Vol. 22, No. 1 March 2025 | DOI https://doi.org/10.33480/techno.v22i1.6474

PERFORMANCE OF THE DELTA MODULATION SYSTEM WITH VARIOUS DELTA STEP SIZES

Djadjat Sudaradjat[1*]; Andi Rosano[2]

Teknik Elektro[1,2]
Universitas Bina Sarana Informatika, Jakarta, Indonesia[1,2]
https://www.bsi.ac.id/[1,2]
djadjat.dsj@bsi.ac.id[1*], andi.aox@bsi.ac.id[2]
(*) Corresponding Author

Abstract—*Delta Modulation Systems are widely used in Analog-to-Digital Converter (ADC) systems. This research aims to determine the optimal delta step size that can be achieved in a Delta Modulation system, as the system's performance is highly influenced by the delta step size. The method used involves simulations with MATLAB to identify the optimal delta step value. The performance of a Delta Modulation system is greatly influenced by the Delta step size. The optimal value in this study was achieved at a Delta step size of 0.4 with the smallest error, namely MSE = 0.1186. If the Delta step size is smaller or larger than this optimal value, the MSE increases. When the frequency of the input signal increases, the Delta step size needs to be increased to follow the changes in the input signal. Otherwise, the MSE will also increase, a phenomenon known as Slope-overload Distortion. Granular Noise occurs when the input signal changes very slowly or is almost constant, while the step size is too large, resulting in a high MSE. To overcome this problem, a dynamic Delta step size is needed, adjusted to the frequency changes of the input signal. Such a system with a dynamic Delta step size is known as Adaptive Delta Modulation.*

Keywords: *Analog to Digital Converter, Delta Modulation, Granular Noise, Low Bit-rate, Slope-overload Distortion.*

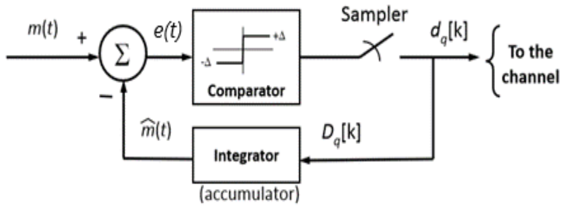
Intisari— *Sistem Modulasi Delta banyak digunakan pada sistem ADC (Analog-to-Digital Converter). Penelitian bertujuan untuk mengetahui besar langkah delta optimal yang dapat dihasilkan dari sebuah sistem Modulasi Delta, karena kinerja sistem Modulasi Delta sangat dipengaruhi oleh ukuran langkah Delta. Metoda yang digunakan adalah dengan simulasi menggunakan MatLab, sehingga kita dapat mengetahui nilai optimal dari langkah delta. Kinerja sistem Modulasi Delta sangat dipengaruhi oleh ukuran langkah Delta. Nilai optimal dalam penelitian ini dicapai pada ukuran langkah Delta sebesar 0,4 dengan kesalahan terkecil yaitu MSE = 0,1186. Jika ukuran langkah Delta lebih kecil atau lebih besar dari nilai optimal ini, maka nilai MSE akan meningkat. Ketika frekuensi sinyal input meningkat, ukuran langkah Delta perlu ditingkatkan untuk mengikuti perubahan sinyal input. Jika tidak, nilai MSE juga akan meningkat, sebuah fenomena yang dikenal sebagai distorsi Slope-overload. Sedangkan derau Granular terjadi ketika sinyal input berubah sangat lambat atau hampir konstan, sementara ukuran langkah terlalu besar, akan mengakibatkan nilai MSE yang tinggi juga. Untuk mengatasi masalah ini, diperlukan ukuran langkah Delta dinamis yang disesuaikan dengan perubahan frekuensi sinyal input. Sistem dengan ukuran langkah Delta dinamis seperti itu dikenal sebagai sistem Modulasi Delta Adaptif.*

Kata Kunci: *Konverter Analog ke Digital, Modulasi Delta, Derau Granular, Laju Bit Rendah, Distorsi Beban Lereng Berlebih.*

INTRODUCTION

In this study, simulations were conducted using MATLAB to analyze the effect of various Delta step sizes on Mean Squared Error (MSE) and signal distortion. Research by (Das, 2020) investigated the effect of Slope-overload Distortion but did not consider the optimal Delta step size. Therefore, this study aims to determine the optimal Delta step size that minimizes Slope-overload Distortion and Granular Noise through simulations using MATLAB. Additionally, this research explores the relationship between Delta step size, signal frequency, and Mean Squared Error (MSE) to enhance the performance of Delta Modulation systems. This study contributes to determining the optimal Delta step size to minimize MSE and proposes an approach to reduce the distortion effect on Delta Modulation.

One of the analog-to-digital conversion systems is the Delta Modulation system, which features a simple operation and low bit rate consumption. In a Delta Modulation system, the difference between the current sample and the previous sample is encoded into a single bit, either 1 or 0. Therefore, Delta Modulation is also known as DPCM (Differential Pulse Code Modulation) with a one-bit memory (Sudaradjat, 2023). The block diagram of the Delta modulator system is shown in Figure 1. The algorithm used is as follows:
(1) If m(t) > m̂(t), a "1" pulse code is generated, causing the integrator to increase m̂(t) by one step size;
(2) Conversely, if m(t) < m̂(t), a "0" pulse code is generated, causing the integrator to decrease m̂(t) by one step size.



Source: (BOKMANS, 2024)
Figure 1. Delta Modulator

This process continues so that m̂(t) always attempts to approximate m(t) at each sampling moment. The comparator compares the analog signal m(t) with the feedback signal m̂(t) and represents it in two voltage levels: positive and negative. The difference between these two inputs is e(t) = m(t) - m̂(t). Assuming the comparator output equation is:

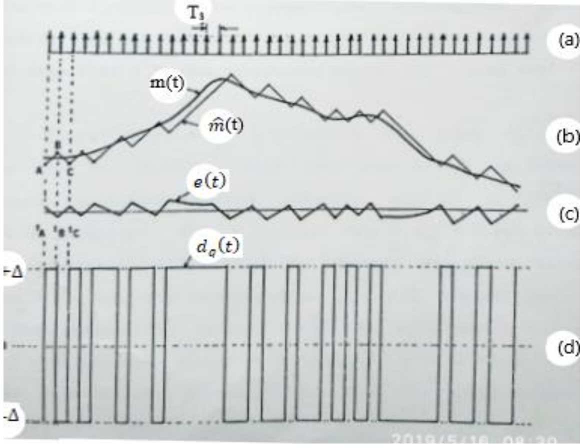
$$d_q(t) = \Delta\, sgn\, [e(t)] \tag{1}$$

Where: Δ is a constant value, referred to in this article as the Delta step size.

From equation (1), it can be concluded that the comparator will produce a voltage of +Δ if e(t) > 0 and -Δ if e(t) < 0. The comparator output is transmitted by the sampler circuit in the form of a digital square pulse dq(t) with a voltage magnitude of ±V.

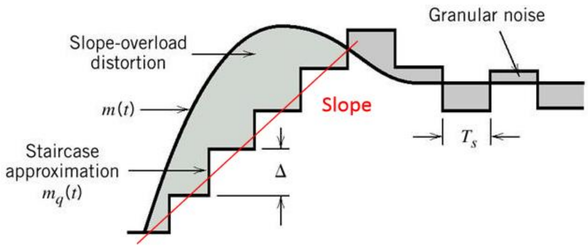
The integrator circuit functions to generate the feedback signal m̂(t), which is obtained by integrating the binary pulse dq(t). If dq(t) > 0, m̂(t) will increase, and if dq(t) < 0, m̂(t) will decrease. The waveform of the Delta Modulation system signal is shown in Figure 2.

For example, at the first sampling moment, the integrator has an initial voltage at point A, as shown in Figure 2(b). Since $m(t_A) > \hat{m}(t_A)$, then $e(t_A) > 0$ and $d_q(t)$ will have a value of +V, as shown in Figure 2(d). As a result, m̂(t) will increase over time, approximately following line AB. At the next sampling moment, at $t = t_B$, $m(t_B) < \hat{m}(t_B)$, so $e(t_B) < 0$ and $d_q(t)$ will have a value of -V. This $d_q(t)$ value will cause m̂(t) to decrease over time, approximately following line BC in Figure 2(b). This same condition occurs in subsequent steps. Consequently, m̂(t) will always try to follow m(t).



Source : (Sudaradjat, 2023)
Figure 2. (a) Sampling pulse. b) Analog signal m(t) and feedback signal m̂(t). (c) Error signal e(t). (d) Binary pulse d q(t).

If the analog input signal m(t) changes too quickly or has a high frequency, m̂(t) will not be able to follow m(t), as shown in Figure 3. This phenomenon is called slope-overload distortion, which causes interference at the receiver.



Source: (Ram´ırez-L´opez, 2025)
Figure 3. Slope-Overload Distortion And Granular Noise.

Meanwhile, granular noise occurs when the input signal m(t) is constant or has a low frequency. These two types of interference are weaknesses of the Delta Modulation system (Zhao, 2023). This article will investigate the performance of the Delta Modulation system in relation to these two weaknesses by measuring the impact of various Delta step sizes on the system's performance. From previous studies referenced, none have mentioned the optimal delta step size that can be achieved in a Delta Modulation system. Therefore, in this study, we aim to determine the optimal delta step size through simulations using MATLAB. The contribution of this research is expected to determine the optimal delta step size, thereby minimizing disturbances such as Slope Overload and Granular Noise. In future research, it is necessary to implement the system in hardware (Microchip Technology, 2023) and compare the results with the simulation outcomes.

MATERIALS AND METHODS

In this study, measurements were conducted on various delta step size values compared to the MSE values with a signal frequency of 1 kHz, ranging from a delta step size of 0.1 to 1.0 with a total of 10 values, as shown in Table 1. From these measurements, the optimal delta step size is determined by the smallest MSE value. The next measurement examines the frequency variations betwen 300 Hz and 4000 Hz compared to the MSE values for several delta step sizes to identify the frequency at which the smallest MSE is obtained. This will indicate the occurrence of Slope Overload and Granular Noise phenomena.

The study begins with designing the research framework, which includes selecting the appropriate analytical methods and data collection techniques. Once the research design is established, the research procedures are detailed with the help of MATLAB software. The algorithm used in this study aims to reduce Slope-overload distortion and Granular noise in the Delta Modulation system in relation to the Delta Step size.

Testing is conducted through simulations and the use of real data to ensure the system's performance. Data is obtained through a data acquisition process involving the collection of both primary and secondary data. Each step of the research is supported by relevant references, ensuring the validity and accuracy of the methods used.

By following these steps, this study can produce scientifically accepted findings and make a meaningful contribution to the field of digital communication.

The following is part of the MATLAB syntax used to obtain measurement data for various Delta Step sizes at different signal frequencies, as shown in Figure 4 (Mandal, 2024).

```
clc;
t=0:2*pi/500000:0.0004*pi; % Time Duration
x=5*sin(2*pi*1000*t);  % Define Message Signal with
peak voltage 5V and frequency 1000Hz
plot(x)
hold on
y=[0]; %Output DM signal i.e. stream of 1 or 0
xr=0; % Output of Integrator i.e. staircase approximation;
initial value =0
del=0.4; % Stepsize
for i=1:length(x)-1
   if xr(i)<=x(i) % If current sample greater than the
previous values or output of the integrator, output of
DM=1
```

```
(Mandal, 2024)       d=1;
      xr(i+1)=xr(i)+del; % Staircase approximated value
   else
      d=0;
      xr(i+1)=xr(i)-del; % If current sample less than the
previous values or output of the integrator, output of
DM=0
   end
   y=[y d];

end
stairs(xr); % Show the staircase approximated signal
hold off
MSE=sum((x-xr).^2)/length(x) % MSE
y  % Output of DM
```

Source : (Mandal, 2024)

Figure 4. A Portion of MATLAB Syntax in the Delta Modulation System

In the MATLAB syntax example above, a step size of 0.4 and a signal frequency of 1000 Hz with a voltage of 5 volts are used. Measurement results are obtained for various step sizes at different signal frequencies to observe the performance of the Delta Modulation system, as will be explained in the following section: **Results and Discussion.**

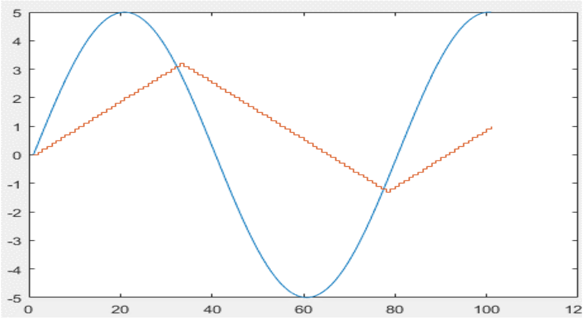
RESULTS AND DISCUSSION

The measurement results for the smallest Mean Squared Error (MSE) against variations in the Delta Step size for a signal frequency of 1 kHz are shown in **Table 1**. The smallest MSE value is obtained at a Delta Step size of **0.40**, indicating that the optimal Delta Step size for this Delta Modulation system is **0.40.**

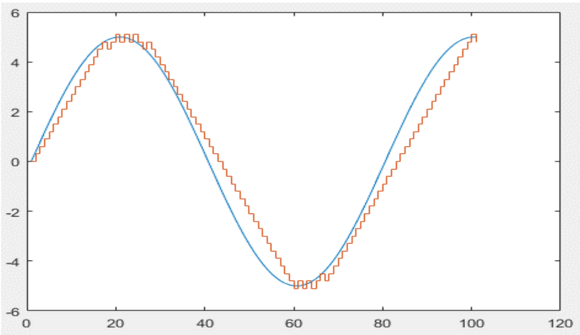
Table 1. Delta Step vs. MSE at a 1 kHz

No	Delta Step	MSE
1	0.10	10.7473
2	0.20	4.7834
3	0.30	0.4357
4	0.40	0.1186
5	0.50	0.1611
6	0.60	0.1910
7	0.70	0.2576
8	0.80	0.2912
9	0.90	0.3354
10	1.00	0.4215

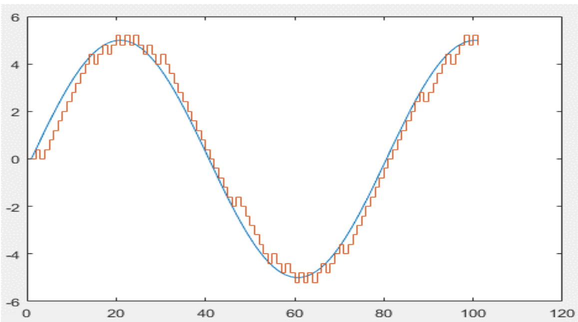
Meanwhile, the changes in the waveform shape are shown in **Figure 5.** It can be observed that the Delta Modulation signal at a Delta Step size of **DS = 0.4** is able to follow the input signal changes effectively. In contrast, at Delta Step sizes of **DS = 0.1, DS = 0.3,** and **DS = 1.0**, the Delta Modulation signal is less effective, as indicated by higher MSE values.



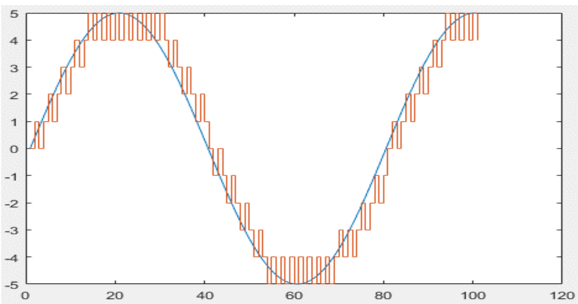
(a). DS=0.1, MSE=10.7473



(b). DS=0.3, MSE=0.4357



(c). DS=0.4, MSE=0.1186



(d). DS=1.0, MSE=0.4215

Figure 5. (a,b,c,d) Shape of Analog Signal m(t) and Feedback Signal m̂(t)

Let us observe the MSE values with respect to changes in frequency, as shown in **Table 2** for **Delta Step 0.30**, **Table 3** for **Delta Step 0.40**, and **Table 4** for **Delta Step 1.0.** It is clear that as the frequency increases, the MSE value also increases. Therefore, if the analog input signal changes too rapidly or has a higher frequency, the Delta Modulation signal may fail to follow the input signal, as illustrated in **Figures 6, 7,** and **8.**

This phenomenon is known as **Slope-overload distortion**, which can cause significant interference at the receiver. This validates the hypothesis discussed in the introduction section.

Table 2. Frequency Vs MSE at Delta Step 0.30

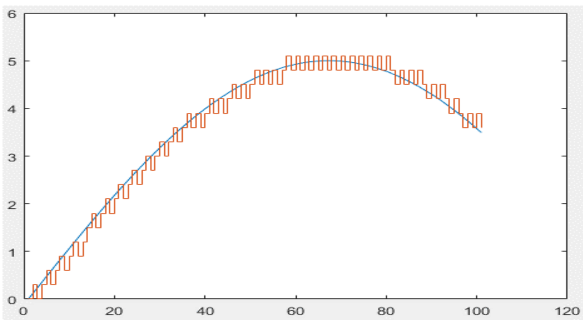
No	Frequency	MSE
1	300	0.0335
2	600	0.0586
3	800	0.0401
4	1000	0.4357
5	1500	5.6162
6	2000	8.1442
7	2500	10.0991
8	3000	11.7329
9	3500	12.2842
10	4000	12.0804

Table 3. Frequency Vs MSE at Delta Step 0.40

No	Frequency	MSE
1	300	0.0581
2	600	0.0791
3	800	0.1028
4	1000	0.1186
5	1500	1.4038
6	2000	5.079
7	2500	8.6183
8	3000	10.7447
9	3500	11.4452
10	4000	11.6901

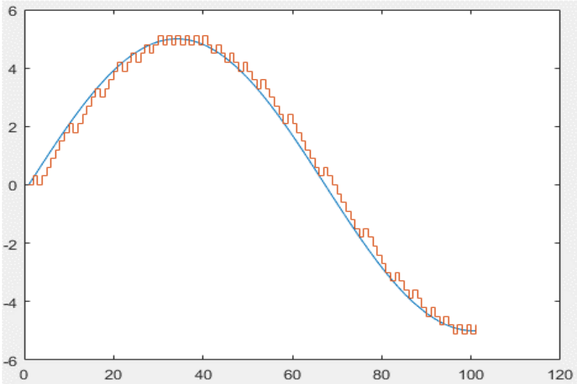
Table 4. Frequency Vs MSE at Delta Step 1,0

No	Frequency	MSE
1	300	0.3522
2	600	0.3656
3	800	0.3911
4	1000	0.4215
5	1500	0.5312
6	2000	0.5915
7	2500	0.5431
8	3000	1.2318
9	3500	3.0643
10	4000	5.1650

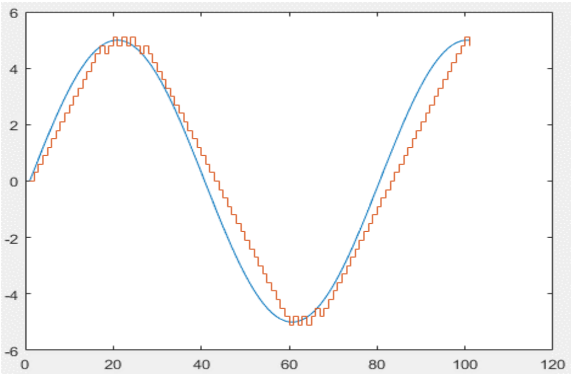


(a). F=300 Hz, MSE=0.0335

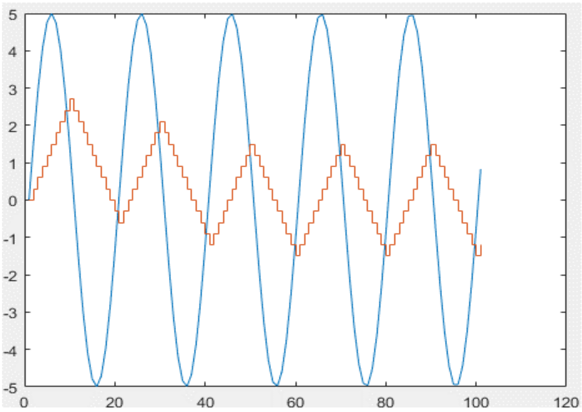
Techno Nusa Mandiri: Journal of Computing and Information Technology
Vol. 22, No. 1 March 2025 | DOI https://doi.org/10.33480/techno.v22i1.6474



(b). F=600 Hz, MSE=0.0586

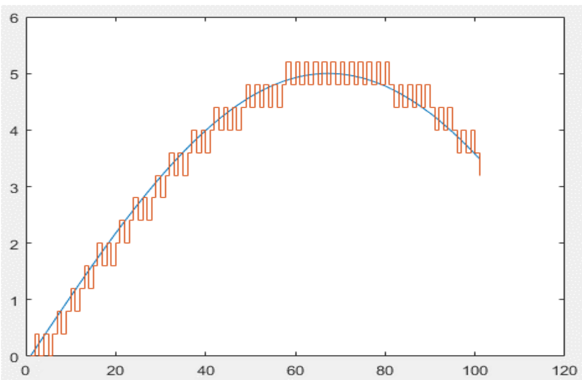


(c). F=1 KHz, MSE=0.4357

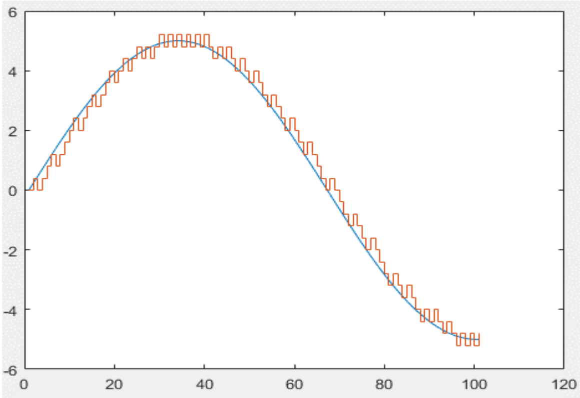


(d). F=4 KHz, MSE=12.0804

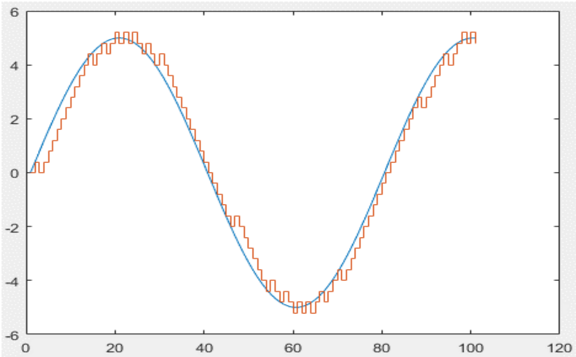
Figure 6. (a,b,c,d) Changes in Signal Waveform with Frequency at Delta Step 0.30



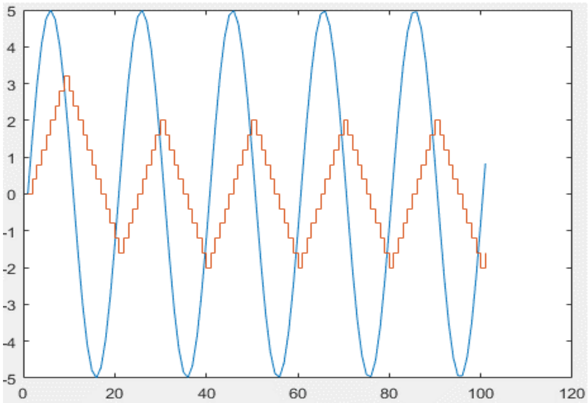
(a). F=300 Hz, MSE=0.0581



(b). F=600 Hz, MSE=0.0791

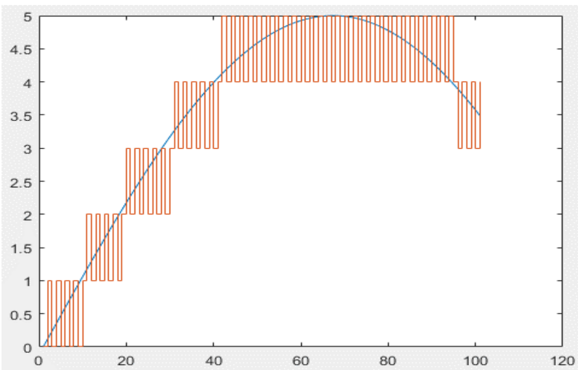


(c). F=1 KHz, MSE=0.1186

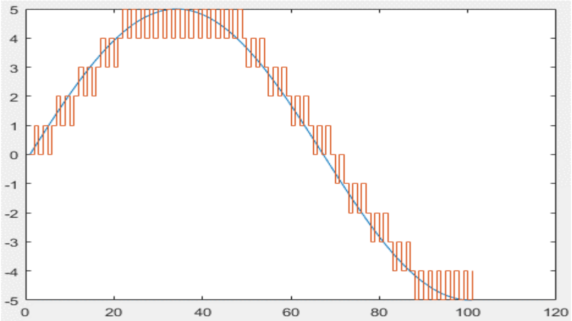


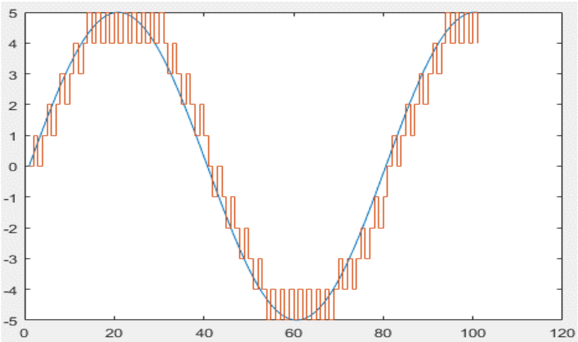
(d). F=4 KHz, MSE=11.6901

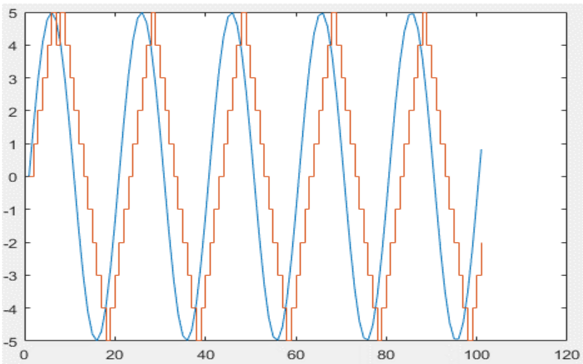
Figure 7. (a,b,c,d) Changes in Signal Waveform with Frequency at Delta Step 0.40



(a). F=300 Hz, MSE=0.3522


(b). F=600 Hz, MSE=0.3656


(c). F=1 KHZ, MSE=0.4215


(d). F=4 KHz, MSE=5.16.50
Figure 8. (a,b,c,d) Changes in Signal Waveform with Frequency at Delta Step 1.0

The changes in signal waveform with respect to frequency are highly influenced by the frequency spectrum composition of the signal. Low- and high-frequency components contribute differently to the overall waveform shape. Analyzing and manipulating the frequency spectrum is a crucial aspect in many signal processing applications, including audio, communication, and imaging.

The specific impacts can be observed in terms of signal distortion, system efficiency, and overall error reduction, particularly in minimizing Slope-overload Distortion and Granular Noise. Additionally, these impacts can influence the accuracy of signal reconstruction and the adaptability of the modulation system to varying input frequencies.

This study also examines two major types of distortion in delta modulation systems: **slope-overload distortion** and **granular noise**, using various Delta Step sizes. The experimental results highlight the following:

Slope-overload Distortion

Slope-overload distortion occurs when the input signal changes more rapidly than the delta modulation system can follow. A smaller Delta Step size increases the likelihood of slope-overload distortion, as the small step cannot keep up with sharp signal changes.
Observation: The graph shows that increasing the Delta Step size reduces slope-overload distortion but only up to a certain limit. A Delta Step size that is too large also becomes ineffective, introducing other forms of distortion.

Granular Noise

Granular noise occurs when the Delta Step size is too large compared to the actual changes in the input signal, resulting in unnecessary fluctuations in the output signal.
Observation: A larger Delta Step size increases granular noise as the system overestimates small signal changes. The data indicates that an excessively large Delta Step size makes the output signal rough and noisy.

CONCLUSION

This study evaluates the performance of the Delta Modulation system using various Delta Step sizes. The main finding of this study is that the Delta Step size plays a crucial role in determining the overall performance of the Delta Modulation system. The magnitude of the Delta Step in Delta Modulation must be adjusted to achieve a balance between reducing slope-overload distortion and granular noise. The selection of the optimal Delta Step size depends on the characteristics of the input signal. In this measurement, the optimal Delta Step size is **0.40** at an input signal frequency of **1 kHz.**

Overall, this study suggests that achieving optimal performance in Delta Modulation requires adjusting the Delta Step size according to the specific needs of the application. This highlights the importance of flexibility and adaptability in the design of Delta Modulation systems for various types of signals and operating conditions.

Future Work, Further studies are needed to explore adaptive algorithms that can automatically adjust the Delta Step size. Additionally, future research can focus on understanding the impact of other factors, such as external noise and interference, on the performance of delta modulation systems.

REFERENCE

Baluni, A. (2021). Analysis and Design of a 20-MHz Bandwidth Continuous-Time Delta-Sigma Modulator With Time-Interleaved Virtual-Ground-Switched FIR Feedback. *IEEE Journal of Solid-State Circuits (Volume: 56, Issue: 3, March 2021)*, 729 - 738.

BOKMANS, B. F. (2024). A Delta-Sigma Modulated Power Converter With Inherent Zero-Voltage Switching. *Power Electronics, https://pure.tue.nl/ws/portalfiles/portal/319222857/A_Delta-Sigma_Modulated_Power_Converter_With_Inherent_Zero-Voltage_Switching.pdf*, 250-260.

Das, S. (2020). A Deterministic Study of Delta Modulation (DM) using Machine Learning Approach. *Conference: 2020 4th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech)*.

Lumbreras, D. (2024). A Novel Three-Dimensional Sigma–Delta Modulation for High-Switching-Frequency Three-Phase Four-Wire Active Power Filters. *Electronics*, 1-16.

Mandal, S. (2024, May 22). *Simulation of Delta Modulation (DM) using MATLAB*. Diambil kembali dari mathworks web site: https://www.mathworks.com/matlabcentral/fileexchange/120993-simulation-of-delta-modulation-dm-using-matlab

Microchip Technology. (2023). Understanding the function of analog-to-digital. *URL https://www.microchip.com/en-us/*.

Mingdong Fan, R. W. (2021). A High-Dynamic-Range Digital RF-Over-Fiber Link for MRI Receive Coils Using Delta-Sigma Modulation. *arXiv, https://arxiv.org/pdf/2105.13305*, 1-12.

Peric, Z., Denic, B., & Despotovic, V. (2021). Algorithm based on 2-bit adaptive delta modulation and fractional linear prediction for Gaussian source coding. *IET Signal Processing, https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/sil2.12040*, 410-423.

Ram´ırez-L´opez, F. (2025). FPGA-based implementation of a delta modulation technique for aerospace communications transmission chain. *International Conference on AeroSpace Science and Technology (ICASST) 2024, https://www.researchgate.net/publication/388787938_FPGA-based_implementation_of_a_delta_modulation_technique_for_aerospace_communications_transmission_chain#fullTextFileContent*, 1-20.

Sudaradjat, D. (2023). Adaptive Delta Modulation Simulation and Analysis Using MatLab. *Paradigma, https://jurnal.bsi.ac.id/index.php/paradigma/article/view/2151/1370*, 89-93.

Suhendra, T. (2023). Effect of Pulse Width Modulation onProportional, Integral, and DerivativeCoefficient Characteristics. *PROtek : Jurnal Ilmiah Teknik Elektro*, 93-101.

Vlachos, A. (2021). Exploring the Effectiveness of Sigma-Delta Modulators in Stochastic Computing-Based FIR Filtering. *IEEE Xplore*.

Wai-Yiu Keung†, §. a.-K. (2024). Spatial Sigma-Delta Modulation for Coarsely Quantized Massive. *arXiv, https://arxiv.org/pdf/2310.14179*, 1-31.

XU, W. (2023). Parallel implement of real-time delta-sigma modulation for digital mobile fronthaul. *Optics Express, https://opg.optica.org/oe/fulltext.cfm?uri=oe-31-26-44401&id=544504*, 1-9.

Zhao, J. (2023). Enhancing the performance of 16384QAM based on delta-sigma modulation using geometric shaping in an IMDD system. *Optica, https://opg.optica.org/ol/viewmedia.cfm?uri=ol-48-20-5253&seq=0*, 5253-5256.