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by Dylan Marsh

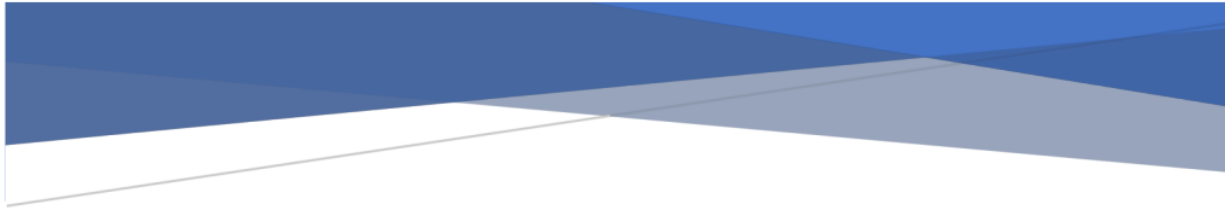
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Introduction

This report will be describing and documenting the behaviour of R-C and R-L circuits and their respective transient graphs whilst charging and discharging. The use of graphs and charts will be implemented to correctly compare and analyse values and results. The reasons for these values will be explored whether they are similar to what is expected or not.

There are three available different methods of gathering results, calculated, simulated, and a practical video. These will all be compared where applicable, whilst also considering the different relevant factors and observable differences.

Aims and Objectives

The aims of this assignment are:

- To implement and use correct equations whilst carrying out calculations to solve any required values.
- To gather results in different formats (Calculated, Multisim, Practical) and analyse the values. Any inaccuracy needs to be described and given reasoning.
- To use and implement scientific principles to interpret data and information gathered throughout.
- To use structured and approved methods to record instrument readings.

Planning and Reflection

This assignment will be approached in a manner so that the method can almost be replicated for every task. By first completing the required calculations, the simulated and/or practical values that are gathered can be compared. Should there be any slight inaccuracies, the reasons will be discovered and discussed.

Throughout this assignment, the objective of exploring RL and RC circuits was achieved. The charging and discharging of an RC circuit was explored in great detail, as well as a RL circuit. Through the use of a transient graph we can conceive a more visual understanding on how the circuit behaves and acts dependant on its current state.

Task 1

Method

The R-C circuit was given and replicated in NI Multisim. The circuit can be seen below. Examining this circuit initially, the time constant seemed a long time. Due to there being a video to compare results to, the time constant could have been longer than expected in order to provide the practical setup time to get to a steady state so the comparisons can be more reasonable.

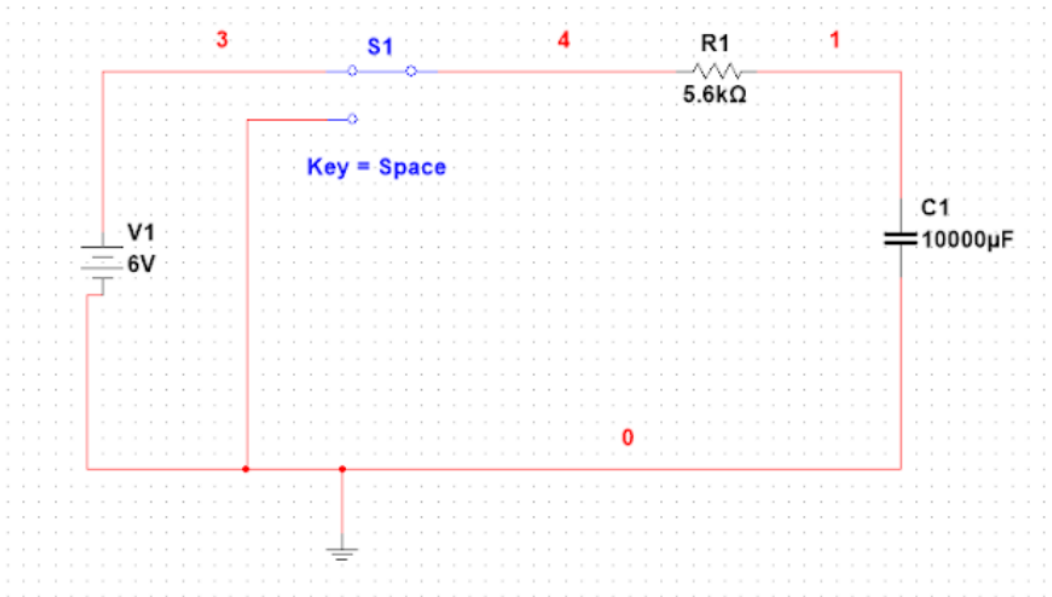


Figure 1 - Task 1 Circuit

The formula to work out one time constant in a R-C circuit is to multiply the resistance by the capacitance.

$$\tau = R \times C$$

$$\tau = 5600 \times 10000^{-6}$$

$$\tau = 56 \text{ seconds.}$$

Three separate times were chosen to ensure mixed results. The three times that were chosen were:

22 seconds

56 seconds (1 time constant)

97 seconds

Calculations for Capacitor Voltage and Current at specified times

The following formula will be used to determine the voltage across the capacitor (V_C) at the three selected times.

$$V_C = V_S \left(1 - e^{-\frac{t}{\tau}} \right)$$

Where ;

V_C – Capacitor Voltage

V_S – Supply Voltage

e – Euler's number (constant)

t – Time (in seconds)

τ – Time constant

When $t = 22$ seconds

$$V_C = 6 \left(1 - e^{-\frac{22}{56}} \right)$$

$$V_C = 1.95V$$

When $t = 56$ seconds (1τ)

$$V_C = 6 \left(1 - e^{-\frac{56}{56}} \right)$$

$$V_C = 3.79V$$

When $t = 97$ seconds

$$V_C = 6 \left(1 - e^{-\frac{97}{56}} \right)$$

$$V_C = 4.94V$$

The following formula will be used to determine the current (I) at the three selected times.

$$i = I \times e^{\left(-\frac{t}{\tau}\right)}$$

Where;

i - Final current

I – Initial current

e – Euler's Number (Constant)

t – Time (in seconds)

τ – Time constant

When *t* = 22 seconds

$$i = 1.1 \times e^{\left(-\frac{22}{56}\right)}$$

$$i = 0.74\text{mA}$$

When *t* = 56 seconds (1 *τ*)

$$i = 1.1 \times e^{\left(-\frac{56}{56}\right)}$$

$$i = 0.41\text{mA}$$

When *t* = 97 seconds

$$i = 1.1 \times e^{\left(-\frac{97}{56}\right)}$$

$$i = 0.19\text{mA}$$

These are the calculated values and will be compared to the simulated and practical values to determine consistency and to identify discrepancies.

The transient graph was simulated, and cursors were added at the specified times so a visual understanding of the current and voltage growth can be interpreted. The results were compared.

Results

Voltage

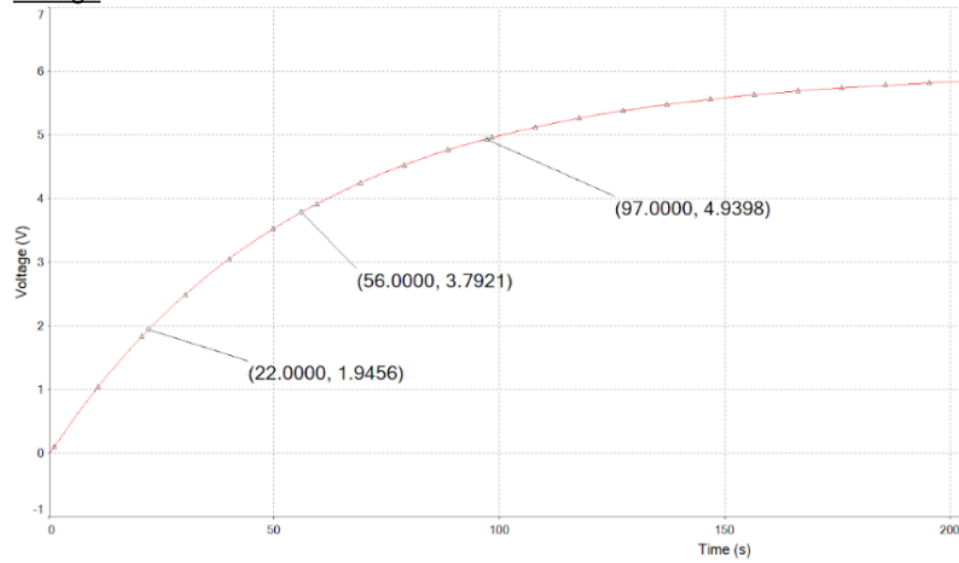


Figure 2 - Task 1 Voltage Transient

Task 1	T1 (22 seconds)	T2 (56 seconds)	T3 (97 seconds)
calc	1.95V	3.79V	4.94V
multisim	1.95V	3.79V	4.94V
prac	2.01V	3.85V	4.99V

Figure 3 - Task 1 Voltage Table

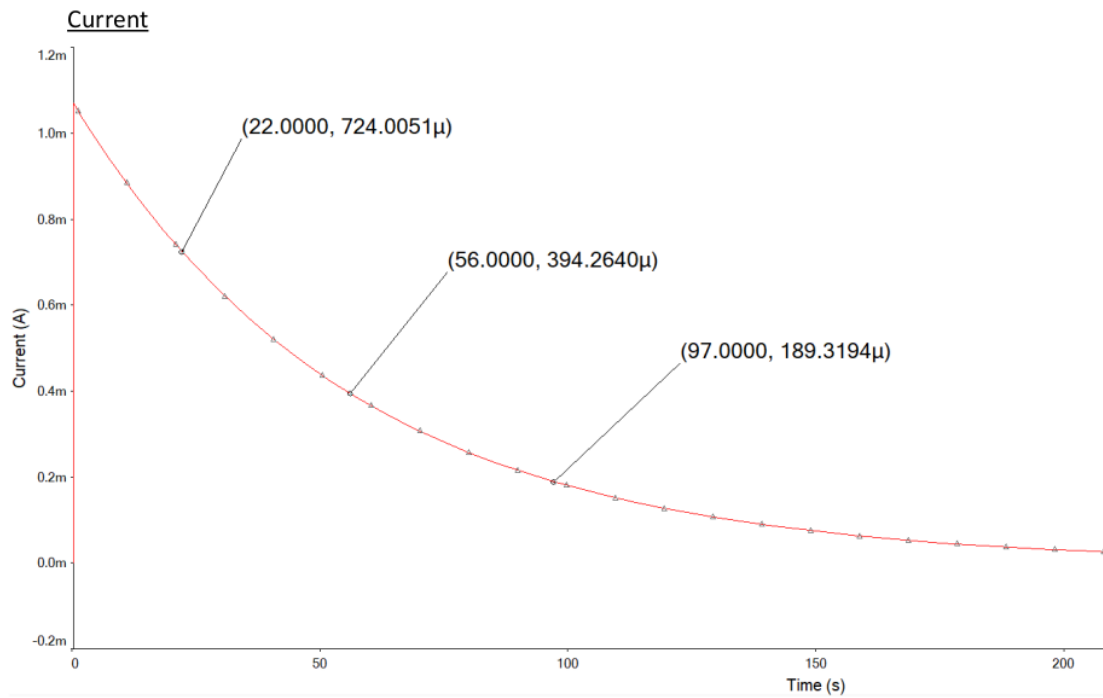


Figure 4 - Task 1 Current Transient

Task 1	T1 (22 seconds)	T2 (56 seconds)	T3 (97 seconds)
calc	0.74mA	0.41mA	0.19mA
multisim	0.72mA	0.39mA	0.18mA
prac	0.68mA	0.37mA	0.18mA

Figure 5 - Task 1 Current Table

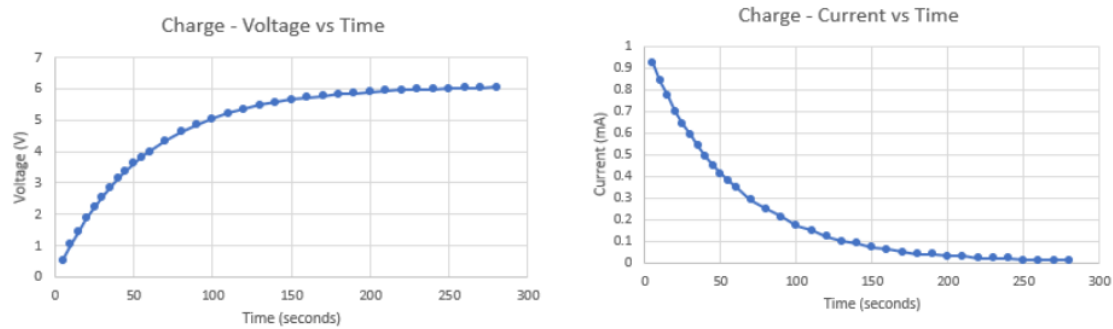


Figure 6 - Task 1 Graphs

Analysis

As can be seen in the excel table the calculated values and the simulated values are identical which is positive as it proves the calculations are correct. However, the practical values are a little skewed in comparison, which is potential evidence of human error. This can be explained because in the video that was used, the supply voltage was 5.9V whereas my simulation used exactly 6V. In addition, to find the voltage and current, the video had to be paused at around the right time to gain voltage and current values. Whereas on Multisim, cursors can be added at exact times to get much closer and precise readings. Resistance in the multimeter can also be a reason the practical values are skewed. When simulating circuits online there are problems that do occur in a practical environment, but wouldn't in a online simulation. It is important all of this is considered.

The graphs show a quick and steady increase in voltage, but a flatline occurring the closer the time reaches 5 time constants, which is regarded as $\approx 100\%$ of the final Voltage value. In the charge operation of a capacitor, it can be viewed as the more voltage stored, the less current that is going to be flowing in the circuit.

Looking at the practical setup, it is evident that some human error can be unavoidably involved. This is due to the time and the switch needing to be applied at the same time.

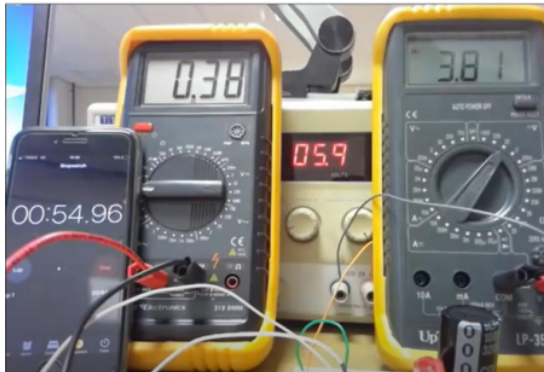


Figure 7 - Task 1 Practical Test

Task 2

Method

The R-C circuit given via the brief was designed and built. The circuit can be seen below. The difference in the circuit between Task 1 and Task 2 is the power supply has been changed to pulse. Making this change allows the switch to toggle when 5τ is elapsed, allowing the discharge operation to be seen in the transient graph.

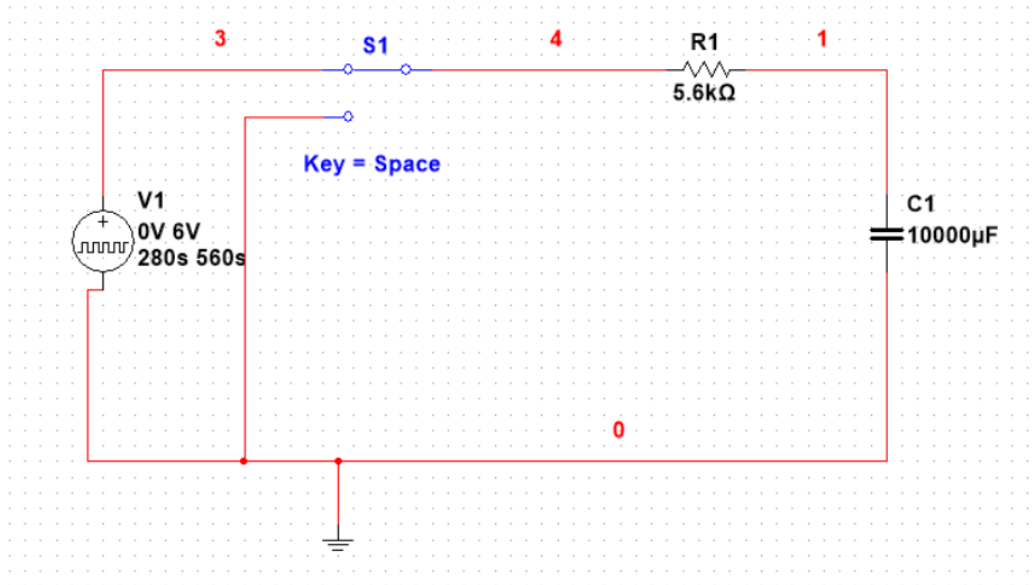


Figure 8 - Task 2 Circuit

The three same times as Task 1 were used (22 seconds, 56 seconds and 97 seconds). Again, these times were chosen so there can be comparisons and to identify trends in the charge and discharge operations.

Calculations for Vc and I at specified times

The following formula will be used to determine the voltage across the capacitor at the three selected time in the circuits discharge state.

$$V_c = V_s \times e^{\left(\frac{-t}{\tau}\right)}$$

When t = 22 seconds

$$V_c = 6 \times e^{\left(\frac{-22}{56}\right)}$$

$$V_c = 4.05V$$

When t = 56 seconds (1 τ)

$$V_c = 6 \times e^{\left(\frac{-56}{56}\right)}$$

$$V_c = 2.21V$$

When t = 97 seconds

$$V_c = 6 \times e^{\left(\frac{-97}{56}\right)}$$

$$V_c = 1.06V$$

The same formula that was previously used to determine the current in Task 1 can be used here as well. The calculations are as follows.

$$i = I \times e^{\left(\frac{-t}{\tau}\right)}$$

When t = 22 seconds

$$i = -1.1 \times e^{\left(\frac{-22}{56}\right)}$$

$$i = -0.74mA$$

When t = 56 seconds (1 τ)

$$i = -1.1 \times e^{\left(\frac{-56}{56}\right)}$$

$$i = -0.41mA$$

When t = 97 seconds

$$i = -1.1 \times e^{\left(\frac{-97}{56}\right)}$$

$$i = -0.19\text{mA}$$

The transient graph was simulated, and cursors were added at the specified times. The results were compared.

Results

Voltage

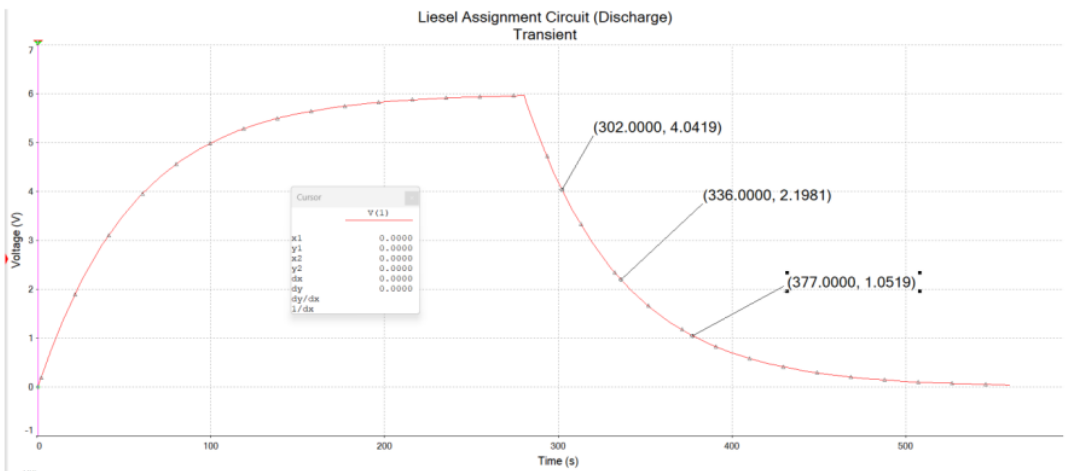
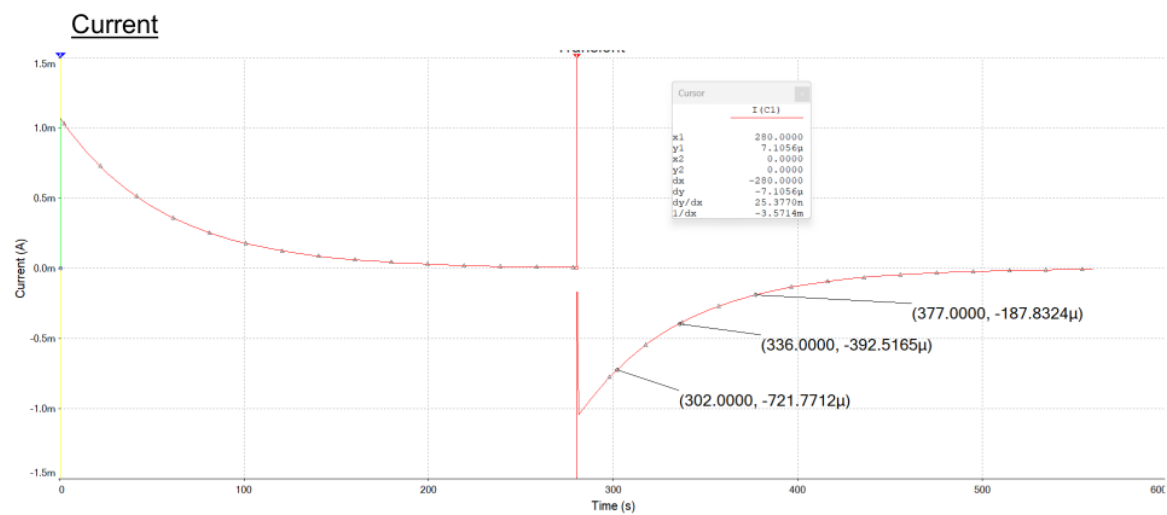


Figure 9 - Task 2 Voltage Transient

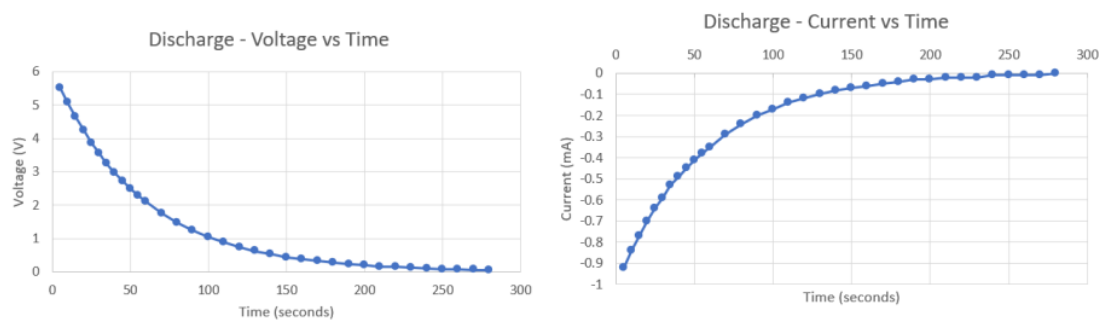
	T1	T2	T3
Task 2	(22 seconds)	(56 seconds)	(97 seconds)
calc	4.05V	2.2V	1.06V
multisim	4.04V	2.19V	1.05V
prac	4.1V	2.25V	1.1V

Figure 10 - Task 2 Voltage Table



Task 2	T1 (22 seconds)	T2 (56 seconds)	T3 (97 seconds)
calc	-0.74mA	-0.41mA	-0.19mA
multisim	-0.72mA	-0.39mA	-0.18mA
prac	-0.68mA	-0.37mA	-0.18mA

Figure 12 - Task 2 Current Table



Analysis

For this certain task, the circuit needs to be studied in its discharging state. This is why on the transient graphs the voltage is initially increasing and the current is initially decreasing. The excel table shows more variety in my results when comparing the discharge to the Charge experiments. The calculated and simulated values are very similar, but the practical values are off between 0.05 to 0.06V at the chosen times. This can be boiled down to the same reasons as in the Charge experiment, the reasons being human error and a 0.1V difference in supply voltage. The graphs show a steep decline initially, when there is more energy to be stored in the capacitor. The energy steadily gets stored in the capacitor, until after 5 time constants which is considered $\approx 100\%$ of the final Voltage value. At 5 time constants (280 seconds), the multimeter only reads 0.05V. As previously mentioned, the only difference in the circuits is the supply in the discharge circuit is changed to pulse. This is so we can see the both the charging and discharging of the voltage.

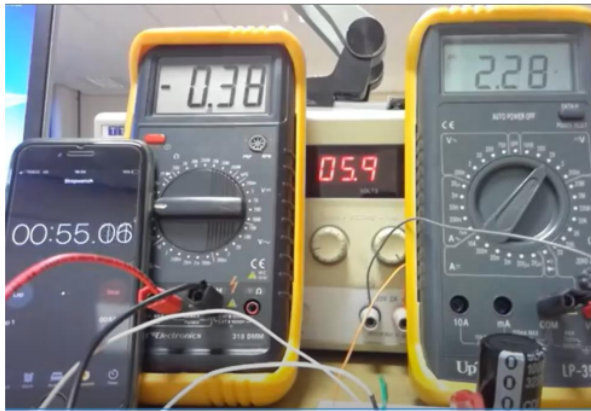


Figure 14 - Task 2 Practical Test

Task 3

Method

A new circuit needs to be built for task 3 which initially includes two resistors in parallel, where the circuit looks as follows;

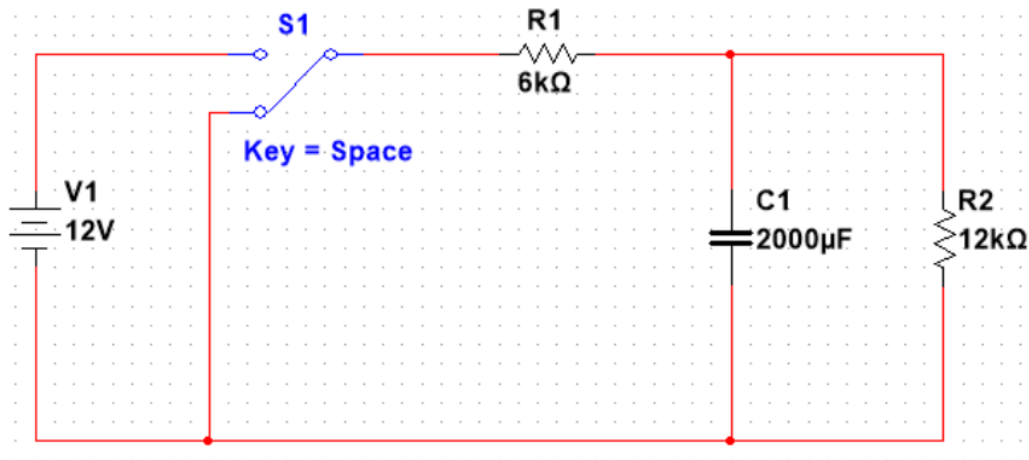


Figure 15 - Task 3 Initial Circuit

This can be simplified by using the product over sum rule. The calculations can be seen below;

$$R_T = \frac{(R1 \times R2)}{(R1 + R2)}$$

$$R_T = \frac{(6000 \times 12000)}{(6000 + 12000)}$$

$$R_T = 4000 \text{ Ohms}$$

The voltage is also determined by the potential divider rule, which is;

$$V_{OUT} = V_{IN} \left(\frac{R2}{R1 + R2} \right)$$

$$V_{OUT} = 12 \left(\frac{12000}{6000 + 12000} \right)$$

$$V_{OUT} = 8 \text{ V}$$

$$\tau = R \times C$$

$$\tau = 4000 \times 2000 \times 10^{-6}$$

$\tau = 8 \text{ seconds}$, meaning 5 time constants is 40 seconds

The circuit current can be calculated through Ohms law.

$$I_{MAX} = \frac{V_S}{R}$$

$$I_{MAX} = 8 / 4000$$

$$I_{MAX} = 2 \text{ mA}$$

Using this, a screenshot of the simplified circuit is below.

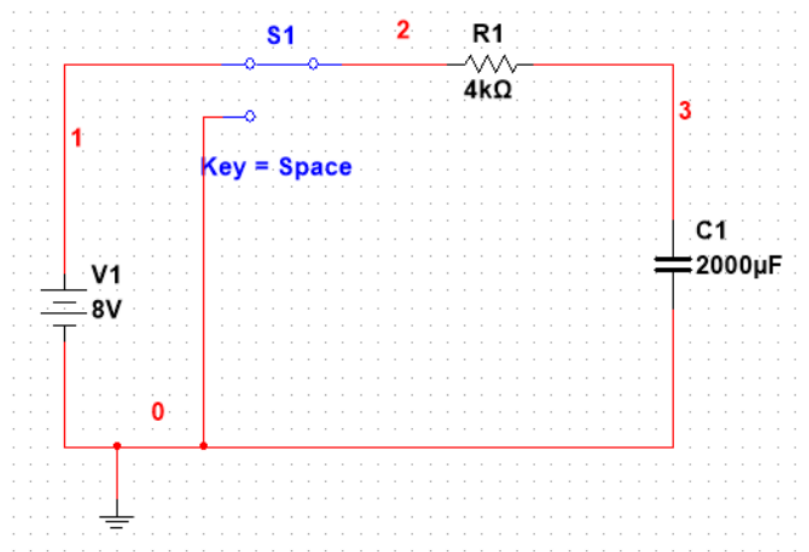


Figure 16 - Task 3 Finalised Circuit

The time that is going to be analysed is 8 seconds due to that time being one time constant as previously calculated.

Results

Using the current decay formula, we can determine what the current should be at the time constant and the chosen times.

Charge

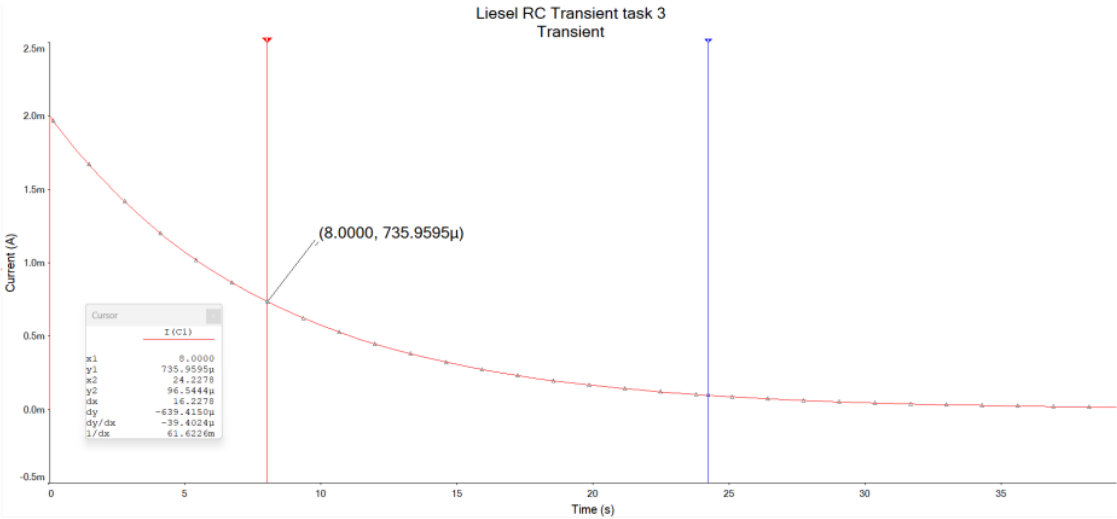


Figure 17 - Task 3 Charge Transient

The following formula is used to determine the current at one time constant.

$$i = I_{MAX} \left(e^{-\frac{t}{\tau}} \right)$$

$$i = 2 \times 10^{-3}(0.368) \text{ , using } e^{-1} \text{ as } 0.368$$

$$= 736 \text{ }\mu\text{A or } 0.736 \text{ mA}$$

It can be seen from the graph above when entering 8 seconds on the X axis and adding a data label, the current is 0.736 mA (when rounded to 3 decimal places) This matches the calculated value.

Task 3	t = (8 seconds)
calc	0.736mA
multisim	0.736mA

Figure 18 - Task 3 Current Table

Discharge

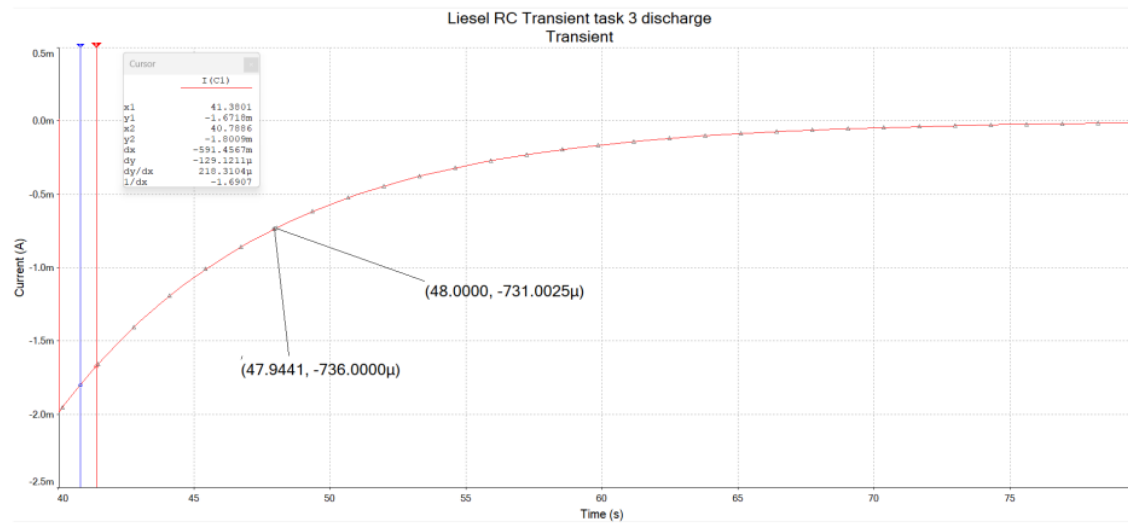


Figure 19 - Task 3 Discharge Transient

Analysis

To obtain the current values for the charging process, the voltage supply had to be replaced with a pulse voltage source, and the settings had to be tampered with. The capacitor starts discharging after 40 seconds, after it has fully charged, which is why the readings say 48 seconds instead of 8 seconds.

At 8 seconds, the current reads 0.7310mA, whilst the calculated value is 0.7357mA. It is clear here that there is a little difference between the calculated and simulated values. To work out the calculated time constant;

$$i = I_{MAX} \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$i = 2 \times 10^{-3}(0.368) , \text{ using } e^{-1} \text{ as } 0.368$$

$$= 736 \mu\text{A or } 0.736 \text{ mA}$$

It can be seen from the graph above (Figure 18) when entering the 736 μA value on the Y axis and adding a data label, the time is 7.9441 seconds, a difference of 0.0536 seconds in comparison to the simulated time constant value.

The calculated results and the simulated results matched which proves consistency and accuracy in the calculations. At the beginning (0 seconds) there is 2 mA flowing through the circuit due to the capacitor storing no voltage. As time continues, more voltage gets stored in the capacitor leading to a decrease in current. At what is regarded as 100% final value (5 time constants) there is a small amount of current of 0.013 mA remaining.

Task 4

Method

The following circuit was built using NI Multisim. The purpose of this task is to explore the transient behaviour in an inductive circuit. Conventionally a normal dc voltage source is used. The circuit has been altered so the sourced voltage point is pulsed. This allows the opportunity to see the current increase as it nears the five time constant value, and to decrease in the next five time constants.

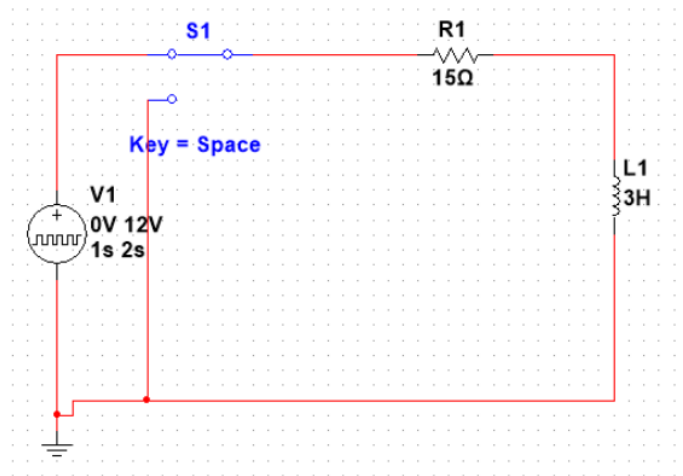


Figure 20 - Task 4 Circuit

Through the use of simple Ohms law, $V=IR$, the equation can be re-arranged to find I , which is V/R . When implementing the numbers it shows $12/15$ which equals $0.8A$. This will be needed later on to find the current values at specific times.

When wanting to find the current at any given time, the following formula is used;

$$i = I_{MAX} \left(1 - e^{-\frac{t}{\tau}} \right)$$

This formula was implemented into an excel table where the growth of the current is clear as the time continued. By the excel table is the corresponding NI Multisim graph, so there is a more visual piece of media.

Results

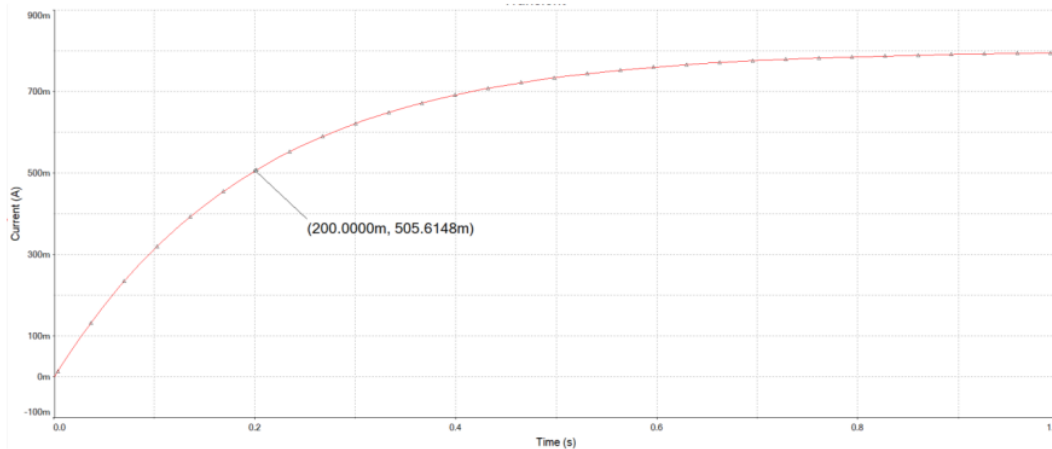


Figure 21 - Task 4 Current Transient (Simulated)

As can be seen in the graph, a data label at 0.2 seconds has been added, and the current at that time is 0.506 A when rounded to 3 decimal places. Comparing this to the calculated value, reading across from 0.2 seconds gives a current value of 0.506 A as well. From viewing the graph it is clear the current goes to a steady state in the latter stages after a considerably rapid start. This can be backed up by the fact that in the first 0.2 seconds, the current increases by over 0.5 A, whereas in the final 0.2 seconds, the current increases by only 0.01 A. The reasoning for this can be due to the inductor strongly resisting the current at the beginning, but weakening over time. In order to figure out the current value immediately before the switch is changed over I can be calculated through Ohms Law as mentioned earlier. $V/R = 12/15 = 0.8\text{A}$ or 800mA.

Due to this circuit being inductive, the formula to determine the time constant will be L/R . $L/R = 3/15 = 0.2$ seconds, meaning 5 time constants (the time for the current to reach $\approx 100\%$) will be 1 seconds.

Time (sec)	Current at these times (A)
0.05	0.177
0.1	0.315
0.15	0.422
0.2	0.506
0.25	0.571
0.3	0.621
0.35	0.661
0.4	0.692
0.45	0.716
0.5	0.734
0.55	0.749
0.6	0.760
0.65	0.769
0.7	0.776
0.75	0.781
0.8	0.785
0.85	0.789
0.9	0.791
0.95	0.793
1	0.795

Figure 22 - Task 4 Current over Time Table

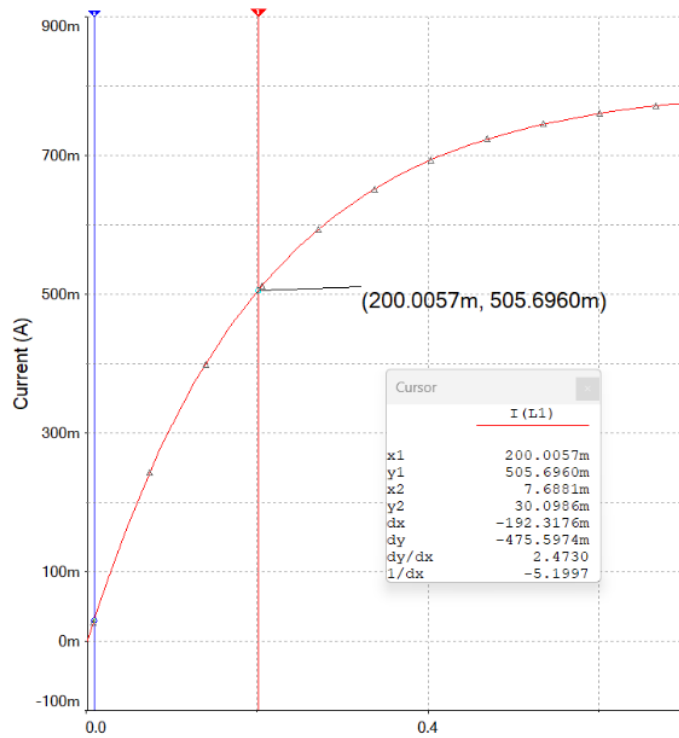


Figure 23 - Task 4 Current Graph (Calculated)

Using the exponential growth formula ($I_{max} (1 - e^{-t/\tau})$), 0.50569 A is the answer that is given. Using the Set Y value => function and adding a data label, the calculated time of one time constant is 200.0057 milliseconds, whereas the simulated value is 200.0000 milliseconds. This leaves a miniscule difference.

Task 4	Method of Result		
Time Constant Value	Calculated	Manual	Simulated
0.2	0.506	0.506	0.506
0.4	0.692	0.692	0.692
0.6	0.76	0.76	0.76
0.8	0.785	0.785	0.785
1	0.795	0.795	0.795

Figure 24 - Task 4 Comparison Table

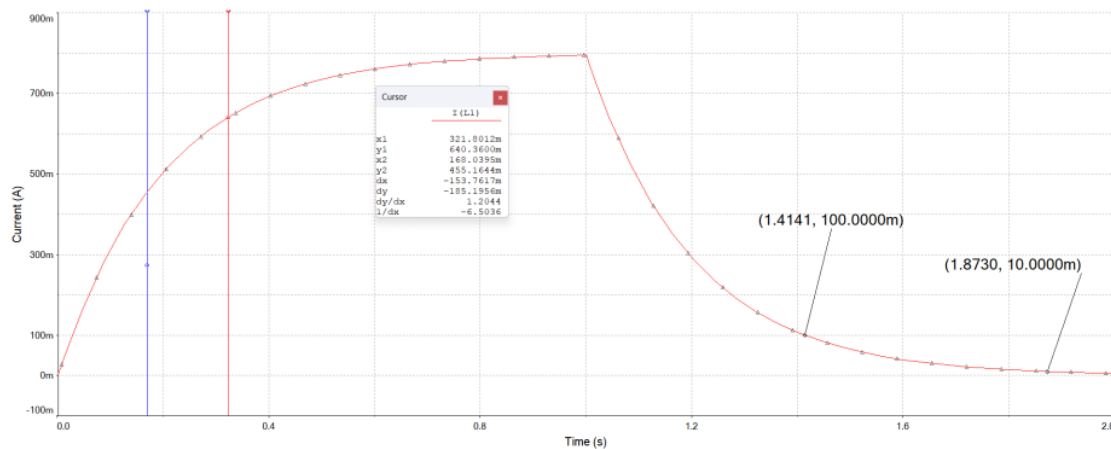


Figure 25 - Task 4 Current Transient (Continued)

Analysis

In order to simulate the time value when the current has fallen to the specified values (100mA and 10mA) the cursors have to be placed at the right points using the set Y value => feature. From inspecting the above graph, the current falls to 100mA 0.414 seconds after charging, and then a further 0.459 seconds to fall to 10mA. In order to compare these simulated values to prove they're definite, a couple of calculations need to be made following the: $i = I_{max}(e^{-t/\tau})$ equation.

Time for current to fall to 100mA equation

$$0.1 = 0.8(e^{-t/0.2})$$

$$0.1/0.8 = e^{-t/0.2}$$

$$\ln(0.1/0.8) = -t/0.2$$

$$t = -0.2 \ln(0.1/0.8)$$

$$t = (-0.2) \ln(0.1/0.8) = 0.416 \text{ seconds}$$

Time for current to fall to 10mA equation

$$0.01 = 0.8(e^{-t/0.2})$$

$$0.01/0.8 = e^{-t/0.2}$$

$$\ln(0.01/0.8) = -t/0.2$$

$$t = -0.2 \ln(0.01/0.8)$$

$$t = (-0.2) \ln(0.01/0.8) = 0.876 \text{ seconds}$$

Conclusion

This report has studied the behaviours into R-C and R-L circuits through the use of comparing calculated values with a circuit that was built both online and in person. It contains an abundance of mathematical formulae which has aided and furthered research conducted on R-C and R-L circuits. Both the R-C and R-L circuits displayed their behaviours through their responses when the switch was toggled.

Despite having results that didn't quite seem to match, further analysis was prompted and eventually reasoning was discovered and factors were reflected upon. The comparisons between the calculated, simulated, and practical values highlighted the importance of understanding the factors that can influence results in different circumstances. The calibration of the measuring instruments being used in the practical investigation is a variable for the values being skewed. Other factors that can play a role in deviating accurate results in the practical experiments can be environmental, like if the components have been previously used, or the room temperature varying beyond the ideal value for the component to behave as intended.

Trends were discovered that can be backed up by different sources of results. When a R-C circuit is charging, voltage rises, current falls. This is the opposite when the circuit is in its discharge state. The behaviour of the circuits were predictable and nothing bizarre occurred.

The behaviours of the R-C and R-L circuits evolved over time hinting that they were time dependent. As time elapsed, the voltage or current would rise or fall reliant upon the state of the circuit. The changes would not occur instantly but in more of an exponential manner until 5-time constants has passed. The discovery of this can be understood and implemented to make the circuit work more predictably.

In future, analysing more complex circuits and varying the component values could provide a deeper insight into the behaviours of the circuits and how they act under different circumstances.

In terms of self-assessment, a pleasing amount of self-learning has been completed through problem analysis and the use of tools and techniques. A lot of the knowledge gained over the course of this assignment will be applied in future to produce high quality and educated pieces of work.