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- You have **80 minutes** to complete this exam.
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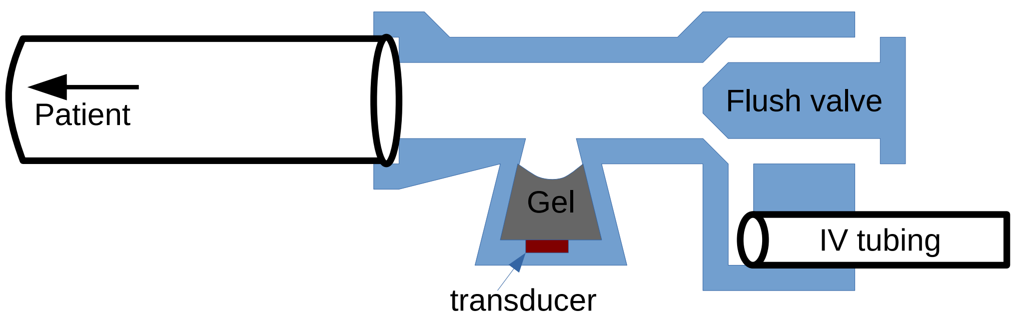
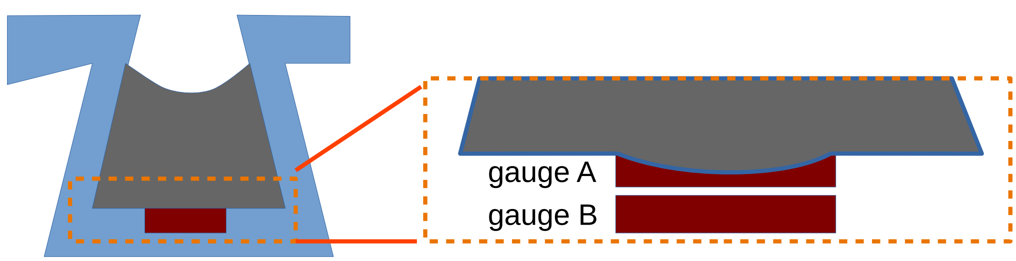
Q		#
1a	/5	
1b	/5	
1c	/5	
2a	/5	
2b	/5	
3a	/5	
3b	/5	
3c	/10	
4a	/5	
4b	/5	
4c	/5	
Tot	/60	

Background:

Your first job after graduation is to design a disposable blood-pressure transducer (as shown below). To increase sensitivity, the design uses a semiconductor strain gauge transducer. This midterm exam poses questions relevant to the design of this system.



Blood-pressure transducer system



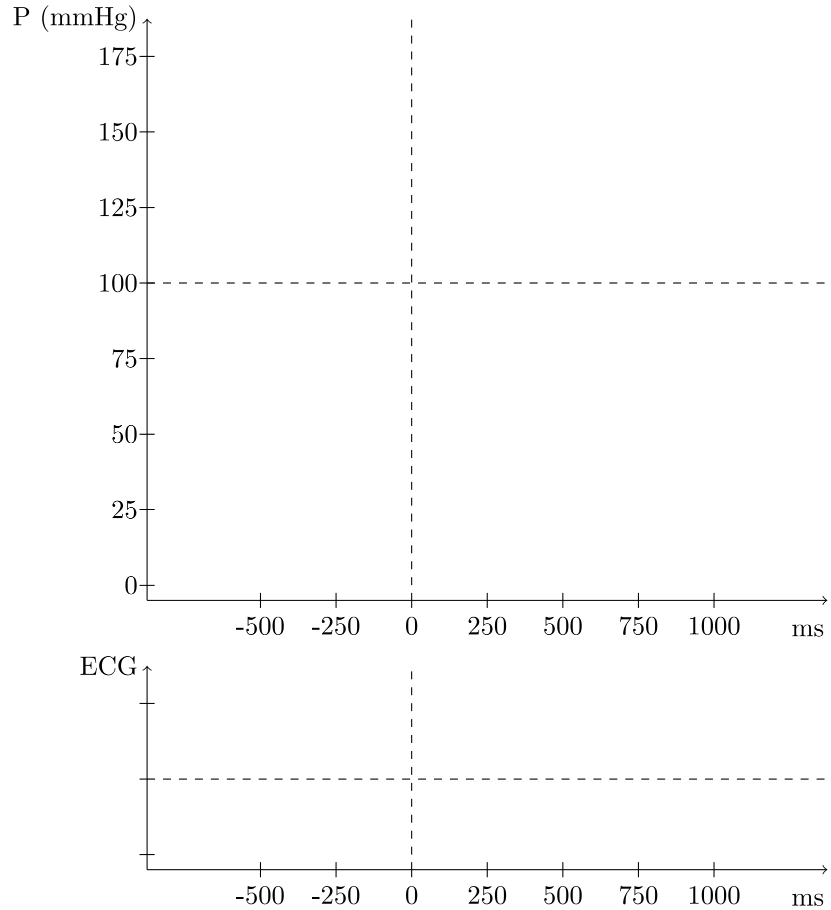
Inset of Gel and transducer. The transducer is composed of two separate strain gauges (right) where gauge A is deformed by the gel, while gauge B is mechanically separate.

Q1a: Consider a patient with a heart rate of 75 bpm, in whom the transducer is attached to an arterial line. The systolic/diastolic blood pressure is 150/90 mmHg.

(a) (5 marks) In the graph below, sketch the ECG as well as the Pressure in the aorta (label it as P_{a}) as a function of time. The first R-wave peak should be at $t = 0\,\mathrm{ms}$. Show the timing of the following R-wave peak.

(b) (5 marks) The patient has a insufficient aortic valve. Briefly (1–2 sentences) explain valve insufficiency, and how it affects blood pressure.

(c) (5 marks) Sketch the pressure in the left ventricle (label it as P_{lv}) for the insufficient valve. Indicate when (on the graph) leakage occurs.

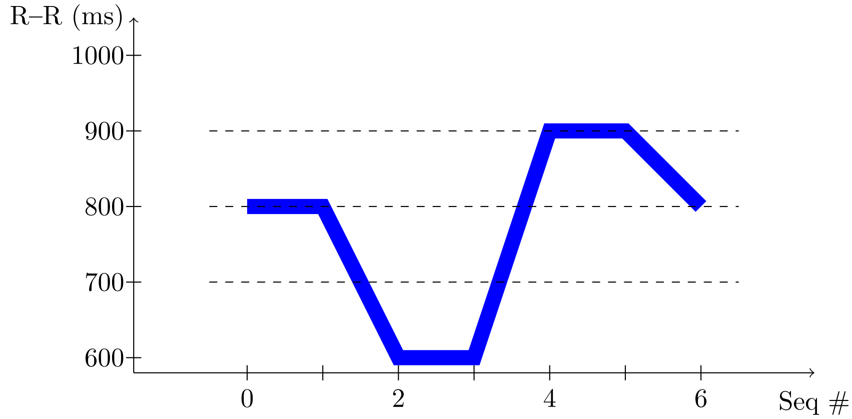


Q2a: Heart-rate variability is undestood to reveal useful information about the patient's health.

A plot of R–R intervals calculated from the patient's QRS are shown below.

(a) (5 marks) Calculate the RMSSD (Root Mean Square of Successive Differences between each heartbeat) parameter for this signal.

(b) (5 marks) Give an example of a frequency-domain method to calculate HRV, and discuss (1–2 sentences) how frequency-domain methods compare to time-domain methods to calculate it.

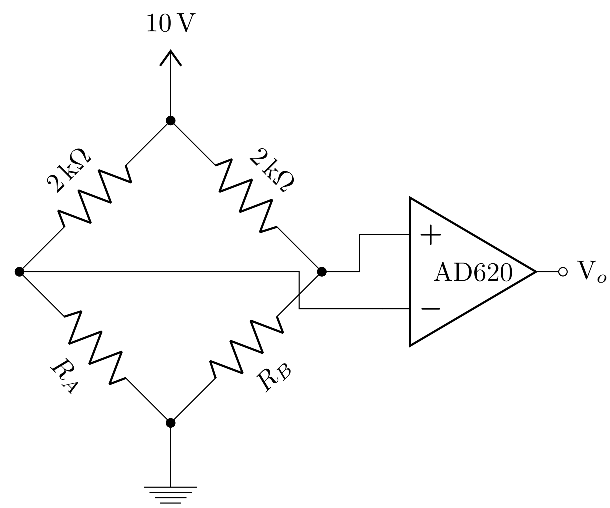


Q3a: In the transducer, each of the gauges is connected to a separate arm of a Wheatstone-bride design (gauge A to R_A and gauge B to R_B). The amplifier is an AD620 instrumentation amplifier with a gain set to 100. Initially, the amplifier is ideal.

(a) (5 marks) Consider that the gauge resistance values vary with temperature. Why (1–2 sentences) is the Wheatstone bridge design so useful for this application?

(b) (5 marks) Calculate the output, V_o, if $R_A = 2.10\,\mathrm{k}\Omega$ and $R_B = 2.15\,\mathrm{k}\Omega$.

(c) (10 marks) If I_B= $2\,\mu$A (but the amplifier is otherwise ideal), what is the new value of V_o? (First, calculate the Thévenin equivalent output impedance for each branch of the Wheatstone bridge. Next, use this value to calculate the output)

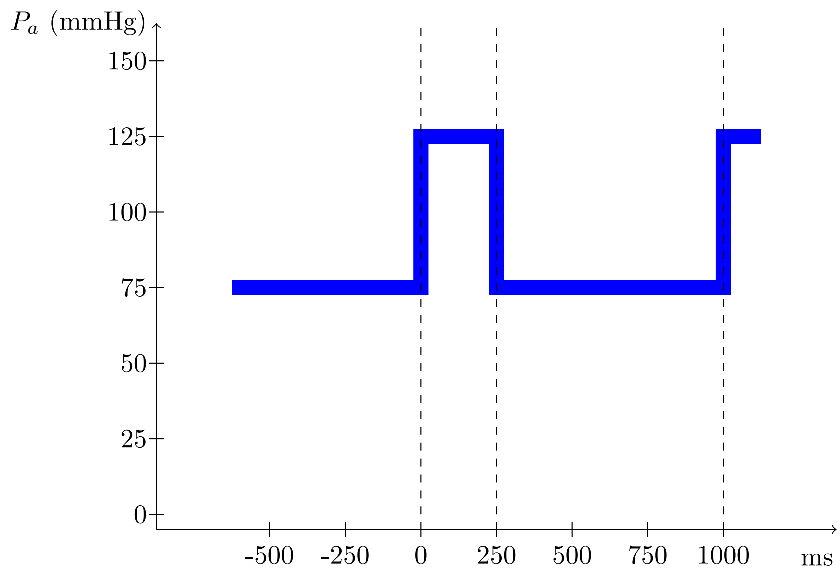


Q4a: Medical device regulations and validation are important for this design.

(a) (5 marks) What kind of electrical shock hazzard does this device represent (macroshock, microshock)? Justify your choice (1–2 sentences).

(b) (5 marks) Given the shock hazzard, describe the role of the gel (1–2 sentences)?

(c) (5 marks) The figure below represents the aortic pressure (P_a). Unfortunately, when the catheter is calibrated, it is identified to behave like an underdamped system. Sketch a possible output signal. Describe (1–2 sentences) a measurement error that could occur with this system.



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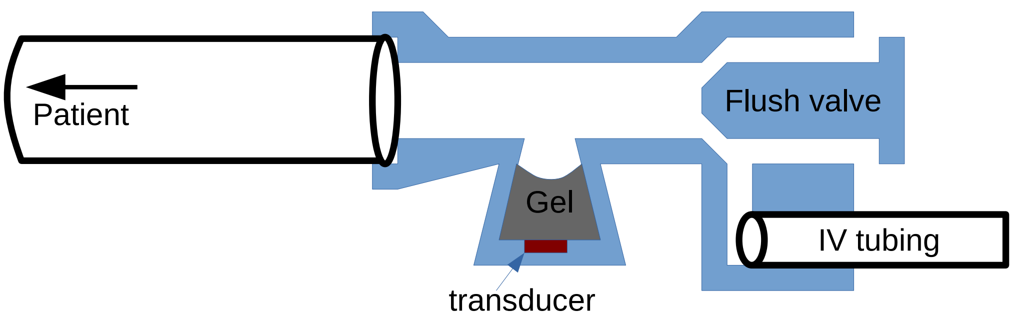
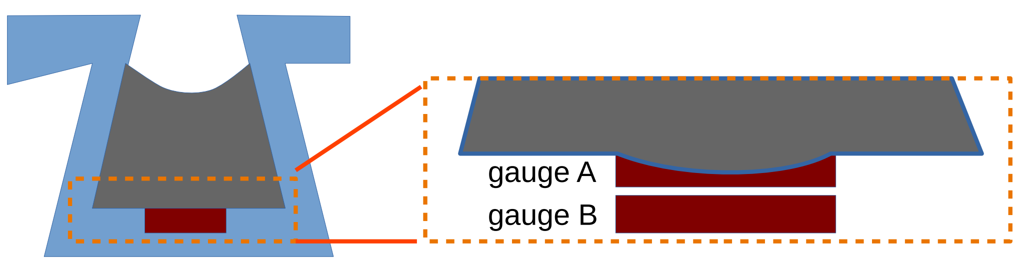


Blood-pressure transducer system



Inset of Gel and transducer. The transducer is composed of two separate strain gauges (right) where gauge A is deformed by the gel, while gauge B is mechanically separate.

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3b	/5	
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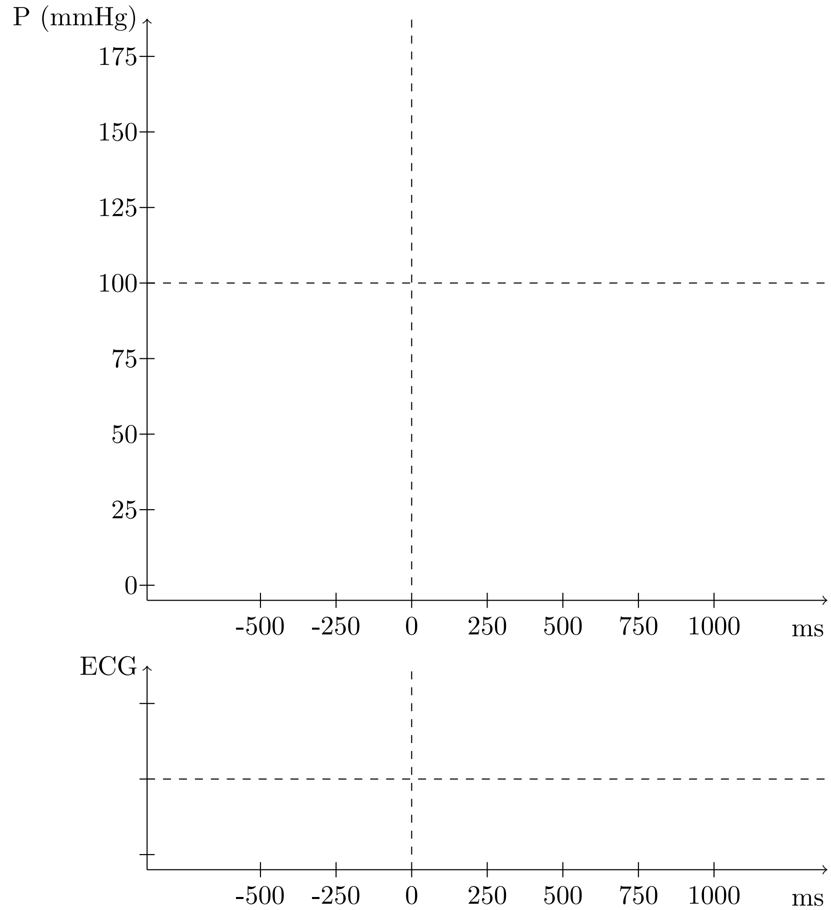
4a	/5	
4b	/5	
4c	/5	
Tot	/60	

Q1a: Consider a patient with a heart rate of 80 bpm, in whom the transducer is attached to an arterial line. The systolic/diastolic blood pressure is 160/100 mmHg.

(a) (5 marks) In the graph below, sketch the ECG as well as the Pressure in the aorta (label it as P_{a}) as a function of time. The first R-wave peak should be at $t = 0\,\text{ms}$. Show the timing of the following R-wave peak.

(b) (5 marks) The patient has a stenotic aortic valve. Briefly (1–2 sentences) explain valve stenosis, and how it affects blood pressure.

(c) (5 marks) Sketch the pressure in the left ventricle (label it as P_{lv}) if the pressure drop across the aortic valve (when open) is 15 mmHg.

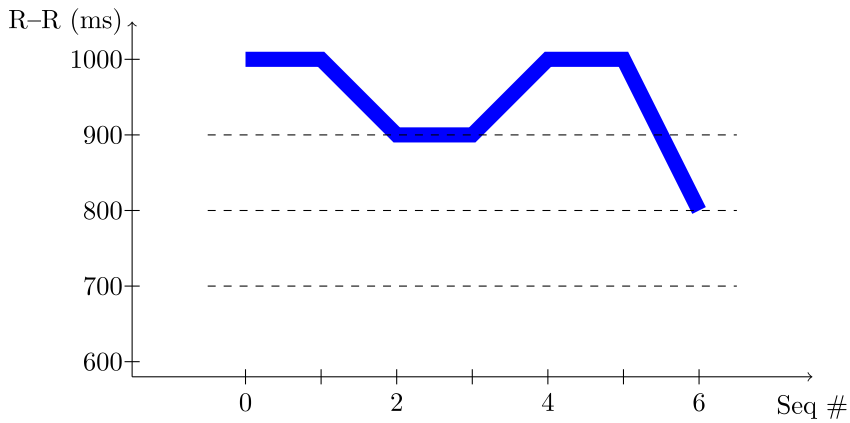


Q2b: Heart-rate variability is undestood to reveal useful information about the patient's health.

A plot of R–R intervals calculated from the patient's QRS are shown below.

(a) (5 marks) Calculate the RMSSD (Root Mean Square of Successive Differences between each heartbeat) parameter for this signal.

(b) (5 marks) Give an example of a parametric method to calculate HRV, and discuss (1–2 sentences) how parametric methods compare to time-domain methods to calculate it.

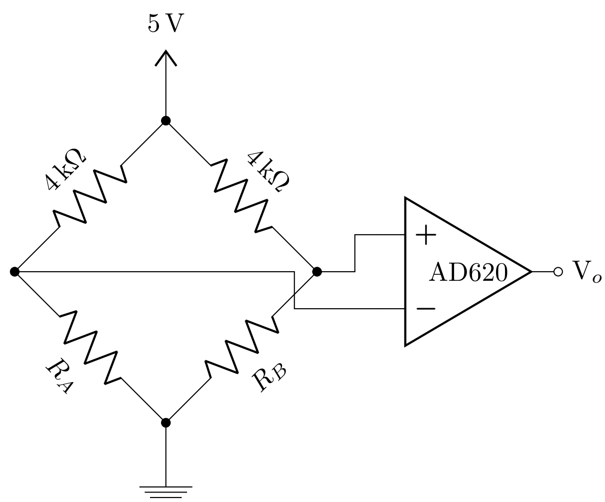


Q3b: In the transducer, each of the gauges is connected to a separate arm of a Wheatstone-bride design (gauge A to R_A and gauge B to R_B). The amplifier is an AD620 instrumentation amplifier with a gain set to 100. Initially, the amplifier is ideal.

(a) (5 marks) Semiconductor strain gauges give increased sensitivity. Explain how (1–2 sentences) how they are able to do this

(b) (5 marks) Calculate the output, V_o, if $R_A = 3.90\,\mathrm{k\Omega}$ and $R_B = 3.95\,\mathrm{k\Omega}$.

(c) (10 marks) If I_B= $1\,\mu$A (but the amplifier is otherwise ideal), what is the new value of V_o? (First, calculate the Thévenin equivalent output impedance for each branch of the Wheatstone bridge. Next, use this value to calculate the output)

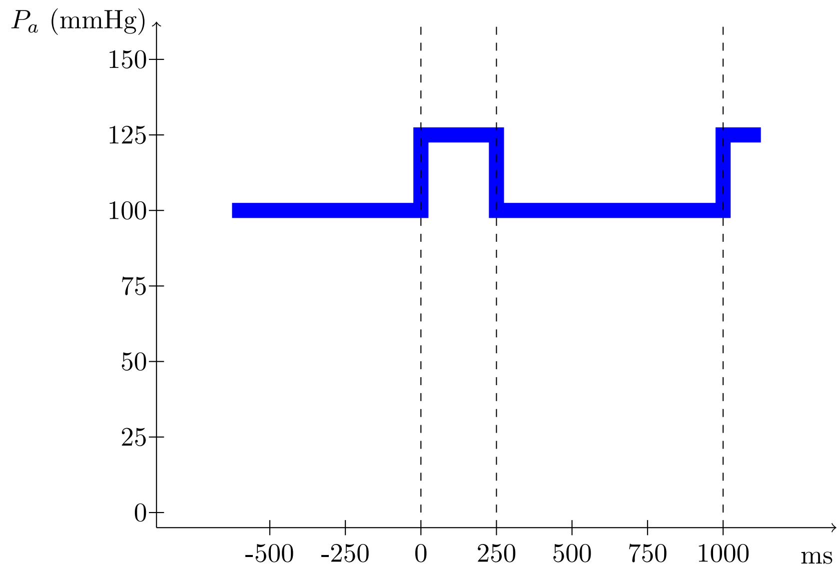


Q4b: Medical device regulations and validation are important for this design.

(a) (5 marks) What kind of electrical shock hazzard does this device represent (macroshock, microshock)? Justify your choice (1–2 sentences).

(b) (5 marks) Given the shock hazzard, what additional considerations would be necessary if the wiring and transducer was inside the body?

(c) (5 marks) The figure below represents the aortic pressure (P_a). Unfortunately, when the catheter is calibrated, it is identified to behave like an overdampted system. Sketch a possible output signal. Describe (1–2 sentences) a measurement error that could occur with this system.



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