



**Faculty of Engineering and Technology  
Electrical and Computer Engineering Department  
COMMUNICATIONS LAB  
ENEE4113**

**Experiment #:6**

**Experiment title: Pulse Amplitude Modulation (PAM)**

**PreLab #3**

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**Section: 2**

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## Part 1: Time and Frequency Characteristics of the pulse train

### Part Notes

1. pulse train
2. Frequency = 1kHz
3.  $V_{ss} = 10 \text{ V}$  so the Amplitude of the signal will be  $10/2 = 5\text{V}$

The measurements of the spectral and time characteristics will be calculated for the same information above for different duty cycles: 10%, 20%, 30%, 40, 50% and 90%.

### Pulse Train Generation-Simulink

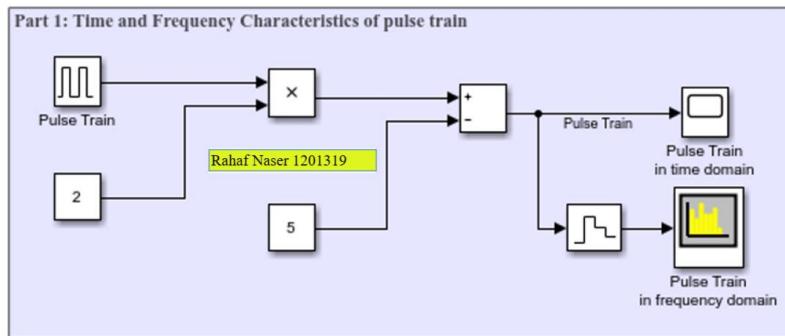


Figure 1: Pulse Train Generation-Simulink

#### a. Pulse Train with 10% duty cycles

##### Pulse Train – Pulse generator block parameters:

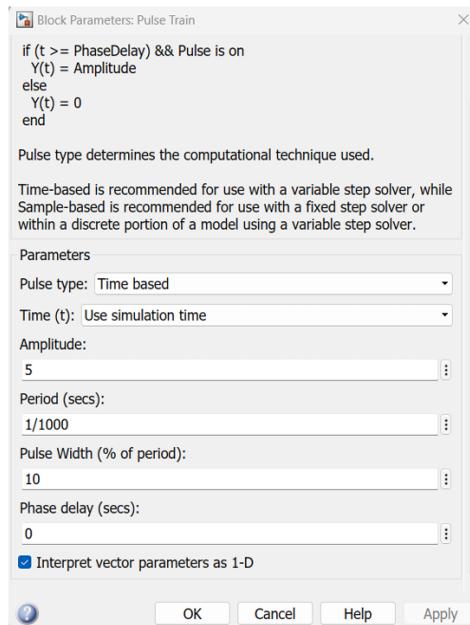


Figure 2: Pulse Train – Pulse generator block parameters

### Representation in time domain:

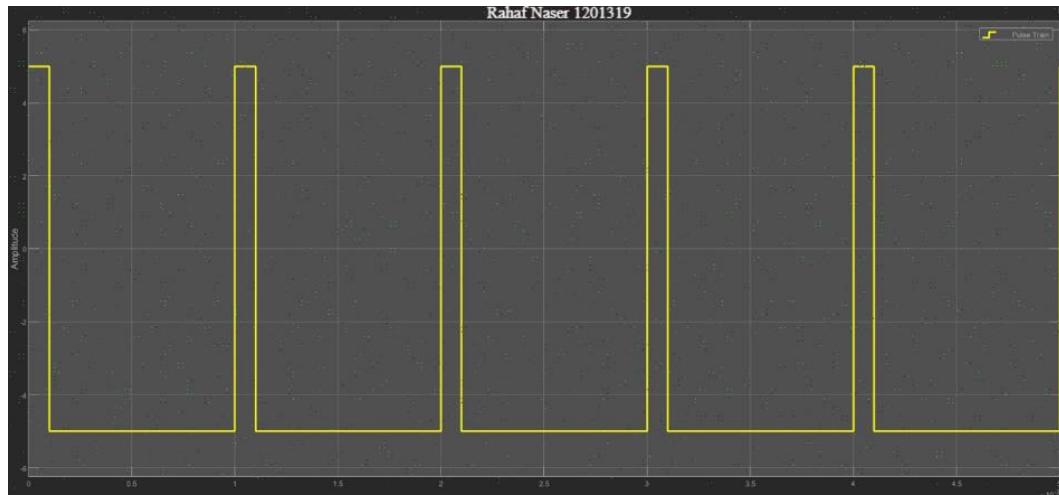


Figure 3: Pulse Train with 10% duty cycles-time domain representation

### Representation in frequency domain:

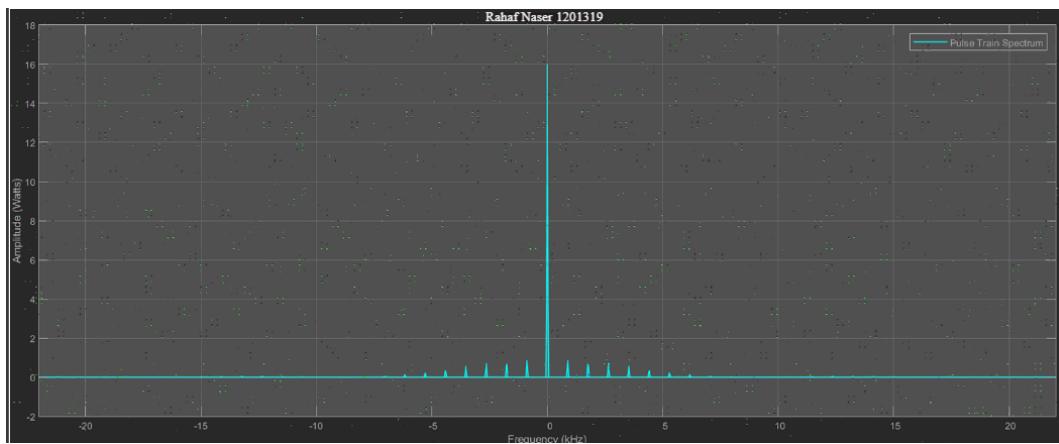


Figure 4: Pulse Train with 10% duty cycles-frequency domain representation

## b. Pulse Train with 20% duty cycles

Pulse Train – Pulse generator block parameters:

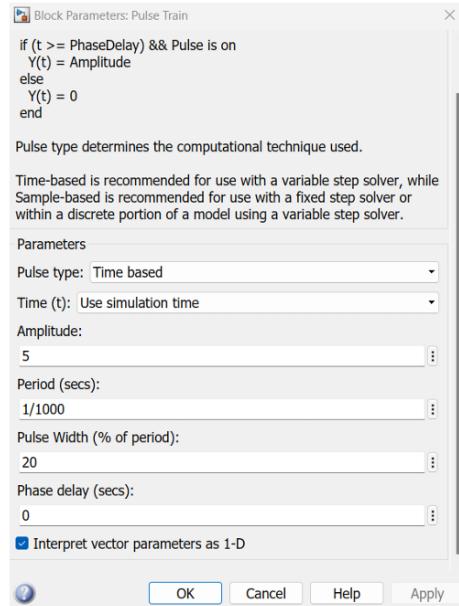


Figure 5: Pulse Train – Pulse generator block parameters

Representation in time domain:

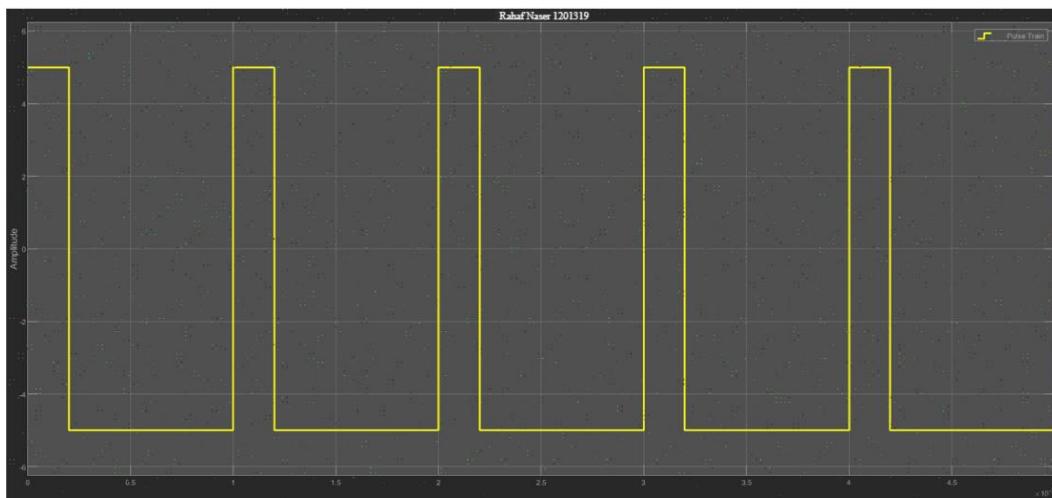


Figure 6: Pulse Train with 20% duty cycles-time domain representation

## Representation in the frequency domain:

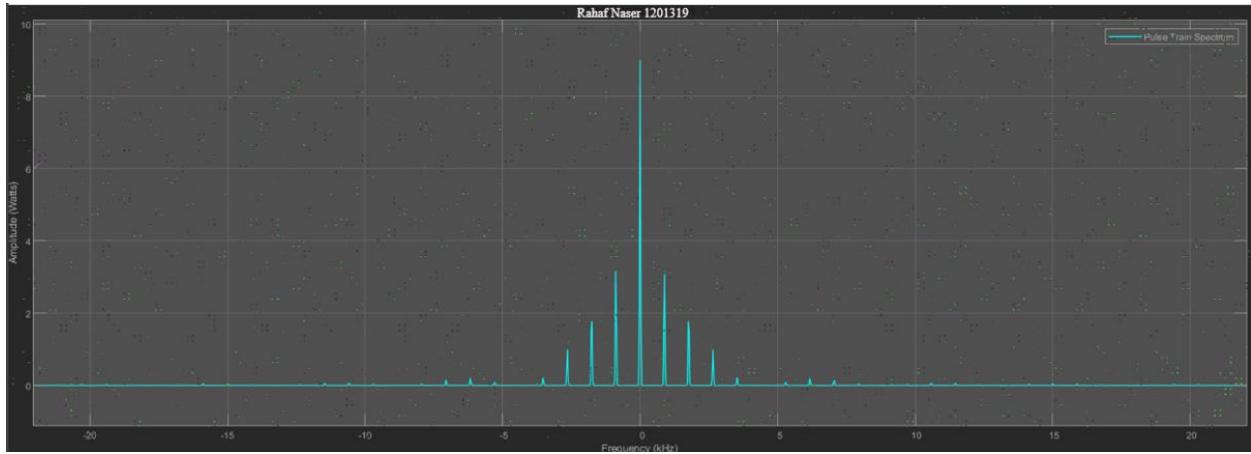


Figure 7: Pulse Train with 20% duty cycles-frequency domain representation

## c. Pulse Train with 30% duty cycles

### Pulse Train – Pulse generator block parameters:

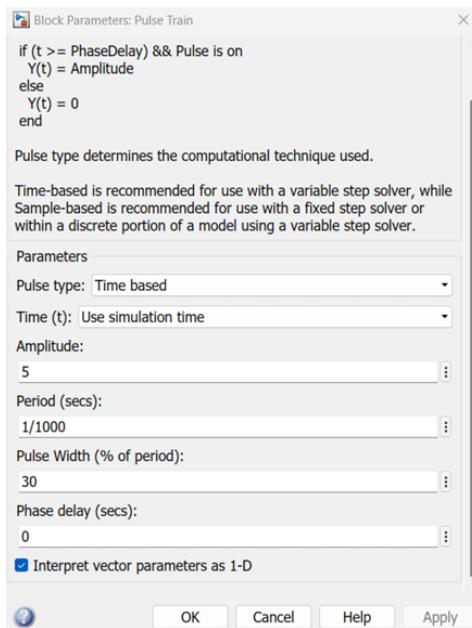


Figure 8: Pulse Train – Pulse generator block parameters

### Representation in time domain:

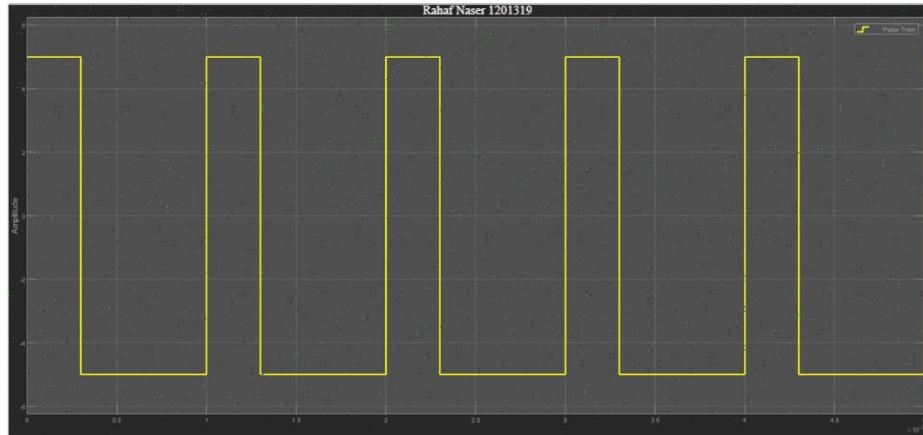


Figure 9: Pulse Train with 30% duty cycles-time domain representation

### Representation in frequency domain:

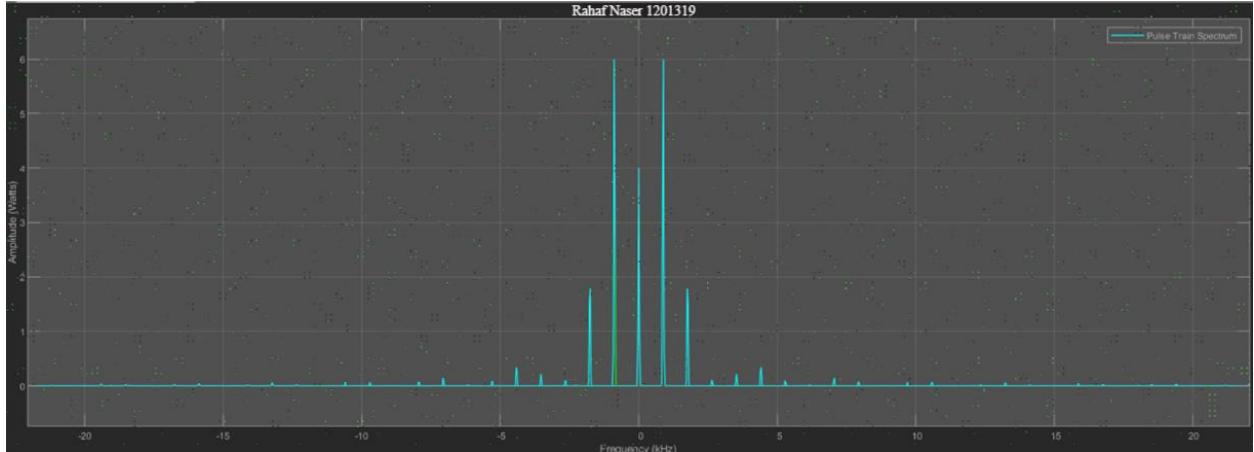


Figure 10: Pulse Train with 30% duty cycles-frequency domain representation

## d. Pulse Train with 40% duty cycles

Pulse Train – Pulse generator block parameters:

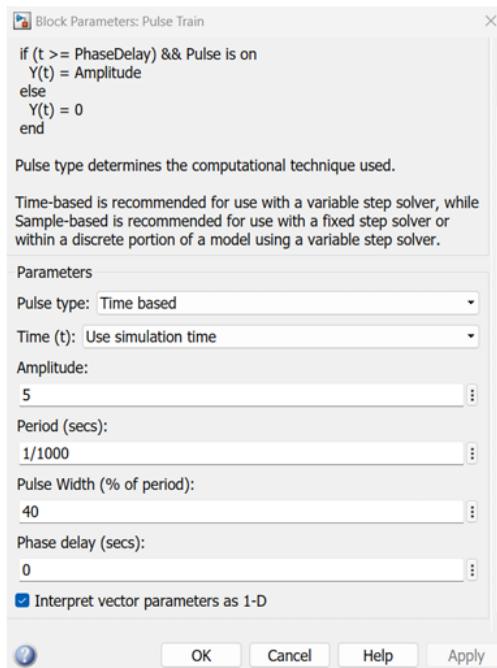


Figure 11: Pulse Train – Pulse generator block parameters

Representation in time domain:

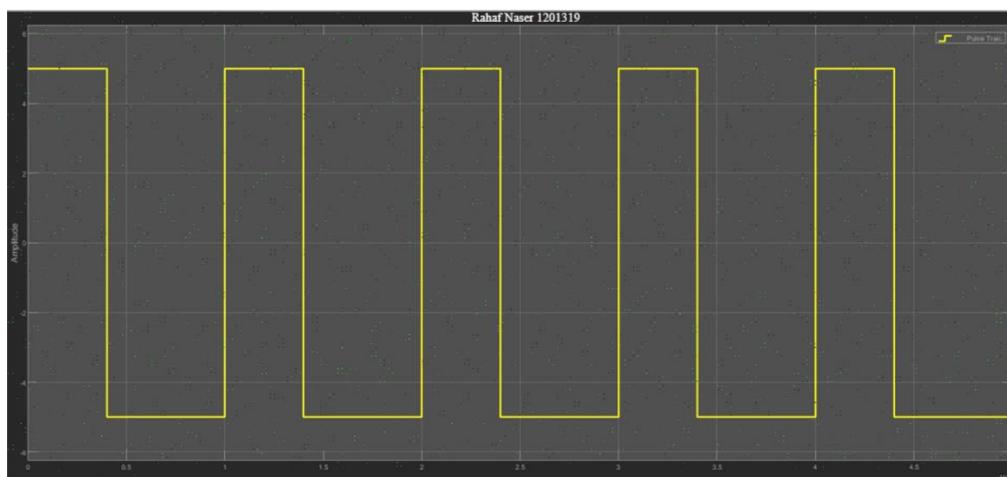


Figure 12: Pulse Train with 40% duty cycles-time domain representation

### Representation in frequency domain:

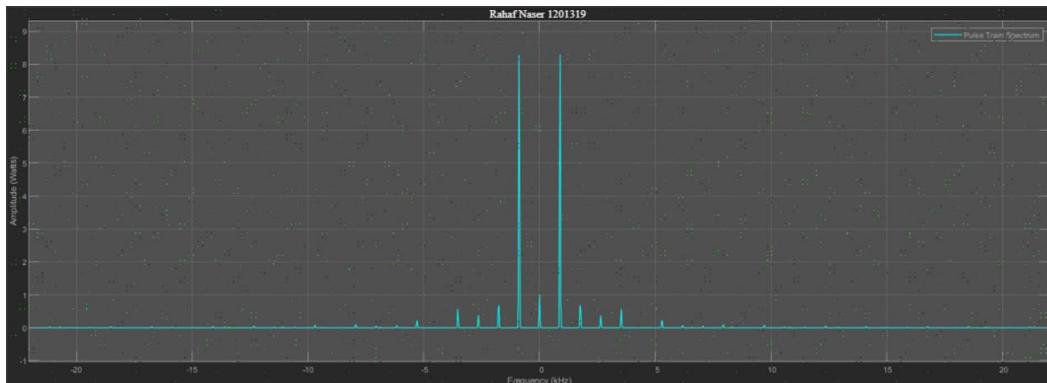


Figure 13: Pulse Train with 40% duty cycles-frequency domain representation

### e. Pulse Train with 50% duty cycles

#### Pulse Train – Pulse generator block parameters:

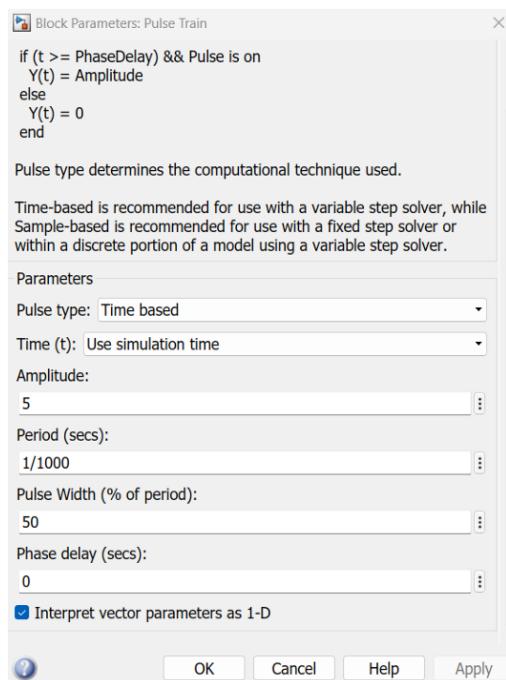


Figure 14: Pulse Train – Pulse generator block parameters

### Representation in time domain:

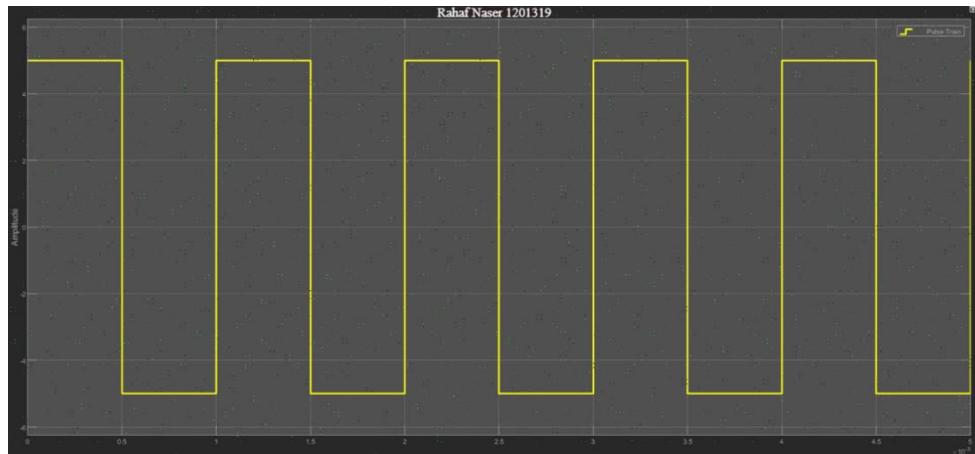


Figure 15: Pulse Train with 50% duty cycles-time domain representation

### Representation in frequency domain:

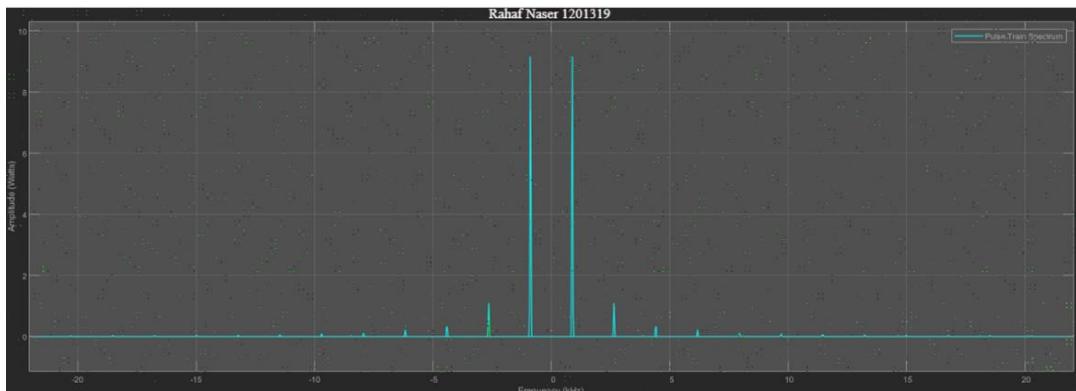


Figure 16: Pulse Train with 50% duty cycles-frequency domain representation

## f.Pulse Train with 90% duty cycles

Pulse Train – Pulse generator block parameters:

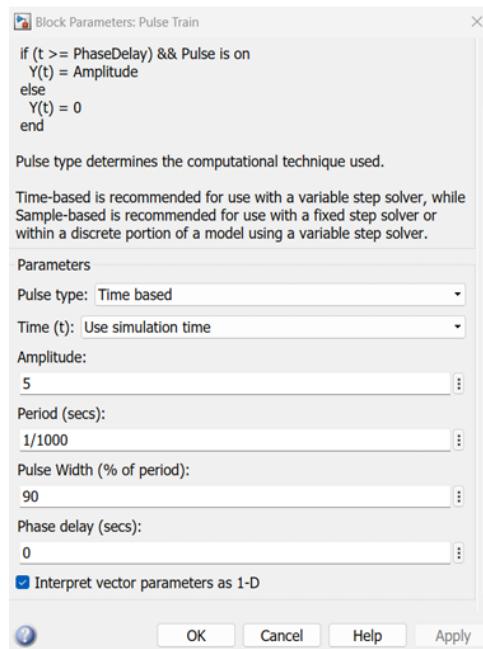


Figure 17: Pulse Train – Pulse generator block parameters

Representation in time domain:

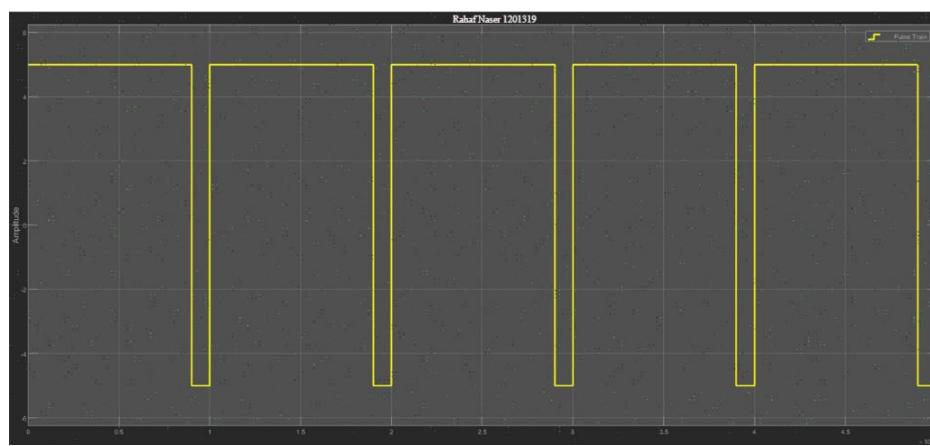


Figure 18: Pulse Train with 90% duty cycles-time domain representation

### Representation in frequency domain:

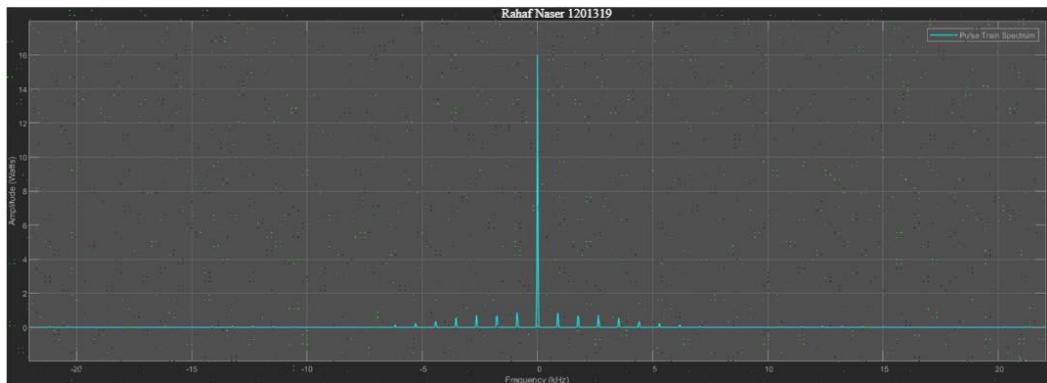


Figure 19: Pulse Train with 90% duty cycles-frequency domain representation

### Discussion:

In this part, the characteristics of a pulse train were analyzed in both the time and frequency domains. The duty cycle variations significantly affect the spectral properties of the signal. As the duty cycle increases, the fundamental frequency component remains the same, but higher harmonics appear more prominently, affecting the signal bandwidth. This observation is crucial in digital communication, where pulse waveforms are used for signal modulation and transmission. The spectral characteristics indicate that a lower duty cycle results in a wider spectral spread, whereas a higher duty cycle produces a more concentrated spectrum. These findings are useful when designing communication systems that require precise bandwidth allocation.

## Part 2: Characteristics of Pulse Amplitude Modulation (PAM)

### Part initial Notes

1. Pulse train
2. Sine wave signal (which is the message signal) with frequency = 500Hz
3.  $V_{ss} = 10 \text{ V}$  so the Amplitude of the sine signal will be  $10/2 = 5\text{V}$
4. Sampling Frequency = 5000Hz so the period of the pulse train will be 1 5000 sec
5. Duty cycle = 50%

## Natural Sampling-Simulink:

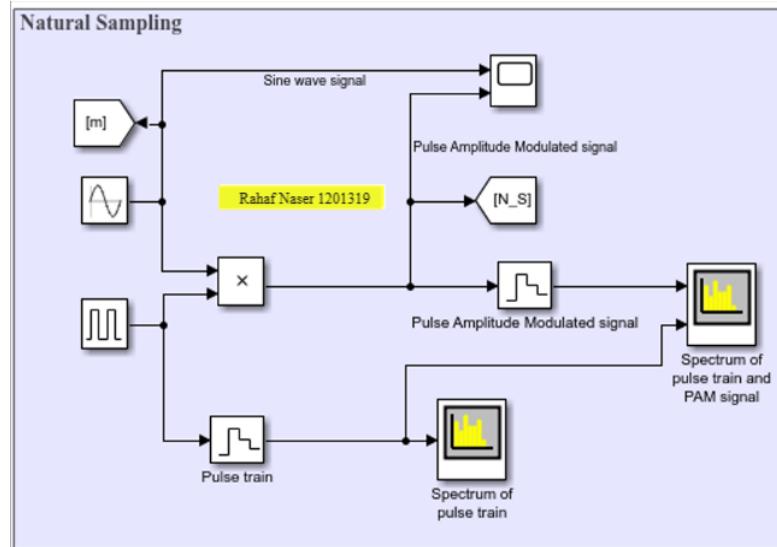


Figure 20: Natural Sampling-Simulink (PAM1)

## Sine wave signal – sign wave block parameters:

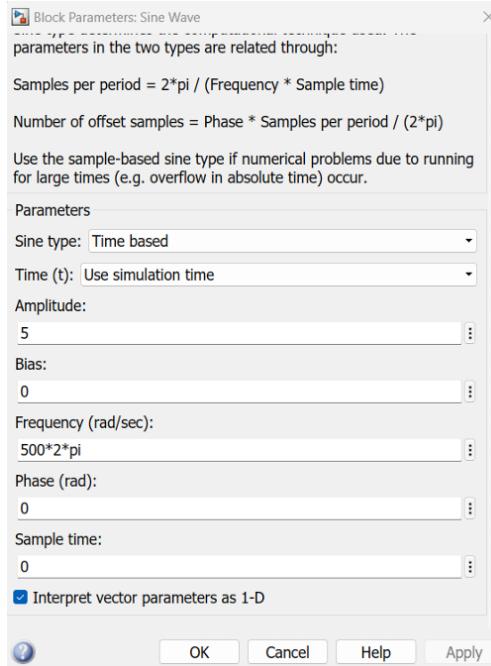


Figure 21: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters:

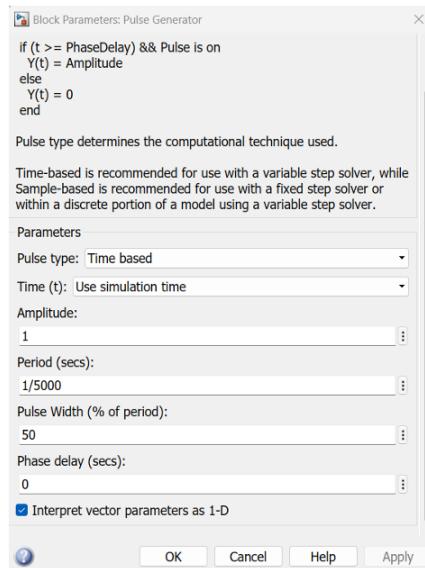


Figure 22: Pulse Train – Pulse generator block parameters

## Zero order block parameters:

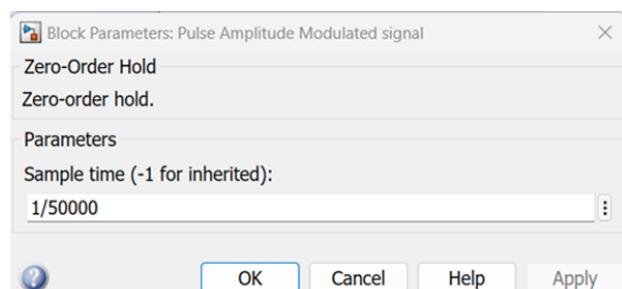


Figure 23: Zero order block parameters

PAM signal with pulse train 50% duty cycles , fm=500

Representation in time domain:

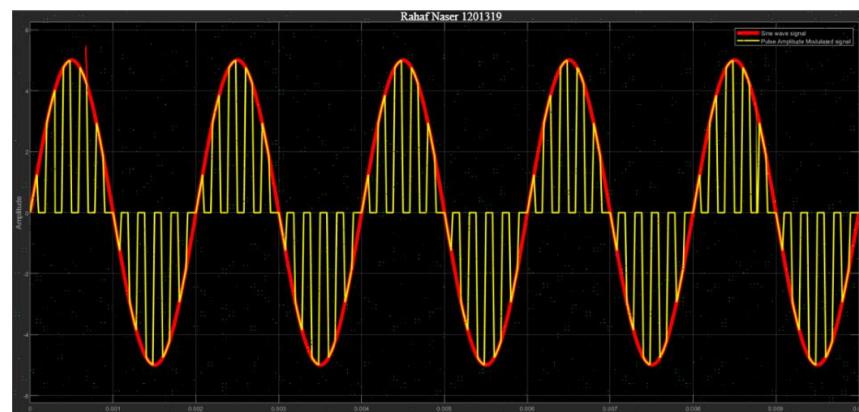


Figure 24: PAM signal vs Sine wave signal with 50% duty cycles-time domain representation

## Representations in frequency domain

### PAM modulated signal vs Pulse train - spectrum

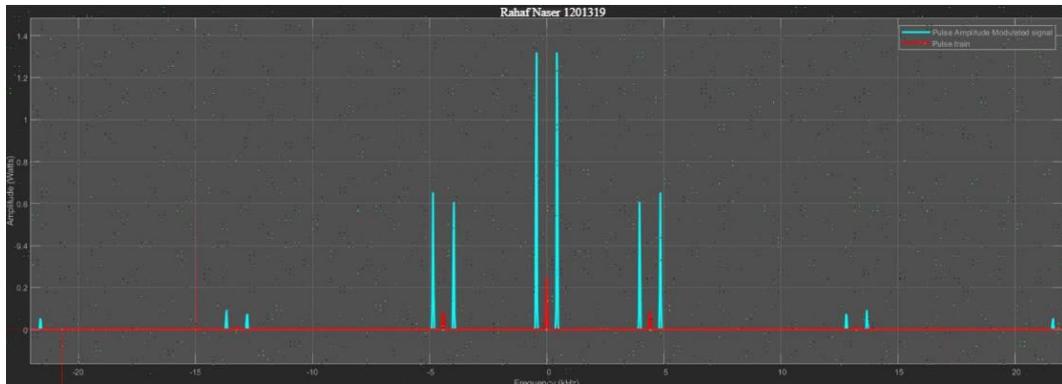


Figure 25: PAM modulated signal vs Pulse train - spectrum

### Pulse train spectrum

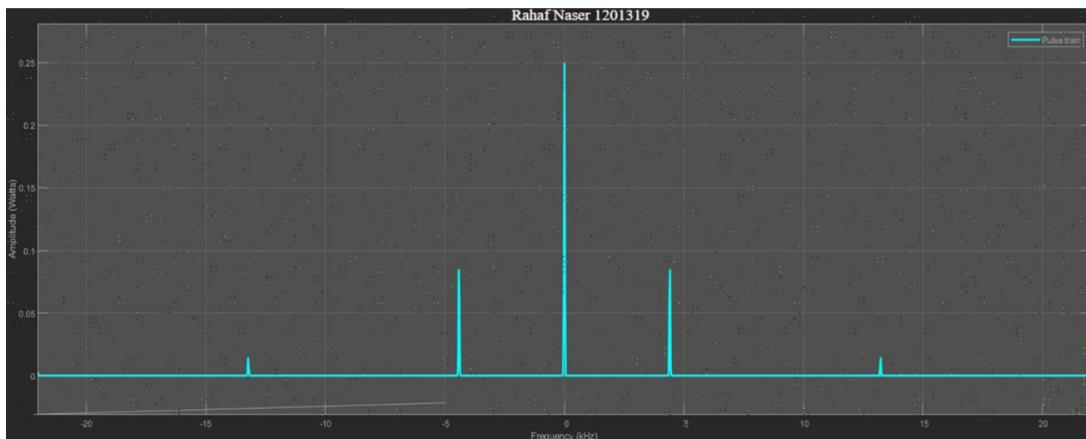


Figure 26: Pulse Train with 50% duty cycles-frequency domain representation

## PAM signal with pulse train 10% duty cycles

### Pulse Train – Pulse generator block parameters

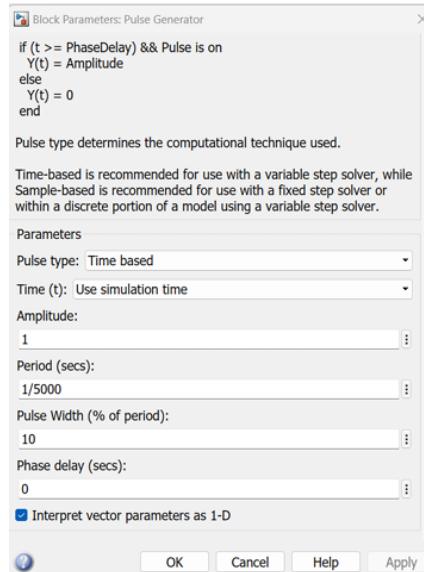


Figure 27: Pulse Train – Pulse generator block parameters

### Representation in time domain:

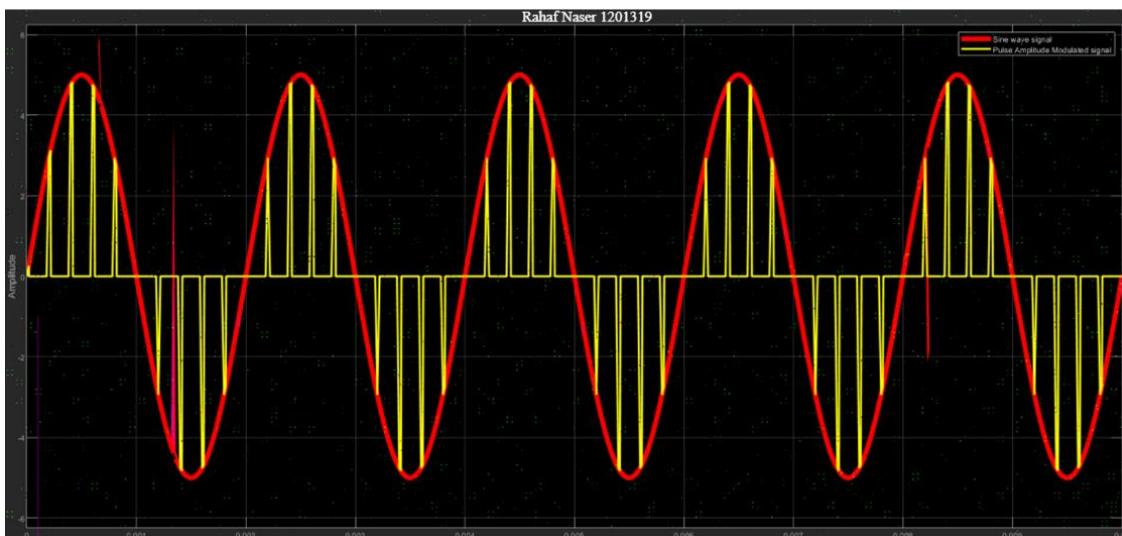


Figure 28: PAM signal vs Sine wave signal with 10% duty cycles-time domain representation

## Representations in frequency domain

### PAM modulated signal vs Pulse train - spectrum

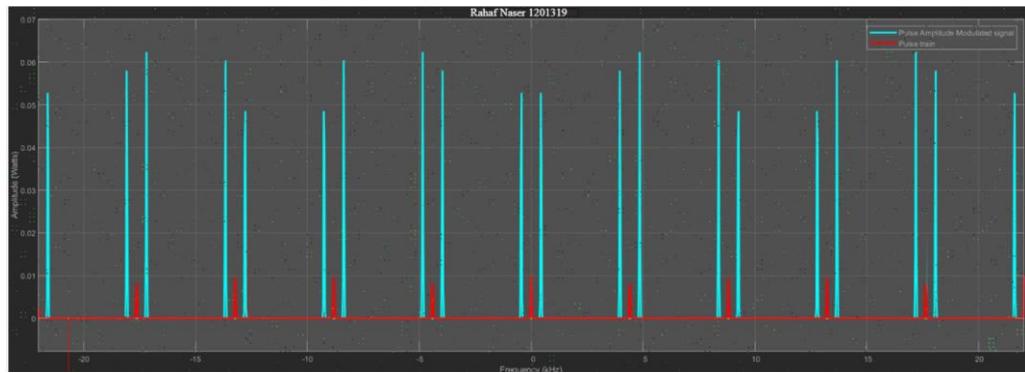


Figure 29: PAM modulated signal vs Pulse train – spectrum

**Effect of the message frequency on the PAM in the Frequency domain by changing message frequency to 1 kHz and 2 kHz respectively.**

**PAM signal with pulse train 50% duty cycles and fm = 1kHz**

**Sine wave signal – sign wave block parameters**

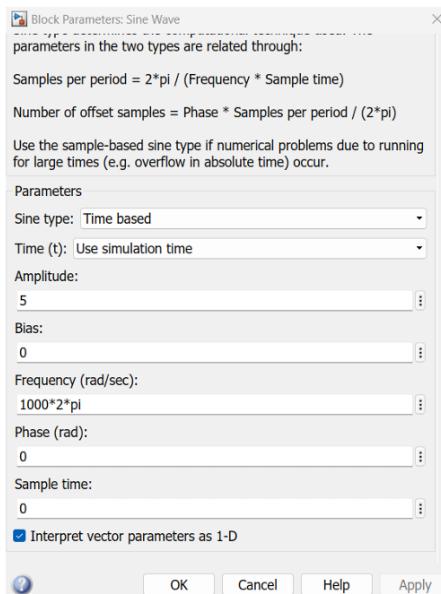


Figure 30: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters

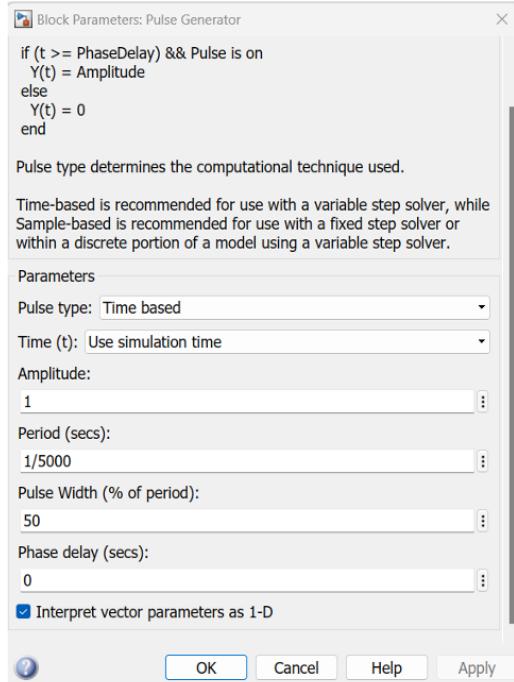


Figure 31: Pulse Train – Pulse generator block parameters

## Representation in time domain:

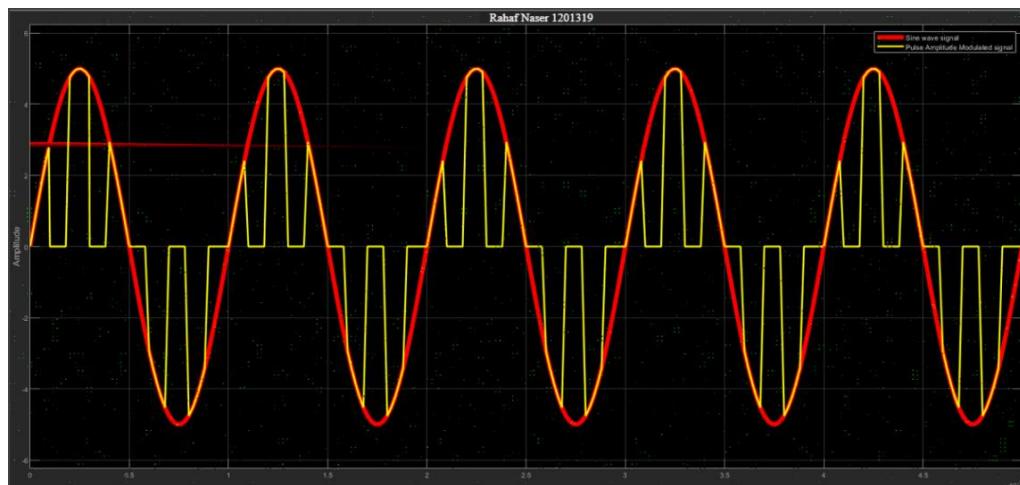


Figure 32: PAM signal vs sine wave signal with pulse train 50% duty cycles and fm = 1kHz

**Representations in frequency domain:**  
**PAM modulated signal vs Pulse train - spectrum**

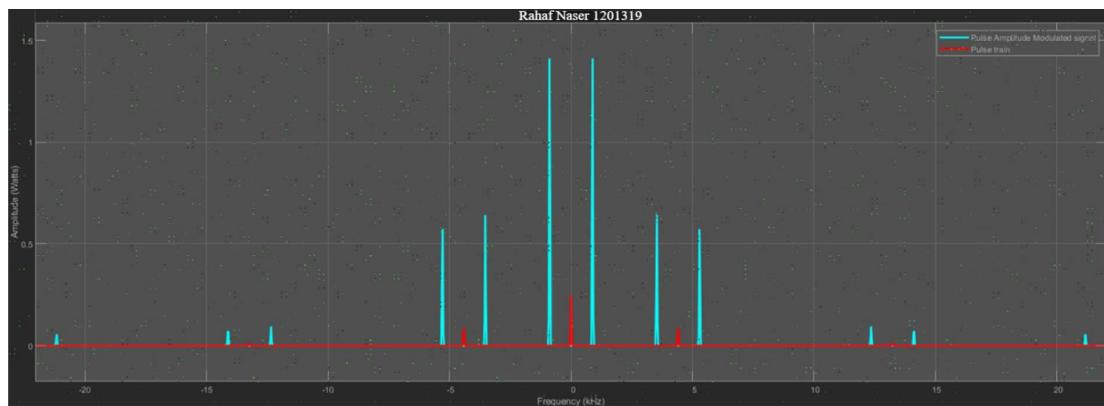


Figure 33: PAM modulated signal vs Pulse train - spectrum

**Pulse train spectrum**

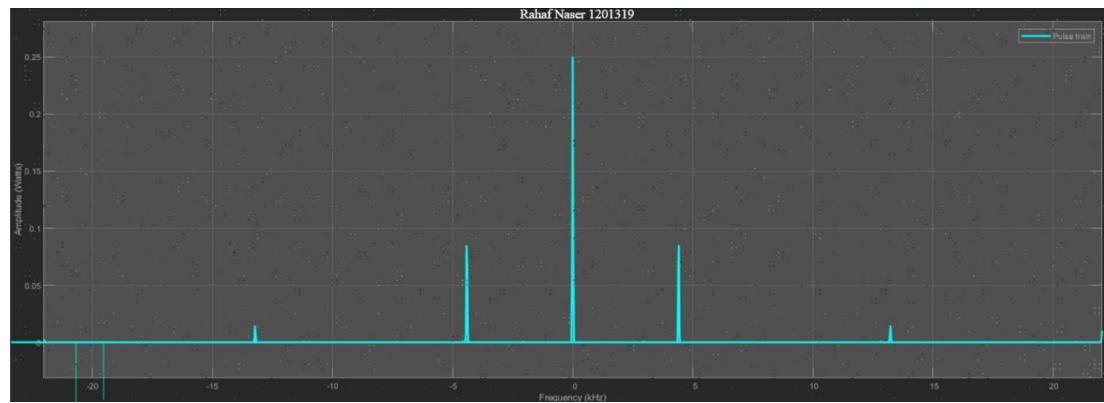


Figure 34: Pulse Train with 50% duty cycles-frequency domain representation

**PAM signal with pulse train 50% duty cycles and fm = 2kHz**

**Sine wave signal – sign wave block parameters :**

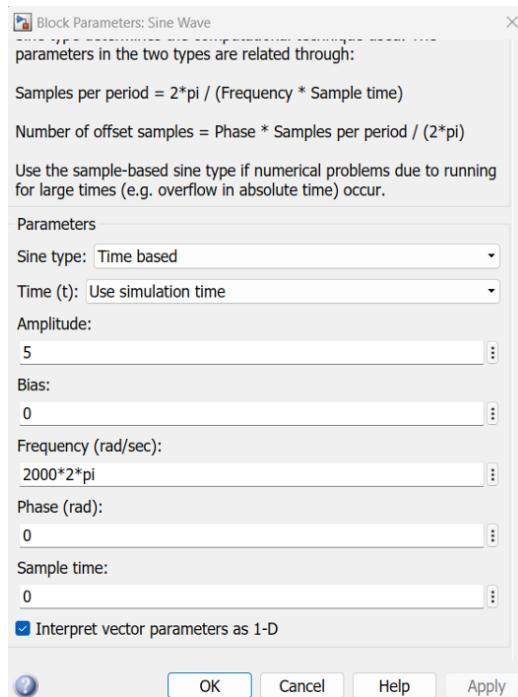


Figure 35: Sine wave signal – sign wave block parameters

**Pulse Train – Pulse generator block parameters:**

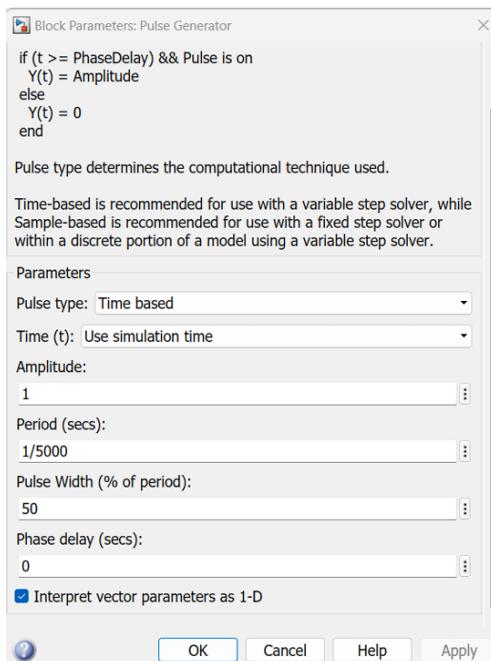


Figure 36: Pulse Train – Pulse generator block parameters

## Representation in time domain:

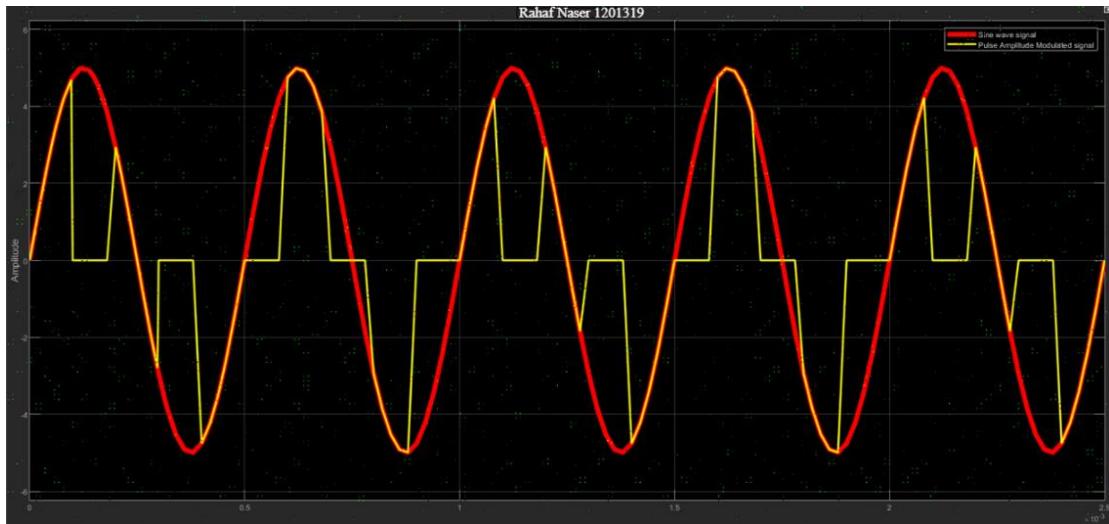


Figure 37: PAM signal vs sine wave signal with pulse train 50% duty cycles and fm = 2kHz

## Representations in frequency domain:

### PAM modulated signal vs Pulse train - spectrum

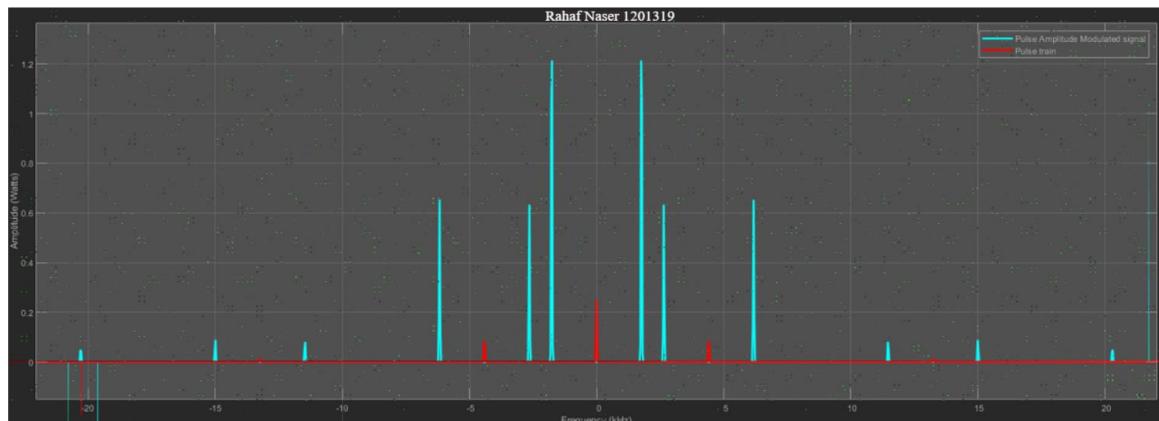


Figure 38: PAM modulated signal vs Pulse train - spectrum

### Pulse train spectrum:

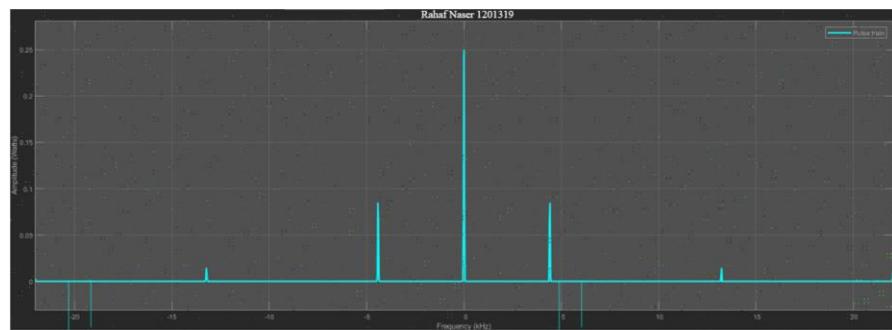


Figure 39: Pulse Train with 50% duty cycles-frequency domain representation

PAM signal with pulse train 10% duty cycles and fm = 500Hz

### Sine wave signal – sign wave block parameters:

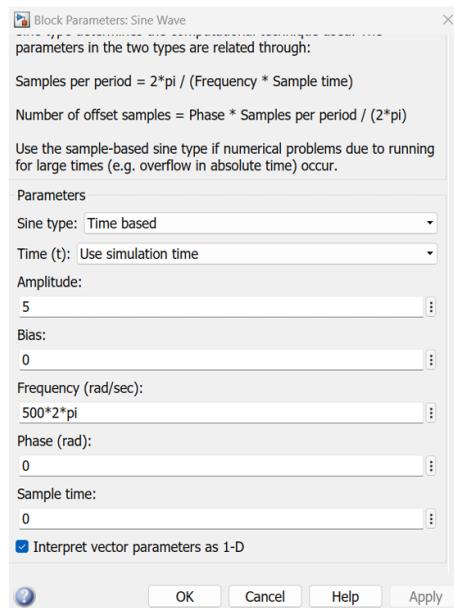


Figure 40: Sine wave signal – sign wave block parameters

### Pulse Train – Pulse generator block parameters:

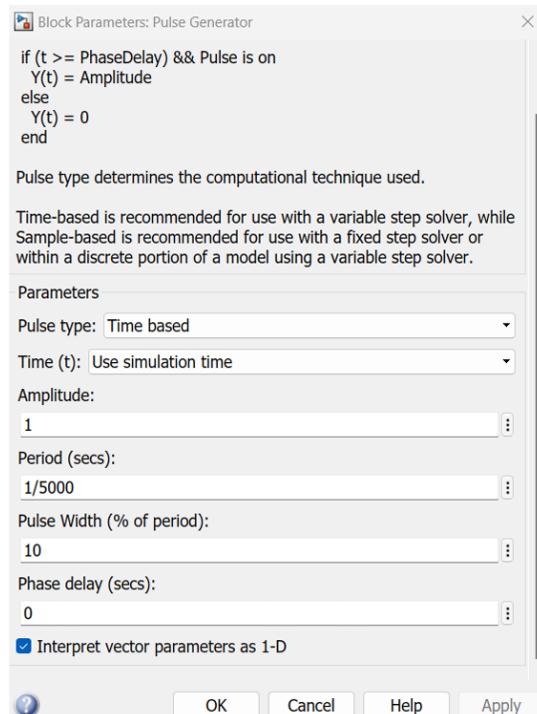


Figure 41: Pulse Train – Pulse generator block parameters

### Representation in time domain:

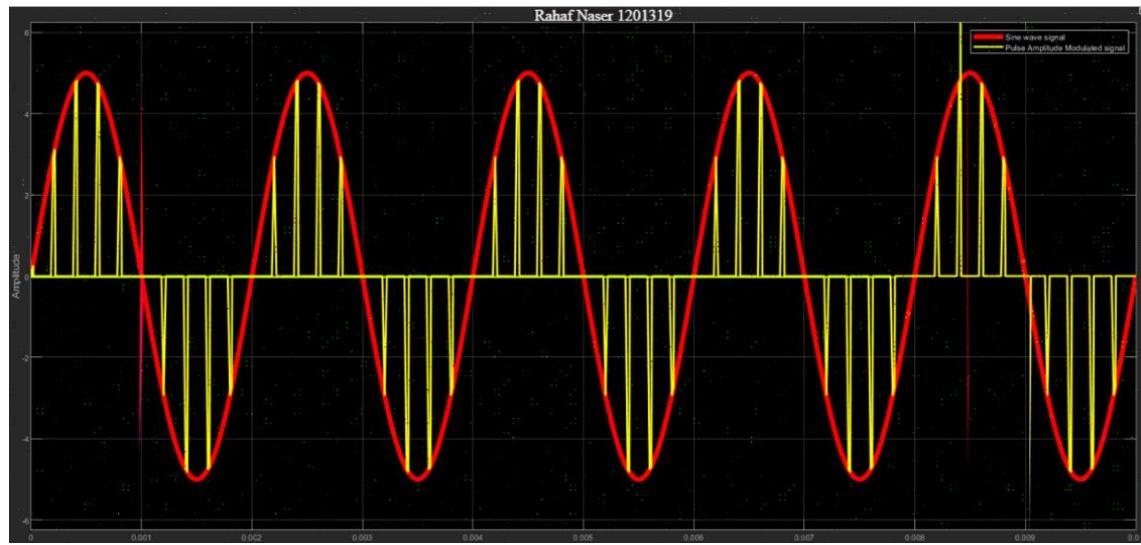


Figure 42: PAM signal vs sine wave signal with pulse train 10% duty cycles and fm = 500Hz

### Representations in frequency domain:

#### PAM modulated signal vs Pulse train - spectrum

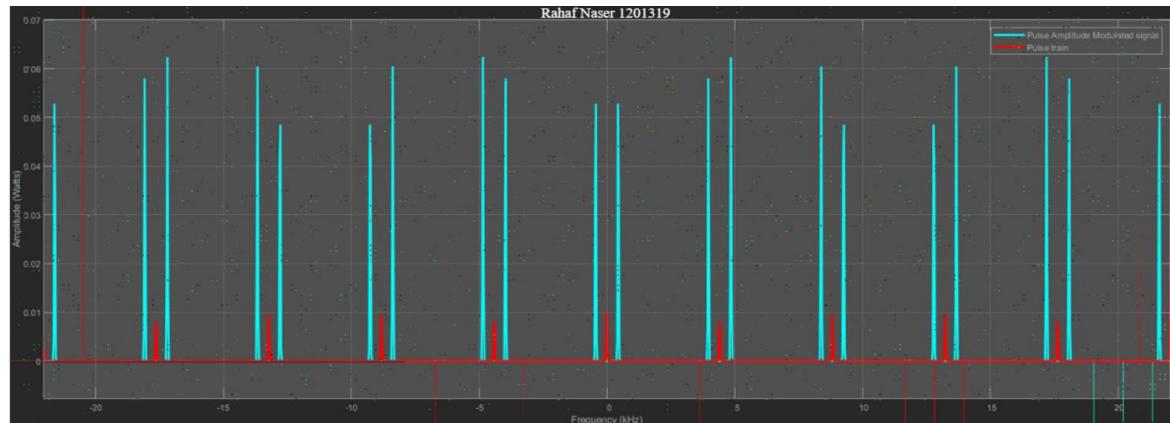


Figure 43: PAM modulated signal vs Pulse train - spectrum

## Pulse train spectrum

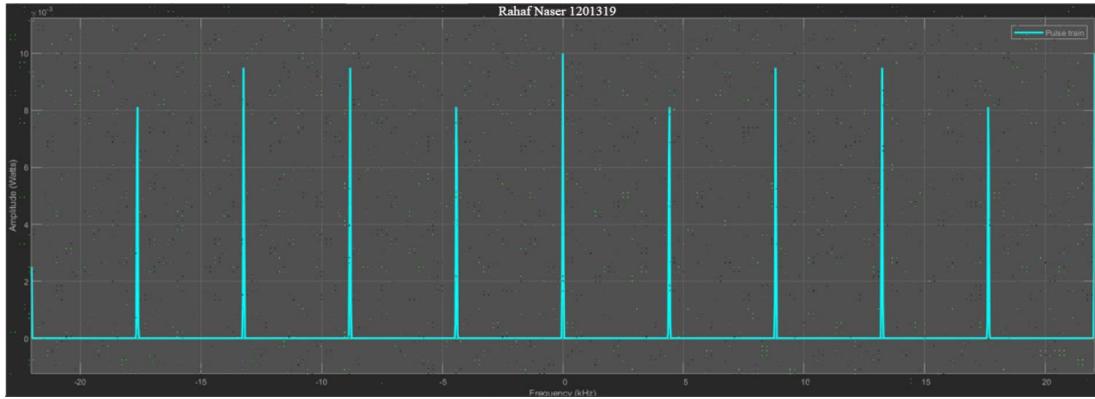


Figure 44: Pulse Train with 10% duty cycles-frequency domain representation

## PAM signal with pulse train 30% duty cycles and fm = 500Hz

Sine wave signal – sign wave block parameters:

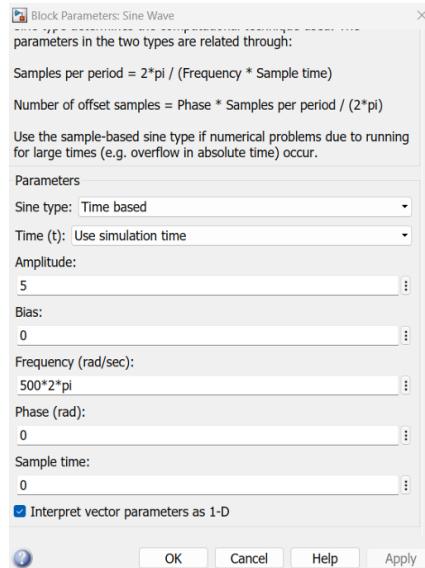


Figure 45: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters:

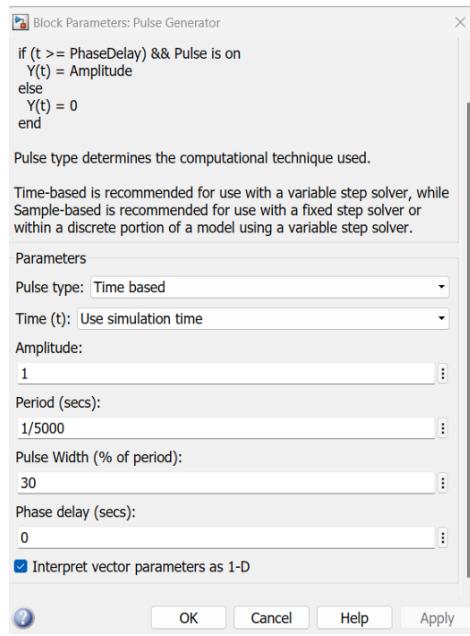


Figure 46: Pulse Train – Pulse generator block parameters

## Representation in time domain:

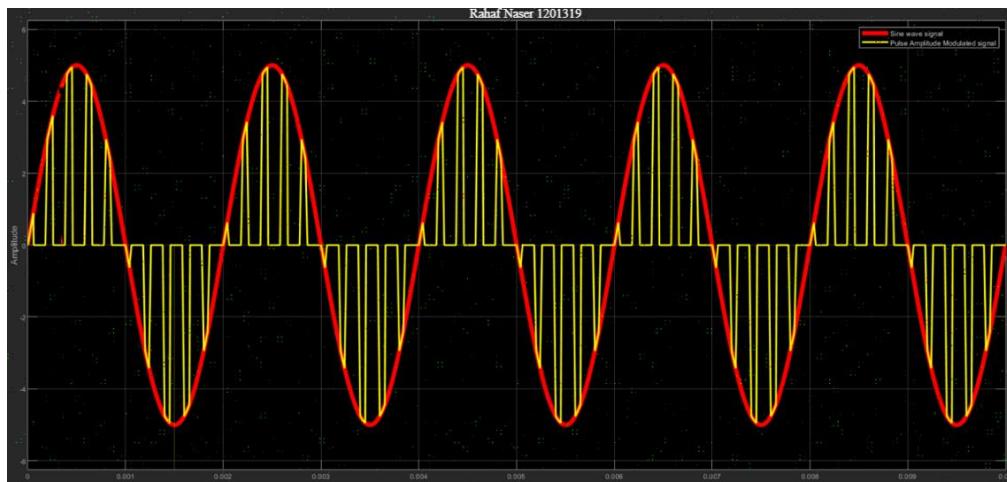


Figure 47: PAM signal vs sine wave signal with pulse train 30% duty cycles and fm = 500Hz

## Representations in frequency domain:

### PAM modulated signal vs Pulse train - spectrum

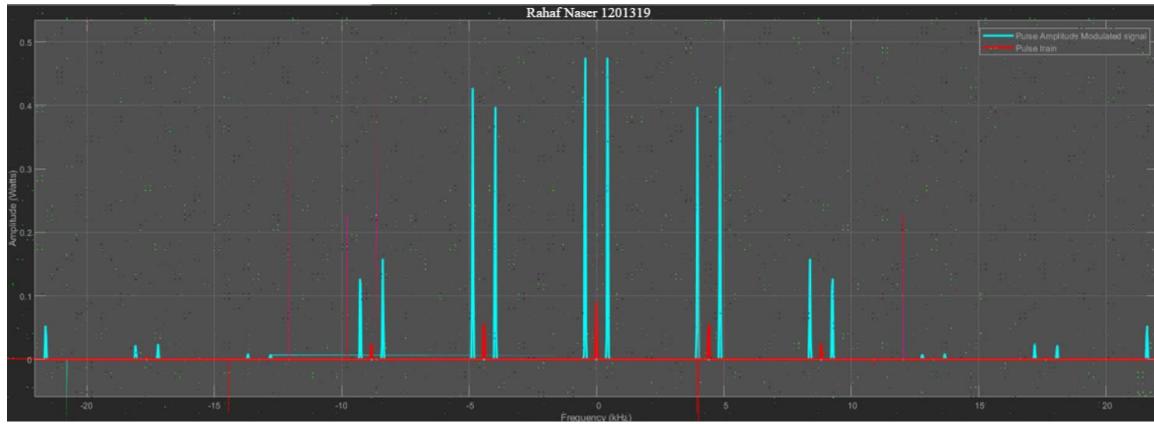


Figure 48: PAM modulated signal vs Pulse train - spectrum

### Pulse train spectrum:

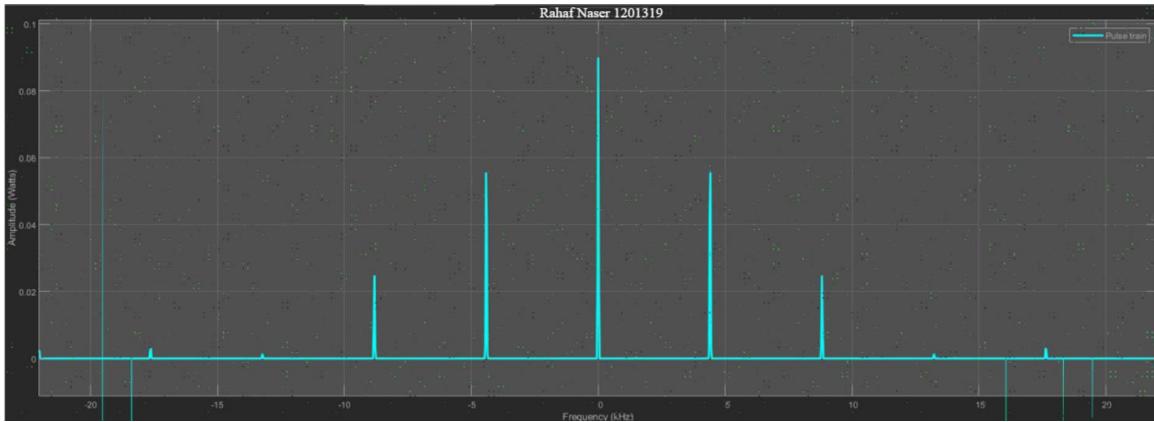


Figure 49: Pulse Train with 30% duty cycles-frequency domain representation

### Sample and Hold (flat topped) Sampling-Simulink

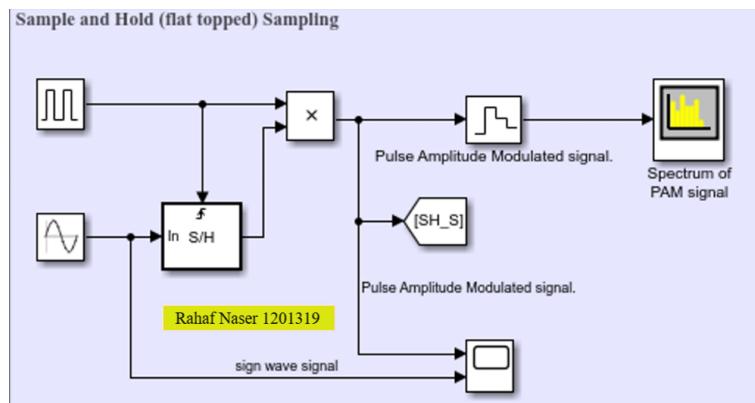


Figure 50: Sample and Hold (flat topped) Sampling-Simulink (PAM2)

## Sine wave signal – sine wave block parameters:

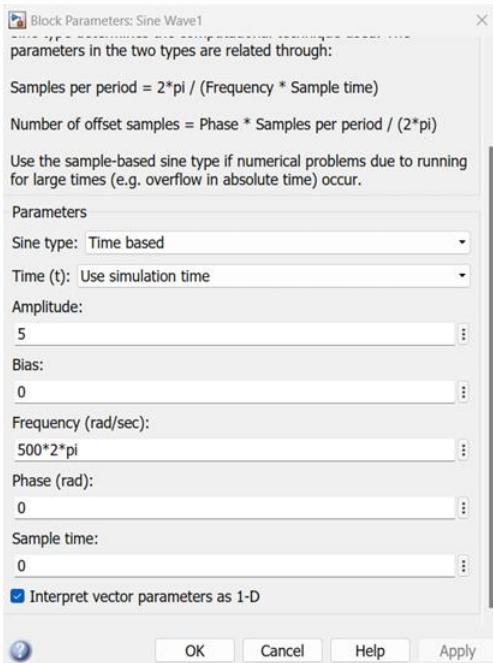


Figure 51: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters:

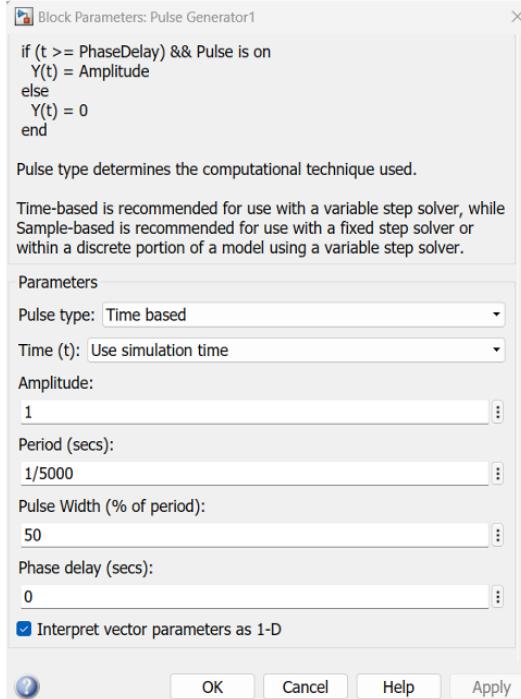


Figure 52: Pulse Train – Pulse generator block parameters

### Zero order Hold block parameters:

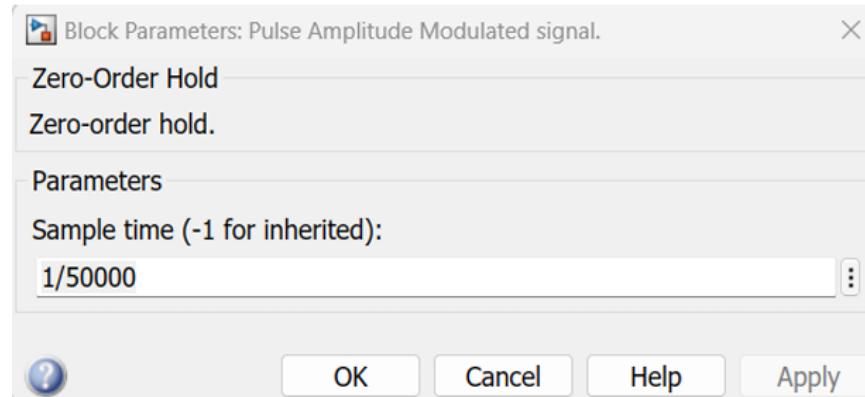


Figure 53: Zero order Hold block parameters

PAM signal with pulse train 50% duty cycles , fm=500:

Pulse Train – Pulse generator block parameters

Representation in time domain:

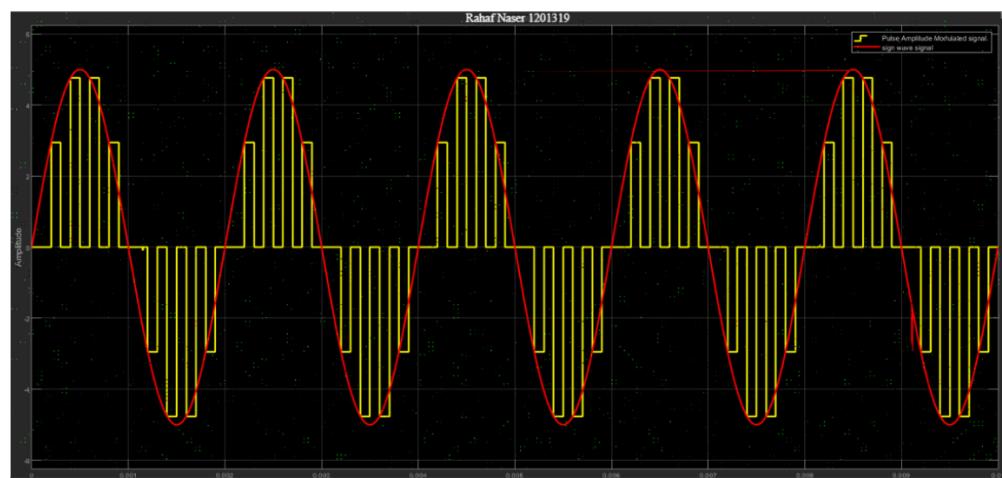


Figure 54: PAM signal vs sine wave signal with pulse train 50% duty cycles

## Representations in frequency domain:

### PAM modulated signal - spectrum

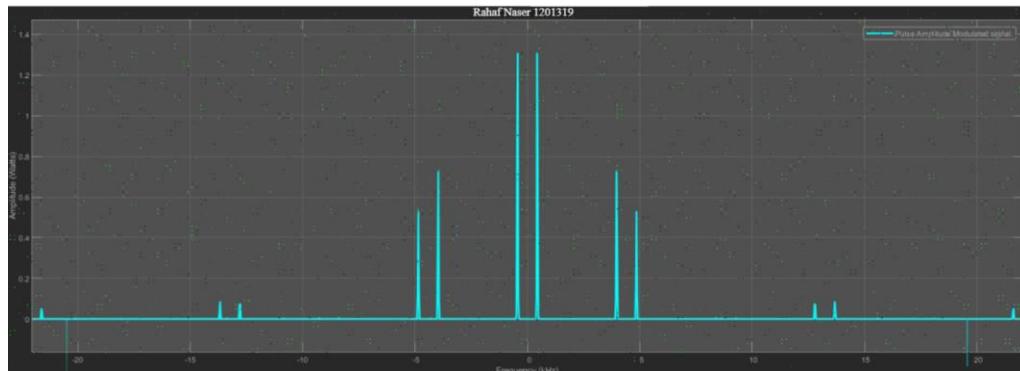


Figure 55: PAM modulated signal - spectrum

### PAM signal with pulse train 50% duty cycles and fm =1000Hz

#### Representation in time domain:

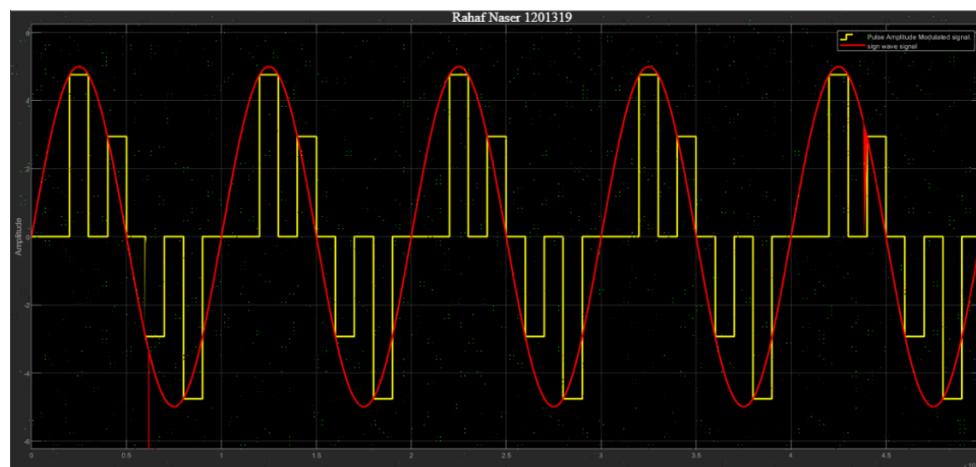


Figure 56: PAM signal vs sine wave signal with pulse train 50% duty cycles, fm=1000

**Representations in frequency domain:**

**PAM modulated signal - spectrum**

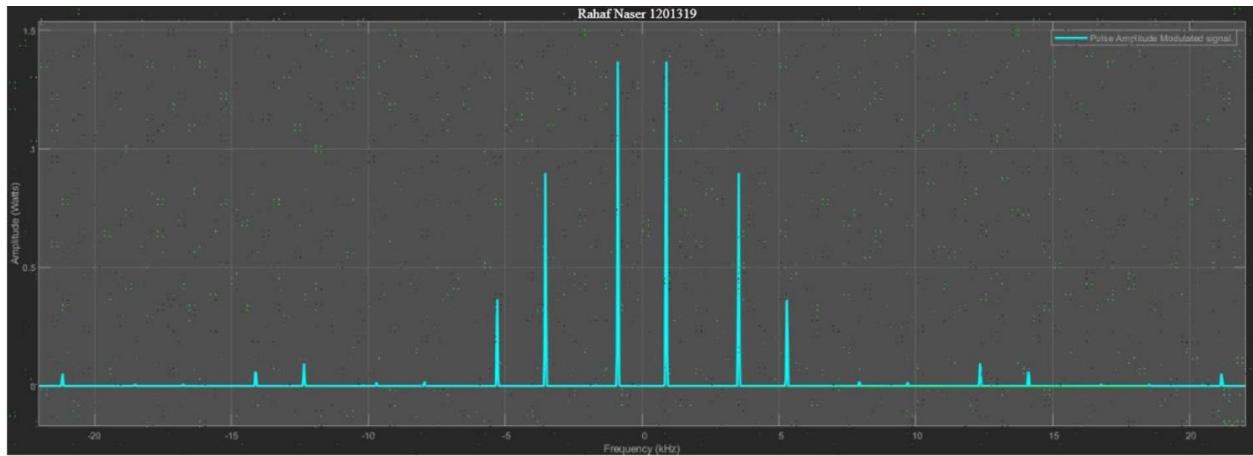


Figure 57: PAM modulated signal - spectrum

**PAM signal with pulse train 50% duty cycles fm = 2000Hz**

**Representation in time domain:**

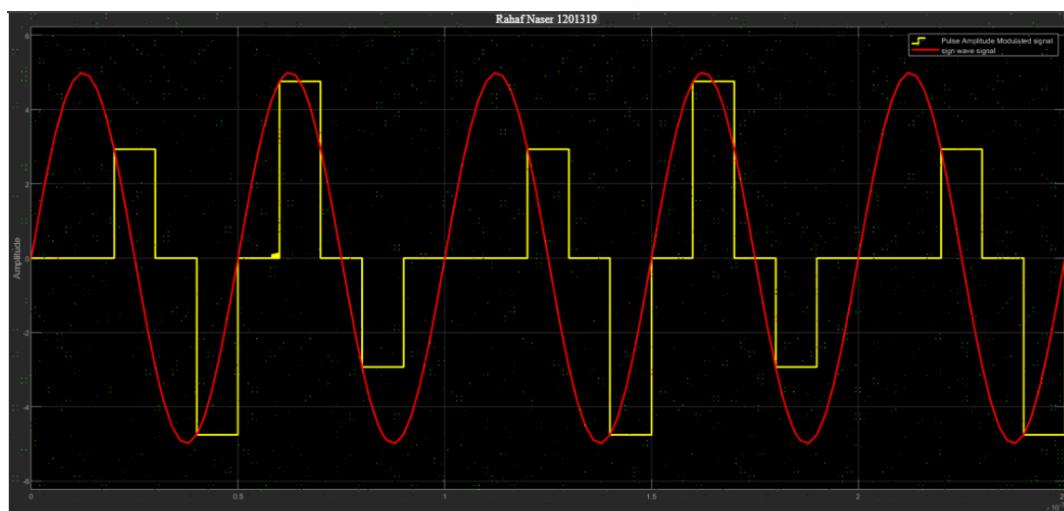


Figure 58: PAM signal vs sine wave signal with pulse train 50% duty cycles and 2000Hz

## Representations in frequency domain:

### PAM modulated signal - spectrum

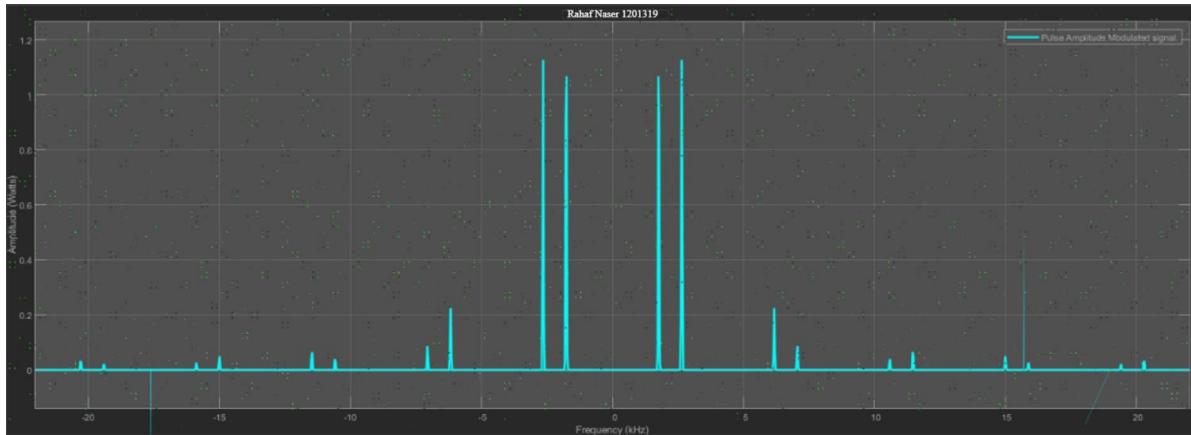


Figure 59: PAM modulated signal - spectrum

### PAM signal with pulse train 10% duty cycles fm =500Hz

#### Representation in time domain:

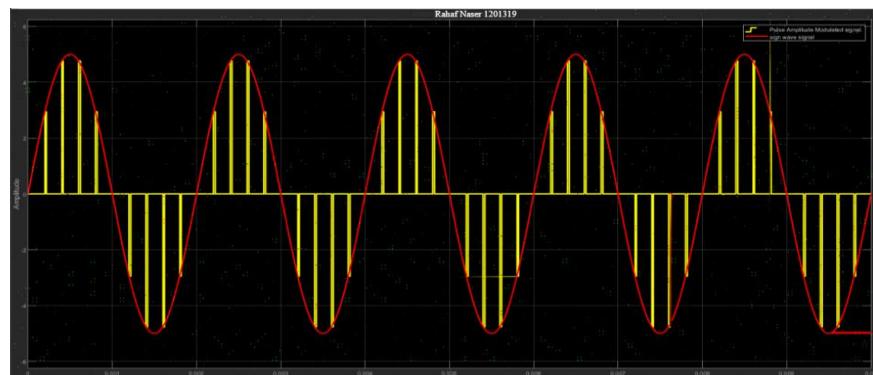


Figure 60: PAM signal vs sine wave signal with pulse train 10% duty cycles and fm=500Hz

## Representations in frequency domain:

### PAM modulated signal - spectrum

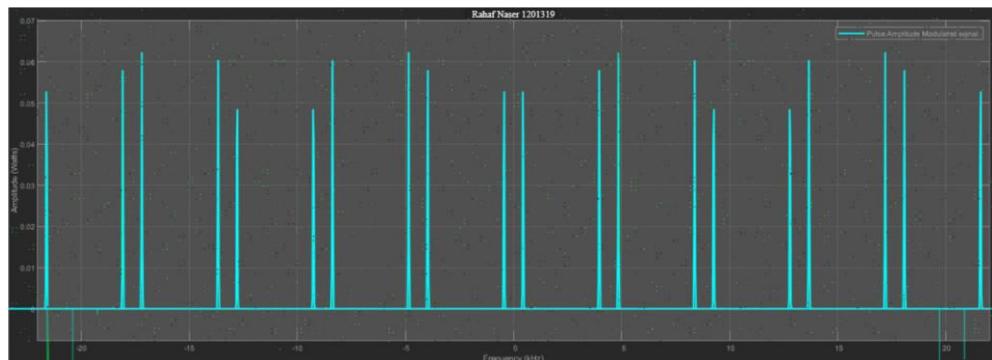


Figure 61: PAM modulated signal - spectrum

## PAM signal with pulse train 30% duty cycles fm =500Hz

Representation in time domain:

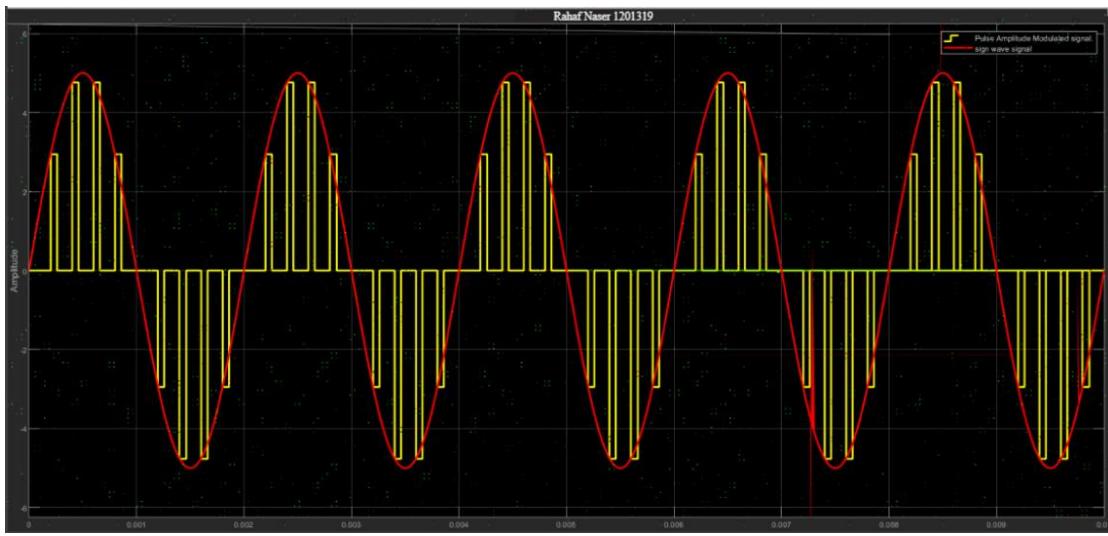


Figure 62: PAM signal vs sine wave signal with pulse train 30% duty cycles and fm=500Hz

Representations in frequency domain:

### PAM modulated signal - spectrum

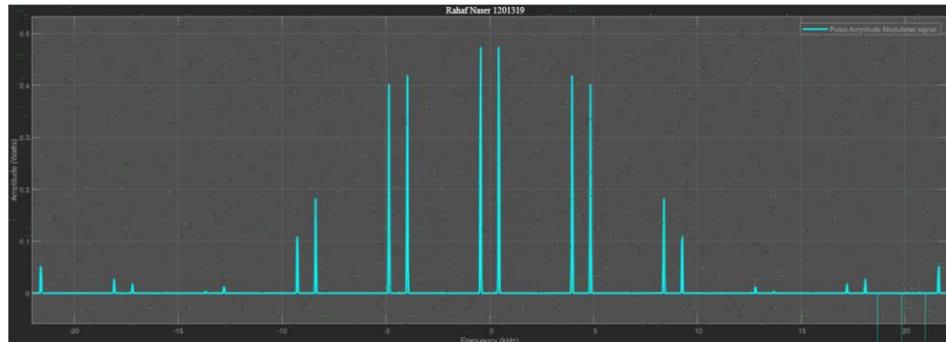


Figure 63: PAM modulated signal - spectrum

**Discussion:** This section examined Pulse Amplitude Modulation (PAM) through natural sampling and flat-top sampling techniques. The PAM process was analyzed by modulating a sine wave signal with a pulse train of varying duty cycles. The modulation results showed that the duty cycle influences the amplitude and shape of the PAM signal. When comparing different message frequencies (500 Hz, 1 kHz, and 2 kHz), it was observed that higher message frequencies lead to more spectral components appearing in the modulated signal, emphasizing the importance of selecting an appropriate sampling frequency. The significance of choosing an optimal duty cycle was also evident, as too low a duty cycle could result in signal distortion, while a higher duty cycle improves signal clarity.

## Part 3: Characteristics of Pulse Amplitude Demodulation

### Part Notes

1. Pulse train with 50% duty cycles
2. Frequency = 500Hz
3.  $V_{ss} = 10 \text{ V}$  so the Amplitude of the signal will be  $10/2 = 5\text{V}$

### Demodulation-Natural Sampling-Simulink:

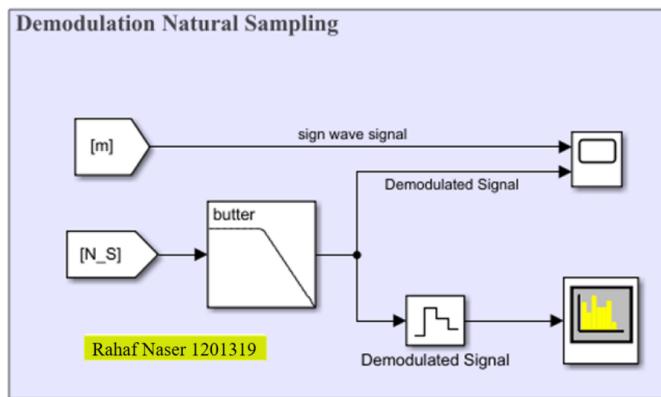


Figure 64: Demodulation-Natural Sampling-Simulink

### Sine wave signal – sign wave block parameters:

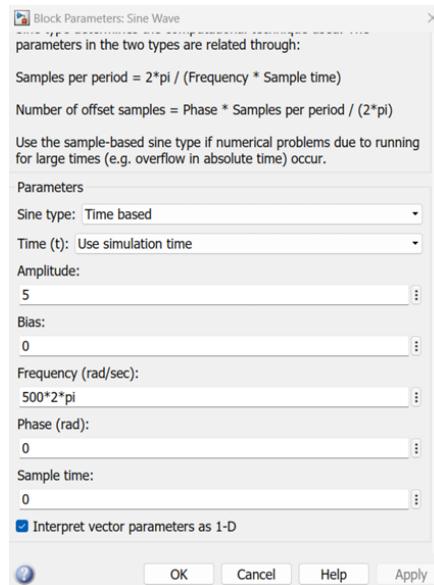


Figure 65: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters:

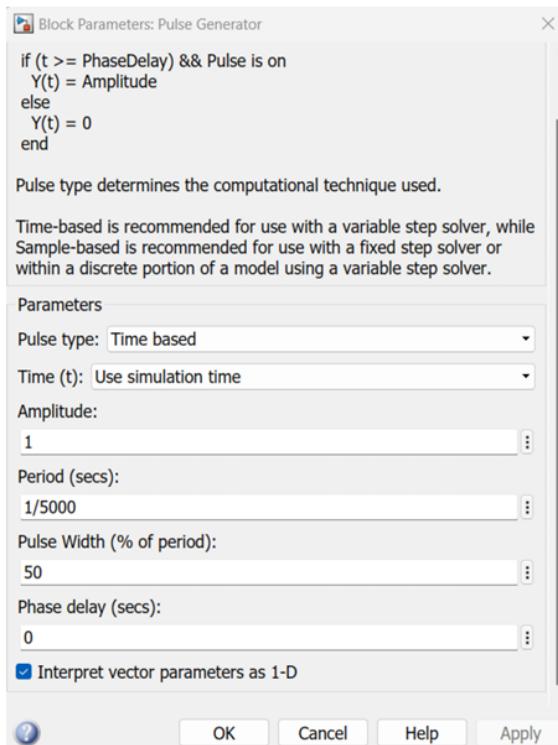


Figure 66: Pulse Train – Pulse generator block parameters

## LPF- Analog Filter Design parameters:

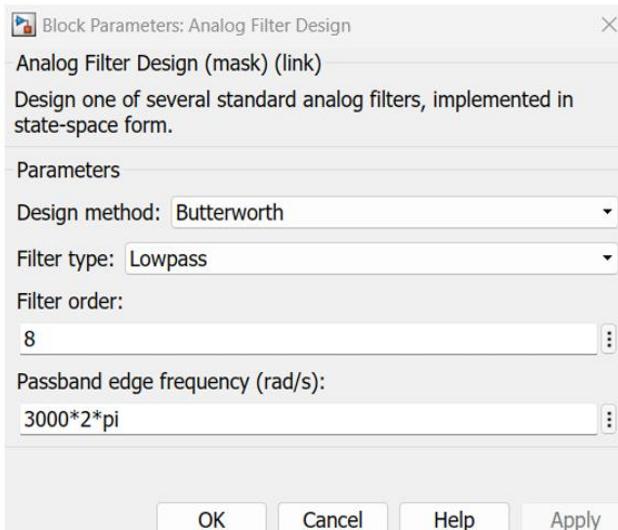


Figure 67: LPF- Analog Filter Design parameters

## Representation in time domain:



Figure 68 : Demodulated signal vs sine wave signal with pulse train 50% duty cycles and fm = 500Hz

## Representations in frequency domain:

### Demodulated signal

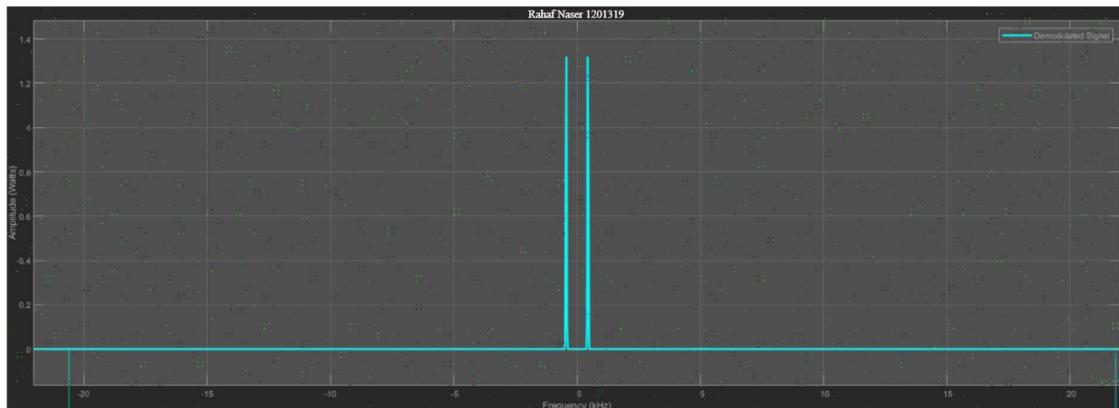


Figure 69: Demodulated signal-spectrum

## Demodulated signal with pulse train 30% duty cycles

### Sine wave signal – sign wave block parameters:

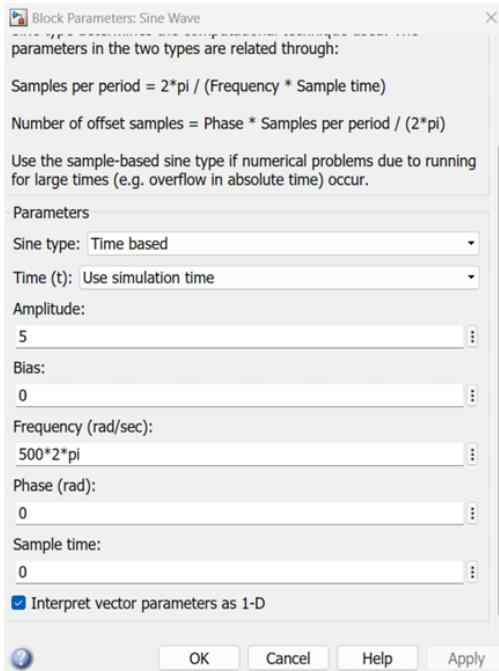


Figure 70: Sine wave signal – sign wave block parameters

### Pulse Train – Pulse generator block parameters:

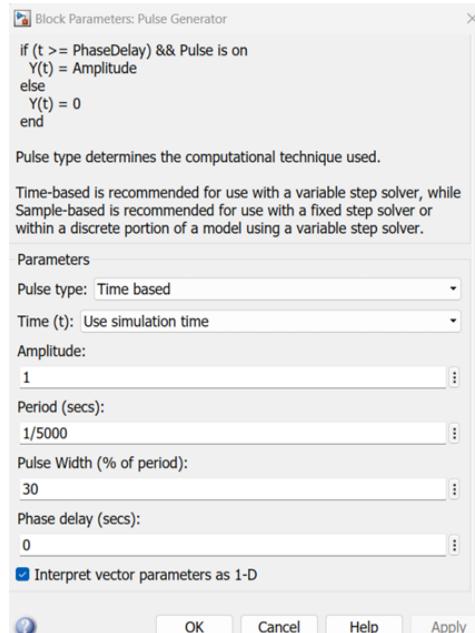


Figure 71: Pulse Train – Pulse generator block parameters

### Representation in time domain:



Figure 72: Demodulated signal vs sine wave signal with pulse train 30% duty cycles and fm = 500Hz

### Representations in frequency domain:

#### Demodulated signal

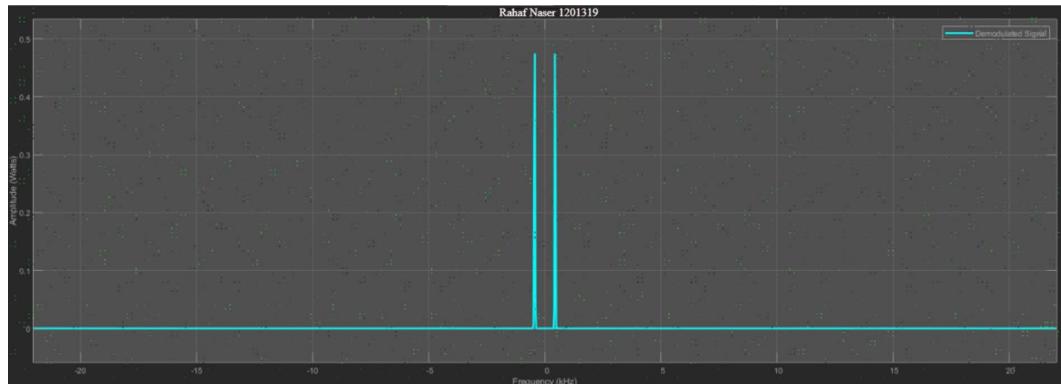


Figure 73: Demodulated signal-spectrum

## Demodulated signal with pulse train 10% duty cycles

### Sine wave signal – sign wave block parameters:

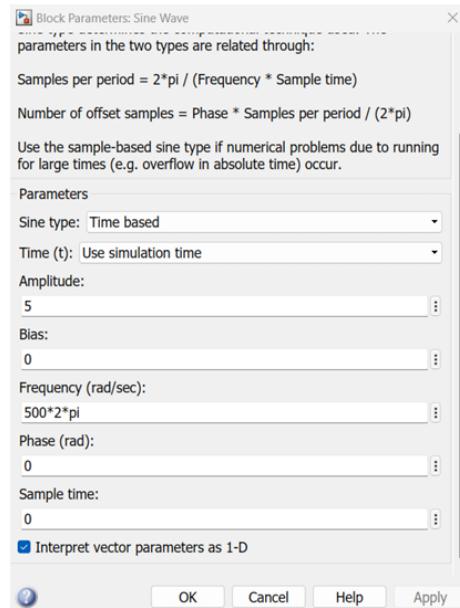


Figure 74: Sine wave signal – sign wave block parameters

### Pulse Train – Pulse generator block parameters:

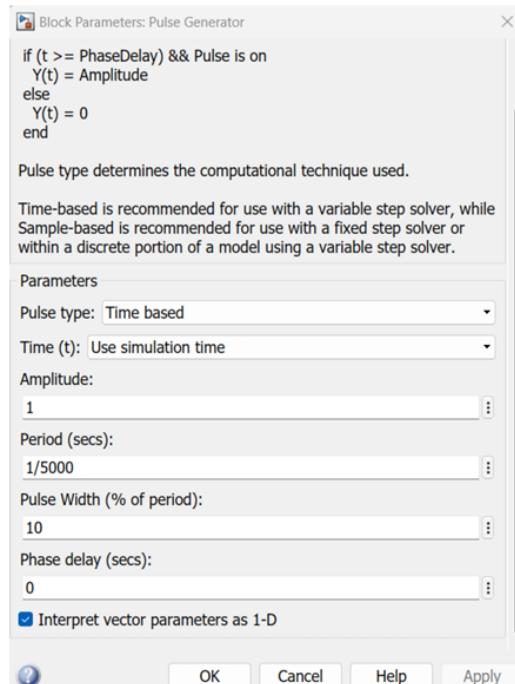


Figure 75: Pulse Train – Pulse generator block parameters

### Representation in time domain:



Figure 76: Demodulated signal vs sine wave signal with pulse train 10% duty cycles and fm = 500Hz

### Representations in frequency domain:

#### Demodulated signal

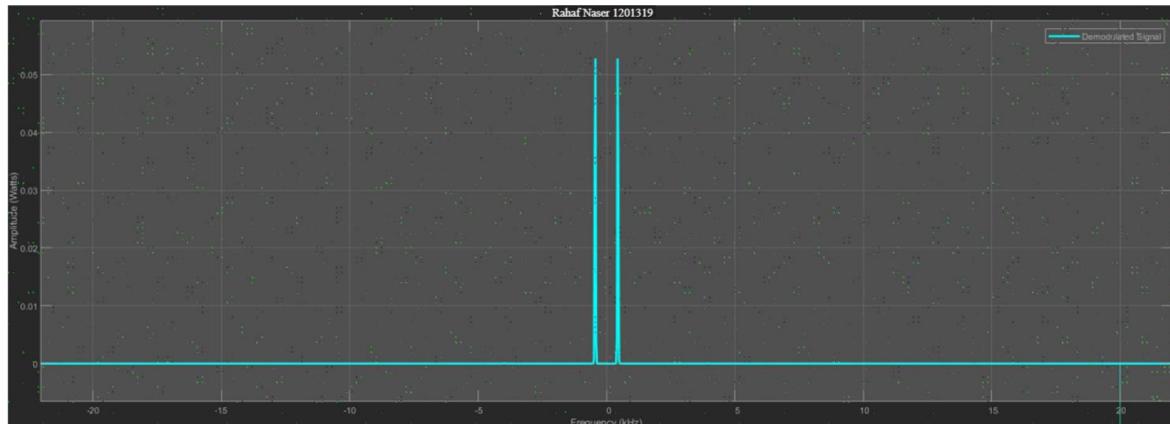


Figure 77: Demodulated signal-spectrum

## Demodulation-flat topped Sampling-Simulink

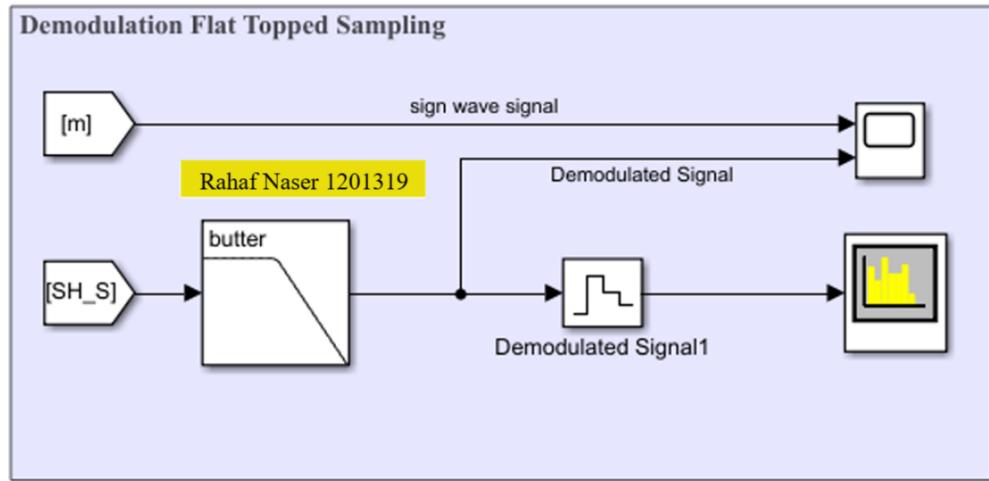


Figure 78: Demodulation-Flat Topped Sampling-Simulink

### Sine wave signal – sign wave block parameters:

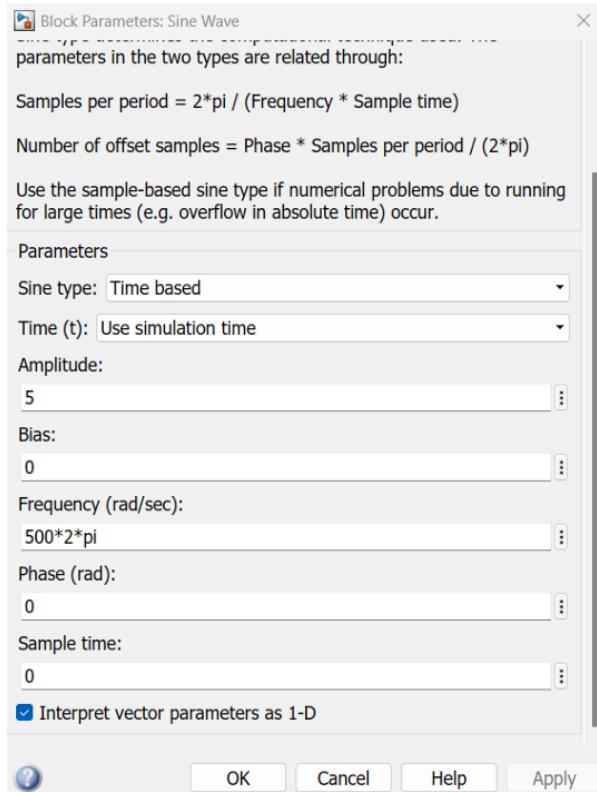


Figure 79: Sine wave signal – sign wave block parameters

## Pulse Train – Pulse generator block parameters:

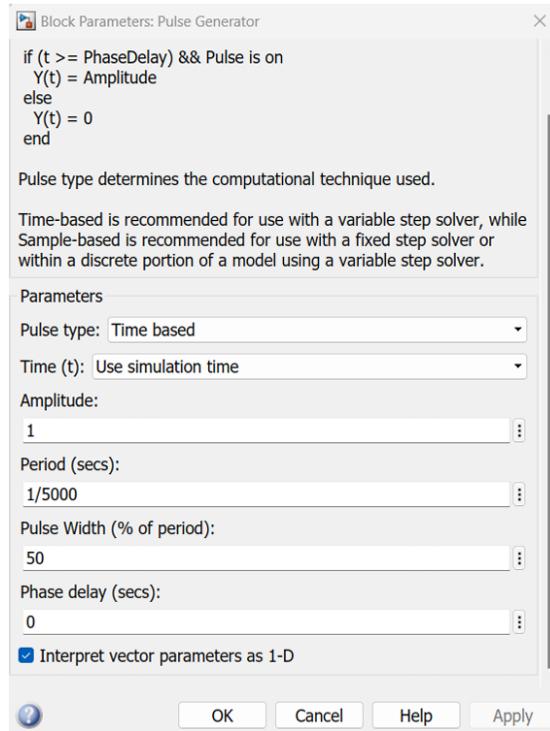


Figure 80: Pulse Train – Pulse generator block parameters

## LPF- Analog Filter Design parameters:

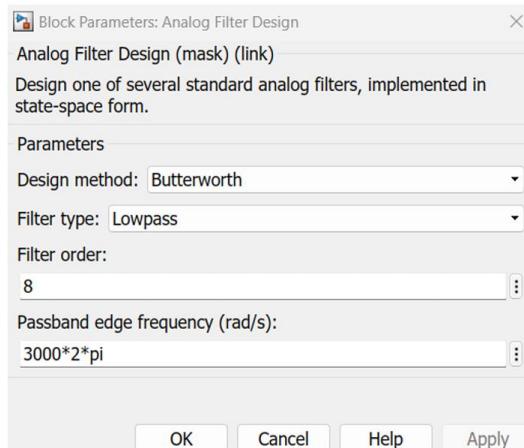


Figure 81: LPF- Analog Filter Design parameters

## Representation in time domain:

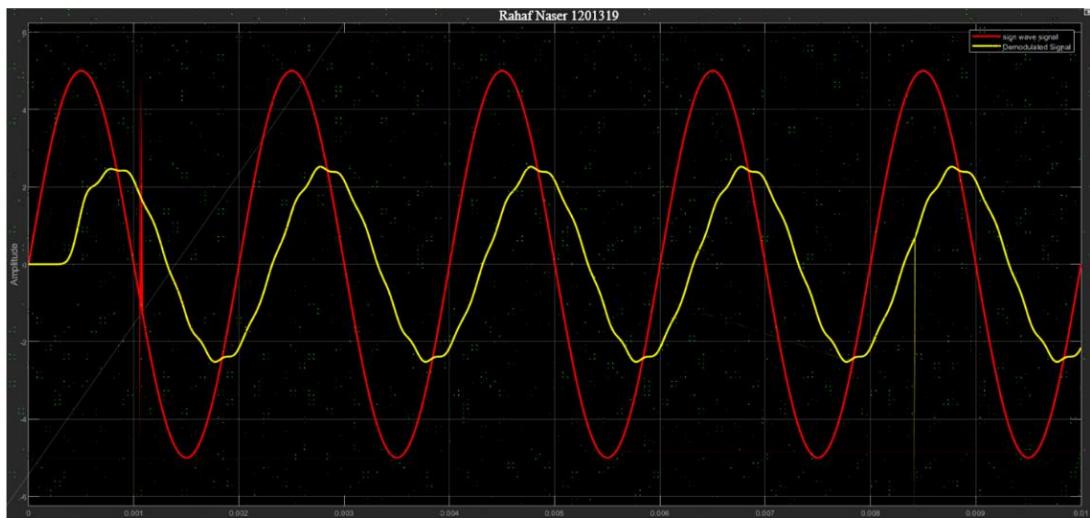


Figure 82: Demodulated signal vs sine wave signal with pulse train 50% duty cycles and  $f_m = 500\text{Hz}$

## Representations in frequency domain:

### Demodulated signal

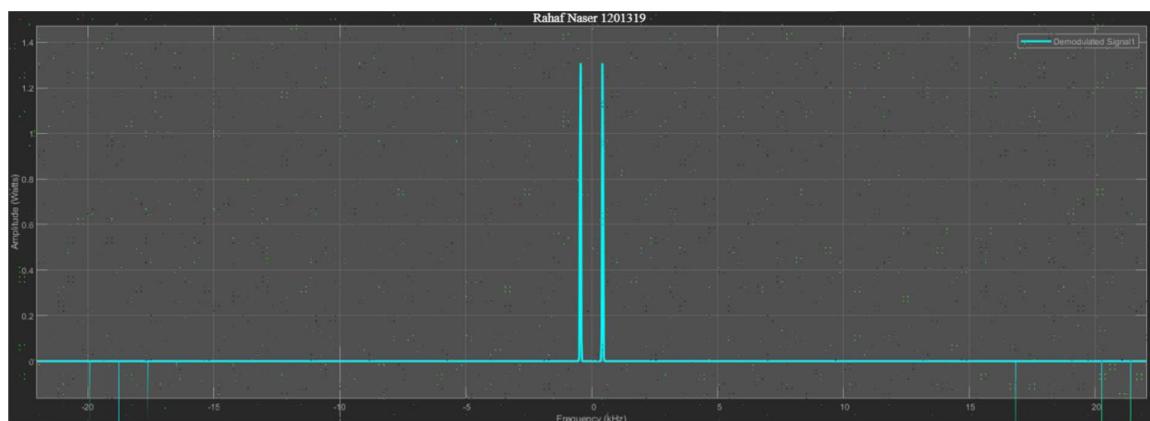


Figure 83: Demodulated signal-spectrum

## Demodulated signal with pulse train 30% duty cycles

Representation in time domain:



Figure 84: Demodulated signal vs sine wave signal with pulse train 30% duty cycles and fm = 500Hz

Representations in frequency domain:

Demodulated signal

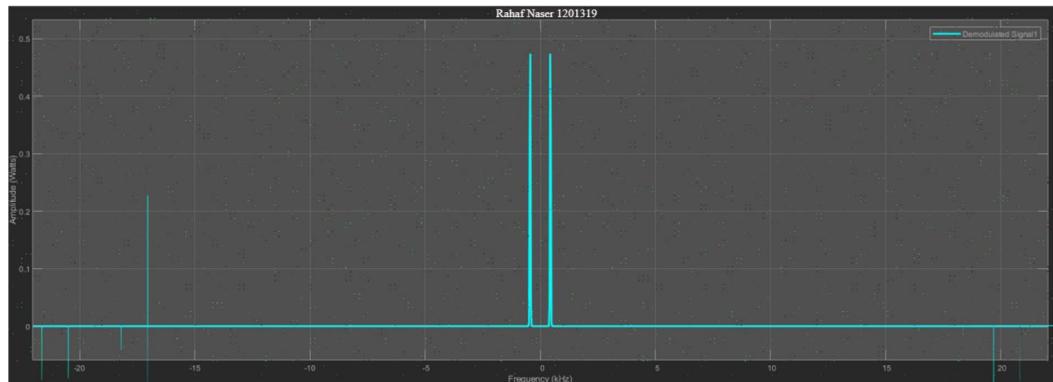


Figure 85: Demodulated signal-spectrum

## Demodulated signal with pulse train 10% duty cycles

Representation in time domain:

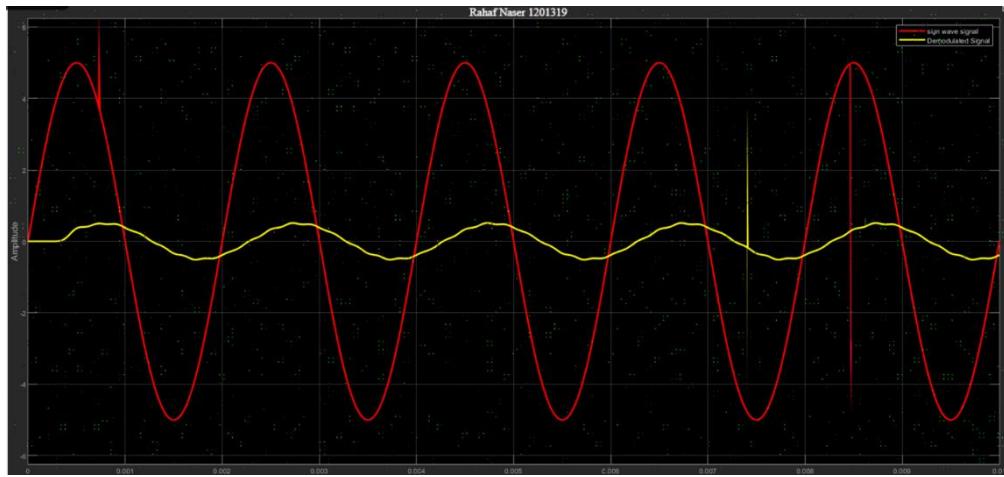


Figure 86: Demodulated signal vs sine wave signal with pulse train 10% duty cycles and fm = 500Hz

Representations in frequency domain:

Demodulated signal

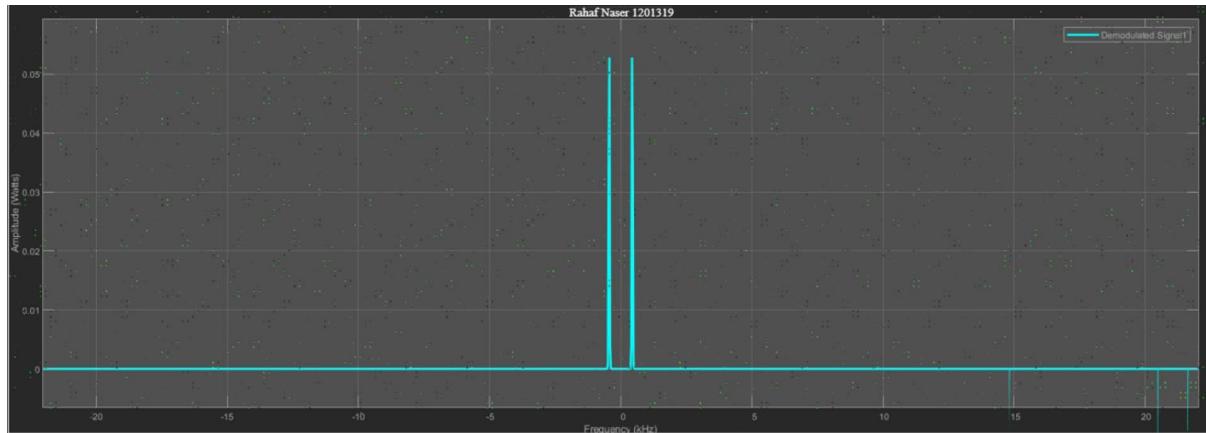


Figure 87: Demodulated signal-spectrum

**Discussion:** The demodulation process was studied using both natural sampling and flat-top sampling techniques. The results demonstrated that an appropriate low-pass filter (LPF) is required to recover the original message signal. The efficiency of demodulation was tested by varying the duty cycle and observing the output signals. It was noted that lower duty cycles resulted in weaker demodulated signals, whereas higher duty cycles provided a more accurate reconstruction of the original signal. The role of the LPF was particularly crucial in eliminating high-frequency components introduced during the modulation process. The findings emphasize the importance of filter design in ensuring high-quality signal recovery in communication systems.

## Part 4: Aliasing in the Time and the Frequency Domains Part Notes

1. Pulse train with 50% duty cycles
2. Sign wave signal (message) Frequency = 3000Hz
3. V<sub>ss</sub> = 5 V so the Amplitude of the signal will be 5/2 = 2.5V

Sine wave signal – sign wave block parameters:

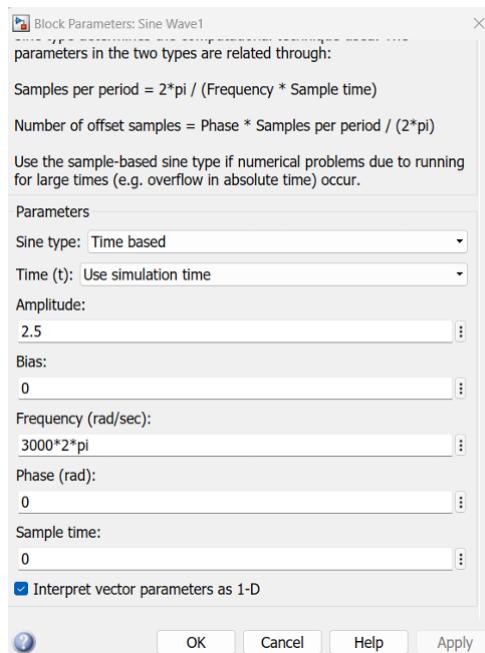


Figure 88: Sine wave signal – sign wave block parameters

## LPF- Analog Filter Design parameters:

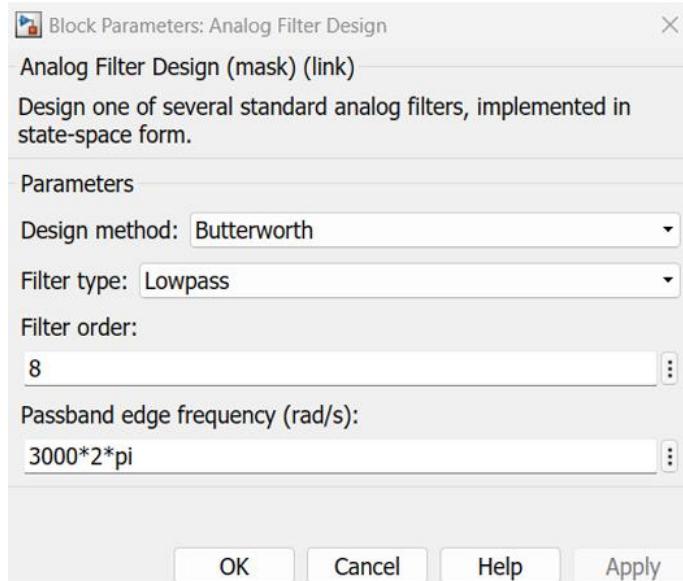


Figure 89: LPF- Analog Filter Design parameters

## Pulse Train – Pulse generator block parameters:

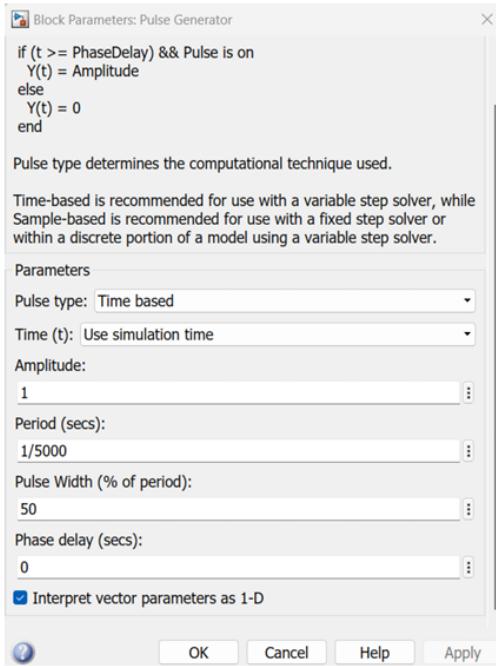


Figure 90: Pulse Train – Pulse generator block parameters

## Natural Sampling

Representation in time domain:



Figure 91: Demodulated signal vs modulated sine wave signal

Representations in frequency domain:

Demodulated signal

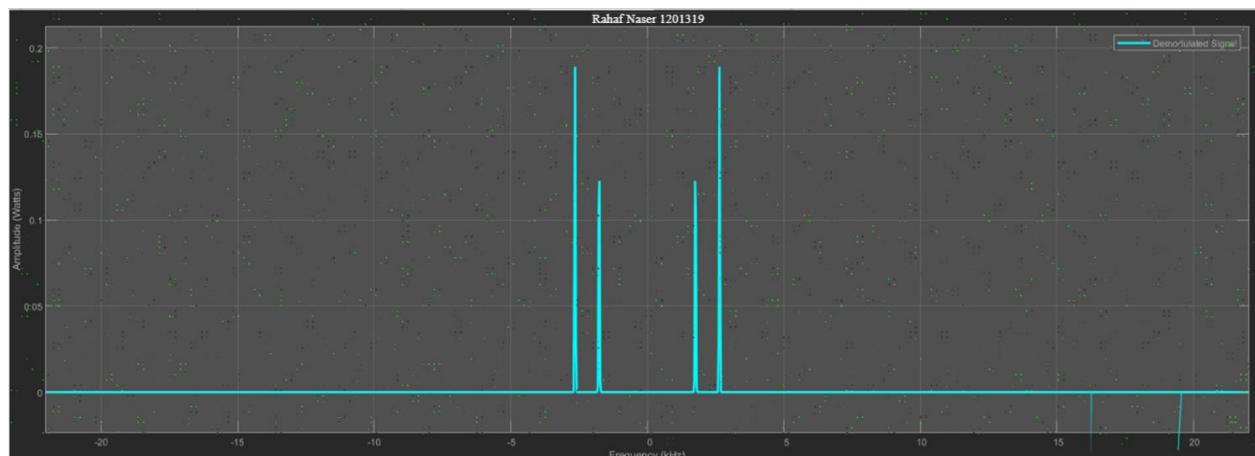


Figure 92: Demodulated signal-spectrum

## Flat topped Sampling

Representation in time domain:



Figure 93: Demodulated signal vs modulated sine wave signal

Representations in frequency domain:

Demodulated signal

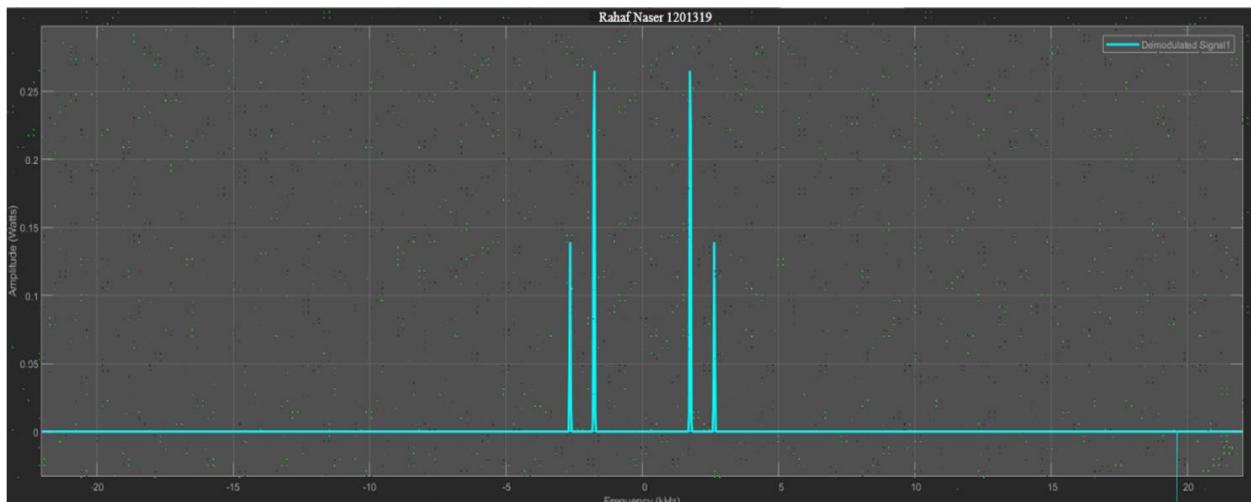


Figure 94: Demodulated signal-spectrum

**Discussion:** This part explored the effects of aliasing when sampling a high-frequency sine wave signal with a pulse train. When the sampling frequency was insufficient relative to the message signal's frequency, aliasing occurred, causing the reconstructed signal to be distorted. The results confirmed the Nyquist sampling theorem, which states that the sampling frequency must be at least twice the highest frequency present in the signal to avoid aliasing. The observations reinforce the importance of proper sampling rate selection in digital signal processing to ensure

accurate signal representation and recovery. The use of anti-aliasing filters before sampling was suggested as a method to mitigate aliasing effects.