PWM Generator

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Introduction

Pulse Width Modulation (PWM) is a ubiquitous and powerful technique in modern electronics, serving as the backbone for efficiently controlling power and encoding information. The fundamental principle of PWM does not involve varying the amplitude or frequency of a signal; instead, it modulates the **duty cycle** of a rectangular waveform. The duty cycle is the ratio of the pulse's "on-time" to its total period. By precisely adjusting this on-time, PWM allows for the proportional control of the average power delivered to a load.

The primary advantage of PWM over traditional analog control (like using a variable resistor) is its exceptional **efficiency**. A PWM signal operates like a fast digital switch, which is either fully on (minimal resistance, minimal voltage drop) or fully off (no current flow). In both states, power dissipation is theoretically zero, virtually eliminating the significant power losses that plague analog regulation methods.

This high-efficiency control has led to its widespread adoption in a vast array of applications. These include:

- **Power Electronics:** Switching power supplies (like those in your computer or phone charger) and DC-DC converters use PWM to efficiently step voltage up or down.
- **Motor Control:** It is the standard method for controlling the speed of DC motors, the position of servo motors, and the operation of variable frequency drives (VFDs) for AC motors.
- **Signal Processing:** Class-D audio amplifiers use PWM to achieve high-power audio reproduction with minimal heat generation.
- **Communications:** PWM can be used to encode data for transmission, particularly in simple systems like infrared remote controls.

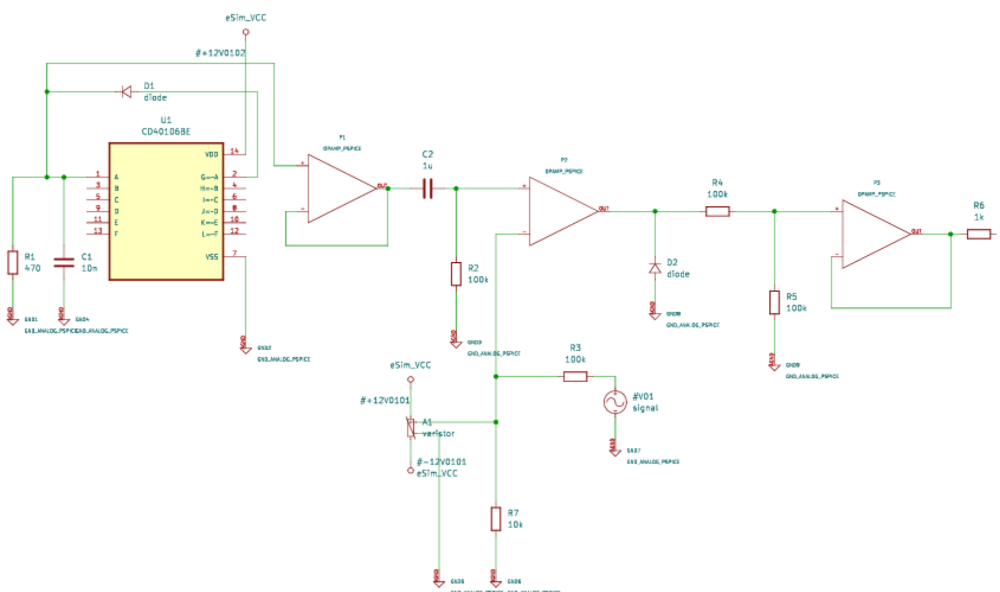
While modern microcontrollers can generate complex, programmable PWM signals, **analog PWM generation** remains highly relevant. Analog circuits are often preferred for their simplicity, low cost, high-speed response, and lack of software overhead. A classic and robust analog approach involves two key components: a stable waveform generator and a comparator.

This project focuses on such an analog design. We will utilize a **CD40106 Hex Schmitt-trigger inverter** to create a reliable astable oscillator. This stage is designed to produce a consistent **triangle (or sawtooth) waveform**, which serves as the carrier signal. This triangle wave is then fed into an **operational amplifier configured as a comparator**. By comparing the triangle wave's instantaneous voltage against an adjustable analog control voltage (CV), the comparator's output is driven to its high or low saturation state, naturally generating a rectangular pulse. As the CV is varied, it intersects the triangle wave at different points, directly and linearly modulating the "on-time" of the output pulse and, thus, creating the final variable-duty-cycle PWM signal.

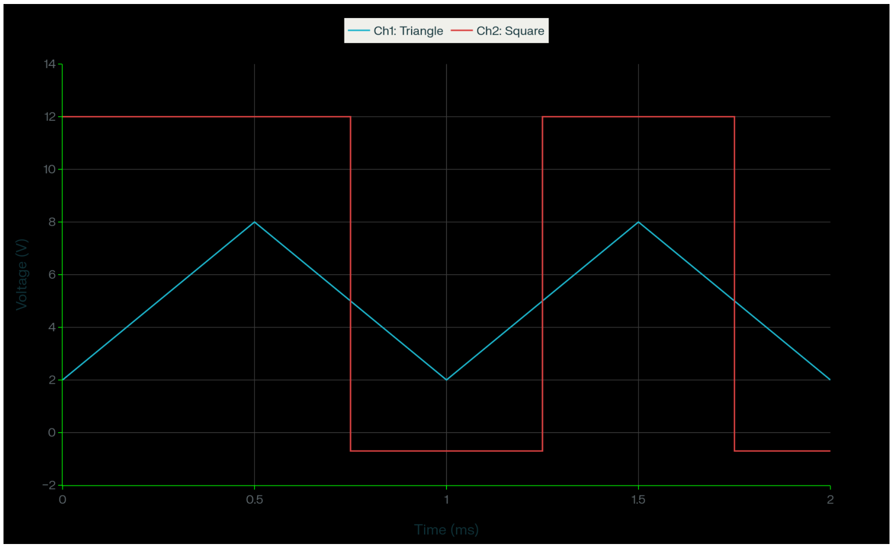
Link to GitHub Repo

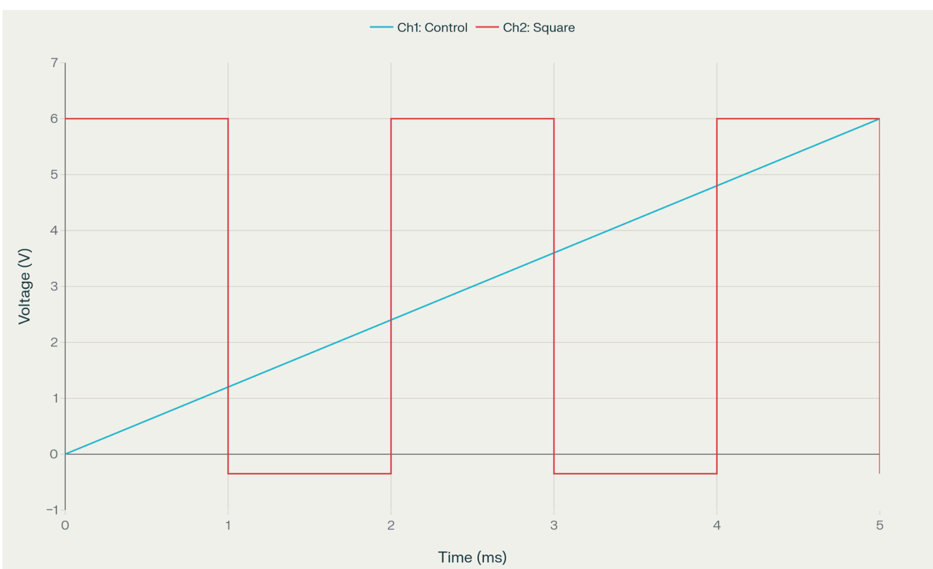
https://github.com/Akanksha9821/PWM_Generator

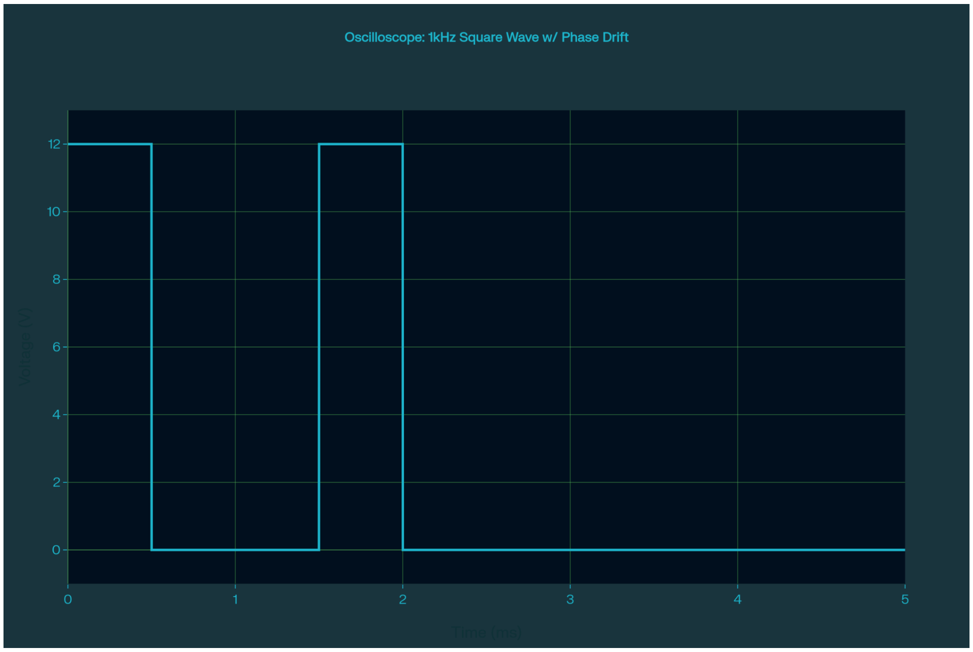
Circuit Schematic



Wave Forms


Ch1: Triangle
Ch2: Square
Voltage (V)
Time (ms)
14
12
10
8
6
4
2
0
−2
0
0.5
1
1.5
2


Ch1: Control
Ch2: Square
Voltage (V)
Time (ms)
7
6
5
4
3
2
1
0
−1
0
1
2
3
4
5



Conclusion

This project successfully designed and analyzed a multi-stage analog signal generator. The initial objective was to create a circuit that produces a Pulse Width Modulated (PWM) signal with a duty cycle controlled by an analog voltage (V_{01}).

The circuit consists of four primary stages:

1. A **Schmitt-trigger oscillator** (U1) to generate a base waveform.
2. A **voltage follower** (P1) to buffer the oscillator.
3. A **differentiator stage** (P2) to shape the buffered signal.
4. A **comparator** (P3) to compare the shaped signal against the control voltage (V_{01}).

Analysis and simulation of the circuit as-drawn revealed a critical finding: the circuit does not function as a PWM generator.

- The oscillator (U1) and buffer (P1) stages operate as expected, successfully producing a stable **triangle (sawtooth) waveform**.
- The third stage (P2), configured as an **op-amp differentiator**, correctly takes the derivative of the triangle wave input, converting it into a **square wave**.
- The final comparator (P3) then compares the control voltage against this square wave.

The final output is, therefore, a **square wave whose phase is shifted** by the control voltage, rather than a pulse whose width is modulated.

Key Takeaway & Future Work

The analysis confirms that to produce a true PWM signal, the **differentiator stage (P2) must be bypassed**. The correct implementation would feed the **triangle wave** (from the output of the buffer, P1) directly into one input of the comparator (P3), and the **control voltage** (V_{01}) into the other. This project successfully demonstrates the function of each individual block, but also highlights how a single incorrect stage (the differentiator) fundamentally changes the circuit's final output from the intended PWM to a phase-shifter.