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Electronic Circuits Testing and Applications

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1 Task 3

1.1 Scope Time Division Calculations (6)

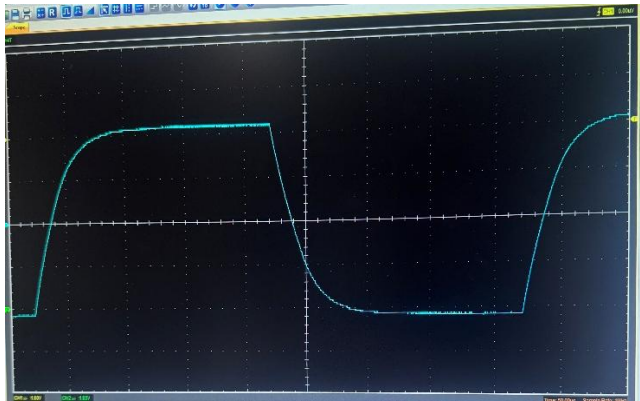
The Oscilloscope was used to estimate the time constant (τ) of the RC circuit by analysing the capacitor charge curve. The time base of the Oscilloscope was set to 50.00 μs (microseconds) per division.

The most effective way to determine the time constant (τ) is to analyse the charging section of the waveform. This means that the time constant (τ) is defined by the time required for the capacitor voltage to reach 63% of its highest value when charging .

As seen in Figure 1, the Oscilloscope maximum voltage is 1V, therefore 63% correlates with 0.63 V. The time division amounts to 1.5.

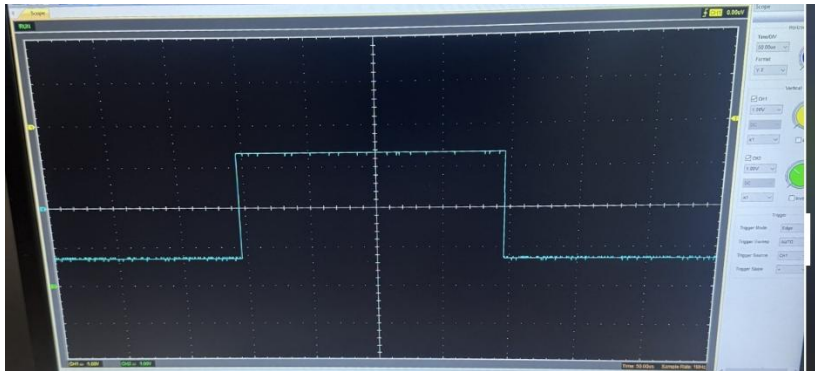
$$\tau = 1.5 \times 50 \times 10^{-6} = 75 \times 10^{-6}$$

$$\tau = 7.5 \times 10^{-5} \text{ s}$$



(Figure 1 – Capacitor/discharge Charge)

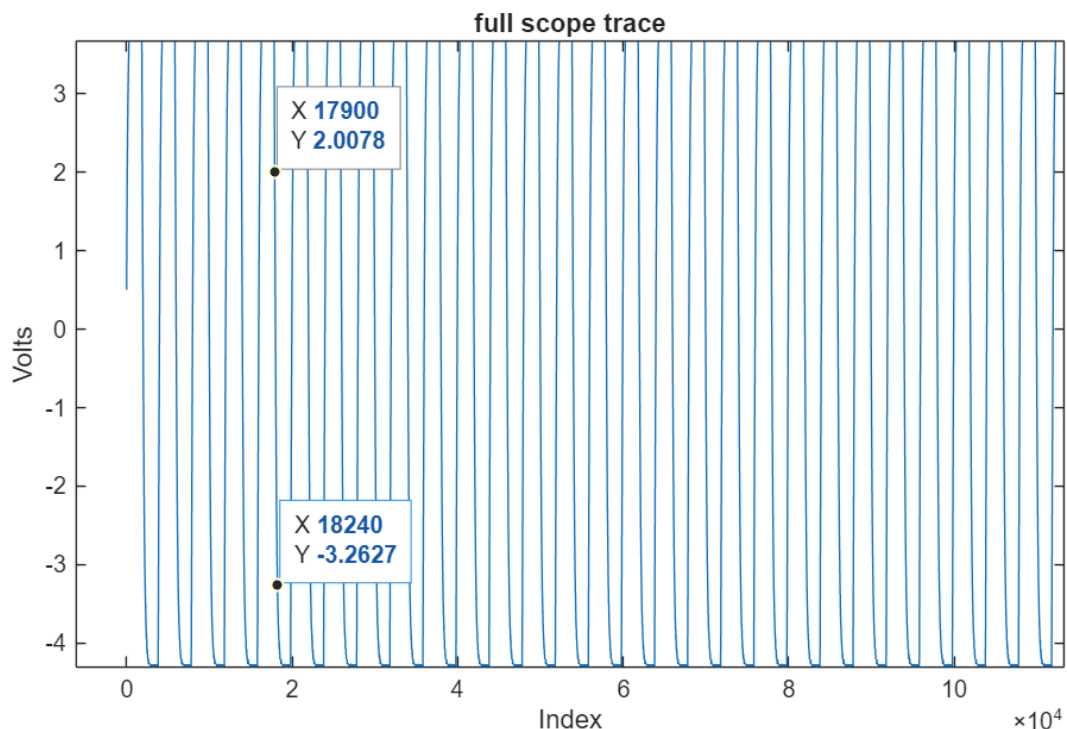
1.2 Function Generator output square wave (6)



(Figure 2 – Capacitor Charge)

Figure 2 is the square wave displaying voltage increase in an RC circuit. The horizontal axis represents time (this is where the divisions are taken from) that has been divided into small intervals which make up larger intervals on the graph, which were used to calculate the time constant in figure 1. The vertical axis represents voltage. The signal starts at a lower voltage level whilst maintaining stability. The signal then transitions to a higher voltage whilst maintaining a plateau. This flat region shows that the signal remains constant for a set amount of time before sharply decreasing back to its original voltage before the increase.

1.3 Capacitor charge and discharge wave marked at correct points. (6)



(Figure 3 – Capacitor and discharge marked)

1.4 Basic Capacitor Calculations

(6)

The time constant of the RC circuit is found by implementing the method: $\tau = RC$

using a resistance of $1.0 \text{ k}\Omega$ and a capacitance of $1.0 \text{ }\mu\text{F}$, the time constant is calculated using the method: $\tau = (1.0 \times 10^3) (1.0 \times 10^{-6}) = 1.0 \times 10^{-3} \text{ s}$

The charging of the Capacitor is found by using the equation: $V(t) = V_o(1 - e^{-(t/RC)})$.

The discharge of a capacitor is found by using the equation: $V(t) = V_o e^{-(t/RC)}$

For the gradient method, the capacitance was found as $2.00 \times 10^{-7} \text{ F}$, therefore: $\tau = (1.00 \times 10^3) (2.00 \times 10^{-7}) = 2.00 \times 10^{-4} \text{ s}$

For the Marker method, the capacitance was found as $1.30 \times 10^{-6} \text{ F}$, therefore: $\tau = (1.00 \times 10^3) (1.30 \times 10^{-6}) = 1.30 \times 10^{-3} \text{ s}$

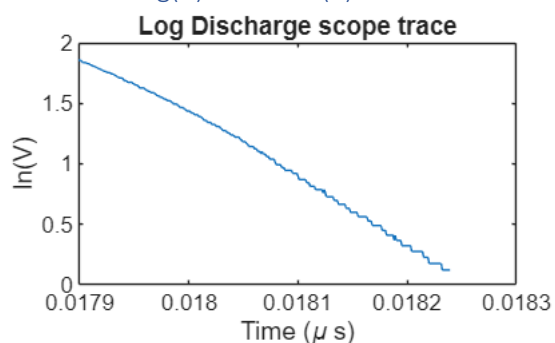
1.5 Capacitor discharge table (5)

Time (S)	Voltage (V)	ln (V)	dy = y2 – y1 dy = ln(V)2–ln(V)1	dx = x2- x1 dx = Time2 – Time1	dy/dx
0.000500	5.5843	1.685658	-0.177677059	0.000500	-355.3541179
0.001000	4.5804	1.507981	-0.199134678	0.000500	-398.269356
0.001500	3.702	1.308846	-0.227380072	0.000500	-454.7601431
0.002000	2.8863	1.081466	-0.266632431	0.000500	-533.264862
0.002500	2.1334	0.814834	-0.364650197	0.000500	-729.300394
0.003000	1.4432	0.450184	-0.385707483	0.000500	-771.4149652
0.003500	0.9412	0.064476	-0.530647002	0.000500	-1061.294005
0.004000	0.502	-0.46617	-0.916529842	0.000500	-1833.059685
0.004500	0.251	-1.3827	0	0.000500	0
0.005000	0	0	0	-0.005000	0

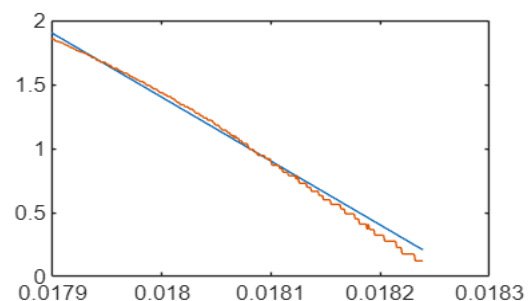
$\tau \text{ dy/dx}$
0.001303629

(Figure 4 – Capacitor Discharge Table)

1.6 Plot log(V) Gradient (5)



(Figure 5 – Ln (v) against Time)



(Figure 6 – Ln (v) against Time with Gradient)

1.7 Gradient Calculations and Compare(8)

1.7.1 Gradient Calculations

The capacitance was determined using the gradient method by plotting the natural logarithm of Voltage (V) against time for discharging capacitor. This produces a straight-line graph based on the relationship.

$$\ln(V) = \ln(V_0) - t / (RC)$$

The gradient of this line is equal to $-1/ (RC)$.

A line of best fit was applied to the data to reduce the effect of noise and fluctuations. From this smoothed line, the capacitance was determined as $2.00 \times 10^{-7} \text{ F}$. Using a resistance value of $1.0 \text{ k}\Omega$, the corresponding time constant was calculated using $RC = C \times R$, giving $RC \approx 2.00 \times 10^{-4} \text{ s}$.

Comparing this result with the capacitance obtained using the marker method, which was $1.30 \times 10^{-6} \text{ F}$. The difference between the two value is $1.10 \times 10^{-6} \text{ F}$. The percentage difference between the two methods is approximately 80.0%, indicating a significant discrepancy between results.

1.7.2 Comparison table

	Capacitance	Delta	Percentage difference
Actual	1 μF	x	X
Marker Calculation	$1.30 \times 10^{-6} \text{ F}$	$0.30 \times 10^{-6} \text{ F}$	30.0 %
Gradient Calculation	$2.00 \times 10^{-7} \text{ F}$	$8.00 \times 10^{-7} \text{ F}$	80.0 %

(Figure 7 – Comparison Table)

1.8 Capacitor Uses (5)

Capacitors are widely used in electrical, automotive and motorcycle systems due to their ability to store and release electrical energy as well as filter and stabilise voltage. In electrical applications, capacitors are commonly used in power supplies to smooth fluctuations in DC voltage, ensuring a more stable and coherent output ([Gómez-Aguilar, J.F., Atangana, A. and Morales-Delgado, V.F. 2017](#)).

Capacitors are also used to store energy within a circuit where a quick discharge is needed, such as a flash from a camera. Capacitors have a vital role in timing circuits, where they control time delays in RC networks. Additionally, they are used in signal filtering to remove unwanted noise or to separate different frequency components in electronic circuits. Another important application is power factor correction in Air Conditioning (AC) systems, where capacitors improve efficiency by reducing reactive power ([Harris Tom, 2002](#)).

In automotive systems, capacitors are used to stabilise voltage in car audio systems, preventing drops of performance when dealing with high power requirements. They are also essential within ignition systems, where they assist in generating high voltages required for spark plugs. Capacitors are also used in Engine Control Units (ECU) to filter and stabilise electrical signals, ensuring reliable operation of electronic components. Furthermore, they assist in reducing electrical noise in systems such as electric windows and windscreen wipers, improving overall performance and consistency ([Robert Bosch GmbH. 2022](#)).

Regarding Motorcycles, capacitors are commonly used in capacitor discharge ignition (CDI) systems. Within these systems, the capacitor stores energy and quickly releases it to create the spark needed for engine ignition, particularly in motorcycles that operate without a battery.

An intuitive role that capacitors also play is through their incorporation into touch screen technology, particularly in smart phones, tablets and control panels. These systems are operated by detecting changes in capacitance when an object like a finger come into contact with the screen. A grid of conductive layers within the screen continuously monitors the capacitance at different locations on the screen. This aspect of design is responsible for making features like multiple touch points and pinch to zoom possible ([Owen, T. \(1992\)](#)).

Capacitors which are used in these systems must be incredibly sensitive and responsive to incrementally small changes in electrical charge, this ensures fast and accurate detection. This technology is also present in touch button appliances for vehicle interior dashboards and industrial control systems. This approach is echoed through the modern age as mechanical switches are swapped out for more sleek designed touch screens and panels. Capacitors used in this application are meant to be very sensitive to ensure a dynamic and user friendly experience ([Huang, Z. et al. \(2024\)](#)).

It is vital to understand that capacitors are intrinsic components that contribute to the efficient operation, stability and reliability of a significant range of electronic systems.

1.9 Inaccuracies Question (4)

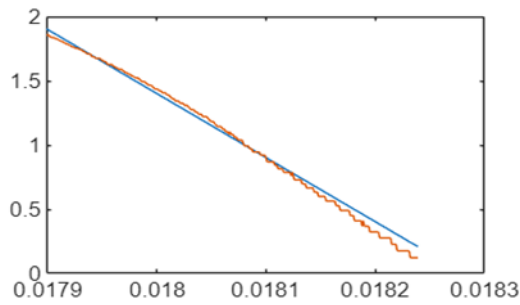
The capacitance of the capacitor was determined using both the marker method and the gradient method, based on the discharge characteristics of an RC circuit.

Using the marker method, the time constant was obtained directly from the data as 0.001303629 s. Substituting this value into the relationship ($C = RC / R$), with a resistance of 1.0 k Ω , gives a capacitance of 1.30 μF . This value is reasonably close to the expected capacitance of 1.0 μF , indicating that this method provides a somewhat accurate estimate.

For the gradient method, a graph of the natural logarithm of voltage against time was plotted. The gradient of this graph is equal to $-1/RC$. A line of best fit was used to obtain a more accurate gradient by reducing the effect of noise in the data.

From this smoothed gradient, the capacitance was determined to be $2.00 \times 10^{-7} \text{ F}$. Using the resistance value of 1.0 k Ω , the corresponding time constant was calculated as $RC \approx 2.00 \times 10^{-4} \text{ s}$.

This value of capacitance is significantly lower than the expected value of $1.0 \times 10^{-6} \text{ F}$, indicating a large deviation and suggesting that the gradient method is less accurate in this experiment (see figure 5).



(Figure 8 – Gradient)

When compared to the expected value of $1.0 \mu\text{F}$, the marker method produced a percentage difference of 30%, whereas the gradient method resulted in a much larger percentage difference of approximately 80.0%. This indicates that the marker method is more reliable in this experiment, while the gradient method is more susceptible to error.

The discrepancy between the two methods can be explained by several sources of inaccuracy. One primary factor is the difficulty in accurately determining the gradient from the logarithmic graph. The data points do not form a perfectly straight line due to noise and fluctuations in the measured signal, making it difficult to select appropriate points and calculate an accurate slope. Since the gradient is used to determine the time constant, any small error in the slope leads to a large error in the calculated capacitance.

Another significant source of error is the small time scale used in the experiment. Because the time values are very small, even slight uncertainties in recording time result in large percentage errors. This has a greater impact on the gradient method, which relies heavily on precise changes in time and voltage.

Additionally, inaccuracies may arise from the measurement equipment. The oscilloscope may introduce errors due to limited resolution, sampling rate, and electrical noise, all of which can affect the recorded voltage values. There may also be uncertainty in the resistance value used in calculations if the actual resistor differs slightly from its nominal value.

To improve the accuracy of the experiment, several steps could be taken. Using a larger resistance value would increase the time constant, making the discharge curve slower and easier to measure accurately. This would reduce the inaccuracies in time measurements. Improving the method of determining the gradient, such as using a best-fit line rather than selecting individual points, would also increase accuracy. Additionally, ensuring that the correct and measured resistance value is used, rather than a nominal value, would reduce systematic error. Finally, reducing electrical noise and using more precise measurement equipment would further improve the reliability of the results.

While the marker method provided a reasonably accurate value for capacitance, the gradient method was less reliable due to its sensitivity to measurement errors. The results highlight the importance of accurate data collection and careful analysis in experimental physics.

1.10 Risk Question (10)

Modern Vehicle depends heavily on Controller Area Network (CAN) bus systems to allow different electronic control units (ECUs) to communicate with each other ([Avatefipour, O. and Malik, H. 2018](#)). However, due to these systems being interconnected, they are more vulnerable to cybersecurity threats, where unauthorised users are able gain access to information regarding the vehicle and potentially interfere with the vehicles functions. To reduce these risks appropriate security measures, need to be put in place in accordance with ISO/SAE 21434 standards.

An effective way to reduce cyber security risks is by using secure communication methods. This involves encrypting messages from the CAN bus system and applying authentication techniques so that only trusted ECUs can send and receive data ([Aliwa, E. et al. 2022](#)). These measures help prevent spoofing attacks, where a malicious device tries to act as a legitimate component within the system.

Another vital approach is network segmentation. By separating safety-critical systems, such as braking and steering, from less critical systems like infotainment. This would make a cyber security attack less damaging. Meaning that even if an attacker gained access to the non-critical systems of a car, they would be unable to gain access to the important aspects of the cars functionality and safety.

Intrusion Detection Systems can be used to monitor CAN traffic for unusual behaviour. These systems can detect irregular patterns of use that may indicate an attack and respond in real time. This can be achieved by isolating affected components and alerting the driver.

Keeping the software updated is a massive part of its security based functionality. Regular updates and secure management of firmware help tackle newly discovered vulnerabilities. Secure over the air (OTA) updates allow manufacturers to fix issues without requiring physical access to the vehicle. This necessary feature makes it easier to protect users and maintain security over time ([Buttigieg, R., Farrugia, M. and Meli, C. 2017](#)).

Controlling access to the system is another key factor. Certain entry points such as diagnostic ports and wireless connections like Bluetooth and Wi-Fi, must be secured using authorisation and prevent unauthorised access ([Wu, W. et al. 2020](#)).

ISO/SAE 21434 highlights the importance of managing cyber security throughout the entire life cycle of a vehicle ([Khalil, K., Gehrmann, C. and Vogel, G. 2025](#)). This means that identifying and assessing risks during the developmental phase of the vehicle are just as imperative as identifying risks during the lifetime of the vehicle. Threat analysis and risk assessment (TARA) are used to identify possible attack routes and implement protection methods. Secure design, monitoring and maintenance reduce effectively.

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