X-Parameters: the new paradigm for interoperable measurement, modeling, and simulation of nonlinear microwave and RF components

X-parameters are the rigorous supersets of S-parameters that are applicable to linear and nonlinear components alike, and valid under small and large-signal conditions. X-parameters unify linear S-parameters, load-pull (scalar and time-domain) measurements on amplifiers, multi-port nonlinear measurements for frequency translation devices, and advanced calibrated nonlinear waveform measurements in a consistent, rigorous, scalable formalism. X-parameters provide a powerful and eminently practical set of solutions to a wide range of problems and therefore have the potential to revolutionize the characterization, modeling, and design of nonlinear microwave components and systems. X-parameters enable the hierarchical design of chains of nonlinear components under large-signal drive, such as multi-stage power amplifiers, multi-chip RF modules, and RF systems. They can be used to reconstruct the time-domain waveforms (even under very large compression), and estimate nonlinear figures of merit (FOM) such as IP3 and ACPR. With complete IP protection, X-parameters provide the currency of exchange between nonlinear component providers and system integrators, mediating interactions between adjacent levels in the active component hierarchy from the transistor level to RF subsystem. They enable significant design efficiencies by providing high-fidelity accuracy with significant simulation speed-up.

This tutorial presents the basic concepts of X-parameters, how they are measured by a nonlinear vector network analyzer (NVNA), generated from complicated schematics (detailed models) in circuit simulators, and how they can be immediately used by a new component in simulators for nonlinear design. Several representative examples applying X-parameters to real problems are provided, including independent experimental validation, to demonstrate their utility and value as the methodology of choice for nonlinear RF and microwave applications. Recent extensions of X-parameter measurement, modeling, and simulation technology to long- term dynamic memory identification are also presented.

David Root – Biography

Dr. David E. Root is presently Agilent Research Fellow at Agilent Technology's High Frequency Technology Center in Santa Rosa, CA. His current responsibilities include nonlinear behavioral and device modeling, large-signal simulation, and nonlinear measurements for new technical capabilities and business opportunities. An IEEE Fellow since 2002, David was 2006-2008 IEEE MTT-S Distinguished Microwave Lecturer, and won the 2007 IEEE ARFTG Technology Award. David has authored or co-authored about 100 scientific journal articles, conference papers, books, chapters, and workshop papers. He holds BS degrees in physics and mathematics, and a PhD degree in physics, all from MIT.