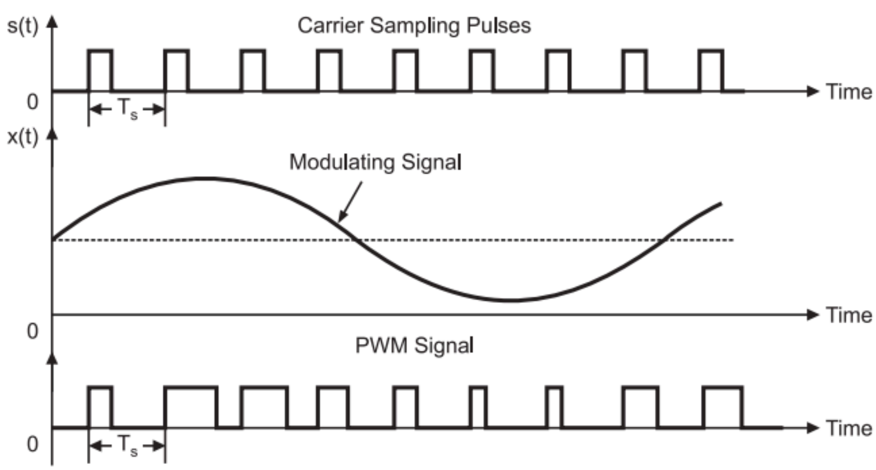
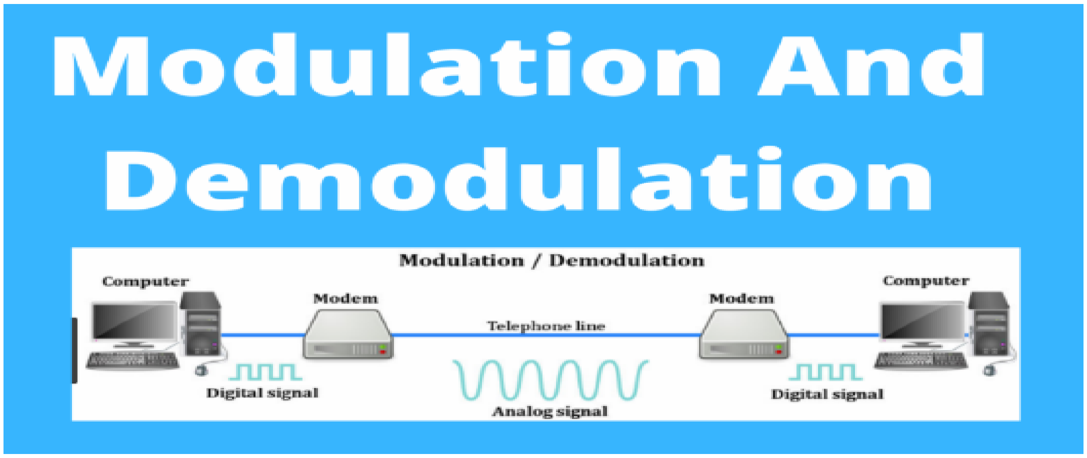
Pulse Width Modulation (PWM) and Demodulation Using LTspice

1. Introduction

Pulse Width Modulation (PWM) is a widely used technique in electronics for encoding information or controlling power delivery by varying the width of pulses in a periodic signal. It has applications in motor control, LED dimming, audio signal processing, and communication systems.

This experiment involves designing and simulating a PWM system in LTspice to encode a message signal and successfully demodulate it using a second-order active low-pass filter.





2. Objective

The goal is to design and simulate a PWM signal using LTspice, ensuring proper message encoding and successful demodulation.

Parameters:

- **Message Signal:** 1 kHz sine wave, 5V amplitude.
- **Carrier Signal:** 10 kHz sine wave, 5V amplitude.
- **Simulation Environment:** LTspice.
- **Permitted Components:** Universal op-amps, resistors, capacitors, diodes.

3. PWM Generation

3.1 Concept

PWM operates by comparing a high-frequency carrier wave (e.g., triangular or sine wave) with a slower message signal. The output is a square wave whose pulse width changes based on the amplitude of the message signal.

Message Signal Amplitude	PWM Pulse Width
High	Wide Pulse
Low	Narrow Pulse

3.2 Circuit Design in LTspice

Components Needed:

- **Message Signal Source:** 1 kHz sine wave, 5 V amplitude.
- **Carrier Signal Source:** 10 kHz sine wave, 5 V amplitude.
- **Comparator Circuit:** USE SUITABLE UNIVERSAL OPAMP (U4 in LTspice).

<u>Working of Universal Op-Amps and Their Use in Signal Processing Circuits</u>

Key Points

- **Universal Op-Amps** are general-purpose amplifiers used in various signal processing applications.
- **Working Principles:**
    - Amplifies the difference between two input voltages (Differential Input).
    - Provides high gain with minimal distortion.
    - Uses negative feedback for precise control.
    - Operates with single or dual power supply.
- **Applications in Signal Processing:**
    - **Amplification:** Used in audio and sensor circuits.
    - **Filtering:** Essential for low-pass, high-pass, and band-pass filters.
    - **Comparators:** Key in PWM generation and waveform shaping.
    - **Integration & Differentiation:** Used in control systems and waveform processing.
    - **ADC/DAC Buffers:** Helps in signal conversion.

Why Square Pulse Was Not Obtained for Other Universal Op-Amps (UA0, UA1, etc.)?

1️⃣ Low Bandwidth (Gain-Bandwidth Product - GBW)

- Square waves contain high-frequency harmonics, and op-amps with low GBW act as **low-pass filters**, smoothing out sharp edges and producing a distorted sine-like output.
- **UA4 and UA5 likely have higher GBW, allowing them to handle square wave transitions properly.**

2️⃣ Limited Slew Rate

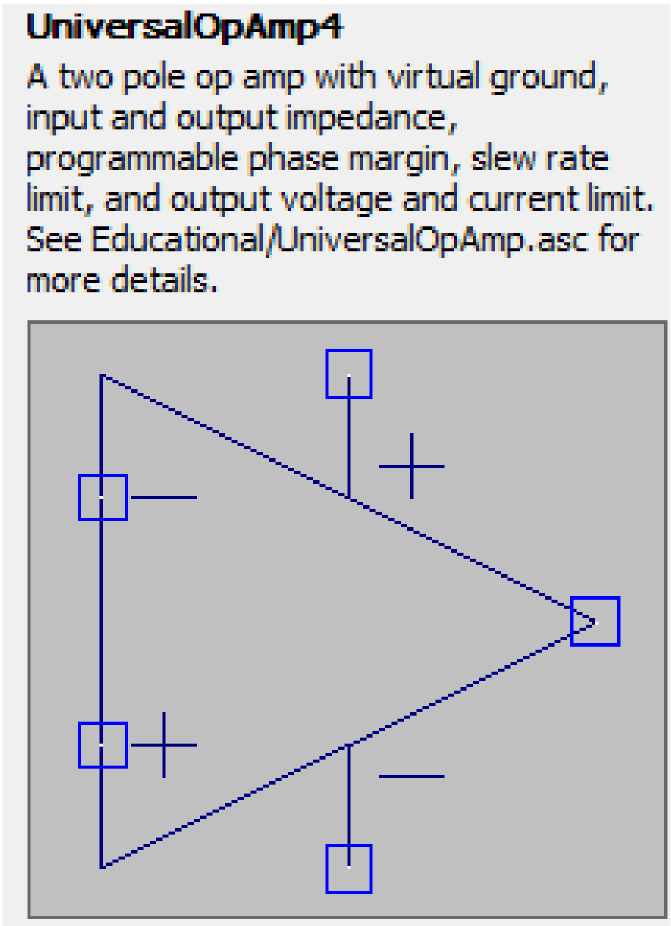
- The **slew rate (dV/dt)** determines how fast the output voltage can change.
- Op-amps with a **low slew rate cannot switch fast enough**, leading to **slow rising and falling edges**, making the output look more like a sine wave.
- **UA4 and UA5 likely have higher slew rates, allowing rapid transitions.**

3️⃣ Internal Compensation Effects

- Some op-amps are **internally compensated** to improve stability, but this can reduce response speed.
- Overcompensated op-amps behave like **low-pass filters**, distorting the square wave.

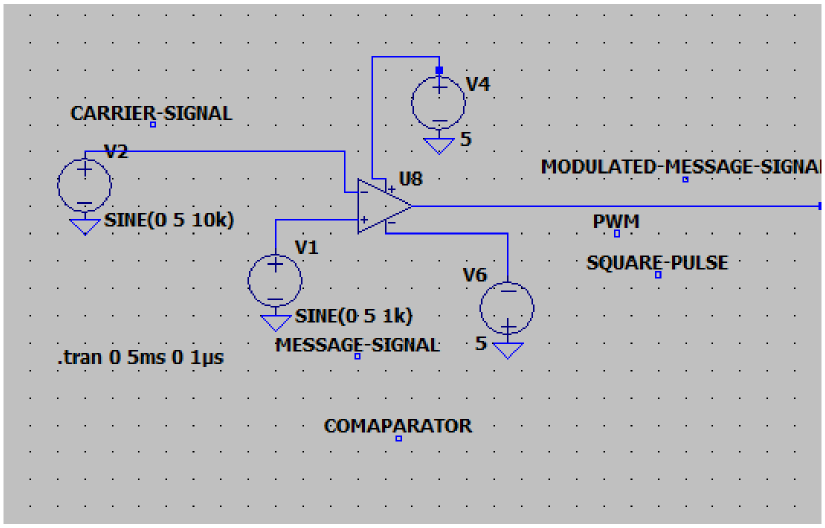
4️⃣Power Supply and Operating Range Issues

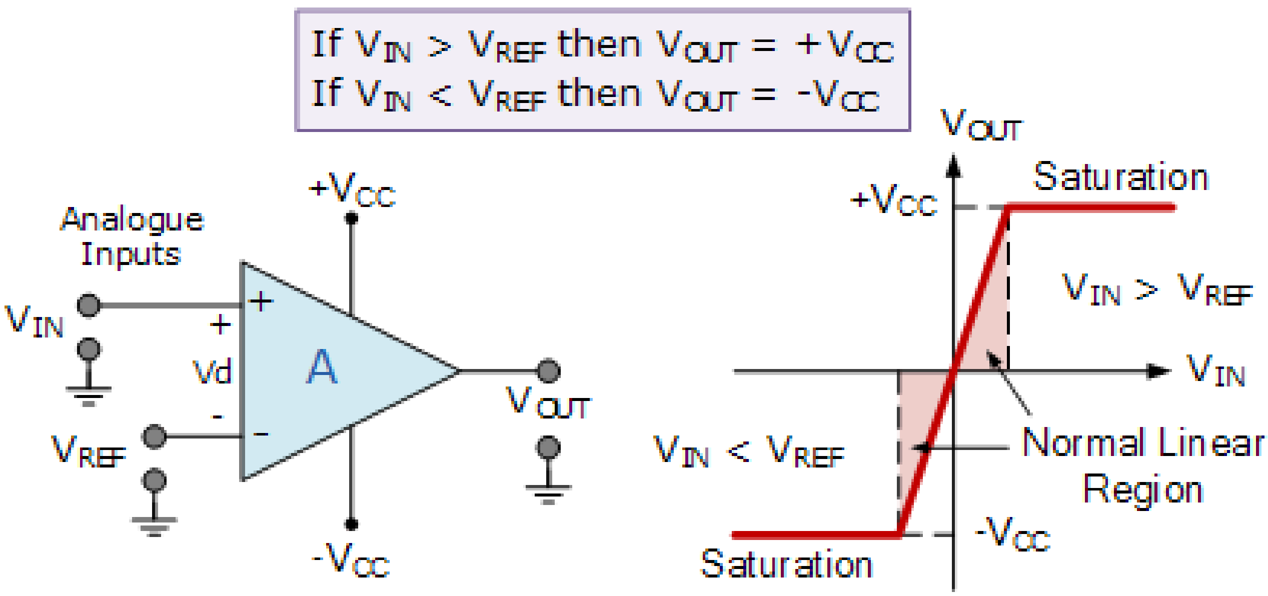
- Certain op-amps require a **higher supply voltage** to function properly.
- If the voltage is too low, the op-amp might not fully switch between high and low states,



Steps:

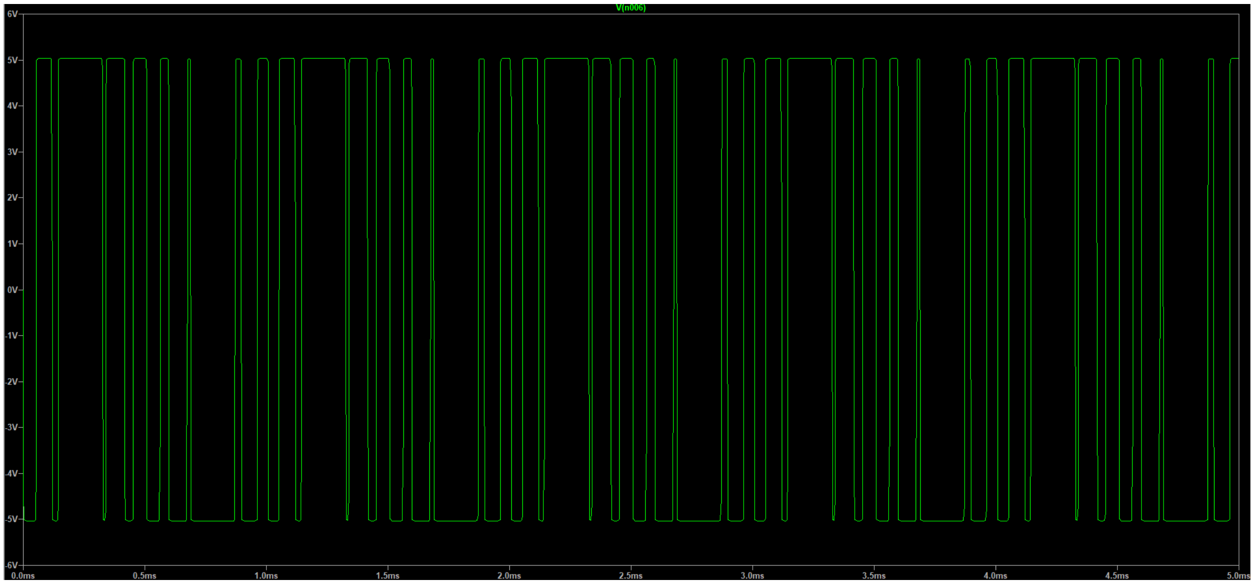
1. Add two voltage sources: one for the message signal and one for the carrier signal.
2. Use an operational amplifier as a comparator:
   - Connect the message signal to the non-inverting input (+).
   - Connect the carrier signal to the inverting input (-).
3. Connect -5V and +5V as supplies for the op-amp comparator.
4. Observe the output waveform (square wave).



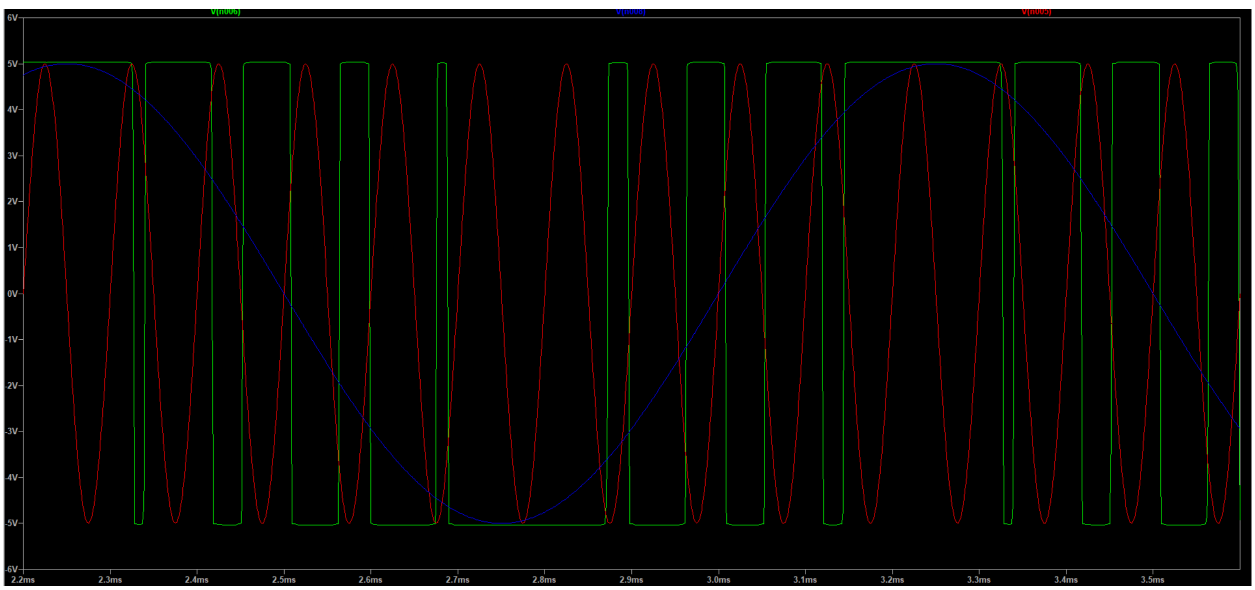


Expected Output:

A PWM waveform where the duty cycle increases with higher message signal amplitude and decreases with lower amplitude.



OUTPUT PWM SIGNAL(SQUARE WAVE)



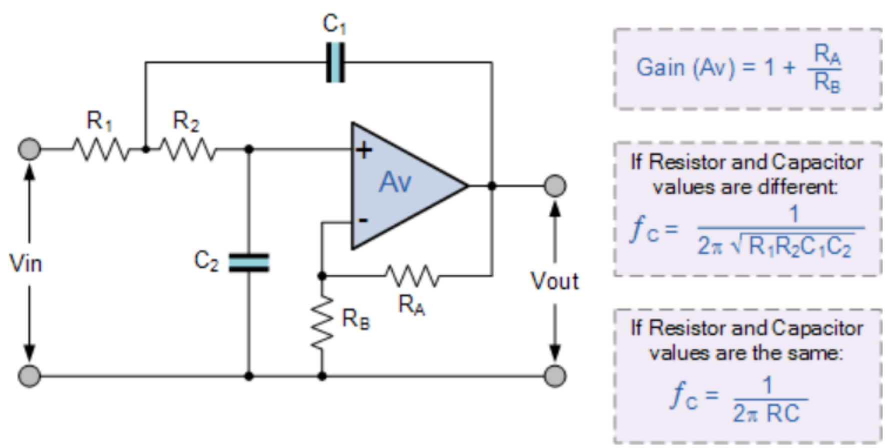
RED-CARRIER WAVE GREEN-PWM PULSE BLUE -MESSAGE SIGNAL

4. PWM Demodulation

4.1 Concept

Demodulation involves recovering the original message signal from the PWM waveform using a low-pass filter to remove high-frequency components.

Instead of a normal low-pass filter, we use an **active Sallen-Key 2nd-order low-pass filter** for better ripple rejection.



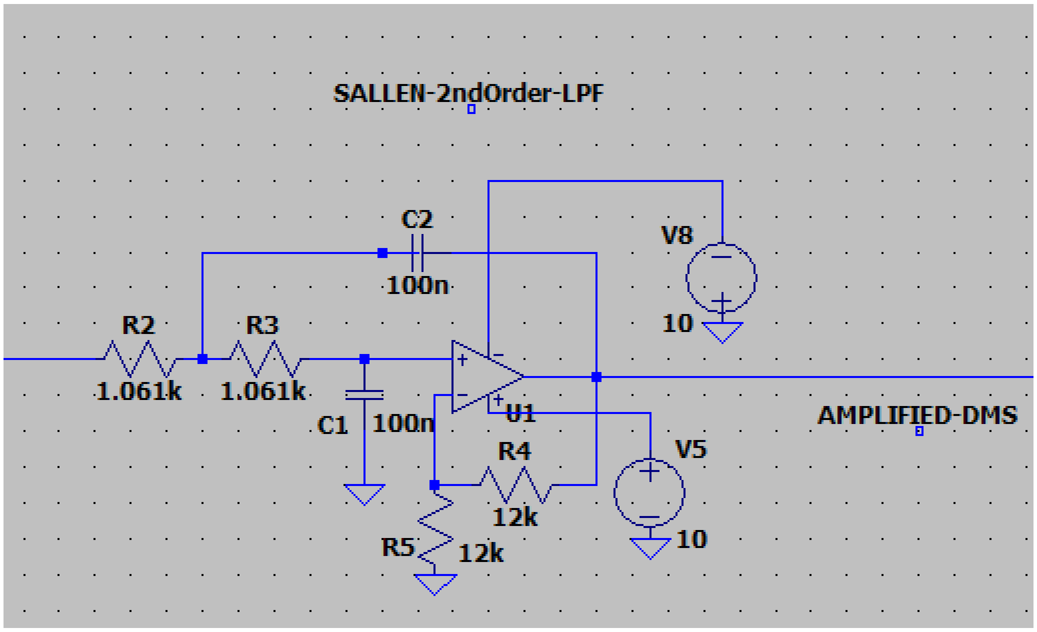
4.2 Active Second-Order Low-Pass Filter Design

Filter Specifications:(CALCULATIONS)

- **Cutoff Frequency:** fc ≈ 1.5 kHz (Message Signal = 1 kHz)
- **Component Values:**
  - **RA = RB = 12 kΩ**
  - **R1 = R2 = 1 kΩ**
  - **C1 = C2 = 100 nF**
- **Op-amp power supply:** -10V and +10V

Steps:

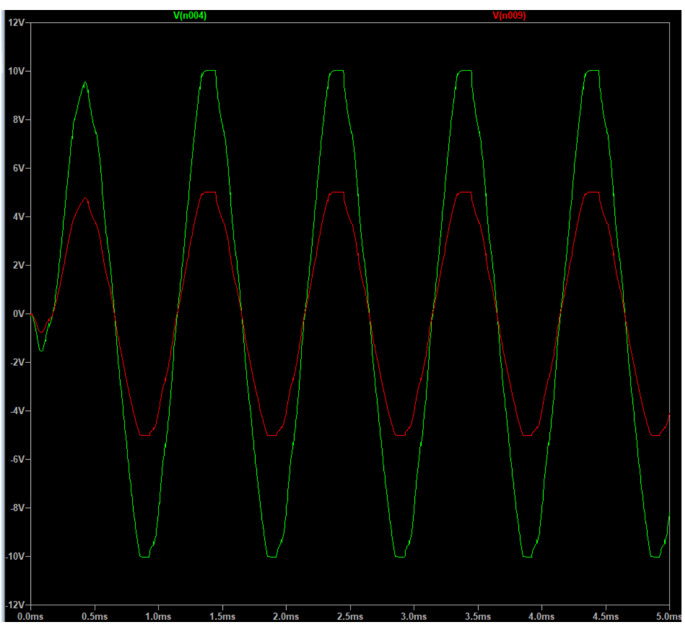
1. Design and simulate the active filter circuit in LTspice using an op-amp.
2. Set the resistor and capacitor values to achieve the desired cutoff frequency.
3. Observe the output waveform after filtering.



5. Final Signal Recovery

To recover the original signal from the amplified op-amp output:

- If **gain = 2 (R1 = R2)**, use a **voltage divider (10kΩ and 10kΩ)** to halve the voltage.
- Verify that the recovered waveform closely matches the original message signal.



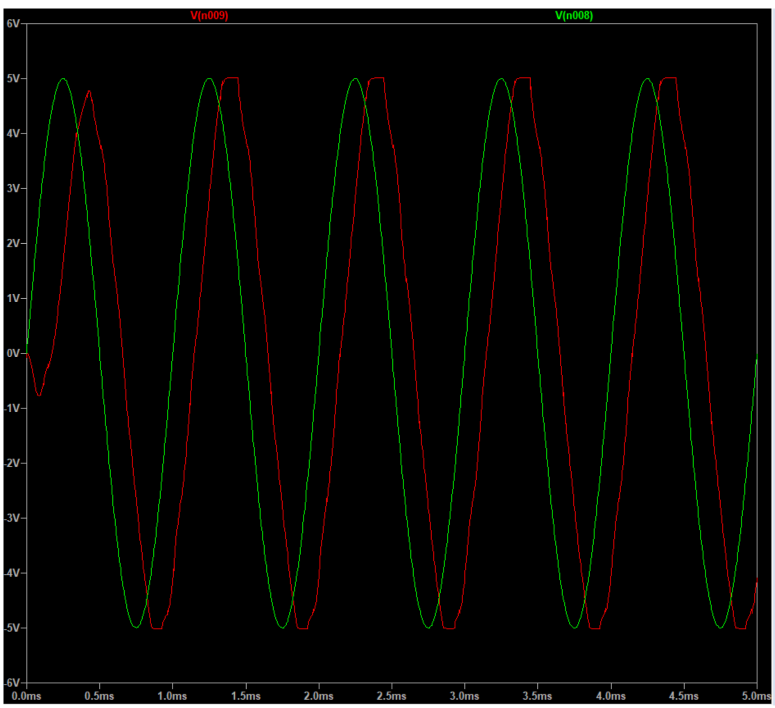
GREEN -AMPLIFIED MESSAGE SIGNAL **RED- FINAL MESSAGE SIGNAL**

6. Results and Observations

6.1 LTspice Simulation Results

- **PWM Generation:**
  - The PWM waveform shows varying pulse widths corresponding to the message signal amplitude.
- **Demodulation:**
  - The active second-order low-pass filter effectively reconstructs the original sine wave message signal.
- **Final Signal Recovery:**
  - The voltage divider successfully adjusts the amplitude to match the original signal.

6.2 Screenshots and Waveforms



RED-ORGINAL MESSAGE SINE WAVE (1Khz,5V)

GREEN-DEMODULATED FINAL MESSAGE SIGNAL

VERIFICATION: BOTH SIGNALS ARE SAME WITH SOME PHASE SHIFT

BONUS

Carrier Signal Extraction using 4th Order Band-Pass Filters

Why a Band-Pass Filter Instead of a High-Pass Filter?

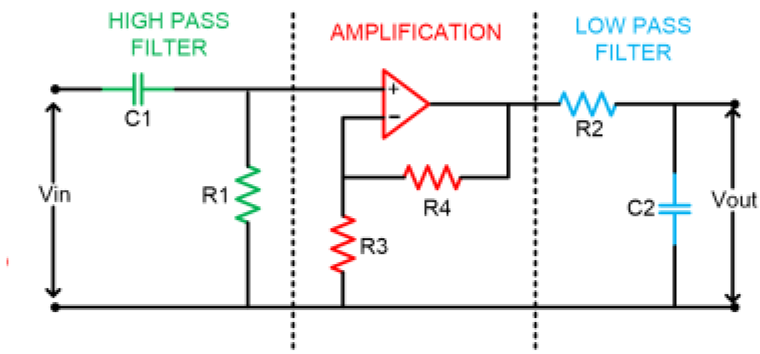
- A **high-pass filter (HPF)** allows all frequencies above the cutoff to pass, which can include unwanted noise and harmonics.
- Using a **4th order band-pass filter (BPF)** provides better **selectivity** by isolating only the carrier frequency range (5 kHz – 15 kHz), reducing unwanted components.
- The **HPF approach caused sharp edges and peaks** because it allowed harmonics of the PWM signal, leading to distortion and ringing effects in the extracted waveform.

Why a Band-Pass Filter (BPF) Instead of a High-Pass Filter (HPF)?

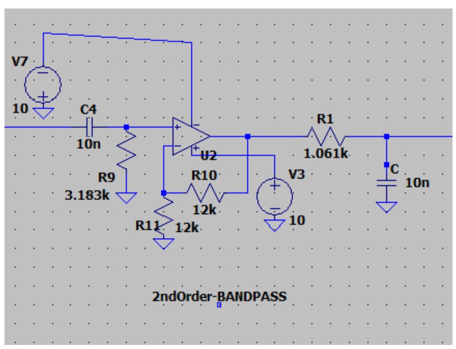
1. **HPF Issue:** Allowed all high frequencies, including unwanted harmonics, leading to distortion, ringing, and sharp edges.
2. **BPF Advantage:** Passed only the required range (5 kHz – 15 kHz), blocking unnecessary low and high frequencies for cleaner output.
3. **Harmonic Suppression:** HPF retained high-frequency harmonics of the PWM signal, causing unwanted peaks and waveform distortion.
4. **Signal Integrity:** BPF provided better selectivity, ensuring accurate extraction of the desired signal.
5. **Practical Performance:** HPF resulted in noise amplification, while BPF improved signal clarity for processing.

Why a 4th-Order Butterworth Filter Instead of a 2nd-Order?

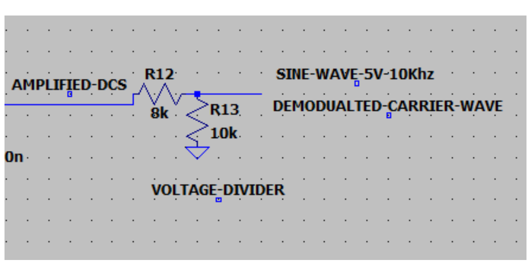
1. **Sharper Roll-Off:** A 2nd-order filter had a gradual slope (-40 dB/dec), allowing unwanted frequencies to interfere. The 4th-order provided a steeper roll-off (-80 dB/dec), reducing noise more effectively.
2. **Better Attenuation:** Ensured stronger suppression of harmonics and out-of-band noise for a cleaner extracted signal.
3. **Minimal Phase Distortion:** Butterworth filters maintain a smooth frequency response, preserving waveform shape.

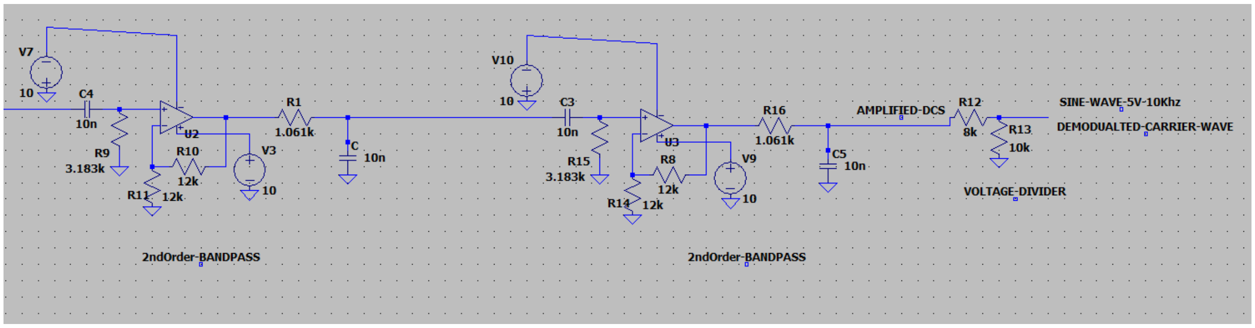


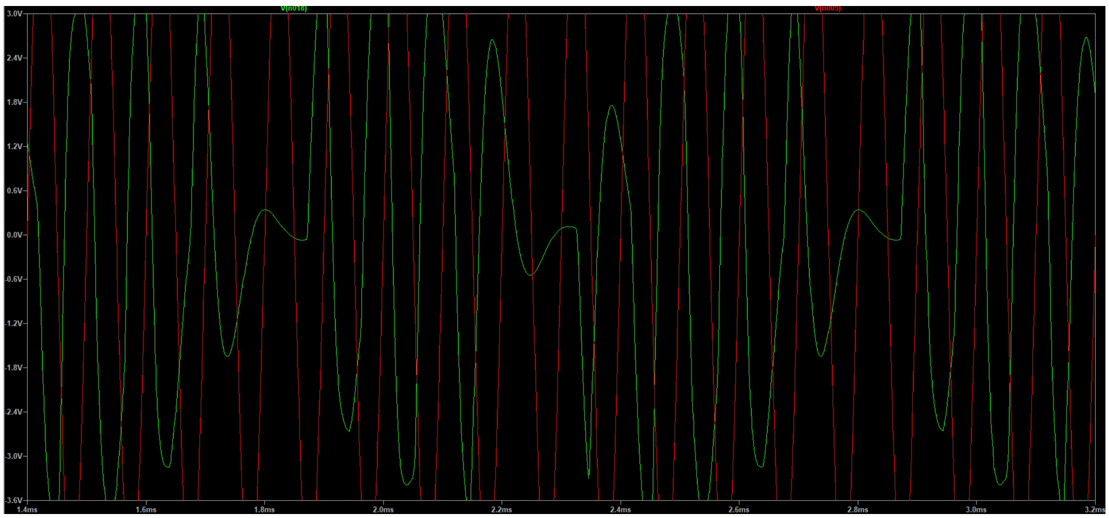
Filter Design Parameters

- **Lower cutoff frequency (5 kHz):**
  - R=3.183KR = 3.183K, C=10nFC = 10nF
- **Upper cutoff frequency (15 kHz):**
  - R=1.061KR = 1.061K, C=10nFC = 10nF
  - 

Voltage Divider for Signal Recovery

- The extracted carrier signal **had an amplified output**, so a **voltage divider** was added to scale it down and recover the original carrier waveform accurately.
- Voltage divider added to scale up the normal 50% convention because there were drops due to R in the 4th order circuit
- 

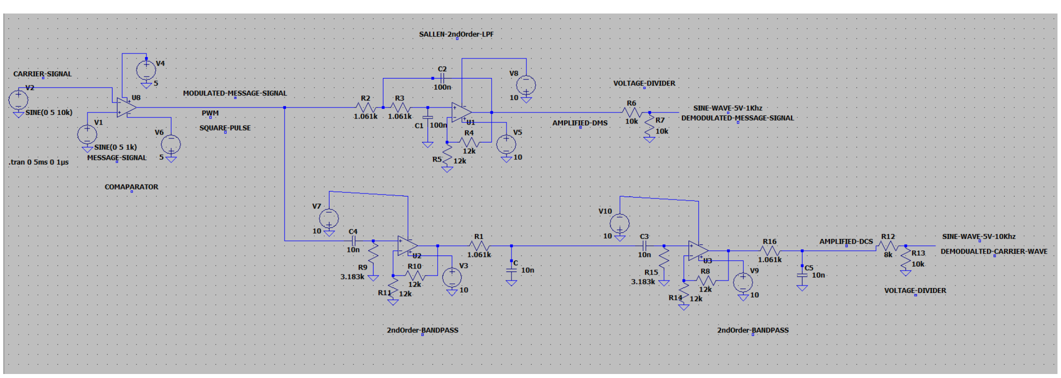




RED -ORIGINAL CARREIR SINE WAVE (10Khz,5V)

GREEN -DEMODUALTED CARREIR SINE WAVE (10Khz,5V)(HAS SOME DISTURBANCES DUE TO PULSE HARMONICS)

SO, THE FINAL CIRCUIT FOR PWM MODULATION AND DEMODULATION



7. Conclusion

This experiment successfully demonstrated the generation and demodulation of a PWM signal using LTspice. The PWM technique effectively encoded the message signal, and the second-order active low-pass filter was able to recover the original signal with minimal distortion. This approach is useful in various applications, including motor control, communication systems, and signal processing.

Future Improvements:

- Experimenting with different filter orders for better signal recovery.
- Implementing a practical hardware version for real-world validation.

REFERENCES:

- LTspice Download Link: LTspice Download

- LTspice Tutorials=: LTspice Tutorial - EP1 Getting Started (You may need to specify the exact source, such as a YouTube link or website.)

- Detailed Tutorials= Refer to the LTspice User Guide available on the official Analog Devices website or online forums like the LTspice user group and EE forums.