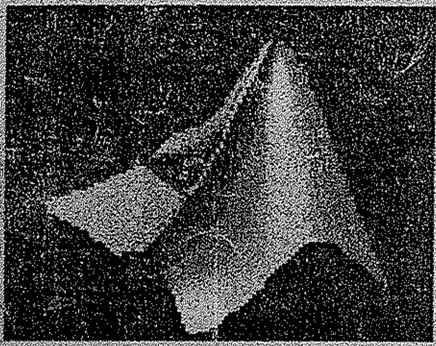
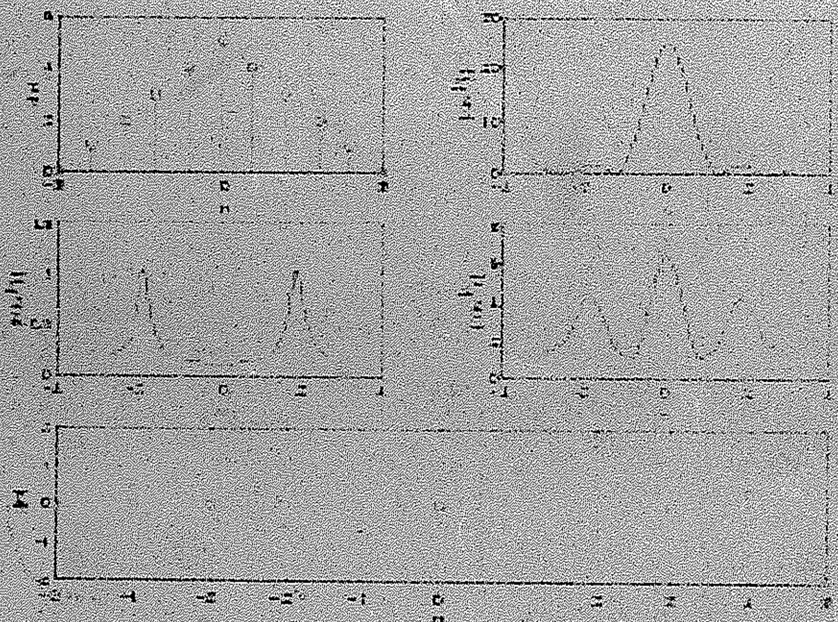


Matlab Primer

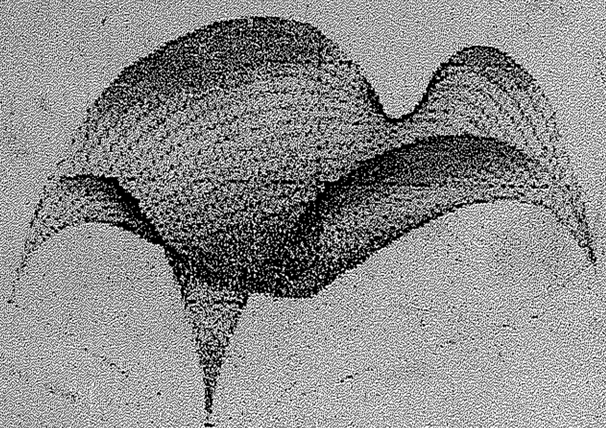
By Bilkent University IEEE Student Branch

```
» syms x
» int(x^2+2)
ans =
  1/3*x^3+2*x

» diff(x^2+2)
ans =
  2*x
```



```
A=
 1 4 6
 3 5 7
```



October 2000

CONTENTS

I. VECTORS

When you run MATLAB, command window appears. All commands are written on that command line. We first begin with entering vectors and basic vector operations. Let's first define a row vector whose elements are (2,4,5).

```
≫a=[2 4 5]
a =
      2     4     5
```

You can also put commas between the elements, there will be no difference.

```
≫a=[2,4,5]
a =
      2     4     5
```

Now let's define a column vector, in order to define a column vector you have to put a semicolon between the elements.

```
≫b=[2;3;5]
b =
      2
      3
      5
```

After defining a vector you may need to know what is the i^{th} element of the vector. For example the 3^{rd} element of the vector b is:

```
≫b(3)
ans =
      5
```

Below the characters of some vector operations are given.

- \+ addition
- \- subtraction
- * *multiplication*
- / division
- ' transpose

Multiply a and b,

```
≫a*b
ans =
     41
```


$c = b^T$, c is b transpose,

```
≫c=b'
c =
      2     3     5
```

add a and c,

```
≫a+c
ans =
      4     7    10
```

Additionally, there are many MATLAB functions which do different operations. Some vector functions are explained.

CROSS: Cross product of two vectors.

```
≫cross(a,c)
ans =
      5     0    -2
```

DOT: Dot product of two vectors.

```
≫dot(a,c)
ans =
     41
```

SUM: Sum of the vector elements.

```
≫sum(a)
ans =
     11
```

LENGTH: Length of the vector.

```
≫length(a)
ans =
      3
```

However, most of the vectors we define have length of hundreds which is not efficient to enter all the elements one by one. There are efficient ways to do it. The following example defines a vector whose first element is -5, last element is 2 and the subsequent elements are increasing by 1.

```
≫d=[-5:2]
d =
   -5   -4   -3   -2   -1   0   1   2
```

The default increment is 1, but you can define it as another value as in the following example, the increment between the elements is 0.4.

```
≫d=[3:0.4:5]
d =
   3.0000   3.4000   3.8000   4.2000   4.6000   5.0000
```

Another very important syntax is semicolon. If we use semicolon after the command line, the elements are not displayed, but they are assigned. This will be useful when you do not want to see the contents of the vector, especially when their length is large. In the following example when we put semicolon after the command line we will not see again the elements of z, however when you want to see the elements of z just type z.

```
≫z=[1 2 6];
≫z
z =
   1   2   6
```


II. MATRICES

The general rules for defining matrices is:

```
≫a=[5 6 2;0 -1 -8;1 0 -2]
a =
   5   6   2
   0  −1  −8
   1   0  −2
```

We use [ ] for identifying matrices; we use space or comma (,) for every term of the rows and we use semicolon for identifying the columns.

To see the ij^{th} element of the matrix:

```
≫a(2,3)
ans =
   -8
```

To see the i^{th} row of the matrix:

```
≫a(3,:)
ans =
   1   0   -2
```

To see the j^{th} column of the matrix:

```
≫a(:,2)
ans =
   6
   -1
   0
```

Let's look at some matrix functions.

SIZE: Size of a matrix.

```
≫ size(a)
ans =
   3   3
```

matrix a is 3x3

INV: Finds inverse of a matrix.

```
>> inv(a)
ans =
   -0.0556   -0.3333    1.2778
    0.2222    0.3333   -1.1111
   -0.0278   -0.1667    0.1389
```

DET: Finds the determinant of a matrix.

```
>>det(a)
ans =
     -36
```

EIG: Finds eigenvalues of a matrix.

```
>> eig(a)
ans =
     3.0000 + 0.0000i
     3.0000 - 0.0000i
    -4.0000
```

EYE: Gives the identity matrix, eye(N) is the N-by-N identity matrix.

```
>> eye(3)
ans =
     1     0     0
     0     1     0
     0     0     1
```

ZEROS: zeros(M,N) is an M-by-N matrix of zeros.

```
>> zeros(2,3)
ans =
     0     0     0
     0     0     0
```

ONES: ones(M,N) is an M-by-N matrix of ones.

```
>>ones(1,5)
ans =
     1     1     1     1     1
```


Matrix Operators

+	addition
-	subtraction
*	multiplication
/	division
^	power
.*	array multiply
./	array divide
.^	array power

Power is used as follows, x^y is x to the power y, it can be used for numbers as well.

```
>> a^2
ans =
    27    24   -42
    -8     1    24
     3     6     6
```

Array operators denotes element-by-element operations. The following examples will make it clearer.

```
>>bilkent=[1 2 3;4 5 6]
bilkent =
     1     2     3
     4     5     6
>>ee=[6 7 8;9 10 11]
ee =
     6     7     8
     9    10    11
```

```
≫ bilkent.*ee
ans =
        6    14    24
       36    50    66
≫ ee./bilkent
ans =
       6.0000      3.5000      2.6667
       2.2500      2.0000      1.8333
≫ bilkent.^3
ans =
        1     8    27
       64   125   216
```

The ij^{th} element of the resulting matrices is obtained by doing the operation between the ij^{th} elements of the two matrices.

III. PLOTS

In most cases when you use MATLAB, you have to plot your data to observe what is going on clearly. Moreover, it is always the case in your homework assignments and projects. Therefore, you should pay special attention to this part. Let's start with the ***plot*** function. First of all we will define a vector, let's call it x.

```
≫ x=[0:0.1:1]
   x =
   Columns 1 through 7
   0    0.1000    0.2000    0.3000    0.4000    0.5000    0.6000
   Columns 8 through 11
   0.7000    0.8000    0.9000    1.0000
```

If we write ***plot(x)***, this will plot the columns of x versus their index numbers. Our data contains values only for integer values but function ***plot*** connects these data points with straight lines.

```
≫plot(x)
```

After this command, we obtain the plot in Figure 1.

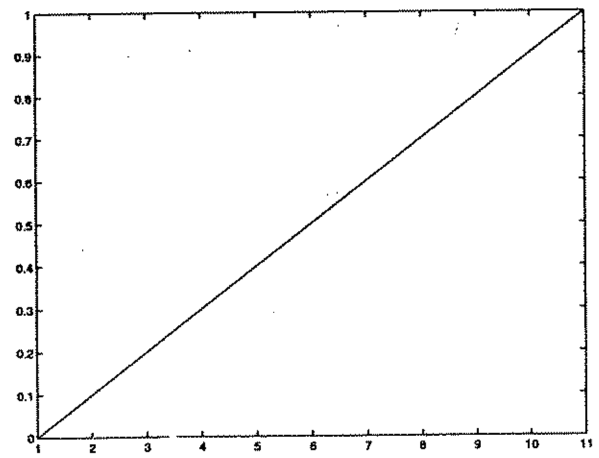


Fig. 1.

Now let's define another vector called y.

```
≫y=x.^2
   y =
   Columns 1 through 7
   0    0.0100    0.0400    0.0900    0.1600    0.2500    0.3600
   Columns 8 through 11
   0.4900    0.6400    0.8100    1.0000
```

If we write ***plot(x,y)***, this time the columns of x will be plotted versus columns of y.

```
≫plot(x,y)
```

We obtain the plot in Figure 2.

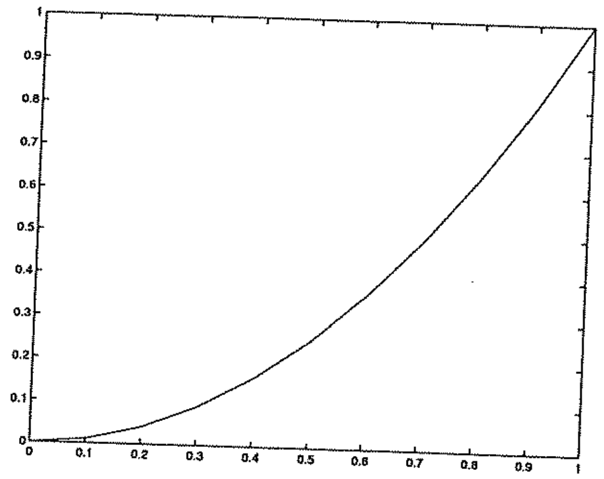


Fig. 2.

You have just learned the basics of how to plot by using MATLAB. But in our homework assignments and projects, we have to indicate what the figure shows. Therefore, we will need to label x-axis and y-axis, give a name to the figure, add text to the figure, and so on. Using the following functions of MATLAB we will do all these.

XLABEL('text') : This function adds the text under x-axis, thus the x-axis is labelled. YLABEL and for 3-D plots ZLABEL are also available in the same format.

TITLE('text') : This function adds the text at the top of the figure.

TEXT(x,y,'text') : This function adds the text at the location (x,y). Therefore, we can indicate special points on the figure by using this function.

GTEXT('text') : When you write this function, the graph window will be displayed with a cross. You can move the cross by using the mouse and when you press the mouse button the text will be displayed at that point.

LEGEND('text') : This function adds a legend at the right top of the figure. This legend can be moved by using the mouse.

GRID: Adds grid lines to the plot. ***Grid***, by itself, toggles the grid state.

Now it is time to use these functions. On the MATLAB command window write the followings:


```
≫ plot(x,y)
≫ xlabel('IEEE')
≫ ylabel('Student Branch')
≫ title('Bilkent University')
≫ legend('EE Department')
≫ grid
```

The plot obtained is shown in Figure 3. Actually in MATLAB 5.3 there are options on the menu bar of Figure window to play with such properties of the graph.

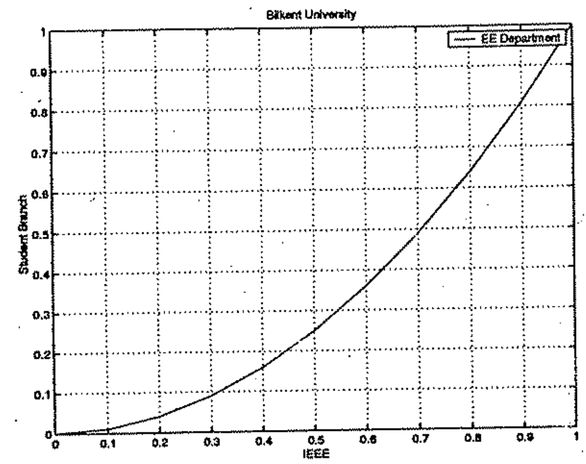


Fig. 3.

What we will do if we have to make more than one plots on same graph? For example we want make plots, plot(x,y) and plot(y,x) on the same graph, if we write,

```
≫ plot(x,y)
≫ plot(y,x)
```

The problem is that first plot goes away and you will see only the second plot. One solution is to plot graphs on the same Figure window. Let's try the following commands:

```
≫ hold on
≫ plot(x,y)
≫ plot(y,x)
```

The result is displayed in Figure 4.

As seen from Figure 4, the function ***hold on*** holds the previous figures. By using this function you can plot many graphs on the same Figure window. To disable this use ***hold off***.

If you want to plot the graph on the same figure but as separate plots, solution is to divide the Figure window into parts like a matrix and plot each graph on different parts. We will use ***subplot*** function to do this.

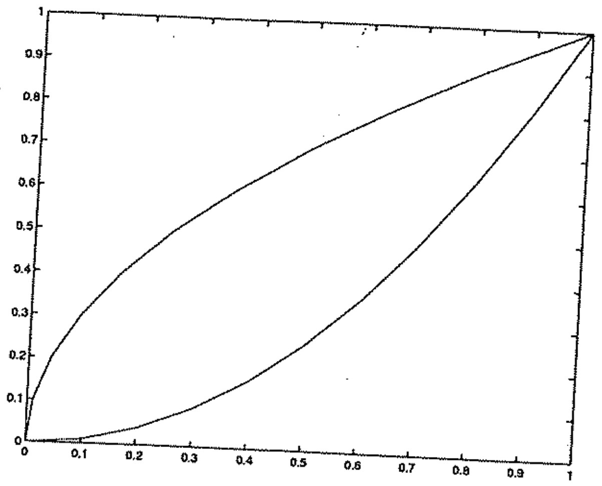


Fig. 4.

SUBPLOT(a,b,c) **:** This function divides the Figure window into an a-by-b matrix of small axes. C indicates the selected axes for the current plot. Now let's try the following commands:

```
≫ subplot(2,1,1)
≫ plot(x,y)
≫ subplot(2,1,2)
≫ plot(y,x)
```

The result is shown in Figure 5.

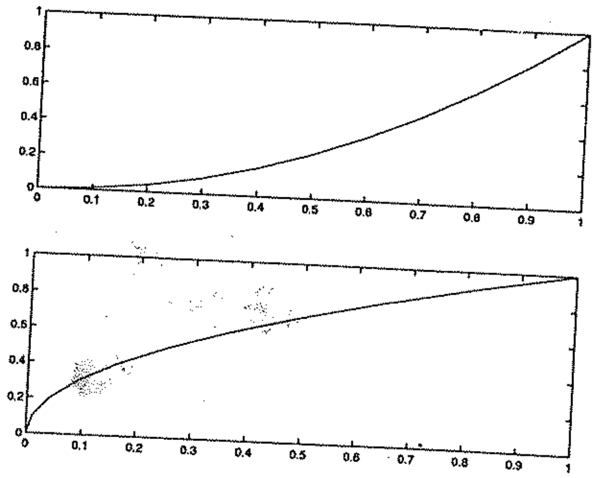


Fig. 5.

But if we would like to plot only one graph on a single Figure window, we have to use the ***figure*** function that opens a new Figure window, therefore the new graph is not plotted over the previous one.

```
≫ plot(y,x)
≫ figure
≫ plot(x,y)
```


By using the commands above, graphs will be plotted on different Figure windows.

Plot function scales the axes automatically but you can define the limits of x-axis and y-axis by using ***axis*** function.

AXIS([xmin xmax ymin ymax]) **:** This function sets limits for the x-axis and y-axis on the current plot.

```
≫ plot(x,y)
≫ axis([0.3 0.7 0.2 0.8])
```

The effect of ***axis*** command is seen in Figure 6.

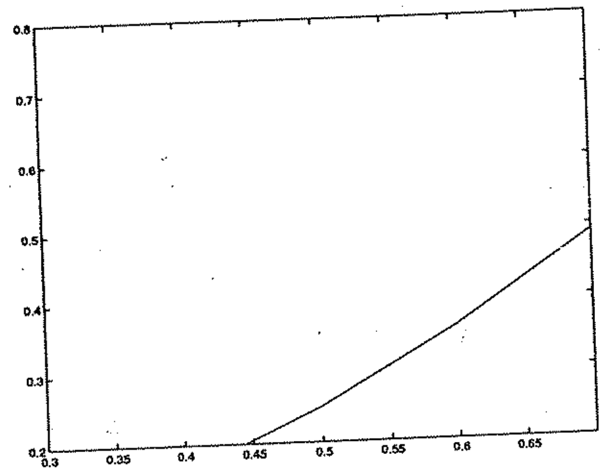


Fig. 6.

Another useful function is ***zoom***. After plotting a graph if you type zoom, on the Figure window click the left mouse button to zoom in on the point under the mouse and click the right mouse button to zoom out. To disable this type again zoom, on the command window. Therefore, zoom function toggles the zoom state.

Sometimes closing all of the windows will be cumbersome work. In such cases, use the ***close all*** function. This will close all the open Figure windows.

If we do not want MATLAB to connect our discrete data values, we will use ***stem*** function. Stem plots the data sequence as stems from the x-axis and these stems will be terminated with circles at the data values. Here you can see examples for both ***stem(x)*** and ***stem(x,y)***.

```
≫ stem(x)
```

We obtain the plot in Figure 7.

```
≫stem(x,y)
```

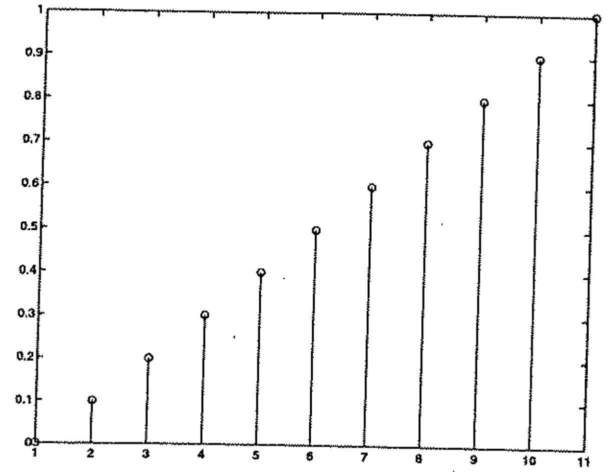


Fig. 7.

The result is displayed in Figure 8.

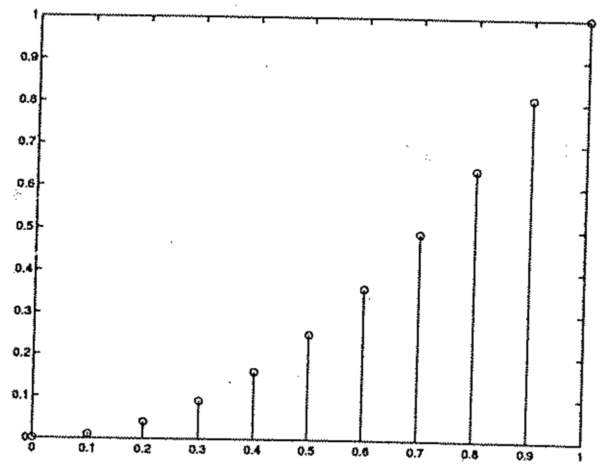


Fig. 8.

Sometimes we need to put marks on data points and use colors. We use the function ***plot(x,y,s)*** where *s* is a character string. This string may contain at most one element from three different columns. You can see these columns by using ***help plot*** command. Here is an example,

```
≫ plot(x,y,'g*:')
```

This command plots a green dotted line with an * at each data point. The resulting plot is in Figure 9.

Also by using this function, we can plot many functions on the same figure with different colors and marks.

```
≫ plot(x,y,'g*:',y,x,'bd-.')
```

The plot is shown in Figure 10.

Now lets look at 3D plots. In 3D either lines or planes can be plotted. Let's plot the following

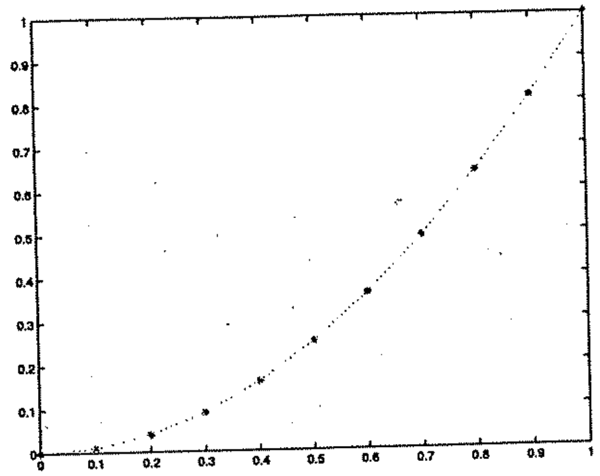


Fig. 9.

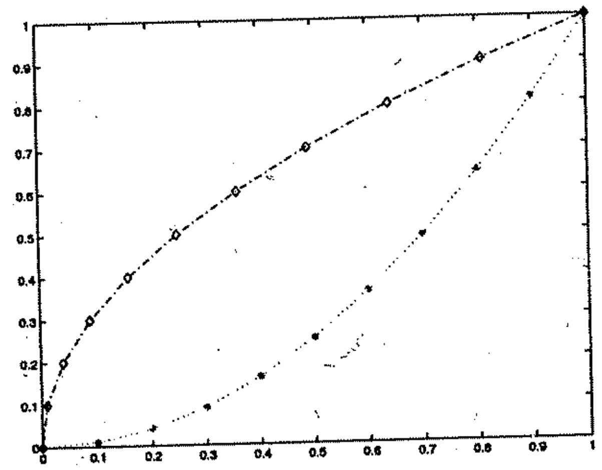


Fig. 10.

function of a helix. $x = sin(t)$, $y = cos(t)$, $z = t$. To plot that function we need a vector t, and then find the corresponding x,y and z vectors and plot them, for plotting three vectors we use ***plot3***.The following code plots our helix in Figure 11.

```
t =0:pi/50:10*pi;
plot3(sin(t),cos(t),t);
xlabel('x-axis');
ylabel('y-axis');
zlabel('z-axis');
```

It is time to plot a plane in 3D. Let's plot the plane, $z = x.e^{-x^2-y^2}$. First we use ***meshgrid*** function and then ***mesh*** function..

```
[x,y] = meshgrid(-3:.2:2, -2:.2:4);
z = x .* exp(-x.^2 - y.^2);
mesh(x,y,z);
```

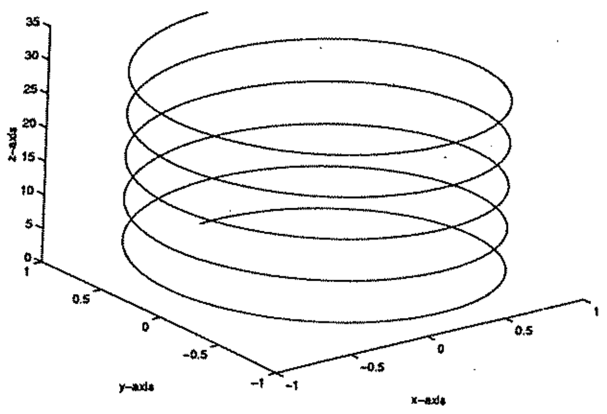


Fig. 11.

In the code above ***meshgrid*** takes x values between -3 and 2, y values between -2 and 4 with 0.2 intervals. Then we put x and y variables in the function and calculate z. Finally we plot with ***mesh*** function, plane is shown in Figure 12.

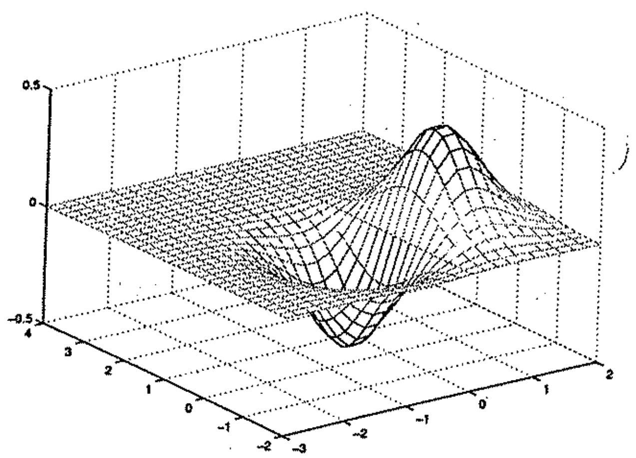


Fig. 12.

IV. WORKSPACE

The environment we work in and the variables here are called workspace. In this chapter we describe some MATLAB functions which enables you to search, save and etc. Some of the functions may not be understood clearly, by just reading their description, but if you try to use them probably there will be no problem, all of them are easy to use.

LOOKFOR: One of the most important functions that we generally use, is the lookfor command. This command is used for searching a function that is related to a keyword. As a result it brings out the functions that are concerned with that key word with explanation.For example, let's try to find out MATLAB functions related to the keyword *identity*.

```
≫ lookfor identity
    EYE Identity matrix.
    SPEYE Sparse identity matrix.
```

HELP: When we want to know how to use functions and their properties we use help command. For example, you made a search by using lookfor and found some functions but you don't know how to use them. In that case we use help command to get explanations about the functions. As an example:

```
≫ help eye
EYE Identity matrix.
    EYE(N) is the N-by-N identity matrix.
    EYE(M,N) or EYE([M,N]) is an M-by-N matrix with 1's on
the diagonal and zeros elsewhere.
    EYE(SIZE(A)) is the same size as A.
    See also ONES, ZEROS, RAND, RANDN.
```

As you see help command also gives other functions related with that subject.

SET PATH: Set path is the command in the *File* menu. This commands allows you to change the directory that MATLAB saves your work, before saving your work you should set the path to the directory where you want save it.

WHOS: This command shows the current variables in the workspace with the details. See the example in the next page.

```
>>whos
    Name    Size   Bytes   Class
       a     2x3      48   doublearray
       b     1x3      24   doublearray
       n     2x3      48   doublearray
       x   23x42    7728   doublearray
Grand total is 981 elements using 7848 bytes.
```

CLEAR ALL: This command clears all the variables you have in your work space. For example, after ***clear all*** command you won't see any variables if you use ***whos***, because all variables are cleared out.

DIARY: This command lets you to save the text you write on the command line. You use this command by first writing ***diary***, it will open a file and start to write your text in that file. When you finish your work, again type ***diary***, now you your job is saved in a file named ***diary***.

SAVE: This command allows you to save your important variables, matrices or constants to path you set. By this way you can keep your important data, in some projects you will have matrix size of thousands, which will be data you obtained after some manipulations and you will need to save that data. Saving format is: ***save fname variable***. For example, you want to save a matrix named A, to a file name ***mydata***, let A,

```
>>A=[1 2;3 4]
A =
      1     2
      3     4
>>save mydata A
```

The matrix A is saved into a file ***mydata.mat***. If you want to use that data you can read it by ***load*** command,

```
>>load mydata
```

Now, the data stored in *mydata.mat* is loaded into the workspace.

DIR: It shows the files in the current path(directory).

```
>>dir
.     dtft.m         fig.fig   odev.m
..    dtft3_a.mat    q4.m
```

In order to see the current path we use ***pwd*** command.


```
>>pwd
ans =
      D:\IEEEBILKENT\MatlabTutorial
```

V. M-FILES AND FUNCTIONS

M-Files

For simple problems, entering your commands in the command window is fast and efficient. However as the number of commands you have to write increases, typing the MATLAB code in command window is not efficient. MATLAB provides a solution to this problem. It allows you to place your MATLAB code in a file. You can tell MATLAB to open the file and execute the code in it. Those files are called m-files. We can open an m-file from menu bar *File/New/M-file.* Then a file will appear, write your code in that file and save it to the directory where you set the path.Assume that we wrote the following code to the m-file we opened and saved as ieeesb.m, by the way if you want to write comments put % character in front of a comment.

```
% m-file ieeesb
%Creates three matrices.
A= zeros (3,3);
B= ones (3,3);
C= [1 5 65];
```

When we write the file name to the command line,

```
≫ ieeesb
```

three matrices will be defined at an instant. Additionally, you can copy the code and paste to the command window, then press ENTER, the code will be executed.

Functions

We can write our own functions in MATLAB. We define functions in m-files. The functions are not much different than the functions written in programming languages. We can use some loop operators and condition statements in these functions.Actually MATLAB is a kind of programming platform. Let's write a simple function to demonstrate the syntax.

```
% This function takes three vectors and returns their sum
% The input are a,b,c vectors and output is vector d

function d=addVectros(a,b,c)
d=a+b+c;
```

Now we have a a simple function, while saving the file you have to be careful, the m-file name should be the same as function name, so we have to save our file as *addVectors.m.* Assume that there were previously defined three vectors *q*,*w* and *e* with same size. If we write the following command, the vector *r* will be the sum *q*, *w* and *e*.


```
≫r=addVectors(q,w,e);
```

Surely we can write much more complicated functions. In order to write them let's learn the syntax of loop and condition statements in MATLAB.

Loops

For

There is no reason to panic when we see FOR loop. Because it is not that different from what we have learned before, while studying JAVA. It executes the statements in the loop in a specific number of times as in JAVA. Also its syntax is not different. The syntax is:

```
FOR variable = expression,
statement
...
statement
END
```

Let's first examine an example of for loop, which creates a vector whose entries are its square of the index.

```
for i=1:5,
A(i)=i^2;
end
```

This loop will be executed until the index *i* is greater than 5. After each step of executing it will increment the index by 1 until it reaches to 5.

We can also use another way to increment or decrease the index.

```
for i=1:-0.1:0,
```

The ***for*** statement above decreases the index from 1 to 0 by 0.1 width steps.

While

This type of loop executes the statements till the condition is not satisfied. This is again similar to the *while* in JAVA language. The general syntax is:

```
WHILE expression,
Statements
END
```

Let's see an example:

```
a=1;
while a<= 10,
B(a)=a^2;
a=a+1;
end
```

As we can see above it is no different than *while* in Java. After loop terminates B is,

B = 1	4	9	16	25	36	49	64	81	100

IF

If a condition in an ***IF*** statement is satisfied, statements owned by that condition will be executed as in the JAVA codes again. The syntax for *IF* statement is:

```
IF Condition,
Statements
ELSEIF Condition,
Statements
ELSE
Statements
END
```

The following code will make it much clear.

```
i=1;
while (i <= 10)
if i==5,
B(i)=5;
elseif i<5,
B(i)=i^2;
else
B(i)=i^3;
end %end of if block
i=i+1;
end % end of while loop
```


In the example the entries of a vector are being assigned. There are three conditions and only one of them can be true at an instant. If the index is five it is assigned as 5; If it is less than five the entry is the square of the index; in other conditions, the entry is cube of the index. The result will be as below.

B = 1	4	9	16	5	216	343	512	729	1000

We can also write functions in a specific function. These are called subfunctions. Let's write a function with a subfunction.

```
function sum=tripleSum(n),
sum=n + square(n) + cube(n);

function s=square(a) %subfunction square
s=a*a;
function c=cube(b) %subfunction cube
c=b*b*b;
```

```
>>w=tripleSum(2)
w =
    14
```

Since we save our m file as ***tripleSum.m*** MATLAB understands that it is our main function, and others are subfunctions.

In some cases you will need to return more than one variables. The following example demonstrates how to write such functions.

```
% It will return two variables addition and dot product of two vectors
% operator(A,B)

function[d,a] = operator(x,y)
a= x+y; % variable a the vector addition
d= dot (x,y); % second variable d is the dot product of vectors
```

```
≫x = [1    2    3];
≫y = [3    2    1];
≫[n,m]=operator(x,y)
n =
    4    4    4
m =
    10
```


VI. MISCELLANEOUS FUNCTIONS

In this chapter we present some important miscellaneous functions. The aim of this chapter is not to teach you all useful functions but to give an insight about the function types available in MATLAB. Here some functions are not explained with all details, please use ***help*** command to get more information about them. Additionally, many functions are classified and explained in ***MATLAB Help Window***, you can reach there from menu bar ***Help/Help Window***.

ADDPATH: In order to run an m-file on the command window with its name, you must specify the path of the directory or folder that contains the file. There are two ways to do this. First, you can select the *Set Path* option from the *File* menu. Then you browse the directory that is desired to access. Another way is to use the ***addpath*** function. You simply type the path of the directory after ***addpath***. Suppose that your m-file, homework.m , is in the signal folder under the c directory. You should type,

```
≫addpath c: \signal
```

Now you can run your m-file just typing,

```
≫homework
```

MEAN: If you want to find the mean of a set of numbers, what you should do is to generate a vector containing that set. Mean function takes the vector as a parameter and returns the mean of the set.Let the set be

3   5   9   6.5   23   15   7.43   16

```
≫ x = [3 5 9 6.5 23 15 7.43 16] ;
≫ mean(x)
ans =
    10.6163
```

In addition, ***std*** function computes the standard deviation, ***cov*** returns the variance of the elements of the vector input. ***Min*** and ***max*** functions return the minimum and maximum element of the vector respectively. If you use the vector x defined above,

```
≫std(x)
ans =
      6.7699

≫min(x)
ans =
      3

≫max(x)
ans =
      23
```

If x is a matrix, the functions above *operate on the columns* of the matrix and returns a row vector that contains the results from the operations on each column.

RAND: In order to obtain random numbers, you can use the rand function. It generates random numbers between 0 and 1 with uniform distribution.

```
≫rand
ans =
      0.4057
```

Sometimes you need matrices whose entries are random numbers, ***rand(N)*** returns N by N matrix with random entries. Simply, to generate N by M matrix with random entries, N and M are should be included to the function as arguments as rand(N,M).

```
≫rand(2,3)
ans =
      0.9355    0.4103    0.0579
      0.9169    0.8936    0.3529
```

In order to obtain integer random numbers, you can generate algorithms. For example, if the interval is 20-30, one way is the following:

```
≫ 20 + fix(rand*11)
```

where ***fix*** rounds toward zero.

Normal distribution can also be obtained with the ***randn*** function. ***randn(M,N)*** returns an M by N matrix with normally distributed entries .

LINSPACE: ***linspace(a,b)*** produces a row vector of 100 linearly equally spaced points in the

a-b interval. You can vary the number of points by including the N as argument. ***linspace(a,b,N)*** returns a row vector with N entries linearly equally spaced between a and b. For example, if you need 7 points linearly equally spaced between -1 and 1,

```
≫ linspace(−1, 1, 7)
ans =
   -1.0000   -0.6667   -0.3333   0   0.3333   0.6667   1.0000
```

HIST: ***hist(x)*** performs the histogram function. Suppose the vector x contains points between a and b, ***hist(x)*** divides the a-b interval into 10 sub-intervals. It determines the number of points in each sub-interval and puts the results in the row vector, y, with 10 elements each corresponding to one sub-interval. Suppose x is:

```
≫ x = [0, 0.5, 1.5, 2.5, 2.5, 2.5, 3.5, 3.5, 4.5, 4.5, 5.5, 6.5, 6.5, 6.5, 6.5, 7.5, 7.5, 8.5, 9 ];
≫ y=hist(x)
    y = 2    1    3    2    2    0    1    4    2    2
```

You can adjust the number of sub-intervals with an additional argument. y=hist(x,K) creates K intervals.

TRAPZ:You can use the ***trapz(x,y)*** method to find the area of the graph specified by the vector x and y, integral of x with respect to y. It is simply the computation of the approximate integral using the trapezoidal method. Let's look at the following example.

```
≫ x=[0:0.01:pi];
≫ y=(sin(x).^3 +cos(x).^2).*(x.^3).*(2.^-x);
≫ trapz(x,y)
ans =
    4.2325
```

INT and DIFF: MATLAB has the capability of performing indefinite integration and differentiation. However, before the operation, you should generate symbolic variables with using the ***syms*** function. Then the expression to be integrated or differentiated should be in the arguments of ***int*** and ***diff*** functions. For example, we want to integrate and differentiate $x^3 + 4x$. First, define x as a symbolic variable.

```
≫ syms x
≫ int(x^3+4*x)
ans =
      1/4*x^4+2*x^2

≫ diff(x^3+4*x )
ans =
      3*x^2+4
```

It is also possible to perform indefinite integrals and differentiation on functions with more than one variable. The second argument determines the variable used in the operation. For example,

```
≫ syms x y;
≫ y=3*x;
≫ int(y^2,x);
ans =
      3*x^3
≫diff(y^2,x)
ans =
      18*x
```

Definite integrals can be also taken by passing the limits of the integrals to the function as arguments. Let's take the integral of y^2 with respect to x from 0 to 1 where y=3*x.

```
≫ syms x y;
≫ y=3*x;
≫ int(y^2,x,0,1)
ans =
      3
```

Moreover, differentiation in higher orders is possible. The order of differentiation is passed as an argument. The following example differentiates 10*y three times with respect to x where y=x^5.

```
≫ syms x y;
≫ y=x^5;
≫ diff(10*y,x,3)
ans =
      600*x^2
```

TAYLOR: You can find the taylor series expansion of functions with using the taylor(f). As in int and diff, the symbolics variables should be generated with syms function. Let's find the taylor series expansion of exp(-x).


```
≫ syms x
≫ taylor(exp(-x))
ans =
      1-x+1/2*x^2 - 1/6*x^3 + 1/24*x^4 - 1/120*x^5
```

It gives the first 6 terms of the infinite series.

LOG: The ***log(x)*** function evaluates the natural logarithm of the x, if x is a scalar or elements of x, if x is a vector. For example,

```
≫ x=[3 4 6 8 ];
≫ log(x)
ans =
      1.0986      1.3863      1.7918      2.0794
```

To take the logarithm of x with bases 2 and 10, functions log2(x) and log10(x) are used respectively.

EXP: Returns e to the x, if x is a scalar, exponential of the elements of x. if it is a vector.For example,

```
≫ x=[1 2 3 4];
≫ exp(x)
ans =
      2.7183      7.3891      20.0855      54.5982
```

VII. SIGNAL PROCESSING

In MATLAB there are many signal processing functions, however we want to introduce only the basic ones that you will need. Again we emphasize that the functions may have more details than explained here, for more details you can refer to ***help*** command.

CONV(a,b): Convolves vectors a and b.

The following example takes two rectangles and convolves them, also the plots of vectors and the convolution are provided. Write this code in an m-file.

```
a=[1 1 1 1 1];
b=[1 1 1 1 1];

subplot(3,1,1);
stem(a);
title('a');

subplot(3,1,2);
stem(b);
title('b');

c=conv(a,b);
subplot(3,1,3);
stem(c);
title('convolution a & b');
```

The results are shown in Figure 13.To approximate a continuous time signal you can take the intervals very small.

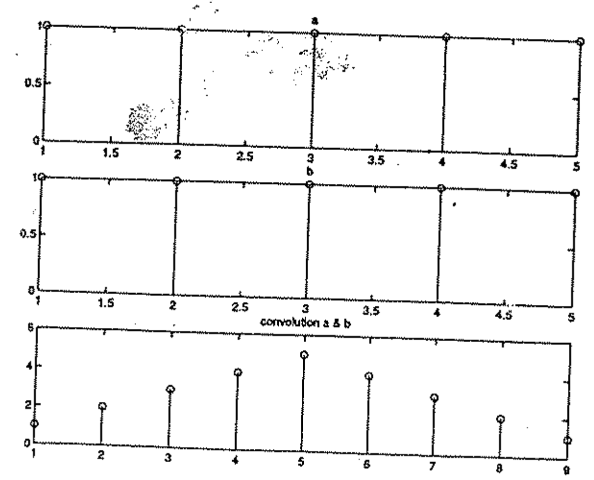


Fig. 13.

FFT: FFT takes the discrete time fourier transform. As you know discrete time fourier is periodic

with 2π, so it is enough to show the fourier transform in 2π interval, and ***fft*** returns the result in interval $[0, 2\pi]$. However, we usually want to see the result in $[-\pi, \pi]$ interval, for this reason after taking ***fft***, we use **fftshift** which shifts the interval to $[-\pi, \pi]$. In other words, if we use only ***fft*** we will obtain the fourier transform in $[0, 2\pi]$ interval, however following ***fft*** if we ***fftshift*** use the result will be in $[-\pi, \pi]$ interval. Let's examine the following example, where ***abs*** takes the absolute value and ***angle*** returns the phase.

```
h=[1 1 1 1 1];% impulse reponse
H=fft(h,32);% this number 32 is because of the fft algorithm, choose it greater than size of
        % h, and power of 2. Know that as rule of thumb. Now H is vector of size 32.
Magn_H=abs(fftshift(H));        % shift it and take the absolute value
Phase_H=angle(fftshift(H));     % shift it and find the phase

n=[-2:1:2]; w=linspace(-pi,pi,32);      % to plot the graphs with better defined x axis values.
subplot(3,1,1); stem(n,h);
xlabel('t');ylabel('h(t)');title('impulse response');
subplot(3,1,2); plot(w,Magn_H);
xlabel('w');ylabel('|H(jw)|');title('Magnitude of Freq. Response');
subplot(3,1,3); plot(w,Phase_H);
xlabel('w');ylabel('Phase of H(jw)');title('Phase of Freq. Response');
```

After executing that code we obtain the plots in Figure 14.

FILTER(B,A,X): This function filters the data in vector X with the filter described by vectors A and B and creates output data Y.

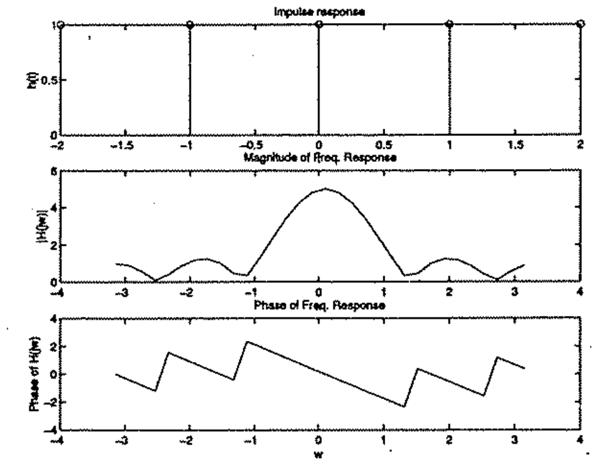


Fig. 14.

Let a filter be characterized by the difference equation

4y[n-2]+2y[n-1]+3y[n]=x[n-2], frequency response of the filter is

$H(e^{\jmath\omega}) = \frac{e^{-2\jmath\omega}}{3+2e^{-\jmath\omega}+4e^{-2\jmath\omega}}$

and $x[n]$ is a triangle , $-5 \langle n \langle 5$. We want to find the output y[n] and its frequency response,

$Y(e^{jw})$.

The following code solves the problem and plots the graphs.

```
x=[0 1 2 3 4 5 4 3 2 1 0]; %define x[n]
n=[-5:5]; %define n's
subplot(3,2,1);
stem(n,x); %plot x[n]
xlabel('n');ylabel('x[n]');

X=fftshift(fft(x,256)); %find frequency response
w=linspace(-pi,pi,256); %take 256 points between −π&π
subplot(3,2,2);
plot(w,abs(X)); %plot the magnitude of the Freq. response of x[n]
xlabel('w');ylabel('|X(e^jw)|');

H=exp(-2*j.*w)./(4*exp(-j.*w).^2+2*exp(-j.*w)+3);%Freq. response of the filter
subplot(3,2,3);
plot(w,abs(H)); %plot the magnitude of the frequency response
xlabel('w');ylabel('|H(e^jw)|');

y=filter([0 0 2],[3 2 4],x);%filter the input
subplot(3,2,4);
plot(w,abs(fftshift(fft(y,256))));% find and plot the freq. response of output
xlabel('w');ylabel('|Y(e^jw)|');
subplot(3,1,3); % we used a trick here
stem(n,y); %plot the output
xlabel('n');ylabel('y[n]');
```

The output of the code is in Figure 15 , x[n], $|X(e^{jw})|$, $|H(e^{jw})|$, $|Y(e^{jw})|$ *and* $y[n]$ are plotted. The filter is a band pass filter and strengthens the signals around center frequencies, while other frequency components are attenuated.

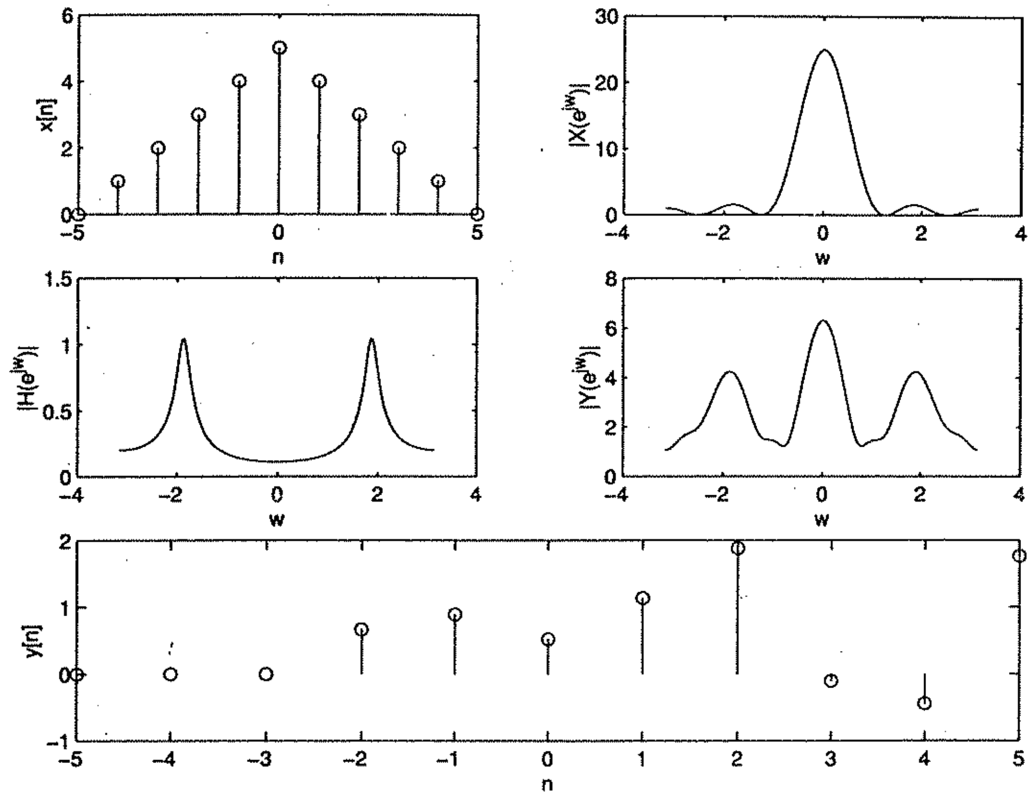


Fig. 15.