PROBLEM SET #6

Issued: Wednesday, April 15, 2020

Due: Friday, May 1, 2020, 8:00 am via Gradescope

1. Fig. PS6.1 below presents the top view of a micromechanical device constructed in a 2 μm-thick structural layer with numerous ports. Here, everything is suspended 2 μm above the substrate except for the anchoring locations indicated by the darkly shaded regions. Data on the structural material used in this problem and on specific geometric dimensions are given in Table PS6.1. Assume that all folding trusses and shuttles are rigid in all directions, including the vertical (i.e., z) direction. Additionally, you may assume that all suspensions beams have the same width and that all gaps are identical.

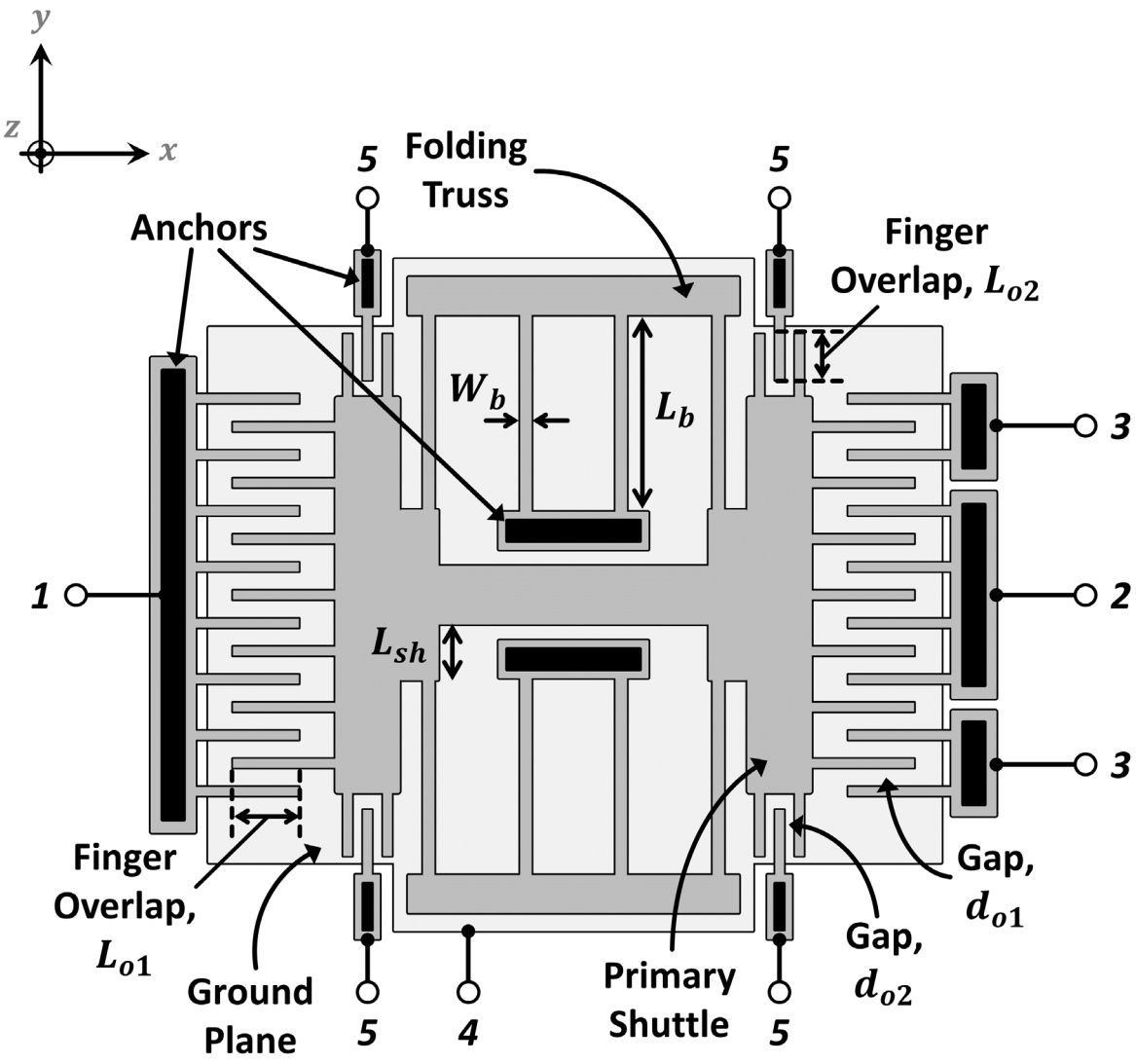

Figure PS6.1

STRUCTURAL MATERIAL PROPERTIES (at 25°C)	*VALUE*	*UNIT*
Young's Modulus, E	150	GPa
Density, ρ	2,300	kg/m^3
Poisson's Ratio, v	0.226	-
Quality Factor, Q	80,000	-
Temp. Coefficient of Young's Modulus, TC_E	-32	ppm/K
Temp. Coefficient of Density, TC_ρ	0	ppm/K
Temperature Coefficient of Expansion, α_s	2.5	ppm/K
GEOMETRIC DIMENSIONS (at 25°C)	***VALUE***	***UNIT***
Beam Length, L_b	50	μm
Shoulder Length, L_{sh}	20	μm
Beam Widths, W_b	2	μm
Thickness, h	2	μm
Finger Gap 1, d_{o1}	1	μm
Finger Gap 2, d_{o2}	2	μm
Finger Overlap 1, L_{ov1}	10	μm
Finger Overlap 2, L_{ov2}	5	μm
Folding Truss Area (each)	200	μm^2
Primary Shuttle Area	3,000	μm^2

Table PS6.1

(a) Write an expression for and calculate the x-directed resonance frequency of this structure at 25°C when all ports are grounded.

(b) Write an expression for and calculate the x-directed resonance frequency of this structure at 100°C when all ports are grounded.

For the rest of the problem assume operation at 25°C.

(c) Draw a transformer-based equivalent circuit modeling the electrical behavior of this device with ports *1*, *2* and *3* as terminals, ports *4* and *5* biased at 60 V and all other ports at DC ground (no

need to show ports *4* and *5* in this circuit). Write expressions for all of its elements and calculate their numerical values with units.

(d) Suppose the device is hooked up as shown in Figure PS6.2, where v_i is a sinusoidal input voltage at the resonance frequency with an amplitude of 10 mV. What is the resulting output current i_o? Provide both an expression and a numerical value with units.

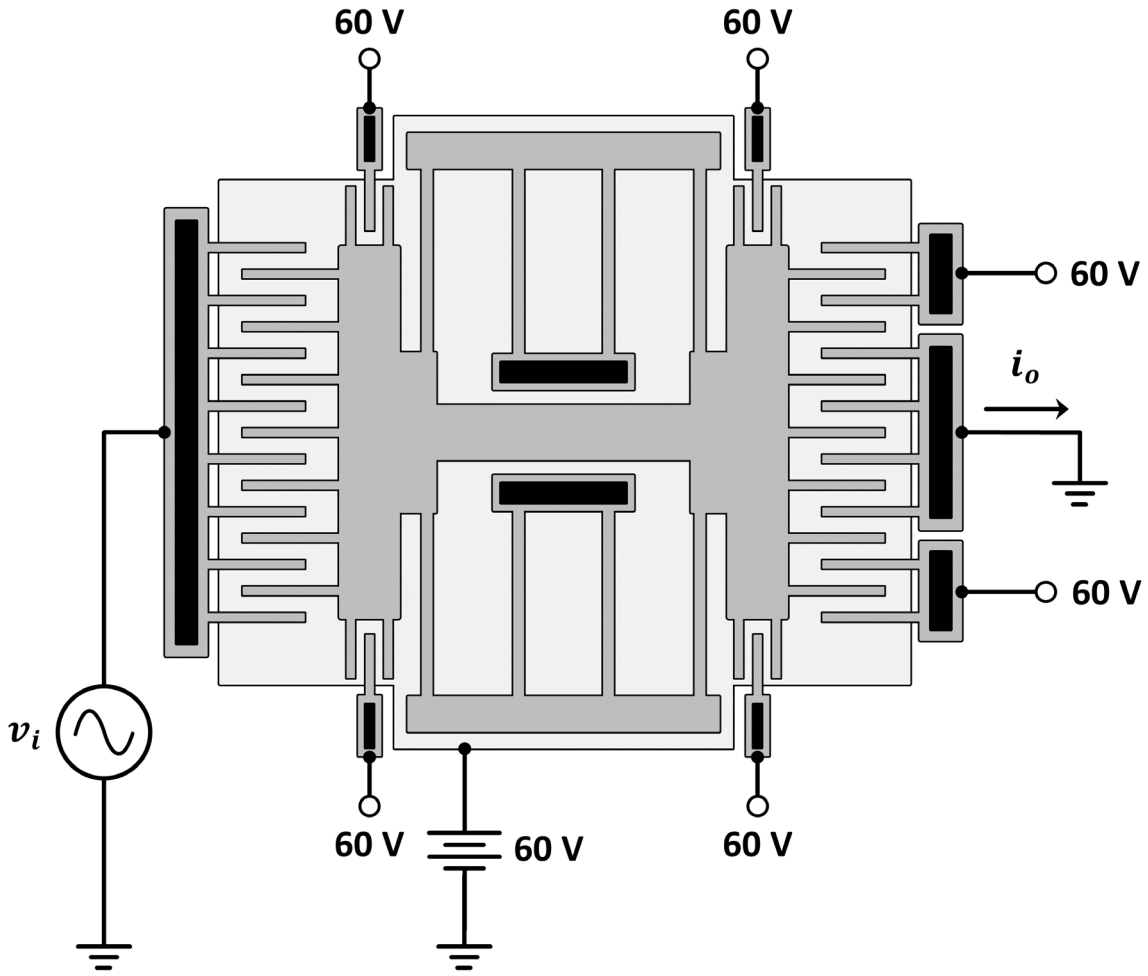

Figure PS6.2

(e) Now suppose that a resistor $R_P = 5$ MΩ is placed in series with the DC-bias voltage V_P at port *4* with the same input voltage v_i present as shown in Figure PS6.3. Now what is the output current i_o? Again, provide an expression as well as a numerical value with units.

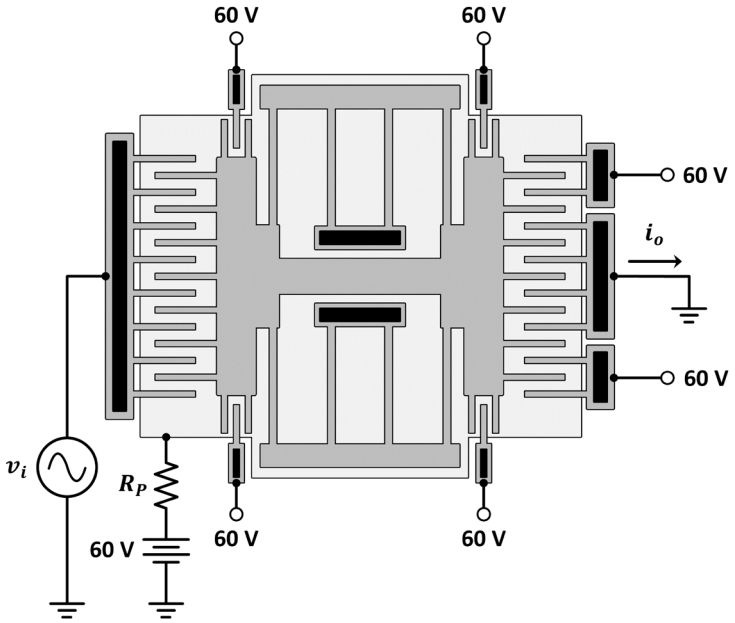

Figure PS6.3

(f) Now suppose the device is connected to the (ideal) op amp circuit shown in Figure PS6.4, where $R_f = 100$ MΩ. What is the quality factor Q of the overall transfer function $^{v_o}/_{v_i}$? Provide both an expression and a numerical value with units.

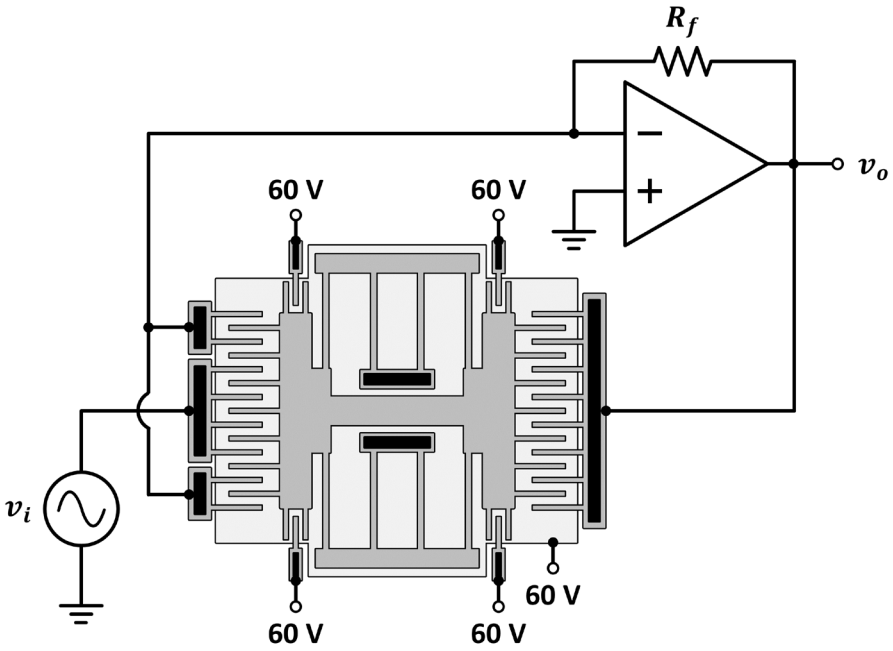

Figure PS6.4