Review of SAW Filter Optimization Techniques

Abstract

Problems of optimum and suboptimum synthesis of SAW bandpass filters with prescribed magnitude and phase (group delay) response including linear-, nonlinear-, and minimum-phase filters are considered. Two different approaches to the optimum synthesis problem of linear-phase SAW filters are discussed. In the first one, a SAW filter to be designed consists of two linear phase IDT, with the frequency response of one of them supposed to be given a priori while the other's optimized providing a weighted Chebyshev (minimax) approximation of the desired magnitude response. There are no constraints on magnitude shape imposed which may be symmetrical, non-symmetrical, multi-passband, etc. Statement of the problem for optimum minimax design which provides the best fit to a design target and leads to a minimum length SAW filter under the design constraints is considered. It is shown how to convert an original SAW filter approximation problem into an auxiliary one by the proper modification of a desired magnitude function and a weight function. This auxiliary approximation problem is solvable by means of the standard linear Chebyshev approximation techniques using the linear programming (simplex method) or the Remez exchange algorithm (the McClellan's computer program), for example. Both the element factor and/or multistrip frequency response might be accounted for if necessary.

The major drawback of the optimum design (for example, using the McClellan's program) is long computational time due to a large number of optimized variables for the narrowband SAW filters which is inversely proportional to the fractional bandwidth. It is shown that given a band-limited frequency response, the number of the optimized variables may be considerably reduced by applying the sampling theorem in the frequency or time domain. An efficient and elegant suboptimum synthesis technique based on the same McClellan's computer program is proposed, with the number of optimized variables considerably reduced without significant sacrificing approximation accuracy. This is accomplished by factorizing a priori an optimized function in the Z-transform domain, with the majority of the stopband equidistant closed-form zeros assigned a priori. The storage and the computation time are greatly reduced if compared to the optimum synthesis. The detailed suboptimal synthesis theory and practical design aspects are discussed and illustrated with design examples.

For designing linear phase SAW filter, three different optimization techniques design are considered and compared, namely:

1) Remez exchange algorithm (REA)
2) linear programming (LP)
3) Iterative Weighted Least Mean Squares (IWLMS) algorithm.

It is shown that mathematically they all result in basically the same optimum solutions. However, the computational time and programming effort are different. The IWLS algorithm developed and implemented by the author is very fast and easy for programming, since many numerical packages including MATLAB contain implementation of the Least Squares algorithm.

An alternative approach to SAW filter design is factorizational synthesis. SAW filter design procedure starts from the overall SAW filter response optimized without a priori constraints imposed on the input/output SAW transducers. Optimum or suboptimum techniques may be applied to synthesize the overall SAW filter response. After converting a trigonometric polynomial to the algebraic polynomial using Z-transform, polynomial roots (zeros) are found by applying a high-order polynomial roots solver. Once all the Z-transform roots are found, they are shared in the systematic manner between input and output SAW transducers, the tap weights of each transducer are recovered from the transducer frequency response. In general case, the algorithm results in two apodized SAW transducers and multistrip coupler is required to couple acoustically the input and output of a dual-track SAW filter. In case of the narrowband SAW filters, one of the SAW transducers can be withdrawal-weighted (or polarity weighted) that allow single track in-line SAW filter topology.

An optimization problem for synthesis of SAW filters with prescribed magnitude and phase response is discussed. The design schemes based on the separate optimization of the real and imaginary parts for the complex-valued frequency response are proposed which are faster and more efficient if compared to the non-linear programming (NLP). It is shown that in terms of the approximation accuracy substantially better solutions can be obtained by applying iterative design algorithms where the tolerance filed for the next iteration is dynamically recalculated using the results of the previous iteration. An alternative approach is also discussed which is easier for programming since it uses Chebyshev approximation of the complex-valued function with Euclidean metric. Single time or iterative optimization of the real and imaginary parts is considered. It is shown that contrary to the REA or LP, IWLS can be easily generalized in the complex domain, with the dynamically reiterated weighting function.

All the optimization techniques (REA, LP, NLP, IWLMS) are implemented by the author with MATLAB and the design examples for each optimization technique are presented.

Note: The lecture is followed by the live demonstration of the optimization software of the author implementing in practice the aforementioned SAW filter optimization techniques.

Contents