Monte Carlo Simulation and Stability Analysis of Non-Foster Matched Electrically-Small Antennas

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Stability is a major factor when synthesizing non-Foster matching circuits for electrically-small antennas, and it becomes more complex when using multiple non-Foster circuits (NFCs) in the system. There has been some debate as to which stability criteria can provide accurate results when determining whether or not a non-Foster circuit will be stable (S. D. Stearns, "Non-foster circuits and stability theory," in 2011 IEEE International Symposium on Antennas and Propagation (APSURSI), Jul. 2011, pp. 1942–1945). Some recent literature suggests the use of the normalized determinant function (NDF) (Q. Tang and H. Xin, "Stability Analysis of Non-Foster Circuit Using Normalized Determinant Function," IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 9, pp. 3269–3277, Sep. 2017) and the pole-zero identification methods (A. Suárez and F. Ramírez, "Stability and Bifurcation Analysis of Multi-Element Non-Foster Networks," IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 4, pp. 1817–1830, Apr. 2018). One of the stability conditions of NFCs is the net reactance of the circuit. It has been shown that NFCs that produce a positive net reactance will be stable, while those that produce a negative net reactance will be unstable (E. Ugarte-Munoz, S. Hrabar, D. Segovia-Vargas, and A. Kiricenko, "Stability of Non-Foster Reactive Elements for Use in Active Metamaterials and Antennas," IEEE Transactions on Antennas and Propagation, vol. 60, no. 7, pp. 3490–3494, Jul. 2012). The tolerance of realistic components impacts the net reactance, and it should be considered when designing NFCs.

To study the effect of component tolerances on NFC stability, the proposed work uses the Monte Carlo analysis in combination with 1) curve fitting methods to locate the poles and zeros of the circuit and 2) the Winslow Stability Probe (WSProbe) provided by Keysight Advanced Design System (ADS) to calculate the NDF. Using modern circuit simulation tools along with computational techniques such as curve fitting can provide circuit designers with a method to rigorously determine the stability of an active circuit. The WSProbe provided by ADS is capable of calculating the NDF of a circuit based on admittance parameters. To validate the NDF calculation and confirm circuit stability, Touchstone files of the simulated circuits can be used for curve fitting to estimate the transfer function and to determine the location of poles of zeros using numerical software (e.g., MATLAB). The discovery of poles in the right-hand plane (RHP) will determine which circuits are unstable. In this work, ADS is used to perform Monte Carlo analysis on an NFC deemed stable by both the NDF and the pole-zero identification, allowing the components in the circuit to be simulated over a set range of tolerance. The stability of the circuits resulting from the Monte Carlo analysis will be analyzed to understand the impact of component tolerances on the stability of non-Foster antennas. More details of the method used and examples will be discussed and demonstrated at the 2023 National Radio Science Meeting.