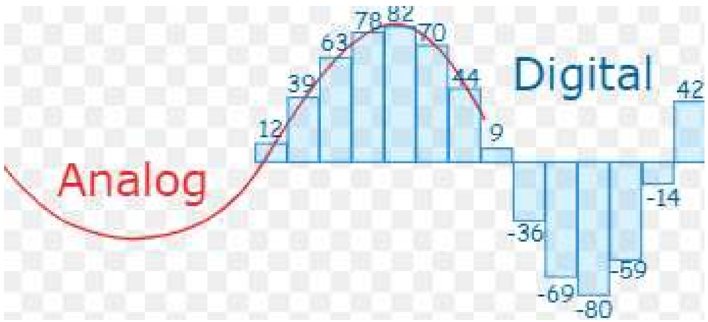
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
ISDN 2602

Laboratory 1: Analog to Digital Conversion (5%)



A) Objectives

In this lab, we will study the analog-to-digital conversion process. In the ideal case, we should investigate the theory and hardware implementation. Due to the limit, we will do it by simulation with MATLAB. There will be in total 4 tasks.

Task 1: (i) To study the process of converting an analog signal to a discrete-time signal by sampling.

(ii) To study the selection of the sampling frequency. Note that, after sampling, the signal is still not digital, given the amplitude is still continuous.

Task 2: To study the process of quantization.

Task 3: To investigate the effect of quantization on signal quality.

Task 4: To see how to use binary codes to represent the quantized levels. After that, we will have our digital signal.

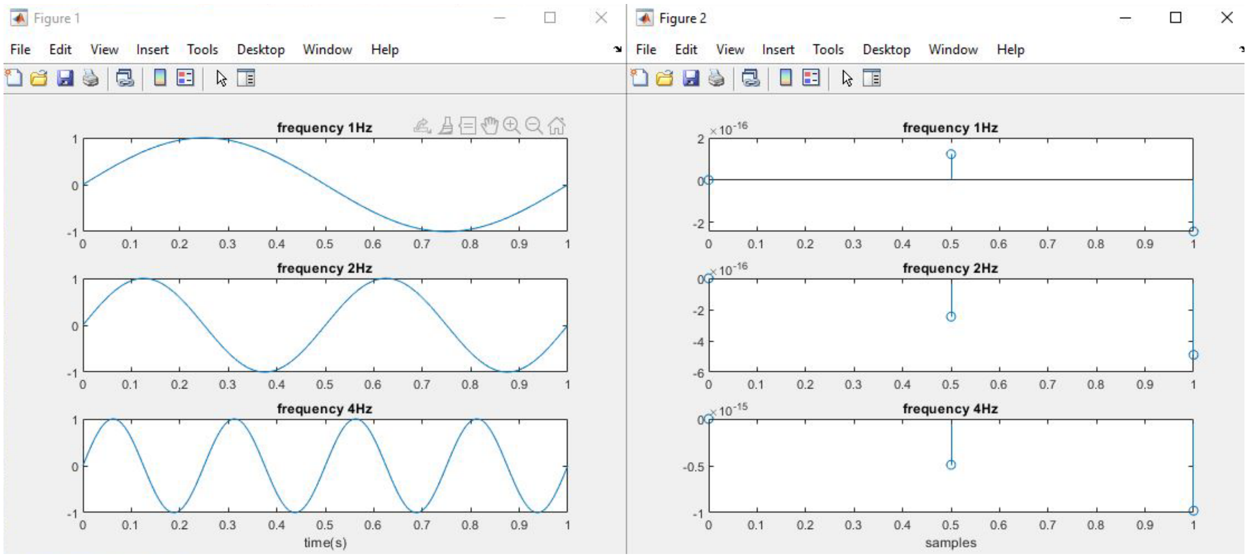
B) Lab tasks

Task 1: Sampling

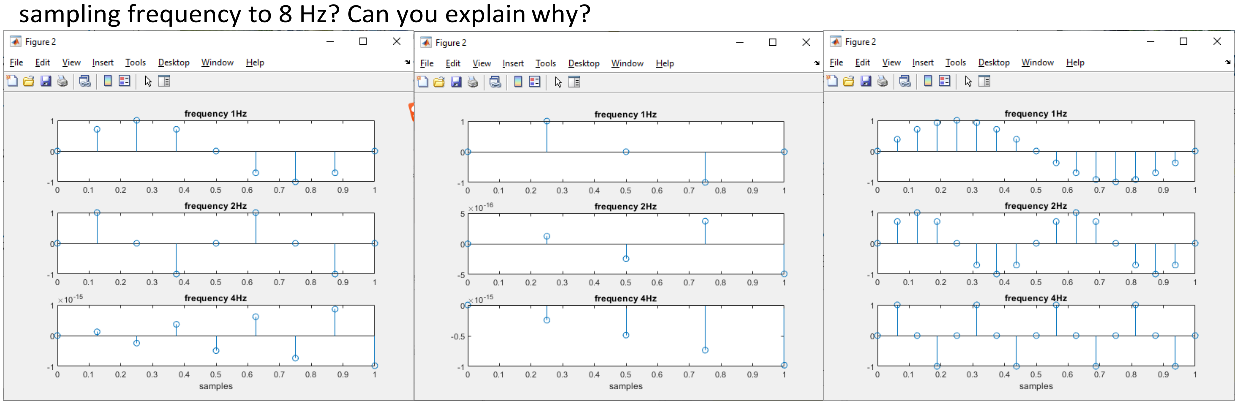
In this task, we will sample several sinusoid signals with different frequencies. The sampling frequency can be changed to observe the effects of sampling.

The code (Task1.m) first generates three sinusoid signals with frequencies 1Hz, 2Hz, and 4Hz, respectively. Check the codes to understand how the amplitude, frequency, and phase of a sinusoid signal are set. Then, the code picks the sampling frequency to be 2 samples/second. Note that the unit of sampling frequency is samples/second. Some people also use Hz as the unit for sampling frequency.

Run the code, and it will show two figures. The first one illustrates the analog signals, and the second shows the sampled version.



Based on the three sampled signals, can you figure out the original signals? Now, try to increase the sampling frequency to 4Hz. Can you figure out the original signals? How about further increasing the sampling frequency to 8 Hz? Can you explain why?



<u>Check Point:</u>

1) Are the three sinusoid signals generated by the code analog signals or digital signals? Explain.

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2) Try increasing the sampling frequency from 2 samples/sec to 4, 8, and 16 samples/sec. For each sampling frequency, can you identify the difference between the three sinusoid signals based on the sampled version? For different sampling frequencies, did you observe any aliasing effect?

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3) Based on the Nyquist sampling theorem, what is the minimum sampling frequency for the group of three sinusoid signals? Compare the number with the results of 2). Do they agree? Explain why.

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<u>Fill in the answers to the blanks.</u>

Task 2: Quantization

In this task, we will study how to quantize an amplitude value within a given range, say [-1v, 1v], to several fixed levels. Like Task 1, we will quantize a single-tone sinusoid signal.

The given code (Task2.m) first defines several parameters. **"b"** denotes the number of bits we want to use to represent the fixed levels, and **"N"** is the number of samples we want to have within one period of the sinusoid signal. The code then creates the sampled signal. Note that the sampled signal is within the range **[-1, 1]**. There are two lines to limit the signal levels to be **[-1, 1-eps]**. (See Check point 1) for more information about "eps".)

Run the code. A figure will show the original signal, the quantized signal, and the quantization error. The standard deviation will also be printed out in the command window.

Remark: The provided code used the "floor" function for quantization. You may also consider other functions.

Check point:

1) Use the **"help"** function to figure out the meaning of "eps" and explain the purpose of the operation that restricts the signal within the range [-1, 1). (Hint: Revise the code to x(x>=1)=1; Run the code, count the number of quantized levels, and answer the question.)

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2) The quantization process is done with three lines of code
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xq=floor((x+1)*2^(b-1));
xq=xq/(2^(b-1));
xq=xq-1+1/2^b;
```
Explain the operation of each line and list the range of values xq can take after each operation.

Codes	Explain the operation in your own words	Range of values in terms of "b"

3) In the first line of above code, we perform x+1 to shift the signal up by 1. However, in the third line, we not only perform xq-1 to shift down by 1, but also add an offset of 1/2^b to the result. Please explain the reason for adding the offset. (Hint: modify the code to remove the offset and observe the difference on the graph.)

4) Increase "b" from 3 to 5. Can you observe the improvement? What is the cost? Determine the corresponding number of bits needed to transmit one period of the sinusoid signal, with b=3 and 5, respectively.

<u>Fill in the answers to the blanks.</u>

Task 3 – Listen to the Effects of Quantization

In this task, we study the effect of quantization by listening to music with different quantization levels.

The given code (Task3.m) first defines the quantization bits, which correspond to the quantization levels. It then loads a file called "music.wav." After that, the code utilizes the function "**audioread**" to read the sampled data from the file and obtain the sampling frequency. Use "help" to understand more about the function "**audioread**". The next line normalizes the sampled data.

Next three lines perform the quantization and calculate the mean squared error. The quantized music signal is then concatenated with the original music signal and played by the function "**sound**". If you run the code, you will be able to hear the original music, a short break, and then the quantized music. Can you tell the difference? The frequency domain comparison between the original and quantized music signals is also shown in a figure.

Check point:

Try increasing the quantization bits and observe the effect of quantization.

1. What is the minimum number of quantization bits needed so that your ear cannot tell the difference between the original and quantized music?

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2. From the frequency domain comparison, what components of the original signal are more influenced by quantization error? Can you explain intuitively?

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3. Quantization is mainly done by the line "sq = (ceil(s*(L-0.5))-0.5)/L". Determine the possible values "sq" can take for the case "L=2 (b=2)" and "L=4 (b=3)". (Give "s" some specific values and check the corresponding "sq".)

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Fill in the answers to the blanks.

Task 4 (Bonus) – Coding

In this task, we will complete the ADC process and generate the binary codes to represent the original analog signal.

The first several lines of the code (Task4.m) are the same as that for Task 2. The encoding process has two steps. In the first step, it converts the decimal quantized levels to binary numbers. Then, the binary numbers are rearranged for ease of illustration. If you run the code, a figure will be generated showing the original analog signal, the quantized signal, and the binary signal. Try increasing the quantization bits from 1 to 5 and observe how it affects the signals.

Check point:

1) The codes for the second step are not well written. Your job is to rewrite the code by using the function "reshape". Use "reshape" to rewrite the codes between "%Rewrite the following codes%" and "%Donot change codes below%".

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2) Set the number of quantization bits to be 3. Explain why there are two long periods, where the encoded signal does not change (output "1" and "-1", respectively)?

Fill in the answers to the blanks.

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