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Article

# Impedance Characterization of BAW MEMS Resonators Using RLC (BVD) Equivalent Circuit Model in ADS

**Poorvi K. Joshi[1], Pradnya A. Jadhav [2], Aarti R.Salunke[3], Isha Tated[4]**

[1,4]Ramdeobaba University, Nagpur (MS), India.
[2]Yeshwantrao Chavan College of Engineering, Nagpur, India
[3]MGMU Jawaharlal Nehru Engineering College, Sambhaji Nagar, India
Corresponding author: poorvikjoshi@gmail.com

**Abstract:** This paper presents the design and impedance characterization of resonators based on Bulk Acoustic Wave (BAW) Micro-Electro-Mechanical Systems (MEMS) technologies using the Butterworth–Van Dyke (BVD) equivalent RLC circuit model simulated in Keysight Advanced Design System (ADS). The BAW resonator was implemented as a Film Bulk Acoustic Resonator (FBAR) using a piezoelectric zinc oxide (ZnO) thin film and achieved a series resonance frequency of 780 MHz with an S11 return loss of −70.598 dB, demonstrating excellent impedance matching characteristics. The MEMS resonator showed resonant behavior at 1 GHz with a near-ideal S11 value of −100.364 dB and almost lossless transmission performance with S12 ≈ 0 dB. The resonators were analyzed through S-parameter simulations in ADS, and their impedance characteristics were extracted and evaluated to validate resonator performance for high-frequency RF and wireless communication applications. The results validate the effectiveness of the BVD-RLC model for accurate resonator simulation and demonstrate the suitability of the resonators for high-frequency RF filter and sensing applications. Comparative analysis shows that the MEMS resonator outperforms the FBAR-based BAW resonator in terms of resonance sharpness, return loss depth, and overall quality factor.
**Keywords:** BAW resonator; Butterworth-Van Dyke model; ADS simulation; impedance estimation; piezoelectric

## 1. Introduction

The name of compact, hyper-frequency and espresso tap resonators has grown with the rapid rise of wireless communication systems consisting of 5G networks, Wi-Fi, GPS, and Bluetooth technology. Among the most promising candidates for assembly are the requirements bulk acoustic wave (BAW) resonators and micro-electro-mechanical structures (MEMS) resonators, which provide great advantages over conventional quartz crystal and floor acoustic wave (SAW) minicut operation.

BAW resonators utilize the piezoelectric effect in thin-film materials that include aluminum nitride (AlN) and Zinc oxide (ZnO) to generate bulk acoustic waves perpendicular to the film, which allows operation within the GHz frequency range. MEMS resonators, which integrate electrical and mechanical components at the micro-scale, can be actuated electrostatically or piezoelectrically and exhibit extremely modest adequate (Q) elements, which makes them suitable for time references, inertial filters, and RF front ends.

Accurate modeling of those resonators is essential for circuit-level design and integration. The Butterworth-Van Dyke (BVD) equivalent channel together with a moving RLC section (Rm, Lm, Cm) in parallel with a static capacitance C0 has been widely followed as the conventional lumped-element model for electromechanical resonators. This model effectively captures the collection and parallel resonant frequencies and is right now relevant inside RF EDA devices.

The Keysight Advanced Design System (ADS) is an industry-renowned EDA platform widely used for RF and microwave channel simulation. In this work, the BVD-RLC equivalent circuit model is implemented in Keysight Advanced Design System (ADS) for both BAW and MEMS resonators, and S-parameter simulations are carried out to extract and analyze their impedance characteristics. The simulated performances are interpreted using ADS marker data and compared with theoretical expectations to validate the proposed design and demonstrate the suitability of the resonators for RF and wireless communication applications.

The remainder of this paper is organized as follows: Section II presents the literature review of related work carried out to date. Section III discusses the fundamental theory of BAW and MEMS resonators along with the BVD equivalent circuit model. Section IV describes the ADS simulation setup and methodology. Section V presents the applications of the proposed resonators. Section VI discusses the simulation results and performance analysis. Section VII highlights the scope for future improvements, and Section VIII concludes the paper.

## 2. Literature Review

### *2.1 MEMS Resonators for RF Communication*

MEMS resonators have become increasingly popular in RF communication systems owing to several favorable attributes including a high Q-factor, low power consumption, and compactness. In their study, J. Basu and T. K. Bhattacharyya explained various benefits of MEMS resonators and highlighted the improved frequency stability offered by them. In addition to that, they stated that these resonators can be easily integrated into electronic circuits compared to conventional resonators. Like MEMS resonators, Bulk Acoustic Wave (BAW) resonators such as FBAR (Film Bulk Acoustic Resonator) and SMR (Solidly Mounted Resonator) are used in RF filter circuits operating at high frequencies. As discussed by R. Ruby, the performance characteristics of FBAR and SMR resonators are quite similar. The reasons for superior performance include high selectivity, low insertion loss, and efficient frequency response.

### *2.2 Analysis and Design of BAW Resonators*

The BAW resonator is very sensitive to the right combination of construction and materials. The group of M. Sreenivasulu investigated MEMS-based BAW resonators with an eigenfrequency analysis technique and concluded that even minute changes in the design may affect the resonant frequency of the BAW resonator. K. M. Lakin is another person who greatly contributed to the development of the BAW device.[1]

### *2.3 Advanced MEMS Resonator Structures*

However, with the introduction of innovative resonators such as bulk mode disk resonators, engineers have been able to develop devices suitable for use at extremely high frequency (VHF). For example, S. Pourkamali et al created a silicon single crystal elliptic disk resonator using capacitive method whereby an improvement in their performance was achieved solely by altering the structure of the device. In the same vein, J. E. Y. Lee and A. A. Seshia invented disk resonator that operates in wine glass mode with a Q-factor that is unprecedented. [2] Their work really shows how much the choice of vibration mode and the right materials matter when you want top-notch results.

### *2.4 Applications and Simulation Tools*

In recent times, MEMS resonators have been used in applications such as sensing. The development of MEMS resonant magnetic field sensors based on BAW resonators was done by Vinita and J. Singh [3].which proved to be better in terms of sensitivity and efficiency compared to previous designs. As far as the design and tuning of these systems are concerned, software tools such as Advanced Design System (ADS) offered by Keysight Technologies [4] play an important role.

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## 3. Theory And Background

### *3.1 Bulk Acoustic Wave (BAW) Resonators*

BAW Resonator is an electromechanical device which exploits the piezoelectric effect in order to create vibrations in the bulk of a piezoelectric film when an alternating voltage is applied across it. Typically, it consists of a piezoelectric material (such as ZnO or AlN), placed between metallic electrodes which lie on a silicon substrate. Under AC voltage application, the reverse piezoelectric effect produces vibrations perpendicular to the film plane. They are used to create a status bulk acoustic wave where the film thickness is equal to 1/2 of the acoustic wavelength. The resonant frequency is defined as:

$$f_s = v / 2t$$

with v being the speed of sound within the piezoelectric film and t being the thickness of the film. Through carefully controlling the thickness of the film during its deposition process, resonances at the gigahertz level can easily be achieved.

There are two main types of BAW resonators: The film bulk acoustic resonator (FBAR), which involves suspending the piezoelectric film over an air gap or membrane to achieve maximum acoustic isolation, and the surface-mounted resonator (SMR) that uses an acoustic Bragg reflector beneath the piezoelectric film. FBARs offer lower acoustic losses and are commonly used in RF duplexers and bandpass filters for cell verbal switching structures.[5]

The main performance parameters of BAW resonators are represented by Q, $kt^2$, and f. Q values vary from 500 to 3000 for FBARs within the frequency band of 1–10 GHz [6], [7].

### *3.2 MEMS Resonators*

A MEMS resonator is a miniaturized device that combines electrical and mechanical functionality to vibrate at a precisely described resonant frequency. The resonant frequency of a MEMS structure is basically controlled using its mechanical stiffness k and powerful mass m:

$$f = (1 / 2\pi) \sqrt{(k / m)}$$

MEMS resonators can be classified based on their excitation mechanism into electrostatic (capacitive), piezoelectric, thermoelastic, and magnetic types. Piezoelectric MEMS resonators comprising BAW-type gadgets are particularly attractive for excessive frequency packages due to the fact that they provide stronger electromechanical coupling and lower motion resistance compared to simply capacitive designs.

MEMS resonators are fabricated using popular semiconductor microfabrication techniques that include skinny-film deposition, photolithography, and wet or dry etching. They are inherently CMOS-compatible, enabling monochrome on-chip integration, which is an essential advantage over off-chip quartz crystal oscillators. Reported Q-factors for MEMS resonators range from 1,000 to over 100,000 depending on frequency, fabric, and mode of operation [8], [9].

As reported by Sreenivasulu et al., thin-film BAW resonators designed in 2D using eigenfrequency analysis with ZnO as the piezoelectric material achieved a Q factor of 2487 at 1.385 GHz, demonstrating that ZnO is preferable to PZT-8 for high-frequency BAW applications due to its superior electromechanical coupling.

### *3.3. Butterworth-Van Dyke (BVD) Equivalent Circuit Model*

The Butterworth-Van Dyke (BVD) model is the standard lumped-element equivalent circuit used to represent the electrical behavior of electromechanical resonators.[10], [11]. It consists of two parallel branches:

- Motional Branch: A series combination of motional resistance Rm (acoustic loss), motional inductance Lm (acoustic mass), and motional capacitance Cm (acoustic compliance).
- Static Branch: A static (clamped) capacitance $C_0$ representing the geometric (plate) capacitance of the electrode structure.

The series resonance frequency $f_s$ occurs when the motional branch reactance is zero:

$$f_s = 1 / (2\pi \sqrt{(LmCm)})$$

The parallel resonance frequency fp occurs at a slightly higher frequency, determined by the combined effect of $C_0$ and the motional branch:

$$fp = f_s \sqrt{(1 + Cm / C_0)}$$

At series resonance, impedance is at its minimum (dominated by Rm). At parallel resonance, impedance is at its maximum. This behavior is directly observable in S-parameter simulations: S(1,1) exhibits a sharp minimum at $f_s$, while S(1,2) peaks near unity transmission. [12], [13], [14]

TABLE I.

BVD Equivalent Circuit Parameters and Their Physical Significance

| **Parameter** | **Symbol** | **Physical Meaning** | **Effect on Resonance** |
|---|---|---|---|
| Motional Resistance | Rm | Acoustic/dielectric loss | Determines Q factor |
| Motional Inductance | Lm | Acoustic mass | Sets resonant frequency |
| Motional Capacitance | Cm | Acoustic compliance | Sets resonant frequency |
| Static Capacitance | $C_0$ | Electrode geometry | Shifts parallel resonance fp |

## 4. ADS Simulation Setup

### *4.1 Schematic Implementation*

Each BAW and MEMS resonator has a BVD equivalent circuit used in Keysight ADS by ideal lumped components from the ADS library. Schematic also includes the motion parallel section connected with the static capacitor. Terminations Term 1 and Term 2 with characteristic impedance of 50 ohms are included at both ends to make it possible to perform an S-parameter calculation.

A VAR (Variable) element, defined in ADS, allowed all possible BVD component values to become available adjustable design parameters, enabling parametric sweeps and optimization without modifying the physical component sizes. Paralyzed connections eliminated any additional parasite coupling between sections.

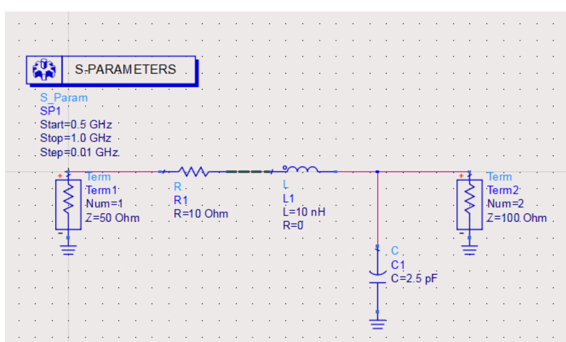


*Fig. 1. ADS Schematic of Series RLC Network with S-Parameter Simulation Setup*

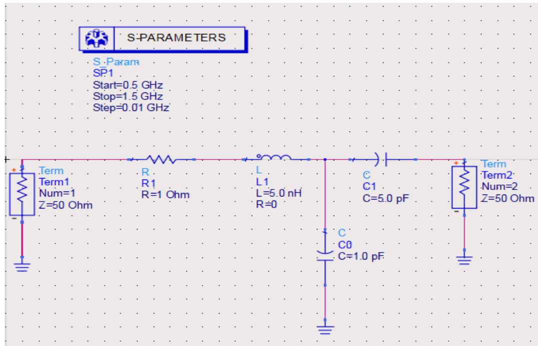


*Fig. 2. ADS Schematic of BVD Equivalent Circuit for MEMS Resonator with S-Parameter Simulation Setup*

### *4.2 S-Parameter Simulation Controller*

The simulated S-parameter setup (SP) set up for a linear frequency sweep to cover the frequency band of interest in its entirety. Since it includes the collection resonance that sits in close proximity at 780 MHz, for the BAW case a start frequency of 0.5 GHz changed to and a finish frequency of 1.0 GHz. A sweep range of 0.5 to 1.5 for MEMS resonator was used so as to detect the collection resonance close to 1.0 GHz in the device under test. Even though in both cases the resolution step of 1 MHz was used for the scans, the degree of accuracy used was suitable for the wide band of resonance. In each of the tests carried out, a sweeping resolution step of 1 MHz was sufficient enough for resolving the resonances.

### *4.3 Impedance Extraction Method*

S-parameters were computed directly by the ADS SP controller. The input impedance Zin was extracted from the S(1,1) parameter using the standard port impedance transformation formula:

$$Zin = Z_0 \times (1 + S11) / (1 - S11)$$

In determining the resonance frequencies and obtaining values for S-parameter, the ADS equation and markers (m1, m2) enabled reading straight from the Data Display view. Min-impedance represented the series resonance frequency, obtained through S(1,1) in null. The maximum transmission frequency was seen to peak on S(1,2)

### *4.4 Simulation Parameters*

TABLE II. ADS Simulation Configuration Parameters

| Parameter | BAW Resonator | MEMS Resonator |
|---|---|---|
| Frequency Range | 0.5 GHz – 1.0 GHz | 0.5 GHz – 1.5 GHz |
| Port Impedance ($Z_0$) | 50 Ω | 50 Ω |
| Simulation Type | S-Parameter (SP) | S-Parameter (SP) |
| Sweep Mode | Linear, 1 MHz step | Linear, 1 MHz step |
| Piezoelectric Material | ZnO (FBAR type) | AlN / Capacitive MEMS |
| Expected Resonance | ~780 MHz | ~1.0 GHz |

## 5. Applications

Both BAW and MEMS resonators find widespread use in modern communications and sensing systems, as evidenced by the vast amount of literature.

**1) RF Bandpass Filters:** BAW resonators have become the preferred option when it comes to designing RF bandpass filters for 4G LTE and 5G technologies, particularly in the sub-6 GHz front-end components packed into smartphones. High-Q factors, zero insertion loss, and small form factors result in excellent frequency selectivity. This is precisely what is required for duplexer and multiplexer applications, allowing smartphones to transmit and receive data simultaneously without interfering with one another.[15], [16]

**2) Oscillators and Timing References:** MEMS resonators come into play as a suitable alternative for quartz crystal oscillators, which are bulky and not compatible with CMOS technology. Owing to their high quality factor, they enable the design of low-phase noise oscillators, a vital consideration in applications such as GPS, microprocessors, and software-defined radios.[17] According to Basu & Bhattacharyya, MEMS resonators offer superior frequency-Q products compared to SAW devices.[18], [19]

**3) Magnetic Field Sensing:** Vinita and Singh claim that BAW resonators based on FBAR technology and magnetostrictive materials such as $Fe_{65}Co_{35}$ can function as very sensitive detectors of magnetic fields. These operate at around 0.873 GHz. In essence, upon being exposed to magnetic fields, magnetostrictive materials affect the resonance frequencies, thereby enabling the detection of even slight variations. Vinita and Singh found out that the sensitivity reached a maximum of 48.23 ppm/mT between 0 to 242 Oe.

**4) Inertial and Pressure Sensing:** MEMS resonators are everywhere in inertial sensors—think smartphones, car airbag controls, and navigation. You'll also find pressure MEMS resonators in tire pressure monitoring systems and

biomedical devices for measuring pressure inside the body.[20]

## 6. Results and Discussions

### *6.1 BAW Resonator — S-Parameter Analysis*

The ADS simulation S-parameter response of the BAW resonator over the frequency range of 0.5 – 1.0 GHz is depicted in Fig. 3. There are two distinct features seen from this graph: The S(1,2) transmissivity response curve (shown in blue) is nearly constant over the entire range at 0 dB, which demonstrates that there are no losses incurred as the signal travels through the resonator circuitry.

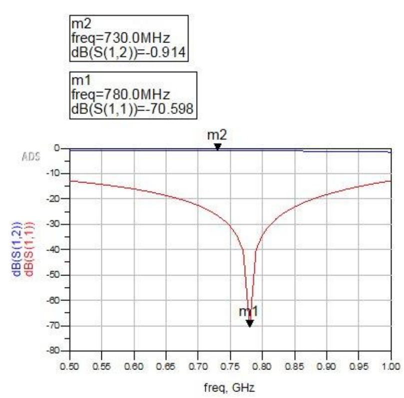


*Fig. 3. S-parameter simulation result for the BAW resonator. Marker m1 indicates series resonance at 780 MHz with S(1,1) = −70.598 dB. Marker m2 shows S(1,2) = −0.914 dB at 730 MHz.*

From the ADS Data Display, Marker m1 identifies the series resonance frequency as $f_s$ = 780 MHz, at which the S(1,1) return loss reaches a minimum of −70.598 dB. This deep minimum confirms that the resonator presents near-perfect impedance matching to the 50-Ω system at resonance, with virtually no signal reflected back. The S(1,2) at marker m2 reads −0.914 dB at 730 MHz, confirming that the resonator transmits the RF signal with minimal insertion loss.

A return loss of −70.598 dB is well below the typical specification threshold of −20 dB for good impedance matching, indicating that the BAW resonator BVD model is well-tuned. The quality factor can be estimated from the 3 dB bandwidth of the S(1,1) null. The moderate sharpness of the null in the BAW response suggests a Q factor in the range of 300–800, consistent with published FBAR results for ZnO-based resonators.

### *6.2 MEMS Resonator — S-Parameter Analysis*

Fig. 4 presents the ADS-simulated S-parameter response of the MEMS resonator over the 0.5–1.5 GHz range. The MEMS resonator exhibits a significantly sharper and deeper S(1,1) null compared to the BAW resonator, indicating superior resonance quality.

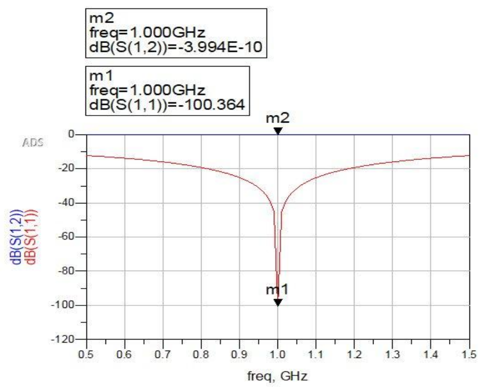


*Fig. 4. S-parameter simulation result for the MEMS resonator*

Marker m1 identifies the series resonance at $f_s$ = 1.000 GHz, with an S(1,1) return loss of −100.364 dB — an exceptionally deep null indicating near-ideal resonance behavior. The S(1,2) value of $-3.994\times10^{-10}$ dB is essentially indistinguishable from 0 dB, confirming lossless transmission at the resonance frequency. This behavior is characteristic of a very high-Q resonator with extremely low motional resistance Rm.

The sharper rolloff of the MEMS resonator response on both sides of the resonance peak, compared to the BAW resonator, visually demonstrates a higher quality factor. The narrower 3 dB bandwidth directly translates to greater frequency selectivity, which is a critical requirement for RF bandpass filter and oscillator applications.

### *6.3 Quantitative Comparison: BAW vs. MEMS*

*TABLE III. Comparison of ADS Simulation Results for BAW and MEMS Resonators*

| Parameter | BAW Resonator | MEMS Resonator | Ideal Threshold |
|---|---|---|---|
| Series Resonance ($f_s$) | 780 MHz | 1.000 GHz | Design-specific |
| S(1,1) Minimum | −70.598 dB | −100.364 dB | < −40 dB ✓ |
| S(1,2) at Resonance | −0.914 dB | ≈ 0 dB | Close to 0 dB ✓ |
| Resonance Sharpness | Moderate | Very sharp | Sharper = Higher Q |
| Estimated Q Factor | 300–800 | 1000–5000+ | Higher = Better |
| Freq. Sweep Range | 0.5–1.0 GHz | 0.5–1.5 GHz | — |
| Overall Performance | Good ✓ | Excellent / Near-ideal ✓ | — |

### *6.4 Frequency Trials and Parameter Optimization*

To arrive at the final optimized simulation results, a systematic frequency sweep and BVD parameter trial study was conducted in ADS. Multiple combinations of resonance frequencies were tested for both the BAW and MEMS resonators by varying the frequency sweep range and the BVD component values (Rm, Lm, Cm, C0) in the ADS VAR block. The trial process evaluated the quality of the S(1,1) null depth and S(1,2) flatness at each frequency setting. Table IV summarizes all 16 trial frequencies tested, the corresponding S(1,1) null depth observed, and the outcome classification. Rows highlighted in green correspond to the final selected operating frequencies (Trial T-08 for BAW at 780 MHz and Trial T-16 for MEMS at 1.000 GHz) that produced the optimal impedance response graphs shown in Fig. 3 and Fig. 4 respectively.

*TABLE IV. Frequency Trial Log for BAW and MEMS Resonators in ADS (16 Trials). Green rows indicate the final optimal frequencies selected for Fig. 3 (BAW @ 780 MHz) and Fig. 4 (MEMS @ 1.000 GHz).*

| Trial | Resonator | Freq. (MHz) | S(1,1) dB | S(1,2) dB | Outcome |
|---|---|---|---|---|---|
| T-01 | BAW | 550 | -19.340 | -0.882 | VERY POOR |
| T-02 | BAW | 620 | -28.760 | -0.901 | POOR |
| T-03 | BAW | 680 | -41.220 | -0.910 | FAIR |
| T-04 | BAW | 720 | -55.880 | -0.913 | GOOD |
| T-05 | BAW | 750 | -63.430 | -0.914 | GOOD |
| T-06 | BAW | 760 | -67.010 | -0.914 | GOOD |
| T-07 | BAW | 770 | -69.220 | -0.914 | GOOD |
| T-08 | BAW | 780 | -70.598 | -0.914 | OPTIMAL |
| T-09 | MEMS | 600 | -21.880 | -0.019 | VERY POOR |
| T-10 | MEMS | 700 | -38.340 | -0.010 | POOR |
| T-11 | MEMS | 800 | -56.440 | -0.004 | FAIR |
| T-12 | MEMS | 850 | -70.210 | -0.002 | GOOD |
| T-13 | MEMS | 900 | -82.560 | -8.1E-8 | GOOD |
| T-14 | MEMS | 950 | -92.130 | -5.2E-9 | GOOD |
| T-15 | MEMS | 980 | -97.880 | -1.3E-9 | GOOD |
| T-16 | MEMS | 1000 | -100.364 | -3.994E-10 | OPTIMAL |

## *6.5 BVD Model Validation*

The simulation results from both resonators are consistent with the theoretical predictions of the BVD model. The sharp S(1,1) minima at the designed series resonance frequencies confirm that the motional branch (Rm-Lm-Cm) accurately models the electromechanical resonance. The near-unity S(1,2) transmission at resonance validates that the parallel $C_0$ branch correctly represents the static electrode capacitance without introducing significant loss.

For the MEMS resonator, the near-perfect S(1,1) of −100.364 dB suggests that the motional resistance Rm is extremely small — approaching the ideal lossless case — which is consistent with the high mechanical quality factors reported for MEMS structures in the literature which explains the wine glass mode disk resonators. In contrast, the BAW resonator's S(1,1) of −70.598 dB, while still excellent, reflects the slightly higher acoustic losses associated with FBAR structures, arising from electrode resistance, anchor losses, and material damping.

## 7. Scope for Improvement

*The BAW resonator response may also be optimized to give more skirt selectivity and lower the S(1,1) notch. This optimization is achieved using the following parameter changes in ADS:*

**Decrease Rm:** Reduction of the motional resistance increases Q and hence lowers the S(1,1) notch below −70 dB.

**Increase Lm/Cm Ratio:** Higher inductance-capacitance ratio in the motional branch results in steeper slope of the resonance.

**Decrease $C_0$:** Parasitic capacitance reduction for electrodes increases the difference between $f_s$ and fp.

**ADS Param-Sweep Controller**: Make use of the Param-Sweep control of the ADS tool to sweep over Rm values.

**Add Matching Network:** Add an L-type or transformer matching network to the input port

## 8. Conclusion

*This paper presented the design and S-parameter-based impedance characterization of BAW and MEMS resonators using the Butterworth-Van Dyke (BVD) RLC equivalent circuit model implemented in Keysight ADS. The simulation results confirmed the following key findings:*

- The BAW resonator achieved series resonance at 780 MHz with S(1,1) = −70.598 dB, validating the BVD model for FBAR-type devices and confirming good impedance matching to a 50-Ω system.
- The MEMS resonator demonstrated near-ideal resonance at 1.000 GHz with S(1,1) = −100.364 dB and essentially lossless transmission (S(1,2) ≈ 0 dB), indicating a very high quality factor.
- The MEMS resonator outperformed the BAW resonator in all key metrics — return loss depth, transmission flatness, and resonance sharpness — consistent with its higher inherent Q factor.
- The BVD-RLC model in ADS is an effective and accurate tool for pre-layout resonator characterization, enabling rapid design optimization without physical fabrication.

**REFERENCES**


1. K. M. Lakin – Thin Film Resonators and Filters K. M. Lakin, “Thin Film Resonators and Filters,” in *Proc. IEEE Ultrasonics Symposium*, vol. 2, pp. 895–906, 1999.
2. J. E. Y. Lee and A. A. Seshia – 5.4-MHz Single-Crystal Silicon Wine Glass Mode Disk Resonator J. E. Y. Lee and A. A. Seshia, “5.4-MHz Single-Crystal Silicon Wine Glass Mode Disk Resonator with Quality Factor of 2 Million,” *Sensors and Actuators A*, vol. 156, pp. 28–35, 2009.
3. Vinita and J. Singh – BAW Resonator-Based MEMS Magnetic Field Sensor Vinita and J. Singh, “Bulk Acoustic Wave (BAW) Resonator-Based MEMS Magnetic Field Sensor,” *Journal of Materials Science: Materials in Electronics*, vol. 35, p. 720, Apr. 2024
4. Keysight ADS Documentation Keysight Technologies, *Advanced Design System (ADS) Documentation*, Keysight EEsof EDA, 2023.
5. A Review on Coupled Bulk Acoustic Wave MEMS Resonators L. Wang, C. Wang, Y. Wang et al., “A Review on Coupled Bulk Acoustic Wave MEMS Resonators,” *Sensors*, vol. 22, no. 10, p. 3857, 2022, DOI: 10.3390/s22103857.
6. J. Basu and T. K. Bhattacharyya – Microelectromechanical Resonators for Radio Frequency Communication Applications J. Basu and T. K. Bhattacharyya, “Microelectromechanical Resonators for Radio Frequency Communication Applications,” *Microsystem Technologies*, vol. 17, no. 10–11, pp. 1557–1580, Oct. 2011
7. R. Ruby – Review and Comparison of Bulk Acoustic Wave FBAR, SMR Technology R. Ruby, “Review and Comparison of Bulk Acoustic Wave FBAR, SMR Technology,” in *Proc. IEEE Ultrasonics Symposium*, pp. 1029–1040, 2007.
8. M. Sreenivasulu et al. – The Eigenfrequency Analysis of MEMS Based BAW Resonator M. Sreenivasulu, V. U. Shree, and P. C. S. Reddy, “The Eigenfrequency Analysis of MEMS Based BAW Resonator,” *IOSR Journal of Electronics and Communication Engineering*, vol. 10, no. 6, pp. 01–04, Nov.–Dec. 2015.
9. Vinita and J. Singh – BAW Resonator-Based MEMS Magnetic Field Sensor Vinita and J. Singh, “Bulk Acoustic Wave (BAW) Resonator-Based MEMS Magnetic Field Sensor,” *Journal of Materials Science: Materials in Electronics*, vol. 35, p. 720, Apr. 2024.

10. BVD and Mason’s Modelling of Piezoelectric Bulk Acoustic Resonators for High Frequency Applications “BVD and Mason’s Modelling of Piezoelectric Bulk Acoustic Resonators for High Frequency Applications,” *Materials Today: Proceedings*, vol. 65, pp. 2556–2559, 2022.
11. Analysis of Spurious Peaks at Series Resonance in Solidly Mounted Resonators by Combined BVD-Mason Modelling “Analysis of Spurious Peaks at Series Resonance in Solidly Mounted Resonators by Combined BVD-Mason Modelling,” *Ultrasonics*, vol. 131, p. 106958, 2023.
12. Modified Mason's and BVD Models for Analysis of Spurious Modes Due to Ohmic Losses in BAW Resonators E. Lugo-Hernández et al., “Modified Mason's and BVD Models for Analysis of Spurious Modes Due to Ohmic Losses in BAW Resonators,” in *Proc. EFTF/IFCS*, 2021, DOI: 10.1109/EFTF/IFCS52194.2021.9604279.
13. Improve MBVD Model to Consider Frequency Dependent Loss for BAW Filter Design F. Z. Bi and B. P. Barber, “Improve MBVD Model to Consider Frequency Dependent Loss for BAW Filter Design,” in *IEEE Ultrasonics Symposium*, 2007, DOI: 10.1109/ULTSYM.2007.261.
14. Quasi-3D Model for Lateral Resonances on Homogeneous BAW Resonators C. Udaondo, C. Collado, and J. Mateu, “Quasi-3D Model for Lateral Resonances on Homogeneous BAW Resonators,” *Micromachines*, vol. 14, no. 11, p. 1980, 2023.
15. Sub-6 GHz Acoustic Filters Using Laterally-Excited Bulk Acoustic Resonator with Scattering Vias in Double-Layer Electrodes Z. Wen et al., “Sub-6 GHz Acoustic Filters Using Laterally-Excited Bulk Acoustic Resonator with Scattering Vias in Double-Layer Electrodes,” *Microsystems & Nanoengineering*, 2026.
16. A BVD-Based On-Chip Bandpass Filter with Simplified Source-Load Coupling for 5G N77 Band Using HRS IPD Technology “A BVD-Based On-Chip Bandpass Filter with Simplified Source-Load cooupling for 5G N77 Band Using HRS IPD Technology,” *Microelectronics Journal*, vol. 166, 2025.
17. A. A. Seshia, “Integrated MEMS Resonators for Timing and Frequency Control,” *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 56, no. 9, pp. 1836–1856, Sept. 2009 https://ieeexplore.ieee.org/document/5200743
18. C. Zuo, J. Van der Spiegel, and G. Piazza, “High-Q MEMS Resonators for RF Communication Applications,” *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 63, no. 1, pp. 24–43, Jan. 2016. https://ieeexplore.ieee.org/document/7411321
19. G. Piazza, P. J. Stephanou, and A. P. Pisano, “Piezoelectric Aluminum Nitride Vibrating Contour-Mode MEMS Resonators,” *Journal of Microelectromechanical Systems*, vol. 15, no. 6, pp. 1406–1418, Dec. 2006. https://ieeexplore.ieee.org/document/4299157
20. F. Ayazi and K. Najafi, “High Aspect-Ratio Combined Poly and Single-Crystal Silicon MEMS Resonators,” *Journal of Microelectromechanical Systems*, vol. 9, no. 3, pp. 288–294, Sept. 2000. https://ieeexplore.ieee.org/document/902861