A Lab Report on Communication Systems

Amplitude Modulation and Demodulation, Line Coding and Data Communication, Sample and hold circuit, PCM and Delta Modulation

[076BEI009] Aryal, Avinash ; [076BEI010] Neupane, Bharat; [076BEI014] Adhikari, Diwas ; [076BEI019] Pandey, Kshitiz;
Department of Electronics Engineering, Pulchowk Campus

***Abstract*—This Communication Systems lab report presents the results of four experiments conducted under the subject Communication Systems[EX 656] under Department of Electronics and Communication Engineering at Pulchowk Campus. The experiments include Amplitude modulation and demodulation, line coding and data communication, sample and hold circuit, and PCM and delta modulation. The purpose of the experiments was to understand the fundamental concepts of communication systems and to gain practical experience in the implementation of these concepts. Each experiment was designed to explore a specific aspect of communication systems, such as signal modulation, coding, and transmission. The experiments were carried out using various tools and techniques, including simulation software, hardware modules, and signal generators. The results of the experiments are presented in this report, along with detailed analysis and conclusions. Overall, this lab report provides a comprehensive understanding of communication systems and their practical applications.**

I. Introduction

THE experiments conducted in the Communication Systems lab based on the curriculum of Bachelor in Electronics, Communication and Information Engineering (BEI) are crucial for understanding the fundamentals of communication systems. AM modulation and demodulation experiments explore the concept of signal modulation, which is an essential building block of communication systems. Line coding and data communication experiments examine the encoding and transmission of digital signals over communication channels. The sample and hold circuit experiment focus on sampling and quantization of analog signals, and the PCM and delta modulation experiments explore the concept of digital signal modulation.

To conduct these experiments, a background in signal processing, communication theory, and electronics is necessary. Students should have a basic understanding of signal processing, frequency domain analysis, and circuit design. In this lab, students used Multisim 14 software for circuit simulation and design. Matlab was used for data analysis and visualization. Hardware tools such as signal generators, oscilloscopes, and data acquisition systems were used for practical experiments.

Other available technologies that were not used in this lab include simulation software like LTSpice, PSpice, and QUCS, and programming languages like Python and C++ for signal processing and data analysis. Advanced hardware tools such as software-defined radios (SDRs) and spectrum analyzers are also available for more sophisticated experiments.

A. Amplitude Modulation and Demodulation

The process of changing the characteristics (phase, frequency or amplitude) of high frequency carrier signal in accordance with the instantaneous value of message signal is modulation. The amplitude modulation is defined as the high frequency carrier signal is changed in accordance with the instantaneous value of message signal keeping phase and frequency constant. The major objective of amplitude modulation (AM) is to strengthen the signal during its transmission such that it can travel a larger distance providing wider coverage.

Let us consider a carrier wave represented by the equation,

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

And a message signal or modulating signal having equation,

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

Now, the resulting AM modulated signal will have it's amplitude changing according the equation of message signal.

$$s(t) = A_c[1 + K_a m(t)] \cos(2\pi f_c t)$$

where,

K_a = Amplitude Sensitivity of AM modulation

This can be further clarified by Fig.1

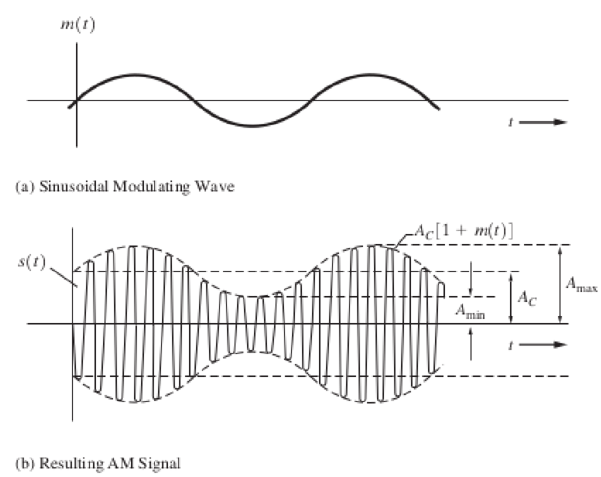

Fig. 1: Modulating signal and resulting AM modulated signal

B. Line Coding and Data Communication

Information sources that provide digital data deliver numbers that are not suitable for transmission. The data must be formatted in a proper way to make them suitable for transmission through a communication channel. Line coding is the process of converting binary data (a sequence of bits) into voltage pulses that represent the information. When a pulse is used to represent each bit it is called binary communication. If a pulse is used to represent multiple bits it is called m-ary communication. A line code should exhibit the following properties.

1) Error detection capability: The receiver needs to be able to distinguish the waveform associated with a "high" from the waveform associated with a "low", even if there is a considerable amount of noise and distortion in the channel.

2) DC content: Many telecom channels are AC coupled (DC blocking), so it is desirable to have zero DC in the waveform produced by a given line code. If a signal with significant DC content is used in AC coupled lines, it will cause DC wander (received signal baseline will vary with time). Furthermore, it is not possible to pass DC through transformers and DC blocking capacitors.

3) Power spectrum and bandwidth: The power spectrum and bandwidth of the transmitted signal should be matched to the frequency response of the channel to avoid significant distortion. The bandwidth should be minimized as much as possible to improve efficiency.

4) Self-synchronization: The waveform produced by the line code should contain enough timing information such that the receiver can synchronize with the transmitter and decode the received signal properly. This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.

The different types of line coding techniques can be seen in Fig. 2

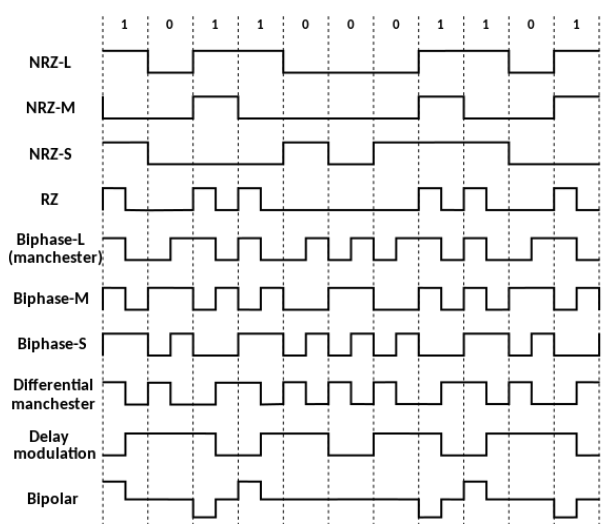

Fig. 2: Different types of line coding techniques

The types of line coding techniques that we observed in our experiment are:

1) Unipolar NRZ: Unipolar Non-Return-to-Zero (NRZ) is a type of digital encoding where the signal is represented by a single voltage level. In this encoding, a high voltage level represents a binary 1 and a low voltage level represents a binary 0. The signal does not return to zero during the bit interval, hence the name Non-Return-to-Zero.

2) Unipolar RZ: Unipolar Return-to-Zero (RZ) is a type of digital encoding where the signal is represented by a positive or negative pulse of a fixed duration. In this encoding, a pulse at a high voltage level represents a binary 1, while no pulse or a pulse at a low voltage level represents a binary 0. The signal returns to zero during each bit interval, hence the name Return-to-Zero.

3) Polar RZ: Polar Return-to-Zero (RZ) is a type of digital encoding where the signal is represented by a positive or negative pulse of a fixed duration, with both positive and negative pulses used to represent binary 1 and 0. In this encoding, a positive pulse represents a binary 1, while a negative pulse represents a binary 0. The signal returns to zero during each bit interval, hence the name Return-to-Zero.

4) Manchester: Manchester coding is a type of digital encoding where the signal is represented by transitions between two voltage levels during each bit interval. In this encoding, a transition from a high voltage level to a low voltage level represents a binary 1, while a transition from a low voltage level to a high voltage level represents a binary 0. The transition in the middle of each bit interval is used to synchronize the receiver's clock.

C. Sample and Hold Circuit

A sample and hold circuit is an electronic circuit that is used to sample an analog input signal at a specific point in time and then hold that voltage level for a certain period. This circuit is commonly used in analog-to-digital converters, signal processing systems, and in applications where a continuous analog signal needs to be converted into a series of discrete values.

The main function of a sample and hold circuit is to capture and maintain the voltage level of an analog signal for a short period so that it can be sampled by an analog-to-digital converter (ADC) or used in other analog signal processing circuits. This circuit consists of a switch, a capacitor, and an amplifier. The switch is used to connect the input signal to the capacitor to store its voltage level. The capacitor is charged to the voltage level of the input signal and the switch is then opened to disconnect the input signal from the capacitor. The amplifier is used to maintain the voltage level of the capacitor during the hold period and to amplify the signal as needed.

The accuracy of the sample and hold circuit is critical in ensuring the correct conversion of the analog signal into digital values. Factors that can affect the accuracy of the circuit include the switch settling time, the capacitor leakage, the amplifier offset voltage, and the circuit's temperature stability.

The sample and hold process is shown in Fig. 3

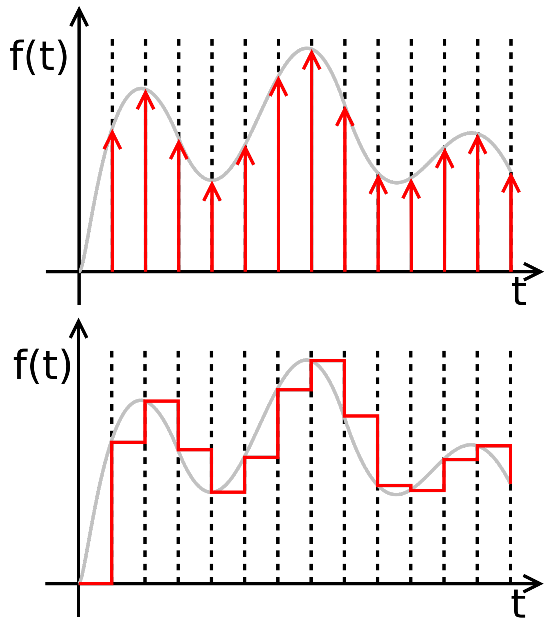

Fig. 3: Sample and hold process

D. PCM and Delta Modulation

Pulse-code modulation (PCM) is a method used to digitally represent sampled analog signals. It is the standard form of digital audio in computers, compact discs, digital telephony and other digital audio applications. In a PCM stream, the amplitude of the analog signal is sampled at uniform intervals, and each sample is quantized to the nearest value within a range of digital steps.

A PCM stream has two basic properties that determine the stream's fidelity to the original analog signal: the sampling rate, which is the number of times per second that samples are taken; and the bit depth, which determines the number of possible digital values that can be used to represent each sample. Pulse-code modulation is shown in Fig. 4

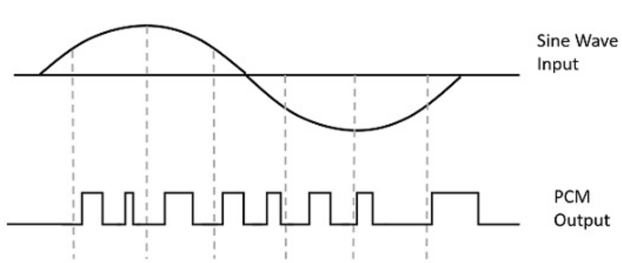

Fig. 4: PCM modulation

A delta modulation (DM or Δ-modulation) is an analog-to-digital and digital-to-analog signal conversion technique used for transmission of voice information where quality is not of primary importance. DM is the simplest form of differential pulse-code modulation (DPCM) where the difference between successive samples is encoded into n-bit data streams. In delta modulation, the transmitted data are reduced to a 1-bit data stream. Its main features are:

1) The analog signal is approximated with a series of segments.
2) Each segment of the approximated signal is compared to the preceding bits and the successive bits are determined by this comparison.
3) Only the change of information is sent, that is, only an increase or decrease of the signal amplitude from the previous sample is sent whereas a no-change condition causes the modulated signal to remain at the same 0 or 1 state of the previous sample.

To achieve high signal-to-noise ratio, delta modulation must use oversampling techniques, that is, the analog signal is sampled at a rate several times higher than the Nyquist rate. Delta modulation can be observed in Fig. 5

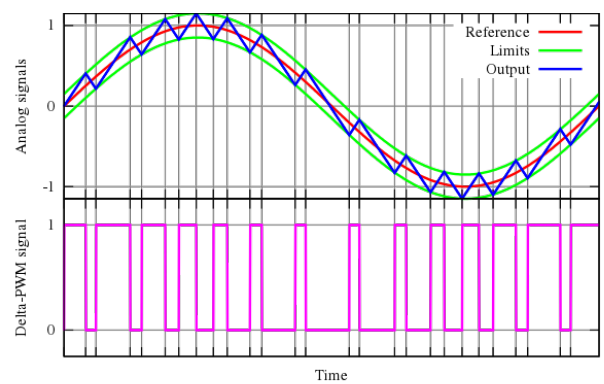

Fig. 5: Delta modulation

II. Materials and Methods

The materials used in this experiment were:

1) Signal generators
2) Oscilloscopes
3) Frequency counter
4) Data acquisition systems
5) Audio modules
6) Power supply
7) Sample and hold module
8) PCM and Delta modulation module
9) Connecting wires
10) Multisim 14
11) MATLAB

In AM modulation and demodulation experiment, we calculated the modulation index for different cases. The modulation index is given by equation 1:

$$\mu = \frac{message\ signal\ amplitude(A_m)}{carrier\ signal\ amplitude(A_c)} \tag{1}$$

III. Results

The experiments on AM modulation and demodulation, line coding, sample and hold circuit, and PCM and delta modulation were conducted to explore the fundamental concepts of communication systems. The experiments were designed to demonstrate the key techniques used in communication systems and to provide hands-on experience in analyzing signals and circuits. In this results section, we present the findings and observations from each experiment. The results are analyzed in terms of the impact of various parameters on the performance of the circuits, the quality of the signals, and the accuracy of the encoding and decoding techniques.

A. AM modulation and demodulation

This experiment was conducted in simulation software(*Multisim 14*) as well as in hardware apparatus. The result obtained in Multisim 14 is shown in Fig. 6

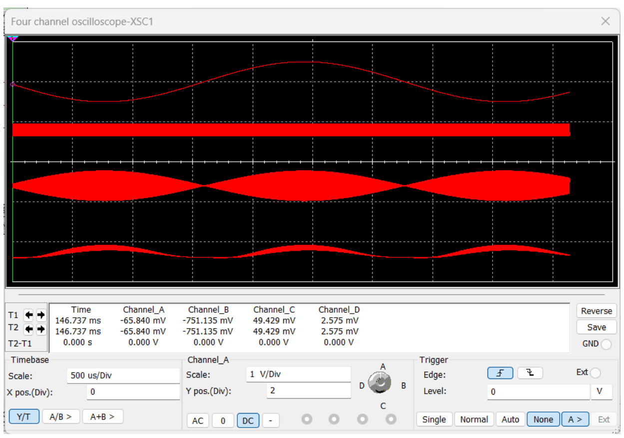

Fig. 6: Carrier, message and modulated signal in AM modulation

Here we can see that the carrier signal appears to be enveloped by the message signal in modulated wave. This suggests that the amplitude of carrier signal varies as per the instantaneous value of message signal.
Upon performing this experiment in hardware apparatus, we observed similar waveform. We altered the values input signals to obtain under-modulation, perfect-modulation and over-modulation. We calculated the modulation index in all three cases, the obtained values were:

1) Under-modulation: $Modulation\ Index(\mu) = 0.4255$, which suggests that only 42.55% of the carrier signal is modulated.
2) Perfect-modulation: $Modulation\ Index(\mu) \approx 1.00$, which suggests that 100% of the carrier signal is modulated.
3) Over-modulation: $Modulation\ Index(\mu) = 1.861$, which suggests that 186% modulation is done to the carrier signal.

Demodulation of the modulated signal was also performed and the frequency of demodulated signal was observed to be 299.4 Hz where the frequency of original signal was 300Hz.
The calculations done to obtain these results is given in the APPENDIX-A.

B. Line Coding

We performed this experiment in simulation software(MATLAB). We generated a bit stream and observed the output when it is represented using different line coding techniques. The results obtained is given in Fig.7

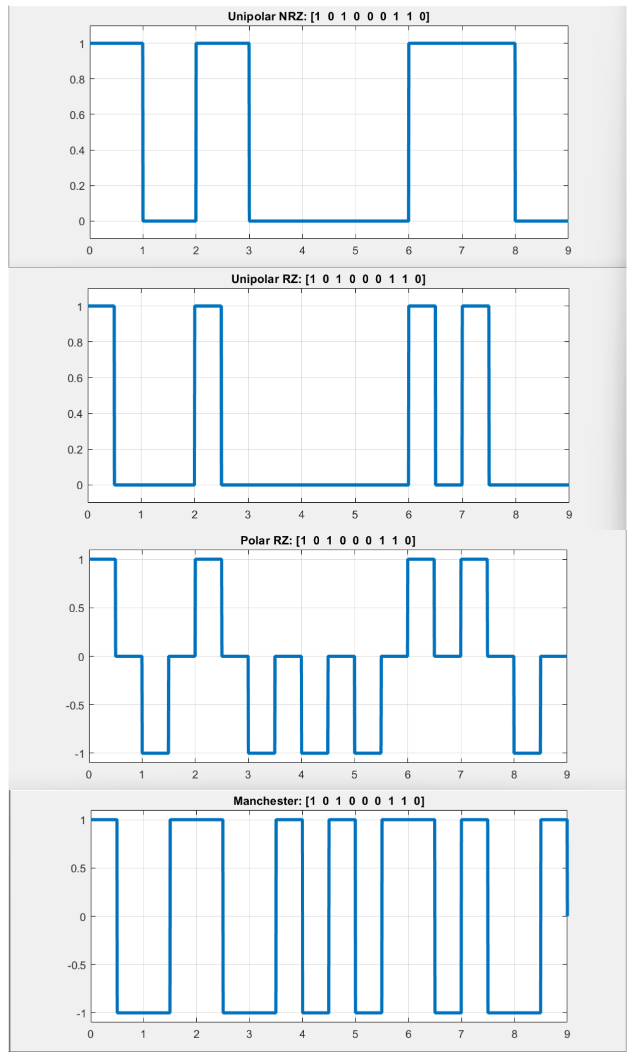

Fig. 7: Same bit-stream represented using different line-coding techniques

Unipolar NRZ is simple to implement, but has a DC component that can cause problems with long-distance transmission and clock recovery, used when simplicity is important and the distance is short.

Unipolar RZ has a built-in clock recovery mechanism, but also has a DC component, used when clock recovery is important and the distance is moderate.

Polar RZ eliminates the DC component and allows for longer distance transmission, but requires a more complex decoding circuit, used when long distance transmission is important and complexity is not a concern.

Manchester coding has a built-in clock recovery mechanism and eliminates the DC component, but requires more bandwidth. Use when clock recovery is important and bandwidth is not a concern.

C. Sample and Hold Circuit:

We performed this experiment in both simulation software(Multisim 14) and hardware apparatus. In hardware part of the experiment, we used sample and hold module. In software part, we connected the circuit using op-amps and observed the result. We also performed de-sampling to obtain the original waveform. The waveform obtained in simulation software is shown in Fig.8

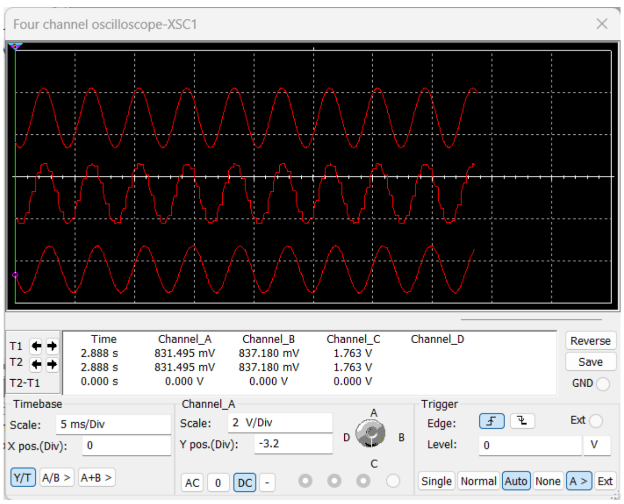

Fig. 8: Sample and hold circuit output, taken from Multisim

Similar output was observed in hardware experiment, however with a certain noise. In both hardware and simulation part of this experiment, we played with the sampling rate and we observed that, if the sampling was done in smaller intervals, more accurate output was observed. The higher the sampling rate, the more frequently the circuit takes samples and updates the held value, resulting in a more accurate representation of the input signal.

Conversely, a lower sampling rate can result in a loss of information, as the circuit may not be able to capture rapid changes or fluctuations in the input signal. In extreme cases, a very low sampling rate can result in the signal being completely distorted or aliased, meaning that the frequency content of the original signal is no longer accurately represented.

Overall, selecting an appropriate sampling rate for a sample and hold circuit requires a tradeoff between accuracy and processing speed, as higher sampling rates generally require more processing power and resources. Therefore, the selection of a sampling rate should be based on the specific application and the desired tradeoffs between accuracy, processing speed, and resource utilization.

D. PCM and Delta modulation:

This experiment was also performed in both simulation software(Multisim 14) and hardware apparatus. For hardware part of the experiment, we used PCM and Delta modules whereas for simulation part, we connected the circuit by ourselves. The waveform observed in Multisim is shown in Fig.9 and Fig.10

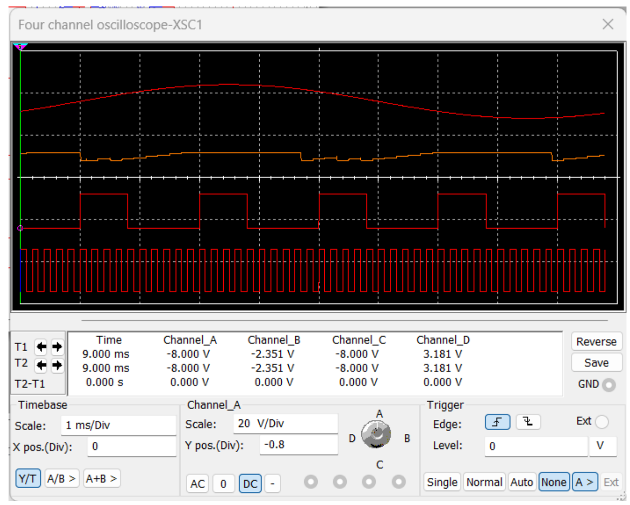

Fig. 9: PCM modulation

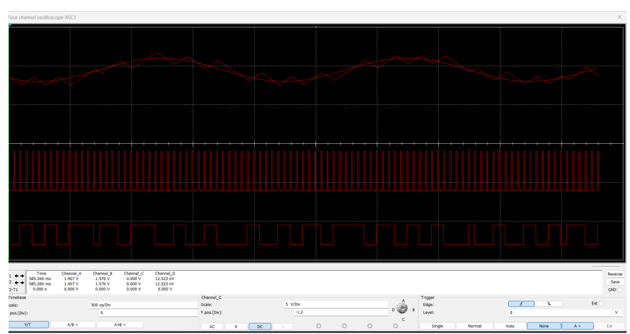

Fig. 10: Delta modulation

PCM provides a higher signal-to-noise ratio than Delta Modulation but requires more processing power and bandwidth. Delta Modulation is a simpler technique suitable for low-power applications but suffers from slope overload distortion. Both techniques can introduce quantization error, and the choice of which one to use depends on the specific application requirements and trade-offs between complexity, SNR, bandwidth, and quantization error.

PCM is commonly used in digital audio, video, and telecommunications, while Delta Modulation is used in voice compression and low-bit-rate audio. The advancement of technology leads to the development of new techniques and improvements to existing ones in the field of analog-to-digital conversion.

IV. Discussion and Summary

In this series of experiments conducted under the subject of Communication Systems, we explored and analyzed various fundamental concepts in analog and digital communication. We began by examining AM modulation and demodulation, where we learned how to transmit an analog signal using amplitude modulation and how to recover the original message signal using a demodulator circuit.

Next, we delved into the world of digital communication and studied the concept of line coding. Through this experiment, we understood the importance of converting digital data into a suitable format for transmission over a communication channel.

Moving on, we investigated the sample and hold circuit, which is a critical component of analog-to-digital converters. We learned how this circuit helps to sample and maintain a continuous-time signal at specific time intervals, and how it plays a crucial role in the accurate conversion of analog signals to digital form.

Finally, we explored pulse code modulation (PCM) and delta modulation, two digital communication techniques used for encoding and transmitting analog signals. We gained an understanding of how PCM converts an analog signal into a digital signal by sampling and quantizing the signal, and how delta modulation uses a single bit to represent the difference between consecutive samples of the signal.

Overall, these experiments provided a comprehensive overview of the various concepts and techniques used in analog and digital communication systems, and their applications in real-world scenarios. By conducting these experiments, we gained valuable practical experience and deepened our understanding of the theoretical principles of communication systems.

Appendix A
Hand Calculations

A. *Modulation index calculation in AM modulation:*

1) Under-modulation:

$$\begin{aligned} V_{max} &= 0.804V \\ V_{min} &= 0.324V \\ ModulationIndex(\mu) &= \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \\ \mu &= 0.4255 \end{aligned}$$

2) Over-modulation:

$$\begin{aligned} V_{max} &= 0.804V \\ V_{min} &= -0.242V \\ ModulationIndex(\mu) &= \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \\ \mu &= 1.861 \end{aligned}$$

Acknowledgment

We would like to express our sincere gratitude to the Department of Electronics and Communication Engineering at Pulchowk Campus for providing us with the necessary resources to conduct the experiments. We are grateful to our subject teacher, Asst. Prof. Dr. Nanda Bikram Adhikari sir, for his guidance, support, and insightful feedback throughout the course. We would also like to acknowledge our lab teacher and our mentor, Er. Bikal Adhikari sir, for his valuable assistance and guidance during the experiments. Their expertise and commitment has been instrumental in the successful completion of these experiments and in our overall understanding of the subject of Communication Systems.

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