FACULTY OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENEE 4113, Communication Laboratory

Experiment. 5 Report

Phase Modulation and Demodulation

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Abstract

This experiment explores Phase Modulation (PM) and its demodulation techniques, providing both theoretical and practical insights. The experiment demonstrates the phase variation of a carrier signal based on the instantaneous amplitude of the modulating signal. The study also investigates the relationship between PM and Frequency Modulation (FM), highlighting their similarities and differences. The experiment is conducted using a sinusoidal message signal, with the PM modulated signal analyzed in both time and frequency domains. Demodulation is performed using differentiation and envelope detection, as well as Phase-Locked Loop (PLL) methods. The results confirm that PM effectively encodes information through phase variations and that PLL is a reliable demodulation technique. The findings emphasize the impact of modulation index on spectral characteristics and demonstrate the role of loop filters in signal recovery.

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Theory

Phase Modulation

Phase Modulation (PM) is a type of angle modulation where the phase of the carrier signal is varied according to the instantaneous amplitude of the modulating signal. Unlike Frequency Modulation (FM), where the frequency deviation is directly proportional to the amplitude of the modulating signal, in PM, the phase deviation is directly related to the modulating signal.

A phase-modulated signal can be mathematically expressed as:

Expression of an angle modulated signal

- $s(t) = A_c \cos\left(2\pi f_c t + K_P \mathrm{m}(t)\right)$

where:

- A_c is the carrier amplitude,
- f_c is the carrier frequency,
- K_P is the phase deviation constant (radians per volt),
- m(t) is the modulating signal.

Since phase changes over time affect frequency, PM and FM are closely related. FM can be obtained by differentiating the message signal before applying it to a PM modulator, whereas PM can be generated from FM by integrating the message signal before applying it to an FM modulator.[1]

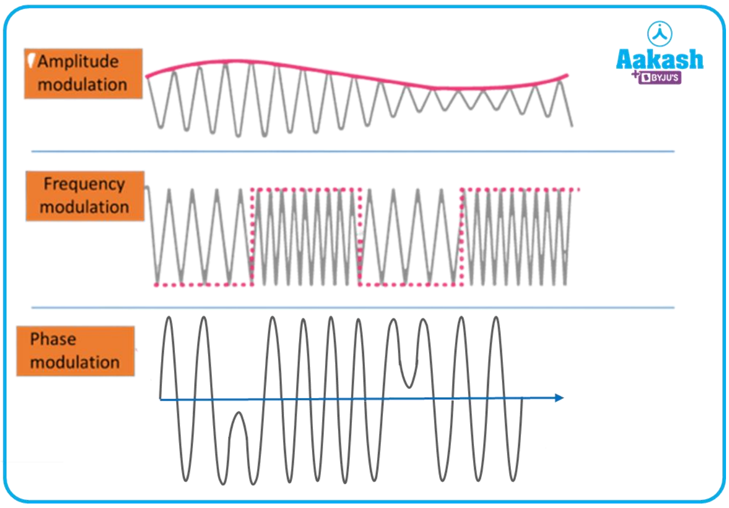

Figure 1 PM modulation

Comparison Between PM and FM

Both PM and FM belong to angle modulation but differ in their approach:

- PM: The phase of the carrier signal is varied, indirectly affecting frequency.
- FM: The frequency of the carrier wave is directly modified based on the message signal.
-

A key relationship between them is:

FM ≈ d(PM) /dt

This means PM can be obtained by integrating the message signal before applying FM, and vice versa.

Demodulation of Phase Modulation (PM)

Demodulation is the process of retrieving the original message signal from a phase-modulated waveform. PM demodulation can be performed using two primary methods:

1. Differentiation and Envelope Detection

Since FM is the derivative of PM, a PM signal can be first differentiated to obtain an FM-like signal. This signal is then passed through an envelope detector, which extracts the amplitude variations corresponding to the original message signal.

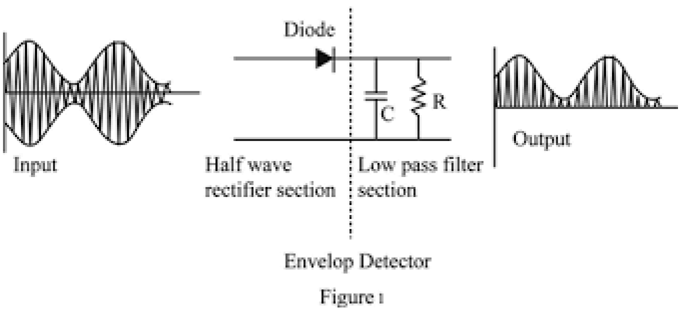

Figure 2 Envelope Detection [2]

2. Phase-Locked Loop (PLL) Demodulation

A Phase-Locked Loop (PLL) is a feedback control system that locks onto the phase of the incoming PM signal and tracks it to recover the modulating signal. The PLL consists of three key components:

- Phase Detector (PD): Compares the phase of the received PM signal with a locally generated signal.

- Low-Pass Filter (LPF): Removes high-frequency components and provides a smooth error signal.
- Voltage-Controlled Oscillator (VCO): Adjusts the frequency of the local signal to match the incoming phase variations.

The output of the PLL provides a recovered version of the original message signal.

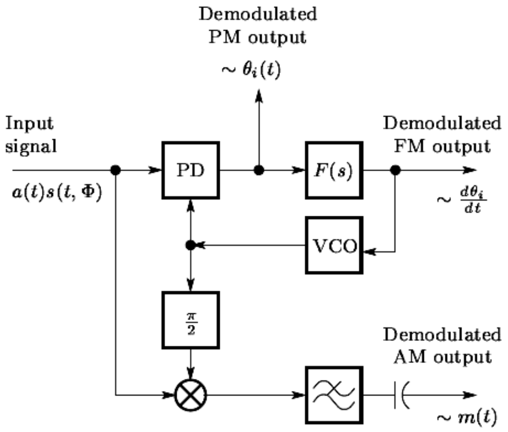

Figure 3 PLL [3]

Applications of Phase Modulation

- Digital Communication: Used in Phase Shift Keying (PSK) for wireless networks and satellite communications.
- Radar and Sonar: Helps measure the velocity of moving objects.
- Audio Processing: Employed in music synthesis, such as Yamaha's FM synthesis.

Advantages and Disadvantages of PM

Advantages:

- Improved noise immunity compared to AM.
- Efficient bandwidth utilization when optimized.
- Less affected by amplitude distortion.

Disadvantages:

- Complex receiver design due to phase synchronization requirements.
- Higher bandwidth consumption in some cases.
- Phase ambiguity in digital PM techniques like PSK.

Procedure and data analysis

Part One: Phase Modulation

1. Displaying the FM signal in time domain

In this part, the message signal was phase modulated and analyzed in the time domain using the CASSY Lab software.

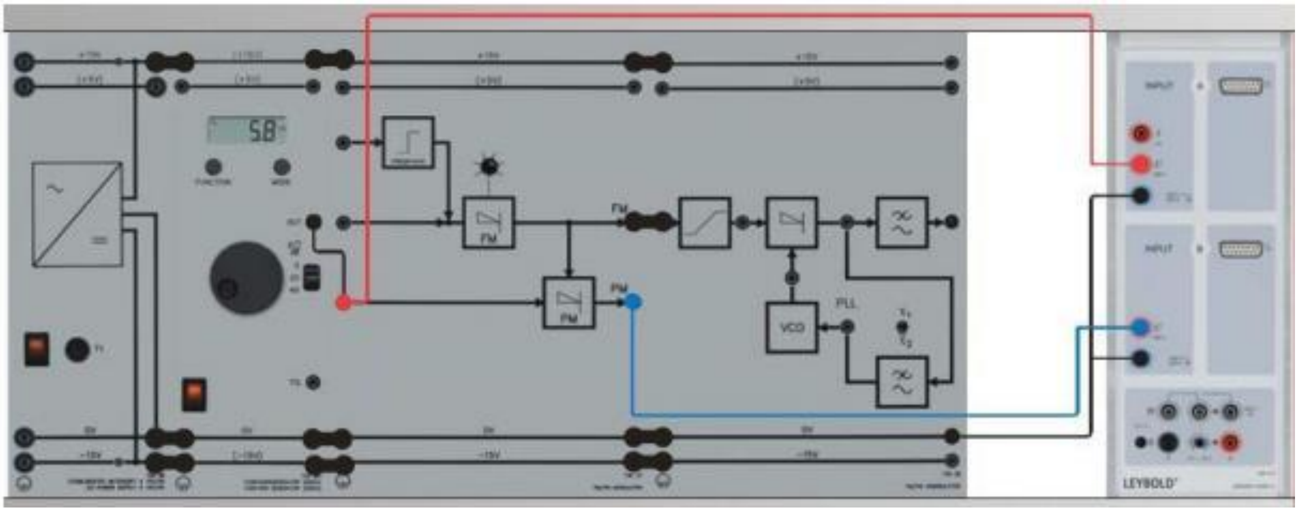

Figure 4 PM modulation connection

After configuring the circuit as illustrated in Figure 4: PM modulation connection, the function generator was adjusted to produce a sinusoidal message signal with a peak-to-peak amplitude of 2V and a frequency of 1kHz. The carrier frequency knob was set to approximately 20kHz.

The carrier frequency was confirmed by tuning the carrier knob and analyzing the frequency domain representation via FFT, where an impulse at 20kHz indicated the carrier frequency was properly set.

→Plots of message signal in both time domain and frequency domain

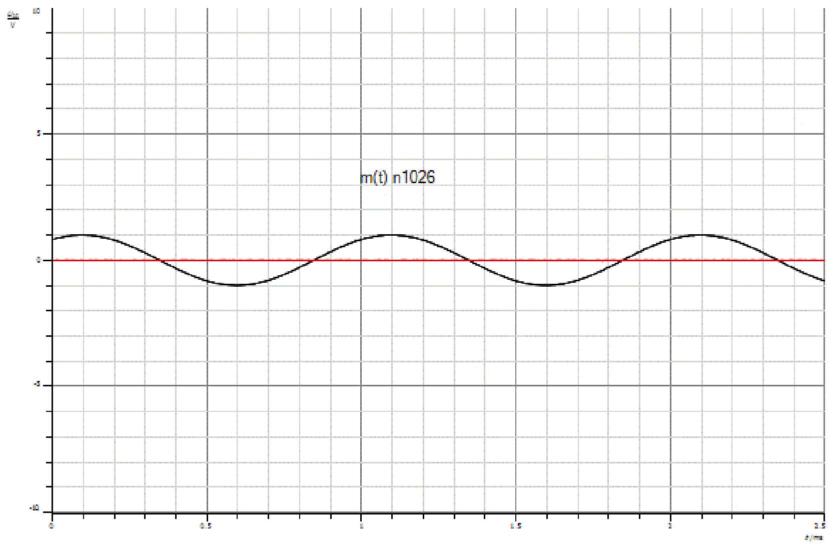

Figure 5: Message signal m(t) in Time Domain

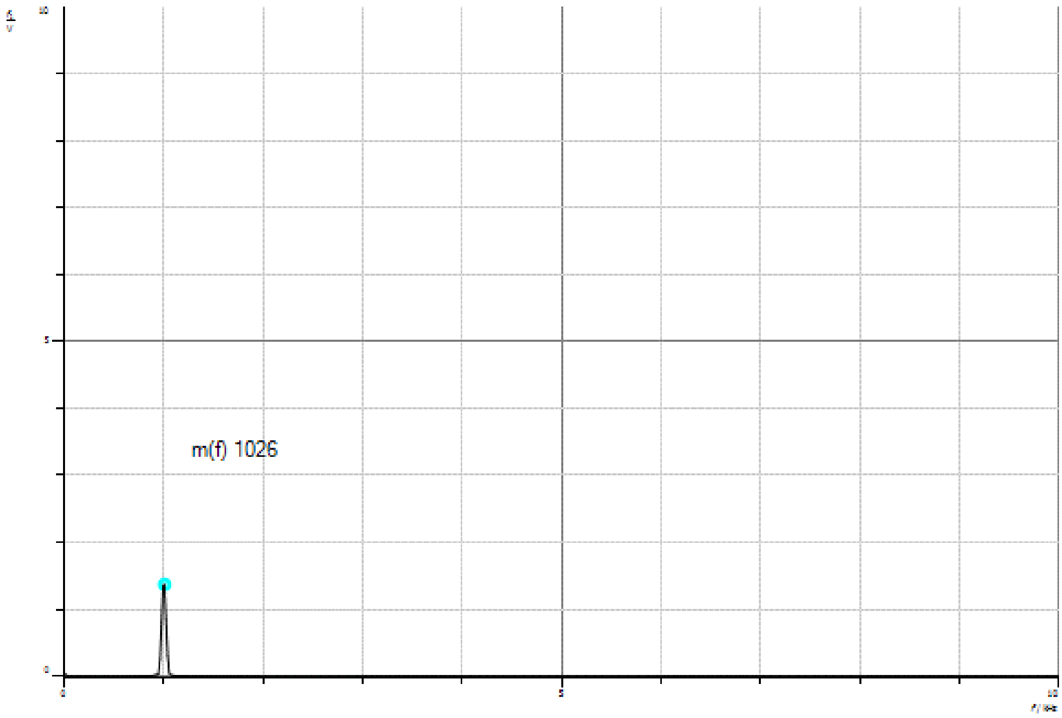

Figure 6: Message signal m(t) in frequency Domain

→Plots of PM-modulated signal s(t) in both time and frequency domain

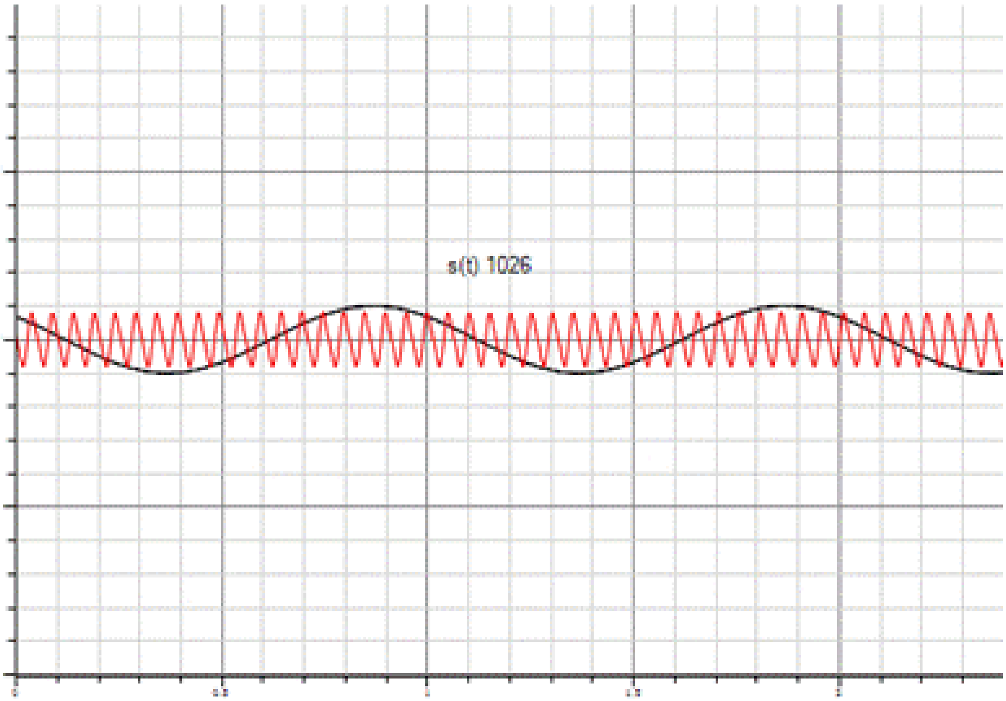

Figure 7 Modulated signal s(t) in time domain

The message signal is represented by the black signal, while the modulated signal s(t) is represented by the red signal.

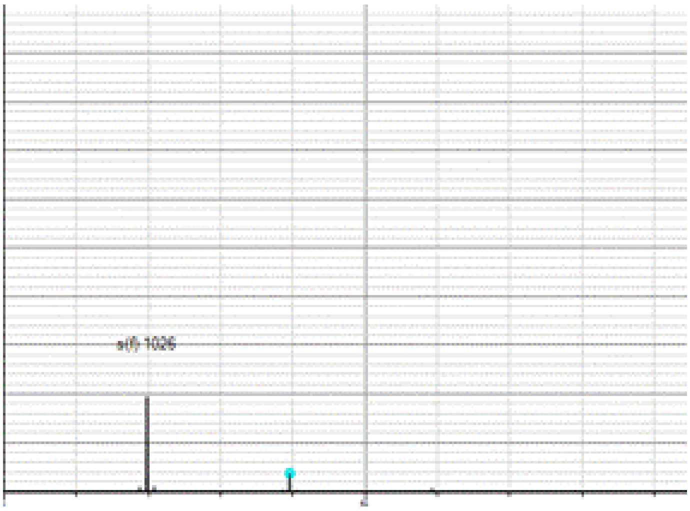

Figure 8: Modulated signal in frequency domain

In phase modulation (PM), the carrier signal's phase shifts depending on the amplitude of the message signal. The stronger the message signal, the bigger the phase shift. This happens because PM works by adjusting the phase of the carrier wave based on how the message signal changes. So, when the message signal rises, the carrier's phase moves forward, and when it falls, the phase shifts back. This is how PM encodes information, translating amplitude variations into phase changes.

2. Frequency Domain (Spectrum)

2.1 The Characteristic of the FM Modulator

The objective of this section was to determine the sensitivity of the PM modulator Kp using a 20kHz carrier signal by modulating a DC signal message in the range of -1V to 1V. The phase shift (in μs) between the carrier oscillations of the FM and PM output was determined. The following table was generated:

Message Voltage (Volt)	$\Delta \mathbf{t}(\mu s)$	$\Delta\, \boldsymbol{\vartheta}$
-1	16	115.2
-0.6	17	122.4
-0.2	18	129.6
0.2	18	129.6
0.6	21	151.2
1.0	25	180.0

Table 1: $\Delta\, \boldsymbol{\vartheta}$ of PM modulation

The equation used to calculate $\Delta\, \vartheta$ is: $\Delta\, \vartheta = (\Delta t)\,(fc)360° = (\Delta t \div Tc)\ 360°$.

given that the carrier frequency is 20KHz, the period is:T= 1/fc=50 μs

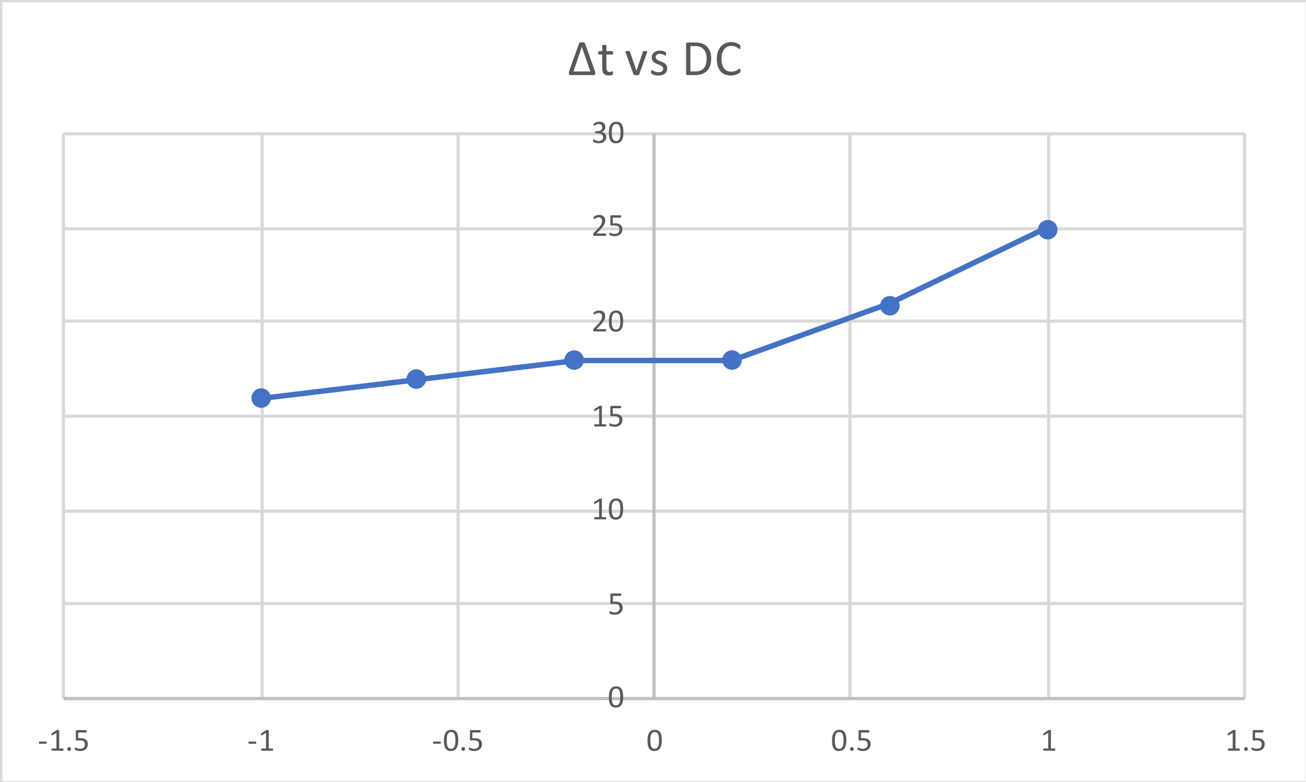

Figure 9: Δt vs DC message

The figure below shows the graph of Δt corresponding to each $\Delta\,\vartheta$ value.

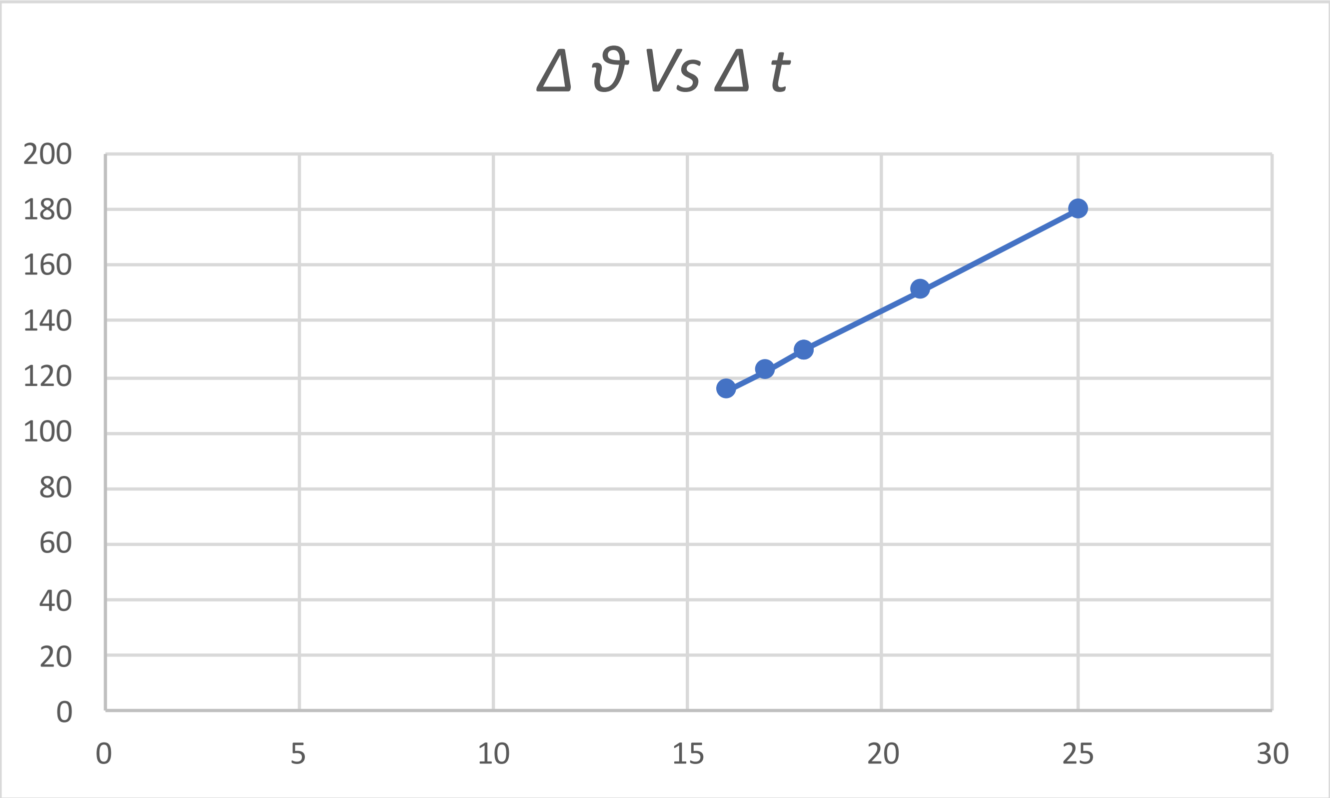

Figure 10: Δ ϑ Vs Δ t

It is noted from the figure that a linear relationship exists between $\Delta\vartheta$ and Δt, while a nonlinear relationship exists between DC message voltage and Δt.

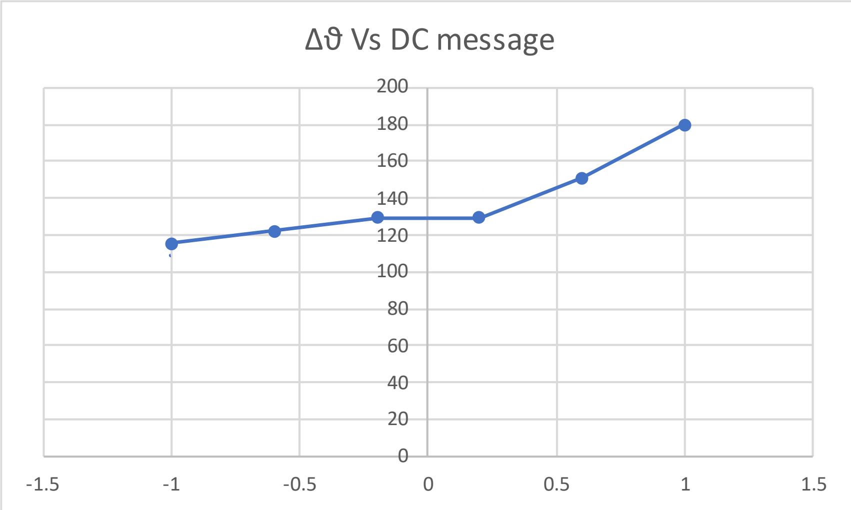

Figure 11: $\Delta\vartheta$ Vs DC message

To determine the value of Kp, it is known that the theoretical equation relating the phase shift $\Delta\vartheta$ to the message signal m(t) is $\Delta\vartheta$ = Kp*m(t). The slope of this equation represents the value of Kp. Kp = 29.31429 from figure (8).

2.2 Displaying the PM Spectrum

The modulated signal spectrum was plotted using a message signal with Vss=2V and fm=3000Hz , and then with fm=200Hz .

It was observed that increasing the frequency resulted in a wider spectrum. The resulting spectrum was similar to that of a frequency-modulated (FM) signal.

1- Vss = 2v, fm = 3KHz

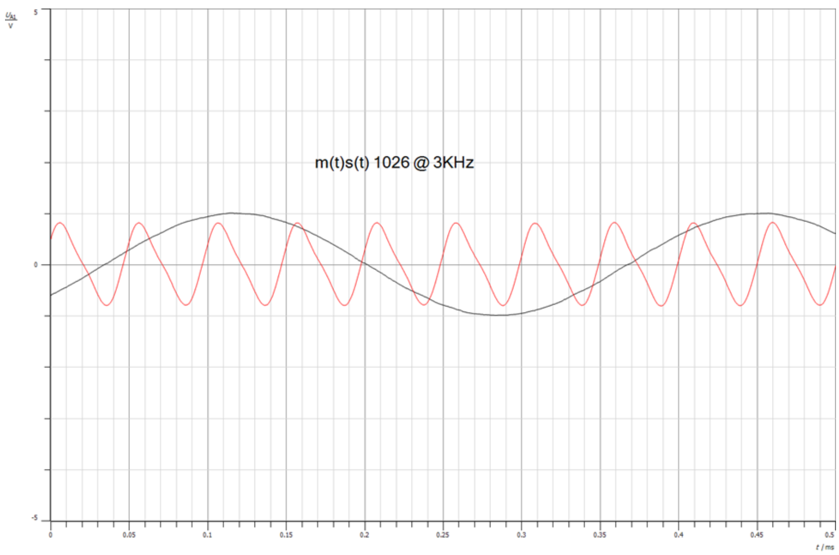

Figure 12: PM Signal in time domain

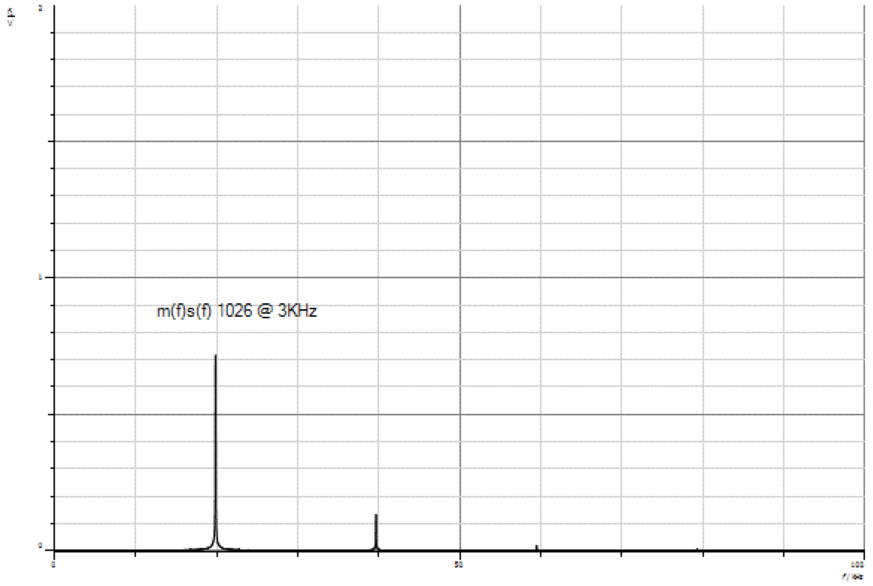

Figure 13: PM Signal in frequency domain

2- Vss= 2v, fm = 200Hz

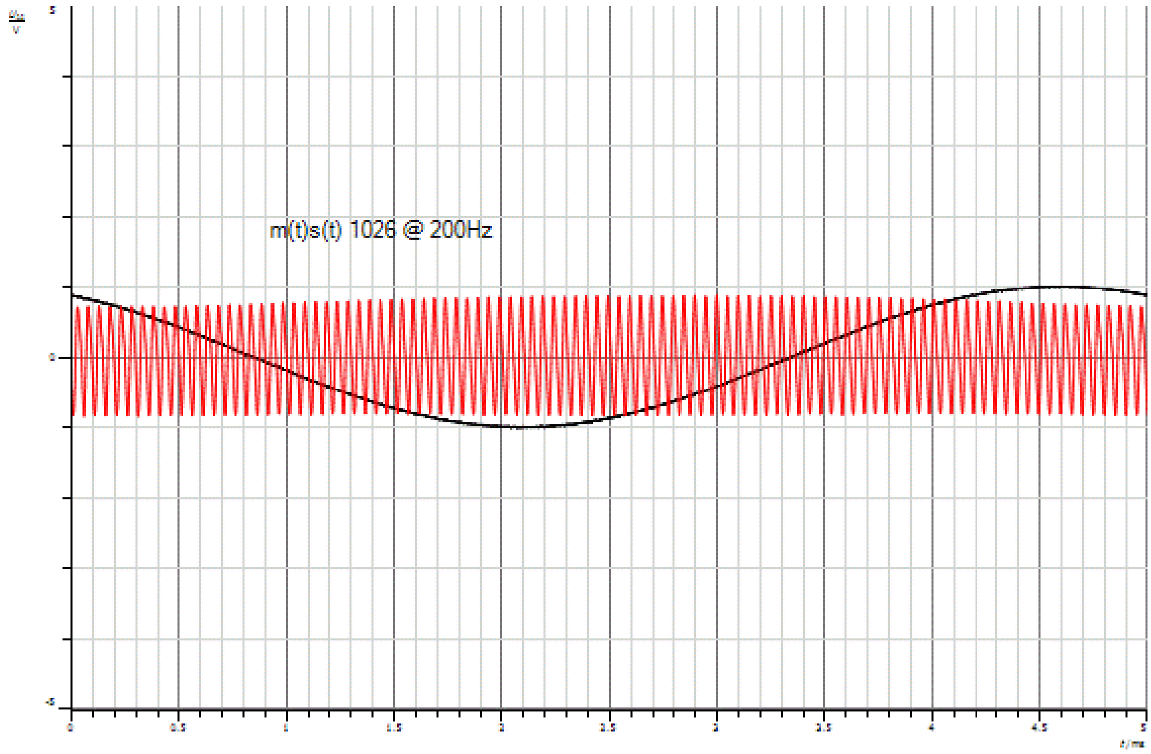

Figure 8: PM Signal in time domain, when fm=200Hz

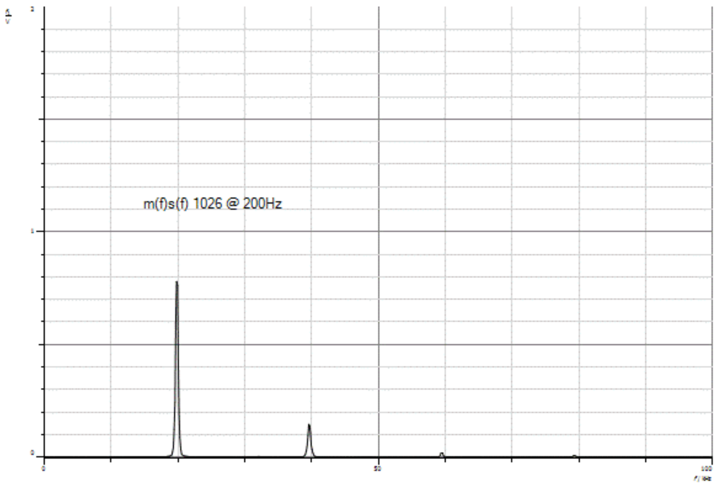

Figure 9: PM Signal in frequency domain, when fm=200Hz

It was observed that increasing the frequency resulted in a wider signal, and the resulting spectrum was similar to that of a frequency-modulated (FM) signal.

Discussion:

1. **Time Domain Analysis:**

- With a higher message frequency (3 kHz), the phase variations occur more rapidly, making the PM signal appear more distorted.
- At a lower message frequency (200 Hz), the phase changes are slower, resulting in a smoother signal.

2. **Frequency Domain Analysis (Spectrum):**

- For higher message frequencies, the PM signal's spectrum shows a broader spread with more sidebands appearing at multiples of the message frequency.
- Conversely, at lower message frequencies, the spectrum is more compact with fewer sidebands.

3. **PM vs. FM Spectrum:**

While PM and FM both produce sidebands around the carrier frequency, their behavior differs:

- In FM, the modulation index $\beta = \Delta f / fm$ depends on the message frequency, meaning the bandwidth expands significantly when fm is low.
- In PM, the modulation index depends on the message signal's amplitude (Vss), so the spectrum's spread is less influenced by fm.
- FM generally shows a more symmetric sideband structure, while PM's sideband distribution is more sensitive to amplitude changes.

Part two: Phase Demodulation

After setting up the circuit as shown in the schematic below, the message signal and the recovered message signal were obtained and are displayed.

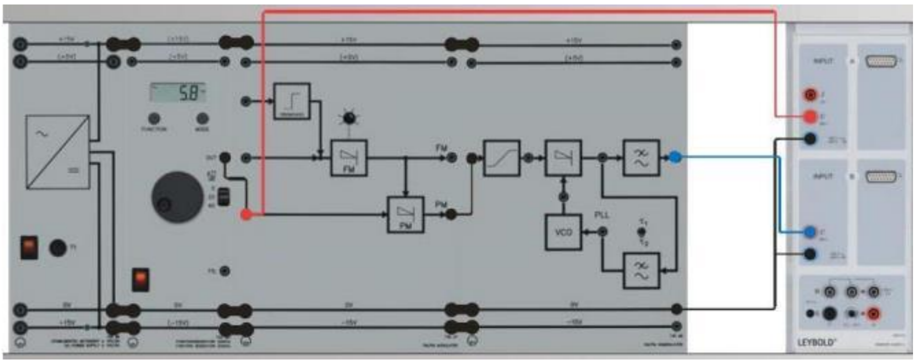

Figure 10: demodulation connection

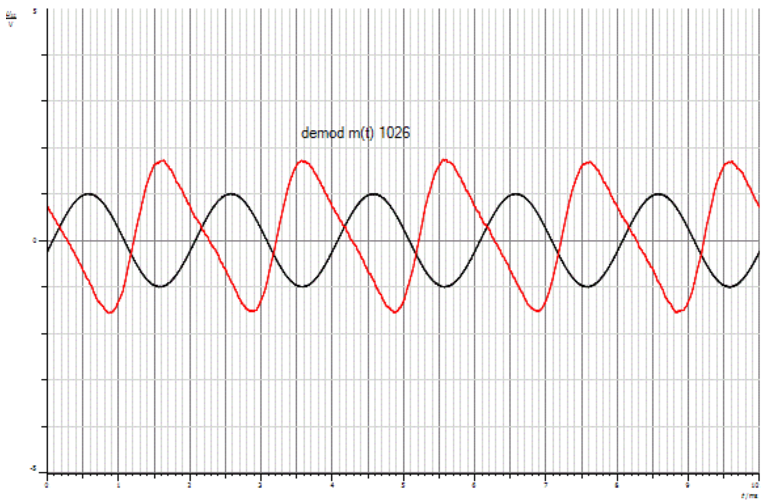

Figure 11: demodulated signal in time domain

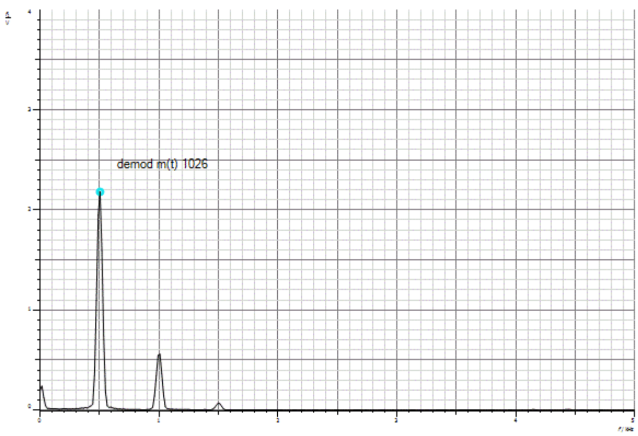

Figure 12: demodulated signal in frequency domain

The demodulation was carried out using a PLL demodulator. A phase shift of 180° was observed between the modulating signal (red) and the demodulated signals (blue) due to the two filters present in the demodulation circuit.

2.1: Studying loop filter τ1 and τ2 without pre-emphasis

The amplitude of the demodulated signal was determined using the spectrum analysis for each loop filter by applying a sinusoidal modulating signal m(t) with VSS = 2V and initially setting fm = 500Hz. The recorded values are presented in the table below.

Message Frequency (Hz)	500	1000	1500	2000	3000	4000
Ad using $\boldsymbol{\tau 1}$ filter	8.98	3.45	1.75	1.04	0.44	0.24
Ad using $\boldsymbol{\tau 2}$ filter	2.08	1.53	1.21	0.97	0.55	0.31

Table 2: The values of the Ad in different values of frequency without pre-emphasis.

The data was then processed in Excel to generate gain vs. fm curves for different values of τ1. It was observed that the loop filter with τ1 had a broader bandwidth compared to the loop filter with τ2, which influenced the gain response accordingly.

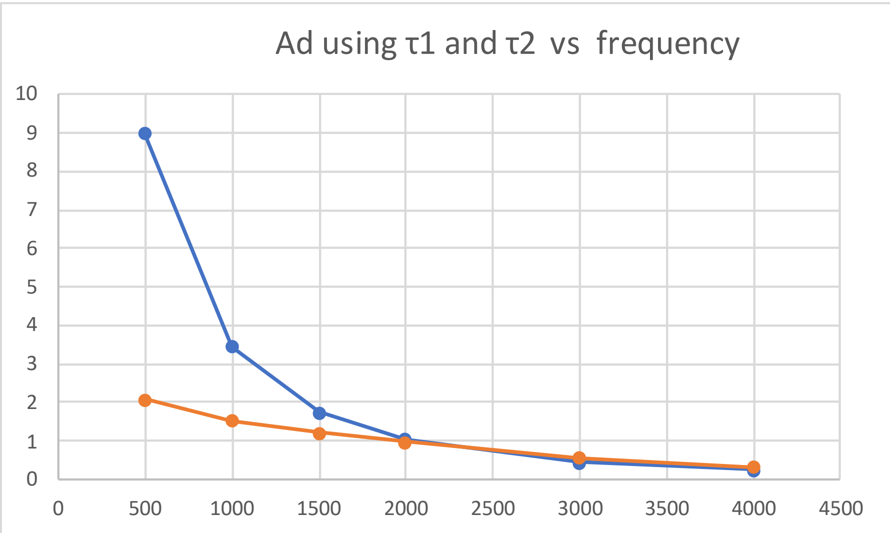

Figure 13: gain versus fm (without pre-emphasis)

The graph shows the amplitude of the demodulated signal (Ad) versus message frequency for two different loop filters, $\tau 1$ and $\tau 2$. The key differences between the two filters are:

1) Amplitude Response:

- The $\tau 1$ filter produces a significantly higher amplitude response at lower frequencies (e.g., 500 Hz) but drops sharply as frequency increases.
- The $\tau 2$ filter has a much lower amplitude response overall but decreases more gradually.

2) Frequency Dependence:

- The $\tau 1$ filter allows a higher amplitude demodulated signal at lower frequencies but attenuates faster at higher frequencies.
- The $\tau 2$ filter maintains a more stable response across frequencies, leading to less variation in output amplitude.

3) Smoothing Effect:

- The $\tau 2$ filter seems to act as a better low-pass filter, reducing variations and keeping a more uniform response over the frequency range.
- The $\tau 1$ filter allows stronger signals at lower frequencies but suppresses high frequencies more aggressively.

In short, The $\tau 1$ filter is more sensitive to lower-frequency signals but less effective for higher-frequency signals. And the $\tau 2$ filter provides a more consistent demodulation across frequencies but with lower amplitude.

Conclusion

This experiment successfully implemented and analyzed Phase Modulation in both time and frequency domains. The modulation index was determined, showing a direct correlation between message amplitude and phase deviation. Through differentiation and envelope detection, as well as PLL demodulation, the original message signal was accurately recovered. The study further revealed that increasing the message frequency results in a broader signal spectrum, similar to FM behavior. The effect of different loop filters was examined, demonstrating how bandwidth and gain response influence demodulation performance. The experiment confirms that PM is a robust modulation technique with applications in digital communication, radar, and audio processing. Future improvements may include testing additional filter types to enhance signal clarity and further exploration of noise effects in PM demodulation.

References

[1] **https://electronicscoach.com/phase-modulation.html** [Accessed on 16th march at 5:00 PM]

[2]

https://www.google.com/url?sa=i&url=https%3A%2F%2Felectronics.stackexchange.com%2Fquestions%2F552461%2Fwhy-does-a-phase-shift-happen-in-the-demodulated-am-signal-using-envelope-detect&psig=AOvVaw2vZv89yVnaevQvQDxzKMkv&ust=1742340420537000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCKCCrpKikowDFQAAAAAdAAAAABAE

[Accessed on 16th march at 7:25 PM]

[3]

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FCoherent-PM-FM-and-AM-demodulation-by-APLL_fig4_271520378&psig=AOvVaw0xLQrY8-jg3L--1yDZ6qBJ&ust=1742340506614000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCPDmnaqikowDFQAAAAAdAAAAABAE [Accessed on 16th march at 7:40 PM]

[5] Dr. Wael lectures slides [Accessed on 16th march at 3:50 PM]