Heaven's Light is Our Guide

Rajshahi University of Engineering and Technology

Course Code

ECE 3208

Course Title

Communication Engineering Sessional

Lab Reports

Submitted to	**Submitted by**
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Professor	Roll: 2010025
Dept of ETE, RUET	

Exp. No.	Experiment Name	Exp. Date
01	Analog Signal Transmission and Reception	Dec 03, 2024
02	Study of Amplitude & DSB-SC Modulation & Demodulation	Jan 07, 2025
03	Determination of Modulation Index of FM Wave	Jan 21, 2025
04	Study of Time Division Multiplexing (TDM) & Demultiplexing	Feb 11, 2025
05	Study of Pulse Code Modulation (PCM)	Feb 25, 2025
06	Study of Digital Modulation (ASK, FSK, PSK)	Feb 25, 2025

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Course Code

ECE 3208

Course Title

Communication Engineering Sessional

Experiment Date: December 3, 2024,
Submission Date: January 14, 2025

Lab Report 1:
Analog Signal Transmission and Reception

Submitted to	**Submitted by**
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Dept of ETE, RUET	

Contents

Analog Signal Transmission and Reception

Theory

Analog signal transmission and reception are fundamental concepts in communication engineering. Analog signals are continuous signals that vary over time and can take any value within a given range. These signals are used to transmit information such as audio, video, and other data over various mediums like air, cables, and optical fibers [1]. In this experiment, we focus on Amplitude Modulation (AM) and demodulation.

Amplitude Modulation (AM): In AM, the amplitude of the carrier wave is varied in proportion to the information signal. This technique is widely used in radio broadcasting [2].

The reception of analog signals involves demodulation, which is the process of extracting the original information signal from the modulated carrier wave. This is achieved using various demodulation techniques corresponding to the modulation methods used during transmission [2].

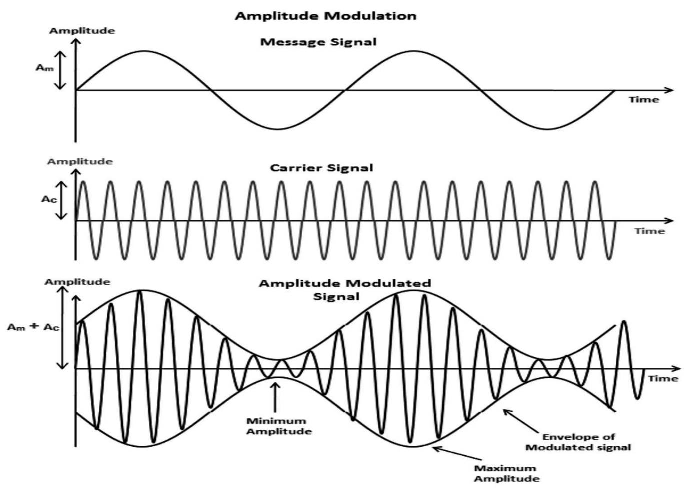

Figure 1: Illustration of Signals and Amplitude Modulation (AM)[3]

Analog signal transmission and reception are susceptible to noise and interference, which can degrade the quality of the received signal. Techniques such as filtering and amplification are employed to mitigate these effects and improve signal quality [1].

Overall, understanding analog signal transmission and reception is crucial for designing and analyzing communication systems that rely on analog signals [4].

Required Apparatus

- Analogue Signal Processing (Model No. DL 3155M60R)
- Oscilloscope
- Connecting Wires

Block Diagram

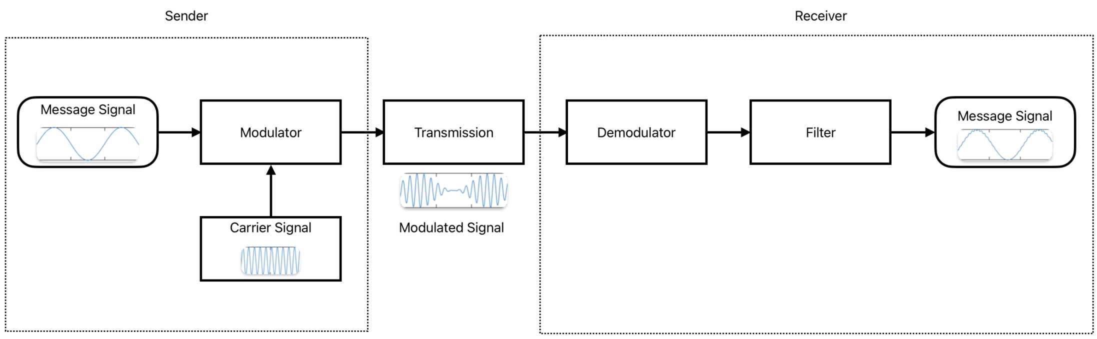

Figure 2: Block diagram of analog signal transmission and reception

Procedure

1. The Analogue Signal Processing board (Model No. DL 3155M60R) was connected to the power supply.
2. An analog signal was generated using the signal generator on the Analogue Signal Processing board.
3. The output of the signal generator was connected to the input of the modulator section on the board.
4. The modulator was set to perform Amplitude Modulation (AM) using the carrier signal provided by the board.

5. The waveform of the message signal and the modulated signal was observed and recorded using the oscilloscope.

6. The output of the modulator was connected to the input of the demodulator section on the board.

7. The modulated signal was demodulated to retrieve the original message signal.

8. The demodulated signal was passed through a filter to remove any noise and interference.

9. The waveform of the demodulated signal was observed and recorded using the oscilloscope.

10. The waveforms of the original message signal, the modulated signal, and the demodulated signal were compared.

Matlab Simulation

Code:

The following Matlab code simulates the generation, modulation, and demodulation of an analog signal using Amplitude Modulation (AM).

```matlab
% Define parameters
Fs = 1000; % Sampling frequency
t = 0:1/Fs:1; % Time vector

% Create message signal
Am = 1; % Amplitude of message signal
fm = 5; % Frequency of message signal
message_signal = Am * sin(2 * pi * fm * t);

% Create carrier signal
Ac = 1; % Amplitude of carrier signal
fc = 50; % Frequency of carrier signal
carrier_signal = Ac * sin(2 * pi * fc * t);

% Perform Amplitude Modulation (AM)
modulated_signal = (1 + message_signal) .* carrier_signal;

% Demodulate the signal
demodulated_signal = modulated_signal .* carrier_signal;
[b, a] = butter(5, fc/(Fs/2)); % Design a low-pass filter
filtered_signal = filter(b, a, demodulated_signal);

```

```
% Plot the signals
figure;
subplot(4,1,1);
plot(t, message_signal);
title('Message Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,2);
plot(t, carrier_signal);
title('Carrier Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,3);
plot(t, modulated_signal);
title('AM Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,4);
plot(t, filtered_signal);
title('Demodulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

Output

Experiment Outputs

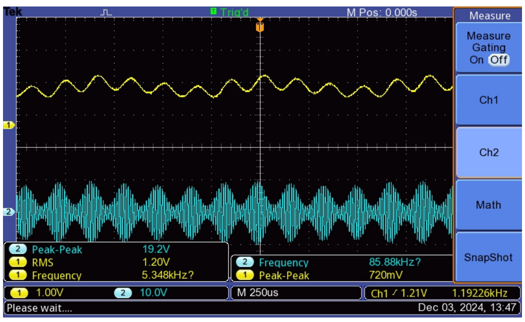

Figure 3: Waveform of the Original Message Signal (Yellow) and the Modulated Signal (Blue)

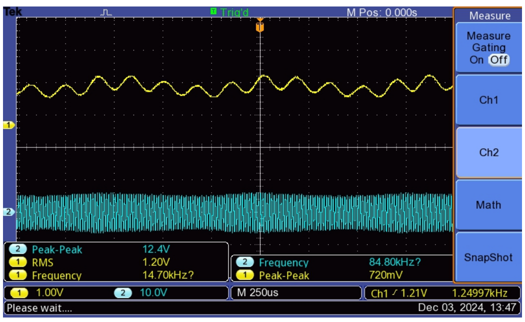

Figure 4: Waveform of the Modulated Signal (Yellow) and the Modulated Signal (Blue) with different message signal

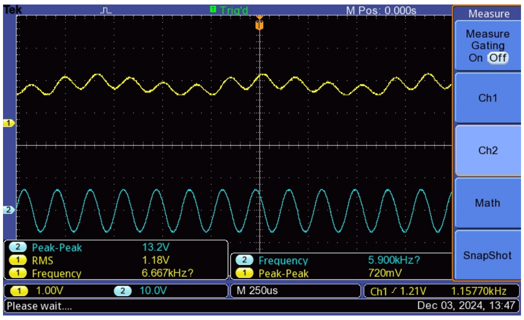

Figure 5: Waveform of the original message signal (Yellow) and the demodulated signal (Blue)

Matlab Simulation Outputs

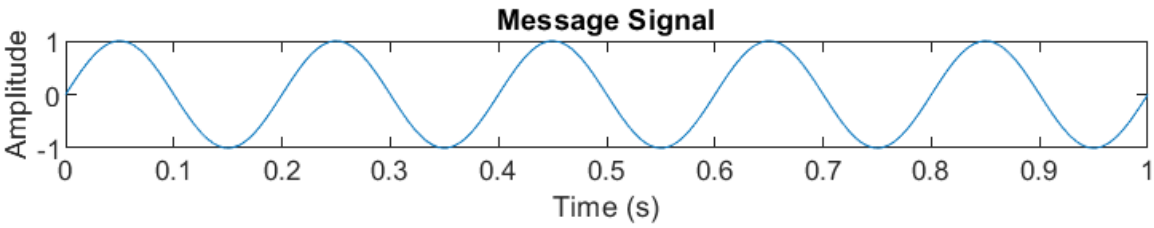

Figure 6: Original Message Signal

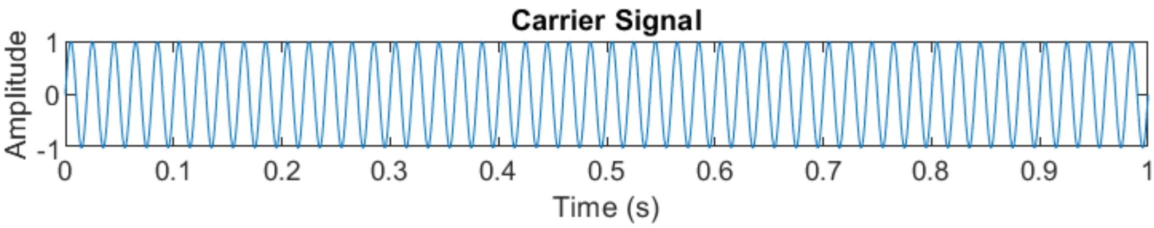

Figure 7: Carrier Signal

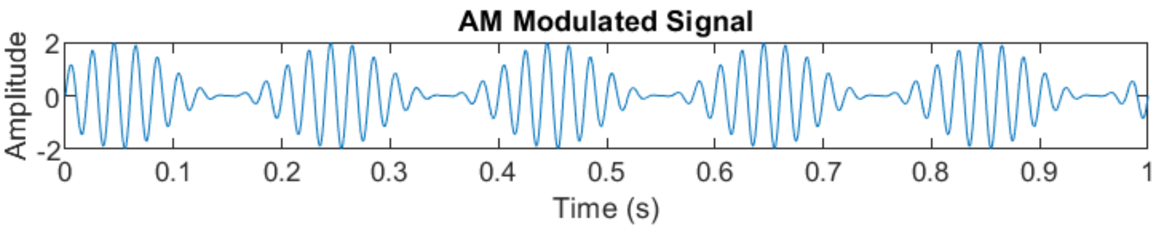

Figure 8: Modulated Signal

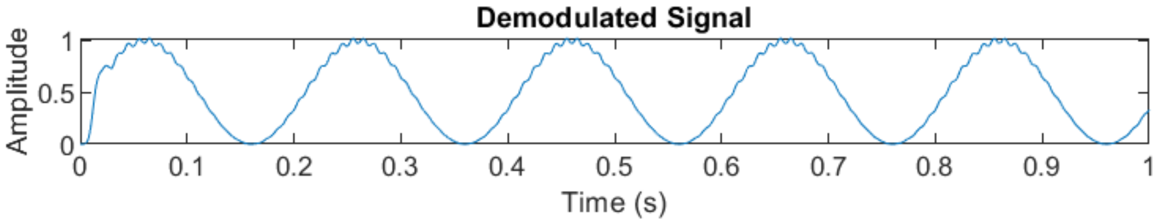

Figure 9: Demodulated Signal

Discussion

The experiment and Matlab simulation demonstrate the process of analog signal transmission and reception using Amplitude Modulation (AM). The original message signal is modulated by varying the amplitude of the carrier signal, resulting in the modulated signal. The modulated signal is then demodulated to retrieve the original message signal.

The waveforms of the original message signal, the modulated signal, and the demodulated signal are observed and compared. The demodulated signal closely resembles the original message signal, demonstrating the effectiveness of the demodulation process.

Precautions & Conclusion

Precautions:

- All connections were ensured to be secure before powering on the equipment to avoid short circuits or damage.
- The signal generator settings were verified to ensure the correct frequency and amplitude were used for modulation.
- The oscilloscope probes were handled carefully to avoid damaging the equipment or the circuit.
- Live wires or terminals were avoided to prevent electric shock.
- The modulator and demodulator settings were double-checked to ensure accurate modulation and demodulation.
- The work area was kept clean and organized to prevent accidental disconnections or interference.
- The manufacturer's guidelines for operating the Analogue Signal Processing board and other equipment were followed.

Conclusion:

Analog signal transmission and reception are essential concepts in communication engineering. The experiment and Matlab simulation provide a hands-on demonstration of Amplitude Modulation (AM) and the demodulation process. By observing the waveforms of the original message signal, the modulated signal, and the demodulated signal, we can understand the impact of modulation and demodulation on analog signals [1].

The experiment highlights the importance of modulation techniques in transmitting information over various communication channels [4]. It also emphasizes the need for demodulation to recover the original message signal from the modulated carrier wave. Overall, analog signal transmission and reception play a vital role in modern communication systems and are fundamental to the field of communication engineering [2].

References

[1] S. Haykin, *Communication Systems.* John Wiley & Sons, 2001.

[2] B. Sklar, *Digital Communications: Fundamentals and Applications.* Prentice Hall, 2001.

[3] "Draw a diagram of amplitude modulated waves." Jan. 2025, [Online; accessed 9. Jan. 2025]. [Online]. Available: https://www.vedantu.com/question-answer/draw-a-diagram-of-amplitude-modulated-waves-class-13-physics-cbse-5f625ed7e5bde9062ff6c68c

[4] J. G. Proakis and M. Salehi, *Digital Communications.* McGraw-Hill, 2007.

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Rajshahi University of Engineering and Technology

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ECE 3208

Course Title

Communication Engineering Sessional

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Lab Report 2: Study of Amplitude & DSB-SC Modulation & Demodulation

Submitted to
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Contents

Study of Amplitude & DSB-SC Modulation & Demodulation

Theory

Required Apparatus

- ANALOGUE SIGNAL TRANSMISSION DL 3155M60
- Frequency Generator
- Oscilloscope
- Connecting Wires

Block Diagram

AM and DSB-SC Modulation Block Diagram

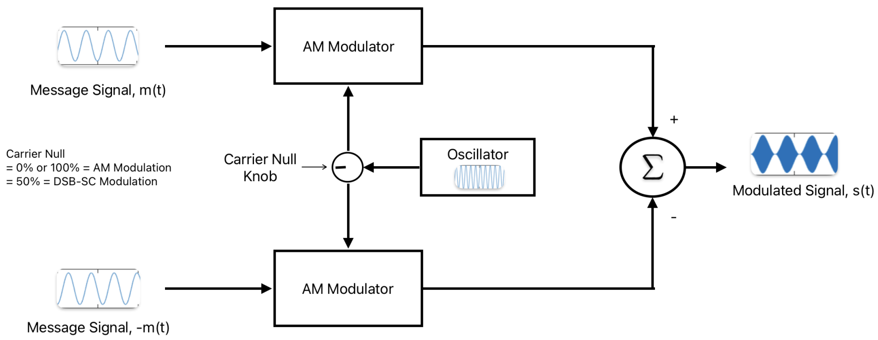

Figure 1: Block Diagram of AM and DSB-SC Modulation (Balanced Modulator)

AM and DSB-SC Modulation and Demodulation Block Diagram

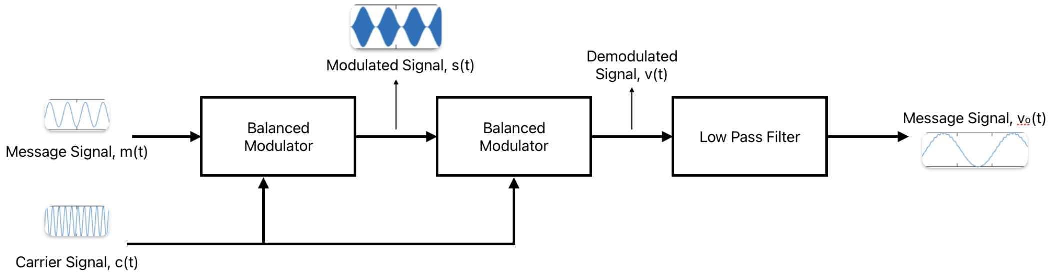

Figure 2: Block Diagram of AM and DSB-SC Modulation and Demodulation

Procedure

1. Generate a lower frequency message signal and a higher frequency carrier signal using a function generator.
2. Use the balanced modulator on the AM/SSB/DSB-SC board (ACT-02 AM DSB-SC/SSB Kit) for modulation.
3. Pass the message signal to the balanced modulator and observe the message, carrier, and modulated signals.
4. Adjust the carrier null knob to perform AM and DSB-SC modulation, observing under, over, and 100% modulation for AM.
5. Use another balanced modulator and a low pass filter to demodulate and recover the original message signal for both AM and DSB-SC.
6. Observe waveforms on the oscilloscope at each step.

Experimental Data

Modulation Type	$\mathbf{A_m}$	$\mathbf{F_m}$	$\mathbf{A_c}$	$\mathbf{F_c}$	$\mathbf{A_{max}}$	$\mathbf{A_{min}}$
AM Under Modulation	0.4V	1.75kHz	2.2V	298.8kHz	2.52V	0.5V
AM 100% Modulation	0.54V	1.762kHz	2.22V	301.5kHz	2.54V	0V
AM Over Modulation	0.9V	1.75kHz	2.24V	300.32kHz	2.64V	1.2V
DSB-SC Modulation 1	0.9V	1.75kHz	2.28V	300.3kHz	-	-
DSB-SC Modulation 1	1.88V	1.75kHz	2.28V	300.3kHz	-	-

Table 1: Experimental Data for Modulation Types

Calculations

The modulation index (μ) for AM can be calculated using the formula:

$$\mu = \frac{A_{\text{max}} - A_{\text{min}}}{A_{\text{max}} + A_{\text{min}}}$$

AM Under Modulation

Given:

$$A_{\text{max}} = 2.52V, \quad A_{\text{min}} = 0.5V$$
$$\mu = \frac{2.52 - 0.5}{2.52 + 0.5} = \frac{2.02}{3.02} \approx 0.668$$

AM 100% Modulation

Given:

$$A_{\text{max}} = 2.54V, \quad A_{\text{min}} = 0V$$
$$\mu = \frac{2.54 - 0}{2.54 + 0} = \frac{2.54}{2.54} = 1$$

AM Over Modulation

Given:

$$A_{\text{max}} = 2.64V, \quad A_{\text{min}} = 1.2V$$
$$\mu = \frac{2.64 - (-1.2)}{2.64 + (-1.2)} = \frac{3.84}{1.44} \approx 2.67$$

For DSB-SC modulation, the modulation index is not applicable as the carrier is suppressed.

Matlab Simulation

Code (AM):

The following Matlab code simulates the generation, modulation, and demodulation of an analog signal using Amplitude Modulation (AM).

```
% Parameters
% Amplitude of message signal in Volts
%Am = 0.4; % For Under Modulation
%Am = 0.54; % For 100% Modulation
Am = 0.9; % For Over Modulation
Fm = 1.761e3; % Frequency of message signal in Hz
Ac = 2.24; % Amplitude of carrier signal in Volts
Fc = 300.4e3; % Frequency of carrier signal in Hz
Fs = 1e6; % Sampling frequency in Hz
t = 0:1/Fs:1e-2; % Time vector for 1 ms
Ka = 1.87;

% Message signal
m_t = Am * cos(2 * pi * Fm * t);

% Carrier signal
c_t = Ac * cos(2 * pi * Fc * t);

% AM Modulated signal
s_t = Ac * (1 + Ka * m_t) .* cos(2 * pi * Fc * t);

% Demodulation
r_t = s_t .* cos(2 * pi * Fc * t);

% Low-pass filter design
[b, a] = butter(6, Fm/(Fs/2)); % 6th order Butterworth filter

% Filter the demodulated signal
m_rec = filter(b, a, r_t);

% Plotting the signals
figure;
subplot(4,1,1);
plot(t, m_t);
title('Message Signal');
xlabel('Time (s)');
ylabel('Amplitude (V)');

```

```
subplot(4,1,2);
plot(t, c_t);
title('Carrier Signal');
xlabel('Time (s)');
ylabel('Amplitude (V)');

subplot(4,1,3);
plot(t, s_t);
title('AM Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude (V)');

subplot(4,1,4);
plot(t, m_rec);
title('Demodulated Message Signal');
xlabel('Time (s)');
ylabel('Amplitude (V)');
```

Code (DSB-SC):

The following Matlab code simulates the generation, modulation, and demodulation of an analog signal using Double Sideband Suppressed Carrier (DSB-SC) modulation.

```
% Define parameters
Fs = 1000000; % Sampling frequency
t = 0:1/Fs:0.01; % Time vector

% Create message signal
Am = 1.88; % Amplitude of message signal
% Am = 0.9; % Amplitude of message signal
fm = 1750; % Frequency of message signal
message_signal = Am * sin(2 * pi * fm * t);

% Create carrier signal
Ac = 2.28; % Amplitude of carrier signal
fc = 300000; % Frequency of carrier signal
carrier_signal = Ac * sin(2 * pi * fc * t);

% Perform Double Sideband Suppressed Carrier (DSB-SC) Modulation
modulated_signal = message_signal .* carrier_signal;

% Demodulate the signal
demodulated_signal = modulated_signal .* carrier_signal;
[b, a] = butter(5, fm/(Fs/2)); % Design a low-pass filter
filtered_signal = filter(b, a, demodulated_signal);
```

```
% Plot the signals
figure;
subplot(4,1,1);
plot(t, message_signal);
title('Message Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,2);
plot(t, carrier_signal);
title('Carrier Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,3);
plot(t, modulated_signal);
title('DSB-SC Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,4);
plot(t, filtered_signal);
title('Demodulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

Output

Experimental Output

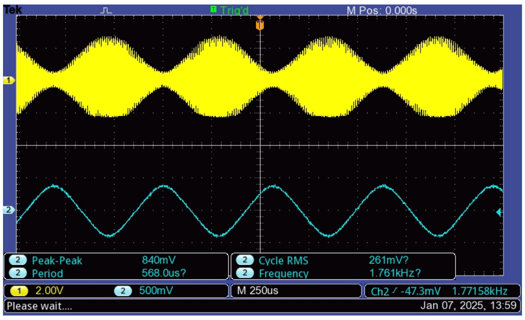

Figure 3: AM; Yellow: Under-modulated, Blue: Message

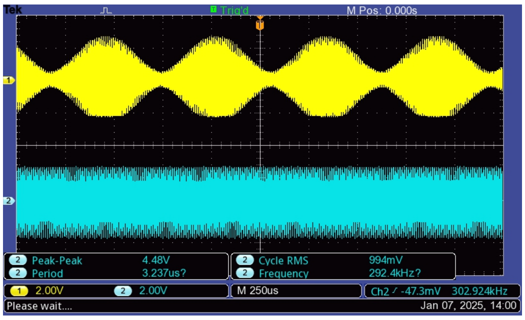

Figure 4: AM; Yellow: Under-modulated, Blue: Carrier

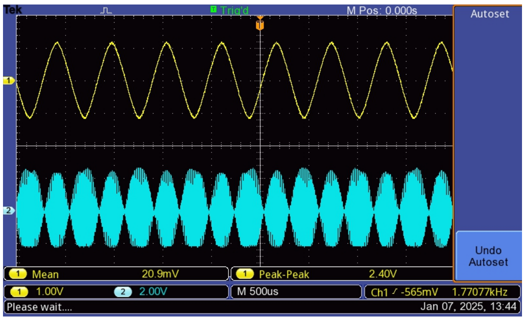

Figure 5: AM; Yellow: Message, Blue: 100% Modulated

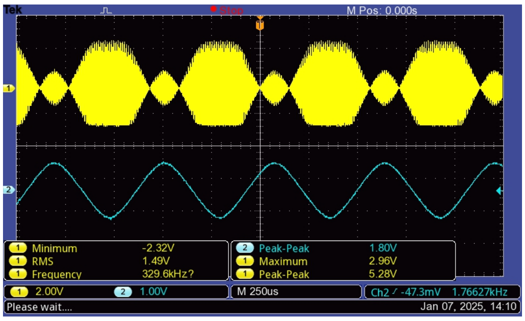

Figure 6: AM; Yellow: Over-modulated, Blue: Message

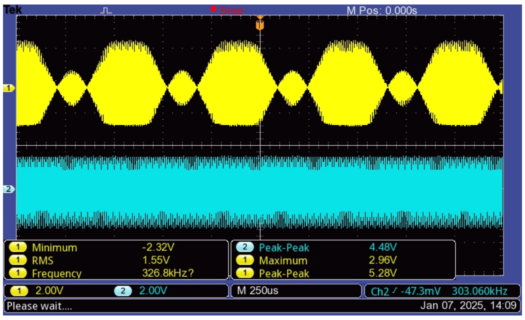

Figure 7: AM; Yellow: Over-modulated, Blue: Carrier

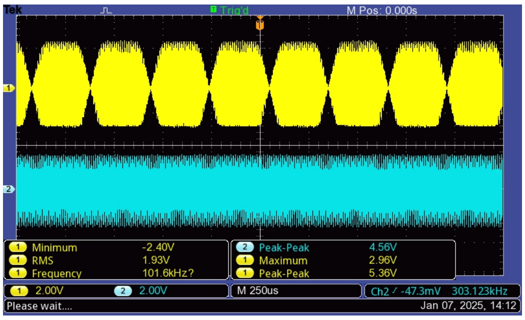

Figure 8: DSBSC; Yellow: Modulated, Blue: Carrier

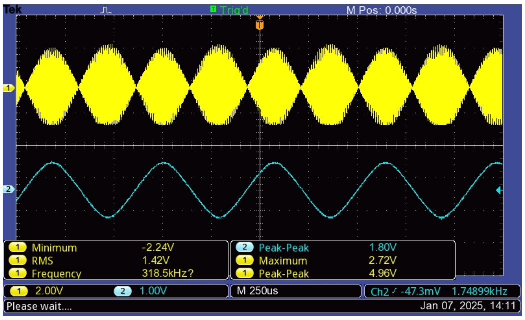

Figure 9: DSBSC; Yellow: Modulated, Blue: Message 1

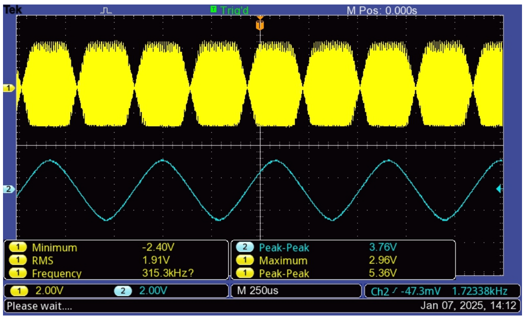

Figure 10: DSBSC; Yellow: Modulated, Blue: Message 2

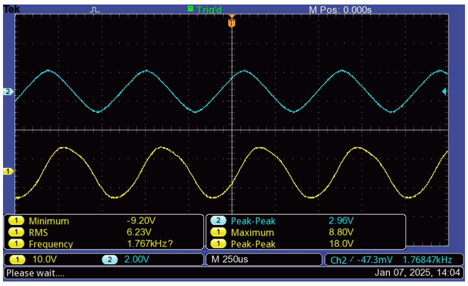

Figure 11: DSBSC; Yellow: Message, Blue: Demodulated Message

Matlab Simulation Output

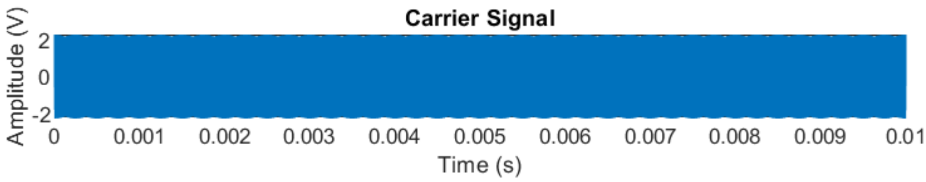

Figure 12: AM; Carrier

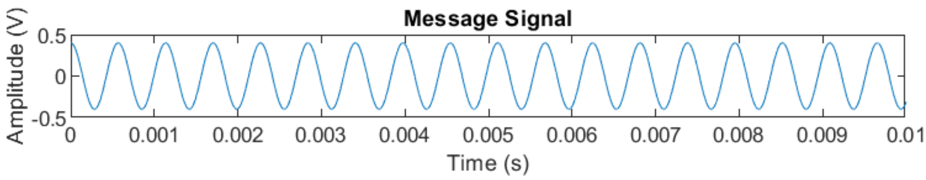

Figure 13: AM Under-modulated; Message Signal

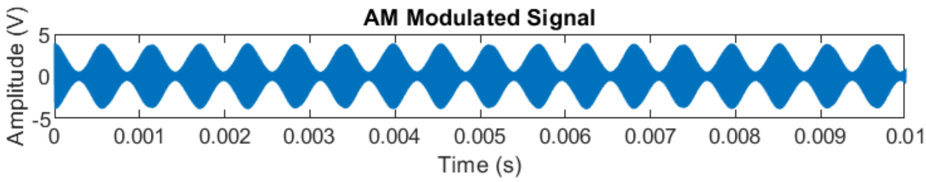

Figure 14: AM Under-modulated; Modulated Signal

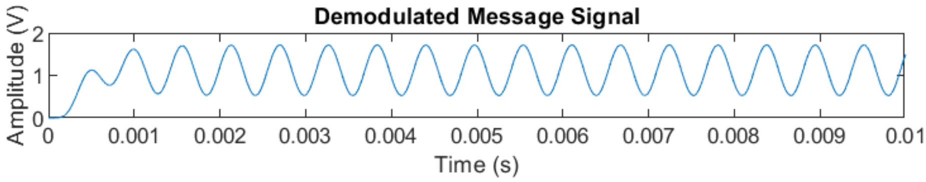

Figure 15: AM Under-modulated; Demodulated Signal

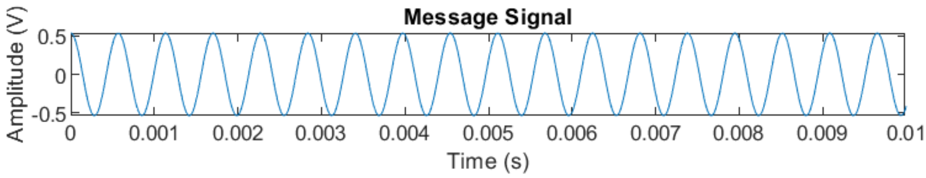

Figure 16: AM 100% Modulated; Message Signal

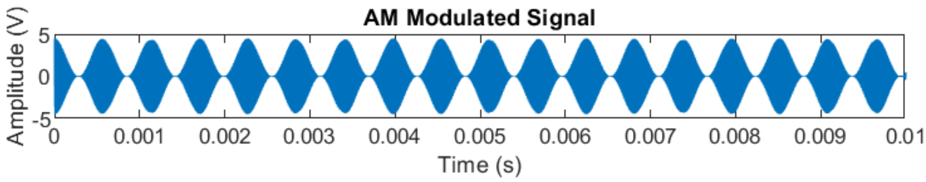

Figure 17: AM 100% Modulated; Modulated Signal

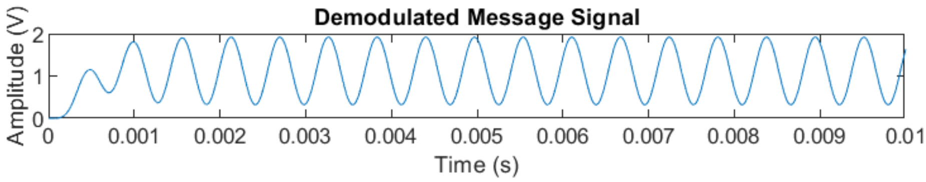

Figure 18: AM 100% Modulated; Demodulated Signal

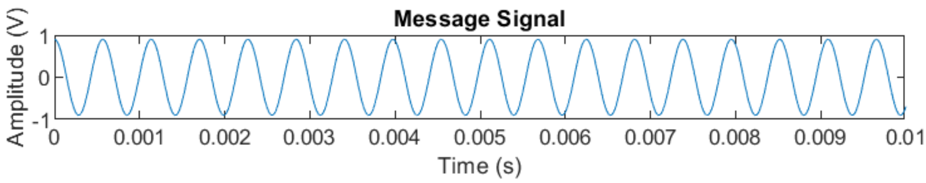

Figure 19: AM Over-modulated; Message Signal

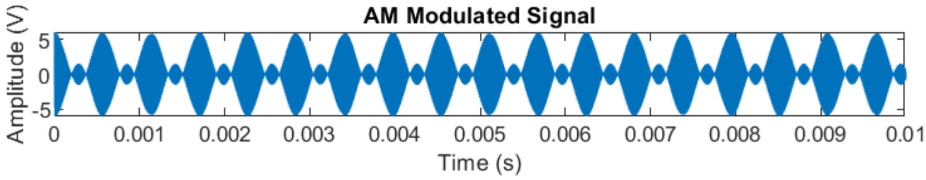

Figure 20: AM Over-modulated; Modulated Signal

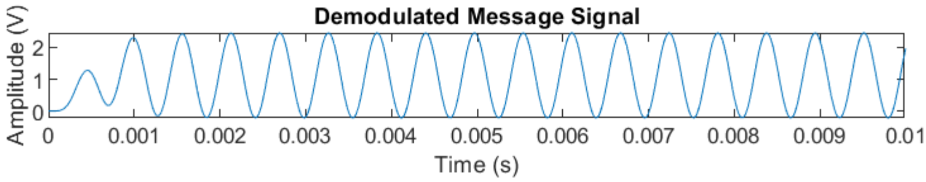

Figure 21: AM Over-modulated; Demodulated Signal

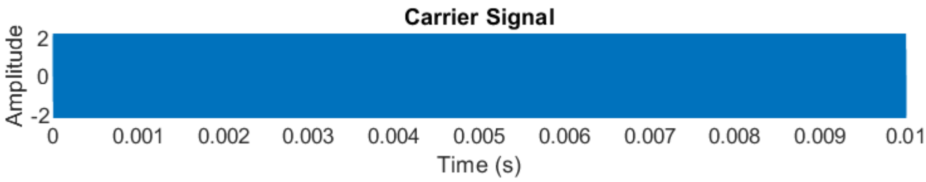

Figure 22: DSB-SC, Carrier Signal

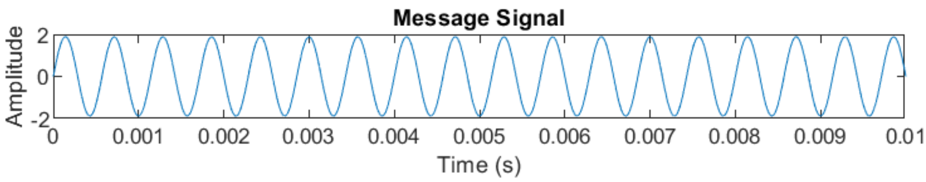

Figure 23: DSB-SC, Message Signal 1

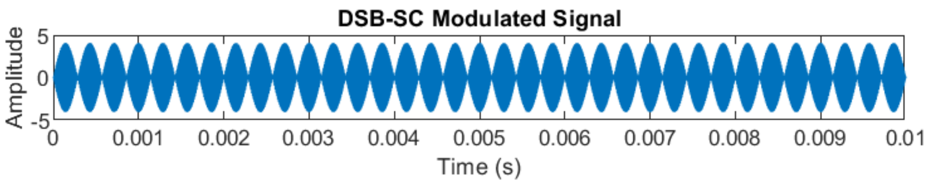

Figure 24: DSB-SC, Modulated Signal 1

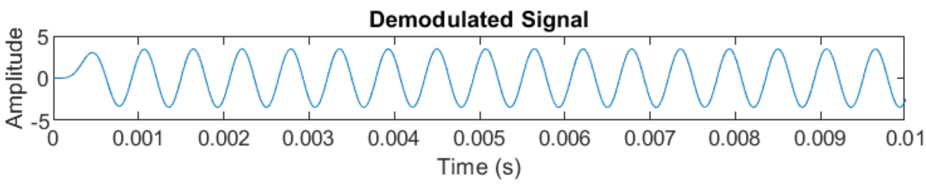

Figure 25: DSB-SC, Demodulated Signal 1

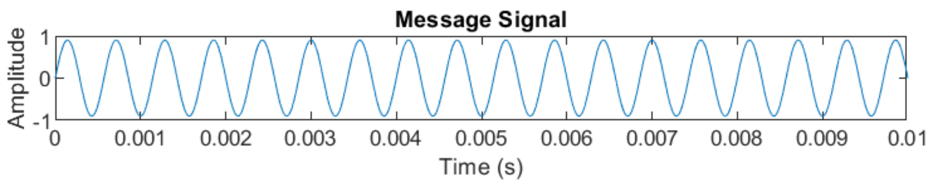

Figure 26: DSB-SC, Message Signal 2

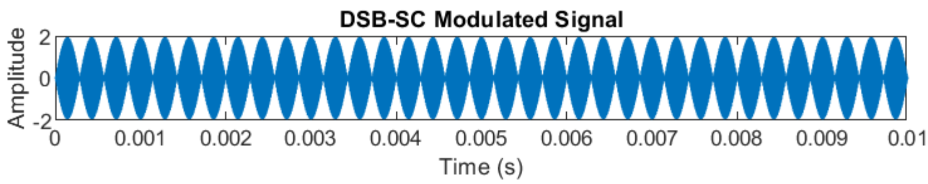

Figure 27: DSB-SC, Modulated Signal 2

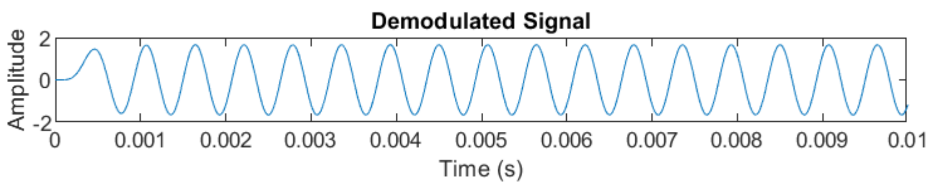

Figure 28: DSB-SC, Demodulated Signal 2

Discussion

In this experiment, the principles of Amplitude Modulation (AM) and Double Sideband Suppressed Carrier (DSB-SC) modulation and demodulation were explored. Experimental data and Matlab simulations provided insights into these modulation techniques under various conditions.

From the experimental data:

- For AM under modulation, the modulation index was approximately 0.668, indicating that the message signal's amplitude was less than the carrier's, resulting in a modulated signal with less variation in amplitude.
- For AM 100% modulation, the modulation index was 1, showing that the message signal's amplitude equaled the carrier's, resulting in a modulated signal with maximum amplitude variation without distortion.
- For AM over modulation, the modulation index was about 2.67, indicating that the message signal's amplitude exceeded the carrier's, resulting in significant distortion and envelope inversion in the modulated signal.

Matlab simulations supported these findings, visually representing the carrier, message, modulated, and demodulated signals for each modulation type. The effects of under, 100%, and over modulation on the AM signal and the successful demodulation of the original message signal were demonstrated.

For DSB-SC modulation, the carrier was suppressed, and only the sidebands were transmitted. Matlab simulations visualized the DSB-SC modulated signal and its demodulation, confirming the effectiveness of coherent detection in recovering the message.

This experiment highlighted the importance of the modulation index in AM and the efficiency of DSB-SC modulation in terms of power and bandwidth, reinforcing theoretical concepts through practical observations and simulations.

Conclusion

In conclusion, a comprehensive understanding of Amplitude Modulation (AM) and Double Sideband Suppressed Carrier (DSB-SC) modulation techniques was provided by this experiment. Through both experimental observations and Matlab simulations, the effects of different modulation indices on AM signals and the efficiency of DSB-SC modulation in terms of power and bandwidth were analyzed. The results demonstrated the importance of the modulation index in determining the quality of AM signals and highlighted the advantages of DSB-SC modulation for efficient communication. These findings are consistent with the theoretical concepts discussed in the literature [1, 2]. Overall, the practical applications and benefits of these modulation techniques in communication systems were reinforced by this experiment.

References

[1] S. Haykin, *Communication Systems.* Wiley, 2008.

[2] J. G. Proakis, *Digital Communications.* McGraw-Hill, 2007.

Heaven's Light is Our Guide

Rajshahi University of Engineering and Technology

Course Code

ECE 3208

Course Title

Communication Engineering Sessional

Experiment Date: January 21, 2025,
Submission Date: February 11, 2025

Lab Report 3: Determination of Modulation Index of FM Wave

Submitted to	Submitted by
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Contents

Determination of Modulation Index of FM Wave

Theory

Frequency Modulation (FM) encodes information by varying the instantaneous frequency of a carrier wave, making it more resistant to noise than Amplitude Modulation (AM).
The message signal:

$$m(t) = A_m \cos(2\pi f_m t)$$

The carrier signal:

$$c(t) = A_c \cos(2\pi f_c t)$$

The FM modulated signal:

$$s(t) = A_c \cos\left(2\pi f_c t + \beta \sin(2\pi f_m t)\right)$$

where $\beta = \frac{\Delta f}{f_m}$.
The demodulated signal:

$$V_0(t) = \frac{f_{\text{inst}}(t) - f_c}{\Delta f}$$

To determine Δf:

1. Observe the modulated signal on an oscilloscope.
2. Measure the maximum (f_{max}) and minimum (f_{min}) frequencies.
3. Calculate $\Delta f = \frac{f_{\text{max}} - f_{\text{min}}}{2}$.

The bandwidth (B) of an FM signal, according to Carson's rule:

$$B \approx 2(\Delta f + f_m) = 2f_m(\beta + 1)$$

FM is widely used in radio broadcasting and two-way radio communication due to its noise immunity and efficient bandwidth use [1, 2].

Required Apparatus

- ANALOGUE SIGNAL TRANSMISSION DL 3155M60
- Oscilloscope
- Connecting Wires
- Power Supply

Block Diagram

FM Modulation and Demodulation

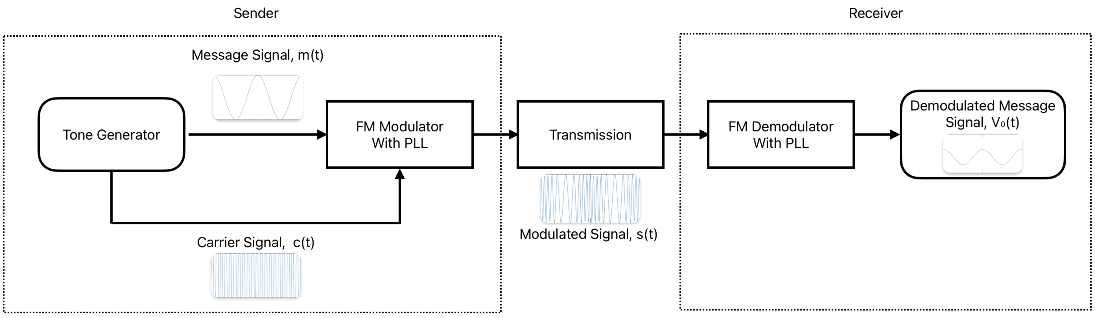

Figure 1: Block Diagram of FM Modulation and Demodulation

Procedure

1. The FM modulator and demodulator were connected as shown in the block diagram.
2. The message signal was applied to the modulator and the modulated signal was observed on the oscilloscope.
3. The frequency deviation and the modulating frequency were measured from the oscilloscope.
4. The modulation index was calculated using the measured values.
5. The experiment was repeated with different message signals and modulation frequencies to observe their effects.
6. The observed values of frequency deviation, modulating frequency, and modulation index for each experiment were recorded.

Experimental Data

Reading no	Message Signal's		Modulated Signal's Minimum		Modulated Signal's Maximum	
	Time Period, (s)	Frequency, (kHz)	Time Period, (s)	Frequency, (kHz)	Time Period, (s)	Frequency, (kHz)
1	1.4×10^{-4}	7.142	1.1×10^{-5}	90.90	3×10^{-5}	33.33
2	1.4×10^{-4}	7.142	1.05×10^{-5}	95.24	3.3×10^{-5}	30.3
3	9×10^{-5}	11.11	1.2×10^{-5}	83.33	2.5×10^{-5}	40
4	2.4×10^{-4}	3.937	1.1×10^{-5}	90.91	2.4×10^{-5}	41.67

Calculations

The modulation index (β) is calculated using the formula:

$$\beta = \frac{\Delta f}{f_m}$$

where Δf is the frequency deviation and f_m is the frequency of the message signal. The bandwidth (B) of an FM signal can be calculated using Carson's rule:

$$B \approx 2(\Delta f + f_m) = 2f_m(\beta + 1)$$

1. For Reading 1:

$$f_m = 7.142 \text{ kHz}$$
$$\Delta f = \frac{90.90 - 33.33}{2} \text{ kHz} = 28.785 \text{ kHz}$$
$$\beta = \frac{28.785}{7.142} \approx 4.03$$
$$B \approx 2 \times 7.142 \text{ kHz} \times (4.03 + 1) \approx 71.42 \text{ kHz}$$

2. For Reading 2:

$$f_m = 7.142 \text{ kHz}$$
$$\Delta f = \frac{95.24 - 30.3}{2} \text{ kHz} = 32.47 \text{ kHz}$$
$$\beta = \frac{32.47}{7.142} \approx 4.55$$
$$B \approx 2 \times 7.142 \text{ kHz} \times (4.55 + 1) \approx 81.42 \text{ kHz}$$

3. For Reading 3:

$$f_m = 11.11 \text{ kHz}$$
$$\Delta f = \frac{83.33 - 40}{2} \text{ kHz} = 21.665 \text{ kHz}$$
$$\beta = \frac{21.665}{11.11} \approx 1.95$$
$$B \approx 2 \times 11.11 \text{ kHz} \times (1.95 + 1) \approx 67.11 \text{ kHz}$$

4. For Reading 4:

$$f_m = 3.937 \text{ kHz}$$
$$\Delta f = \frac{90.91 - 41.67}{2} \text{ kHz} = 24.62 \text{ kHz}$$
$$\beta = \frac{24.62}{3.937} \approx 6.25$$
$$B \approx 2 \times 3.937 \text{ kHz} \times (6.25 + 1) \approx 63.50 \text{ kHz}$$

Results

The modulation index (β) and bandwidth (B) for each reading are summarized as follows:

- For Reading 1:
  - Modulation Index: $\beta \approx 4.03$
  - Bandwidth: $B \approx 71.42$ kHz
- For Reading 2:
  - Modulation Index: $\beta \approx 4.55$
  - Bandwidth: $B \approx 81.42$ kHz
- For Reading 3:
  - Modulation Index: $\beta \approx 1.95$
  - Bandwidth: $B \approx 67.11$ kHz
- For Reading 4:
  - Modulation Index: $\beta \approx 6.25$
  - Bandwidth: $B \approx 63.50$ kHz

Matlab Simulation

Code:

```
% Parameters
fs = 1000;              % Sampling frequency
t = 0:1/fs:1;           % Time vector
fc = 100;               % Carrier frequency
kf = 50;                % Frequency sensitivity
Am = 1;                 % Amplitude of message signal
fm = 10;                % Frequency of message signal
```

```

% Message signal
m = Am * cos(2 * pi * fm * t);

% Carrier signal (square wave)
c = square(2 * pi * fc * t);

% FM Modulation
int_m = cumsum(m) / fs;  % Integral of message signal
s = cos(2 * pi * fc * t + 2 * pi * kf * int_m);

% FM Demodulation
y = diff([0 s]) * fs;    % Differentiate the FM signal
y = abs(hilbert(y));     % Envelope detection

% Modulation Index
beta = kf * Am / fm;
disp(['Modulation Index (beta): ', num2str(beta)]);

% Plotting
figure;

subplot(4,1,1);
plot(t, m);
title('Message Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,2);
plot(t, c);
title('Carrier Signal (Square Wave)');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,3);
plot(t, s);
title('FM Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

subplot(4,1,4);
plot(t, y(1:length(t)));
title('Demodulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

```
% Zoomed-in view of FM Modulated Signal to show frequency variations
zoom_factor = 10;  % Factor to zoom in
zoom_t = t(1:fs/zoom_factor);  % Zoomed-in time vector
zoom_s = s(1:fs/zoom_factor);  % Zoomed-in FM signal

figure;
plot(zoom_t, zoom_s);
title('Zoomed-in FM Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

Output

Experimental Output

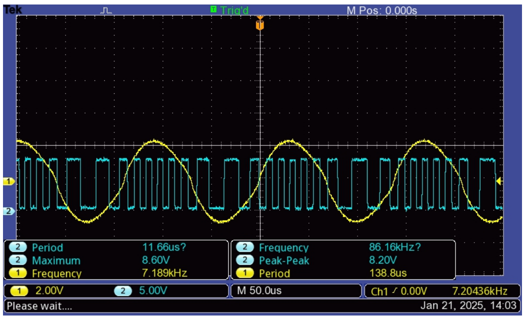

Figure 2: FM; Yellow: Message, Blue: Modulated Signal 1

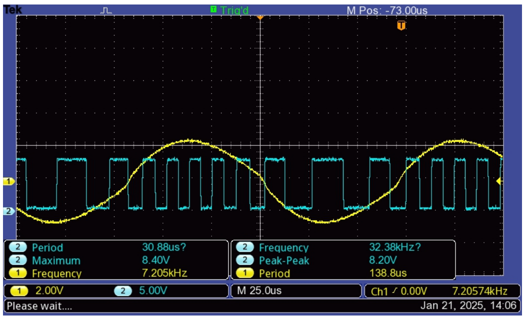

Figure 3: FM; Yellow: Message, Blue: Modulated Signal 2

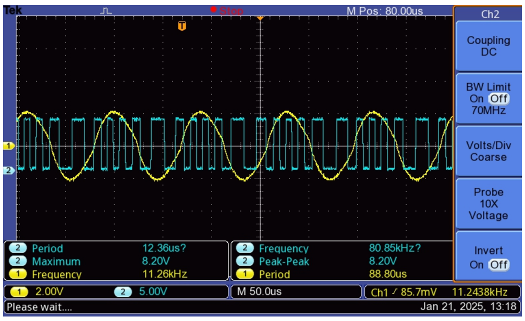

Figure 4: FM; Yellow: Message, Blue: Modulated Signal 3

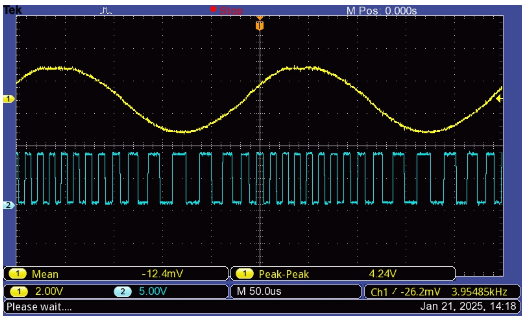

Figure 5: FM; Yellow: Message, Blue: Modulated Signal 4

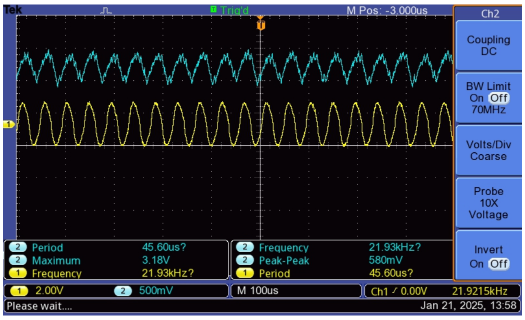

Figure 6: Demodulated; Yellow: Message, Blue: Demodulated Signal 1

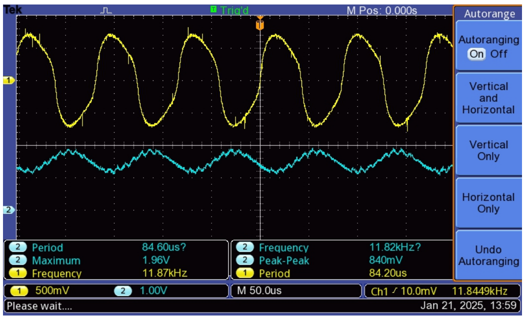

Figure 7: Demodulated; Yellow: Message, Blue: Demodulated Signal 2

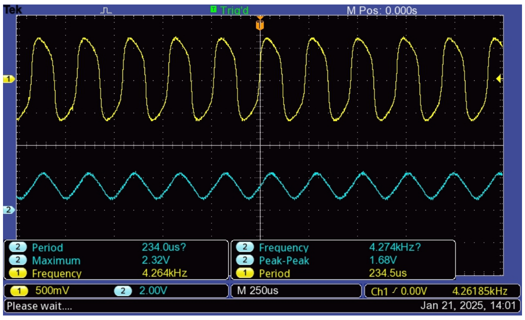

Figure 8: Demodulated; Yellow: Message, Blue: Demodulated Signal 3

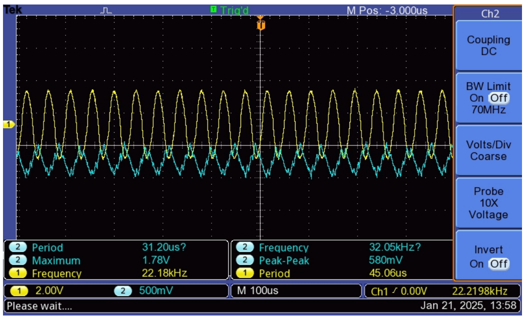

Figure 9: Demodulated; Yellow: Message, Blue: Demodulated Signal 4

Matlab Simulation Output

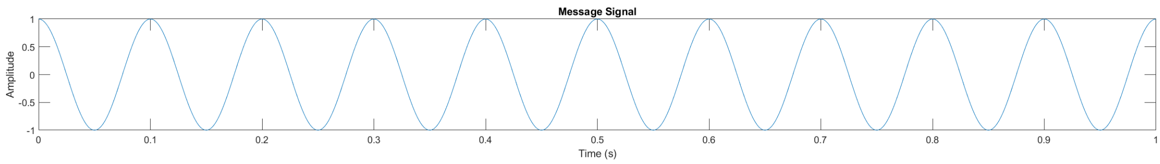

Figure 10: Message Signal

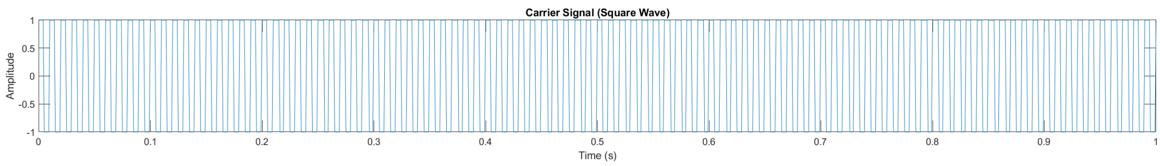

Figure 11: Carrier Signal, Square Wave

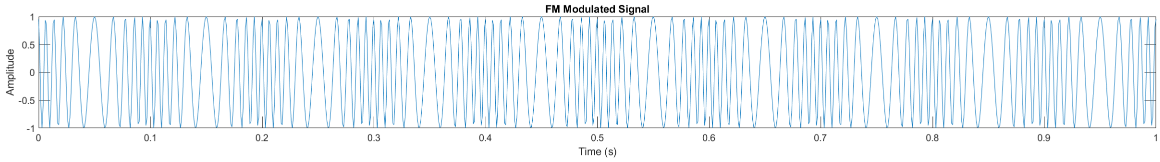

Figure 12: FM Modulated Signal

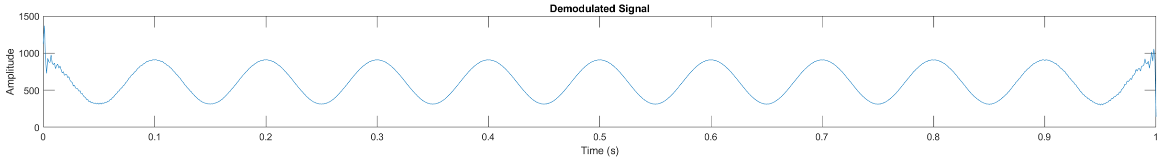

Figure 13: Demodulated Signal

Discussion and Conclusion

The modulation index (β) was found to be crucial in Frequency Modulation (FM) as it determined the bandwidth and the number of significant sidebands. In this experiment, β was calculated for different message signals and modulation frequencies using $\beta = \frac{\Delta f}{f_m}$. Significant variations in β (1.95 to 6.25) were observed, impacting the bandwidth and quality of FM signals. The Matlab simulations confirmed the relationship between β and bandwidth, highlighting the importance of selecting an appropriate β for efficient communication. Valuable insights into the effects of β on FM signals and its significance in FM modulation were provided by this experiment.

Matlab simulations confirmed the relationship between β and bandwidth, highlighting the importance of selecting an appropriate β for efficient communication. Valuable insights into the effects of β on FM signals and its significance in FM modulation were provided by this experiment. The results obtained from the experiment and Matlab simulations were consistent, demonstrating the accuracy and reliability of the calculations. Overall, the experiment was successful in determining the modulation index of FM waves and understanding its impact on signal quality and bandwidth.

References

[1] S. Haykin, *Communication Systems.* Wiley, 2008.

[2] J. G. Proakis and M. Salehi, *Digital Communications.* McGraw-Hill, 2007.

Heaven's Light is Our Guide

Rajshahi University of Engineering and Technology

Course Code
ECE 3208

Course Title
Communication Engineering Sessional

Experiment Date: February 11, 2025,
Submission Date: February 25, 2025

Lab Report 4:
Study of Time Division Multiplexing (TDM) & De-multiplexing

Submitted to	**Submitted by**
Dr. Md. Kamal Hosain	Md. Tajim An Noor
Professor	Roll: 2010025
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Contents

Study of Time Division Multiplexing (TDM) & De-multiplexing

Theory

Time Division Multiplexing (TDM) allows multiple message signals to share a common communication channel by dividing time into slots, each allocated to a different signal [1]. This technique maximizes bandwidth utilization by ensuring each signal gets a dedicated time slot for transmission. Initially, each message signal is filtered to limit its bandwidth, preventing interference with other signals. The signals are then sampled at a rate slightly higher than the Nyquist rate to avoid aliasing and ensure accurate reconstruction at the receiver [2].

The sampled signals are interleaved in time by a commutator, assigning each sample to a specific time slot. This interleaving allows simultaneous transmission of multiple signals over a single channel without interference. At the receiver, a decommutator separates the interleaved samples, assigning them back to their respective message signals [3].

Reconstructing the original message signals from the separated samples is achieved using low-pass filters that smooth out the samples and recreate the continuous-time signals. Synchronization between the commutator and decommutator is essential for proper TDM functioning. Any misalignment can lead to errors in the reconstructed signals, making synchronization mechanisms critical [4]. Overall, TDM is a powerful technique enabling efficient and reliable communication in various applications, including telecommunications and data networks.

Required Apparatus

- TDM Pulse Amplitude Modulation/Demodulation Kit
- Oscilloscope
- Connecting Wires
- Power Supply

Diagrams

Block Diagram of TDM System

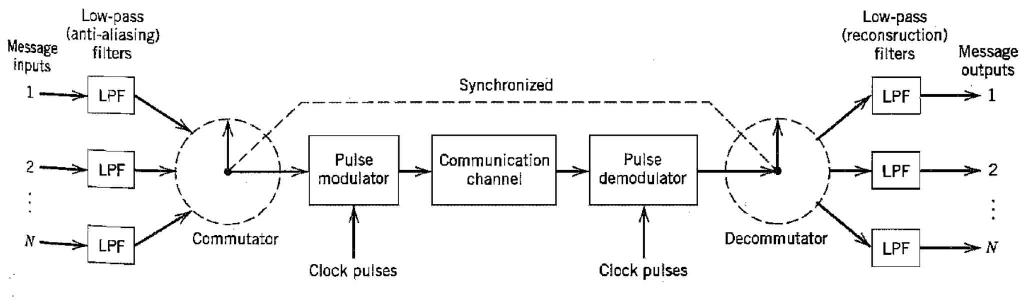

Figure 1: Block Diagram of TDM System [3]

Circuit Connection of the Kit

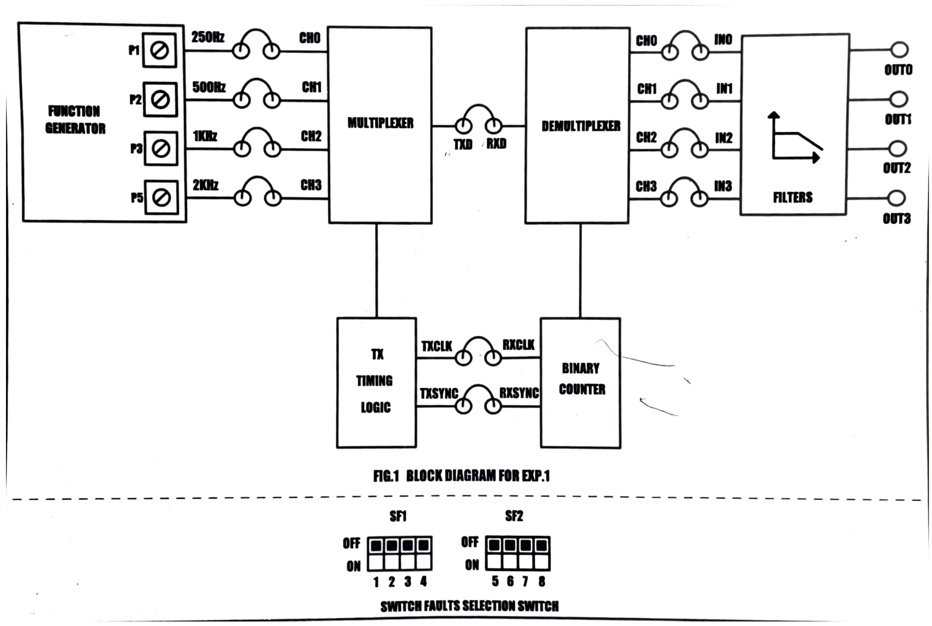

Figure 2: Circuit Connection of the TDM Kit

Procedure

1. The TDM pulse amplitude modulation/demodulation kit was set up and connected to the power supply.

2. The oscilloscope was connected to the output ports of the kit to visualize the signals.

3. The kit was configured to use 5 sources for the TDM process.
4. 4 different signals were selected from the available sources.
5. The selected signals were passed through the multiplexer on the kit.
6. Observe the output message at different ports using the oscilloscope.
7. Record the observations and ensure the signals are correctly multiplexed and de-multiplexed.

Experimental Data

Signal Number	Frequency (Hz)
1	250
2	500
3	1000
4	2000

Table 1: Message Signal Frequencies

Observation

1. The message signal was observed using the oscilloscope.
2. The multiplexed signal was visualized on the oscilloscope.
3. The de-multiplexed signal was also observed using the oscilloscope.
4. Finally, the output message signal was checked using the oscilloscope.
5. Some faults in the kit were noted, so the outputs were not accurate.

Matlab Simulation

Code:

```
% Parameters
fs = 10000;             % Sampling frequency
t = 0:1/fs:0.01;        % Time vector for 10 ms
frequencies = [250, 500, 1000, 2000];  % Frequencies of input signals
num_signals = length(frequencies);     % Number of input signals

% Generate input signals
input_signals = zeros(num_signals, length(t));
```

```
for i = 1:num_signals
    input_signals(i, :) = sin(2 * pi * frequencies(i) * t);
end

% TDM Multiplexing
multiplexed_signal = reshape(input_signals, 1, []);

% TDM Demultiplexing
demultiplexed_signals = reshape(multiplexed_signal, num_signals, []);

% Plotting
figure;

% Plot input signals
subplot(3,1,1);
hold on;
for i = 1:num_signals
    plot(t, input_signals(i, :));
end
title('Input Signals');
xlabel('Time (s)');
ylabel('Amplitude');
legend('250 Hz', '500 Hz', '1 kHz', '2 kHz');
hold off;

% Plot multiplexed signal
subplot(3,1,2);
plot(0:1/fs:(length(multiplexed_signal)-1)/fs, multiplexed_signal);
title('Multiplexed Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot demultiplexed signals
subplot(3,1,3);
hold on;
for i = 1:num_signals
    plot(t, demultiplexed_signals(i, :));
end
title('Demultiplexed Signals');
xlabel('Time (s)');
ylabel('Amplitude');
legend('250 Hz', '500 Hz', '1 kHz', '2 kHz');
hold off;
```

Output

Experimental Output

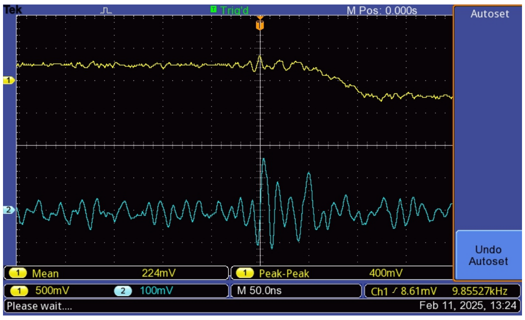

Figure 3: Message (Yellow) and Faulty Output Message (Blue)

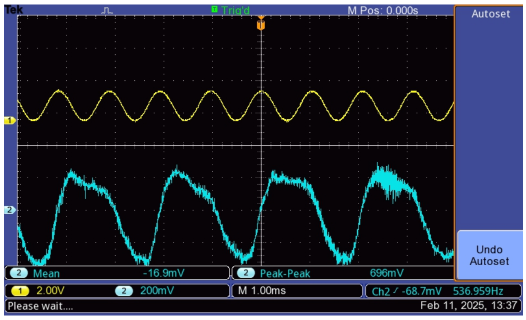

Figure 4: Message (Yellow) and Output Message (Blue)

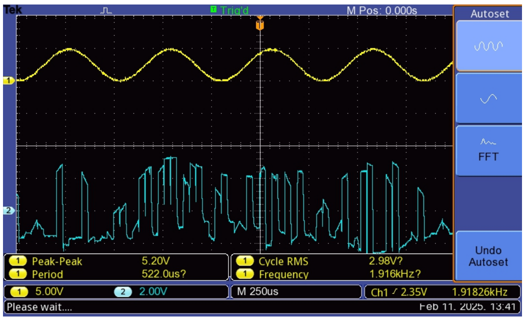

Figure 5: Message (Yellow) and Multiplexed Signal (Blue)

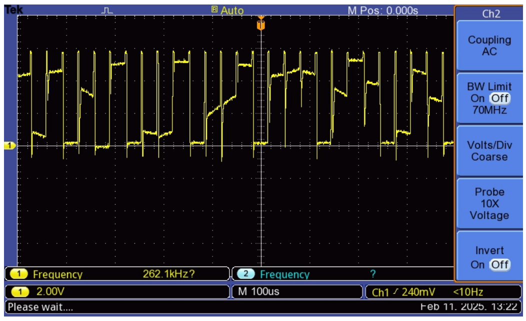

Figure 6: Only Multiplexed Signal (Blue)

Matlab Simulation Output

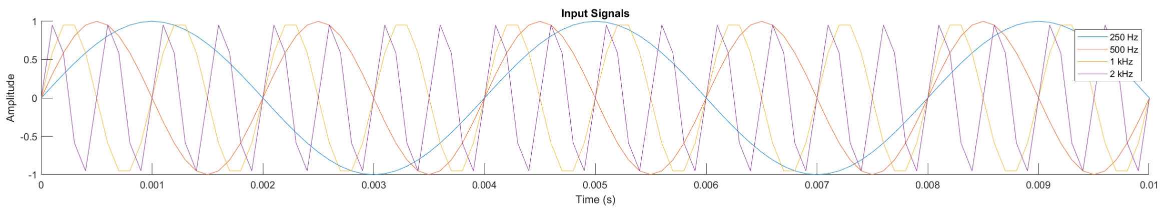

Figure 7: Message Signal

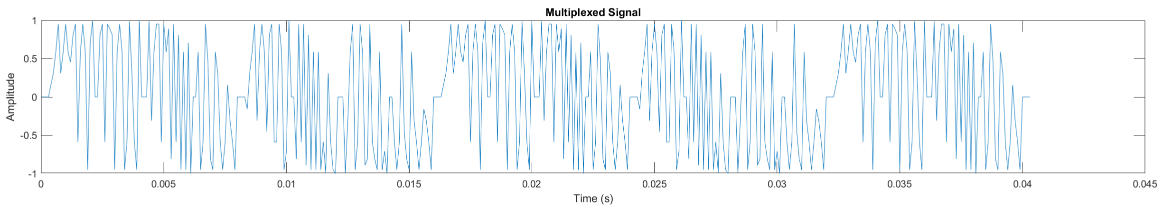

Figure 8: TDM Multiplexed Signal

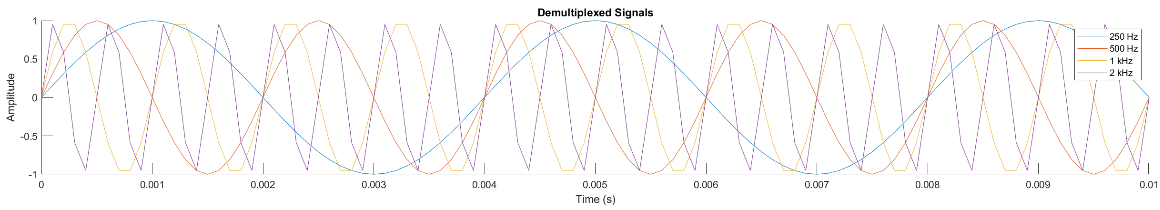

Figure 9: Output Message Signal

Discussion and Conclusion

In this experiment, we explored the principles and practical implementation of Time Division Multiplexing (TDM) and De-multiplexing. Using a TDM Pulse Amplitude Modulation/Demodulation Kit and an oscilloscope, we observed the multiplexing and de-multiplexing processes. The oscilloscope visualized the signals at various stages, and despite some inaccuracies due to faults in the kit, the experiment effectively demonstrated the fundamental concepts of TDM. The Matlab simulation provided additional insights, with the simulation output aligning with theoretical expectations.

In conclusion, this experiment offered valuable insights into TDM and its practical applications. The combination of theoretical study, hands-on experimentation, and Matlab simulation provided a comprehensive understanding of the topic. Future experiments could focus on addressing the kit's faults for more accurate results and exploring advanced TDM techniques for complex communication systems.

References

[1] J. G. Proakis and M. Salehi, *Digital Communications*, 5th ed. McGraw-Hill, 2008.

[2] A. V. Oppenheim, A. S. Willsky, and S. H. Nawab, *Signals and Systems*, 2nd ed. Prentice Hall, 1996.

[3] S. Haykin and M. Moher, *Communication Systems*, 5th ed. Wiley, 2009.

[4] B. Sklar and F. Harris, *Digital Communications: Fundamentals and Applications*, 2nd ed. Prentice Hall, 2001.

Heaven's Light is Our Guide

Rajshahi University of Engineering and Technology

Course Code
ECE 3208

Course Title
Communication Engineering Sessional

Experiment Date: February 25, 2025,
Submission Date: April 22, 2025

Lab Report 5:
Study of Pulse Code Modulation (PCM)

Submitted to	Submitted by
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Professor	Roll: 2010025
Dept of ETE, RUET	

Contents

Study of Pulse Code Modulation (PCM)

Theory

Pulse Code Modulation (PCM) digitally represents analog signals, used in digital audio, telephony, and more. It involves sampling and quantization [1].

Sampling

Sampling converts a continuous signal into discrete samples. According to the Nyquist-Shannon theorem, the sampling rate must be at least twice the highest frequency in the signal [2]. Mathematically:

$$x[n] = x(nT_s)$$

where T_s is the sampling interval.

Quantization

Quantization maps sampled values to a finite set of levels, introducing quantization error. The quantized signal is:

$$x_q[n] = Q(x[n])$$

Encoding

Quantized values are encoded into binary form. The number of bits used determines the resolution [3].

Advantages of PCM

- High noise immunity
- Efficient storage and transmission
- Compatibility with digital systems

Applications of PCM

- Digital telephony
- Audio recording
- Data communication

Required Apparatus

- DigitalModulationDemodulationKit (DL 3155M61)
- Oscilloscope
- ConnectingWires
- PowerSupply

Diagrams

Block Diagram of PCM System

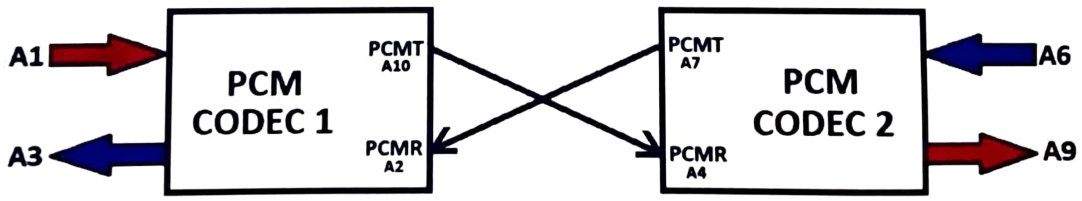

Figure 1: Block Diagram of PCM System

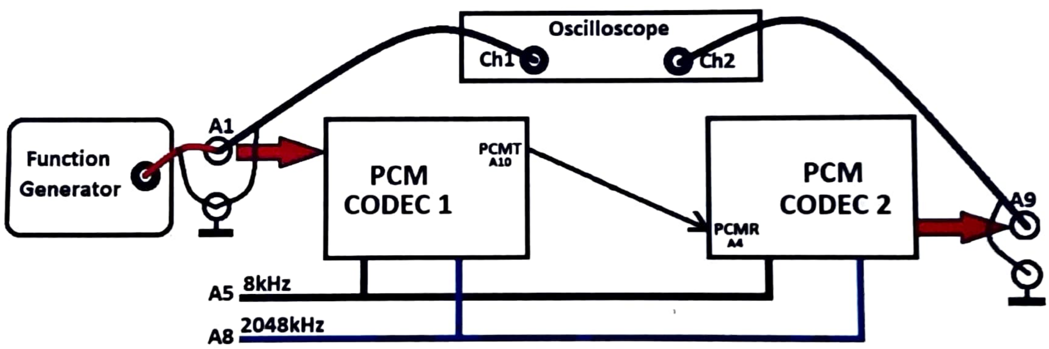

Figure 2: Block Diagram of PCM System (Detailed)

PCM Section of Kit DL 3155M61

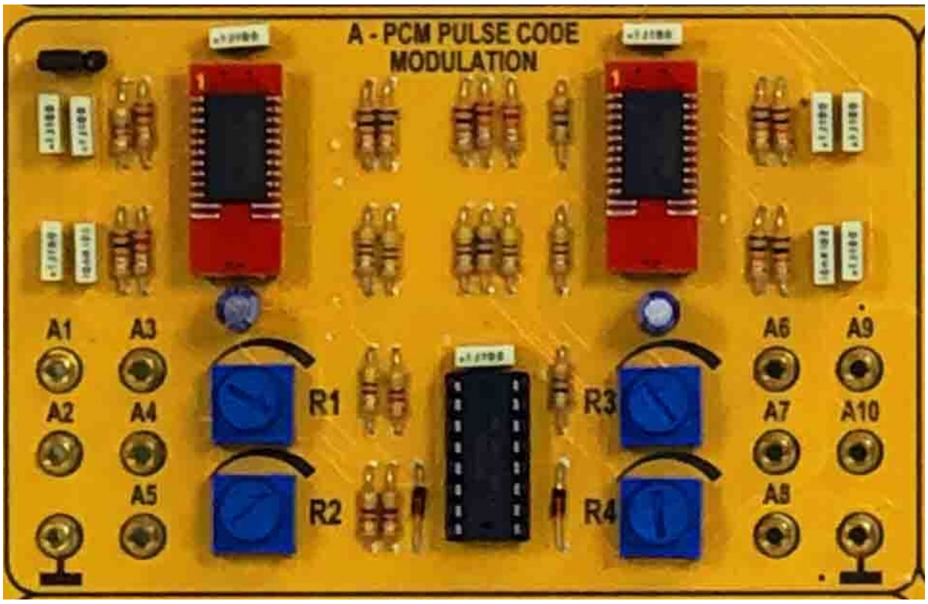

Figure 3: PCM Section of Kit DL 3155M61

Procedure

1. The signal input (analog signal) was connected to pin A1.
2. The PCM signal was observed on pins A10 and A4.
3. The demodulated signal was observed on pin A9.
4. Alternatively, the signal input was connected to pin A6.
5. The PCM signal was observed on pins A7 and A2.
6. The output signal was observed on pin A3.
7. The 8kHz and 2048kHz signals were noted on pins A5 and A8.
8. An oscilloscope was used to observe and verify the signals.

Observation

We observed significant noise in the PCM and demodulated signals due to:

- Faulty connections or components.
- External interference.

- Inaccurate sampling or quantization.
- Insufficient filtering of the analog signal.

Ensure secure connections, functional components, and proper shielding and filtering to reduce noise.

Matlab Simulation

Code:

```
% Parameters
fs = 10000;            % Sampling frequency
t = 0:1/fs:0.01;       % Time vector for 10 ms
f = 1000;              % Frequency of input signal
A = 1;                 % Amplitude of input signal
n_bits = 8;            % Number of bits for quantization

% Generate input signal
input_signal = A * sin(2 * pi * f * t);

% Quantization
L = 2^n_bits;          % Number of quantization levels
q_step = (2 * A) / L; % Quantization step size
quantized_signal = round(input_signal / q_step) * q_step;

% PCM Encoding
pcm_encoded = de2bi((quantized_signal / q_step) + (L/2), n_bits,
↪  'left-msb');

% PCM Decoding
decoded_signal = (bi2de(pcm_encoded, 'left-msb') - (L/2)) * q_step;

% Plotting
figure;

% Plot input signal
subplot(3,1,1);
plot(t, input_signal, 'LineWidth', 1.5);
title('Input Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot PCM modulated signal
subplot(3,1,2);
```

```
stairs(t, quantized_signal, 'LineWidth', 1.5);
title('PCM Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot demodulated signal
subplot(3,1,3);
plot(t, decoded_signal, 'LineWidth', 1.5);
title('Demodulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

Output

Experimental Output

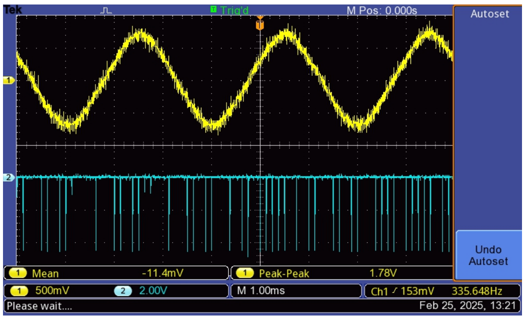

Figure 4: Input Signal (Yellow) and PCM Signal (Blue)

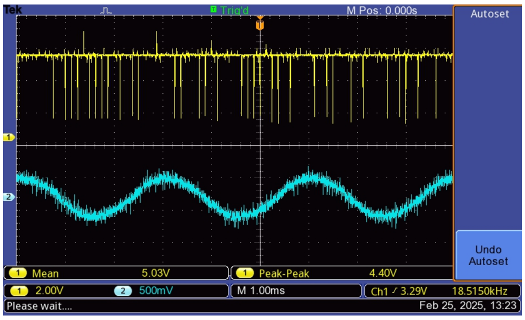

Figure 5: PCM Signal (Yellow) and Demodulated Signal (Yellow)

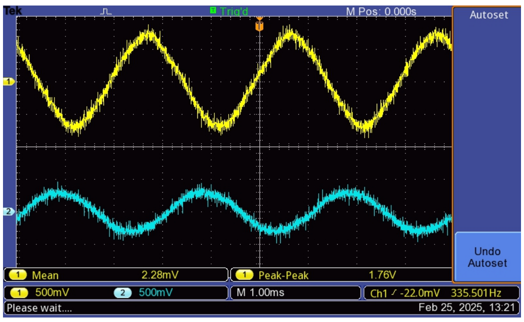

Figure 6: Input Signal (Yellow) and Demodulated Signal (Blue)

Matlab Simulation Output

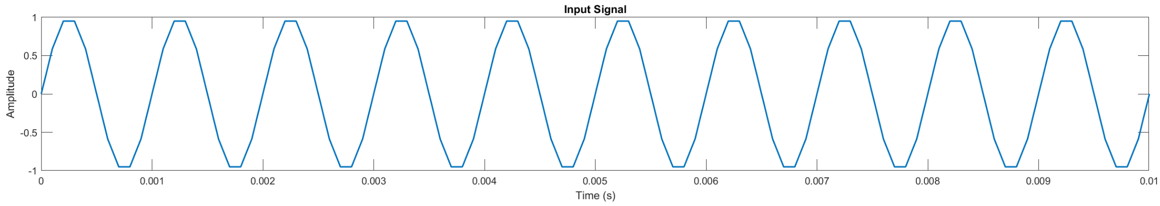

Figure 7: Message Signal

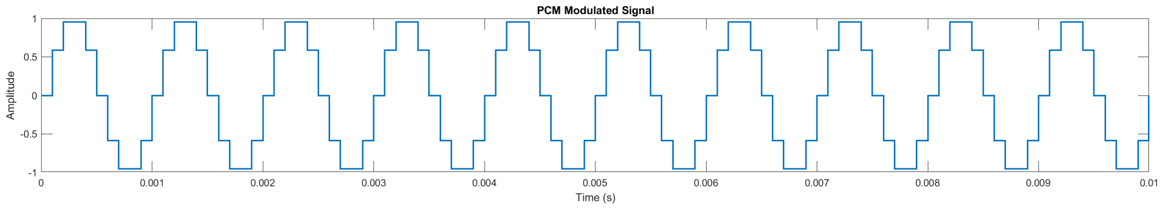

Figure 8: PCM Signal

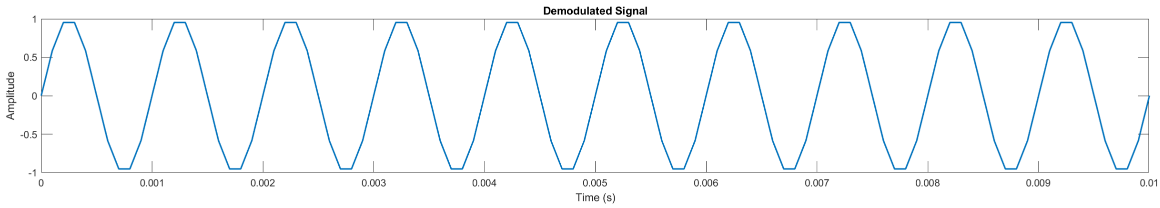

Figure 9: Output Message Signal

Discussion and Conclusion

The core principles of Pulse Code Modulation (PCM) were effectively demonstrated through the experiment. By adhering to the outlined procedure, the PCM signal and its demodulated output were successfully observed, thereby validating the theoretical concepts of sampling, quantization, and encoding. Notably, significant noise in the PCM and demodulated signals was highlighted, which could be attributed to factors such as faulty connections, external interference, and inaccuracies in sampling or quantization. Addressing these issues through secure connections, functional components, and proper shielding and filtering was deemed crucial.

The theoretical understanding was further reinforced by the Matlab simulation, which provided a clear visualization of the PCM process. The simulation output closely aligned with the expected results, confirming the accuracy of the implemented code. Overall, a comprehensive understanding of PCM was offered by the experiment and simulation together, emphasizing the importance of precision in electronic communication systems. Future work could focus on enhancing noise reduction techniques and exploring advanced PCM applications.

References

[1] A. V. Oppenheim, A. S. Willsky, and S. H. Nawab, *Signals and Systems*. Prentice-Hall, Inc., 1996.

[2] C. E. Shannon, "Communication in the presence of noise," *Proceedings of the IRE*, vol. 37, no. 1, pp. 10–21, 1949.

[3] J. G. Proakis and D. G. Manolakis, *Digital Signal Processing: Principles, Algorithms, and Applications*. Pearson Prentice Hall, 2007.

Heaven's Light is Our Guide

Rajshahi University of Engineering and Technology

Course Code

ECE 3208

Course Title

Communication Engineering Sessional

Experiment Date: February 25, 2025,

Submission Date: April 22, 2025

Lab Report 6:

Study of Digital Modulation (ASK, FSK, PSK)

Submitted to	**Submitted by**
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Contents

Study of Digital Modulation (ASK, FSK, PSK)

Theory

Digital modulation encodes digital data into waveforms by varying the carrier signal's amplitude, frequency, or phase. Common types include ASK, FSK, and PSK [1].

Amplitude Shift Keying (ASK)

Amplitude Shift Keying (ASK) varies the carrier signal's amplitude based on binary data:

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{if } m(t) = 1 \\ 0 & \text{if } m(t) = 0 \end{cases}$$

where A is the amplitude, f_c the carrier frequency, and $m(t)$ the message signal [2].

Frequency Shift Keying (FSK)

Frequency Shift Keying (FSK) varies the carrier signal's frequency based on binary data:

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{if } m(t) = 1 \\ A\cos(2\pi f_2 t) & \text{if } m(t) = 0 \end{cases}$$

where f_1 and f_2 are the frequencies for binary 1 and 0 [3].

Phase Shift Keying (PSK)

Phase Shift Keying (PSK) varies the carrier signal's phase based on binary data:

$$s(t) = A\cos(2\pi f_c t + \theta), \quad \theta = \begin{cases} 0 & \text{if } m(t) = 1 \\ \pi & \text{if } m(t) = 0 \end{cases}$$

where A is the amplitude, f_c the carrier frequency, and $m(t)$ the message signal [4].

Required Apparatus

- ETEK DCS-6000-06 (ASK Modulation & Demodulation Kit)
- ETEK DCS-6000-07 (FSK Modulation & Demodulation Kit)
- ETEK DCS-6000-08 (PSK(BPSK) Modulation & Demodulation Kit)
- Oscilloscope
- Connecting Wires
- Power Supply
- Signal Generator (To make Square Waves to offset to mimic digital signal)

Diagrams

Block Diagram & Waveform of ASK System

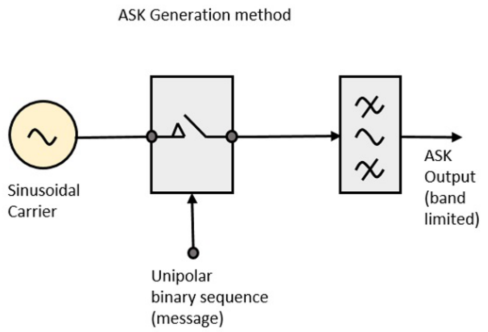

Figure 1: Block Diagram of ASK System

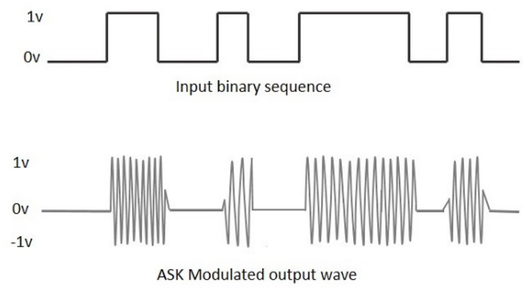

Figure 2: Waveform of ASK System

Block Diagram & Waveform of FSK System

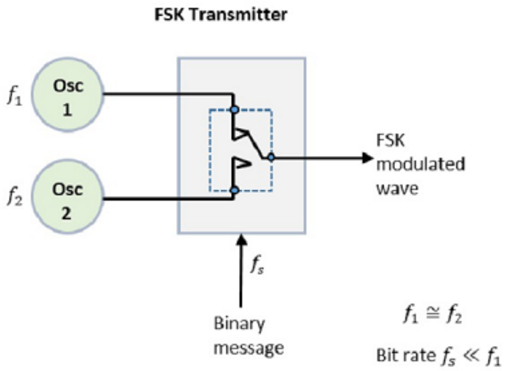

Figure 3: Block Diagram of FSK System

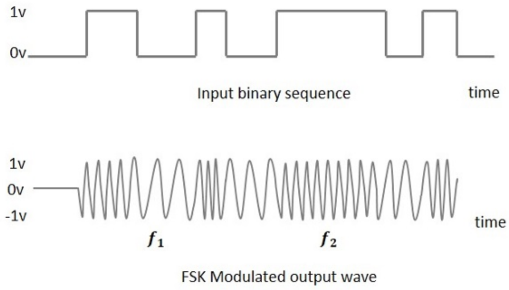

Figure 4: Waveform of FSK System

Block Diagram & Waveform of BPSK System

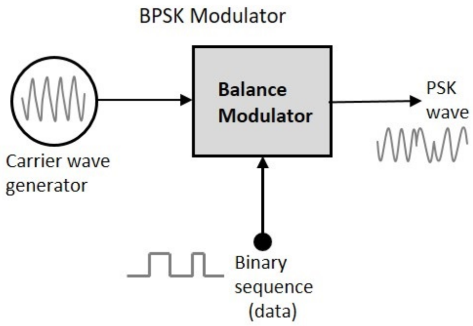

Figure 5: Block Diagram of BPSK System

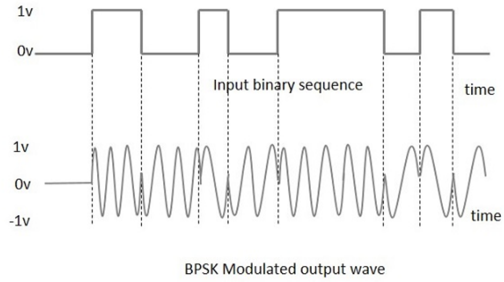

Figure 6: Waveform of BPSK System

Procedure

1. The ASK Modulation & Demodulation Kit (ETEK DCS-6000-06) was connected to the power supply.

2. The signal generator was connected to the input of the ASK modulator to generate a square wave signal.

3. The modulated ASK signal was observed on the oscilloscope.

4. The output of the ASK modulator was connected to the input of the ASK demodulator.

5. The demodulated signal was observed on the oscilloscope and compared with the original input signal.

6. The above steps were repeated for the FSK Modulation & Demodulation Kit (ETEK DCS-6000-07) and PSK(BPSK) Modulation & Demodulation Kit (ETEK DCS-6000-08).

Observation

- In ASK, the amplitude of the carrier signal changes with the binary data: present for 1, absent for 0.
- In FSK, the frequency of the carrier signal changes with the binary data: f_1 for 1, f_2 for 0.
- In PSK, the phase of the carrier signal changes with the binary data: 0 for 1, π for 0.
- For ASK demodulation, the demodulated signal closely matches the original binary data by detecting the carrier signal's presence or absence, but it wasn't perfect.

Matlab Simulation

Code:

```matlab
% Parameters
fs = 10000;            % Sampling frequency
t = 0:1/fs:1;          % Time vector for 1 second
f_carrier = 100;       % Further lowered Carrier frequency
bit_rate = 10;         % Bit rate
bits = [1 0 1 1 0 1 0 0 1 0]; % Input digital signal

% Generate input digital signal (square wave)
samples_per_bit = round(fs / bit_rate); % Ensure samples_per_bit is an integer
t = 0:1/fs:(length(bits) * samples_per_bit - 1) / fs; % Adjust t to match input_signal length
input_signal = repelem(bits, samples_per_bit);

% ASK Modulation
carrier_signal = sin(2 * pi * f_carrier * t); % Generate carrier signal
ask_signal = input_signal .* carrier_signal; % Modulate carrier with input signal
```

```
% FSK Modulation
f1 = 50;   % Further lowered frequency for bit 0
f2 = 150;  % Further lowered frequency for bit 1
fsk_signal = (input_signal == 0) .* sin(2 * pi * f1 * t) + (input_signal == 1) .* sin(2 * pi * f2 * t);

% PSK Modulation
psk_signal = sin(2 * pi * f_carrier * t + pi * input_signal);

% ASK Demodulation
ask_demodulated = ask_signal .* carrier_signal; % Multiply with carrier signal
[b, a] = butter(6, f_carrier/(fs/2));          % Low-pass filter design
ask_demodulated = filter(b, a, ask_demodulated); % Apply low-pass filter
ask_demodulated = ask_demodulated > 0.25;       % Thresholding for binary signal

% Plotting
figure;

% Plot input digital signal
subplot(5,1,1);
plot(t, input_signal, 'LineWidth', 1.5); % Thicker line
title('Input Digital Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot ASK signal
subplot(5,1,2);
plot(t, ask_signal, 'LineWidth', 1.5); % Thicker line
title('ASK Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot FSK signal
subplot(5,1,3);
plot(t, fsk_signal, 'LineWidth', 1.5); % Thicker line
title('FSK Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot PSK signal
```

```
subplot(5,1,4);
plot(t, psk_signal, 'LineWidth', 1.5); % Thicker line
title('PSK Modulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');

% Plot ASK demodulated signal
subplot(5,1,5);
plot(t, ask_demodulated, 'LineWidth', 1.5); % Thicker line
title('ASK Demodulated Signal');
xlabel('Time (s)');
ylabel('Amplitude');
```

Output

Experimental Output

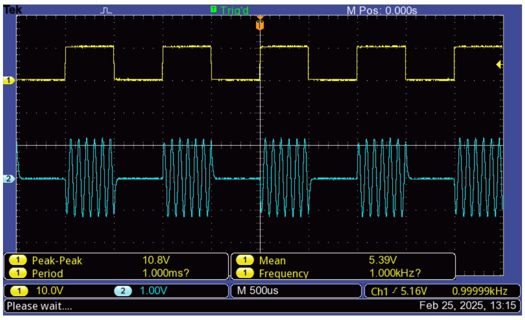

Figure 7: ASK Modulation; Message (Yellow), Modulated Signal (Blue)

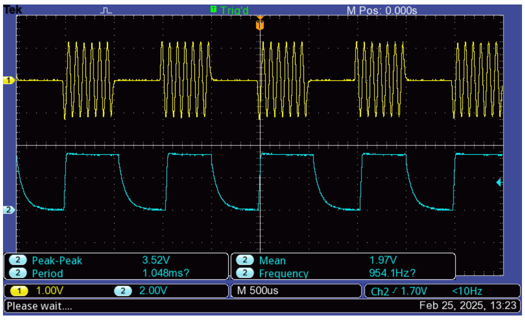

Figure 8: ASK Demodulation; Modulated Signal (Yellow), Demodulated Signal (Blue)

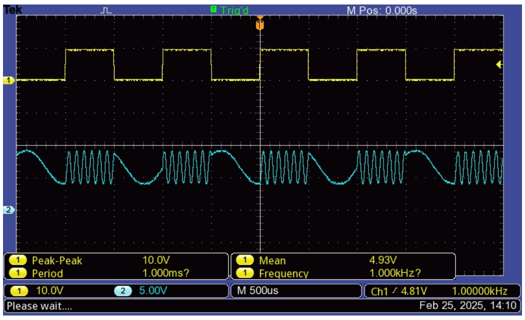

Figure 9: FSK Modulation 1; Message (Yellow), Modulated Signal (Blue)

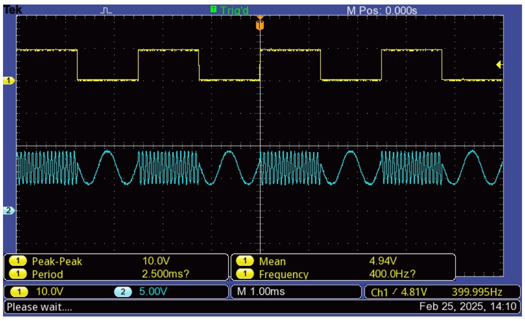

Figure 10: FSK Modulation 2; Message (Yellow), Modulated Signal (Blue)

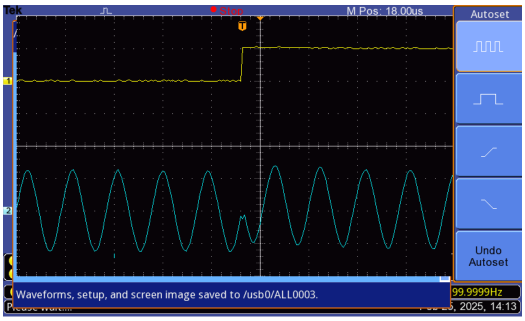

Figure 11: PSK Modulation 1; Message (Yellow), Modulated Signal (Blue)

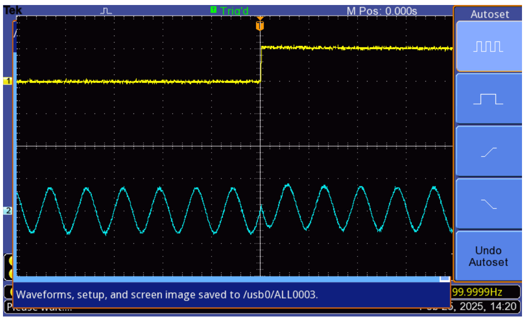

Figure 12: PSK Modulation 2; Message (Yellow), Modulated Signal (Blue)

Matlab Simulation Output

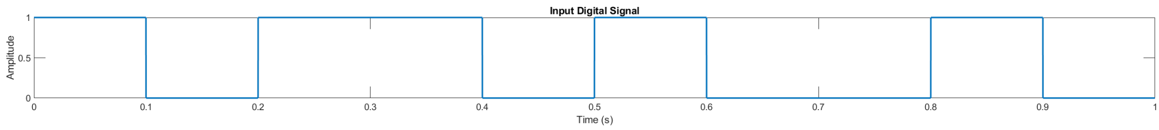

Figure 13: Digital Message Signal

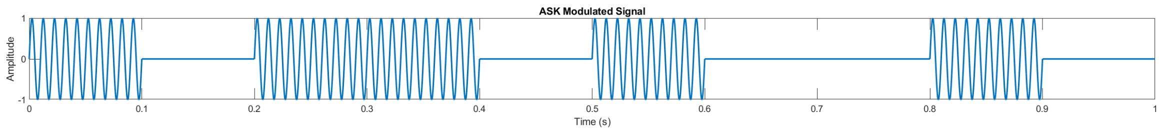

Figure 14: ASK Modulated Signal

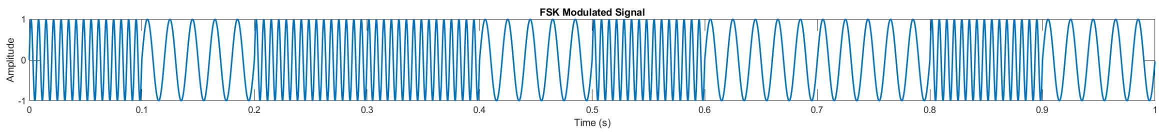

Figure 15: FSK Modulated Signal

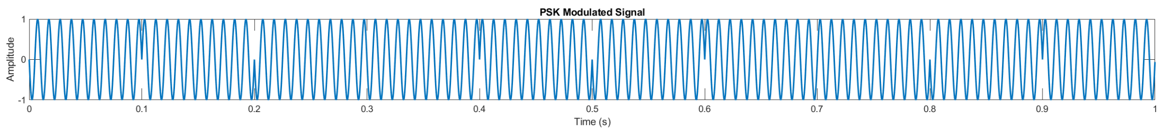

Figure 16: PSK Modulated Signal

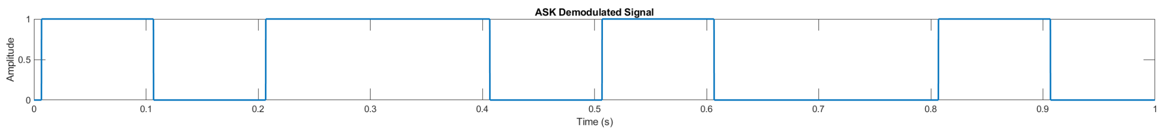

Figure 17: ASK Demodulated Signal

Discussion and Conclusion

The experiment aimed to study digital modulation techniques: Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK). Using specific modulation and demodulation kits, we observed the modulated and demodulated signals on an oscilloscope and compared them with the original input signals.

In ASK, the carrier signal's amplitude changed with the binary data, present for 1 and absent for 0. In FSK, the frequency changed, with f_1 for 1 and f_2 for 0. In

PSK, the phase changed, with 0 for 1 and π for 0. For ASK demodulation, the demodulated signal matched the original binary data by detecting the carrier signal's presence or absence. However, a slight curve in the demodulated message signal indicated it was not a perfect digital signal.

In conclusion, the experiment demonstrated the principles of ASK, FSK, and PSK modulation and demodulation. The oscilloscope observations confirmed the theoretical expectations. The slight imperfection in the ASK demodulated signal suggests minor distortions in real-world implementations, which should be considered in practical applications. Overall, the experiment provided valuable insights into digital modulation techniques and their practical implications.

References

[1] J. G. Proakis and M. Salehi, *Digital Communications.* McGraw-Hill, 2007.

[2] B. Sklar, *Digital Communications: Fundamentals and Applications.* Prentice Hall, 2001.

[3] S. Haykin, *Communication Systems.* Wiley, 2001.

[4] B. Lathi and Z. Ding, *Modern Digital and Analog Communication Systems.* Oxford University Press, 2009.