Experiment No. 7

Sampling, Periodicity, Harmonics and Sound Manipulation

Objectives

1. To learn about the periodicity of continuous and discrete signals.
2. To be able to understand the sampling of different signals.
3. To learn about the harmonics and fundamental frequency.
4. To learn how to read audio signals and different operations on audio signals using MATLAB.

Equipment

1. PC
2. Installed MATLAB version 8.1under the release name R2017a

Sampling

A continuous time signal can be represented in its samples and can be recovered back when sampling frequency fs is greater than or equal to the twice the highest frequency component of message signal. i.e.

$$f_s \geq 2f_m$$

The above expression known as Nyquist–Shannon sampling theorem is a theorem in the field of signal processing which serves as a fundamental bridge between continuous-time signals and discrete-time signals. It establishes a sufficient condition for a **sample rate** that permits a discrete sequence of *samples* to capture all the information from a continuous-time signal of finite bandwidth. Generating a continuous signal and sampling it at a given rate is demonstrated here. In simulations, we may require to generate a continuous time signal and convert it to discrete domain by appropriate sampling.

MATLAB or any other simulation software process everything in digital i.e. discrete in time. Therefore, we cannot generate a real continuous-time signal on it, rather we can generate a "continuous-like" signal by using a very high sampling rate. When plotted, such signals look like continuous time signal processing.

Activity-1: Use MATLAB to generate a simple continuous-like sinusoidal signal $x(t) = \cos(2\pi f t)$ with frequency $f = 10\ kHz$. In order to make it appear as a continuous signal when plotting, use a sampling rate of $f_s = 500\ kHz$. Now sample the signal $x(t)$ using two different sampling frequencies $f_{s1} = 20\ kHz$ and $f_{s2} = 50\ kHz$. Plot all the results in the same window using MATLAB. Observe the effect of different sampling rates on signal $x(t)$.

```
clear
clc
close all
fs=500e3;              %Very high sampling rate 500 kHz
f=10e3;                %Frequency of sinusoid
```

```
nCyl=5;                %generate five cycles of sinusoid
t=0:1/fs:nCyl*(1/f); %time index
x=cos(2*pi*f*t);
subplot(311),plot(t,x,'linewidth',1.5,'color','b');
hold on
stem(t,x,'r');
title('Continuous Signal x(t) = cos(2\pift)'); xlabel('Time(s)');
ylabel('Amplitude');


% Chnaging Sampling Frequency
fs1=20e3;                  %30kHz sampling rate
t1=0:(1/fs1):nCyl*(1/f); %time index
x1=cos(2*pi*f*t1);
fs2=50e3;                  %50kHz sampling rate
t2=0:(1/fs2):nCyl*(1/f); %time index
x2=cos(2*pi*f*t2);
subplot(312),plot(t,x); hold on; stem(t1,x1);
title('x(t) sampled at fs=20 kHz'); xlabel('Time(s)');
ylabel('Amplitude');
subplot(313),plot(t,x); hold on; stem(t2,x2);
title('x(t) sampled at fs=50 kHz'); xlabel('Time(s)');
ylabel('Amplitude');
```

Periodicity

Periodicity means, something repeats after fixed interval. A signal is said to be **periodic signal** if it has a definite pattern and repeats itself at a regular interval of time. Whereas, the signal which does not at the regular interval of time is known as an **aperiodic signal** or **non-periodic signal**.

Continuous Time Periodic Signal

A continuous time signal x(t) is said to be periodic if and only if

$$x(t + T) = x(t)\, for\, -\infty < t < \infty$$

Where, T is a positive constant that represents the time period of the periodic signal. The smallest value of the time period (T) which justifies the definition of the periodic signal is known as **fundamental time period** of the signal and is denoted by (T_o).

Also,

$$x(t + mT) = x(t)$$

Where, m is an integer. This means if the definition is satisfied for $T = T_o$, then it is also satisfied for $T = 2T_o$, $T = 3T_o$ … and so on with T_o as the fundamental time period. Therefore, the fundamental time period defines the duration of one complete cycle of the periodic signal x(t). The reciprocal of the time period (T) of the periodic signal is called the frequency (f) of the signal, i.e.

$$f = \frac{1}{T}$$

Since the angular frequency is given by,

$$\omega = 2\pi f$$

$$\therefore \text{Time period, } T = \frac{2\pi}{\omega}$$

Some examples of continuous-time periodic signals are shown in Figure-1.

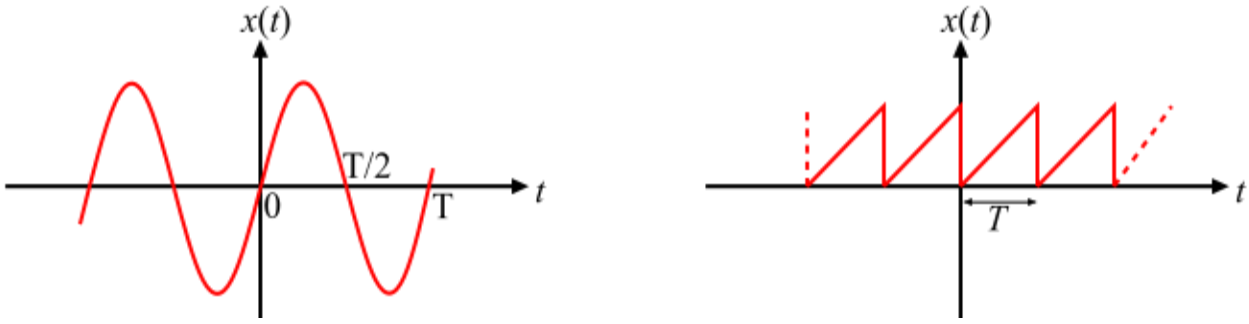


Figure 1

Discrete Time Periodic Signal

A discrete-time signal x(n) is said to be periodic if it satisfies the following condition:

$$x(n) = x(n + N); \quad for\ all\ integers\ n$$

Here, N is the time period of the periodic signal and a positive integer. The smallest value of the time period (N) which satisfies the above condition is known as fundament time period of the signal. The fundamental time period (N) may be defined as the minimum number of samples taken by signal to repeat itself.

The angular frequency of the discrete time periodic sequences is given by,

$$\omega = \frac{2\pi}{N}$$

Therefore, the time period of the sequence is,

$$N = \frac{2\pi}{\omega}$$

Some examples of the discrete time periodic sequences are shown in Figure-2.

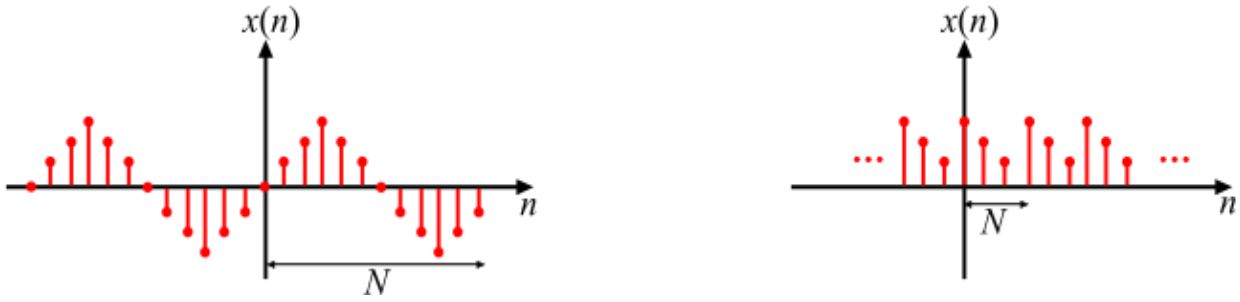


Figure 2

Activity-2: Examine whether the following signals are periodic or not? If periodic then determine the fundamental period of the signal.

$$\boldsymbol{x(t) = \sin(10\pi t)}$$

Solution:

Since the signal x(t) is a sinusoidal signal, hence, it is a periodic signal.
Now, comparing x(t) with standard signal, i.e., sin ωt, we get:

$$\omega = 10\pi$$

$$\therefore \textit{Fundamental Period, } T = \frac{2\pi}{\omega} = \frac{2\pi}{10\pi}$$

$$T = \frac{1}{5}\ sec$$

$$\boldsymbol{x(t) = \sin(\pi t)\, u(t)}$$

Solution:

Here, x(t) is the product of sinusoidal signal $sin(\pi t)$ and unit step signal $u(t)$. As we know, the signal $sin(\pi t)$ is periodic with time period $T = \frac{2\pi}{\omega}$ while the signal $u(t)$ exists only for $0 < t < \infty$. Thus, $u(t)$ is not a periodic signal.

Therefore, the signal x(t) is an aperiodic or non-periodic signal.

Harmonics

Harmonics are multiples of the fundamental frequency of a periodic signal. When a signal is decomposed into its constituent frequencies using Fourier analysis, the fundamental frequency is the lowest frequency component, and harmonics are integer multiples of this frequency. For example, if the fundamental frequency is f, the second harmonic is 2f, the third harmonic is 3f, and so on. Now, let's discuss even and odd harmonics:

1. Even harmonics: Even harmonics are those frequency components in a signal that have frequencies equal to an even multiple of the fundamental frequency. For instance, if the fundamental frequency is f, the even harmonics would be 2f, 4f, 6f, and so forth. Even

harmonics are characterized by symmetrical waveforms around the centerline or zero-crossing point of the signal.

2. Odd harmonics: Odd harmonics, on the other hand, are frequency components in a signal that have frequencies equal to an odd multiple of the fundamental frequency. So, if the fundamental frequency is f, the odd harmonics would be 3f, 5f, 7f, and so on. Odd harmonics are characterized by asymmetrical waveforms.

Different waveforms can be obtained by adding one type of harmonic e.g. adding infinite odd harmonics of sine/cosine where generates a square wave. Both will have a 90^o phase shift from each other.

Practically it is not possible to add all the (infinite) number of harmonics to obtain a perfect square wave but as the number of harmonics is increased from 10 onwards we obtain a decent square wave.

Activity-3: Generate a sinusoidal signal $x(t) = \sin(2\pi f t)$ with fundamental frequency $f = 50\ Hz$. Generate four harmonics of $x(t)$. Now add these five signals to make a new signal. Plot all the signals in the same window using MATLAB. Also plot the frequency spectrum of the original signal $x(t)$ along with the signal consisting of combination of harmonics and analyze all the outputs.

```
close all
clear
clc
fs = 1000;      % Sampling rate [Hz]
Ts = 1/fs;      % Sampling period [s]
fNy = fs / 2;   % Nyquist frequency [Hz]
duration = 10; % Duration [s]
t = 0 : Ts : duration-Ts; % Time vector
no_of_Samples = length(t);     % Number of samples
% Original signal
x = 220.*sin(2*pi*50*t);
% Harmonics
x1 = 100.*sin(2*pi*100*t);
x2 = 100.*sin(2*pi*200*t);
x3 = 100.*sin(2*pi*300*t);
x4 = 100.*sin(2*pi*400*t);
```

```
% Contaminated signal

x_out = x + x1 + x2 + x3 + x4;

% Frequency Analysis

f = 0 : fs/no_of_Samples : fs - (fs/no_of_Samples); % Frequency
vector

x_fft = abs(fft(x));

x_out_fft = abs(fft(x_out));

% Plot

subplot(421);plot(t, x);xlim([0 5*(1/50)]);

subplot(422);plot(t, x1);xlim([0 5*(1/100)]);

subplot(423);plot(t, x2);xlim([0 5*(1/200)]);

subplot(424);plot(t, x3);xlim([0 5*(1/300)]);

subplot(425);plot(t, x4);xlim([0 5*(1/400)]);

subplot(426);plot(t, x_out);xlim([0 0.11]);

subplot(427);plot(f,x_fft);xlim([0 fNy]);

subplot(428);plot(f,x_out_fft);xlim([0 fNy]);
```

Sound Manipulation in MATLAB

Sound manipulation refers to the process of modifying or altering audio signals to achieve specific objectives or desired outcomes. It involves applying various techniques and operations to audio data, such as filtering, equalization, noise removal, time stretching, pitch shifting, mixing, and more. Sound manipulation can be used for a wide range of purposes, including audio enhancement, audio effects, audio synthesis, audio restoration, and audio analysis.

In the context of MATLAB, sound manipulation involves utilizing the built-in signal processing functions and tools to process and transform audio signals. These operations can be performed on audio files or live audio streams, allowing for real-time audio processing and manipulation. MATLAB provides a rich set of functions for audio processing, enabling users to apply complex algorithms and techniques to manipulate sound in various ways.

Playback: An analog signal input to the sound card is sampled and digitized by sound software, such as the “sound recorder” in windows. The recorded sound signal is saved in a wav file. This file can be retrieved in MATLAB and played back.

Mono/Stereo: MATLAB Understands the Mono & Stereo Sounds as Single Column and 2 Column Vectors respectively. In STEREO different data using 2 hardware channels. STEREO was different data for left and right speakers. Mono is represented by single column vector and stereo by two column vectors in MATLAB.

MATLAB is a powerful tool for sound manipulation and signal processing. Here are some common sound manipulation tasks in MATLAB:

1. Read and write audio files: You can use the audioread() function to read audio files into MATLAB and the audiowrite() function to save audio files from

```
% read audio file
file_path = 'File Path';
[y, fs] = audioread(file_path);


% write audio file
audiowrite('new_audio_file.wav', y, fs);
```

2. Play audio: You can use the sound() function to play audio in MATLAB. This function plays audio in the default audio output device of your computer.

```
sound(y, fs);
```

3. Plot audio waveforms: You can use the plot() function to plot the waveform of an audio signal. This can help you visualize the shape and amplitude of the

```
t = (0:length(y)-1)/fs; % create time vector
plot(t, y);
xlabel(time)
xlabel('Time (s)');
ylabel('Amplitude');
title('Audio Signal');
```

Lab Tasks (Psychomotor)

1. Generate 5 cycles of a triangle wave with a fundamental frequency of 1 kHz using MATLAB. Sample the signal with 3 different sampling rates in such a way that Nyquist criteria should be fulfilled/not-fulfilled. Plot all signals in the same window with proper labeling.

2. Briefly explain whether the given signal is periodic/aperiodic? Also plot four cycles of this signal using MATLAB.

$$y(t) = cos\left(\frac{\pi t}{2} + 3\right) + cos\left(\frac{2\pi t}{3} + 5\right)$$

3. Refer to activity 3 of this lab and perform same task for a harmonic signal of your choice with the following requirements:

    1. Fundamental frequency: 100 Hz
    2. Number of harmonics: 5 (include the fundamental frequency)

4. Download an audio file from the link given below and play it using MATLAB. Also plot the signal.

    http://www.wavsource.com/sfx/sfx.htm

Lab Tasks (Cognitive)

Q. No.	Cognitive Assessment Question	Marks
1	A triangle wave has frequency 1 kHz. Determine the minimum sampling frequency required by the Nyquist criterion.	2
2	For a 1 kHz signal, determine whether sampling at 3 kHz satisfies the Nyquist criterion and state the consequence if it does not.	2
3	For y(t)=cos(πt/2+3)+cos(2πt/3+5), determine whether the ratio of the component frequencies is rational and use this to decide whether the sum is periodic.	2
4	A harmonic signal has fundamental frequency 100 Hz and contains the fundamental plus five harmonics. Determine the frequencies of the first five harmonics.	2
5	Explain why an audio signal sampled below twice its highest frequency can produce an aliased frequency that was not present in the original signal.	2

Lab Exercise and Summary

Summary should cover Introduction, Procedure, Data Analysis and Evaluation.

Student's Signature: _____ **Date: _____**

LABORATORY SKILLS ASSESSMENT (Cognitive)

Obtained Marks	/10

Instructor's Signature: _____ Date: _____

LABORATORY SKILLS ASSESSMENT (Psychomotor)

Psychomotor Activity 1 — Experimental Setup

S. No	Criteria	Performance	Description	Marks
1	**Sampling & Signal Setup (4)**	Level 4	Correctly prepares MATLAB and defines the triangle wave, sinusoidal/harmonic and audio-signal environment.	4
		Level 3	Correctly prepares the required environment with minor errors or assistance.	3
		Level 2	Partially prepares the required environment and requires considerable assistance.	2
		Level 1	Shows limited ability to prepare the required environment and requires substantial assistance.	1
2	**Experiment Configuration (4)**	Level 4	Correctly organizes the script for multiple sampling rates, periodicity test, harmonic generation and audio plotting.	4
		Level 3	Completes the experiment configuration with minor errors or assistance.	3
		Level 2	Partially completes the experiment configuration and requires considerable assistance.	2
		Level 1	Experiment configuration is largely incomplete and requires substantial assistance.	1
3	**Sampling & Frequency Parameters (2)**	Level 2	Correctly defines fundamental frequency, sampling rates, harmonic frequencies and time vector.	2
		Level 1	Defines fundamental frequency, sampling rates, harmonic frequencies and time vector with minor errors or assistance.	1
Total Obtained				/10

If a student is absent:

Criteria	Description	Marks
Absent	Student is absent from the laboratory activity.	**0**

Psychomotor Activity 2 — Implementation + Results

S. No	Criteria	Performance	Description	Marks
1	Sampling/ Harmonic Implementation & Safe Working Practice (4)	Level 4	Correctly implements sampling cases, periodicity calculation and harmonic generation independently and follows proper laboratory practices.	4
		Level 3	Implements the assigned work with minor errors or assistance and generally follows proper laboratory practices.	3
		Level 2	Partially implements the assigned work and requires considerable assistance or repeated guidance.	2
		Level 1	Implementation is largely incomplete, requires substantial assistance, or shows poor adherence to proper laboratory practices.	1
2	Execution & Audio/Plot Verification (2)	Level 2	Correctly executes the signal/audio operations and generates the required outputs.	2
		Level 1	Executes the signal/audio operations and generates the required outputs with minor errors or assistance.	1
3	Sampling & Harmonic Results (4)	Level 4	Correctly shows sampling effects, periodicity result, harmonic combination and audio waveform.	4
		Level 3	Produces mostly correct results/plots with minor errors or omissions.	3
		Level 2	Produces partially correct results/plots with noticeable errors or omissions.	2
		Level 1	Results/plots are largely incorrect or incomplete.	1
	Total Obtained			/10

If a student is absent:

Criteria	Description	Marks
Absent	Student is absent from the laboratory activity.	**0**

Instructor's Signature: _____ **Date:** _____

LABORATORY SKILLS ASSESSMENT (Affective)

Affective Activity — Lab Report + Viva Voce

S. No	Criteria	Performance	Description	Marks
1	Lab Report Completeness & Organization (4)	Level 4	Report is complete, well-organized, properly presented, and demonstrates responsible completion of the assigned Signals and Systems laboratory work.	4
		Level 3	Report is complete with minor omissions or organizational issues and demonstrates satisfactory responsibility for the assigned work.	3
		Level 2	Report is partially complete with several omissions and demonstrates limited responsibility for the assigned work.	2
		Level 1	Report has major omissions or poor organization and demonstrates minimal responsibility for the assigned work.	1
2	Code, Results & Conclusion (2)	Level 2	MATLAB code, results/plots, and conclusion are correctly presented and discussed, demonstrating ownership of the assigned work.	2
		Level 1	MATLAB code, results/plots, or conclusion are presented with minor errors or omissions.	1
3	Viva Voce (4)	Level 4	Clearly explains the assigned MATLAB code, signal/system concepts, analysis, results, and plots, demonstrating individual responsibility, participation, and effective communication.	4
		Level 3	Explains most of the assigned work and results correctly, with minor difficulty, and demonstrates good individual participation.	3
		Level 2	Explains basic aspects of the assigned work with some prompting and demonstrates basic participation.	2
		Level 1	Demonstrates limited understanding or involvement and requires substantial prompting to explain the assigned work.	1
	Total Obtained			/10

The student has not submitted the report and has not appeared in the Viva Voce.

Criteria	Description	Marks
Lab Report and Results Not Submitted	Student has not submitted the report and results file.	0
Absent in Viva Voce	Student is absent from the viva voce.	0

Instructor's Signature: _____ **Date:** _____