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Electronic Circuits Testing and Applications

Vehicle Electronics

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1. Task 3

1.1. Scope Time Division Calculations

It is necessary to set the oscilloscope time division to a period which will allow us to capture, display and measure the waveform created in the RC circuit.

A resistor value of $100\ \Omega$ and a capacitor value of $4.7\ \mu\text{F}$ were chosen to build the circuit.

Using:

$$\tau = R \cdot C$$

The Time Constant for the circuit can be calculated.

$$0.47\text{ milliseconds} = 100 \times 4.7 \times 10^{-6}$$

Full charge, or full discharge of the capacitor is achieved in 5 Time Constant periods, thus a total of at least 10 Time Constant periods is required to be displayed to see a full charge and discharge cycle.

The horizontal time division was set to 500 milliseconds, which will display just over one full charge and discharge cycle on the trace.

The vertical division range was set to 1V and the signal generator output amplitude also set appropriately, (Figure 1).

Sample capture rate of the oscilloscope is 1 Ms/s.

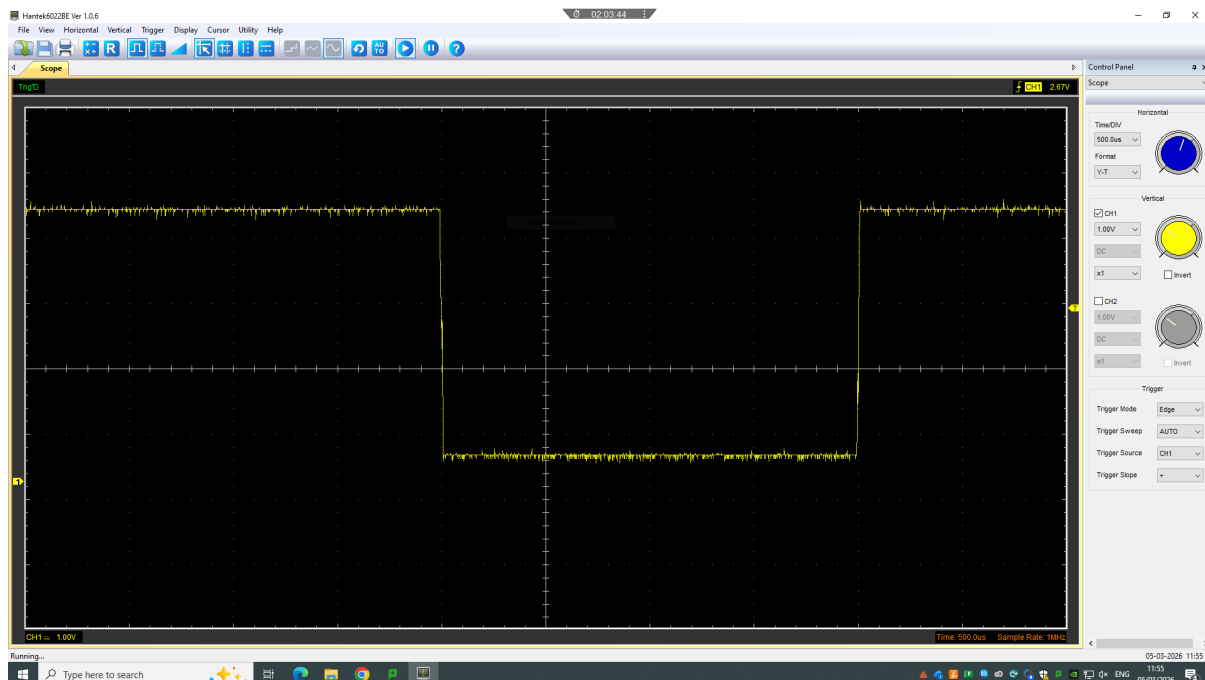


Figure 1

1.2. Function Generator output square wave

The output frequency of the signal generator was calculated to be around 40 times the Time Constant (0.47 ms) of the RC circuit:

$$4.7 \times 10^{-4} \times 40 = 0.0188$$

$$\text{circuit frequency} = 1/0.0188$$

$$= 53.19 \text{ Hz}$$

the signal generator was set just below this at 50 Hz.

1.3. Capacitor charge and discharge wave marked at correct points.

The oscilloscope traced the typical exponential curves of capacitor discharge and charging cycles (Figure 2). Data points were captured every microsecond and stored before being input into a spreadsheet. A graph was then plotted using the spreadsheet for basic capacitor calculations on the discharge and charging curves of the RC circuit.

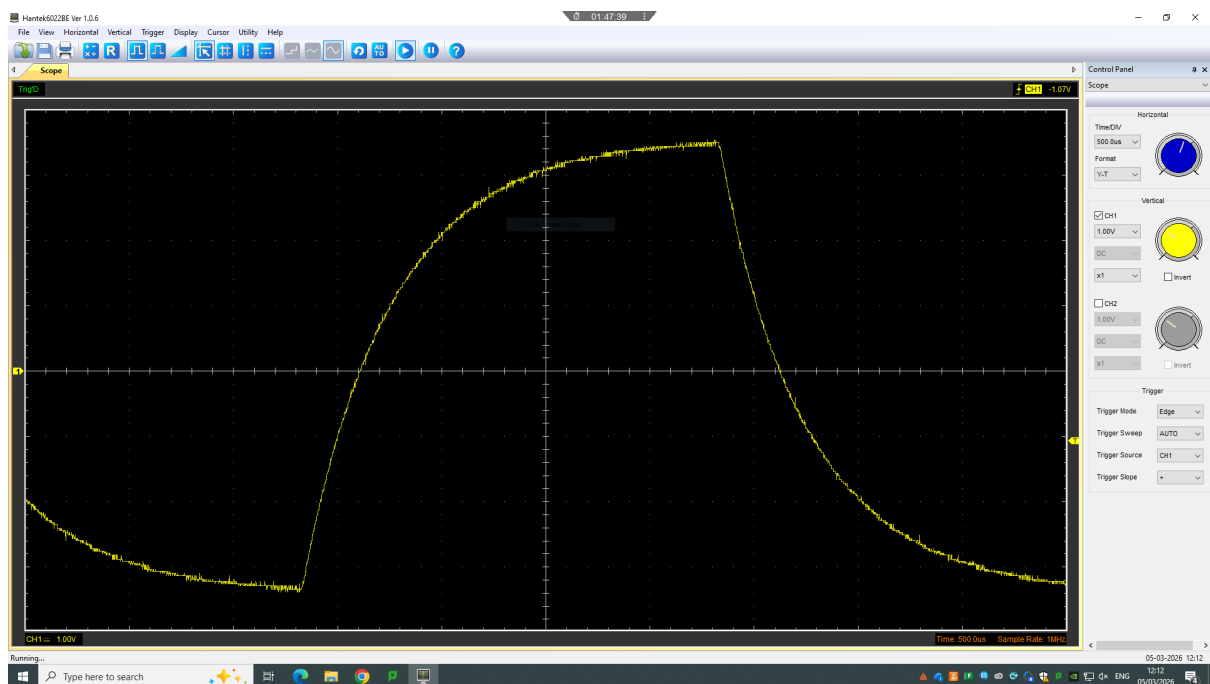


Figure 2

The capacitor discharges 63.2% of its maximum charge in one Time Constant period.

In the discharge cycle it is therefore possible to select the point on the graph that represents only 36.8% of charge remaining and measure the time elapsed for this charge to have been depleted from maximum.

This time is equivalent to one Time Constant period and thus allows us to calculate the actual value of capacitance using:

$$\tau = R \cdot C$$

Similarly for the charging cycle the point at which voltage reaches 63.2% of the maximum is also equivalent to one Time Constant Period and thus the capacitance can be calculated by using the elapsed time from minimum to this point (Figure 3).

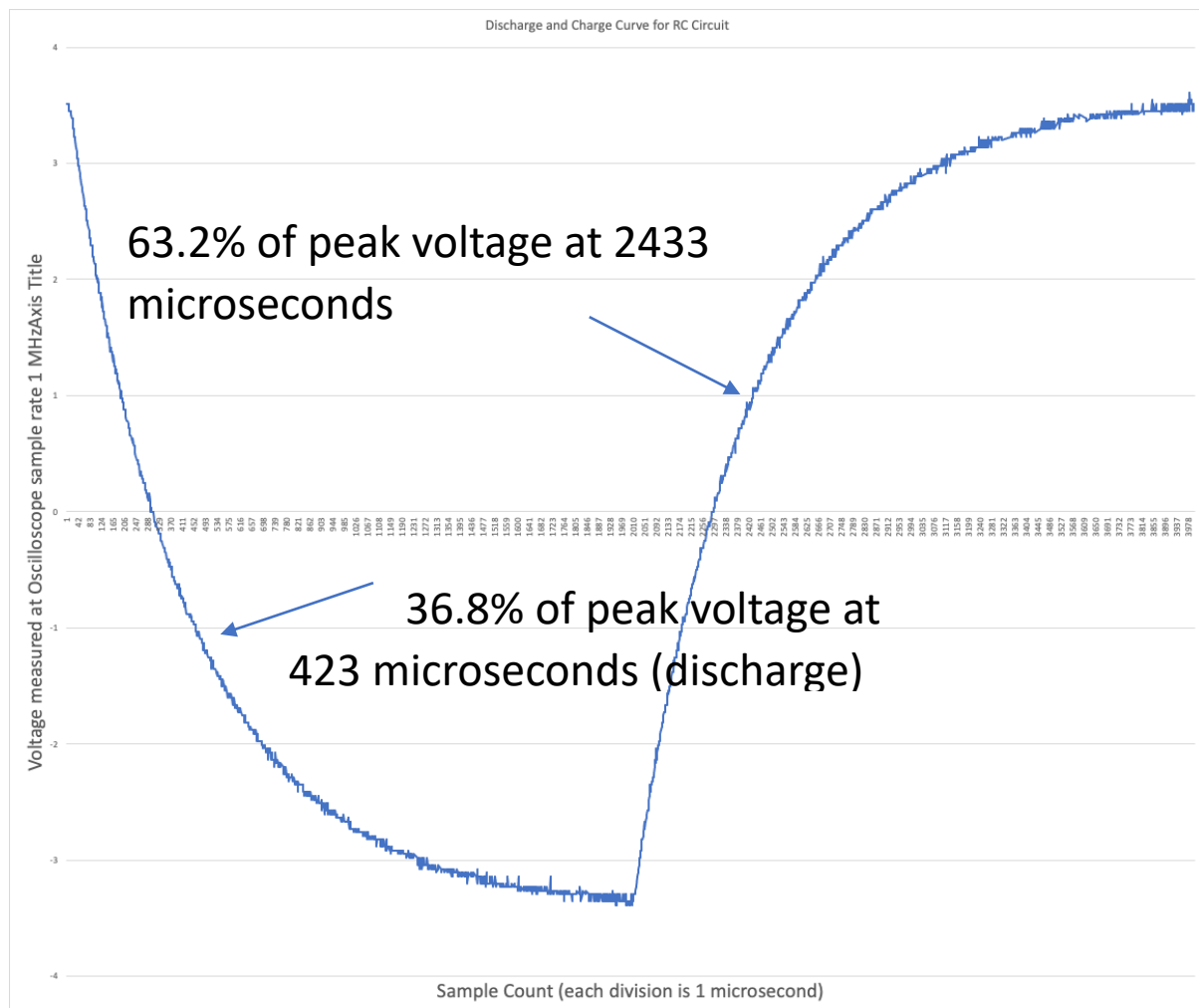


Figure 3

1.4. Basic Capacitor Calculations

Looking at the discharge curve (all measured voltages are offset by -3.3882v):

Peak voltage is 6.9V

The capacitor discharges 63.2% of its maximum charge in one Time Constant period.

Thus leaving 36.2% of charge.

$$0.368 \times 6.9 = 2.5392$$

(offset is -3.3882v)

$$2.5392 - 3.882 = -0.849V$$

(the closest sample to this value occurs at 423 microseconds with value 0.8157V)

Using the basic formula:

$$\tau = R \cdot C$$

$$423 \times 10^{-6} = 100 \times C$$

$$C = 4.23 \text{ Micro Farads}$$

Looking now at the charge curve:

The capacitor reaches 63.2% of its maximum charge, similarly in one Time Constant period.

$$0.632 \times 6.9 = 4.3608$$

$$(\text{offset is } -3.3882\text{V})$$

$$4.3608 - 3.3822 = 0.9726\text{V}$$

(the median sample for this value occurs at 2433 microseconds with value 0.9726V)

Using the basic formula:

(time from total discharge = 2433 - 2000 microseconds = 433 microseconds)

$$\tau = R \cdot C$$

$$433 \times 10^{-6} = 100 \times C$$

$$C = 4.33 \text{ Micro Farads}$$

These measured values of 4.23 uF and 4.33 uF compare favourably with the value printed on the canister of 4.7 uF (typical tolerance on a capacitor value being between 10 and 20% of stated rating). The average value from the two calculations suggests 4.28 uF.

1.5. Capacitor discharge table

Time (s)	Voltage (V)	ln (V)	dy = y2 – y1 dy = ln(V)2 - ln(V)1	dx = x2 - x1 dx = Time2 – Time1	dy/dx
0.0002	4.3294	1.4654	x	x	x
0.0004	4.1098	1.4133	-0.0324	0.0002	-162
0.0006	1.7255	0.5455	-0.8678	0.0002	-4339
0.0008	1.098	0.0934	-0.4521	0.0002	-2260.5
0.001	0.7215	-0.3264	-0.4198	0.0002	-2099
0.0012	0.4392	-0.8228	-0.4964	0.0002	-2482
0.0014	0.2509	-1.3827	-0.5599	0.0002	-2799.5
0.0016	0.1568	-1.8527	-0.47	0.0002	-2350
0.0018	0.0941	-2.3633	-0.5106	0.0002	-2553
0.00198	0.0313	-3.4641	-1.1008	0.00018	-6113.33

Table 1

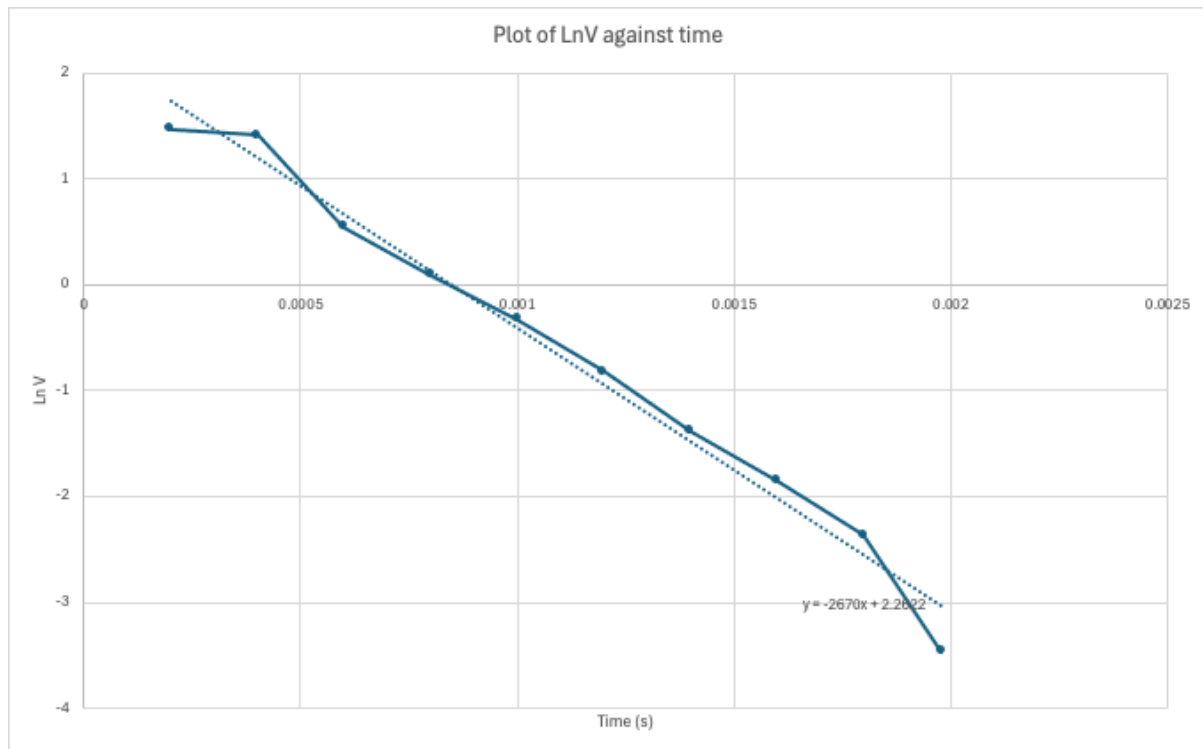
1.6. Plot log(V) Gradient

Using a spreadsheet the data from Table 1 was captured and plotted in a graph.

A best fit line was also added to the graph.

It is clear that the trend of the plotted data is close to a straight line graph in the central portion but trends away from this towards the limits of the discharge cycle.

It is best to make the gradient calculation from the central portion of the graph, excluding the very fast initial discharge rate and the very slow final depletion rate.



1.7. Gradient Calculations and Compare

1.7.1. Gradient Calculations

A capacitor discharges according to the following formula:

$$V = V_0 e^{-t/RC}$$

Taking logarithm both sides of the above equation it can be seen that:

$$\begin{aligned} \ln(V) &= \ln(V_0) + \ln(e^{-t/RC}) \\ &= \ln(V_0) - t/RC \{\ln(e)\} \end{aligned}$$

But, $\ln(e) = 1$

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

Which matches the equation of a straight line, $y = mx + c$

In this case $\ln(V_0)$ being the constant and $-1/RC$ being the gradient (m) of a downward sloping straight line.

Using the 6 central gradient figures and excluding the outliers we can calculate an average gradient of -2424.

Thus using:

$$\tau = R \cdot C$$

We can see that the Time Constant for the capacitor from this graphing methodology is the reciprocal of the gradient.

$$1/2424 = 0.000413$$

This compares with the answer of 0.000423 from the previous method.

Using a value of 100 ohms for the resistor in the circuit, we can now calculate the capacitance of the capacitor.

$$0.000413 = 100 \times C$$

$$C = 0.000413 / 100$$

$$= 4.13 \text{ Micro Farads}$$

1.7.2. Comparison table

	Capacitance	Delta	Percentage difference
Actual	4.7 μF	x	X
Marker Calculation	4.28 μF	0.42 μF	8.9%
Gradient Calculation	4.13 μF	0.57 μF	12.1%

Table 2

In Table 2, it can be seen that the measured capacitance of the capacitor, discovered by both methodologies is lower than the capacitance marked on the can of the component.

Both the marker approach and the gradient approach yield answers which are very close to each other, suggesting that the actual capacitance is roughly 10% lower than specification, this is within normal tolerance of commonly manufactured capacitors.

1.8. Capacitor Uses

Capacitors are common and essential components in almost all electronic circuits. As vehicles have become more complicated over time and more electronics are finding their way into the vehicles, capacitors and capacitance have found even more uses and are now ubiquitous. Examples of such uses are:

1. One of the most common applications for capacitors is in smoothing DC electric current sourced from AC supplies. The DC supply that is commonly used in a vehicle to power vehicle electrics is source from a battery which is charged by an alternator which generates AC. A rectifier bridge and smoothing capacitors provide a 12V DC supply to charge the battery. (Zogbi, 2024)

2. Capacitors can also be used for signal filtering. blocking low frequency DC signals from interfering with high frequency AC signals in audio or communication systems (ODG, 2026)
3. Since they store energy, capacitors are commonly used to provide backup power to microcontrollers and memory chips to ensure continued functioning during short power failures (Ariat Technology, 2026)
4. In industrial power grids, capacitors are commonly used to improve power transmission efficiency by reducing the effect of highly inductive loads, common in large industrial plant installations (Tense, 2026)
5. It is quite common in high power car audio systems to use capacitors to deliver large bursts of current to sub-woofers in order to avoid dimming headlights during large bass transients (Evolution Lithium, 2026)
6. Capacitors are often used to protect sensitive items such as a car's Engine Control Unit (ECU) and electronic sensors from high voltage spikes (Global Well PCBA, 2026)
7. In an airbag protective system it is crucial that the high electrical energy supply required to fire the airbag, in the event of an accident, does not fail. A capacitor can provide that rapid delivery of the firing signal, even if other parts of the electrical system are compromised (Eureka, 2025)
8. In electric and hybrid electric vehicles, super capacitors are often used as part of the regenerative braking and power delivery systems to provide storage and instant release of energy during acceleration (Eureka, 2025)
9. Motorcycles will often have a Capacitive Discharge Ignition CDI system which uses capacitors to ensure a strong well timed spark at the spark plug (Study Smarter, 2026)
10. In racing or other applications where a excess weight needs to be minimised often a motorcycle will be run "battery less" utilising a capacitor to store energy required for onboard systems powered directly from a lightweight generator (Classic British Spares, 2026)

1.9. Inaccuracies Question

There are a number of different reasons why a capacitor might not measure the same value as marked on the capacitor can, most common of which are:

- Manufacturing Tolerance, as previously mentioned capacitors usually have an allowable range +/- 10% or even 20% for less critical circuit designs (BT, 2026)
- Capacitors can suffer from temperature drift from ambient heat or from heat generated in the component itself (Hewlett Packard, 1998)
- Over time the characteristics of certain dielectrics can change, degrading the capacitive performance of the component (Mao, 2023)

1.10. Risk Question

As vehicles have become ever more reliant on microprocessors to manage not only the engine of the vehicle but virtually all systems, including braking, stability management, traction control, lighting, safety systems, passenger comfort and even passenger

convenience, it has become apparent that a failure in these systems or an attack by a bad actor could be extremely dangerous.

The vehicle's CAN BUS has become a potential entry point for cyber-attack, including virus, not only installed by user or garage based means but also via online connectivity and/or automatic updates.

As cars become more autonomous, the importance of this potential danger is increasing.

In order to protect against this threat, an international standard has been established to which all new vehicles will comply. This standard is ISO/SAE 21434 Road Vehicles - Cybersecurity Engineering (kiwi, 2026)

The same principles which are applied to any mission critical system, whether that be banking and finance systems or aircraft control systems and many other such applications are now being applied to vehicle systems engineering.

In order to get Type Approval, all vehicles since July 2022 must have Automotive Cybersecurity Management System ACMS certification.

This means that the vehicle must be equipped with security technology which will prevent the vehicle from cyberattacks.

Applicable technology is identified through risk analysis of potential threats and which assets in the vehicle are exposed to such threats. Security testing is then completed, using ethical hacking procedures, for example, to ensure that mitigating technology utilised is effective in addressing any risks and minimising danger or security exposure to occupants and other road users.

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