GRAPHICAL MODELLING AND PARAMETER COMPARISON OF AM, FM, PAM AND PWM USING PYTHON

PROJECT REPORT

Submitted by

SONA SAJEEV(AB23PHY029)

Under the guidance of

Dr. Frincy Francis
Assistant Professor,
Department of Physics & Centre of Research
St. Teresa's College (Autonomous), Ernakulam.

In partial fulfilment of the requirement of award of Bachelor Degree of science in Physics.

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM
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ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled "**GRAPHICAL MODELLING AND PARAMETER COMPARISON OF AM, FM, PAM AND PWM USING PYTHON**" is an authentic work done by **SONA SAJEEV(AB23PHY029)**, St Teresa's College, Ernakulam, under my supervision at Department of Physics & Centre of Research, St. Teresa's College, Ernakulam, for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2025-26. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

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ST. TERESA'S COLLEGE (AUTONOMOUS)

ERNAKULAM

B.Sc. PHYSICS

PROJECT REPORT

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YEAR OF WORK : **2025-26**

This is to certify that this project work entitled, **"GRAPHICAL MODELLING AND PARAMETER COMPARISON OF AM, FM, PAM AND PWM USING PYTHON"** is an authentic work done by **SONA SAJEEV .**

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DATE: 16. 04. 26

EXAMINER:

ATHIRA PRAKASH.

DECLARATION

I SONA SAJEEV final B.Sc. Physics student, Department of Physics & Centre of Research, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project work entitled **"GRAPHICAL MODELLING AND PARAMETER COMPARISON OF AM,FM,PAM AND PWM USING PYTHON"** has been originally carried out under the guidance and supervision of **Dr.FRINCY FRANCIS**, Assistant Professor, Department of Physics & Centre of Research, St. Teresa's College (Autonomous), Ernakulam, in partial fulfilment for the award of the Degree of Bachelor of Physics. I further declare that this project is not partially or wholly submitted for any other purpose and the data included in the project is collected from various sources and is true to the best of my knowledge.

PLACE: Ernakulam SONA SAJEEV

DATE:

ACKNOWLEDGEMENT

I first thank GOD, the Almighty, for giving us immense strength to make this project happen. I would like to extend our heartfelt gratitude to **Dr.FRINCY FRANCIS**, Assistant Professor, Department of Physics and Centre of Research, St. Teresa's College (Autonomous), Ernakulam for her invaluable guidance, encouragement and more that her tireless efforts that pushed us through this project. Her valuable contributions have been instrumental in shaping the success of this project and achieving our goals.

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I would like to express my profound gratitude to my parents, friends and well-wishers whose support made this project come true.

GRAPHICAL MODELLING AND PARAMETER COMPARISON OF AM, FM, PAM AND PWM USING PYTHON

ABSTRACT

This project presents a Python-based simulation and graphical analysis of four major modulation techniques: Amplitude Modulation (AM), Frequency Modulation (FM), Pulse Amplitude Modulation (PAM), and Pulse Width Modulation (PWM). The study focuses on generating time-domain waveforms and analyzing how variations in key parameters such as amplitude, frequency, and pulse width affect the modulated signals. By systematically changing these parameters, the resulting changes in waveform shape and signal behavior are observed and compared. The project provides a clear visual understanding of modulation principles through computational methods, combining communication theory with practical programming for effective signal analysis.

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CHAPTER 1

INTRODUCTION

1.1 MODULATION

Modulation is the process of changing a high-frequency carrier wave in order to transmit a low-frequency message signal over a long distance. The original information signal, such as voice or music, has low frequency and cannot travel far by itself. Therefore, it is combined with a high-frequency carrier wave that can travel long distances through space. In modulation, one of the properties of the carrier wave—amplitude, frequency, or phase—is varied according to the message signal. This allows the information to be carried efficiently from the transmitter to the receiver. Without modulation, long-distance communication like radio, television, and mobile communication would not be possible.

1.2 DIFFERENT TYPES OF MODULATION

Modulation is classified into three main types: analog modulation, pulse modulation, and digital modulation. In analog modulation, a continuous high-frequency carrier wave is modified according to the message signal, and it includes Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Modulation (PM), where the amplitude, frequency, or phase of the carrier is varied respectively. In pulse modulation, the message signal is transmitted using pulses instead of a continuous wave, and it includes Pulse Amplitude Modulation (PAM), Pulse Width Modulation (PWM), and Pulse Position Modulation (PPM), where the amplitude, width, or position of pulses is changed according to the signal.

In digital modulation, digital data is transmitted by modifying a carrier wave, and common types include Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK). These different types of modulation are used in various communication systems depending on the requirement and application.

1.3 WHY WE PREFER AM, FM, PWM AND PAM?

We prefer AM, FM, PAM, and PWM in our project because they are simple, fundamental, and easy to generate and compare using Python. These modulation techniques clearly show how different parameters of a carrier signal change with respect to the message signal. In AM, we can vary the amplitude and observe how the waveform changes. In FM, we can vary the frequency and study the effect on the signal pattern. In PAM, we can change the amplitude of pulses and compare how the sampled signal looks. In PWM, we can vary the pulse width and observe the difference in duty cycle. These changes are clearly visible in graphical plots, which makes comparison easier. Using Python, we can easily adjust parameters like modulation index, frequency, and pulse width and immediately see the output graphs. This helps us understand the theoretical concepts practically. Therefore, AM, FM, PAM, and PWM are preferred because they are easy to implement, analyze, and visually compare in a project.

1.4 ADVANTAGES OF MODULATION

Modulation has many important advantages in communication systems. First, it allows signals to travel long distances because low-frequency message signals cannot travel far on their own. By converting them into high-frequency carrier waves, the transmission becomes efficient. Second, modulation reduces the size of the antenna required for transmission, since antenna height is inversely proportional to frequency; higher frequency signals require smaller antennas. Third, modulation prevents mixing of different signals, allowing multiple signals to be transmitted simultaneously without interference (multiplexing). Fourth, it improves the quality of transmission by reducing noise and distortion, especially in methods like FM. Fifth, modulation enables efficient use of bandwidth and spectrum allocation. Finally, it makes wireless communication possible, which is essential for radio, television, mobile phones, and satellite communication.

1.5 WHAT ARE WE STUDYING THROUGH THIS PROJECT?

In this project, we are studying the fundamental concepts of modulation and how different modulation techniques affect signal transmission. We analyze how a low-frequency message signal is combined with a high-frequency carrier wave using methods such as AM, FM, PAM, and PWM. By generating and comparing graphs using Python, we study how changing parameters like amplitude, frequency and pulse width alters the waveform. This helps us understand the practical behavior of signals beyond theoretical formulas. We also observe differences in waveform shape, bandwidth effect, and signal characteristics for each type of modulation. The project strengthens our understanding of analog and pulse modulation techniques. It connects communication theory with computational simulation. Overall, we are studying how modulation works, how parameters influence signal behavior, and how graphical analysis helps in understanding communication systems.

REFERENCE

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2. Simon Haykin, Communication Systems, Wiley.
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4. Communication Systems, Oxford University Press.
5. NCERT Physics Class 12, Chapter: Communication Systems.
6. Python simulation work performed for AM, FM, PAM, and PWM waveform analysis.

CHAPTER 2

TYPES OF MODULATIONS

2.1 AMPLITUDE MODULATION (AM)

Amplitude Modulation is a type of analog modulation in which the height (amplitude) of a high-frequency carrier wave is changed according to the message signal, such as voice or music. The frequency of the carrier remains constant, but its amplitude increases and decreases depending on the strength of the message signal. When the message signal is strong, the carrier amplitude becomes large; when it is weak, the carrier amplitude becomes small.

AM is one of the earliest and simplest modulation techniques. It is easy to generate and detect, which makes the transmitter and receiver circuits simple and inexpensive. However, AM has some disadvantages. It is highly affected by noise because noise mainly changes amplitude, and in AM the information is stored in amplitude. It also has low power efficiency since much of the transmitted power is carried by the carrier instead of the actual information. AM is mainly used in medium-wave radio broadcasting and aviation communication.

2.2 FREQUENCY MODULATION (FM)

Frequency Modulation is another type of analog modulation in which the frequency of the carrier wave is varied according to the message signal, while the amplitude remains constant. When the message signal changes, the carrier frequency slightly increases or decreases around its original value.

The major advantage of FM is its strong resistance to noise. Since noise mostly affects amplitude and FM keeps amplitude constant, the signal quality is much better than AM. This is why FM radio provides clearer and higher-quality sound. However, FM requires a wider bandwidth and slightly more complex circuits compared to AM. FM is widely used in radio broadcasting, television sound transmission, and two-way communication systems.

2.3 PULSE AMPLITUDE MODULATION (PAM)

Pulse Amplitude Modulation is a type of pulse modulation. In this method, the continuous message signal is sampled at regular time intervals, and the amplitude of each pulse is made proportional to the message signal at that instant. The width and position of the pulses remain constant, but their heights change according to the signal.

PAM is important because it is a basic step in digital communication systems. It is simple to generate and helps in converting analog signals into digital form. However, since information is stored in amplitude, it is still sensitive to noise. PAM is used in telephone communication systems and as a preliminary stage in advanced digital modulation techniques.

2.4 PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation is also a type of pulse modulation, but in this method, the width (duration) of each pulse is varied according to the message signal, while the amplitude of the pulses remains constant. If the message signal is strong, the pulse becomes wider; if it is weak, the pulse becomes narrower.

PWM has better noise immunity compared to PAM because the information is stored in pulse width instead of amplitude. It is also very efficient in controlling power. For this reason, PWM is widely used in motor speed control, LED brightness control, power electronics, and switching regulators. Although the circuit design is slightly more complex than PAM, PWM is very efficient and practical in many real-life applications.

CHAPTER 3

1. PYTHON PROGRAM FOR AMPLITUDE MODULATION (AM)

PROGRAM:

```
import numpy as np

import matplotlib.pyplot as plt


# --- Parameters ---

Am = 1       # Amplitude of message signal

fm = 5       # Frequency of message signal (Hz)

Ac = 2.0     # Amplitude of carrier signal (Note: Ac > Am for proper
modulation)

fc = 100     # Frequency of carrier signal (Hz)

Ka = 0.5     # Amplitude sensitivity (modulation index should be <= 1,
here Ka*Am/Ac <= 1)

Fs = 10000   # Sampling frequency (Hz)

t_stop = 0.5   # Duration of the signal (seconds)


# --- Time vector ---

t = np.arange(0, t_stop, 1/Fs) # Time array

# --- Signal Generation ---
```

```
# Message signal m(t)
mt = Am * np.cos(2 * np.pi * fm * t)

# Carrier signal c(t)
ct = Ac * np.cos(2 * np.pi * fc * t)

# AM Modulated signal s(t) = Ac * [1 + Ka * m(t)/Ac] * cos(2*pi*fc*t)
# Or in a simpler form used below: s(t) = (Ac + Ka * mt) * cos(2*pi*fc*t)
# Make sure (Ac + Ka * mt) is always positive to avoid over-modulation
(which distorts the signal)
st = (Ac + Ka * mt) * np.cos(2 * np.pi * fc * t)

# Envelope of the AM signal
envelope = Ac + Ka * mt

# --- Plotting ---
plt.figure(figsize=(15, 8))

# Plot Message Signal
plt.subplot(3, 1, 1)
plt.plot(t, mt, 'b')
```

```
plt.title('Message Signal m(t)')
plt.xlabel('Time (s)')
plt.ylabel('Amplitude')
plt.grid(True)

# Plot Carrier Signal
plt.subplot(3, 1, 2)
plt.plot(t, ct, 'k')
plt.title('Carrier Signal c(t)')
plt.xlabel('Time (s)')
plt.ylabel('Amplitude')
plt.grid(True)

# Plot AM Signal with Envelope
plt.subplot(3, 1, 3)
plt.plot(t, st, 'r', label='AM Signal s(t)')
plt.plot(t, envelope, ':b', label='Envelope', alpha=0.7) # Plotting the
envelope
plt.plot(t, -envelope, ':b', alpha=0.7) # Plotting the negative envelope
plt.title('Amplitude Modulated Signal s(t)')
plt.xlabel('Time (s)')
```

```
plt.ylabel('Amplitude')
plt.grid(True)
plt.legend()

plt.tight_layout() # Adjusts subplot params so that the subplot(s) fits in to the figure area
plt.show()
```

2. PYTHON PROGRAM FOR FREQUENCY MODULATION (FM)

PROGRAM:

```
import numpy as np
import matplotlib.pyplot as plt

# Parameters
fs = 50000                # High sampling frequency for 3kHz
t = np.arange(0, 0.05, 1/fs) # Duration set to 0.05s to see waves clearly

f_m = 100                 #Message signal frequency
f_c = 5000                # Fixed high carrier frequency
modulation_index = 5      # Beta
```

```
# Signals
message = np.sin(2 * np.pi * f_m * t)
carrier = np.sin(2 * np.pi * f_c * t)
fm_signal = np.sin(2 * np.pi * f_c * t + modulation_index * np.sin(2 *
np.pi * f_m * t))


# Plotting
plt.figure(figsize=(10, 8))


# Message Signal
plt.subplot(3, 1, 1)
plt.plot(t, message, 'g')
plt.title('Message Signal')
plt.grid(True)
plt.xlim(0, 0.01) # Adjust this to 0.005 or 0.002 for higher frequencies


# Carrier Signal
plt.subplot(3, 1, 2)
plt.plot(t, carrier, 'r')
plt.title('Carrier Signal')
plt.grid(True)
```

```
plt.xlim(0, 0.01)


# FM Signal
plt.subplot(3, 1, 3)
plt.plot(t, fm_signal, 'b')
plt.title('Frequency Modulated Signal')
plt.xlabel('Time (s)')
# Adjust xlim here to match the message plot
plt.xlim(0, 0.01)
plt.grid(True)


plt.tight_layout()
plt.show()
```

3. PYTHON PROGRAM FOR PULSE AMPLITUDE MODULATION (PAM)

PROGRAM:

```
import numpy as np
import matplotlib.pyplot as plt
from scipy import signal
```

```
# --- Parameters (Adjust these based on the specific page you want to
replicate) ---
fs = 1000 # Sampling frequency for the simulation (high for smooth
curves)
t = np.arange(0, 1.0, 1/fs)  # Time vector from 0 to 1 second


fm = 4      # Message signal frequency (4Hz across all pages)
amp = 0.5   # Message amplitude (Page 1: 0.5, Page 2: 1.5, Page 3/4:
1.0)
pf = 1000     # Pulse frequency (Page 1/2: 20Hz, Page 3: 10Hz, Page 4:
40Hz)
duty = 0.2 # Duty cycle of the pulse train (approximate width of pulses)


# 1. Generate Original Message Signal
# Equation: Message = Amp * sin(2 * pi * fm * t)
message = amp * np.sin(2 * np.pi * fm * t)


# 2. Generate Pulse Train (Carrier Signal)
# Using scipy's square wave function to create a pulse train from 0 to 1
pulse_train = (signal.square(2 * np.pi * pf * t, duty=duty) + 1) / 2


# 3. Generate PAM Modulated Signal
```

```
# Natural Sampling: The message is multiplied by the pulse train
pam_signal = message * pulse_train

# --- Plotting ---
plt.figure(figsize=(12, 10))

# Subplot 1: Original Message
plt.subplot(3, 1, 1)
plt.plot(t, message, color='steelblue')
plt.title(f'Original Message Signal (fm={fm}Hz, Amp={amp})')
plt.ylabel('Amplitude')
plt.grid(True)

# Subplot 2: Pulse Train
plt.subplot(3, 1, 2)
plt.plot(t, pulse_train, color='steelblue')
plt.title(f'Pulse Train (Carrier Signal) (pf={pf}Hz)')
plt.ylabel('Amplitude')
plt.ylim(-0.1, 1.1)
plt.grid(True)
```

```
# Subplot 3: PAM Modulated Signal
plt.subplot(3, 1, 3)
plt.plot(t, pam_signal, color='teal', linewidth=1)
# To match the "Sampled Message" red dots in your images:
# We find the peaks of the pulses to place the red dots
sample_indices = np.where(np.diff(pulse_train) > 0.5)[0]
plt.scatter(t[sample_indices], message[sample_indices], color='red',
s=20, label='Sampled Message', zorder=3)
# Vertical lines to show the sampling effect
plt.vlines(t[sample_indices], 0, message[sample_indices], colors='red',
alpha=0.5)


plt.title(f'PAM Modulated Signal')
plt.xlabel('Time (s)')
plt.ylabel('Amplitude')
plt.legend(loc='upper right')
plt.grid(True)


plt.tight_layout()
plt.show()
```

4. PYTHON PROGRAM FOR PULSE WIDTH MODULATION (PWM)

PROGRAM:

```
import numpy as np

import matplotlib.pyplot as plt


# 1. Parameters

fs = 10000          # Sampling frequency

t = np.arange(0, 0.1, 1/fs)


fm = 50            # Message frequency (e.g., the intensity level)

fc = 1000           # PWM Switching frequency (Carrier)

Am = 0.5            # Message amplitude (0 to 1)


# 2. Signals

# Message signal: The reference we want to represent via PWM

message = Am * np.sin(2 * np.pi * fm * t)


# Sawtooth Carrier: Used to determine the switching points

# This creates a ramp from -1 to 1 at frequency fc

from scipy import signal
```

```
carrier = signal.sawtooth(2 * np.pi * fc * t)

# 3. PWM Logic
# If Message > Carrier, the pulse is HIGH (1), else LOW (0)
pwm = np.where(message > carrier, 1.0, 0.0)

# 4. Visualization
plt.figure(figsize=(12, 8))

# Message and Carrier Overlap
plt.subplot(2, 1, 1)
plt.plot(t, message, 'r', label='Message (Reference)', linewidth=2)
plt.plot(t, carrier, 'k--', label='Sawtooth Carrier', alpha=0.5)
plt.title('PWM Generation: Message vs. Carrier')
plt.legend()
plt.grid(True)

# Resulting PWM Signal
plt.subplot(2, 1, 2)
plt.step(t, pwm, 'b', where='post')
plt.title('Resulting Pulse Width Modulated Signal')
```

```
plt.ylim(-0.2, 1.2)
plt.xlabel('Time (s)')
plt.grid(True)

plt.tight_layout()
plt.show()
```

CHAPTER 4

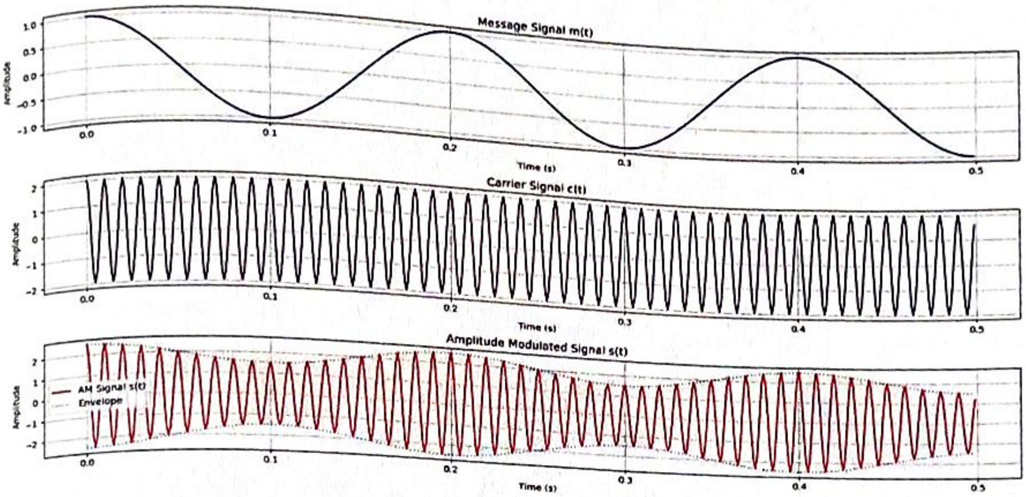
PROGRAM OUTPUT

1. AMPLITUDE MODULATION (AM)

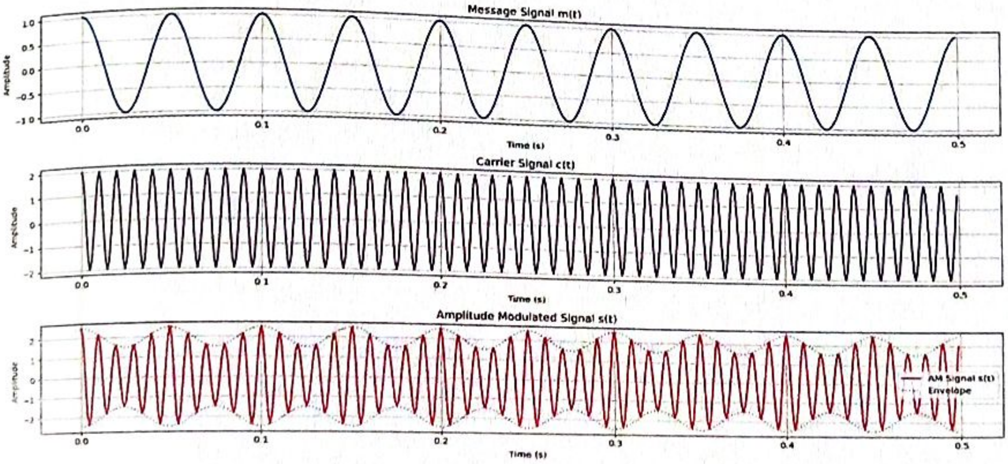
AMPLITUDE OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND FREQUENCY IS VARIED

AMPLITUDE:1 V

i. FREQUENCY:5 Hz



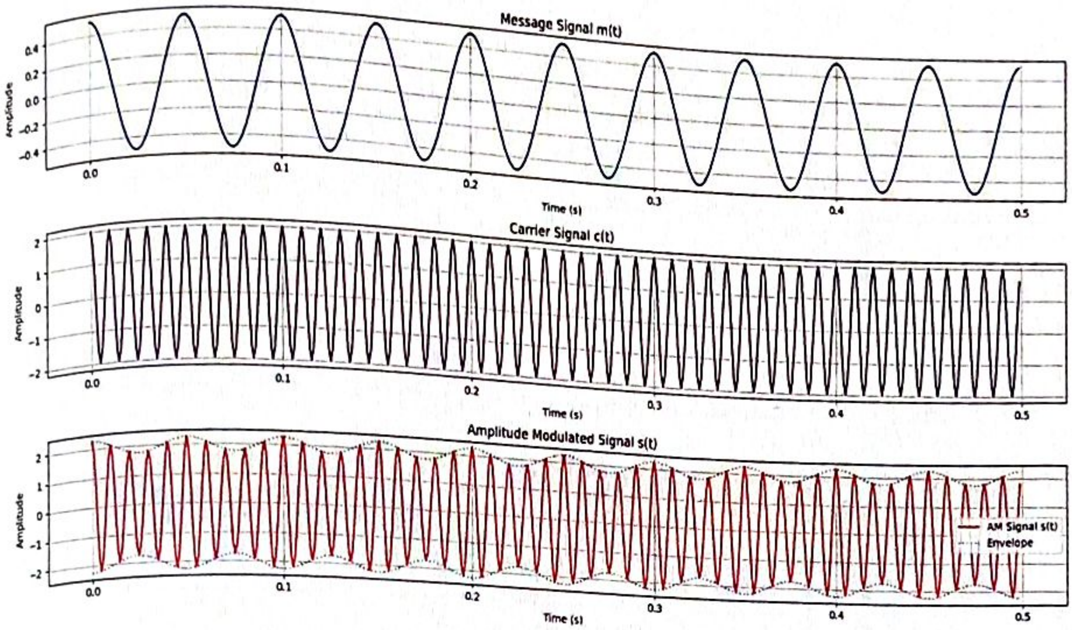
ii. FREQUENCY:20 Hz



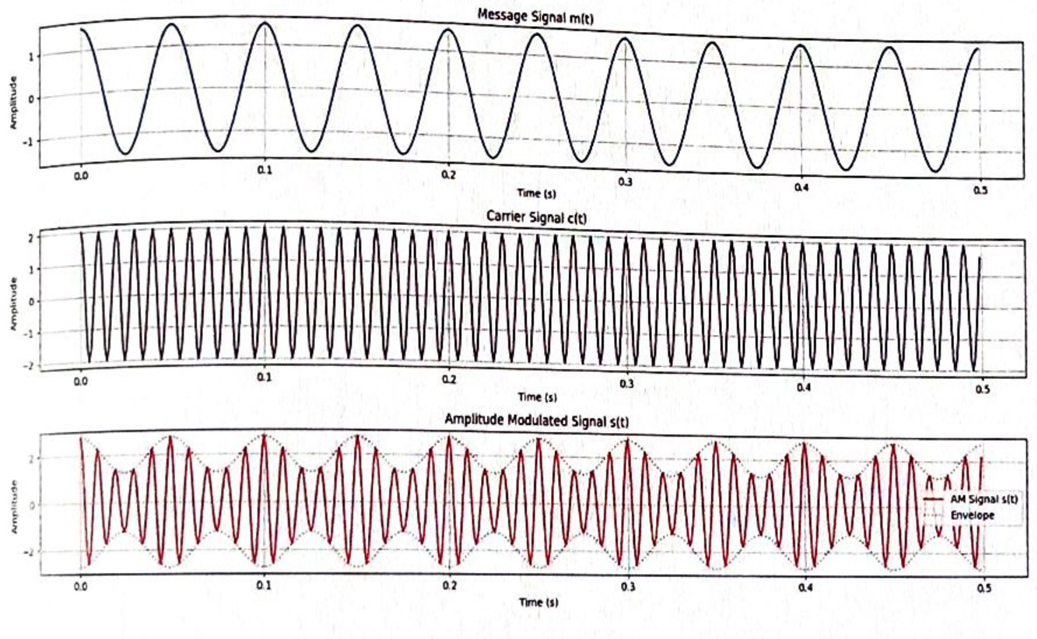
FREQUENCY OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND AMPLITUDE IS VARIED

FREQUENCY= 20Hz

i. AMPLITUDE=0.5 V



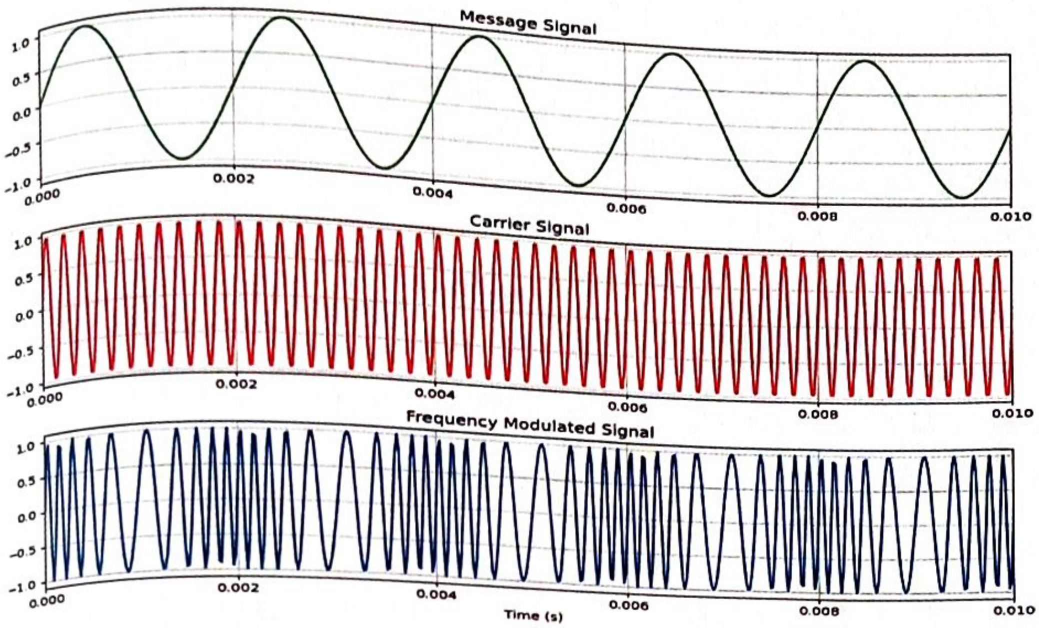
ii. AMPLITUDE=1.5 V



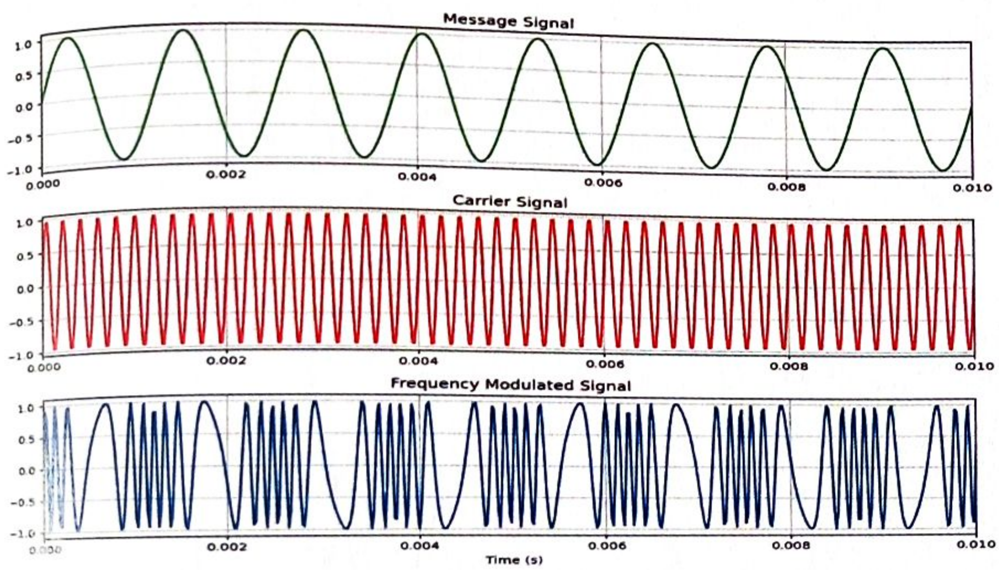
2. FREQUENCY MODULATION (FM)

AMPLITUDE OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND FREQUENCY IS VARIED

i. FREQUENCY= 500 Hz



ii. FREQUENCY= 800 Hz

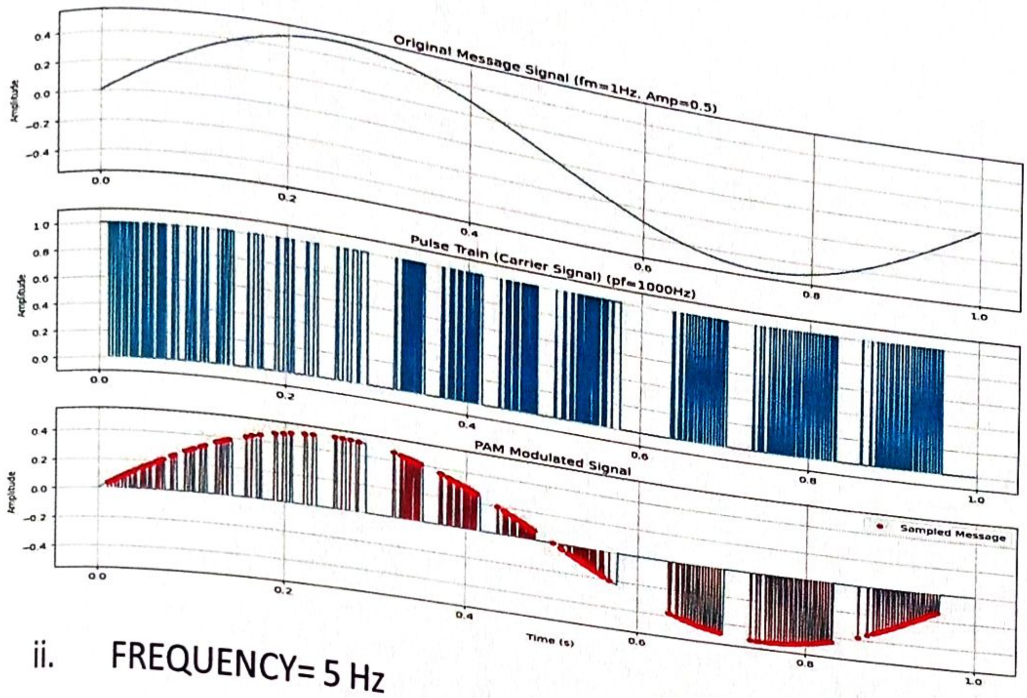


3. PULSE AMPLITUDE MODULATION (PAM)

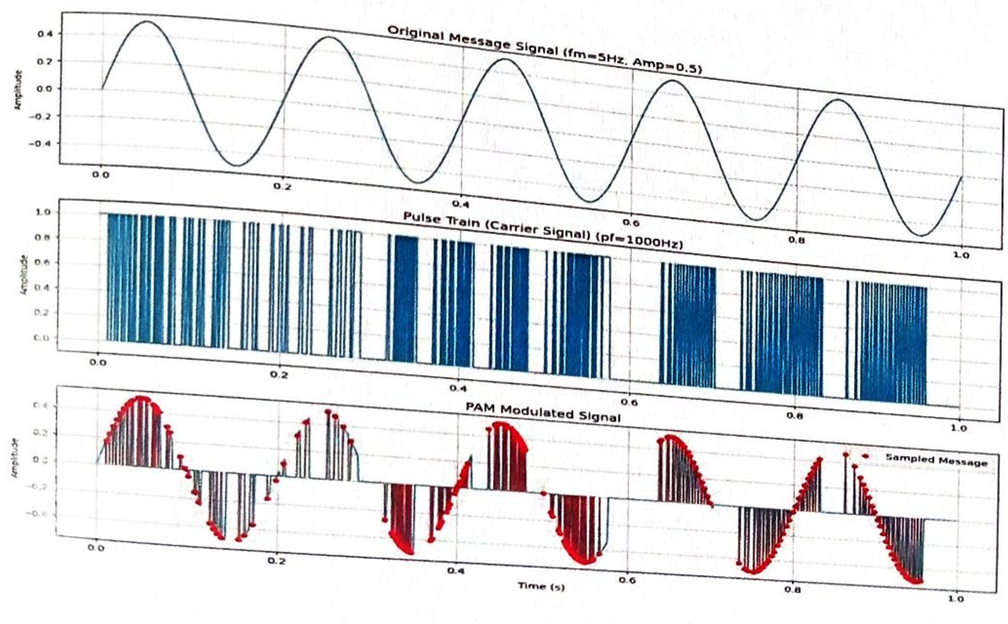
AMPLITUDE AND PULSE FREQUENCY OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND FREQUENCY IS VARIED

AMPLITUDE= 0.5 V   PULSE FREQUENCY= 1000 Hz

i. FREQUENCY= 1 Hz



ii. FREQUENCY= 5 Hz

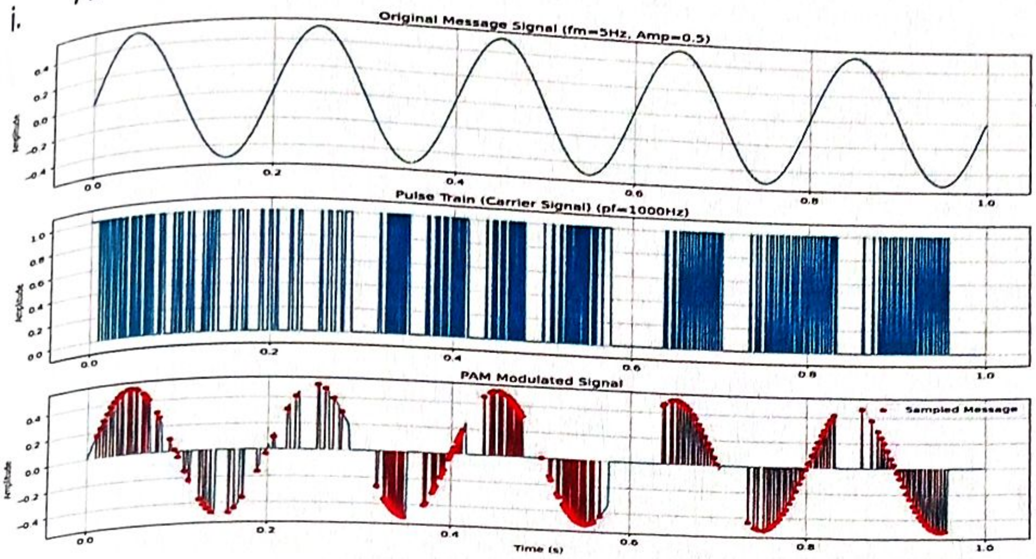


FREQUENCY AND PULSE FREQUENCY OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND AMPLITUDE IS VARIED

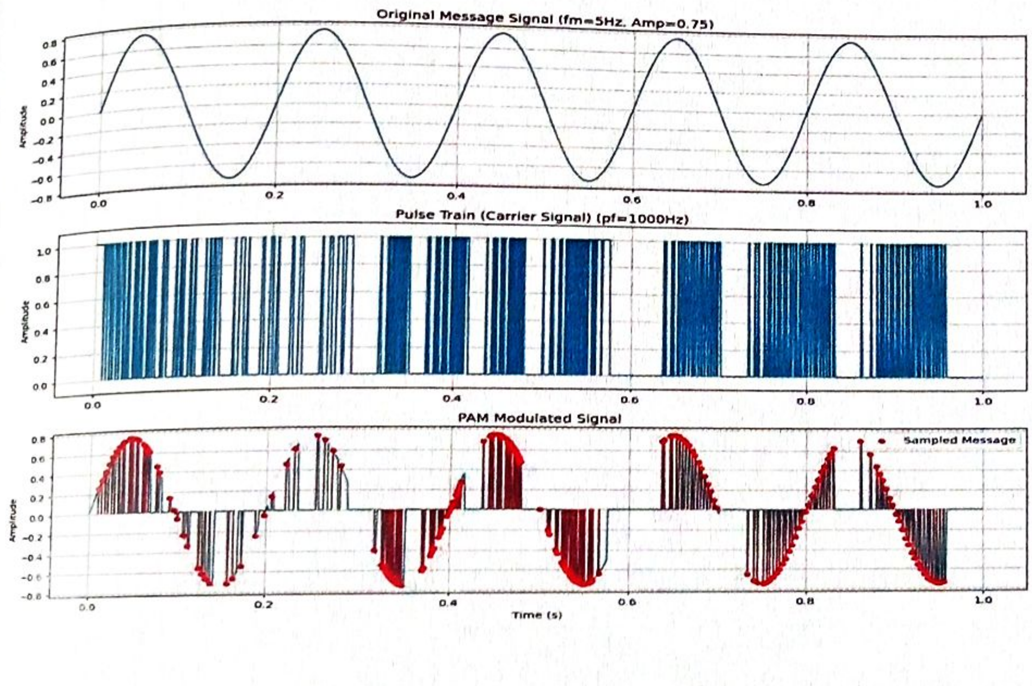
FREQUENCY= 5Hz

PULSE FREQUENCY= 1000Hz

i. AMPLITUDE= 0.25 V



ii. AMPLITUDE= 0.75 V

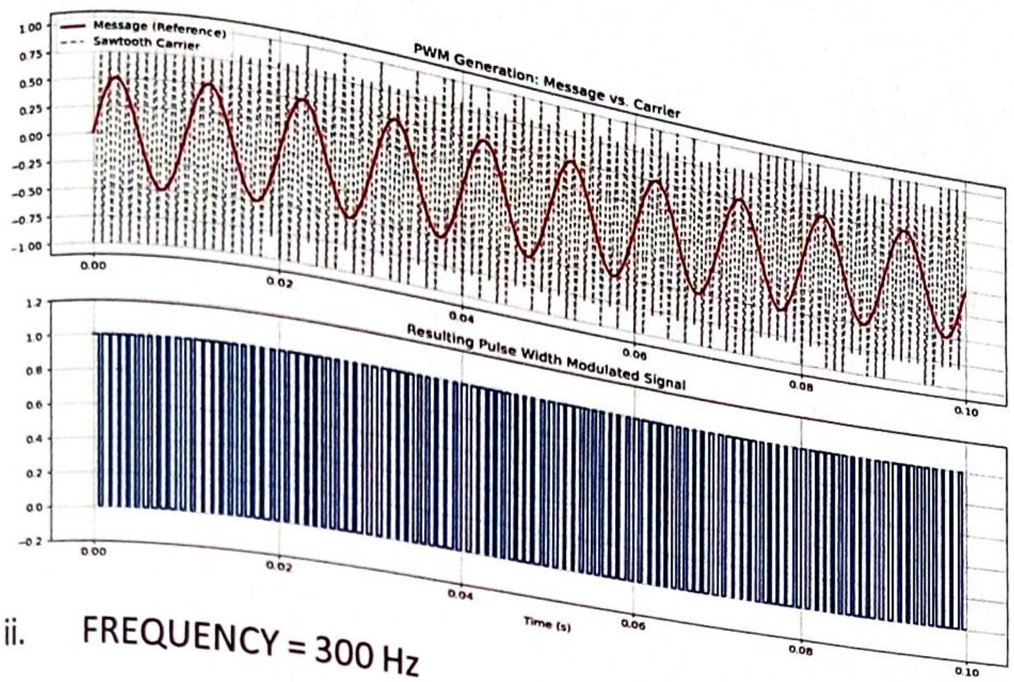


4. PULSE WIDTH MODULATION (PWM)

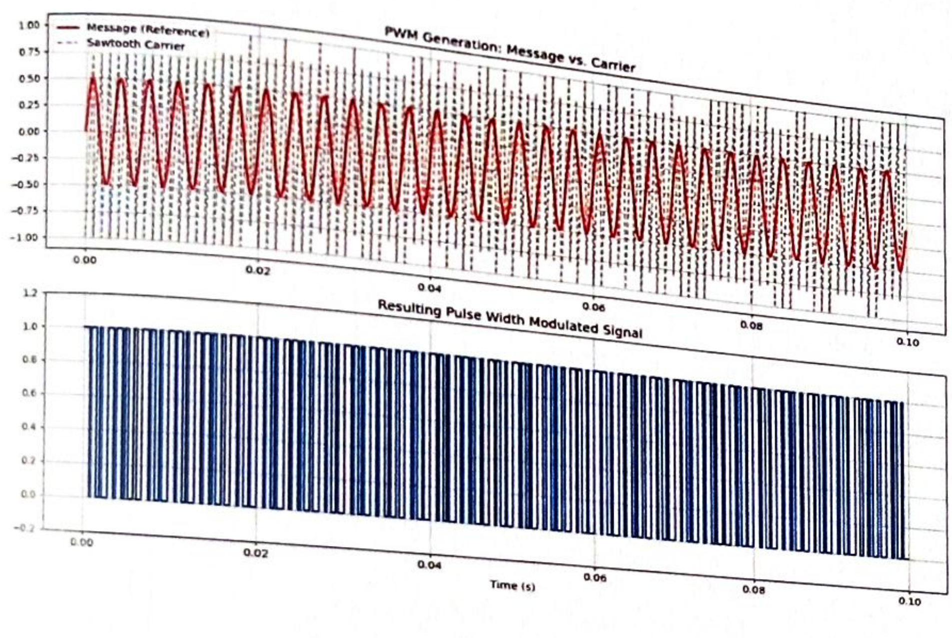
AMPLITUDE OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND FREQUENCY IS VARIED

AMPLITUDE = 0.5 V

i. FREQUENCY = 100 Hz



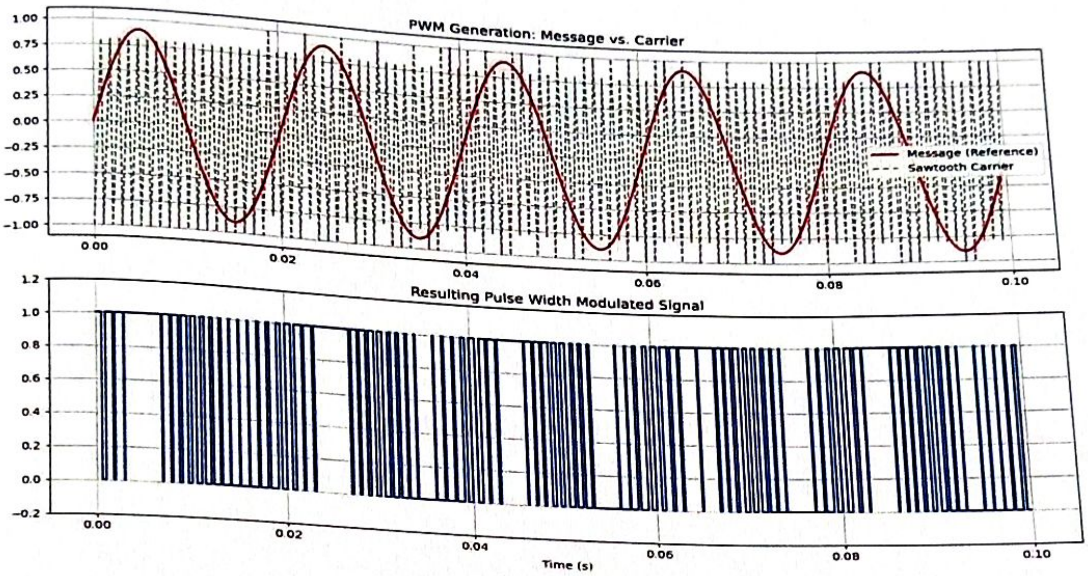
ii. FREQUENCY = 300 Hz



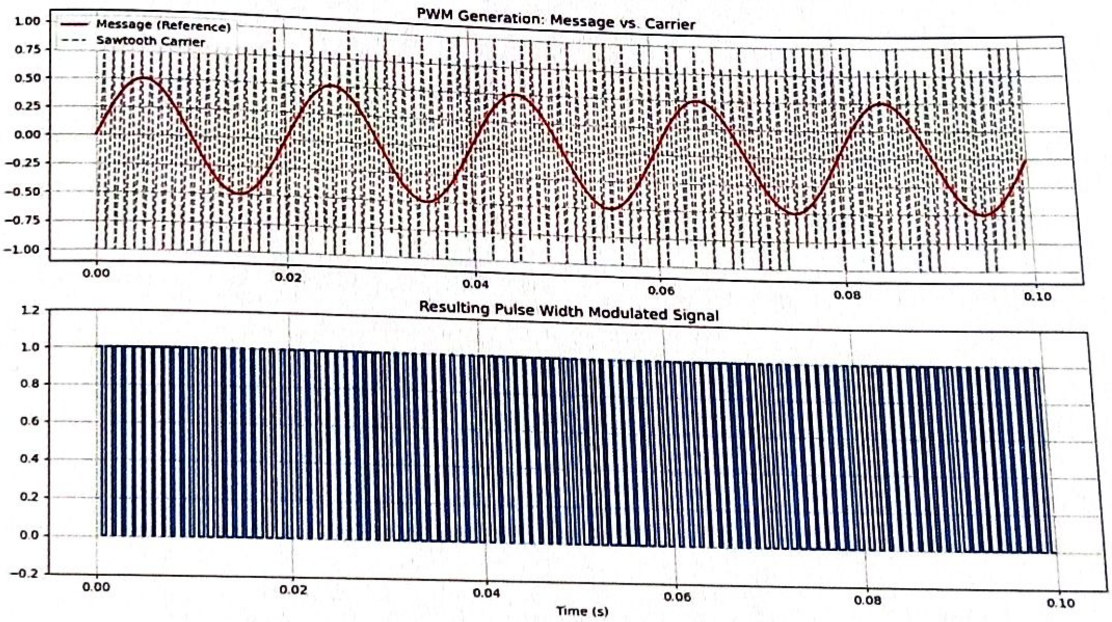
FREQUENCY OF THE MESSAGE SIGNAL IS KEPT CONSTANT AND AMPLITUDE IS VARIED

FREQUENCY = 50 Hz

i. AMPLITUDE = 0.5 V



ii. AMPLITUDE= 0.9 V



CHAPTER 5

VARIATION IN THE MODULATED OUTPUT WHEN THE INPUT PARAMETERS ARE CHANGED

AMPLITUDE MODULATION (AM)

1. Message Frequency = 5 Hz, Amplitude = 1

- Message Signal (Blue): Low-frequency oscillation, smooth and slow.
- Carrier Signal (Black): High-frequency oscillation compared to the message.
- AM Signal (Red): The envelope clearly follows the 5 Hz message. Easy to distinguish modulation because the carrier is much faster than the message.

At low message frequency, the envelope is wide and smooth, making modulation effects very visible.

2. Message Frequency = 20 Hz, Amplitude = 1

- Message Signal (Blue): Faster oscillations compared to the 5 Hz case.
- Carrier Signal (Black): Still higher frequency, but the message is closer to the carrier's rate.
- AM Signal (Red): Envelope changes more rapidly, making it harder to visually separate from the carrier.

Increasing message frequency makes the envelope tighter and less distinguishable, but modulation still occurs.

3. Message Frequency = 20 Hz, Amplitude = 1.5

- Message Signal (Blue): Same frequency as case 2, but larger amplitude.
- Carrier Signal (Black): Same as before.
- AM Signal (Red): Envelope is more pronounced — peaks and troughs are deeper because the message amplitude is larger.

Higher message amplitude increases modulation depth, making the envelope more exaggerated.

4. Message Frequency = 20 Hz, Amplitude = 0.5

- Message Signal (Blue): Same frequency as case 2, but smaller amplitude.
- Carrier Signal (Black): Same as before.
- AM Signal (Red): Envelope is shallow — modulation is weaker, and the carrier dominates visually.

Lower message amplitude reduces modulation depth, making the envelope less noticeable.

PULSE AMPLITUDE MODULATION (PAM)

1. Frequency varied (Amplitude constant at 0.5V, Pulse frequency = 1000Hz)

- Message Signal (1Hz vs 5Hz):

o At 1Hz, the sinusoid is slow and smooth, so the sampling points (red dots) are well spaced and capture the waveform accurately.

o At 5Hz, the sinusoid oscillates faster. With the same 1000Hz pulse train,

fewer samples per cycle are taken, so the PAM signal looks less smooth and

more "staircase-like."

Increasing message frequency while keeping pulse frequency constant reduces

sampling resolution per cycle, which can lead to distortion if the sampling rate

is not sufficiently high (Nyquist criterion).

2. Amplitude varied (Frequency constant at 5Hz, Pulse frequency = 1000Hz)

• Message Signal (0.25V vs 0.75V):

o At 0.25V, the sinusoid has smaller peaks, so the sampled PAM signal has

lower amplitude values.

o At 0.75V, the sinusoid has larger peaks, so the PAM samples are higher in

amplitude.

Changing amplitude directly scales the PAM signal's sample values. The modulation process preserves the proportionality of amplitude, so the PAM

output is essentially a scaled version of the input.

FREQUENCY MODULATION

Message Frequency = 500 Hz

Message Signal (Green): Low-frequency oscillation, completing 5 cycles within the 0.01 s time frame.

Carrier Signal (Red): Constant high-frequency oscillation that serves as the base for modulation.

FM Signal (Blue): The frequency changes (compressions and stretches) occur at a slower rate. The transitions between high and low frequency are wide and easily distinguishable because the message is relatively slow compared to the carrier.

ii. Message Frequency = 800 Hz

Message Signal (Green): Faster oscillations compared to the 500Hz case, completing 8 cycles in the same 0.01 s window.

Carrier Signal (Red): Remains at the same high frequency as the 500 Hz case.

FM Signal (Blue): The frequency transitions occur much more rapidly. The "bunches" of compressed waves appear more frequently, making the modulation look tighter and more "crowded" visually compared to the 500 Hz case.

At a higher message frequency, the rate of change in the carrier's frequency increases. This results in more frequent shifts between the maximum and minimum instantaneous frequencies, reflecting a faster rate of information transmission within the same time period

PULSE WIDTH MODULATION (PWM)

. Frequency Comparison

This compares the message signal at f = 50 *vs.* f = 100 while keeping amplitude constant.

- Frequency = 50: * Observation: The sine wave completes fewer cycles in the given time frame (0.0 to 0.1s).
    - PWM Effect: There are a high number of carrier pulses for every single sine wave cycle. This results in a very "smooth" transition of pulse widths, providing high resolution for the reconstructed signal.
- Frequency = 100: * Observation: The sine wave frequency has doubled.
    - PWM Effect: The "bunches" of wide and narrow pulses occur twice as often. Because the carrier frequency is fixed, there are now half as many pulses per sine wave cycle compared to the f=50 case. This represents a decrease in sampling resolution.

2. Amplitude Comparison

This compares the message signal at A = 0.5 vs. A = 0.9 while keeping frequency constant at 50.

- Amplitude = 0.5 (Low Modulation):

- Observation: The peaks of the red sine wave only reach halfway up the carrier signal's height.
- PWM Effect: The pulses never reach a 100% duty cycle (fully "on") nor a 0% duty cycle (fully "off"). The variation between the widest pulse and the narrowest pulse is relatively small. The resulting average power of this signal is lower.

- Amplitude = 0.9 (High Modulation):
  - Observation: The peaks of the sine wave almost reach the very top and bottom of the carrier signal.
  - PWM Effect: This creates a much higher Modulation Index. At the peaks, the pulses are almost solid (maximum width), and at the troughs, they are extremely thin (minimum width). This maximizes the dynamic range of the output signal.

CHAPTER 6

CONCLUSION

OVERALL ACHIEVEMENT

This project successfully implemented and analyzed Amplitude Modulation (AM), Frequency Modulation (FM), Pulse Amplitude Modulation (PAM), and Pulse Width Modulation (PWM) using Python simulation. The graphical approach made it possible to clearly visualize how each modulation technique modifies a carrier signal based on the message signal

EFFECT OF PARAMETER VARIATION

The study showed that changes in amplitude, frequency, modulation index, and pulse characteristics directly affect the shape and behavior of the modulated waveform. In AM, amplitude controls modulation depth, while frequency affects the envelope pattern. In FM, message frequency determines the rate of frequency deviation. In PAM, amplitude scaling and sampling frequency influence signal accuracy. In PWM, amplitude affects duty cycle variation, and frequency impacts pulse resolution.

PRACTICAL UNDERSTANDING THROUGH PYTHON

Using Python enabled systematic parameter control and immediate graphical comparison. This computational approach strengthened the practical understanding of theoretical communication concepts and made waveform behavior easier to interpret.

FINAL INFERENCE

Overall, the project demonstrated how modulation techniques differ in performance and characteristics. It highlighted the importance of parameter selection in communication systems and proved that graphical modelling is an effective method for studying and comparing signal transmission techniques.