Mason Equivalent Circuit Model: Theory and Applications

Abstract

The lecture discusses the theory and applications of the Mason equivalent circuit model. First, it considers the general problem of thickness-mode and lateral-field excitations in layered piezoelectric structures. For an arbitrary piezoelectric layer, the lecture introduces model variables, parameters, and material constants. Furthermore, it discusses properties of the three basic layer types: piezoelectric, dielectric, and metallic layers. In particular, a dielectric layer is treated as a degenerate case of a piezoelectric layer without acoustoelectric conversion.

ODE and piezoelectric layer three-port representation

Next, the lecture derives a system of ordinary differential equations (ODE) describing wave propagation in piezoelectric layers for two propagation-mode configurations. Based on this ODE system together with the acoustoelectric analogy, the lecture derives the Mason equivalent circuit (or Mason equivalent scheme). As a result, a piezoelectric layer is represented as a three-port electrical circuit described by a closed-form impedance matrix. Furthermore, the impedance matrix elements are expressed directly in terms of the material parameters.

Mason equivalent circuit implementations

Basically, Mason equivalent circuit consist of the acoustical transmission line excited by the electroacoustic transformer. Furthermore, the lecture considers several Mason equivalent circuit implementations, including one-transformer and two-transformer equivalent circuits, as well as transformerless and distributed Mason models (also known as the Redwood model). Although these equivalent circuits have different topologies, they remain mathematically and physically equivalent. Moreover, the lecture derives all lumped-element parameters in closed form.

BAW resonator analysis

Next, the lecture applies the Mason model to ideal Bulk Acoustic Wave (BAW) resonators containing a piezoelectric layer placed between two electrodes. It is shown that the original Mason equivalent circuit can be simplified near the fundamental resonance or selected higher-order harmonics. Consequently, the model reduces to the Butterworth–Van–Dyke (BVD) equivalent circuit containing a smaller number of RLC–elements and no transformers or dependent sources. Furthermore, the lossless BVD model can be extended to include first-order material losses, resulting in the modified BVD (mBVD) model.

MATLAB and ADS implementations

Furthermore, the lecture discusses MATLAB® implementation of the Mason equivalent circuit model based on the closed-form three-port impedance matrix. Alternatively, the Mason model can be implemented directly in commercial electronic circuit simulators such as Keysight PathWave Advanced Design System (ADS).

The lecture then compares MATLAB and ADS implementations of the Mason model. MATLAB implementation is simple, computationally efficient, and well suited for programming and numerical analysis. In contrast, ADS implementation naturally can account for parasitic effects and it can be easily integrated with external electrical circuits.

Mason model applications and simulation examples

Finally, the lecture illustrates Mason model applications using several simulation examples. In particular, it demonstrates BAW resonator admittance calculation and determination of series and parallel resonance frequencies. Another important application is visualization of acoustic field distributions inside a BAW resonator.

Moreover, the author's companion lectures show how the Mason model can be generalized for modeling and simulation of arbitrary multilayer acoustic stacks.

In summary, the Mason equivalent circuit model complemented with its simplified BVD and mBVD forms provides an effective framework for design, modeling, and simulation of BAW resonators

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