

2118085

by Oliver Cox

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① VERY GOOD EVIDENCE OF KNOWLEDGE AND UNDERSTANDING. EVIDENCE OF CRITICAL ANALYSIS REPORT IS WELL PRESENTED.

MARK AS GOOD.

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Introduction

In this assignment the overall aim is to investigate the behaviour of R-L and R-C series circuits through the use mathematic formulae. The circuits themselves are to be connected to a direct current voltage source. Simulation as well as practical construction are used alongside theoretical prediction, followed by testing to measure voltage and current for each circuit. Measurements are taken at the transient period for charging and discharging. The theoretical prediction utilises the rearranging of formulae to calculate engineering problems. Multisim is the simulation software chosen for this assignment. Results from all sources are analysed, with comparisons made between all three systems. The findings are collated in the conclusion.

Task 1 Transient Behaviour for the Charging of a Capacitor

Task 1 Calculations

$$R=5.6 \times 10^3 \quad C=10000 \times 10^{-6}$$



Steady state conditions = 5τ

$$\tau = RC \therefore \tau = (5.6 \times 10^3)(10000 \times 10^{-6}) = 56\text{s} \therefore 5\tau = 5 \times 56 = 280\text{s}$$

This means steady state is achieved at 280s

The three random time values chosen were 45, 95 and 185

$$\text{Maximum Current, } I_{\text{MAX}} = VR = 55.610^3 = 892.9 \times 10^{-6}\text{A}$$

$$\text{Where } t=45\text{s, } V_c = V_{\text{MAX}}(1 - e^{-t/\tau}) = 5(1 - e^{-45/56}) = 2.761\text{V}$$

$$\text{Where } t=95\text{s, } V_c = V_{\text{MAX}}(1 - e^{-t/\tau}) = 5(1 - e^{-95/56}) = 4.083\text{V}$$

$$\text{Where } t=185\text{s, } V_c = V_{\text{MAX}}(1 - e^{-t/\tau}) = 5(1 - e^{-185/56}) = 4.816\text{V}$$

$$\text{Where } t=45\text{s, } i = I_{\text{MAX}}(e^{-t/\tau}) = 892.9 \times 10^{-6}(e^{-45/56}) = 399.8\mu\text{A}$$

$$\text{Where } t=95\text{s, } i = I_{\text{MAX}}(e^{-t/\tau}) = 892.9 \times 10^{-6}(e^{-95/56}) = 163.7\mu\text{A}$$

$$\text{Where } t=185\text{s, } i = I_{\text{MAX}}(e^{-t/\tau}) = 892.9 \times 10^{-6}(e^{-185/56}) = 32.82\mu\text{A}$$

Task 1 Multisim circuit

The circuit shown in figure 1 was built on Multisim. It has a 5V pulse voltage DC supply, a SPDT switch, a resistor with a value of $5.6\text{k}\Omega$, a $10000\text{ }\mu\text{F}$ capacitor and a ground. All components are connected in series. Five τ was calculated at 280s, so the simulation was run for 560s. Pulse width was set to 280s. The transient feature was used to create the graphs below.

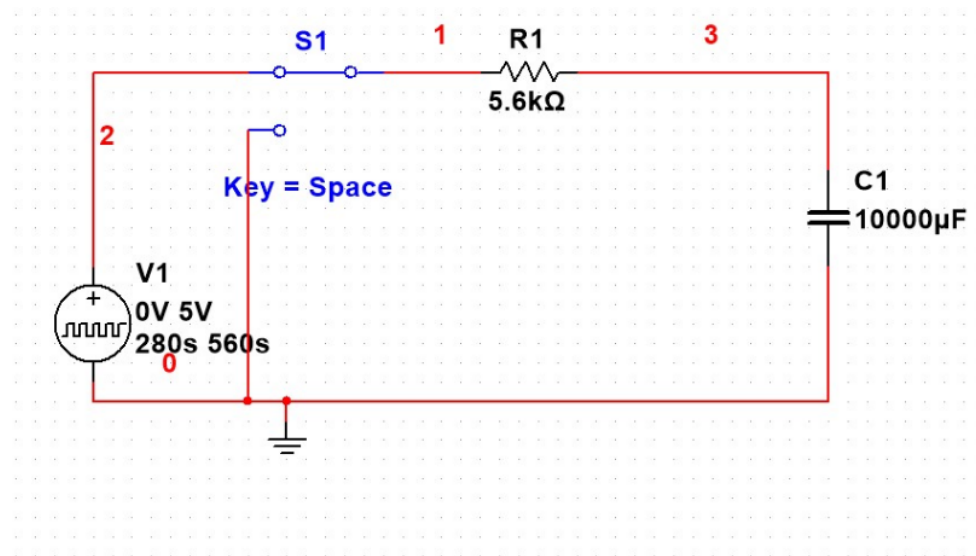


Figure 1: RC charging circuit

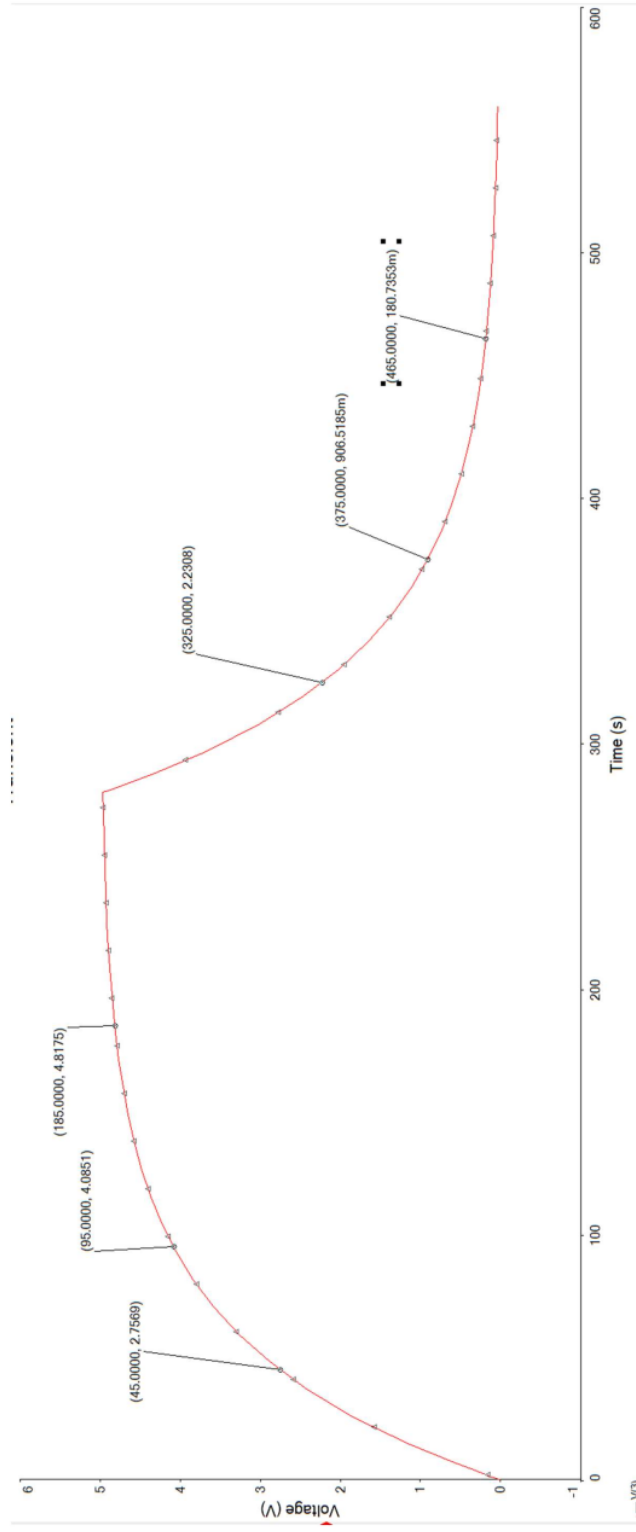


Figure 2: Simulated RC circuit charge/discharge voltage

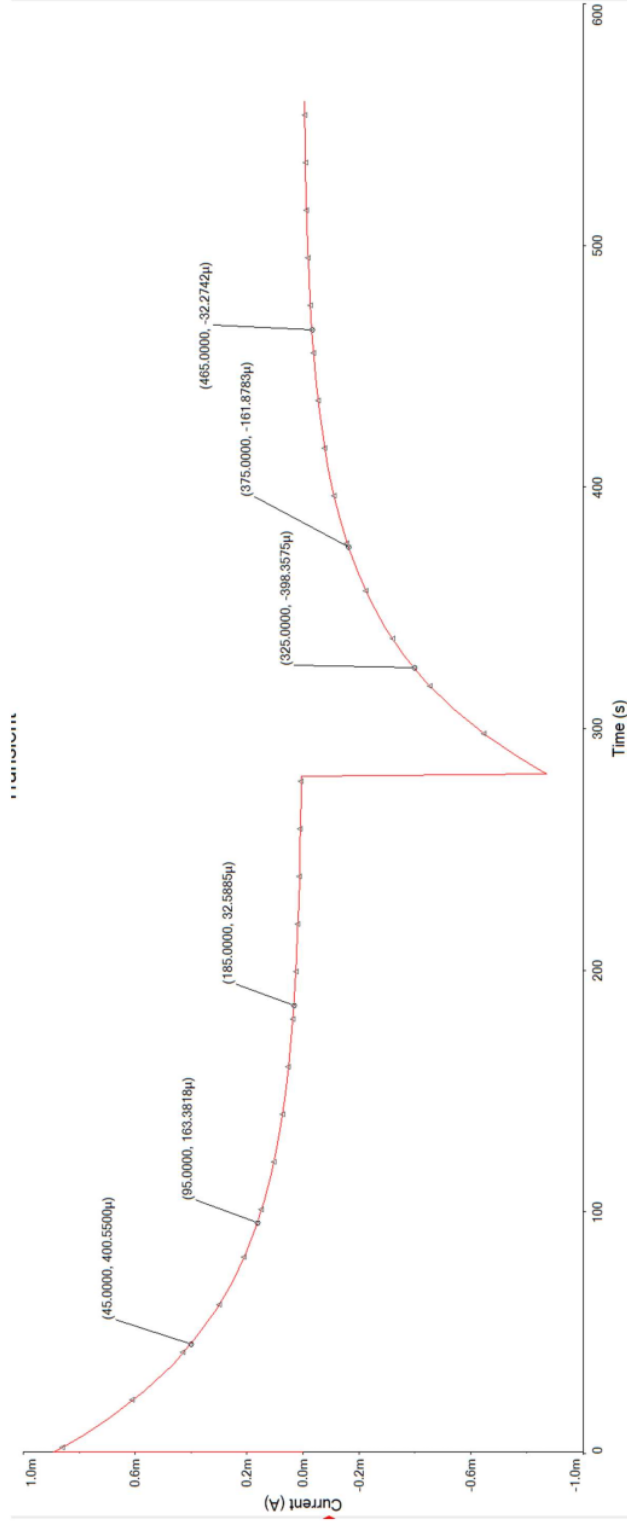


Figure 3: Simulated RC circuit current charge/discharge

The above graphs show capacitor voltage equalling the supply voltage by 280s . That is the point at which steady state conditions are met. Also, at the point the RC circuit reaches 5τ the current is zero as the capacitor is fully charged.

Practical RC circuit for charging capacitor

A physical copy of the circuit in figure 1 was created  a breadboard. One difference to note is the supply voltage for the physical circuit was 6V DC. Two multimeters were used. One configured to measure voltage and the other to measure current. The positive from the supply was connected to the positive leg of the capacitor to charge it.

Time (s)	Current (A)	Voltage (V)
5	0.97	0.58
10	0.84	1.07
15	0.76	1.49
20	0.7	1.86
25	0.67	2.24
30	0.59	2.55
35	0.54	2.87
40	0.49	3.13
45	0.45	3.39
50	0.41	3.61
55	0.38	3.82
60	0.35	4
70	0.29	4.34
80	0.24	4.63
90	0.21	4.85
100	0.17	5.05
110	0.15	5.21
120	0.12	5.35
130	0.1	5.47
140	0.09	5.57
150	0.07	5.65
160	0.06	5.72
170	0.05	5.78
180	0.04	5.83
190	0.04	5.87
200	0.03	5.9
210	0.03	5.93
220	0.02	5.96
230	0.02	5.98
240	0.02	5.99
250	0.01	6.01
260	0.01	6.02
270	0.01	6.03
280	0.01	6.04
290	0.01	6.05
300	0.01	6.06

Figure 4: Practical RC circuit charging table of results

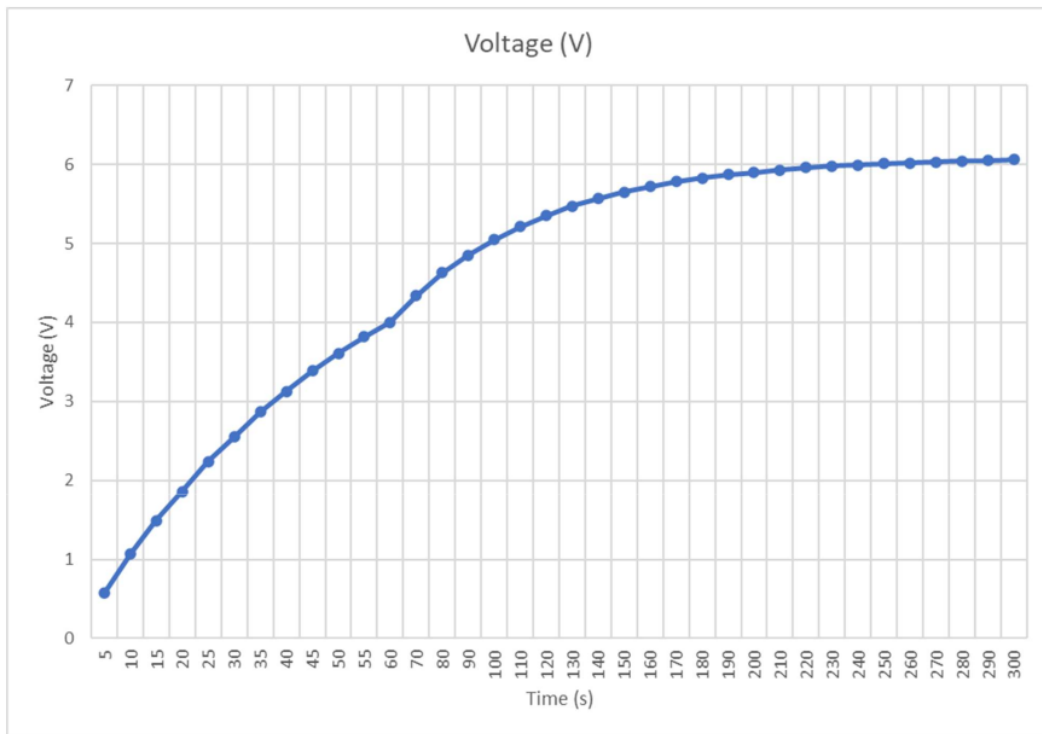


Figure 5: Practical RC circuit voltage charge

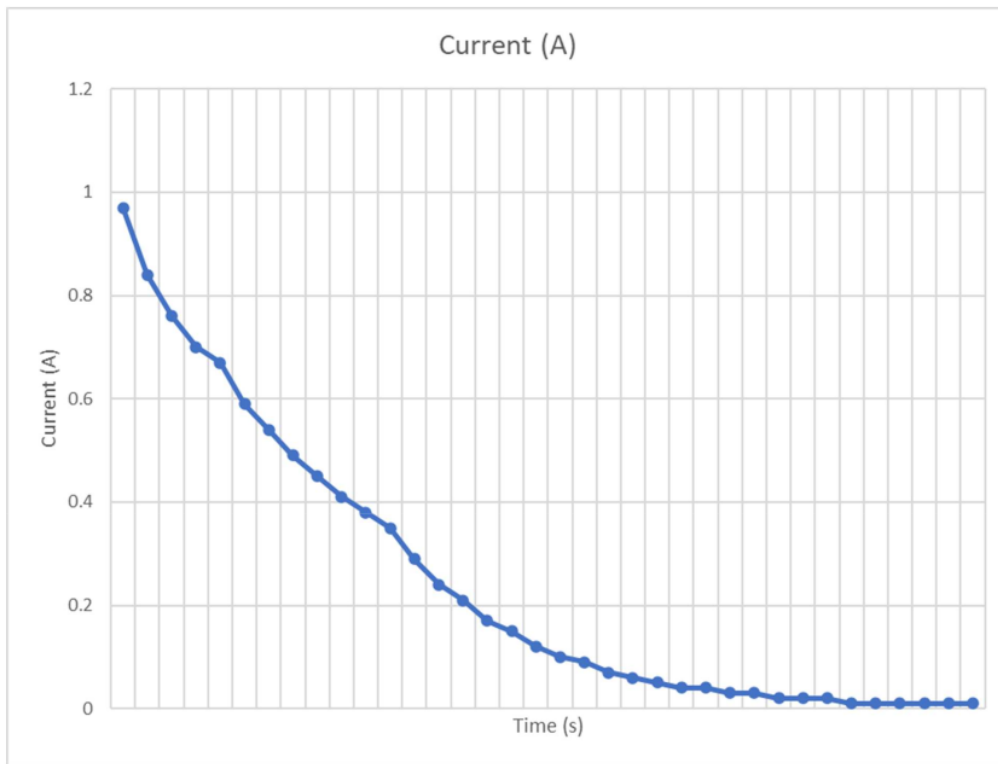


Figure 6: Practical RC circuit current charge

Task 1 Comparison and conclusion

The table below shows the differences between the practical circuit values and those from the calculated and simulated circuit. This difference was caused by the practical circuit using 6 VDC whilst the simulated and calculated used 5VDC. It does however follow the same trend as the other two. When compared the calculated and the simulated circuits are the same, confirming the equation used for the calculated RC charging of a capacitor is correct. Also a charge of a capacitor is transient is proven. The trends show a rapid rise with steady state achieved after 5τ .



Time	Simulated	Practical	Calculation
45s	2.76V	3.39V	2.761V
95s	4.08V	4.92V	4.083V
185s	4.81V	5.85V	4.816V

The same difference can be seen for the practical results due to the difference in supply voltage when looking at the current for the RC charging circuits. This was down to human error. The results for the calculated and simulated circuits are similar, proving the current falls as the capacitor is charged with a reading of zero after steady state conditions are reached.

Time	Simulated	Practical	Calculation
45s	399.8 uA	0.45 A	399.8 uA
95s	163.67 uA	0.19 A	163.7 uA
185s	32.801 uA	0.04 A	32.82 uA

Task 2 Transient Behaviour for the Discharging of a Capacitor

Task 2 Calculations

$$R = 5.6 \times 10^3 \quad C = 10000 \times 10^{-6}$$

Steady state conditions = 5τ

$$\tau = RC \therefore \tau = (5.6 \times 10^3)(10000 \times 10^{-6}) = 56s \therefore 5\tau = 5 \times 56 = 280s$$

This means steady state is achieved at 280s

The three random time values chosen were 45, 95 and 185

$$\text{Maximum Current, } I_{MAX} = VR = 55.610^3 = 892.9 \times 10^{-6}A$$

$$\text{Where } t=45s, V_c = V_{MAX}(e^{-t/\tau}) = 5(e^{-45/56}) = 2.239V$$

$$\text{Where } t=95s, V_c = V_{MAX}(e^{-t/\tau}) = 5(e^{-95/56}) = 0.916V$$

$$\text{Where } t=185s, V_c = V_{MAX}(e^{-t/\tau}) = 5(e^{-185/56}) = 0.184V$$

$$\text{Where } t=45s, i = -I_{MAX}(e^{-t/\tau}) = -892.9 \times 10^{-6}(e^{-45/56}) = -399.8\mu A$$

$$\text{Where } t=95s, i = -I_{MAX}(e^{-t/\tau}) = -892.9 \times 10^{-6}(e^{-95/56}) = -163.7\mu A$$

$$\text{Where } t=185s, i = -I_{MAX}(e^{-t/\tau}) = -892.9 \times 10^{-6}(e^{-185/56}) = -32.82\mu A$$

Task 2 Multisim circuit

Using the same circuit again (figure 1). The pulse width was set to 5τ calculated at 280s. The voltage results for discharge are shown in figure 2 above. The current results for discharge are shown above in figure 3. For the discharge the time results on the graph carry on from the initial 280s runtime. Therefore, the three random time values must be added to 280 in order

to get the correct measurement. 45s into the discharge is 225s into the run time. 95s into the discharge is 275s into the runtime. 185s into the discharge is 465s into the runtime.



Practical RC circuit for discharging capacitor

The same circuit as in task one figure 1 was used here. One difference was the positive leg of the capacitor being connected to the ground allowing the capacitor to discharge. This causes the current to be negative and therefore showing the current direction.

Time (s)	Current (A)	Voltage (V)
5	-0.92	5.52
10	-0.83	5
15	-0.76	4.59
20	-0.7	4.21
25	-0.64	3.87
30	-0.58	3.56
35	-0.53	3.24
40	-0.49	2.96
45	-0.45	2.72
50	-0.4	2.47
55	-0.37	2.27
60	-0.34	2.07
70	-0.28	1.74
80	-0.24	1.46
90	-0.2	1.23
100	-0.17	1.03
110	-0.14	0.87
120	-0.12	0.73
130	-0.1	0.62
140	-0.08	0.52
150	-0.07	0.44
160	-0.06	0.37
170	-0.05	0.31
180	-0.04	0.26
190	-0.03	0.22
200	-0.03	0.19
210	-0.02	0.16
220	-0.02	0.13
230	-0.01	0.11
240	-0.01	0.1
250	-0.01	0.08
260	-0.01	0.07
270	-0.01	0.06
280	-0.01	0.05
290	0	0.04
300	0	0.04

Figure 7

The table of results above clearly show the capacitor is charged fully. Voltage starts close to 6V, dropping down to 0V. This follows the transient trend. As expected, the current results are negative and increase as steady state is achieved.

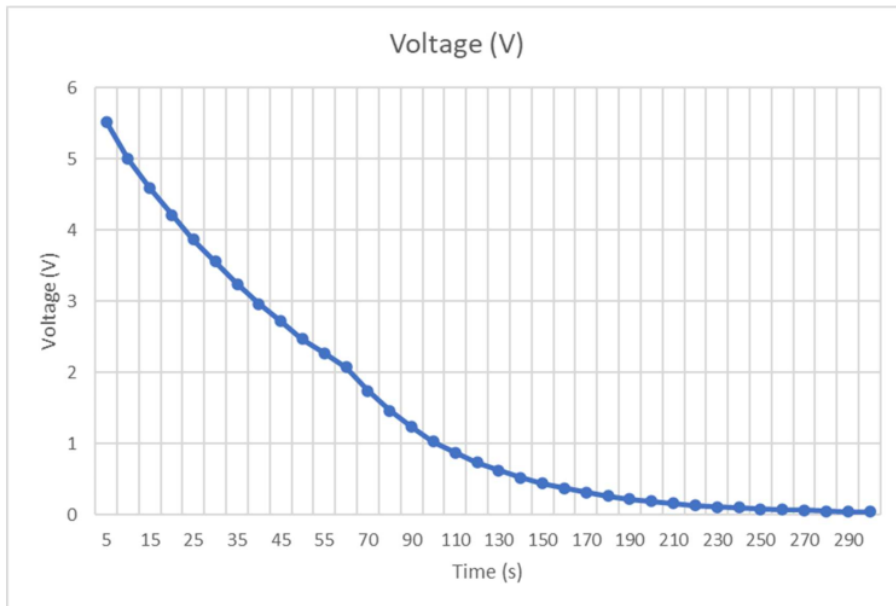


Figure 8

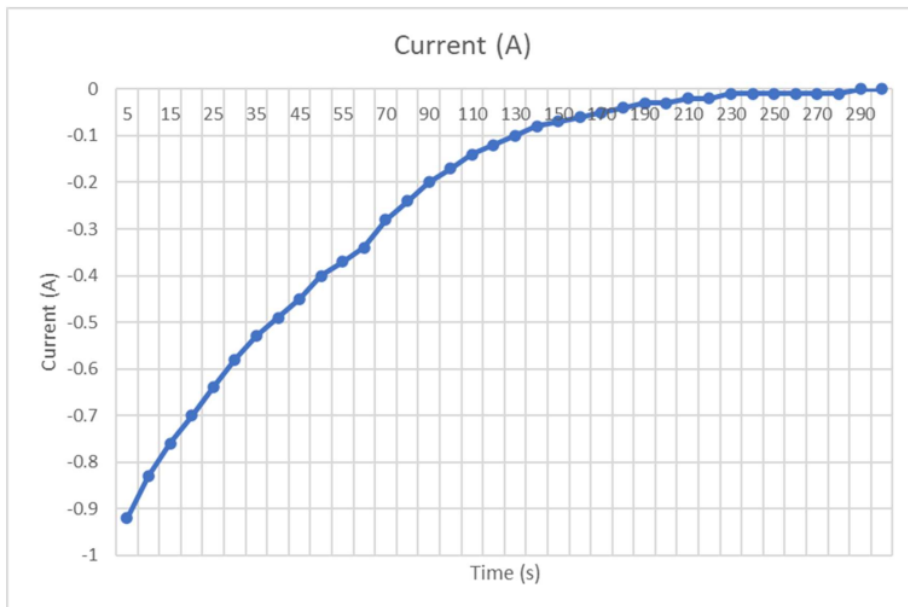


Figure 9

Task 2 Comparison and conclusion

The tables below show the differences between the practical circuit values and those from the calculated and simulated circuit. These differences were caused by the practical circuit using 6 VDC whilst the simulated and calculated used 5VDC. It does however follow the same trend as the other two. When compared the calculated and the simulated circuits are very similar, with any difference being due to rounding errors during the calculation stage. This confirms the equation used for the calculated RC discharging of a capacitor is correct. Also, the discharge of a capacitor is transient is proven. All results follow the transient trend and current direction

Time	Simulated	Practical	Calculation
45s	2.23V	2.72V	2.239V
95s	0.91V	1.13V	0.916V
185s	0.18V	0.24V	0.184V

Time	Simulated	Practical	Calculation
45s	-398.36 μ A	-0.45 A	-399.8 μ A
95s	-161.88 μ A	-0.18 A	-163.7 μ A
185s	-32.27 μ A	-0.04 A	-32.82 μ A

Task 3 Transient Behaviour for a more Complex Circuit

Equivalent circuit

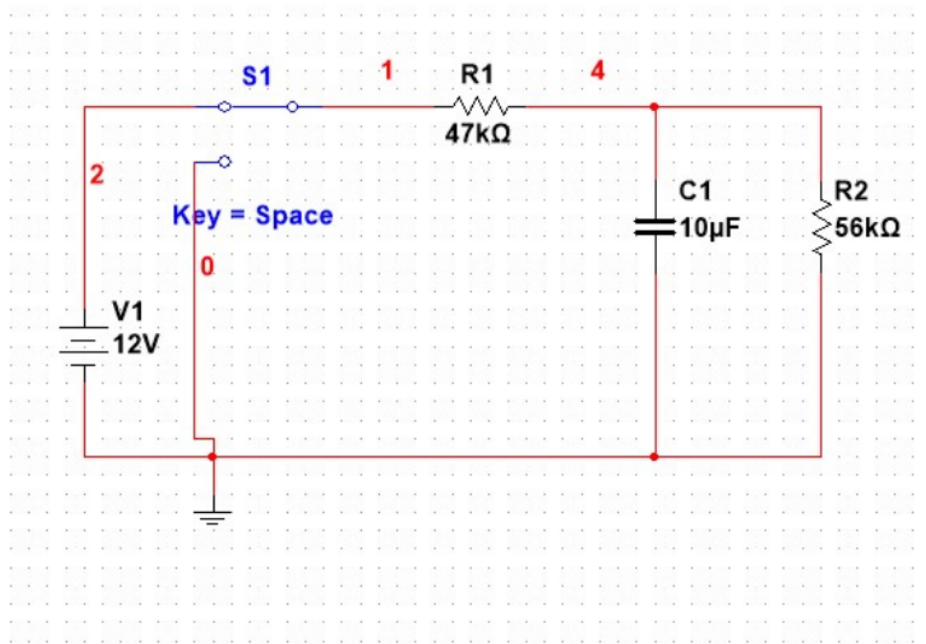


Figure 10:Complex RC circuit

For the above circuit the two resistors are in parallel. This means they act as a potential divider. By creating an equivalent circuit, a new supply voltage V_s can be created.

$$R_2/R_1+R_2 \times V_s = 56k/56k+47k \times 12 = 6.5V$$

For the calculation of τ a circuit reduction is required. The calculation for this reduction of the resistors is:

$$R_1 \times R_2/R_1+R_2 = 47k \times 56k/47k+56k = 25553 \Omega$$

Figure 11 shows the equivalent circuit.

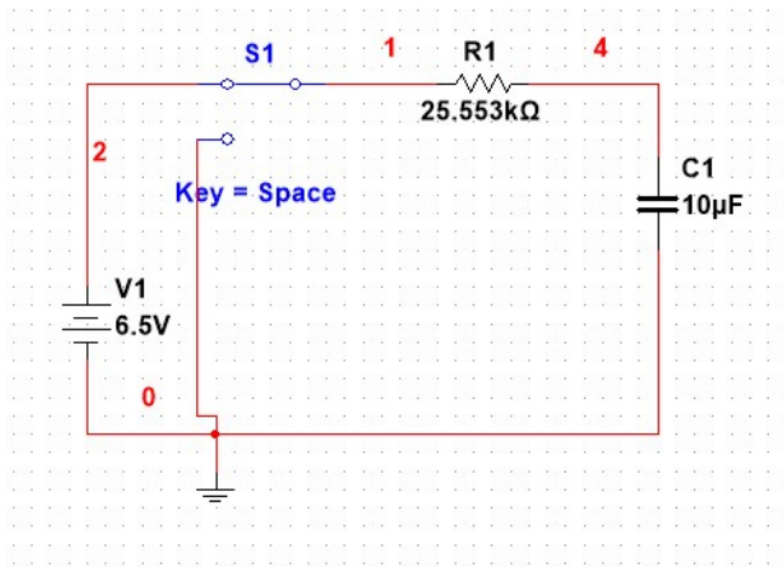


Figure 11:RC complex equivalent circuit

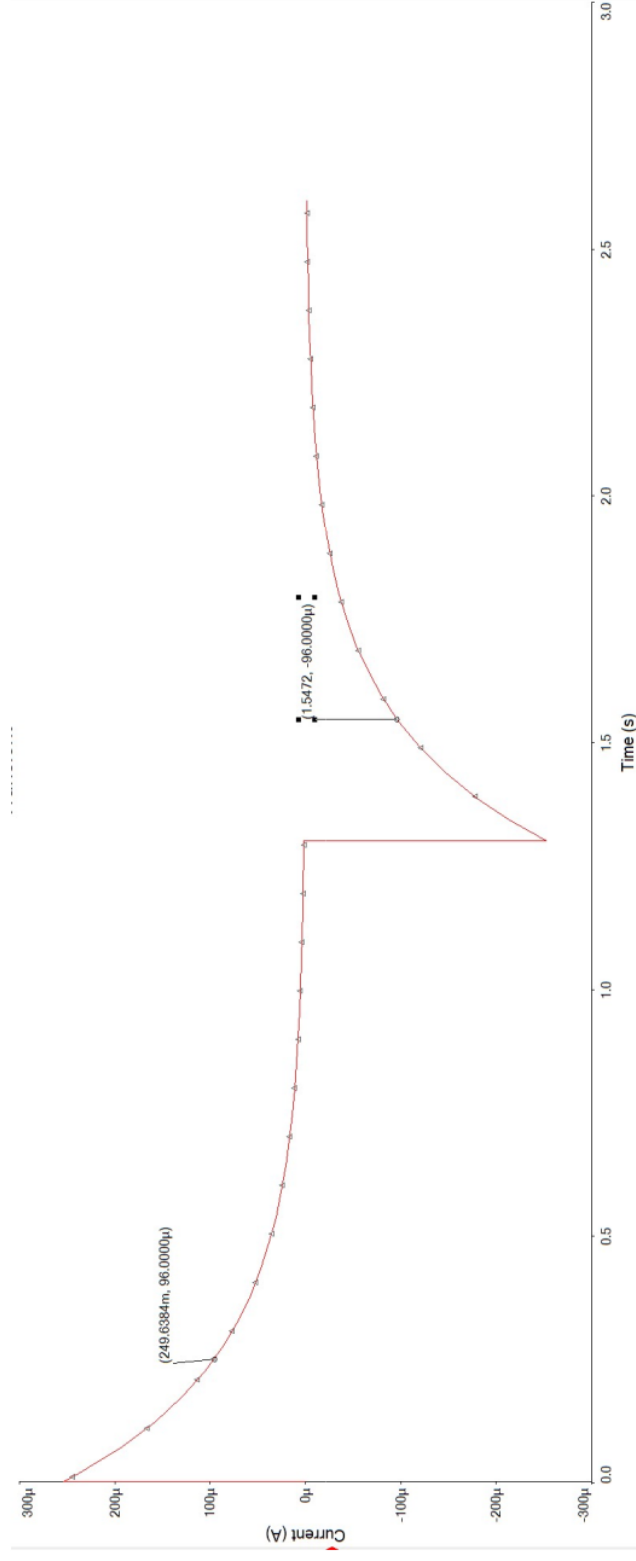


Figure 12: RC complex circuit time constant estimate

Figure 12 shows the graph for the time constant, which occurs at 96uA and -96uA. The plot above shows the time at which this is achieved, 0.250s and 1.547s respectively. As the pulse width was 1.3s, 1.3s must be subtracted from 1.547s to give the time constant. $1.547 - 1.3 = 0.247s$.

Task 3 calculations

$$R = 25.553 \times 10^3 \quad C = 10 \times 10^{-6}$$

Steady state conditions = 5τ

$$\tau = RC \therefore \tau = (25.553 \times 10^3)(10 \times 10^{-6}) = 0.255 \text{ s} \therefore 5\tau = 5 \times 0.255 = 1.275 \text{ s}$$

This means steady state is achieved at 1.3s

$$\text{Maximum Current, } I_{\text{MAX}} = V/R = 6.5/25.553 \times 10^3 = 254 \times 10^{-6} \text{ A}$$

From I_{MAX} , the time constant can be calculated by calculating 37.8% of I_{MAX} .

$$\tau = (254 \times 10^{-6})(0.378) = 96 \times 10^{-6} \text{ or } 96 \times 10^{-6}$$

Task 3 Comparison and conclusion

	Calculated	Simulated
Time (s)	0.255	0.250 & 0.247

Charging

When comparing the results of calculated and simulated they are almost identical with differences being down to rounding. This verifies both methods. The graph shows the time constant at 0.250s whilst the calculated time constant value was 0.255s.

Discharging

The discharging time constants are again similar, with the calculated value being 0.255 and the simulated at 0.247. This slight difference is likely due to rounding errors. However, it could also be caused by the pulse voltage. As the pulse width of 1.3s needed to be subtracted extra inaccuracies may have been introduced.

Initial and final currents taken from the supply

The initial current is given by V/R with the values of resistance and voltage being taken from the equivalent circuit.

$$\text{Initial current, } I_{\text{initial}} = 6.5/25.553 \times 10^3 = 254 \times 10^{-6} \text{ A}$$

The following formula can calculate final current.

$$I_{\text{final}} = I_{\text{MAX}}(e^{-t/\tau}) = (254 \times 10^{-6})(e^{-5}) = 1.71 \times 10^{-6} \text{ Eventually reaching } 0 \text{ A.}$$

Task 4 Transient Behaviour for the Inductive Circuit

The circuit below was built to test and investigate the transient period of an RL circuit discharging and charging.

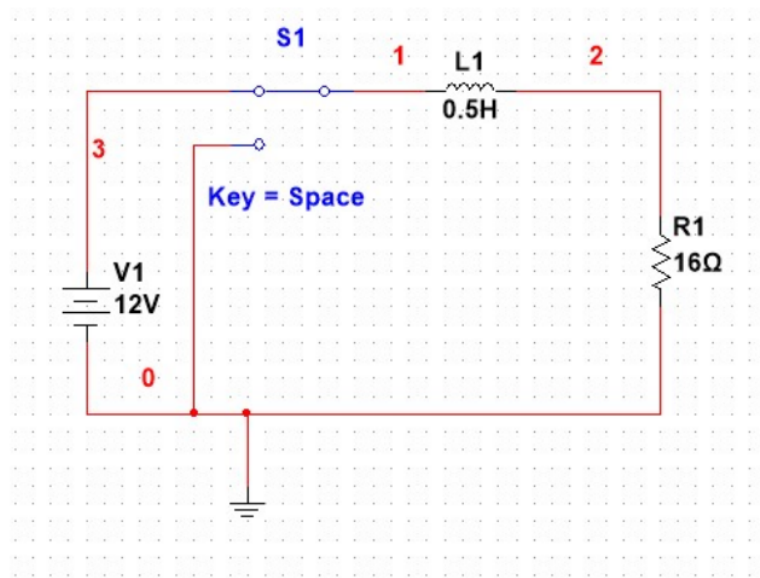


Figure 13: RL circuit

To calculate Time constant, $\tau = L/R$.

Five time constant were calculated as follows.

$$\tau = 0.5/16 = 0.031\text{s}$$

$$2\tau = \tau \times 2 = 0.031 \times 2 = 0.062\text{s}$$

$$3\tau = \tau \times 3 = 0.031 \times 3 = 0.093\text{s}$$

$$4\tau = \tau \times 4 = 0.031 \times 4 = 0.124\text{s}$$

$$5\tau = \tau \times 5 = 0.031 \times 5 = 0.155\text{s}$$

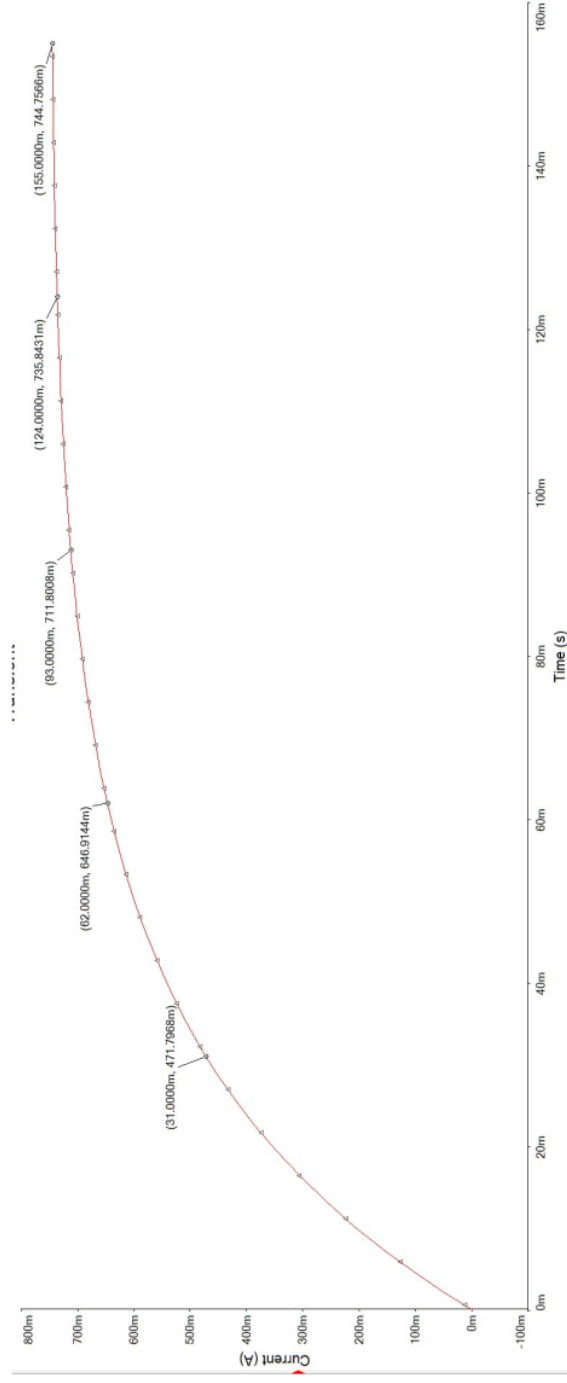


Figure 14: simulated time constants

Figure 14 shows the results for the simulated first five time constants.

Charging current

$$I_{\text{MAX}} = V_s / R = 12 / 16 = 0.75 \text{ A}$$

$$\text{Charging current, } i = I_{\text{MAX}}(1 - e^{-t/\tau})$$

$$\text{At } \tau, i = 0.75(1 - e^{-0.031/0.031}) = 474 \text{ mA}$$

$$\text{At } 2\tau, i = 0.75(1 - e^{-0.062/0.031}) = 648.50 \text{ mA}$$

$$\text{At } 3\tau, i = 0.75(1 - e^{-0.093/0.031}) = 712.66 \text{ mA}$$

$$\text{At } 4\tau, i = 0.75(1 - e^{-0.124/0.031}) = 736.62 \text{ mA}$$

$$\text{At } 5\tau, i = 0.75(1 - e^{-0.155/0.031}) = 744.94 \text{ mA}$$

Manually plotted calculated current

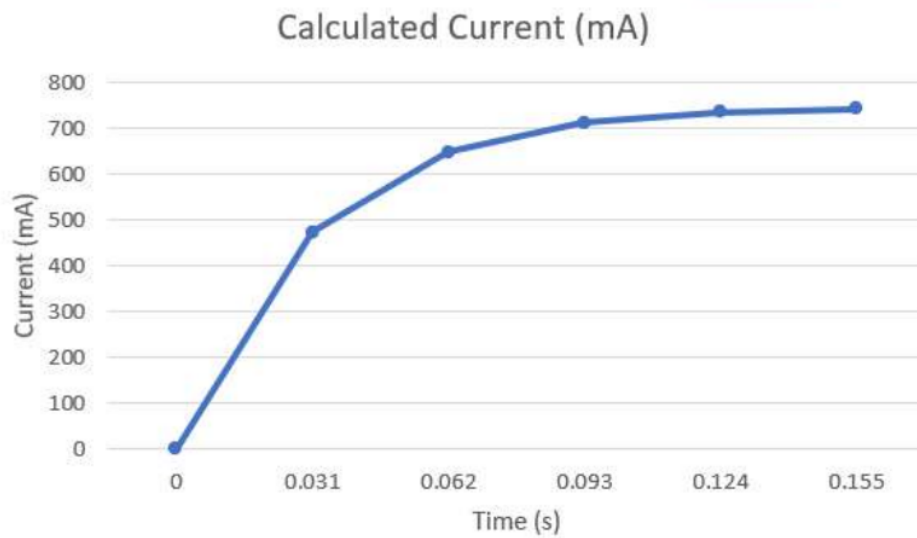


Figure 15: Calculated current graph

Comparison table

Time	Calculated	Simulated
0.031s	474mA	471.79mA
0.062s	648.50mA	646.91mA
0.093s	712.66mA	711.80mA
0.124s	736.26mA	735.84mA
0.155s	744.94mA	744.75mA

The table of results above shows the calculated and simulated values are almost identical, with the differences coming from rounding errors in the calculations. The RL circuit differs from the RC circuit as when it is charged up, the current rises following the transient trend. The trend shows that the current rises quickly initially, and then stabilises upon reaching 5τ .

Comparison of time constants

Time constants	Calculated	Simulated
1 τ	0.031	0.031
2 τ	0.062	0.062
3 τ	0.093	0.093
4 τ	0.124	0.124
5 τ	0.155	0.155

The results table shows the calculated and simulated time constants are all identical.

Calculation of elapsed time

The equation for instantaneous current, $i = I_{MAX}(e^{-t/\tau})$

This equation must be rearranged to find time elapsed, $i/I_{MAX} = e^{-t/\tau}$

$$\ln(i/I_{MAX}) = -t/\tau$$

$$\tau \ln(i/I_{MAX}) = -t$$

$$t = -\tau \ln(i/I_{MAX})$$

$$\text{At } 400 \text{ mA, } t = -0.031(\ln(400 \times 10^{-3}/0.75)) = 19.49 \text{ ms}$$

$$\text{At } 200 \text{ mA, } t = -0.031(\ln(200 \times 10^{-3}/0.75)) = 40.97 \text{ ms}$$

Simulated results for discharging elapsed time results

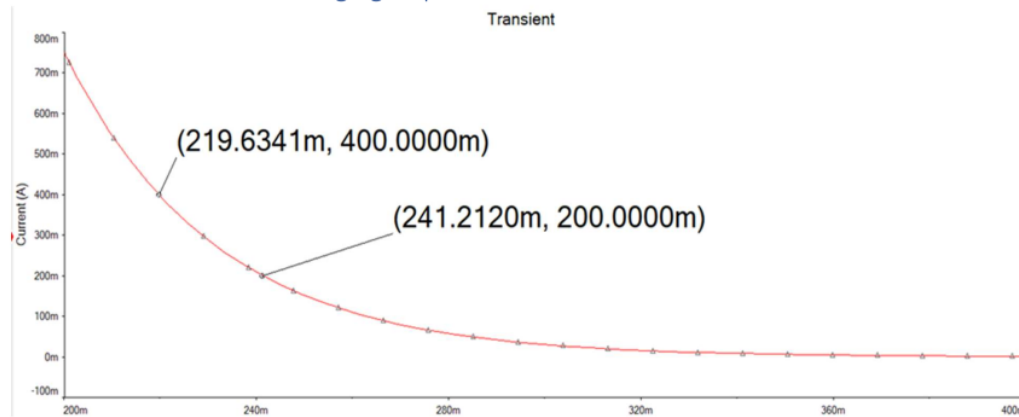


Figure 16: Simulated discharging elapsed time graph

Comparison and conclusion

Current (mA)	Calculated (ms)	Simulated (ms)
400	19.49	19.63
200	40.97	41.21

The comparison table above shows both calculated and simulated values for elapsed time are very close, with rounding errors during the calculation again likely to be the cause. As the switch is being opened at 200mS, 200mS must be subtracted from the values at 400 mA and 200 mA.

Task 5 Conclusions and recommendations

All results from task one are as expected. The trend for the transient period is followed by the calculated method and both simulated, and practical circuits. Due to a different supply voltage the practical values differed from the simulated. However, it follows the same progression. Human error when recording the practical values could have caused further discrepancies between results.

During task 1, as the capacitor is charged the voltage increased rapidly, stabilising by $5T$. The current worked in opposite to this, quickly decreasing from the maximum value and becoming steady near 0mA.

The results from task two show the simulated, calculated, and practically tested values followed the trend of a transient period. The practical results differ again due to a different supply voltage having been used to the simulated and calculated tests. It did follow the same trend regardless.

For the discharge of the capacitor, the voltage dropped and followed a similar trend to the current during the charging of a capacitor from task one. One difference to note is the current in task two is negative. Similarities can be drawn in that the current starts off at the maximum before rapidly dropping before settling at steady state. The reason for the current being a negative value is the direction of the current flows in the opposite direction when discharging.

Task 3 involved creating an equivalent circuit. All time constant values calculated and simulated for this task were very close to one another. As noted above, a minor difference between calculated, 0.255 and simulated, 0.244 was found. Likely due to rounding errors.

A recommendation would be to align the supply voltage for the simulated and practical circuits. Moving both to 5V. This would allow much better comparisons between the two sets of results.

Scaling for the measured current would be another improvement. A was used but due to the low values mA would have been better, giving more accurate readings and a graph plot.

FINAL GRADE

GENERAL COMMENTS

Instructor

73/100

PAGE 1

PAGE 2



Comment 1

do not include equations in your headings

PAGE 3

PAGE 4



Comment 2

show circuit diagram

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9



Comment 3

show an image of this

PAGE 10



Comment 4

good work



Comment 5

where are the simulated graphs?



Comment 6

potential dividers use series resistors



Comment 7

explain

GRADING FORM: NEW CSG-RUBRIC

OLIVER COX

73

1. ENGAGEMENT WITH LITERATURE



NA

0

2. KNOWLEDGE AND UNDERSTANDING



Excellent knowledge is evident in the both introduction of the theme and discussions of all results. Some improvement are suggested in comments.1 8/25

18

3. COGNITIVE AND INTELLECTUAL



Excellent evaluation which covers main points well, some further explanation in areas as marked are suggested. 21/30

21

4. PRACTICAL APPLICATION



Advanced application of circuit testing methodology and overall quality of results is very good. See comment on missing graph. 18/25

18

5. TRANSFERABLE SKILLS



Fluent, accurate and coherent report which covers main points well, see comments. 16/20

16