

TAP 129- 7: Discharge of high-value capacitors

Introduction

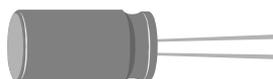
One use of capacitors is as backup sources of energy in the case of power failure in, for example, memory systems, where total loss of power may result in the loss of essential data. Such capacitors operate at low voltages but generally have very high capacitance. These questions illustrate how knowledge of the mathematical model which describes the exponential decay of the charge on a capacitor is put to good use in choosing a suitable capacitor for a given application.

These questions involve working with data on such commercially available capacitors and using an Excel spreadsheet to examine the properties of a range of such devices.

What to do

There are data tables included giving details of high-value capacitors. You will be asked questions about the use of these and also asked to open up a spreadsheet and work with it. Work through the questions in order and follow the instructions given to help you.

High capacitance memory back-up capacitors



A range of high capacitance memory back-up capacitors for applications which require memory retention under power failure conditions. Such applications include automotive energy management systems, domestic and industrial control systems.

Technical specification	
Operating temperature range	-40°C to +70°C
Capacitance tolerance	-20% to +80%
Rated voltage	2.5 V

Value / F	Inflow I / mA	Body		Lead		
		L	dia	L	dia	pitch
0.33	0.12	21	6.8	15	0.7	2.5
1.0	0.18	22	8	15	0.7	3.5
3.3	0.30	23	12.5	15	0.8	5.0
10	0.6	35	18	15	0.8	7.5

Value	price per item
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F	1–9	10–49	50–99
0.33	£1.90	£1.75	£1.62
1.0	£2.09	£1.93	£1.78
3.3	£2.62	£2.41	£2.23
10	£4.39	£4.05	£3.73

A customer requires a capacitor as a backup for a power supply that can provide a voltage which does not drop below 2.0 V for several hours. The effective load (resistance) connected across the power supply is 5 Ω . You are required to choose a capacitor from the selection above. This spreadsheet allows you to examine the discharge curve of capacitors that you select.



Open the Excel Spreadsheet see TAP 129-8

When you open up the spreadsheet you will see that a capacitor of 10.0 F has been chosen connected to a load of 10 k Ω . The charge and pd across the capacitor are calculated every half hour and displayed in the table and on the named graphs. You can change the initial conditions like this:

1. To change the time interval to an hour, type 1.0, press the arrow key or enter.
2. Then press key F9.
The spreadsheet will not be recalculated until you press F9.
3. Try changing the value of capacitance and look at the effect on the table and on the graphs.

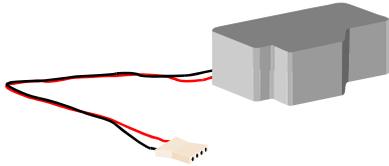
You can change other quantities in the same way, for example, the load resistance and the time interval. Remember that the load must be in k Ω and the time in hours.

When you are satisfied that you can handle the spreadsheet confidently, switch back to the questions.

Questions

1. Calculate the amount of energy which can be stored in the 10 F capacitor when charged to 2.5 V.
2. The capacitor in question 1 is connected across a 10 k Ω resistor. What is the time constant of this circuit?
3. What is the significance of the time constant?

Back-up power alkaline battery packs



A 4.5 volt alkaline battery used to back-up memory and clocks in laptop and desktop computers.

Technical specification	
Voltage	4.5 V
Capacity	1200 mAh
Temperature range	~30 °C to 60 °C
Dimensions	58 × 23 × 26 mm

price per item	
1–9	10–24
£10.40	£9.36

- Look at the second line in the above table called the 'capacity'. Note that this is the product of current and time. Convert the value given to coulombs.
- Use the data to estimate how much energy this battery stores. (Hint: look up the definition of potential difference if necessary.)
- Compare the energy available from this battery with that stored in the capacitor in question 1.

To answer the next question, use the spreadsheet.

- Use the data in the table above and the spreadsheet to determine which capacitor will provide a backup voltage of not less than 1.5 V for at least 2 hours into a load of 10 k Ω . Assume that the second column gives the maximum current allowed.
- Did you identify more than one suitable capacitor from the list? If so, which would you choose and why?

9. What are the factors you would consider if you had to decide between a battery or a high-value capacitor for backup energy supply? What would be your choice in this case and why?
10. Another user needs a capacitor to provide a pd across a load of $1.0\text{ M}\Omega$ which does not fall more than 10% from 2.5 V in 24 hours. Is any one of the above capacitors suitable?

Taking it further – checking the spreadsheet model

Go back to the spreadsheet. You will see that there are two columns containing calculated values of charge, Q . These have been done in two different ways. The column on the far right has been calculated using the exponential equation

$$Q = Q_0 e^{-t/RC}$$

and the capacitor equation

$$Q = CV.$$

This equation links the two continuous variables Q and t and gives 'exact' values for Q . The column on the far left has been calculated by an iterative method based on the differential equation

$$\Delta Q = -\frac{Q}{RC} \Delta t$$

in which each successive value of Q is used to calculate the next one, knowing the current flowing for a short (but finite) time. It is a useful exercise to compare the two methods by superimposing the two graphs of Q against t . You will be able to see that they differ. If you change the value of the time interval Δt over which each calculation is done, you will see that the amount of agreement between the two graphs also changes. Experiment with Δt to see what you have to do to improve the agreement. How far you get with this will depend on how practised you are with using spreadsheets. You may find it useful to change the scale on the axes. To do so, click on the axis for which you want to modify the scale and select 'format' then 'selected axis'. You can rescale the maximum and minimum values of that scale. Select the other scale and repeat if necessary.

Practical advice

This unit contains a range of activities designed around the exponential decay of the charge on a capacitor. The use of data from the current RS catalogue sets the work into a relevant modern context. Before starting the unit, students should be familiar with the basic capacitor equations $Q = C V$ and $W = \frac{1}{2} Q V$ etc. They will also need to be able to use a spreadsheet and, although some guidance is given, it may not be enough for students who are less confident. If students can work together on a network, they could be taken through some of the steps as a group exercise, or perhaps can be helped individually if time and staff are available. The spreadsheet calculations are done by iteration and by using the exponential equation, and the spreadsheet work later in the unit focuses on these aspects, hopefully helping students to understand the idea that the iterative calculation approaches the analytical solution as $\Delta t \rightarrow 0$.

Social and human context

There is an element of economic awareness in this work, in that students make a choice between capacitor or battery backup.

Answers and worked solutions

1. 31 J
2. 10^5 s
3. Time for charge or pd to fall to $1/e$ of its original value.
4. 4.3×10^3 C
5. 1.9×10^4 J
6. Much larger
7. 3.3 F or 10 F
8. Yes, see above answer. Choose 3.3 F, which is cheaper, or choose 10 F, which has more margin for error in capacitance.
9. Consider size, cost, operating temperature, lifetime; choose capacitor – cheaper, can be recharged, so longer life likely.
10. Yes, 10 F will do (3.3 F will not).

External references

This activity is taken from Advancing Physics Chapter 10, 130D