Q = C V capacitor experiment using an LM334Z current source

We like the usual capacitor experiment where we manually change the value of a series variable resistor in order to try maintain a constant charging current. There is educational merit in trying to vary the resistor at noticeably different rates and reaching a point where this is no longer possible. Noting this current, the time and the voltage across the capacitor allows the calculation of Q, the charge, from Q = It where I is the constant charging current, and enables a graph of Voltage v Charge to be plotted. The gradient of this graph, Q/V, is the value of the capacitance of the capacitor being charged.

We received a query about the construction of a constant current circuit for use in the above experiment. We had previously used a single, silicon, NPN transistor constant current circuit successfully.

As the enquiry was about the use of an LM334Z integrated circuit we ordered some [1] and set about doing the experiment.

The LM334Z is a three pin device, it comes in a TO92 style package, and has a maximum device current of 10 mA.

In the most basic configuration the addition of a single resistor is all that is needed to set the value of the constant current (Figure 2). Online information states that the value of this resistor can be calculated using the equation: $R_{set} = 67.7\ \text{mV}/I_{set}$. I_{set} is the desired constant current and R_{set} is the total value of resistance between the R and V- pins of the LM334Z.

A 68 Ω resistor would give a current of approximately 1 mA, 136 Ω would give about 0.5 mA.

Instead of using a single fixed value resistor we used a combination of a fixed resistor (15 Ω to limit the max value of current to just under 5 mA, well under the device's max current) in series with a 2000 Ω multi-turn preset resistor (Figure 1 and 4). This allowed us to vary the value of the current but not exceed its maximum

>>

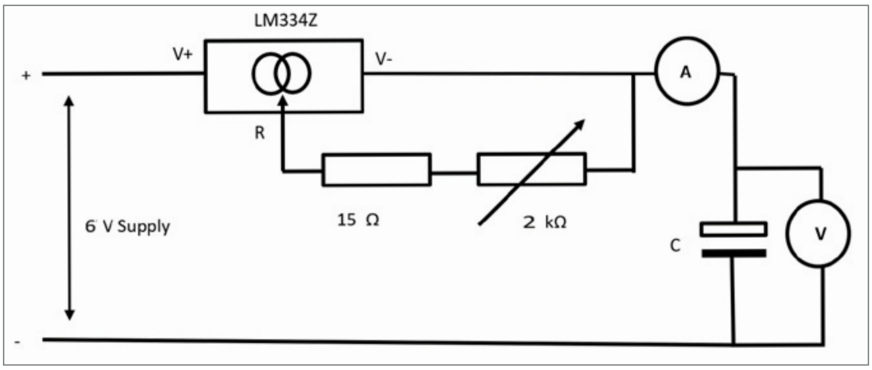


Figure 1 - The circuit diagram of the LM334Z constant current source in the capacitor experiment.

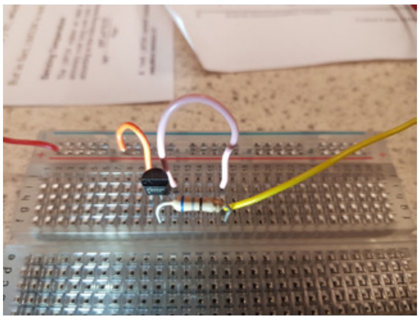


Figure 2 - The LM334Z prototype circuit with 15 Ω resistor giving a constant current of 0.98 mA.

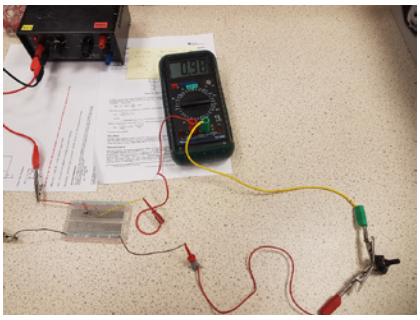


Figure 3 - Using a 500 Ω variable resistor to confirm constant current over a range of load resistances.

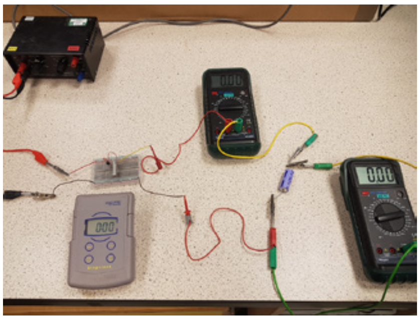


Figure 4 - The capacitor experiment as shown in Figure 1.

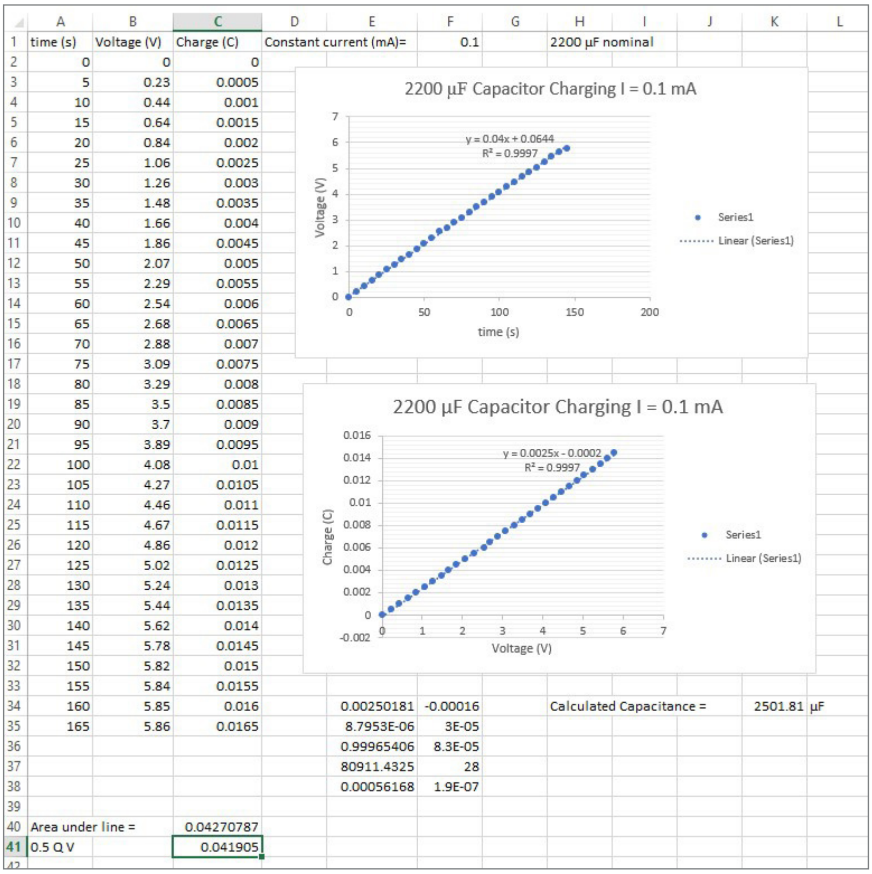
current capability. The ammeter is only required when setting the current. Circuit diagram - For the datasheet and pinout information see [2].

To set the value of the current use a 500 Ω variable load resistor (in place of the capacitor) and an ammeter (Figure 3). Adjust the multiturn preset resistor until the ammeter displays the desired current.

Results

The spreadsheet in Figure 5 shows typical results using a 2200 µF electrolytic capacitor with the current set to 0.1 mA. The Voltages on the Voltmeter were noted every 5 s. The calculated value of capacitance was 2501 µF. Electrolytic capacitors have a wide tolerance range, typically +/- 20%!

The area under the best fit straight line (calculated from the integral of the equation of best fit) is also compared to the Energy (½ Q V) stored in the capacitor. <<



	A	B	C	D	E	F	H	K	L
1	time (s)	Voltage (V)	Charge (C)	Constant current (mA)=		0.1	2200 µF nominal		
2	0	0	0						
3	5	0.23	0.0005						
4	10	0.44	0.001						
5	15	0.64	0.0015						
6	20	0.84	0.002						
7	25	1.06	0.0025						
8	30	1.26	0.003						
9	35	1.48	0.0035						
10	40	1.66	0.004						
11	45	1.86	0.0045						
12	50	2.07	0.005						
13	55	2.29	0.0055						
14	60	2.54	0.006						
15	65	2.68	0.0065						
16	70	2.88	0.007						
17	75	3.09	0.0075						
18	80	3.29	0.008						
19	85	3.5	0.0085						
20	90	3.7	0.009						
21	95	3.89	0.0095						
22	100	4.08	0.01						
23	105	4.27	0.0105						
24	110	4.46	0.011						
25	115	4.67	0.0115						
26	120	4.86	0.012						
27	125	5.02	0.0125						
28	130	5.24	0.013						
29	135	5.44	0.0135						
30	140	5.62	0.014						
31	145	5.78	0.0145						
32	150	5.82	0.015						
33	155	5.84	0.0155						
34	160	5.85	0.016		0.00250181	-0.00016	Calculated Capacitance =	2501.81	µF
35	165	5.86	0.0165		8.7953E-06	3E-05			
36					0.99965406	8.3E-05			
37					80911.4325	28			
38					0.00056168	1.9E-07			
39									
40	Area under line =		0.04270787						
41	0.5 Q V		0.041905						

Figure 5 - Typical results for a 2200µF capacitor.

References

[1] https://www.bitsbox.co.uk/

[2] https://www.ti.com/lit/ds/symlink/lm334.pdf?ts=1649740909939&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM334%253Futm_source%253Dgoogle%2526utm_medium%253Dcpc%2526utm_campaign%253Dapp-null-null-GPN_EN-cpc-pf-google-eu%2526utm_content%253DLM334%2526ds_ k%253DLM334%2526DCM%253Dyes%2526gclsrc%253 Daw.ds%2526gclid%253DCjwKCAjwo8-SBhAlEiwAopc9W1WoVoWYhAnz10DA6VQCNQejUXWUIa WVIHY9eV5p6_AfOw-IiUMKzBoCOD0QAvD_BwE