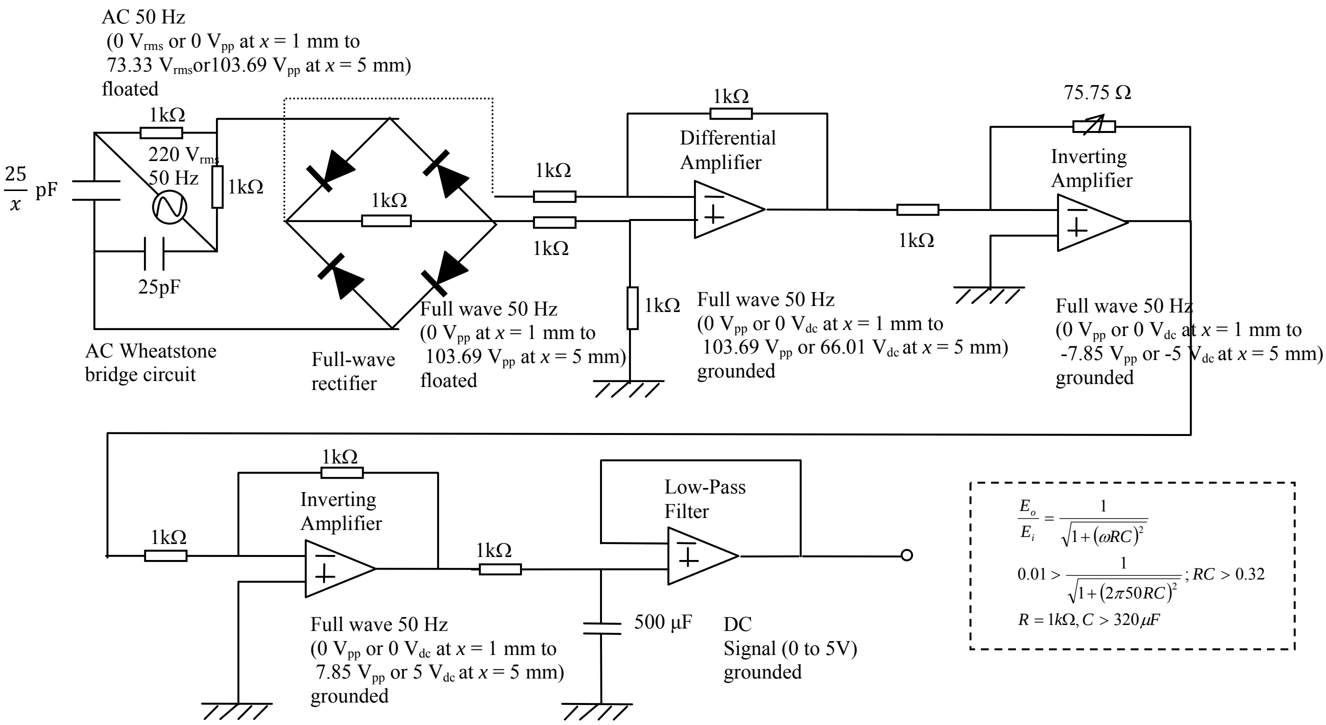
Midsem Examination Sensing and Actuation AT74.03 October 13, 2011

Time: 9:00-10:30 h. Open Book
Marks: 100

Attempt all questions.

Q.1 The output from a motion detector is in the form of capacitance which follows the relation, $C = \frac{25}{x}$, when C is capacitance in pF, x is distance from reference in mm varying from 1-5 mm. Design a signal manipulation circuit for this motion detector that converts the output signal to dc voltage varying between 0-5 V corresponding to distance from reference varying between 1-5mm. Assume AC source at V_{rms} of 220V, 50 Hz is available. There is a requirement that noise from AC source at 50 Hz at the output signal must be attenuated more than 99%. (20)

Solution



AC Wheatstone Bridge Circuit

$$V_o = V_s\left(\frac{25}{25+25/x} - \frac{1}{1+1}\right) \quad (1)$$

$$V_{pp} = \sqrt{2}V_{rms} \quad (2)$$

At $x = 1$ mm,
$$V_o = 0; V_{pp} = 0 \quad (3)$$

At $x = 5$ mm,
$$V_o = 73.33; V_{pp} = 103.69 \quad (4)$$

Full Wave Rectifier

$$V_{dc} = \frac{2V_{pp}}{\pi} \tag{5}$$

At $x = 1$ mm,
$$V_{dc} = 0 \tag{6}$$

At $x = 5$ mm,
$$V_{dc} = 66.01 \tag{7}$$

Inverting Amplifier

$$G = -\frac{5}{66.01} = 0.07575 \tag{8}$$

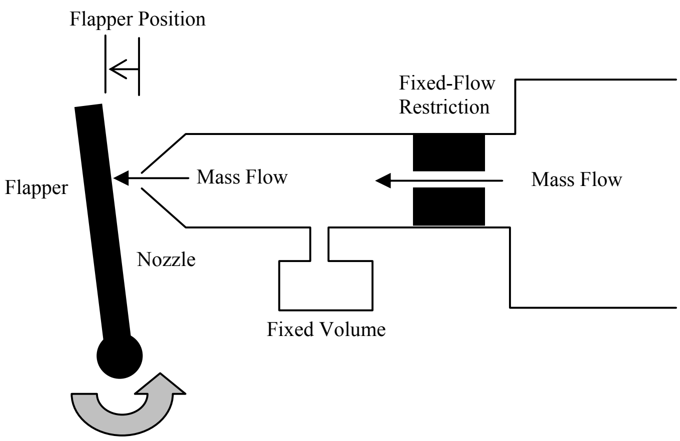
Low Pass Filter

$$\frac{E_o}{E_i} = \frac{1}{\sqrt{1+(\omega RC)^2}} \tag{9}$$

$$0.01 > \frac{1}{\sqrt{1+(2\pi 50RC)^2}} \tag{10}$$

$$RC > 0.32 \tag{11}$$

Q.2 At an equilibrium point of a nozzle-flapper transducer, the pressure in the fixed volume is measured at 120,000 Pa. When change of flapper position is detected 0.6 mm the pressure in the fixed volume at steady state is measured at 119,980 Pa. Determine change of flapper position when the pressure in the fixed volume at steady state is measured at 120,100 Pa. (15)



<u>Solution</u>

The relation between change of flapper position and change of pressure in the fixed volume at steady state is represented by

$$\frac{p_{o,p}}{x_{i,p}} = K \tag{1}$$

By substitution

$$\frac{-20 \text{ Pa}}{0.6 \text{ mm}} = -33.33 \text{ Pa/mm} \tag{2}$$

When the pressure in the fixed volume is 120,100 Pa, the change of flapper position is

$$\frac{100\ \text{Pa}}{x_{i,p}} = -33.33\ \text{Pa/mm} \quad (3)$$

$$x_{i,p} = -3\ \text{mm} \quad (4)$$

Q.3 A piezoelectric transducer, having sensitivity of 300 mV/cm and time constant of 5 seconds, is applied to measure the motion of a robot end effector. Determine the output voltage as a function of time, when the motion of a robot end effector is a step function with magnitude of 2 mm. (15)

Solution

Transfer function of piezoelectric transducer is represented by

$$\frac{e_0}{x_i} = \frac{K\tau s}{\tau s + 1} = \frac{300 \cdot 5s}{5s+1} \quad (1)$$

when

$$x_i(t) = 0.2; x_i(s) = \frac{0.2}{s} \quad (2)$$

Thus,

$$e_0(s) = \frac{300 \cdot 5s}{5s+1} \cdot \frac{0.2}{s} = \frac{300}{5s+1} = \frac{60}{s+1/5} \quad (3)$$

$$e_0(t) = 60e^{-t/5}\ \text{mV} \quad (4)$$

Q.4 Ultrasonic wave having the speed of 1,560 m/s in sea water is applied to determine location of an underwater robot in a sea. Assume an ultrasonic transmitter is installed on the underwater robot which transmits ultrasonic wave in omni-direction. The four ultrasonic receivers are installed at the coordinate r_1 = (0 m, 0 m, 0 m), r_2 = (100 m, 0 m, 0 m), r_3 = (200 m, 0 m, 0 m), and r_4 = (0 m, 0 m, 20 m). Determine all the possible locations of the underwater robot when the following conditions are detected.

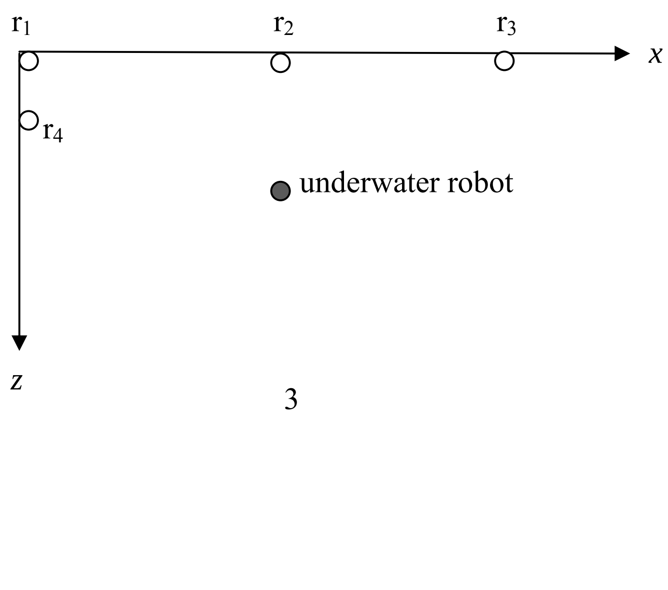
(1) The receiver number 2, r_2, senses the ultrasonic wave before the other receivers.

(2) The receiver number 3, r_3, senses the ultrasonic wave 9 milliseconds after r_2.

(3) The receiver number 1, r_1, senses the ultrasonic wave 20.1 milliseconds after r_2.

(4) The receiver number 4, r_4, senses the ultrasonic wave 17.9 milliseconds after r_2.

Assume there is no obstruction and reflection of ultrasonic wave. (20)



Solution

Travelling time of ultrasonic wave from the robot to the receiver number 2,

$$t_2 = \frac{\sqrt{(x-100)^2 + (y)^2 + (z)^2}}{1560} \quad (1)$$

Travelling time of ultrasonic wave from the robot to the receiver number 3,

$$t_3 = t_2 + 0.009 = \frac{\sqrt{(x-200)^2 + (y)^2 + (z)^2}}{1560} \quad (2)$$

Travelling time of ultrasonic wave from the robot to the receiver number 1,

$$t_1 = t_2 + 0.0201 = \frac{\sqrt{(x)^2 + (y)^2 + (z)^2}}{1560} \quad (3)$$

Travelling time of ultrasonic wave from the robot to the receiver number 4,

$$t_4 = t_2 + 0.0179 = \frac{\sqrt{(x)^2 + (y)^2 + (z-20)^2}}{1560} \quad (4)$$

From (1),

$$2433600t_2^2 = x^2 + y^2 + z^2 - 200x + 10000 \quad (5)$$

From (2),

$$2433600t_2^2 + 43804.8t_2 + 197.12 = x^2 + y^2 + z^2 - 400x + 40000 \quad (6)$$

From (3),

$$2433600t_2^2 + 97830.72t_2 + 983.20 = x^2 + y^2 + z^2 \quad (7)$$

From (4),

$$2433600t_2^2 + 87122.88t_2 + 779.75 = x^2 + y^2 + z^2 - 40z + 400 \quad (8)$$

(6)-(5),

$$43804.8t_2 + 197.12 = -200x + 30000 \quad (9)$$

(7)-(5),

$$97830.72t_2 + 983.20 = 200x - 10000 \quad (10)$$

From (9) and (10),

$$t_2 = 0.13287 \text{ second} \quad (11)$$

$$x = 119.91 \text{ m} \quad \underline{(12)}$$

Substitute (11) and (12) into (6),

$$42567.40 = y^2 + z^2 \quad (13)$$

Substitute (11) and (12) into (8),

$$40541.20 = y^2 + z^2 - 40z \quad (14)$$

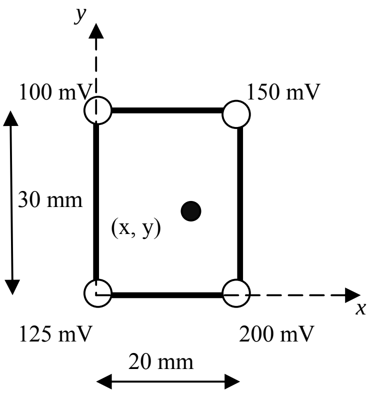
From (13) and (14),

$$z = 50.66 \text{ m} \quad \underline{(15)}$$

Substitute (15) into (13),

$$y = \pm 200 \text{ m} \quad \underline{(16)}$$

Q.5 Four calibrated load cells, each having sensitivity of 0.5 mV/N, are installed at the four corners of a humanoid robot's foot to determine the zero moment point during a single foot support phase. Determine location of the zero moment point when the compression forces read from the four sensors indicate as shown in the figure. (15)



Solution

Moment around zero moment point along y axis,

$$\frac{(100+125)}{0.5}x = \frac{(150+200)}{0.5}(20-x) \tag{1}$$

$$x = 12.17 \text{ mm} \tag{2}$$

Moment around zero moment point along x axis,

$$\frac{(125+200)}{0.5}y = \frac{(100+150)}{0.5}(30-y) \tag{3}$$

$$y = 13.04 \text{ mm} \tag{4}$$

Thus the zero moment point locates at

$$(x, y) = (12.17 \text{ mm}, 13.04 \text{ mm}) \tag{5}$$

Q.6 Design a sensor used to determine center of mass of a flexible object in real time. (15)