Faculty of Engineering & Technology

Department of Electrical & Computer Engineering

ENEE4113-COMMUNICATIONS LAB

Report#2

Experiment#7: Pulse Code Modulation (Quantizers and Encoders)

Experiment#8: Pulse Code Modulation (Part 2)

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Section: 1

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Abstract

These experiments explore the field of digital signal processing. The purpose of Experiment 7 is to employ pulse code modulation (PCM) to transform analog signals into digital format. It compares the effectiveness of uniform and non-uniform quantizers, compressors, and expanders by looking at their resolutions.A digital multiplexing system that combines pulse amplitude modulation (PAM) and pulse code modulation (PCM) is investigated in Experiment 8. In order to enhance PCM performance, Differential Pulse Code Modulation (DPCM) is introduced and quantization noise for sinusoidal and triangular signals is examined. When taken as a whole, these experiments show how well various quantization schemes work in digital communication and offer information on modulation and conversion methods for digital signals.

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Theory

PCM (Pulse Code Modulation)

A digital approach known as pulse code modulation (PCM) involves periodically sampling an analog signal and converting the observed amplitude into a series of binary values. These values are then conveyed by modulating an intermittent, or pulsed, carrier. It is the accepted method for transmitting data in telecommunications.[1]

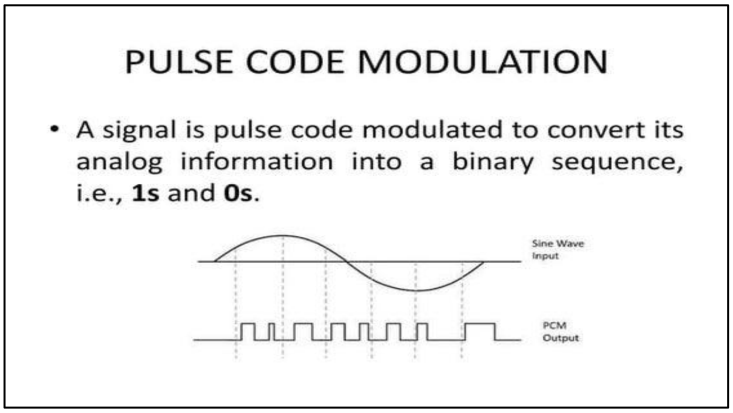

Figure 1:he output of the PCM signal with respect to the sine wave [1]

Pulse Code Modulation transforms analog data into a binary sequence of zeros and ones in a digital signal. The original analog signal can be obtained using the demodulation procedure.[2]

✧ Pulse-code modulation system components:

The following steps are involved in the pulse code modulation process:

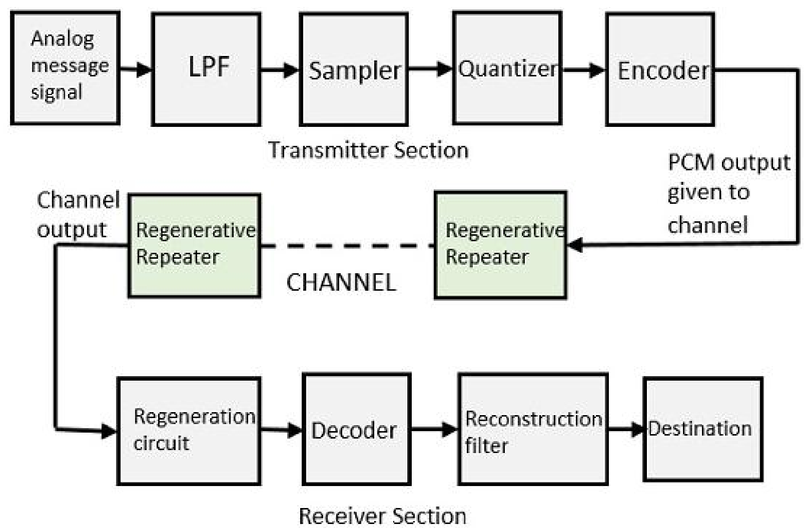

Figure 2:Block diagram of the Pulse Code Modulation process[2]

Sampler

In order to rebuild the original signal, the sampler assists in gathering sample data at any point during the message signal. The sample rate is higher than the message signal's highest frequency component, according to the sampling theorem.[2]

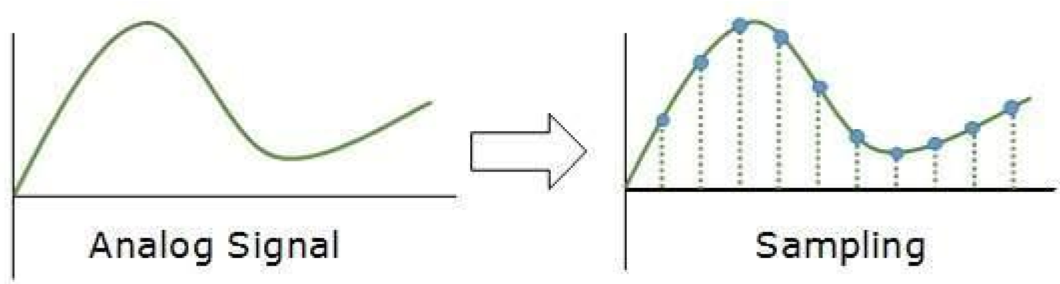

Figure 3:Sampling of analog signal[2]

Quantizer

In order to turn a continuous signal into a discrete one, quantization involves assigning a finite number of values to represent the signal's amplitude. This technique also helps to minimize inaccuracy. When the sampled output is run through a quantizer, it helps compress the values that are obtained while also reducing the number of superfluous bits.[2]

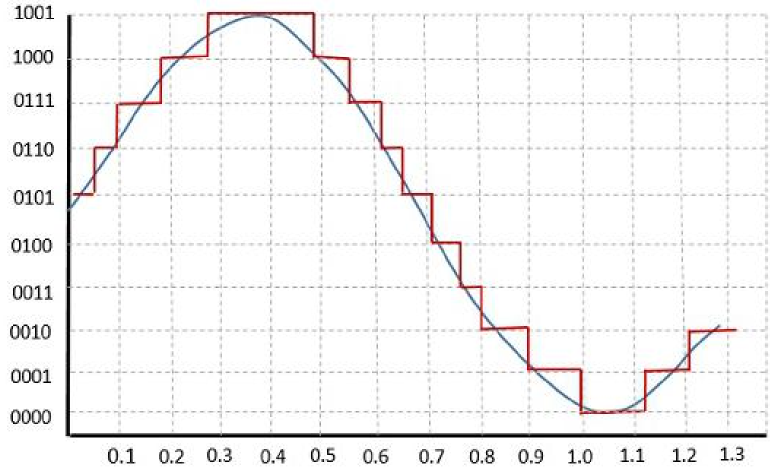

Figure 4: The process of quantization of analog signal[2]

Types of Quantization

The quantization performed by a quantizer is basically of two types:

- **UniformQuantization**
  Uniform quantization, sometimes referred to as linear quantization, maintains the same step size over the entire input range. There are two types of uniform quantization: mid-tread and mid-rise quantization. The origin is symmetric in both types. [3]

- **Non-uniform Quantization**
  Non-uniform quantization, commonly referred to as non-linear quantization, involves an unequal step size. In non-uniform quantization, there will be more quantization levels at low input signal amplitudes. Conversely, fewer quantization levels—that is, higher step sizes—will be present when the output signal's amplitude is high.[3]

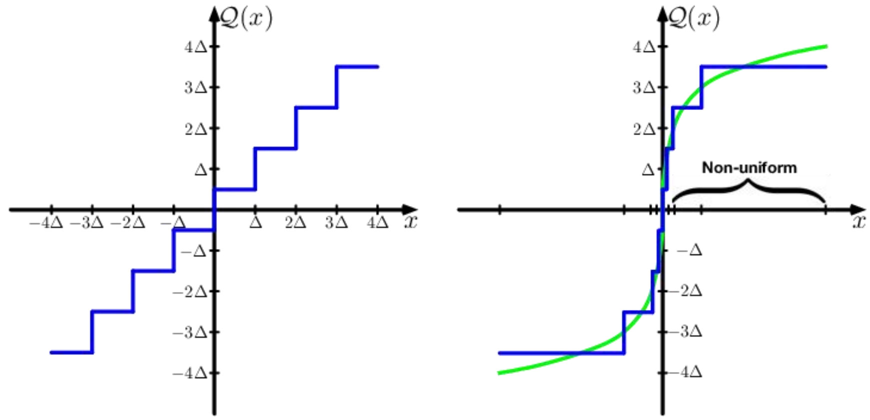

Figure 5:Midtread type uniform and non-uniform quantization[3]

It is challenging to design non-uniform quantizers since it is unknown how the signal level will change in advance. An other method is to use a uniform quantizer after first subjecting the speech signal to a nonlinearity.

The signal amplitude is compressed due to the nonlinearity. In other words, "Weak signals amplified, strong signals saturated at a level" means that the signal is expanded at the receiver in an inverse relationship to the nonlinearity. Companding is the process of compressing and expanding.[4]

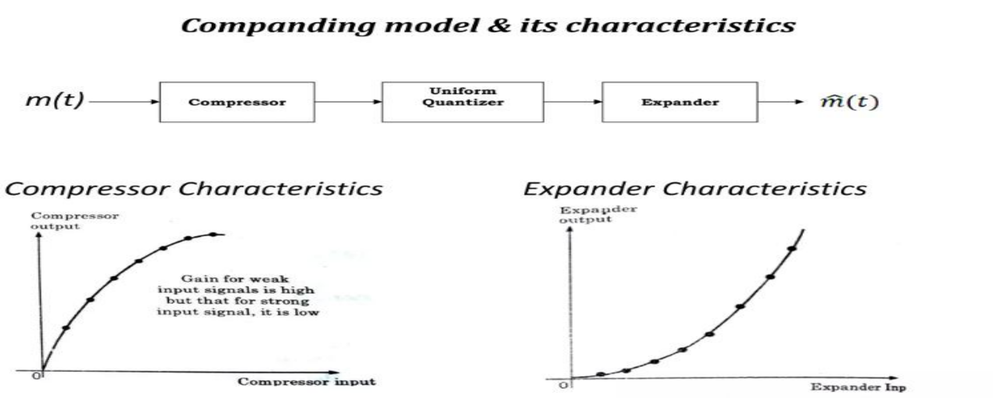

Figure 6: Compacding model & its characteristics[4]

Encoding

The process of expressing the sampled values as a binary number in the range of 0 to n is known as encoding. n is selected as a power of two based on the level of accuracy needed. By decreasing the step size between consecutive quantization levels, increasing n lowers the quantization noise. The drawback of this is that more digital data is needed in order to represent the analog signal.[5]

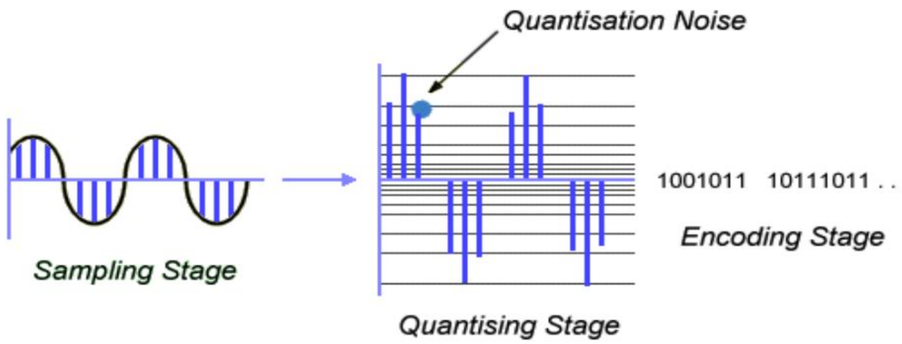

Figure 7:Stages in the analogue-to-digital conversion process[5]

Quantization Noise

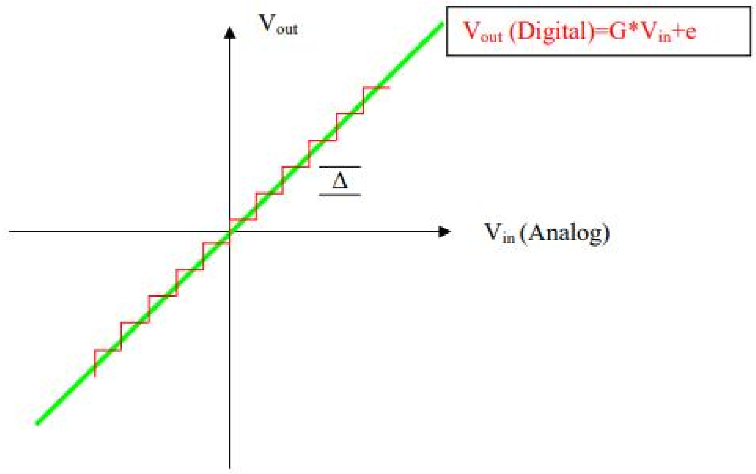

Figure 8:Staircase curve of a linear N Bit ADC Converter[8]

The technique of giving an analog voltage range a defined value is known as quantization.We can see how the input signal is represented by two curves in the above case, where the level of the input signal is "busy" and moderate. The scaled form of the input signal, Vin, without any quantization applied, is represented by the green curve. Conversely, though, the red curve symbolizes the Analog-to-Digital Converter's (ADC) output. The converter's step size is represented by the symbol Δ, which shows the size of each quantization level. The red curve illustrates way the ADC discretizes and approximates the analog signal, with each sample being quantized using Δ to the closest accessible level.[8]

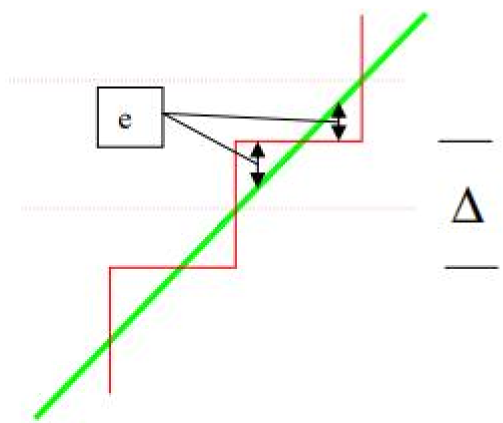

Figure 9: Staircase[8]

The analog range that relates to a particular ADC value in the given context is shown by the pink dots. The difference between the actual analog value and the quantized value is represented by the black arrows, which show the quantization error for two distinct places. These arrows show how the analog signal is approximated by discrete numbers during the quantization process, which always introduces distortion.[8]

Rather than the quantity of samples generated per second, the number of quantization levels utilized affects the Quantization Noise (QN). An analog signal is approximated by a finite number of quantization levels when it is quantized. The difference between the quantized representation of the analog signal and the real signal causes the QN. It is a type of noise that tampers with the quantized signal, adding error or distortion. A more accurate representation of the original analog signal results from an increase in the number of quantization levels, which generally causes the QN's magnitude to drop. But in order to increase the number of quantization levels, the digital representation of the signal also needs a higher bit depth and more storage space. [8]

PCM Transmission with TDM

1. **Pulse-code modulation (PCM):** PCM is a commonly used technology that samples analog data to convert them into digital format. Numerous applications, such as digital audio in computers, Compact Discs (CDs), digital telephony, and other digital audio systems, make substantial use of this technique. The value of the analog signal in a PCM stream is obtained by measuring its amplitude at regular intervals. The next stage involves converting these measurements into digital form by estimating each sample to the nearest value within a predetermined series of digital steps.[6]

2. **Time-division multiplexing (TDM):** TDM is a technology that allows the transmission of several independent signals over a single transmission line. Each signal can alternately emerge on the line in a cyclic pattern thanks to coordinated switches at either end. This technique allows many digital or analog signals to be transmitted simultaneously when the bit rate of the transmission media is higher than the rate of the signal. TDM, which was first created for telegraphy systems in the late 19th century, was widely used in digital telephony in the second half of the 20th century.[6]

3. **TDM PCM system for communication:** A PCM TDM system depends on a number of critical parameters: The bit rate of the PCM TDM signal, the message sampling rate, the number of message channels (n), and the bandwidth (Bm) of each message channel.
Regardless of the number of channels (n), the bandwidth and message sample rate in a conventional system are usually fixed. Because of this, the bit rate of the PCM TDM signal grows with the number of channels, necessitating a wider bandwidth for transmission.[6]

However, a different strategy is used in the PCM TDM format. Notwithstanding the fact that n is fixed at n = 2 in this instance, the bit rate of the PCM TDM signal is maintained constant. As a result, n has no effect on the bandwidth of the transmission channel.
When n rises from 1 to 2, the message sample rate must be cut in half to account for this.[7]

Difference Pulse Code Modulation (DPCM)

Differential Pulse Code Modulation, or DPCM, is a method for transforming analog signals into digital format that works similarly to PCM. The term "differential" PCM comes from the fact that DPCM quantizes the difference between the actual sample and its expected value, which sets it apart from PCM.
When it comes to signal-to-noise ratio, DPCM usually provides a passable performance level. The number of quantization levels and the precision of the prediction method used are two examples of the variables that affect the quality of the reconstructed signal and the amount of noise injected.[9]

Operations are carried out at both the transmitter and receiver ends of the DPCM process. The figure below provides information on these operations.

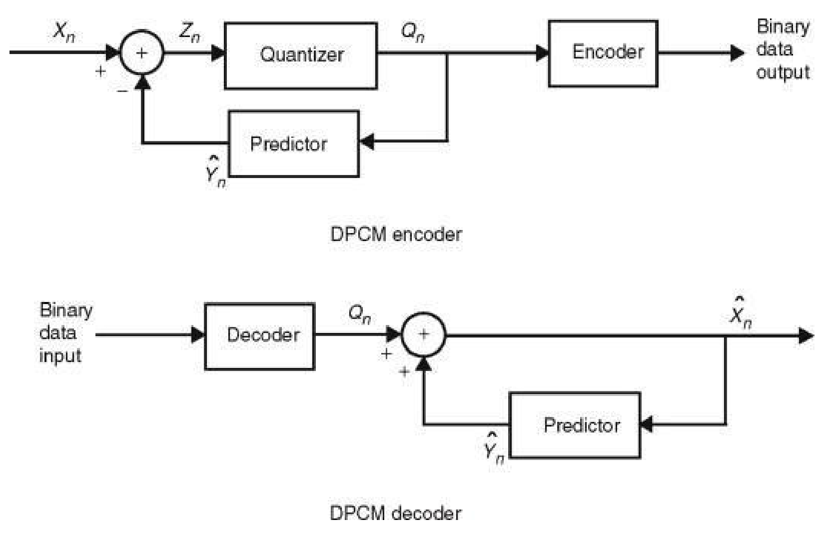

Figure 10:DPCM operations[9]

Procedure For Exp. #7 :

Part One: Linear Quantization: (Characteristic of linear Quantizer with DC input)

Initially, the parts were put together as the following figure illustrates:

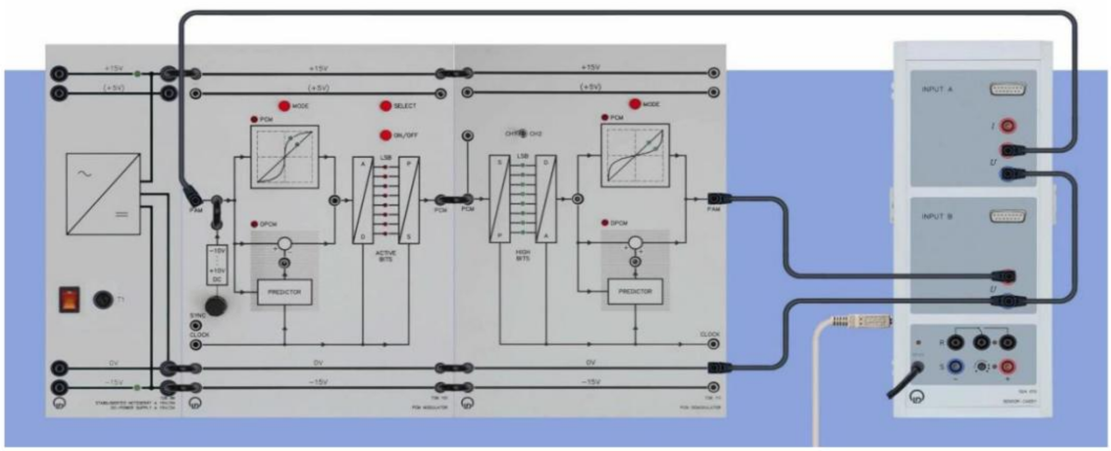

Figure 11: The Pulse Code Modulation setup

The eight bits were turned on. An we use the CASSY Lab example Quant.labx . And gradually twisting the potentiometer knob, the input DC voltage was increased.

Figure 12:output of uniform linear quantizer

The step size :

$$\Delta = (10 - -10) / 256 = 0.078125$$

As we notice as the input voltage grows, so does the output voltage.

Part Two: Non-linear Quantization: (Characteristic of Non- linear Quantizer with DC input)

The voltage of the potentiometer was progressively raised while the output voltage was being closely monitored. An we notice observed the growth of a non-linear quantizer curve, as following :

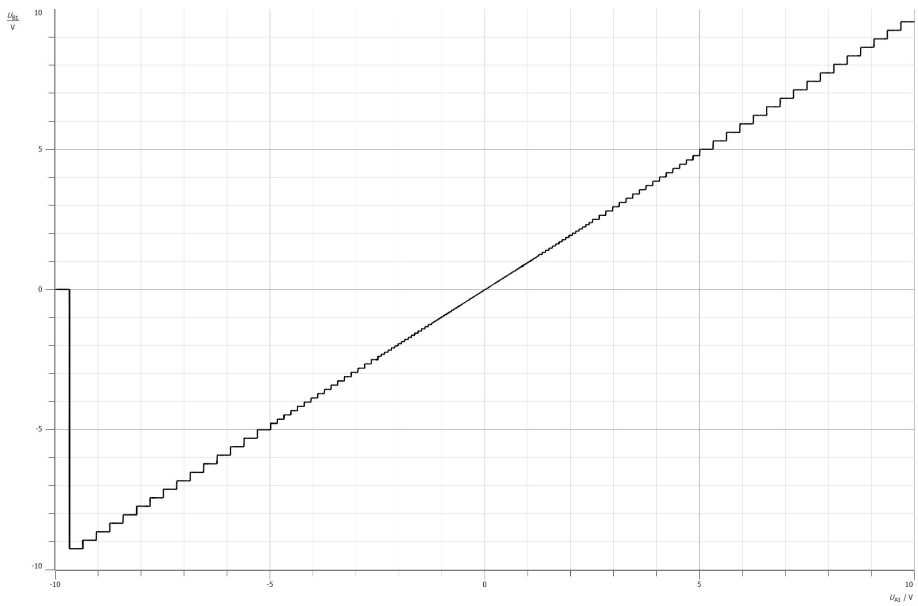

Figure 13: Non- linear Quantizer

We notice that different step sizes are used between levels in non-uniform quantization.

Part Three: Compressor / Expander characteristic:

the same connection as the previous part.

Compressor Characteristics:

The output of the compressor characteristic curve is shown in the figure below.

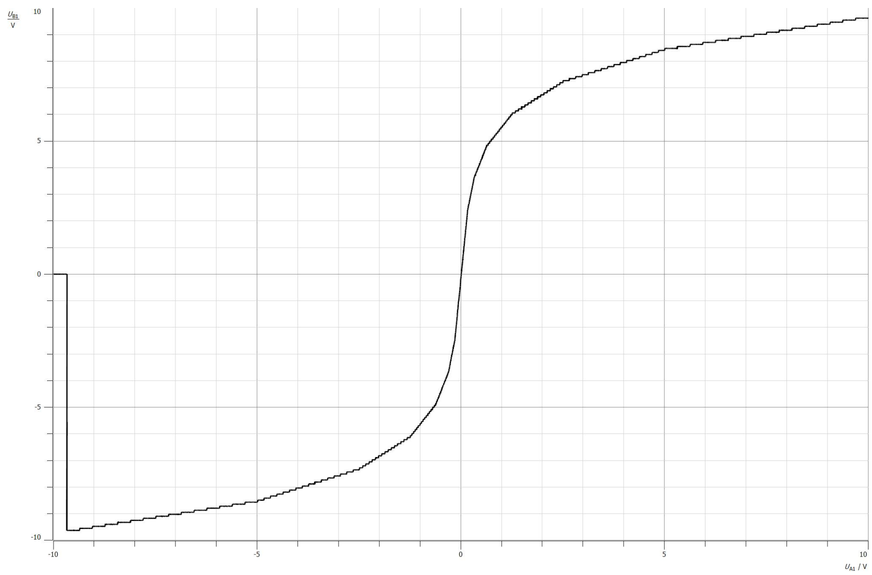

Figure 14:The compressed signal

we notice that the signal is compressed on the modulation side.

Expander Characteristics:

The voltage of the potentiometer was gradually raised.

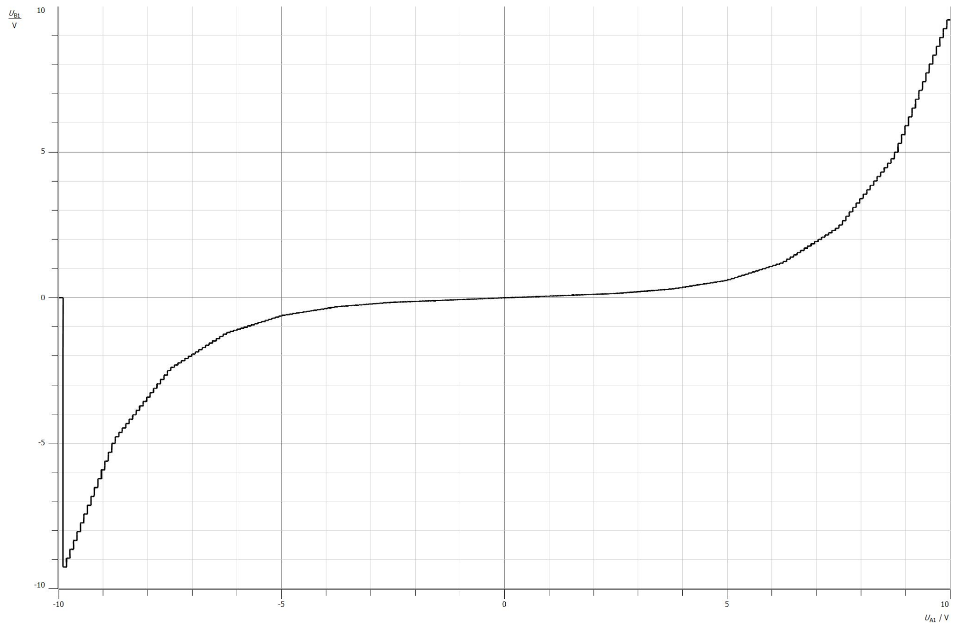

Figure 15: The expansion signal

The signal is compressed during modulation and expanded back during demodulation.

Part Four: Quantizer Resolution for both linear and non-linear quantizer:

The three least significant bits (LSBs) of the PCM modulator were turned off, And the connection from the first section did not alter.

Linear – Linear Quantizer:

The outcome of the linear-linear quantization with five bits is displayed in Figure below.

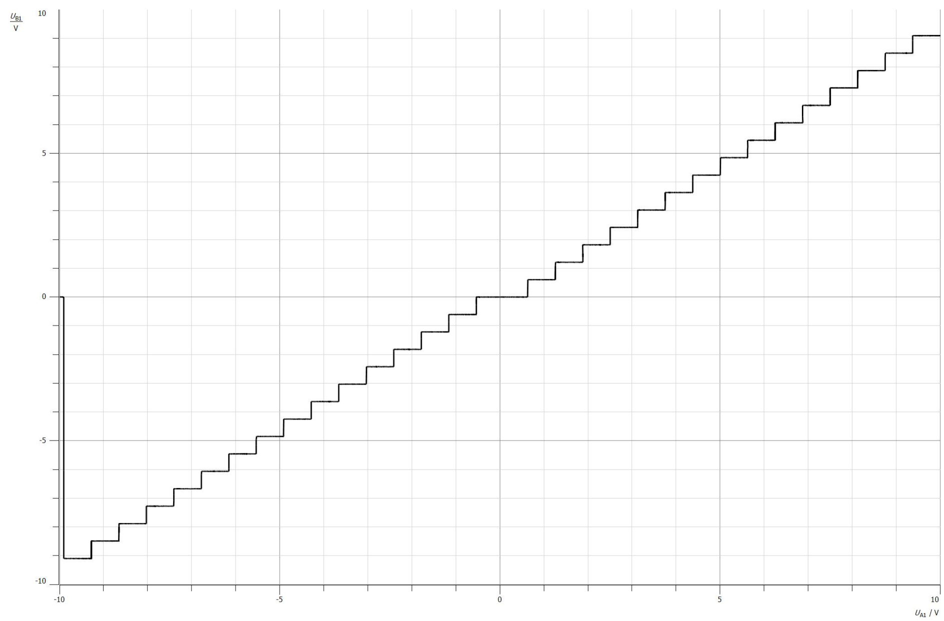

Figure 16:Linear-linear quantization output

We noticed that as the number of bits is decreased is leading to a reduction in quantization levels and an increase in interval size.

Non-Linear – Non-Linear Quantizer:

Non-linear quantization was used on this part, and the potentiometer voltage was gradually raised .

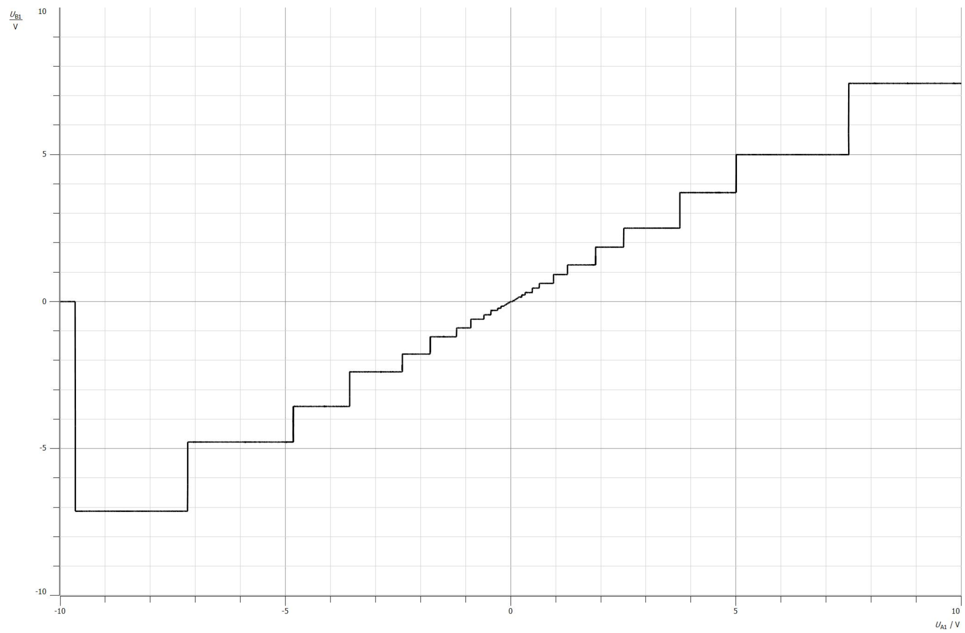

Figure 17:Non-Linear – Non-Linear Quantization output

In non-linear quantization, the 8-bit coder offers lowers quantization noise and improve accuracy.

On the other hand, the 5-bit coder can show more quantization noise .

Non-Linear – Linear Quantizer:

Non-linear quantization was selected for the PCM demodulator and linear quantization for the PCM modulator.

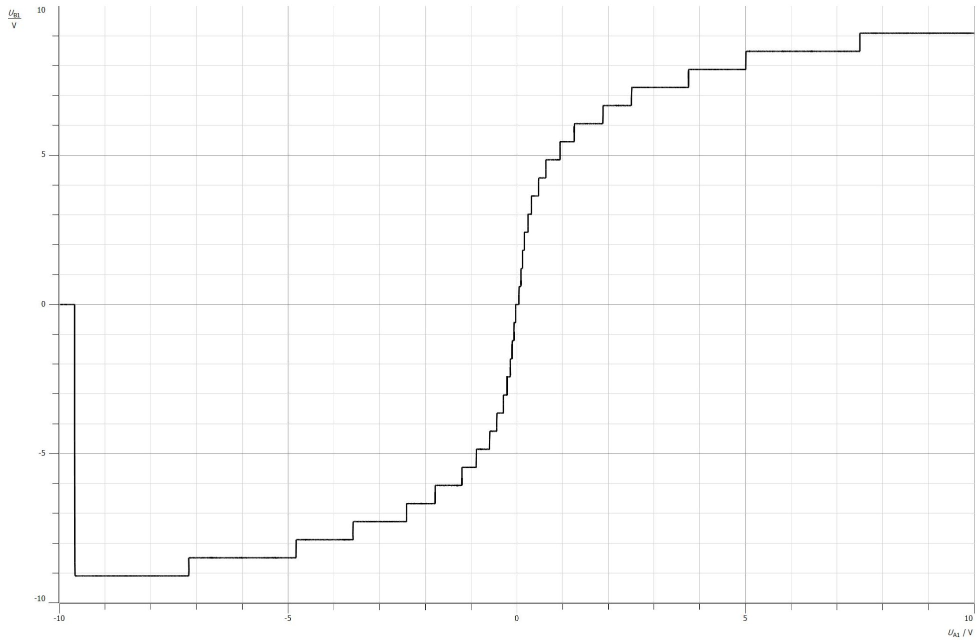

Figure 18:Non-Linear – Linear Quantization output

An 8-bit coder offers more accurate signal representation and better detail than a 5-bit coder due to its higher bit depth.

Linear – Non-Linear Quantizer:

The PCM demodulator was configured for linear quantization, the PCM modulator was configured for non-linear quantization.

The outcome of linear-to-non-linear quantization is displayed in the figure below.

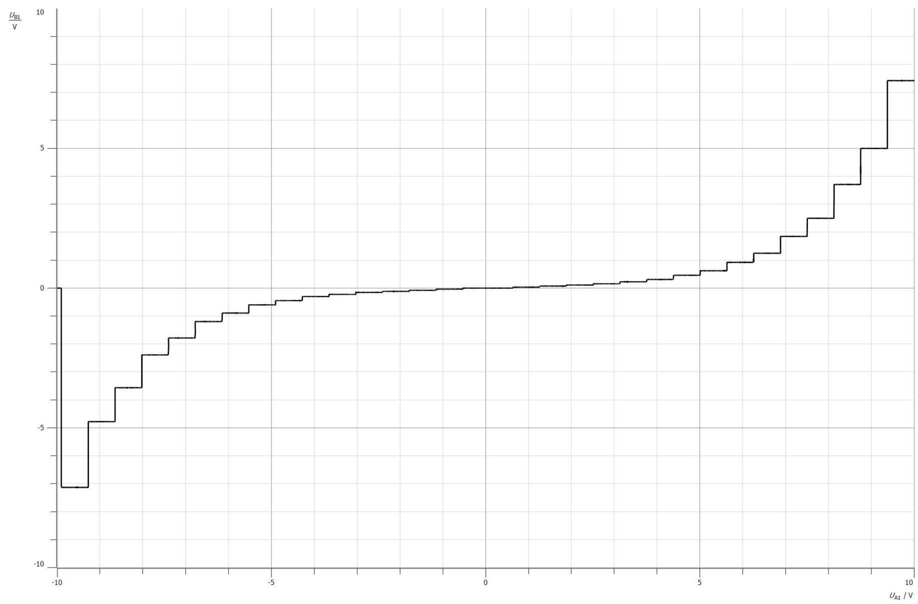

Figure 19:Linear – Non-Linear Quantization output

Part Five: Encoding

An 8-bit configuration was used to record the linear quantization levels and their binary equivalents.

And the PCM modulator and demodulator were both configured for linear quantization.

The table below listed the input and output voltages as well as their bit patterns.

Input voltage (UA1)	Output Voltage (UB1)	Bit pattern
-9 V	-8.80	01110100
-7 V	-6.82	01011010
-5 V	-4.93	01000001
-3 V	-2.96	00100111
-1 V	-0.99	00001101
0 V	-0.08	00000001
1 V	0.90	10001100
3 V	2.87	10100110
5V	4.81	11111111
7 V	6.74	11011001
9	8.7	11110011

Table 1:The recorded consecutive values for bit pattern changes

The table illustrates how different input voltage mappings to binary patterns by the linear quantizer result into differences in the output.

Procedure For Exp. #8 :

Part One: PCM Transmission with TDM

In this part, The components were assembled as shown below.

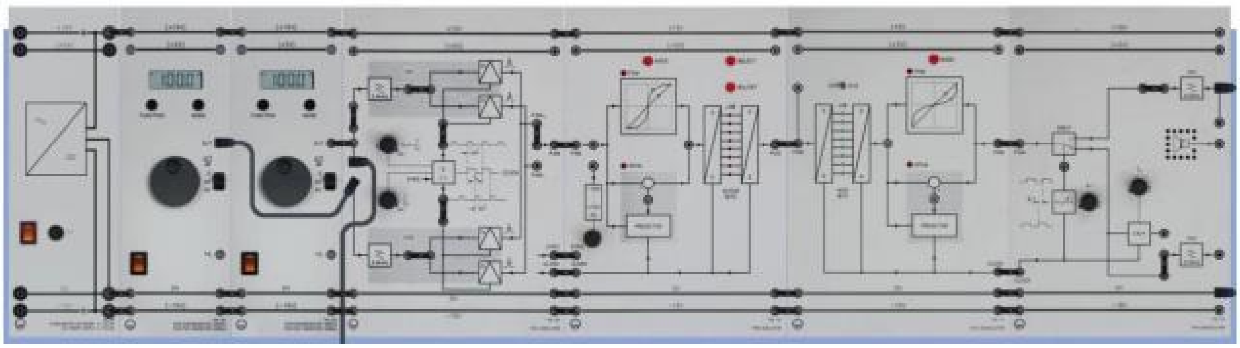

Figure 20:PCM Transmission with TDM

The result of measurement

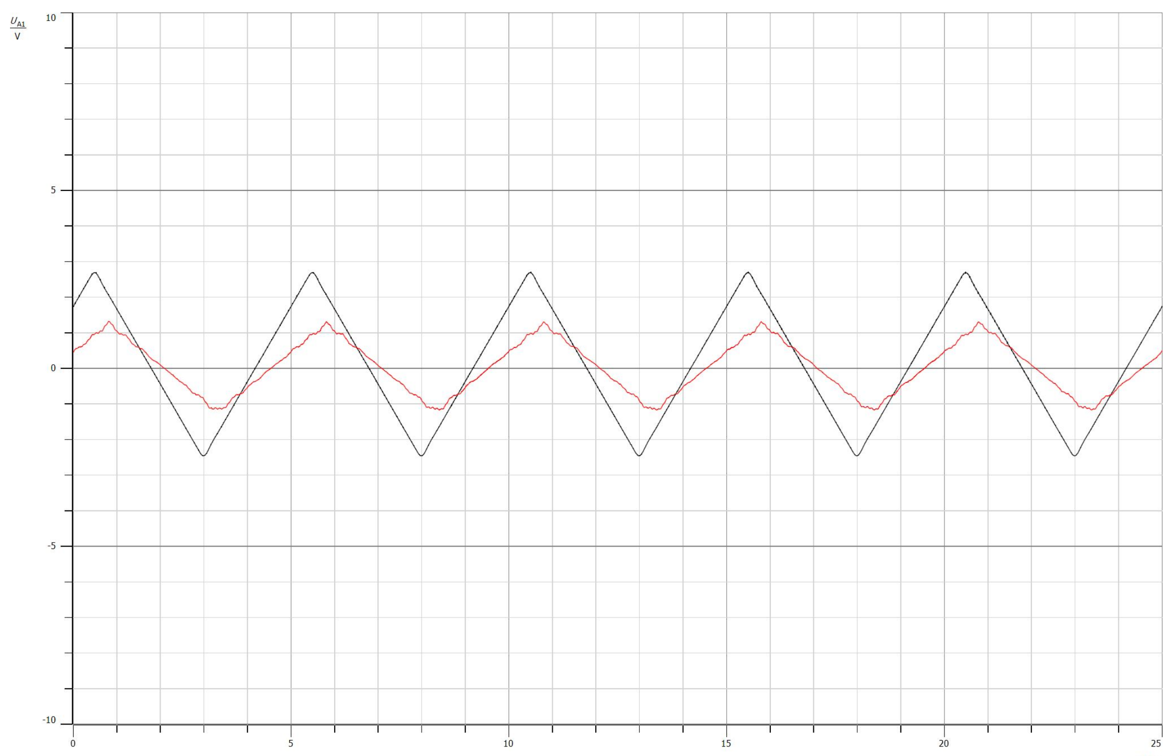

Figure 21:modulated and demodulated signals(Triangle Wave)

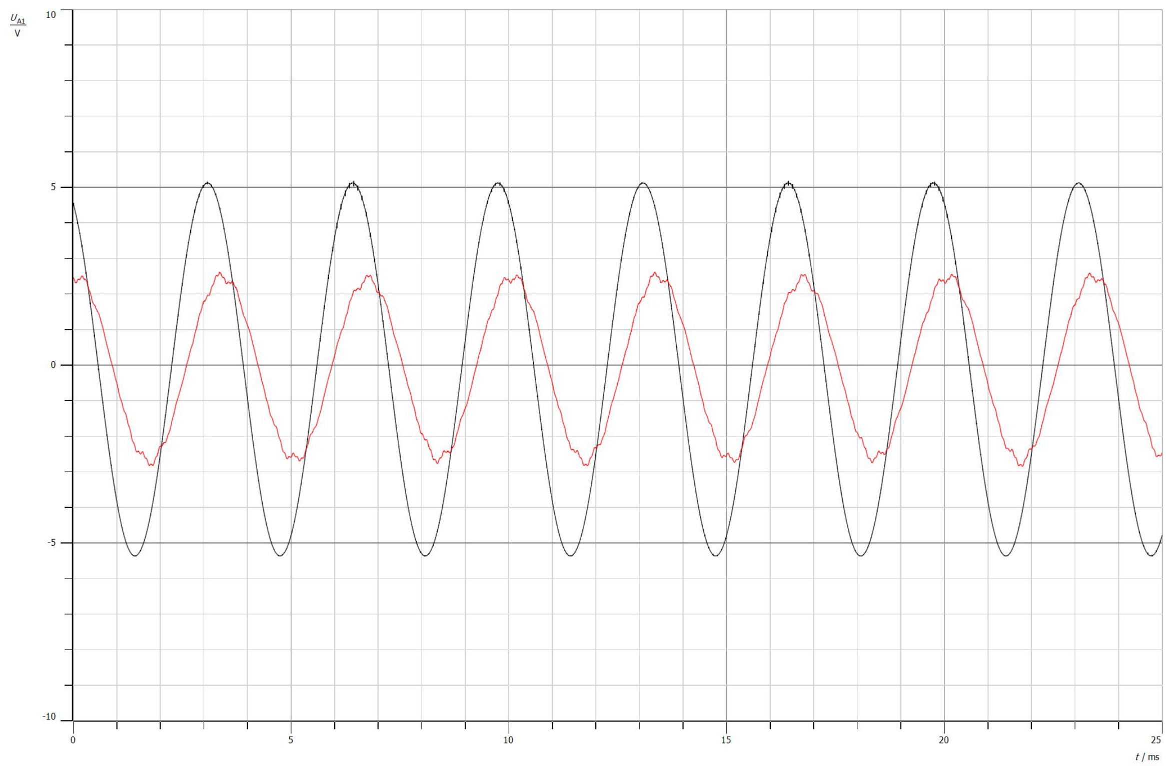

Figure 22:modulated and demodulated signals (sine Wave)

There was some distortion and noise in the output of the PAM decoder, and there was noticeable quantum noise that caused the signals to differ slightly from the original signals.

Part Two: Quantization Noise

Section 2.1: Triangle Signal

The parts were put together in this section as seen below.

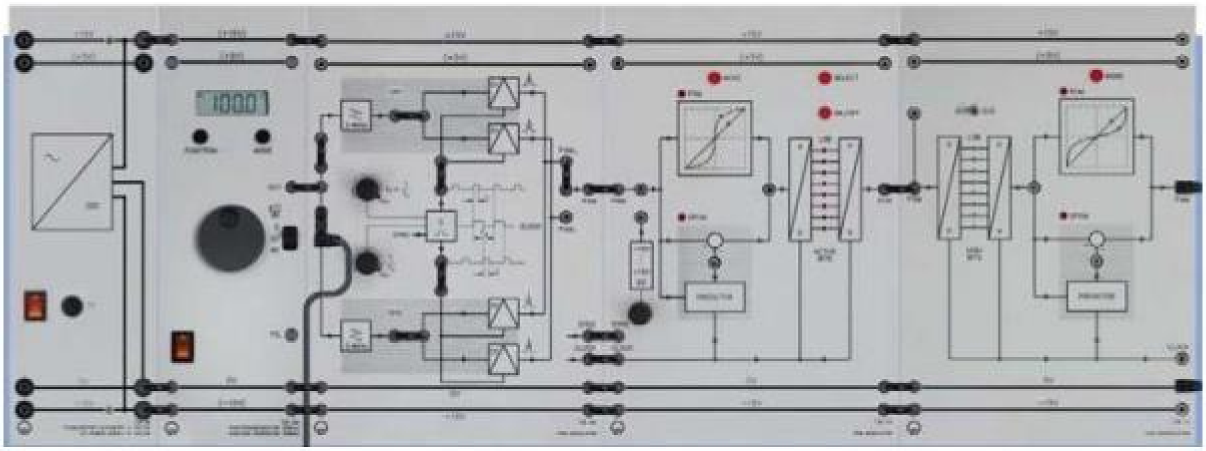

Figure 23:Triangle Signal

In order to collect as much information as possible during the analog-to-digital conversion, all quantization bits were enabled. The experiment examined quantization noise effects in PCM systems using the CASSY Lab example QNoise.labx.

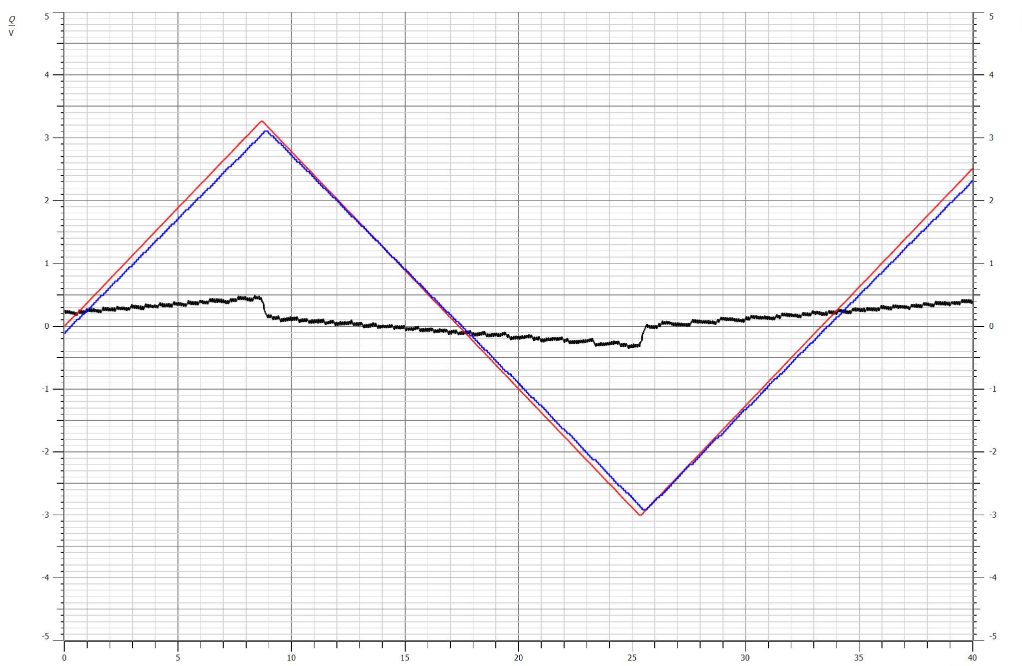

Figure 24:Error between modulated and demodulated for the triangle with f=30Hz

The error (black line) between the two triangles can be seen and examined by comparing them. The distortion introduced during the encoding and decoding stages of the PCM system is represented by this mistake.

The measurement was repeated with a 5-bit resolution, using the most significant bits for quantization and encoding while disregarding the least significant 3 bits.

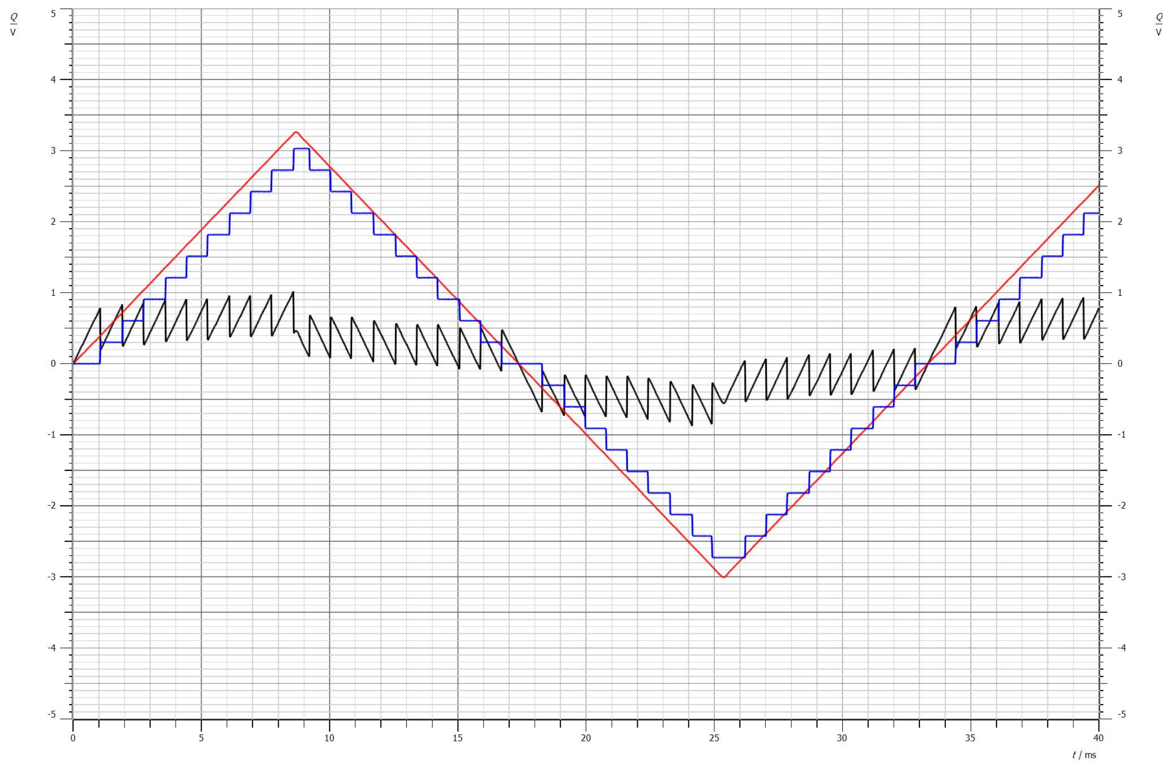

Figure 25:Error between modulated and demodulated - 5 bits - 30Hz

Reducing the number of bits lowers the resolution of the quantized signal, resulting in a coarser representation of the original analog signal and increasing the error between the original and reconstructed signals.

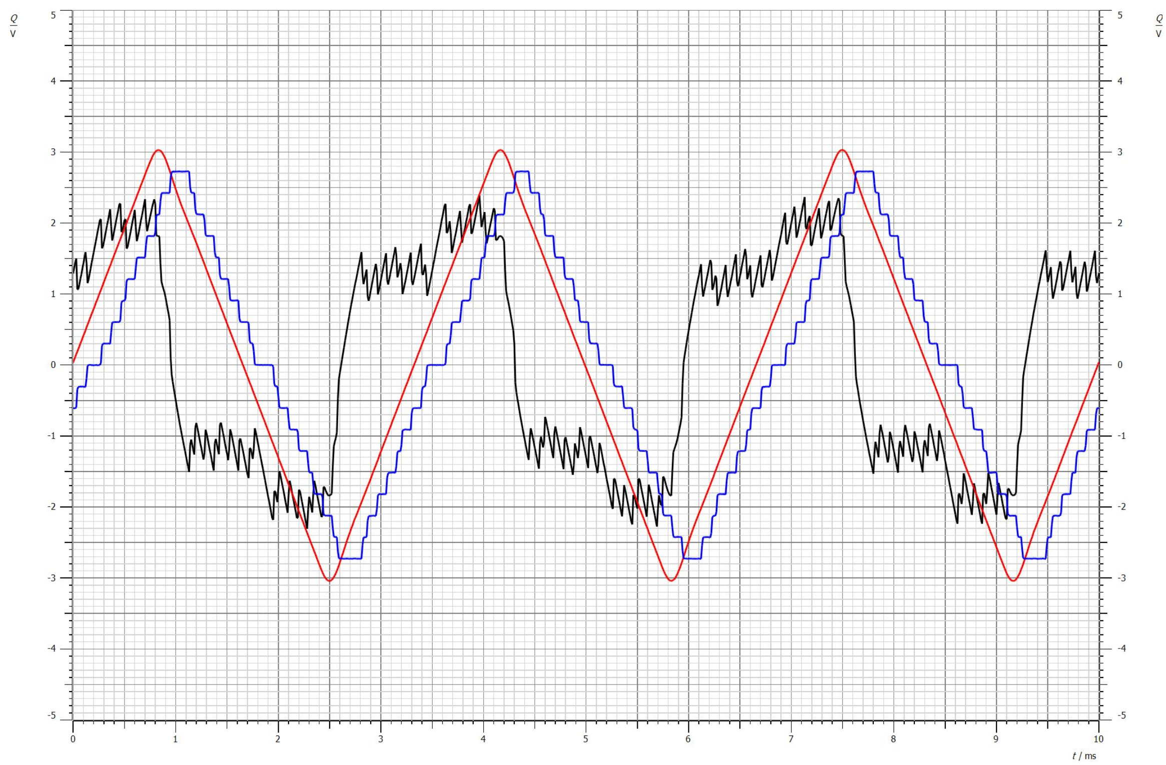

Figure 26:Error between modulated and demodulated - 5 bits - 300Hz

We observe that higher fidelity in the demodulated signal is achieved with reduced quantization error. Conversely, lower resolution results in a coarser representation of the original signal.

Section 2.2 Sinusoidal Signal

the same procedure as above part was repeated, but a sinusoidal modulating signal was used and The setup connections remained as before.

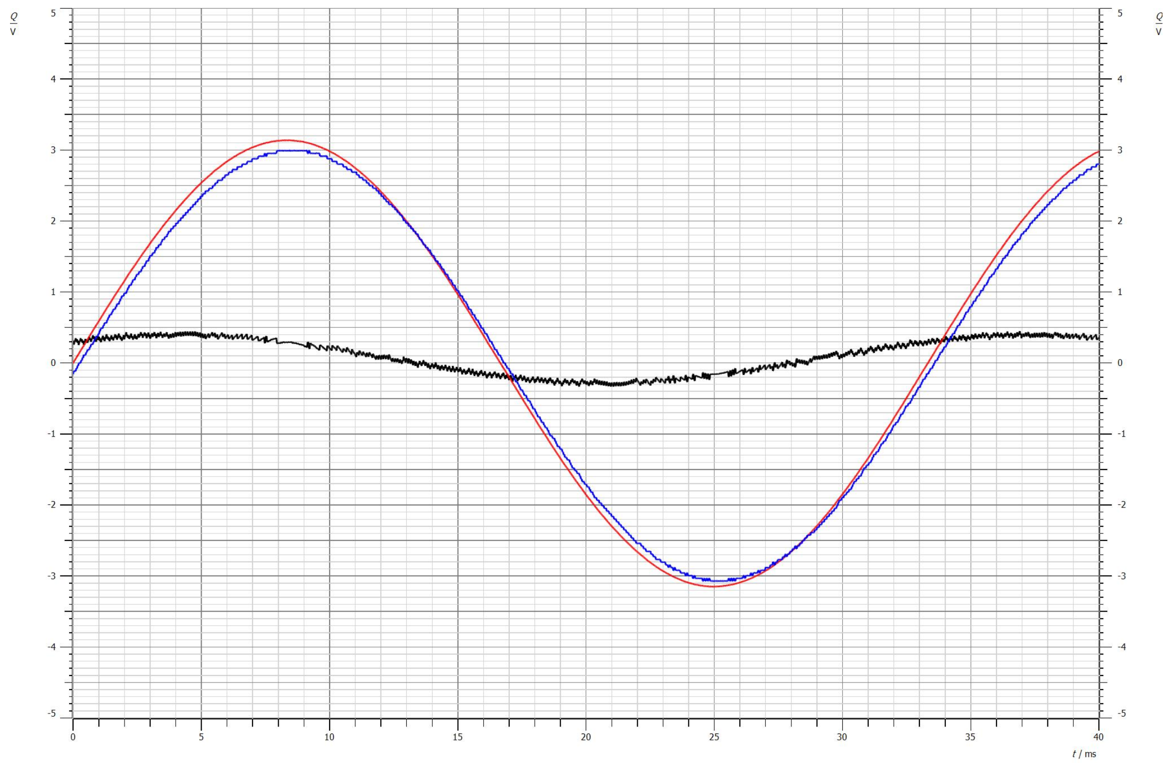

Figure 27:Error between modulated and demodulated for the sinusoidal

The error (black line) between the two Sinosoidal Signals can be seen and examined by comparing them. The distortion introduced during the encoding and decoding stages of the PCM system is represented by this mistake.

The measurement was repeated with a 5-bit resolution, using the most significant bits for quantization and encoding while disregarding the least significant 3 bits.

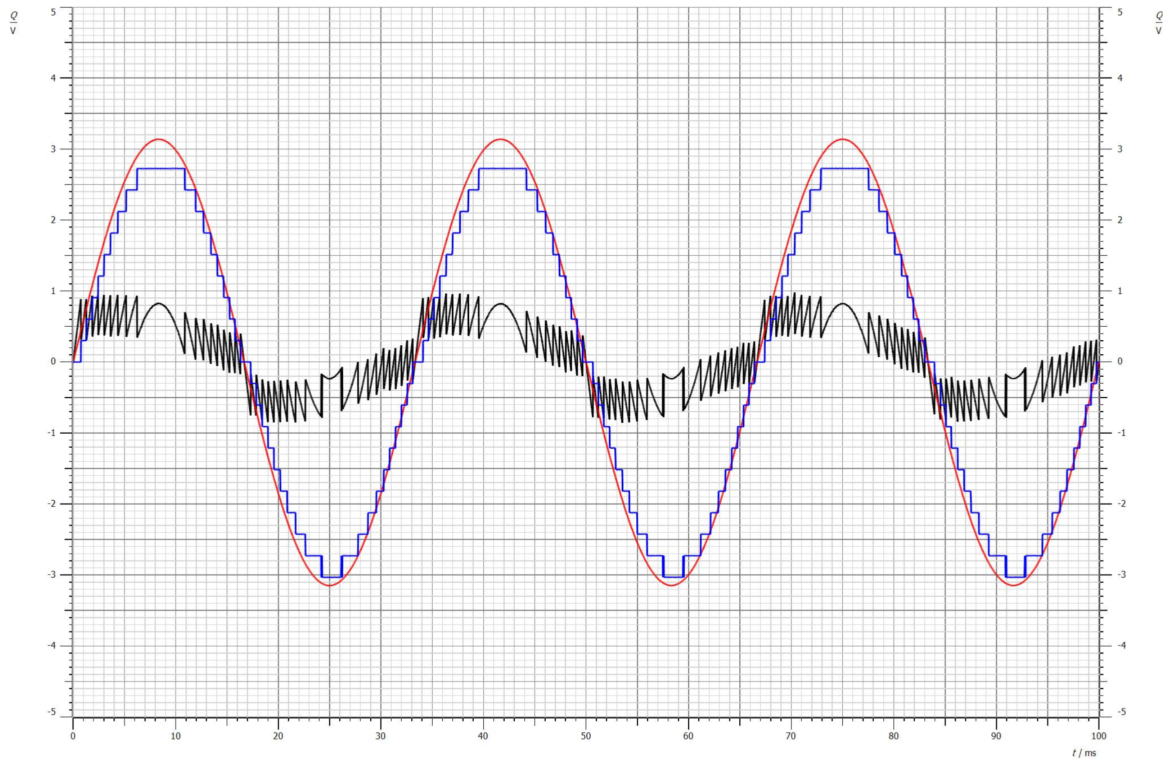

Figure 28:Error between modulated and demodulated (Sine Wave)- 5 bits - 30Hz

Reducing the number of bits decreases the resolution of the quantized signal, leading to a coarser representation of the original analog signal and increasing the error between the original and reconstructed signals.

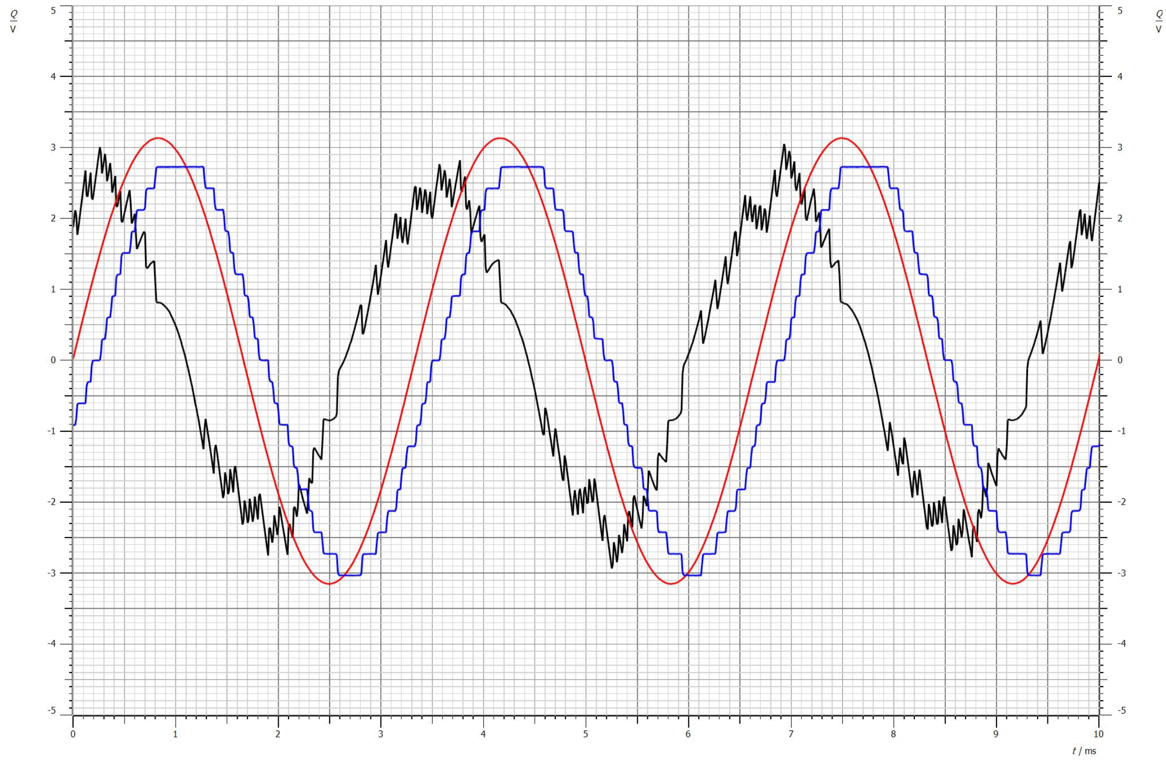

Figure 29:Error between modulated and demodulated (Sine Wave)- 5 bits - 300Hz

We observe that higher fidelity in the demodulated signal comes with reduced quantization error, while lower resolution leads to a coarser representation of the original signal.

Part Three: Difference Pulse Code Modulation (DPCM)

DPCM: is a redundancy reducing method.

The parts were put together as you can see below.

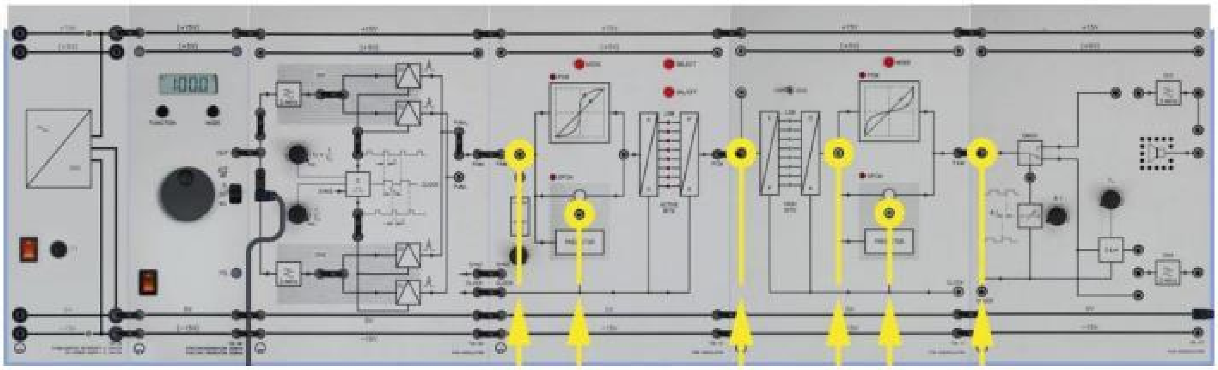

Figure 30:Difference Pulse Code Modulation

Records were kept separately for the following signals:

1. The predictor of the DPCM modulator.

Figure 31:The predictor of the DPCM modulator.

2. The output of the DPCM modulator.

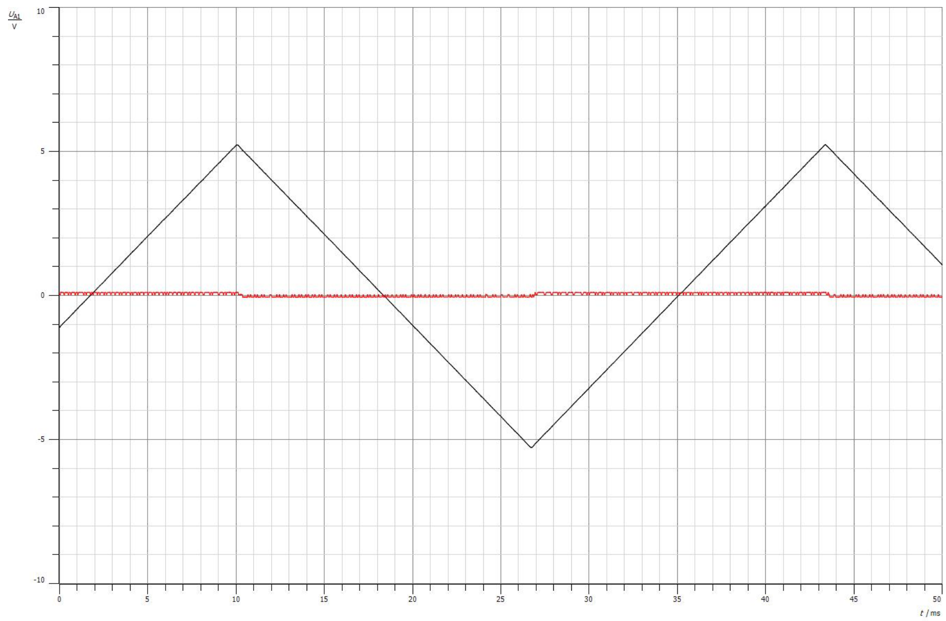

Figure 32:The output of the DPCM modulator

3. The input of the DPCM demodulator.

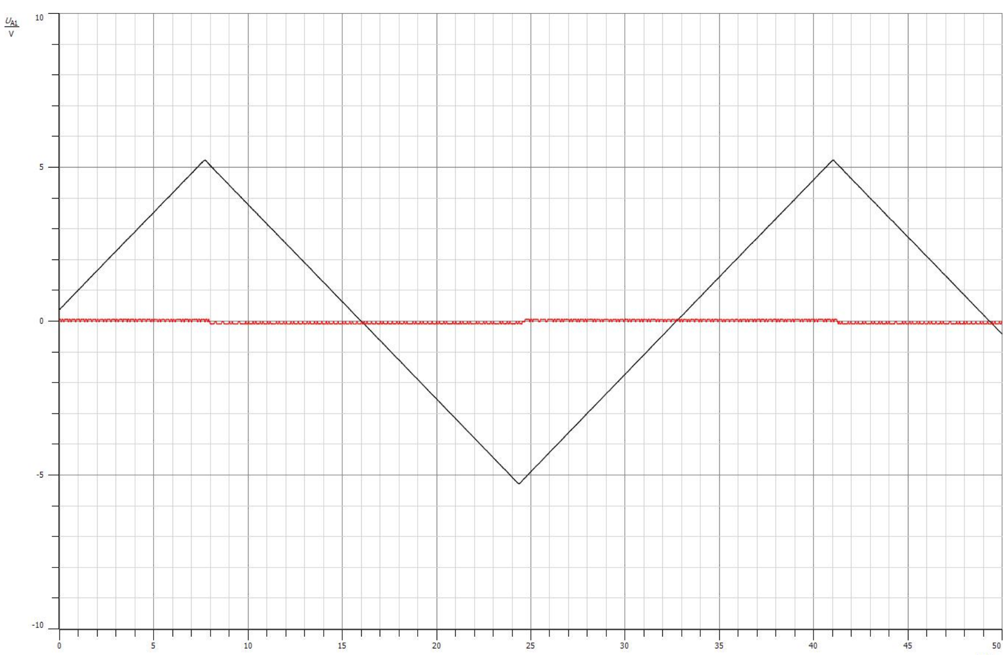

Figure 33:The input of the DPCM demodulator

4. The predictor of the DPCM demodulator.

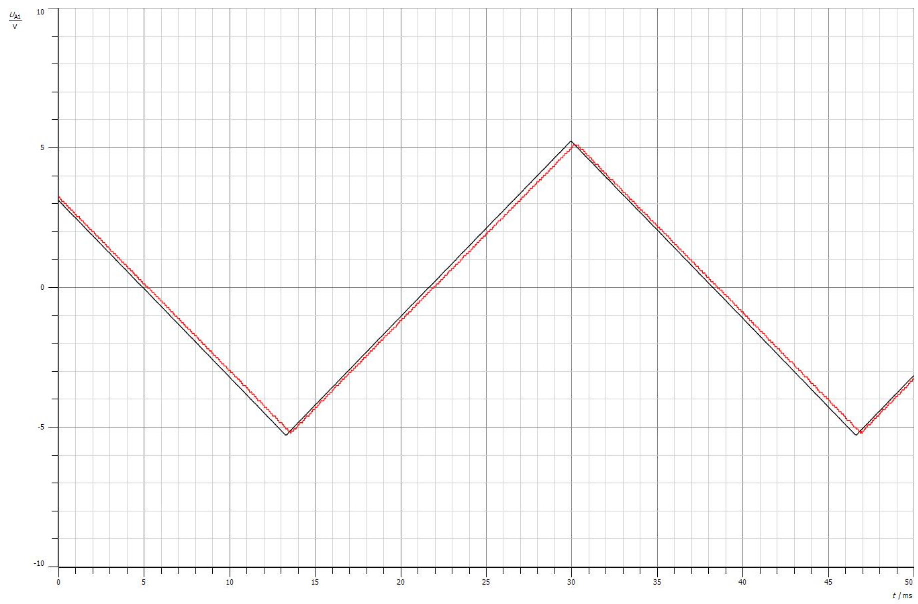

Figure 34:The predictor of the DPCM demodulator

5. The PAM output of the DPCM demodulator.

Figure 35:The PAM output of the DPCM demodulator.

6. The predictor of the DPCM modulator For 4 bits.

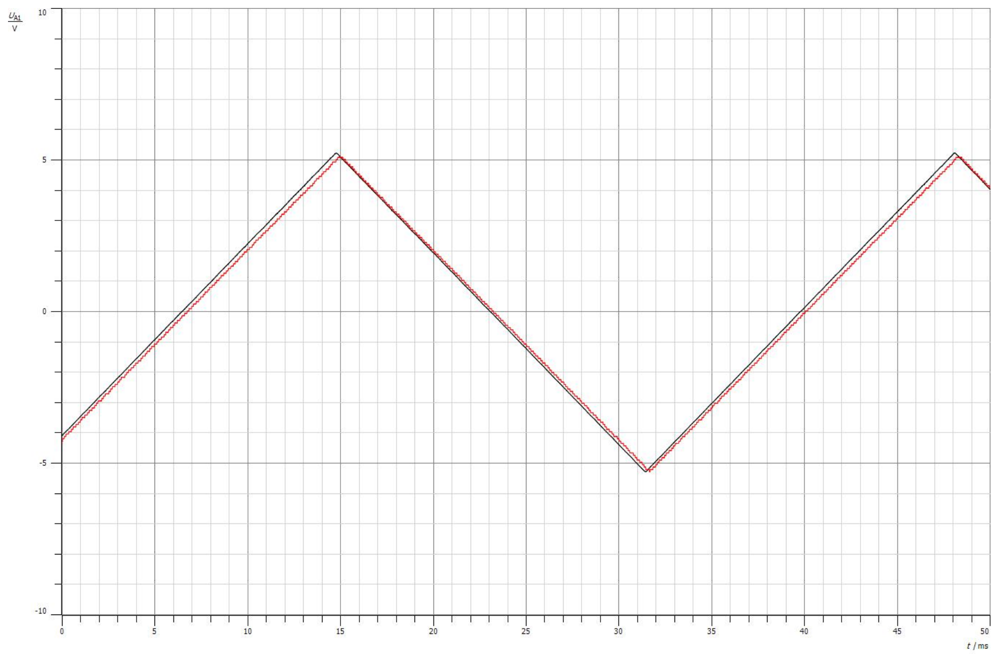

Figure 36:The predictor of the DPCM modulator For 4 bits

7. The output of the DPCM modulator For 4 bits.

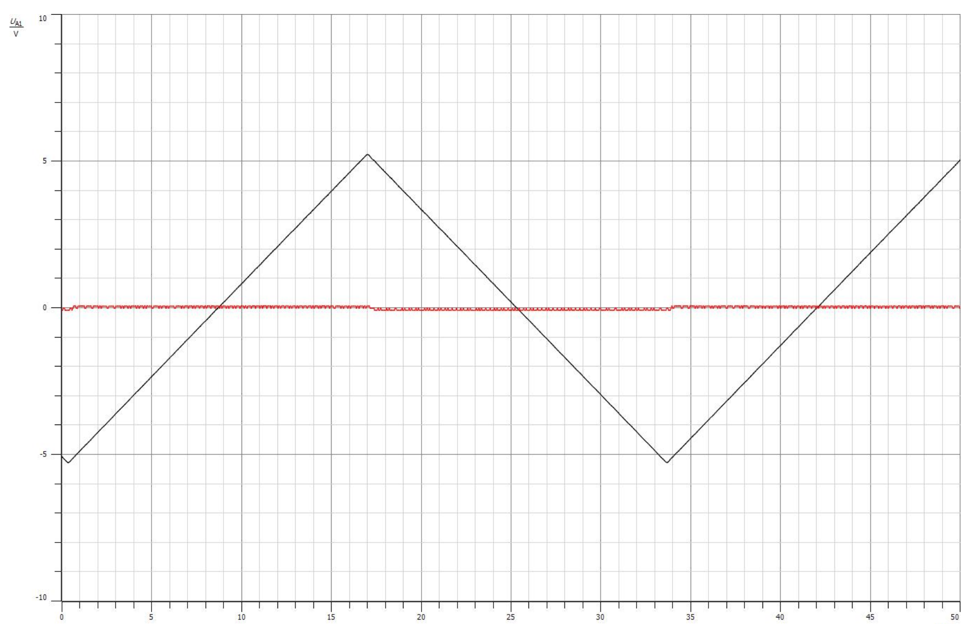

Figure 37:The output of the DPCM modulator For 4 bits.

8. The Error For 4 bits.

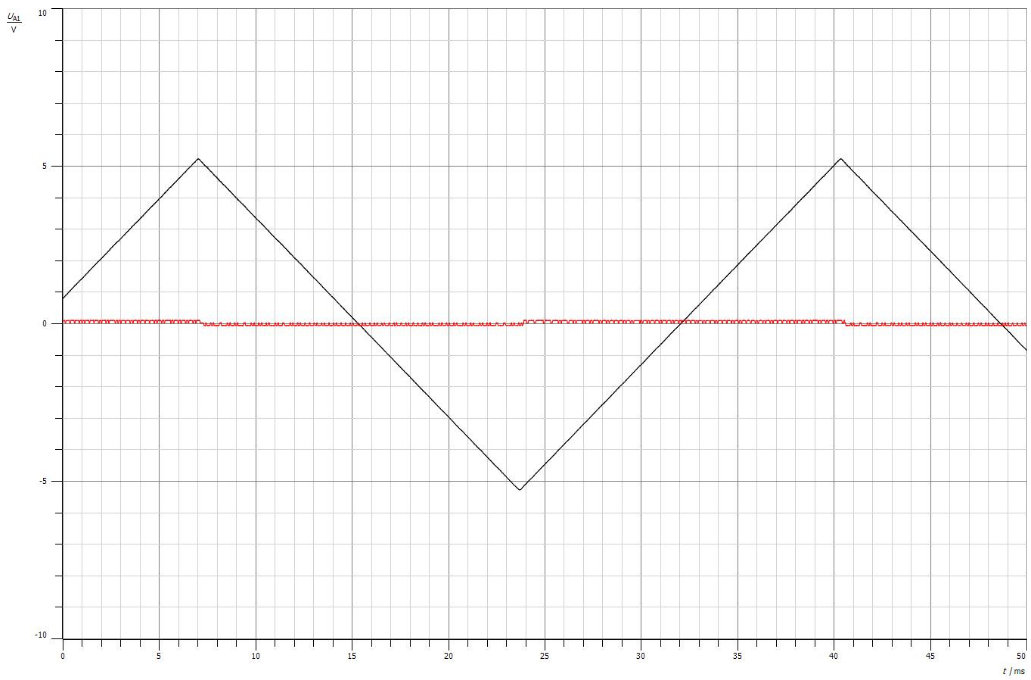

Figure 38:The Error For 4 bits

9. The predictor of the DPCM demodulator For 4 bits.

Figure 39:9.The predictor of the DPCM demodulator For 4 bits.

10. The PAM output of the DPCM demodulator For 4 bits.

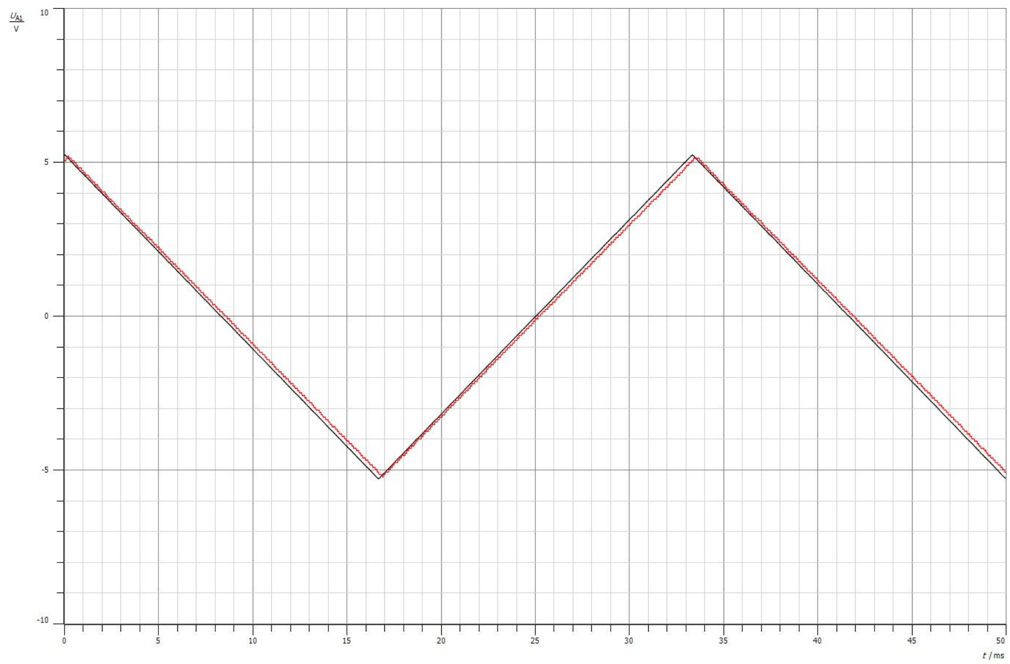

Figure 40:The PAM output of the DPCM demodulator For 4 bits.

- The predictor of the DPCM modulation display a variable pattern in order to calculate the differences between future samples.
- In comparison to the input signal, the waveform in the DPCM modulation output had less amplitude.
- The DPCM modulation output signal and the input signal to the DPCM demodulation were nearly identical.
- Similar to the DPCM modulation predictor, the DPCM demodulation predictor also showed a similar pattern.
- With barely noticeable variations, the DPCM demodulation PAM output largely matched the original input signal.

Conclusion

In Experiment 7, we looked at the sampler, quantizer, and encoder as well as the parts of pulse code modulation (PCM), contrasting linear versus non-linear quantization. The results were in line with theoretical predictions and showed how quantization techniques may be used in practice.

In the eighth experiment, we investigated the application of Time-Division Multiplexing (TDM), quantization noise, and Differential Pulse Code Modulation (DPCM) in PCM transmission. We examined the efficient multiplexing of signals by TDM, the reduction of quantization noise by DPCM, and the conversion of analog to digital data by PCM. This study improved our knowledge about digital communication networks.

References

[1] https://www.gartner.com/en/information-technology/glossary/pcm-pulse-code-modulation

[accessed on 3/8/2024 at6:42pm]

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[accessed on 3/8/2024 at 7:16pm]

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