**Faculty of Engineering and Technology**

**Electrical and Computer Engineering Department**

**Communications Lab – ENEE4113**

**Report #: 2**

**Experiment #: 7**

**Experiment Title: Pulse Code Modulation (Quantizers and Encoders)**

---

**Prepared By:** Rahaf Naser 1201319

**Partners Names and IDs:** Quasi abo sondos 1221082

**Section #:** 2

**Instructor:** Dr. Nofal Nofal

**Teacher Assistant:** Eng. Halema Hmedan

**Date and Place of the Experiment:** 13/4/2025, Aggad341

## Abstract

This experiment aims to study different types of full system quantizers (uniform and non-uniform) and encoders, as well as the characteristics of the compressor and expander quantizers, each alone. It also aims to compare the resolution of each quantization type.

# Table of Contents

# Table of Figures

## List of Tables

# 1.Theory

Quantization is a powerful technique used to compress large language models (LLMs) and other neural networks, making them more efficient and accessible. It achieves this by reducing the precision of the model's weights and activations, essentially converting high-precision data into a lower-precision format [1].

## 1.1.Linear Quantization

Linear quantization is one of the most popular quantization schemas for LLMs. In simple terms, it involves mapping the range of floating-point values of the original weights to a range of fixed-point values evenly, using the high-precision data type for inference [2].

## 1.2.Non-Linear Quantization (Companding)

Non-linear quantization introduces **non-uniform step sizes**, typically using **μ-law or A-law companding techniques**. These methods compress the signal before quantization, allocating more quantization levels to **small amplitude signals**, which are more perceptually significant in audio applications. At the receiver, the signal is expanded back to its original form. This process improves the **dynamic range** and **perceived quality** of the signal, especially in speech processing [2].

## 1.3.Compressor and Expander

Companding is the process of compression and then expansion. With a combined system, the higher-amplitude analog signals are compressed (amplified less than the lower-amplitude signals) prior to transmission and then expanded (amplified more than the lower-amplitude signals) in the receiver [3].

The data rate is important in telecommunication because it is directly proportional to the *cost* of transmitting the signal. Saving bits is the same as saving money. Companding is a common technique for reducing the data rate of audio signals by making the quantization levels *unequal*. If the quantization levels are equally spaced, 12 bits must be used to obtain telephone quality speech. However, only 8 bits are required if the quantization levels are made *unequal*, matching the characteristics of human hearing [3].

The human ear is more sensitive to quantization noise in small signals than large signals. A-law and m-law coding apply a logarithmic quantization function to adjust the data resolution in proportion to the level of the input signal. Smaller signals are represented with greater precision – more data bits – than larger signals. The result is fewer bits per sample to maintain an audible signal-to-noise ratio (SNR) [3].

Companding can be carried out in three ways:

(1) run the analog signal through a nonlinear circuit before reaching a linear 8 bit ADC.

(2) use an 8 bit ADC that internally has unequally spaced steps.

(3) use a linear 12 bit ADC followed by a digital look-up table (12 bits in, 8 bits out) [3].

### 1.4.Quantizer Resolution

The next step in the process of converting an analog signal into digital form is the discretization of the sampled signal amplitude or quantization. In practice, because the quantization process takes a finite amount of time, the sampled signal amplitude has to be held constant during this time. The sampling process is usually performed by a sample-and-hold circuit, which can be logically represented as in Figure 2.13. The analog-to-digital converter performs the quantization process [4].

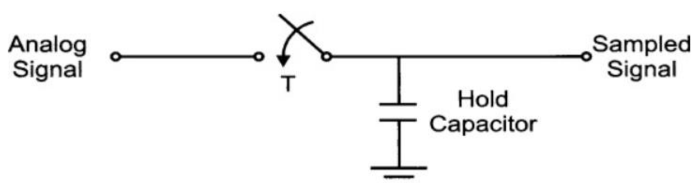


*Figure 3.4.1: quantization process[4]*

### 1.5.Encoding

**Encoding** is the process of turning thoughts into communication. The encoder uses a ‘medium’ to send the message — a phone call, email, text message, face-to-face meeting, or other communication tool. The level of conscious thought that goes into encoding messages may vary. The encoder should also take into account any ‘noise’ that might interfere with their message, such as other messages, distractions, or influences [5].

## 2. Procedure and discussion

### 2.1. Linear Quantization: (Characteristic of linear Quantizer with DC input)

In this part, we set the PCM modulator and demodulator panels to linear quantization,

enable all 8 bits on the A/D converter, and increase the input DC voltage from -10V to +10V using the potentiometer.

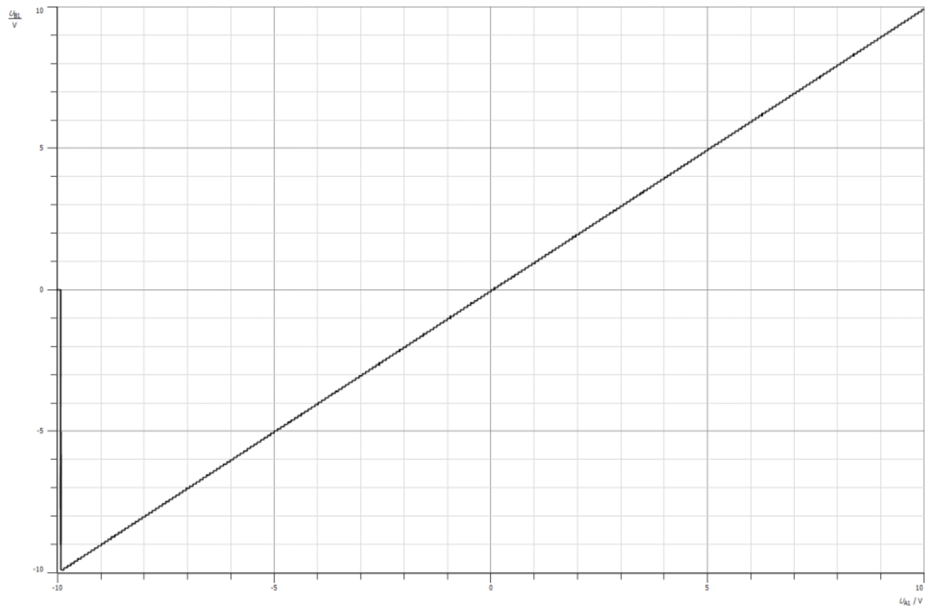

*Figure 2.1.1: Linear quantization result*

The result in Figure 2.1.1 shows a staircase-like linear relation between input and output. Each step corresponds to a quantization level. With 8 bits, we obtain 28=2562^8 = 25628=256 levels, which ensures high resolution and minimal quantization error. The output closely follows the input, validating the uniform nature of the quantizer.

### 2.2. Non-linear Quantization: (Characteristic of Non-linear Quantizer with DC input)

In this part, we kept the same setup as above, set the PCM modulator and demodulator to **non-linear quantization**, and increased the DC voltage from -10V to +10V.

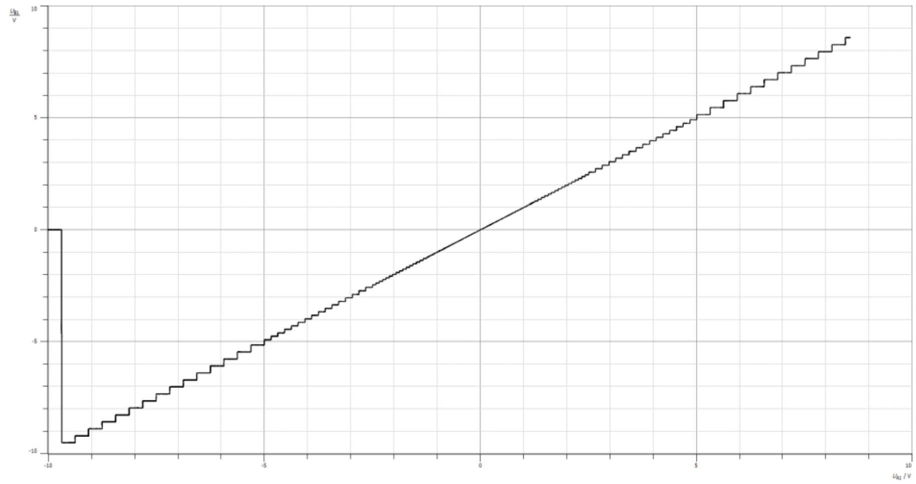

*Figure 2.2.1: Non-linear quantizer*

The result in Figure 2.2.1 shows that lower voltage ranges have finer resolution (smaller step sizes), while higher voltages have coarser steps. This approach prioritizes precision for small amplitude signals, which is important in audio and speech processing.

## 2.3. Compressor and Expander Characteristics

**Compressor Characteristics:**

In this part, we set the modulator to non-linear quantization, and the demodulator to linear, and increase the DC voltage from -10V to +10V.

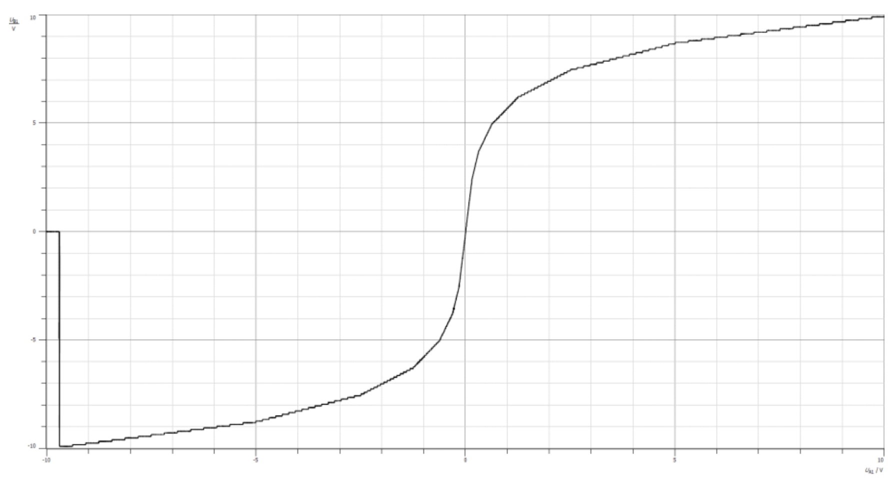

*Figure 2.3.1: Compressor Characteristics result*

The result in Figure 2.3.1 shows the **compression** phase of companding. The input is compressed using a logarithmic scale, reducing the dynamic range. The output curve demonstrates how high input amplitudes are, preparing them for efficient transmission.

**Expander Characteristics:**

In this part, we set the modulator to linear and the demodulator to non-linear, and repeat the voltage sweep and observe the result.

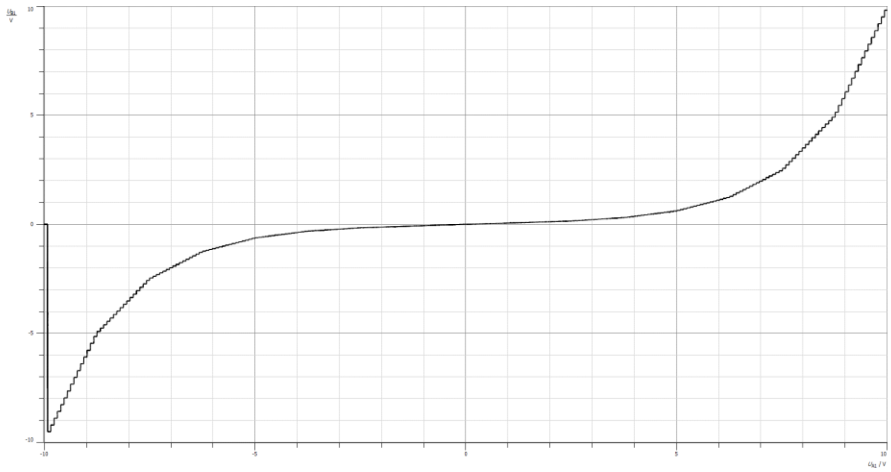

*Figure 2.3.2: Expander Characteristics result*

Here, the receiver expands the signal back to its original dynamic range. The curve is the inverse of the compressor. This approach ensures that the quantization noise is minimized in lower amplitude signals, aligning with human perception sensitivity.

## 2.4.Quantizer Resolution for both linear and non-linear quantizer

**Linear – Linear Quantizer:**

In this part, we set both panels to linear quantization, deactivate the 3 least significant bits (5-bit quantizer), and sweep the input voltage and observe the quantized output.

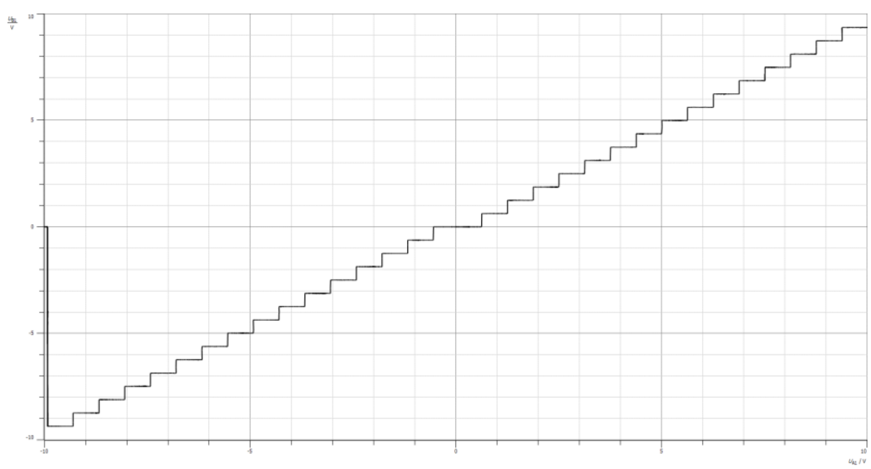

*Figure 2.4.1: Linear – Linear Quantizer*

Compared to the 8-bit quantizer, the 5-bit version produces a noticeably rougher staircase. With only 32 levels, the resolution decreases, and the quantization error increases. This results in more distortion, particularly in areas with small changes in input voltage.

**Non-Linear – Non-Linear Quantizer:**

In this part, we set both panels to non-linear quantization and use 5-bit resolution as above.

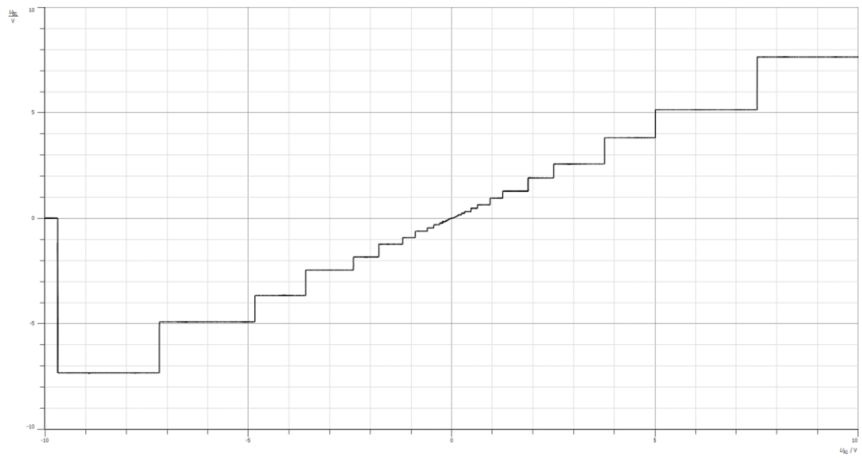

*Figure 2.4.2: Non-Linear – Non-Linear Quantizer*

While the number of levels is reduced, non-linear quantization still retains finer steps at lower amplitudes. This allows for relatively better fidelity than linear quantization in low-voltage regions, even with fewer bits.

**Non-Linear – Linear Quantizer:**

In this part, the Modulator is set to linear, the demodulator set to non-linear, and Keep 5-bit resolution.

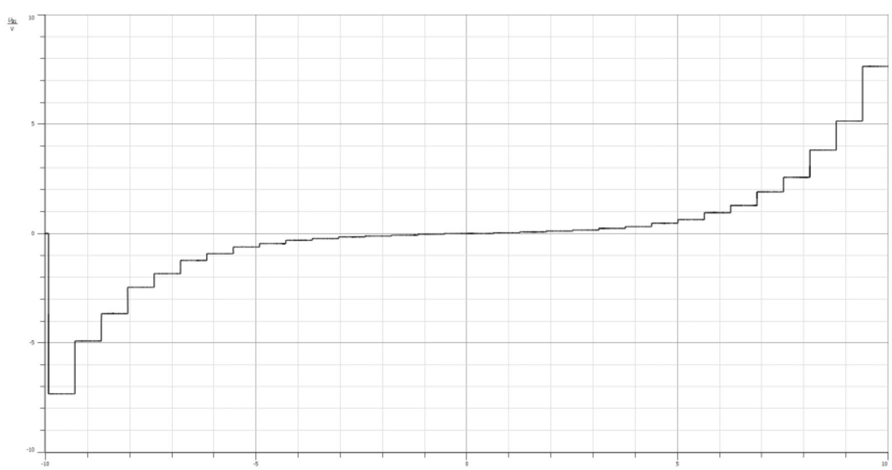

*Figure 2.4.3: Non-Linear – Linear Quantizer*

This mismatched configuration leads to distortion, as the decoder expects a non-linear encoded signal. The output curve appears warped and non-symmetric. Reducing the bits worsens the issue due to fewer quantization levels and format mismatch.

**Linear – Non-Linear Quantizer:**

In this part, Modulator: non-linear, Demodulator: linear, and 5-bit resolution.

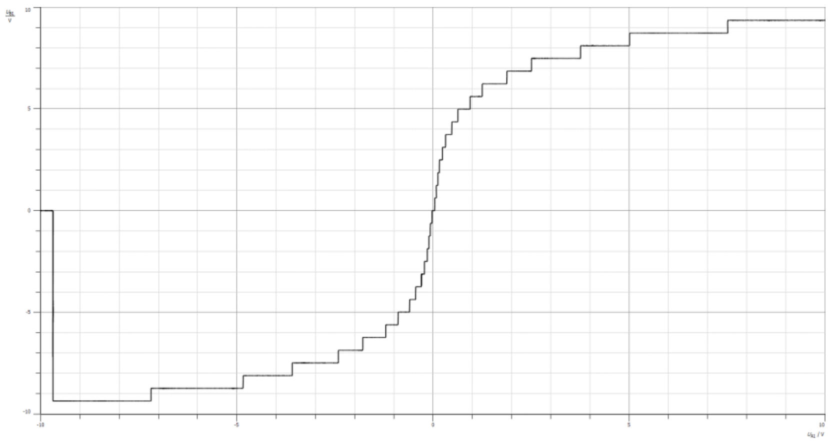

*Figure 2.4.4: Linear – Non-Linear Quantizer*

Like the previous case, mismatched companding formats introduce distortion. The characteristic curve appears compressed, with nonlinear scaling of voltage. At 5-bit resolution, the mismatch further increases output inaccuracies.

## 2.5.Encoding

In this part, both panels are set to **linear quantization**, 8-bit resolution enabled, Activate CH2 on the demodulator encoder, Load Code.labx file, and slowly adjust the potentiometer and record UA1, UB1. The corresponding binary pattern shown by the green LEDs.

*Table 5.1:Encoding results*

| Input Voltage (UA1) | Output Voltage(UB1) | Bit pattern |
|---|---|---|
| -9 V | -8.97 | 01110011 |
| -7 V | -7.26 | 01011101 |
| -5 V | -5.07 | 01000001 |
| -3 V | -3.04 | 00100111 |
| -1 V | -1.01 | 00001101 |
| 0 V | -0.05 | 10000001 |
| 1 V | 0.93 | 10001100 |
| 3 V | 2.95 | 10100110 |
| 5 V | 4.91 | 10111111 |
| 7 V | 6.93 | 11011001 |
| 9 V | 8.96 | 11110011 |

The results in Table 5.1 show that each output bit pattern represents a specific quantization level.

The **most significant bit (MSB)** often indicates the **sign** or **polarity** of the signal. A common encoding technique used here is **Sign-Magnitude PCM**, where the MSB represents the sign (0 for negative, 1 for positive), and the remaining bits encode the magnitude. The uniform step size and increasing binary pattern confirm the behavior of a linear quantizer.

## 3. Conclusion

This experiment showed the differences between linear and non-linear quantization, showing how non-linear methods improve accuracy for low-amplitude signals. It also showed the effects of bit resolution on signal quality—lower resolution increases distortion. The compressor/expander setup confirmed the benefits of companding, and the encoding part showed how binary patterns represent signal levels.

## 4.References


[1] https://www.datacamp.com/tutorial/quantization-for-large-language-models

[Accessed on 16/4/2025 at 22:30]

[2] https://www.datacamp.com/tutorial/quantization-for-large-language-models

[Accessed on 16/4/2025 at 22:55]

[3]https://ecedunia.blogspot.com/2016/03/companding.html#:~:text=Companding%20is%20the%20process%20of,amplitude%20signals)%20in%20the%20receiver

[Accessed on 16/4/2025 at 23:25]

[4] https://www.sciencedirect.com/topics/engineering/quantization-level#:~:text=The%20spacing%20between%20quantization%20levels,width%20or%20the%20quantizer%20resolution.&text=In%20practice%2C%20the%20input%20signal,bit%20quantizer%20for%20bipolar%20inputs

[Accessed on 16/4/2025 at 23:30]

[5] https://ecampusontario.pressbooks.pub/commbusprofcdn/chapter/1-2/

[Accessed on 16/4/2025 at 23:45]