Autocar challenge TASK 5

What is Pulse Width Modulation (PWM)?

Pulse Width Modulation (PWM) is a technique used to control the amount of power delivered to an electrical device by adjusting the width of the pulses in a signal. PWM is widely used in electronics for controlling various applications such as motors, LEDs, audio signals, and even in communication systems.

Instead of providing a continuous voltage level, PWM delivers a series of high and low pulses (a square wave) with varying durations. By adjusting the proportion of time the signal stays "high" (on) versus "low" (off) in each cycle, we can control the average voltage and, consequently, the power delivered to a device.

Think of **PWM (Pulse Width Modulation)** like turning a light switch on and off really fast. Instead of keeping the light always on or always off, you keep switching it on and off quickly. By adjusting how long you keep it on versus off, you can control the brightness of the light.

PWM in Real Life: A Simple Example

Imagine you have a fan that can only be fully on or fully off—there's no middle speed. But you want to make it spin slower. How can you do that?

- You could **turn it on and off repeatedly**.
- If you turn it on for half a second and off for half a second, the fan will spin at **half speed**.
- If you turn it on for most of the time (let's say 9 seconds on, 1 second off), the fan will spin **almost at full speed**.
- If you turn it on for just a little bit (1 second on, 9 seconds off), it will spin **very slowly**.

This technique of controlling how long something is on or off is exactly what PWM does!

Key Terms in PWM

1. **Frequency**:
    a. This is how fast you are turning the light switch on and off.

b. If you switch it on and off **10 times in one second**, the frequency is **10 Hz**.

c. Higher frequency means switching faster. For things like LEDs, you want a high frequency so that the blinking is so fast that our eyes don't notice it.

2. **Duty Cycle**:

    a. This is a fancy way of saying **how much time you spend with the switch on**.

    b. If you keep the switch **on for half the time** and **off for half the time**, that's a **50% duty cycle**.

    c. If you keep it on most of the time (like 90% on, 10% off), that's a **90% duty cycle**.

    d. A higher duty cycle means more power is delivered (e.g., a brighter LED or a faster motor).

3. **Period**:

    a. The **total time** it takes for one complete cycle of on and off.

    b. For example, if it takes **1 second** to turn on and off once, the period is **1 second**.

4. **Waveform**:

    a. A graph that shows when the switch is on (high) or off (low) over time.

    b. It looks like a series of square waves: up (on) and down (off).

How Does PWM Work?

- **On-Time (Pulse Width):** The duration for which the signal is high (on).
- **Off-Time:** The duration for which the signal is low (off).
- **Period (T):** The total time for one complete cycle of on-time and off-time.
- **Frequency (f):** The number of cycles per second, measured in Hertz (Hz). It's the inverse of the period.
- **Duty Cycle:** The ratio of the on-time to the total period, expressed as a percentage

Key Components of PWM

1) Frequency

The **frequency** of a PWM signal determines how fast the pulses are repeated in one second. The higher the frequency, the smoother the output power control. For example:

- **Low Frequency (1 kHz or less):** Suitable for motor control.
- **High Frequency (10 kHz to 100 kHz):** Suitable for audio signals or LED dimming, where flicker is not acceptable.

2) Duty Cycle

The **duty cycle** controls the average power delivered by the PWM signal. It's defined as:

$$\text{Duty Cycle} = \left(\frac{t_{\text{on}}}{T}\right) \times 100$$

where ton is the time the signal is high, and T is the total period.

- **0% Duty Cycle:** Signal is always off, delivering no power.
- **100% Duty Cycle:** Signal is always on, delivering full power.
- **50% Duty Cycle:** Signal is on half the time and off half the time, delivering 50% of the power.

3) Period

The **period** is the total time for one complete cycle of the PWM signal.

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

- T = Period in seconds
- f = Frequency in Hz

The period of a PWM signal is the duration of one complete cycle of the waveform, encompassing both the high and low states. It also can be calculated as:

$$T = t_{\text{on}} + t_{\text{off}}$$

where toff is the time the signal is low.

4) Capture Compare Register (CCR)

The **Capture Compare Register (CCR)** is used in microcontrollers to set the duty cycle of a PWM signal. The value in this register determines when the signal switches from high to low (or low to high) during each cycle.

- **CCR = 0:** 0% duty cycle (always low).
- **CCR = ARR (Auto-Reload Register):** 100% duty cycle (always high).
- By setting different values in the CCR, we can adjust the duty cycle dynamically.

PWM Waveform Example

Let's say we have a system clock of 72 MHz and we want a PWM signal of **1 kHz** with varying duty cycles:

1. **Step 1: Calculate the Period**

$$T = \frac{1}{f} = \frac{1}{1000\,\text{Hz}} = 0.001\,\text{s} = 1\,\text{ms}$$

2. **Step 2: Set the Timer Frequency**
   - Prescaler value divides the clock.
   - If the prescaler is set to 71:

$$\text{Timer Frequency} = \frac{72\,\text{MHz}}{71+1} = 1\,\text{MHz}$$

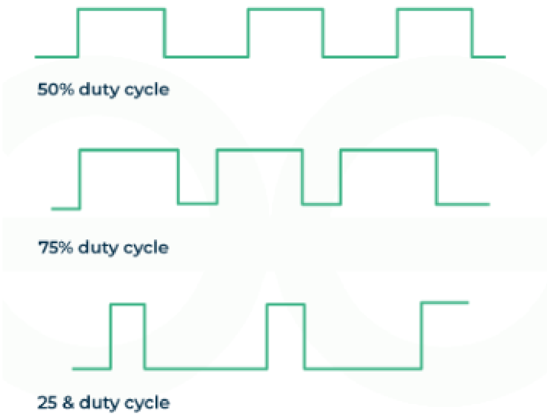
3. **Step 3: Set Auto-Reload Register (ARR)**

$$\text{ARR} = \frac{\text{Timer Frequency}}{\text{Desired PWM Frequency}} = \frac{1\,\text{MHz}}{1\,\text{kHz}} = 1000$$

4. **Step 4: Calculate Capture Compare Register (CCR) Values for Duty Cycles**
   - **50% Duty Cycle**: $CCR = \frac{50}{100} \times 1000 = 500$
   - **75% Duty Cycle**: $CCR = \frac{75}{100} \times 1000 = 750$

5) Waveform of PWM Signal

A typical PWM waveform consists of a series of rectangular pulses where the width of each pulse represents different duty cycles. The waveform can be visualized as follows:



In this diagram:

- The duration of each high state varies according to different duty cycles.
- The frequency remains constant across all cycles.

6) Calculation

To calculate various parameters related to PWM:

- Average Voltage Output: The average voltage can be calculated using the formula:

$$V_{\text{avg}} = V_{\text{max}} \times \left(\frac{\text{Duty Cycle}}{100}\right)$$

where $Vmax$Vmax is the peak voltage when the signal is high.

- RMS Voltage: The RMS value for a PWM waveform can be calculated as:

$$V_{\text{RMS}} = V_{\text{max}} \times \sqrt{\frac{\text{Duty Cycle}}{100}}$$

For example, if $V_{\text{max}} = 5\,V$ and Duty Cycle = 60%:

$$V_{\text{avg}} = 5\,V \times 0.6 = 3\,V$$

$$V_{\text{RMS}} = 5\,V \times \sqrt{0.6} \approx 4.08\,V$$

These calculations provide insights into how changing duty cycles affect average and RMS voltages in practical applications.In summary, Pulse Width Modulation is an effective method for controlling power delivery and encoding information within digital signals through careful manipulation of frequency, duty cycle, and period. Understanding these parameters allows for efficient design and implementation in various electronic systems.

PWM Calculation Example

Objective: Create a PWM signal with a frequency of **2 kHz** and a **25% duty cycle**.

- **Given**: System Clock = 16 MHz, Prescaler = 15

Step 1: Calculate Timer Frequency

$$\text{Timer Frequency} = \frac{16\,\text{MHz}}{\text{Prescaler} + 1} = \frac{16\,\text{MHz}}{16} = 1\,\text{MHz}$$

Step 2: Calculate Auto-Reload Register (ARR)

$$\text{ARR} = \frac{\text{Timer Frequency}}{\text{PWM Frequency}} = \frac{1\,\text{MHz}}{2\,\text{kHz}} = 500$$

Step 3: Calculate Capture Compare Register (CCR) for 25% Duty Cycle

$$\text{CCR} = \frac{25}{100} \times \text{ARR} = 0.25 \times 500 = 125$$

Thus, to generate a 2 kHz PWM signal with a 25% duty cycle:

- **ARR** = 500
- **CCR** = 125

This configuration will provide a PWM signal that stays high for 25% of each cycle and low for the remaining 75%.

Summary of PWM Concepts

Term	Definition
Frequency	Cycles per second (Hz)
Duty Cycle	Percentage of time signal is high
Period	Time for one complete cycle
CCR	Sets when the signal changes from high to low
ARR	Determines the total count for one period