

Generalized Antenna Scattering Matrix For Simulation of Antenna Systems with Nonlinear and Time-Varying Components

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Typical scattering matrices for antennas only capture the port behavior of an antenna. This is adequate for many applications, but the radiating and scattering behavior of the antenna is lost. The generalized antenna scattering matrix corrects this by describing the coupling between guided waves at the ports and spherical waves in the far field. The generalized antenna scattering matrix is given by

$$\hat{\mathbf{S}} = \begin{bmatrix} \mathbf{\Gamma} & \mathbf{R} \\ \mathbf{T} & \mathbf{S} \end{bmatrix} \begin{bmatrix} v \\ \mathbf{a} \end{bmatrix} = \begin{bmatrix} w \\ \mathbf{b} \end{bmatrix}, \quad (1)$$

where $\hat{\mathbf{S}}$ is the generalized scattering matrix, $\mathbf{\Gamma}$ describes the antenna port behavior, $\mathbf{R}$ describes the antenna receiving behavior, $\mathbf{T}$ describes the antenna transmitting behavior, $\mathbf{S}$ describes the antenna scattering behavior, v and w are incoming and outgoing waves on the antenna ports, respectively, and $\mathbf{a}$ and $\mathbf{b}$ are incoming and outgoing waves on the spherical waveguide ports (J. E. Hansen, *Spherical Near-field Antenna Measurements*, 1988). This reduces the full three-dimensional behavior of an antenna into a single matrix.

Nonlinear and time-varying antennas have been an emerging area of research in recent years. Electrically small antennas have inherent limitations, such as narrow bandwidth. These authors have worked to mitigate these limitations by introducing nonlinear and time-varying components (P. Jayathurathnage, F. Liu, M. S. Mirmoosa, X. Wang, R. Fleury, and S. A. Tretyakov, "Time-Varying Components for Enhancing Wireless Transfer of Power and Information," in *Phys. Rev. Appl.*, vol. 16, no. 1, p. 014017, Jul. 2021). An issue that has arisen is that most electromagnetic simulation software is based on an assumption of linearity and time-invariance, making it incompatible with nonlinear and time-varying devices. Because of this, some authors have worked to develop new simulation techniques specifically for time-varying systems (S. F. Bass, A. M. Palmer, K. R. Schab, K. C. Kerby-Patel and J. E. Ruyle, "Conversion Matrix Method of Moments for Time-Varying Electromagnetic Analysis," in *IEEE TAP*, vol. 70, no. 8, pp. 6763-6774, Aug. 2022). This technique has only been demonstrated using the Method-of-Moments, however. This work will describe a novel simulation technique that utilizes the generalized antenna scattering matrix in order to simulate antenna systems with nonlinear and time-varying components. We will demonstrate that this technique is full-wave solver agnostic and can be used to characterize a wide variety of antenna systems.