Cairo University
Faculty of Engineering

Department of Computer Engineering

ELC 325B – Spring 2023

Digital Communications

Assignment #1

Quantization

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Contents

Part 1:……… 4

Comment: .... **Error! Bookmark not defined.**

Part 2:……… 6

Comment: .... **Error! Bookmark not defined.**

Part 3:……… 7

Comment: 7

Part 4:……… 8

Comment: 8

Part 5:……… 9

Comment: 9

Part 6:……… 10

Comment: 10

Index: 12

Figures

Figure 1 Fig Mid-Rise Staircase ....
Figure 2 Fig Mid-Tread Staircase ....
Figure 3 Fig Our Mid Rise output..
Figure 4 Fig Our Mid-Tread output..
Figure 5 Fig SNR for different number bits for mid Rise ....
Figure 6 Fig SNR for different number bits for mid Tread...
Figure 7 Fig SNR of uniform quantizer with non-uniform input signals .... Error! Bookmark not defined.
Figure 8 Fig SNR of non-uniform quantizer with different u values **10**

Part 1: Implementing a uniform scalar quantization function.

Since there are two types of uniform quantization, we have implemented both, which are Mid-Rise quantization and Mid-Tread quantization.

Comment:

- This function is responsible for approximating the sampled data into discrete values to be able to generate certain code for each level, in order to transmit the data, and the decoder there at the receiver should be able to understand which level is transmitted and decode it to its correct level.
- In the first part we have implemented the Mid-Rise uniform quantizer which has this staircase
- It was called like this because:
    - The origin lies in the middle of the raising part of the staircase.
- The quantization levels in this type are even in number.

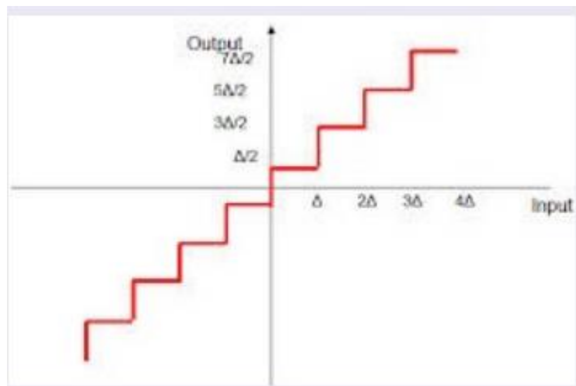

Figure (1)

Part 2: Implementing a uniform scalar quantization function with Mid-Tread.

- In the second part we have implemented the Mid-Tread uniform quantizer which has this staircase
- It was called like this because:
    - The origin lies in the middle of the Tread part of the staircase.
    - The quantization levels in this type are odd in number.
    - Both types are symmetric about the origin.

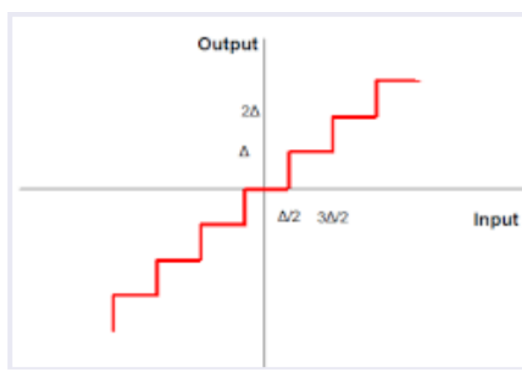

Figure (2)

Part 3: Test the quantizer/dequantizer functions on a deterministic input.

3a) Plotting the Mid-Rise output:

- This is the output for the following instructions:
  - Generating ramp signal, from -6 to 6 with increment 0.01.
  - Using 3 bits to generate 8 levels of quantization.
  - mp = 6.

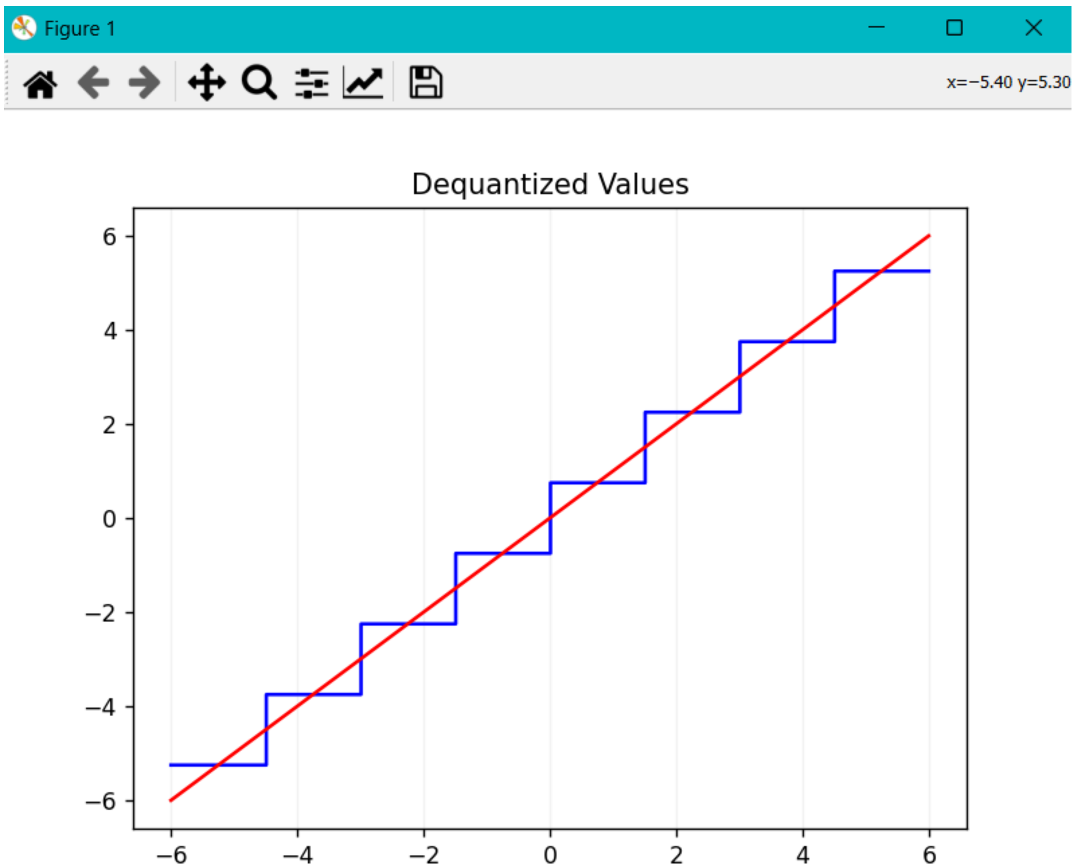

Figure (3)

Here the red line represents the ramp signal, while the blue staircase represents our mid-rise, and you will notice that the input is passing through the raise of each level.

3b) plotting the Mid-Tread output:

- Here is the output for the same data above but using the mid-tread quantizer:

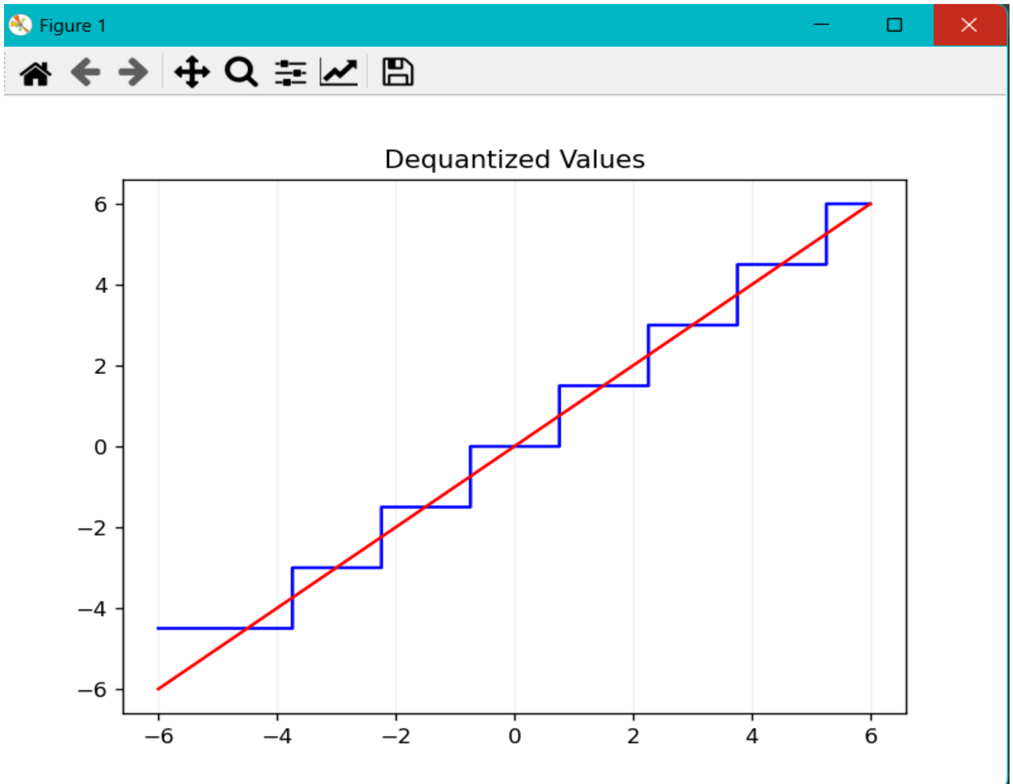

Figure (4)

Here the red line represents the ramp signal, while the blue staircase represents our mid-tread, and you will notice that the input is passing through the tread of each level.

Part 4(1):

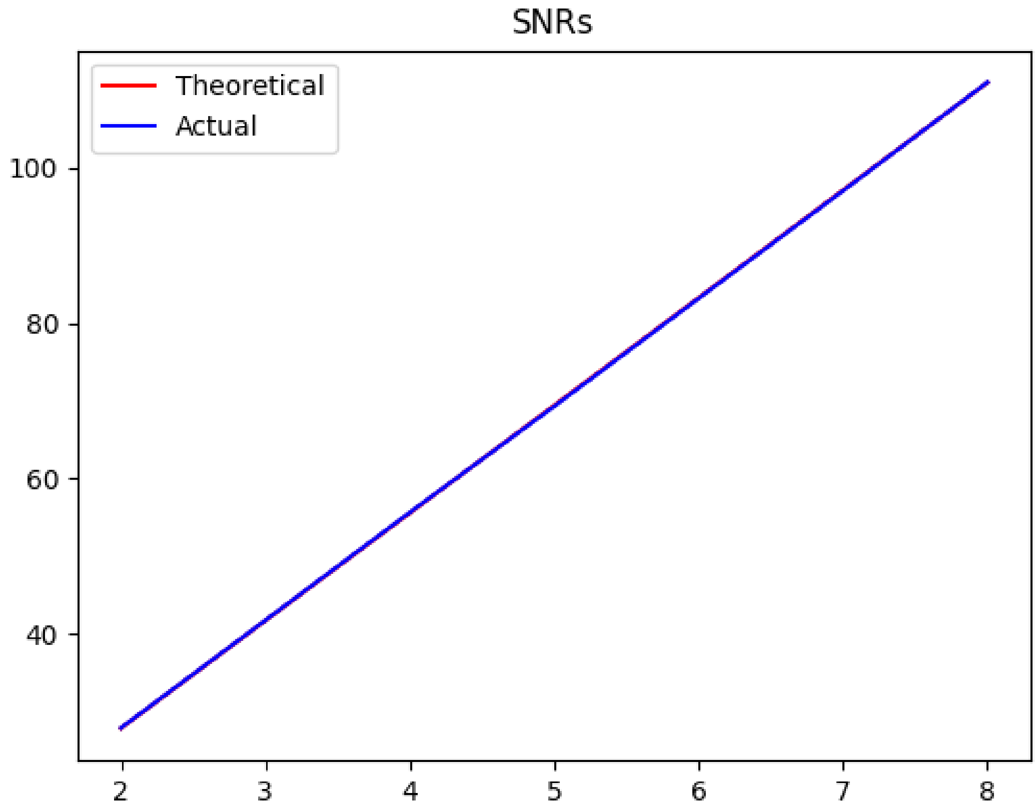

Figure (5)

Comment:

As the data generated are uniformly distributed so we can use uniform quantization using Mid-Rise.

We notice that the actual and theoretical SNR increase as the number of bits used for sampling increases because the error decreases.

So, the two lines are almost identical. (The red line is behind the blue line)

Part 4(2):

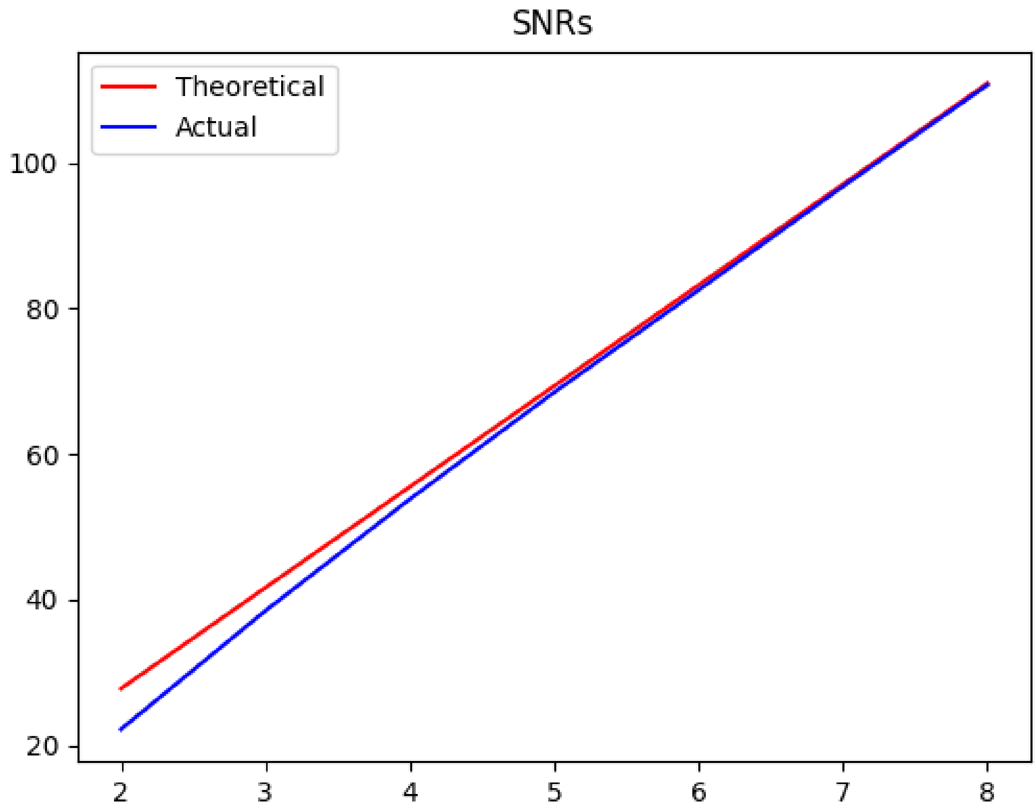

Figure (6)

Comment:

It is same as the previous part, but the error is relatively higher because the approximation due to the odd number of levels above and below zero. So the difference between actual SNR and Theoretical is higher in case of small number of bits.

Part 5: Testing the uniform quantizer on a non-uniform random input:

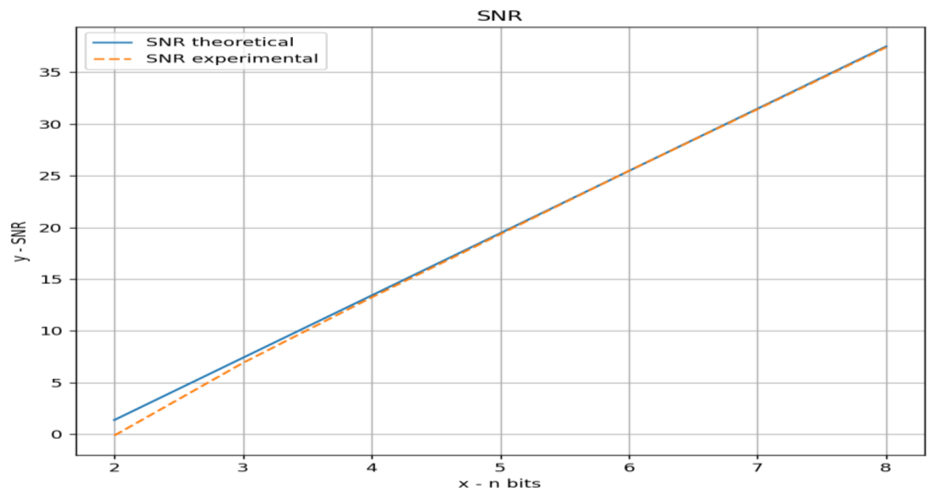

Figure (7)

Comment:

- This output is plotted in dB so it is linear, while if it was not in dB, it should take a curvature form.
- Here we can see that as the number of bits increases the resolution increases so the SNR will also increase.
- That is because the probability of error will decrease and even when there is an error, the difference between it and the nearest level to it will be small because we have increased the number of levels.
- That is according to the equation which defines the number of levels which is:
- Where R is the number of bits.

$$L = 2^R$$

- And we can also see, that as we increase the number of bits
  The theoretical SNR which can be evaluated from this equation:
  where:
  - L is the number of levels
  - mp is the absolute value of the maximum value.
  - P is the signal power.

$$SNR = \frac{\widetilde{m^2}}{N_q} = \frac{3L^2 P}{m_p^2}$$

- Will be close to the actual SNR which will be evaluated from evaluating the difference between the quantized samples and the input sample and dividing the signal power by the noise power.
- And this also happens because of the same reason as the resolution increases so the probability of the error decreases.

Part 6: Finally, we now need to use a non-uniform quantizer (u-law) on our quantization functions.

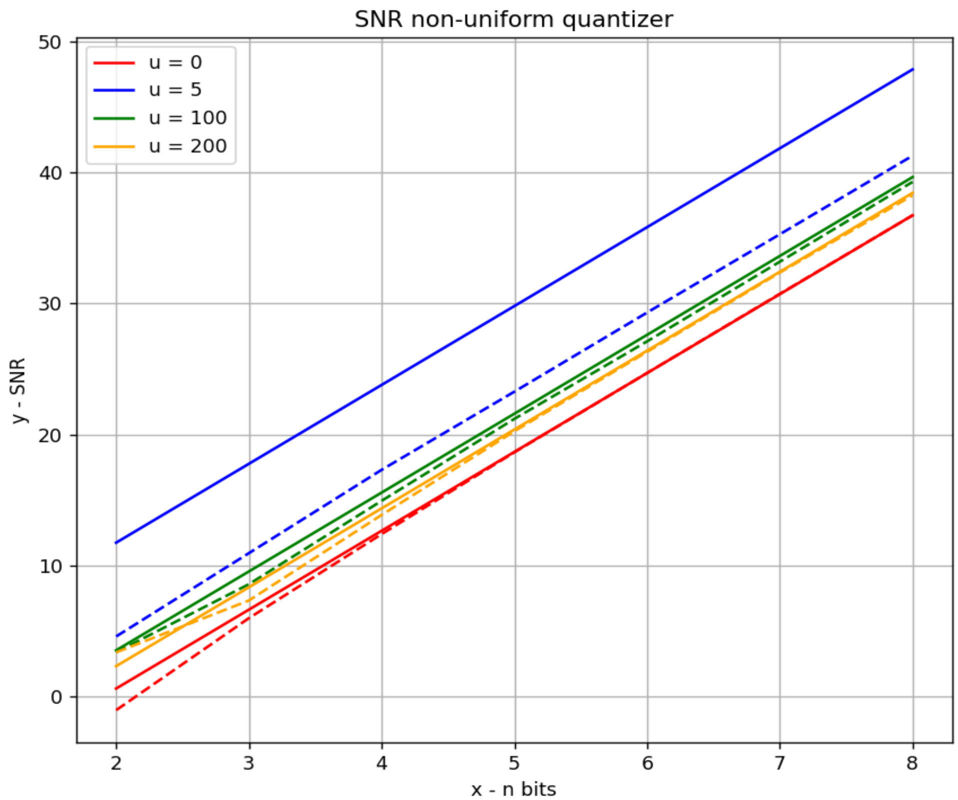

Figure (8)

Comment:

- Since to be able to apply this method, we need to use the Compander system.
- This happens by using two utility functions.
    - Compressor:
        - It is responsible for compressing the input, by applying a log function to be able minimize the differences between the input values.
    - Expander:
        - After applying the quantization, we have to return it to its original shape, and this may happen by using the inverse function for the compressor system.

- So, in our case we have used this equation as our compressor:
  - Y here is the input to our quantizer function
  - Ln is the natural logarithmic function.
  - (m^) is our input signal but after Normalization
  - u is a constant which we design our system on it to be able to compress the data as we want, and in this experiment, we have applied different values of u to be able to observe what happen when we change its value.

μ-Law Quantizer

$$y = \frac{\ln(1 + \mu \hat{m})}{\ln(1 + \mu)}$$

- After that we insert Y to the quantizer functions.
- Then we apply this function as the Expander function
- After we got the result, we have evaluated the SNR For different values of u and get the results shown In Fig (6).

$$F^{-1}(y) = \operatorname{sgn}(y)\frac{(1+\mu)^{|y|} - 1}{\mu}, \quad -1 \leq y \leq 1.$$

- And the results are logically correct,
- Since as we increase the value of U the quantization output will increase since we have a better resolution during quantizing the samples, because we decrease the value of the error, so the signal power will increase and the noise power will decreases, and since SNR = (Signal Power / Noise Power), so SNR should also increase.

Index: