EAS327 "Environmental Instrumentation" Mid-term 13 Feb,2003

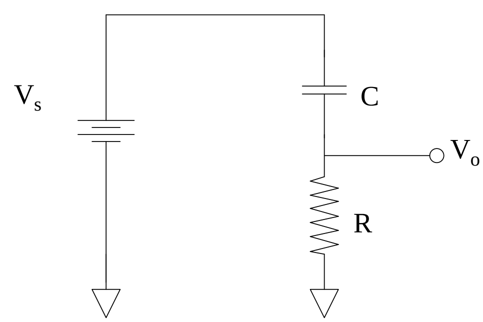
Professor: J.D. Wilson Time available: 80 mins Value: 15%

Instructions: Closed book exam. Please record your answers in the exam booklet. Pertinent data are given on back page, and should be scanned before answering any questions.

Multi-choice (10 x $\frac{1}{2}$% → 5%)

1. In the circuit shown, in which the capacitor and resistor constitute a high-pass RC filter, the battery voltage V_s is constant. The steady-state output voltage V_o relative to the floating ground is[1]

   (a) infinite
   (b) fluctuating
   (c) V_s
   (d) zero ✓✓
   (e) none of the above



2. If the battery is replaced by an alternating voltage source $V_s(t)$ generating a sine wave having frequency f, then if f is infinitely-large, the output voltage $V_o(t)$ relative to the floating ground is[2]

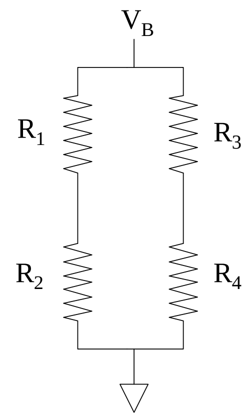
   (a) infinite
   (b) steady
   (c) $V_s(t)$ ✓✓
   (d) zero
   (e) none of the above

3. If the capacitor in the above circuit is replaced by a resistor identical to the other (R), then (irrespective of whether the supply voltage is steady or oscillating) V_o/V_s is

   (a) 0
   (b) 1/2 ✓✓
   (c) 1
   (d) undefined
   (e) none of the above

[1]Hint: a capacitor offers infinite resistance to a steady current.
[2]Hint: a capacitor offers zero resistance to rapidly alternating current.

4. This Wheatstone Bridge is balanced if



   (a) $R_1 R_2 = R_3 R_4$
   (b) $R_1 R_3 = R_2 R_4$
   (c) $R_1 R_4 = R_2 R_3$ ✓✓
   (d) $V_B = 0$
   (e) all of the above

5. The equation $Q_{Hx} = -k\,\frac{dT}{dx}$, where dT/dx is a temperature gradient, expresses

   (a) Newton's law of viscosity
   (b) Fourier's law of conduction ✓✓
   (c) Fick's law of diffusion
   (d) all of the above
   (e) none of the above

6. If a thermocouple having Seebeck coefficient $N = 60$ [μV K^{-1}] is read by a voltage receiver having offset (ie. zero-error) $V_{os} = 30\ \mu$V, the magnitude of the error induced in each reading of temperature difference is ____ [K]

   (a) $\frac{1}{2}$ ✓✓
   (b) 1
   (c) 2
   (d) 30
   (e) 60

7. A certain resistance thermometer has a linear $R - T$ characteristic, ie. its resistance $R = R(T)$ varies linearly with temperature according to the equation

$$R = R(T_0)\ [1 +\ \alpha\ (T - T_0)\ ]$$

   If this device is placed in a half-bridge, the voltage-temperature characteristic $V_o(T)$ will be

   (a) the same as that of an RC-lowpass filter
   (b) very sensitive
   (c) offset by an amount T_0
   (d) linear
   (e) non-linear ✓✓

8. If an a.c. voltage has amplitude A, the mean-square voltage is $A^2/2$. Given that the familiar "110 volts" designation for mains power actually cites the "root-mean-square" (r.m.s.) voltage, the voltage *amplitude* at an ordinary mains power outlet must be ____ [volts].

   (a) 440
   (b) 220
   (c) 110
   (d) $110/\sqrt{2}$
   (e) $110\sqrt{2}$ ✓✓

9. Regarding an ordinary 3-pin power outlet, ____ pins are connected to earth-ground (power-line ground) while ____ pins are "hot" (110 volts r.m.s.) relative to power-line ground.

   (a) 1; 2
   (b) 1; 1
   (c) 3; 1
   (d) 2; 2
   (e) 2; 1 ✓✓

10. The purpose of short-circuiting the input to a digital voltmeter or data-logger, and noting the indicated measurement (N), is to ____

    (a) remove any common mode voltage
    (b) assess the necessary full scale range setting
    (c) ground the input
    (d) float the input
    (e) ascertain the "zero reading" for subsequent corrections ✓✓

Short Answer/Calculation (5 %)

Answer **one** question from this section. Give diagrams where appropriate to clarify your working, which should be shown. Justify any assumptions or simplifications you make.

1. Suppose a dry aspen leaf (represented as a thin disc of diameter $d = 0.05$ m) is measured to be 0.2^oC warmer than the wind, which is blowing over the leaf at speed $U = 1$ m s^{-1}. Calculate the net radiative heat load on the leaf, Q^*. Assume the air has density $\rho = 1$ kg m^{-3}; for other details see data at end of paper.

   or

2. Draw a tidy and complete circuit schematic representing a half-bridge (resistors R_1, R_2) that is driven by a floating voltage source (internal resistance R_s), and whose output voltage V_o (voltage relative to ground measured at the node between R_1, R_2) is monitored by a single-ended voltage receiver (input resistance R_{in}).

Long Answer (5 %)

Write up to two pages, including diagrams, on **one** of the topics given. Please give a well-constructed and interesting response, in good English (good organization, good spelling, good grammar), using essay- or point-by-point style, and based around a small number of key points.

1. Suppose you are given a function generator capable of producing a sine wave of fixed amplitude A_s and (any) arbitrary frequency f. You are also given an oscilloscope, a resistor of known resistance R, and a capacitor of *unknown* capacitance C. Using appropriate diagrams and explanations, describe how, using the given supplies, you might determine the value of C. (Hint: use the properties of the RC lowpass filter, concerning which some data are given at the back of the exam).

   or

2. Write an essay explaining in what sense there is "commonality" in the behaviors of a lowpass RC filter, and an ordinary thermometer (in other words, explore the parallels between these systems). This is probably easiest done by focusing on the *step response* (see relevant data at back of exam).

Data:

- Kinematic viscosity of air: $\nu \approx 1.5 \text{ x } 10^{-5}$ $[m^2 s^{-1}]$
- Thermal diffusivity[3] of air: $\kappa \equiv D_H \approx 2.1 \text{ x } 10^{-5}$ $[m^2 s^{-1}]$
- Specific heat capacity of air at constant pressure: $c_p \approx 1000$ $[J\ kg^{-1} K^{-1}]$
- $C\ \frac{dT}{dt} = A\ (\ Q^* + Q_H + Q_E\ ) +\ P$

  Energy balance for a thermometer having bulk heat capacity C and surface area A The Q's are (left-to-right) the net radiative, sensible, and latent heat flux densities (W m^{-2}), and P is (any) internal heating.

- $\frac{dV_o}{dt} = \frac{V_s(t) - V_o}{\tau}$

  Differential equation giving the relationship between the output $V_o(t)$ from a lowpass RC filter (time constant $\tau = RC$) and the input $V_s(t)$. The particular case of the "step response" corresponds to the specification: at $t = 0$, $V_o = V_s = 0$, while for $t > 0$, $V_s =$ constant.

- $y(t) = Y_2 +\ (Y_1 - Y_2)\ \exp\left(-\ \frac{t}{\tau}\right)$

  Response of a 1^{st} order (RC lowpass type) system to step $Y_1 \rightarrow Y_2$ in input.

- $Q_H = \rho\ c_p\ \frac{T_1 - T_2}{r_H}$

  Ohm's law model for sensible heat exchange.

- $r_H = \frac{d}{D_H N_u}$ $[s\ m^{-1}]$

  Resistance r_H for heat transfer.

- $N_u = 0.6\ R_e^{0.5}\ (R_e \leq 2 \text{ x } 10^4), N_u = 0.032\ R_e^{0.8}\ (R_e > 2 \text{ x } 10^4)$

  Nusselt number for a thin disc (diameter d) in air, assuming forced convection.

- $G(f) = \left(\frac{A_o}{A_s}\right)^2 = \frac{1}{1 + (f/f_0)^2}$

  "Power gain" (ie. ratio of square of output amplitude A_o to square of input amplitude A_s) of an RC lowpass filter having half-power frequency $f_0 = \frac{1}{2\pi RC}$.

[3]Symbols κ, D_H are both used for this quantity.