencies.