**Instructions:**

- This test has 5 pages and 4 questions. Answer all questions and subparts. Marks are indicated.
- You have **80 minutes** to complete this exam.
- This is a closed book exam; however, you are permitted to bring one 8.5"×11" sheet of notes.
- You are permitted to use a non network-connected calculator.
- Answers should be written in this exam document. Write your answers in the space provided. If you require more space, attach extra pages to the exam, and indicate that extra space was used.
- All electronics components may be assumed ideal, unless stated otherwise.
- You may need the following table of filter properties.

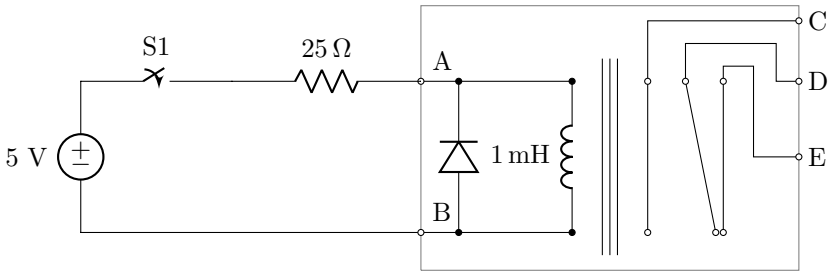
| $N$ | $F_s$(40dB) | $F_s$(60dB) | $F_s$(80dB) | $\hat{F}_p$ | $\zeta$ | $\hat{F}_p$ | $\zeta$ | $\hat{F}_p$ | $\zeta$ | $\hat{F}_p$ | $\zeta$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FILTER = Chebychev 0.05dB | | | | | | | | | | | |
| 2 | 21.58 | 68.23 | 215.77 | 2.162 | 0.668 | | | | | | |
| 4 | 3.37 | 5.89 | 10.42 | 0.885 | 0.833 | 1.221 | 0.250 | | | | |
| 6 | 1.90 | 2.67 | 3.85 | 0.569 | 0.860 | 0.870 | 0.412 | 1.091 | 0.120 | | |
| 8 | 1.48 | 1.86 | 2.39 | 0.422 | 0.870 | 0.670 | 0.464 | 0.912 | 0.228 | 1.050 | 0.069 |
| FILTER = Chebychev 0.10dB | | | | | | | | | | | |
| 2 | 18.11 | 57.28 | 181.13 | 1.820 | 0.652 | | | | | | |
| 4 | 3.10 | 5.41 | 9.55 | 0.789 | 0.808 | 1.153 | 0.229 | | | | |
| 6 | 1.81 | 2.54 | 3.64 | 0.513 | 0.834 | 0.834 | 0.375 | 1.063 | 0.108 | | |
| 8 | 1.43 | 1.79 | 2.30 | 0.382 | 0.843 | 0.645 | 0.423 | 0.894 | 0.204 | 1.034 | 0.062 |
| FILTER = Chebychev 0.20dB | | | | | | | | | | | |
| 2 | 15.21 | 48.08 | 152.05 | 1.535 | 0.628 | | | | | | |
| 4 | 2.85 | 4.95 | 8.75 | 0.701 | 0.774 | 1.095 | 0.205 | | | | |
| 6 | 1.72 | 2.40 | 3.44 | 0.460 | 0.799 | 0.803 | 0.335 | 1.038 | 0.095 | | |
| 8 | 1.39 | 1.73 | 2.21 | 0.343 | 0.807 | 0.623 | 0.377 | 0.878 | 0.179 | 1.021 | 0.054 |
| FILTER = Chebychev 0.50dB | | | | | | | | | | | |
| 2 | 11.99 | 37.84 | 119.67 | 1.231 | 0.579 | | | | | | |
| 4 | 2.55 | 4.42 | 7.78 | 0.597 | 0.709 | 1.031 | 0.170 | | | | |
| 6 | 1.61 | 2.23 | 3.19 | 0.396 | 0.731 | 0.768 | 0.276 | 1.011 | 0.077 | | |
| 8 | 1.33 | 1.64 | 2.09 | 0.297 | 0.739 | 0.599 | 0.310 | 0.861 | 0.144 | 1.006 | 0.043 |
| FILTER = Chebychev 1.00dB | | | | | | | | | | | |
| 2 | 9.95 | 31.41 | 99.31 | 1.050 | 0.523 | | | | | | |
| 4 | 2.34 | 4.03 | 7.08 | 0.529 | 0.637 | 0.993 | 0.140 | | | | |
| 6 | 1.54 | 2.11 | 3.01 | 0.353 | 0.657 | 0.747 | 0.227 | 0.995 | 0.062 | | |
| 8 | 1.29 | 1.58 | 2.01 | 0.265 | 0.664 | 0.584 | 0.256 | 0.851 | 0.117 | 0.997 | 0.035 |
| FILTER = Chebychev 2.00dB | | | | | | | | | | | |
| 2 | 8.13 | 25.59 | 80.91 | 0.907 | 0.443 | | | | | | |
| 4 | 2.14 | 3.65 | 6.41 | 0.471 | 0.538 | 0.964 | 0.109 | | | | |
| 6 | 1.46 | 1.99 | 2.82 | 0.316 | 0.555 | 0.730 | 0.176 | 0.983 | 0.048 | | |
| 8 | 1.25 | 1.52 | 1.93 | 0.238 | 0.560 | 0.572 | 0.197 | 0.842 | 0.090 | 0.990 | 0.027 |

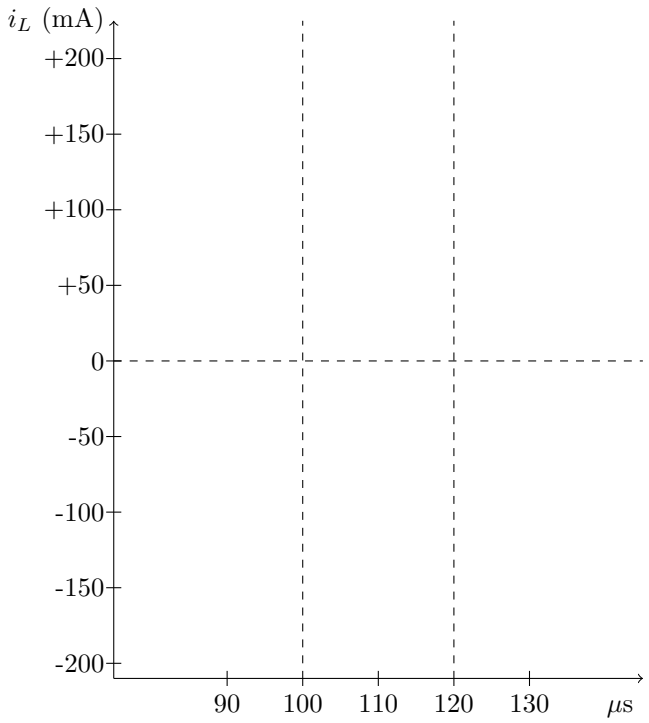
| Q | | # |
|---|---|---|
| 1a | /5 | |
| 1b | /5 | |
| 1c | /5 | |
| 1d | /5 | |
| 2a | /5 | |
| 2b | /5 | |
| 2c | /5 | |
| 2d | /5 | |
| 3a | /5 | |
| 3b | /5 | |
| 3c | /5 | |
| 3d | /5 | |
| 4a | /10 | |
| 4b | /5 | |
| Tot | /75 | |

Q1a: Electrical Isolation

Electrical safety is obviously an important factor in biomedical electronics. Below a relay is used which is rated to provide 1 kV of electrical isolation. The terminals C, D and E switch mains power (120 V AC).

1. (5 marks) Describe (1 sentence) how the a relay provides electrical isolation, and indicate the line of electrical isolation in the circuit below.
2. (5 marks) If a drink is poured over the right side of the circuit (possibly creating shorts between terminals C, D and E), what protection can the relay offer (1–2 sentences)?
3. (5 marks) Initially switch S1 is closed. At $t = 100\,\mu$s, S1 is opened. Sketch the current in the inductor, $i_L$, as a function of time (on the graph).
4. (5 marks) Describe the role of the diode, and indicate when it is active (on the graph).



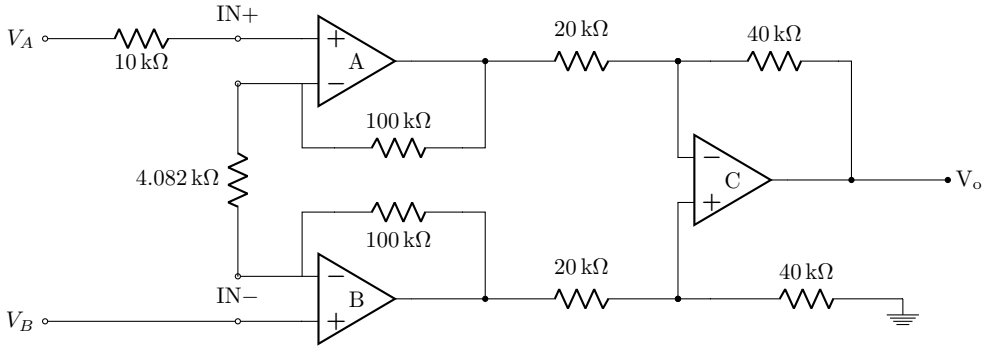
Q2a: Consider the following instrumentation amplifier (IA) connected to two sources ($V_A$ with an output impedance, and ($V_A$ with no output impedance). Initially, Op amps are ideal, with power supply, $V_{EE} = -15\,V$ and $V_{CC} = 15\,V$.

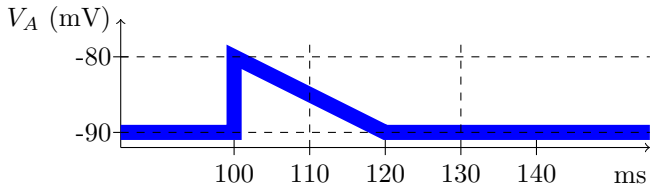
(a) (5 marks) Identify which components in the circuit are part of the IA. Describe why (1 sentence) the resistors are laser-trimmed to have matched values (or as close as possible)?

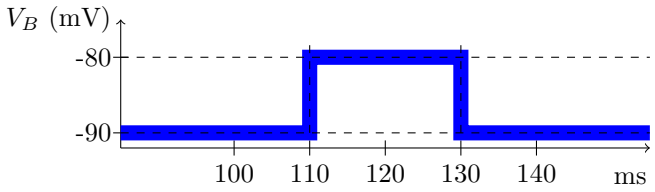
(b) (5 marks) What is the gain of the IA?

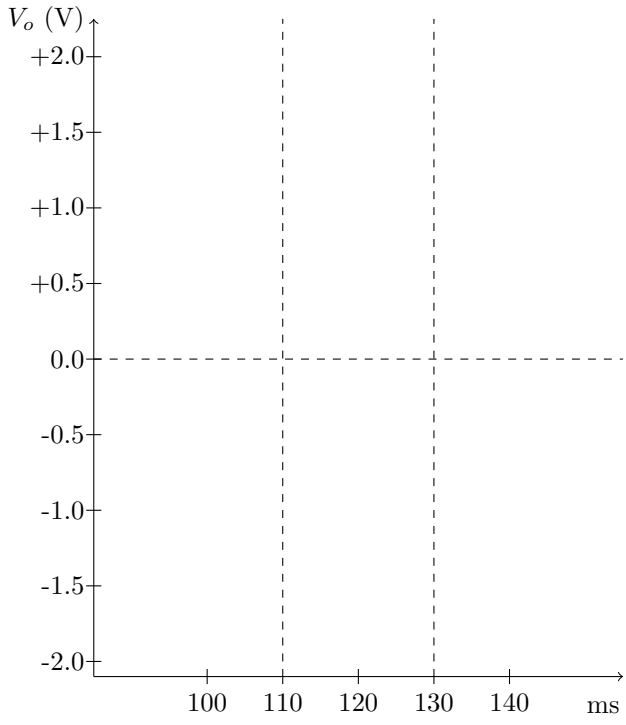
(c) (5 marks) Given an ideal IA, calculate and sketch the output, $V_o$, for the inputs $V_A$ and $V_B$ shown.

(d) (5 marks) Now consider that opamps A and B in the IA have an $I_B = 0.5\,\mu A$ (opamp C is still ideal). Calculate and sketch the output, $V_o$, for the inputs $V_A$ and $V_B$ shown (on the same graph)

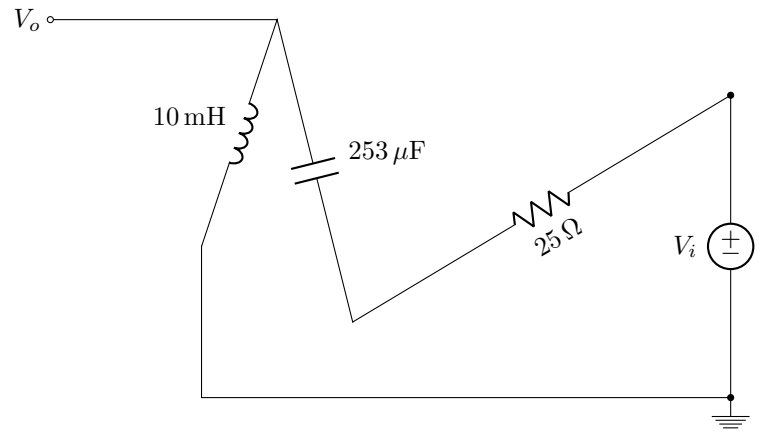


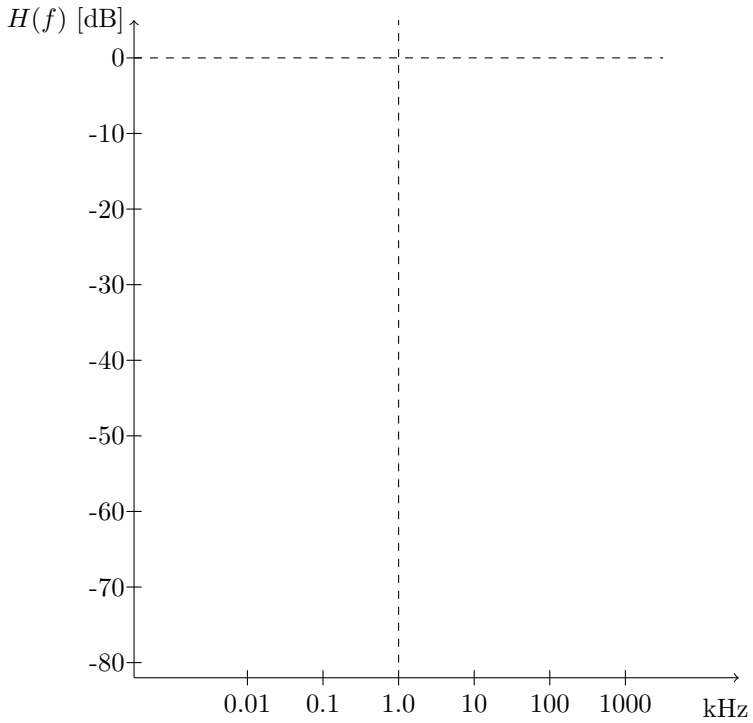



Q3a: (a) (5 marks) What type of filter is this? (high pass, low pass, band pass, band stop)
(b) (5 marks) What is the cut-off frequency ($f_c$) and damping constant ($\zeta$)?
(c) (5 marks) Sketch the amplitude of $H(f) = \frac{V_o}{V_i}$ as a function of frequency. Label the passband, stopband and roll-off rate.
(d) (5 marks) If the circuit is over-, under- or critically-damped, indicate this on the graph of $H(f)$.

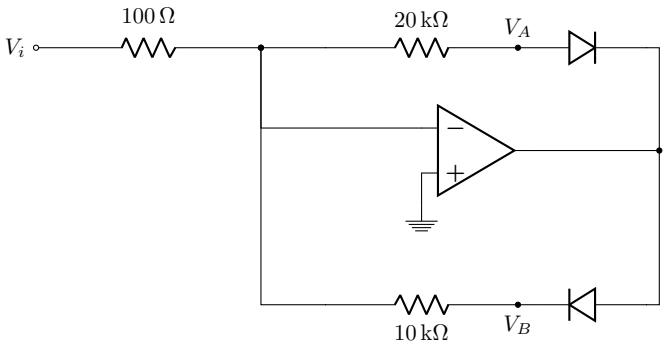


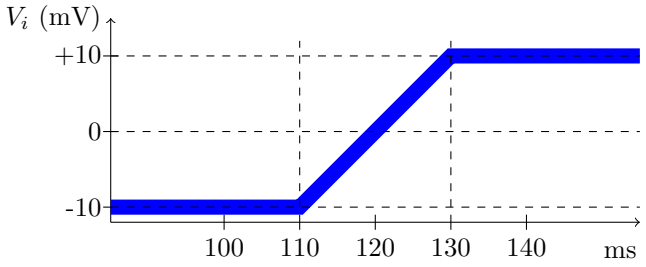



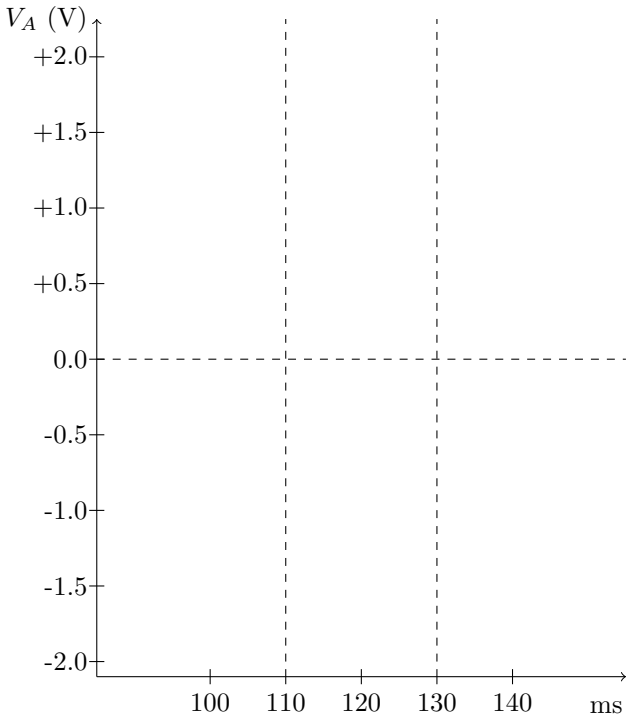
Q4a: Op amps are ideal, with power supply, $V_{EE} = -15\,V$ and $V_{CC} = 15\,V$.

(a) (10 marks) For the input $V_i$ shown, calculate and graph the signal $V_A$.

(b) (5 marks) What is envelope detection? Describe (1–2 sentences) why a rectifier is necessary for envelope detection.



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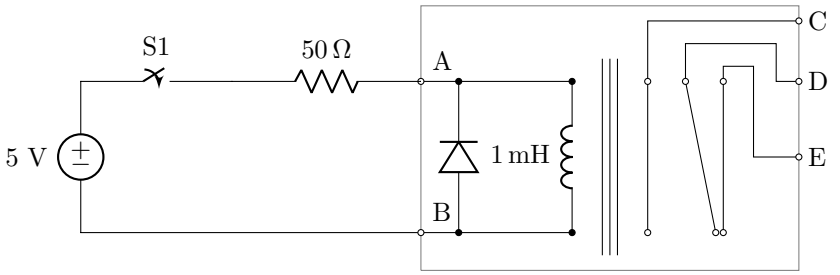
|---|---|---|---|---|---|---|---|---|---|---|---|
| FILTER = Chebychev 0.05dB | | | | | | | | | | | |
| 2 | 21.58 | 68.23 | 215.77 | 2.162 | 0.668 | | | | | | |
| 4 | 3.37 | 5.89 | 10.42 | 0.885 | 0.833 | 1.221 | 0.250 | | | | |
| 6 | 1.90 | 2.67 | 3.85 | 0.569 | 0.860 | 0.870 | 0.412 | 1.091 | 0.120 | | |
| 8 | 1.48 | 1.86 | 2.39 | 0.422 | 0.870 | 0.670 | 0.464 | 0.912 | 0.228 | 1.050 | 0.069 |
| FILTER = Chebychev 0.10dB | | | | | | | | | | | |
| 2 | 18.11 | 57.28 | 181.13 | 1.820 | 0.652 | | | | | | |
| 4 | 3.10 | 5.41 | 9.55 | 0.789 | 0.808 | 1.153 | 0.229 | | | | |
| 6 | 1.81 | 2.54 | 3.64 | 0.513 | 0.834 | 0.834 | 0.375 | 1.063 | 0.108 | | |
| 8 | 1.43 | 1.79 | 2.30 | 0.382 | 0.843 | 0.645 | 0.423 | 0.894 | 0.204 | 1.034 | 0.062 |
| FILTER = Chebychev 0.20dB | | | | | | | | | | | |
| 2 | 15.21 | 48.08 | 152.05 | 1.535 | 0.628 | | | | | | |
| 4 | 2.85 | 4.95 | 8.75 | 0.701 | 0.774 | 1.095 | 0.205 | | | | |
| 6 | 1.72 | 2.40 | 3.44 | 0.460 | 0.799 | 0.803 | 0.335 | 1.038 | 0.095 | | |
| 8 | 1.39 | 1.73 | 2.21 | 0.343 | 0.807 | 0.623 | 0.377 | 0.878 | 0.179 | 1.021 | 0.054 |
| FILTER = Chebychev 0.50dB | | | | | | | | | | | |
| 2 | 11.99 | 37.84 | 119.67 | 1.231 | 0.579 | | | | | | |
| 4 | 2.55 | 4.42 | 7.78 | 0.597 | 0.709 | 1.031 | 0.170 | | | | |
| 6 | 1.61 | 2.23 | 3.19 | 0.396 | 0.731 | 0.768 | 0.276 | 1.011 | 0.077 | | |
| 8 | 1.33 | 1.64 | 2.09 | 0.297 | 0.739 | 0.599 | 0.310 | 0.861 | 0.144 | 1.006 | 0.043 |
| FILTER = Chebychev 1.00dB | | | | | | | | | | | |
| 2 | 9.95 | 31.41 | 99.31 | 1.050 | 0.523 | | | | | | |
| 4 | 2.34 | 4.03 | 7.08 | 0.529 | 0.637 | 0.993 | 0.140 | | | | |
| 6 | 1.54 | 2.11 | 3.01 | 0.353 | 0.657 | 0.747 | 0.227 | 0.995 | 0.062 | | |
| 8 | 1.29 | 1.58 | 2.01 | 0.265 | 0.664 | 0.584 | 0.256 | 0.851 | 0.117 | 0.997 | 0.035 |
| FILTER = Chebychev 2.00dB | | | | | | | | | | | |
| 2 | 8.13 | 25.59 | 80.91 | 0.907 | 0.443 | | | | | | |
| 4 | 2.14 | 3.65 | 6.41 | 0.471 | 0.538 | 0.964 | 0.109 | | | | |
| 6 | 1.46 | 1.99 | 2.82 | 0.316 | 0.555 | 0.730 | 0.176 | 0.983 | 0.048 | | |
| 8 | 1.25 | 1.52 | 1.93 | 0.238 | 0.560 | 0.572 | 0.197 | 0.842 | 0.090 | 0.990 | 0.027 |

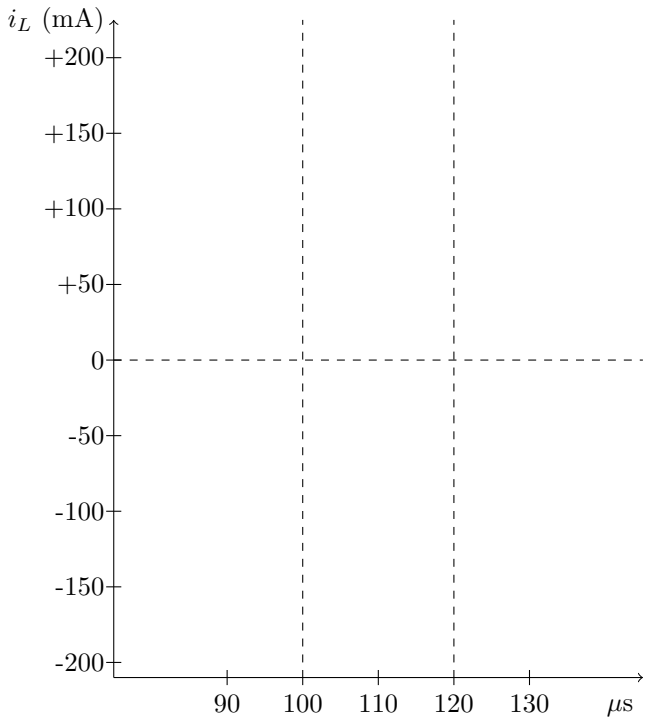
| Q | | # |
|---|---|---|
| 1a | /5 | |
| 1b | /5 | |
| 1c | /5 | |
| 1d | /5 | |
| 2a | /5 | |
| 2b | /5 | |
| 2c | /5 | |
| 2d | /5 | |
| 3a | /5 | |
| 3b | /5 | |
| 3c | /5 | |
| 3d | /5 | |
| 4a | /10 | |
| 4b | /5 | |
| Tot | /75 | |

Q1b: Electrical Isolation

Electrical safety is obviously an important factor in biomedical electronics. Below a relay is used which is rated to provide 1 kV of electrical isolation. The terminals C, D and E switch mains power (120 V AC).

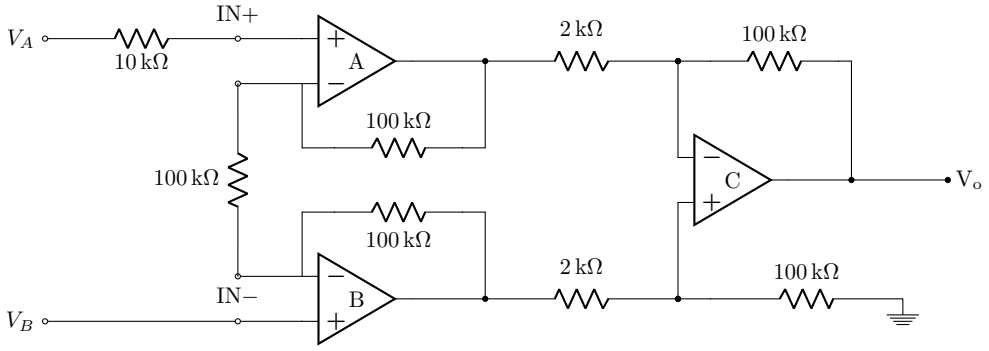
1. (5 marks) Describe how a relay works (1 sentence); what happens when current is applied?
2. (5 marks) Describe (1 sentence) how the a relay provides electrical isolation, and indicate the line of electrical isolation in the circuit below.
3. (5 marks) Initially switch S1 is open. At $t = 100\,\mu$s, S1 is closed. Sketch the current in the inductor, $i_L$ vs time ($t$). Calculate and show any relevant time constants.
4. (5 marks) The relay switches when $i_L = 50\,$mA. At what time does this switch occur?

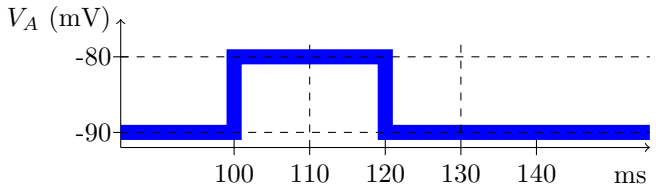


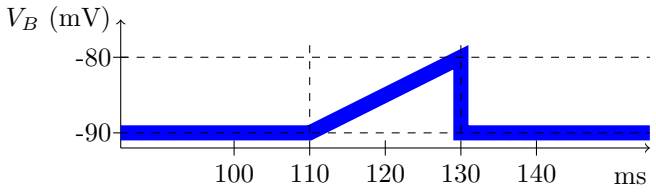



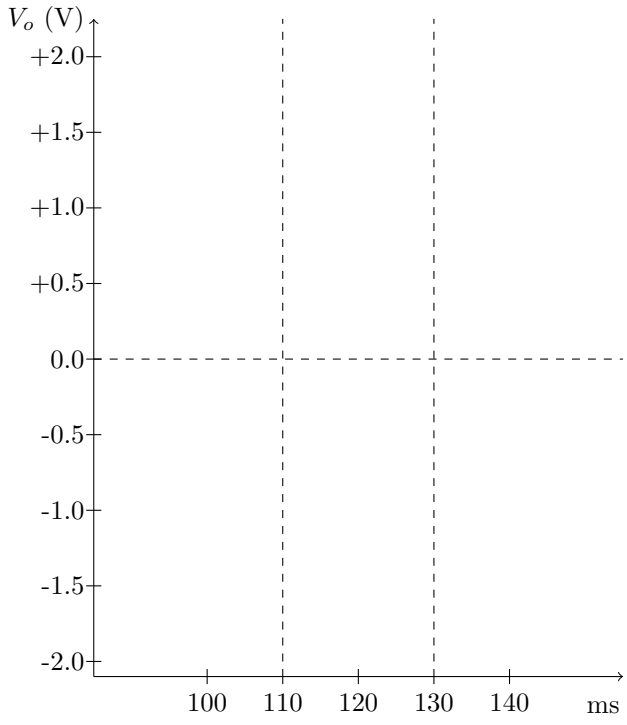
Q2b: Consider the following instrumentation amplifier (IA) connected to two sources ($V_A$ with an output impedance, and ($V_A$ with no output impedance). Initially, Op amps are ideal, with power supply, $V_{EE} = -10\,V$ and $V_{CC} = 10\,V$.

(a) (5 marks) What is the gain of the IA?
(b) (5 marks) Identify which components in the circuit are part of the IA. Describe one benefit (1 sentence) of the IA design (over a difference amplifier).
(c) (5 marks) Given an ideal IA, calculate and sketch the output, $V_o$, for the inputs $V_A$ and $V_B$ shown.
(d) (5 marks) Now consider that opamp C the IA has $V_{OS} = 5\,mV$ (opamps A and B are still ideal). Calculate and sketch the output, $V_o$, for the inputs $V_A$ and $V_B$ shown (on the same graph)

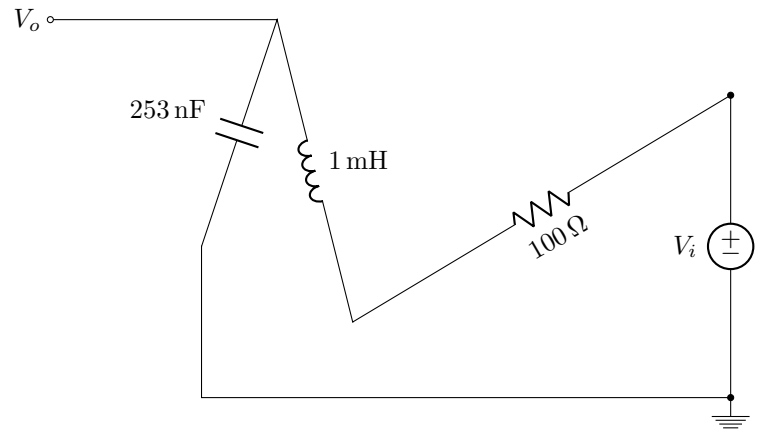


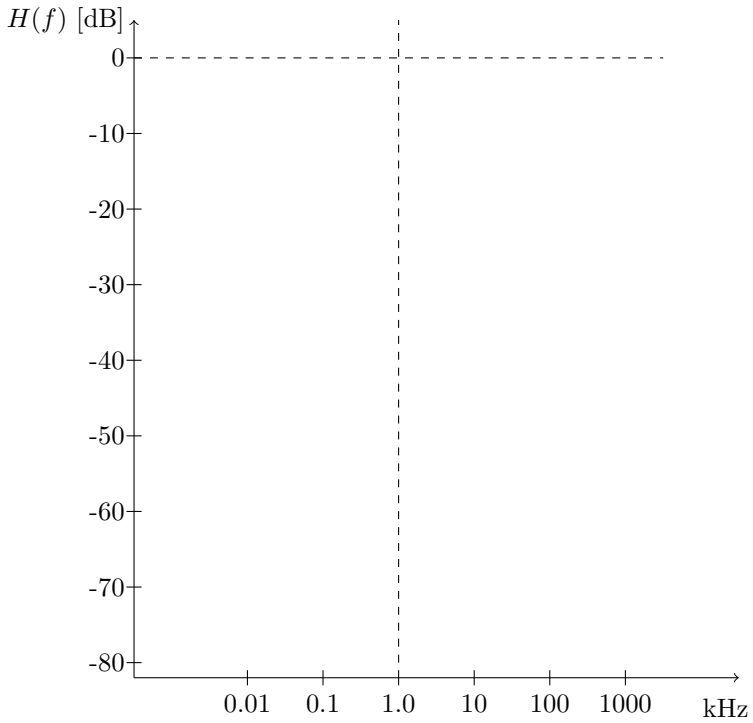



Q3b: (a) (5 marks) What type of filter is this? (high pass, low pass, band pass, band stop)
(b) (5 marks) What is the cut-off frequency ($f_c$) and damping constant ($\zeta$)?
(c) (5 marks) Sketch the amplitude of $H(f) = \frac{V_o}{V_i}$ as a function of frequency. Label the passband, stopband and roll-off rate.
(d) (5 marks) If the circuit is over-, under- or critically-damped, indicate this on the graph of $H(f)$.

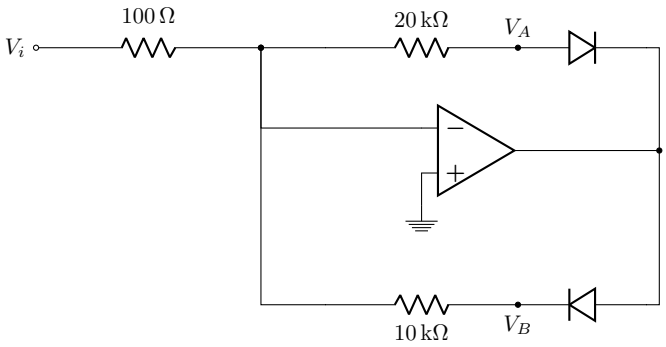


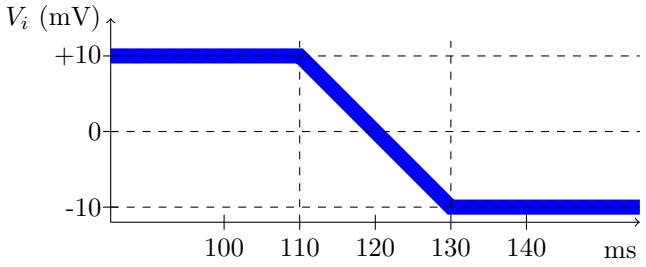



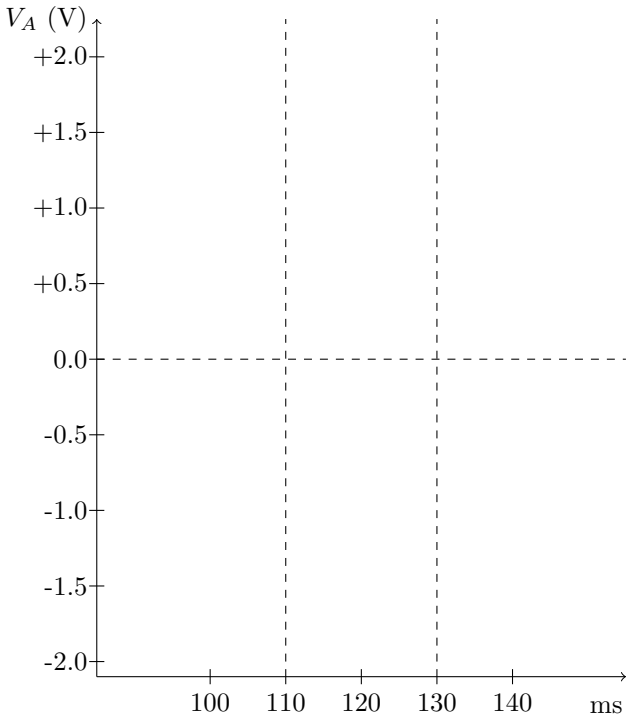
Q4b: Op amps are ideal, with power supply, $V_{EE} = -10\,V$ and $V_{CC} = 10\,V$.

(a) (10 marks) For the input $V_i$ shown, calculate and graph the signal $V_B$.

(b) (5 marks) What is envelope detection? Describe (1–2 sentences) why a rectifier is necessary for envelope detection.



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