

# FBAR Modeling and Simulation using the Mason Model

## Abstract

This lecture focuses on the application of the Mason equivalent circuit model to the modeling and simulation of Film Bulk Acoustic Wave Resonators (FBARs). In the general case, an FBAR structure may comprise an arbitrary number of piezoelectric and dielectric layers along with two finite-thickness metallic electrodes. The overall FBAR Mason model is obtained by cascading equivalent Mason circuits of individual layers. Once the overall layer-stack Mason model is available, the FBAR impedance can be calculated, and the series and shunt (parallel) resonance frequencies can be determined.

## ***BAW Thickness-Mode Excitation***

First, the lecture considers the theory of thickness-mode Bulk Acoustic Wave (BAW) excitation in a finite-thickness piezoelectric layer. A system of ordinary differential equations (ODEs) describing BAW propagation inside a piezoelectric slab is derived. Furthermore, the lecture introduces model variables, parameters, and material constants for piezoelectric, dielectric, and metallic layers.

## ***Layer Mason Equivalent Circuit Model***

Next, the lecture derives the Mason electrical equivalent circuit based on the ODE system and electroacoustic analogy. As a result, a piezoelectric layer is represented as a three-port electrical circuit comprising an acoustic transmission line, an electroacoustic transformer, and a static capacitance. Furthermore, the lecture shows that it is convenient to describe the Mason equivalent circuit in terms of a  $3 \times 3$  impedance matrix. Moreover, the values of the Mason equivalent circuit components are expressed directly in terms of the layer material parameters.

## ***Mason Equivalent Circuits for Different Layer Types***

Furthermore, the lecture discusses the properties and physical interpretation of Mason equivalent circuit components for different layer types. In particular, a dielectric layer is treated as a degenerate case of a piezoelectric layer with no acousto-electric conversion. Consequently, the Mason equivalent circuit simplifies to an acousto-electric circuit containing only an acoustic transmission line and a static capacitance, with no electroacoustic transformer.

## ***Modeling of FBAR Electrodes***

Next, for simplicity, finite-thickness metallic layers representing FBAR electrodes can be modeled as purely acoustic layers in the form of acoustic transmission lines interfaced with infinitely thin perfect conductors located above or below the acoustic layer. In contrast to a dielectric layer, a purely acoustic layer is a two-port acoustic transmission line and does not contribute to the FBAR static capacitance.

### ***FBAR Layer-Stack Mason Equivalent Circuit Model***

At the next stage, the lecture generalizes the Mason model to arbitrary multilayer stacks by cascading equivalent circuits of individual layers and applying interfacial and terminal boundary conditions. For this purpose, the author introduces a Hybrid Transmission Matrix (HTM) for a layer, which relates acoustic field variables (stress and particle velocity) at the acoustic ports to electrical variables (current and voltage) at the electrical port, both before and after adding the layer to the stack. In addition, the lecture explains the relationship between the Mason impedance matrix and the corresponding HTM representation.

### ***Layer Transmission Matrix Properties***

For convenience, the author decomposes the HTM into acoustic, acousto-electric, electro-acoustic, and electric matrix blocks. The lecture then derives closed-form matrix equations relating the HTM blocks to the corresponding Mason impedance matrix blocks. In addition, the physical meaning of the matrix blocks and terms is explained.

### ***Layer Cascading Algorithm***

The overall HTM of the multilayer stack is obtained recursively by multiplying the HTMs of all constituent layers. Finally, the lecture converts the overall HTM into a three-port impedance matrix describing the FBAR Mason equivalent circuit of the complete layer stack.

### ***Mason Model Implementation***

The Mason model can be implemented either analytically in closed form or as an electrical equivalent circuit with frequency-dependent components. In the general case, the Mason equivalent circuit representation can be readily integrated with external electrical circuits including parasitics. The lecture compares both approaches and discusses their advantages and limitations.

### ***FBAR Impedance Calculation Using the Mason Model***

Furthermore, the lecture derives closed-form equations for multilayer FBAR impedance in terms of the overall stack HTM or Mason impedance matrix. Once the overall HTM or impedance matrix of the layer stack is available, terminal boundary conditions (strain-free external interfaces) are applied to derive a closed-form expression for the FBAR impedance.

### ***MATLAB and ADS Mason Model Implementation***

The lecture discusses FBAR Mason modeling implementation using [MATLAB®](#) as well as [Keysight PathWave Advanced Design System \(ADS\)](#). Furthermore, the advantages and limitations of both simulation platforms are compared.

### ***FBAR Simulation Examples Using the Mason Model***

Finally, the lecture illustrates Mason model applications using practical FBAR simulation examples, including impedance calculation and determination of series and parallel resonance frequencies. The lecture compares MATLAB and ADS simulation approaches.

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