PROBLEM SET #6

Issued: Thursday, April 13, 2017

Due: Thursday, April 27, 2017, 10:00 a.m. in the EE C247B homework box near 125 Cory.

The figure below presents the top view of a micromechanical device constructed in a 2μm-thick structural layer with numerous ports. Here, everything is suspended 2μm above the substrate except for the anchoring locations indicated as the darkly shaded regions. Data on the structural material used in this problem and on specific geometric dimensions are given in the box below the figure. Also, assume that all folding trusses and shuttles are rigid in all directions, including the vertical (i.e., z) direction. In addition, all suspension beam widths are 2μm. As usual, the mechanical structure is electrically connected to the ground plane, since it is anchored to it.

Note that some of the electrode terminals have the same number, e.g., "3". Assume that all terminals bearing the same number are electrically connected.

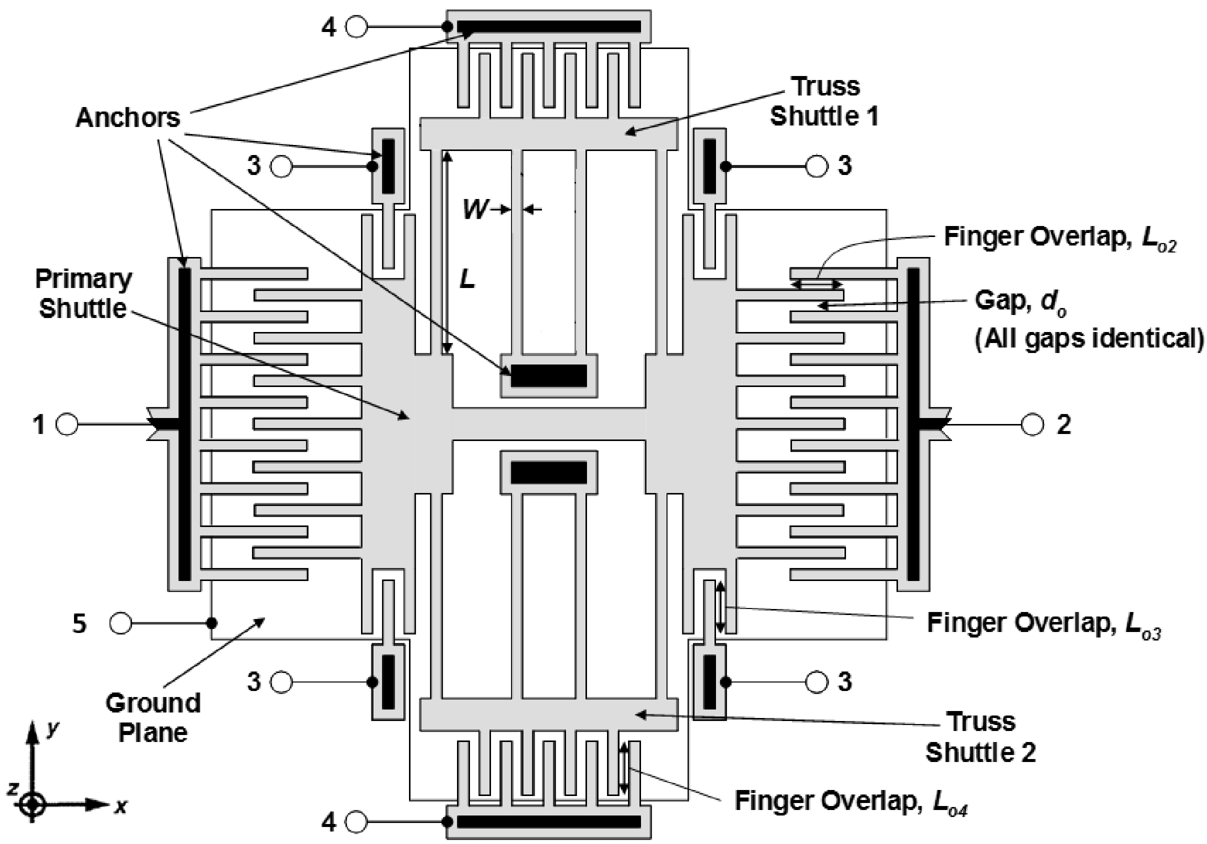

Fig. PS6.1

Structural Material Properties:
Young's Modulus, E = 150 GPa; Density, ρ = 2,300 kg/m^3
Poisson ratio, ν = 0.226; Q = 100,000
Geometric Dimensions:
L = 50μm; W = 2μm; Thickness, h = 2μm; All Finger Gaps, d_o = 1 μm
All Finger Overlaps, L_o= 10 μm, Truss Shuttle 1 Area = 300 μm^2
Truss Shuttle 2 Area = 300 μm^2, Primary Shuttle Area = 4,000 μm^2

Answer the following questions concerning this structure.

(a) Calculate the x-directed resonance frequency of this structure when all ports are grounded.

(b) Calculate the x-directed resonance frequency of this structure when ports 1, 2, and 4, are grounded, and all other ports are biased to 50V.

(c) Draw a transformer-based equivalent circuit modeling the electrical behavior of this device seen between ports 1 and 2 with all other ports held at 50V. Write expressions for all of its elements and calculate their numerical values.

(d) Draw a transformer-based equivalent circuit modeling the small-signal resonance electrical behavior of this device seen between ports 1 and 3 with all other ports held at 50V. Give numerical values for the electromechanical coupling factors, i.e., the transformer turns ratios. Ignore off-resonance signals.

(e) With all ports except 1 and 2 dc-biased to 50V, suppose you drive port 1 with an ac voltage v_i and detect the output voltage v_o across a capacitor C_D = 0.05fF shunted to ground at port 2, as shown in the figure below. Draw a plot of $|v_o(s)/v_i(s)|$ versus frequency. Indicate on the frequency axis the natural resonance frequency, i.e., the frequency for the case where no voltages are applied, of the purely mechanical device. Also indicate on the appropriate axes the equations and numerical values for all important features, e.g., peak magnitudes and frequencies, the magnitudes of constant valued regions, etc.

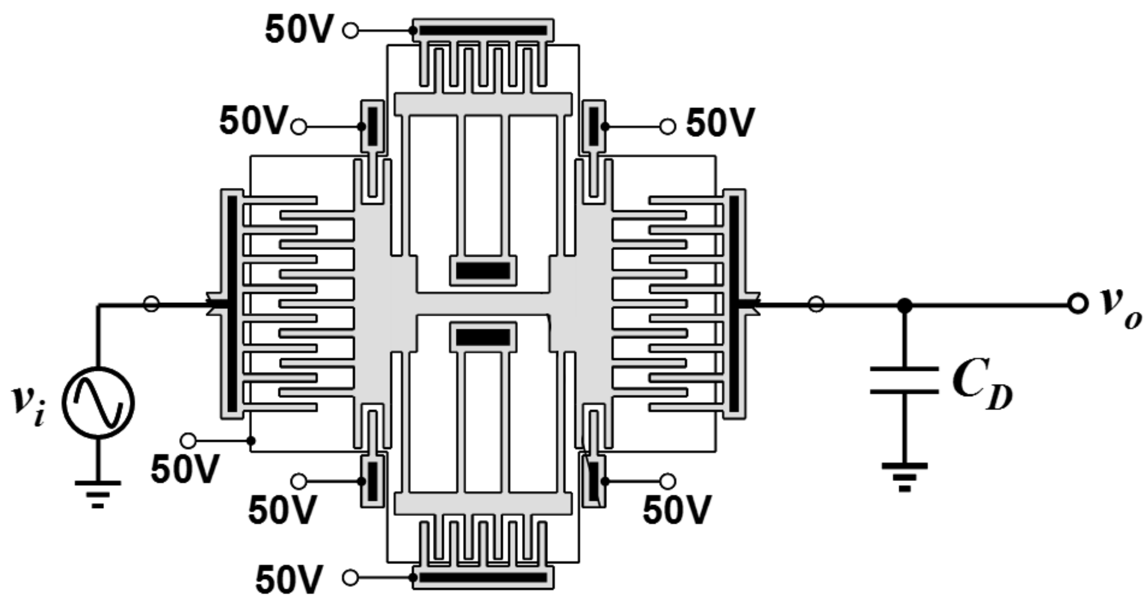

Fig. PS6.2

(f) List two major problems with the circuit of (e)?

(g) Now suppose you keep the bias conditions of part (e) but use the circuit below to detect the output, where parasitic capacitance is now captured by C_P = 100fF, and where C_F = 0.05fF and R_2 = 1000GΩ. If the gain of the op amp is 100, at what frequency does the output peak? Draw the $|v_o(s)/v_i(s)|$ versus frequency plot on the same plot as (g), but as a dashed line. Again, include expressions and numbers for major features.

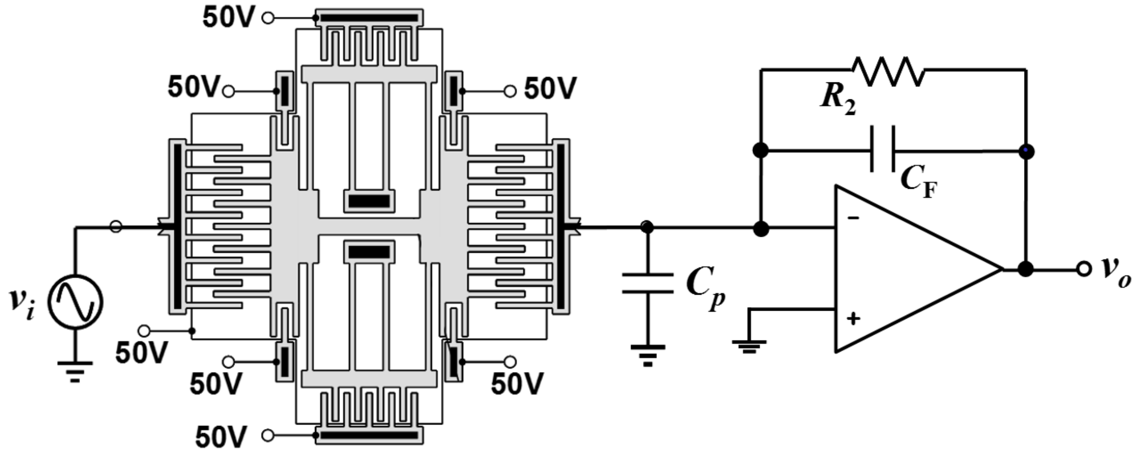

Fig. PS6.3