Present and Future Filter Design Philosophy: Paradigm Shift in Progress

Richard V. Snyder, RS Microwave, Butler, NJ USA
r.snyder@ieee.org

The design of passive filter networks has traditionally been a process in which approximations are made to a desired transfer function using reactive and resistive elements exhibiting the same frequency-dependent functional form. Lumped elements display a reactive variation linearly dependent upon ω. The immitance of single-mode distributed elements depends upon various simple transcendental functions of ω, while the behavior of elements based on sections of evanescent guide depend on more complicated transcendental functions. The various functional forms are chosen to accurately represent the "natural" (actual) behavior of the particular elements, as a function of frequency. Over the years, a variety of synthesis techniques have been developed that allow for extracting sets of such elements from the transmission and reflection functions associated with approximating the desired transfer function when terminated with a specified source and load impedance. Because the rules for disassociating a polynomial by removal of a portion dictate that the remainder polynomial retain the same functional form, it is difficult to perform exact synthesis, using elements with two or more forms of frequency variation, unless non-reciprocal (gyrator or active) elements are included to provide isolation between extracted elements. We know that physically it is not difficult to combine lumped, distributed and evanescent elements in the same network. Optimization allows for insertion of elements with different frequency dependencies, but exact synthesis is generally not possible. In the conventional case, single form synthesis results in a network that requires particular elements (i.e. inductors, capacitors, lengths of line, sections of dispersive waveguide, resistors, mutual couplings, posts, irises, etc.). What is the exact equivalent representation for each of these required elements? For example, what is the equivalent representation of an "inductive" post? The answer is not simple, as the correct representation depends on the structure in which the post is contained, the frequency range, the ratio of diameter to length, and perhaps properties of the materials used for implementation. For accuracy and use in linear circuit simulators, multi-mode equivalent circuits are frequently used to represent even the simplest of elements. As an alternative, it is possible to use E-M analysis software to compute the actual response of the isolated and coupled elements over a particular range of frequencies, assuming it is possible to geometrically represent the particular element in some regular manner. Using this technique in combination with genetic algorithms or more traditional optimization methods, one can readily, albeit slowly, combine elements with the various functional dependencies. Network topologies have evolved and it is possible to synthesize rather optimum non-minimum phase ("quasielliptic") filters, accurately representing the irises or lumped elements used in cross coupling as small subnetworks embedded into the whole. Again, the synthesis limitations (lumped elements, distributed periodic, non-periodic (evanescent) and even active or gyrator types in the same network) can be overcome with E-M analysis, parameter extraction and optimization. Rotation of coupling matrices allows elimination of some couplings, reassignment of input and output terminals, and use of unavoidable couplings in some cases. As filter networks become physically smaller, the interactions between the elements, and the effect of these interactions upon the equivalent circuits, is increasingly important. The grand challenge facing designers today is multivariable synthesis followed by implementation of networks that incorporate accurately characterized elements and interfaces. An example of such success will be filters built as coupled quantum wells, using the cross coupled topology, fabricated using nanotechnology and implemented with a minimum of labor. In this paper, we will review the status of multivariable synthesis, parameter extraction of element equivalent circuits and the use of E-M simulation in conjunction with optimization to implement filters. Perhaps 10 years from now, with 10 GHz machines on every desk, we will be able to design complicated filters using direct solutions of Maxwell's equations, in just a few minutes. Is this where we are going?