Goals

- Learn how to operate within the MATLAB programming environment
- Learn the basics of array and matrix manipulation
- Learn basics of MATLAB syntax
- Apply MATLAB to the solution of electric circuit problems
  - Operating point
  - DC sweep
What is MATLAB?

● The language of technical computing

“MATLAB integrates mathematical computing, visualization, and a powerful language to provide a flexible environment for technical computing. The open architecture makes it easy to use MATLAB and its companion products to explore data, create algorithms, and create custom tools that provide early insights and competitive advantages.”

● Popular in engineering applications
  ■ Extensible - toolboxes for various tasks
    ● Test and measurement
    ● Mathematical modeling and analysis
    ● Signal processing
    ● Image processing and geographic mapping
    ● Controls engineering

What is MATLAB?

● MATLAB’s name is derived from “Matrix Laboratory”, and its great strength is in handling matrices and operations on matrices

● The goal for many of our circuit solutions will be to state the problem in a format that is easily solved using matrices
Supporting Materials

- PSpice and MATLAB for Electronics, J.O. Attia, pages 117 - 125, 128 - 130, 148 - 152
- MATLAB tutorials on course web site
  - Parts of Tutorials 1, 2, 3, 4, 5, 11, and 16 are relevant

Example 1.1

From Figure 1.1, PSpice and MATLAB for Electronics
For the circuit of Example 1.1
- What are the voltages at all the named circuit nodes?
- How to solve?
  - We have solved this circuit by hand and in PSpice. What do we need to know to solve it in MATLAB?

\[
\frac{10V - V_2}{500 \Omega} = \frac{V_2 - V_5}{4k\Omega} + \frac{V_2 - V_3}{1k\Omega} \quad \text{at node 2}
\]

\[
\frac{V_2 - V_3}{1k\Omega} = 5mA + \frac{V_3}{2k\Omega} \quad \text{at node 3}
\]

\[
\frac{V_2 - V_4}{1k\Omega} = \frac{V_4 - V_5}{3k\Omega} \quad \text{at node 4}
\]

\[
\frac{V_4 - V_5}{3k\Omega} + 5mA = \frac{V_5}{5k\Omega} \quad \text{at node 5}
\]
Solve the Circuit

- Reformat the equation at each node

\[
13V_2 - 4V_3 + 0V_4 - V_5 = 80 \\
-2V_2 + 3V_3 + 0V_4 + 0V_5 = -10 \\
-3V_2 + 0V_3 + 4V_4 - V_5 = 0 \\
0V_2 + 0V_3 - 5V_4 + 8V_5 = 75
\]

- Show the matrices

\[
\begin{bmatrix}
13 & -4 & 0 & -1 \\
-2 & 3 & 0 & 0 \\
-3 & 0 & 4 & -1 \\
0 & 0 & -5 & 8
\end{bmatrix}
\begin{bmatrix}
V_2 \\
V_3 \\
V_4 \\
V_5
\end{bmatrix}
=
\begin{bmatrix}
80 \\
-10 \\
0 \\
75
\end{bmatrix}
\]
Solve the Circuit

- Goals
  - Code the matrices in MATLAB
  - Perform the matrix solution
  - Extract and display the desired result, the voltages at each circuit node
- We need to learn about the MATLAB user environment
- We need to know how to enter and do operation on matrices

MATLAB Environment

- Multi-window environment
  - Command Window
  - Command History
  - Workspace window
- Help (local)
  - help and lookfor commands
- Help through web
  - Helpwin or helpdesk commands
- Editor for text and m-files
QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.
Entering Code

- You can input MATLAB commands directly into the Command Window, read them from a text file, or use the Editor.
- For now we will use the Editor
- Like any code you write, MATLAB code should be documented
  - Any text that follows the “%” symbol is considered a comment
  - Make a habit of including your team member names in all code

Basic MATLAB Operations

- Assignment
  - A = 5; B = 7;
- Arithmetic
  - C = A+B;
- Functions
  - A*B - Multiplication
  - A/C - Division
  - A^2 - Exponentiation
  - sqrt(A) – Square Root
  - sin(D) – Sine of Angle D (D in radians)
Basic MATLAB Operations

- **Division**
  - **Right division**
    - $a/b$ is equivalent to $a/b$
    - $X = A/B$ solves $X^A = B$
  - **Left division**
    - $a\backslash b$ is equivalent to $b/a$
    - $X = A\backslash B$ solves $A^X = B$

- **Inverse function**
  - If $Z \times I = V$, we can express $I$ as
    - $I = Z \backslash V$
    - $I = \text{inv}(Z) \times V$

Arithmetic Operations

- There are 2 types of arithmetic
  - **Matrix arithmetic**
    - Defined by rules of linear algebra
  - **Array arithmetic**
    - Carried out element by element
    - Array operations use the period (.) character
    - The exceptions are .+ and .- since they are the same for matrix and array operations
Example

- * Operation
  - $C = A \times B$ is the linear algebraic product of the matrices $A$ and $B$. For nonscalar $A$ and $B$, the number of columns of $A$ must equal the number of rows of $B$
  
  $$C(i, j) = \sum_{k=1}^{n} A(i, k) B(k, j)$$

- .* Operation
  - $C = A.*B$ is the element-by-element product of the arrays. $A$ and $B$ must have the same size unless one is a scalar.

Matrix Operations

- Assignment
  - $X = [5 \ 4 \ 3 \ 7]$;
  - $Y = 1:4$; ($[1 \ 2 \ 3 \ 4]$)

- Addition
  - $4+X$; ($[9 \ 8 \ 7 \ 11]$)
  - $Y+X$; ($[6 \ 6 \ 6 \ 11]$)

- Multidimensional arrays
  - $Z = [1 \ 2; 3 \ 4]$; % 2 rows, 2 columns
  - $Z = [1 \ 2 \ 3 \ 4]$; % alternate format
Matrix Operations

- **Multiplication**
  - \(X = [5 \ 4 \ 3 \ 7];\)
  - \(Y = [1 \ 2 \ 3 \ 4];\)
  - \(2 \times X = [10 \ 8 \ 6 \ 14]\)
  - \(X \times Y\) does not work, but \(X \times Y\) works
  - \(X. \times 0.5\)
- \(U = [1 \ 2 \ 3; \ 4 \ 5 \ 6];\)
- \(\text{Size}(X) = [1 \ 4]\) one row, 4 columns
- \(\text{Size}(U) = [2 \ 3]\) two rows, 3 columns

**Matrix Operations**

- **Accessing Matrix Elements**
  - \(U = [1 \ 2 \ 3; \ 4 \ 5 \ 6];\)
  - \(U(1,2) = 2\)
    - 2nd element of row 1
  - \(U(:,2) = [2 \ 5]^T\)
    - 2nd column of matrix
  - \(U(1,2:3) = [2 \ 3]\)
    - 2nd and 3rd elements of row 1
Solve the Circuit

\[
\begin{bmatrix}
13 & -4 & 0 & -1 \\
-2 & 3 & 0 & 0 \\
-3 & 0 & 4 & -1 \\
0 & 0 & -5 & 8
\end{bmatrix}
\begin{bmatrix}
V_2 \\
V_3 \\
V_4 \\
V_5
\end{bmatrix}
= \begin{bmatrix}
80 \\
-10 \\
0 \\
75
\end{bmatrix}
\]

in equation form, \( Y * V = I \)

\( Y = \begin{bmatrix}
13 & -4 & 0 & -1 \\
-2 & 3 & 0 & 0 \\
-3 & 0 & 4 & -1 \\
0 & 0 & -5 & 8
\end{bmatrix}; \)

\( I = \begin{bmatrix}
80 \\
-10 \\
0 \\
75
\end{bmatrix}; \) or \( \begin{bmatrix}
80 \\
-10 \\
0 \\
75
\end{bmatrix}' \)

\( V = inv(Y) * I; \) or \( Y \backslash I; \)

% Solution to Example 1.1, K. Scoles
% This script solves for the nodal voltages V given the
% admittance vector Y and the current vector I
% YV = I
% Define the 4x4 Y matrix:
Y = [13 -4 0 -1; -2 3 0 0; -3 0 4 -1; 0 0 -5 8];
% Define the I vector (transpose of a row vector)
I = [80 -10 0 75];
% Add a printed line so we know which voltages these are
fprintf('Nodal voltages V2, V3, V4, and V5 are 
')
V = inv(Y)*I
Solve the Circuit

V(1) = 10.00 V
V(2) = 7.95 V
V(3) = 1.97 V
V(4) = 9.85 V
V(5) = 15.53 V

V(1) is known by inspection

Example 1.2

From Figures 1.2/1.3, PSPICE and MATLAB for Electronics
Solve the Circuit

- If the dc voltage source VS ramps from 0 V to 10 V with 2 V steps, what would be the corresponding currents through R6?
- Display a solution table with voltages and currents

![Diagram of the circuit with nodes and currents](image)
Solve the Circuit

\[-VS + R_1 i_1 + R_2 (i_1 - i_2) + R_4 (i_1 - i_3) = 0\]
\[R_2 (i_2 - i_1) + R_3 i_2 + R_6 (i_2 - i_3) = 0\]
\[R_4 (i_3 - i_1) + R_6 (i_3 - i_2) + R_5 i_3 = 0\]

\[(R_1 + R_2 + R_4) i_1 - R_2 i_2 - R_4 i_3 = VS\]
\[-R_2 i_1 + (R_2 + R_3 + R_6) i_2 - R_6 i_3 = 0\]
\[-R_4 i_1 - R_6 i_2 + (R_4 + R_5 + R_6) i_3 = 0\]

\[
\begin{bmatrix}
600 & -100 & -400 \\
-100 & 250 & -50 \\
-400 & -50 & 750
\end{bmatrix}
\begin{bmatrix}
i_1 \\
i_2 \\
i_3
\end{bmatrix}
=
\begin{bmatrix}
VS \\
0 \\
0
\end{bmatrix}
\]

\(0 \leq VS \leq 10V, \text{ 2V steps}\)

\(I(R_6) = i_3 - i_2\)
This problem is similar to our first example, except \( V_S \) has 6 different values rather than just one.

- \( R \times I = V \), so \( I = \text{inv}(R) \times V \) or \( I = R \backslash V \)

The temptation might be to do a loop for each value of \( V_S \) and collect the solutions, but you can solve the problem and display the result using matrix operations only.

### Solve the Circuit

#### Populate an \( R \) matrix

- Populate the 3x3 \( R \) matrix:
  - \( R1=100; \) % all values in ohms
  - \( R2=100; \)
  - \( R3=100; \)
  - \( R4=400; \)
  - \( R5=300; \)
  - \( R6=50; \)
  - \( R = [R1+R2+R4 -R2 -R4; -R2 R2+R3+R6 -R6; -R4 -R6 R4+R5+R6]; \)
Solve the Circuit

- Build a 3x6 matrix with all values of VS in the first row and 0 everywhere else
  - % Populate the V vector
  - % format is [start:step:end]
  - V = [0:2:10] % there will be 6 columns
  - A=zeros(2, 6) % zeros in 2 rows and 6 columns
  - VS = [V;A] %V matrix is placed above the A matrix

Solve the Circuit

- Result

\[
\begin{bmatrix}
0 & 2 & 4 & 6 & 8 & 10 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]
If we multiply this matrix by inv(R), the resulting matrix will have the currents $i_1$, $i_2$, and $i_3$ for each value of $VS$ in the appropriate columns.

```matlab
II = inv(R) * VS
II =
    0   0.0062  0.0124  0.0187  0.0249  0.0311
    0   0.0032  0.0064  0.0096  0.0128  0.0160
    0   0.0035  0.0071  0.0106  0.0141  0.0176
```

To display the results properly, we would like to show the value of $VS$ for each set of currents.

```matlab
I=[V;II] % add matrix II below matrix V
```
Solve the Circuit

• Result

\[
I = \\
\begin{bmatrix}
0 & 2.0000 & 4.0000 & 6.0000 & 8.0000 & 10.0000 \\
0 & 0.0062 & 0.0124 & 0.0187 & 0.0249 & 0.0311 \\
0 & 0.0032 & 0.0064 & 0.0096 & 0.0128 & 0.0160 \\
0 & 0.0035 & 0.0071 & 0.0106 & 0.0141 & 0.0176
\end{bmatrix}
\]

• Subtract \(i_2\) from \(i_3\) and express in scientific notation to see more detail

\[
I_{R6} = II(3,:) - II(2,:)
\]

\[
> \text{format short e}
\]

\[
> I_{R6}
\]
Solve the Circuit

- Result
  
  \[ I_{R6} = \]
  
  \[
  \begin{array}{cccccc}
  0 & 0.0003 & 0.0007 & 0.0010 & 0.0013 & 0.0017 \\
  \end{array}
  \]

  \[ I_{R6} = \]
  
  \[
  \begin{array}{cccccc}
  0 & 3.3613 \times 10^{-4} & 6.7227 \times 10^{-4} & 1.0084 \times 10^{-3} & 1.3445 \times 10^{-3} & 1.6807 \times 10^{-3} \\
  \end{array}
  \]

- If you compare this solution with our previous one, you see the results are the same

---

**Solve the Circuit**

<table>
<thead>
<tr>
<th>VS (V)</th>
<th>Ib (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>2.0</td>
<td>0.34</td>
</tr>
<tr>
<td>4.0</td>
<td>0.67</td>
</tr>
<tr>
<td>6.0</td>
<td>1.01</td>
</tr>
<tr>
<td>8.0</td>
<td>1.34</td>
</tr>
<tr>
<td>10.0</td>
<td>1.68</td>
</tr>
</tbody>
</table>
This Week’s Lab Exercises

- **Part I**
  - Exercises to learn MATLAB syntax and do matrix operations

- **Part II**
  - Solve an operating point problem using MATLAB
  - Solve a dc sweep problem using MATLAB

Deliverables

- MATLAB m-file containing code to produce all requested solutions
  - The code must have your name at the top
  - The code must be documented
  - The code must print to the screen only what is requested
  - Each solution must be identified with the problem number
  - Submit m-file to the course WebCT site
- A written report based on the solution to Problem 10
Solve the Problem

• Add a code line to show the problem #

> I_R6 = II(3,:)-II(2,:);
> format short e
> disp(’Problem 2 Solution’)
> I_R6

Solve the Problem

• Result

Example 1.2 Solution

I_R6 =

Columns 1 through 4

0 3.3613e-04 6.7227e-04 1.0084e-03

Columns 5 through 6

1.3445e-03 1.6807e-03
Problem 10

Find the proper rating for fuses F1, F2 and F3 if V1 ramps from 5V to 15V with 1V steps