EAS327 "Environmental Instrumentation" Mid-term 10 Feb,2004

Professor: J.D. Wilson Time available: 80 mins Value: 20%

Instructions: Closed book exam. Please record your answers in the exam booklet. Pertinent data and diagrams are at the back, and should be read before answering any questions.

Multi-choice (20 x $\frac{1}{2}$% → 10%)

1. The circuit shown in Figure (1) is known as a
   - (a) lowpass RC filter
   - (b) highpass RC filter
   - (c) Wheatstone bridge
   - (d) Half-bridge or voltage divider ✓✓
   - (e) Error-detector

2. In a rigorous interpretation of Figure (1), the internal resistance of the voltage supply should be considered to have been
   - (a) ignored
   - (b) subtracted from the supply voltage V
   - (c) added to the output voltage V_o
   - (d) lumped with R_1
   - (e) lumped with R_2 ✓✓

3. Referring to Figure (1), if $V_o = 2$ V and $R_1 = R_2 = 7.5$ KΩ, then the supply voltage V is ____ volts
   - (a) 7.5
   - (b) 7.5/2
   - (c) 4 ✓✓
   - (d) 2
   - (e) 1

4. Referring to Figure (1), if $V_o = 2$ V and $R_1 = R_2 = 1$ KΩ, then the current through R_1 is _____ amps

   (a) 0
   (b) 0.5
   (c) 0.5 x 10^{-3}
   (d) 1x 10^{-3}
   (e) 2 x 10^{-3} ✓✓

5. Referring to Figure (1), if $V = 12$ V and $R_1 = 5$ KΩ and $R_2 = 15$ KΩ, then the output voltage V_o is _____ volts

   (a) 12
   (b) 8
   (c) 4
   (d) 3 ✓✓
   (e) 1

6. If the output from Figure (1) is to be taken to a 12 bit datalogger with Full Scale Range ± 5 volts, then the smallest detectable change in output voltage δV_o is _____ volts

   (a) 1.22 x 10^{-3}
   (b) 2.44 x 10^{-3} ✓✓
   (c) 1
   (d) 1.22
   (e) 2.44

7. If in Figure (1) $R_2 = 10$ KΩ but the current through R_2 is zero, then

   (a) $V_o = V$
   (b) $R_1 = \infty$
   (c) $V_o = 0$
   (d) $R_1 = 0$
   (e) both (a) and (b) are true ✓✓

8. If in Figure (2) $\tau = RC = 10^{-3}$ sec, then the half-power frequency f_o is
   (a) 1000 Hz
   (b) 1000 KHz
   (c) 159 Hz ✓✓
   (d) 159 KHz
   (e) none of the above

9. If the frequency of the input sine wave in Figure (2) is $f >> f_o$ then the output amplitude V_o is
   (a) V_s
   (b) $V_s/\sqrt{2}$
   (c) 1
   (d) 1/2
   (e) ≈ 0 ✓✓

10. If the frequency of the input sine wave in Figure (2) is $f \equiv f_o$ then the output amplitude V_o is
    (a) V_s
    (b) $V_s/2$
    (c) $V_s/\sqrt{2}$ ✓✓
    (d) 1/2
    (e) ≈ 0

11. With reference to Figure (3), the condition that $\frac{R_1}{R_1+R_2} = \frac{R_3}{R_3+R_4}$ has the result that
    (a) the bridge is in balance
    (b) $V^- = V^+$
    (c) the error voltage vanishes
    (d) $R_1R_4 = R_2R_3$
    (e) all of the above ✓✓

12. Suppose a data-logger displays a number N representing the voltage $V^+ - V^-$ across its two input terminals, and that it can be assumed that the logger is "linear," ie., that $N = \alpha(V^+ - V^-) + \beta$. Furthermore, suppose the Full Scale Range (FSR) of the logger is $FSR = \pm 10$ volts. If we measure a reading N^+ when $V^+ - V^-$=10.0 volts, and a reading N^- when $V^+ - V^- = -10.0$ volts, then the quantity $(N^+ - N^-)/20.0$ is

 (a) the "offset" of the logger, β
 (b) zero
 (c) variable
 (d) the sensitivity, α ✓✓
 (e) none of the above

13. Consideration of the energy balance of an ordinary (and dry) thermometer leads to the conclusion that the "system output", ie. the thermometer temperature T, responds to *several* environmental inputs, including air temperature T_a, air motion (eg. wind speed U), and the radiation environment as characterized by incoming solar radiation ($K \downarrow$), etc. Thus in general the measured temperature $T = T(T_a, U, K \downarrow, ...)$. However a steady-state response to T_a alone, ie. a response $T = T(T_a)$ at steady state, is assured

 (a) since this is a first-order, linear system
 (b) only if the radiation exchange term Q^* can be eliminated ✓✓
 (c) only if the time constant is short
 (d) only if the time constant is long
 (e) only if the thermometer s held in still air ($U = 0$)

14. Which of the following does not apply to the thermocouple

 (a) floating voltage source
 (b) internal resistance $R_s = 0$ ✓✓
 (c) responds *linearly* to temperature *difference*
 (d) difficult to measure, microvolt (μV)-level signal
 (e) sensitivity N (units, μV K^{-1}) known as the "Seebeck coefficient"

15. A "floating differential voltage receiver" has two inputs labelled V^+, V^-. Which of the following statements is untrue

 (a) the resistance from either terminal to powerline-ground is infinite
 (b) the resistances from the terminals to receiver common are large and equal
 (c) the resistance from one terminal to the other is small (ideally, zero) ✓✓
 (d) the resistance from one terminal to the other is large (ideally, infinite)
 (e) the common mode voltage relative to the receiver common is $(V^+ + V^-)/2$, ie. half the sum of the voltages applied at the terminals

16. If a potential drop V occurs across a resistance R, such that a current i flows, then the rate of power dissipation in the resistor (P) is

   (a) iR [volts]

   (b) V^2/R [Joules]

   (c) i^2R [Watts]

   (d) V^2/R [Watts]

   (e) both (c) and (d) are correct ✓✓

17. A lowpass filter has frequency-dependent power gain $G(f)$. If the input to this filter is a sinusoidal signal $x(t) = A_{in} \sin(2\pi f t)$, the output from the filter will be:

   (a) sinusoidal, but with the frequency doubled

   (b) sinusoidal, but with the frequency halved

   (c) sinusoidal, with the infinitely high frequency

   (d) sinusoidal, with the infinitely low frequency

   (e) sinusoidal, with the same frequency, and with amplitude $\sqrt{G}A_{in}$ ✓✓

18. A tank, of volume D^3, is kept in a well-stirred condition by a powerful fan, and initially contains a pure gas "A." At $t = 0$ it begins to be flushed by an inflow (volumetric flow rate Q [$\mathrm{m}^3\ \mathrm{s}^{-1}$]) of pure gas "B," that displaces (at equal rate) mixed gas through an outlet. The transition of the tank's contents from "pure A" to "pure B" takes place with time constant

   (a) $(A - B)/Q$

   (b) $A - B$

   (c) D^3/Q ✓✓

   (d) Q/D^3

   (e) $A - BD^3/Q$

19. Given two identical thermistors R_{1T}, R_{2T} and two identical control resistors R_{1c}, R_{2c}, a differential temperature sensor could be constructed by placing ____ in the full bridge shown in Figure (4).

   (a) one thermistor in each of slots 1,2

   (b) one thermistor in each of slots 3,4

   (c) one thermistor in each of slots 1,3

   (d) one thermistor in each of slots 2,4

   (e) both (c) and (d) would work ✓✓

20. If the governing equation for a ψ-sensor is an o.d.e. of form

$$\frac{d\psi}{dt} = \frac{\psi_0 - \psi}{\tau} \tag{1}$$

where t is time and τ is a property of the sensor, then we may say

(a) the sensor is a linear device

(b) the sensor is a first-order system

(c) the sensor has time constant τ

(d) $\psi_0(t)$ is the input and $\psi(t)$ the response of the sensor

(e) all of the above ✓✓

Short Answer (10 %)

Answer any **two** questions 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 cyclist is riding at $U = 5$ m s^{-1} on a calm morning when the air temperature is $T_a = 2^o$ C. S/he has forgotten to wear gloves, and his/her hands are very cold due to convective heat loss. Treating the hand as a sphere of diameter $d = 8$ cm, and assuming forced convection and that the skin surface temperature $T_s = 10^o$ C, compute the rate of loss of heat (J s^{-1}) from each hand. Compute the density ρ using the ideal gas law, assuming the pressure $P = 100$ kPa.

   Noting that core body temperature $T_c = 37^o$ C, draw a heat transfer "circuit" (for which driving forces are temperature differences and heat fluxes are moderated by transfer resistances) that could serve as a model for an assessment of how reasonable is the assumption that the outer surface of the hand has temperature $T_s = 10^o$ C.

2. Draw a tidy and complete circuit schematic representing a Wheatstone bridge (resistors R_1, R_2, R_3, R_4), that is driven by a grounded voltage source (no-load voltage V_s, internal resistance R_s), and whose error voltage ΔV is monitored by a balanced (ie. differential), grounded receiver (input resistances to ground R_{in}).

3. Using a diagram composed of the usual circuit symbols, explain the procedure by which, given a battery whose voltage is known to be exactly $V_s = 1.35$ volts and access to whatever tools and hookup wire you wished, you would perform a 3-point calibration check of a datalogger having full scale range ± 5 volts (ie. determine the data-logger readings corresponding to 3 known voltages). You may neglect the internal resistance of the battery, since it will be negligible compared to the logger's input resistance.

Data:

- Voltage resolution δV of an n-bit recorder with full scale range $\pm N$ is

$$\delta V = \frac{2N}{2^n \ - \ 1} \tag{2}$$

- $P = \rho \, R \, T$

  The ideal gas law. P [Pascals], pressure; ρ, [$kg \ m^{-3}$] the density; T [Kelvin], the temperature; and $R = 287 \quad [J \ kg^{-1} \ K^{-1}]$, the specific gas constant for air).

- Kinematic viscosity of air: $\nu \approx 1.5 \text{ x } 10^{-5} \ [m^2 s^{-1}]$

- Thermal diffusivity[1] 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.

- $N_u = 2 + 0.54 \, R_e^{0.5} \ (R_e \leq 300), N_u = 0.34 \, R_e^{0.6} \ (50 \leq R_e \leq 1.5\text{x}10^5)$

  Nusselt number for a sphere in air (forced convection).

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

  Resistance r_H for heat transfer.

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

  "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 $f_0 = \frac{1}{2\pi RC}$.

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

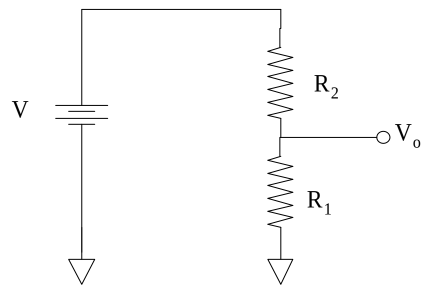

Figure 1: For this circuit it is implicit that no current is drawn from the output terminal. The output voltage $V_o = V\,\frac{R_1}{R_1+R_2}$

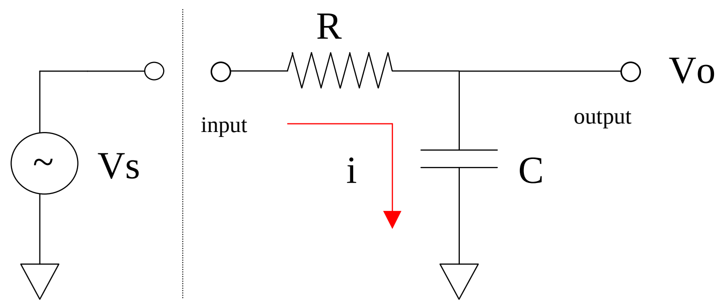

Figure 2: RC circuit driven by a sine wave generator (amplitude V_s), where again, it is implicit that no current is drawn from the output terminal. The amplitude V_o at the output terminal can be computed from $V_o^2 = V_s^2/\left[1 + (f/f_o)^2\right]$ where $f_o = \frac{1}{2\pi RC}$ is the "half-power frequency".

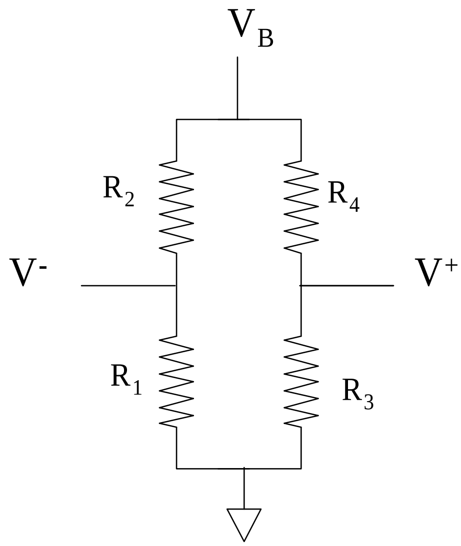

Figure 3: Error detection circuit. The "error voltage" is $V^{+} - V^{-}$.

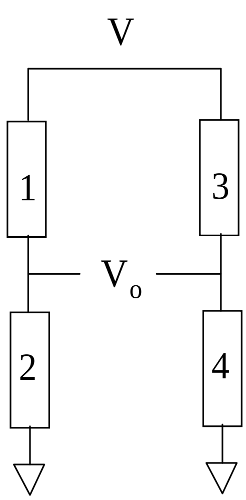

Figure 4: Template for construction of a differential temperature sensor.