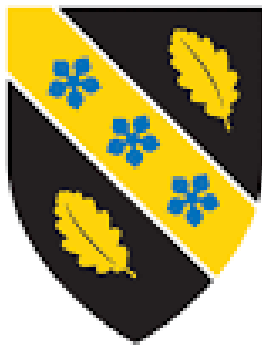


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1 Introduction

This report looks at an experiment of an RC circuit where a circuit was built and scoped to show the basic function of a capacitor charging and discharging. It aims to demonstrate how to calculate the capacitance by two different methods. The values found by these methods will be compared to the actual capacitance. The first method is to manually calculate the value from known time constants and the equation $F = \frac{s}{\Omega}$. The second method will use the gradient of a graph taken as the time constant (τ) that can be then re-arranged to calculate the value of capacitance using the equation $\tau = RC$. An RC circuit has been made and results taken and recorded.

2 Methodology

This experiment investigates the capacitor in a RC circuit. Using a the hantek6022BE oscilloscope to view the wave form generated by the circuit below, the capacitance could be calculated. The function generator used the power from the USB port on the pc that the scope was plugged into. The scope has a crocodile clip and a hook that connects to the circuit allowing the circuits properties to be displayed through a wave form.

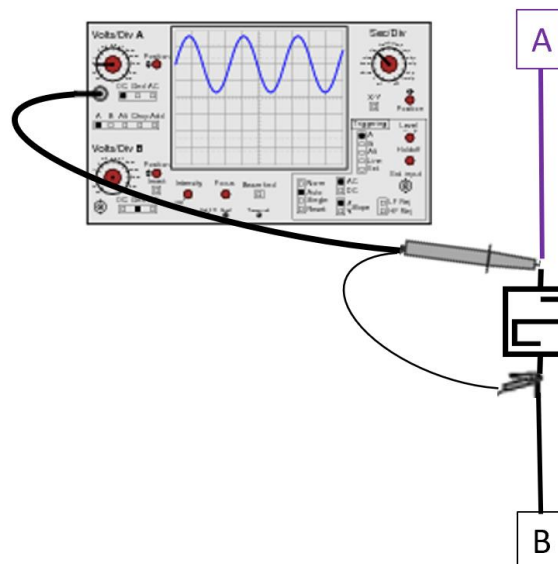


Figure 1 - Scoping the Function Generator

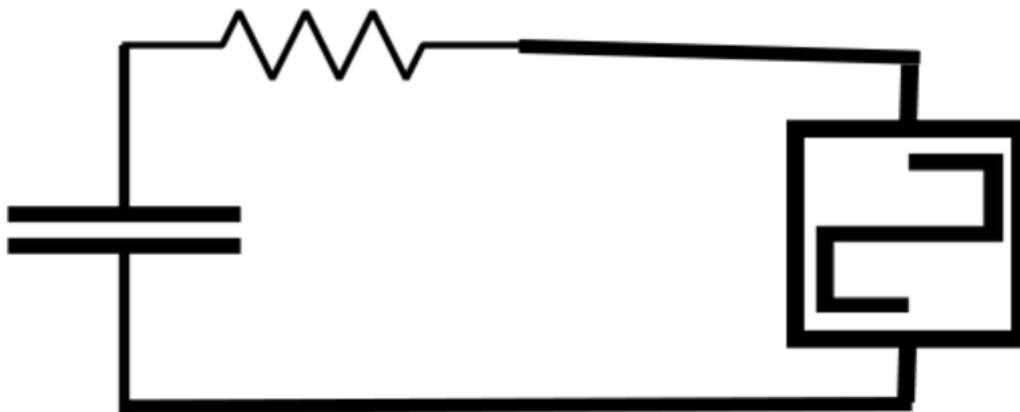


Figure 2 - Wiring Diagram of RC Circuit

An initial square wave was emitted from a function generator which is shown in section 3.2, this checked that the function generator was working correctly and allowed the frequency to be changed manually by a physical dial to give a bigger wave form (smaller frequency) or a smaller wave form (higher frequency). When calibrating the frequency of the square wave range, there had to be enough time that the capacitor could fully charge and discharge. Once the frequency was set the capacitor and resistor were added to the circuit via the use of a bread board shown in figure 3.

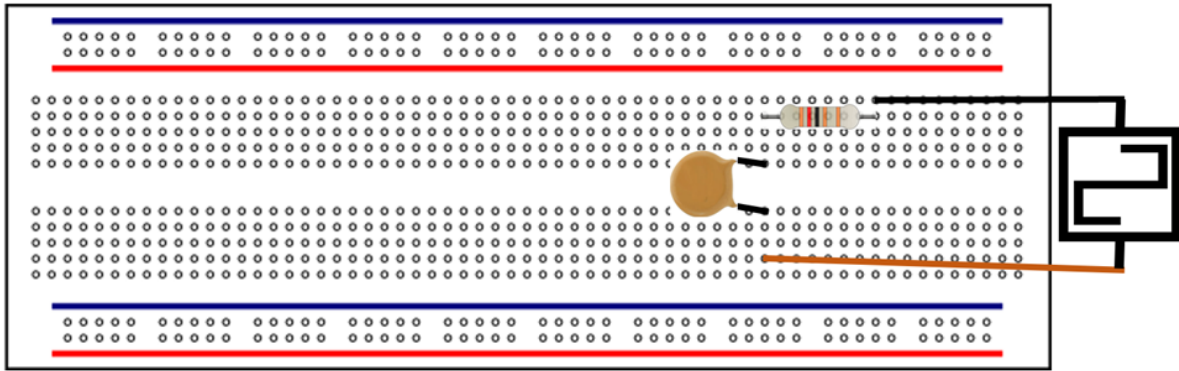


Figure 3 – Breadboard RC circuit

Breadboards are useful for making a circuit that is temporary. However, in this case the breadboards did have some internal resistance to them which is why for this experiment the circuit ended up being made without the breadboard. It was connected exactly as it is in figure 2 just without the use of the breadboard. The circuit was then scoped on either side of the resistor capacitor combination allowing for the wave form to be displayed showing the capacitor to be charging and discharging. The wave form of both the square wave and the charging and discharging was captured and the results were recorded. These were then imputed into excel showing 10-time divisions and the log of the voltage was plotted to then be able to calculate the capacitance. The same was done manually without the use of the software (as talked about in the introduction) to calculate the value of the capacitance.

3 Task 3

3.1 Scope Time Division Calculations

In order to create a RC Circuit a function generator emitted a square wave that is similar to what would be displayed on an oscilloscope when viewing a hall effect sensor such as an ABS sensor or crank / camshaft sensor. The frequency of the square wave must leave enough time for the selected capacitor to fully charge and discharge. A 100-ohm resistor and a 1 microfarad capacitor was chosen.

$$\therefore \tau = R * C = 100 * (1 * 10^{-6})$$

$$\text{Function generator frequency} = \frac{1}{40\tau} = \frac{1}{4 * 10^{-6}} = 250\text{HZ}$$

$$\text{Frequency (f) of wave} = 250\text{Hz}$$

$$\text{Period (P) of a wave} \frac{1}{f} = \frac{1}{250} = 0.004$$

From the formula:

$$f = \frac{1}{\text{Period}(\tau)} \quad \& \quad \text{Period}(\tau) = \frac{1}{f} \quad \& \quad \text{DivNumberTime} = 10$$

Then:

$$\text{Period}(\tau) = \frac{0.004}{10} = 0.0004 \text{ seconds}$$

Equation 1 - Scope Time Division

From this calculation it is clear that to be able to see the full wave of the capacitor charging and discharging that the closest time rounded to the nearest time divisions available on the hantek software is 500ms. This then gave a clear picture of the wave form, displaying the full charging and discharging wave showing that the result calculated is the correct value.

3.2 Function Generator Output Square Wave

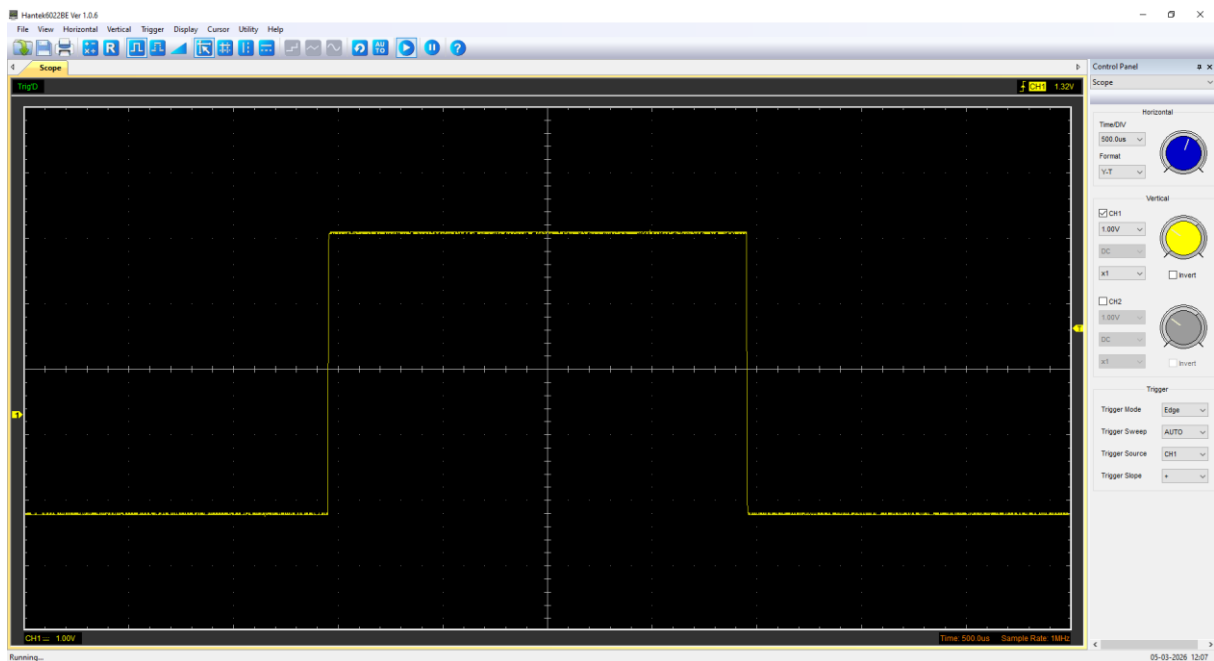


Figure 4 - Square Wave

The scope was connected to the function generator as shown in Figure 1. This allowed the oscilloscope to display the square wave that is being emitted as shown in Figure 4.

3.3 Capacitor Charge and Discharge Wave Marked at Correct Points

RC circuits are a type of first order circuit that contain a capacitor. Other types of first order circuits can use an inductor. In this case a capacitor is used. This capacitor will fill with electricity and when needed it will release that energy into the circuit. A capacitor takes time to charge (fill with electricity) and discharge (release electricity). This is why there is a waiting time when working on electric systems. In automotive vehicle maintenance it is generally a good idea to wait 10 to 15 minutes before proceeding because it allows the capacitor to fully discharge.

When a capacitor is charging and discharging there will be a time constant. This time constant or τ is equal to 63.2% of the charge voltage and 36.8% of the discharge voltage. This has been marked at the correct points on the figures below showing one time constant for both the charging wave and the discharging wave.

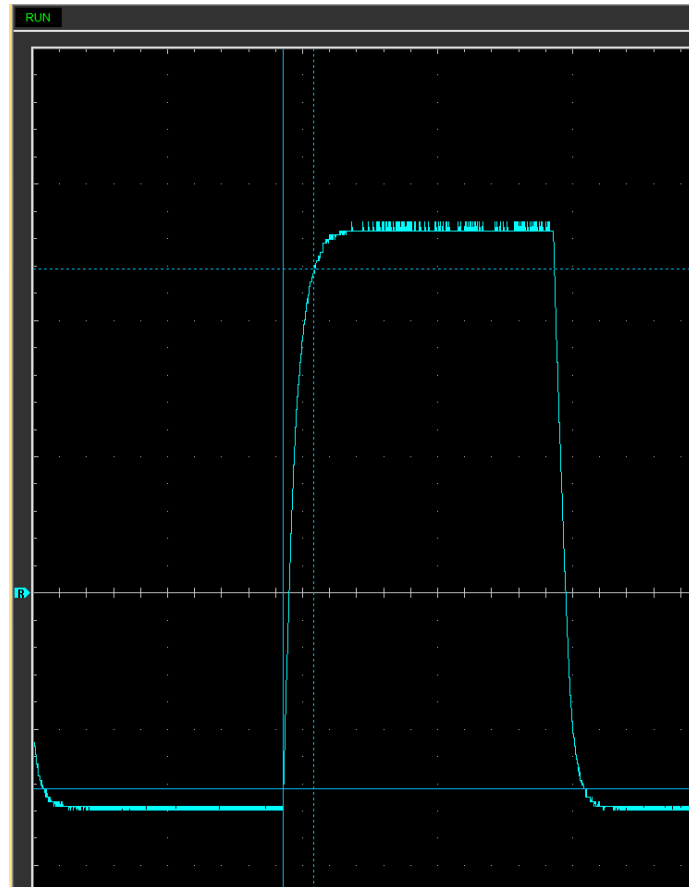


Figure 5 – Capacitor Charge

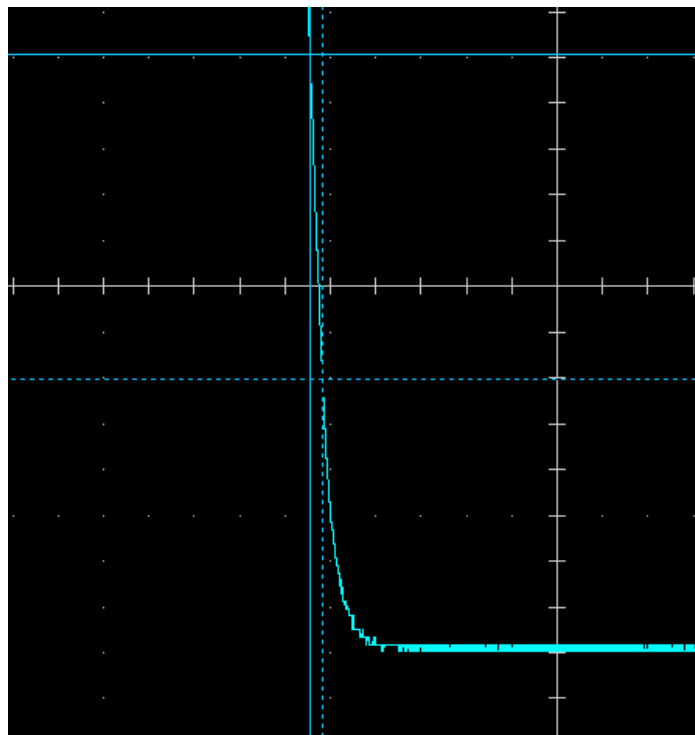


Figure 6 - Capacitor Discharge

In order to mark the voltage and time at the correct points on the graph to find the time constant the following formula was used:

$$(Peak(V) - Start(V) * 63.2\% + Start(V) = V \text{ top cursor})$$

$$\therefore (4(V) - 0.8(V) * 63.2\% + 0.8(V) = 2.8224(V))$$

Equation 2 - Voltage Marker

This gives a value of 123ms for the time constant.

3.4 Basic Capacitor Calculations

There are many types of capacitors that can be used across a range of circuits however the underlying principle of how they work is the same for all capacitors. Capacitors can be thought of as a temporary battery for certain scenarios. Just like in a battery where there is an anode and a cathode there are two sides to a capacitor. These two plates are separated by a dielectric (insulating material). When current flows through the capacitor it will cause the capacitor to store a voltage in the same way as a battery stores electricity. 1 side of the capacitor will become loaded with electrons (negative charge) and there is a potential difference between the two plates. A good way to think of a capacitor is like a dam that can hold back the water (electrons) while still allowing a consistent flow through. The number of electrons the capacitor can store is known as C (capacitance) measured in farads (F). Since:

$$F = \frac{S}{\Omega} \qquad \tau = RC$$

Equation 3 – Resistor Capacitor Time constant

Therefore, since the value of s is known to be equal to the time constant (τ) then we can use the time constant found in the section above. The resistor is known to be 100 ohms as chosen from the calculation, in section 3.1, when choosing the right capacitor and resistor pair to allow for the 40 time periods.

$$\frac{123}{100} = 0.123 * 10^{-5} (F)$$

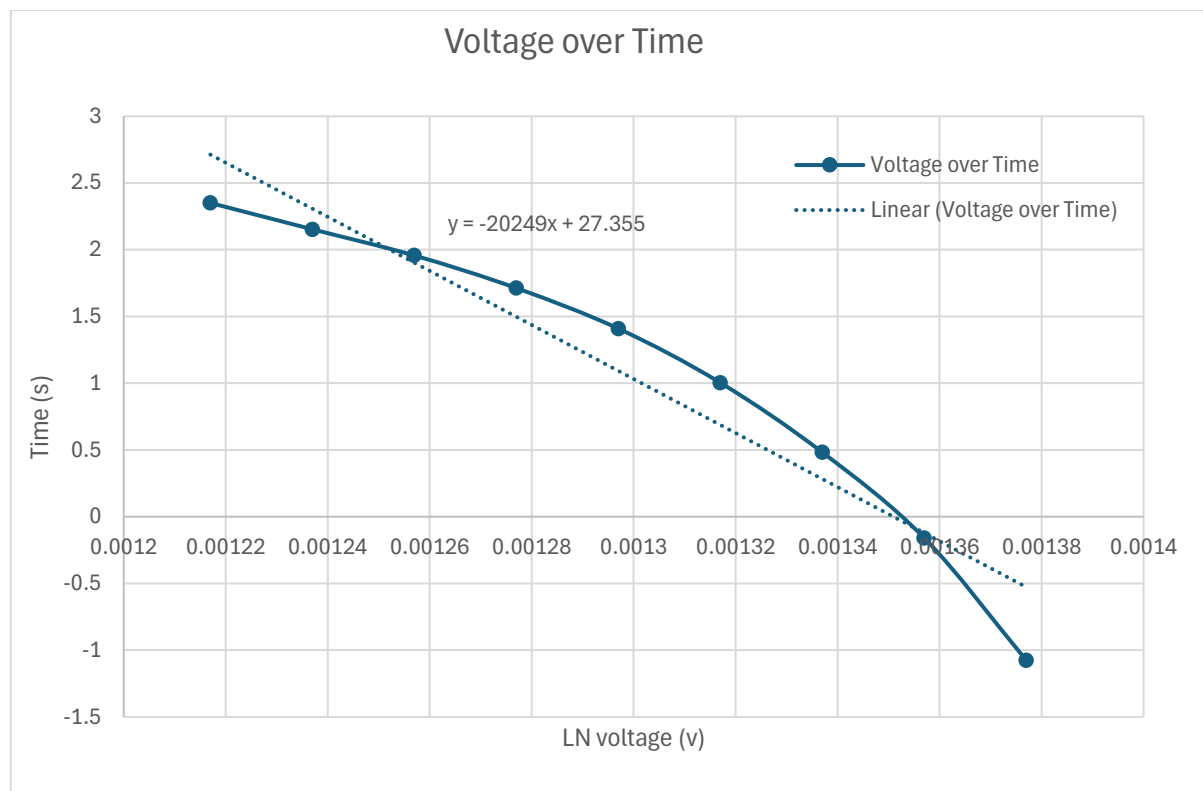
This provides a value of 1.23 microfarads.

3.5 Capacitor Discharge Table

Table 1 - Capacitor Discharge Table

Time (s)	Voltage (V)	ln (V)	$dy = y_2 - y_1$	$dx = x_2 - x_1$	dy/dx
			$dy = \ln(V)_2 - \ln(V)_1$	$dx = \text{Time}_2 - \text{Time}_1$	
0.001217	3.8588	1.350356254	x	x	x
0.001237	3.1686	1.15328985	-0.197066404	2E-05	-9853.320218
0.001257	2.6039	0.957010321	-0.196279529	2E-05	-9813.97644
0.001277	2.0392	0.712557574	-0.244452747	2E-05	-12222.63735
0.001297	1.5059	0.409390726	-0.303166848	2E-05	-15158.3424
0.001317	1.0039	0.003892415	-0.405498311	2E-05	-20274.91557
0.001337	0.5961	-0.517346841	-0.521239255	2E-05	-26061.96277
0.001357	0.3137	-1.159318164	-0.641971323	2E-05	-32098.56615
0.001377	0.1255	-2.07544952	-0.916131357	2E-05	-45806.56783
0.001397	0.1256	0	0	2E-05	0

3.6 Plot Log(v)



3.7 Gradient Calculations and Compare

The second (gradient) method to find the capacitance utilises the use of excel to create a graph that provides a gradient that can be taken in the form of $y = mx + c$ where m is the gradient equal to RC . However, because m is negative in this case so as seen below, minus one over m equals RC otherwise m would be equal to $-RC$. Log of V is equal to c in $y = mx + c$ and t is equal to x .

3.7.1 Gradient Calculations

$$\tau = -\frac{1}{\text{Gradient}} = \left(-\frac{1}{RC} = RC = \tau\right)$$

Equation 4 - Gradient Calculation

$$\therefore \tau = \frac{1}{20249} = 49.385 * 10^{-6}$$

Therefore:

$$\tau = RC$$

And because the value of resistance is known to be 100 ohms the equation:

$$\tau = RC$$

Can be rearranged to find:

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

$$\frac{(49.385 * 10^{-6})}{100} = 0.49385 * 10^{-6} \text{ or } 0.49385$$

3.7.2 Comparison Table

Table 2 - Comparison Table

	Capacitance	Delta	Percentage difference
Actual	1 μ F	x	X
Marker Calculation	1.23 μ F	+0.23	20.63%
Gradient Calculation	0.49385 μ F	-0.50615	67.76%

Interestingly there is a large difference between the two results. The marker calculated value is 1.23 microfarads while the gradient calculated value is 0.49 microfarads. This gives a delta between the two calculated values of 0.74 difference. However, the marker calculated value is much closer to the actual value with only a difference of +0.23. Whereas the gradient calculated value has a difference from the actual value of -0.5 giving a percentage difference of 67.7%.

3.8 Capacitor Uses

Capacitors are used in motor vehicles on the audio systems to reduce electromagnetic interference that can be viewed as external noise. During regenerative braking capacitors charge and then when the driver accelerates it discharges releasing all that stored energy. They are also used in the ignition system to smooth out electrical spikes during start up. Seat belt pretensioners have capacitors that enable the activation of the explosive inside that tightens the belt. Airbags have a similar set up using capacitors. Capacitors are used to smooth the dc ripples in the voltage from the rectifier. On Motorcycles the capacitors charge up to allow the rapid flow of electricity to the ignition coils to create high voltage. This ability in motorcycles can be utilised motor vehicles to allow the stop start system to run effectively without draining the main battery. Outside of the automotive and motorcycle sector capacitors are used in various other applications such as in microwaves.

3.9 Inaccuracies Question

The reason why there is a big discrepancy of 67% between the actual capacitance and the gradient calculation could be because when doing the experiment, the connection on the circuit was faulty and temperamental. The capacitor could also have been damaged or worn down from constant use and being knocked. Reducing its overall capacitance. Internal resistance of the circuit could have meant that the capacitor wouldn't charge fully. This would indicate that the capacitor had the capability to be filled to 1 microfarad but never reached the maximum capacitance. The dielectric material in the capacitor enhance the energy output and

ultimately strengthen the accuracy of the waveform (Ye et al., 2026). However, when using the marker calculation method a value of 1.23 microfarads was found throwing doubt over the internal resistance explanation. This is much closer to the actual capacitance with a percentage difference of only 20.63%. Which is 47.13% closer to the actual value than the value found in the gradient calculation.

3.10 Risk Question

The ISO 21434 proposes a TARA (threat analysis and risk assessment) that enables each specific application to be targeted by engineers (Siddiqui et al., n.d.). It also addresses risk through a risk analysis ontology and TARA method (Khalil et al., 2025), carried out under the judgment of the engineer developing the TARA and ontology. This international standard addresses ways to mitigate risk by enabling the weaknesses and entry points to be secured through the use of encrypted algorithms. Keeping this TARA up to date is imperative. The ISO 21434 mentions that “threat scenarios can be updated during event evaluation(Grimm et al., 2023)” indicating that there are vulnerabilities in the CANBUS system that will need to be updated overtime. The TARA should be up to date with the current improvements to the security of the CANBUS. Attacks on modern CAN BUS systems take advantage of the weaknesses that are present. Through diagnostic tools, OBD (on board diagnostic) ports are a good entrance point that can allow the attacker to gain access to the CAN data frames (Pan et al., 2017), potentially allowing malware and other harmful viruses in. Diagnostic tools are a traditional way of updating firmware and re-mapping the configuration of the ECUs. However modern vehicles allow for wireless updates, such as electric vehicles like tesla, meaning that there doesn't have to be a physical entry point anymore, it can be a digital access point that could allow an attacker access to the CAN BUS system. Lines of code that were embedded into the ECU caused the vehicles window to open under certain conditions (speeds above 200km/h)(Hoppe et al., 2011), showing that once the malware is present on the system it can go undetected until the attack is carried out. This is an inherent weakness of the CANBUS system showing that there are also vulnerabilities when updating the firmware and encryptions. Preventing any risk is therefore imperative and much easier than finding dormant malware. Only trusted devices should be plugged into the OBD ports to ensure that the device used cannot compromise the CAN network in anyway. Wireless updates should only be allowed from trusted sources such as manufacturers and dealerships. If these general rules are followed, then it ensures a good overall level of security that when paired with the software security (firmware and encryptions) should be sufficient to mitigate any risk posed by external or internal threats.

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