N-Path Network Analysis using the Floquet Scattering Matrix Method

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Recent advances in integrated circuit technology have allowed researchers to explore temporal modulation as a means of achieving non-reciprocity. In this paper, we present a semi-analytical, efficient, and general method for calculating the response of N-path circuit networks. The method exploits several of the unique properties of N-path networks, allowing the simulation time to be independent of the number of paths in the network. In addition, co-simulation results of non-reciprocal devices incorporating N-Path networks (a circulator, an isolator and a gyrator with filtering capabilities) are reported.

Many modern RF and optical systems rely on one or more devices which break time-reversal symmetry. A gyrator is one such non-reciprocal device. The purpose of a gyrator is simply to provide a non-reciprocal (direction dependent) phase shift to an injected signal. They are often utilized in conjunction with resonant circuits to achieve amplitude non-reciprocity, as in the case of an isolator or a circulator.

N-path networks, a class of commutated circuit networks that were first introduced in the 1950s, have begun to play a role in the design of gyrators. Generally, N-path networks consist of a set of identical, linear, time-invariant “internal networks” (paths) connected by a set of commutated switches to the input and output ports. The switches are timed such that, at any given moment, there is exactly one network connected to the input and one network connected to the output. By appropriately commutating an N-path network, several of the harmonics typically present in temporally modulated systems are cancelled at the ports. This characteristic serves to preserve the spectrum of the signal while still achieving the desired non-reciprocal response.

Historically, N-path networks have been characterized using analytical techniques in tandem with commercial solvers. While the analytical technique employed in (N. Reiskarimian and H. Krishnaswamy, Nat. Comms., 7, 11217, 2016) provides an exact expression for the case of first-order internal networks, the procedure is unclear for higher-order circuits. Furthermore, commercial solvers often fail to converge for excitation frequencies close to the commutation/modulation frequency. The reported method avoids the complexity of the analytical procedure by representing the fields as a summation over temporal Floquet harmonics. In addition, a relation between the fields on each path is derived to completely describe the problem in terms of a single path. This simplification dramatically reduces the memory requirements and simulation time for systems with a large number of paths.