

# Electric Circuits Laboratory for an Engineering Science Curriculum

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## *I-Introduction:*

The course Circuits and Systems I, taught in the Engineering Science Program at Borough of Manhattan Community College corresponds to a typical course taken by second year engineering students in the fields of Electrical, Mechanical and Chemical Engineering. The course is mostly concentrated in the analysis of DC Circuits and the time response of First and Second Order Circuits. This course had been taught for several years without any concurrent laboratory component due to a lack of funding to develop and implement a laboratory. This resulted in a separation between theory and reality, which produced lack of experimental skills and low motivation for the course, except among students intending to pursue a degree in Electrical Engineering. A NSF grant allowed us to develop a laboratory<sup>(1)</sup> that included experiments covering the majority of the contents taught in lecture<sup>(2)</sup>. The experimental set-up included instruments that could be used both in stand-alone as well as in PC-controlled mode. Students initially had challenging weeks learning circuit simulation software, developing proto-boarding skills, importing into and doing data processing with Matlab<sup>(3)</sup>, and preparing reports. However, as the course progressed, they became more and more satisfied with their new learned skills and obtained a more solid understanding of the lecture material.

## *II-Contents in the laboratory manual:*

The table of contents in the developed manual is shown below. Not all listed laboratory activities can be performed in a 14 weeks term, however, having extra activities is desirable for special projects and extra credit.

- OBJECTIVES
- INTRODUCTION
- DC INSTRUMENTATION AND ELECTRICAL COMPONENTS
- CIRCUIT SIMULATION AND DATA ANALYSIS SOFTWARE BASICS
- VOLTAGE AND CURRENT DIVISION
- EQUIVALENT CIRCUITS, KIRCHHOFF, NODE AND MESH ANALYSIS
- PROPORTIONALITY AND SUPERPOSITION
- THEVENIN AND NORTON THEOREMS
- MAXIMUM SIGNAL TRANSFER AND CIRCUIT INTERFACES
- DEPENDENT SOURCES
- TRANSISTORS
- SIGNAL WAVEFORMS AND AC INSTRUMENTATION
- SIGNAL SPECTRA
- OPERATIONAL AMPLIFIERS
- RC CIRCUIT TIME RESPONSE

- SERIES RLC CIRCUIT TIME RESPONSE
- APPENDIXES:
  - A. ELECTRONICS WORKBENCH TUTORIAL
  - B. MATLAB TUTORIAL
  - C. THE GLOBAL PB-503 PROTOBOARD
  - D. THE AGILENT 34401A PROGRAMMABLE DIGITAL MULTIMETER
  - E. THE AGILENT E3640A PROGRAMMABLE DC POWER SUPPLY
  - F. ELECTRICAL COMPONENTS
  - G. THE TEKTRONIX TDS220 PROGRAMMABLE OSCILLOSCOPE
  - H. THE BK PRECISION WAVE FUNCTION GENERATOR

### *III-The model of a typical laboratory activity:*

There is a pre-laboratory phase and a laboratory session. The length of each laboratory session is 3 class hours ( 135 minutes ).

Pre-laboratory phase: In this phase the students review the theoretical concepts, develop analytical solutions and evaluate those solutions manually or using MATLAB. They also execute circuit simulations using EWB to predict the outcome of experiments and analyze these results with MATLAB. Students are required to submit in the form of a pre-laboratory report the analytical solutions, circuit schematics, simulation results generated with EWB, plots generated with MATLAB and the answers to any questions posted for this phase. The Matlab programs used for data processing and plot generation must also be included.

Laboratory phase: In this phase students assemble the required circuits and take measurements. The report must be computer generated in MS-Word.

### *IV-Sample laboratory activity write-up:*

## VOLTAGE AND CURRENT DIVISION

### OBJECTIVES:

To test how resistors in series act as voltage dividers and how resistors in parallel act as current dividers.

### EQUIPMENT AND COMPONENTS:

Digital multimeter, proto-board, DC power supply, 10 k $\Omega$  potentiometer and resistors of 10 k $\Omega$  and 33 k $\Omega$ .

### INTRODUCTION:

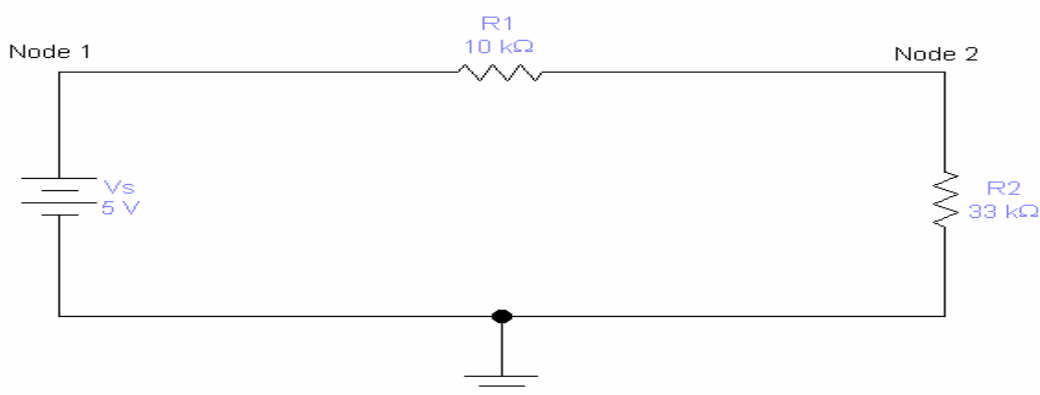
When resistors are connected in series, the voltage across any of those individual resistors is proportional to the resistance of the resistor. Similarly, when resistors are connected in parallel, the current through any of those individual resistors is proportional to the conductance of the resistor. These facts are widely used in circuit analysis and design.

## REFERENCES:

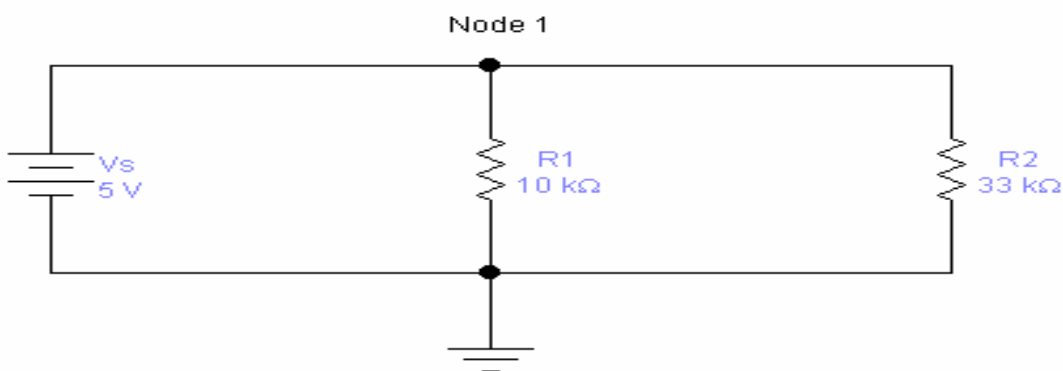
- Appendixes:
  - Proto-board
  - DMM
  - Power supply
  - EWB
  - Matlab
- Text book.

## PRE-LABORATORY ACTIVITIES:

### EWB CIRCUIT SIMULATIONS:



Circuit # 1: Voltage divider



Circuit # 2: Current divider

1. Using EWB edit circuits # 1 and #2 and save them in different files.  $V_1$  and  $V_2$  are the element voltages across  $R_1$  and  $R_2$  respectively.  $I_1$  and  $I_2$  are the element currents through  $R_1$  and  $R_2$ .

2. For each circuit run DC sweep with  $V_s$  ranging from 0V to 5V in steps of 0.5V. These simulations will provide the node voltages at nodes 1 and 2 in circuit # 1 and at node 1 in circuit # 2. Save all 3 data files as text files.

#### MATLAB DATA ANALYSIS:

##### Voltage division:

1. Calculate the element voltages  $V_1$  and  $V_2$  in circuit # 1 from the node voltage data files obtained in the EWB simulation.
2. Derive theoretical expressions for  $V_1$  and  $V_2$  as a function of  $V_s$ ,  $R_1$  and  $R_2$  using voltage division.
3. Calculate  $V_1$  and  $V_2$  from the derived expressions with the same range of  $V_s$  values used for the simulations.

##### Current division:

1. Calculate the element currents  $I_1$  and  $I_2$  in circuit # 2 using the node voltage data files from the simulation and the values of  $R_1$  and  $R_2$ .
2. Derive an expression for  $I_s$  as a function of  $V_s$ ,  $R_1$  and  $R_2$ . Use the expression to calculate  $I_s$  for each value of  $V_s$  used in the simulation.
3. Derive theoretical expressions for  $I_1$  and  $I_2$  as a function of  $I_s$ ,  $R_1$  and  $R_2$  using current division.
4. Calculate  $I_1$  and  $I_2$  from the derived theoretical expressions using the  $I_s$  values calculated in step 2 above.

#### INSTRUCTIONS FOR THE PRE-LABORATORY REPORT:

Follow the general guidelines for report preparation plus the following specific instructions.

Make a 4-panel plot as follows:

- 1<sup>st</sup> panel:  $V_1$ -simulation and  $V_1$ -theory in y-axis,  $V_s$  in x-axis.
- 2<sup>nd</sup> panel:  $V_2$ -simulation and  $V_2$ -theory in y-axis,  $V_s$  in x-axis.
- 3<sup>rd</sup> panel:  $I_1$ -simulation and  $I_1$ -theory in y-axis,  $I_s$  in x-axis.
- 4<sup>th</sup> panel:  $I_2$ -simulation and  $I_2$ -theory in y-axis,  $I_s$  in x-axis.

#### LABORATORY ACTIVITIES:

Measure the resistance of the resistors to use for this lab. Their values can be different from the ones shown in the circuit diagrams. In this experiment do not use the power from the proto-board. You must use the programmable power supply and DMM. For the voltage and current division experiments, you must control the experiment from the PC.

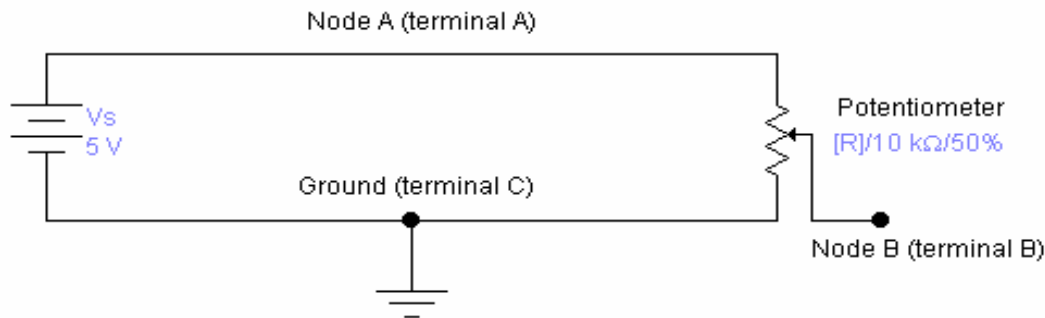
Voltage division: ( PC controlled experiment! )

1. With the power supply turned off assemble on the proto-board circuit #1, then connect the DMM as needed to measure the voltage  $V_1$  across  $R_1$ .
2. Set the control program in the PC to sweep  $V_s$  from 0 to 5 V in increments of 0.5 V and to measure voltage. Start the program and when asked, save the data file in your disk. Note: The saved data file will contain the values of  $V_s$  in the first column, the values of  $V_1$  in the second column and the values will be in volts.
3. Repeat the process to measure  $V_2$ .

Current division: ( PC controlled experiment! )

1. With the power supply turned off, assemble on the proto-board circuit # 2, then connect the DMM to measure the current  $I_1$  through  $R_1$ . Caution! Make sure to connect and set correctly the multimeter for current measurement.
2. Set the control program in the PC to sweep  $V_s$  from 0 to 5 V in increments of 0.5 V and to measure current. Start the program and when asked, save the data file in your disk. The saved data file will contain the values of  $V_s$  (in volts) in the first column and the values of  $I_1$  (in A) in the second column.
3. Repeat the process to measure  $I_2$ .

Voltage division using a potentiometer: ( Manually controlled experiment! )



Circuit # 3: Potentiometer voltage divider

A potentiometer is a very useful and simple device that offers an adjustable resistance. It has three terminals A, B and C. The resistance across terminals A and C is the total resistance of the potentiometer (10 k $\Omega$  in our case) and is fixed. The resistance across terminals B and (A or C) can be adjusted by sliding the electrical contact of terminal B (turning the wiper handle) over some length of the potentiometer.

1. With the power supply turned off, assemble on the proto-board circuit #3.

2. Slide the wiper handle of the potentiometer to one end and measure the voltage across terminals A and B ( $V_{AB}$ ). Then disconnect terminal A from the proto-board and measure the resistance across these terminals.
3. Repeat step 2 for four more different positions of the wiper handle.
4. Generate a data file containing the values of the resistance on the first column and the values of  $V_{AB}$  on the second column.

### LABORATORY REPORT:

Follow the general guidelines for report preparation plus the following specific instructions.

#### For voltage and current division:

Make calculations and produce a plot similar to the one in the pre-laboratory. However, now you will be using experimental rather than simulation data and also real measured resistance values.

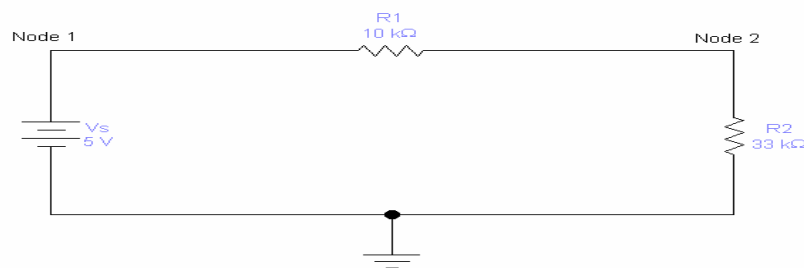
#### For the potentiometer:

Make a graph of  $V_{AB}$  versus  $R_{AB}$ .

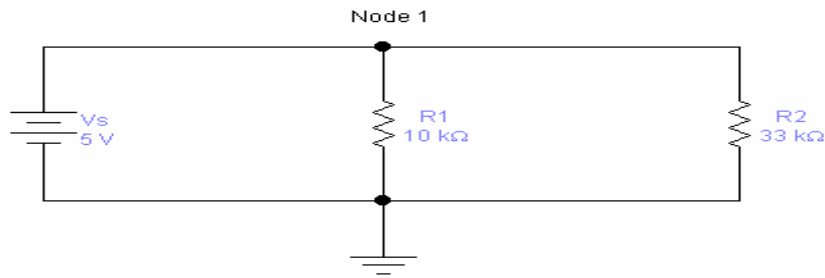
*V-Sample pre-laboratory report for the activity described in IV above.*

## PRE-LABORATORY REPORT VOLTAGE AND CURRENT DIVISION

Main circuits to consider:



Circuit # 1: Voltage divider



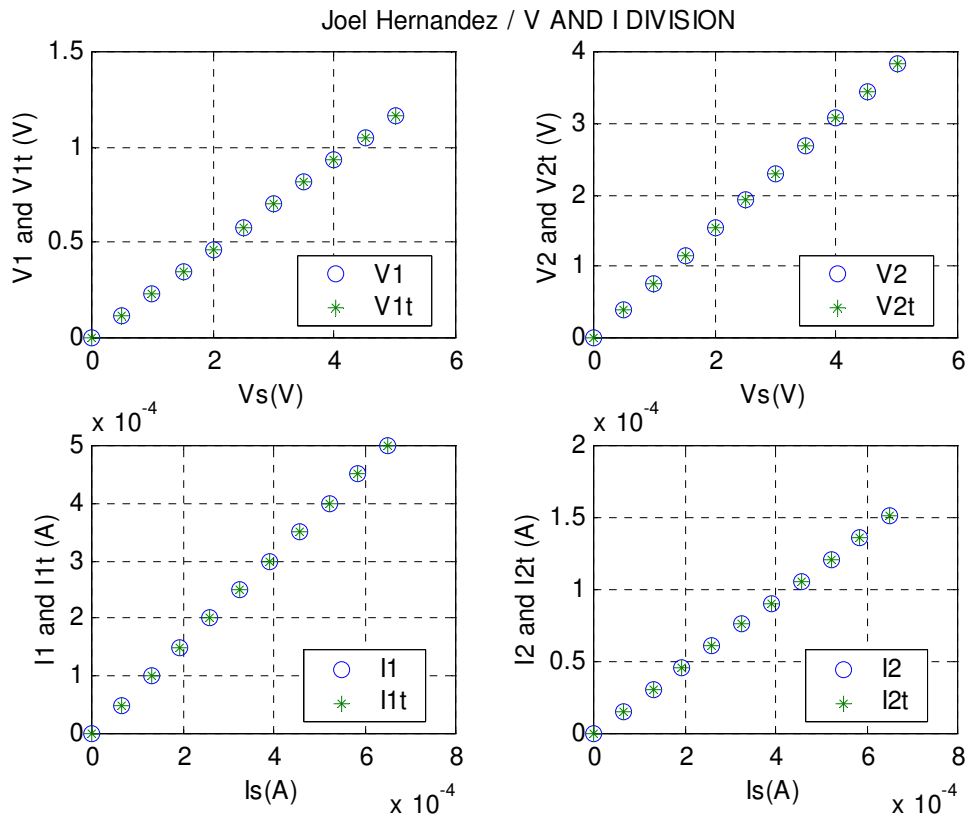
Circuit # 2: Current divider

EWB simulations performed:

Two DC-sweeps are conducted in circuit # 1, one for node 1 as the output and the other for node 2. One DC-sweep is done in circuit # 2 with node 1 as the output voltage. In all 3 simulations  $V_s$  is swept from 0V to 5V in steps of 0.5V.

The data from each simulation is saved as a text file. Each file contains the swept  $V_s$  values in the first column and the output node voltage in the second column.

Results are presented in the form of a 4-panel plot as follows:



Data processing:

Simulation data is used to calculate the element voltages V1, V2 and the element currents I1 and I2. In doing this, attention was given to the fact that the simulations give node voltages, not element voltages.

In addition to this, theoretical calculations are done to find the element voltages and currents applying the division rules as follows:

$$V1t=r1/(r1+r2)*Vs$$

$$V2t=r2/(r1+r2)*Vs$$

$$I1t=g1/(g1+g2)*Is$$

$$I2t=g2/(g1+g2)*Is$$

Matlab program for prelab:

%V and I division. Prelab

```
clc,clear,r1=10000;r2=33000;g1=1/r1;g2=1/r2;
```

```
%VOLTAGE DIVISION SECTION
```

```
load c1n1.txt;load c1n2.txt
```

```
%simulation calculations
```

```
Vs=c1n1(:,1);vn1=c1n1(:,2);vn2=c1n2(:,2);
```

```
V1=vn1-vn2;V2=vn2-0;
```

```
%theoretical calculations
```

```
V1t=r1/(r1+r2)*Vs;V2t=r2/(r1+r2)*Vs;
```

```
%CURRENT DIVISION SECTION
```

```
load c2n.txt
```

```
%simulation calculations
```

```
vn=c2n(:,2);
```

```
I1=vn/r1;I2=vn/r2;
```

```
%theoretical calculations
```

```
req=1/(1/r1+1/r2);
```

```
Is=Vs/req;
```

```
I1t=g1/(g1+g2)*Is;I2t=g2/(g1+g2)*Is;
```

```
%PLOT
```

```
subplot(2,2,1),plot(Vs,V1,'o',Vs,V1t,'*'),title('Joel / V,I DIVISION')
```

```
legend('V1','V1t',0),xlabel('Vs(V)'),ylabel('V1 and V1t (V)'),grid
```

```
subplot(2,2,2),plot(Vs,V2,'o',Vs,V2t,'*'),
```

```
legend('V2','V2t',0),xlabel('Vs(V)'),ylabel('V2 and V2t (V)'),grid
```

```
subplot(2,2,3),plot(Is,I1,'o',Is,I1t,'*'),
```

```
legend('I1','I1t',0),xlabel('Is(A)'),ylabel('I1 and I1t (A)'),grid
```

```
subplot(2,2,4),plot(Is,I2,'o',Is,I2t,'*'),
```

```
legend('I2','I2t',0),xlabel('Is(A)'),ylabel('I2 and I2t (A)'),grid
```

*VI-Conclusions:*

This comprehensive laboratory plan allowed the achievement of the goals pursued.



First, students gained hands-on skills in the assembly and testing of circuits on the proto-board, as well as in the operation of electric instruments in stand-alone and automatic control modes.

Second, the triple solution to the same problem ( analytically at the beginning, followed by a simulation, and ending with a real experiment ), produced a better understanding of the lecture material.

Third, students showed great motivation for the course and satisfaction for the way in which they could master different techniques for the analysis and realization of diverse electrical circuits.

Finally, they were impressed by the usefulness of data transfer operations among different software packages like Matlab, LabView, and Electronics Workbench and by how all the results could be shown at the end in a single MS-Word report.

#### *VI-Bibliography:*

- (1) Hernandez J., "Circuits and Systems I Laboratory Manual", Borough of Manhattan Community College, NY, 2003.
- (2) Etter D. M., "Engineering Problem Solving with Matlab", 2<sup>nd</sup> Ed., Prentice Hall, N.J., 1997.
- (3) Alexander C.K. and Sadiku M. N. O, "Fundamentals of Electric Circuits", 2/e McGraw Hill, N.J., 2003

#### *VII Biography:*

**JOEL HERNANDEZ:** Dr. Hernandez is an Assistant Professor of Physics and Engineering at Borough of Manhattan Community College in New York City. He obtained his Ph. D. from the Graduate School of CUNY in New York City.

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