UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: December 2020

Module Number: EE5305 **Module Name: Sensors, Transducers and Measurement Techniques(N/C)**

[Three Hours]

[Answer **all questions,** each question carries **10 marks]**

Q1 a) In an experiment, 100 measurements of the peak-to-peak voltages of a signal are measured as shown in Table Q1. Calculate the,

i) Mean square value of the signal $\overline{s}^2$

ii) Mean square value of noise $\overline{s_n}^2$

iii) Signal to noise ratio (SNR)

[3.0 Marks]

b) For a photodetector without noise the photocurrent i_{ph} is given by

$$i_{ph} = e\,N/T = 2eBN$$

with the usual notations.

i) In a photodetector the mean square noise in the number of photogenerated carriers is given by N. Calculate the mean square current for the shot (quantum) noise.

ii) Define the other shot noise currents and give an equation for the total shot noise of a photodetector.

iii) In a photodetector at a temperature T, the thermal noise power in a small frequency interval of df centered around f is given by,

$$P_{n,th}(f)df = \{4hf / [\exp(hf/k_BT) - 1]\}\,df$$

where k_B is the Boltzmann constant and h the Planck's constant.

Making suitable approximations calculate the thermal noise for a photodetector having a resistance R.

iv) From your answers to c) ii) and c) iii), calculate the Signal to Noise Ratio (SNR) for a photodetector.

[5.0 Marks]

c) i) Sketch the characteristics for a PN junction photodetector and define the regions of operations and their equivalent circuit representation.

ii) Describe the region of operation for a solar cell.

[2.0 Marks]

Q2 a) A PZT piezoelectric disc is resonant at 50 kHz.

i) Calculate the thickness of the disc.

Data for PZT: Compressional wave speed = 4350 ms^{-1} ;
Shear wave speed = 2400 ms^{-1}

ii) Sketch the input impedance of a piezoelectric disc as a function of frequency and show the resonance frequency.

iii) State the one-dimensional piezoelectric equations for the piezoelectric disc operating as a transmitter and receiver of acoustic waves.

iv) Sketch the basic structure of a transducer built with this piezoelectric disc and identify its main components.

v) Sketch a typical radiation pattern for this transducer.

[4.0 Marks]

b) The transducer in a) iv) is mounted on a boat and used as a depth profiler.

i) Sketch a diagram that shows this application.

ii) The boat travels at 10 NM/hour on sea. Six "pings" of the transducer is received at 10 second intervals with time delays as shown in Table Q2.

Sketch the approximate profile of the sea floor.

Data: 1NM (Nautical Mile) = 1.852 KM (Kilo Meter);
Sound speed in sea water = 1500 ms^{-1}

[3.0 Marks]

c) i) Sketch the basic structure of a probe used in medical ultrasonic scanners.

ii) Explain how the beam of the transducer can be swept to increase its coverage.

[3.0 Marks]

Q3 a) i) State the main difference between the thermoelectric effects and Joule heating.

ii) Figure Q3 a) shows the typical arrangement of a thermocouple used in measuring the temperature of a furnace. T1, T2 and Tref are the temperatures of the furnace, voltmeter connection point and reference junction respectively. A and B are the different metals used to form the thermocouple.

I. Mark the voltages across the four segments in Figure Q3 a) as V1, V2, V3 and V4 as dictated by the thermoelectric effects.

II. Using Kirchhoff's Voltage Law, state the relationships between the magnitudes of V1, V2 , V3 and V4, and show that the temperature measurement is not affected by the voltage drops in the Cu extension wires.

[4.0 Marks]

b) Resistance Temperature Detectors (RTDs) are based on resistance measurements to obtain temperature. There are two, three and four wire configurations of RTDs.

i) Draw a circuit diagram to show how the two-wire configuration of an RTD along with a Wheatstone bridge can be used to measure the temperature of an object.

ii) The RTD four-wire configuration shown in Figure Q3 b) is preferred over other configurations when measurement accuracy is important. Explain why this arrangement will have minimum errors in the measurement due to cable resistance.

[3.0 Marks]

c) The term "thermistor" is a combination of the terms "thermal" and "resistor". Thermistors can be classified as NTC thermistors or PTC thermistors based on the type of material used in them.

i) Indicate the relationship between resistance and temperature for NTC and PTC thermistors in the graph shown in Figure Q3 c). (Redraw the graph in your answer script)

ii) State the type of thermistor (NTC or PTC) that can be used as an inrush current limiter in an electrical load and redraw the electrical system shown in Figure Q3 d) indicating how you would interface a thermistor to limit the inrush current in this system.

[3.0 Marks]

Q4 a) Consider a Doppler radar that transmits on a frequency f_T. A target airplane is moving at a speed of V_{tgt} at an angle α to the radial direction as shown in Figure Q4 a). Distance between the radar and the airplane is R.

A frequency meter on the airplane observes the transmitted signal at a frequency f_{tgt}. The reflected echo from the airplane arrives at the radar at T_{RT} seconds after it was emitted. Frequency of this received signal sensed by the radar is f_R.

(Take the speed of light $c = 3\text{x}10^8$ m/s)

i) Derive an expression for the distance R between the airplane and the radar in terms of c and T_{RT}

ii) Find an expression for the signal frequency observed by the frequency meter at the airplane f_{tgt} in terms of f_T, V_{tgt}, α and c.

iii) Show that the frequency of the echo received by the radar f_R is given by

$$f_R = f_T \frac{c + V_{tgt}\cos(\alpha)}{c - V_{tgt}\cos(\alpha)}$$

iv) Derive an expression for the Doppler shift (i.e. $f_R - f_T$) and simplify the expression considering the relative magnitudes of V_{tgt} and c. Clearly state your assumptions.

[3.0 Marks]

b) The radar in Figure Q4 a) operates at a frequency f_T = 6 GHz. The airplane is travelling in a straight line making an angle α towards the radial direction of the radar. Velocity of the airplane is 200 km/hour. The reflected echo from the target arrives at the radar at T_{RT} = 66 μs. The Doppler shift is found to be 1111Hz. Calculate the

i) Distance to the target

ii) Angle α

[3.0 Marks]

c) Pyroelectric Infrared Sensors (PIR) are widely used as motion detectors. A typical PIR is shown in Figure Q4 c) i). Inside the sensor, there are two identical pyroelectric materials electrically connected to facilitate motion detection.

i) Show how the pyroelectric materials are electrically connected inside the sensor indicating the polarities of the connections in your sketch. (Assume that both materials receive identical amounts of IR radiation.)

ii) Briefly explain the operating principle of this PIR motion detector. Support your answer by drawing the output signal from the pyroelectric material connections you indicated in c) i) when the person moves as shown in Figure Q4 c) ii).

[4.0 Marks]

Q5 The circuit of a transformer coupled Class A audio power amplifier driving an 8 Ω speaker is shown in Figure Q5 a). The circuit component values result in a dc base current of 6 mA and the input signal V_{in} results in a peak base current swing of 4 mA. The transistor characteristics are shown in Figure Q1 b). Determine,

a) V_{ce} max

b) V_{ce} min

c) I_c max

d) I_c min

e) rms values of load current and voltage

f) power dissipated by the transistor

g) efficiency of the amplifier circuit

[10 Marks]

TABLE Q1

Number of measurements	Measured peak-to-peak voltage (V)
30	1.0
20	1.05
15	1.1
20	0.95
15	0.9

TABLE Q2

Ping Number	Time stamp (s)	Time delay (ms)
1	0	67
2	10	68
3	20	68
4	30	67
5	40	65
6	50	66

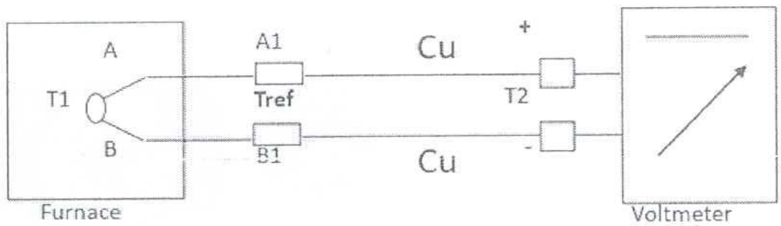

Figure Q3 a)

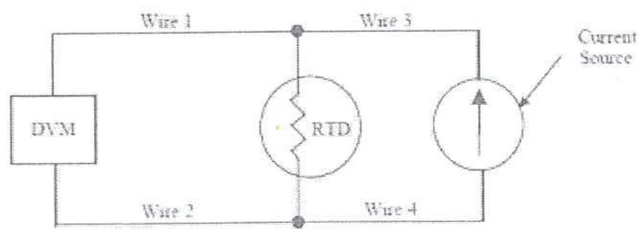

Figure Q3 b)

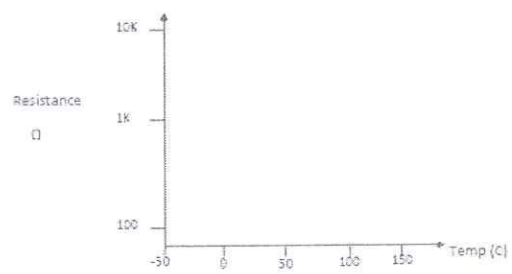

Figure Q3 c)

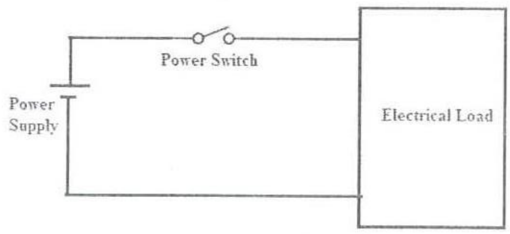

Figure Q3 d)

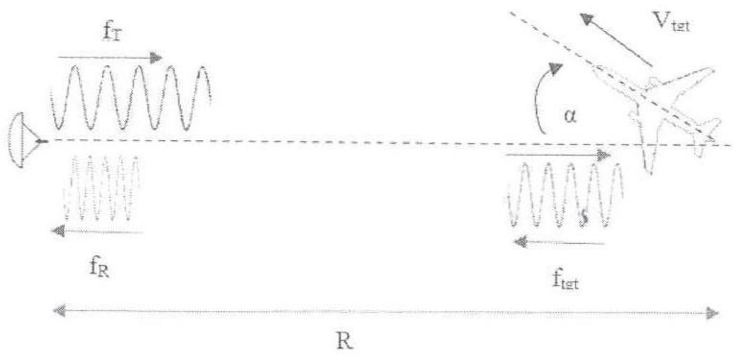

Figure Q4 a)

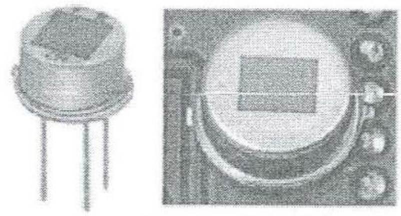

Figure Q4 c) i)

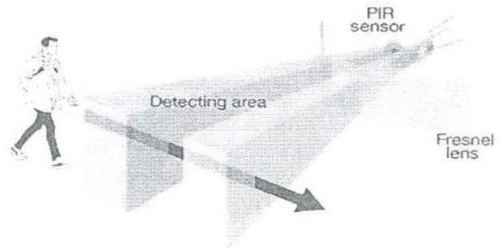

Figure Q4 c) ii)

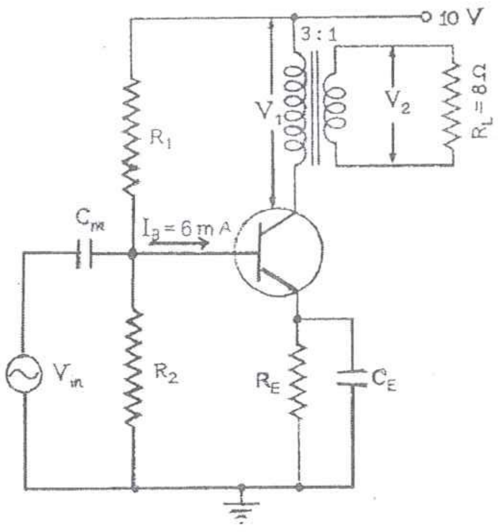

Figure Q5 a)

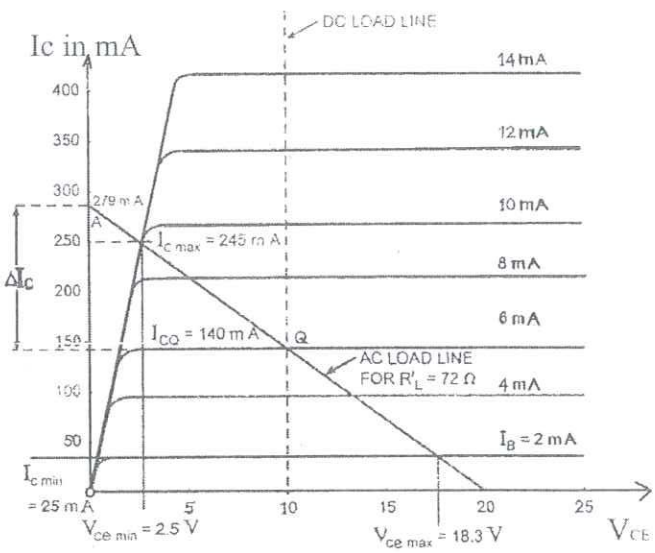

Figure Q5 b)