LAB 3

QUANTIZATION
&
BINARY CODING AND DECODING

OBJECTIVES

- Use different quantization methods and study the impact of quantization in signal quality
- Convert quantized samples to binary bits and study the impact of error on signal quality

INTRODUCTION

Quantization

The three steps in analog to digital converter (ADC) is sampling, quantization, and binary coding. After sampling the signal, the amplitudes of the samples will have infinite possibility even if the signal's amplitude is withing a limited range. For example, a sample might have an amplitude 2.5478 and the next sample might have 2.5477 and another sample could be 1.46783 and so forth. To represent these samples by binary bits it will require large number of bits. To limit the number of bits per sample, the samples are quantized to specific number of levels, so the possible levels can be represented by a desired number of bits. For example, if we desire to represent a sample by 8 bits, then the number of possible levels is 2^8 = 265 levels.

$$L = 2^n$$

Where L is the number of levels a sample value might have, and n is the number of bits per sample. There are four different methods for uniform quantization, listed below and shown in figure below.

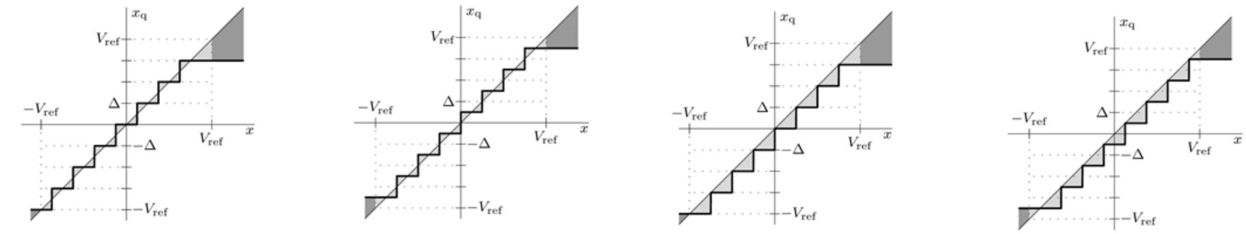
Rounding Asymmetric $\quad x_q = \Delta \left\lfloor \frac{x}{\Delta} + \frac{1}{2} \right\rfloor \quad$ where $\Delta = \frac{V_{ref}}{2^{B-1}}$

Rounding Symmetric $\quad x_q = \Delta \left(\left\lfloor \frac{x}{\Delta} \right\rfloor + \frac{1}{2} \right)$

Truncating Asymmetric $\quad x_q = \Delta \left\lfloor \frac{x}{\Delta} \right\rfloor$

Truncating Symmetric $\quad x_q = \Delta \left(\left\lfloor \frac{x}{\Delta} - \frac{1}{2} \right\rfloor + \frac{1}{2} \right)$

V_{ref} is the absolute maximum value in the signal.



Rounding Asymmetric   Rounding Symmetric   Truncating Asymmetric   Truncating Symmetric

In the lab you will be quantizing audio files using different methods and different number of bits. Writing a code is very important in determining the speed of the digital signal processor and the ability to use the code for another task. It is recommended to write a function that will do the quantization of different methods and number of bits. Build a function and name it QuantizationXX where XX the first letters of your first and last name. An example of this code is

```
function [QntzSig Delta] = QuantizationMB(OrgSig, B, QM)
% OrgSig is the original audio file or signal
% B is the number of bits per sample
% QM can be 1 for Rounding Asymmetric, 2 for Rounding Symmetric
% 3 for Truncating Asymmetric, 4 for Truncating Symmetric
Vref = max(abs(OrgSig));
Delta = Vref/(2^(B-1))
if QM == 1
    QntzSig = Delta*floor(OrgSig/Delta + 1/2);
elseif QM ==2
    QntzSig = Delta*(floor(OrgSig/Delta) + 1/2);
elseif QM == 3
    QntzSig = Delta*floor(OrgSig/Delta);
elseif QM == 4
    QntzSig = Delta*(floor(OrgSig/Delta - 1/2) + 1/2);
end
% the following statements check if the quantized level bigger
%than the maximum level then it set it to the maximum level.
if (QM == 1)|(QM==3)
    QntzSig(QntzSig >(Vref-Delta)) = Vref-Delta;
    QntzSig(QntzSig <-Vref) = -Vref;
else
    QntzSig(QntzSig >(Vref-Delta/2)) = Vref - Delta/2;
    QntzSig(QntzSig <-(Vref-Delta/2)) = -Vref + Delta/2;
end
end
```

Binary Coding and Decoding

After quantization, the next step is to represent each sample by binary bits. The three popular coding methods are the two's complement, offset binary, and Gray code. The two's complement uses the most significant bit (MSB) for sign so 0 for positive quantity and 1 for negative quantity. The remaining bits contribute to the magnitude of the sample value, such that the next MSB has $2^{-1}V_{ref}$, the next one is $2^{-2}V_{ref}$, and the least significant bit $2^{-(B-1)}V_{ref}$. Where B is the number of bits used per sample. The equations for the two's complement decoding for rounding asymmetric quantization is

$$x_q = V_{ref}\left(-c_{B-1}2^0 + c_{B-2}2^{-1} + \cdots + c_1 2^{-(B-2)} + c_0 2^{-(B-1)}\right)$$

The equation for the binary offset decoding for rounding asymmetric quantization is

$$x_q = V_{ref}\left(-1 + c_{B-1}2^0 + c_{B-2}2^{-1} + \cdots + c_1 2^{-(B-2)} + c_0 2^{-(B-1)}\right)$$

Where B is the number of bits per sample. C_{B-1} is the most significant bit (MSB) and C_0 is the least significant bit (LSB). If the quantization is rounding symmetric quantization, then we add $\Delta/2$ to x_q in the above two equations.

Examples of two's complement decoding of the 4-binary codes 0000, 0001, 0111, 1111, 10000 is shown below for $V_{ref}=1$ and rounding asymmetric.

$x_{0000} = 1(-0\times2^0 + 0\times2^{-1} + 0\times 2^{-2} + 0\times 2^{-3}) = 0$
$x_{0001} = 1(-0\times2^0 + 0\times2^{-1} + 0\times 2^{-2} + 1\times 2^{-3}) = 0.125$
$x_{0111} = 1(-0\times2^0 + 1\times2^{-1} + 1\times 2^{-2} + 1\times 2^{-3}) = 0.875$
$x_{1111} = 1(-1\times2^1 + 1\times2^{-1} + 1\times 2^{-2} + 1\times 2^{-3}) = - 0.125$
$x_{1000} = 1(-1\times2^1 + 0\times2^{-1} + 0\times 2^{-2} + 0\times 2^{-3}) = -1$

If the quantization is rounding symmetric then the decoding for the 0111, 0000, and 1000 are
$x_{0111} = 0.875 + 0.0625 = 0.9375$
$x_{0000} = 0 + 0.0625 = 0.0625$
$x_{1000} = -1 + 0.0625 = -0.9375.$

PRELAB EXERCISES

1. The maximum value of the signal x(t) is 5 vols. This signal is quantized to 8 bits. Find the value of the sample 3.7859 if it was quantized using rounding asymmetric and the two's compliment binary code for it.
2. Decode the following codes 01011011 and 010110000

Call the instructor to verify the prelab exercise.

Attendant Signature: ____

LAB EXERCISES

In the course website http://www.engineering.uco.edu/~mbingabr/ there are four audio files for this Lab. The first three files are music, song, and sentence without noise. The fourth file is a sentence with noise. All equations and theory can be found in the power point slides of the lecture for chapter 3 and in your textbook. Samples of codes you might need for this lab are provided in the textbook for chapter 3 and in the introduction.

First Task: Examine the impact of quantization methods on clean signal

a) Quantize the clean music, song, and sentence using rounding asymmetric to 16 levels (4 bits/sample) and reduce the bits to 3, 2, 1. Do you hear a difference between the original signals and the quantized signals in general? Which of the three files was affected the most with the low-level bits/sample? Explain your answers.

b) Quantize the clean sentence using rounding asymmetric and rounding symmetric to 8 levels (3 bits/sample). Which of the quantization method provides better sound quality? Explain your answer.

c) Quantize the sentence with noise to 16 levels (4 bits/sample) using rounding asymmetric and rounding symmetric. Do you hear a difference between the different quantization methods for the 4bits/sample? Reduce the number of bits/samples to 3 and 2 bits/samples. Did any of the quantization method had better reduction to noise as the number of bits decrease to 2 bits/samples?

Second Task: Convert samples to binary bits and examine the impact of noise.

a) Quantize the samples of the clean sentence to 16 levels (4 bits/sample) using rounding symmetric method. Convert the sample value to binary bits using the two's complement coding method. Store the binary information on a table with four columns and the number of rows equals the number of samples in the sentence. The four binary bits of each sample will be stored in a row in the table, see a sample of the table below.

MSB			LSB
1	0	0	1
1	0	1	1
0	0	0	1

b) Generate a column with rows equal the number of samples in the sentence. Fill the column with zeros and ones at random by using the random function in Matlab.

```
>> rand(10,1) > 0.5   % will generate column of 10 elements of zeros and ones at random.
```

Call this column a random noise. Corrupt the MSB column of the binary data of the sentence in part **a** by Ex-NOR this column with the noise column.

>> ~xor (a, b);
Based on probability and statistics what is the rate of corruption, bit error rate (BER)? Reconstruct the sentence samples from the corrupted binary data in the table. How severe is the corruption based on speech recognition (subjective measure)? Use objective measure such as the mean square error (MSE) to evaluate the corruption. Do the same thing to the second, third, and fourth column of the binary data and then reconstruct the sentence by decoding. Compare the quality and MSE of the reconstructed sentences from the corrupted bits for each column.

LAB REPORT FOR THIS LAB