

EECS 145L Final Examination Solutions (Fall 2008)

UNIVERSITY OF CALIFORNIA, BERKELEY
College of Engineering, Electrical Engineering and Computer Sciences Department

	Sensor or actuator	Input	Output
1.1	Photodiode	Light	Electrical current [2 points off for voltage]
1.2	Light-emitting diode	Electrical current [2 points off for voltage] [1 point off for electrical energy]	
1.3	Thermistor	Temperature	Resistance [2 points off for current]
1.4	Thermocouple	Temperature difference	Differential voltage [2 points off for current] [2 points off for resistance]
1.5	Solid-state temperature sensor	Temperature (plus power supply voltage)	Electrical current [1 point off for voltage] [2 points off for resistance*]
1.6	Platinum resistance thermometer	Temperature	Resistance
1.7	Peltier heat pump	Voltage x current	Heat transfer
1.8	Metal film strain sensor	Strain $\Delta L/L$	Resistance [2 points off for voltage]
1.9	Piezoelectric crystal**	Pressure or force or deformation	Charge or voltage [1 point off for current] [2 points off for resistance] [2 points off for capacitance]
1.10	Ag(AgCl) electrode**	Ionic potential or current	Electrical potential or current [2 points off for concentration]

* Although a voltage is applied to the solid-state temperature sensor and a current flows through it, it is not a resistor because the current depends on temperature, not on the applied voltage.

** The Piezoelectric crystal and the Ag(AgCl) electrode can also serve as actuators

2.1 $R = 3 \text{ V} / 30 \text{ mA} = 100 \Omega$

2.2 Since the ideal op-amp has infinite input impedance, $I_1 = 0$ and $I_2 = 0$. The virtual short rule gives $V_2 = V_1 = 0$. So $IR = 0$ and since all the current through the op-amp, $I_D = 0$ and $V_0 = 0\text{V}$

2.3 $I_1 = 0, I_2 = 0, V_2 = 3 \text{ V}, IR = 30 \text{ mA}, I_D = 30 \text{ mA}, V_D = 0.6217 \text{ V}, V_0 = 3.6217 \text{ V}.$

2.4 $I_1 = 0, I_2 = 0, V_2 = 3 \text{ V}, IR = 30 \text{ mA}, I_D = 30 \text{ mA}, V_D = (173/273) 0.6217 \text{ V} = 0.3940, V_0 = 3.3940 \text{ V}.$

	Frequency (Hz)	Differential Gain	Common-mode gain
3.1	0	0	0
3.2	0.01	0.1	0.0001
3.3	0.1	10	0.010
3.4	1	707	0.707
3.5	2.649	990	0.99
3.6	60	33	0.033
3.7	614	990	0.99

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3.8	1,000	707	0.707
3.9	3,162	10	0.010
3.10	10,000	0.1*	0.0001*

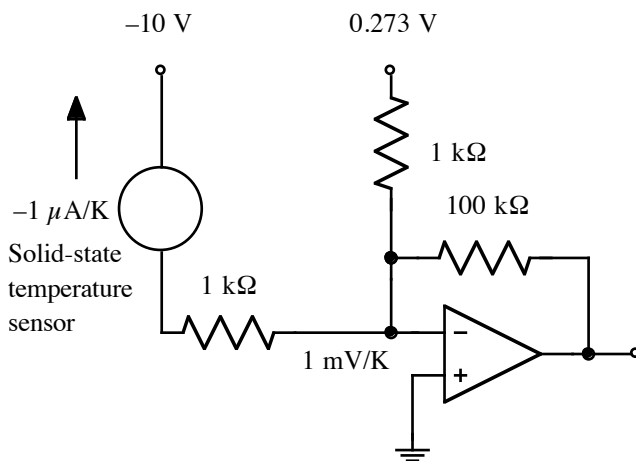
* Gain shown is that of the two filters only. Since both amplifiers are at their bandwidth limit of 10 kHz, they will reduce the system gain by a factor of 2 to 4, depending on their construction.

[4 points off for an error of a factor of 10 in overall gain]

[4 points off for giving only filter gains and ignoring amplifier gains]

[1 point off for each inconsistent common mode gain answer]

4.1 Want a sensitivity of 0.1 V/K and a shift of -273K . Inverting amplifier sums $(1 \text{ mV/K}) T + 0.273 \text{ V}$ and amplifies by a factor of -100 .



[3 points off for not converting °K to °C]

[2 points off for using a 100 kΩ series resistor and not using a bias voltage

$> (100 \text{ k}\Omega)(273+50)(1 \text{ }\mu\text{A/K}) = 32.2 \text{ volts}$]

4.2 Mount two strain gauges on a membrane cemented to a vacuum tank. The external pressure will cause the membrane to stretch. Place the two resistive strain gauges in a bridge and connect the bridge to an instrumentation amplifier.

Bridge output is

$$V_+ - V_- = V_b \left[\frac{R + \Delta R}{2R + \Delta R} - \frac{R}{2R + \Delta R} \right] = V_b \left[\frac{\Delta R}{2R + \Delta R} \right] \approx V_b \frac{\Delta R}{2R}$$

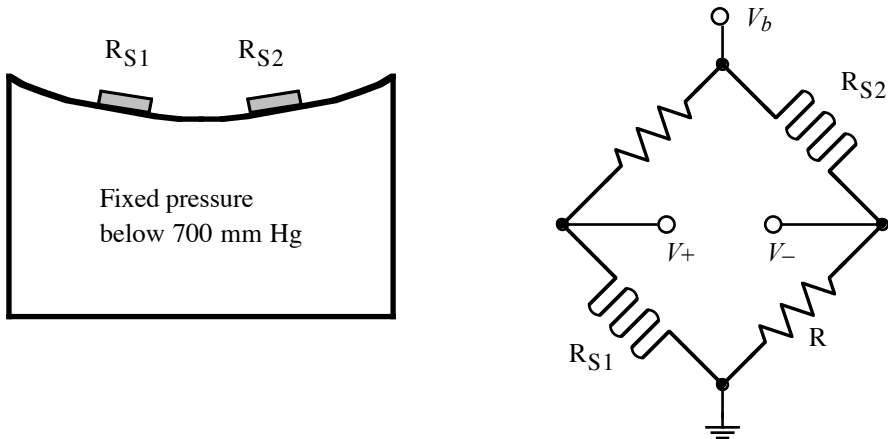
Strain is proportional to pressure: $\Delta L/L = kP$, where k depends on Young's modulus and the membrane geometry

$$\Delta R/R = 2\Delta L/L = 2kP$$

$$\text{Instrumentation amplifier output } V_0 = G(V_+ - V_-) = V_b kPG$$

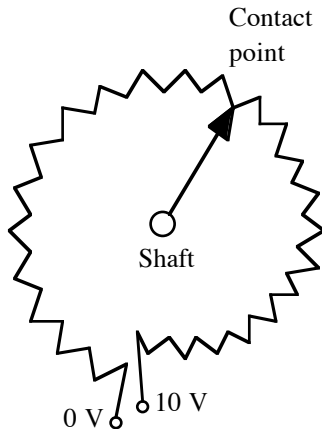
Want to choose $V_b kG = 0.1 \text{ V/mm Hg}$, so that $\Delta P = 100 \text{ mm Hg}$ gives $\Delta V_0 = 10 \text{ V}$

Choose R so that $V_+ - V_- = 0$ at 700 mm Hg .



[The membrane is under tension on both sides. However, no points off for incorrectly assuming tension on one side, compression on the other side.]
 [3 points off for not using a bridge circuit]
 [2 points off for not mounting the strain gauges on a membrane]
 [2 points off for not providing a fixed pressure on one side of the membrane]

4.3 Attach the shaft of a circular resistor to a weathervane or wind sock that rotates to point in the direction of the wind.



[3 points off for not tracking wind direction]

4.4 Attach four strain gauges to a flexible sheet and measure the force of the wind, similar to measuring the force of the weights in the strain lab. Connect the strain gauge in a bridge and connect the bridge output to an instrumentation amplifier with a gain G .

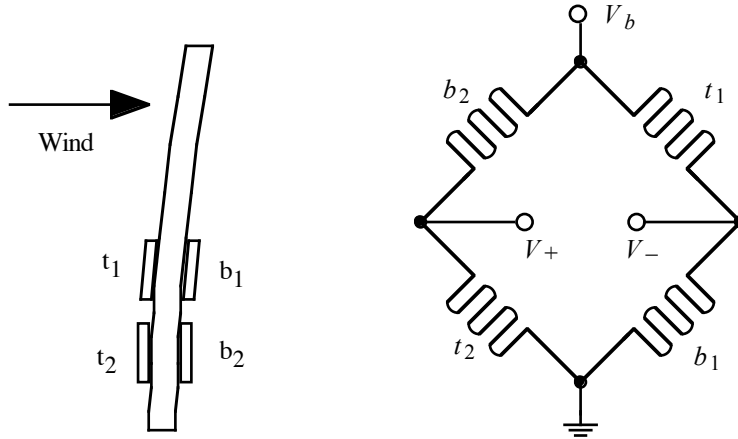
$\Delta L/L = kW$, where W is wind speed, and k depends on Young's modulus and the sheet geometry
 Bridge output is

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$$V_+ - V_- = V_b \left[\frac{R + \Delta R}{2R} - \frac{R - \Delta R}{2R} \right] = V_b \frac{\Delta R}{R}$$

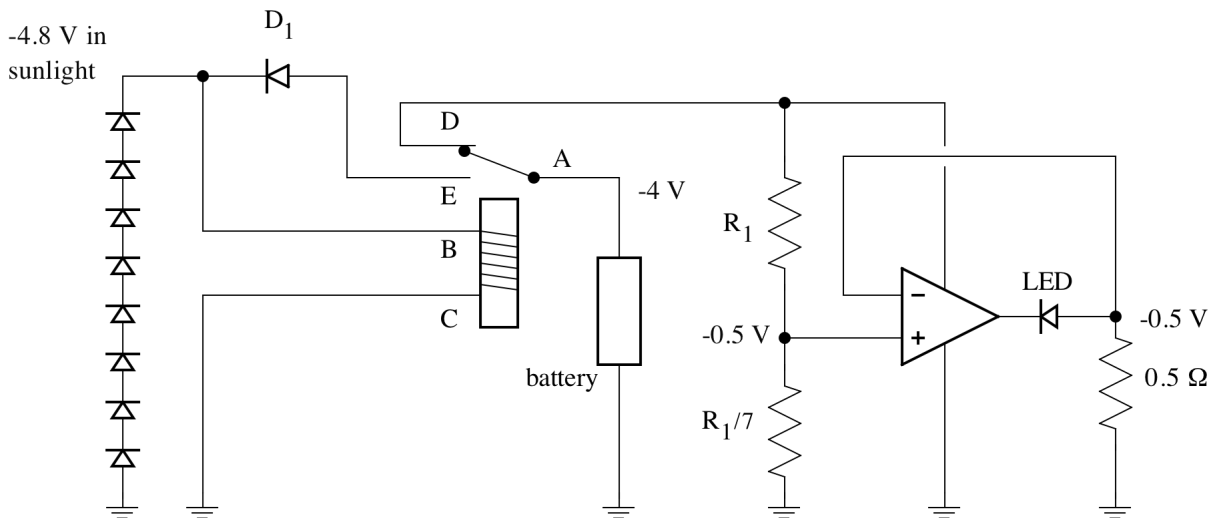
Instrumentation amplifier output $V_0 = G (V_+ - V_-) = 2 V_b G k W$

Want to choose $V_b k G = 1 \text{ V per } 40 \text{ km/hr}$



- [2 points off for not tracking wind direction]
- [3 points off for not using a bridge circuit]
- [2 points off for not mounting the strain gauges on anything]

5.1

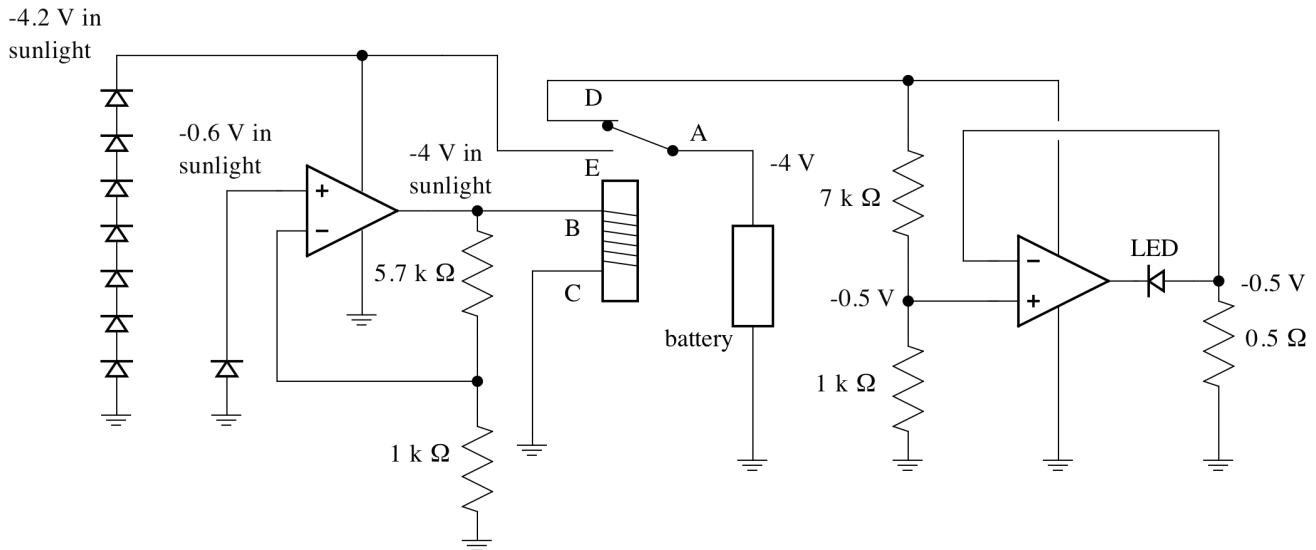


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5.2 During daylight the eight photovoltaic cells produce a maximum of 4.8 V across the BC coil, which activates the relay to connect A to E and charge the battery. D_1 prevents the battery voltage from holding the relay in the AE position at night.

5.3 At night the voltage across the BC coil is below 4 V because of the voltage drop across reverse-biased diode D_1 , A is connected to D, which connects the battery to the voltage-controlled current driver circuit. The op-amp is powered by the battery and drives 1 A through the LED, as desired.

An alternative accepted design used one photodiode to sense the sunlight and an amplifier to control the relay so that the remaining 7 photodiodes will charge the battery through contact AE (see circuit below). At night there would be no current through the relay coil and the battery would be connected to the LED current control circuit through contact AD. This design is simpler to understand but uses an additional op-amp.



[8 points off for a circuit that connects both the photodiodes and the battery directly to the BC coil during the day. When the sun goes down the battery will keep the coil energized and A will remain connected to E. Since the coil draws much less current than the LED the battery would stay at 4 V until the sun comes out again.]

[3 points off if the op-amp is not powered; in this problem op-amps have 5 leads, just like in the lab]

[3 points off if 4 V battery not used]

[2 points off for not controlling the current through the LED with a voltage-controlled current driver—connecting 4V, the LED and a resistor in series is a poorer design]

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145L FINAL EXAM GRADE STATISTICS

Problem	1	2	3	4	5	Total
Average	37.8	33.5	33.0	33.4	31.1	168.7
rms	3.7	10.3	10.0	7.9	7.3	34.9
Maximum	40	40	40	40	40	200

Total score distribution:

10-19 0	20-29 1	30-39 0
40-49 0	50-59 0	60-69 0
70-79 0	80-89 1	90-99 0
100-109 0	110-119 1	120-129 0
130-139 1	140-149 1	150-159 1
160-169 5	170-179 6	180-189 9
190-199 6	200 1	

145L COURSE GRADE STATISTICS

Grade	Undergraduate Scores	Graduate Scores
A+	966, 966, 966	983
A	938, 941, 946, 951, 953, 957, 962	948, 953
A-		929
B+	911, 913, 914, 921, 922	
B	898, 899, 901, 905	
B-	890, 890	
C+	867, 870, 877	
C		
C-		
D+	823	
D	807	
D-		
F	351, 669, 753	
Maximum	1000	
Average	889.1	
rms	116.6	