Normal Modes of a Biased Resonator—2D

Introduction

Silicon micromechanical resonators have long been used for designing sensors and are now becoming increasingly important as oscillators in the consumer electronics market. In this sequence of models, a surface micromachined MEMS resonator, designed as part of a micromechanical filter, is analyzed in detail. The resonator is based on that developed in Ref. 1.

This model performs a modal analysis on the resonator, with and without an applied DC bias. The analysis begins from the stationary analysis performed in the accompanying model Stationary Analysis of a Biased Resonator—2D; please review this model first.

Model Definition

The geometry, fabrication, and operation of the device are discussed for the "Stationary Analysis of a Biased Resonator" model.

This model performs a modal analysis on the structure, with and without applied DC voltage biases of different magnitudes. The bias already exists as a parameter in the model so the prestressed eigenfrequency solver needs no adjustment to the physics settings. To compute the unbiased eigenfrequency, the solver settings are adjusted to solve only the structural mechanics problem.

Results and Discussion

Figure 1 shows the mode shapes for the resonator under different bias conditions.

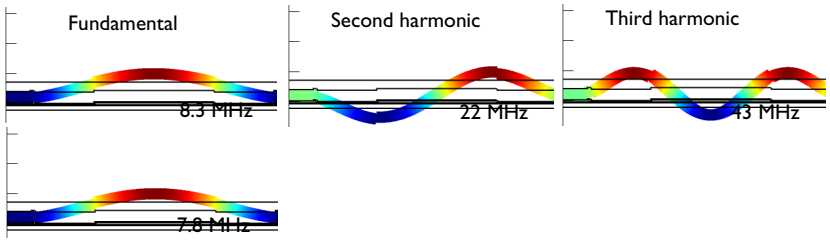

Figure 1: Mode *shapes for the resonator under different bias conditions (top line: 0 V; bottom line: 45 V). The mode frequencies are indicated in the figure. The colors visualize the relative y-displacement magnitude.*

The mode shape does not change significantly with applied bias and the first three modes have the expected shapes for a clamped-clamped beam. The frequency of the fundamental is reduced significantly by the applied bias, an effect known as spring softening (the response of higher-order modes was not computed as a function of applied bias).

The spring softening effect can be seen in detail in Figure 2. A clear decrease in the resonant frequency is evident with increasing bias voltage. This figure should be compared with Figure 16 of Ref. 1, where the same effect is apparent. The agreement with Ref. 1 is reasonable.

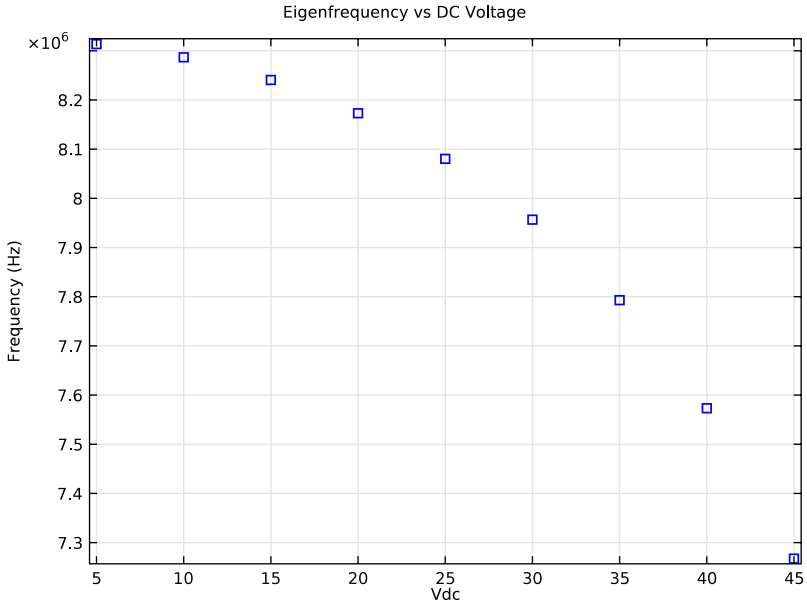

Figure 2: Mode frequency shown against the applied DC voltage bias. The spring softening effect is evident. Compare with Fig. 16 of Ref. 1.

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Notes About the COMSOL Implementation

This model excludes certain dependent variables from the solver settings in order to compute the unbiased eigenfrequency. By not computing for the electric potential or the displacement of the air domains, the model is equivalent to a pure solid mechanics problem, solved in the absence of external forces. Excluding dependent variables in the solver in this manner can be useful for debugging models as well as for computing uncoupled problems in this manner.

Reference

1. F.D. Bannon III, J.R. Clark, and C. T.-C. Nguyen, "High-Q HF Microelectromechanical Filters", *IEEE Journal of Solid State Circuits*, vol. 35, no. 4, pp. 512–526, 2000.

Model Library path: `MEMS_Module/Actuators/biased_resonator_2d_modes`

Modeling Instructions

Open the existing stationary study (filename: biased_resonator_2d_basic.mph).

1 From the **View** menu, choose **Model Library**.

2 Go to the **Model Library** window.

3 In the **Model Library** tree, select **MEMS Module>Actuators>biased resonator 2d basic**.

4 Click **Open**.

ROOT

Add an unbiased eigenfrequency study. The settings for this study need to be modified so that only the structural part of the problem is solved.

1 In the **Model Builder** window, right-click the root node and choose **Add Study**.

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Find the **Studies** subsection. In the tree, select **Custom Studies>Eigenfrequency**.

3 Click **Finish**.

STUDY 2

Step 1: Eigenfrequency

1 In the **Model Builder** window, under **Study 2** click **Step 1: Eigenfrequency**.

2 In the **Eigenfrequency** settings window, locate the **Study Settings** section.

3 In the **Desired number of eigenfrequencies** edit field, type `3`.

Set up the solver to solve only for the solid mechanics variables.

Solver 2

1 In the **Model Builder** window, right-click **Study 2** and choose **Show Default Solver**.

2 In the **Model Builder** window, expand the **Solver 2** node, then click **Dependent Variables 1**.

3 In the **Dependent Variables** settings window, locate the **General** section.

4 From the **Defined by study step** list, choose **User defined**.

5 In the **Model Builder** window, expand the **Study 2>Solver Configurations>Solver 2>Dependent Variables 1** node, then click **Electric potential (mod1.V)**.

6 In the **Field** settings window, locate the **General** section.

7 Clear the **Solve for this field** check box.

8 Clear the **Store in output** check box.

9 In the **Model Builder** window, under **Study 2>Solver Configurations>Solver 2>Dependent Variables 1** click **mod1.xy**.

10 In the **Field** settings window, locate the **General** section.

11 Clear the **Solve for this field** check box.

12 Clear the **Store in output** check box.

13 In the **Model Builder** window, right-click **Study 2** and choose **Rename**.

14 Go to the **Rename Study** dialog box and type `Unbiased Eigenfrequency` in the **New name** edit field.

15 Click **OK**.

Correct study name in preceding text if necessary

16 In the **Study** settings window, locate the **Study Settings** section.

17 Clear the **Generate default plots** check box.

18 Click the **Compute** button.

Set the data set to be in the material frame for post-processing. This allows the use of the deformation sub-feature.

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RESULTS

Data Sets

1 In the **Model Builder** window, expand the **Results>Data Sets** node, then click **Solution 2**.

2 In the **Solution** settings window, locate the **Solution** section.

3 From the **Frame** list, choose **Material (X, Y, Z)**.

Plot the mode shapes.

2D Plot Group 4

1 In the **Model Builder** window, right-click **Results** and choose **2D Plot Group**.

2 In the **2D Plot Group** settings window, locate the **Data** section.

3 From the **Data set** list, choose **Solution 2**.

4 Right-click **Results>2D Plot Group 4** and choose **Rename**.

5 Go to the **Rename 2D Plot Group** dialog box and type `Unbiased Modes` in the **New name** edit field.

6 Click **OK**.

Unbiased Modes

1 Right-click **Results>2D Plot Group 4** and choose **Surface**.

2 In the **Surface** settings window, locate the **Expression** section.

3 In the **Expression** edit field, type `v`.

4 Right-click **Results>Unbiased Modes>Surface 1** and choose **Deformation**.

5 In the **Deformation** settings window, locate the **Expression** section.

6 In the **X component** edit field, type `u`.

7 In the **Y component** edit field, type `v`.

8 Click the **Plot** button.

Create a view to visualize the modes.

DEFINITIONS

In the **Model Builder** window, expand the **Model 1** node.

View 3

1 Right-click **Definitions** and choose **View**.

2 In the **View** settings window, locate the **View** section.

3 Select the **Lock axis** check box.

Axis

1 In the **Model Builder** window, expand the **View 3** node, then click **Axis**.

2 In the **Axis** settings window, locate the **Axis** section.

3 In the **x minimum** edit field, type `-25`.

4 In the **x maximum** edit field, type `25`.

RESULTS

Unbiased Modes

Compare the mode shapes with those shown in Figure 1 for all the modes computed. To switch between the modes click **Unbiased Modes** and choose a different value from the **Eigenfrequency** list.

Add a prestressed eigenfrequency study.

ROOT

In the **Model Builder** window, right-click the root node and choose **Add Study**.

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Find the **Studies** subsection. In the tree, select **Preset Studies>Prestressed Analysis, Eigenfrequency**.

3 Click **Finish**.

STUDY 3

Step 1: Stationary

1 In the **Model Builder** window, right-click **Study 3** and choose **Rename**.

2 Go to the **Rename Study** dialog box and type `Biased Eigenfrequency` in the **New name** edit field.

3 Click **OK**.

Create a parametric sweep over DC bias voltage.

4 Right-click **Study 3** and choose **Parametric Sweep**.

BIASED EIGENFREQUENCY

Parametric Sweep

1 In the **Parametric Sweep** settings window, locate the **Study Settings** section.

2 Click **Add**.

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3 In the table, enter the following settings:

Parameter names
Vdc

4 Click **Range**.

5 Go to the **Range** dialog box.

6 In the **Start** edit field, type 5.

7 In the **Stop** edit field, type 45.

8 In the **Step** edit field, type 5.

9 Click the **Add** button.

Solve for only the first eigenfrequency.

Step 2: Eigenfrequency

1 In the **Model Builder** window, under **Biased Eigenfrequency** click **Step 2: Eigenfrequency**.

2 In the **Eigenfrequency** settings window, locate the **Study Settings** section.

3 In the **Desired number of eigenfrequencies** edit field, type 1.

Disable the default plots.

4 In the **Model Builder** window, click **Biased Eigenfrequency**.

5 In the **Study** settings window, locate the **Study Settings** section.

6 Clear the **Generate default plots** check box.

7 Click the **Compute** button.

RESULTS

Data Sets

1 In the **Model Builder** window, expand the **Results>Data Sets** node, then click **Solution 5**.

2 In the **Solution** settings window, locate the **Solution** section.

3 From the **Frame** list, choose **Material (X, Y, Z)**.

Create a plot of the biased mode shape.

Unbiased Modes 1

1 In the **Model Builder** window, under **Results** right-click **Unbiased Modes** and choose **Duplicate**.

2 Right-click **Unbiased Modes 1** and choose **Rename**.

3 Go to the **Rename 2D Plot Group** dialog box and type `Biased Modes` in the **New name** edit field.

4 Click **OK**.

5 In the **2D Plot Group** settings window, locate the **Data** section.

6 From the **Data set** list, choose **Solution 5**.

7 Click the **Plot** button.

Confirm the mode shape is similar to the unbiased fundamental mode.

Create a plot of eigenfrequency vs. applied DC voltage.

1D Plot Group 6

1 In the **Model Builder** window, right-click **Results** and choose **1D Plot Group**.

2 In the **1D Plot Group** settings window, locate the **Data** section.

3 From the **Data set** list, choose **Solution 5**.

4 Right-click **Results>1D Plot Group 6** and choose **Point Graph**.

5 Select Point 1 only.

6 In the **Point Graph** settings window, locate the **y-Axis Data** section.

7 In the **Expression** edit field, type `emi.freq`.

8 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **Outer solutions**.

9 Click to expand the **Title** section. From the **Title type** list, choose **Custom**.

10 Find the **Type and data** subsection. Clear the **Type** check box.

11 Clear the **Description** check box.

12 Clear the **Unit** check box.

13 Find the **User** subsection. In the **Prefix** edit field, type `Eigenfrequency vs DC Voltage`.

14 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.

15 Find the **Line markers** subsection. From the **Marker** list, choose **Square**.

16 From the **Positioning** list, choose **In data points**.

17 In the **Model Builder** window, right-click **1D Plot Group 6** and choose **Rename**.

18 Go to the **Rename 1D Plot Group** dialog box and type `Eigenfrequency vs DC Voltage` in the **New name** edit field.

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19 Click **OK**.

Compare this plot with that in Figure 2. Note the spring softening effect.

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