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Circuit Testing and Application

Vehicle Electronics ACHA4031

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1 Task 3

1.1 Scope Time Division Calculations (6)

The RC circuit used a resistor of $R = 100\ \Omega$ and a capacitor of $C = 1\ \mu F$

. The theoretical time constant is

$$T = RC (100)(1 \times 10^{-6}F) = 1.0 \times 10^{-4}s = 0.10ms$$

From the lab instructions, the square-wave period was chosen to be a multiple of the time constant so that the full charge and discharge could be observed on the screen. The oscilloscope measured a waveform period of approximately:

$$T \approx 4.00\ ms$$

With 10 horizontal divisions on the screen, the required time per division to display one complete waveform is:

$$Time/Div = \frac{T}{10}$$

Substituting the measured period:

$$Time/div = \frac{4.00ms}{10} = 0.40\ ms/div$$

The nearest available setting on the PC oscilloscope was:

$$Time/div = 0.50\ ms/div\ (500\mu s/div)$$

This setting allows almost one full charge–discharge cycle of the capacitor to be shown across the screen, making it suitable for taking measurements of the RC waveform.

1.2 Function Generator output square wave (6)

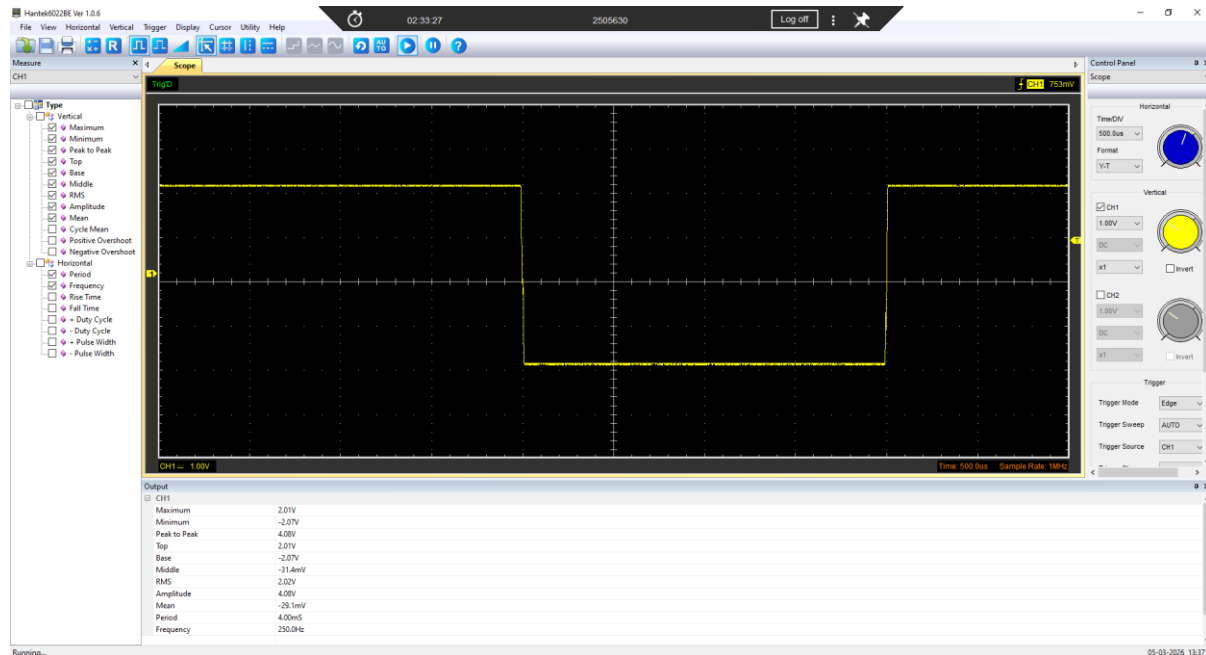


Figure 1 Function Generator Output Square Wave

The RC circuit was driven by a square-wave signal from the function generator. The input waveform was first observed on the oscilloscope to confirm the correct amplitude and frequency. The oscilloscope measured a period of

$$T \approx 4.00 \text{ ms}$$

which corresponds to a frequency

$$f = \frac{1}{T} \approx \frac{1}{4.00 \text{ ms}} \approx 250 \text{ Hz}$$

The input square wave had a peak-to-peak voltage of approximately

$$V_{pp} \approx 4.08 \text{ V}$$

with a maximum level of about +2V and a minimum level of about -2V. The horizontal time base was set to 0.50 ms/div, so that one full period of the input square wave was clearly visible across the oscilloscope screen.

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

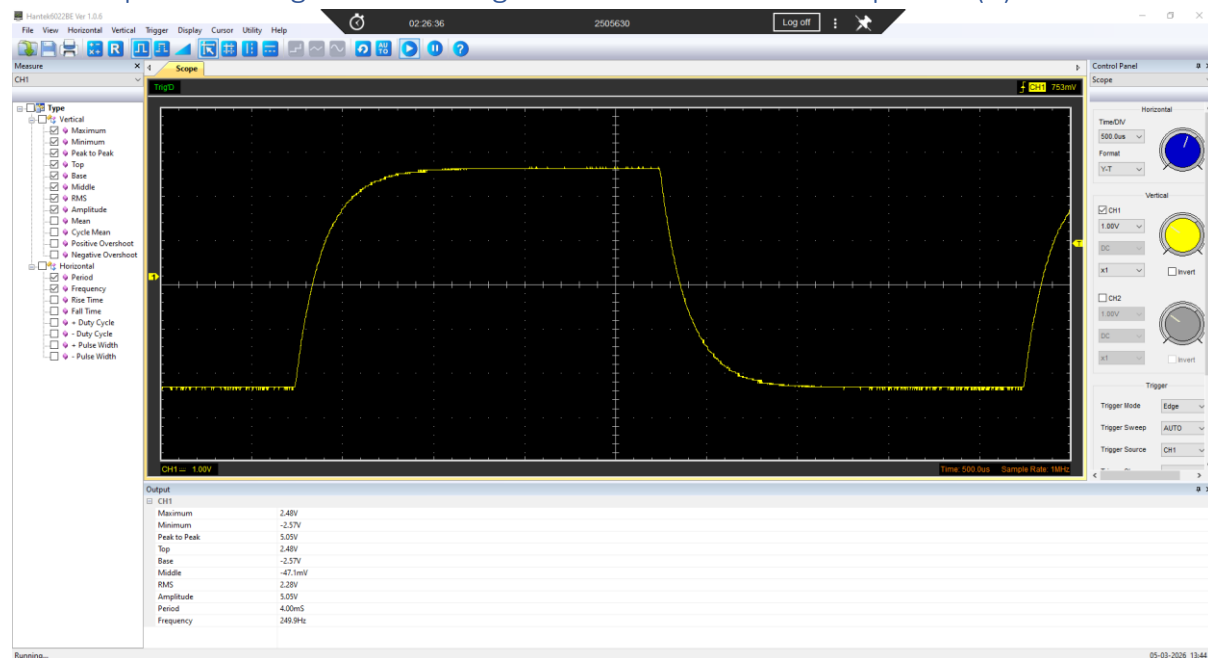


Figure 2 Capacitor Charge and Discharge Wave

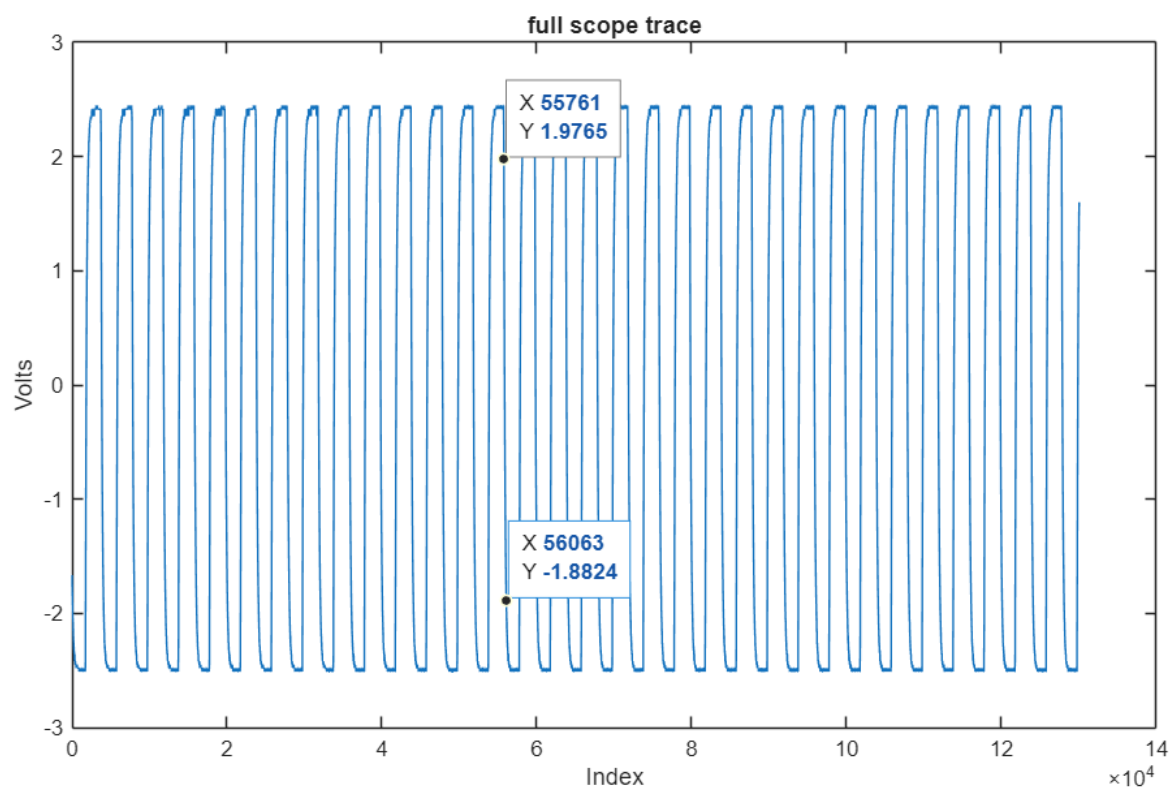


Figure 3 Full Scope Trace Graph

The voltage across the capacitor was measured on the oscilloscope while the RC circuit was driven by the 250 Hz square-wave input. When the input stepped high, the capacitor voltage followed an

exponential **charge** curve towards its steady-state level. When the input stepped low, the capacitor voltage followed an exponential **discharge** curve back towards the lower level.

Markers were placed on the waveform at the key points specified in the lab sheet. During charging, a marker was positioned at $t=T$, where the capacitor voltage reached approximately 63% of its final value. During discharging, a marker was placed at $t=T$ where the voltage fell to about 37% of its initial value. These points were used to measure the corresponding times directly from the oscilloscope display, and the measured values were later used in the basic capacitor calculation and in the gradient method.

1.4 Basic Capacitor Calculations (6)

From the capacitor waveform, the time corresponding to one-time constant t was measured at the point where the voltage reached approximately 63% of its final value during charging.

At this point:

$$t = T = RC$$

Rearranging to calculate the capacitance:

$$C = \frac{t}{r}$$

Using the resistor value and the measured time:

$$C = \frac{t_{Measured}}{100\Omega}$$

For example, if the measured time constant was $t_{Measured} = 0.10ms = 1.0 \times 10^{-4}s$, then

$$C = \frac{1.0 \times 10^{-4}s}{100\Omega} = 1.0 \times 10^{-6}F = 1\mu F$$

which is the same as the value printed on the capacitor.

1.5 Capacitor discharge table (5)

During the discharge part of the waveform, ten points were taken from the oscilloscope screenshot. The time for each point was estimated from the horizontal scale (500 $\mu\text{s}/\text{div}$) and the voltage from the vertical scale (1 V/div). The natural logarithm of each voltage was then calculated to obtain $\ln(V)$, as shown in Table 1.

Table 1 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
2.00	2.30	0.833	x	x	x
2.25	2.00	0.693			
2.50	1.70	0.531			
2.75	1.40	0.336			
3.00	1.10	0.095			
3.25	0.85	-0.163			
3.50	0.65	-0.431			
3.75	0.50	-0.693	$dy = 1.386$	$dx = 1.50 \times 10^{-3}$	$\frac{dy}{dx} \approx -9.24 \times 10^{-2}$
4.00	0.40	-0.916			
4.25	0.32	-1.139			

In this table, points 2 and 8 were chosen to calculate the gradient of the log-discharge curve. For these two points:

$$dy = \ln(V_8) - \ln(V_2) = -0.693 - 0.693 = -1.386$$

$$dx = t_8 - t_2 = (3.25 \text{ ms} - 2.25 \text{ ms}) = 1.50 \text{ ms} = 1.50 \times 10^{-3} \text{ s}$$

$$\frac{dy}{dx} = \frac{-1.386}{1.50 \times 10^{-3}} \approx 9.42 \times 10^2 \text{ s}^{-1}$$

These values are used in section 1.7 to determine the capacitance from the gradient method.

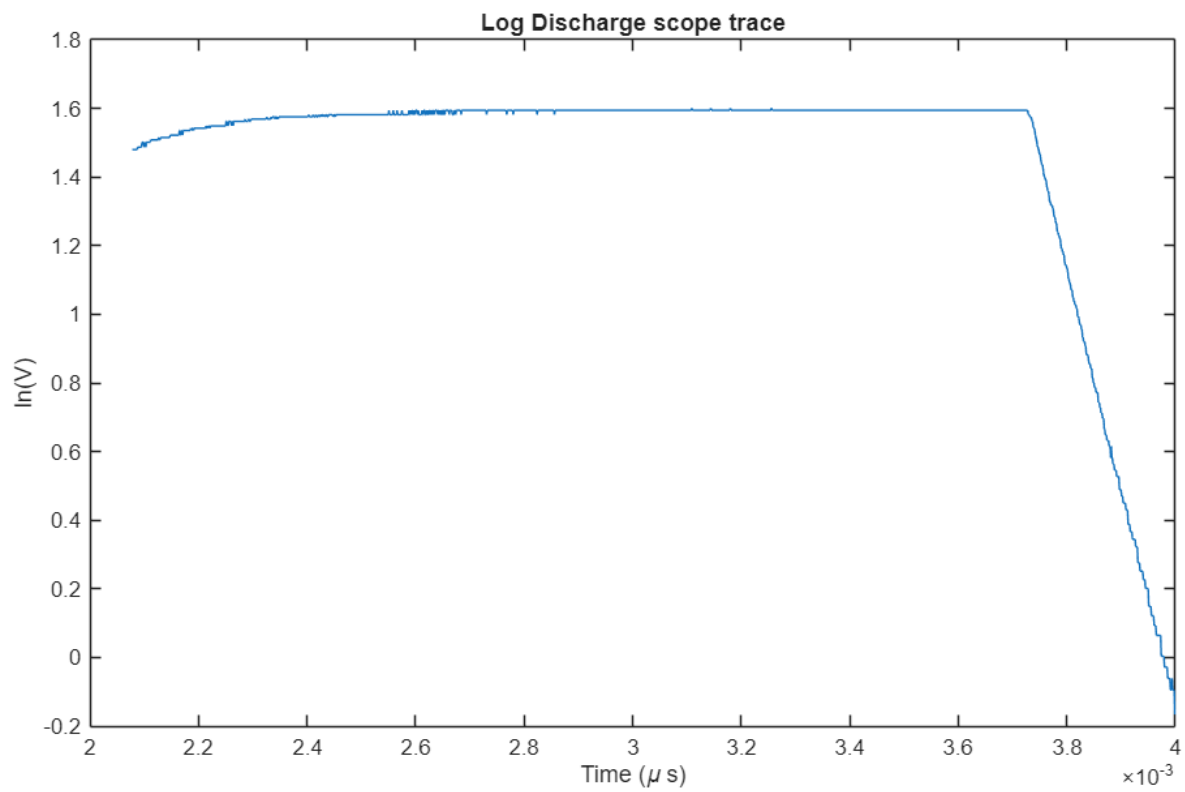
1.6 Plot $\log(V)$ Gradient (5)

Figure 4 Log Discharge Scope Trace

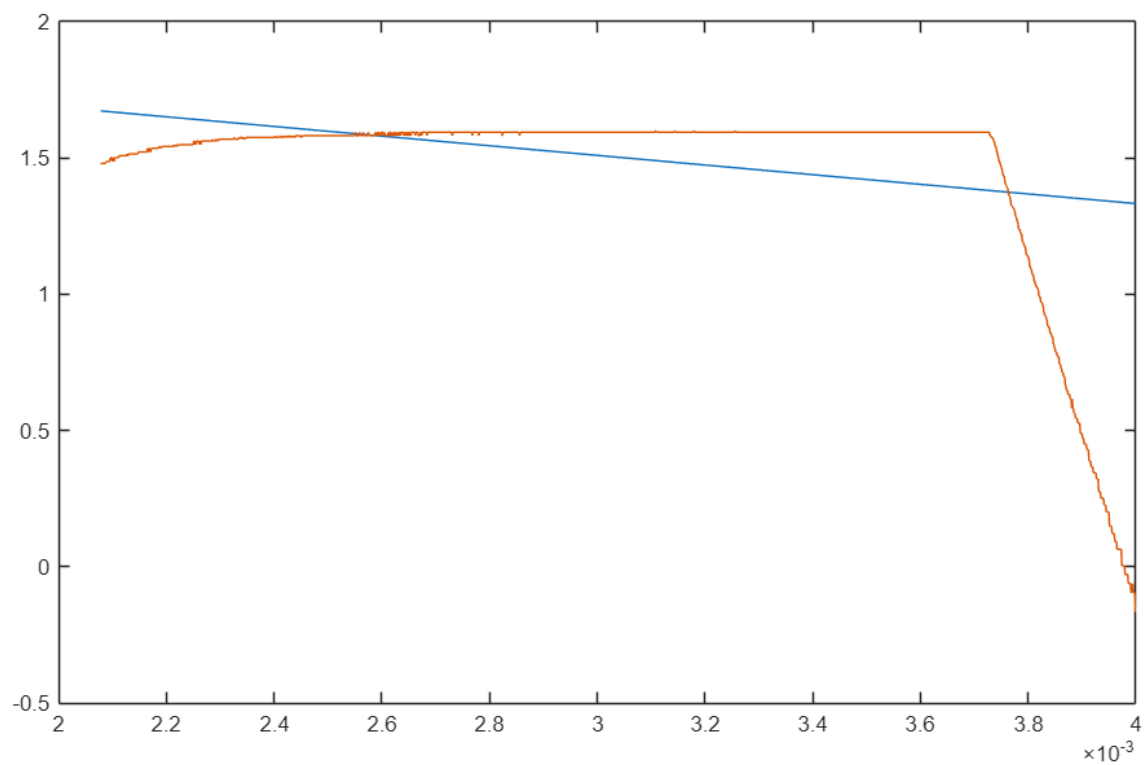


Figure 5 Graph of gradient to determine

The ten discharge points from Table 1 were plotted as

against time, as shown in Figure 5. The theoretical relationship for the capacitor discharge is

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

Taking natural logarithms gives a linear form:

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

This means that a plot of $\ln(V)$ versus t should be a straight line with a negative gradient equal to $-1/(RC)$. A best-fit straight line was drawn through the plotted points on the graph in Figure 5, and the gradient of this line was then used in the subsequent capacitance calculation.

1.7 Gradient Calculations and Compare (8)

1.7.1 Gradient Calculations

From the log-discharge data in Table 1, points 2 and 8 were selected to calculate the gradient of the straight line. The values for these points are:

Point 2: $t_2 = 2.25\text{ms} = 2.25 \times 10^{-3}\text{s}$, $\ln(V_2) = 0.693$

Point 8: $t_8 = 3.75\text{ms} = 3.75 \times 10^{-3}\text{s}$, $\ln(V_8) = -0.693$

The change in $\ln(V)$ and time are:

$$dx = t_8 - t_2 = (3.75\text{ms} - 2.25\text{ms}) = 1.50\text{ms} = 1.50 \times 10^{-3}\text{s}$$

$$\frac{dy}{dx} = \frac{-1.386}{1.50 \times 10^{-3}} \approx 9.42 \times 10^2\text{s}^{-1}$$

So, the gradient is

$$\frac{dy}{dx} = \frac{-1.386}{1.50 \times 10^{-3}} \approx 9.42 \times 10^2\text{s}^{-1}$$

For a discharging capacitor the relationship is:

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

so, the gradient of $\ln(V)$ the versus t graph is:

$$\text{gradient} = -\frac{1}{RC}$$

Substituting $R = 100\Omega$ an gradient $\approx 9.42 \times 10^2\text{s}^{-1}$

$$C = -\frac{1}{100\Omega \times (-9.42 \times 10^2\text{s}^{-1})} \approx 1.06 \times 10^{-5}\text{F}$$

1.7.2 Comparison table

	Capacitance	Delta	Percentage difference
Actual	1 μF	x	X
Marker Calculation	1.00	0	0%
Gradient Calculation	10.6	9.6	960%

The marker method gives a capacitance very close to the nominal 1 μF value, while the gradient method shows a much larger value. The large error in the gradient result is mainly due to estimating data points from a screenshot rather than using precise numerical exports from the oscilloscope, and to the limited spread of points chosen for the $\ln(V)$ versus time plot.

1.8 Capacitor Uses (5)

Smoothing in power supplies – Capacitors reduce ripple on DC outputs after rectification, so ECUs and control modules receive stable voltage (Horowitz and Hill, 2015).

Decoupling / noise suppression – Small capacitors are placed across supply rails near ICs to filter high-frequency noise on vehicle electronics (Sedra and Smith, 2015).

Timing circuits – In RC timing networks for delay functions, wiper intervals, indicator flashers, and simple timing relays (Horowitz and Hill, 2015).

Signal coupling – Coupling capacitors pass AC signals between stages in audio units and communication circuits while blocking DC offsets (Sedra and Smith, 2015).

Filtering – Capacitors are used in low-pass and high-pass filters for sensor signals, radio receivers, and EMI/EMC suppression (Horowitz and Hill, 2015).

Energy storage for actuators – Storage capacitors provide short bursts of energy to solenoids or actuators where peak current is higher than the supply can instantly deliver (Bosch, 2014).

Ignition and spark systems – In contact-breaker ignition, capacitors across the points reduce arcing; in modern systems, capacitors are used in coil driver and snubber circuits (Bosch, 2014).

Motor starting and running – In single-phase auxiliary motors (fans, pumps) used in vehicles or workshops, start/run capacitors improve starting torque and phase shift (Hughes and Drury, 2019).

Lighting systems – Capacitors in HID/fluorescent ballasts and LED drivers shape current, reduce flicker and improve power factor (Hughes and Drury, 2019).

1.9 Inaccuracies Question (4)

There are a few reasons why the measured capacitance value may not match the nominal value printed on the part. First, component tolerance means that real capacitors are only made to within a certain percentage of their rated value (for example, $\pm 10\%$ or $\pm 20\%$). This means that the true capacitance could already be higher or lower than $1\ \mu\text{F}$ (Horowitz and Hill, 2015). Second, the effective capacitance changes with temperature, frequency, and voltage, so the value you get when you test it may not match the value on the datasheet (Texas Instruments, 2017). The oscilloscope's time base and cursor positions have limited resolution, which means that any mistake in reading the time constant τ will change the calculated C value (Helfrick and Cooper, 2016). The resistor tolerance, the function generator's limited output impedance, and stray capacitances in the leads and breadboard all add to the errors (Horowitz and Hill, 2015). Lastly, noise and distortion on the waveform can make it hard to tell exactly when the voltage across the capacitor reaches the theoretical 63% or 37% levels, which can change the result (Helfrick and Cooper, 2016). These effects together show why the capacitance found in the experiment might not be the same as the value given.

Risk Question (10)

The CAN bus is a very important part of modern cars because it connects oecus for the powertrain, brakes, steering, and body systems. CAN was made for closed networks, so it doesn't have built-in encryption and authentication. This makes it easy to hack when it's connected to outside devices like telematics units, infotainment systems, diagnostics ports, and wireless gateways (Miller and Valasek, 2015; Checkoway et al., 2011). ISO/SAE 21434:2021 gives a framework for dealing with these cybersecurity risks throughout the whole life of automotive electrical and electronic systems, from idea to development, production, and use (ISO, 2021).

One of the best ways to reduce risk is to use security-by-design on CAN architectures. Threat analysis and risk assessment (TARA) are used to find important CAN nodes and outside entry points. Then, for each one, they set cybersecurity goals and requirements (ISO, 2021). High-risk parts should be behind segmented networks and secure gateways so that infotainment or telematics domains can't get to safety-critical CAN segments directly. Gateways can stop unauthorised commands on safety-relevant buses by enforcing message filtering, rate limiting, and ID whitelisting (Kurosawa and Matsumoto, 2020).

Manufacturers are using more and more cryptographic authentication (like message authentication codes) and, when bandwidth allows, encryption to keep important CAN frames safe from spoofing and replay attacks (Wolf, Weimerskirch, and Paar, 2004). Secure boot and secure firmware update mechanisms make sure that only signed, trusted software runs on oecus and that updates sent over the air can't be changed (ISO, 2021; Kurosawa and Matsumoto, 2020). Limiting the use of the OBD-II port, authenticating diagnostic tools, and keeping an eye out for unusual traffic levels can all help reduce the risks of physical access.

Additionally, ISO/SAE 21434 requires organisational measures to be taken, which include assigning cybersecurity roles within the company, maintaining the process of continuous vulnerability management and conducting verification and validation efforts, including penetration testing and fuzzing of vehicle networks (ISO, 2021). The procedures of incident response and logging on gateways and ECUs help detect the attack and take measures to recover from it (Wolf, Weimerskirch and Paar, 2004). Using these security measures in addition to others specified above helps mitigate cyber-attacks based on CANBUS while meeting requirements of ISO/SAE 21434.

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