FACULTY OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENEE 4113, Communication Laboratory

Experiment. 8 Report

Pulse Code Modulation, PCM2

Prepared by: Layan Salem 1221026

Partners:

Waleed Rimawi

Noora Khdour

Supervised by: Dr. Qadri Mayyala

T.A: Eng. Hazem Awaysa

Section : 1

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Abstract

This experiment explores Pulse Code Modulation (PCM) and its practical application in digital communication systems. The aim was to analyze the encoding and decoding processes of analog signals using PCM with linear and non-linear quantization. The experiment also included Time Division Multiplexing (TDM) to transmit two analog signals simultaneously over one channel and examined the effects of quantization noise under different bit depths and message frequencies. Additionally, Differential Pulse Code Modulation (DPCM) was implemented to observe its efficiency in reducing redundancy. The results demonstrate that higher quantization resolution enhances signal fidelity, and that DPCM can significantly reduce the bit rate while maintaining acceptable signal quality. Non-linear quantization was shown to improve performance at low amplitudes, especially for audio-like signals. Overall, the experiment confirms the importance of proper sampling, bit allocation, and encoding strategies in optimizing digital transmission systems.

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Theory

Pulse-code modulation (PCM):

Pulse Code Modulation is an analog signal representation method that uses digital representation. The three main steps of the above are sampling, quantization, and encoding. The continuous analog signal is first sampled at regular intervals. Next, each sample is quantized to a nearest value in a finite set of levels. Finally the quantized values are encoded into binary numbers. The process of PCM is widely used in digital communication systems because it can transmit signals with virtually no degradation, while introducing some noise due to quantization.[1]

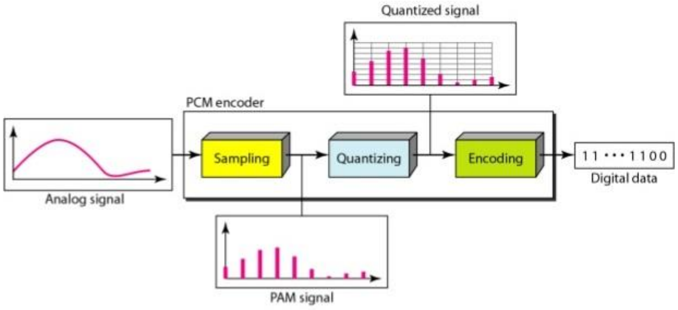

Figure 1 PCM block diagram [2]

Time-Division Multiplexing (TDM)

TDM allows multiple signals to share a single transmission channel by dividing time into segments and assigning each signal a distinct time slot. During each cycle, the system switches between inputs quickly enough to give the impression of simultaneous transmission. This method is efficient in systems where the bandwidth of a single channel can support multiple data streams.

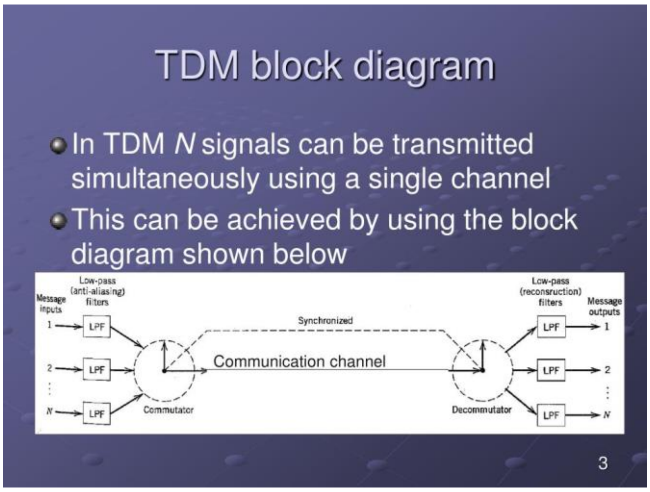

Figure 2 TDM block diagram [3]

PCM Transmission with TDM

Combining PCM with TDM In systems where PCM is integrated with TDM, each incoming analog signal is sampled and encoded independently, resulting in a digital sample. The digital samples are then interleaved in the output according to their time slots to be sent over the shared channel. The key parameters in this instance are the number of channels in the system, the bandwidth per channel, and the total bit rate, which may increase as more channels are added. The system will need to consider this when calculating the required bandwidth for transmission.

Quantization Noise

Quantization noise is the error associated with converting an analog signal into a digital representation. The conversion is based on sampling the amplitude of the continuous signal and assigning it to discrete values, resulting in a small error between the actual signal and the signal represented. The amount of quantization noise will depend on the quantity of quantizing levels; the use of quantizing levels will result in smaller quantizing steps and will be associated with a lower amount of noise. Conversely, as the number of bits decreases the total amount of quantization noise will increase which results in the degradation of the quality of the signal.

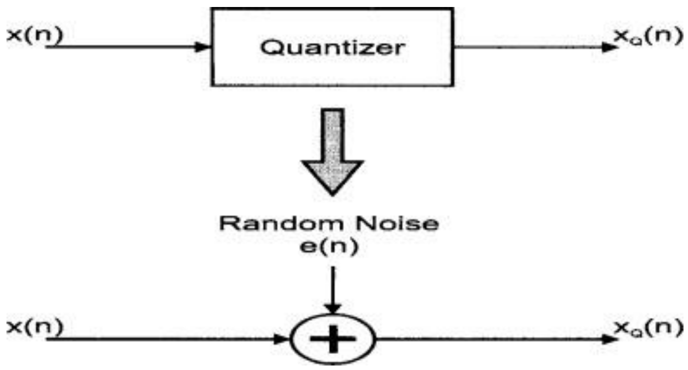

Figure 3 Quantization Noise

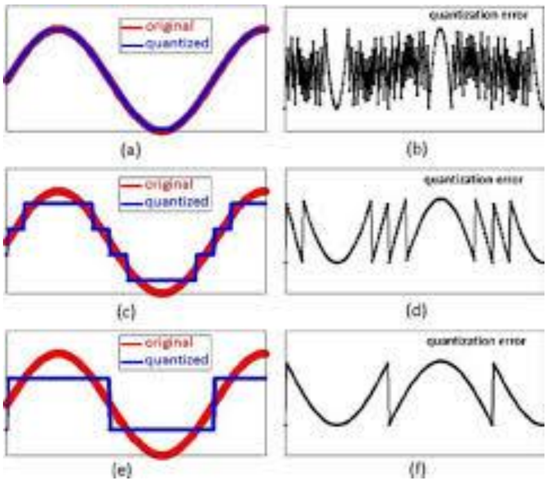

Figure 4 Quantization Noise for sinusoidal [4]

Difference Pulse Code Modulation (DPCM)

Differential Pulse Code Modulation (DPCM): DPCM is an improvement over PCM and is based on the observation that two back-to-back samples of an analog signal are usually very similar; thus, instead of encoding each sample independently, it encodes the difference between the current signal sample and a prediction of the current sample based on prior samples, then quantizes and encodes the difference. In the receiver, the predictor reconstructs the signal using only the past decoded values. DPCM alleviates redundancy found in conventional PCM and is a more efficient way of encoding signals, especially when adjacent samples of an analog signal are correlated.

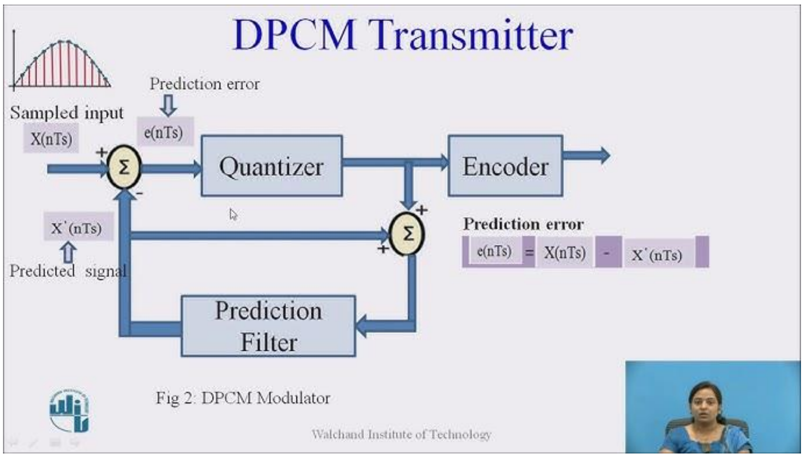

Figure 5 Differential Pulse Code Modulator transmitter [5]

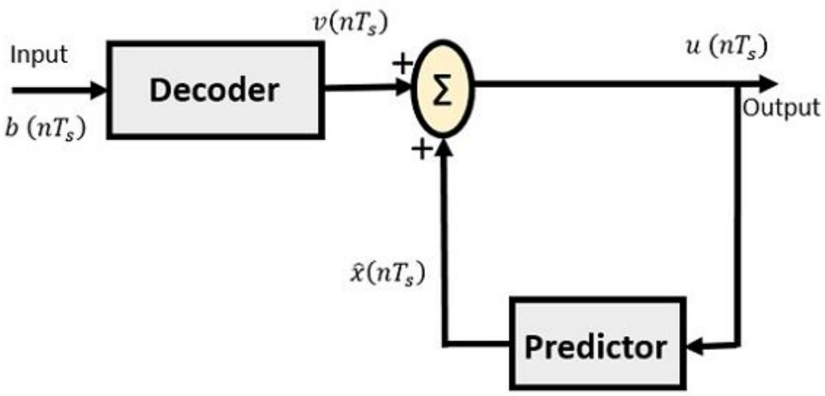

Figure 6 Differential Pulse Code Modulation Receiver [6]

Procedure and data analysis

Part One: PCM Transmission with TDM

In this part of the experiment, the transmission of sampled, quantized, and binary encoded data of two analog signals over one communication channel will be carried out utilizing the concept of time division multiplexing.

In the experiment, CASSY UA1 is connected to Input PAM Modulator CH1, and CASSY UB1 is connected to Output PAM Demodulator CH1. The PCM modulator and demodulator panels are set to linear quantization, and all the coded bits are activated. In the PAM Modulator, the clock generator's duty cycle is set to maximum, and the sampling frequency is set to minimum. Function Generator 1 generates a sine wave with fm1 = 300 Hz and VSS = 10 V, while Function Generator 2 produces a triangle wave with fm2 = 200 Hz and VSS = 5 For the PAM Demodulator, the time shift knob (Δt) is set to the minimum position (anticlockwise). The measurement is started by pressing F9. Additionally, CASSY UA1 is connected to Input PAM Modulator CH2, and CASSY UB1 is connected to Output PAM Demodulator CH2. This enables the examination of communication schemes to recover both message signals using time division multiplexing (TDM).

Pictures were taken for 5 cycles of the PAM modulator and demodulator for both CH1 (sine wave) and CH2 (triangle wave).

In this section, the experiment investigates how two analog signals can be transmitted simultaneously over a single communication channel using Time Division Multiplexing (TDM) and Pulse Code Modulation (PCM).

Two different analog signals were generated using function generators: a sine wave of frequency 300 Hz and a triangle wave of frequency 200 Hz. These signals were fed into the PAM Modulator channels (CH1 and CH2), where they were sampled and modulated using a clock signal set to its maximum duty cycle and minimum frequency.

The output from the PAM Modulator was encoded through a PCM Modulator with linear quantization and all bits activated. These signals were then demodulated using a corresponding PCM Demodulator, and the results were observed using Cassy Lab software.

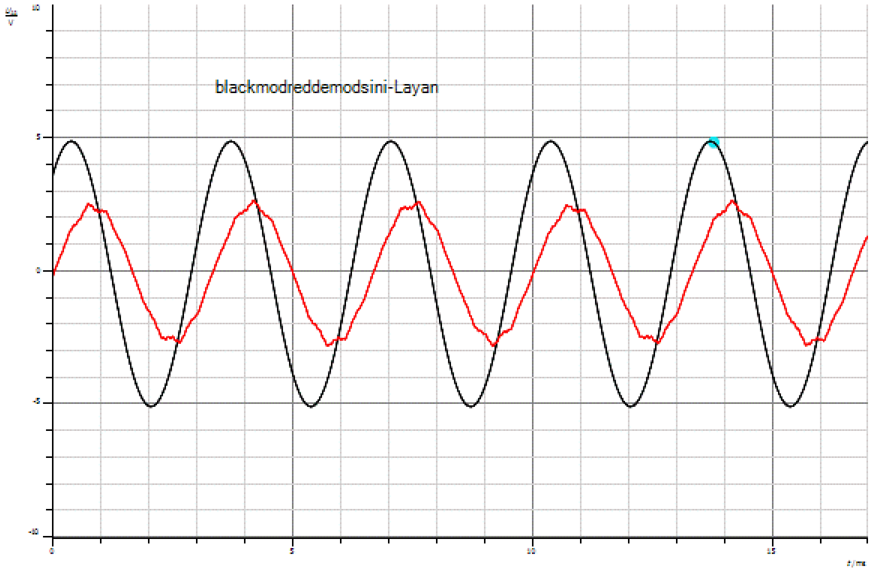

Figure 7: modulated and demodulated signals for sine wave

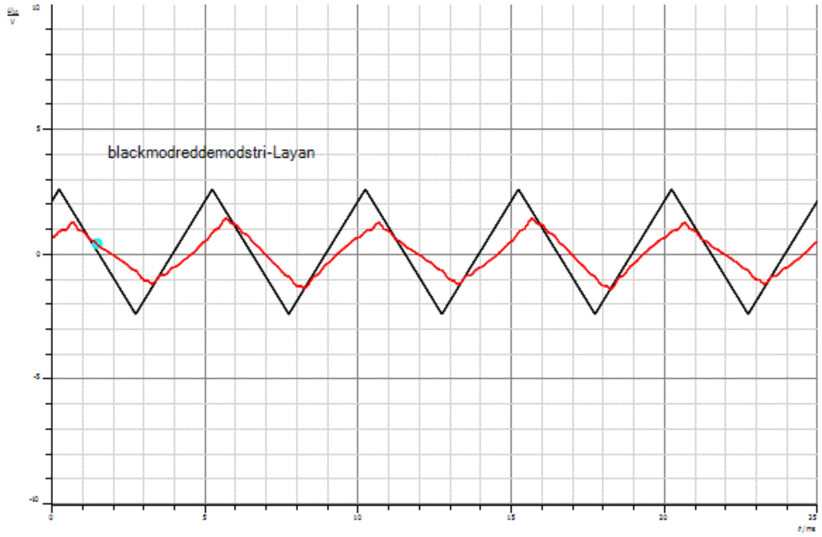

Figure 8: modulated and demodulated signals for triangle wave

The waveform of the decoded signal differed from the original due to quantization steps, introducing a staircase appearance. While some distortion and quantization noise were present, both original messages were successfully recovered via the TDM scheme.

The experiment effectively demonstrated the feasibility of transmitting two separate analog signals (sine and triangle waves) over a single channel using TDM. The staircase-like appearance of the decoded signals highlights the impact of quantization. Despite the visible distortion and quantization noise, both signals were accurately recovered, proving that PCM with TDM can maintain integrity in multi-channel systems.

The use of different frequencies and amplitudes showed the robustness of this method, though it also made clear the trade-off between signal quality and system complexity.

Part Two: Quantization Noise

2.1: Triangle Signal

To examine quantization noise, a single triangle waveform (fm = 30 Hz, VSS = 12 V) was connected to both PAM Modulator channels. The signal was processed using linear quantization, and its reconstruction was analyzed using the QNoise.lab2 file in CASSY Lab.

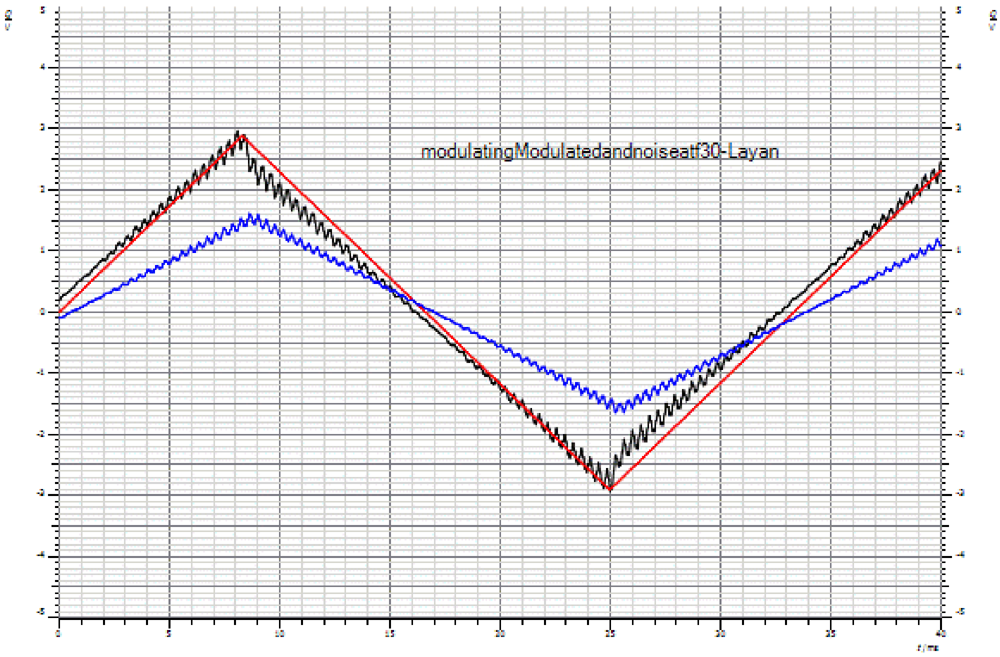

Figure 9: the error between modulated and demodulated for the triangle with f=30Hz

Quantization noise, the difference between the original and reconstructed signal, was clearly visible. This process was repeated with the resolution reduced to 5 bits.

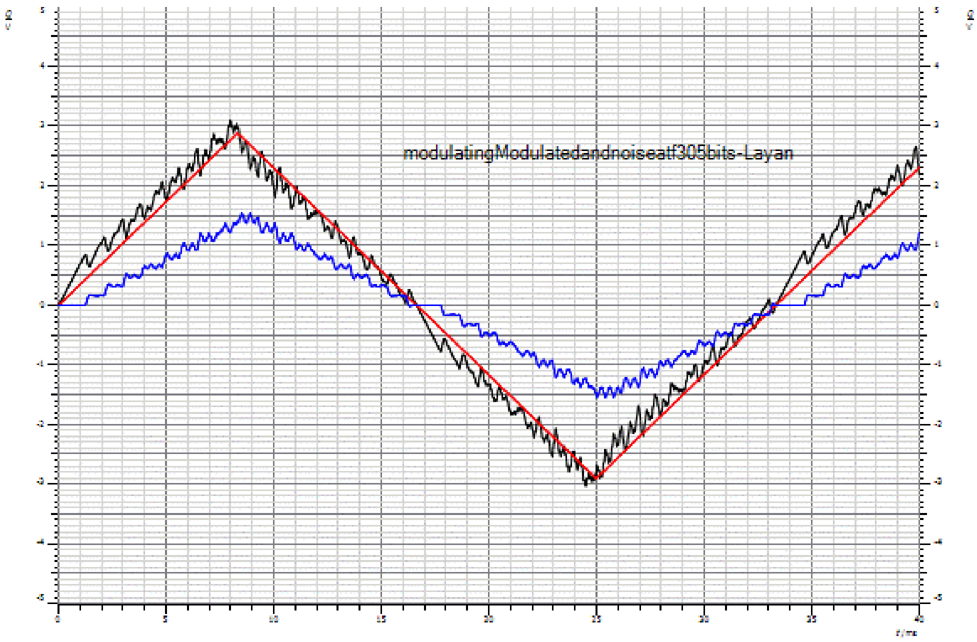

Figure 10: the error between modulated and demodulated 5 bits

As expected, reducing bit depth increased quantization error due to fewer available levels. A similar test was conducted with a higher message frequency (300 Hz).

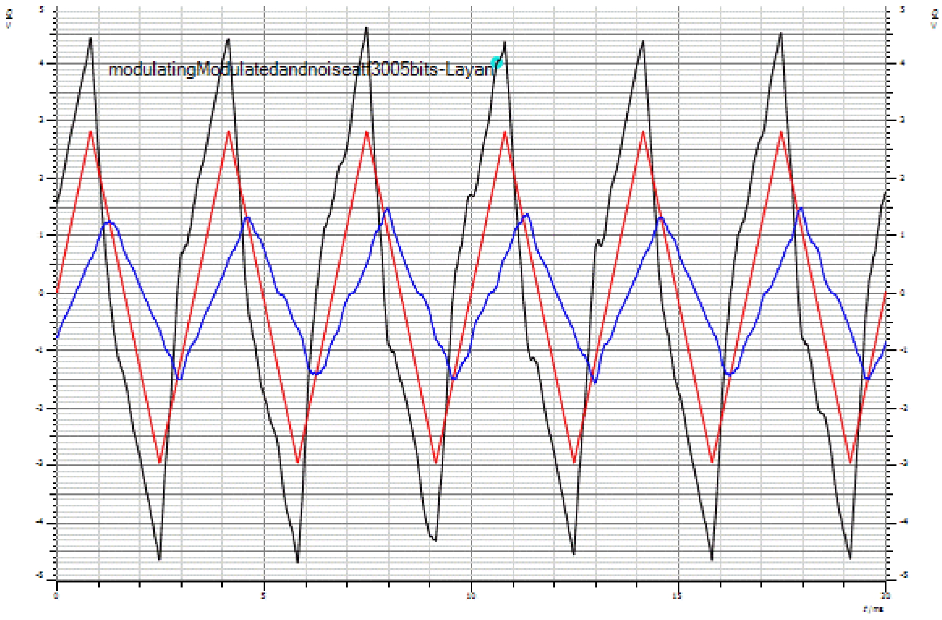

Figure 11: the error between modulated and demodulated for changing the frequency to 300 Hz.

Aliasing became noticeable at this higher frequency, as it approached or exceeded the Nyquist rate, further degrading the reconstructed signal.

As shown in the figures, the difference between the original and the demodulated signals increased as the bit resolution decreased. This aligns with theory: lower bit depth increases quantization step size, introducing more quantization noise. Moreover, raising the message frequency to 300 Hz introduced aliasing, confirming the importance of adhering to the Nyquist sampling criterion. These observations underline the limitations of PCM at lower bit depths and higher frequencies.

2.2 Sinusoidal Waveform

The same setup was used with a sinusoidal signal (30 Hz, then 300 Hz), and similar patterns were observed, though the noise characteristics varied due to the shape of the waveform.

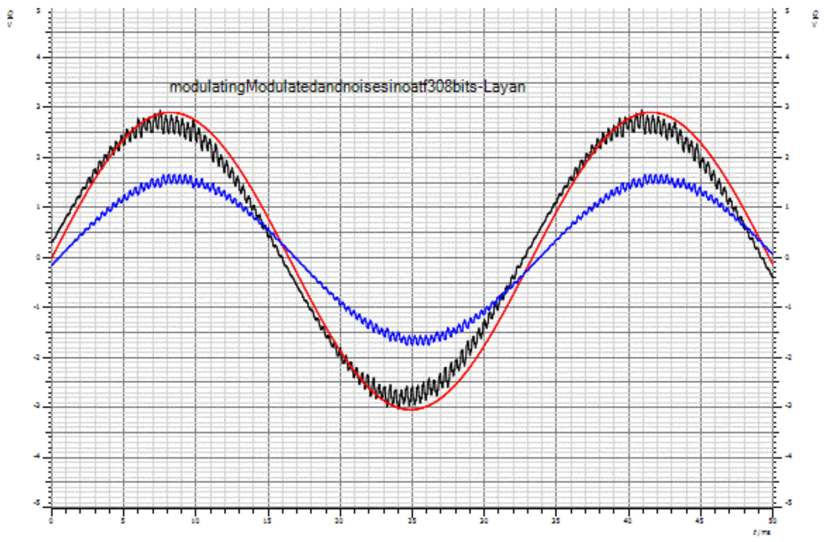

Figure 12: error between modulated and demodulated for the sinusoidal fm=30hz

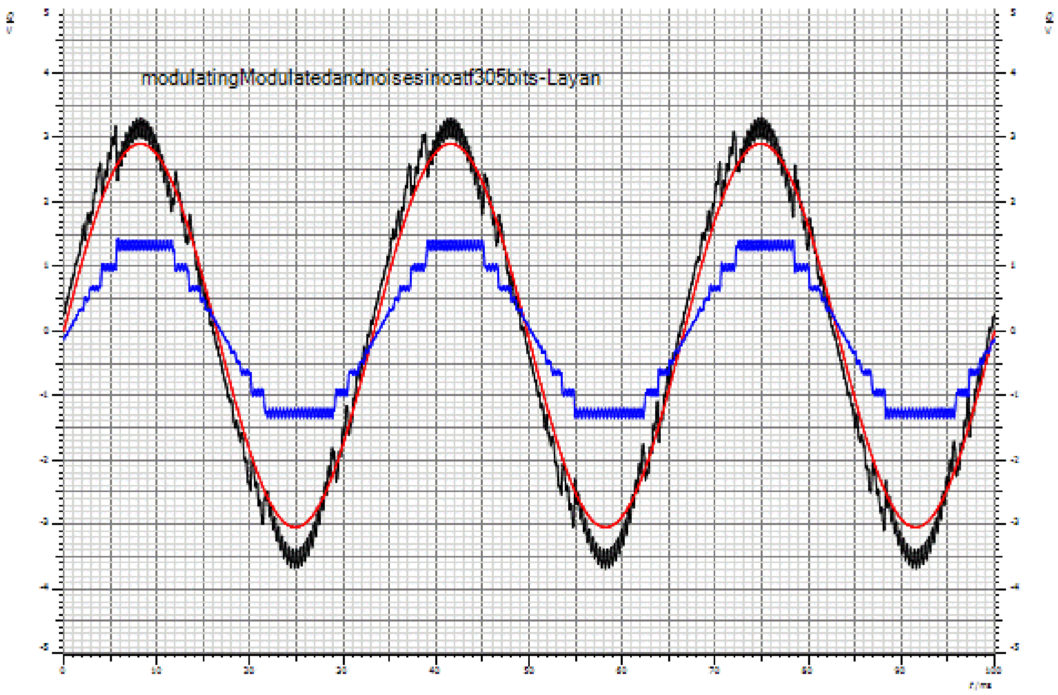

Figure 13: error between modulated and demodulated for the sinusoidal 5bits

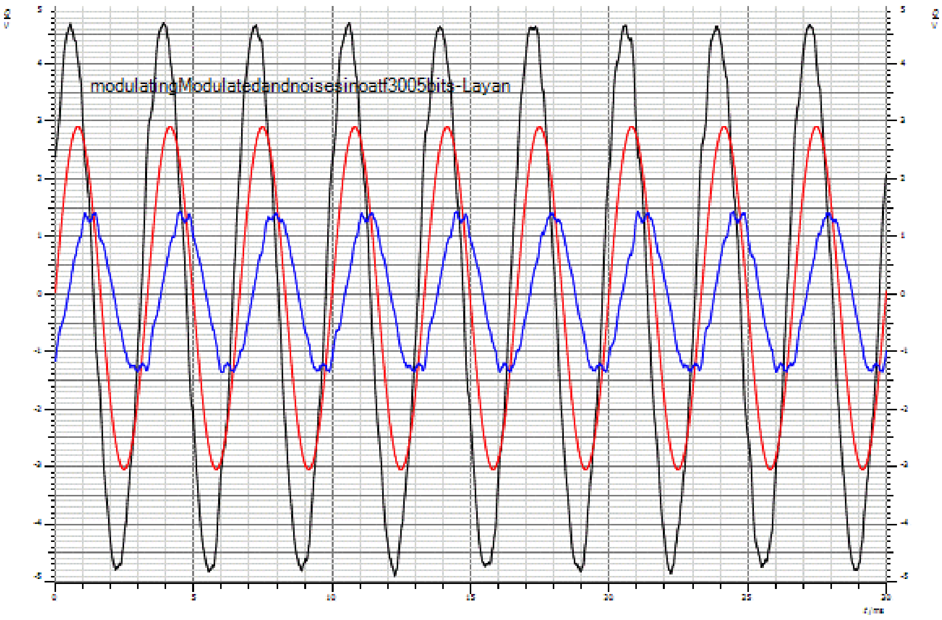

Figure 14: error between modulated and demodulated for the sinusoidal fm=300Hz

Quantization noise became more intricate with the sinusoidal waveform due to its smooth, varying slope interacting with the quantization levels.

Non-linear quantization was then tested with the sinusoidal signal to observe improvements in signal recovery.

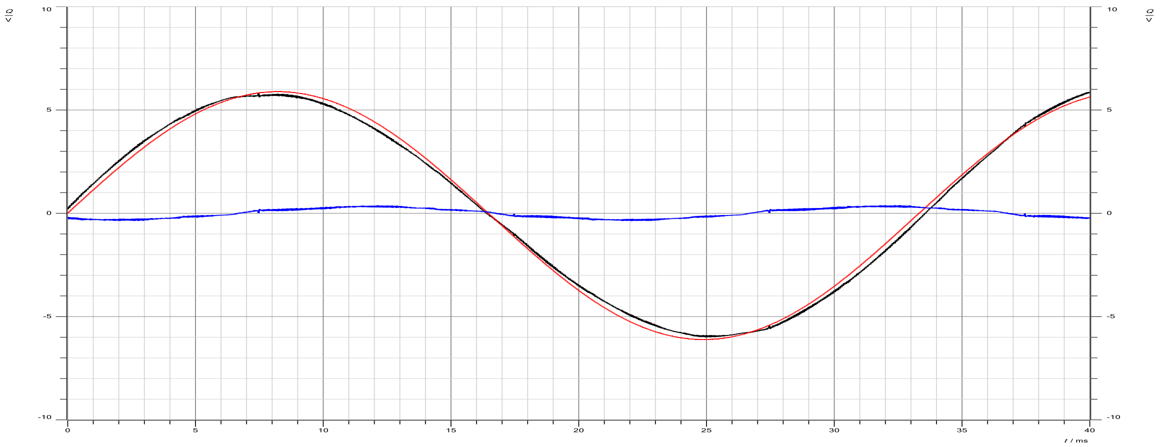

Figure 15non-linear quantization sinusoidal 30Hz

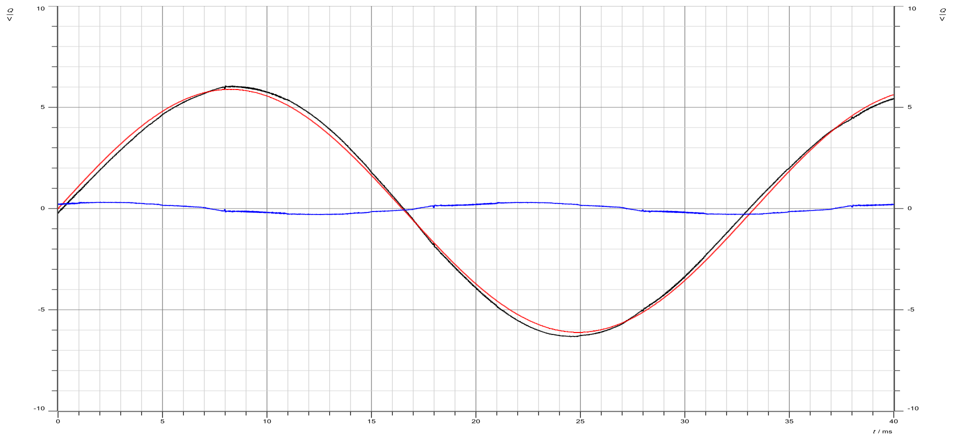

Figure 16 non-linear quantization sinusoidal 30Hz ,5bits

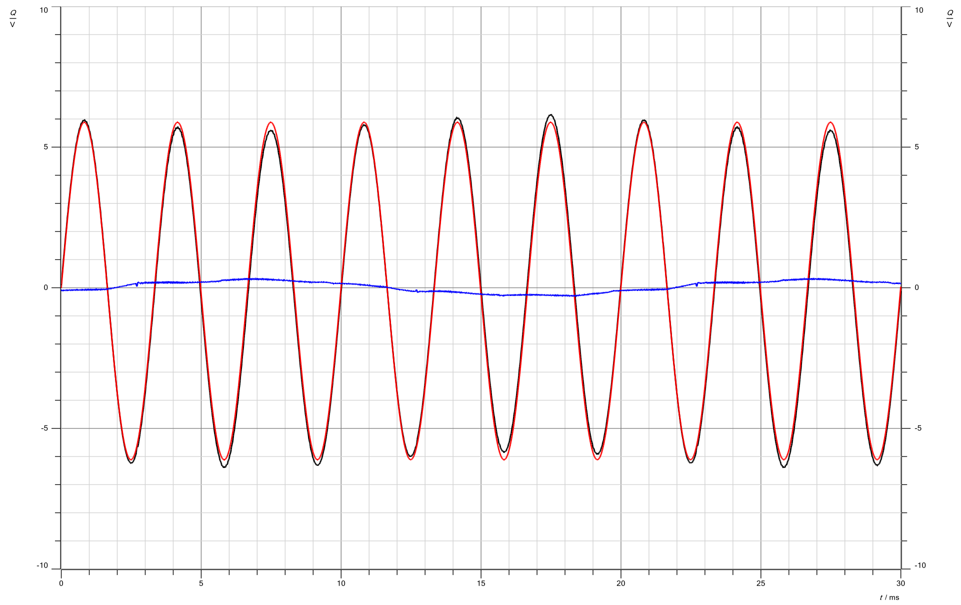

Figure 17 message frequency (fm) of 300Hz and resolution 5bits.

Using non-linear quantization reduced noise, especially at lower frequencies, but higher message frequencies still introduced noticeable distortion.

For the sinusoidal waveform, quantization noise appeared more smoothly distributed compared to the triangle signal due to the sine wave’s continuous slope. At 5-bit resolution and high frequencies, the distortion became pronounced. Testing non-linear quantization showed noticeable improvements—especially at low frequencies as it compresses amplitude levels and reduces error in quiet segments, which is especially useful in voice and audio transmission.

Part Three: Difference Pulse Code Modulation (DPCM)

A triangle waveform (30 Hz, VSS = 12 V) was input into both PAM Modulator channels, and the system was configured for DPCM. After initializing the system by grounding and then removing the signal, normal operation was resumed.

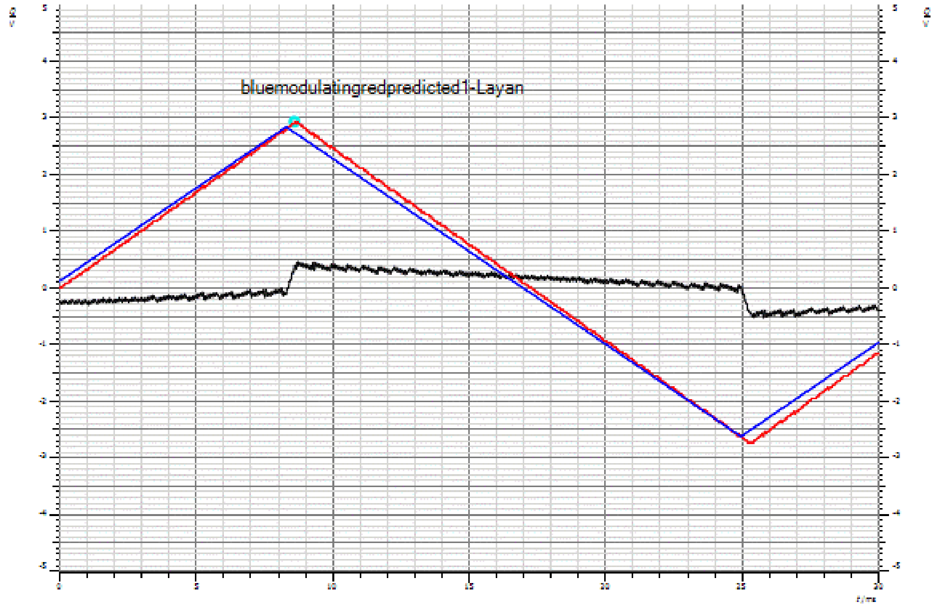

Figure 18: Predictor of the DPCM modulator

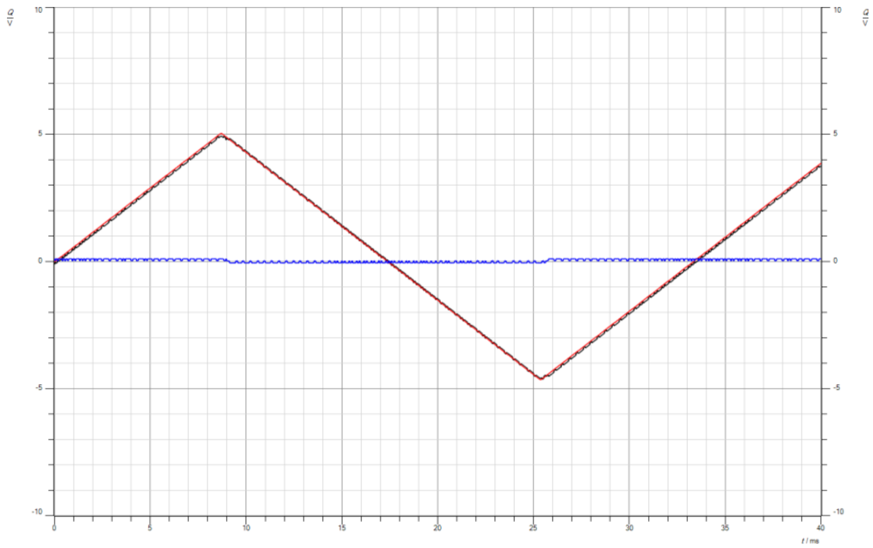

Figure 19: output of the DPCM modulation

DPCM effectively encoded the differences between samples, reducing redundancy. The output was then passed through the DPCM demodulator.

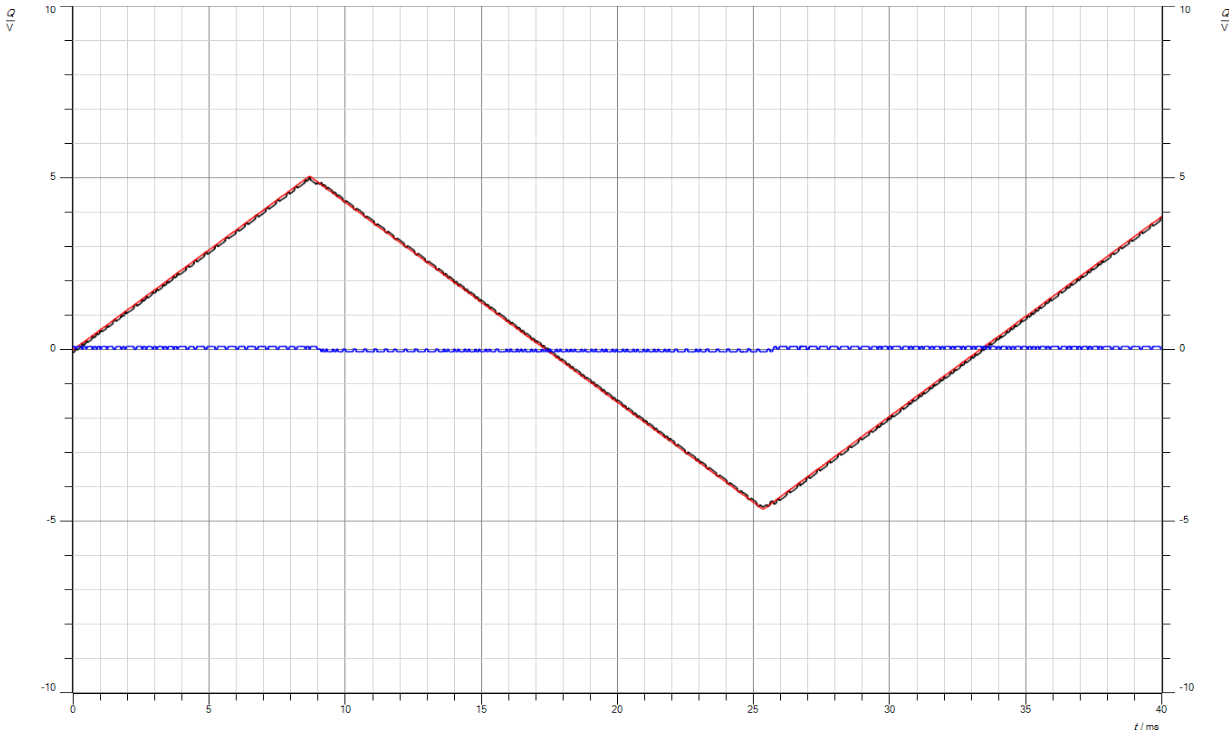

Figure 20: The input of the DPCM demodulator

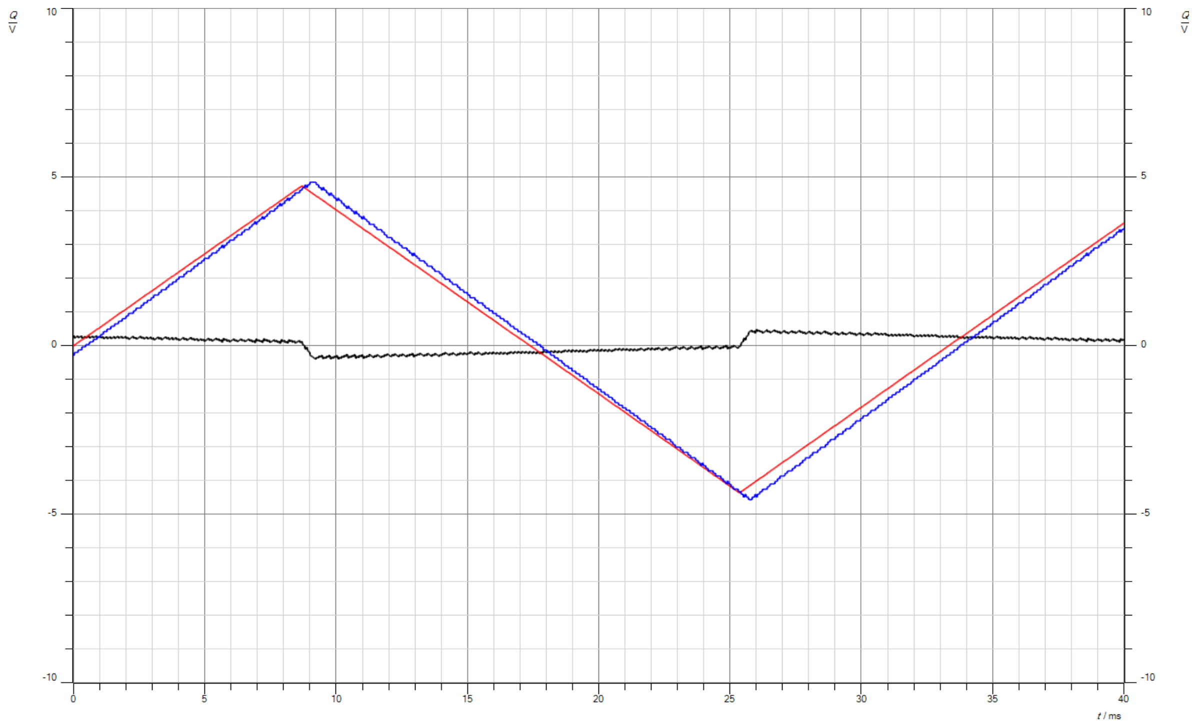

Figure 21: Predictor of the DPCM demodulator

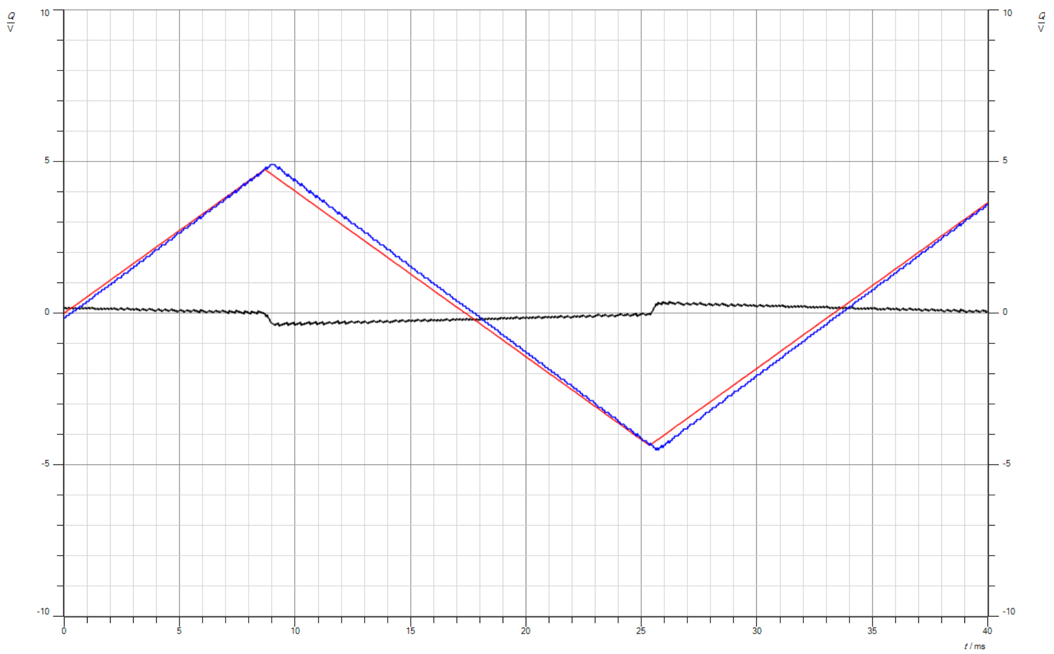

Figure 22 the PAM output of the DPCM demodulator

The decoded output closely resembled the original triangle waveform. The process was repeated using a reduced resolution of 4 bits.

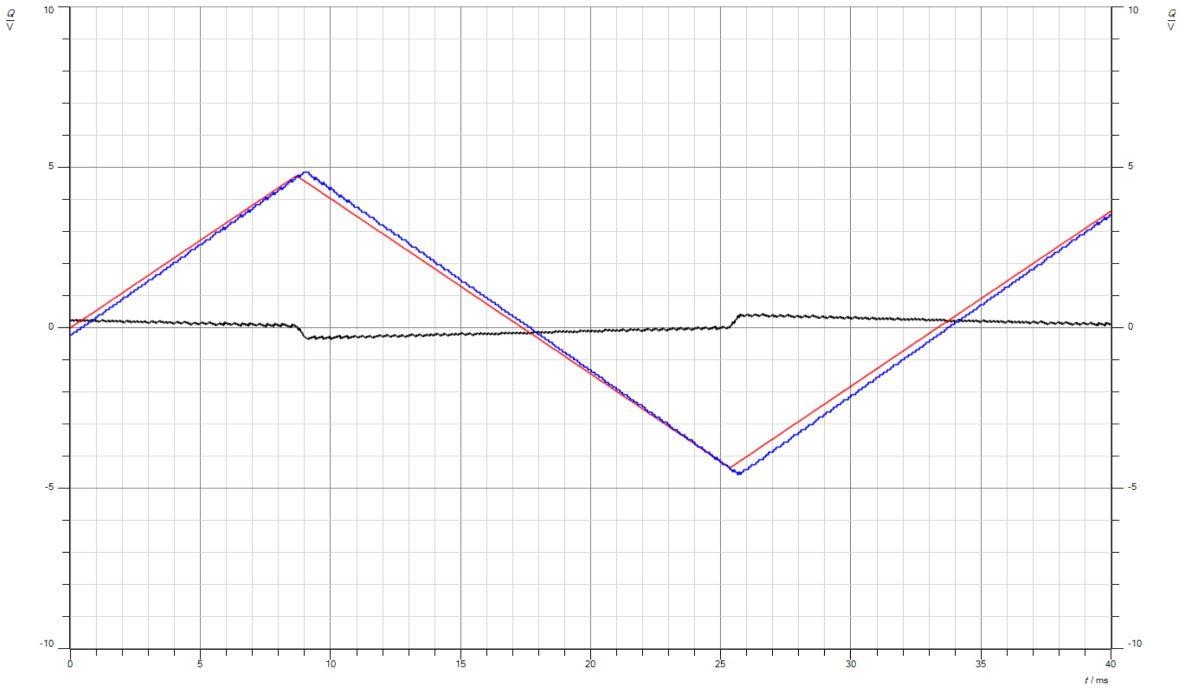

Figure 23: Predictor of the DPCM modulator4bits

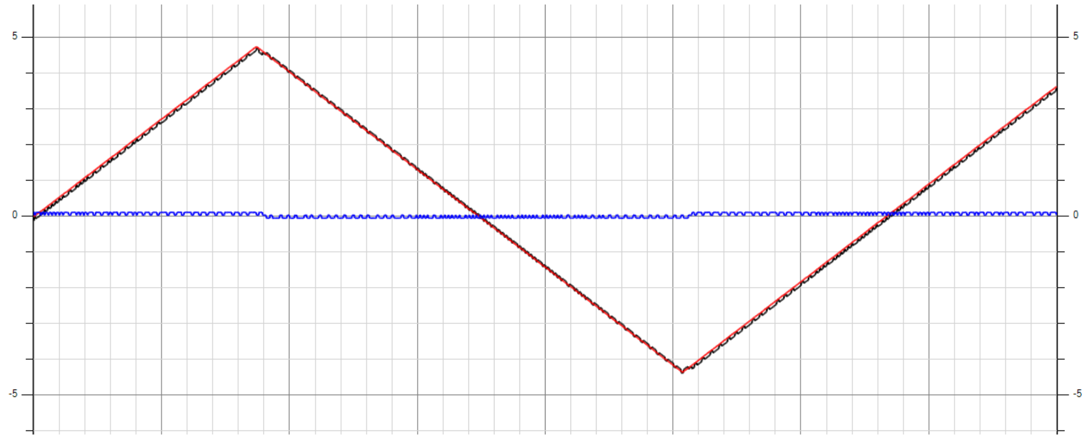

Figure 24: the output of the DPCM modulator 4bits

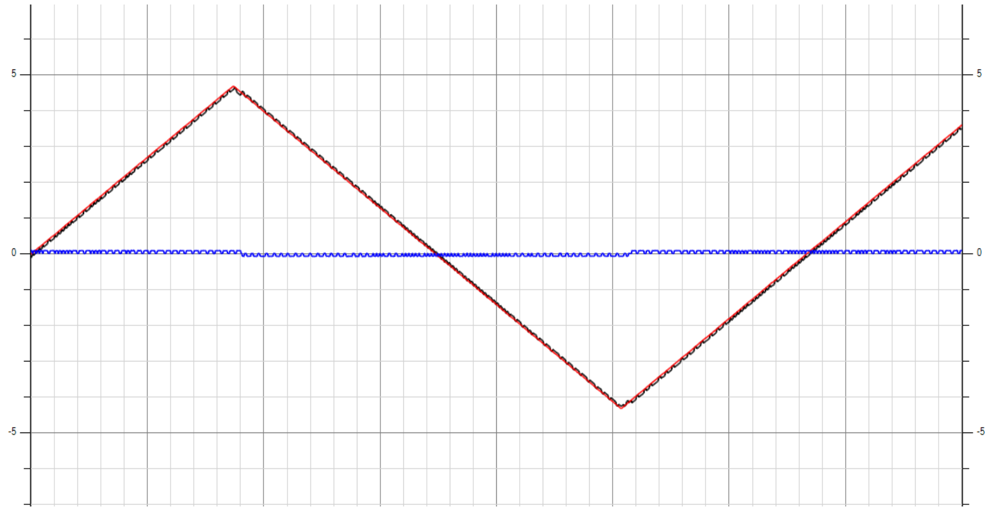

Figure 25: the Input of the DPCM demodulator 4bits

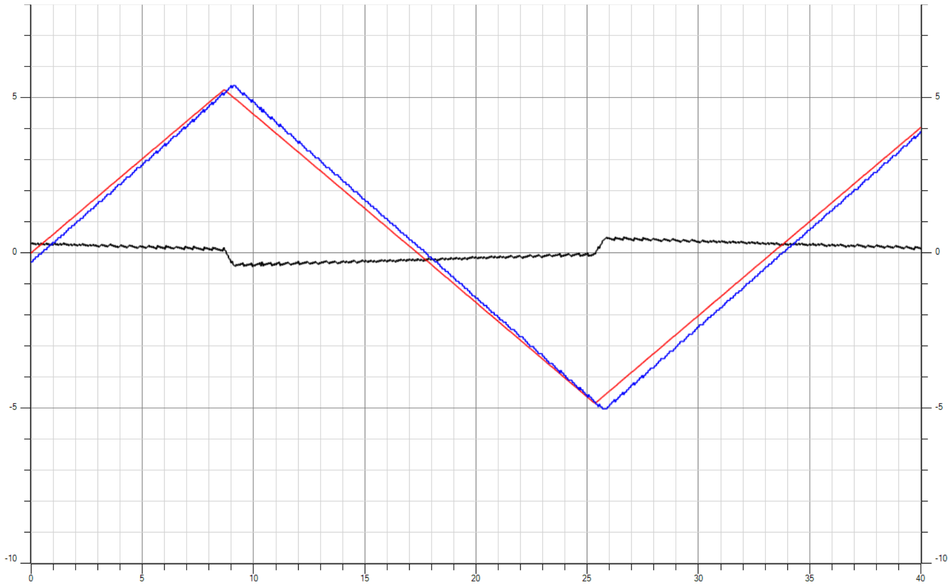

Figure 26: Predictor of the DPCM demodulator 4bits

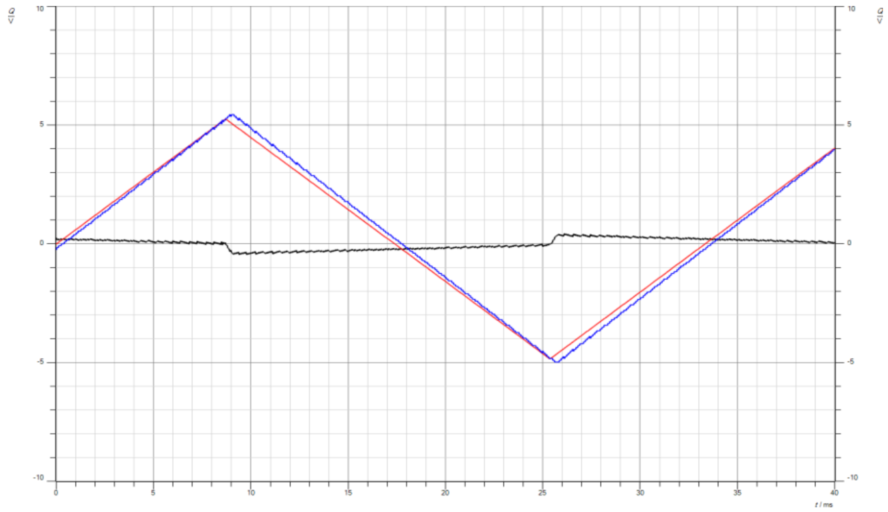

Figure 27: PAM output of the DPCM demodulator 4bits

Even with reduced resolution, DPCM demonstrated efficient data representation with acceptable signal reconstruction, showcasing its potential for bandwidth-efficient transmission.

The DPCM scheme successfully reduced redundancy by encoding differences between successive samples rather than absolute amplitudes. The decoded waveform closely resembled the original, even with fewer bits. This efficiency demonstrates why DPCM is advantageous for correlated signals like speech, where minor differences between samples dominate. The experiment confirmed that even with 4-bit resolution, DPCM maintains signal intelligibility better than standard PCM.

Conclusion

The experiment successfully highlighted the key factors that influence the performance of Pulse Code Modulation systems. It was observed that increasing the number of quantization levels improves signal fidelity at the cost of increased bandwidth. The use of Time Division Multiplexing allowed simultaneous transmission of multiple signals over a single channel with effective reconstruction. Quantization noise, particularly at lower resolutions and higher message frequencies, affirmed the importance of adhering to the Nyquist criterion. Differential PCM proved to be a more efficient alternative to conventional PCM by reducing redundancy without compromising the signal shape significantly. Furthermore, non-linear quantization methods like μ-law showed potential in minimizing noise at lower amplitudes. Overall, the experiment reinforced theoretical principles and provided practical insight into signal digitization and transmission strategies.

References

[1] https://www.elprocus.com/pulse-code-modulation-and-demodulation [Accessed on 12th April at 5:00 PM]

[2] https://www.google.com/url?sa=i&url=http%3A%2F%2Fecedunia.blogspot.com%2F2016%2F03%2Fpulse-code-modulation.html&psig=AOvVaw04oDSFVTSglHh0g-Bnz9nq&ust=1744479364582000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCMjtiZnC0IwDFQAAAAAdAAAAABAE. [Accessed on 12th April at 7:50 PM]

[3] https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.slideserve.com%2Felliot%2Ftime-division-multiplexing-tdm&psig=AOvVaw2CGVbjB0JCsg1Nuc3kE7a1&ust=1744479541078000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCKCpofLC0IwDFQAAAAAdAAAAABAE [Accessed on 12th April at 7:40 PM]

[4] https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FColor-online-Quantization-of-a-sinusoidal-signal-and-the-corresponding-quantization_fig6_50250631&psig=AOvVaw3O2_exWcgbbttJUe22QdlS&ust=1744480111379000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCNiW9v7E0IwDFQAAAAAdAAAAABAE [Accessed on 12th April at 8:10 PM]

[5] https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DaFNdPj03JDQ&psig=AOvVaw0i7dMAHqLlLddbcoEPK56a&ust=1744480181704000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCOCP5sDF0IwDFQAAAAAdAAAAABAI [Accessed on 13th April at 3:00 PM]

[6] https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.tutorialspoint.com%2Fdigital_communication%2Fdigital_communication_differential_pcm.htm&psig=AOvVaw3xFdcgSgvfpCuQ5so90exz&ust=1744480302755000&source=images&cd=vfe&opi=89978449&ved=0CBEQjRxqFwoTCIDMvtjF0IwDFQAAAAAdAAAAABAI [Accessed on 13th April at 3:25 PM]

[7] Dr. Wael lectures slides [Accessed on 13th April at 3:45 PM]