

1909753

by Aaron Rees

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1. Executive Summary

In this report LR and RC circuits were explored and tested. The main principles of these circuits are that the current and voltage increases or decreases exponentially depending on different factors. The exponential equations are shown below. These equations are altered depending on if the circuit is charging or discharging.

$$I = I_{max}(1 - e^{-\frac{t}{\tau}})$$

$$V = V_{max}(e^{-\frac{t}{\tau}})$$

These circuits are heavily based around Tau (τ). This is used with every circuit as Tau equals one time constant. One time constant should always be at the same point of the exponential curve for these circuits. After five time constants the circuit should reach steady state, this is where the current and voltage stop moving and have reached their final value.

The aims of this report were to test 3 different circuits, all in different circumstances and using a variety of methods. These being calculations, multisim and practical Testing. Once tested the results were tabulated to compare to prove that all results were correct and the circuits do behave as they should. Errors of the results were explained to show the reason for any differences between results.

2. Practical task, circuit analysis and calculation

Circuit 1 - Charging

Figure 1 shows the first circuit that was tested and investigated. The values of the resistor and the capacitor were specifically chosen so the one time constant would be equal to 56s which would make the time taken to reach steady state roughly 5 minutes. The reason for this was to enable results to be recorded practically with ease as it would prove difficult if the circuit reached steady state too quickly.

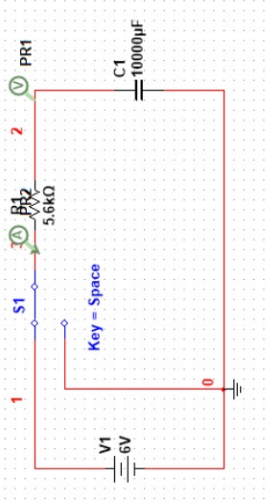


Figure 1

The circuit in figure 1 was tested by simply using two multimeters connected to the circuit, one was set to measure current and was connected in series with the circuit. The other multimeter was connected in parallel with the capacitor. A stopwatch was also used to time the practical experiment. The circuit was then tested by switching the supply on and noting the results at specific times for both current and voltage as the time went on up to 5 minutes. The results were taken more frequently at the start because the rate of change was higher and less frequent in the end as the circuit would reach steady state and would not change much. Figure 2 shows the setup of the practical experiment.

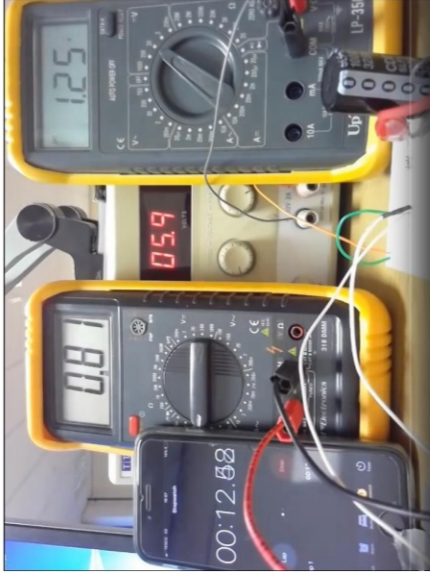


Figure 2

Figure 3 graph of the practical results of current against time while the circuit is charging over 300 seconds.

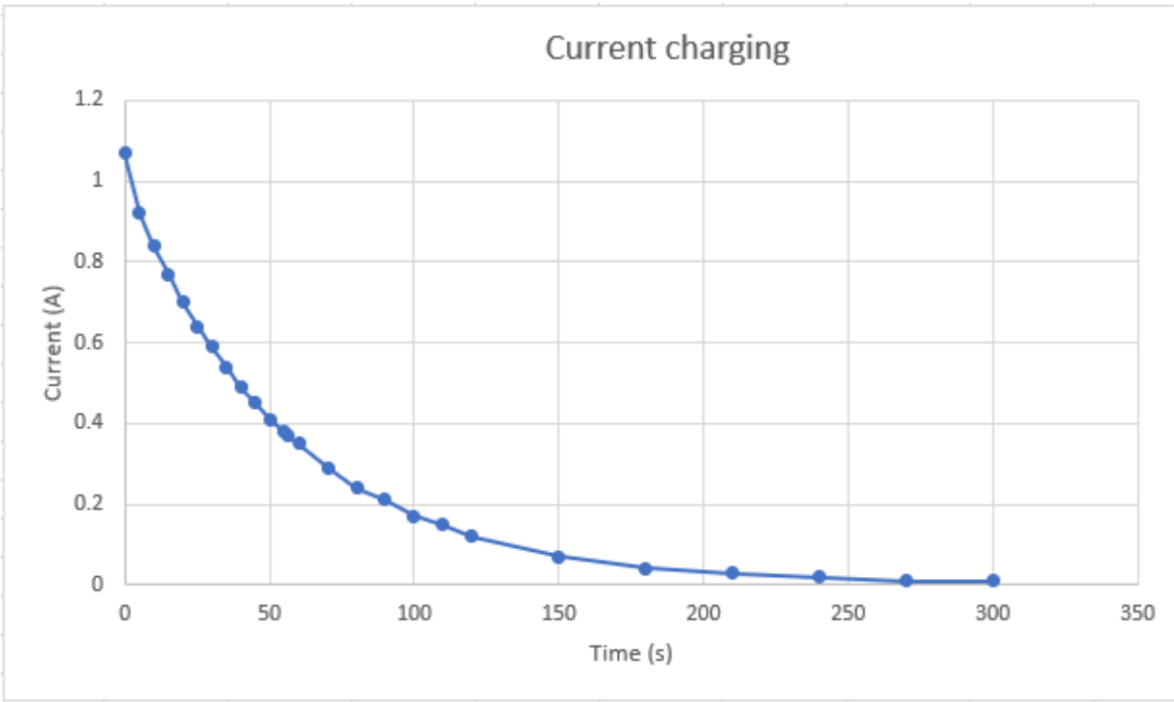


Figure 3

Figure 4 graph of the practical results of voltage against time while the circuit is charging over 300 seconds.

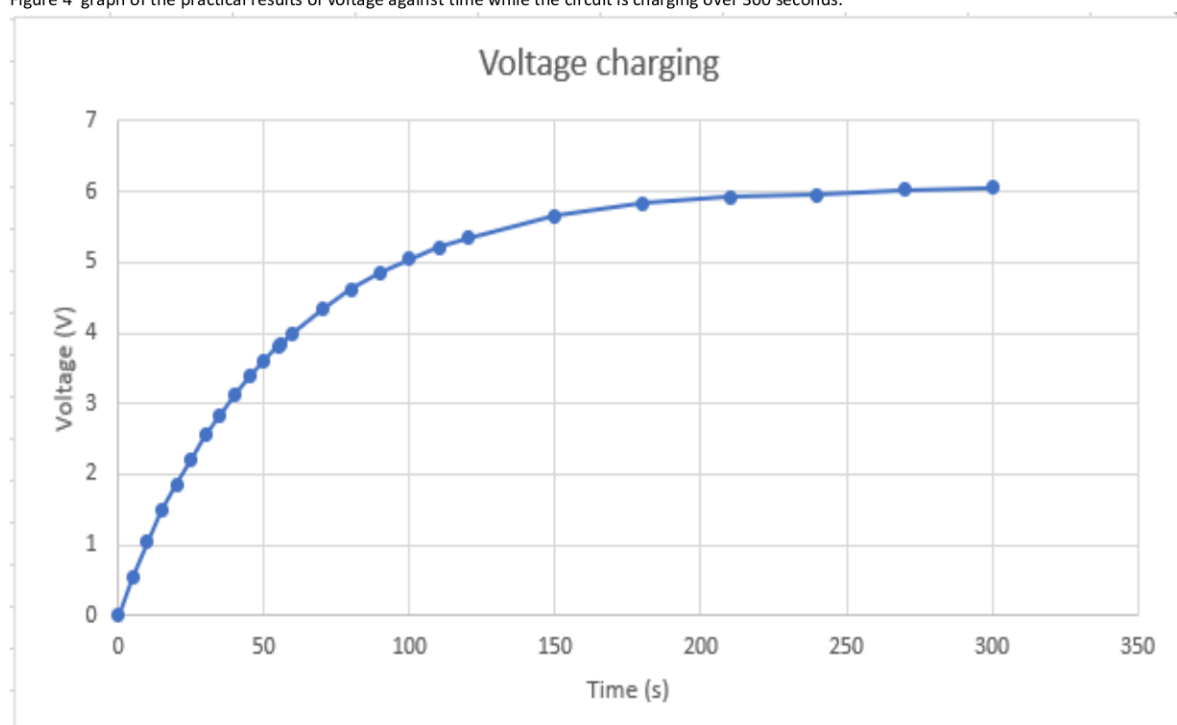


Figure 4

Below are the calculations necessary for the circuit in figure 1.

$$\tau = RC = 5.6 \times 10^3 \times 10000 \times 10^{-6} = 56s$$

$$I_{max} = \frac{V}{R} = \frac{6}{5.6 \times 10^3} = 1.07mA$$

$$voltage \text{ at } 1\tau = \frac{63.2}{100} \times 6 = 3.792V$$

$$Current \text{ at } 1\tau = \frac{36.8}{100} \times 1.07 \times 10^{-3} = 0.394mA$$

The random time values for charging voltage:

$$V_c = V_{max} \left(1 - e^{-\frac{39}{56}} \right) = 3V$$

$$V_c = V_{max} \left(1 - e^{-\frac{192}{56}} \right) = 5.81V$$

$$V_c = V_{max} \left(1 - e^{-\frac{241}{56}} \right) = 5.91V$$

The random time values for charging current:

$$I = I_{max} \left(e^{-\frac{39}{56}} \right) = 0.533mA$$

$$I = I_{max} \left(e^{-\frac{192}{56}} \right) = 34.7uA$$

$$I = I_{max} \left(e^{-\frac{241}{56}} \right) = 14.467uA$$

Figure 5 shows the voltage against time graph while the circuit is charging simulated on multisim. The blue cursor is placed at one time constant which multisim shows it 55.9470s. The red cursor is set to the maximum voltage which multisim shows is 5.9708V.

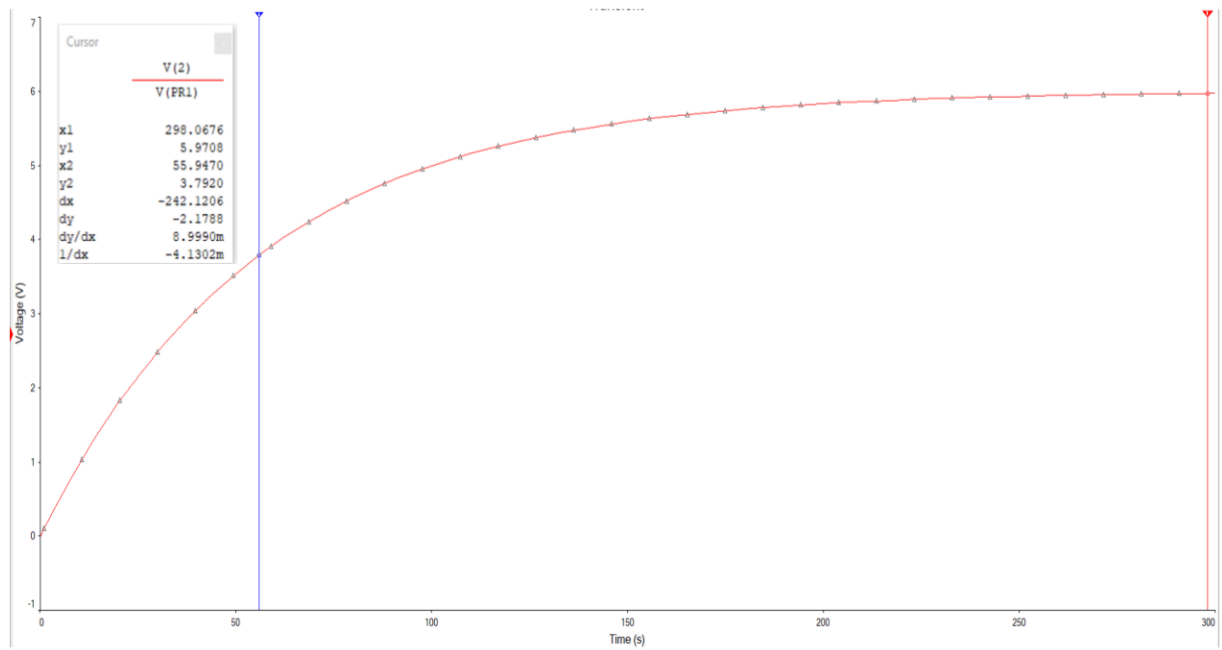


Figure 5

Figure 5 shows the current against time graph while the circuit is charging simulated on multisim. The blue cursor is placed at one time constant which multisim shows it 55.9896s. The red cursor is set to the current at 300s which multisim shows is essentially 0.

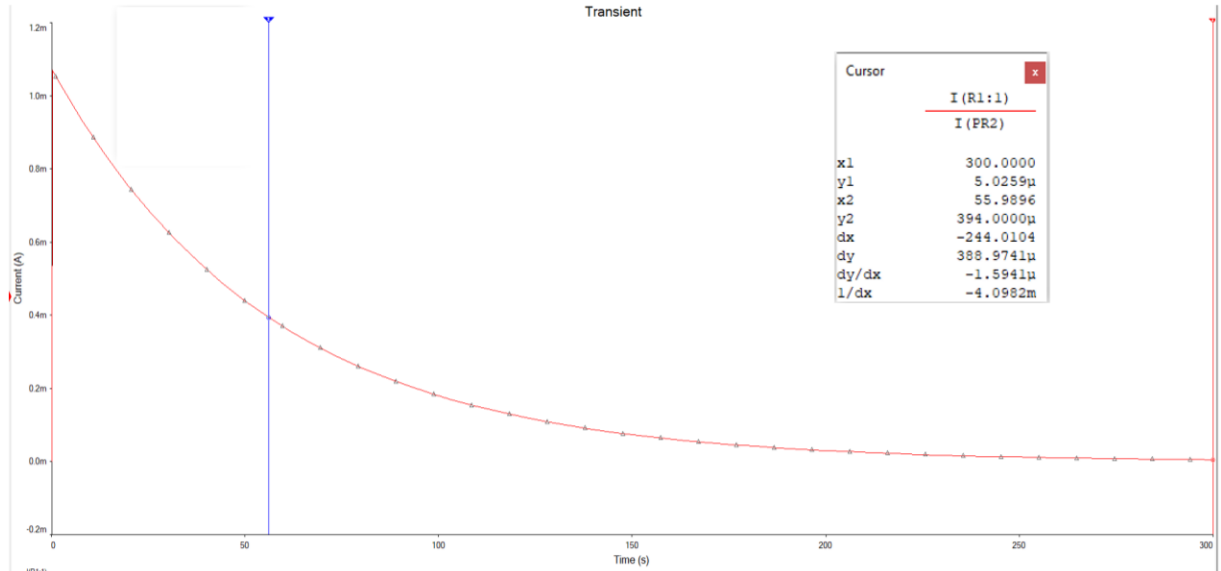


Figure 6

Figure 7 shows the current against time graph while the circuit is charging. The cursors have been placed the same random times on the graph that were used in the calculations. The blue cursor has been placed at 39s with a current of 34.6803uA and the red has been placed at 193s with a current of 34.6803uA.

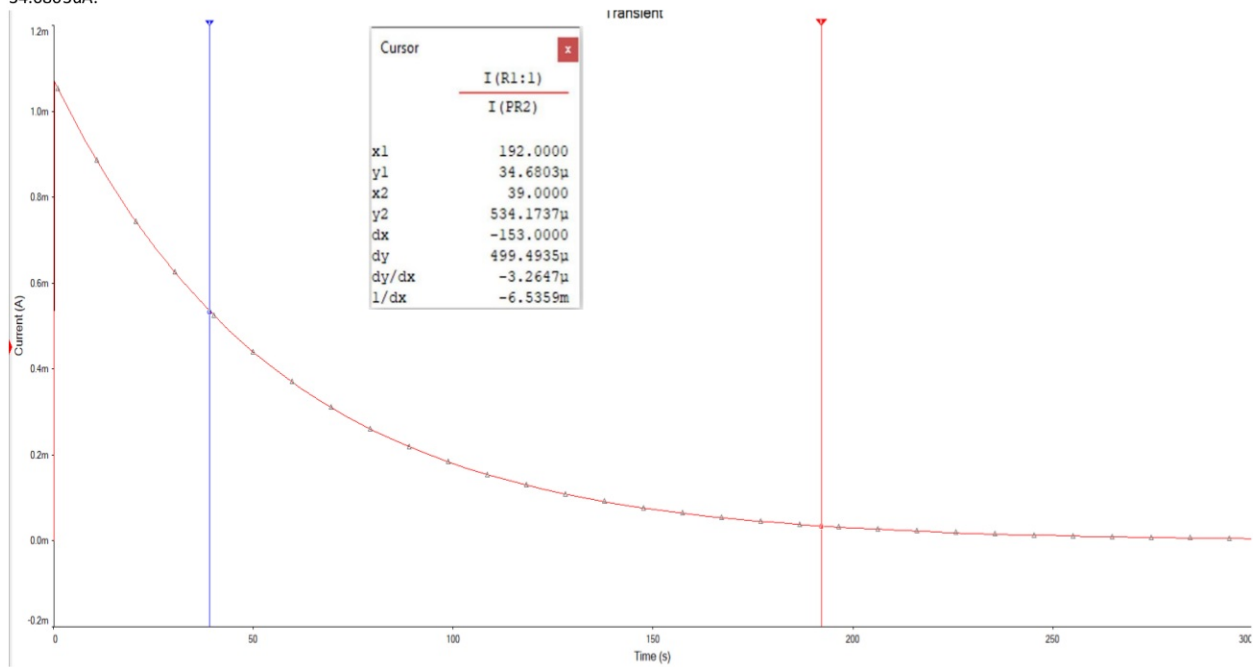


Figure 7

Figure 8 shows the current against time graph while the circuit is charging. The red cursor has been placed at the same random time of 241s with a current of 14.4363uA.

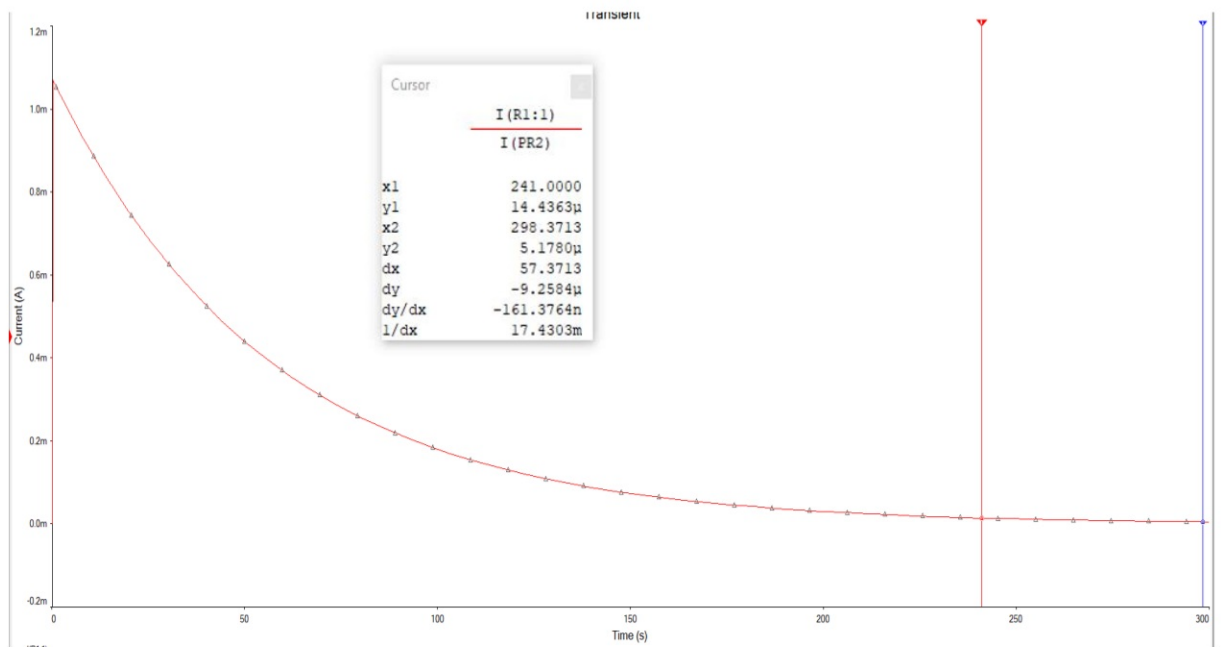


Figure 8

Figure 9 shows the voltage against time graph while the circuit is charging. The cursors have been placed at the same random times on the graph that were used in the calculations. The red cursor has been placed at 39s with a voltage of 3.0086V and the blue has been placed at 193s with a voltage of 5.8058V.

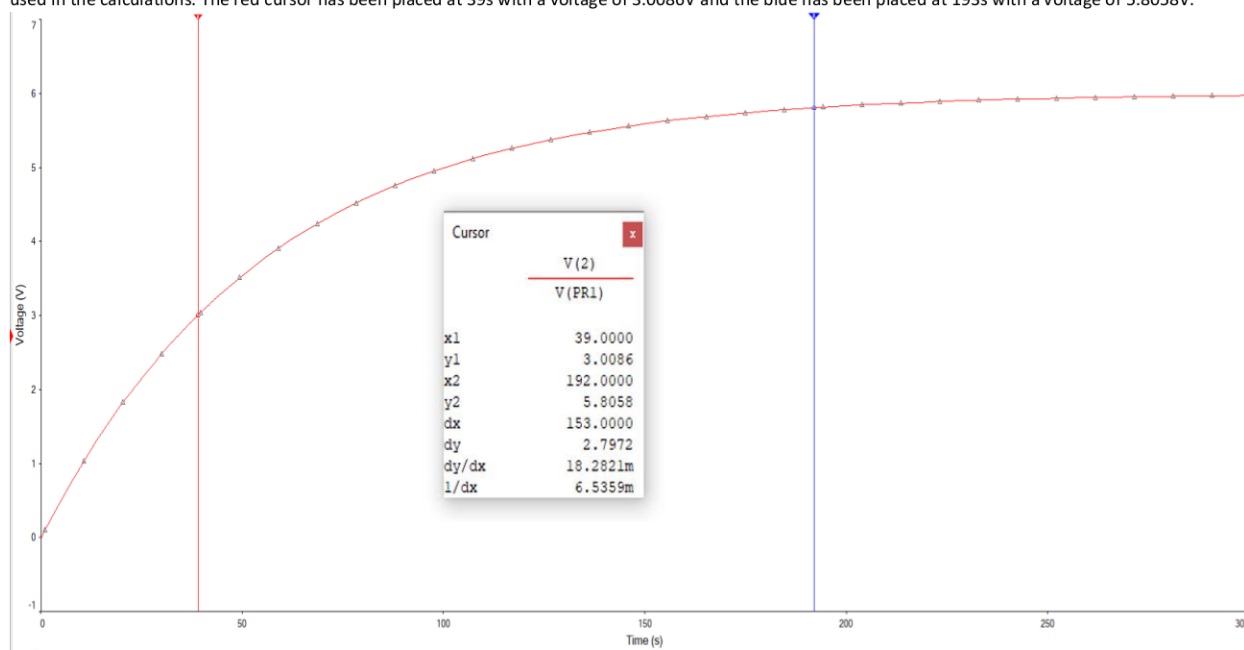


Figure 9

Figure 10 shows the voltage against time graph while the circuit is charging. The red cursor has been placed at the same random time of 241s with a voltage of 5.9192V.

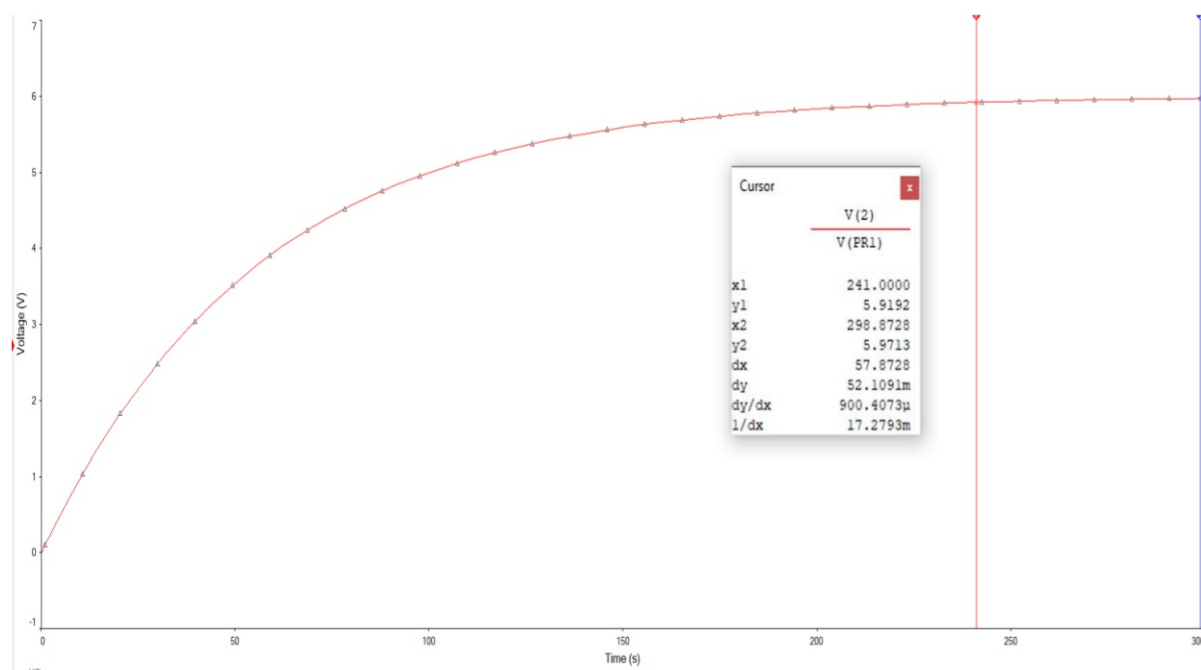


Figure 10

Circuit 1 – Discharging

Using the same circuit in figure 1 the same practical experiment was done while the circuit was discharging instead. Figure 11 shows a graph of the practical results of current against time while the circuit is discharging over 300 seconds.

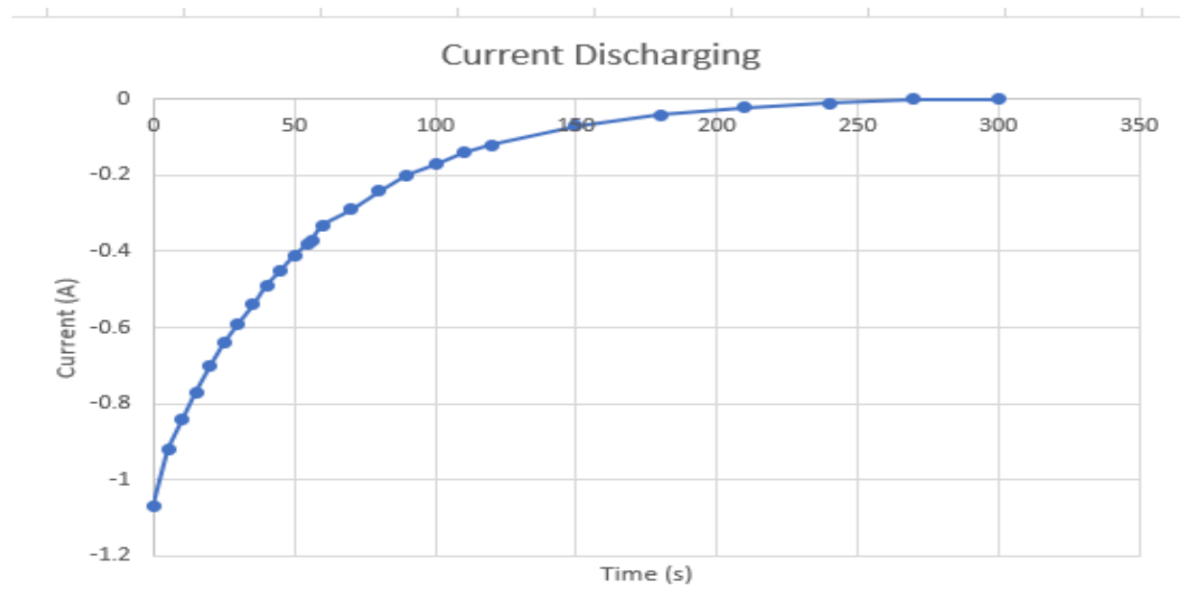


Figure 11

Figure 12 shows a graph of the practical results of voltage against time while the circuit is discharging over 300 seconds.

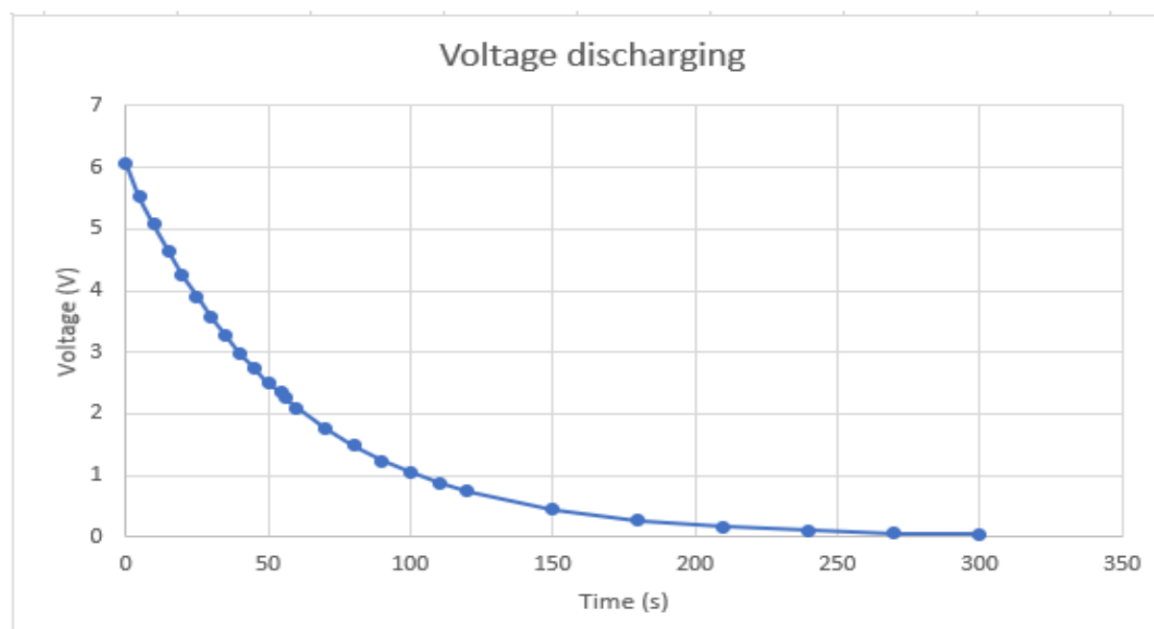


Figure 12

The same random values were chosen and calculated and the values of voltage and current were calculated at 1 time constant. These calculations are shown below.

$$\text{voltage at } 1\tau = \frac{36.8}{100} \times 6 = 2.208V$$

$$\text{Current at } 1\tau = \frac{63.2}{100} \times 1.07 \times 10^{-3} = 0.676mA$$

The random time values for discharging voltage:

$$V_c = V_{max} \left(e^{-\frac{39}{56}} \right) = 2.99V$$

$$V_c = V_{max} \left(e^{-\frac{192}{56}} \right) = 0.195V$$

$$V_c = V_{max} \left(e^{-\frac{241}{56}} \right) = 0.08V$$

The random time values for discharging current:

$$I = I_{max} \left(1 - e^{-\frac{39}{56}} \right) = -0.533mA$$

$$I = I_{max} \left(1 - e^{-\frac{192}{56}} \right) = -34.7\mu A$$

$$I = I_{max} \left(1 - e^{-\frac{241}{56}} \right) = -14.467\mu A$$

Figure 13 shows the voltage against time graph while the circuit is discharging simulated on multisim. The cursors have been placed at one time constant on charge and discharge which multisim shows it 56.1160s on the red cursor and 55.7132s on the blue.

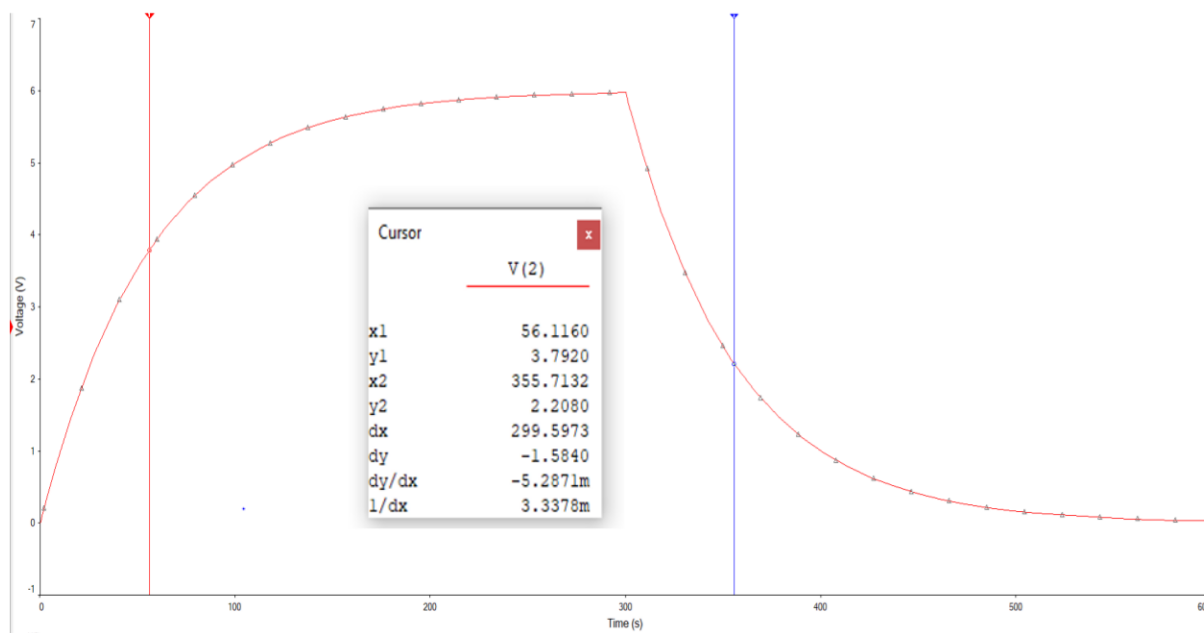


Figure 13

Figure 13 shows the current against time graph while the circuit is discharging simulated on multisim. The cursors have been placed at one time constant on charge and discharge which multisim shows it 56.1574s on the red cursor and 56s on the blue.

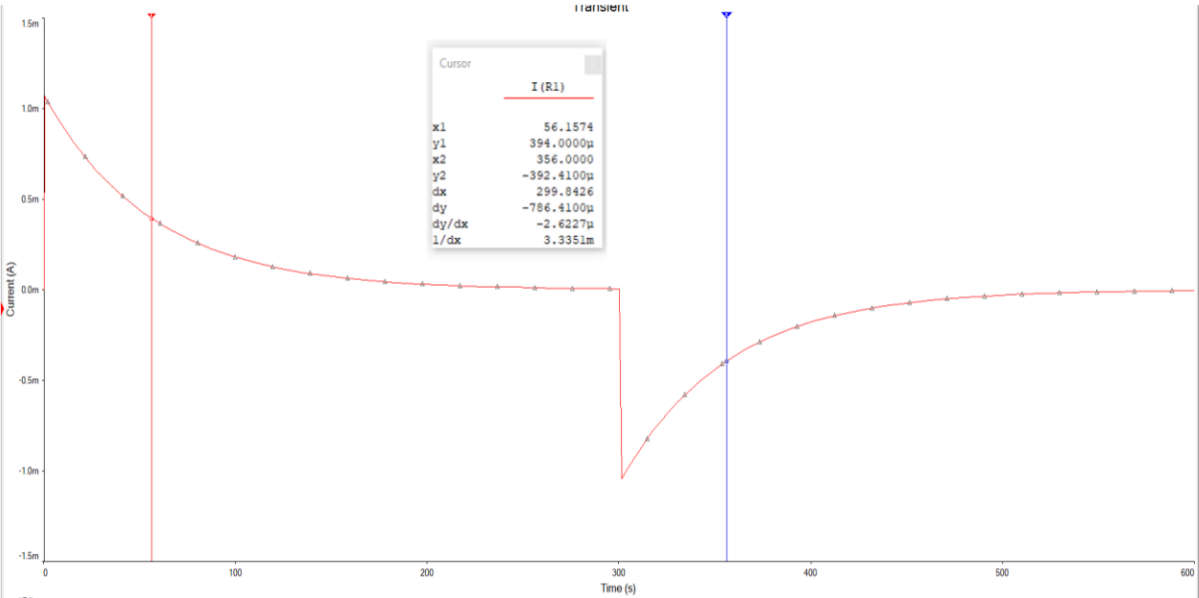


Figure 14

Figure 15 shows the voltage against time graph while the circuit is charging. The cursors have been placed at the same random times on the graph that were used in the calculations. The red cursor has been placed at 39s with a voltage of 3.0680V and the blue has been placed at 193s with a voltage of 199.8252mV.

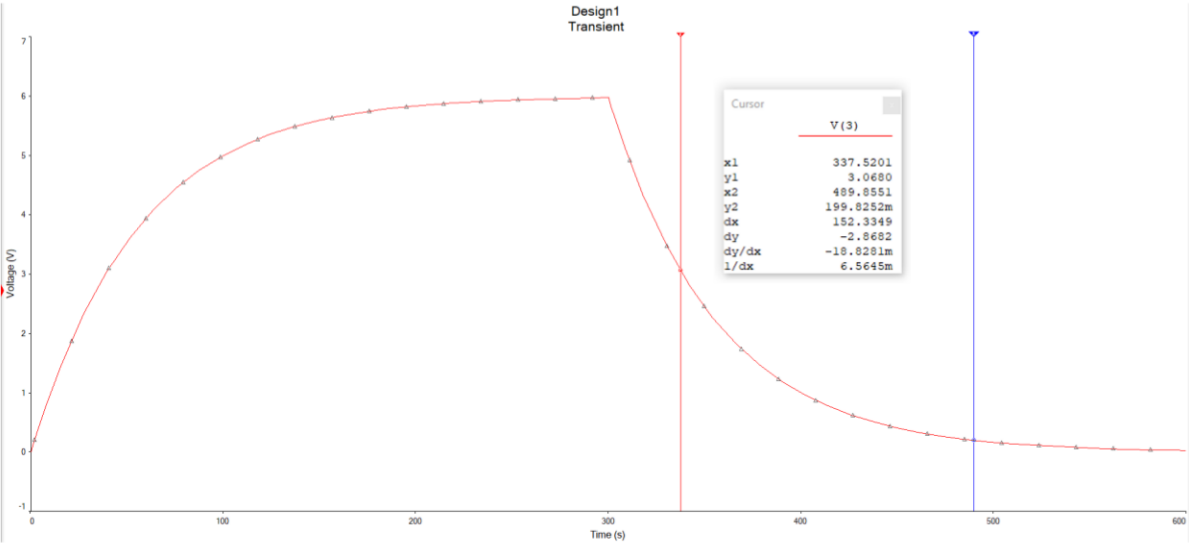


Figure 15

Figure 16 shows the voltage against time graph while the circuit is discharging. The red cursor has been placed at the same random time of 241s with a voltage of 79.9492mV.

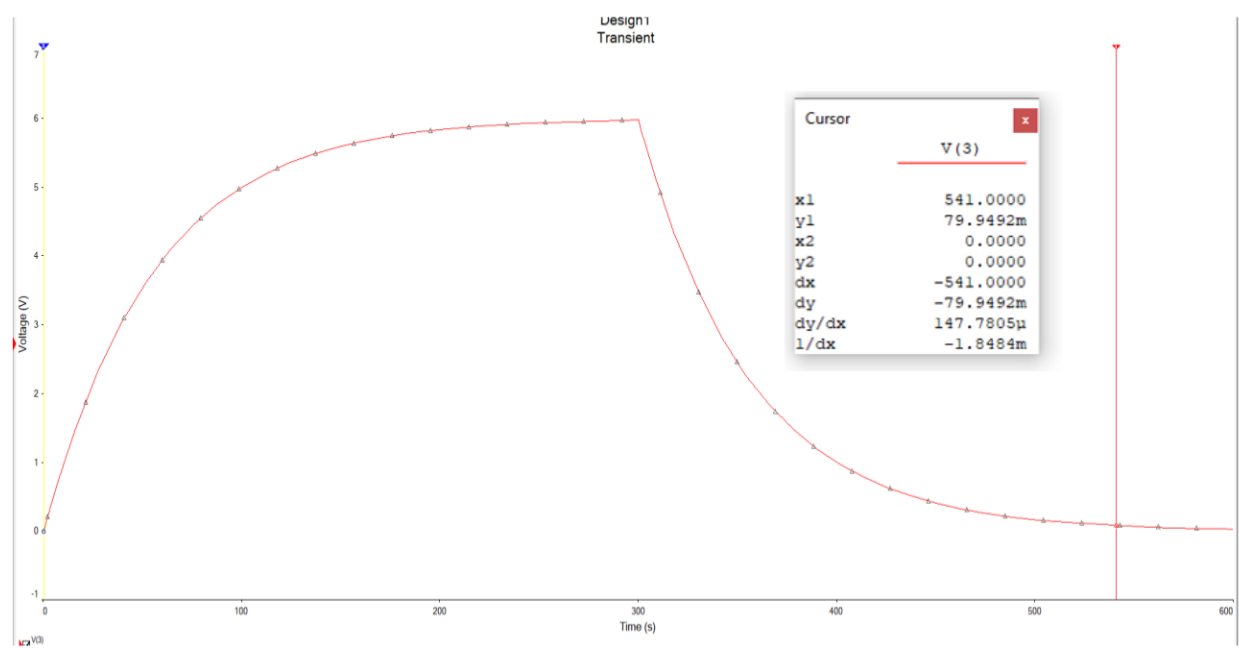


Figure 16

Figure 17 shows the current against time graph while the circuit is discharging. The cursors have been placed the same random times on the graph that were used in the calculations. The red cursor has been placed at 39s with a current of -532.9766uA and the blue has been placed at 193s with a current of -34.3667uA.

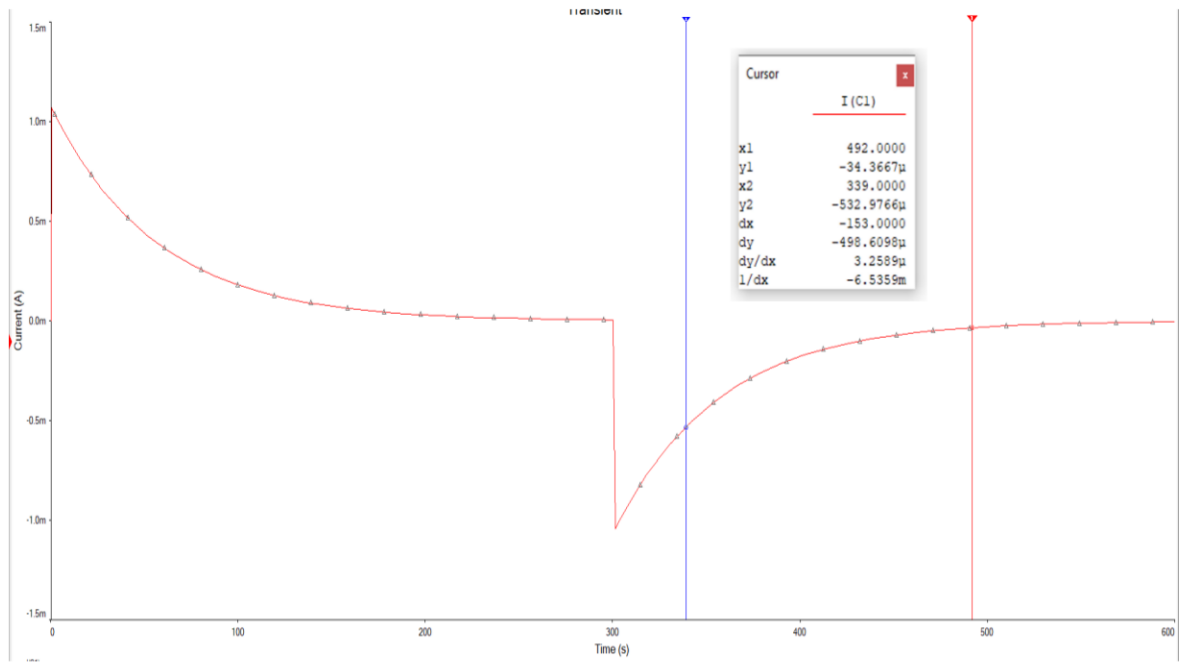


Figure 17

Figure 18 shows the current against time graph while the circuit is discharging. The red cursor has been placed at the same random time of 241s with a current of -14.2766uA.

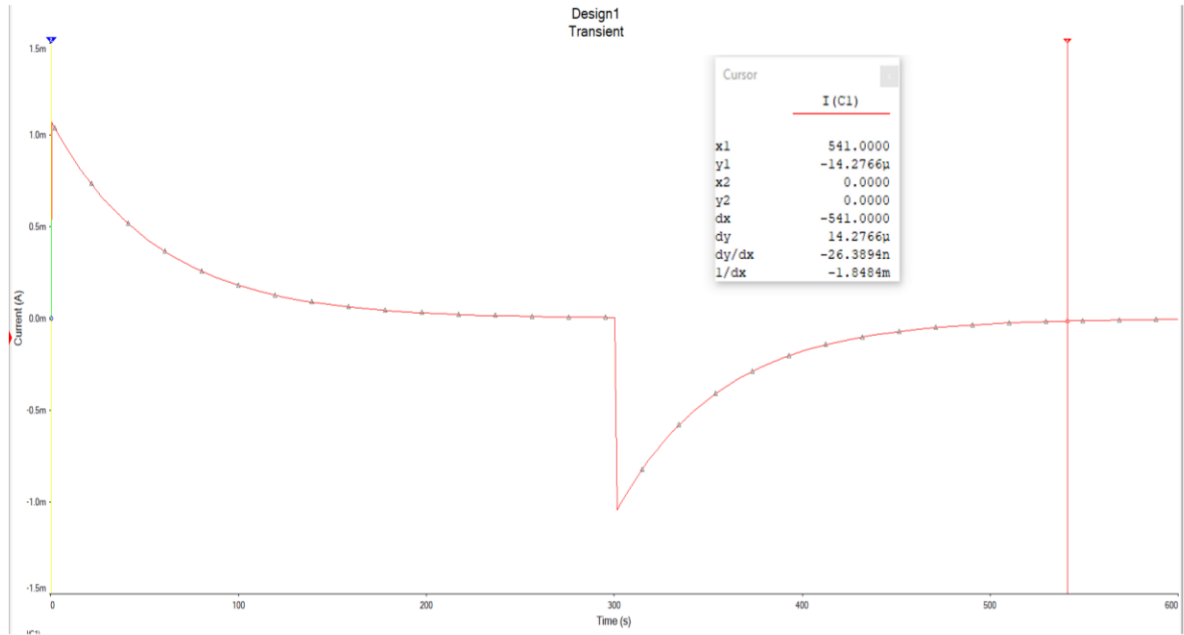


Figure 18

Circuit 2

Figure 19 shows the second circuit that was investigated and tested.

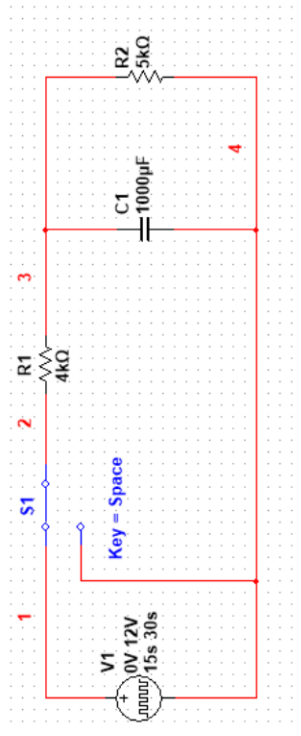


Figure 19

The circuit in figure 19 must be simplified using an equivalent circuit to calculate the time constant using the equivalent resistance of the circuit. This was done by using the calculations below.

$$\text{Total circuit resistance} = \frac{R1 \times R2}{R1 + R2} = \frac{4 \times 10^3 \times 5 \times 10^3}{4 \times 10^3 + 5 \times 10^3} = 2.2k\Omega$$

$$\tau = RC = 2.2 \times 10^3 \times 1000 \times 10^{-6} = 2.2s$$

$$\text{Equivalent Voltage} = \frac{R2}{R1 + R2} \times 12 = \frac{5 \times 10^3}{4 \times 10^3 + 5 \times 10^3} \times 12 = 6.6V$$

$$I_{max} = \frac{6.6}{2.2 \times 10^3} = 3mA$$

$$\text{Current at } 1\tau = \frac{36.8}{100} \times 3 \times 10^{-3} = 1.104mA$$

The initial current while the circuit is charging would be 3mA which is calculated below; the final current would be 0A.

$$I_{max} = \frac{6.6}{2.2 \times 10^3} = 3mA$$

The initial current while the circuit is discharging would be -3mA; the final current would be 0A.

Figure 20 shows the current against time graph while the circuit is discharging simulated on multisim. The cursors have been placed at one time constant on charge and discharge which multisim shows it 2.2290s on the red cursor and 2.2317s on the blue.

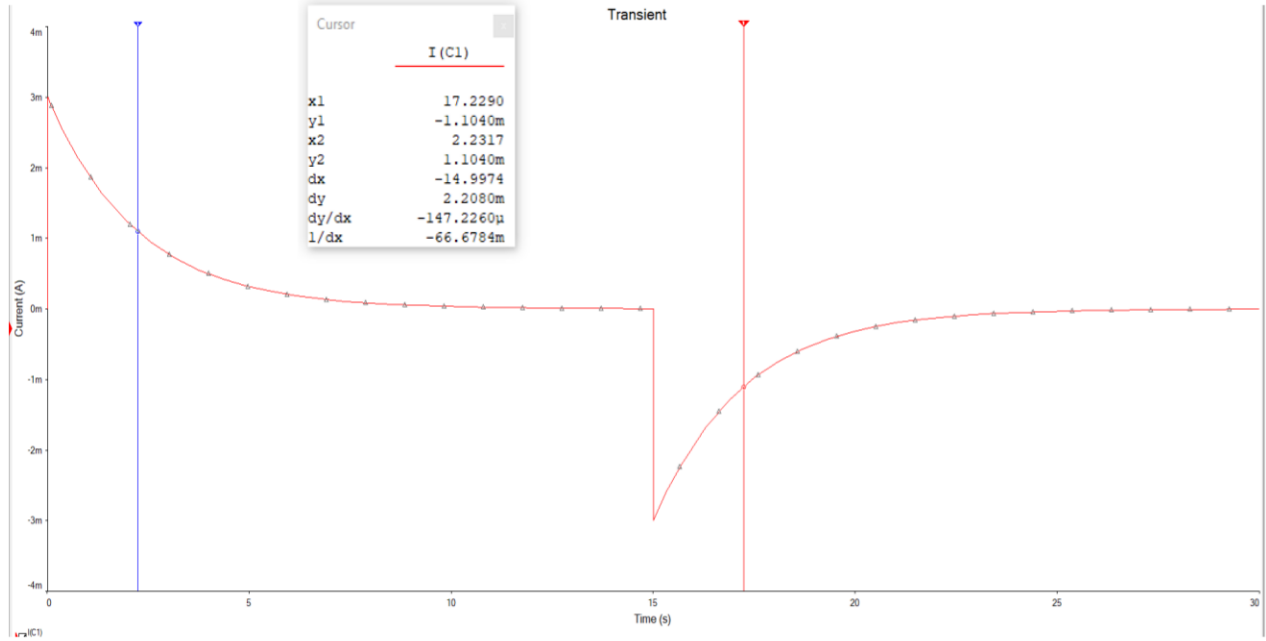


Figure 20

Circuit 3

Figure 21 shows the third circuit that was investigated and tested.

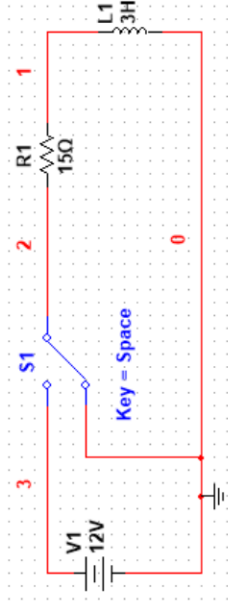


Figure 21

Below are all calculations that were necessary for this circuit.

$$I_{max} = \frac{V}{R} = \frac{12}{15} = 0.8A$$

$$\text{Current at 1 time constant} = \frac{63.2}{100} \times 0.8 = 0.5056A$$

$$\tau = \frac{L}{R} = \frac{3}{15} = 0.2s$$

The following calculations were made to create the charge graph.

$$I = I_{max}(e^{-\frac{t}{\tau}})$$

$$0.8 \left(e^{-\frac{0}{0.2}} \right) = 0A$$

$$0.8 \left(e^{-\frac{0.1}{0.2}} \right) = 0.315A$$

$$0.8 \left(e^{-\frac{0.2}{0.2}} \right) = 0.506A$$

$$0.8 \left(e^{-\frac{0.3}{0.2}} \right) = 0.621A$$

$$0.8 \left(e^{-\frac{0.4}{0.2}} \right) = 0.692A$$

$$0.8 \left(e^{-\frac{0.5}{0.2}} \right) = 0.734A$$

$$0.8 \left(e^{-\frac{0.6}{0.2}} \right) = 0.760A$$

$$0.8 \left(e^{-\frac{0.7}{0.2}} \right) = 0.776A$$

$$0.8 \left(e^{-\frac{0.8}{0.2}} \right) = 0.785A$$

$$0.8 \left(e^{-\frac{0.9}{0.2}} \right) = 0.791A$$

$$0.8 \left(e^{-\frac{1}{0.2}} \right) = 0.795A$$

The following calculations were made to create the discharge graph.

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

$$0.8 \left(1 - e^{-\frac{0}{0.2}} \right) = 0.8A$$

$$0.8 \left(1 - e^{-\frac{0.1}{0.2}} \right) = 485.225mA$$

$$0.8 \left(1 - e^{-\frac{0.2}{0.2}} \right) = 294.364mA$$

$$0.8 \left(1 - e^{-\frac{0.3}{0.2}} \right) = 178.504mA$$

$$0.8 \left(1 - e^{-\frac{0.4}{0.2}} \right) = 108.268mA$$

$$0.8 \left(1 - e^{-\frac{0.5}{0.2}} \right) = 65.668mA$$

$$0.8 \left(1 - e^{-\frac{0.6}{0.2}} \right) = 39.629mA$$

$$0.8 \left(1 - e^{-\frac{0.7}{0.2}} \right) = 24.158mA$$

$$0.8 \left(1 - e^{-\frac{0.8}{0.2}} \right) = 14.653mA$$

$$0.8 \left(1 - e^{-\frac{0.9}{0.2}} \right) = 8.887mA$$

$$0.8 \left(1 - e^{-\frac{1}{0.2}} \right) = 5.390mA$$

The following is a transposition of the original exponential equation to find what time does the current fall to 100mA.

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

$$\frac{I}{I_{max}} = e^{-\frac{t}{\tau}}$$

$$\frac{0.1}{0.8} = e^{-\frac{t}{0.2}}$$

$$125 = e^{-\frac{t}{0.2}}$$

$$\ln 125 = e^{-\frac{t}{0.2}}$$

$$-2.079 = \frac{t}{0.2}$$

$$-2.079 \times 0.2 = t$$

$$t = 0.416s$$

The following is a transposition of the original exponential equation to find what time does the current fall to 10mA.

$$I = I_{max}(e^{-\frac{t}{\tau}})$$

$$\frac{I}{I_{max}} = e^{-\frac{t}{\tau}}$$

$$\frac{0.01}{0.8} = e^{-\frac{t}{0.2}}$$

$$0.0125 = e^{-\frac{t}{0.2}}$$

$$\ln 0.0125 = e^{-\frac{t}{0.2}}$$

$$4.382 = \frac{t}{0.2}$$

$$4.382 \times 0.2 = t$$

$$t = 0.876s$$

Figure 22 shows the calculated results of current over the base of time over 1 second while the circuit is charging.

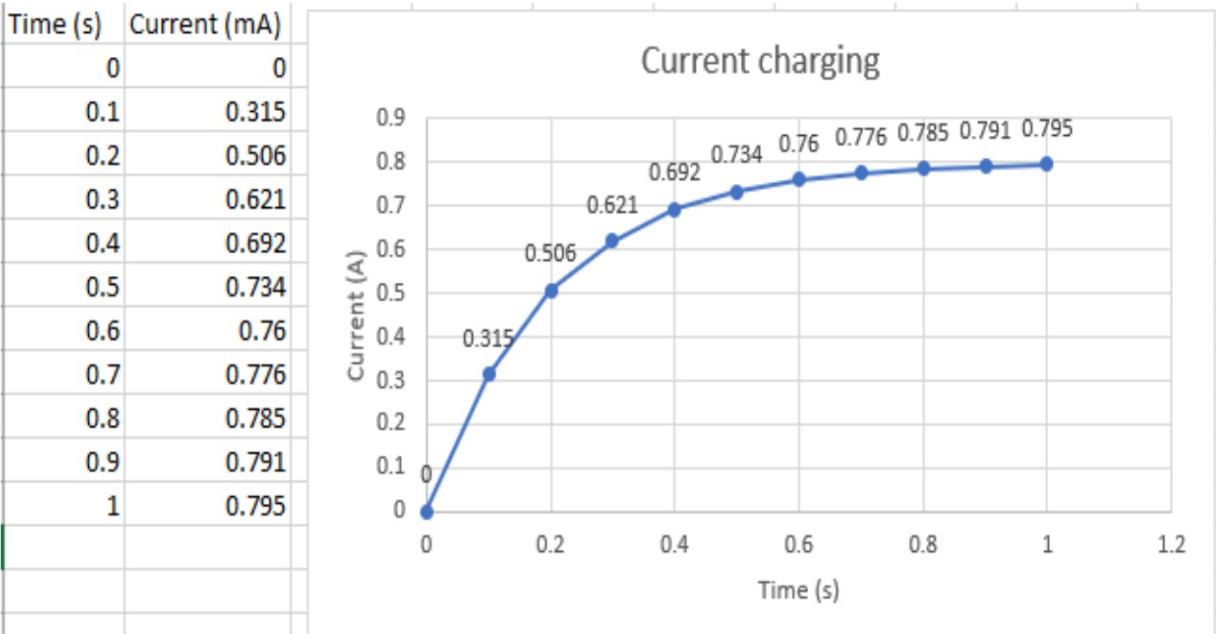


Figure 22

Figure 23 shows the calculated results of current over the base of time over 1 second while the circuit is charging.

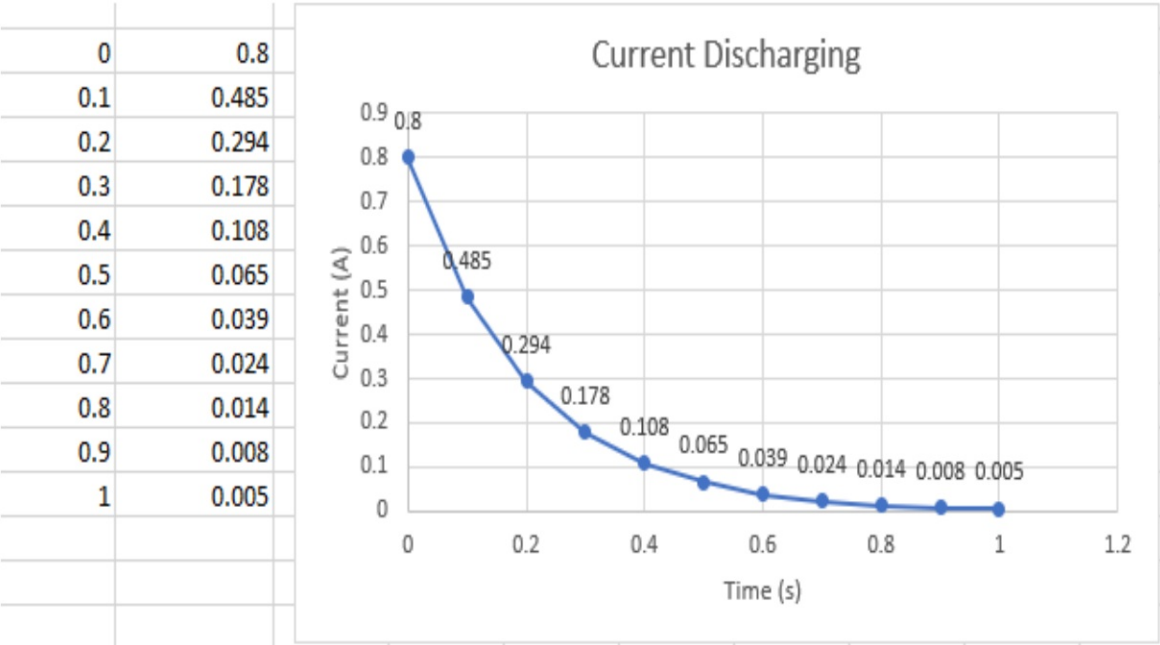


Figure 23

Figure 24 shows the current against time graph while the circuit is charging. The red cursor is placed at 1 second of the circuit charging which has a voltage of 794.6264mV.

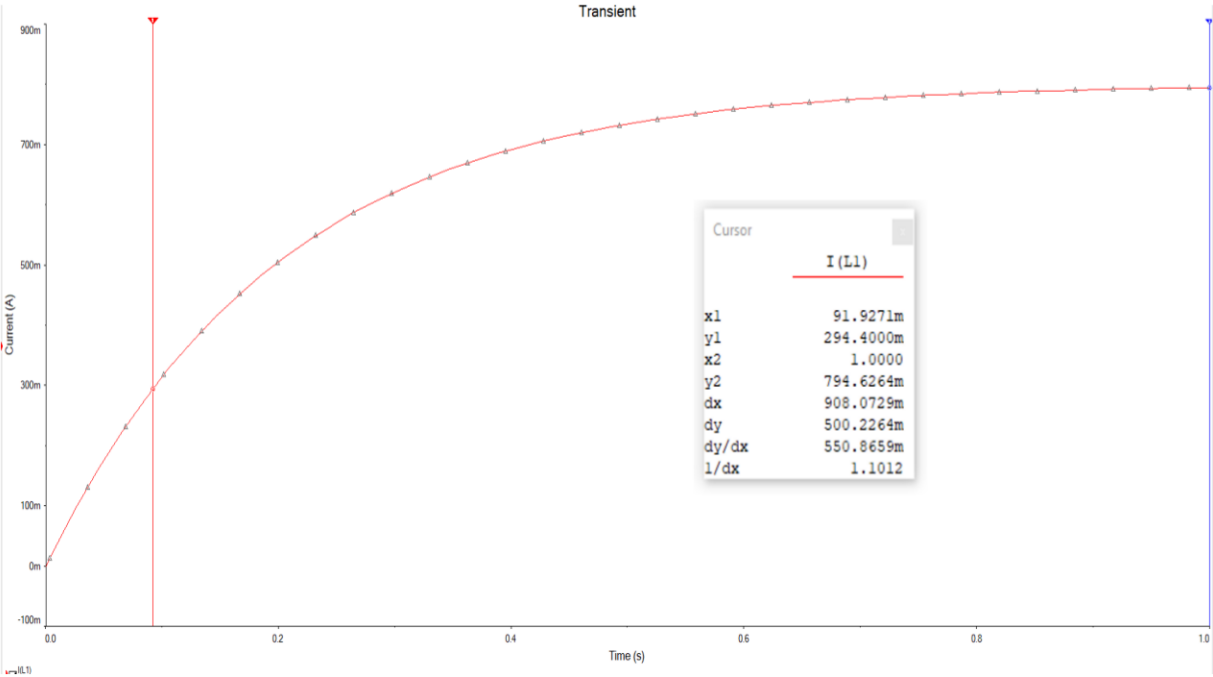


Figure 24

Figure 25 shows the current over time graph while the circuit is charging and then discharging. The cursor is placed at the point just before the switch is changed over where the value of current is 777.5984mA.

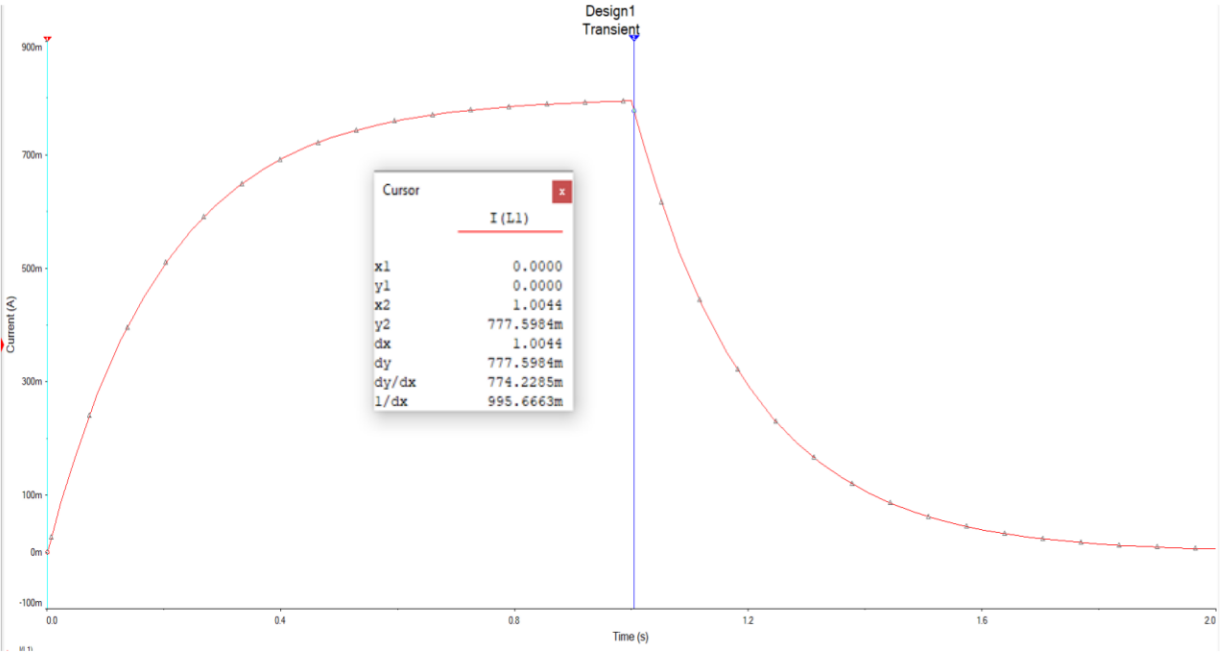


Figure 25

Figure 26 shows the current against time graph where the circuit is charging and then discharging. The blue cursor has been placed where the current has fallen to 100mA where the time is 0.4141s into the discharge. The red cursor has been placed where the current has fallen to 10mA where the time is 0.8730s into the discharge.

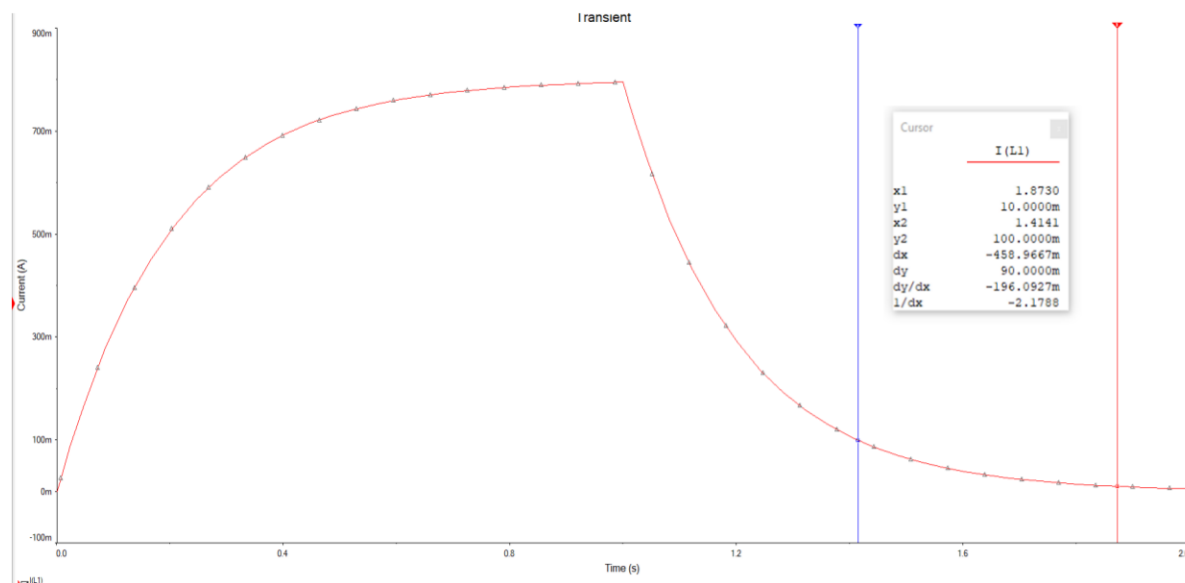


Figure 26

3. Testing, results and analysis

This section contains all results of the tests which were carried out on all 3 circuits. All results have been analysed and explained.

Circuit 1 – Charging

Figure 27 shows all the voltage results table for the 3 chosen times for calculated, multsim and practical. The results were taken while the circuit is charging.

Voltage comparison charging

Time (s)	Calculated	Multisim	Practical
39	3V	3.0086V	3.1V
192	5.81V	5.8058V	5.9V
241	5.91V	5.9192V	5.95V

Figure 27

As can be seen in figure 27 the results taken from all 3 sources prove each other correct. There are however, slight errors. The percentage error can be calculated by using the following formula below for all errors. All errors are compared to the multsim results as they are the closest to perfect results, therefore the exact value will be taken as the multsim value.

$$\frac{\text{approximate} - \text{exact}}{\text{exact}} \times 100 = \text{percentage error}$$

The table in figure 28 shows the errors for the calculated and practical results for each chosen time.

Time (s)	Calculated	Practical
39	0.28%	3.04%
192	0.07%	1.62%
241	0.16%	0.52%

Figure 28

Figure 29 shows all the current results table for the 3 chosen times for calculated, multsim and practical. The results were taken while the circuit is charging.

Current comparison charging

Time (s)	Calculated	Multsim	Practical
39	533.25uA	534.1737uA	480uA
192	34.7uA	34.6803uA	35uA
241	14.467uA	14.4363uA	20uA

Figure 29

As can be seen in figure 29 the results taken from all 3 sources prove each other correct. There are however slight errors. The table of percentage errors can be seen in figure 30.

Current comparison charging

Time (s)	Calculated	Practical
39	0.17%	10.14%
192	0.06%	0.92%
241	0.21%	38.53%

Figure 30

Circuit 1 – Discharging

Figure 31 shows all the voltage results table for the 3 chosen times for calculated, multism and practical. The results were taken while the circuit is discharging.

Voltage comparison discharging

Time (s)	Calculated	Multisim	Practical
39	2.99V	3.0680V	2.99V
192	0.195V	199.8252mV	0.21V
241	0.08V	79.9492mV	0.1V

Figure 31

As can be seen in figure 31 the results taken from all 3 sources prove each other correct. There are however slight errors. The table of percentage errors can be seen in figure 32.

Time (s)	Calculated	Practical
39	2.54%	2.54%
192	2.41%	5.09%
241	0.06%	25.08

Figure 32

Figure 33 shows all the current results table for the 3 chosen times for calculated, multsim and practical. The results were taken while the circuit is discharging.

Current comparison discharging

Time (s)	Calculated	Multsim	Practical
39	-532.25uA	-532.9766uA	-490uA
192	-34.7uA	-34.3667uA	-35uA
241	-14.467uA	-14.2766uA	-19uA

Figure 33

As can be seen in figure 33 the results taken from all 3 sources prove each other correct. There are however slight errors. The table of percentage errors can be seen in figure 34.

Time (s)	Calculated	Practical
39	0.05%	8.06%
192	0.97%	1.84%
241	1.33%	33.08%

Figure 34

As can be seen throughout the different tables of results, the calculated results have very little error compared to the practical error which is massively out in some cases. The reasons for this are that the practical results can have an error due to human error from writing down the results and from reading the graph slightly incorrectly. These added up would make the error even bigger. The error for the practical is very high compared to the calculated error, this extra error could be down to faulty components which increased current draw. The reasons for the calculated error can be down to rounding errors from using previous answers to calculate the final answer. This however only results in a small error as can be seen by the low percentage error for the calculated results.

Circuit 2

Figure 35 shows the time constants for the second circuit while the circuit is charging and discharging. This shows the results for both calculations and multisim.

	Calculated	Multisim
Charging	2.2222s	2.2317s
Discharging	2.2222s	2.2290s

Figure 35

Figure 35 shows that the calculations are correct as the multisim proves the answer with very little error. The percentage error for charge and discharge can be seen in the table in figure 36.

	Percentage error
Charging	0.44%
Discharging	0.32%

Figure 36

These errors are so small that they do not affect the results. These errors can be due to cursor placement on the multisim graphs which would alter the answer very slightly to have an error.

Figure 37 shows the initial and final current of the circuit when calculated and when simulated.

	Calculations	Multisim
Initial current	3mA	3mA
Final current	0mA	0mA

Figure 37

As can be seen the results match up perfectly as the maximum possible current is 3mA and will always begin at 3mA and the final current will always end up to essentially 0mA.

Circuit 3

Figure 38 shows a table of the time taken for the third circuit to discharge to 100mA and then 10mA. The results were taken from multisim values, calculated and the graph that was plotted.

Time	Multisim	Calculated	Plotted graph
100mA	0.4141s	0.416s	0.42s
10mA	0.8730s	0.876s	0.82s

Figure 38

Figure 38 shows that all separate sources of results are correct as they are all very close to the same value with very little error. The exact percentage of the errors can be seen in figure 39.

Time	Calculated	Plotted graph
100mA	0.46%	1.42%
10mA	0.34%	6.07%

Figure 39

As can be seen the percentage errors are low, however the errors from the graph are much higher than the calculated values. This can be down to rounding errors when calculating the values to make the graph. Also, it is heavily down to the amount of point that were on the graph that, as if there were more the curve would have been better and therefore more accurate. Even still there is human error from reading that graph which would make the answer less accurate. The calculated errors can come from rounding errors while calculating the answers. This would only make the answers slightly incorrect which explains the very low percentage error.

4. Conclusions and recommendations

After all the tests and analysing the results, conclusion of this report is that these types of circuits exponentially increase or decrease the current or voltage depending on charge or discharge. The rate of how fast they increase or decrease is dependent on the values of the components. A proven constant is that one τ always happens at the same point of the graph and the graph reaches steady state at five τ . The results prove that this happened when simulated, calculated is proven practically. The results that were taken proved the other methods well as the percentage error was low. However, the percentage error was sometimes high for the practical methods or methods involving plotting the graph manually. The reasons for this is that there were many different errors stacking up. A recommendation for this would be to take more results so that when plotted the curve of the graph is more correct and reading can be taken easier. When taking readings it is recommended to use cursor function to decrease the human error by placing the cursor exactly where it should be to get a correct result.

FINAL GRADE

GENERAL COMMENTS

78/100

Instructor

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GRADING FORM: NEW CSG-RUBRIC

AARON REES

78

1. ENGAGEMENT WITH LITERATURE



NA

2. KNOWLEDGE AND UNDERSTANDING



2. Excellent level of knowledge, few minor errors and omissions as marked
23/25

23

3. COGNITIVE AND INTELLECTUAL



3. Sound evaluation. Test results are tabulated and proof of results given in graphical analysis, consider using multiple cursors to save space in the report. Data has been accurately analysed. 22/30

22

4. PRACTICAL APPLICATION



4. Very good application of basic methods, clear to the reader. 16/25

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5. TRANSFERABLE SKILLS



5. Coherent, fluent and organised, graphs are good, written communication is very good. Appropriate conclusions drawn. 17/20

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