Lab 8

Getting started with Analog to Digital Conversion and Sampling

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1 Introduction

The lab report introduces an exploration into Analog to Digital Conversion (ADC) and sampling techniques using National Instruments' (NI) USB-DAQ hardware and MATLAB software. The primary objective was to bridge continuous analog signals from the physical world into discrete digital signals that can be processed on a computer. Through practical exercises, foundational skills in configuring and utilizing the NI USB-6001 DAQ system for signal acquisition were developed, including manipulating data acquisition settings in MATLAB and analyzing the impacts of sampling rates and quantization errors on signal fidelity.

The lab emphasized understanding the trade-offs and limitations inherent in digitizing analog signals, such as quantization noise and sampling artifacts. The exercises demonstrated the effects of varying sampling rates and signal frequencies on digital audio quality. Additionally, signal degradation at lower sampling rates and the effects of quantization resolution on signal accuracy were explored.

Through experimentation with synthetic and real-world signals, this lab provided practical experience in digital signal processing concepts, preparing students for more advanced applications in biomedical engineering and other technical fields.

2 Results

2.1 Basic Setup of the DAQ System

In Part 1 of this lab, the DAQ system was set up to enable Analog to Digital Conversion. The NI USB-6001 DAQ device was connected to a computer, and its functionality was confirmed in MATLAB by executing the 'daq.getDevices' command, which verified that the device was properly recognized. After establishing the connection, the DAQ configuration process continued with the addition of an analog input channel. This setup allowed the device to receive and process analog signals within a specific voltage range, adjusted for the parameters of the experiment.

The DAQ's operating parameters were verified by checking the device's voltage range, supported sampling rates, and channel capabilities, confirming that the device could handle the specified signal characteristics. MATLAB was used to set up the acquisition parameters, ensuring that the input signal could be accurately digitized for analysis. The DAQ was then prepared to acquire a test signal, with MATLAB configured to handle data acquisition through the appropriate commands and settings. This setup provided a foundation for capturing and analyzing continuous analog signals, converting them into a digital format suitable for the subsequent steps of the experiment.

2.2 Inputting and Acquiring a Test Signal

In Part 2, a test signal was input and acquired using the configured DAQ system. A sine wave with a frequency of 500 Hz and an amplitude of 2V was generated by a function generator and connected to the DAQ. To allow simultaneous monitoring, the signal was also routed to an oscilloscope using a BNC to banana connector cable and alligator clips, enabling direct observation of the analog waveform. The DAQ was set to sample at a rate of 10,000 samples per second over a 0.01-second acquisition period, providing sufficient data to capture the characteristics of the input signal. MATLAB commands were employed to initiate the data acquisition and plot the resulting samples, displaying the digitized sine wave on a time scale.

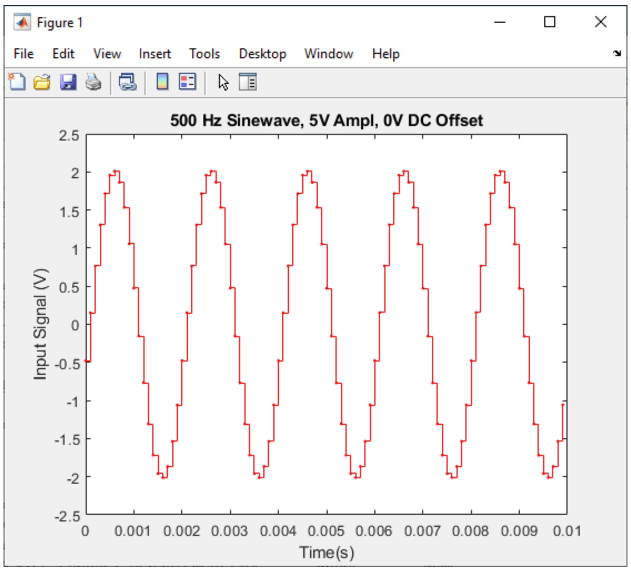

Figure 1: 500 Hz Sinewave, 5V Amplitude, 0V DC Offset

The acquired signal was plotted, showing a clear sinusoidal shape that matched the properties of the input signal. This step demonstrated the DAQ's ability to accurately capture and digitize an analog signal when properly configured with an adequate sampling rate. The successful acquisition and plotting of the signal validated the setup and provided a foundation for further experimentation with different signal types and configurations in later parts of the lab.

2.3 Limitations of Digitization: Quantization Error

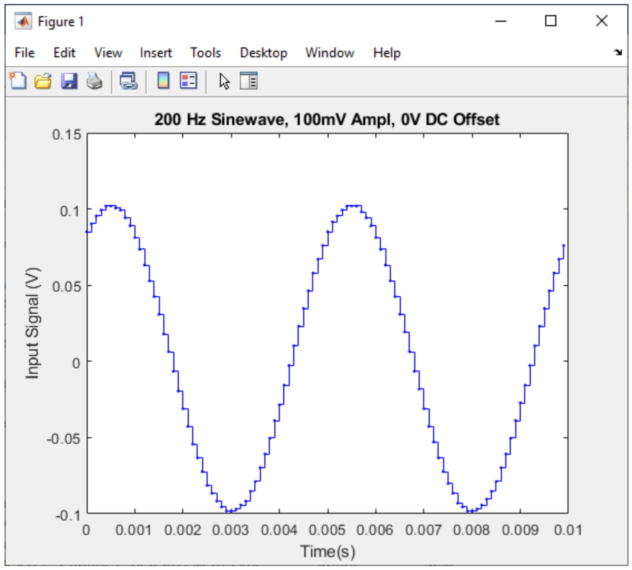

Figure 2: 200 Hz Sinewave, 100mV Amplitude, Sampling Rate = 1500 Samples/Second

In Part 3, the lab explored the limitations of digitization, specifically focusing on quantization error, by analyzing two configurations of a 200 Hz sine wave signal at low amplitudes. In Configuration 1 (Figure 2), a sine wave with a 10 mV amplitude and 0V DC offset was sampled at a rate of 1500 samples per second. The resulting plot shows a stepped waveform with visible quantization effects, as the limited resolution of the DAQ's 14-bit ADC struggles to accurately represent the small amplitude changes of the signal. The digitized signal appears jagged, with clear discrete steps, indicating that the quantization levels do not adequately capture the subtle variations in the analog waveform. This quantization error becomes significant when working with low-amplitude signals, as the DAQ can only approximate the signal within the resolution of its 14-bit ADC.

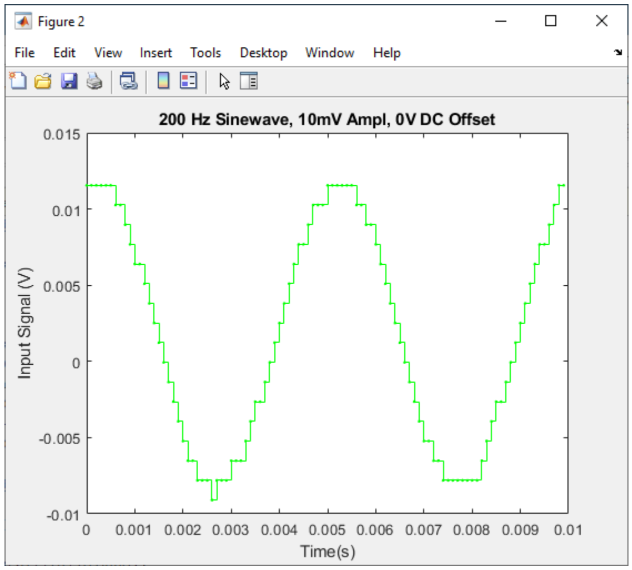

Figure 3: 200 Hz Sinewave, 100mV Amplitude, Sampling Rate = 10000 Samples/Second

In Configuration 2 (Figure 3), the sine wave amplitude was increased to 100 mV while maintaining the same frequency and DC offset, and the sampling rate was increased to 10,000 samples per second. The resulting waveform displays a much smoother sinusoidal shape with fewer visible steps, as the increased amplitude and higher sampling rate allow for a more accurate representation of the signal. The increased amplitude reduces the relative impact of quantization error, as the DAQ has more discrete levels to represent the larger signal. The higher sampling rate captures the waveform with greater detail, minimizing the stair-step effect seen in Configuration 1.

Comparing both configurations, it is clear that the amplitude of the input signal and the sampling rate significantly impact the quality of the digital representation. Lower amplitudes and sampling rates increase quantization artifacts, distorting the waveform and deviating from the original analog signal. This part of the lab illustrated the importance of selecting appropriate signal amplitudes and sampling rates to achieve a more accurate digital representation, particularly when working with signals at low amplitudes.

2.4 Sampling Music or Speech

In Part 4, the lab investigated the effects of different sampling rates on audio signal fidelity by digitizing a segment of the song "Happy Birthday." The audio signal was played from a phone and sampled using the DAQ device at three different rates: 20 kHz, 5 kHz, and 1 kHz. At the highest sampling rate of 20 kHz, the digitized audio maintained a clear and accurate representation of the original song, with minimal distortion and preserved tonal quality. This high sampling rate helped retain the nuances and details of the original music.

At a sampling rate of 5 kHz, the playback quality noticeably declined. Although the melody of "Happy Birthday" was still recognizable, the sound lacked clarity, and certain high-frequency details were lost, resulting in a muffled or slightly distorted sound. This drop in quality reflects the trade-off when reducing the sampling rate, as fewer samples per second capture less detail from the original signal.

At the lowest sampling rate of 1 kHz, the audio was heavily distorted, with significant artifacts. Much of the song's tonal quality was lost, making it challenging to recognize the melody clearly. This very low sampling rate was insufficient for accurately capturing the range of frequencies present in the music, leading to severe degradation in sound quality. This exercise demonstrated how lower sampling rates can dramatically impact audio fidelity, especially in applications requiring accurate representation of complex signals like music. It highlighted the necessity of selecting an adequate sampling rate to ensure accurate digital reproduction, particularly in contexts where sound quality is critical.

2.5 A/D Sampling Rate - Deeper Investigation

In Part 5, the lab examined the relationship between sampling rate and the accurate digitization of higher-frequency signals. A 1 kHz sine wave was generated and sampled at multiple rates: 20,000 Hz, 10,000 Hz, 4,000 Hz, 2,500 Hz, 1,800 Hz, 1,600 Hz, 1,400 Hz, and 1,200 Hz. At the higher sampling rates (20,000 Hz and 10,000 Hz), the digitized signal closely matched the original analog signal, with smooth, continuous sinusoidal waveforms observed upon playback. The high sampling rates provided ample data points to accurately capture the 1 kHz frequency, resulting in clear audio with minimal distortion.

As the sampling rate decreased to 4,000 Hz and 2,500 Hz, some minor distortion began to appear, but the 1 kHz frequency was still recognizable. However, at even lower rates, such as 1,800 Hz and 1,600 Hz, more significant distortion emerged, with visible artifacts and an increasingly "stepped" appearance in the waveform. By the time the sampling rate dropped to 1,400 Hz and 1,200 Hz, the audio was heavily distorted, with a pronounced loss in fidelity, making it difficult to identify the original 1 kHz tone. This degradation occurred because the lower sampling rates provided fewer points per cycle, resulting in an inaccurate representation of the original signal's frequency and waveform.

This part of the lab highlighted the importance of selecting an appropriate sampling rate based on the frequency of the signal being captured. As demonstrated, sampling rates that are too low relative to the signal frequency result in noticeable distortion and can cause the signal to be misrepresented. Thus, for accurate digitization of signals, especially those with higher frequencies, a sufficiently high sampling rate is essential to ensure fidelity and avoid issues such as aliasing and waveform distortion.

3 Discussion and Conclusion

This lab provided a comprehensive exploration of Analog to Digital Conversion (ADC) and the essential role of sampling rates and quantization in digital signal representation. By configuring the NI USB-6001 DAQ system and observing the impact of various sampling parameters on different signal types, the lab highlighted the trade-offs inherent in digitizing analog signals. Parts 1 and 2 established a foundation for accurately capturing signals by ensuring correct DAQ setup and input signal acquisition. Part 3 demonstrated how quantization error, particularly in low-amplitude signals, can lead to signal distortion, emphasizing the importance of choosing an appropriate amplitude and bit resolution. In Part 4, the effect of sampling rate on audio fidelity was evident, as lower rates introduced distortion and reduced clarity in the playback of ”Happy Birthday.” Part 5 further reinforced that an adequate sampling rate is essential for preserving the integrity of higher-frequency signals, as lower sampling rates resulted in pronounced distortion and loss of signal detail.

Overall, this lab underscored key principles in digital signal processing, such as the importance of sampling rate, quantization error, and bit resolution, which are crucial considerations in applications like biomedical engineering, audio processing, and communications. Understanding these concepts equips students with the knowledge needed to optimize signal acquisition systems for precise and accurate digital representations of real-world analog signals.

4 References

[1] Dr. Iman Salama. “Lab 8 – Getting started with Analog to Digital Conversion and Sampling” Northeastern University. 2 November 2024.