مدينة زويل للعلوم والتكنولوجيا
Zewail City of Science and Technology

CIE 337: Final Project Report

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Part I

Testing your System Simulator

Test your overall system for the input signal $m(t)$ and the following cases

$$m(t) = 5\cos(2\pi f_m t), \qquad \text{where } f_m = 10$$

	Case 1	Case 2	Case 3	Case 4
Sampler	$f_s = 40$	$f_s = 20$	$f_s = 20$	$f_s = 15$
Quantizer	$\mu = 0, L = 8, m_p = 5$	$\mu = 0, L = 32, m_p = 5$	$\mu = 100, L = 32, m_p = 5$	$\mu = 0, L = 16, m_p = 5$
Encoder	Unipolar NRZ	Polar NRZ	Manchester	Unipolar NRZ

Test Cases Comparisons:

Case 1:

- **Sampling Frequency (fs)**: 40 Hz
- **Quantization**: μ=0, L=8, mp=5
- **Encoder**: Unipolar NRZ

Result:

- **Sampling**: Properly captures the input signal (as fs > 2fm, satisfying Nyquist criterion).
- **Quantization**: The signal is quantized with 8 levels, introducing a moderate quantization error.
- **Encoding**: The Unipolar NRZ encoding does not invert the signal, making it straightforward.

Case 2:

- **Sampling Frequency (fs)**: 20 Hz
- **Quantization**:μ=0,L=32, mp=5
- **Encoder**: Polar NRZ

Result:

- **Sampling**: Meets the Nyquist criterion but with less resolution compared to Case 1.
- **Quantization**: Higher number of quantization levels (32) reduces quantization error.
- **Encoding**: Polar NRZ encoding introduces polarity (inverts the signal during certain periods).

Case 3:

- **Sampling Frequency (fs)**: 20 Hz
- **Quantization**: μ=100, L=32,mp=5
- **Encoder**: Manchester

Result:

- **Sampling**: Similar to Case 2, the Nyquist criterion is met.
- **Quantization**: High value of μ\muμ introduces non-linear compression (companding), affecting the dynamic range.
- **Encoding**: Manchester encoding adds complexity by splitting the signal into two phases per bit.

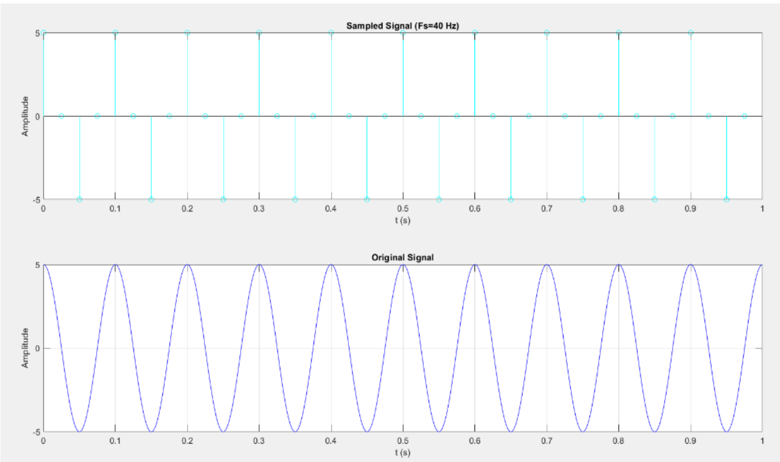
Case 4:

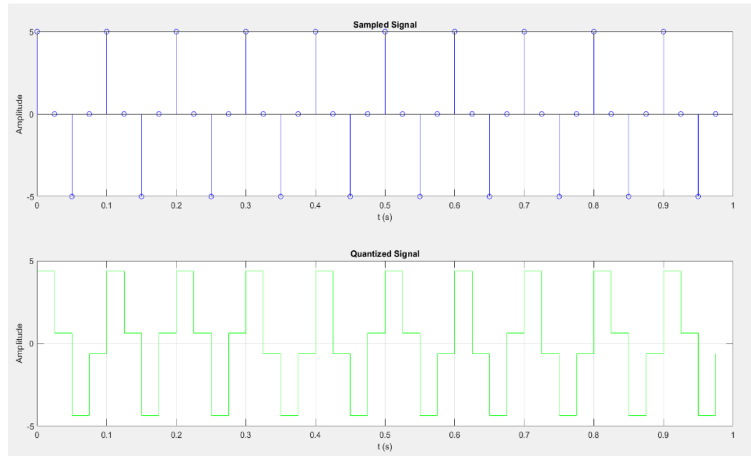
- **Sampling Frequency (fs)**: 15 Hz
- **Quantization**:μ=0,L=16, mp=5
- **Encoder**: Unipolar NRZ

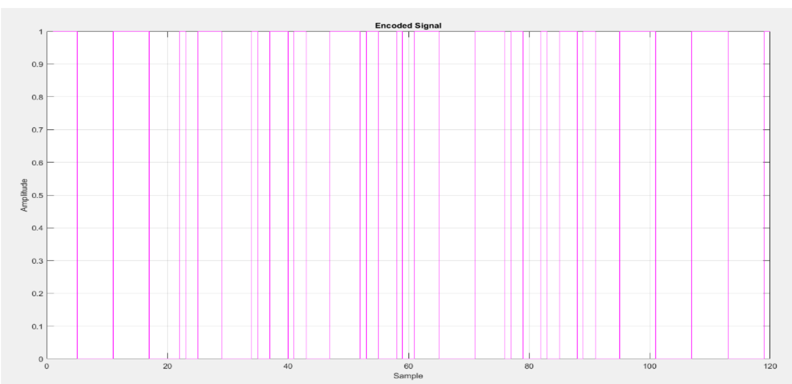
Result:

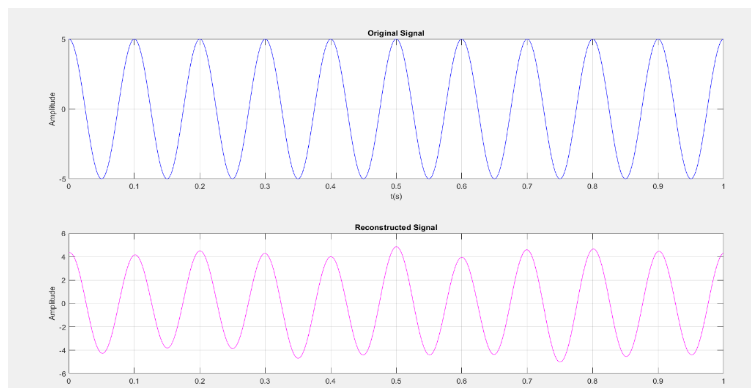
- **Sampling**: Slightly below the Nyquist rate, leading to aliasing.
- **Quantization**: 16 levels are used, providing better precision than Case 1 but worse than Case 2.
- **Encoding**: Similar to Case 1 with Unipolar NRZ, simpler representation but prone to distortion due to aliasing.

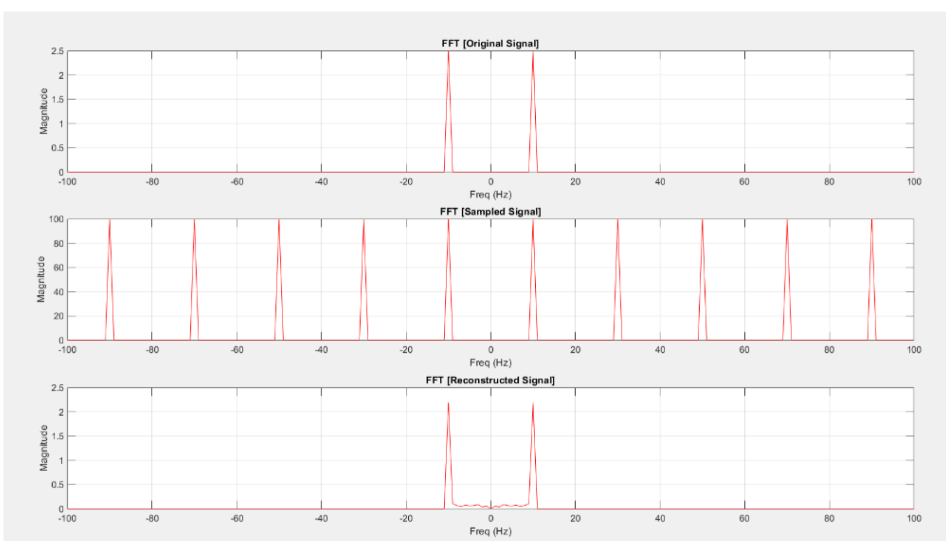
Results For Test Case 1:











1. Original Signal

- **Graph**: Shows a continuous sine wave.
- **Observation**: This is the base signal before any processing. It's smooth and continuous, representing the original analog signal.

2. Sampling

- **Graph**: A discrete signal formed by sampling the original signal at 40 Hz.
- **Observation**: The sampled points capture the shape of the original signal well, as expected since the sampling frequency (40 Hz) is greater than twice the maximum frequency of the original signal. This satisfies the Nyquist criterion and prevents aliasing.

3. Quantization

- **Graph**: A step-like waveform that represents the quantized version of the sampled signal.
- **Observation**: The signal is quantized into 8 levels (as indicated by L=8), which introduces quantization noise or error. The steps show the rounding of the continuous amplitude to discrete levels.

4. Encoding (Unipolar NRZ)

- **Graph**: A signal that represents the encoding stage using Unipolar Non-Return-to-Zero (NRZ) encoding.
- **Observation**: The encoded signal remains non-inverted, which is characteristic of Unipolar NRZ encoding. The signal does not return to zero between bits, making it straightforward but less energy-efficient.

5. Reconstructed Signal

- **Graph**: A sine wave that should resemble the original signal but with some distortions.
- **Observation**: The reconstructed signal after sampling, quantization, and encoding resembles the original sine wave but may show slight differences due to quantization and reconstruction errors. The pink waveform in this graph indicates a fairly accurate reconstruction, although some high-frequency components or noise might be visible.

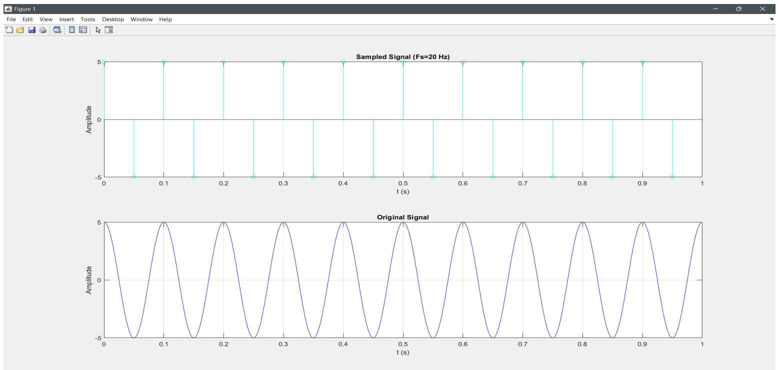
6. FFT Analysis

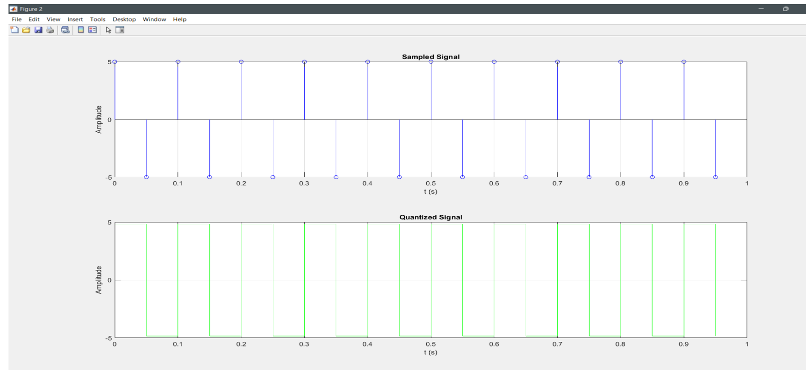
- **Graph**: Shows the Fast Fourier Transform (FFT) of the original, sampled, and reconstructed signals.
- **Observation**:
  - **Original Signal FFT**: Displays the frequency content of the original sine wave, with a clear peak at the fundamental frequency.
  - **Sampled Signal FFT**: Displays the frequency spectrum after sampling. The frequency peaks should align with the original, though additional artifacts or mirror images might be present due to sampling.
  - **Reconstructed Signal FFT**: Shows the frequency spectrum of the reconstructed signal. Ideally, it should closely match the original FFT, but some discrepancies might be visible due to processing.

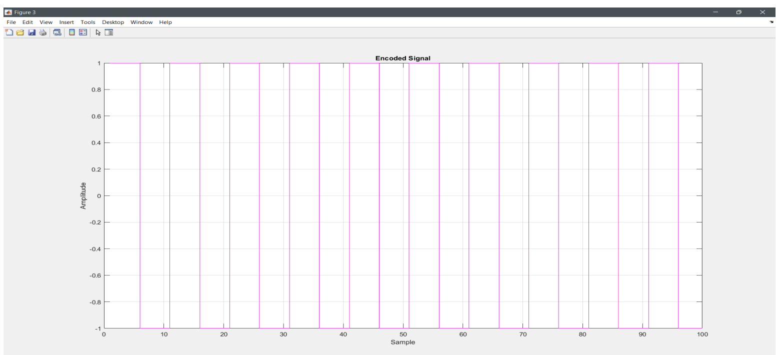
Conclusion:

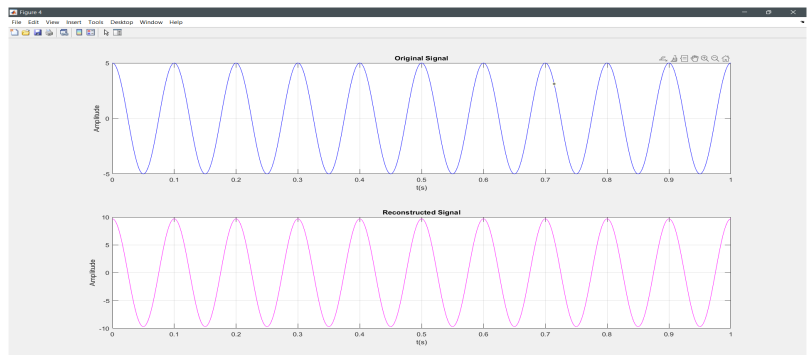
The test case illustrates a proper signal processing workflow, from sampling to quantization, encoding, and reconstruction. The sampling rate of 40 Hz is appropriate for the original signal, ensuring no aliasing. The quantization process introduces some error, as expected, and the Unipolar NRZ encoding is effective though straightforward. The reconstructed signal is a good approximation of the original, with the FFT analysis providing insight into the preservation or distortion of the frequency components.

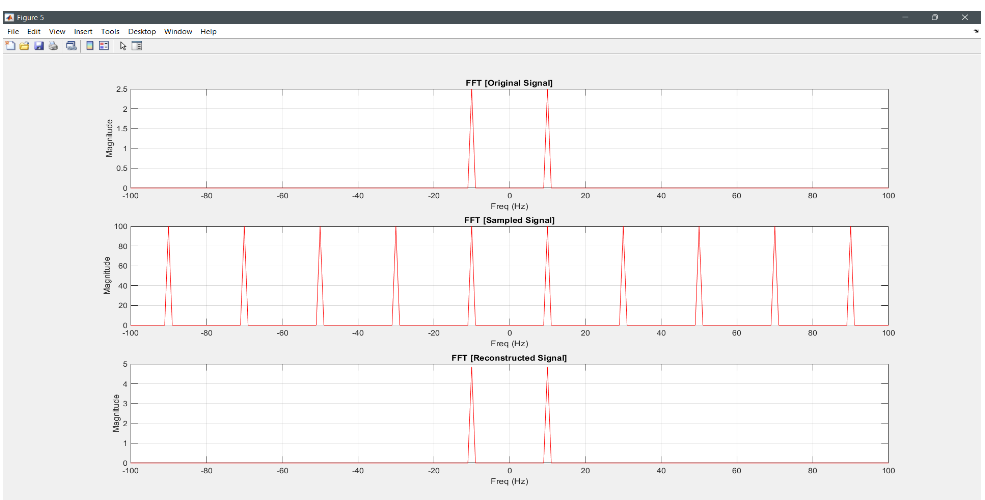
Results For Test Case 2:











1. Original Signal

- **Graph: Shows the original sine wave.**
- **Observation: The base signal remains smooth and continuous, similar to Case 1, representing the unprocessed analog signal.**

2. Sampling

- **Graph: A discrete signal formed by sampling the original signal at 20 Hz.**
- **Observation: The sampling frequency is just enough to satisfy the Nyquist criterion, assuming the signal's maximum frequency is less than or equal to 10 Hz. However, the resolution is lower compared to Case 1, which may affect the fidelity of the reconstructed signal.**

3. Quantization

- **Graph: Shows a step-like waveform representing the quantized version of the sampled signal.**
- **Observation: The signal is quantized into 32 levels (L=32), which reduces quantization error compared to Case 1 (where L=8). The steps are finer, indicating a closer approximation to the original signal.**

4. Encoding (Polar NRZ)

- **Graph: Displays the signal after Polar NRZ encoding.**
- **Observation: Unlike Unipolar NRZ encoding, Polar NRZ encoding introduces polarity. This means the signal can have both positive and negative values, which is evident in the graph. The signal flips or inverts during certain periods, reflecting the encoded bit pattern.**

5. Reconstructed Signal

- **Graph: A sine wave showing the reconstructed signal after the processing stages.**
- **Observation: The reconstructed signal closely resembles the original sine wave, with slight distortions potentially due to lower sampling resolution compared to Case 1. However, the higher quantization levels help in reducing quantization noise, resulting in a cleaner reconstruction.**

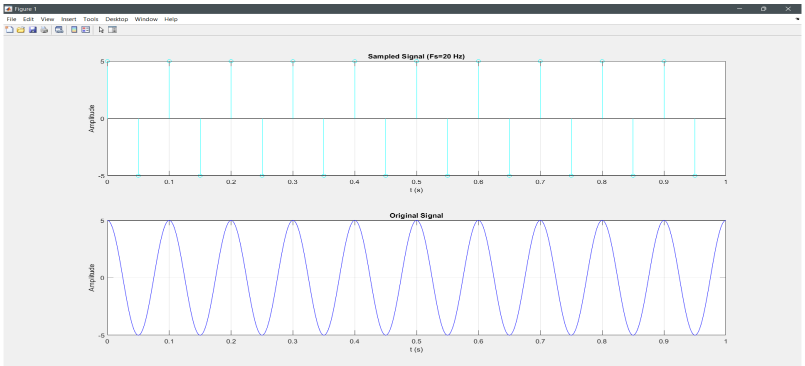
6. FFT Analysis

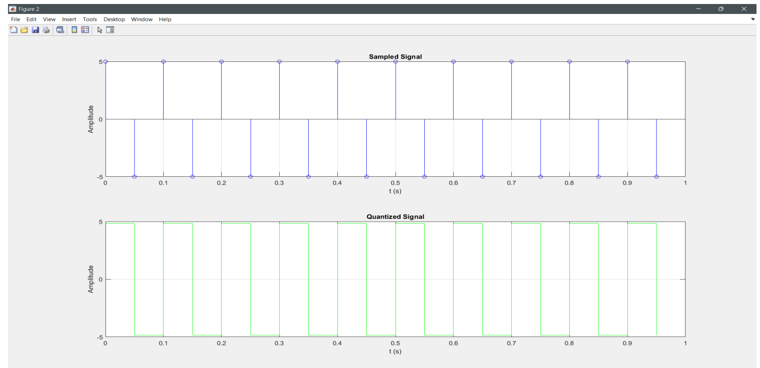
- **Graph: Displays the Fast Fourier Transform (FFT) of the original, sampled, and reconstructed signals.**
- **Observation:**
    - **Original Signal FFT: Similar to Case 1, it shows the frequency content of the original sine wave with a peak at the fundamental frequency.**
    - **Sampled Signal FFT: Shows the frequency spectrum after sampling, with peaks at the expected frequencies but possibly with less sharpness due to the lower sampling rate.**
    - **Reconstructed Signal FFT: Displays the frequency content of the reconstructed signal. Ideally, it should be close to the original, but slight discrepancies may be present due to the lower sampling rate and encoding process.**

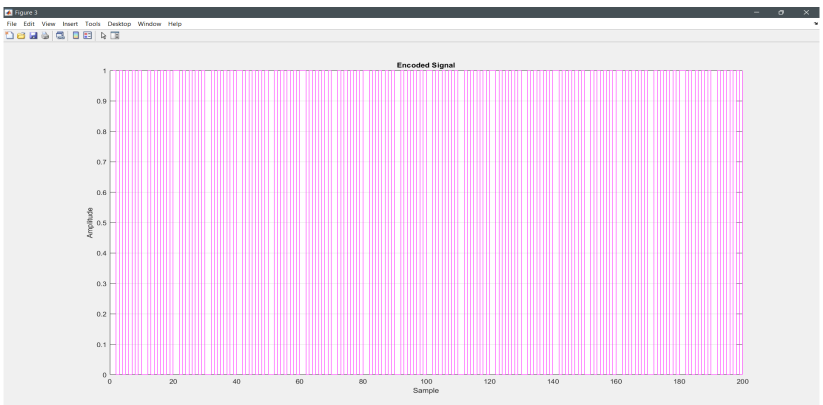
Conclusion:

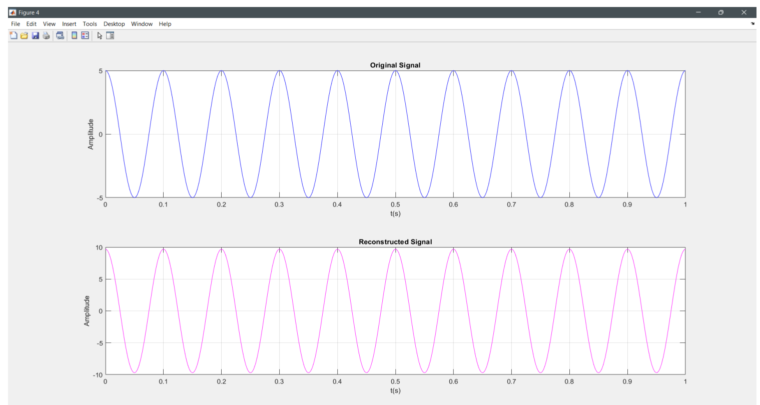
In this case, the signal processing chain is slightly different due to the lower sampling frequency and higher quantization levels. The sampling still meets the Nyquist criterion but with less resolution, affecting the overall signal fidelity. The higher number of quantization levels helps to reduce quantization noise, improving the quality of the reconstructed signal. Polar NRZ encoding adds polarity to the signal, which is reflected in the encoded signal graph. Overall, the reconstructed signal is a good approximation of the original, with some trade-offs due to the sampling frequency and encoding scheme.

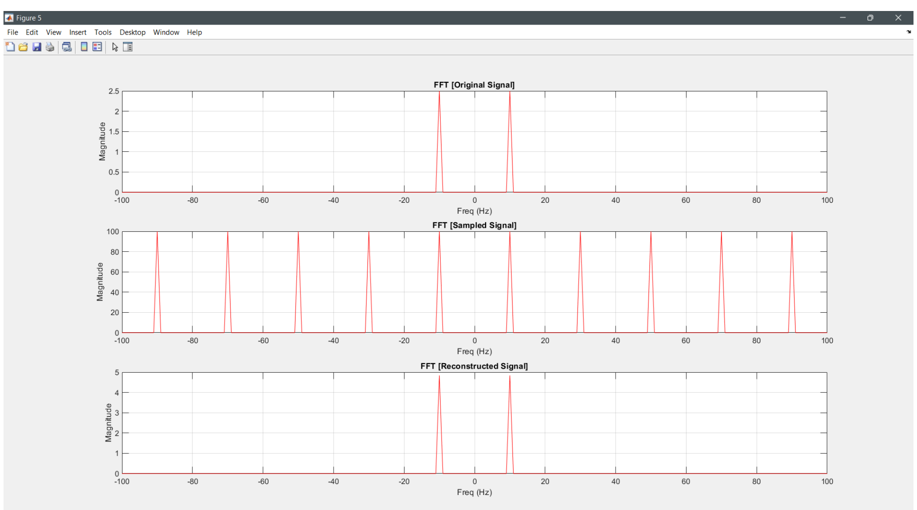
Results For Test Case 3:











1. Original Signal

- **Graph: Displays the original sine wave.**
- **Observation: The base signal is smooth and continuous, representing the analog input signal before any processing.**

2. Sampling

- **Graph: Shows the sampled signal at 20 Hz.**
- **Observation: The sampling frequency meets the Nyquist criterion, similar to Case 2. However, since the sampling rate is just enough to meet the criterion, the resolution is lower, which might impact the reconstruction accuracy.**

3. Quantization

- **Graph: Represents the quantized version of the sampled signal.**
- **Observation: The quantization process uses 32 levels, but with a high μ value of 100, which indicates non-linear companding (compressing the signal). This process affects the dynamic range, meaning that small amplitude signals are given more resolution, while larger amplitudes are compressed, leading to non-linear distortion.**

4. Encoding (Manchester)

- **Graph: Illustrates the encoded signal using Manchester encoding.**
- **Observation: Manchester encoding is more complex than Polar or Unipolar NRZ. It encodes each bit with two phases—typically a transition from high to low for a "1" and low to high for a "0" within the bit period. This ensures that there is always a transition in the middle of each bit, making it easier to synchronize. However, this adds complexity and doubles the bandwidth requirement.**

5. Reconstructed Signal

- **Graph: Shows the reconstructed signal after processing.**
- **Observation: The reconstructed signal resembles the original sine wave, but due to the high μ value and Manchester encoding, there may be some artifacts or distortion. The companding effect may introduce some non-linearities, and Manchester encoding's complexity might slightly alter the reconstructed waveform.**

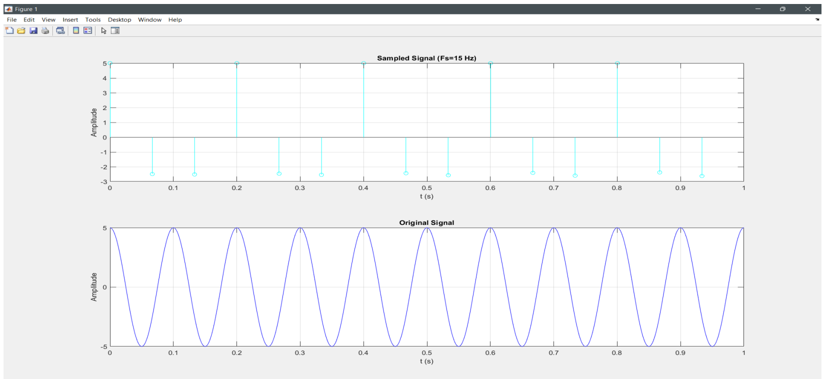
6. FFT Analysis

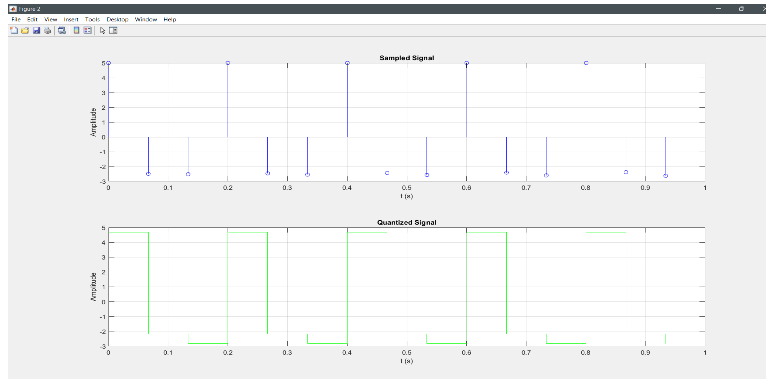
- **Graph: Presents the Fast Fourier Transform (FFT) of the original, sampled, and reconstructed signals.**
- **Observation:**
  - **Original Signal FFT: Shows the frequency components of the original sine wave with a peak at the fundamental frequency.**
  - **Sampled Signal FFT: Displays the frequency spectrum after sampling. The frequency peaks should align with the original, although slight artifacts might be present due to the lower sampling rate and companding.**
  - **Reconstructed Signal FFT: Shows the frequency content of the reconstructed signal. The FFT of the reconstructed signal should closely match the original, but discrepancies due to companding and Manchester encoding might introduce some additional frequency components or distortions.**

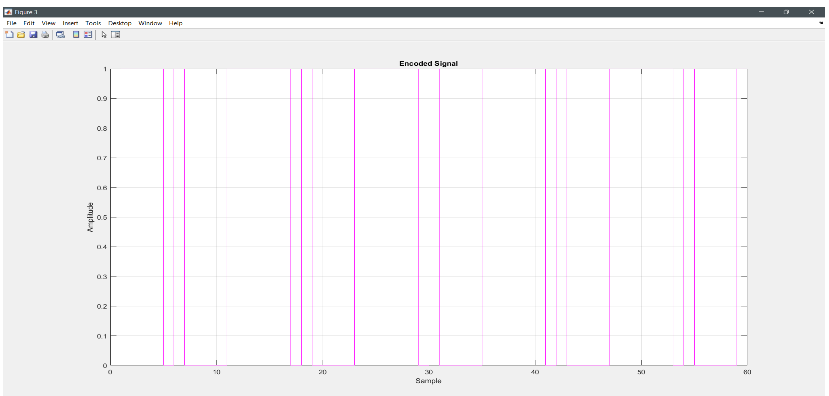
Conclusion:

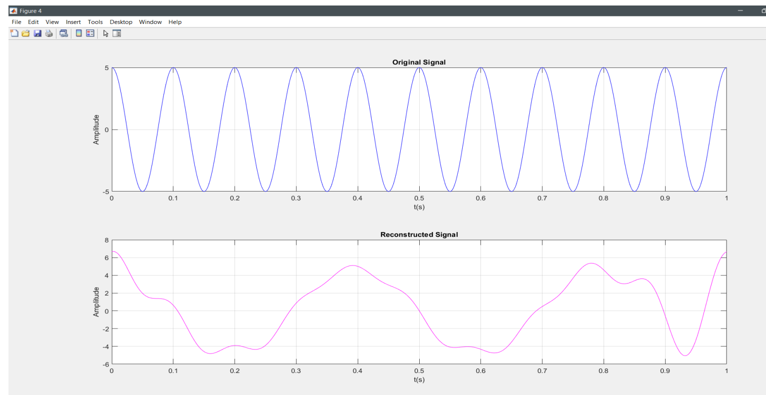
In this test case, the signal processing chain is more complex due to the high μ value for companding and Manchester encoding. The sampling rate is the same as in Case 2, so it meets the Nyquist criterion but with limited resolution. The quantization process, influenced by the high μ value, introduces non-linear compression, which affects the dynamic range of the signal. Manchester encoding, while improving synchronization, adds complexity and potentially introduces additional artifacts or distortions. The reconstructed signal is a good approximation of the original, but the additional processing steps make it more prone to subtle errors or distortions, as reflected in the FFT analysis.

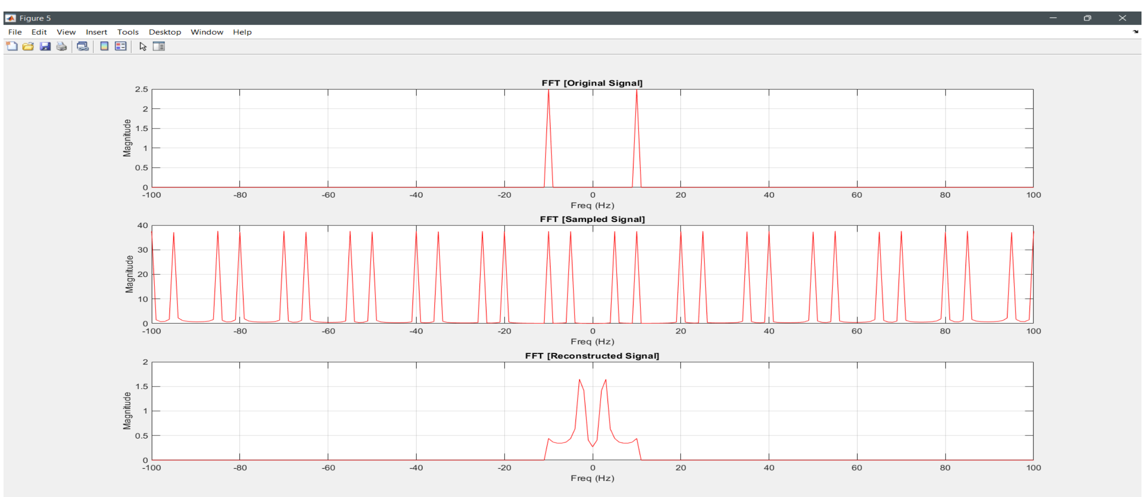
Results For Test Case 4:











Result Analysis Of Case 4:

- **Sampling:** The conclusion of aliasing due to undersampling is correct. Sampling below the Nyquist rate inevitably leads to this distortion, where high-frequency components of the original signal are misinterpreted as lower frequencies.
- **Quantization:** The assessment of quantization precision is accurate. A higher number of quantization levels (L=16) generally provides better resolution than fewer levels (as in Case 1), but it's still coarser than Case 2 with an even higher number of levels.
- **Encoding:** The description of Unipolar NRZ encoding is correct. It's a simple scheme but susceptible to noise and distortion, especially when combined with aliasing.

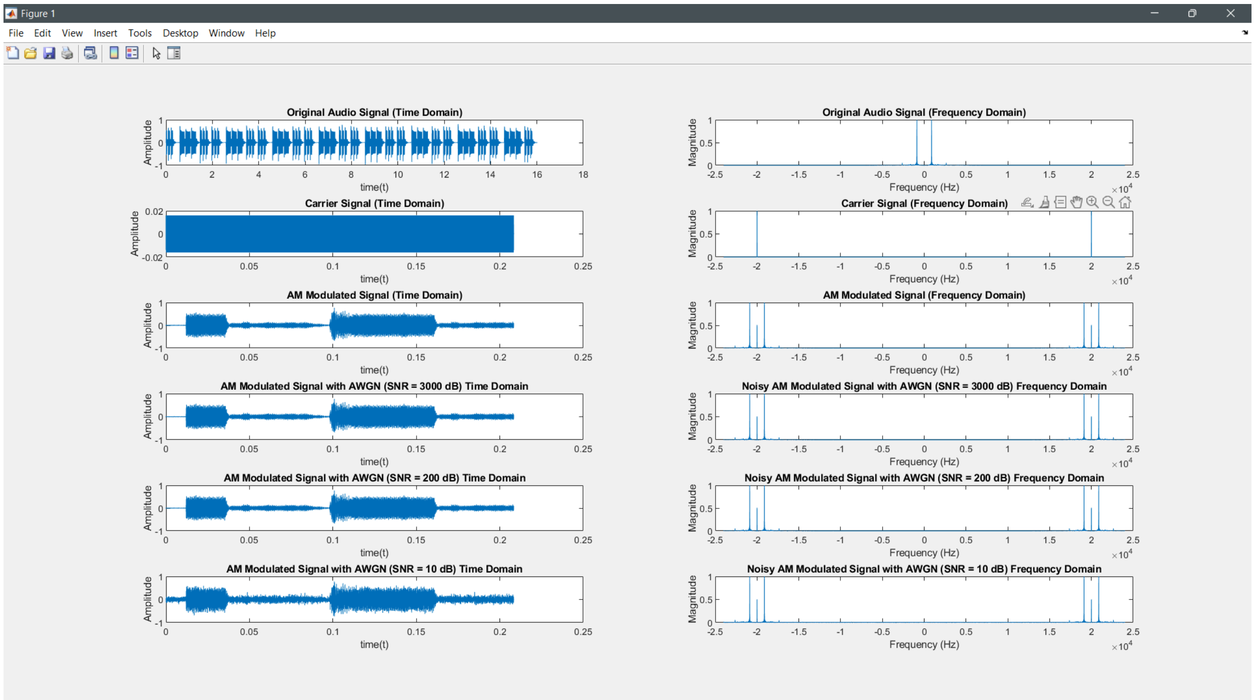
Potential Improvements:

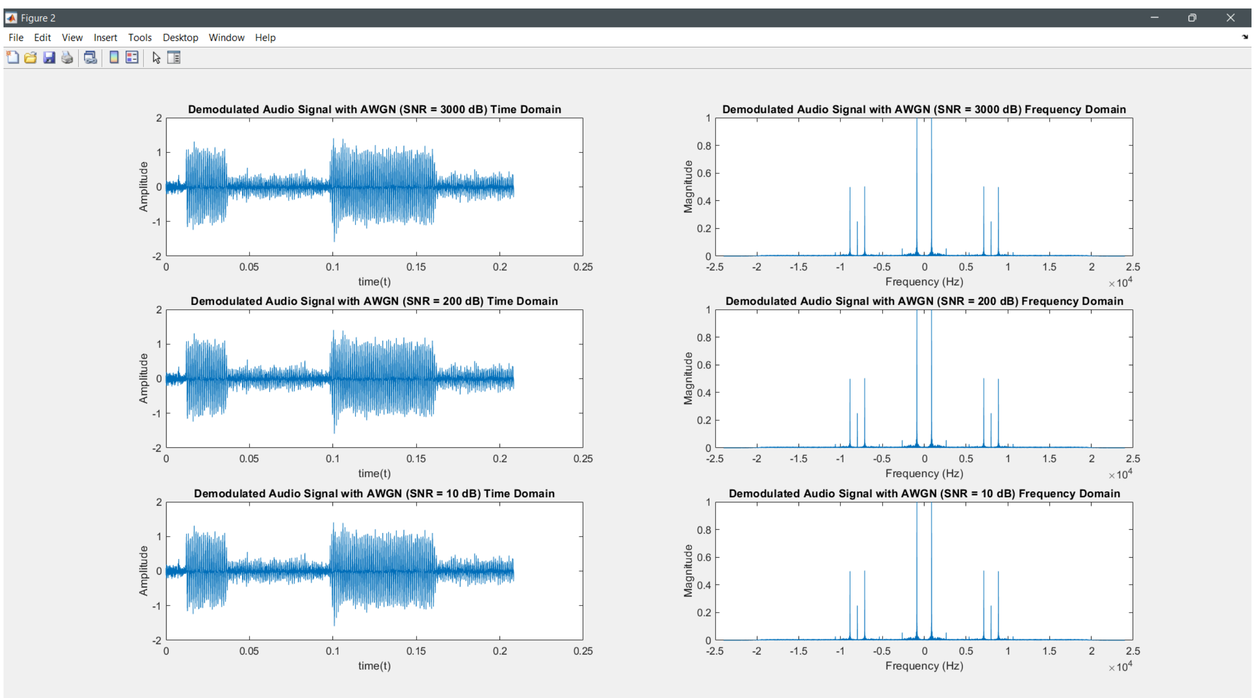
- **Sampling Frequency:** Increase the sampling frequency to at least twice the maximum frequency component in the signal (Nyquist rate) to avoid aliasing.
- **Quantization:** Consider increasing the number of quantization levels (L) to improve precision, but balance this with the desired bitrate.
- **Encoding:** Explore more robust encoding schemes like bipolar or Manchester coding to reduce the impact of noise and distortion.

Additional Considerations:

- **Signal Bandwidth:** Knowing the actual bandwidth of the signal would help determine the minimum required sampling frequency.
- **Quantization Noise:** The choice of quantization step size (mp) also affects quantization error.
- **Error Analysis:** It would be beneficial to quantify the impact of aliasing and quantization error on the reconstructed signal.

Part II





Analysis of AM Modulation and Noise Impact

- AM Modulation: The figure clearly demonstrates the principle of amplitude modulation, where the audio signal modulates the amplitude of the carrier signal. This is evident in both the time and frequency domain representations.
- Noise Impact: As the SNR decreases, the impact of AWGN becomes more pronounced. The noise corrupts the modulated signal, making it difficult to recover the original audio information through demodulation. This is reflected in the increased noise levels in both time and frequency domains for lower SNR values.
- Demodulation Performance: The demodulated signals show that while the overall shape of the original audio signal can be recovered, the quality deteriorates significantly with increasing noise. The frequency domain plots of the demodulated signals exhibit noise spreading across the spectrum, affecting the fidelity of the recovered audio.

Part II figures showcase the time and frequency domain representations of demodulated audio signals subjected to different levels of Additive White Gaussian Noise (AWGN).

Key Observations:

- Time Domain:
    - The demodulated signals exhibit a clear degradation in waveform quality as the SNR decreases.
    - The signal at 3000 dB SNR retains its original shape with minimal distortion.
    - As the SNR drops to 200 dB and 10 dB, the waveform becomes increasingly noisy and distorted, making it difficult to discern the original audio content.
- Frequency Domain:
    - The spectrum of the demodulated signal at 3000 dB SNR is relatively clean with minimal noise spread.
    - As the SNR decreases, the noise floor rises significantly, obscuring the original signal components.
    - The 10 dB SNR spectrum is dominated by noise, making it challenging to identify the underlying audio information.

Implications

- Noise Impact: The results clearly demonstrate the detrimental effects of AWGN on demodulated audio signals. As noise levels increase, the quality of the recovered audio deteriorates rapidly.
- SNR Importance: Maintaining a high SNR is crucial for achieving acceptable audio quality in demodulation systems.
- Potential Improvements: To mitigate the impact of noise, consider implementing error correction codes, noise reduction techniques, or more robust modulation schemes.