Laboratory work 1. DC circuit analysis.

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Table 1: Values of voltage sources and resistors

Parameter		R_{i1}, kΩ	R_{i2}, Ω	R_1,	R_2,	R_3,	R_4,	R_5,	R_6,	V_{s1},	V_{s2},
Testboard number	1	1,0	100	1,5	2,0	2,4	3,3	1,5	1,0	20	5
	2	1,0	120	1,3	2,0	2,7	3,6	1,8	1,1	22	6
	3	1,0	100	1,8	2,0	2,4	3,3	1,3	1,0	24	6
	4	1,0	120	1,2	2,0	2,7	3,6	1,2	1,1	20	8
	5	1,0	100	1,5	2,0	2,4	3,3	1,5	1,0	22	6
	6	1,0	120	1,3	2,0	2,7	3,6	1,2	1,1	24	8
	7	1,0	100	1,8	2,0	2,4	3,3	1,3	1,0	20	6

1. Build a voltage divider circuit as shown in Figure 1, using part A of the testboard only. Measure the voltage across the load resistor for different values of its resistance given in Table 2. During the measurement, the input voltage must be kept at the fixed level V_{s1}. Record the measured values in Table 2.

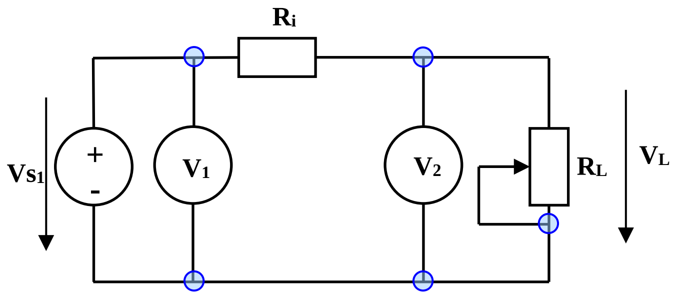


Figure 1. Voltage divider

Table 2: Measured values of load voltage

R_L	**100 Ω**	**200 Ω**	**500 Ω**	**800 Ω**	**900 Ω**	**1 kΩ**
U_L, V Calculated	2	3.67	7.33	9.78	10.42	11
U_L, V LTspice	2	3.67	7.33	9.78	10.42	11
U_L, V Measured						
R_L	**1.1 kΩ**	**1.2 kΩ**	**1.5 kΩ**	**2 kΩ**	**5 kΩ**	**10 kΩ**
U_L, V Calculated	11.52	12	13.2	14.67	18.33	20
U_L, V LTspice	11.52	12	13.2	14.67	18.33	20
U_L, V Measured						

Ltspice Simulation

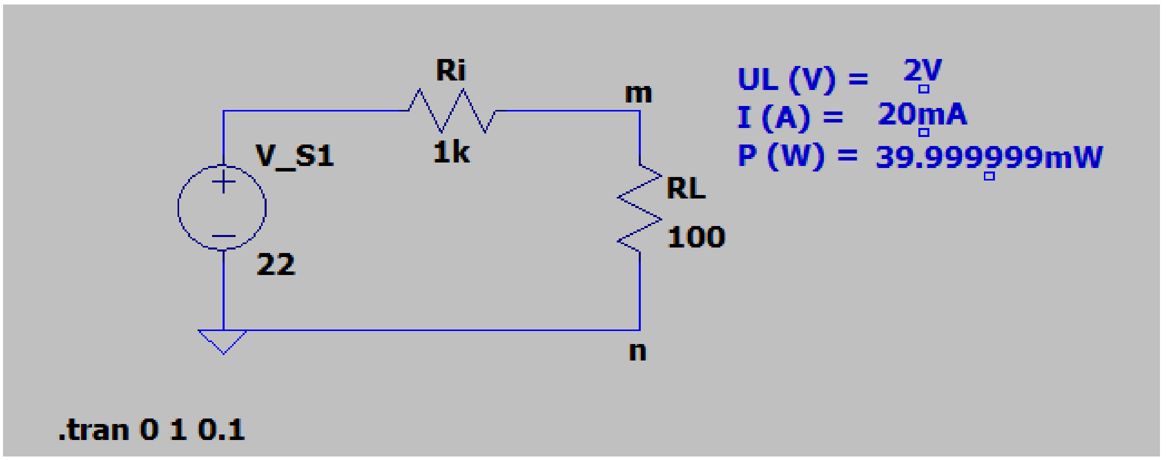


Figure 1: LTspice simulation for the Voltage Divider circuit when RL = 100 Ω

The equation used for Calculation

$$U_L = V_{S1} * \frac{RL}{Ri + RL} = 22 * \frac{100}{1000 + 100} = 2\ V$$

$$I = \frac{U_L}{RL} = \frac{2}{100} = 20\ mA$$

$$P = U_L * I = 2 * (20 * 10^{-3}) = 40 * 10^{-3}\ W$$

2. Build a circuit as specified in Fig. 2. Set the voltages V_{s1} and V_{s2} according to Table 1. and measure the current through and voltage across each resistor. Write the measured values of currents and voltages in Tables 3 and 4, respectively.

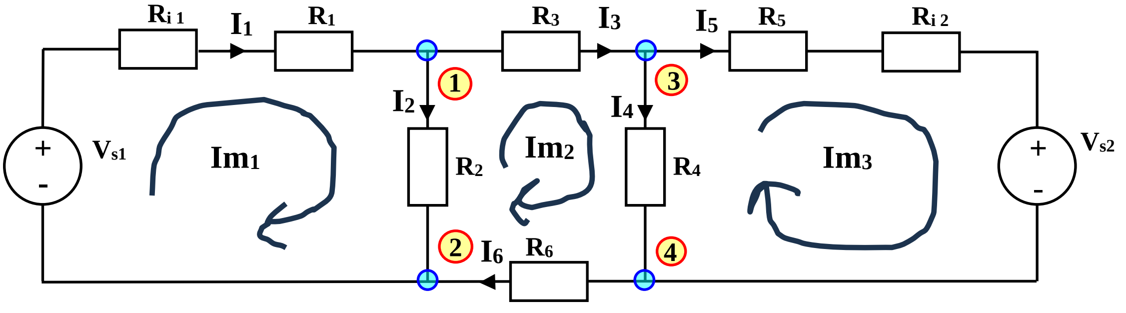


Figure 2. Circuit for measurement of currents and voltages

Table 3: Measured values of branch currents

Quantity	I_1	I_2	I_3	I_4	I_5	I_6
Value, mA Calculated	5.60	4.56	1.03	1.45	-0.414	1.03
Value, mA LTspice	5.60	4.56	1.03	1.45	-0.414	1.03
Value, mA Measured						

Mesh Analysis for calculating the loop currents

<u>Loop 1 – Im_1</u>

$$-V_{s1} + Im_1(R_{i1} + R_1) + R_2(Im_1 - Im_2) = 0$$
$$Im_1(R_{i1} + R_1 + R_2) - Im_2(R_2) = V_{s1}$$

<u>Loop 2 – Im_2</u>

$$Im_2(R_3) + R_4(Im_2 - Im_3) + Im_2(R6) - R_2(Im_1 - Im_2) = 0$$
$$-Im_1(R_2) + Im_2(R_3 + R_4 + R_6 + R_2) - Im_3(R_4) = 0$$

<u>Loop 3 – Im_3</u>

$$Im_3(R_5 + R_{i2}) + V_{s2} - R_4(Im_2 - Im_3) = 0$$
$$-Im_2(R_4) + Im_3(R_5 + R_{i2} + R_4) = -V_{s2}$$

$$\begin{pmatrix} (R\_i1 + R1 + R2) & -R2 & 0 \\ (-R2) & (R2 + R3 + R4 + R6) & -R4 \\ 0 & -R4 & (R4 + R5 + R\_i2) \end{pmatrix} \begin{pmatrix} Im_1 \\ Im_2 \\ Im_3 \end{pmatrix} = \begin{pmatrix} V_{s1} \\ 0 \\ -V_{s2} \end{pmatrix}$$

$$\boldsymbol{Im_1 = 5.5964\ mA}$$
$$\boldsymbol{Im_2 = 1.0323\ mA}$$
$$\boldsymbol{Im_3 = -0.4137\ mA}$$

Branch Currents and Mesh Currents equivalence

$$I_1 = Im_1 = 5.5964\ mA$$
$$I_2 = Im_1 - Im_2 = 4.5641\ mA$$
$$I_3 = Im_2 = 1.0323\ mA$$
$$I_4 = Im_2 - Im_3 = 1.4460\ mA$$
$$I_5 = Im_3 = -0.4137\ mA$$
$$I_6 = Im_2 = 1.0323\ mA$$

Table 4: Measured values of voltages

Quantity	V_{R1}	V_{R2}	V_{R3}	V_{R4}	V_{R5}	V_{R6}	V_{Ri1}	V_{Ri2}
Value, V Calculated	7.2753	9.1283	2.7871	5.2056	-0.7447	1.1355	5.5964	-0.0496
Value, V LTspice	7.2753	9.1283	2.7871	5.2056	-0.7447	1.1355	5.5964	-0.0496
Value, V Measured								

Nodal Analysis for calculating Nodal voltages

$$V3 = 0V \ as \ it \ is \ ground$$
$$G = \frac{1}{R} \rightarrow this \ is \ conductance$$
$$G_{i11} = \frac{1}{Ri1 + R1} \quad and \ G_{i25} = \frac{1}{Ri2 + R5}$$

<u>Node V1</u>

$$(V1 - V_{s1} - V2) * G_{i11} - (0 - V1) * G_3 - (V2 - V1) * G_2 = 0$$
$$V1(G_{i11} + G_3 + G_2) - V2(G_{i11} + G_2) = V_{s1} * G_{i11}$$

<u>Node V2</u>

$$-(V1 - V_{s1} - V2) * G_{i11} + (V2 - V4) * G_6 + (V2 - V1) * G_2 = 0$$
$$-V1(G_{i11} + G_2) + V2(G_{i11} + G_6 + G_2) - V4(G_6) = -V_{s1} * G_{i11}$$

<u>Node V4</u>

$$-(V2 - V4) * G_6 + (V4 + V_{s2} - 0) * G_{i25} + (V4 - 0) * G_4 = 0$$
$$-V2(G_6) + V4(G_6 + G_{i25} + G_4) = -V_{s2} * G_{i25}$$

$$\begin{pmatrix} (G_{i11} + G_3 + G_2) & -(G_{i11} + G_6 + G_2) & 0 \\ -(G_{i11} + G_2) & (R2 + R3 + R4 + R6) & -G_6 \\ 0 & -G_6 & (G_6 + G_{i25} + G_4) \end{pmatrix} \begin{pmatrix} V1 \\ V2 \\ V4 \end{pmatrix} = \begin{pmatrix} V_{s1} * G_{i11} \\ -V_{s1} * G_{i11} \\ -V_{s2} * G_{i25} \end{pmatrix}$$

$$\boldsymbol{V1 = 2.7871\ V}$$
$$\boldsymbol{V2 = -6.3411\ V}$$
$$\boldsymbol{V4 = -5.2056\ V}$$

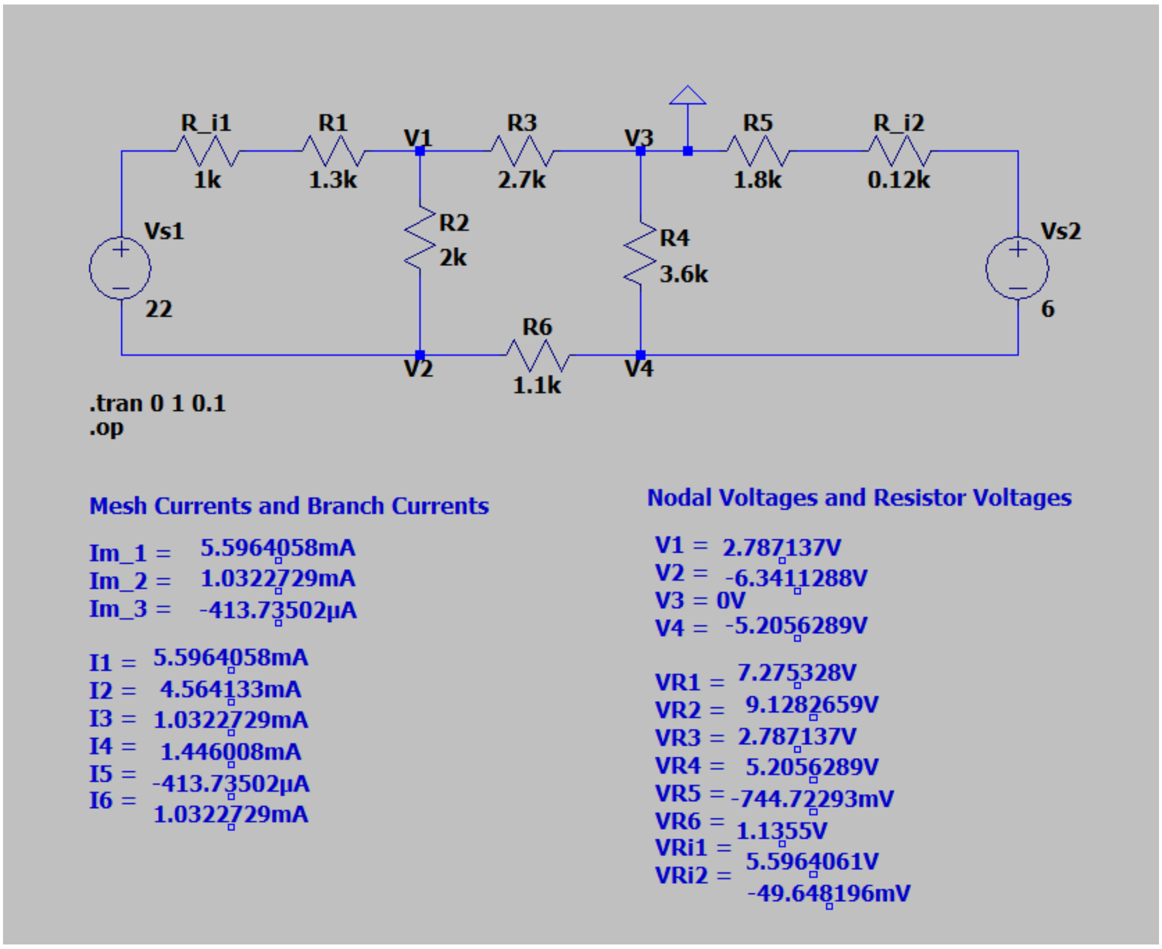
Sample Calculation for V_{R1} :

$$V_{R1} = I_1 * R1 = 5.5964\ mA * 1300 = 7.2753\ V$$

<u>Tellegens Theorem</u>

$$Power = -I1 * V_{s1} + V_{Ri1} * I1 + V_{R1} * I1 + V_{R2} * I2 + V_{R3} * I3 + V_{R4} * I4 + V_{R4} * I4 + V_{R5} * I5 + V_{Ri2} * I5 + V_{s2} * I5 + V_{R6} * I6 = 3.0198 * 10^{-14}\ W \approx 0\ W$$

LTspice Simulation for question 2



3. Build a circuit as shown in Fig. 3 and measure the following voltages:

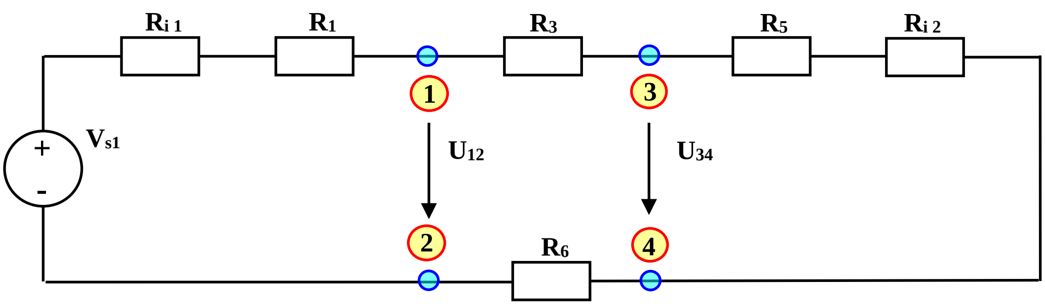


Figure 3. Voltage divider circuit without resistors R_2 and R_4

Voltage,V	V12	V34
Calculated values,V	15.6908	5.2668
LTspice values,V	15.6908	5.2668
Measured values,V		

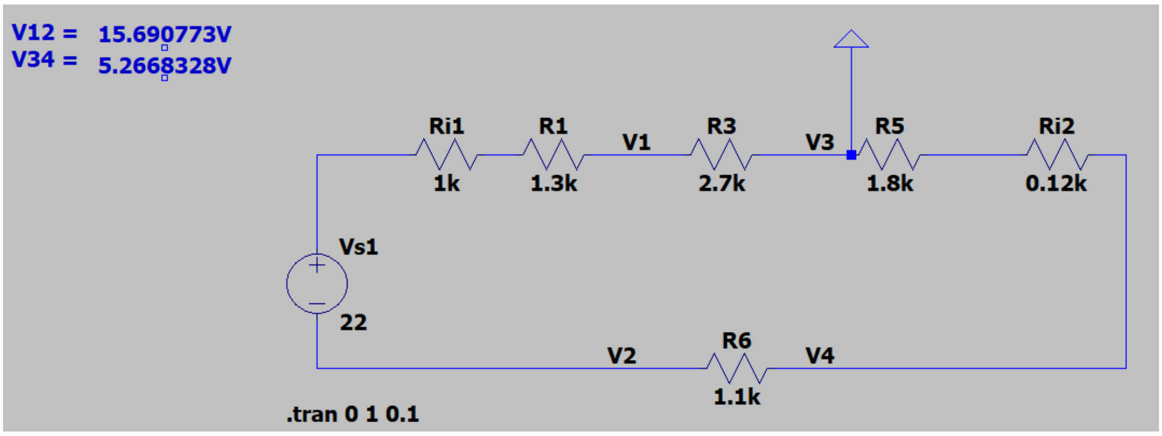
Calculation of V12 and V34 :

$$R_{total} = R_{i1} + R_1 + R_3 + R_5 + R_{i2} + R_6 = 8.02\ k\Omega$$

$$\boldsymbol{V12} = V_{s1} * \frac{R_3 + R_5 + R_{i2} + R_6}{R_{total}} = \mathbf{15.6908\ V}$$

$$\boldsymbol{V34} = V_{s1} * \frac{R_5 + R_{i2}}{R_{total}} = \mathbf{5.2668\ V}$$

LTspice Simulation circuit for question 3



4. Build a circuit as specified in Fig. 4 and measure the following voltages :

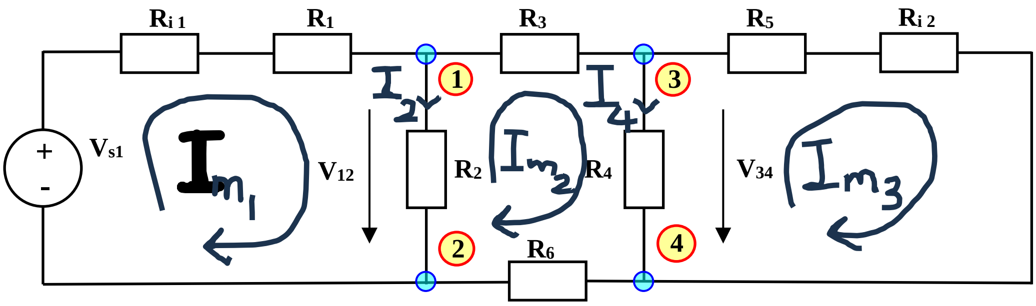


Figure 4. Voltage divider circuit with resistors R2 and R4

Voltage,V	V12	V34
Calculated values,V	8.4444	2.0930
LTspice values,V	8.4444	2.0930
Measured values,V		

Calculations for V12 and V34

Mesh Analysis for calculating the loop currents

Loop 1 – Im_1

$$-V_{s1} + Im_1(R_{i1} + R_1) + R_2(Im_1 - Im_2) = 0$$
$$Im_1(R_{i1} + R_1 + R_2) - Im_2(R_2) = V_{s1}$$

Loop 2 – Im_2

$$Im_2(R_3) + R_4(Im_2 - Im_3) + Im_2(R6) - R_2(Im_1 - Im_2) = 0$$
$$-Im_1(R_2) + Im_2(R_3 + R_4 + R_6 + R_2) - Im_3(R_4) = 0$$

Loop 3 – Im_3

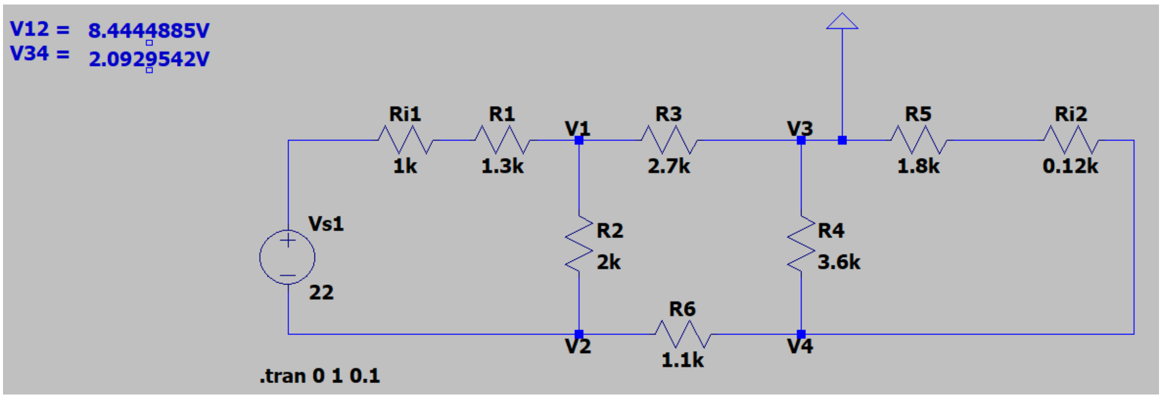
$$Im_3(R_5 + R_{i2}) - R_4(Im_2 - Im_3) = 0$$
$$-Im_2(R_4) + Im_3(R_5 + R_{i2} + R_4) = 0$$

$$\begin{pmatrix} (R\_i1 + R1 + R2) & -R2 & 0 \\ (-R2) & (R2 + R3 + R4 + R6) & -R4 \\ 0 & -R4 & (R4 + R5 + R\_i2) \end{pmatrix} \begin{pmatrix} Im_1 \\ Im_2 \\ Im_3 \end{pmatrix} = \begin{pmatrix} V_{s1} \\ 0 \\ 0 \end{pmatrix}$$

$$\boldsymbol{Im_1 = 5.8937\ mA}$$
$$\boldsymbol{Im_2 = 1.6715\ mA}$$
$$\boldsymbol{Im_3 = 1.0901\ mA}$$

$$\boldsymbol{V12} = V_{R2} = I_2 * R_2 = (Im_1 - Im_2) * R_2 = \boldsymbol{8.4444\ V}$$
$$\boldsymbol{V34} = V_{R4} = I_4 * R_4 = (Im_2 - Im_3) * R_4 = \boldsymbol{2.0930\ V}$$

LTspice Simulations for question 4



5. Circuit simulation by means of LTSpice

5.1. use LTSpice to create a model for the circuit specified in Fig. 4 (use values from Table 1) and determine the voltages: $\mathbf{V_{12}}$ = **15.6908** un $\mathbf{V_{34}}$ =**5.2668**

5.2 remove from the circuit resistors R_2 un R_4 and determine the following voltages $\mathbf{V_{12}}$ = **8.4444** un $\mathbf{V_{34}}$ = **2.0930**.

6. Use MATLAB code to create a Word file containing graphical results (in MATLAB code replace the values of elements of array Vsle with the measured values of the output voltage from Table 2, as well as set the value of variable V1 to the corresponding value from Table 1).

MATLAB program for calculations and Word file creation

```
                  % Calculations

% assign a value from Table 1 to variable U1

U1=20;
Rsl=0:50:1e4;
Ri = 1e3;
Isl=U1./(Rsl+Ri);
Psl=(Isl.^2).*Rsl;
Pkop=(Isl.^2).*(Rsl+Ri);      % the total power
L_K=100*Psl./Pkop;            % efficiency

                  % Experimental data

Rsle = [100 200 500 800 900 1e3 1.1e3 1.2e3 1.5e3 2e3 5e3 10e3];
Usle = [2  8.8 9.5 10 10.47 13.3 15   16    16.5 17  17.5 17.7];

Psle=(Usle.^2)./Rsle;
fg(1)=figure(1)
plot(Rsl,Psl,Rsle,Psle,'o','LineWidth',2),
grid on,title('Power'),xlabel('Rsl'),ylabel('Psl')
fg(2)=figure(2)
plot(Rsl,Isl.*Rsl,Rsle,Usle,'o','LineWidth',2),
grid on,title('Usl,Usle'),xlabel('Rsl'),ylabel('Usl')

                  % Creating a Word file
word = actxserver('Word.Application');         % run Word application
word.Visible = 1;                              % make it visible
document = word.Documents.Add;                 % create a new document
selection = word.Selection;
selection.ParagraphFormat.Alignment = 1;       % text alignment
selection.Font.Size=12;                        % change font size
selection.TypeText('Laboratory work 3.');      % input some text
selection.TypeParagraph;                       % new line
selection.TypeText('Graphical results.');
grname = {'The output power against the load resistance', ...
          'The output voltage against the load resistance'}
for n=1:2,
  print(fg(n),'-dmeta');                       % copy graph into clipboard
  invoke(word.Selection,'Paste');              % paste graph to the document
  selection.ParagraphFormat.Alignment = 1;
  selection.Font.Size=11;
  selection.TypeText([num2str(n),'.att. ', grname{n}]);
end
```

Appendix

MATLAB Code used for calculations in Lab 1 – Part 1

```
clc,format compact, clear

%% Lab 1 - Part 1

%% Question 1


R_L = [100,200,500,800,900,1e3,1.1e3,1.2e3,1.5e3,2e3,5e3,10e3]; % in ohms
R_i = 1e3; % in ohms
V_s1 = 22; % in V
R_tot = R_i + R_L; % total resistance in ohms

I=V_s1 ./ R_tot  % current in certain resistances of R_L in A
V_L = I.*R_L % Load voltage in specific R_L values in V

%% -------Question 2------------

%% Mesh currents

R_i1=1e3; % in ohms
R_i2=120; % in ohms
R1=1.3e3; % in ohms
R2=2e3; % in ohms
R3=2.7e3; % in ohms
R4=3.6e3; % in ohms
R5=1.8e3; % in ohms
R6=1.1e3; % in ohms
V_s1=22; % in V
V_s2=6; % in V

% Conductance Values in Siemens
G_i1 = 1/R_i1;
G_i2 = 1/R_i2;
G1 = 1/R1;
G2 = 1/R2;
G3 = 1/R3;
G4 = 1/R4;
G5 = 1/R5;
G6 = 1/R6;

% Matrix Calculation

coefs = [(R_i1+R1+R2)     -R2                  0
          -R2          (R2+R3+R4+R6)          -R4
            0             -R4           (R4+R5+R_i2)];
results = [V_s1; 0; -V_s2];
solutions = coefs\results

Im_1 = solutions(1)*1e3 % in mA for mesh 1
Im_2 = solutions(2)*1e3 % in mA for mesh 2
Im_3 = solutions(3)*1e3 % in mA for mesh 3
```

```
% Branch Currents

I1 = Im_1 % in mA
I2 = Im_1-Im_2 % in mA
I3 = Im_2 % in mA
I4 = Im_2-Im_3 % in mA
I5 = Im_3 % in mA
I6 = Im_2 % in mA


% Voltages of the Resistors

V_R1=I1*R1*1e-3 % in V
V_R2=I2*R2*1e-3 % in V
V_R3=I3*R3*1e-3 % in V
V_R4=I4*R4*1e-3 % in V
V_R5=I5*R5*1e-3 % in V
V_R6=I6*R6*1e-3 % in V
V_Ri1=I1*R_i1*1e-3 % in V
V_Ri2=I5*R_i2*1e-3 % in V

%% Telegens theorem
% Power in Watts
TELLEGENS_Power=-
I1*V_s1+V_Ri1*I1+V_R1*I1+V_R2*I2+V_R3*I3+V_R4*I4+V_R5*I5+V_Ri2*I5+V_s2*I5+V_R6
*I6

%% Nodal voltages

G_i11=1/(R_i1+R1); % Conductance for R_i1 and R1 in series, in Siemens
G_i25=1/(R_i2+R5); % Conductance for R_i2 and R5 in series, in Siemens

% Matrix Calculation

n_coefs = [G_i11+G2+G3       -(G_i11+G2)           0
          -(G_i11+G2)         G_i11+G6+G2          -G6
                0                -G6         G6+G_i25+G4    ];
n_results = [V_s1*(G_i11); -V_s1*(G_i11); -V_s2*(G_i25)];

n_solutions = n_coefs\n_results;

V1 = n_solutions(1) % in V
V2 = n_solutions(2) % in V
V4 = n_solutions(3) % in V
V3 = 0 % It is Zero, as it is the Ground, in V


%% --------Question 3-----------

R_total_p3 =R_i1+R1+R3+R5+R_i2+R6;% in ohms
V12 =V_s1*((R3+R5+R_i2+R6)/(R_total_p3)) % in V
V34 =V_s1*((R5+R_i2)/(R_total_p3)) % in V



%% ------Question 4-----

% Mesh Current Analysis
```

```
% Matrix Calculation

coefs = [(R_i1+R1+R2)      -R2                  0
          -R2          (R2+R3+R4+R6)           -R4
            0               -R4           (R4+R5+R_i2)];
results = [V_s1; 0; 0];
solutions = coefs\results;

Im_1 = solutions(1)*1e3; % in mA
Im_2 = solutions(2)*1e3; % in mA
Im_3 = solutions(3)*1e3; % in mA

I2 = (Im_1-Im_2)*1e-3; % Branch current in R2, in mA
I4 = (Im_2-Im_3)*1e-3; % Branch current in R4, in mA

V_R2 = I2*R2; % Voltage across R2, in V
V_R4 = I4*R4; % Voltage across R4, in V

V12_w24 = V_R2 % in V
V34_w24 = V_R4 % in V
```