EECS 145L Final Examination Solutions (Fall 2010)

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1.1 The **Digital Position Encoder** consists of a strip (or circular disk) that contains a binary or Gray code pattern (magnetic or optical) that is read by a row of sensors. It is used to provide a digital code that is the position of the sensors along the strip.
[4 points off for describing an array of sensors but not the digital pattern that they sense]
[6 points off for describing a circular resistor]
[6 points off for a single sensor and no mask pattern]

1.2 The **Thermocouple** consists of two dissimilar wires connected to form two junctions. It is used to determine the temperature difference between the two junctions.
[2 points off for measuring temperature rather than a temperature difference]

1.3 The **Thermistor** consists of a semiconductor element with wires attached at teach end. It is used to determine temperature by measuring its resistance.
[3 pints off for not describing a semiconductor or an element that increases the concentration of electron carriers with temperature]

1.4 The **Isolation Amplifier** consists of a high-frequency modulator (RF or optical) in the input stage that allows a signal to be conducted through an air-core transformer or an optical fiber to the output stage where it is demodulated to recover the original signal. It is used to prevent dangerous low-frequency currents from passing between the input and output stages.
[4 points off for not modulating the input signal at high frequency]
[5 points off for describing shielding and differential amplification]

1.5 The **Silicon Photodiode** consists of a layer of silicon that is doped n-type on one side and p-type on the other. One of these layers is optically transparent. It is used to detect light by measuring the current produced by electron and hole carriers produced by interacting photons.
[2 points off for not describing that the difference in construction between a standard diode and a photodiode is that one of the n-type or p-type doping layers is transparent]

2.1 From textbook, example 2.1, page 91:
common mode $V_- = V_+$

Virtual short rule $V_- = V_2 = V_+ = V_1$

Since $V_1 = V_2$ there is no current through R_1

Since R1 and R_2 are in series there is no current through either R_2 and $V_3 = V_1$; $V_4 = V_2$

All these are therefore equal: $V_+ = V_2 = V_4 = V_- = V_1 = V_3$

$$G_c = \frac{V_3 + V_4}{V_- + V_+} = 1$$

2.2 From textbook, example 2.2, pages 91 and 92:

Virtual short rule $V_- = V_1$ and $V_+ = V_2$

The same current flows through R_1 and R_2: $\quad \dfrac{V_2 - V_1}{R_1} = \dfrac{V_4 - V_3}{R_1 + 2R_2}$

Differential gain of the first stage: $\dfrac{V_4 - V_3}{V_+ - V_-} = \dfrac{R_1 + 2R_2}{R_1}$

3.1 $V_3 = V_-(R_1 + R_2)/R_1$ $V_4 = V_+(R_1 + R_2)/R_1$

$$\frac{V_4 + V_3}{V_+ + V_-} = \frac{R_1 + R_2}{R_1}$$

3.2 $\dfrac{V_4 - V_3}{V_+ - V_-} = \dfrac{R_1 + R_2}{R_1}$

3.3 The new design is inferior because its first stage common mode gain is as high as the differential gain and prone to saturation. The standard design has a first stage common mode gain of only one.

4.1 Gain-bandwidth product is 100 MHz; gain is 100; bandwidth is 1 MHz.
Instrumentation amplifier input noise rms = 12.9 nV x sqrt(1 MHz) = 12.9 μV
Resistor input noise rms = 128.7 μV (from equation sheet)
Total output noise = 100 x sqrt (128.7^2 + 12.9^2) μV = 12.93 mV.
[1 point off for simple addition of noise contributions- same for 4.2-4.6]
[1 point off for not multiplying by the gain to get *output* voltage- same for 4.2-4.6]
[1 point off for correct setup but numerical error- same for 4.2-4.6]
[2 points off for not considering amplifier noise; even though it might be small, you can't ignore it if you don't know how large it is- same for 4.2-4.6]

4.2 Gain-bandwidth product is 100 MHz; gain is 10,000; bandwidth is 10 kHz.
Instrumentation amplifier input noise rms = 12.9 nV x sqrt(10 kHz) = 1.29 μV
Resistor input noise rms = 12.87 μV
Total output noise = 10,000 x sqrt (12.87^2 + 1.29^2) μV = 129.3 mV.

4.3 Gain-bandwidth product is 100 MHz; gain is 10,000; bandwidth is 10 kHz.
Instrumentation amplifier input noise rms = 12.9 nV x sqrt(10 kHz) = 1.29 μV
Resistor input noise rms = 12.87 μV / sqrt(300/75) = 6.45 μV
Total output noise = 10,000 x sqrt (6.45^2 + 1.29^2) μV = 65.8 mV.

4.4 Gain-bandwidth product is 100 MHz; gain is 10,000; bandwidth is 10 kHz.
Instrumentation amplifier input noise rms = 12.9 nV x sqrt(10 kHz) = 1.29 μV
Resistor input noise rms = 12.87 μV / sqrt(1 MΩ/ 500 kΩ) = 9.10 μV
Total output noise = 10,000 x sqrt (9.10^2 + 1.29^2) μV = 91.9 mV.

4.5 Gain-bandwidth product is 100 MHz; gain is 10,000; bandwidth is 10 kHz.
Instrumentation amplifier input noise rms = 12.9 nV x sqrt(10 kHz) = 1.29 μV
Single 500 kΩ resistor input noise rms = 9.10 μV (from 2d)
Total output noise = 10,000 x sqrt (9.10^2 + 9.10^2 + 1.29^2) μV = 129.3 mV.
[Note: Since the rms noise is proportional to the square root of the resistance, the noise from two R/2 resistors in series must be added in quadrature to equal the noise from a single resistor R. Simple addition of noise would make two R/2 resistors in series noisier than a single resistor R]

4.6 T = 300 K $(12.9/128.7)^2$ = 3 K
(i.e. To reduce the resistor noise by a factor of 10 from 12.9 μV to 1.29 μV, it is necessary to reduce the temperature by a factor of 100)
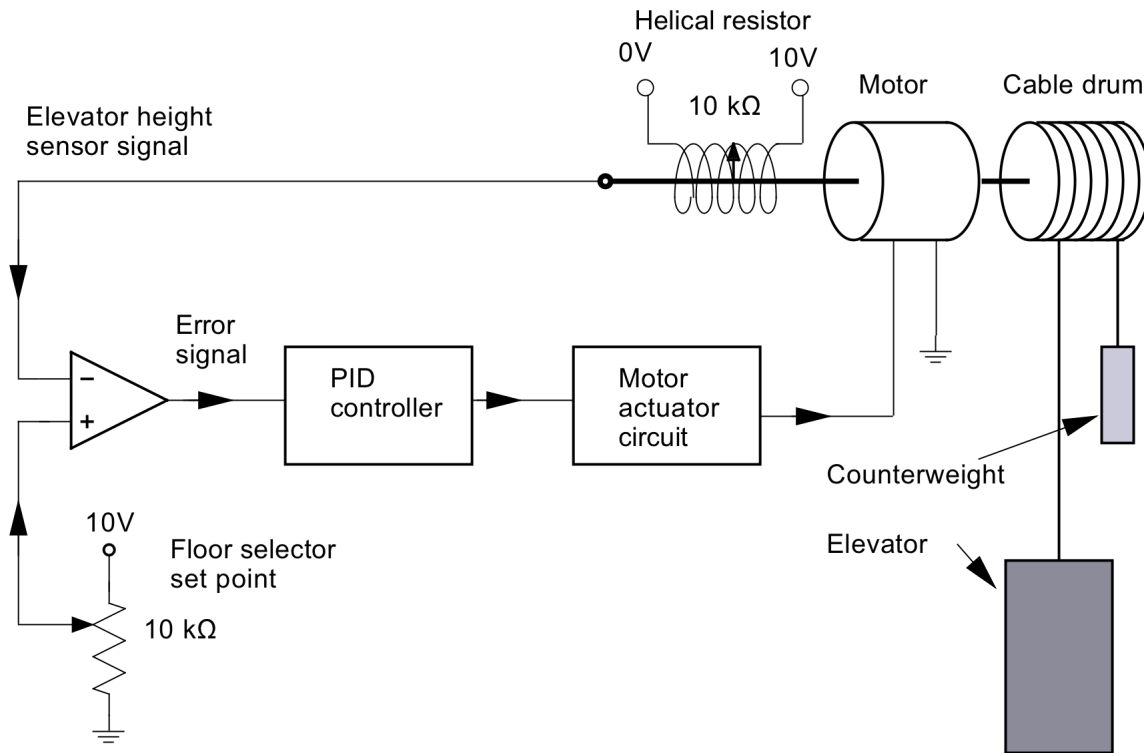
5
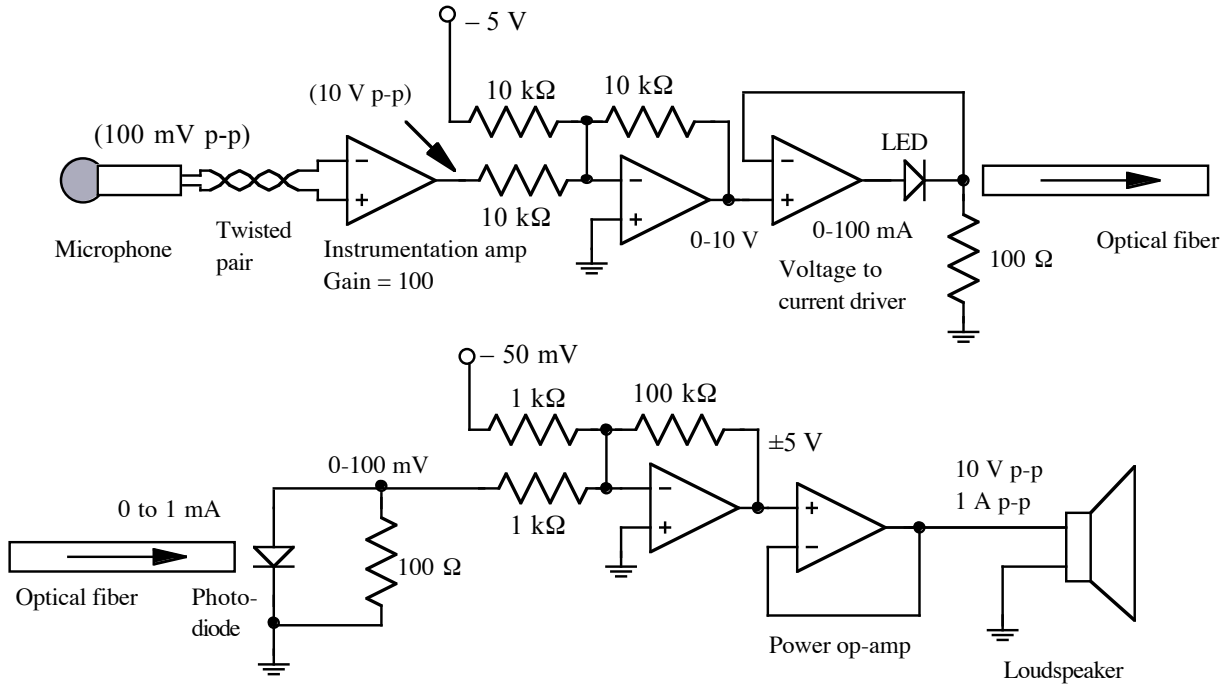
[4 points off for no microphone differential amplifier (the microphone had differential output and the common mode 60 Hz pickup of 10 mV needed to be eliminated)]

[2 points off for using 60 Hz notch filter since it rejects 60 Hz microphone signals]

[5 points off for not using a voltage controlled current driver for the LED]

[3 points off if it was not clear how the circuit converts 100 mV from the microphone into 100 mA into the LED]

[3 points off for using a 10 kΩ resistor to convert photodiode 1 mA to 10V since a photodiode cannot produce 10 V]

[3 points off if it was not clear how the circuit converts a 1 mA photodiode current into a 10 V, 1A speaker signal]

Note: Since the microphone waveform oscillates about zero, it is necessary to level shift before driving the LED and after the photodiode current to voltage converter. This was not required for full credit.

6.1

Helical resistor

0V   10V   Motor   Cable drum

10 kΩ

Elevator height
sensor signal

Error
signal

PID
controller

Motor
actuator
circuit

Counterweight

10V

Floor selector
set point

10 kΩ

Elevator

[2 points off if the error signal is not produced by negative feedback i.e. if sense is less than set, the error signal should be positive to raise the elevator and increase sense; full credit if this is explained

Note also that the PID amplifiers invert and the summing amplifier inverts so the simple PID circuit does not invert]

[7 points off if sense and set points are not subtracted to make an error signal]

6.2

High-gain amplifiers

Summing amplifier

P

R

LPF

I

HPF

D
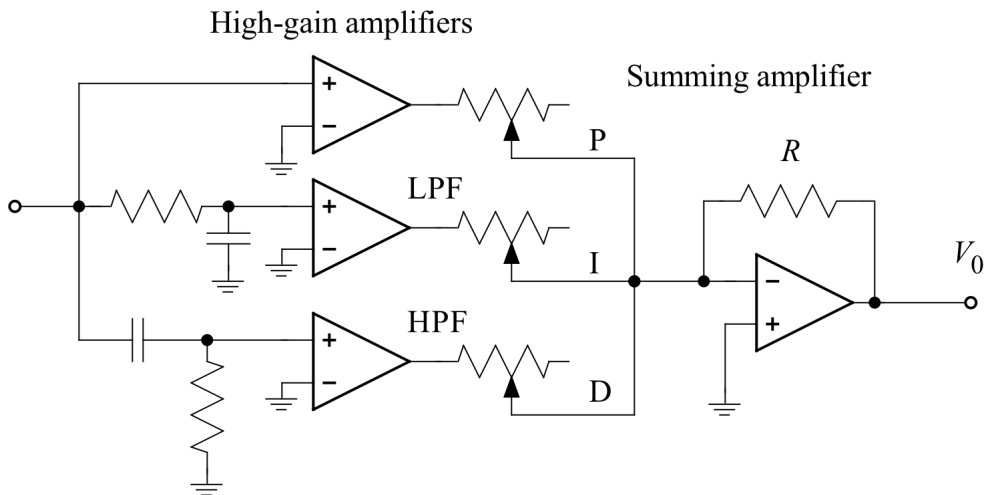
V_0

[5 points off for proportional, integral, and differential circuits in series rather than as inputs to a summing amplifier; a HPF and a LPF in series puts all frequencies in the stop zone]

[8 points off for an inadequate description but no circuit]

[5 points off for a description of the role of the proportional, integral, and differential control components but no circuit]

[3 points off if no manual controls of PID coefficients]

[5 points off if no PID circuits]

[4 points off if no summing amplifier]

[4 points off if the controller does not have sufficient gain to generate ±5V signals from small position errors (error << 1 floor is << 1 V)]

6.3

Assume that the elevator is on floor 1 and both the floor selector set point and the elevator height signal are at 1V. The error signal is zero. Since the passenger load is average, the weight of the elevator is the same as the counter weight and no motor effort is needed to hold the elevator. When new floor is selected by changing the floor selector set point resistor from say 1V to 2V, an error signal of -1 V is immediately produced which is sent to the controller. The controller produces a signal that drives the motor in the direction to raise the elevator and make sense closer to set. When the correct floor 2 is reached, both sense and set are at 2V, and the error signal is zero. Again, no motor effort is needed to hold the elevator.

[5 points off for a general description of negative feedback but no answer to the question]

6.4

When the elevator is empty, it weighs less than the counterweight and the motor control circuit needs -5V to hold the elevator. With high proportional gain, only a small displacement of the elevator above the set point floor is needed to produce enough amplified error signal to produce -5V. When 10 people get on, the elevator will drop slightly and a small error signal of opposite sign will cause the control circuit to produce +5V and again hold the elevator. This small long-term offset can be compensated with time integral of the error signal. In a real elevator, additional systems (e.g. friction brakes) will prevent motion while the doors are open.

[5 points off for a general description of negative feedback but no answer to the question]

145L FINAL EXAM GRADE STATISTICS

Problem	1	2	3	4	5	6	Total
Average	35.9	19.5	24.4	24.9	38.1	36.0	178.7
rms	3.5	1.6	2.7	4.6	2.9	10.1	18.1
Maximum	40	20	25	30	40	45	200

Total final exam score distribution:

120-124	1	125-129	0
130-134	0	135-139	1
140-144	0	145-149	0
150-154	0	155-159	1
160-164	0	165-169	0
170-174	1	175-179	7
180-184	4	185-189	1
190-194	4	195-200	3

145L COURSE GRADE STATISTICS

Grade	Undergraduate Scores	Graduate Scores
A+	**1**	**0**
A	**3**	**2**
A−	**7**	**0**
B+	**4**	**1**
B	**1**	**0**
B−	**0**	**0**
C+	**1**	**0**
C	**1**	**0**
C−	**2**	**0**
D+	**0**	**0**
D	**0**	**0**
D−	**0**	**0**
F	**0**	**0**

Maximum	1000
Average	907.4
rms	66.2