UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: July 2017

Module Number: EE5305 **Module Name: Sensors, Transducers and Measurement Techniques**

[Three Hours]

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

Q1 a) Figure Q1 a) shows the structure of the ADXL50 MEMS sensor. The dashed line indicates the continuation.

i) State the meaning of the acronym MEMS.

ii) State the law that governs the operation of the device.

iii) Name the main component parts A, B, C and D of the device.

iv) The principle of operation of the device is based on differential capacitance. Demonstrate that the relationship between the net capacitance and the displacement of the central capacitor plate can be taken as linear in a differential capacitor.

Note: The Taylor series of a function, F(d) can be approximated in the neighbourhood of some nominal value d_0 as

$$[F(d_0+\Delta) = F(d_0) + \Delta\, \partial F(d_0)/\partial d + \tfrac{1}{2}\Delta^2\, \partial^2 F(d_0)/\partial d^2 + \ldots..]$$

v) Explain the need for the 0° and 180° phase difference in the sensing electronics.

vi) In Figure Q1 a), the mass of the moving part of the device is 0.1×10^{-6} g. The gap $x_0 = 2$ μm and the width $w = 1$ μm. The sensing element has 40 teeth on one half. The average acceleration measured over a time 1 μs interval is 10 m/s². Estimate,

I) the force on the moving part.

II) the displacement of the moving part.

III) the total capacitance measured.

The permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1}

[Hint: Calculate the capacitance normalized to cross sectional area A.]

[7 Marks]

b) i) Name and define the force governing the operation of a gyroscope.

ii) Give the design of a MEMS gyroscope and explain the operation.

[3 Marks]

Q2 a) i) State the audible frequency range of the human ear.

ii) State the energy conversion processes for audio microphones and speakers.

iii) Figure Q2 a) shows a schematic diagram of a condenser microphone.

I) Identify the input and the output.

II) Derive an expression for the output.

[3 Marks]

b) i) Ceramic elements used for constructing acoustic transducers are not piezoelectric in their natural state. Explain why this is and the processes needed to make the ceramic piezoelectric.

ii) State the dimensions that determine the operating frequency of a piezoelectric disc and a cylinder respectively.

iii) Describe what is meant by the resolution and the resolution needed for underwater target detection.

iv) Figure Q2 b) shows an echo detection application. The transducer operates in transmit/receive mode and has a narrow beam width. The distances to the targets are shown. Synthesize the received echo time diagram by choosing a high resolution transmit signal. The relative amplitudes of the received echoes should give an indication of the sizes of the targets.

[4 Marks]

c) i) A transducer transmits an acoustic signal from water to a solid stainless steel medium at an angle 5° normal to the surface. Calculate the angle of the refracted waves into the solid with respect to normal to the surface. Take the compressional, shear and Rayleigh wave speeds in stainless steel as 5810 ms^{-1}, 2950 ms^{-1} and 2700 ms^{-1} respectively

ii) State the direction of the particle motion in the solid for the waves that propagate in the solid in part c) i).

iii) The presence of more than one type of wave inside the solid gives confusing results in Non-Destructive Testing (NDT) applications. Describe an arrangement that can propagate only one type of wave inside the solid thus improving the target detection capability.

[3 Marks]

Q3 a) i) Sketch the frequency response of the human eye and indicate the positions of the three primary colours RGB.

ii) Sketch the energy (E) versus the quantum mechanical wave number (k) diagrams for a direct gap semiconductor and an indirect gap semiconductor.

iii) Explain the three band-to-band transitions for a direct gap semiconductor.

iv) State the transition processes associated with the operation of a LED and a LASER.

v) Give a practical definition for population inversion in a LASER.

[4 Marks]

b) i) State the best junction structures for a LED and a LASER.
ii) Sketch the junction structure, excess carrier distribution, refractive index and optical field distribution for a LED and a LASER.
iii) State two features that are essential for the operation of a LASER.
iv) State the conditions necessary for LASER oscillation.
v) Give two examples of how feedback is introduced in a LASER.
vi) State the parameters that determine the operating speed of a LED and a LASER respectively.

[6 Marks]

Q4 a) Explain the difference between a voltage amplifier and a power amplifier.

[2 Marks]

b) State the differences between Class A, Class B, Class AB and Class C amplifiers.

[2 Marks]

c) Explain what is meant by the crossover distortion in Class B amplifiers.

[2 Marks]

d) Consider the idealized push-pull Class B power amplifier shown in Figure Q4. In the circuit $R_2 = 0\ \Omega$, $V_{cc} = 20$ V, $N_2 = 2\ N_1$, $R_L = 20\ \Omega$ and the transistor has $h_{fe} = 20$. The input to the circuit is a sinusoid. For the maximum output signal, $V_{max} = V_{cc}$. Determine,
i) the output signal power.
ii) the collector dissipation in each transistor.

[4 Marks]

Q5 a) i) State the three main sources of experimental uncertainties/errors.
ii) To determine the quantity $q = x^2y - xy^2$, a scientist measures the parameters x and y given by,

$$x = 3.0 \pm 0.1 \text{ and } y = 2.0 \pm 0.1$$

Calculate the value for q and its uncertainty.

[4 Marks]

b) i) Explain the advantages of negative feedback amplifiers.
ii) An amplifier without feedback gives a fundamental output of 36 V with 7% second harmonic distortion when the input is 0.028 V.
I) If 1.2 % of the output is fed back into the input as negative voltage series feedback, calculate the output voltage.
II) If the fundamental output is maintained at 36 V but the second harmonic distortion is reduced to 1%, calculate the input voltage.

[6 Marks]

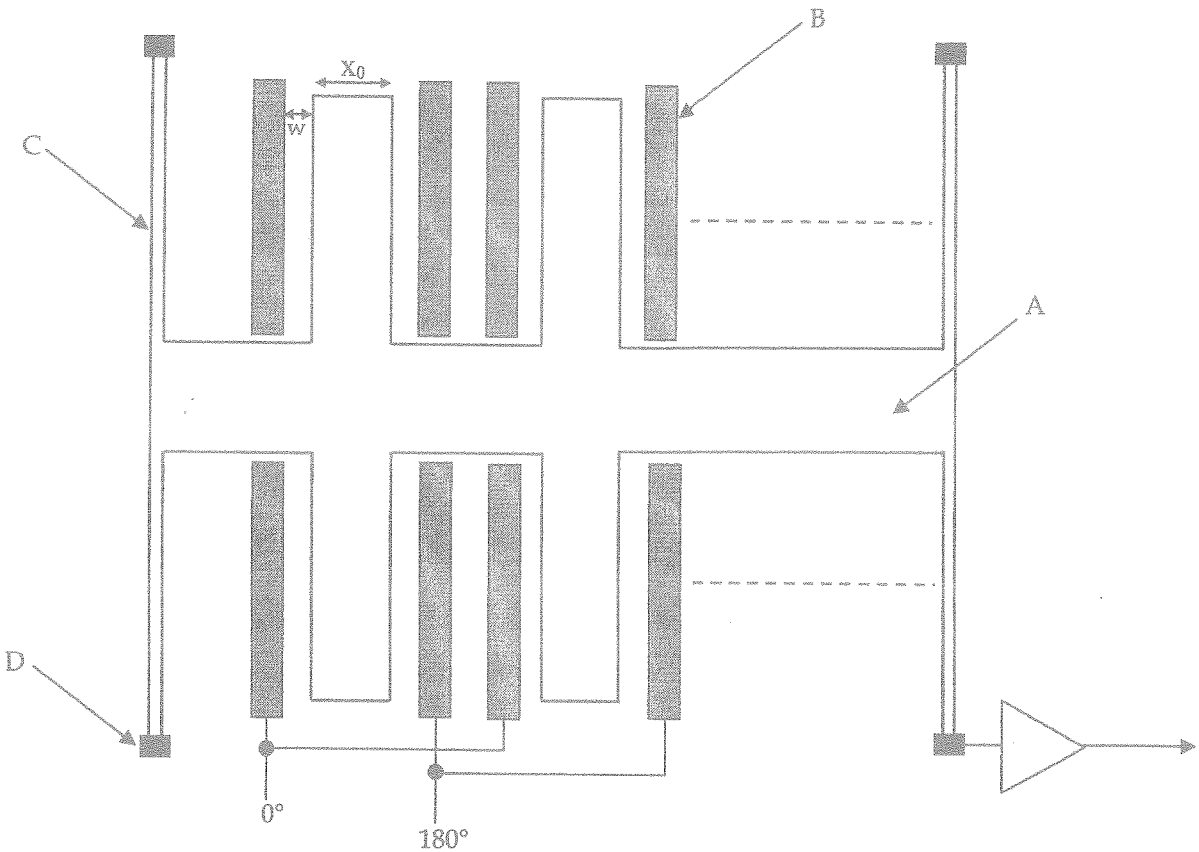

Figure Q1 a)

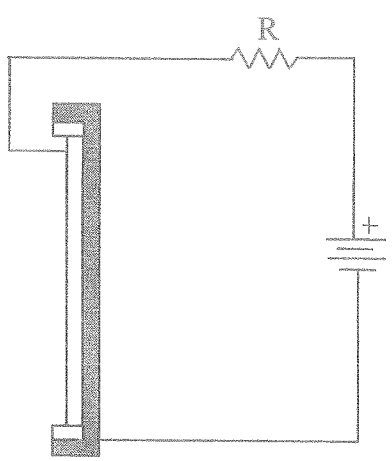

Figure Q2 a)

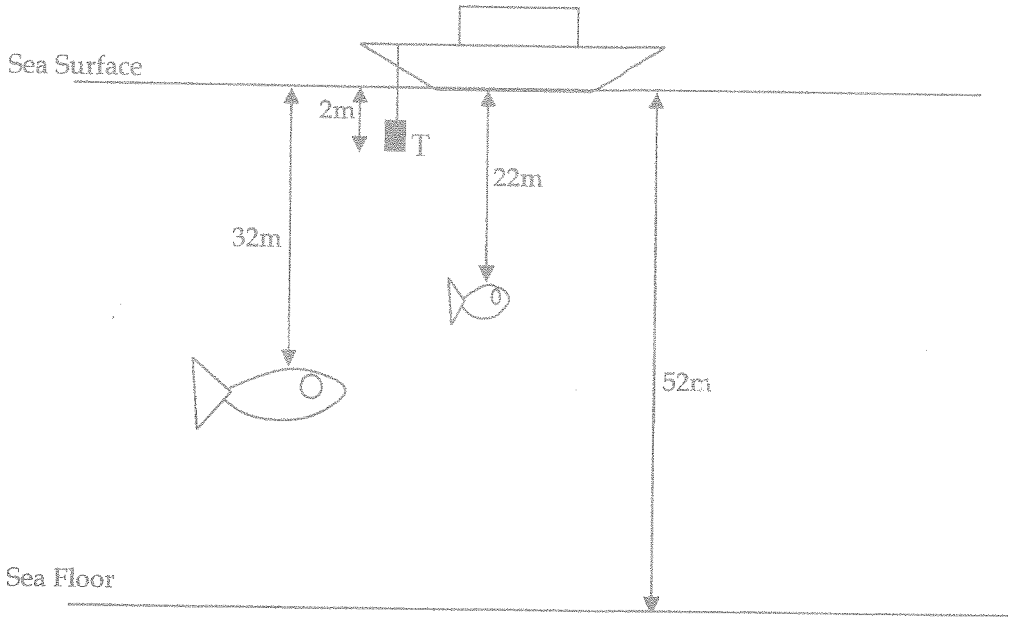

Figure Q2 b)

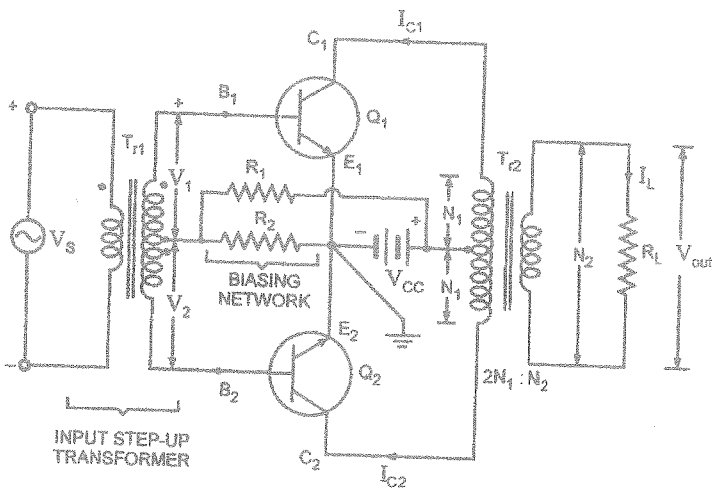

Figure Q4