Numerical Analysis of Waveguide-Coupled Microwave Cavities

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The calculation of the eigenmodes in three-dimensional cavities is a standard task within electromagnetic field simulation. For lossless cavities of arbitrary shape, the geometric modelling with finite methods leads to simple or generalized eigenvalue problems of large dimensions which are real-valued and symmetric with real eigenvalues $\lambda = \omega^2$. A number of efficient algebraic solvers are available and well-established in both commercial and laboratory codes.

Any kind of loss mechanism, such as conduction or radiation through open ports of the structure, necessarily corresponds to damped oscillations and complex-valued eigenvalues, and in most cases these losses (and the related parts of the system matrix) additionally depend on frequency. In a mathematically strict sense, this defines a complex, non-linear eigenvalue problem, where the system matrix may be a complicated function of the eigenvalue itself. For small losses, such systems can often be linearized, but it is clear that this approach has its limitations if high-precision results for the eigenfrequency and/or the quality factor (Q) of the modes are required.

We discuss the feasibility of several approaches to handle such lossy eigenvalue problems, and in particular the case of cavities coupled to waveguiding structures. The analyzed methods include modal approaches (R. Schuhmann and T. Weiland, *PRSTAB* **2**, 2000, pp. 1-9), polynomial eigenmode formulations and linearization approaches augmented by fixed-point iterations and (B. Bandlow, *PhD Thesis*, Univ. Paderborn, Germany, 2011), and a novel non-linear solver (B. Bandlow and R. Schuhmann, *SCEE 2014*). As reference solutions, time domain simulations with subsequent, advanced signal processing techniques (C. Claßen et al., *IEEE TAP*, **62**,3, 2014) can find the complex eigenvalues as well as the fields of single eigensolutions is a sufficient way, at least for moderate Q values. Further on, all methods are validated using a simple quasi-1D example with a partially loaded rectangular waveguide where a semi-analytical solution is available.