IMPERIAL COLLEGE LONDON

Design Engineering MEng EXAMINATIONS 2019

For Internal Students of the Imperial College of Science, Technology and Medicine
This paper is also taken for the relevant examination for the Associateship or Diploma

Engineering Analysis EA 1.3 - Electronics

Monday 20 June 2019

SOLUTIONS

This paper contains NINE questions.

Attempt ALL questions.

The numbers of marks shown by each question are for your guidance only; they indicate approximately how the examiners intend to distribute the marks for this paper.

This is a CLOSED BOOK Examination.

1. For the circuit shown in *Figure* 1, find the value of R_L such that V_{OUT} is 3.3V.

[6]

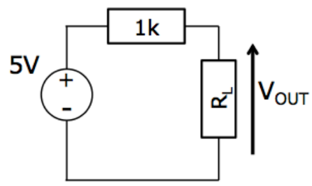


Figure 1

Solution

This question tests student's understanding of a simple voltage divider.

Vout = $5 \times R_L / (1 + R_L) = 3.3$, therefore $R_L = 1.94$k.

2. Figure 2 shows a circuit with three resistors R1, R2 and R3 connected as shown. The circuit has three terminals: A to R1, B to R2, and C to R3 as shown. It is known that R2 = 2kΩ and R3 = 1kΩ.

(i) A 10V battery with a positive (+ve) and a negative (-ve) terminal is connected between A and B respectively. If the voltage measured between terminals B and C (i.e. V_{BC}) is -4V, calculate the values of R1.

(ii) If the battery is connected to terminals A and C instead, what is the voltage measured between terminals B and C (i.e. V_{BC})?

[10]

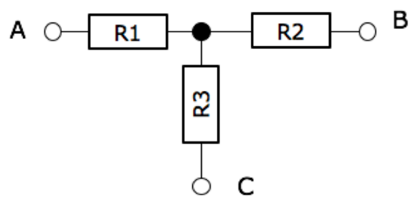
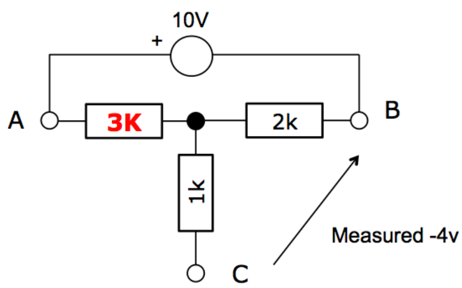


Figure 2

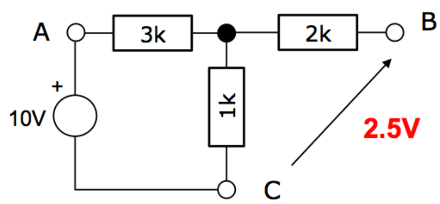
Solution

This question is linked to Lab 2, Test 1. Given a star-connected 3-resistor network, how to find the resistor values from voltages. The solution is an application of voltage divider principle. The key is to realise that the measurements are done by voltmeter which has infinite impedance and draws zero current.

First use i): B is the reference. Therefore V_{BC} is negative, and it is a simple voltage divider with R1 and R2 dividing 10V to give 4V. Since R2 is 2k, R3 must be 3k.



ii): Now C is the reference and 10V is across A and C. The voltage divider is R1 and R3. V_{BC} is therefore ¼ of 10V = 2.5V.



3. Given that the circuit shown in *Figure 3*, can be simplified to a 4kΩ resistor, calculate the value of R.

[8]

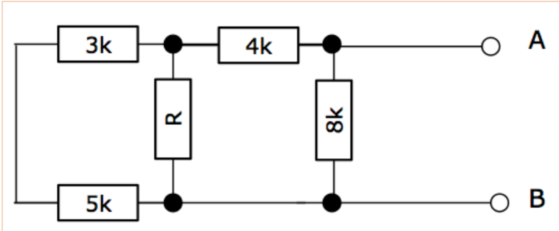
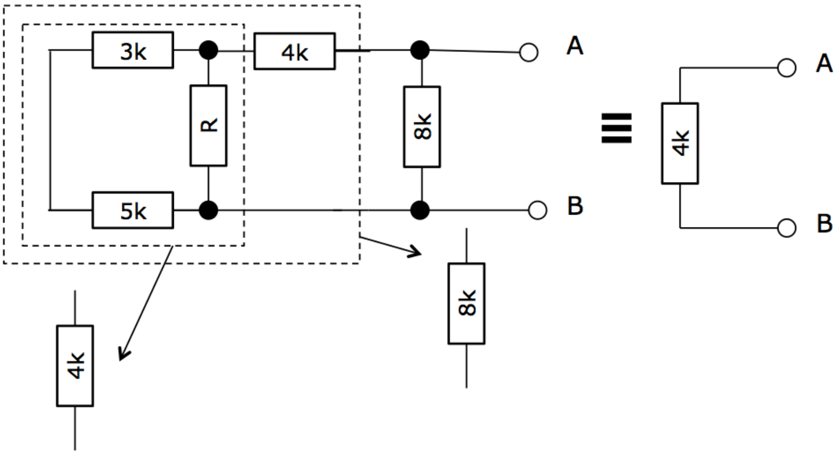


Figure 3

SOLUTION

This question tests student's understanding of equivalent circuit and how to derive total resistance value when resistors are connected in series and in parallel.



Hence R = 8k.

4. A 7.4V battery is used to power a robotic car with a single board computer and two dc motors. When the motors are idle, the car draws a current of 20mA and the battery voltage is measured to be 7.38V. When the motors are running at full speed, the car draws a current of 1A

   (i) Derive the Thévenin equivalent circuit for the battery.

   (ii) What is the voltage of the battery when the motors are running at full speed?

[12]

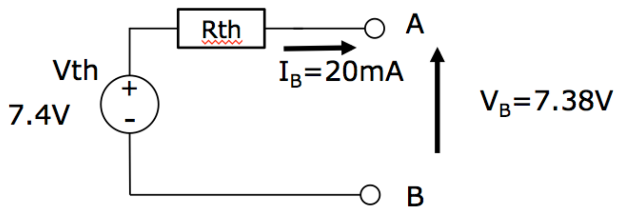
SOLUTION

This question tests student's understanding of the Thévinen theorem and how to apply this to a real-life situation.

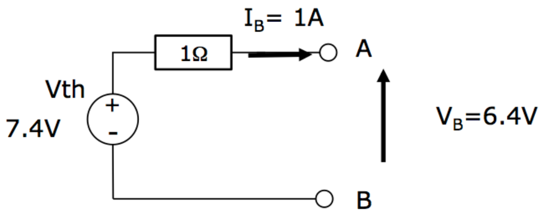
(i)

$$V_{th} - I_B R_{th} = V_B$$

Rth = 0.02V/20mA=1Ω



(ii)



5. *Figure 4* shows a circuit with three resistors, two voltage sources and a current source.

(i) Derive the value of V_X.

(ii) Hence or otherwise, derive the current I_B flowing out of the 10V voltage source.

(iii) What is the value of V_Y?

[12]

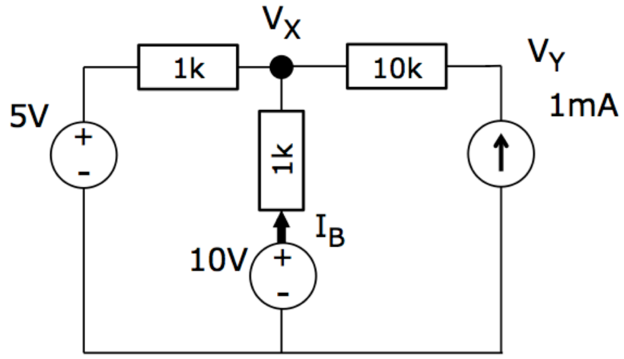


Figure 4

SOLUTION

(i) & (ii)

Apply KCL at node V_X (+ve current flowing out of node and use kΩ and mA):

$$\frac{V_X - 5}{1} + \frac{V_X - 10}{1} - 1 = 0$$

$$\Rightarrow 2V_X - 16 = 0$$

Therefore, $V_X = 8$V, and $I_B = 2$mA.

(iii) KCL at node Y:

$$\frac{V_Y - V_X}{10} - 1 = 0$$

$$\Rightarrow V_Y = 18V$$

6. The ASCII table is shown in the Appendix. Given that all numbers are represented as 8-bit values, complete the missing entries that are not shaded in the following table (*Figure 5*). (No marks will be awarded for this question unless you show how the solutions are derived.)

[6]

If the ASCII character is transmitted in UART format with 8-bit data and no parity bit, sketch the timing waveform of the digital signal for this character.

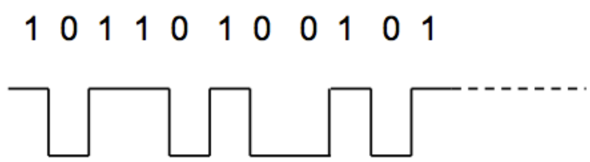
[6]

Hexadecimal	Binary	Unsigned Decimal	ASCII
	01001011		

Figure 5

SOLUTION

Hexadecimal	Binary	Unsigned Decimal	ASCII
4B	01001011	**75**	**'K'**



7. In the circuit shown in *Figure 6*, the switch is at position 1 (i.e. open) for a long time before moving to position 2 (i.e. closed) at time t = 0 sec.

(i) What is the capacitor voltage $v_C(t)$ as $t \rightarrow \infty$? [3]

(ii) What is the time constant of the function $v_C(t)$ for $t \geq 0$ sec? [3]

(iii) Write down the equation for v_C as a function of time t. [3]

(iv) Sketch the waveform of $v_C(t)$ *vs* time t for $t \geq 0$. [3]

(v) After the switch has been in position 2 (i.e. closed) for a long time, it was then opened. What is the equation for the voltage v_C as a function of time t from the moment that the switch was opened (i.e. reset the time axis to zero at that instance)? [4]

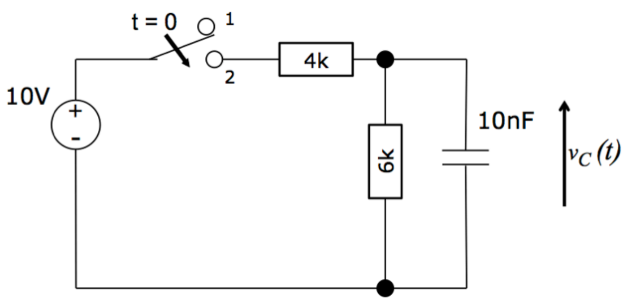


Figure 6

SOLUTION

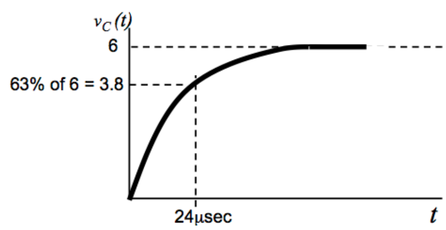
This question tests student's understanding of transient behaviour with RC circuits.

(i) Steady-state voltage is simply that of the voltage divider, i.e. 6V.

(ii) Time constant is the product of the Thevenin resistance 6k in parallel with 4k (i.e 2.4k), and the capacitor 10nF. Therefore τ = 24μs.

(iii) $v_c(t) = 6(1 - e^{-t/24\times10^{-6}})$.

(iv)



(v) When the switch is open, the 4k resistor is not in play. Therefore the time constant because 6k x 10n = 60μs. Hence the equation is a decaying exponential:

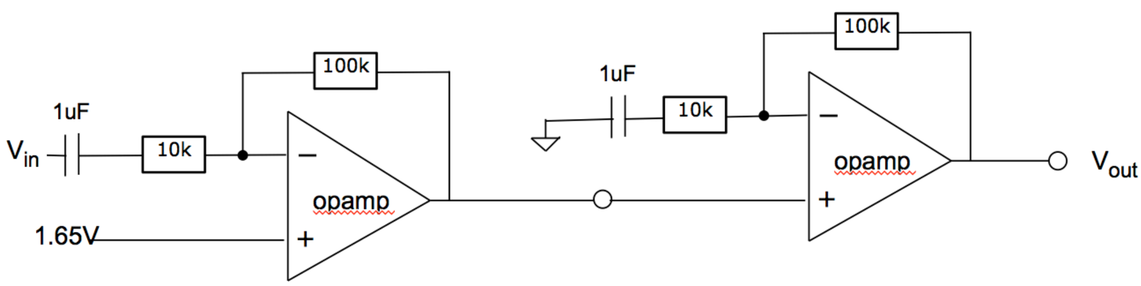
$$v_c(t) = 6(e^{-t/60\times10^{-6}})$$

8. Bats map their surroundings using ultrasound signals in the frequency range up of 12kHz to 160KHz for echolocation. You are required to detect the presence or absence of bats by amplifying the bats signals using an ultrasonic senor that produces an output signal range from 0V to 33mV. Using a minimum number of operational amplifiers with a gain-bandwidth product of 2MHz, design a circuit to amplify the bat signal such that the output is in the range of 0V to 3.3V. You may assume that available to you are: 1) a 3.7V battery, 2) a 1.65V voltage reference, 3) any resistors or capacitors.

[12]

SOLUTION

This question examines student's ability to use an opamp and take into account the gain-bandwidth limitation. We need a gain of x100. At frequency of 160MHz, each opamp will only provide a gain of around 10x. Therefore we need to use two opamp one after another. One possible design is:

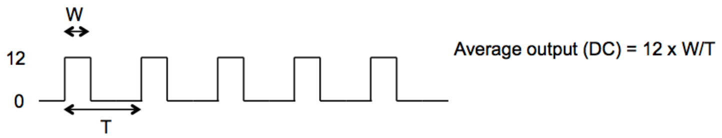


9.	An LED light strip operating at 12V produces a maximum light brightness of 3000 lumens. Human eyes typically will not be able to detect flickers above 15Hz. You are designing a circuit to control the brightness of the light using pulse-width modulation (PWM).	
	(i) State the advantages of using PWM to control LED lighting.	[4]
	(ii) Draw the timing waveform of the PWM signal and explain how such a signal can be used to control the different brightness of the LED strip	[4]
	(iii) If you are required to control the brightness of the LED strip in the range of 0 to 2800 lumens, provide the specification of the PWM signals that you need to produce to control the LED strip.	[4]

SOLUTION

(i) PWM is method to convert a digital number to an average analogue voltage, but only two (binary) voltage values. It is advantages because we can control a transistor switch to connect the drive output to the supply voltage and to zero. By controlling the duty-cycle of the digital control signal, we can provide an average DC voltage between 0 and V+ where V+ is the supply voltage value.

(ii)



(iii) Voltages as shown in diagram. Duty cycle is between 0 and 93.3%.

