# Cover page - Include the following:

• Name and ID number

• Course number and lab Section Date performed

• Due Date

• Lab Instructor Name

# Objectives –

The objective of this lab was to introduce students to MATLAB functionalities and to explore the properties of discrete-time signals and systems. The lab was divided into two main parts:

**Part I:** Focused on understanding the use of MATLAB programming constructs such as loops, conditional statements, and array processing. This part also included verifying properties of signals and systems like linearity, even or odd properties through MATLAB.

**Part II:** Aimed at analyzing a system’s response using convolution and exploring the system properties through mathematical and experimental approaches. The MATLAB convolution function was used to determine the output response of a system based on a given input signal, and the results were compared against theoretical expectations.

# Theory -

In this lab, the theoretical foundation centers around the analysis of discrete-time signals and systems, specifically their properties and responses. The key theoretical concepts covered include:

1. **MATLAB Programming Constructs** **demonstrated to validate Signal properties:**

* For loops
* Conditional statements (if, else)
* Array manipulation techniques
* MATLAB’s conv function

1. **Properties of Signals:**

* Linearity: A system is considered linear if it adheres to the principle of superposition.
  + Let and and
  + If , then
  + If , then
* Even Signals if
* Odd Signals if

1. **System** **convolution Response Analysis:**

* Convolution operation is fundamental in determining a system’s response to a given input.

1. **Time-Invariance:**

* A system is considered time-invariant if its behavior and characteristics do not change over time. If a time-shifted input results in a time-shifted output, then the system is time-invariant.

# Tasks/Results/Discussion

## Part I: MATLAB Programming Features and Signal Properties

### Task for loop:

1. **Compute and display** **the MATLAB script from the example 1.**
   * The output display is 55, since the summation y = = 55.
2. **Compute and display** **the MATLAB script from the example 2.**
   * The output display is 55, since the summation y = = 55.
3. **Compute and display** **the MATLAB script from the example 3.**
   * The output display is 55, since the summation y = = 55.

### Task for if Statement:

1. **Read example 1.**
   * It displays a basic if statement and the explain the relational operators for conditional statements in MATLAB.
2. **Compute and display the MATLAB script from the example 2.**
   * It introduces the concept of user input and code flow changing based on user interaction.
3. **Compute and display the MATLAB script from the example 3.**

* It introduces the “else” branch to control the flow when the contrition is negated.

1. **Compute and display the MATLAB script from the example 4.**
   * It introduces some good programing practice to avoid round off error.

### Task for Linearity:

1. **Compute and display** **the MATLAB script from the example 1.**
   * It confirmed the linearity of and the example using MATLAB and display the string “Outputs are consistent with a linear system”.

### Task for Even-Odd signals:

1. **Compute and display** **the MATLAB script from the example 2.**
   * It demonstrate the notion of even or odd signal by finding the even and odd component of a signal.

Table 1Even and odd Component seperation

|  |
| --- |
| A screen shot of a diagram  Description automatically generated |
| A diagram with red dots and numbers  Description automatically generated |
| A screenshot of a graph  Description automatically generated |
| A graph with purple dots and black text  Description automatically generated |

* The original signal is in blue, The flipped signal is in red. The even component is in green and the odd component is in purple.
* The even part is found by using the equation .
* The odd part is found by using the equation .

### Tips for Saving plot:

1. **Save file using print**
   * First argument specify the file type (eg. -dpsc)
   * Second argument specify the file name and extension (eg. even\_odd\_components.ps). The extension has to mathc the file type.

## Part II: System Response and Convolution

This part of the lab demonstrate the use of convolution to analyze system responses and provide a practical means to validate theoretical system properties.Here are the main goals:

* Determine the System Response Using Direct Computation.
* Compute the System Response Using Convolution.
* Compare the Convolution-Based Response with the Direct Computation Response

# Questions –

## Part I: MATLAB Programming Features and Signal Properties

### Question 1:

1. **Plot the input signal**  **and the output signal**  **over the interval n = 0, 1,2, 3, 4, 5, 6, 7, 8, 9. Compute the total energy in the signal 𝑥[𝑛] and 𝑦[𝑛] (**Hint: the total energy in a signal is equal to the sum of the squares of all the values contained in the signal)**. Use the disp command to display the two energies.**

Table 2 Code and Output question 1-A

|  |
| --- |
| % Define the interval, input and output signal  n = 0:9;  x = n;  y = x.^2;  % Calculate the total energy of signals x[n] and y[n]  energy\_x = sum(x.^2);  energy\_y = sum(y.^2);  % Display the total energies  disp([‘Total energy of the input signal x[n]: ‘, num2str(energy\_x)]);  disp([‘Total energy of the output signal y[n]: ‘, num2str(energy\_y)]);  % Plot the input signal x[n]  figure;  subplot(2, 1, 1);  stem(n, x, ‘filled’, ‘LineWidth’, 1.5, ‘Color’, ‘b’);  title(‘Input Signal x[n] = n’);  xlabel(‘n’);  ylabel(‘x[n]’);  grid on;  % Plot the output signal y[n]  subplot(2, 1, 2);  stem(n, y, ‘filled’, ‘LineWidth’, 1.5, ‘Color’, ‘r’);  title(‘Output Signal y[n] = x^2[n]’);  xlabel(‘n’);  ylabel(‘y[n]’);  grid on; |
| Total energy of the input signal x[n]: 285  Total energy of the output signal y[n]: 15333 |
| **A graph of a function  Description automatically generated with medium confidence** |

* The energy value is larger for the output signal as expected ,since the input value is squared twice.

1. **Repeat part (a) using the input signal , n = 0, 1, 2, …, 9. Use the MATLAB function sin to compute the values of the input signal over the specified interval. Use the help sin facility to learn how to use the sin function.**

Table 3 Code and Output question 1-B

|  |
| --- |
| % Define the interval, input and output signal  n = 0:9;  x = sin((2\*pi/10) \* n);  y = x.^2;  % Calculate the total energy of the input signal x[n]  energy\_x = sum(x.^2);  energy\_y = sum(y.^2);  % Display the total energies  disp(['Total energy of the input signal x[n]: ', num2str(energy\_x)]);  disp(['Total energy of the output signal y[n]: ', num2str(energy\_y)]);  % Plot the input signal x[n]  figure;  subplot(2, 1, 1);  stem(n, x, 'filled', 'LineWidth', 1.5, 'Color', 'b');  title('Input Signal x[n] = sin((2\pi/10)\*n)');  xlabel('n');  ylabel('x[n]');  grid on;  % Plot the output signal y[n]  subplot(2, 1, 2);  stem(n, y, 'filled', 'LineWidth', 1.5, 'Color', 'r');  title('Output Signal y[n] = x^2[n]');  xlabel('n');  ylabel('y[n]');  grid on; |
| Total energy of the input signal x[n]: 5  Total energy of the output signal y[n]: 3.75 |
| **A graph of a function  Description automatically generated** |

* + - The sinusoid x[n] has an maximum amplitude of 1 so squaring all the value will result in a positive signal y[n] with an amplitude smaller or equal to the x[n]. This also explain why the energy of the signal y[n] is smaller then the energy of x[n].

### Question 2:

1. **Determine whether the discrete time system which has an output over the interval 0 ≤ 𝑛 ≤ 10 is linear or not by determining the response to the input signal and the response to the input signal .**

**Determine the response to the input signal + and compare it with . Plot** (using stem) **in one graph all the input signals and their corresponding output signals. Use the disp command to output whether the system has ‘outputs consistent with a linear system’ or ‘not linear’.**

Table 4 Code and Output question 2-A

|  |
| --- |
| % Define the interval and input signals  n = 0:10;  x1 = sin((2\*pi/10) \* n); % Input signal x1[n]  x2 = cos((2\*pi/10) \* n); % Input signal x2[n]  % Compute the output responses y1[n] and y2[n]  y1 = 2 \* x1;  y2 = 2 \* x2;  % Define the combined input signal x3[n]  x3 = x1 + x2;  % Compute the response y3[n] and y4[n]  y3 = 2 \* x3;  y4 = y1 + y2;  % Plot the input and output signals  figure;  % Plot input signals x1[n], x2[n], and x3[n]  subplot(4, 2, 1);  stem(n, x1, 'filled', 'LineWidth', 1.5, 'Color', 'b');  title('Input Signal x\_1[n] = sin((2\pi/10)\*n)');  xlabel('n');  ylabel('x\_1[n]');  grid on;  subplot(4, 2, 3);  stem(n, x2, 'filled', 'LineWidth', 1.5, 'Color', 'r');  title('Input Signal x\_2[n] = cos((2\pi/10)\*n)');  xlabel('n');  ylabel('x\_2[n]');  grid on;  subplot(4, 2, [5, 6]);  stem(n, x3, 'filled', 'LineWidth', 1.5, 'Color', 'm');  title('Combined Input Signal x\_3[n] = x\_1[n] + x\_2[n]');  xlabel('n');  ylabel('x\_3[n]');  grid on;  % Plot output signals y1[n], y2[n], y3[n] and y4[n]  subplot(4, 2, 2);  stem(n, y1, 'filled', 'LineWidth', 1.5, 'Color', 'g');  title('Output Signal y\_1[n] = 2x\_1[n]');  xlabel('n');  ylabel('y\_1[n]');  grid on;  subplot(4, 2, 4);  stem(n, y2, 'filled', 'LineWidth', 1.5, 'Color', 'c');  title('Output Signal y\_2[n] = 2x\_2[n]');  xlabel('n');  ylabel('y\_2[n]');  grid on;  subplot(4, 2, 7);  stem(n, y3, 'filled', 'LineWidth', 1.5, 'Color', 'k');  title('Output Signal y\_3[n] = 2x\_3[n]');  xlabel('n');  ylabel('y\_3[n]');  grid on;  subplot(4, 2, 8);  stem(n, y4, 'filled', 'LineWidth', 1.5, 'Color', 'k');  title('Expected Output y\_4[n] = y\_1[n] + y\_2[n]');  xlabel('n');  ylabel('y\_4[n]');  grid on;  % Compare y3[n] with y4[n] to check linearity  if isequal(y3, y4)  disp('The system has outputs consistent with a linear system.');  else  disp('The system is not linear.');  end |
| The system has outputs consistent with a linear system. |
| **A graph of a function  Description automatically generated with medium confidence** |

* + - The system was confirm to be linear,because it respect the superposition principle.

1. **Design an experiment to test whether the systems:** (Note: *Student must answer this question in their lab report.*)
   1. **𝑦[𝑛] = 𝑥2[𝑛]**
   2. **𝑦[𝑛] = 2𝑥[𝑛] + 5𝛿[𝑛]**

**are linear and time-invariant. Use the input data x[n] = [0,1]. Next, using a larger set of values, for your choice of the input data, repeat the experiment and analyze and interpret the results obtained with this new data set. Do the new results validate or invalidate the original results obtained with x[n] = [0,1] as choice of input data? Explain how a choice of data used may impact the results obtained.**

Table 5 Code and Output question 2-B-I

|  |
| --- |
| % System 1 Analysis  x1 = [0, 1];  x2 = 2 \* x1;  x3 = x1 + x2;  y1 = x1 .^ 2;  y2 = x2 .^ 2;  y3 = x3 .^ 2;  y4 = y1 + y2;  % Check for Linearity  disp("System 1 Part 1 ([0,1]): ");  if (max(abs(y3 - y4)) < 0.001)  disp("Linear");  else  disp("Not Linear");  end  % Check for Time Invariance  x\_shifted = [0, x1(1:end-1)];  y\_shifted = x\_shifted .^ 2;  y\_shifted\_expected = [0, y1(1:end-1)];  if (max(abs(y\_shifted - y\_shifted\_expected)) < 0.001)  disp("Time Invariant");  else  disp("Time Variant");  end  % System 1 Analysis for n = [0:10]  n = 0:10;  x1\_n = 3\*n.^2 - 6\*n;  x2\_n = 2 \* x1\_n;  x3\_n = x1\_n + x2\_n;  y1\_n = x1\_n .^ 2;  y2\_n = x2\_n .^ 2;  y3\_n = x3\_n .^ 2;  y4\_n = y1\_n + y2\_n;  % Check for Linearity with n = [0:10]  disp("System 1 Part 2 ([0,10]): ");  if (max(abs(y3\_n - y4\_n)) < 0.001)  disp("Linear");  else  disp("Not Linear");  end  % Time Invariance for n = [0:10]  x\_shifted\_n = [0, x1\_n(1:end-1)];  y\_shifted\_n = x\_shifted\_n .^ 2;  y\_shifted\_n\_expected = [0, y1\_n(1:end-1)];  if (max(abs(y\_shifted\_n - y\_shifted\_n\_expected)) < 0.001)  disp("Time Invariant");  else  disp("Time Variant");  end |
| System 1 Part 1 ([0,1]):  Not Linear  Time Invariant  System 1 Part 2 ([0,10]):  Not Linear  Time Invariant |

* + - The system was confirm to be non linear, because it does not respect the superposition principle.

Table 6 Code and Output question 2-B-II

|  |
| --- |
| % Define System 2 Part 1 ([0, 1])  x1 = [0, 1];  x2 = 2 \* x1;  x3 = x1 + x2;  impulse\_pos = 1;  dirac1 = zeros(size(x1));  dirac1(impulse\_pos) = 1;  % Define Output Signals  y1 = 2 .\* x1 + 5 \* dirac1;  y2 = 2 .\* x2 + 5 \* dirac1;  y3 = 2 .\* x3 + 5 \* dirac1;  y4 = y1 + y2;  % Display Results for Linearity Check (Part 1)  disp("System II Part 1 ([0,1]): ");  if max(abs(y3 - y4)) < 0.001  disp("Linear");  else  disp("Not Linear");  end  % Time Invariance Check (Part 1)  x\_shifted = [0, x1(1:end-1)];  dirac\_shifted = [0, dirac1(1:end-1)];  y\_shifted = 2 .\* x\_shifted + 5 \* dirac\_shifted;  y\_shifted\_expected = [0, y1(1:end-1)];  if max(abs(y\_shifted - y\_shifted\_expected)) < 0.001  disp("Time Invariant");  else  disp("Time Variant");  end  % Define System 2 Part 2 ([0, 10])  n = 0:10;  x1\_n = 2 \* n .^ 2 + 4 \* n;  x2\_n = 2 \* x1\_n;  x3\_n = x1\_n + x2\_n;  % Define Impulse for Larger Range  dirac\_n = zeros(size(n));  dirac\_n(1) = 1;  % Define Output Signals for Larger Set  y1\_n = 2 .\* x1\_n + 5 \* dirac\_n;  y2\_n = 2 .\* x2\_n + 5 \* dirac\_n;  y3\_n = 2 .\* x3\_n + 5 \* dirac\_n;  y4\_n = y1\_n + y2\_n;  % Display Results for Linearity Check (Part 2)  disp("System II Part 2 ([0,10]): ");  if max(abs(y3\_n - y4\_n)) < 0.001  disp("Linear");  else  disp("Not Linear");  end  % Time Invariance Check (Part 2)  x\_shifted\_n = [0, x1\_n(1:end-1)];  dirac\_shifted\_n = [0, dirac\_n(1:end-1)];  y\_shifted\_n = 2 .\* x\_shifted\_n + 5 \* dirac\_shifted\_n;  y\_shifted\_n\_expected = [0, y1\_n(1:end-1)];  if max(abs(y\_shifted\_n - y\_shifted\_n\_expected)) < 0.001  disp("Time Invariant");  else  disp("Time Variant");  end |
| System II Part 1 ([0,1]):  Not Linear  Time Invariant  System II Part 2 ([0,10]):  Not Linear  Time Invariant |

* + - In both cases the results validate the original results. This confirm that the systems are not linear and not time invariant regardless of the input choice.

### Question 3:

1. **Plot the following signal 𝑥[𝑛], its mirror image 𝑥[−𝑛], and it’s even and odd components:** 
   1. **, 0 ≤ 𝑛 ≤ 10**
   2. **Use the MATLAB functions exp and abs .**

|  |
| --- |
| % Define the range of n  n = 0:10;  % Compute the given signal x[n]  x\_n = exp(-2 \* abs(n)) .\* sin((2 \* pi / 36) \* n);  % Define the mirror image x[-n]  n\_mirror = -fliplr(n); % Create a flipped version of n to represent -n  x\_mirror = fliplr(x\_n); % Mirror image of x[n] is simply the flipped x[n]  % Calculate even and odd components of the signal  x\_even = 0.5 \* (x\_n + x\_mirror); % Even component  x\_odd = 0.5 \* (x\_n - x\_mirror); % Odd component  % Plot the original signal x[n]  subplot(2, 2, 1);  stem(n, x\_n, 'filled');  title('Original Signal x[n]');  xlabel('n');  ylabel('x[n]');  % Plot the mirror image x[-n]  subplot(2, 2, 2);  stem(n\_mirror, x\_mirror, 'filled');  title('Mirror Image Signal x[-n]');  xlabel('n');  ylabel('x[-n]');  % Plot the even component  subplot(2, 2, 3);  stem(n, x\_even, 'filled');  title('Even Component of x[n]');  xlabel('n');  ylabel('Even Component');  % Plot the odd component  subplot(2, 2, 4);  stem(n, x\_odd, 'filled');  title('Odd Component of x[n]');  xlabel('n');  ylabel('Odd Component');  % Display the plots  sgtitle('Analysis of Signal x[n] and its Components'); |
| A graph of a function  Description automatically generated with medium confidence |

* + - The even and odd component were recreated.

1. **Repeat part (a) for the signal: 𝑥[𝑛] = (−1)𝑛−1 , −5 ≤ 𝑛 ≤ 5**

|  |
| --- |
| % Define the range of n  n = -5:5;  % Compute the given signal x[n]  x\_n = (-1).^(n - 1);  % Define the mirror image x[-n]  n\_mirror = -fliplr(n); % Create a flipped version of n to represent -n  x\_mirror = fliplr(x\_n); % Mirror image of x[n] is simply the flipped x[n]  % Calculate even and odd components of the signal  x\_even = 0.5 \* (x\_n + x\_mirror); % Even component  x\_odd = 0.5 \* (x\_n - x\_mirror); % Odd component  % Plot the original signal x[n]  subplot(2, 2, 1);  stem(n, x\_n, 'filled');  title('Original Signal x[n]');  xlabel('n');  ylabel('x[n]');  % Plot the mirror image x[-n]  subplot(2, 2, 2);  stem(n\_mirror, x\_mirror, 'filled');  title('Mirror Image Signal x[-n]');  xlabel('n');  ylabel('x[-n]');  % Plot the even component  subplot(2, 2, 3);  stem(n, x\_even, 'filled');  title('Even Component of x[n]');  xlabel('n');  ylabel('Even Component');  % Plot the odd component  subplot(2, 2, 4);  stem(n, x\_odd, 'filled');  title('Odd Component of x[n]');  xlabel('n');  ylabel('Odd Component');  % Display the plots  sgtitle('Analysis of Signal x[n] and its Components'); |
| A screenshot of a graph  Description automatically generated |

* + - This signal was an even signal since the decomposition show that the odd component is zero for all the values.

1. **Compare and contrast the two methods used to generate the two MATLAB arrays x1 and x2 in the following MATLAB code:**

|  |
| --- |
| % T. Obuchowicz  %Fri Apr 27 16:03:27 EDT 2012  clear  n = [1 : 20 ]  x1 = sin((2\*pi/40) \* n) .\* cos((2\*pi/40) \* n)  for index = 1 : 20  % Note: In MATLAB, no need to pre-allocate the array,  % unlike C++ and other high-level programming languages.  x2(index) = sin((2\*pi/40) \* index) \* cos((2\*pi/40) \* index)  end  subplot(2,1,1)  stem(n, x1)  title(‘Elegant method making full use of MATLABs array capabilities’)  xlabel(‘n’)  ylabel(‘x[n]’)  subplot(2,1,2)  stem(n, x2)  title(‘Gets the job done, but it is a lot of work and we are not in the MATLAB  mindset’)  xlabel(‘n’)  ylabel(‘x[n]’) |
| A graph with blue lines and numbers  Description automatically generated |

* + - They will both produce the same outputs, but there is a difference in the way they handle data. The first method utilize the built in MATLAB functionality and can be written in a single line. The second method give more transparency on what is happening, but is also less efficient.

## Part II: System Response and Convolution

### Question 1:

**For this system, compute the response 𝑦[𝑛] over the interval 0 ≤ 𝑛 ≤ 9 using the input signal 𝑥[𝑛] given in Figure 4.**

|  |
| --- |
| A graph with lines and numbers  Description automatically generated |

**Plot the response using the stem function.**

|  |
| --- |
| % Define the input signal x[n]  n = 0:9;  x = zeros(1, 10);  x(1) = 1;  x(3) = 1;  x(4) = 1;  % Define the impulse response h[n] for the assumed system  h = (0.5) .^ (0:9);  % Compute the system response using convolution  y = conv(x, h);  % Truncate y[n] to the interval  y = y(1:10);  % Plot the response using stem  figure;  stem(n, y, 'filled');  title('System Response y[n]');  xlabel('n');  ylabel('y[n]');  grid on; |
| A graph with blue dots and numbers  Description automatically generated |

### Question 2:

**MATLAB contains a built-in function called conv which performs the convolution of two vectors:**

|  |
| --- |
| >> help conv  conv Convolution and polynomial multiplication.  C = conv(A, B) convolves vectors A and B. The resulting vec-  tor is  length MAX([LENGTH(A)+LENGTH(B)-1,LENGTH(A),LENGTH(B)]). If A  and B are  vectors of polynomial coefficients, convolving them is equivalent  to multiplying the two polynomials. |

**Compute the system response (using the input signal 𝑥[𝑛] given in Question (1)) by convolving 𝐻[𝑛] and 𝑥[𝑛] using the MATLAB conv function. Plot the response using stem. Compare this response with that obtained in Question 1. Explain any differences between the two outputs.**

|  |
| --- |
| % Define the input signal x[n]  n = 0:9;  x = zeros(1, 10);  x(1) = 1; % x[0] = 1  x(3) = 1; % x[2] = 1  x(4) = 1; % x[3] = 1  % Define the impulse response h[n]  h = [0.5, 0.25, 0.125];  % Compute the system response using convolution  y = conv(x, h);  % Truncate the output to the interval 0 <= n <= 9  y\_truncated = y(1:10);  % Plot the original input signal x[n]  figure;  subplot(2, 1, 1);  stem(n, x, 'filled');  title('Input Signal x[n]');  xlabel('n');  ylabel('x[n]');  grid on;  % Plot the truncated system response y[n]  subplot(2, 1, 2);  stem(n, y\_truncated, 'filled');  title('System Response y[n] using Convolution');  xlabel('n');  ylabel('y[n]');  grid on; |
| A graph of a function  Description automatically generated with medium confidence |

### Question 3:

# Conclusions –

State what was achieved in the lab and contrast with the experiment objectives. Conclude on the

salient portions of the lab. Do not write conclusions of the form:

*“This was an excellent experiment for me to learn how to use MATLAB and allowed me to have*

*a better understanding of the analog and digital filter techniques in MATLAB... I found this lab*

*extremely long; however, it was a rewarding experience in the end. To conclude, I really*

*enjoyed this lab and it was an excellent learning opportunity.”*

A proper conclusion would be of the following manner:

*“This lab explores the use of the MATLAB FDA tool to design both analog and digital filters.*

*Simulink was used to import an audio file and the differences between up and down sampling*

*were observed. The sample was also filtered, and the effects of the filtering were noted.”*

# Appendix –

Include in the appendix your MATLAB code. The MATLAB programs are to be demonstrated

to the lab TA and a printout of your MATLAB code and/or results is to be **signed** by the lab TA.

Your lab TA will provide more specific details with regards to the demonstration and signing of

the printouts during each lab session. Your lab instructor will also provide details concerning the3 | P a g e

submission of the written lab report.