

Investigation of Numerical Techniques for Analyzing Periodic Leaky-Wave Antennas Using Commercial Full-Wave Solvers

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Accurately determining the attenuation and phase constants (α and β) is the most important aspect of any leaky-wave antenna (LWA) design. Specialized methods have been used in the past, which often involve sophisticated analytical approaches that are tailored to a specific type of structure. The objective here is to explore various numerical techniques that can be used together with any general-purpose full-wave solver to accurately obtain the complex wavenumber $\beta - j\alpha$ of the leaky wave on an arbitrary periodic LWA, and to deduce the pros and cons of each technique. The techniques are based on simulating a structure composed of a cascade of N unit cells in the commercial solver and then sampling the field or voltage in each unit cell of the structure. The methods can also be applied to a uniform LWA, in which case the field or voltage is sampled along the structure with an arbitrary period.

Five different numerical techniques are compared: *i*) linear regression method; *ii*) Generalized Pencil of Function (GPOF) method; *iii*) ABCD matrix method; *iv*) de-embedding methods; *v*) extra cell(s) method. These methods are applied on various structures, including microstrip-based planar structures and waveguide-based structures. The methods are validated using a combination of simulation and existing closed-form solutions.

In the linear regression method, an N cell structure is analyzed in the commercial solver, using wave ports at both ends. A field (or voltage) is sampled at periodic intervals in the solver. Taking the natural logarithm of the complex voltages, separating the real and imaginary parts, and then using a linear regression fit of the complex voltages vs. distance along the structure, we directly obtain α and β . The GPOF method uses the same complex voltages as input and directly calculates the complex wavenumbers of the incident and reflected waves on the structure, and in addition it also gives the complex amplitudes of the incident and reflected waves propagating along the structure. In the ABCD matrix method, an N cell structure is analyzed (using wave ports on both ends), and the ABCD matrix of the entire structure is obtained from the S -parameters that are output from the solver. From the ABCD matrix the complex wavenumber is obtained from standard periodic structure theory (though there is a phase ambiguity problem for determining the phase constant β). The de-embedding methods (two variations are given) require the simulation of both a $2M$ cell and an $N = 2M + P$ cell structure to de-embed the ABCD matrices of the two M cell structures on both sides of the $2M + P$ cell structure to obtain the ABCD matrix of the central P cell structure. The method then uses this to calculate α and β of the leaky wave. The extra cell(s) method is similar to the de-embedding methods but uses a “one-sided” de-embedding. It requires the simulation of an N cell structure and a $N + P$ cell structure (or $P + N$ cell structure) to de-embed the N cells to find the ABCD matrix of the P cell structure, where P can be one (a single extra cell), or a larger integer. As in the de-embedding methods, α and β of the leaky wave are found from this ABCD matrix.

The pros and cons of each method are investigated and compared. The relevant points for comparison include: how well the methods converge as the number of cells in the simulated structures increases; the ease by which the values of α and β can be obtained from the simulations; and the sensitivity of the results for α and β with respect to numerical simulation errors in the full-wave solver.