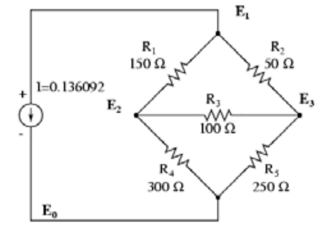
LAB-01: MATLAB Based Circuit Simulator



Objective: The purpose of this exercise is to develop a MATLAB based circuit simulator starting from a netlist description. You will be utilizing MATLAB features and functions for DC analysis.

Submission Procedure for Labs: Please print out the lab work checklist (the last page of this lab instruction document) and write your names and IDs on it. Before attending the lab session, solve the prelab problems on paper with your names and IDs written on it. Show your prelab and checklist to a TA at the beginning of each lab session. The TA will check off the prelab problems you have completed. At the end of the session, the TA will mark and collect your checklist when you show the TA the in-lab problems that you have completed; show your Matlab code and its output. Completion of the pre-lab problems at the beginning of the lab session and the in-lab problems by the end of the session will entitle you to 50% of the lab marks. The remaining 50% will be used to assess the correctness of the prelab and in-lab problem solutions written into your lab report, which you will submit on a date to be announced. Make sure that the TA signs and collects your checklist at the end of the lab session. A lab report will not be marked and will be assessed zero point if no checklist had been collected.

Background:

Electronic circuits could be quite complex. Manually solving for all node voltages and branch currents is no easy task. Computer aided design (CAD) tools are routinely employed in simulating circuits. They generally convert a circuit schematic provided by the user into a netlist. The *netlist* is a general description of the electronic circuit connectivity. The netlist identifies the circuit element type (resistor, current source … etc.), its connecting nodes and parameter value.

For example the circuit shown in Fig. 1, can be described by the following netlist:

R1	1	2	30
R2	2	0	20
R3	2	3	50
R4	3	0	20
Idc	0	1	2.7

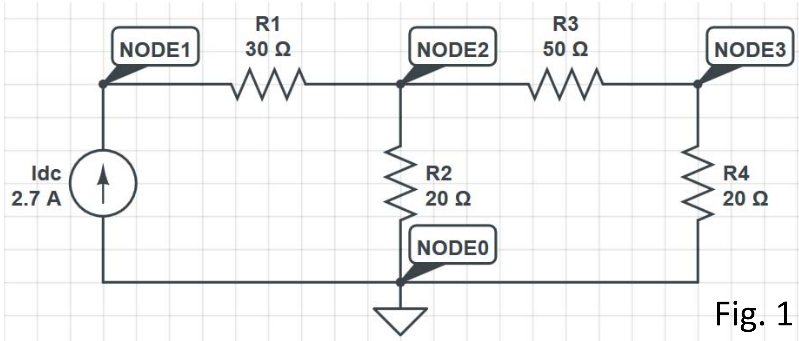


Fig. 1

Observe the above netlist and the corresponding circuit. The netlist consists of the element name followed by two node numbers and finally the value in Ohms for resistive elements, Amperes for current sources and Voltages for voltage sources.

For the sake of simplicity we will only consider DC circuits consisting of current sources and resistive elements in this lab. As you are aware voltage sources can be transformed into current sources. In addition, you will have ample opportunity to upgrade your initial circuit simulator to include voltage sources, capacitors and inductors in your final optimization project.

The primary objective of the circuit simulator is to determine the voltages at node 1, 2 and 3. As you would expect this task requires solving three equations simultaneously. Using nodal analysis we apply Kirchhoff's current law (KCL) at nodes 1, 2 and 3 resulting in:

$$\frac{V_1 - V_2}{R_1} - I_{dc} = 0$$
$$\frac{V_2 - V_1}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_2 - V_3}{R_3} = 0 \qquad \text{Equations (1-3)}$$
$$\frac{V_3 - V_2}{R_3} + \frac{V_3 - 0}{R_4} = 0$$

Equations (1-3) are simply a system of linear equations, which can be expressed as the following matrix operation:

$$A\,x = b$$

$$A = \begin{bmatrix} \frac{1}{R_1} & \frac{-1}{R_1} & 0 \\ \frac{-1}{R_1} & \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} & \frac{-1}{R_3} \\ 0 & \frac{-1}{R_3} & \frac{1}{R_3} + \frac{1}{R_4} \end{bmatrix}, \qquad b = \begin{bmatrix} I_{dc} \\ 0 \\ 0 \end{bmatrix}, \qquad x = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

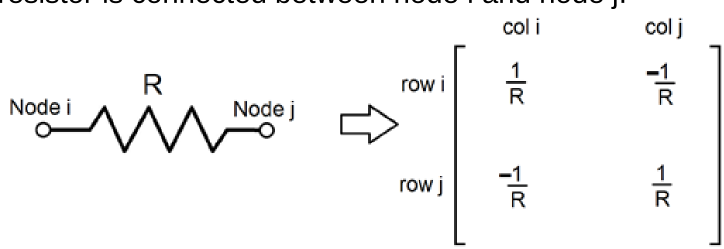
The matrix *A* represents the resistive elements in the circuit, while the current sources are placed on the right-hand side in vector *b*. The unknown nodal voltages are in vector *x*. Solving for the nodal voltages is equivalent to finding:

$$x = A^{-1}b \quad \text{Or} \quad x = A \setminus b$$

using the Matlab backslash (left "divide") operator. It would be very useful to "automate" the generation of the matrix *A* by inspecting the circuit schematic or netlist. This is possible through recognizing that each circuit element has a specific *stamp*. As we are only considering circuits with resistors and current sources in this exercise we will be examining two types of stamps.

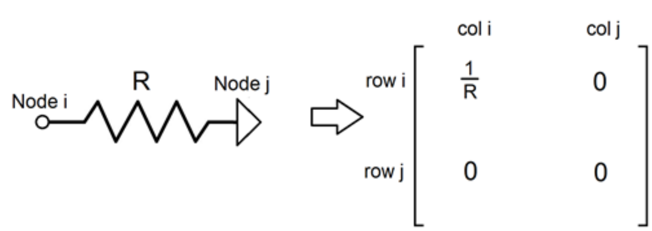
Resistor Stamp

Resistor stamps are used to construct the matrix *A*. There are two possible connection scenarios. First the resistor is connected between node i and node j:



Note the symmetry across the diagonal. This is because the resistor is connected to two variable nodes. The same current leaving node i enters node j.

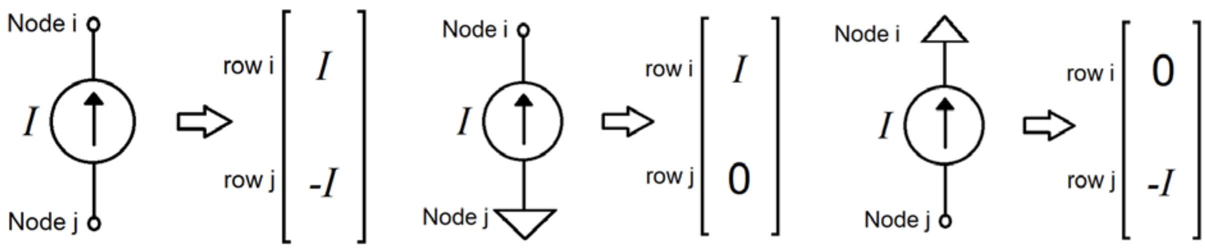
The second possibility is that the resistor is connected between node i and ground:



This looks symmetric, but since we are not going to solve for the voltage of the reference (or ground node, which we know is 0 volt), row j and column j will not appear in the final system of linear equations (see below).

Current Source Stamp

Current stamps are used to construct the right-hand side vector *b*. There are three possible scenarios depending on the current direction and connectivity:



The direction of the current is important relative to the sign of the current value in the *b* vector. If one of the terminals is connected to ground, then there is no corresponding KCL equation and the corresponding entry is set to 0. In this exercise the netlist description for a current source specifies the node numbers in the direction of the current flow as a convention, for example:

Ia 3 4 ➔ indicates a current source flowing from node 3 to node 4
Ib 0 1 ➔ indicates a current source flowing from ground to node 1

Netlist Mapping

At this stage we are in the position of relating our netlist to the matrix *A* and *b* by inspection. The first step is to identify the size of matrices *A* and *b*. The number of equations is equal to the number of nodes (not including the reference node). In our example, the *A* would be a 3 by 3 matrix and *b* would be a 3 by 1 vector.

R1	**1**	**2**	**30**
R2	**2**	**0**	**20**
R3	**2**	**3**	**50**
R4	**3**	**0**	**20**
Idc	**0**	**1**	**2.7**

$$A = \begin{bmatrix} \frac{1}{R_1} & \frac{-1}{R_1} & 0 \\ \frac{-1}{R_1} & \frac{1}{R_1} & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & \frac{1}{R_2} & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & \frac{1}{R_3} & \frac{-1}{R_3} \\ 0 & \frac{-1}{R_3} & \frac{1}{R_3} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{1}{R_4} \end{bmatrix} =$$

$$\begin{bmatrix} \frac{1}{R_1} & \frac{-1}{R_1} & 0 \\ \frac{-1}{R_1} & \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} & \frac{-1}{R_3} \\ 0 & \frac{-1}{R_3} & \frac{1}{R_3} + \frac{1}{R_4} \end{bmatrix}, \quad b = \begin{bmatrix} I_{dc} \\ 0 \\ 0 \end{bmatrix}$$

Remember, resistors contribute to the left-hand side of the equations (matrix *A* itself), while current sources contribute to the right-hand side vector *b*.

Pre-Lab:

Q1: Write the netlist description for the circuit diagram in Fig. 2.

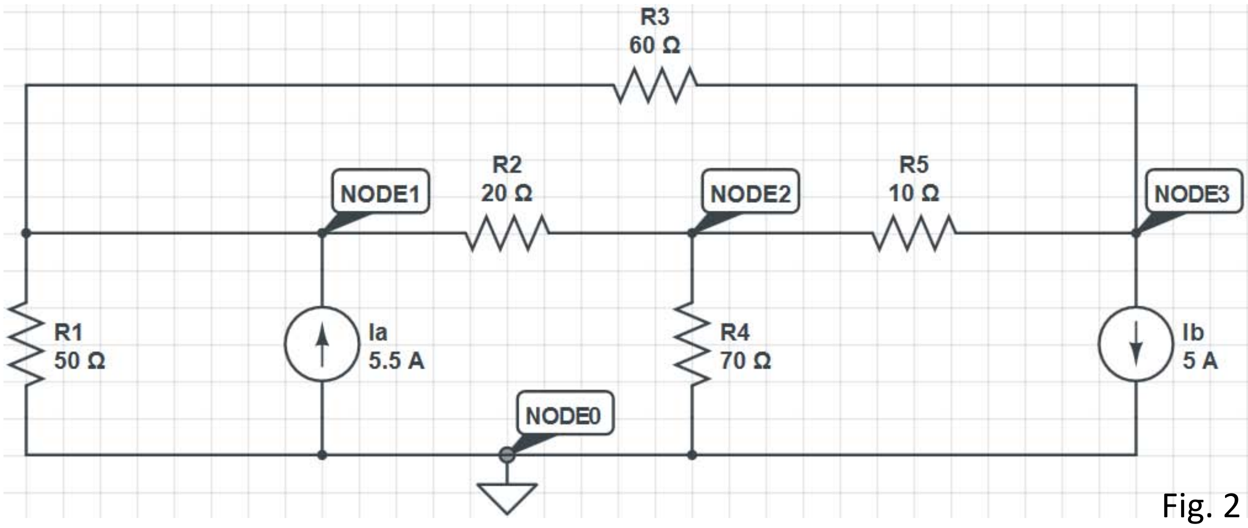


Fig. 2

Q2: From the netlist description you found in Q1, write the matrices *A*, *b* and *x* using the circuit element stamp method introduced in the background section of this lab exercise.

Q3: Solve the system of equations $A\,x = b$ (on paper) to obtain the voltages at nodes 1, 2 and 3.

In-Lab:

A generalized block diagram of a circuit simulator is shown in Fig. 3.

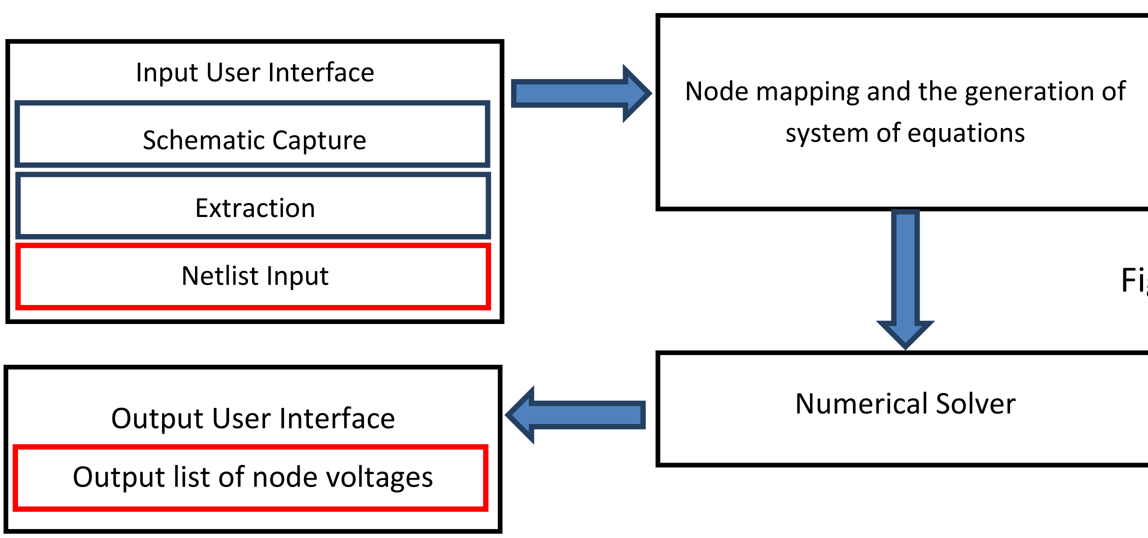


Fig. 3

In this lab, we will assume the netlist is supplied by the user or capture software. Essentially our starting point will be a circuit netlist stored in a .txt file. You are to design a MATLAB based circuit simulator, which reads a user supplied netlist, performs the node mapping, generation of systems of equations and finally solves these equations numerically. The output would be the list of unknown node voltages (vector *x*).

1) Design a MATLAB function which accepts a filename (e.g. 'netlist_1.txt') and outputs the matrices *A* and *b*.

```
function [A, b] = mappNETLIST (filename)
```

All netlist files supplied to your function are assumed to use the letter "R" as the first letter for the label/name of a resistor and the letter "I" for that of a current source. Your function must:

a) Open the text file and *parse** its contents.
b) Decide on size of the matrices *A* and *b.*
c) For each circuit element generate the appropriate stamp in matrices *A* and *b*.

The `mappNETLIST` function should make effective use of MATLAB loops, if statements and indexing features. It must also be able to dynamically adapt to different netlist size (circuit sizes) and configurations.

(*Hint: You may find the following MATLAB function of interest*: `textread`)

2) Create a netlist text file representing the circuit in Fig. 2. Apply your `mappNETLIST` function to that file and compare the contents of matrices *A* and *b* with your manual calculation in the (Pre-lab Q2).

3) Write a MATLAB script `solveVoltages`, which employs your `mappNETLIST` function and evaluates the unknown node voltages for the circuit in Fig. 2. You may use the MATLAB back-slash operator:

```
[A, b] = mappNETLIST ('netlist_1.txt');

x = A\b;
```

Your script should print all node voltages onto the command line.

4) Now we use the `Netlist_Example.txt` file in your Lab 1 file package. The file contains a netlist schematic for a slightly more complicated circuit (shown in Fig. 4) with up to 10 different node voltages. Use your MATLAB circuit simulator to determine these voltages.

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[*] **Parsing** or **syntactic analysis** is the process of analyzing a string of symbols, either in natural language or in computer languages, according to the rules of a formal grammar.

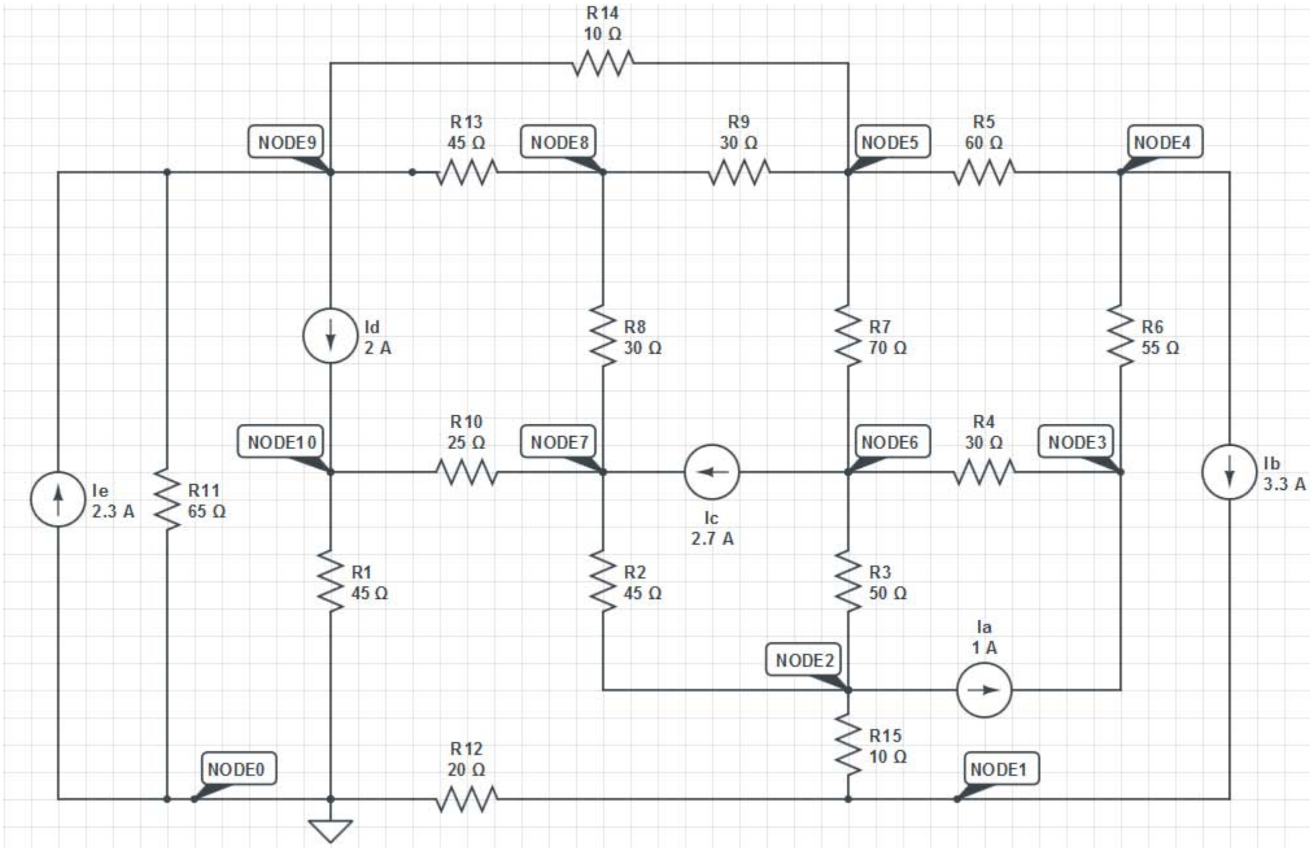

Fig. 4

Lab Report:

The lab report must include a title page with the name and student number for both group members. The report must also include a print-out of:

1) Pre-Lab (hand written is fine)
2) MATLAB output for the numbered in-lab section questions.
3) All MATLAB code

At the end of your lab report provide a 0.5 page concise summary of what you have learned.

Lab 1 Work Check-list

Student #1 Name and ID:

Student #2 Name and ID:

Pre-Lab Work

Item	Points	Completion	Assessed Mark
Q1	0.5		
Q2	0.5		
Q3	0.5		
Total	1.5		

In-Lab Work

Item	Points	Completion	Assessed Mark
Q1	1.5		
Q2	1		
Q3	1		
Q4	1		
Total	4.5		

Total Lab 1 Score out of 6 Points:

TA Name:

TA Signature: