Using Characteristic Mode Theory to Estimate Air-Substrate Microstrip Patch Antenna Input Impedance

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The input impedance of an antenna is a crucial parameter when designing antenna systems. Although this impedance may be transformed into a desired value by using a matching network, a better solution when possible is to design the antenna itself to present the desired input impedance. For certain types of antennas, this design process is well-researched and fairly straightforward; rectangular microstrip patch antennas are one example. For many other cases, full-wave parametric simulations are the only viable alternative. Here, an alternate analysis technique for these situations is developed to estimate the input impedance of a particular class of antennas.

The theory of characteristic modes is a frequency-domain analysis technique that has recently seen a resurgence of popularity within the field of antenna analysis and design. In its most basic formulation, it provides an orthogonal set of whole-domain basis functions for the current on an arbitrary perfect electrical conductor (PEC) structure. These basis functions have been used to estimate the input impedance of wire and planar PEC antennas with delta-gap sources; here, they are used to develop two related methods for estimating the input impedance of air-substrate (that is, comprised exclusively of PEC), coaxial probe-fed microstrip patch antennas. Both methods, the virtual probe model and the wire probe model, are based on simplifying a coaxial feed probe as an electric current line source. In the virtual probe model, the line source is impressed in free space, whereas the wire probe model adds a wire between the patch and ground plane, which is included in the characteristic mode analysis. A case study of an L-shaped microstrip patch antenna is given, with input impedance estimates compared to the results of a commercial full-wave solver (HFSS) and to experimental measurements. It is shown that both of the developed models provide good input resistance estimates over frequency, but only the wire probe model also provides good estimates of input reactance, since the effects of the feed probe are included. The results of this case study are used to draw important conclusions for the use of characteristic modes in antenna feed analysis. The idea of impedance maps in the context of antenna feed placement design is also applied and briefly discussed.