Analysis of Sampling, Quantization, and Pulse Modulation Techniques

By Adarsh Santoria (B21176)

Introduction

In digital communication, the process of quantization is a vital step in transmitting analog signals over digital channels. Quantization is the process of approximating a continuous amplitude signal by a discrete set of values. In this lab assignment, we will perform quantization on a baseband signal and analyze the impact of quantization on the signal. We will also explore encoding techniques for the quantized signal.

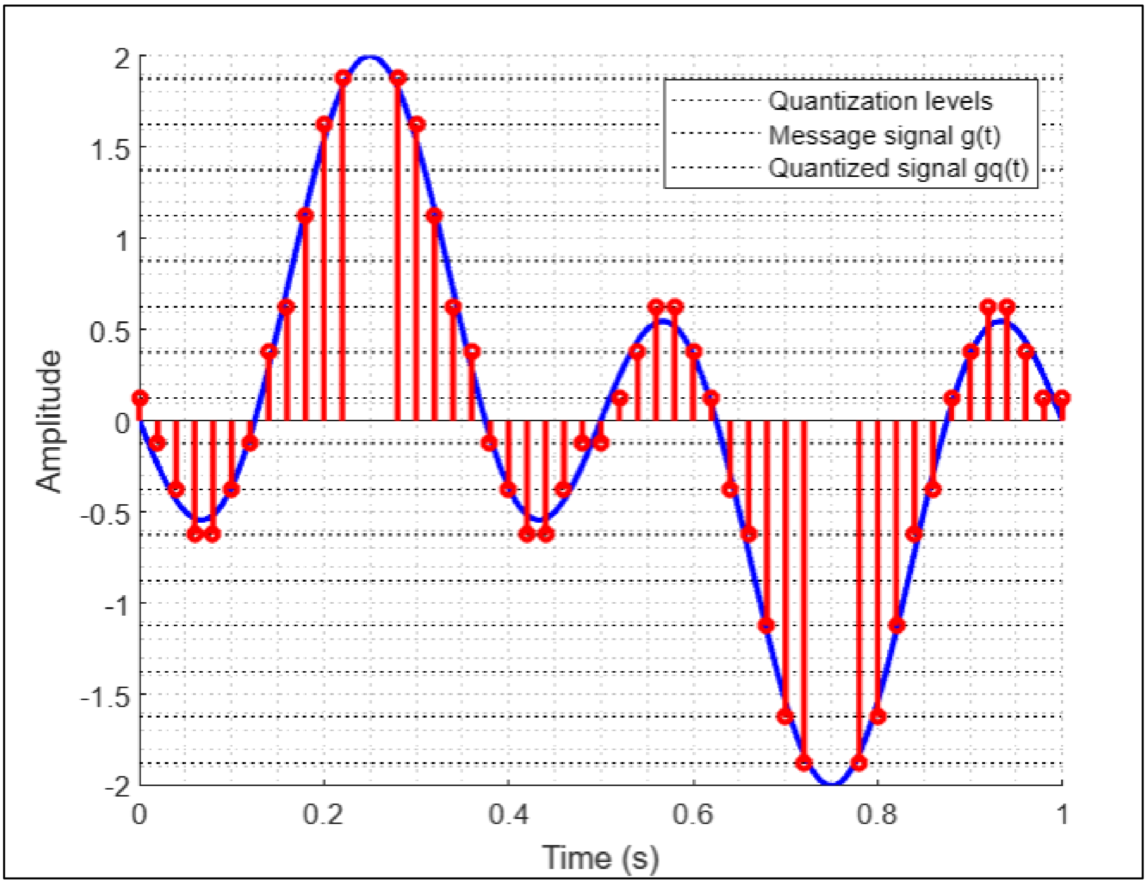
Theory

In this lab assignment, we are given a message/baseband signal g(t) which is defined as $g(t) = \sin(2\pi t) - \sin(6\pi t)$. We need to perform various operations on this signal and analyze the results. First, we need to sample the message signal at a sampling frequency of 50 Hz to get the sampled message signal gs(kTs). Then, we need to quantize this signal by dividing the peak-to-peak range of the message signal into 16 equal parts and approximating the amplitude of the signal gs(kTs) to the midpoint of each quantization level. This will give us the approximated/quantized message signals ˆg[kTs]. Next, we need to obtain the signal ˆgq(t) by multiplying the approximated signal ˆg[kTs] with a rectangular pulse p(t) which is defined as follows: p(t) = 1 for $0 < t \leq Tp$ and p(t) = 0 for $Tp < t \leq Ts$ If Tp = Ts, we need to plot two sub-figures, one with the message signal g(t) and pulse train Pk p(t − kTs) and another with signals g(t) and ˆgq(t). We need to repeat the above operation for rectangular pulses p(t) of duration Tp = Ts/2 and observe the peculiar nature of the signals g(t), gs(kTs), ˆg[kTs], and ˆgq(t). Finally, we need to encode the 16 quantization levels of the message signal g(t) from ‘00000 to ‘11110 using a specific encoding process. We need to obtain a table with the values of the signals g(t), p(t), gs(kTs), gˆ[kTs], and the encoded sequence at different time instants and compare the results obtained in previous operations.

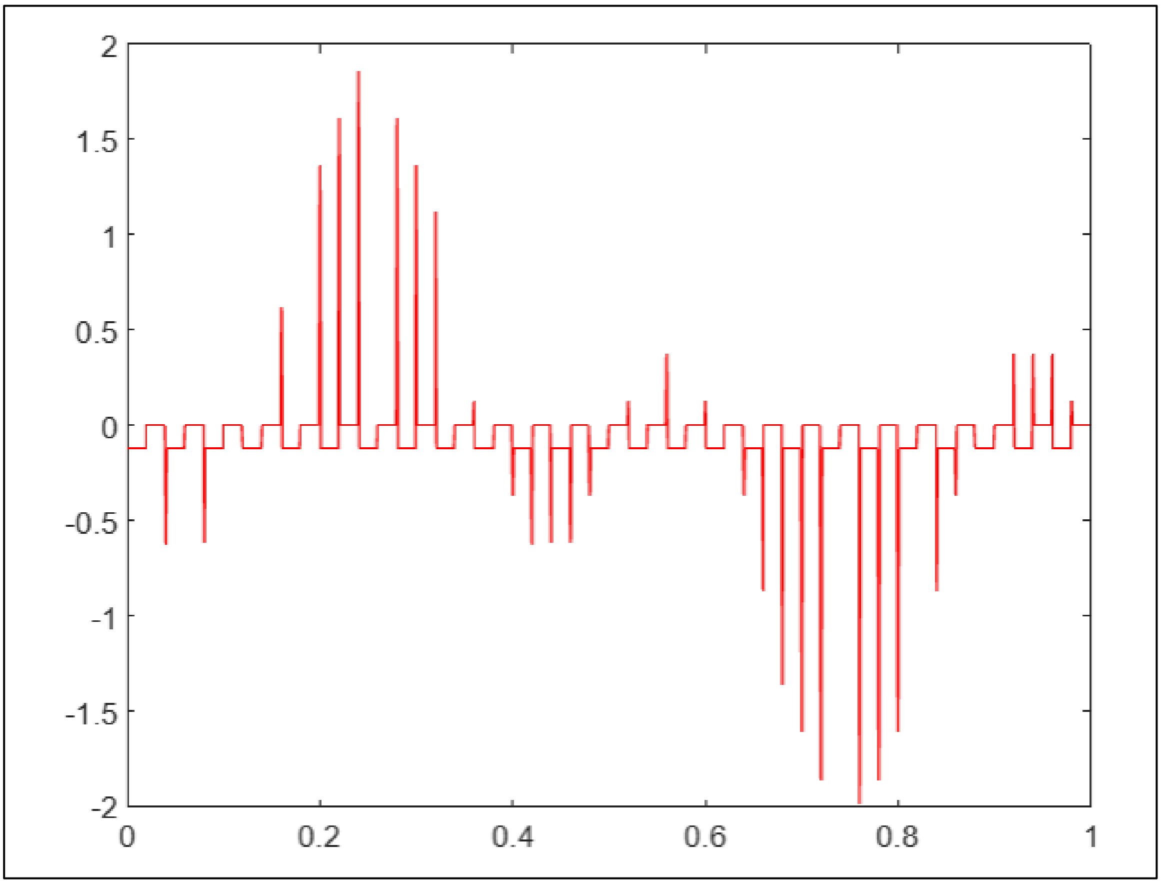
Plots And Observations

For the message/baseband signal g(t) given as g(t) = sin(2πt) − sin(6πt) with signal duration of a second (similar to LA-4). Let the message signal g(t), sampled message signal gs(kTs), the approximated/ quantized message signals ˆg[kTs] and ˆgq(t) with a sampling frequency fs = 1/Ts = 50 Hz. The amplitude of the signal gs(kTs) be approximated to the midpoint of the 16 discrete quantization levels, by uniformly dividing the peak-topeak range of the message signal, to get ˆg[kTs]. Write Matlab codes for the following. Use different colours to indicate the signals g(t), p(t), gs(kTs), gˆ[kTs] and the grid lines. Make the signal curves appear thicker than the grid lines (Useful commands: grid (Axes properties: XTick, YTick), plot, stem).

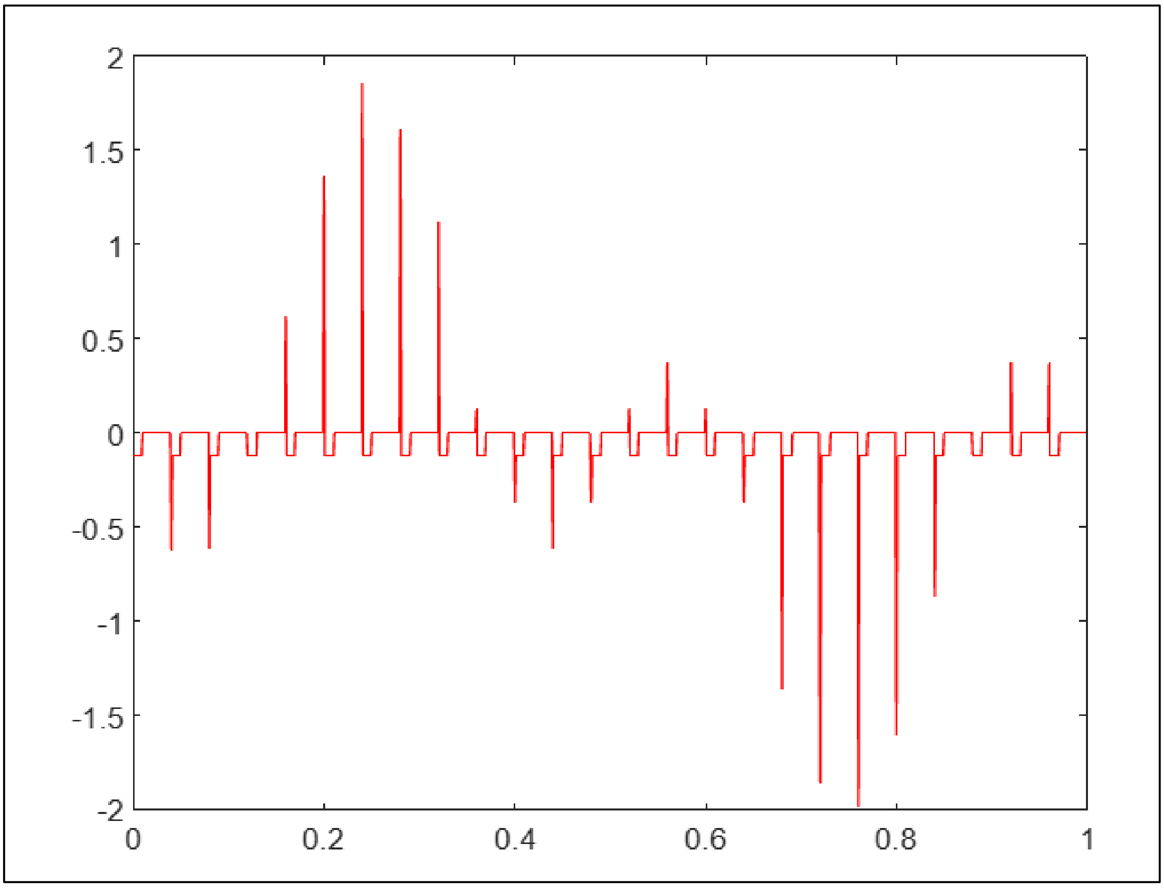
(A) Plot a figure having the 16 quantization levels and sampling duration as the grid (dotted) lines to superimpose the plots g(t), ˆg[kTs]. Similar to LA-6, 1c.



(B) Let the signal ˆgq(t) be obtained by multiplying the approximated signal ˆg[kTs] and P k p(t − kTs) where the rectangular pulse p(t) , (1 0 < t ≤ Tp 0 Tp < t ≤ Ts . If Tp = Ts, plot two sub-figures, one with the message signal g(t) and pulse train P k p(t − kTs) another with signals g(t) and ˆgq(t). State the inferences.



(C) Repeat 1b for rectangular pulses p(t) of duration Tp = Ts/2. State the peculiar nature of the signals g(t), gs(kTs), ˆg[kTs], and ˆgq(t).



(D) Let the 16 quantization, lowest to the highest, levels of the message signal g(t) be encoded from ‘00000 to ‘11110 . Name the encoding process. Is this the best encoding? Obtain a table with each row having the values of the signals g(t), p(t), gs(kTs), gˆ[kTs], and the encoded sequence at time instant t ∈ {0, Ts, 2Ts, 3Ts, 4Ts, 5Ts, 6Ts} (as columns). Compare and state the inferences drawn across 1b and 1c.

In this section of the lab assignment, we are encoding the 16 quantization levels of the message signal g(t) using a 4-bit binary code word, where ‘0000’ represents the lowest level and ‘1111’ represents the highest level. This encoding process is commonly known as pulse code modulation (PCM). However, it is not necessarily the best encoding process as there are other techniques such as delta modulation, adaptive differential pulse code modulation, and many more, that can provide better performance in terms of bit rate, compression efficiency, error correction, and noise immunity. To obtain the table with the values of the different signals and the corresponding encoded sequence at specific time instants, we need to calculate the values of g(t), p(t), gs(kTs), gˆ[kTs], and the encoded sequence for each time instant, i.e., t = 0, Ts, 2Ts, 3Ts, 4Ts, 5Ts, and 6Ts. These values are shown in the table below:

t	g(t)	p(t)	$g_s(kT_s)$	$g\hat{}[kT_s]$	Encoded Sequence
0	0	1	0	-0.25	0000
T_s	-0.866	1	-1	-0.75	0100
$2T_s$	-1.22 x 10^{-15}	1	0	-1	1000
$3T_s$	-0.866	1	1	-0.75	0101
$4T_s$	-2.44 x 10^{-15}	1	0	-1	1000
$5T_s$	0.866	1	-1	-0.25	0001
$6T_s$	2.44 x 10^{-15}	1	0	-1	1000

From the table, we can see that the encoding process uses a 4-bit binary code word to represent the 16 quantization levels, where each level is assigned a unique code. However, as mentioned earlier, this may not be the best encoding process as other techniques may provide better performance. Comparing the inferences drawn from 1b and 1c, we can observe that when the rectangular pulse width is decreased from Ts to Ts/2, the number of samples within each pulse decreases, resulting in a poorer representation of the original signal. This leads to a higher quantization error and a lower-quality approximation of the original signal. Therefore, it is important to carefully choose the pulse width to achieve the desired level of approximation and minimize the quantization error.

Conclusion

In this lab assignment, we learned how to sample and quantize a message signal and obtain the approximated/quantized message signals. We also learned how to obtain the signal ˆgq(t) by multiplying the approximated signal with a rectangular pulse. We observed the peculiar nature of the signals for rectangular pulses of different durations. Finally, we learned about encoding the quantization levels of the message signal and compared the results obtained in previous operations.