Faculty of Engineering & Technology Electrical & Computer Engineering Department

Communication Lab - ENEE4113

Experiment 8: Pulse Code Modulation (Part 2)
Report #3

Prepared by:
Maha Maher Mali 1200746

Partners:
Alaa Saleem 1200001
Lama Naser 1200190

Instructor: Dr. Ashraf Al Rimawi

Teacher Assistant: Eng. Mohammed Battat

Section: 3

Date: 21-8-2023

Abstract

The main goal of this experiment is to study a digital multiplexing system that combines PAM and PCM, analyzing Quantization Noise for triangle and sinusoidal signals. In addition to that, this experiment introduces DPCM, enhancing PCM performance by encoding differences between consecutive samples. The objective of this experiment is to understand and explore the concept of Pulse Code Modulation (PCM), also to have the functionality of the digital multiplexing system examined

Table of Contents

Table of Figures

Table of Equation

Acronyms and Abbreviations

TDM	Time-Division Multiplexing
PCM	Pulse-Code Modulation
A/D	Analog To Digital Convertor
DPCM	Differential Pulse Code Modulation
CASSY	Measurement Device

Theory

Part One: PCM Transmission with TDM

Pulse-Code Modulation (PCM)

A signal is pulse code modulated (PCM) to convert its analog information into a binary sequence, 1s and 0s. The output of a PCM will resemble a binary sequence. The following figure 1 shows an example of PCM output with respect to instantaneous values of a given sine wave.[1]

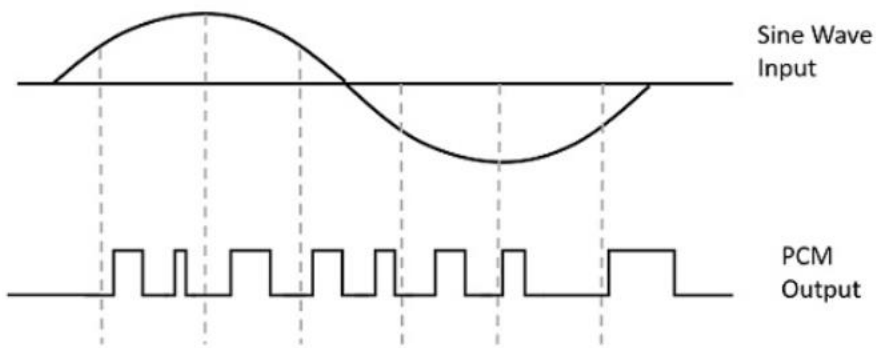

Figure 1: pulse code modulation (PCM) [1]

Instead of a pulse train, PCM produces a series of numbers or digits, and hence this process is called as digital. Each one of these digits, though in binary code, represent the approximate amplitude of the signal sample at that instant.[1]

In Pulse Code Modulation, the message signal is represented by a sequence of coded pulses. This message signal is achieved by representing the signal in discrete form in both time and amplitude.[1]

Time-division multiplexing (TDM)

Time-division multiplexing (TDM) is a method that uses switches on both ends of a transmission line. It lets us send different signals through a single route. Each signal takes turns appearing on the line. This is helpful when a signal has a higher bit rate than the path it's traveling on. [2]

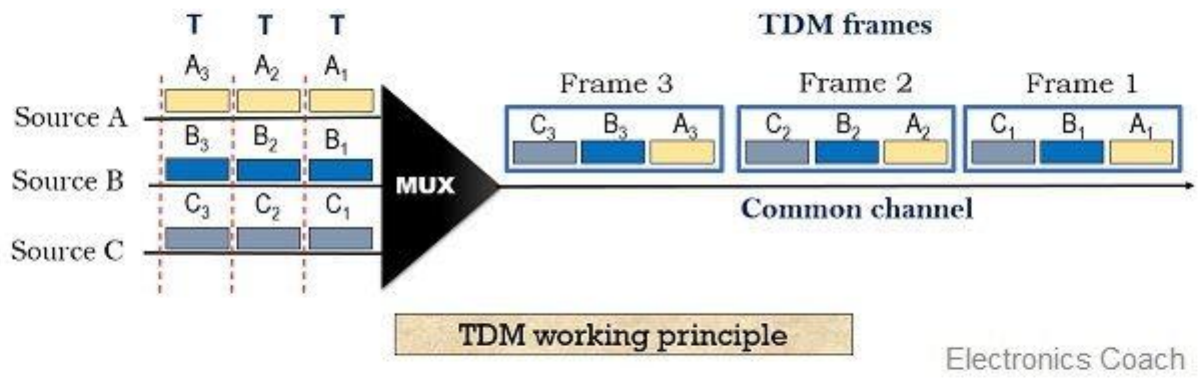

Figure 2: Time-division multiplexing (TDM) [2]

Analog multiplexing is a way of sharing one communication channel by taking turns. It's like different signals waiting in line to speak. This is done using time-division multiplexing, where each signal gets its own time to talk. So, signal 1 talks first, then signal 2, and so on.[2]

TDM PCM Communication System:

In a PCM TDM system, we need to consider a few important things: how many message channels we have (n), how much space each message channel needs (Bm), how often we sample the messages, and how fast the PCM TDM signal goes.[3]

In a normal system, the bandwidth and sampling rate of messages are usually constant, Whatever the number of channels (n). As a result, with the increase in the number of channels, the bitrate The PCM TDM signal rate also increases, which requires a wider transmission bandwidth.[3]

However, in the PCM TDM format, a different approach is taken. The bit rate of the PCM TDM signal is kept fixed, no matter of n (although n remains fixed at n = 2 in this case). Consequently, the transmission channel's bandwidth can remain constant and independent of n. To provide for this, the message sampling rate needs to be halved when n increases from 1 to 2. [3]

Part Two: Quantization Noise

Quantization noise results when a continuous random variable is converted to a discrete one or when a discrete random variable is converted to one with fewer levels. The difference between an input value and its quantized value (such as round-off error) is referred to as quantization error. A device or algorithmic function that performs quantization is called a quantizer. An analog-to-digital converter is an example of a quantizer. [4]

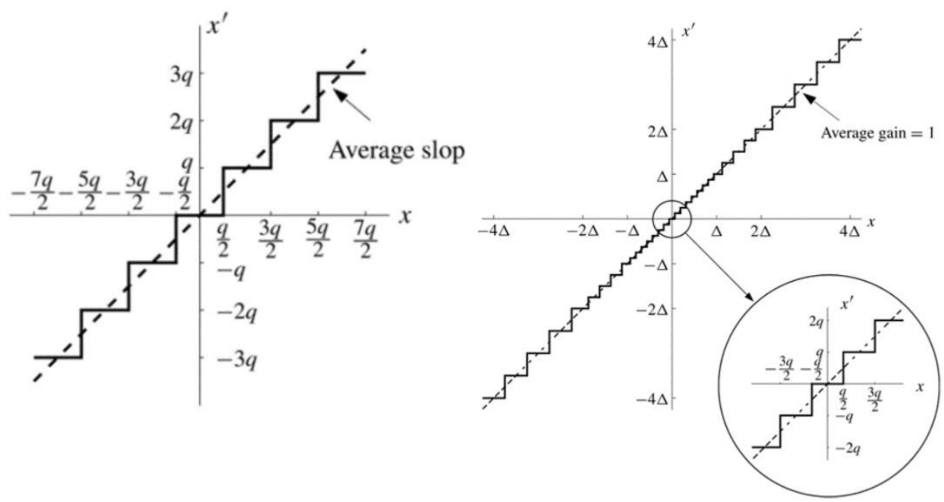

Figure 3: Quantization Noise [5]

Quantization error is the difference between the analog signal and the closest available digital value at each sampling instant from the A/D converter. Quantization error also introduces noise, called quantization noise, to the sample signal. The higher the resolution of the A/D converter, the lower the quantization error and the smaller the quantization noise. The relationship between resolution (in bits) and quantization noise for an ideal A/D converter can be expressed as: [6]

$$Signal\ to\ Noise\ (S/N)\ =\ -20 * log\ (1/2^{\wedge}n)$$

Equation 1 : Signal to Noise (S/N)

where n is the resolution of the A/D converter in bits. S/N is the signal to noise and is expressed in dB. This relationship can also be approximated as: [6]

$$S/N\ =\ 6 * n$$

Equation 2: Signal to Noise (S/N) in dB

Typical S/N ratios for ideal A/D converters are 96dB for 16 bits, 72dB for 12 bits, and 48dB for 8 bits. [6]

In order to reduce Quantization Noise to make the digital signal better and clearer, we use different methods based on what we want. We can improve it by taking more samples and using more bits for each sample. This helps to take more details in the signal. Also, we can do something called oversampling and filtering to remove unwanted parts of the signal. Different ways of counting the signal's levels can help avoid problems. Lastly, we can add a bit of random noise to help fix issues and make things sound smoother. Even though some errors are normal, we can make them smaller by using the right methods.[7]

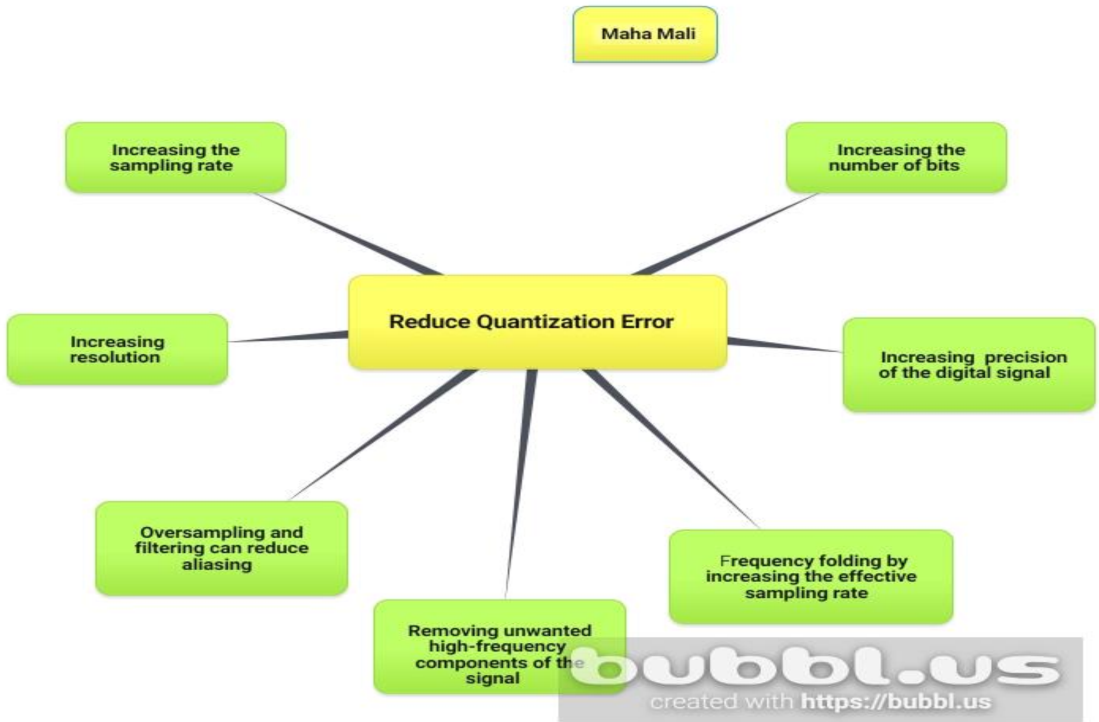

Figure 4:Reduce Quantization Error

Part Three: Difference Pulse Code Modulation (DPCM)

DPCM, which stands for Differential Pulse Code Modulation, is a bit like PCM but a little different. It's a way to change analog signals into digital ones. The special thing about DPCM is that it doesn't just look at each sample by itself. Instead, it checks how much each sample is different from what we expect it to be. That's why it's called "differential" PCM. [8]

The DPCM uses the common property of PCM in which the high degree of correlation between adjacent samples is used. This correlation is generated when the signal is sampled at the rate greater than the Nyquist rate. Correlation means that the signal does not adapt change quickly from one sample to another. [8]

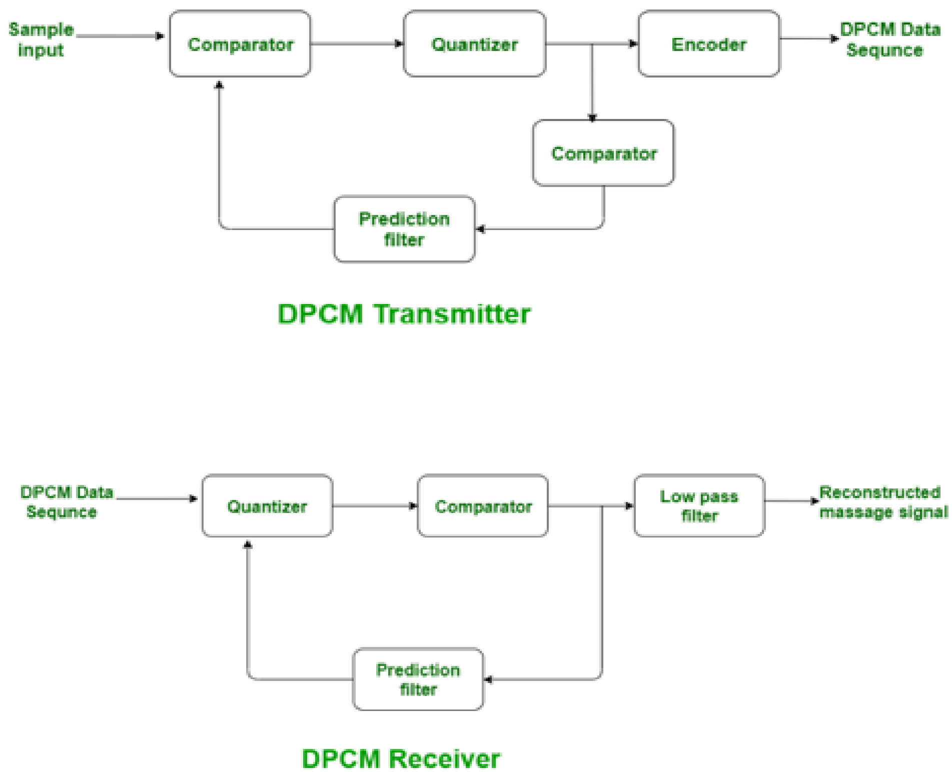

Figure 5: DPCM operations [9]

Procedure, Data analysis and Discussion

Part 1: PCM Transmission with TDM

In this part of the experiment, the transmission was be required for sampled, quantized, and binary encoded data of two analog signals over one communication channel using the concept of time division multiplexing. The components were connected as shown in figure below.[10]

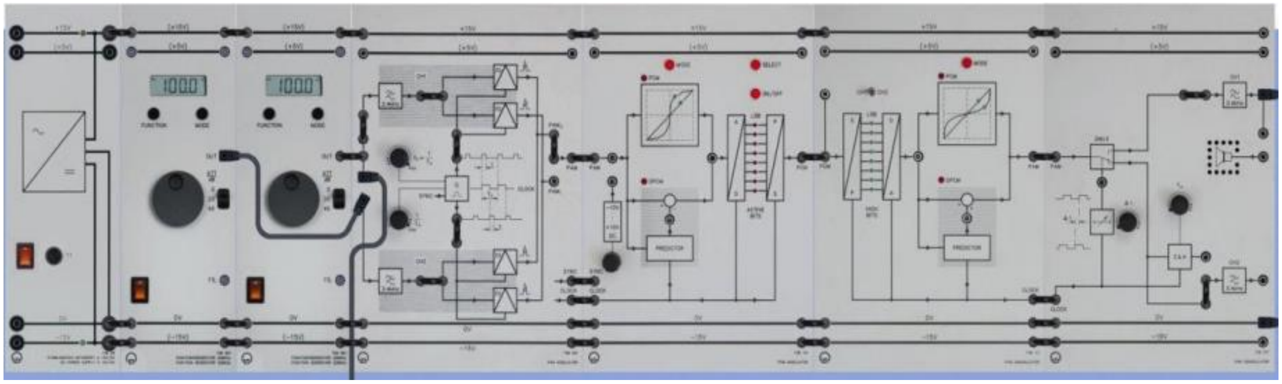

Figure 6: PCM Transmission with TDM [4]

To complete the experiment, these steps were used as described in the laboratory manual: the CASSY UA1 was connected to input PAM Modulator CH1, and CASSY UB1 was connected to output PAM Demodulator CH1.Also, the PCM modulator and demodulator panels were set to linear quantization. Finally, all the coded bits were activated.[10]

For the PAM Modulator, the duty cycle of the clock generator (Sampler) was set to the max, but the sampling frequency of clock generator was set to the min. Moreover, the function generator 1 was set to sine signal and $f_{m1} = 300Hz$, $V_{ss} = 10\,V$ .Also, the function generator 2 was set to Triangle signal and f_{m2}=200Hz, V_{ss}=5 V. [10]

In other hand, for the PAM Demodulator the time shift knob Δt was set to the Minimum position, and we got the following plot as shown in figure 7 for 5 cycles.

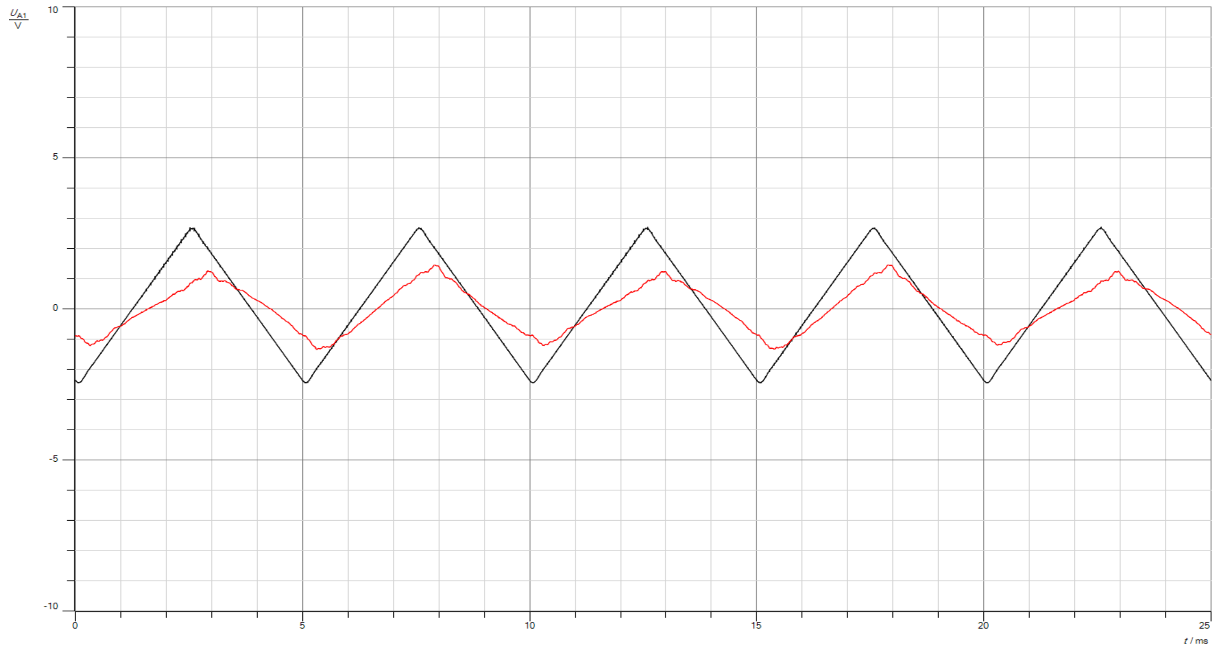

Figure 7: Modulated and Demodulated Signals for ch1

Then, the CASSY UA1 was connected to Input PAM Modulator CH2, and the CASSY UB1 was connected to Output PAM Demodulator CH2. In addition to that, the measurement was then started

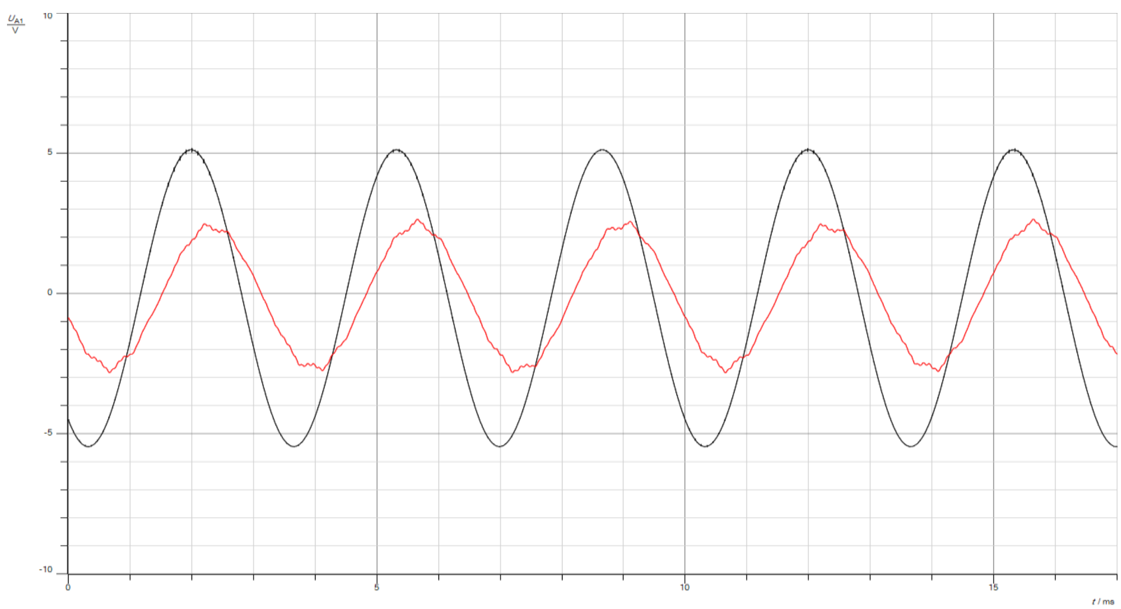

Figure 8: Modulated and Demodulated Signals for ch2

Set the duty cycle of the clock generator (Sampler) to the max. 6. Set the sampling frequency of the clock generator to the min. 7. Set Function generator 1: Sine, fm1 = 300 Hz, VSS = 10 V. 8. Set Function generator 2: Triangle, fm2 = 200 Hz, VSS = 5 V

When we looked at the PAM Modulator's output as shown in figures 7 and 8 , we noticed something. The shape of the quantized and binary-encoded signal wasn't the same as the original signal. This happened because of how we turned the signal into steps, which made some details go missing and the signal look like steps.

Next, when we looked at the output of PAM Demodulator's, we saw something. The signals we got back weren't exactly the same as what we started with. They had some of distortion and noise. This was particularly noticeable in the presence of quantization noise, which resulted in deviations from the original analog signals.

It is important to note that while the recovered outputs may not perfectly match the original analog signals, the communication scheme still provided a means of transmitting and recovering multiple message signals over the shared channel using time division multiplexing.

When we change some settings in the PAM modulator and demodulator panels, such as linear quantization and coded bits activation, the signal we get at the end should look almost like the one we started with. However, the accuracy of the demodulated signal can be affected by various factors, such as noise, distortion, and the chosen modulation parameters.

We can take the signal we got after demodulation and look at it closely to see how well the PAM modulation and demodulation worked. This means comparing the signal we got with the one we started with to see if they match. This helps us figure out if the demodulation process worked well.

Part 2: Quantization Noise
Triangle Signal

The components were connected as shown in figure below.[10]

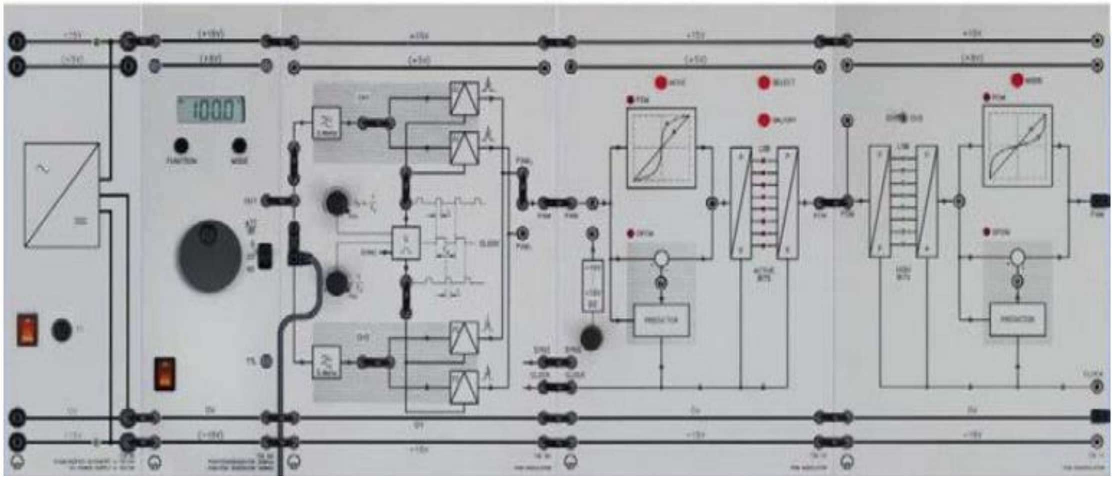

Figure 9: Quantization Noise (Triangle Signal) [4]

At first both channels (CH1 and CH2) of the PAM Modulator with one function generator were connected. Then, the function generator was set to: triangle signal, $f_m = 30Hz$, $V_{ss} = 12\,V$. This connection was made to prevent any time gaps from occurring at the output of the PCM demodulator. Also, the PCM modulator and demodulator was set to linear quantization and all bits was activated. [10]

To measure the input signal to the PAM modulator CH2, the CASSY UA1 was connected. Similarly, the CASSY UB1 was connected to measure the output signal from the PCM demodulator. Then, Load the CASSY Lab 2 example QNoise.labx was loaded. After that the measurement was started. [10]

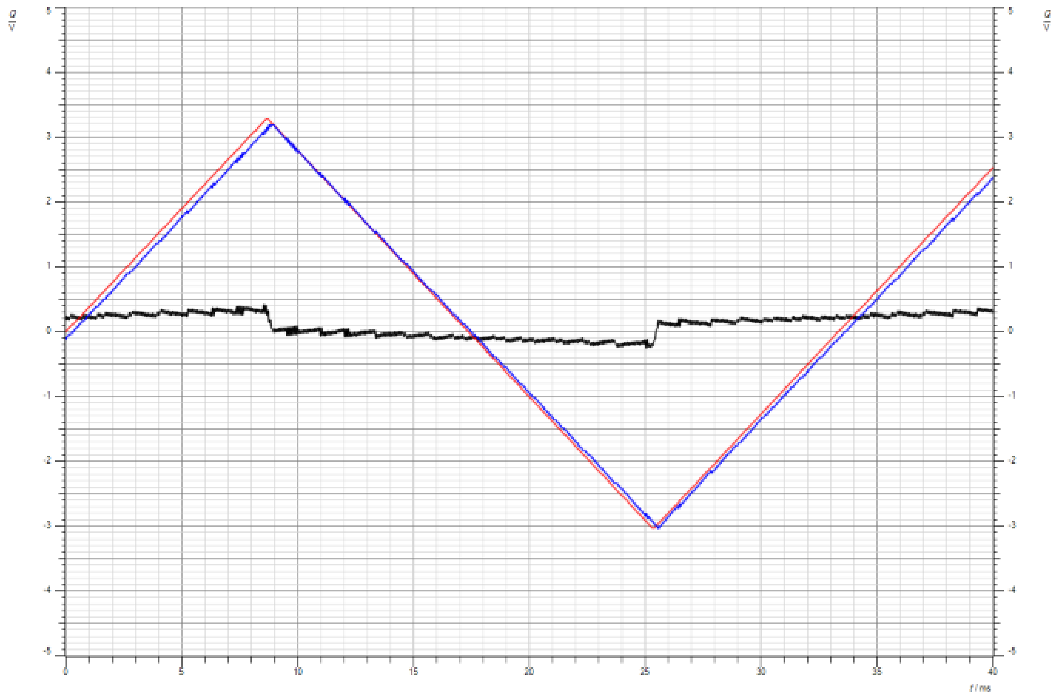

Figure 10:the error between modulated and demodulated for the triangle with f=30Hz

If we look at the two triangles and see how they're different, we can figure out the error that happened during the encoding and decoding stages of the PCM system. This error represents the distortion. It is primarily caused by the quantization process, where the continuous analog signal is divided into discrete digital values.

The magnitude of error between the triangles shows us how well the PCM system is working. A smaller error means the signal we got back looks a lot like the original analog signal, which is good. This means that the quantization process was able to accurately represent the original analog signal. But if the error is bigger, it means some important parts might be missing or not as clear during the quantization process.

The shape and distribution of the error between the triangles can also show the nature of quantization noise. Quantization noise is a type of distortion that arises due to the approximation of continuous values into discrete levels. It often appears as random differences around the original signal, showing as high-frequency noise in the recovery waveform.

Looking at the errors between the triangles can help us in evaluating the impact of quantization parameters, such as the number of quantization levels and the step size. By changing these parameters, different levels of quantization noise can be observed. This helps us decide how clear the signal is and how much noise we're willing to accept.

The measurement was repeated with a resolution of 5 bits by deactivating the least significant 3 bits. This means that only the 5 most significant bits were considered for quantization and encoding, while the least significant 3 bits were ignored. [10]

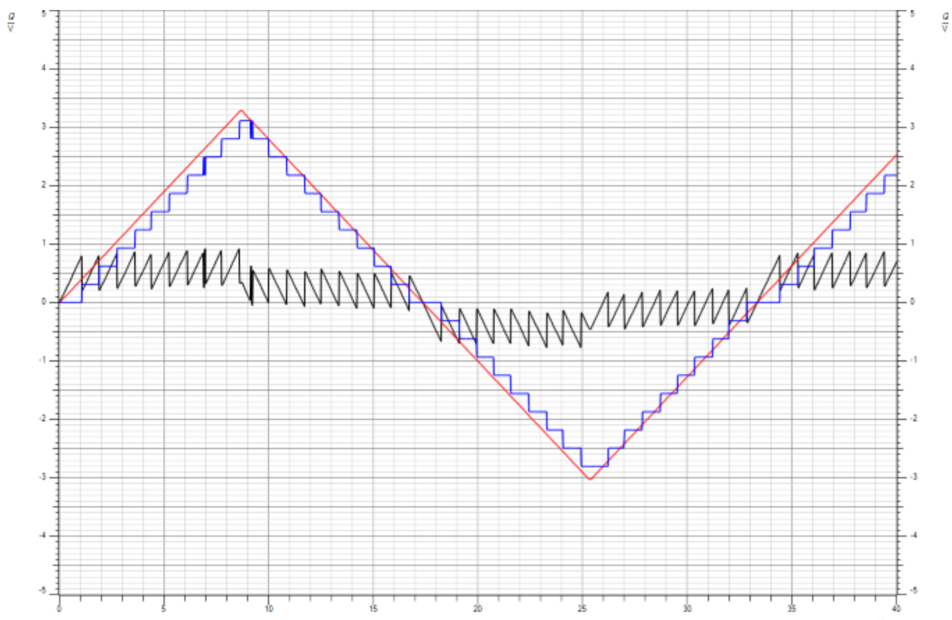

Figure 11: the error between modulated and demodulated 5 bits

When we decrease the number of bits, there is an impact on the errors between the original signal and the recover signal. In simple terms, errors generally increase when the number of bits is reduced. This means that the recover signal will appear less accurate and more distortion due to the reduction in the bits used to represent the signal, as shown in figure 11.

So, when we use fewer bits, the errors between the original and the recover signals usually get bigger. This errors the recover signal not as close to the original one. The trick is finding the right balance between keeping things clear and dealing with the limits of how detailed we can be and the extra noise that comes with it.

The measurement was done using a triangle waveform with a frequency of 300 Hz and a peak-to-peak voltage V_{ss}=12 V. The CASSY UA1 device was connected to the input of the PAM modulator CH2 to measure the modulating signal, and the CASSY UB1 device was connected to the output of the PCM demodulator to measure the recover analog signal.

The recorded measurements would show the waveform of the modulating signal, indicating the shape and amplitude of the triangular waveform generated by the function generator with a frequency of 300 Hz. Additionally, the output waveform from the PCM demodulator would be observed, reflecting the recover analog signal with a resolution limited to 5 bits.

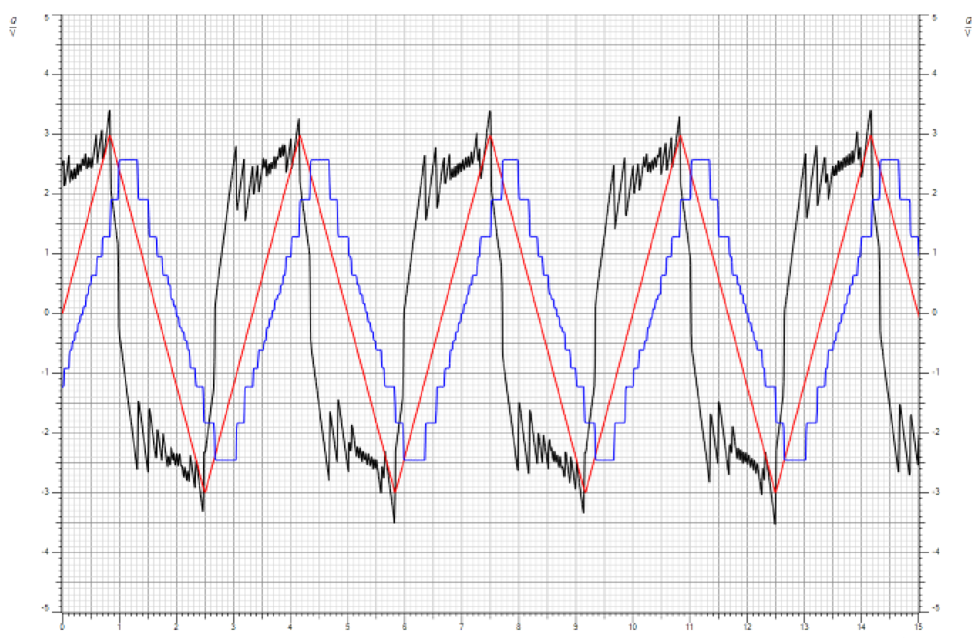

Figure 12: the error between modulated and demodulated for changing the frequency to 300 Hz

Changing both the resolution and the message frequency can have important effects on the quantization process and the quality of the demodulated signal in a PCM system.

Resolution means how many bits we used for quantization and encoding in the PCM system. More bits make the signal look more like to the original analog signal, because we have more available quantization levels. This makes the signal we get back more accurate, then the error gets smaller. But if we use fewer bits, the signal won't look as analog. Fewer number of quantization levels can introduce quantization noise and distortions, making the signal we get back not as good. We can see the errors more, and some small details might not show up well.

The message frequency refers to the frequency of the modulating signal or the input signal to the PCM system. The impact of the message frequency on the quantization process and the quality of the demodulated signal depends on the sampling rate and the Nyquist-Shannon sampling theorem. If the message frequency is relatively low compared to the sampling rate, the quantization process can accurately take into account the differences in the original signal. The demodulated signal has good quality and keeps the characteristics of the original signal.

Sinusoidal Signal

In this part of the experiment, we did the same steps as Part 2, but instead of using a triangle waveform, we used a sin waveform for the input signal. [10]

The setup and connections remained the same, with the PAM modulator connected to a function generator and the CASSY UA1 and CASSY UB1 devices connected to measure the input and output signals, respectively. [10]

At first, the same procedure as Part 2 was repeated, but with the use of non-linear quantization. This means that instead of using a linear quantization scheme, a non-linear mapping was applied to map the input signal to the quantization levels.

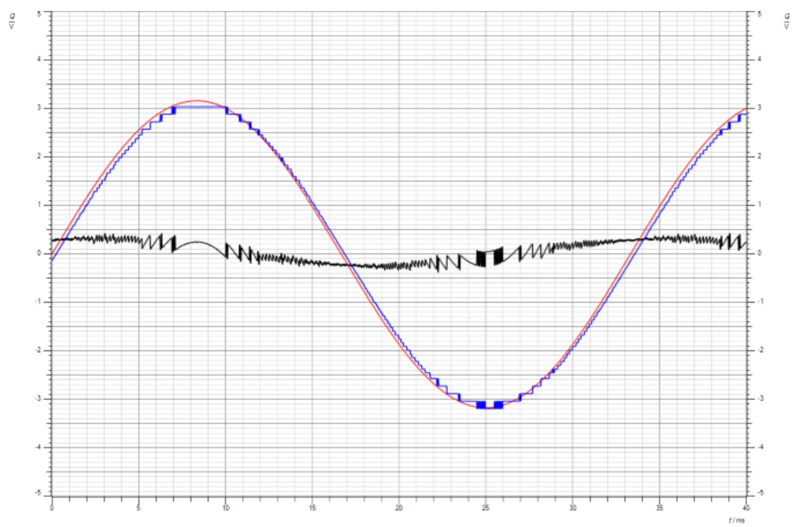

Figure 13: the error between modulated and demodulated for the sinusoidal 8 bit

By using a sinusoidal modulating signal, the resulting quantization noise shows a different characteristic compared to the triangular waveform. The quantization noise in this case is influenced by the amplitude and frequency of the sinusoidal signal, as well as the chosen resolution for quantization.

The sinusoidal signal contains different frequency components, and when quantized, these components can interact with the quantization levels and introduce additional harmonics and distortions. This leads to a more complex and intricate structure of the quantization noise compared to the simpler and more predictable noise pattern observed with a triangular waveform.

In this part of the experiment, the same procedure as Part 2 was repeated, but with the use of non-linear quantization and resolution of 5 bits.

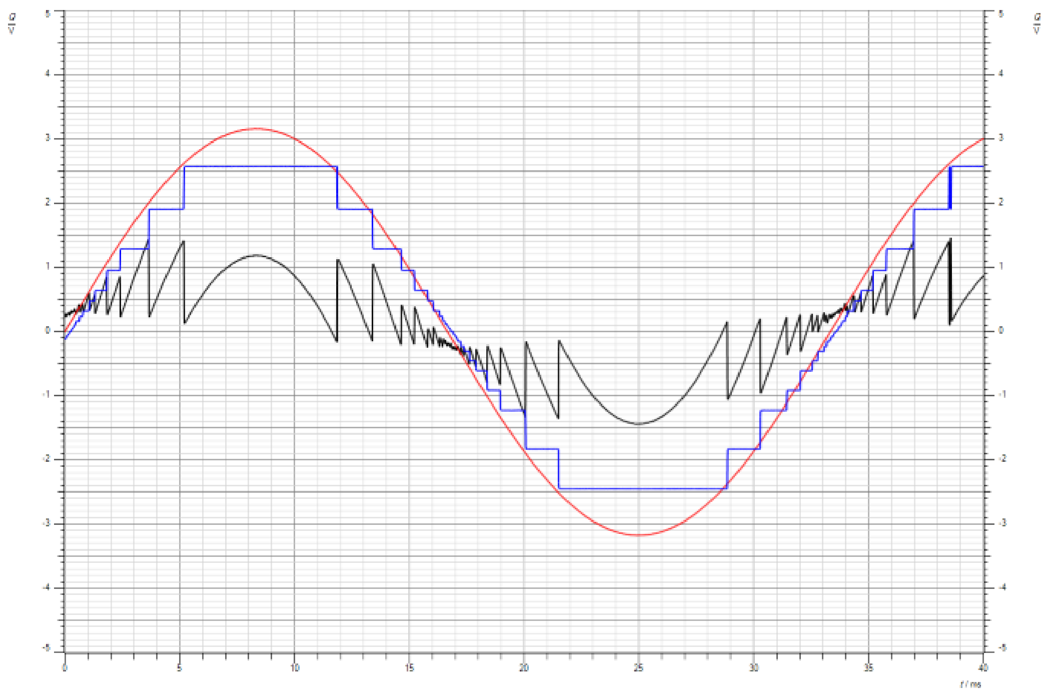

Figure 14: the error between modulated and demodulated for the sinusoidal 5 bit

When we reduce the number of resolutions from 8 bit to the 5 bit the error increased as shown in figure 14

In this part of the experiment, the same procedure as Part II was repeated, but with the use of non-linear quantization and resolution of 5 bits. And the function generator was set to Sine waveform, f_m = 300 Hz, V_{SS} = 12 V

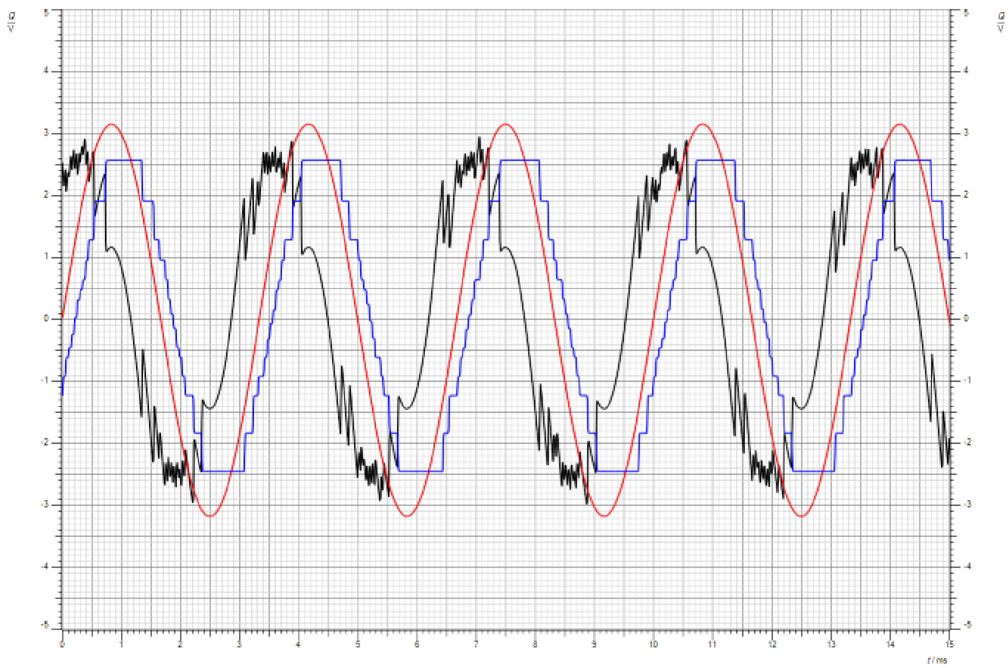

Figure 15: the error between modulated and demodulated for the sinusoidal 5 bit and f=300Hz

The non-linear quantization process introduces a deviation from the linear relationship between the input signal and the quantized output. This can be achieved by using a non-linear transfer function or employing a companding technique, such as A-law or µ-law compression.

By applying non-linear quantization, the experimenters aimed to investigate the impact of non-linear distortion on the quantization process and the quality of the demodulated signal.

Part 3: Difference Pulse Code Modulation (DPCM)

The components were connected as shown in figure below.[10]

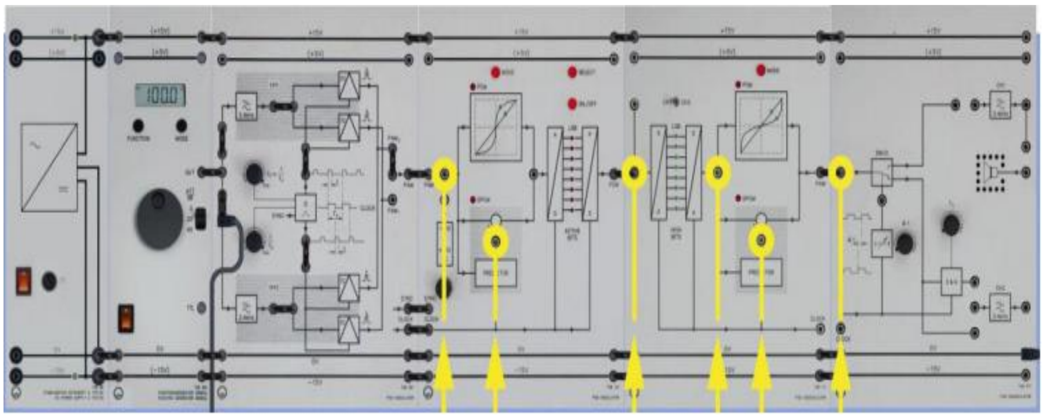

Figure 16: Difference Pulse Code Modulation [10]

At first, the PAM input of the PCM modulator was connected to 0 volts. Then, the PCM modulator was changed to the DPCM mode, and at the same time, we also set the PCM demodulator to the DPCM mode. [10]

The PAM input of the PCM modulator was disconnected from 0 V. The amplitude of the modulation signal from the function generator was then reduced to 0 V. Also, the sampled signal, obtained from the PCM modulator, was then fed into the modulator itself, and the desired amplitude (V_{ss} = 12 V) was reset to ensure accurate encoding.[10]

In addition to that, the channel UA1 of the CASSY system was connected to the input signal of the PAM modulator. For channel UB1, separate records were taken for the following signals:

- The predictor of the DPCM modulator.
- The output of the DPCM modulator.
- The input of the DPCM demodulator.
- The predictor of the DPCM demodulator.
- The PAM output of the DPCM demodulator.

❖ The predictor of the DPCM modulator

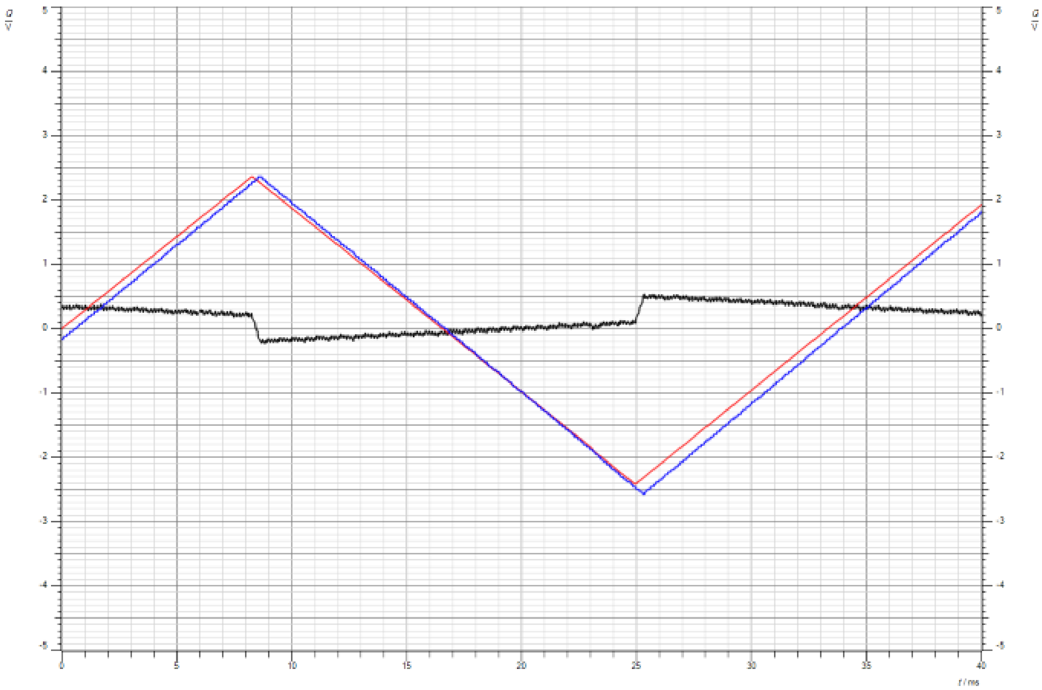

Figure 17: predictor of the DPCM modulator with 8 bit

The predictor in the DPCM modulator showed a changing pattern, which means it could determine the difference between one sample and the next one.

The predictor in DPCM does a job: it tries to determine how much the current sample is different from what it expected based on the past samples. A good predictor should be able to understand how the signal changes. When we look at how the predictor works, we can see if it's good at determining the differences between samples.

❖ The output of the DPCM Modulator

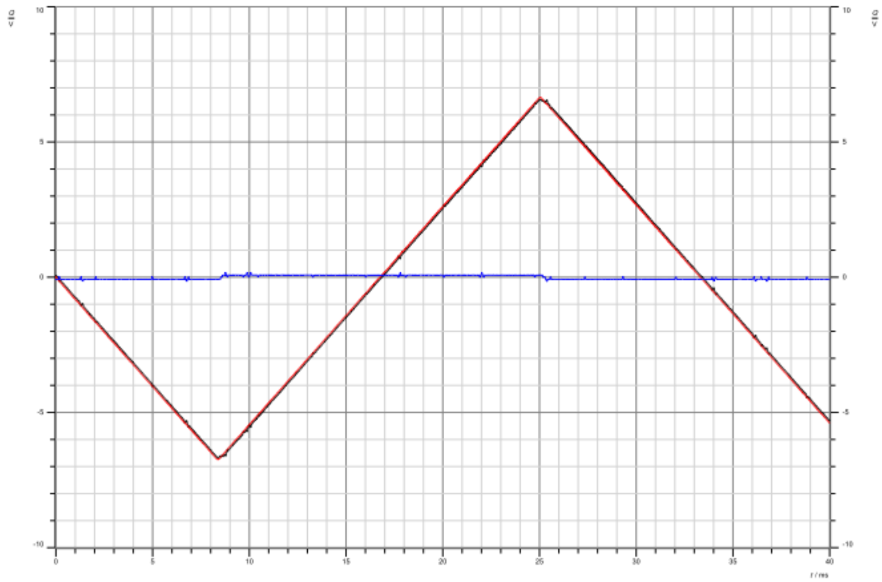

Figure 18: The output of the DPCM modulator with 8 bits

The output of the DPCM modulator showed a waveform with reduced amplitude compared to the input signal.

DPCM takes the change between one sample and the next and sends it. So, what we get from the DPCM modulator shows these changes. The smaller size means DPCM is good at taking how samples close to each other are related. This makes the signal smaller but still clear, as we don't need to repeat the same information.

❖ The Input of the DPCM Demodulator

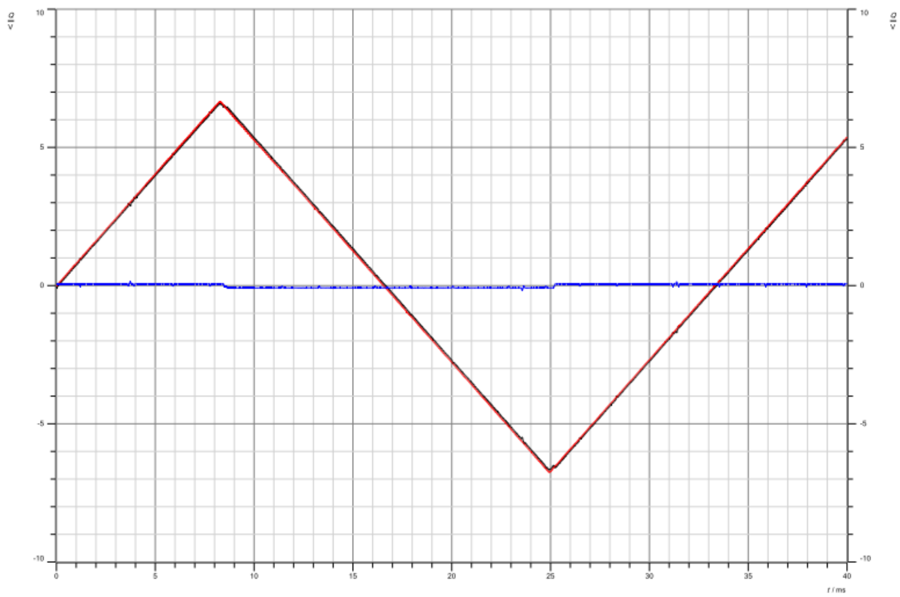

Figure 19: The input of the DPCM demodulator with 8 bits

The input signal of the DPCM demodulator appeared similar to the output signal of the DPCM modulator.

The input signal of the DPCM demodulator is like the signal we sent from the DPCM modulator. It should look a lot like the signal we got from the DPCM modulator because it shows how the samples changed. If there's any extra noise or changes during the sending, the input signal might not be as clear, which can affect how well the demodulation works.

❖ The predictor of the DPCM demodulator

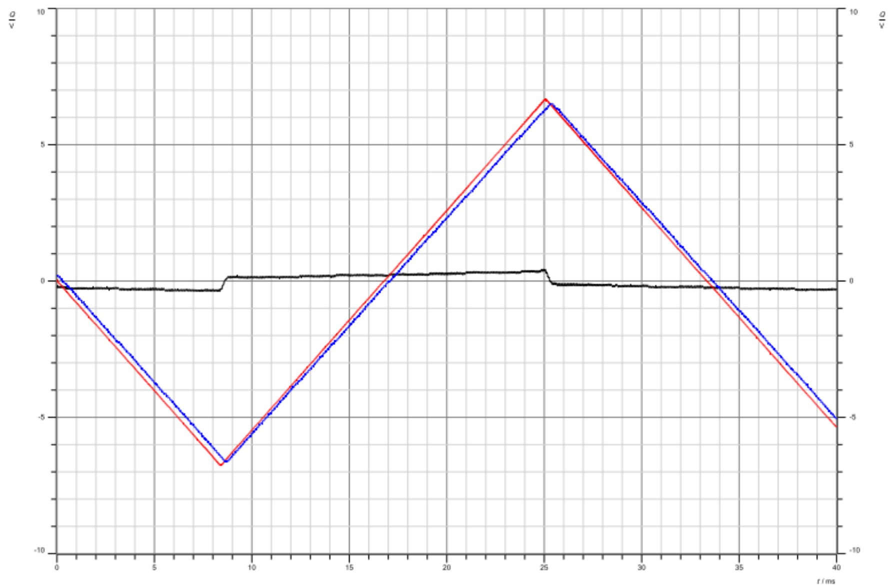

Figure 20: The predictor of the DPCM demodulator with 8 bits

The predictor of the DPCM demodulator showed a movement similar to the predictor of the DPCM modulator.

Just like the DPCM modulator, the DPCM demodulator also uses a predictor to guess how samples change from one to the next. It's best if the predictor in the demodulator works the same as the one in the modulator. This helps in making the original signal come back accurately. When we check both predictors, we can see if they match well or if there are any differences.

- The PAM output of the DPCM demodulator

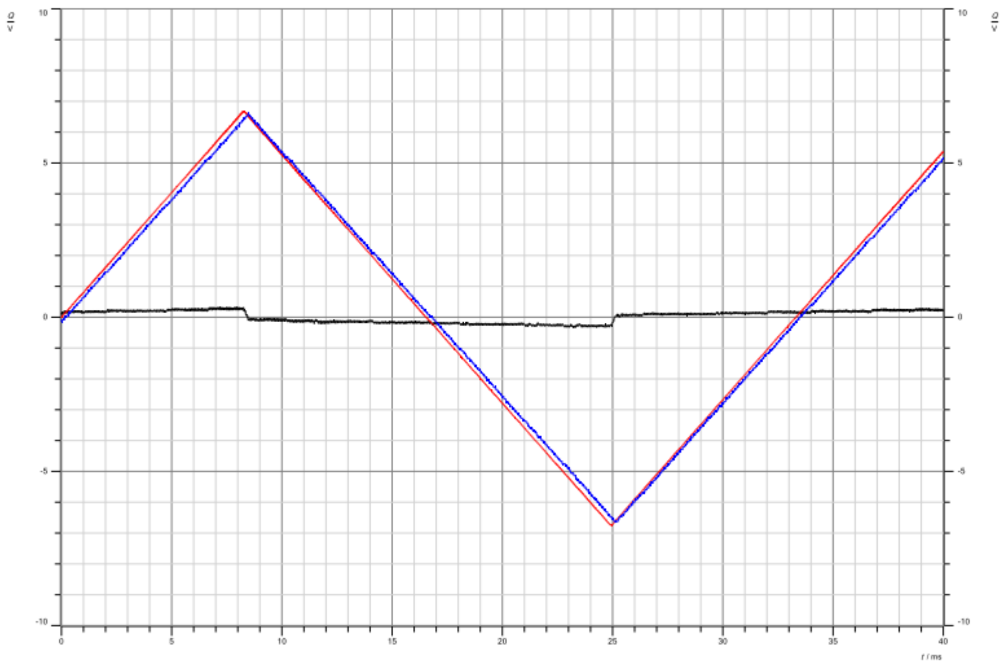

Figure 21:The PAM output of the DPCM demodulator 8 bit

The PAM output of the DPCM demodulator resembled the original input signal, although small distortions might be present.

The PAM output of the DPCM demodulator represents the reconstructed analog signal after demodulation. It should ideally resemble the original input signal, but some distortions may occur due to quantization errors and other limitations of the modulation and demodulation process. By analyzing the quality of the PAM output, we can evaluate the effectiveness of the DPCM modulation and demodulation in reconstructing the original analog signal.

Then the previse part was repeated with a resolution of 4 bits by deactivating the indicated bits in the PCM modulation and demodulation process.

- The predictor of the DPCM modulator

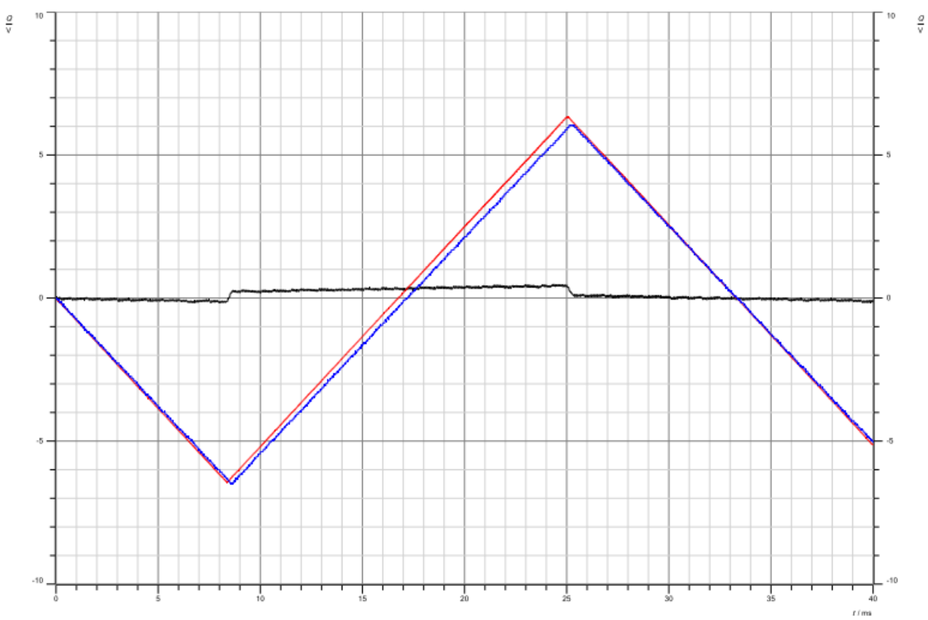

Figure 22: The predictor of the DPCM modulator 4 bit

The predictor of the DPCM modulator showed a more limited range of patterns compared to the previous higher resolution case.

Since there are only 4 bits for counting, the predictor in the DPCM modulator can only determine within a small range how samples change from one to the next. This might make the determines less accurate, especially for signals with small changes or quick shifts. Having fewer options can lead to more wrong determines and less accuracy in making the original analog signal again.

- The output of the DPCM modulator.

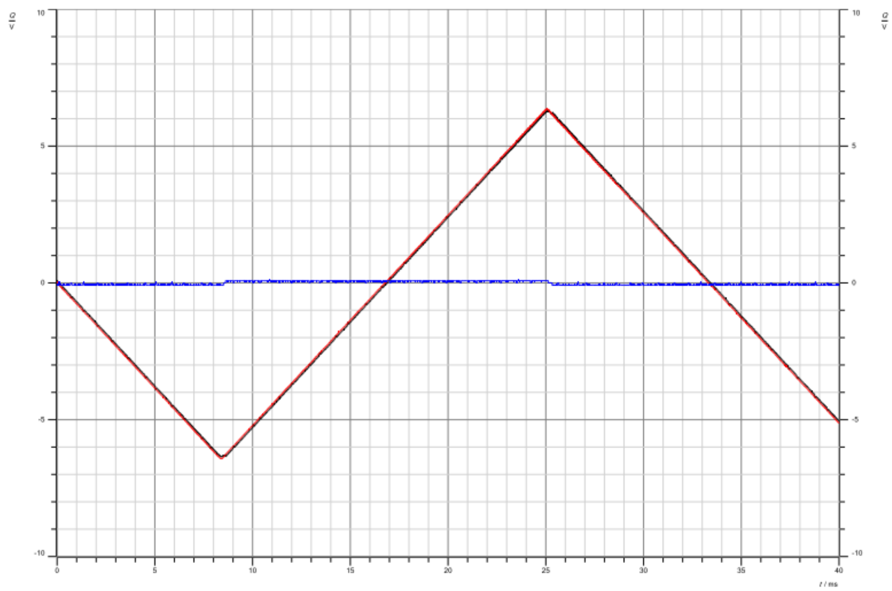

Figure 23: The output of the DPCM modulator 4 bit

The output of the DPCM modulator showed a waveform with more reduced amplitude and a larger representation compared to the higher resolution case.

Because there are only a few bits, the signal from the DPCM modulator can only show a small range of how samples change. This makes the signal look smaller and not as detailed. This means we might lose some small details and changes in the signal because we can't show them with the limited bits we have.

- The input of the DPCM Demodulator

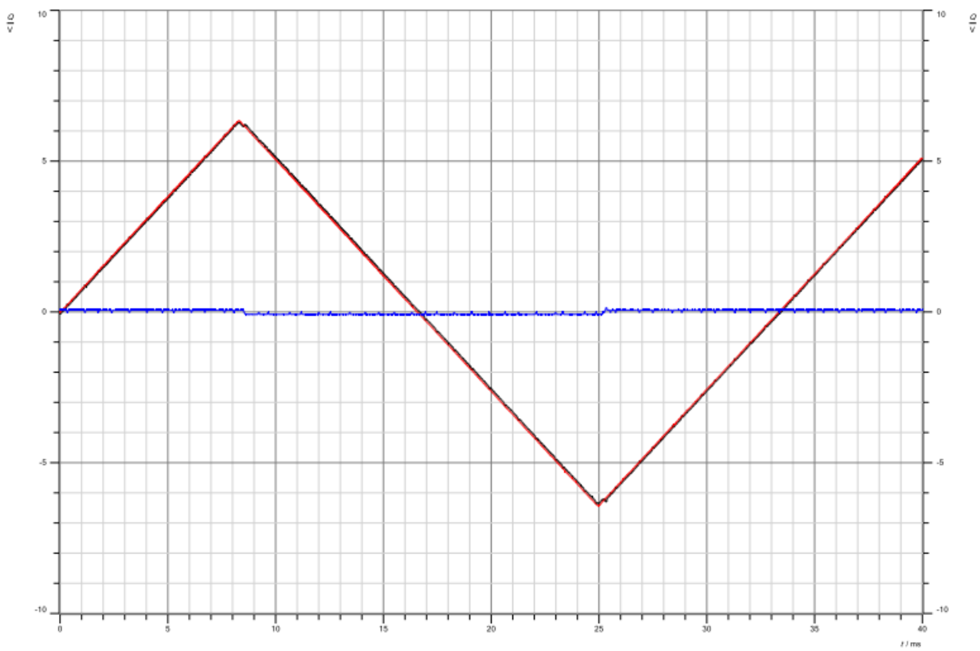

Figure 24: The input of the DPCM demodulator 4 bit

The signal that goes into the DPCM demodulator looks a bit like what comes out of the DPCM modulator, but it's not as accurate and we can see more quantization effects.

The input signal of the DPCM demodulator represents the received encoded signal. With only 4 bits for encoding, the fidelity of the transmitted signal is compromised. The reduced resolution introduces quantization errors and limited dynamic range, leading to a loss of fidelity in the received signal. The quantization effects become more pronounced, resulting in a more noticeable degradation in the reconstructed signal compared to the higher resolution case.

❖ The predictor of the DPCM demodulator

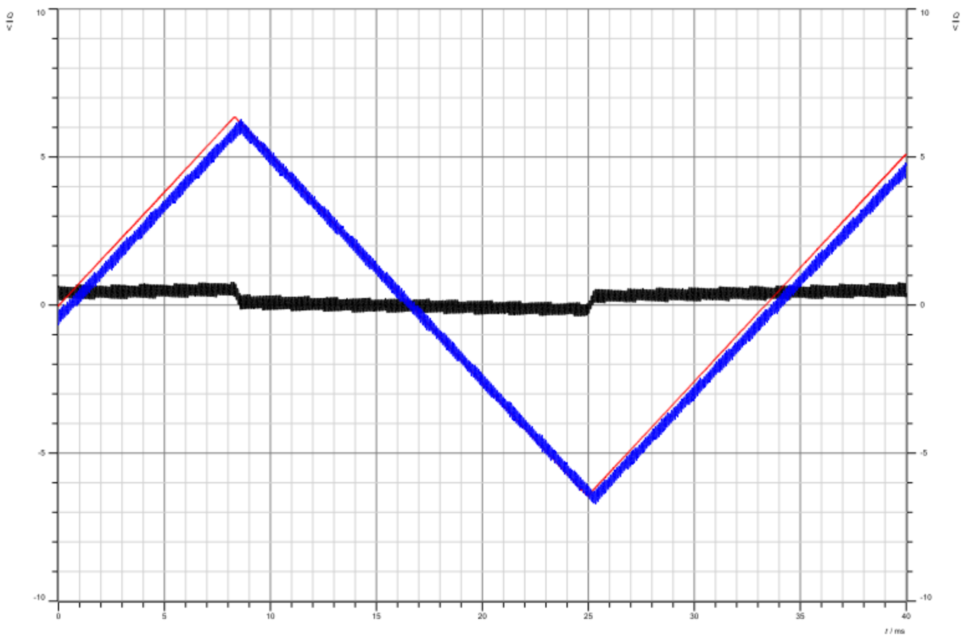

Figure 25: The predictor of the DPCM demodulator 4 bit

The predictor of the DPCM demodulator showed a limited range of designs similar to the predictor of the DPCM modulator but with reduced accuracy.

Just like the DPCM modulator, the predictor in the DPCM demodulator can only guess changes within a small range. This makes the guesses less accurate, so the signal might not come back as clear. Small details and changes might not be guessed well, which makes the signal not as close to the original.

❖ The PAM Output of the DPCM Demodulator

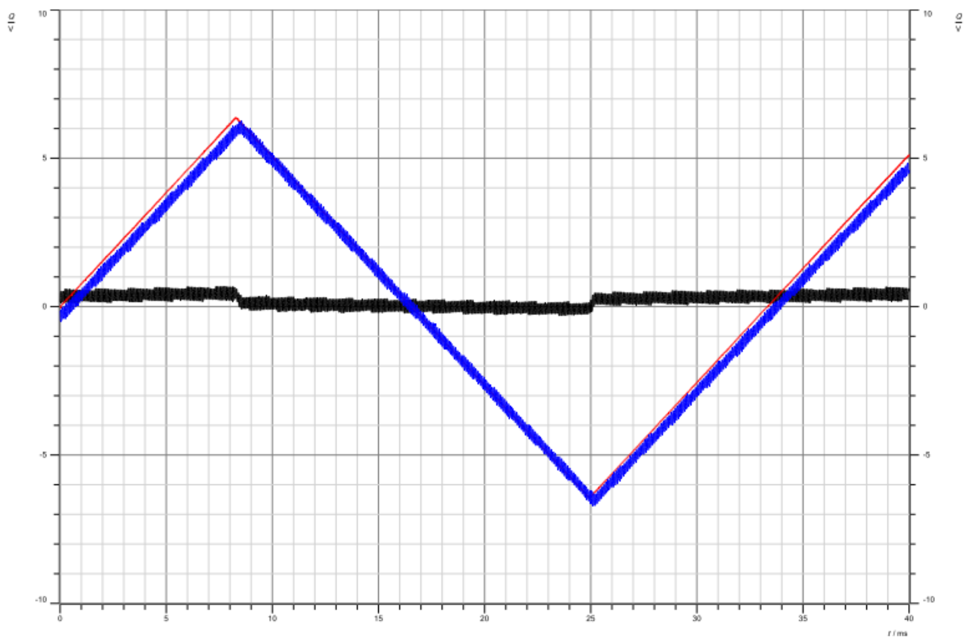

Figure 26: The PAM output of the DPCM demodulator 4 bit

The signal we get from the DPCM demodulator looks even worse compared to the case with higher details. The signal we made looks more noisy and not as clear.

When we have only 4 bits to encoding and decoding, the signal we get from the DPCM demodulator looks much worse. The signal becomes noisier because of the limited counting options, and this noise is easier to see in the recover signal. We lose small details and the signal looks less clear and accurate, not really like the original signal anymore.

By reducing the number of bits used for encoding and decoding in the PCM/DPCM process, the detection resolution of the system is affected. The resolution refers to the number of discrete levels that can be represented in the digital signal.

In general, decreasing the number of bits reduces the available levels for representing the analog signal. This reduction in resolution leads to a coarser quantization and increased quantization error. The quantization error is the difference between the original analog signal and the quantized digital representation.

With a lower resolution, the system can potentially lose fine details and accuracy in representing the analog signal. Smaller changes or nuances in the input signal may not be accurately captured, resulting in a loss of fidelity in the reconstructed signal.

Conclusion

In this experiment, we learned Pulse Code Modulation (PCM) transmission with TDM, a method that changes analog signals into digital form. Also, we discovered that the number of bits we use for quantization and the way we predict changes play a big role in how well the recover signals match the originals. More bits mean clearer signals, but fewer bits lead to noisier outcomes.

We also saw how making determines about signal changes can affect the final results. Overall, we learned that finding the right balance between detail, noise, and accuracy is important when using PCM. This experience provided us knowledge into the world of digital signals and how they can represent analog information in a communication system.

References

[1]https://www.tutorialspoint.com/digital_communication/digital_communication_pulse_code_modulation.htm . Accessed on 22-8-2023 at 10:12 AM.

[2] https://en.wikipedia.org/wiki/Time-division_multiplexing .
Accessed on 22-8-2023 at 11:30 AM.

[3] D2-06.pdf (auburn.edu).
Accessed on 22-8-2023 at 11:50 AM.

[4] https://www.sciencedirect.com/topics/engineering/quantization-noise .
Accessed on 22-8-2023 at 11:50 AM.

[5] https://gamaxlabsol.com/quantization-noise-what-is-it-and-why-should-you-care/ .
Accessed on 23-8-2023 at 11:50 AM.

[6] https://www.tek.com/en/support/faqs/what-quantization-error-and-how-does-signal-noise-relate .
Accessed on 23-8-2023 at 11:50 AM.

[7] https://www.linkedin.com/advice/0/what-best-methods-reduce-quantization .
Accessed on 23-8-2023 at 11:50 AM.

[8] https://techdifferences.com/difference-between-pcm-and-dpcm.html .
Accessed on 23-8-2023 at 11:50 AM.

[9] https://www.geeksforgeeks.org/difference-between-delta-modulation-dm-and-differential-pulse-code-modulation-dpcm/ .
Accessed on 23-8-2023 at 11:50 AM.

[10] Lab manual.