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The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-2016 (2 hours)

EEE217 Avionic Systems

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** According to their role and function, avionic subsystems are divided into a number of groups. What are these groups?

(5)

b. For a certain aircraft the Mach number is $M = 0.6$, the calibrated airspeed $V_c = 500$ km/h and the static temperature $T_s = 255\,^{o}$K:

i. Calculate the altitude H and the true airspeed V_T.

ii. Calculate the total air pressure P_T.

(6)

c. When the aircraft is flying at a higher altitude H=12192m (40000ft), the true airspeed is V_T= 900 km/h and the static pressure is P_s=18.82 kPa:

i. Calculate the static air temperature T_s and the Mach number M.

ii. Calculate the impact pressure Q.

iii. Calculate the calibrated air speed V_c.

(9)

Gas constant for unit mass of dry air : R_a =287.0529 J/^{o}K .kg

$$\textit{Impact pressure} = P_0\left(\left(1+\frac{(\gamma-1)(V_c/A_0)^2}{2}\right)^{\gamma/(\gamma-1)}-1\right) \quad \textit{and} \quad \frac{P_T}{P_s} = \left(1+\frac{(\gamma-1)}{2}M^2\right)^{\frac{\gamma}{(\gamma-1)}}$$

$$\gamma = \frac{\text{specific heat of air at constant pressure}}{\text{specific heat of air at constant volume}}$$ and P_T is the total pressure.

<u>At sea level:</u> the static pressure P_0 =101.325 kPa, the absolute static air temperature is T_0 =288.15 ^{o}K, and the air density ρ_0 =1.225 kg/m^3.

2. **a.** For a 4-channel redundant configuration, give the number of failures which can be tolerated:

i. When each channel is equipped with a monitor which detects failures.

ii. When the output of the channels is compared and a non-adaptive majority voting scheme is adopted.

iii. When the output of the channels is compared and an adaptive majority voting scheme is adopted.

(6)

b. An electronic unit has 3 circuits, circuit 1, circuit 2 and circuit 3. Table 2.1 (page 3) gives the constant failure rates of the components used in the three circuits and the number of each component used in each circuit. Assuming that the unit will fail if one of the circuits fails and that a circuit fails if one of its components fails:

i. Show that the failure rate of the electronic unit is $\lambda = 883 \times 10^{-9}$/hour, and calculate the mean time to failure, *MTTF*, of the electronic unit.

ii. Calculate the probability of failure of the electronic unit during a 15-hour operation.

To meet stricter reliability requirements, an *n*-unit redundancy configuration is used:

iii. Calculate the probability of losing the function of the unit during a 15-hour operation, when *n*=3 and failure is detected using a majority voting scheme.

iv. Calculate the *MTTF* of the 3-unit redundancy configuration.

v. Calculate the probability of losing the function of the electronic unit during a 15-hour operation, when *n* = 2, and failure is detected using monitors, and only 1 unit is active at a time.

vi. Show that for the 2-unit redundancy configuration the hazard rate is not constant and that it would not exceed the failure rate of the electronic unit. **(14)**

<u>*The following may be assumed:*</u>

Reliability function for <u>*m-out-of-n system (active):*</u> $R(t) = \sum_{k=m}^{n} \frac{n!}{k!(n-k)!} \left[e^{-\lambda k t}\right]\left[1 - e^{-\lambda t}\right]^{n-k}$

Reliability function for <u>*m-out-of-n system (passive):*</u> $R(t) = e^{-\lambda m t} \sum_{k=m}^{n} \frac{(m \lambda t)^{k-m}}{(k-m)!}$

In general the mean time to failure is given by: $MTTF = \int_0^{\infty} R(t)\,dt$

In general the hazard rate is given by: $z(t) = \frac{f(t)}{R(t)}$, where $f(t)$ is the failure probability density.

(see also table-'list of components' overleaf)

Table 2.1 List of components

Component	Failure rate	No. in Circuit 1	No. in Circuit 2	No. in Circuit 3
Metal film resistor	2×10^{-9} /hour	10	12	15
Tantalum capacitor	10×10^{-9} /hour	4	5	4
Low-power transistor	5×10^{-9} /hour	5	4	3
Electrolytic capacitor	100×10^{-9} /hour	1	2	0
Analogue IC	45×10^{-9} /hour	2	3	1
Digital IC	7×10^{-9} /hour	2	2	3

Table 2.1 List of components

3. **a.** An electromechanical actuator consisting of a brushless dc motor, a nut and a ball screw, figure 3.1 (page 4), is driving the carbon brakes of an aircraft. The brushless dc motor has a torque constant $k = 0.51$ Nm/A, a winding resistance $R = 8\,\Omega$, and a rotor inertia $J_m = 2.45\times10^{-4}$ kg.m^2. Furthermore, the screw pitch length of the electromechanical actuator is λ =5.5mm, and the gear ratio between the nut and the shaft of the brushless motor is 35:1. Furthermore, the reaction force from the carbon brakes increases linearly with position, $F_r(x) = a\,x$, and $a = 24\times10^6$ N/m. For a linear displacement $x = 1.25\,\text{mm}$:

i. Calculate the torque T_m delivered by the brushless dc motor.

ii. Calculate the current I, and the copper loss P_c of the brushless dc motor.

iii. Calculate the efficiency of the brushless dc motor when the actuator is moving at a linear speed v =2.0 mm/s. **(10)**

b. The brushless dc motor is controlled so as to have a maximum angular displacement θ_m in a time T, following a parabolic velocity profile, $\Omega(t) = 4\Omega_m\left(\frac{t}{T} - \frac{t^2}{T^2}\right)$, where Ω_m is the maximum speed of the motor.

i. Show that the angular displacement of the rotor is given by:

$$\theta(t) = 4\Omega_m\left(\frac{t^2}{2T} - \frac{t^3}{3T^2}\right)$$

ii. Calculate the maximum speed of the motor Ω_m for a maximum angular displacement $\theta_m = 63\,\text{radians}$ in a time $T = 0.3\text{s}$.

iii. Show that for a constant torque T_m, the energy delivered by the motor in the time T is given by:

$$E = \frac{2}{3}\,\Omega_m\,T_m\,T$$

iv. Calculate the maximum total torque applied on the motor Ω_m for a maximum angular displacement $\theta_m = 63\,\text{radians}$ in a time $T = 0.3\text{s}$. **(10)**

The following may be assumed:

The losses in the mechanical transmission of the actuator are neglected.

(see also figure- 'electromechanical actuator' overleaf)

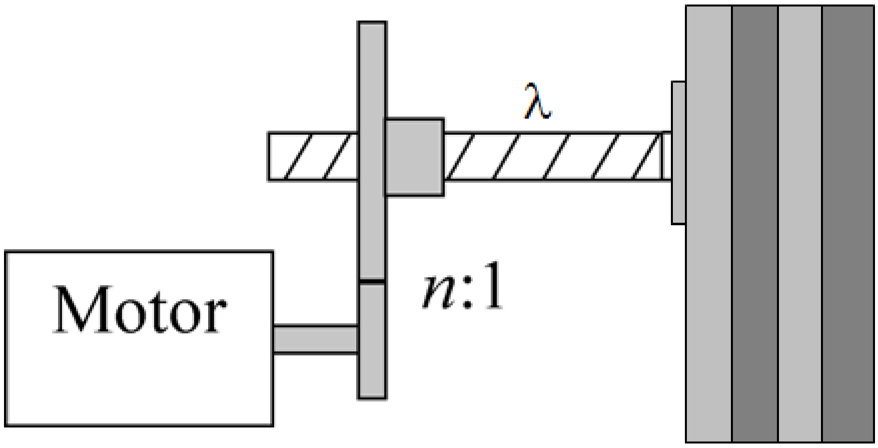

Figure 3.1 Schematic of electromechanical actuator.

4. **a.** Sketch a figure illustrating the main components of a MIL STD 1553 B bus system and summarise its main features. **(6)**

b. A potentiometer used to measure linear position x can slide $x_{max} = 40$mm, has a resistance R_p = 20kΩ, and is capable of dissipating 20mW of power in most environments.

i. Calculate the maximum voltage $V_{s\,max}$, which can be applied to the potentiometer.

ii. When the potentiometer is loaded with a resistance R_m, show that the output voltage is given by:

$$V_o = \frac{a}{\left(1 + a(1-a)\frac{R_p}{R_m}\right)} V_s$$

where $a = x/x_{max}$, and calculate the output voltages for positions x=10mm and x=20mm, respectively, for $R_m = 100\,\text{k}\Omega$ and $V_s = 20\,\text{V}$.

iii. Calculate the minimum value of the resistance R_m, for which the maximum error of the potentiometer does not exceed 0.25%.

(7)

c. The output of the potentiometer is now converted to digital format using a 3-bit $(b_2\, b_1\, b_0)$ analogue-to-digital converter (ADC), which drives a logic circuit, controlling red, green and yellow LEDs, figure 4.1. The logic circuit was designed in order to ensure that:

- The red LED is ON only when the position $x < 10\,\text{mm}$ and $x \geq 30\,\text{mm}$.
- The yellow LED is ON only when the position $0\text{mm} \leq x < 15\text{mm}$ and $25\text{mm} \leq x < 40\text{mm}$.
- The green LED is ON only when the position $15\text{mm} \leq x < 25\text{mm}$.

i. Construct the truth table of the logic circuit.

ii. Obtain the Sum-of-Products (SOP) expression of the logic function Red and show that $Red = \overline{b_2}\,\overline{b_1} + b_2 b_1$.

iii. Obtain the Product-of-Sums (POS) expression of the logic function Yellow and show that $Yellow = b_2(b_1 + b_0) + \overline{b_1}(\overline{b_2} + b_0) + \overline{b_0}(\overline{b_2} + b_1)$.

(7)

The following may be assumed:

For a potentiometer the $Error\,(\%) = \dfrac{a(1-a)(R_p/R_m)}{1 + a(1-a)(R_p/R_m)} \times 100$. Where $a = x/x_{max}$

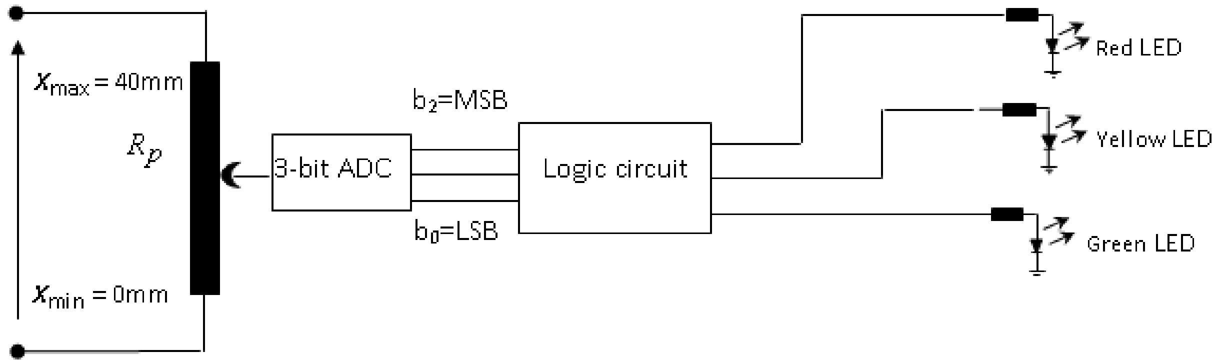

Figure 4.1 Logic circuit and LEDs.

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