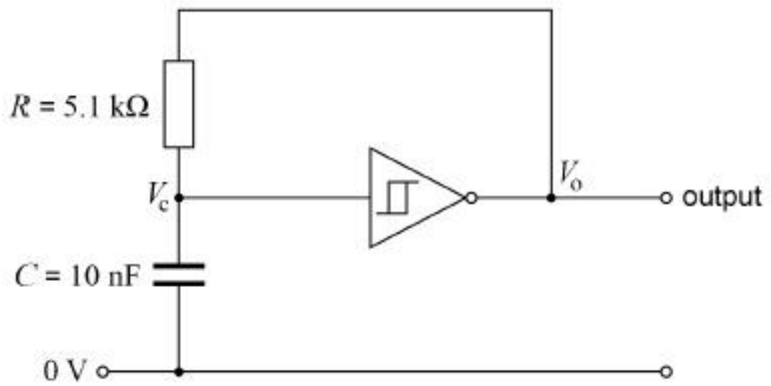
Capacitors

Q1.

(a) **Figure 1** shows an astable circuit based on a NOT logic gate. The symbol in the centre of the logic gate means that the output V_o changes at two different input values of V_c depending on whether the input voltage is rising or falling.

Figure 1



The pulse repetition frequency (PRF) for this particular circuit is given by:

$$\frac{1}{1.4\,RC}$$

Calculate the PRF in kHz

PRF = ____________________ kHz

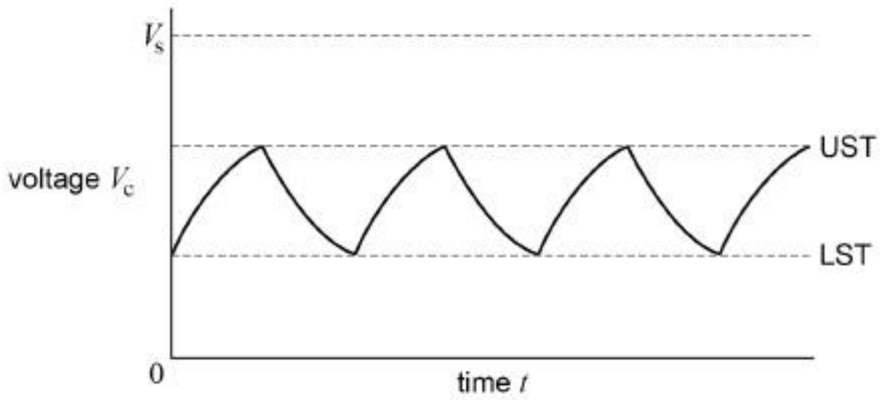
(1)

(b) The supply voltage to the NOT gate is V_s

- When V_c increases and reaches the upper switching threshold (UST), the output of the NOT gate will switch from V_s to 0 V
- When V_c decreases and reaches the lower switching threshold (LST), the output of the NOT gate will switch from 0 V to V_s

The graph in **Figure 2** shows V_c constantly changing as the capacitor charges and discharges.

Figure 2



Draw on **Figure 2** the output voltage V_o for the astable circuit.

(1)

(c) The circuit in **Figure 1** can be modified by the addition of a resistor to vary the PRF.

The astable is to be modified so that it produces a frequency 4 times that of the original.

Calculate the value of the resistor that should be added to the circuit and explain where in the circuit this additional resistor should be placed.

value of resistor = ____________________ kΩ

____

____

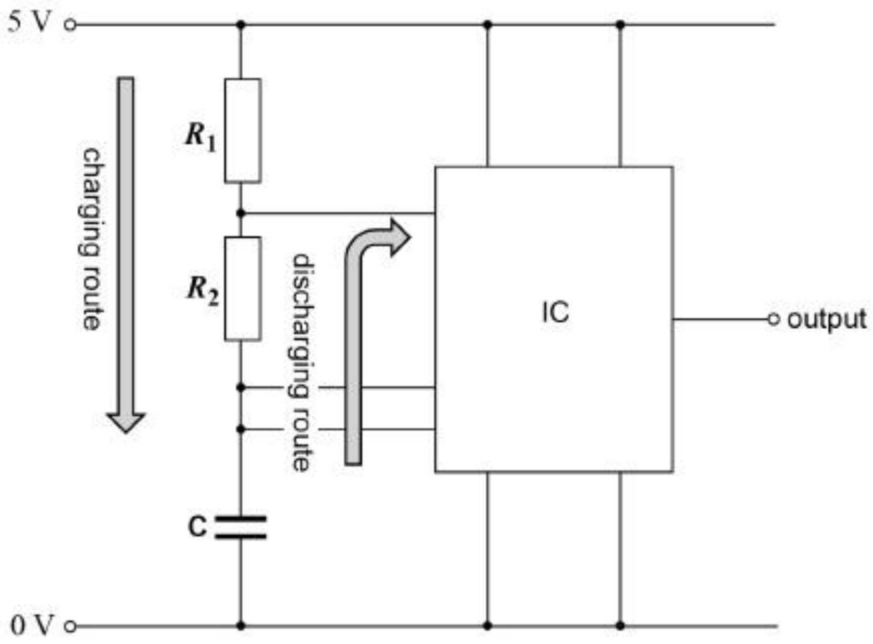
____

____

(2)

(d) In another astable, two resistors (R_1 and R_2) and a capacitor **C** form a timing chain to control the mark and space times for a square wave produced at the output of the integrated circuit (IC) shown in **Figure 3**.

Figure 3



The charging time for the capacitor **C** is: $t_C = 0.7 \times (R_1 + R_2) \times C$

The discharging time for the capacitor **C** is: $t_D = 0.7 \times R_2 \times C$

Calculate, in kΩ, values for $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ needed to produce a 5 kHz signal with 75% duty cycle given that the capacitor **C** has a value of 10 nF

$\boldsymbol{R_1}$ = ____________________ kΩ

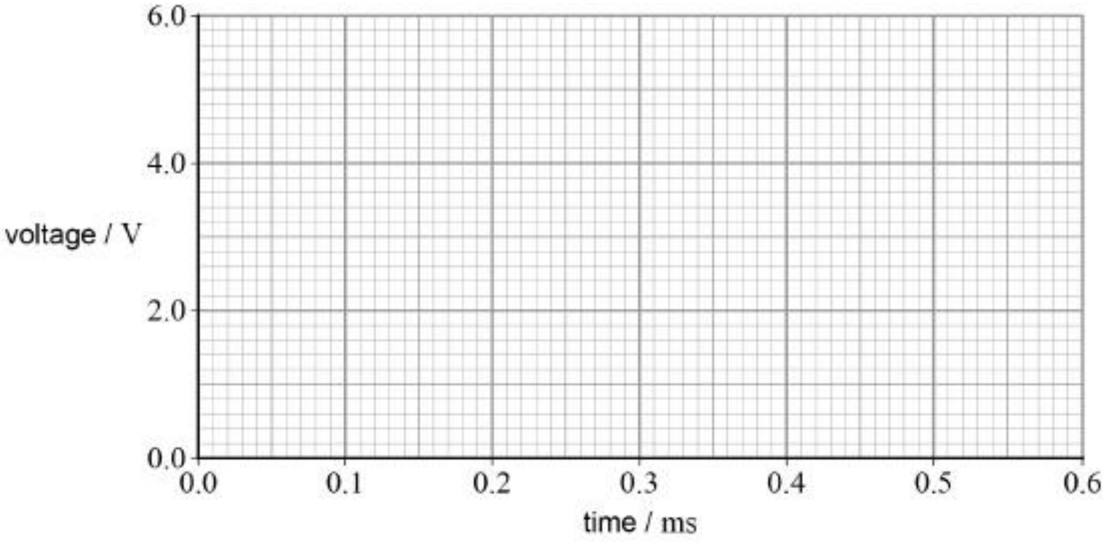
$\boldsymbol{R_2}$ = ____________________ kΩ

(2)

(e) The output of the IC in **Figure 3** is 5 V during the charging period and 0 V during the discharging period.

Draw on **Figure 4** the wave pattern that represents this signal.

Figure 4

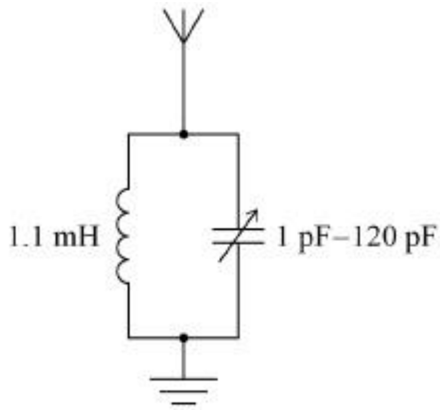


(2)
(Total 8 marks)

Q2.

Figure 1 shows the first-stage filter circuit for a simple AM receiver. The circuit can be adjusted to resonate at 910 kHz so that it can receive a particular radio station.

Figure 1



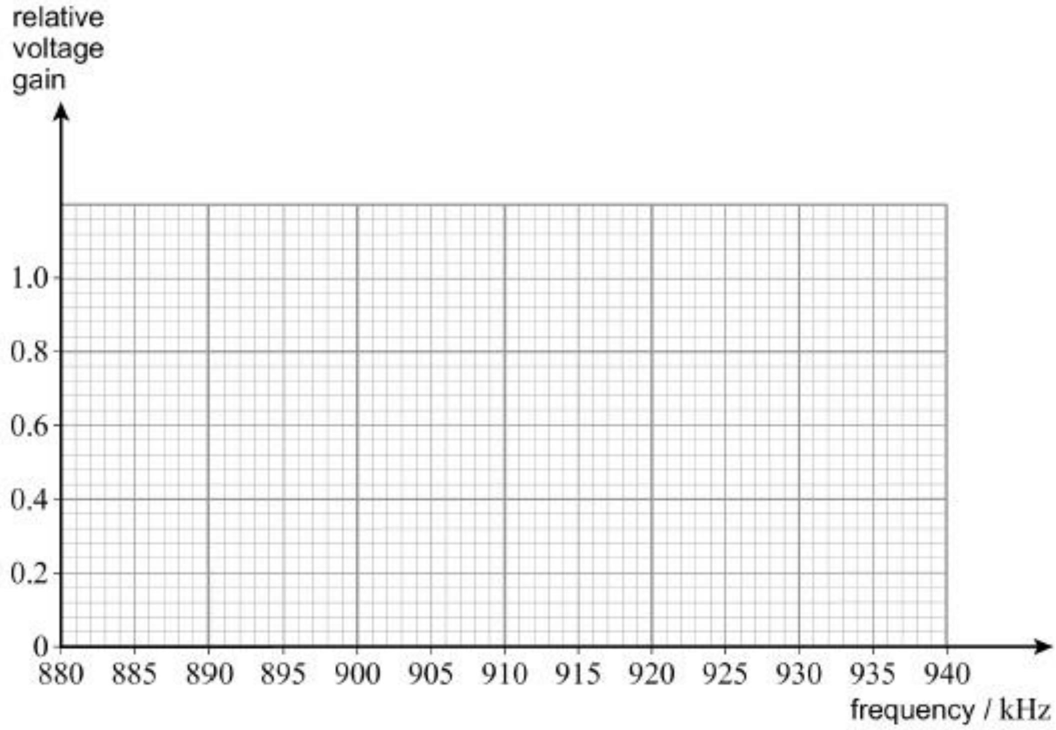
(a) Calculate the value of the capacitance when the circuit resonates at a frequency of 910 kHz.

capacitance = ____________________ pF

(2)

(b) Draw on **Figure 2** an ideal response curve for the resonant circuit, labelling all relevant frequency values based upon a 10 kHz bandwidth.

Figure 2



(3)

(c) The Q-factor for the practical tuning circuit has a smaller value than the ideal one assumed in question (b).

Discuss the changes the listener might notice when tuning to this station due to the practical Q-factor being smaller.

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____

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____

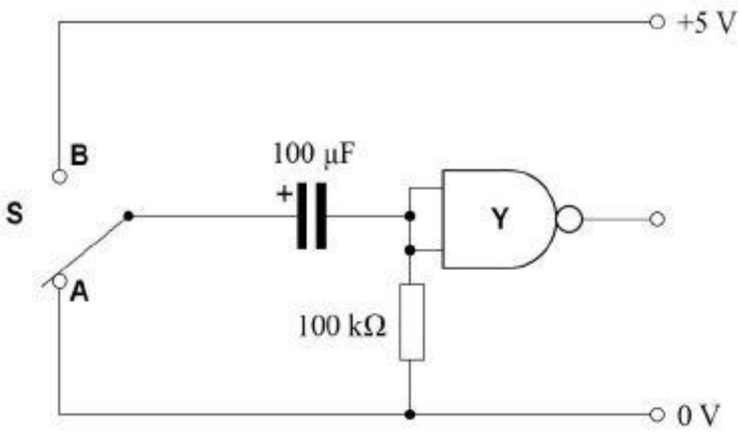
____

(2)
(Total 7 marks)

Q3.

A student experiments with the circuit shown in **Figure 1**.

Figure 1



Y is a NAND gate for which an input of less than 2.5 V is logic state 0 and input greater than 2.5 V is logic state 1.

Switch **S** is set to position **A** for a long time so that the capacitor is uncharged.

(a) Explain why the output of **Y** is logic state 1.

___

___

___

(1)

(b) When **S** is moved to position **B**, the capacitor charges through the 100 kΩ resistor.

Show that the capacitor will be charged to 2.5 V after about 7 s.

(2)

(c) Suggest an application for a circuit such as that shown in **Figure 1**.

___

___

___

(1)

(Total 4 marks)

Q21.

In order to reduce the bandwidth needed for transmission of an audio speech signal, the signal is filtered to remove high frequencies.

(a) Explain what is meant by the **bandwidth** of a signal.

(2)

(b) Name the type of filter needed to remove high frequencies.

(1)

(c) (i) Draw the circuit diagram of a passive filter to remove high frequencies, using a resistor and a capacitor.

Label the input and the output.

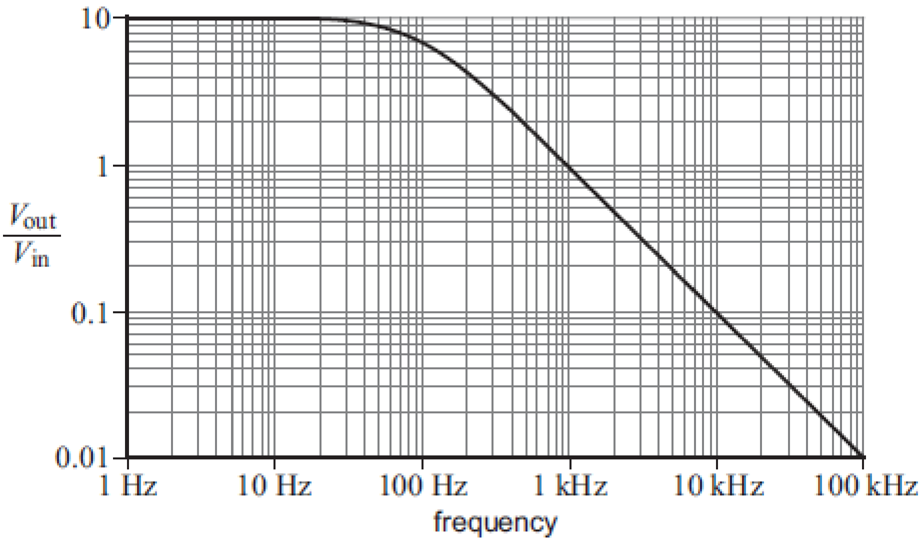
(2)

(ii) The resistor in the filter has a value of 1 kΩ.

Calculate the capacitor value required to give a breakpoint frequency of 4.0 kHz.

(3)

(d) The graph shows the response of a different filter to remove high frequencies.



(i) State how the graph shows that this must be an **active** filter.

____

(1)

(ii) Circle the value closest to the breakpoint frequency of this filter.

30 Hz   100 Hz   200 Hz   1 kHz

(1)

(iii) A 2 V, 5 kHz signal is applied to the input of this filter.

Calculate the output signal voltage.

____

____

(2)

(Total 12 marks)

Q1.

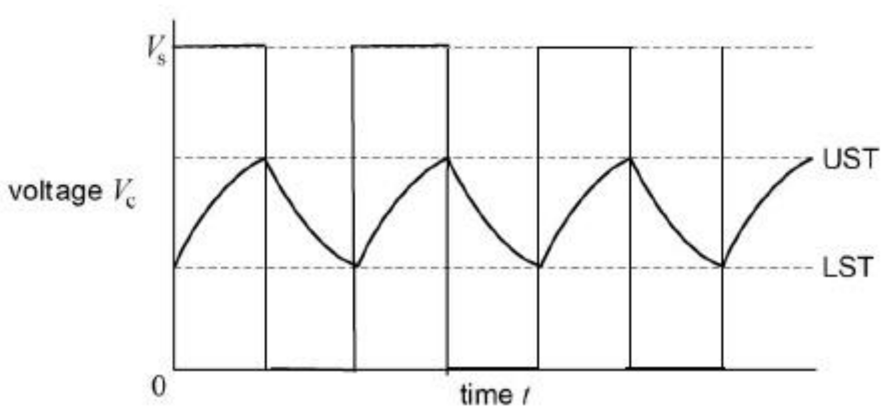
(a) PRF = 1 / (1.4 RC)

$= 1 / (1.4 \times 5.1 \times 10^3 \times 10 \times 10^{-9})$

14 kHz ✓

1

(b) Square wave with correct phase and amplitude ✓



1

(c) New resistor calculated and stated to be 1.7 kΩ ✓

New resistor placed in parallel with original resistor ✓

Ecf from part (a)

2

(d) $T = \frac{1}{f} = \frac{1}{5 \times 10^3}$ = 0.2 ms (200 μs)

$t_C = 0.2 \times 10^{-3} \times \frac{3}{4}$ = 150 μs

$t_D = 0.2 \times 10^{-3} \times \frac{1}{4}$ = 50 μs

$R_2 = \frac{t_D}{0.7 \times C} = \frac{50 \times 10^{-6}}{0.7 \times 10 \times 10^{-9}}$ = 7.1 kΩ (Accept 7kΩ)

$R_1 = \frac{t_C}{0.7 \times C}$ – R2 = 14.3 kΩ (Accept 14kΩ)

1 mark for significant calculation

Eg showing $R_1 = 2R_2$

OR

Calculation for t_C or t_D

1 mark for values of R_1 and R_2

2

(e) Two properties per mark – (max mark 2)✓✓

- A square wave
- Amplitude of 0 V to 5 V
- Periodic time of 0.2 ms
- High for 0.15 ms – Low for 0.05 ms

2

[8]

Q2.

(a) $f = 1 / (2\pi \sqrt{LC})$

$C = 1/ f^2 4\pi^2 L$

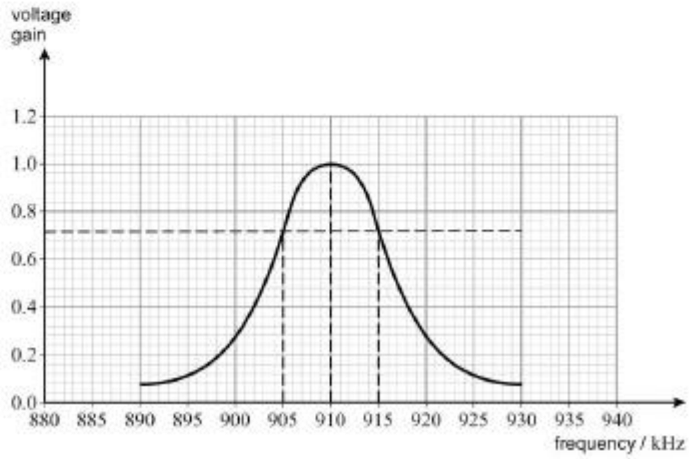
$C = 1/ (910 \times 10^3)^2 \times 4 \times \pi^2 \times 1.1 \times 10^{-3}$

C = 27.8 pF (accept 28pF)

Formula with correct substitution / evidence of correct working

Answer

1
1



(b)

General shape around f_0 and to max of 1.0 on relative voltage gain axis

1

10 kHz bandwidth

at 0.71 gain

1

Frequencies (905 – 910 – 915) kHz (identified / used)

1

(c) Smaller Q factor leads to:

(Any **two** from)
(i) Broader bandwidth
(ii) More noise / (hiss) detected
(iii) Less selectivity
(iv) More susceptible to crosstalk from neighbouring stations on the frequency spectrum.
(v) Less gain due to energy loss / loss of signal detail

2

[7]

Q3.

(a) No pd across 100 kΩ (since no current through it) so both inputs are 0 V / logic 0 and output there for logic 1.✓

1

(b) $\left(V = V_0\left(1 - e^{-\frac{t}{RC}}\right)\right)$ and $RC = 10$ s gives $2.5 = 5.0\left(1 - e^{-\frac{t}{10}}\right)$✓

Solution gives t = 6.93 s.✓

2

(c) Any appropriate time delay application that leaves a device switched ON or OFF for a short time after activation or deactivation.✓

e.g. Car interior light as driver leaves vehicle, intruder alarm exit delay.

1

[4]

Q21.

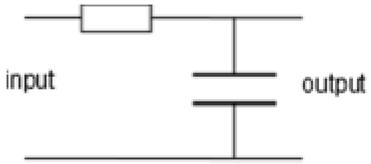
(a) range of frequencies in signal ✓
reference to frequency at which signal drops by e.g. power 3dB (50%) / voltage 6dB (71%) ✓

2

(b) low pass / treble cut ✓

1

(c) (i) RC filter circuit, with input & output labelled ✓
correct R & C positions ✓



2

(ii) substitute values into f = 1 / 2πRC ✓

rearrange for C ✓

40 (39.7) nF ✓

3

(d) (i) gain > 1 ✓

1

(ii) 100Hz ✓

1

(iii) gain = 0.2 ✓ output = 0.4V ✓

2

[12]

Q1.

(a) Most students found the calculation to be quite straight forward with very few '*power of ten*' issues. 84% arrived at the correct answer.

(b) Just under half of the students (46%) were able to transfer the written properties from the stem into the voltage-time diagram.

(c) A surprising number of students did not open with a statement to say that '*if the PRF is x4, then the effective R must be ¼ value*'. This should then have triggered a parallel resistor calculation as a means of adding a resistor to reduce the total resistance. 50% of students gained at least one of the two marks available. *In general, it is important that multi-step calculations are carefully set out and explained to make sure that students can target all marks*.

(d) This question proved to be quite demanding and required students to pull in information from a number of areas. The key was to appreciate that the t_C = ¾ T and t_D = ¼ T
For many, the calculation evolved without a clear plan. However, one mark was available for making significant headway towards the solution. Only 24% of students gained both marks here.

(e) The graph was generally drawn well, although still only accessed by 56% of the students. Some missed out on a mark either because they forgot that the amplitude was 5 V, or got the mark–space ratio wrong.

Q2.

(a) Some students struggled with extracting C from the formula, and one or two lost some powers of ten. Again, it is recommended that students always show all stages of their working, so that some credit can be gained even if the final answer is wrong.

(b) Most students answered this question well, although a significant number failed to show on the graph the appropriate frequencies matched to the ~ 0.7 voltage gain point.

(c) Some students were rather 'clinical' in their response to this question and forgot to relate their answer to the context of the 'listener'.

Q21.

(a) A precise meaning of bandwidth, referring to power or voltage, should be known.

(b) Most were able to name the appropriate filter.

(c) Some attempted active filters, but the question asked for a passive filter. Most were able to rearrange the formula to find breakpoint frequency, with some power of ten errors.

(d) Interpretation of the graph was disappointing. Few were able to identify a filter with a gain >1 as active. Many thought that the frequency at which the gain first dropped from maximum was the breakpoint. Many could not read the gain at 5kHz.