A Rational Function Model for Mutual Coupling in Vivaldi Antenna Arrays

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Mutual coupling in an antenna array alters the element pattern and input impedance relative to its position in the array. Both frequency- and time-domain solvers are used to analyze mutual coupling in antenna arrays. Traditionally, however, the properties of the scattering matrix are only calculated in the frequency domain. Frequency domain scattering parameters of microwave devices are measured with vector network analyzers (VNAs) that translate wide-band frequency domain measurement data into a time-domain response with built-in time-domain option. There are many advantages in studying the time-domain waveform such as wide dynamic range and better signal-to-noise ratio; however, transformation between these two domains is generally not straight forward, and in many instances the transformed data exhibits some distortion in the form of ringing, overshoot, and aliasing in the time domain. The fast Fourier transform (FFT) is the workhorse for transforming measurement data between frequency and time domains. The FFT offers faster computational speed, but it limits the resolution of the time-domain response. Several methods have been proposed over the years to improve the resolution and accuracy of the time-domain response obtained from frequency-domain data, such as chirp-Z transform and generalized pencil of function. One of the drawbacks of these methods however is that, they are computationally very expensive; but more importantly these approaches lack accuracy to fully represent the time-domain behaviors of the network. If one can use an analytical formulation, transforming between the domains can be without distortion.

If the scattering parameters of the network can be represented as rational functions, then transforming between the two domains is possible without distortion since a pole-residue representation analytically transforms to the time domain without any distortion. In general the characteristic function of an arbitrary passive network has an infinite number of poles that can be approximated by a finite-order rational function. The resulting system of equations is ill conditioned, but can be solved by normalizing the frequency, using orthogonal polynomials such as Chebyshev instead of ordinary power series, or in more complicated cases, such as the one reported here, by using a global search algorithm. Once these coefficients are determined, the zeros of the denominator polynomial (poles) are found using a polynomial root-finder technique, and the residues are determined using matrix equations. Note that in these microwave networks, the scattering parameters share the same poles, therefore computing the residues for the scattering matrix elements is very robust once the poles of the system are determined. To study the feasibility of this rational function model, we designed a two element Vivaldi antenna array using CST MWS. With a broadside beam, each element is matched with a return loss better than 10 dB from 7.2 to 20 GHz. The mutual coupling magnitude changes from -13 to -35 dB in this frequency range. Experimental results showed that the rational function can easily capture the behavior of this network, and can be used to transform this information to time-domain data without distortion. One challenge here however is that for wideband arrays, accurately determining the order of the pole-residue is not straightforward, and typically has to be done iteratively. Further discussions on the impact of scanning and the change in rational function models of the scattering parameters will be presented at the time of the meeting.