Faculty of Engineering and Technology

Electrical and Computer Engineering Department

Communications Lab – ENEE4113

Report #: 3

Experiment #: 9

Experiment Title: Delta Modulation (Linear & DCDM)

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Abstract

This experiment aims to study and compare two types of Delta Modulation techniques: **Linear Delta Modulation (LDM)** and **Digitally Controlled Delta Modulation (DCDM)**. Key characteristics such as prediction accuracy, pulse height behavior, granular noise, slope overload, and demodulation quality were examined through a series of practical measurements. The performance of each modulator will be analyzed under various conditions of input signal amplitude and frequency, as well as clock frequency.

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1. Theory

1.1. Delta Modulation (DM) Overview

In a DM system, instead of the absolute signal amplitude being transmitted at each sampling, only the changes in signal amplitude from sampling instant to sampling instant are transmitted. As shown in Figure 1, the transmitted pulse train $e_2(t)$ of positive and negative pulses at the output of the encoder can be assumed to be generated at a constant clock rate. The transmitted pulses from the pulse generator are positive if the change in signal amplitude is positive; otherwise, the transmitted pulses are negative. In the decoder, the delta-modulated pulse train $e_2(t)$ is integrated into the voltage $e_1(t)$, which consists of the original message function plus noise components due to sampling. These are eliminated by a low-pass filter so that the reconstructed signal of the final output is a close replica of the original modulating signal $e_0(t)$ [1].

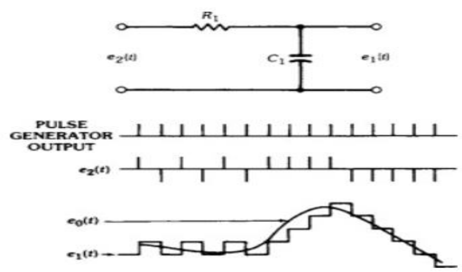


Figure 1:Delta modulation cicuit[1]

1.2. Linear Delta Modulation (LDM)

In Linear Delta Modulation, the modulator compares the incoming analog signal with a predicted signal generated by passing the output of a 1-bit quantizer through an integrator. The result is encoded as a binary signal indicating an increment or decrement in the predicted signal. LDM is simple but suffers from slope overload and granular noise [2].

1.3. Digitally Controlled Delta Modulation (DCDM)

DCDM enhances LDM by dynamically adjusting the step size based on the signal's rate of change. This adaptive mechanism improves performance in tracking rapidly varying signals and reduces both slope overload and granular noise [2].

1.4. Granular Noise

Granular or Idle noise occurs when the step size is too large compared to the small variation in the input signal.

This means that for very small variations in the input signal, the staircase signal is changed by a large amount (Δ) because of the large step size.

Figure 2 shows that when the input signal is almost flat, the staircase signal u(t) keeps on oscillating by ±Δ around the signal.

The error between the input and the approximated signal is called granular noise.

The solution to this problem is to make the step size small [3].

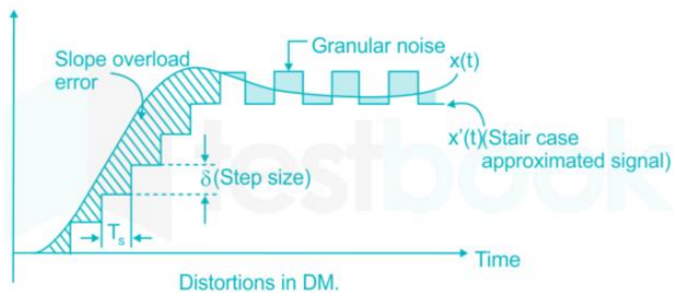


*Figure 2:Granular Noise**[3]***

1.5. Slope Overload Distortion

This distortion arises because of the large dynamic range of the input signal.

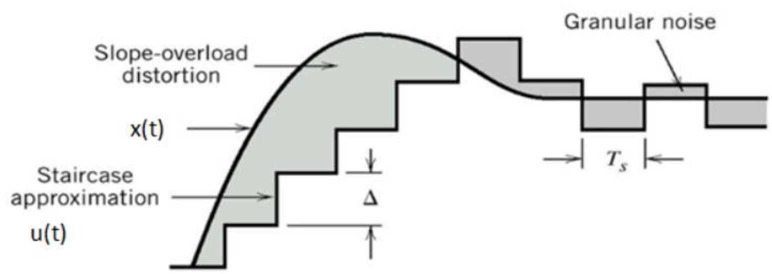


Figure 3:Slope Overload Distortion[3]

We can observe from Figure 3, the rate of rise of input signal x(t) is so high that the staircase signal can not approximate it; the step size 'Δ' becomes too small for the staircase signal u(t) to follow the step segment of x(t).

Hence, there is a large error between the staircase approximated signal and the original input signal x(t).

This error or noise is known as **slope overload distortion**. To reduce this error, the step size must be increased when the slope of signal x(t) is high [3].

1.6. Demodulation

Demodulation reconstructs the analog signal by integrating the digital output. Accuracy depends on the modulator’s ability to track the input signal [4].

2. Procedure and discussion

2.1. Prediction signals in Linear delta modulation (LDM)

The clock frequency was initially set to 100 kHz. The function generator was configured to produce a sine wave with a frequency of 100 Hz and a peak-to-peak voltage (VSS) of 1 V. A wire was used to bridge the input of the integrator to enable the LDM mode. The CASSY Sensor UA1 was connected to the modulating signal, and UB1 was connected to the predicted signal at the output of the integrator. The clock frequency was then gradually reduced to 10 kHz, and the measurement was repeated.

When F clock = 100 KHz:

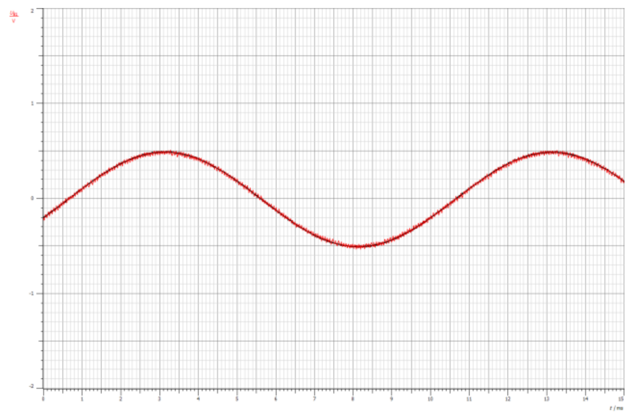


Figure 4: Prediction signals in Linear delta modulation (LDM) when f clock=100KHZ

When f clock = 10KHZ:

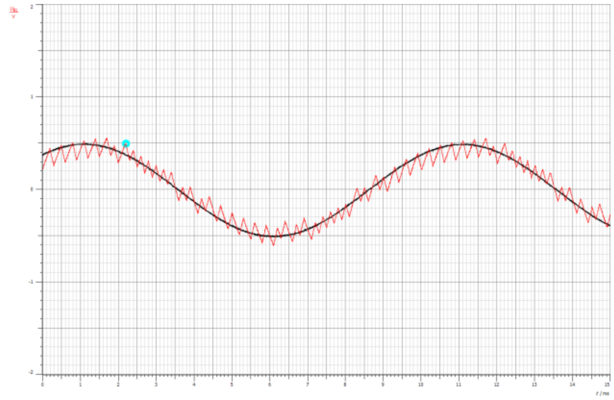


Figure 5: Prediction signals in Linear delta modulation (LDM) when f clock=10 KHZ

LDM provides a decent prediction at high clock frequencies but suffers from slope overload at lower ones.

2.2. Prediction signals in Digital Controlled Delta Modulation (DCDM)

The same setup from Part 1 was retained. The bridging wire was switched to the DCDM mode. All measurements were repeated at both 100 kHz and 10 kHz clock frequencies.

When F clock = 100 KHz:

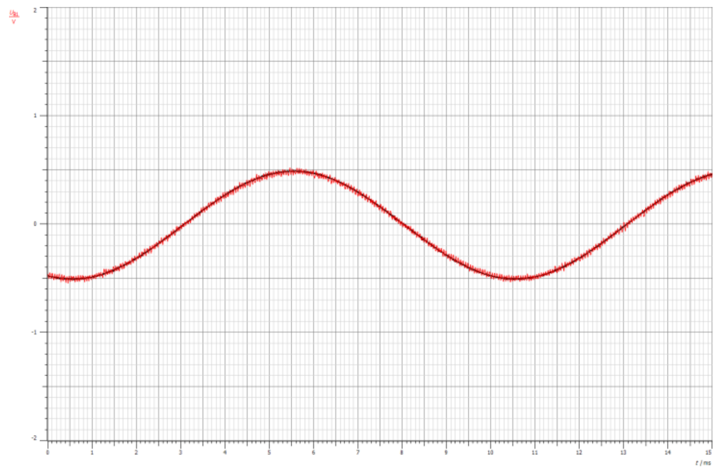


Figure 6: Prediction signals in Digital Controlled Delta Modulation (DCDM) when f clock = 100 KHz

When f clock = 10KHZ:

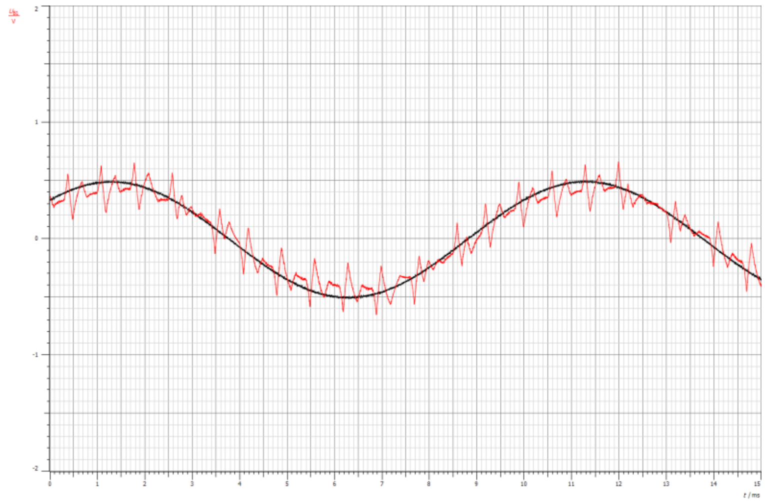


Figure 7: Prediction signals in Digital Controlled Delta Modulation (DCDM) when f clock = 10 KHz

DCDM shows better adaptability and prediction at all frequencies due to variable step size.

2.3. Pulse height in LDM

The clock frequency was adjusted to approximately 50 kHz. The function generator was set to output a sine wave with a frequency of 100 Hz and VSS of 1 V. LDM mode was selected via the bridging wire. The CASSY Sensor UA1 was connected to the modulating signal, while UB1 was connected to the input of ∫2. The measurement was started using F9. VSS was increased in 1 V steps from 1 V to 7 V, and the pulse amplitude at the input of ∫2 was observed. Subsequently, UB1 was connected to the output of ∫2, and the measurements were repeated to observe the predicted signal X(t).

When Vss=1V:

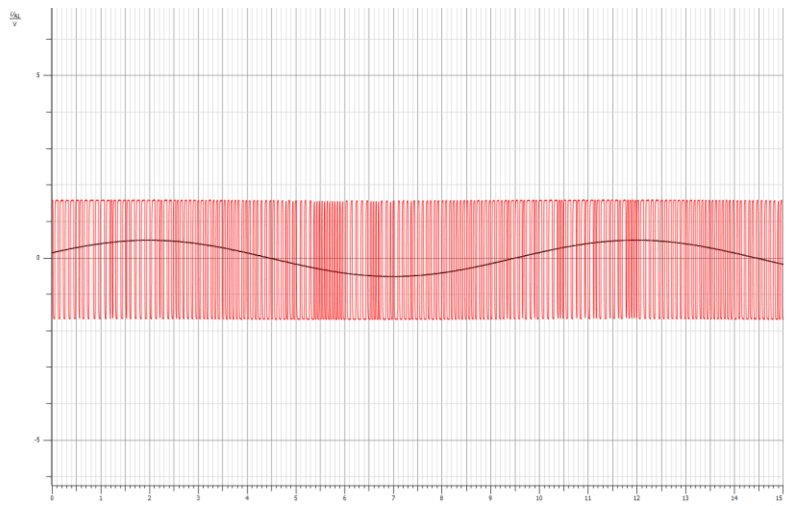


Figure 8: Pulse height in LDM when Vss=1V

When Vss=7V:

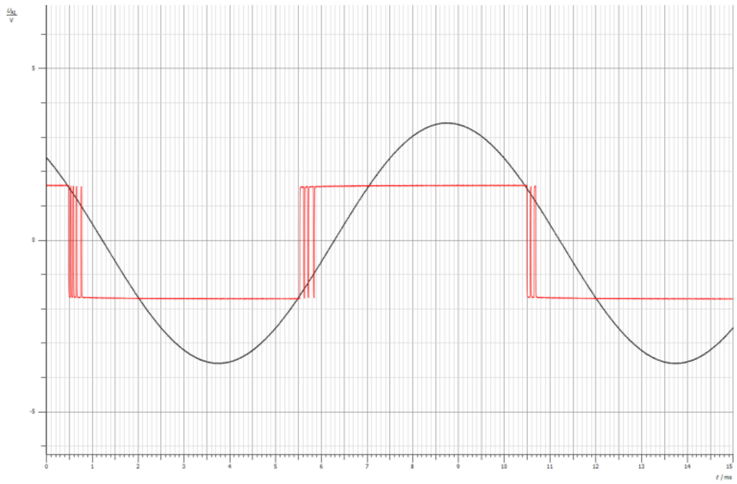


Figure 9: Pulse height in LDM when Vss=7V

In **LDM**, pulse height increases linearly with input amplitude but cannot adapt to rapid changes.

2.4. Pulse height in DCDM

The same hardware setup was used as in Part 3. The bridge was reconnected to DCDM mode. The same steps were followed to observe pulse height variation and prediction behavior with increasing VSS.

When Vss=1V:

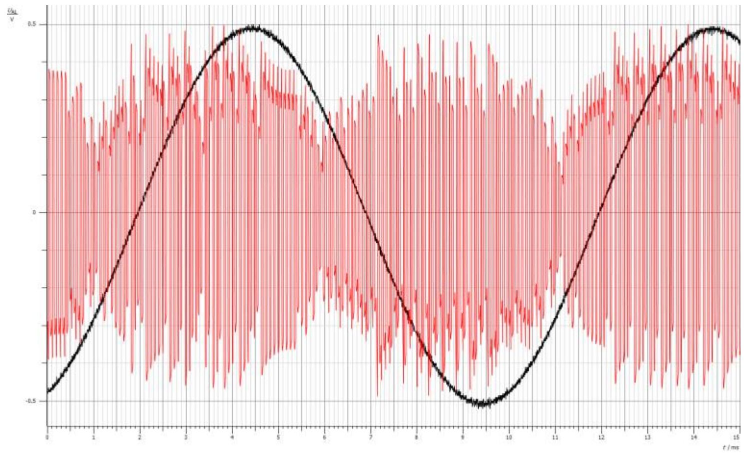


Figure 10:Pulse height in DCDM when Vss=1v

When Vss= 7V:

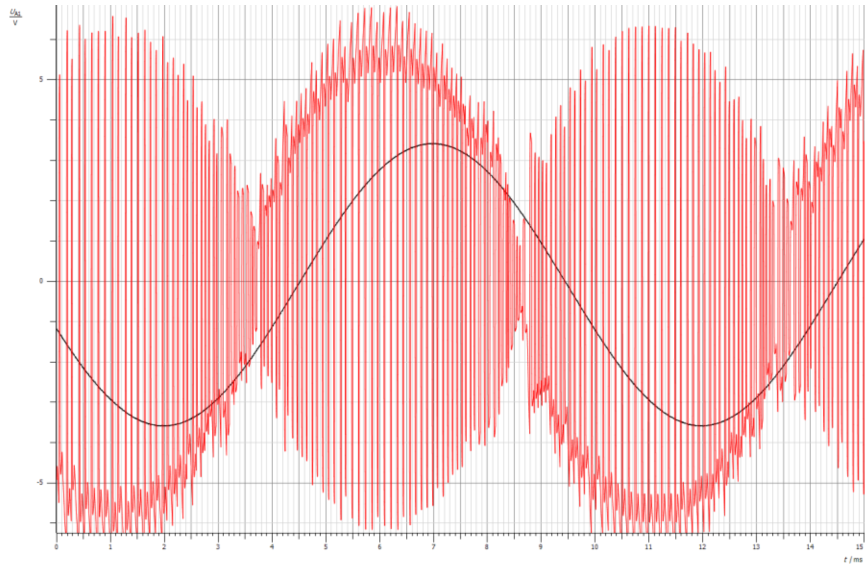


Figure 11: Pulse height in DCDM when Vss=7V

DCDM dynamically adjusts pulse height depending on input, reducing error in high-dynamic signals.

2.5. Output signals of the LDM modulator (RZ/NRZ)

The clock frequency was set to 10 kHz. The function generator was adjusted to a sine wave, fm=100 Hz, VSS = 1 V. The bridge was connected for LDM mode. The CASSY Sensor UA1 was connected to the input of ∫2, and UB1 was connected to the output of the DM modulator (bipolar RZ signal). Measurements were recorded.

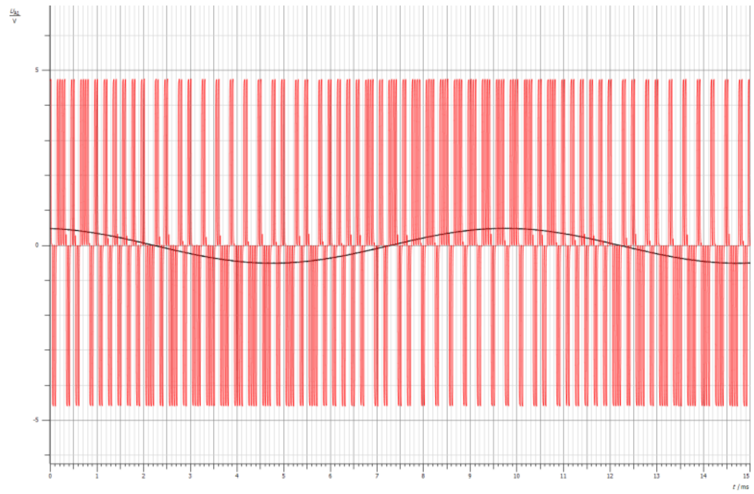


Figure 12: Output signals of the LDM modulator (RZ/NRZ)

- LDM output is bipolar **RZ**; feedback signal is **NRZ**.
- A clear distinction helps identify encoding and feedback structure.

2.6. Granular noise in LDM

With the clock frequency set to 10 kHz, the function generator was configured for a pulse train with fm=200 Hz, VSS = 2 V, and a 50% duty cycle. The system was bridged for LDM. UA1 and UB1 were connected to Sm(t)and X(t), respectively. Measurements were performed at both 10 kHz and 100 kHz. The input to the modulator was then grounded, and the measurements were repeated at both frequencies.

F clock = 10KHZ:

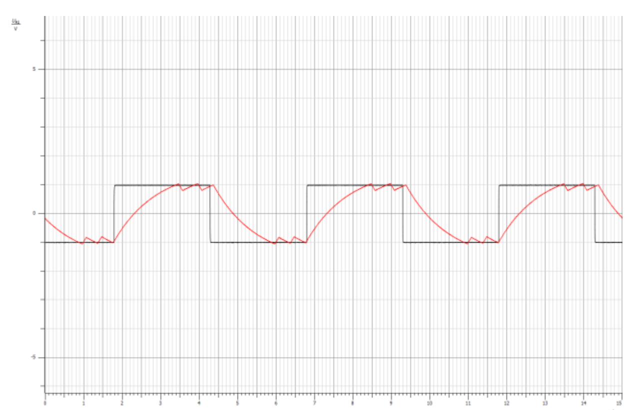


Figure 13: Granular noise in LDM when f clock = 10KHz

F clock = 100KHZ:

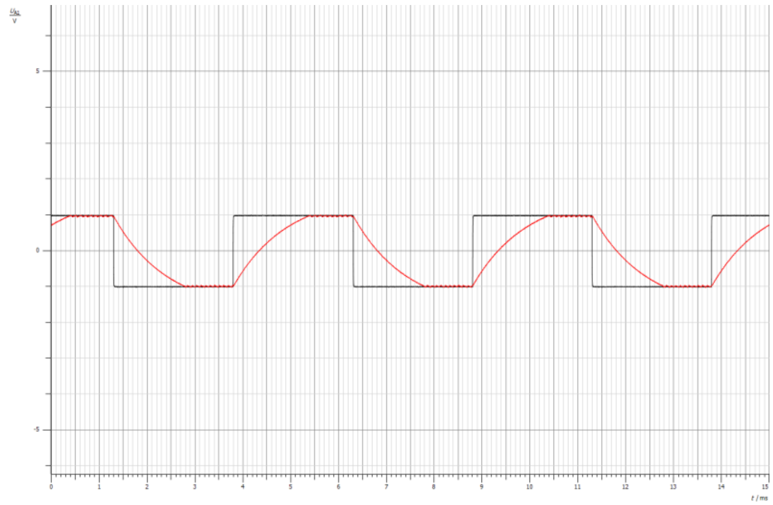


Figure 14: Granular noise in LDM when f clock = 100KHz

LDM experiences high granular noise at low clock frequencies.

2.7. Granular noise in DCDM

Using the same setup from Part 6, the bridge was switched to DCDM mode. All measurements were repeated under identical conditions.

When f clock = 10KHZ:

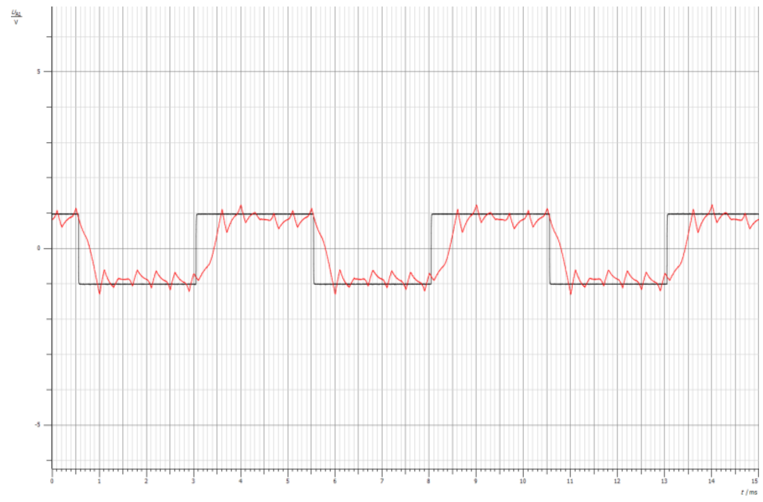


Figure 15: Granular noise in DCDM whe F clock =10 KHz

When f clock = 100KHZ:

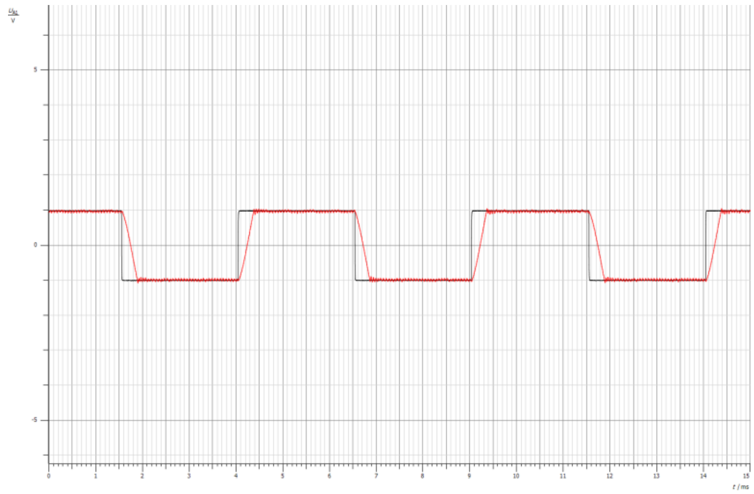


Figure 16: Granular noise in DCDM when F clock =100KHz

- **DCDM** minimizes this through better signal tracking and adaptation.

2.8.Slope-overload in LDM

The clock frequency was set to 100 kHz. The function generator output was set to a sine wave with f_m = 100 Hz and VSS = 4 V. The system was bridged for LDM. Sensors UA1 and UB1 were connected to Sm(t) and X(t), respectively. Measurements were taken, and then the input signal was changed to a pulse train with fm=100 Hz, followed by another at fm=300 Hz. Measurements were repeated for both.

When FM=100Hz:

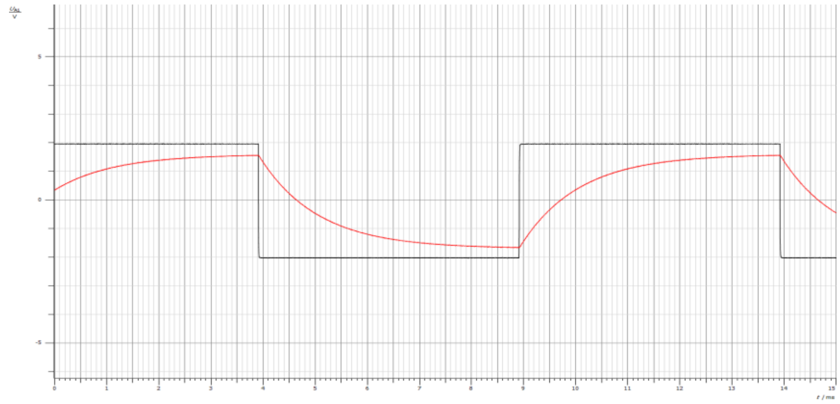


Figure 17:Slope-overload in LDM when Fm =100Hz

When FM = 300Hz:

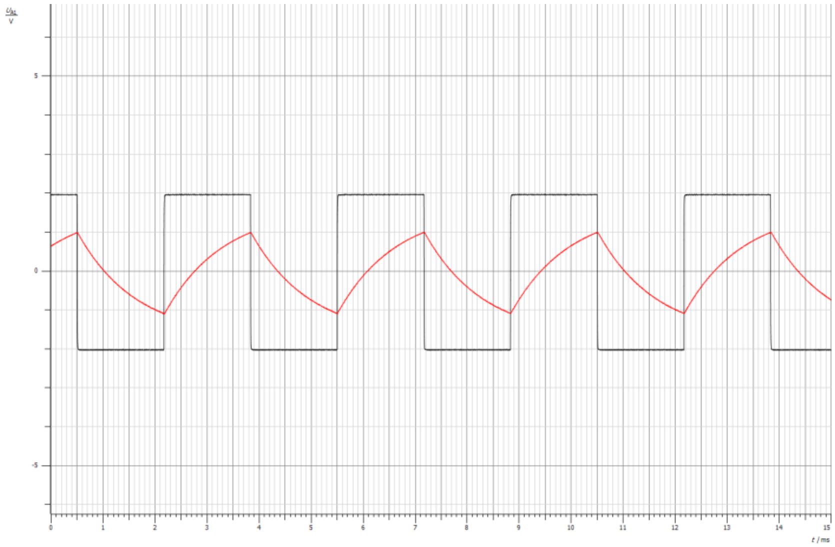


Figure 18: Slope-overload in LDM when Fm =300Hz

- **LDM** fails to follow steep signal slopes, leading to distortion.

2.9.Slope overload in DCDM

The procedure from Part 8 was repeated with the bridge set to DCDM. The input amplitude was increased to VSS = 9 V before repeating all measurements.

When fm = 300 Hz:

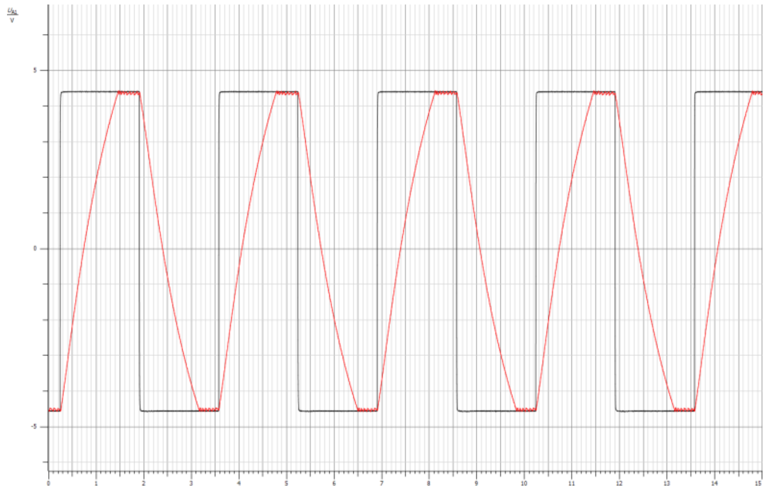


Figure 19: Slope-overload in DCDM when Fm =300Hz

When fm=100Hz:

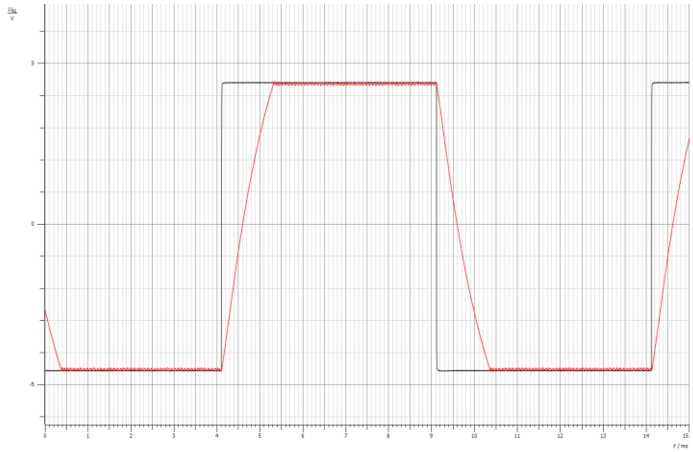


Figure 20: Slope-overload in DCDM when Fm =100Hz

DCDM, with its adaptive mechanism, performs much better.

2.10.Dynamic of LDM and DCDM

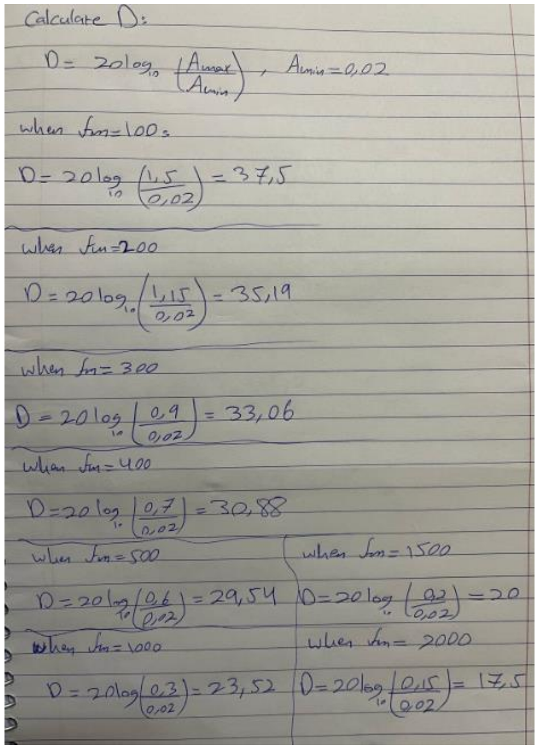
The clock frequency was maintained at 100 kHz. The function generator was configured to a sine wave of fm=100 Hz, VSS = 1 V. The system was first set to LDM mode. UA1 and UB1 were connected to Sm(t) and X(t), respectively. VSS was gradually increased until the prediction signal showed signs of slope overload. This maximum voltage (Amax) was recorded. The same procedure was repeated for frequencies: 200, 300, 400, 500, 1000, 1500, and 2000 Hz. The dynamic range D was calculated using:

$$D = 20\log_{10}\left(\frac{A_{max}}{A_{min}}\right), \quad A_{min} = 0.02\,\mathrm{V}$$

Table 1: Dynamic D, Amax for LDM, Frequency (Hz)

Frequency (Hz)	**100**	**200**	**300**	**400**	**500**	**1000**	**1500**	**2000**
Amax for LDM	1.5	1.15	0.9	0.7	0.6	0.3	0.2	0.15
dynamic D	37.5	35.2	33.06	30.88	29.54	23.52	20	17.5

Calculating D for LDM:



Calculate D:

$D = 20\log_{10}\left(\frac{A_{max}}{A_{min}}\right)$, $A_{min} = 0,02$

when $f_m = 100$:

$D = 20\log_{10}\left(\frac{1,5}{0,02}\right) = 37,5$

when $f_m = 200$

$D = 20\log_{10}\left(\frac{1,15}{0,02}\right) = 35,19$

when $f_m = 300$

$D = 20\log_{10}\left(\frac{0,9}{0,02}\right) = 33,06$

when $f_m = 400$

$D = 20\log_{10}\left(\frac{0,7}{0,02}\right) = 30,88$

when $f_m = 500$

$D = 20\log_{10}\left(\frac{0,6}{0,02}\right) = 29,54$

when $f_m = 1000$

$D = 20\log\left(\frac{0,3}{0,02}\right) = 23,52$

when $f_m = 1500$

$D = 20\log_{10}\left(\frac{0,2}{0,02}\right) = 20$

when $f_m = 2000$

$D = 20\log_{10}\left(\frac{0,15}{0,02}\right) = 17,5$

Figure 21:Calculating D for LDM

Plot **D Vs. fm** for LDM:

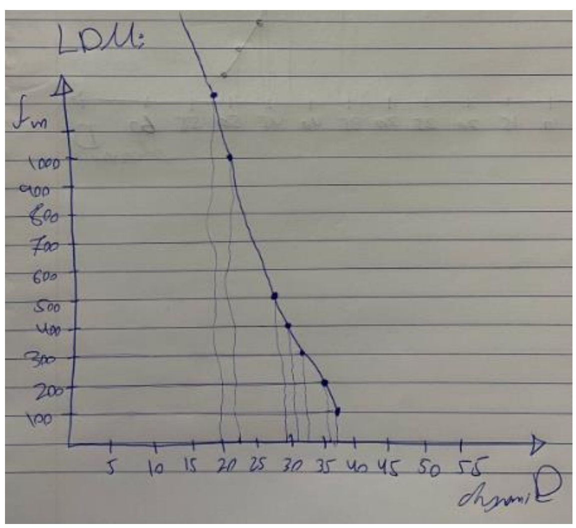


Figure 22:Plot D Vs. fm for LDM PLOT

The same steps were performed for the DCDM mode:

DCDM:

Table 2: Dynamic D, Amax for DCDM, Frequency (Hz)

Frequency (Hz)	100	200	300	400	500	1000	1500	2000
Amax for DCDM	7.55	6	4.5	3.65	2.9	1.5	1.15	0.8
dynamic D	51.5	49.54	47.043	45.2	43.227	37.5	35.19	32.04

Calculating D for DCDM:

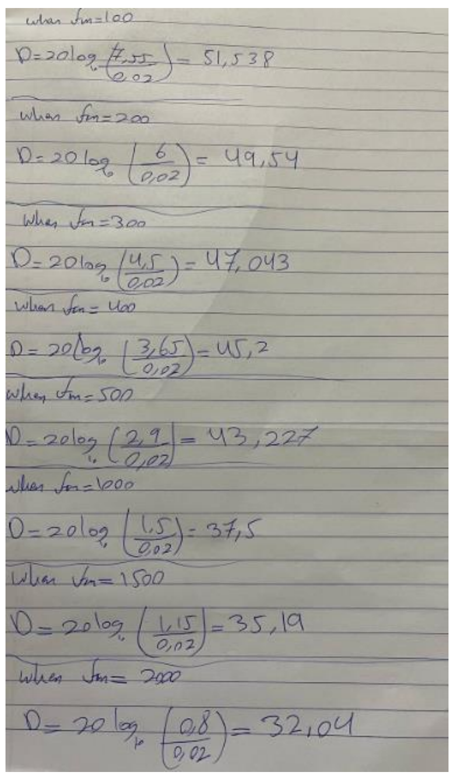

when $f_m=100$
$D=20\log_{10}\left(\frac{7{,}55}{0{,}02}\right)=51{,}538$
when $f_m=200$
$D=20\log_{10}\left(\frac{6}{0{,}02}\right)=49{,}54$
when $f_m=300$
$D=20\log_{10}\left(\frac{4{,}5}{0{,}02}\right)=47{,}043$
when $f_m=400$
$D=20\log_{10}\left(\frac{3{,}65}{0{,}02}\right)=45{,}2$
when $f_m=500$
$D=20\log_{10}\left(\frac{2{,}9}{0{,}02}\right)=43{,}227$
when $f_m=1000$
$D=20\log_{10}\left(\frac{1{,}5}{0{,}02}\right)=37{,}5$
when $f_m=1500$
$D=20\log_{10}\left(\frac{1{,}15}{0{,}02}\right)=35{,}19$
when $f_m=2000$
$D=20\log_{10}\left(\frac{0{,}8}{0{,}02}\right)=32{,}04$

Figure 23: Calculating D for DCDM

Plot **D Vs. fm** for DCDM:

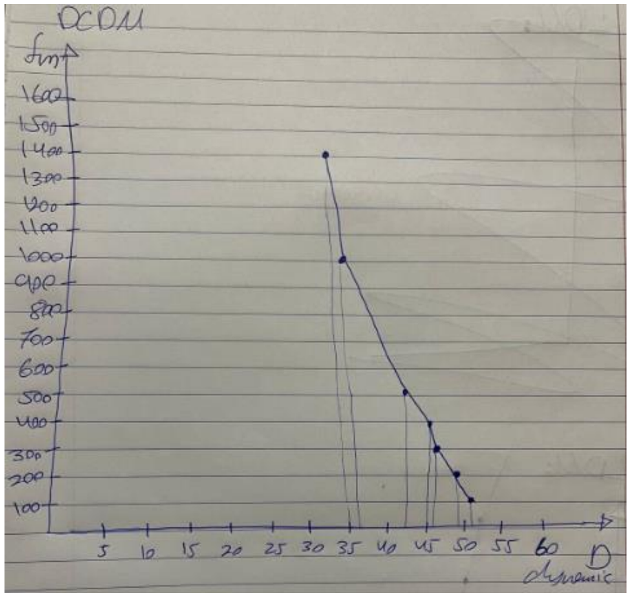


Figure 24: Plot D Vs. fm for DCDM PLOT

- **Dynamic range D** for DCDM is significantly higher at all frequencies.

-LDM struggles as frequency increases due to fixed step size limitations.

- Plotting D vs. fm shows a steeper decline for LDM:

2.11.Demodulation (LDM/DCDM)

The clock frequency was set to 100 kHz. The function generator was set to a sine wave with fm=100 Hz and VSS = 4 V. The bridge was set to LDM for both the modulator and demodulator. UA1 was connected to Sm(t), and UB1 to the demodulated signal SD(t). The signal type was changed to pulse (100 Hz), and later to pulse (300 Hz). Measurements were repeated.

LDM, SIN WAV, When fm=100Hz:

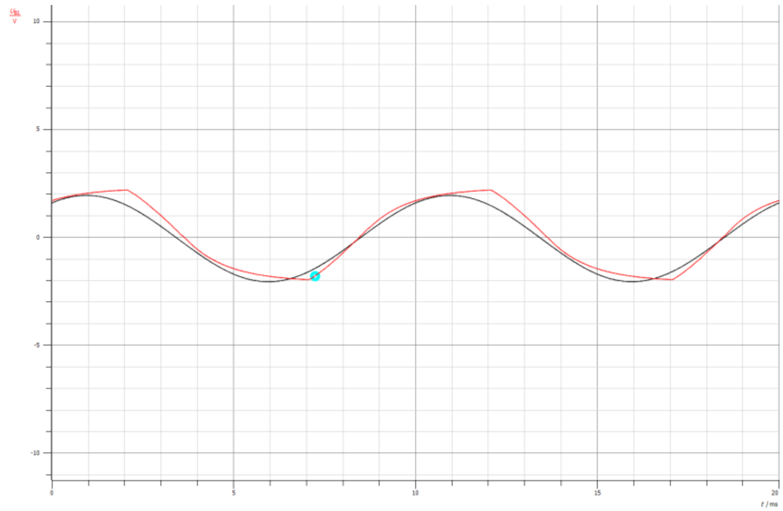


Figure 25:Demodulation ,LDM, SIN WAV, When fm=100Hz

LDM, Sin wave, When fm=300Hz:

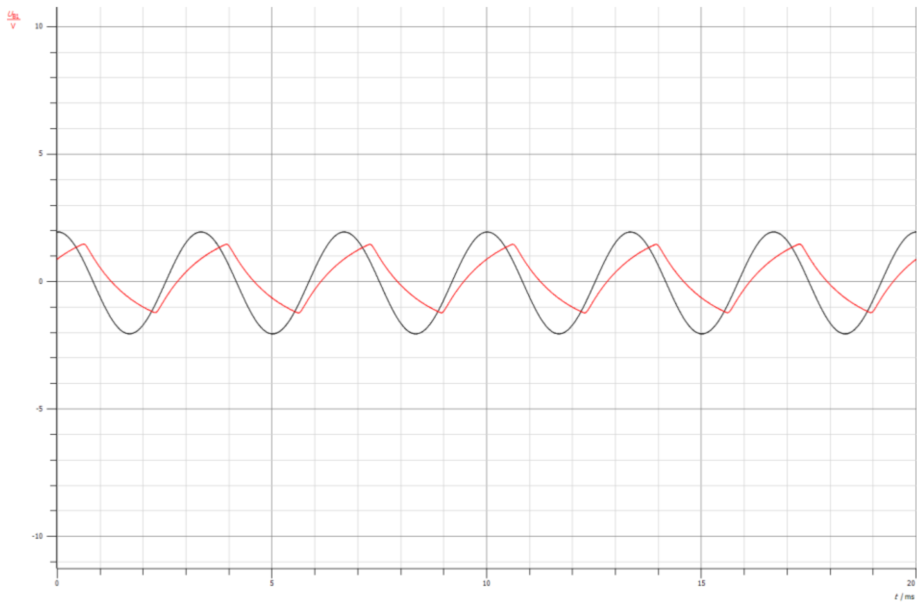


Figure 26:Demodulation ,LDM, SIN WAV, When fm=300Hz

LDM, TRAIN Pulse wave, When fm=100Hz:

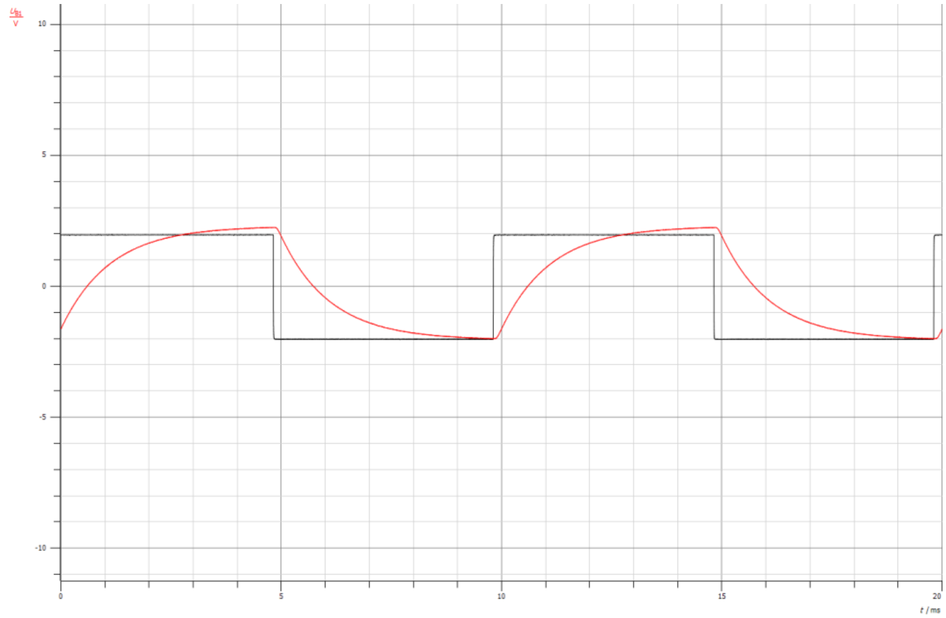


Figure 27:Demodulation ,LDM, Train pulse WAV, When fm=100Hz

LDM, TRAIN Pulse wave, When Fm=300Hz:

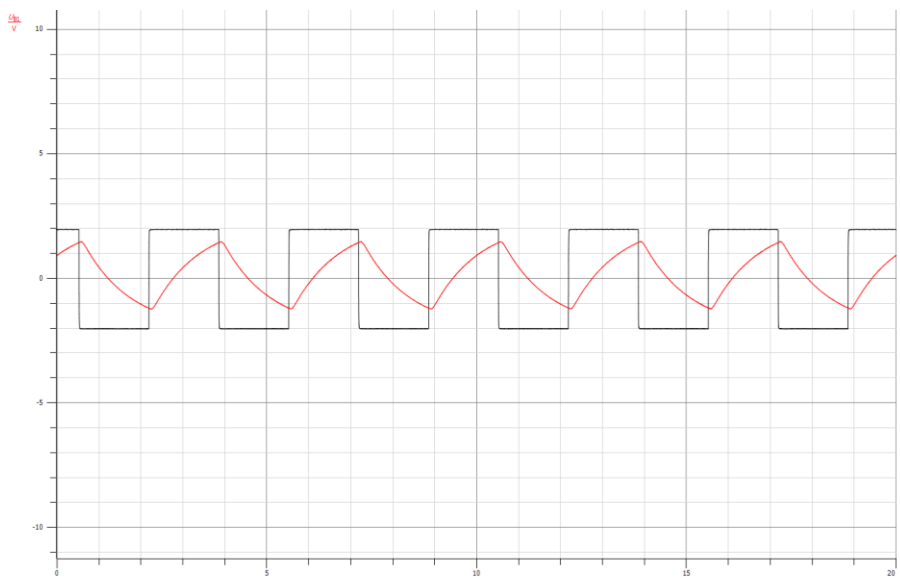


Figure 28:Demodulation ,LDM, Train pulse WAV, When fm=300Hz

DCDM, SIN wave, When Fm=300Hz:

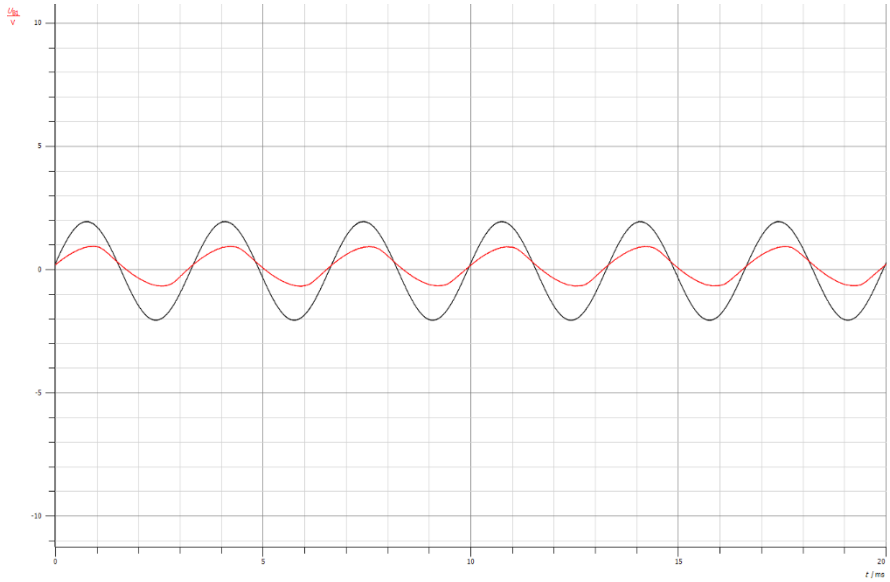


Figure29:Demodulation DCDM, SIN wave, When Fm=300Hz

DCDM, SIN wave, When Fm=100Hz:

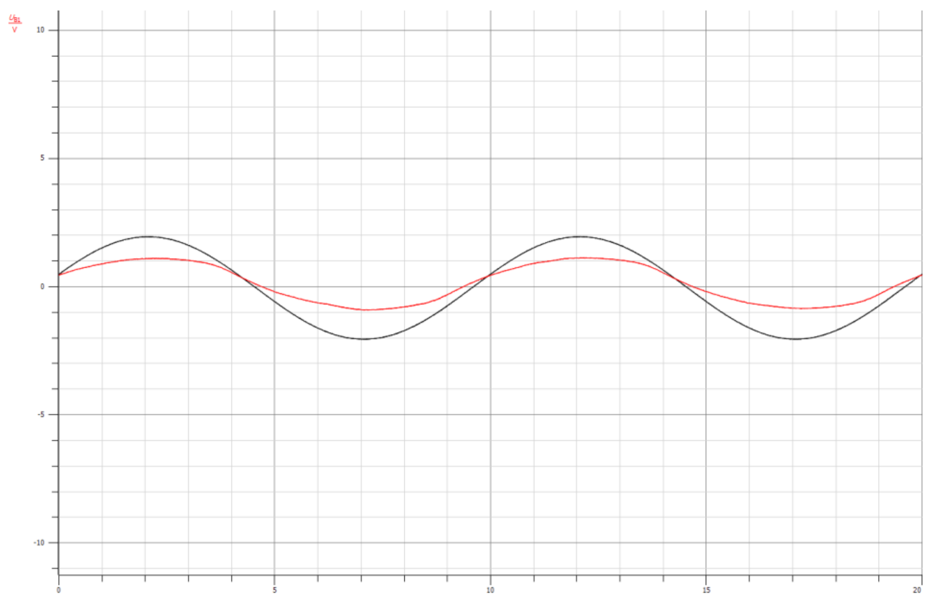


Figure 30:Demodulation DCDM, SIN wave, When Fm=100Hz

DCDM, Train pulse, When Fm= 100Hz:

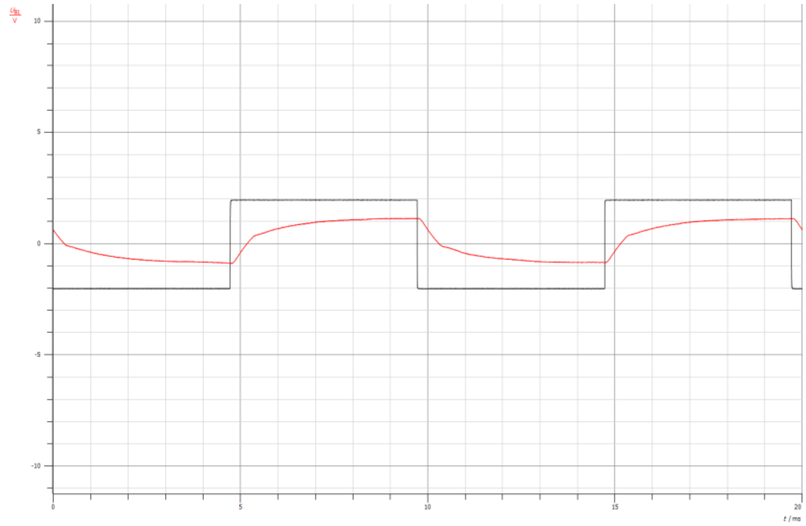


Figure 31:Demodulation DCDM, train pulse wave, When Fm=100Hz

DCDM, Train pulse, When Fm=300Hz:

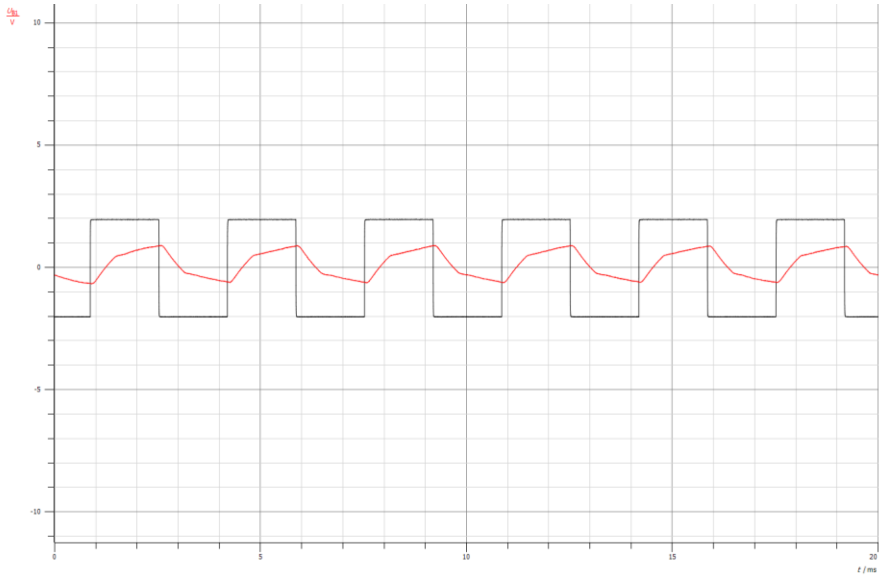


Figure 32:Demodulation DCDM, train pulse wave, When Fm=300Hz

- The **LDM** demodulated signal suffers from distortion with fast or sharp changes.

- **DCDM** demodulation is more faithful to the original signal due to adaptive error correction.

3. Conclusion

In conclusion, this experiment showed the clear differences between Linear Delta Modulation and Digitally Controlled Delta Modulation, both in theory and in practice. LDM was simpler but struggled when the input signal changed quickly, leading to errors and noise because of its fixed step size. On the other hand, DCDM, with its ability to change the step size depending on the input, tracked signals much better, had less distortion, and offered a wider dynamic range. Overall, DCDM proved to be much better for situations where high-quality and flexible signal transmission are needed.

4. References

[1]https://www.sciencedirect.com/topics/physics-and-astronomy/delta-modulation#:~:text=Delta%20modulation%20(DM)%20is%20a,quantized%20into%20only%20two%20levels [Accessed on 26/4/2025 at 21:30]

[2] https://www.mathworks.com/help/dsp/ug/comparison-of-ldm-cvsd-and-adpcm.html

[Accessed on 26/4/2025 at 21:50]

[3] http://electronicspost.com/what-is-slope-overload-distortion-and-granular-noise-in-delta-modulation-and-how-it-is-removed-in-adm/ [Accessed on 26/4/2025 at 22:30]

[4] https://www.sciencedirect.com/topics/engineering/demodulatorA [Accessed on 26/4/2025 at 22:40]