Mixed Scattering Matrix in SAW Devices Modeling

Abstract

This lecture focuses on the role and practical applications of the mixed scattering matrix (P-matrix) in modeling surface acoustic wave (SAW) devices. Moreover, the model is naturally suited for SAW filter design because its structure and parameters closely correspond to the physical nature of interdigital transducers (IDT). Intrinsically, an IDT has two acoustical and one electrical port, which perfectly match the mixed scattering matrix definition. Furthermore, interrelation between generalized electrical and wave variables at the ports enables conversion to the wave scattering matrix widely used in microwave engineering, as well as to admittance or impedance matrices commonly used in commercial circuit simulators.

Properties of the Mixed Scattering Matrix

First, the lecture discusses general properties of the mixed scattering matrix for a lossless reciprocal SAW transducer. For analysis, the mixed scattering matrix is conveniently separated into acoustic, acousto-electric, electro-acoustic, and electric matrix blocks. Furthemore, the lecture explains physical meanings of each matrix block and its terms. Then, the lecture derives interrelations between matrix blocks and matrix terms from energy conservation and reciprocity.

Mixed Scattering Matrix in SAW Transducer Modeling

Assuming that mixed scattering matrices of SAW components are known either analytically or numerically, the lecture considers several practical modeling applications. For example, the mixed scattering matrix can be applied to SAW filter design in order to simulate electrical source/load effects including accurate triple-transit echo analysis. In addition, the lecture analyzes impedance-connected SAW transducer pairs.

Modeling of Reflective SAW Transducers

The mixed scattering matrix is not limited to component-level modeling of SAW devices. In particular, the lecture shows how to apply it to reflective periodic SAW transducers, where interelectrode reflections caused by the mass-electrical load effect are accurately taken into account. First, the lecture introduces the mixed scattering matrix of the elemental cell, with matrix terms determined either theoretically or experimentally. Then, identical elemental cells are cascaded analytically or numerically over the entire IDT structure, resulting in the overall IDT mixed scattering matrix.

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SPUDT/RSPUDT Modeling using Mixed Scattering Matrix

Finally, assuming known mixed scattering matrices of various SPUDT/RSPUDT elemental cells, the lecture considers modeling. of single-phase unidirectional transducers (SPUDT) and reflective SPUDTs (RSPUDT). In contrast to a conventional bidirectional periodic IDT, where all elemental cells are identical and excited only by the applied electrode voltages, a SPUDT/RSPUDT structure comprises several types of elemental cells with different periodicities and excitation, reflection, and transduction properties.

IDT Mixed Scattering Matrix in the Quasi-Static Approximation

In the quasi-static approximation, the model assumes that a short-circuit SAW transducer is non-reflective. Consequently, this assumption significantly simplifies SAW filter modeling. With negligible interelectrode reflections, the mixed scattering matrix reduces to its simplest closed-form representation. Furthermore, conversion between scattering and transmission matrices in the quasi-static approximation also becomes straightforward.

Modeling of Multiport/Multitransducer SAW Devices

Given mixed and/or wave scattering matrices of SAW components, the lecture considers mixed scattering matrix modeling of multiport/multitransducer SAW devices. In the method, passive two-port SAW components such as reflective gratings are modeled using the degenerate case of the mixed scattering matrix containing only nonzero acoustic matrix blocks. Moreover, the analysis can include arbitrary multiport SAW components such as SAW multistrip couplers (MSC).

Mixed Scattering Matrix CAD Integration

Finally, the lecture demonstrates how the mixed scattering matrix formalism can be applied to modeling complex multicomponent SAW devices using MATLAB® or electronic circuit CAD software. In particular, the author demonstrates simulation using the proprietary SAW Filter Analysis Toolbox (SAWFAT). Furthermore, mixed scattering matrix models of SAW components (IDTs, reflective gratings, etc.) can be integrated into electronic circuit simulators such as Keysight Pathwave Advanced Design System (ADS).

Throughout the lecture, the material is illustrated by design and modeling examples as well as by a live computer demonstration.

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