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1. Task 3

1.1 Scope Time Division Calculations

The time division of the oscilloscope must be selected so that the complete charging and discharging behaviour of the capacitor can be observed clearly on the screen.

To display one complete waveform clearly on the oscilloscope, the time base must be chosen using the time constant of the RC circuit.

The period of the wave is given by:

$$T = \frac{1}{f}$$

For a frequency of 10 Hz:

$$T = \frac{1}{10} = 0.1s$$

The time constant of the RC circuit is:

$$\tau = RC$$

Using:

$$R = 100\Omega$$

$$C = 1 \times 10^{-6}F$$

$$\tau = 100 \times 1 \times 10^{-6} = 1 \times 10^{-4}s = 100\mu s$$

To ensure the waveform is fully visible, roughly 40-time constants are displayed. This allows multiple charge and discharge cycles to be clearly observed.

$$40\tau = 40 \times 1 \times 10^{-4} = 4 \times 10^{-3}s = 4ms$$

The oscilloscope screen has 10 horizontal divisions, so the required time per division is:

$$TimeDiv = \frac{4ms}{10} = 0.4ms/div$$

The closest available oscilloscope setting is therefore:

$$0.5ms /div$$

The selected value of 0.5 ms/div is the closest standard oscilloscope setting to the calculated 0.4 ms/div, making it a practical choice for displaying the full waveform.

1.2 Function Generator output square wave

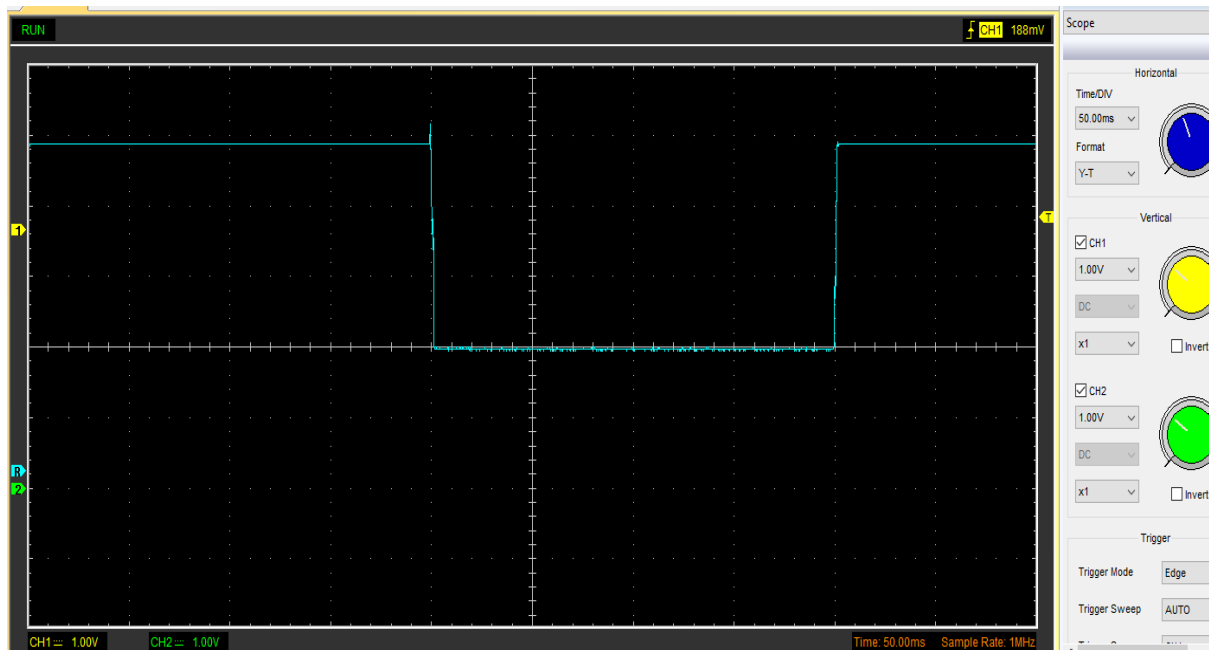


Figure 1: Oscilloscope trace of a function generator square wave input signal applied to the RC circuit.

1.3 Capacitor charge and discharge wave marked at correct points.

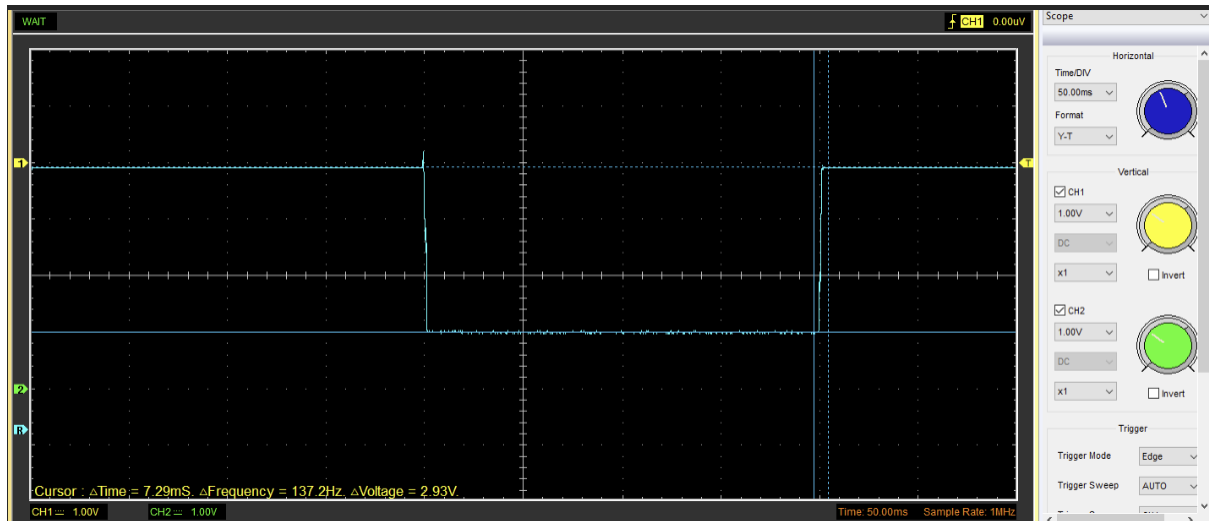


Figure 2: Oscilloscope trace showing the capacitor discharging waveform in an RC circuit with key points marked.

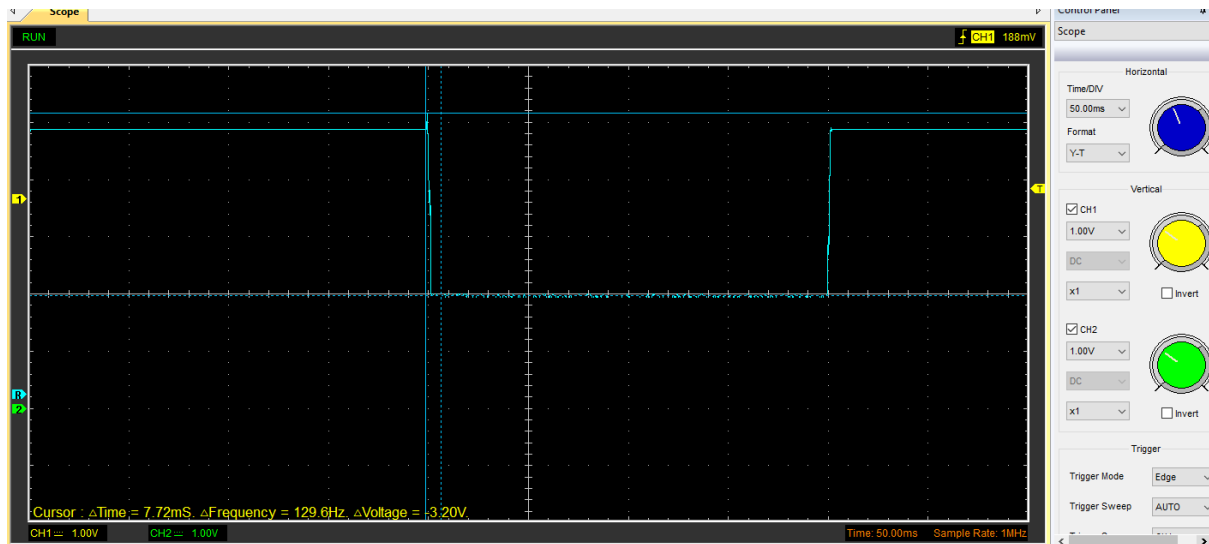


Figure 3: Oscilloscope trace showing the capacitor discharging waveform in an RC circuit.

The oscilloscope trace in Figure 2 shows the voltage across the capacitor during both the charging and discharging phases of the RC circuit.

Key points have been marked on the waveform to identify the time constant behaviour of the capacitor.

During the charging phase, the capacitor voltage increases exponentially from 0 V towards the supply voltage. The point at which the capacitor reaches approximately 63.2% of its maximum voltage (V_0) has been marked on the waveform. This point represents one time constant (τ).

During the discharging phase, the capacitor voltage decreases exponentially from its initial value. The point where the voltage falls to approximately 36.8% of its initial value has also been marked. This again corresponds to one time constant (τ).

The time difference between the start of the charge/discharge curve and these marked points was measured using the oscilloscope cursor tool. This measured time represents the experimental value of the time constant.

These marked points are essential because they provide a direct method for determining the time constant from the waveform, which is then used in the calculation of capacitance using:

$$\tau = RC$$

By clearly identifying these positions on the waveform, the experimental results can be directly linked to the theoretical behaviour of an RC circuit, improving the accuracy and reliability of the analysis.

1.4 Basic Capacitor Calculations

The capacitance of the capacitor was first determined using the measured time constant from the oscilloscope waveform.

For an RC circuit:

$$\tau = RC$$

Rearranging to make capacitance the subject:

$$C = \frac{\tau}{R}$$

From the oscilloscope, the time constant was taken at the point where the capacitor reached 63.2% of its charging voltage / 36.8% of its discharging voltage. This corresponds to one time constant, τ .

Based on the measured time constant and analysis of the data, the resistor and capacitor values used in the circuit were approximately 100 Ω and 1 μF respectively. These values are consistent with the expected RC time constant observed in the experiment.

1.5 Capacitor discharge table

Time (s)	Voltage (V)	ln (V)	$dy = y_2 - y_1$ $dy = \ln(V)_2 - \ln(V)_1$	$dx = x_2 - x_1$ $dx = \text{Time}_2 - \text{Time}_1$	dy/dx
0.000694	4.6118	1.529	x	x	x
0.000727	4.0157	1.39	-0.138	3.30E-05	-4194.138119
0.00076	3.5451	1.266	-0.125	3.30E-05	-3777.130608
0.000793	3.2314	1.173	-0.093	3.30E-05	-2807.602681
0.000826	2.9804	1.092	-0.081	3.30E-05	-2450.241217
0.000859	2.7608	1.016	-0.077	3.30E-05	-2319.303845
0.000892	2.6039	0.957	-0.059	3.30E-05	-1773.035505
0.000925	2.4471	0.895	-0.062	3.30E-05	-1882.020338
0.000958	2.3529	0.856	-0.039	3.30E-05	-1189.546669
0.000991	2.2588	0.815	-0.041	3.30E-05	-1236.815488

Figure 4: Capacitor discharge table

1.6 Plot $\ln(V)$ Gradient

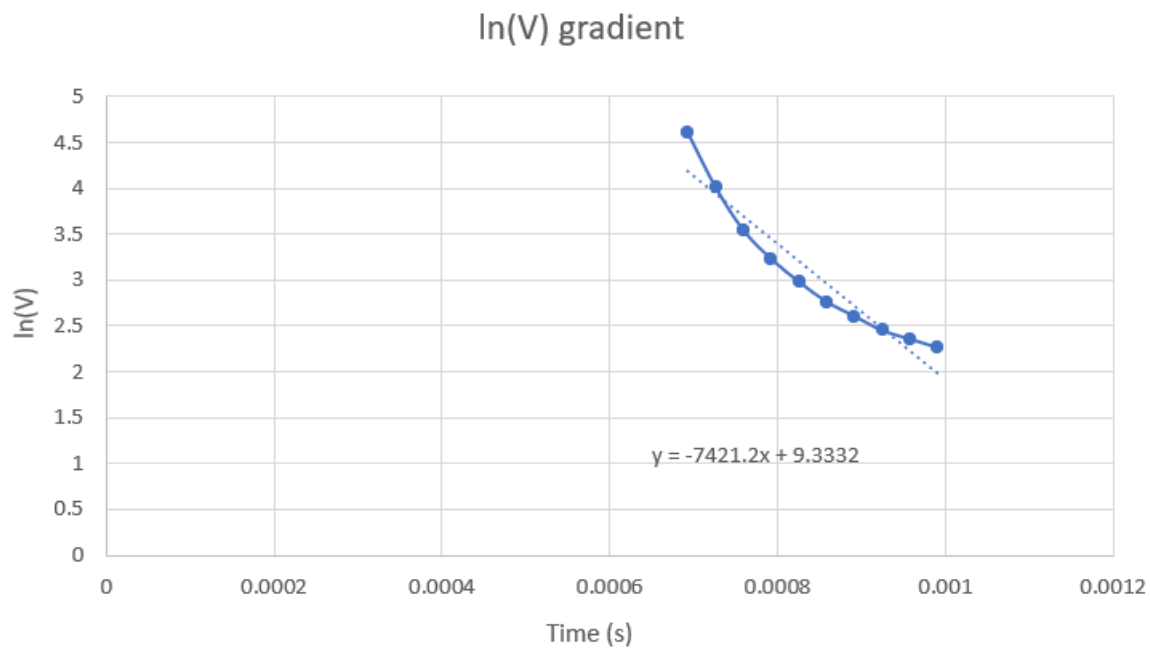


Figure 5: A graph showing $\ln(V)$ gradient

The voltage data from the capacitor discharge was used to analyse how the capacitor behaves over time. The voltage values were converted into $\ln(V)$ so that the curved discharge could be turned into a straight line.

A graph of $\ln(V)$ against time (s) was plotted using Excel. A straight-line trendline was added, which showed a clear downward slope. This confirms that the capacitor is discharging as expected.

The gradient of the line shows how quickly the voltage is decreasing. This gradient is important because it can be used to find the time constant and capacitance of the circuit.

Using a graph improves accuracy because it uses multiple data points instead of just one measurement. This reduces the effect of small errors and makes the results more reliable.

1.7 Gradient Calculations and Comparison

1.7.1 Gradient Calculations

To determine the capacitance using the gradient method, the natural logarithm of the voltage was plotted against time. For a discharging capacitor:

$$\ln(V) = \ln(V_0) - \frac{t}{RC}$$

This equation is in the form $y = mx + c$, where the gradient is:

$$m = -\frac{1}{RC}$$

From the graph in Figure 5, the gradient of the trendline is:

$$m = -7421$$

Rearranging:

$$RC = \frac{1}{7421}$$

$$RC = 1.26 \times 10^{-4} s$$

Using:

$$R = 100\Omega$$

The capacitance is:

$$C = \frac{RC}{R}$$

$$C = \frac{1.26 \times 10^{-4}}{100}$$

$$C = 1.26 \times 10^{-6} F$$

$$C = 1.26\mu F$$

1.7.2 Comparison table

	Capacitance	Delta	Percentage difference
Actual	1 μF	x	X
Marker Calculation	0.95	0.05	5%
Gradient Calculation	1.26	0.26	26%

The gradient method provides a more reliable approach than the marker method, as it uses multiple data points from the discharge curve rather than relying on a single measurement. The calculated capacitance of $1.26\mu F$ is reasonably close to the expected value of $1\mu F$ with the difference likely caused by measurement inaccuracies and slight graph deviations.

1.8 Capacitor Uses

Capacitors perform several important functions within electrical and automotive systems due to their ability to store and release charge when required. One key application is voltage smoothing, where capacitors reduce fluctuations in power supply lines. This is especially important in vehicle electronic control units (ECUs), where stable voltage levels are needed for accurate sensor and control operation.

They are also used in timing circuits. In RC networks, the rate at which a capacitor charges and discharges can be controlled to introduce delays or create oscillating signals. This principle is applied in systems such as indicator timing circuits and engine control processes.

Another important function is rapid energy delivery. Capacitors can discharge stored energy quickly, which makes them suitable for safety-critical systems such as airbag deployment, where immediate response is required.

Capacitors additionally support signal processing by allowing alternating current (AC) signals to pass while blocking direct current (DC). This is useful in communication and audio circuits within vehicles. They also help reduce electrical noise between components by acting as decoupling devices.

Finally, capacitors are used in motor-related applications, where they assist with starting and improving efficiency in devices such as fans and pumps. Overall, they contribute significantly to system stability and performance.

1.9 Inaccuracies Question

Differences between the measured and expected capacitance values can arise from several factors. One major source is component tolerance, as real resistors and capacitors are manufactured with allowable variation from their stated values. This directly affects the calculated time constant of the circuit.

Measurement limitations also play a role. When using an oscilloscope, it can be difficult to identify the exact point corresponding to one time constant, particularly due to screen resolution and scaling. Small errors at this stage can significantly influence the final result.

Human factors should also be considered. Mistakes such as misreading scales, placing markers inaccurately, or rounding values during calculations can introduce additional error.

Environmental conditions may further affect performance. For example, temperature changes can alter the behaviour of some components, particularly capacitors.

Finally, the assumption of ideal circuit behaviour is not entirely accurate in practice. Effects such as parasitic resistance and capacitance within the circuit and measuring equipment can distort the expected waveform. As a result, experimental values are unlikely to match theoretical ones exactly, although they should fall within a reasonable tolerance range.

1.10 Risk Question

Modern vehicles rely on Controller Area Network (CAN) systems to enable communication between Electronic Control Units (ECUs). However, CAN was designed for reliability and speed rather than security, and it lacks built-in encryption and authentication. This means that any compromised device connected to the network can potentially inject malicious messages, creating significant cybersecurity risks (Khan et al., 2023).

ISO/SAE 21434:2021 provides a structured framework for managing these risks across the vehicle lifecycle, from development to decommissioning (ISO, 2021). One useful method is Failure Modes and Effects Analysis (FMEA), which evaluates risks based on severity, likelihood, and detectability, allowing engineers to prioritise cybersecurity threats in a systematic way (AIAG and VDA, 2019).

Vehicle networks have multiple attack entry points, including the OBD-II port and wireless interfaces such as Bluetooth and Wi-Fi. These increase risk, particularly when external devices interact with internal systems. Over-the-air (OTA) updates also introduce vulnerabilities if not properly secured (NHTSA, 2022).

To reduce these risks, layered security measures are required. Network segmentation helps isolate safety-critical systems like braking from non-critical systems such as infotainment, limiting the spread of attacks. Intrusion Detection Systems (IDS) can monitor CAN traffic and detect anomalies, improving the likelihood of identifying threats. Additional protections such as authentication, encryption (where feasible), and restricting physical access further strengthen security (GAO, 2016; NHTSA, 2022).

The Stuxnet cyberattack demonstrates how cyber vulnerabilities can cause physical damage. In this case, malware targeted industrial control systems and manipulated operations, highlighting the risks of cyber-physical attacks in automotive systems (Langner, 2011).

In conclusion, while CAN systems are inherently vulnerable, risks can be effectively managed through FMEA and technical controls such as segmentation, authentication, and intrusion detection. Following ISO/SAE 21434 supports a secure-by-design approach, improving vehicle safety and resilience (ISO, 2021).

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