Investigating the Smoothing Effect of a Capacitor on a Resistive Load

Introduction

Capacitive smoothing is a process in which the voltage from a rectified D.C. supply, which is not stable, is smoothed so that more reliable readings can be obtained of the voltage trace shown on a CRO. Smoothing the D.C supply involves placing a capacitor in parallel across the circuit being supplied by the power pack as shown in the diagram below. However there still may be some ripple in the trace shown on the oscilloscope and the aim of my experiment is to investigate the degree of smoothing that can be achieved with a capacitor.

The circuit was set up as shown in the diagram above and readings of the voltage were recorded from the oscilloscope for different values of capacitance. We used a various capacitors ranging from 10 µF to 1000 µF in order to observe how the degree of smoothing was affected by increasing capacitance. The apparatus used to carry out this experiment were as follows:

- An oscilloscope
- An ammeter
- A D.c. power supply
- A range of capacitors of different values of capacitance
- A resistor load
- Leads
- Voltmeter

Results

The experiment was repeated and more readings recorded in order to diminish the possibility of anomalies and errors occurring and to obtain more reliable results.

Capacitance (C) /µF	Current (I)/mAmps	Frequency (f)/Hz	Sensitivity / Volts per division	Readings (±0.1)/volts		Measured Ripple Voltage (V) (±0.1)/Volts	Calculated ripple voltage: $V=\frac{I}{Cf}$ / Volts
				1st	2nd		
0	1.2	100	0.2	4.6	4.6	9.200	Cannot divide by zero
10	1.2	100	0.2	6.1	6.1	1.220	1.200
22	1.2	100	0.1	6.6	6.6	0.660	0.545
47	1.2	100	0.05	6.0	6.0	0.300	0.255
100	1.2	100	0.05	3.4	3.4	0.170	0.120
220	1.2	100	0.01	7.5	7.5	0.075	0.055
470	1.2	100	0.005	6.3	6.3	0.031	0.026
1000	1.2	100	0.005	3.0	3.0	0.015	0.012

Problems encountered

Using the oscilloscope required us to ensure that the trace that appeared on the screen would be appropriate to read from and to calculate such values as the frequency. In order to do this we had to take into consideration the scales of the axis and how the sensitivity of the CRO would affect our results. One recurring problem that I came across was the flashing of the trace. In order to overcome this problem I had to adjust the CRO settings using the trigger and the hold-off controls so that the trace would remain stable long enough for me to record precise values for the ripple voltage and the frequency. The flashing trace would occur almost every time the capacitance was changed and required holding the trace each time the readings were made.

The focus of the line is important as the thickness of the line can affect the readings when looking at each division. Though the thickness of the line is quite finite, this can affect the ripple voltage by ± 2mm on the scale (the squares are 1cm apart divided into 5 divisions.). The thickness of the line of the trace can be adjusted using the focus control as well as the intensity where we can obtain a trace of minimal thickness and high intensity so that we can see it clearly.

Errors

Errors of great significance and errors that can be considered negligible could have occurred during this experiment, giving rise to anomalous results. There are two categories under which errors can be regarded as; systematic errors and random errors. Systematic errors occur often when there are faults in the apparatus i.e calibration faults and zeroing of the apparatus. Random errors are also called human errors and are a result of the experimenter's technique. Random errors such as taking readings from the oscilloscope and the ammeter are common errors. Parallax error, where the line of vision did not meet in line with the pointer on the scale is an error that could have occurred. To overcome this error, there are some ammeters designed with a mirror helping to ensure that such errors do not occur which I could have used. Zero errors are also common with ammeters. I made sure that the ammeter had been zeroed in order to get fair and reliable results. Zeroing of the ammeter involves making sure that the ammeter is at the point zero between the readings (at each interval).the voltmeter was used for measuring the precision to which the voltage output from the power pack could be recorded so that the internal resistance of the power source would not be greatly significant. For the 6.0V, this was ± 0.1V.

Analysis

From the results table and the graph of the Ripple Voltage against Capacitance, we can clearly see that as the capacitance increases the ripple voltage decreases. A curve of this sort of nature indicates an inverse proportion relationship, between the two variables V and C, as shown by the equation:

$$V = \frac{I}{Cf}$$

Where we can see that $V \alpha \underline{1}$ provided that I and f remain constant. This can be verified if the graph of $\underline{1}$ against the ripple voltage V takes the form of y=mx i.e. a straight line graph to show direct proportion.

An anomaly has been highlighted on the graph, anomalous results can occur as a result of errors in calculation or measurement. To overcome the occurrences of anomalies several readings should be taken to diminish the possibility of anomalies taking place.

To analyse the graph of ripple voltage against capacitance further, the relationships between the two variables and whether or not the graph shows exponential decay, I have produced two more graphs as measured ripple voltage against calculated ripple voltage and a logarithmic graph.

Calculated ripple voltage

Although we have a measured ripple voltage, the ripple voltage can be calculated using the following equation:

$$V= \frac{I}{Cf}$$

Where:

V=calculated ripple voltage

I= the current taken by the circuit

C=capacitance

f= frequency

We can test the relevance of this equation by working with the units of the equation and the units of the equation of capacitance to see if they balance;

$$C=\frac{Q}{V}$$

Where the unit of capacitance is:

$$CV^{-1}$$

The s.i unit of current is amps, however using the definition of current, the amount of charge that flows past a point when a current of 1A flows for one second, we can denote this as Cs^{-1}. Frequency is defined as the number of oscillations per second and so can be represented as s^{-1}. Voltage remains represented as volts. Substituting the units into the equation of the ripple voltage gives us:

$$V= \frac{Cs^{-1}}{CV^{-1}\ s^{-1}}$$

$$V= \frac{Cs^{-1}}{CV^{-1}\ s^{-1}}$$

$$V=V$$

The units do balance showing that the equation is functional.

Time constant

The time constant is the time it takes for the current, charge or p.d to fall to 1/e of its initial value, which is approximately 37% of the initial value. The time constant can be calculated using this equation: $\tau = RC$, where R is the resistance and C is the capacitance. From, this we can see that with a greater value of capacitance the greater the time constant of the R-C circuit. Also, greater resistance also gives a greater time constant however in my experiment the resistance remains constant at a fixed value of 10kΩ, the relationship between τ and C should be proportional. The diagrams below show how the ripple of a smoothed voltage output and an unsmoothed voltage output varies.

A greater capacitance means that the capacitor can store a larger amount of charge and therefore discharges more slowly, resulting in a greater value for the time taken to discharge. The diagram above of the smoothed voltage indicates how there is a smaller ripple over a greater time. Therefore from this we can conclude that a greater time constant as a result of a larger capacitance, gives a smaller amount of ripple.

Graph 2, showing measured ripple voltage against the calculated ripple voltage was done so that we could compare the both sets of values obtained. The gradient of the graph of the calculated ripple voltage against the measured ripple voltage works out to be:

$$\text{Gradient} = \frac{y_2-y_1}{x_2-x_1}$$

$$=\frac{9.2-2.0}{12.0-2.8}$$

$$=\frac{7.2}{9.2}$$

$$= 0.8$$

As a percentage the gradient, which shows how the two variables differ, is 80%. This shows that the measured ripple voltage in my experiment is about

20% larger than the calculated ripple voltage, indicating either error in the method of calculation or the measurement of the ripple voltage from the trace. The most likely faulty method is measuring the voltage from the trace as it introduces the possibility of both systematic and random errors.
The graph of the calculated ripple voltage against the ripple voltage shows a straight line through the origin, taking the form of $y = mx$, where m is the gradient of the line.

Measured Ripple Voltage (V) (±0.1)/Volts	Calculated ripple voltage: $V= \frac{I}{Cf}$ / Volts
9.2	Cannot divide by zero
1.22	1.200
0.66	0.545
0.3	0.255
0.17	0.120
0.075	0.055
0.0315	0.026
0.015	0.012

From the results table above and the graph of ripple voltage against calculated ripple voltage, we can see that the measured ripple voltage is almost as accurate as the calculated ripple voltage, however a greater amount of precision can be obtained from the calculated ripple voltage than the measured as it does not rely on the human eye to read the ripple voltage from the trace on the CRO, a method which introduces error and lacks accuracy and precision. The gradient of the line shows the amount by which the measured ripple voltage and the calculated ripple voltage differ:

Logarithmic graph

$$V= \frac{I}{Cf}$$

$$\log V = \log \frac{1}{C} \quad \frac{I}{f}$$

$$\log V = \log \frac{I}{f} \quad \log \frac{1}{C}$$

$$\log V = \log \frac{I}{f} \quad \log C^{-1}$$

$$\log V = \log \frac{I}{f} - \log C$$

From this we can expect a straight line graph with a negative gradient equal to -1. logV should be plotted along the y-axis and logC along the x-axis. log I/*f* is the point at which the line should intercept the y-axis.

Capacitance/ μF	Calculated ripple voltage: $V=\frac{I}{Cf}$ / Volts	logV	logC
0	Cannot divide by zero	Cannot take logs	Cannot take logs
10	1.200	0.08	-5
22	0.545	-0.26	-4.66
47	0.255	-0.59	-4.33
100	0.120	-0.92	-4
220	0.055	-1.26	-3.66
470	0.026	-1.59	-3.33
1000	0.012	-1.92	-3

I have produced a log graph of logV against logC to check the linearity of the plotted points. The graph shows a negative correlation= -1.00, with logC decreasing as logV also decreases. I have also measured the gradient of my graph which works out to be:

$$\text{Gradient} = \frac{y_2-y_1}{x_2-x_1}$$

$$=\frac{-0.04- -1.6}{-4.8- -3.3}$$

$$=\frac{1.56}{-1.6}$$

$$= -1.04$$

This is approximately the correct gradient according to the log equation above.
From the graph, the point of interception at the y-axis cannot be read off as the scale used for the axis is would not fit it onto the page. However, by calculation, this works out to be:

$$\log\frac{I}{f}= \log\frac{1.2\text{x}10^{-3}}{100}$$

$$= -4.92$$

Conclusion

The graphs that I have produced give us conclusions as to how the degree of smoothing is affected by the capacitance. I can conclude that with a greater capacitance a higher degree of smoothing can be achieved as there is a greater time constant. The exponential decay graph of the smoothed output voltage against time can be represented by a general equation of the form $x=x_0\ e^{-t/RC}$. The relevant equation of this form for my experiment is:

$$V=V_0\, e^{-\tau/RC}$$

where V= the voltage after a time, τ and V_0 = the initial voltage. During one cycle of the d.c voltage supply, as the voltage increases the capacitor stores the charge and then releases its stored energy when the voltage decreases. However, a greater capacitance will allow more charge to build up and therefore take longer to discharge, resulting in a shallower gradient of the graph and a slower rate of decay as shown in the diagram below:

Graph to show the general shape of a capacitor discharging through a resistor

This shows how as time constant increases, rate of decay decreases i.e. when referring to the charging and discharging of a capacitor, as time constant increases the capacitor discharges more slowly. Therefore, the voltage decreases more slowly, leading to a more "smoothed" ripple voltage.

The accuracy of the equation for the calculated ripple voltage has been tested and its validity tested.

Evaluation

Choosing the most suitable apparatus is vital for this experiment. The apparatus used were:

- An oscilloscope
- An ammeter
- A D.c. power supply
- A range of capacitors of different values of capacitance
- A resistor load
- Leads

One recurring problem was the flashing of the trace displayed on the CRO. In order to overcome this problem, the CRO settings had to be altered by adjusting the hold-off control consequently stabilizing the trace. As this was a recurring problem its significance is great when considering main sources of error. To further reduce the flashing of the trace, photographing the screen so that it is easier to obtain reliable and accurate values is another method I should consider.

The thickness of the line is also essential in the measurement of the ripple voltage from both the peaks and troughs of the curve. The Y-sensitivity on the CRO could be changed so that an enlarged ripple trace would be displayed for greater convenience in measuring the ripple voltage and reducing the significance of errors in reading off the CRO.

The evidence from the results of this experiment I think proves to be quite reliable as several readings were taken in order to cancel out the possibility of anomalous values taking place. However there were some anomalies which are highlighted on the relevant graphs, indicating that there is still room for improvement in the experimental technique. I should consider a wider range of values for the capacitors and resistor. The capacitance could actually be measured for greater accuracy so that calculations of the time constant could be furthermore to a higher degree of accuracy. Based on the gradients of the lines of best fit of the graphs that I have produced, I find that the method of carrying out this experiment is quite reliable as they are as predicted. Nevertheless, firm conclusions cannot be drawn from the evidence because, as mentioned before, there is still room for improvement in minimising errors and occurrences of anomalies as far as possible.

Human errors such as taking readings from the oscilloscope and the ammeter are common errors. Parallax error, where the line of vision did not meet in line with the pointer on the scale is an error that could have occurred. To overcome this error, there are some ammeters designed with a mirror helping to ensure that such errors do not occur which I could have used. Zero errors are also common with ammeters. I should also ensure that the ammeter has been zeroed in order to get fair and reliable results. Zeroing of the ammeter involves making sure that the ammeter is at the point zero between the readings (at each interval).

The mains source will also consume some of the energy as it will have internal resistance. This means that values of the current and voltage would actually be greater than what is shown on the meters.