



Cairo University - Faculty Of Engineering  
Computer Engineering Department  
Communication - Spring 2025



---

# Digital Communications: Assignment 1 (Quantization)

Akram Hany  
Amir Kedis (9220166)

Spring 2025

# 1 Introduction

In this report, we provide our solution / implementation for Quantization. Covering concepts like midtread and midrise, SNR, uniform and non-uniform quantizers.

## 2 Theoretical Background

### 2.1 Uniform Quantization

Uniform quantization is a process where the input signal amplitude range is divided into equal intervals. The key parameters in uniform quantization are:

- Number of levels:  $L = 2^n$  where  $n$  is the number of bits
- Level amplitude:  $\Delta = \frac{A_{max} - A_{min}}{L}$
- Quantization step size:  $\Delta = \frac{2A_m}{L}$  where  $A_m$  is the maximum amplitude
- Quantization error:  $q = \frac{\Delta}{2}$

The quantization error is bounded by:  $-\frac{\Delta}{2} < q \leq \frac{\Delta}{2}$

### 2.2 Signal-to-Noise Ratio (SNR)

For uniform quantization, the theoretical SNR can be calculated as:

$$SNR_{avg} = \frac{3\alpha^2 L^2}{\Delta^2 / 12} = 3\alpha^2 2^{2n}$$

Where  $\alpha$  is a signal-dependent parameter. In decibels:

$$SNR_{Peak} = 10 \log_{10}(3\alpha^2) + 6n$$

For a full-scale sinusoidal input:

$$SNR_{Peak} = 10 \log_{10}(3) + 6n$$

### 2.3 Midtread and Midrise Quantizers

Two common types of uniform quantizers are midtread and midrise:

- **Midtread Quantizer:** Has voltage levels centered on integer values, including zero
- **Midrise Quantizer:** Has voltage levels centered on half-integer values, without a level at zero

### 2.4 Non-uniform Quantization

For non-uniform signals in uniform quantizers, the SNR performance degrades. To improve performance, non-uniform quantization through companding can be used, with the SQNR given by:

$$SQNR_{non-uniform} = \frac{3L^2}{\ln^2(1 + \mu)}$$

Where  $\mu$  is the compression parameter.

### 3 Methodology

Our analysis involves implementing both uniform and non-uniform quantization techniques and evaluating their performance through:

1. Implementation of midtread and midrise quantizers
2. Comparison of computational results with theoretical calculations
3. Analysis of SNR performance across different bit depths
4. Evaluation of companding effects on non-uniform signals

## 4 Results and Discussion

### 4.1 Midtread and Midrise Quantization

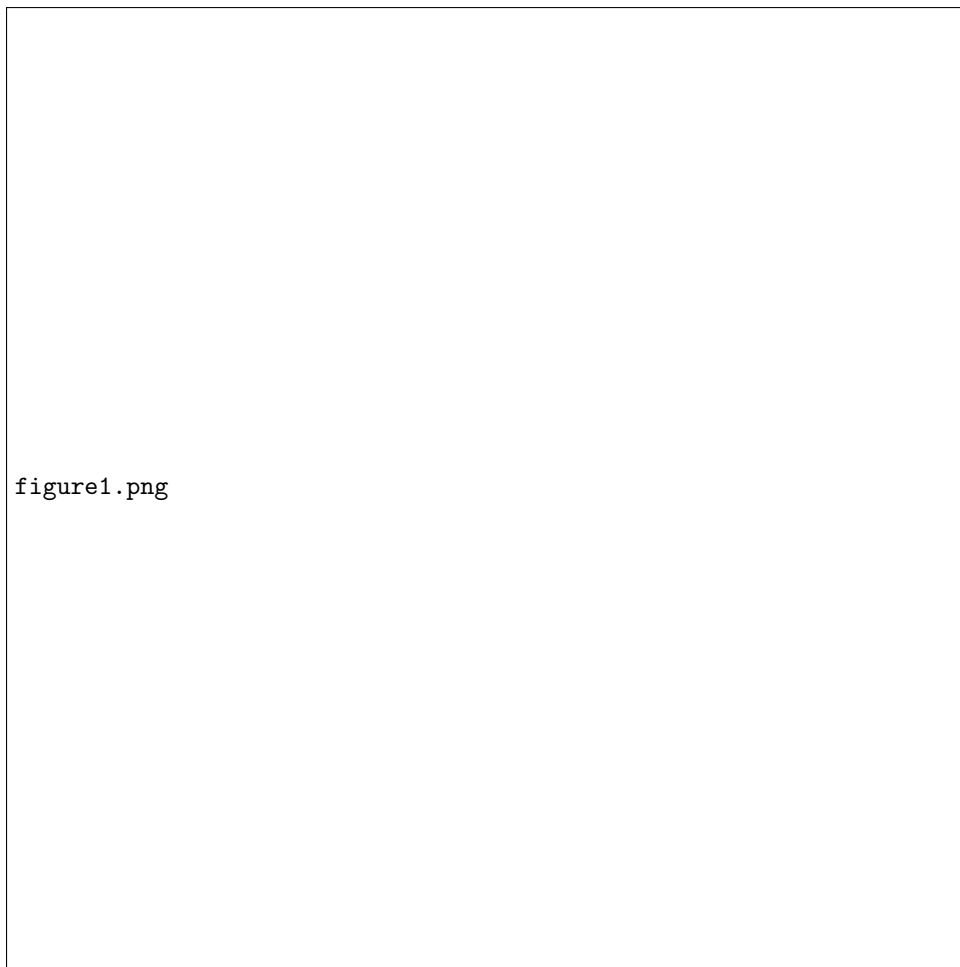


Figure 1: Original signal and its quantized version using midtread ( $m=1$ ) and midrise ( $m=0$ ) quantizers

Figure 1 shows the original signal and its quantized version using both midtread ( $m=1$ ) and midrise ( $m=0$ ) quantizers. The midtread quantizer includes a level at zero, while the midrise quantizer has levels at half-integer values.

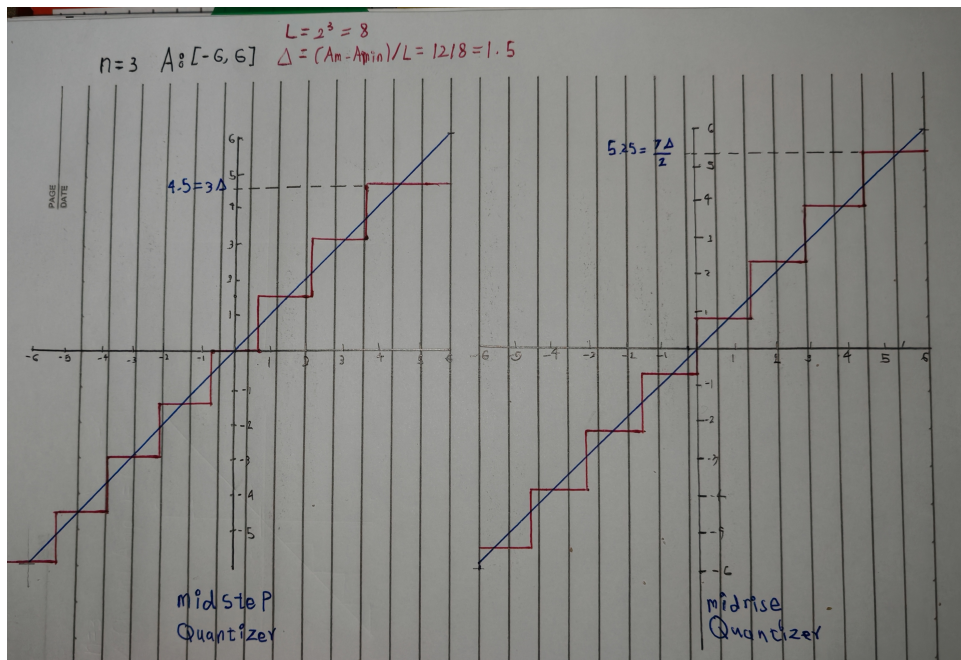


Figure 2: Manual calculation and hand-drawing of quantization processes for verification

Figure 2 presents a manual calculation and hand drawing of the same quantization processes to verify the results.

## 4.2 SNR Analysis

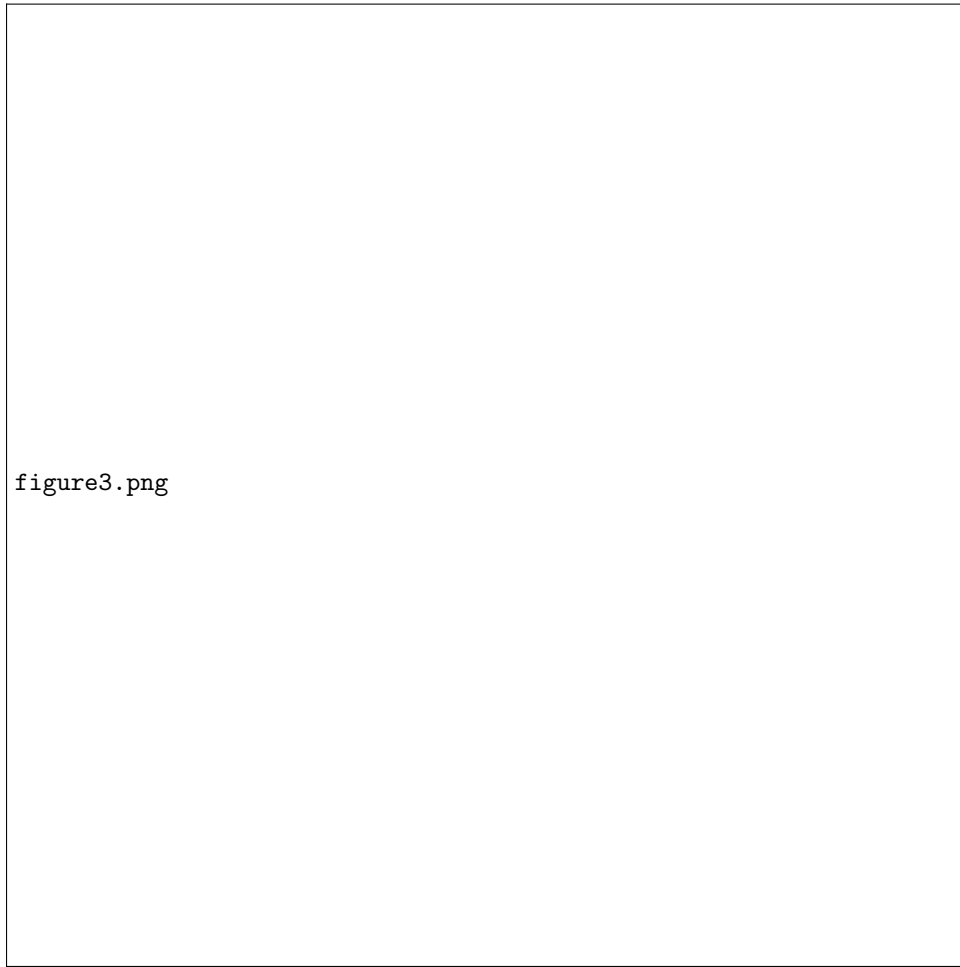


Figure 3: SNR across different bit depths ( $n$ ) - Linear scale

Figure 3 displays the SNR across different bit depths ( $n$ ) for both theoretical and calculated values in linear scale. As expected, the SNR increases linearly with the number of bits.

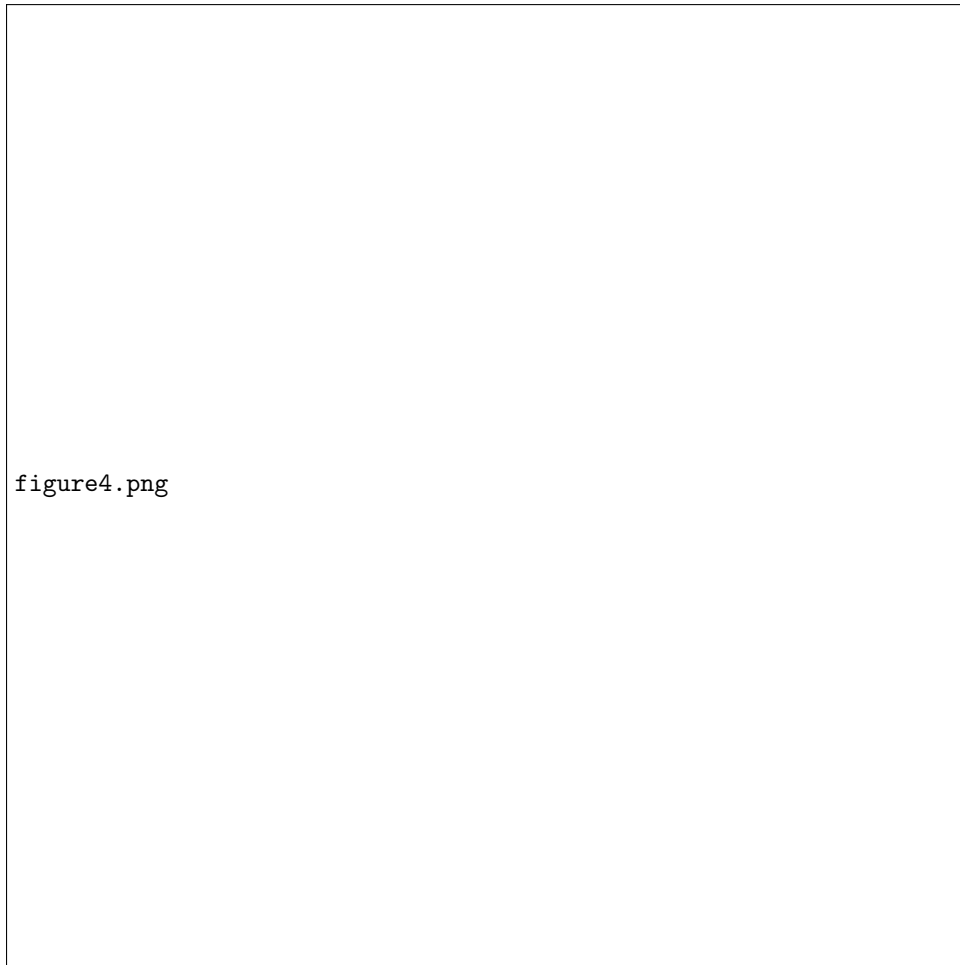


Figure 4: SNR across different bit depths ( $n$ ) - Decibel scale

Figure 4 presents the same data in decibel scale, showing the expected 6 dB improvement in SNR for each additional bit of quantization.

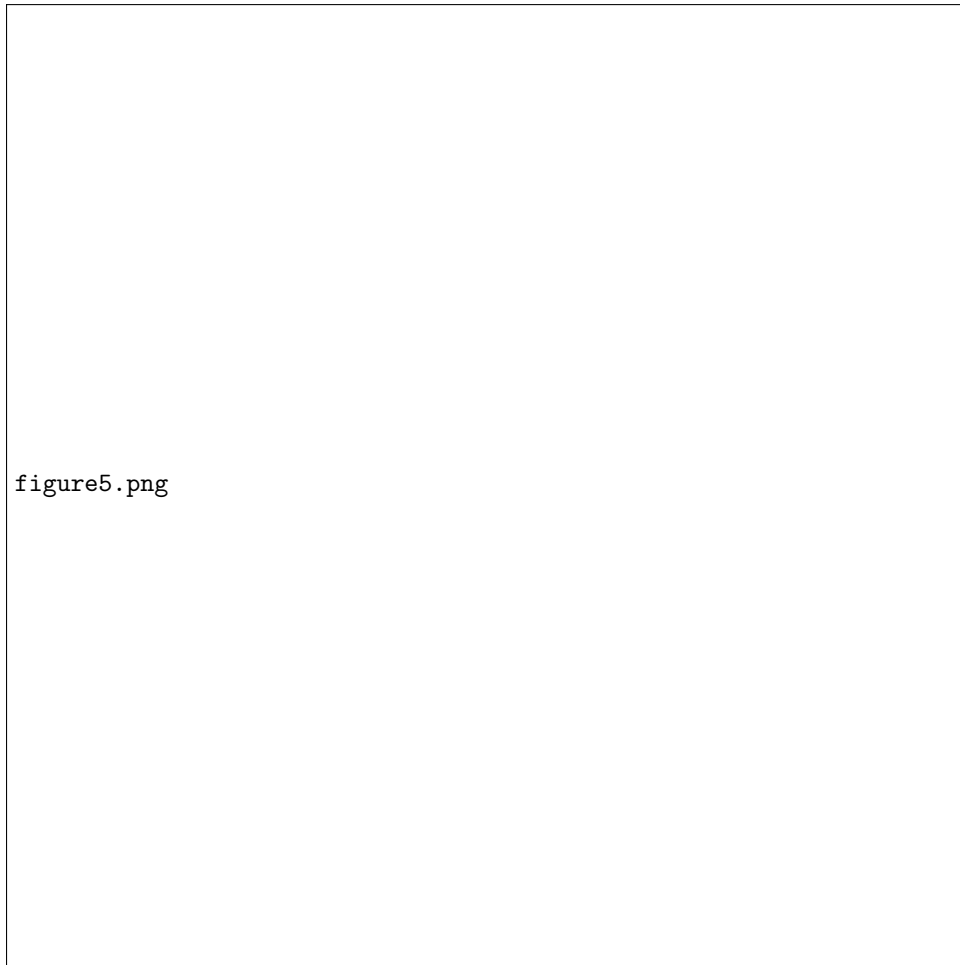


Figure 5: SNR for non-uniform signals in uniform quantizers - Linear scale

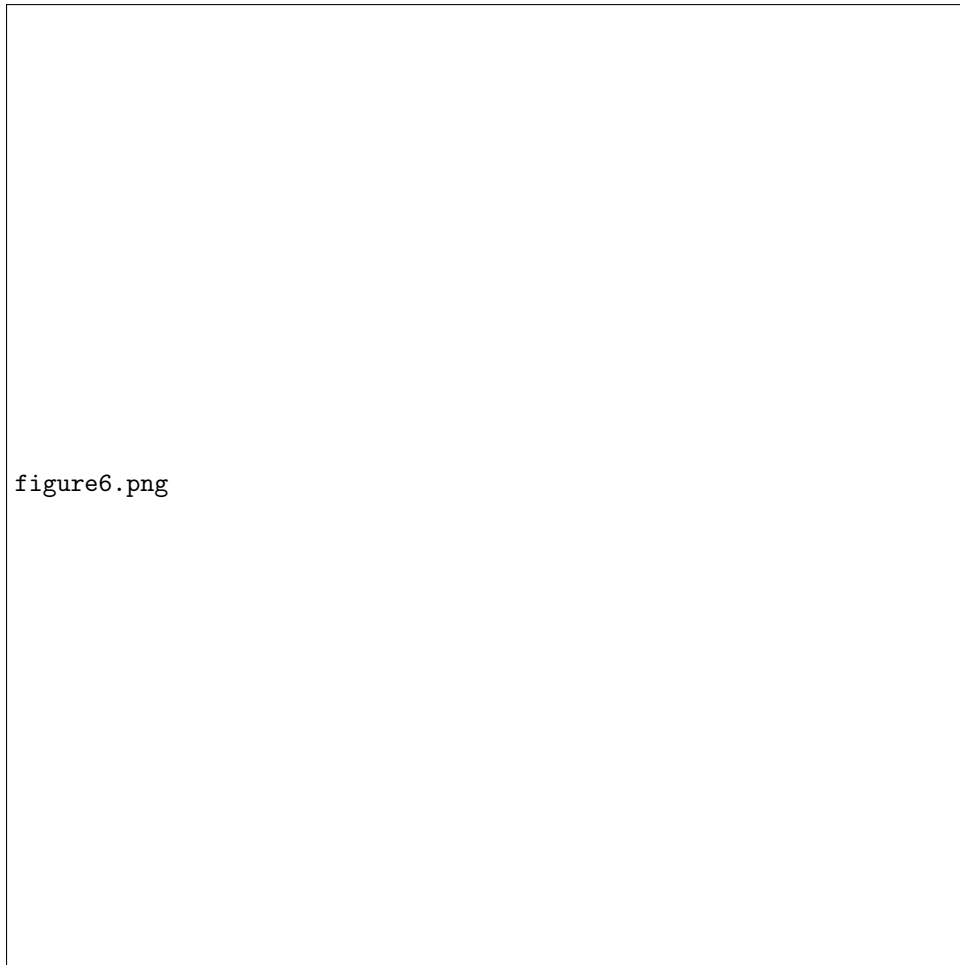


Figure 6: SNR for non-uniform signals in uniform quantizers - Decibel scale

Figures 5 and 6 show the SNR performance for non-uniform signals processed through uniform quantizers, highlighting the degradation in performance compared to uniform signals.



### 4.3 Companding Analysis

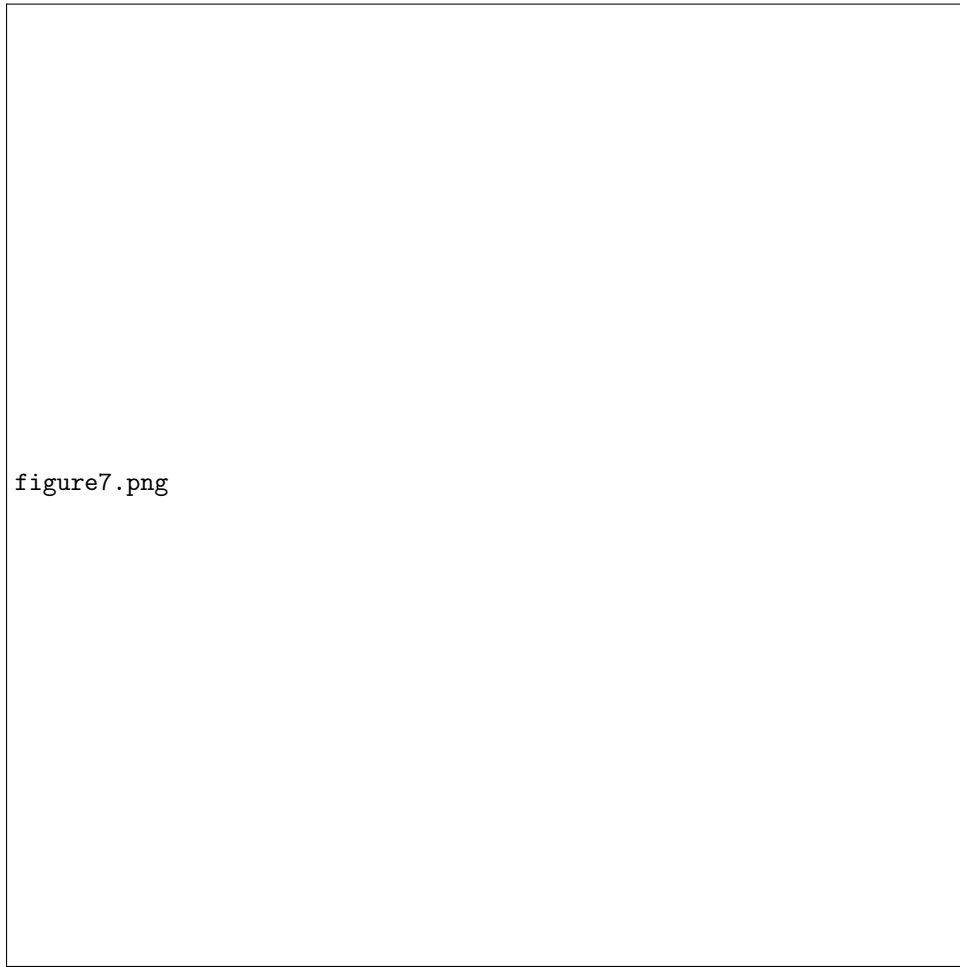


Figure 7: Effect of compression parameter ( $\mu$ ) on SNR performance

Figure 7 illustrates the effect of different compression parameters ( $\mu$ ) on the SNR performance of the compander-expander system, demonstrating how appropriate selection of  $\mu$  can optimize performance for specific signal distributions.

## 5 Conclusion

Our analysis confirms the theoretical expectations regarding quantization performance:

1. The SNR improves by approximately 6 dB for each additional bit in the quantizer
2. Midtread and midrise quantizers show different characteristics, particularly in how they handle signals near zero
3. Non-uniform signals experience degraded performance in uniform quantizers
4. Companding can significantly improve performance for non-uniform signals when the compression parameter is properly selected

These findings highlight the importance of selecting appropriate quantization techniques based on the specific characteristics of the input signal in digital communication systems.

## A Python Implementation

This appendix contains the Python code used to implement the quantization techniques and generate the figures presented in this report.

### A.1 Uniform Quantization Implementation

```
1 plt.show()
```

Listing 1: Uniform Quantization Implementation

### A.2 SNR Analysis Implementation

```
1 plt.show()
```

Listing 2: SNR Analysis Implementation

### A.3 Non-uniform Quantization Implementation

```
1  
2 plt.show()
```

Listing 3: Non-uniform Quantization and Companding Implementation