EECS 145L Final Examination Solutions (Fall 2005)

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

1.1 A PIN photodiode is a diode with a transparent contact and works by converting incident light into electron-hole pairs that are separated by an electric field and collected at the output leads to produce a current that is proportional to the light intensity

[4 points off for stating how it is used but not how it works]

[4 points off if photons or light not mentioned]

[4 points off if electrons not mentioned- this is essential in describing how light is converted into a current]

1.2 A light emitting diode is a doped wide-band-gap semiconductor that works by using electrical power to raise electrons to an excited state. Light is emitted when the electrons return to the ground state.

[4 points off if electrons not mentioned- this is essential in describing how current is converted into light]

1.3 The metal foil strain gauge consists of a thin strip of metal bonded to an insulating layer and works by changing its resistance when strain changes its dimensions.

[4 points off if not stated that the change in resistance is caused by a change in dimension]

1.4 The Peltier thermoelectric heat pump works by using electrical power to drive electrons through alternating p-type and n-type semiconductor elements. Cooling occurs when the electrons enter the n-type material. Heating occurs when the electrons are forced into the p-type material.

[2 points off for not mentioning the role of electrons]

[2 points off for not mentioning alternating p-type and n-type semiconducting elements]

1.5 The ground fault interrupter uses a differential transformer, rectification, and amplification to detect the current difference between two current carrying conductors. If the difference exceeds 5 mA, the amplified signal trips an electromagnetic relay that disconnects both conductors. The relay is reset with a manual push button.

[3 points off not for describing that the GFI detects the ***difference*** between power and ground (hot and neutral)]

[2 points off for not giving a specific current difference that causes a trip]

[2 points off for not describing the reset function]

1.6 The bimetal switch consists of two strips with different thermal expansion coefficients bonded together and works by bending to make an electrical contact at a selected temperature.

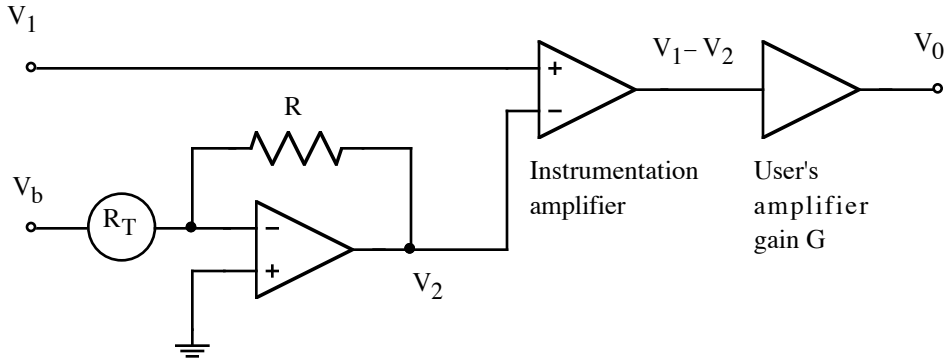
[4 points off if two strips are not mentioned]

1.7 The Ag(AgCl) electrode consists of a silver element bonded to AgCl. It can convert electrons in the silver into Cl– ions in solution by the reaction $AgCl + e^- \rightarrow Ag + Cl^-$ and convert Cl– ions in solution into electrons in the silver by the reverse reaction.

[2 points off for describing only one charge transfer reaction]

[4 points off for not describing either reaction]

2.1



$$V_{OO} = \left[G\,V_{RTI} + V_{RTO} \right] \exp\left[-\beta \left(\frac{1}{T} - \frac{1}{293} \right) \right] \quad \text{Note: Increases with increasing } T$$

$$R_T = 1\ \text{k}\Omega\ \exp\left[+\beta \left(\frac{1}{T} - \frac{1}{293} \right) \right] \quad \text{Note: Decreases with increasing } T$$

$$V_2 = \frac{-V_b R}{R_T} \approx \left[\frac{-V_b R}{1\ \text{k}\Omega} \right] \exp\left[-\beta \left(\frac{1}{T} - \frac{1}{293} \right) \right] \quad \text{Note: } R_T \text{ in denominator so } V_2 \text{ has proper } T \text{ dependence}$$

$$V_0 = G(V_1 - V_2) + V_{OO}$$

To eliminate the offset voltage, we want

$$V_0 = GV_1$$

which requires

$$GV_2 = V_{OO}$$

$$\left[\frac{-V_b GR}{1\ \text{k}\Omega} \right] \exp\left[-\beta \left(\frac{1}{T} - \frac{1}{293} \right) \right] = \left[GV_{RTI} + V_{RTO} \right] \exp\left[-\beta \left(\frac{1}{T} - \frac{1}{293} \right) \right]$$

$$V_b R = -(1\ \text{k}\Omega)(1\ \mu\text{V} + 100\ \mu\text{V/G})$$

[3 points off if compensation decreases with increasing temperature- a common mistake was to use the thermistor as the feedback resistor of an inverting amplifier]

[2 points off if input to the compensation circuit does not have a high input impedance]

[5 points off if it is not clear how the output offset compensating circuit depends on the values of V_{RTI}, V_{RTO}, and G.

[6 points off if the thermistor is used in a bridge with 1 kΩ (or unspecified) resistors- $1/(R_T + 1\ \text{k}\Omega)$ has a very different temperature dependence than the desired $1/R_T$]

2.2 For $G = 100$ at 20°C, $R_T = 1$ kΩ, $V_b = -2$ mV, $R = 1$ Ω

3.1 Sensor: thermistor or solid-state temperature sensor

[3 points off for thermocouple, which would require an electronic ice point- if you had an electronic ice point, you would not need the thermocouple]

Actuator: thermoelectric heat pump

[3 points off for "heater" which is not a specific actuator]

3.2 Sensor: thermocouple or platinum resistance thermometer

[3 points off for using a thermistor or solid-state temperature sensor- they are semiconductors that would be destroyed at 500 °C]

Actuator: resistive heater

[3 points off for using a thermoelectric heat pump as an actuator- it is a semiconductor that would be destroyed at 500 °C]

Another correct answer is a bimetallic switch, which acts both as a sensor and an actuator

3.3 Sensor: piezoelectric crystal or embedded piezoresistors in a silicon disk

Actuator: motor plus compresssor pump or solinoid plus piston

3.4 Sensor: Circular resistor or digital encoder

Actuator: stepping motor

4.1 Green is reflected, so all other wavelengths are absorbed.

4.2 Fluorescent

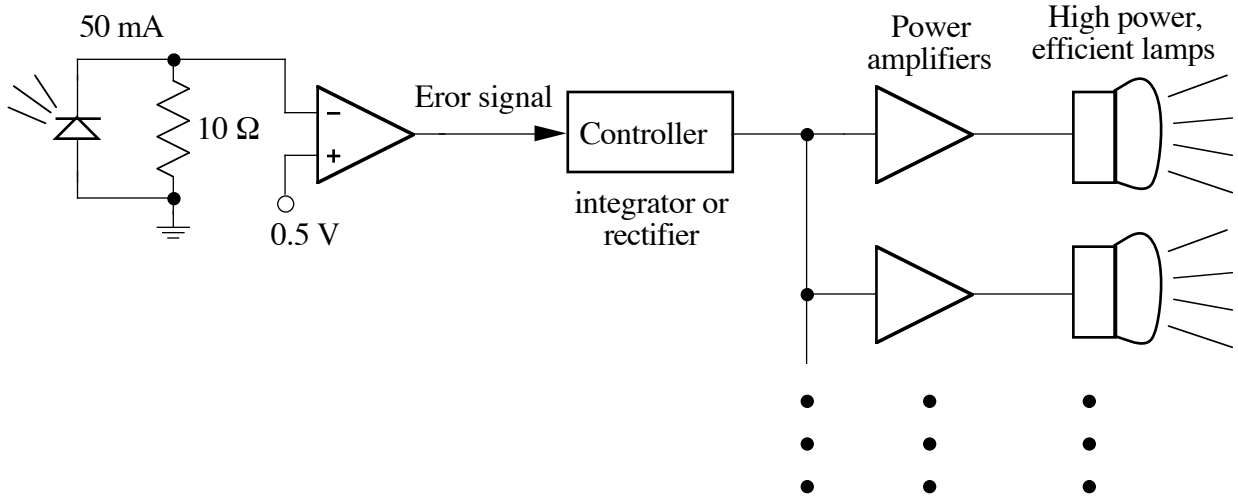
4.3 Assuming 100% quantum efficiency, the power received by a 1 cm^2 photodetector under full sunlight is $(10^{-4}\ m^2)\ (1000\ W\ m^{-2}) = 0.1$ W.

0.1 W of 2 eV photons produces 50 mA of closed-loop photovoltaic current.

Open-circuit conditions produces 0 mA and ≈0.6 V max (voltage saturation).

Load resistor must be < 0.6 V/0.05 A = 12 Ω or photodiode will saturate.

A 10 Ω load resistor will produce 0.5 V when the photodiode receives full sunlight. This determines the set point voltage.

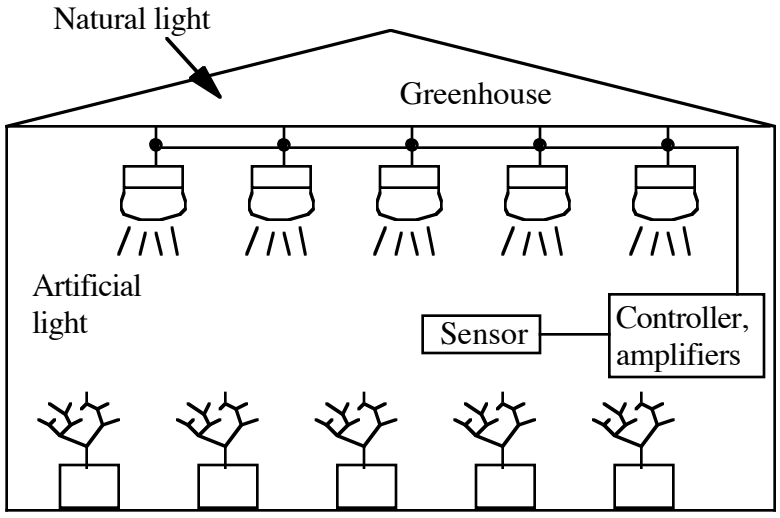


[5 points off if photodiode current not calculated]

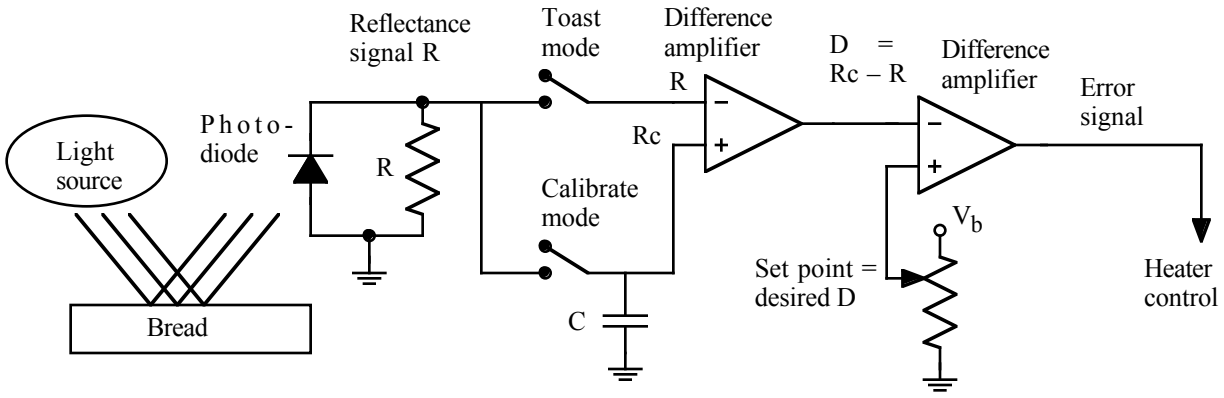
[2 points off if set point not calculated or load resistor is > 12 Ω (which would require a photovoltaic output > 0.6 volts)]

[3 points off for omitting a control circuit that uses the error signal to power the artificial lights]

4.4



5.1



5.2

- The photodiode constantly records R, the light reflected from the surface of the toast. Use optical filtering so that the photodiode does not see the red glow of the heater elements.
- In calibrate mode, the heater is off and the reflected signal Rc is stored on capacitor C
- In toast mode, the heater is on, capacitor C is disconnected from the photodiode, and the first difference amplifier generates D = Rc – R, which is the amount the reflected light intensity has been reduced by toasting. The second difference amplifier generates an error signal, which is the difference between D and the desired darkening D. The heater control turns off the heaters when the error signal goes negative.

  [5 points off for not describing a light source for illuminating the bread]

  [5 points off for not describing the light sensing circuit]

  [5 points off for not saving the initial reflected signal]

  [5 points off for not generating a set point that corresponds to the desired level of toasting]

  [5 points off for not turning off the toaster when D = Rc–R > Desired D.

An alternative accepted solution used a matched second light sensing system that used a piece of toast as a reference and the error signal was derived from the difference between the two light sensing systems. The disadvantage of using a reference toast is that it will become moldy in a few days and this will change its color. This is readily fixed by using a painted reference surface, which will have much better color stability.

145L FINAL EXAM GRADE STATISTICS

Problem	1	2	3	4	5	Total
Average	51.8	10.4	32.1	41.2	30.4	166.0
rms	9.2	4.1	7.0	7.4	3.5	26.7
Maximum	63	20	36	48	33	200

Total score distribution:

70-79	0	80-89	1	90-99	0
100-109	0	110-119	0	120-129	1
130-139	1	140-149	0	150-159	2
160-169	3	170-179	5	180-189	3
190-199	3	200	0		

145L COURSE GRADE STATISTICS

Grade	Undergraduate Scores	Graduate Scores
A+	960.5	
A	955.4, 951.3	
A–	939.3, 926.4	
B+	915.9, 910.4, 908.8, 908.0, 896.3	
B	873.5, 869.8, 865.3	
B–		
C+	812.4, 810.0, 788.5	
C	750.3	
C–		
D+		
D		
D–		
F		
Maximum	1000	1000
Average	884.8	
rms	62.4	

Note: the average grade for the lab report 4, 6, 12, 14 series was 90.1 and the average grade for the lab report 5, 11, 13, 15 series was 92.5. Two bonus points were added to each long lab report in the first series. This bonus did not affect any letter grades.