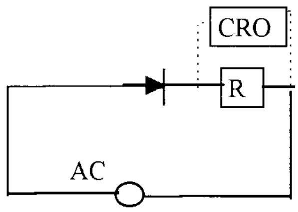
ARTICLE

The Diode:

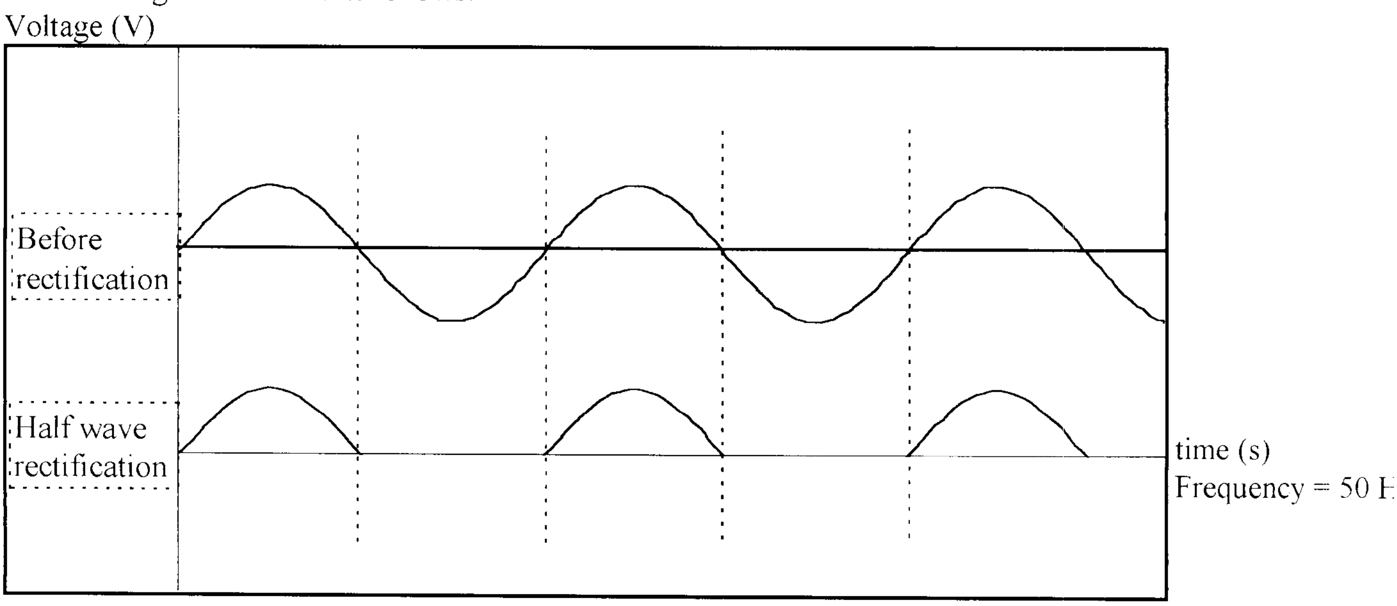
The diode is an electronic device that allows the passage of current in only one direction[1]. The first such consisted of an evacuated glass or steel envelope containing two electrodes—a cathode and an anode. Because electrons can flow in only one direction, from cathode to anode, the diode could be used as a rectifier. The diodes most commonly used in electronic circuits today are semiconductor diodes. The simplest of these is the modern germanium (or silicon) point-contact diode. The wire and a tiny crystal plate are mounted inside a small glass tube and connected to two wires that are fused into the ends of the tube.

Half Wave Rectification:

This circuit is possibly the simplest rectifier circuit and consists of a diode placed in series with an AC supply and the load.
Because the diode permits current flow in one direction only, current flows through the load during alternate half cycles only. The other half cycles are virtually cut off except for a very small leakage current, which can be ignored for all practical purposes.



The diode must be able to withstand this voltage safely for consistent and reliable operation.
The resulting waveform is as follows:

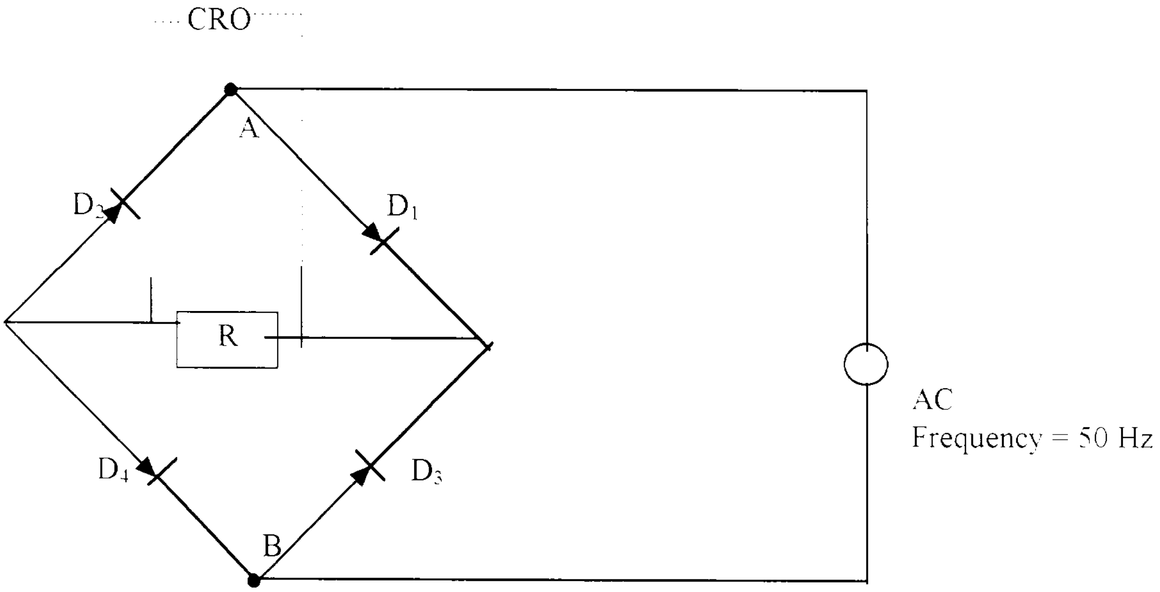


[1] Graf, Rudolf F. and Whalen, George J. The Build-It Book of Electronics Projects. TAB, 1983.

Full Wave Rectification:

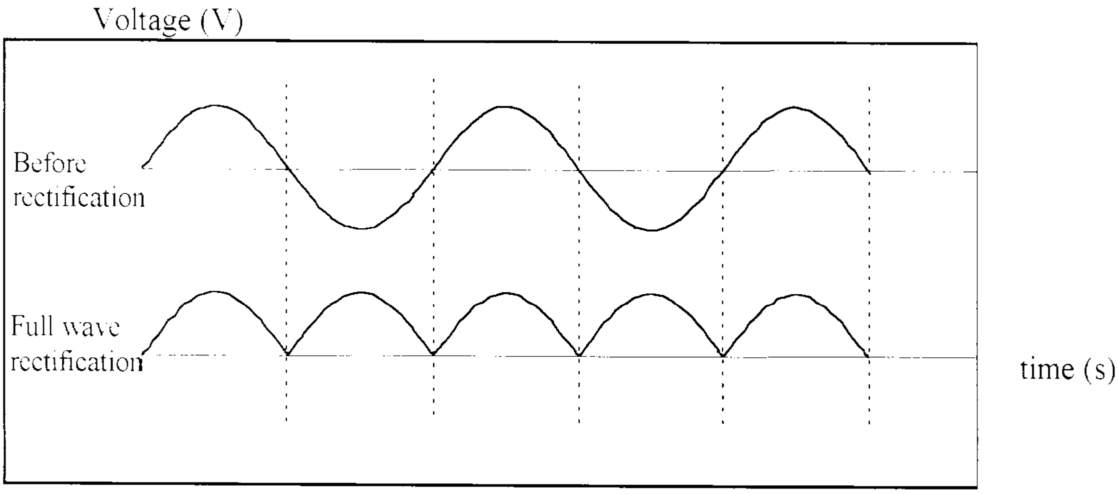
There are two types of circuits able to provide full wave rectification, however, I used the "bridge" type. This circuit ensures that current flows through the load resistance in one direction only during both half-cycles[2]. The full wave rectification doubles the number of current pulses compared to half wave rectification, so the average DC voltage and current are twice as great for the same AC input voltage.

The Full Wave Bridge Circuit:



At the instant when "A" is positive, the current flow is through D_1, the load, and then through D_4, returning to "B". Diodes D_2 and D_3 are biased-off (non-conducting) and have the full AC voltage across them. On the next half-cycle, when "B" is instantaneously positive, the current flow is from "B", through D_3, the load, and D_2 to A. Diodes D_1 and D_4 are biased-off.

The resulting waveform is as follows:



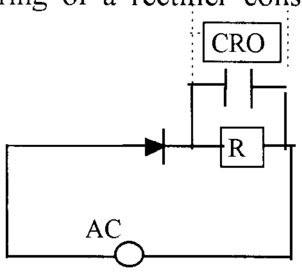
[2] McPartland, J. F., and others, eds. McGraw-Hill's National Electrical Code Handbook. McGraw, 18th ed., 1984.

Smoothing Filters:

The Use Of A Capacitor In A Rectifying Circuit:

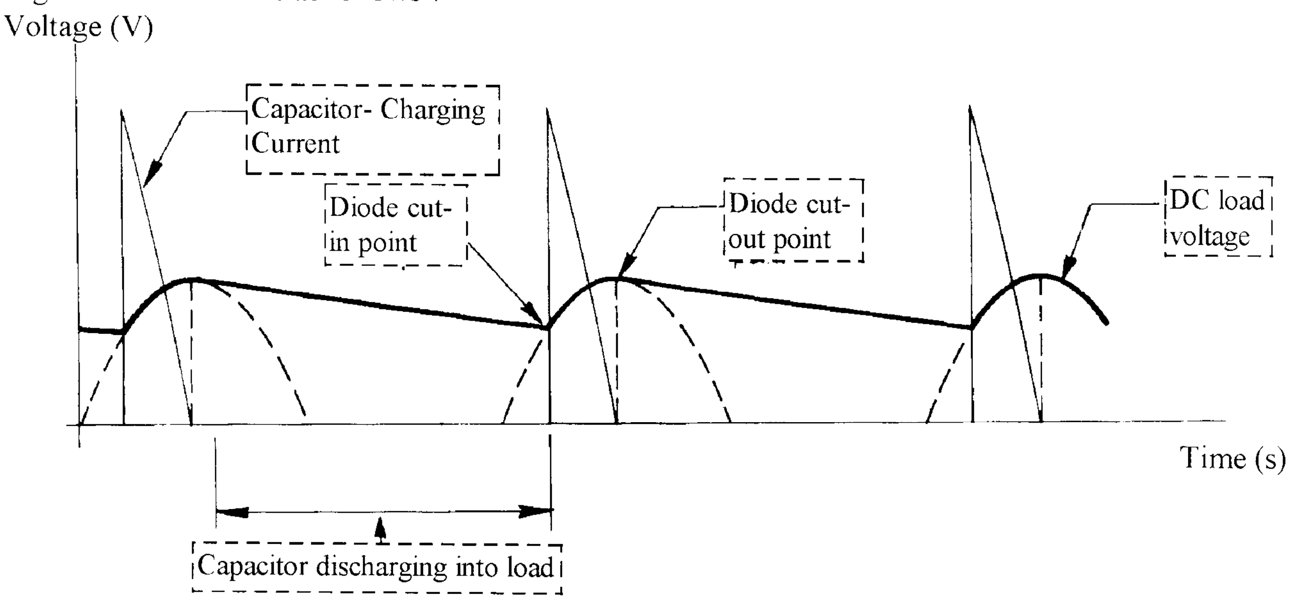
The use of this pulsating output is quite satisfactory for many cases, but there are occasions when smoothing out of these ripples is necessary for satisfactory operation of associated equipment (battery chargers, etc). A smoothing filter is designed to reduce these ripples and produce a comparatively steady DC output voltage.

The simplest circuit for filtering of a rectifier consists of a capacitor placed in parallel with the load as illustrated:



The capacitor stores energy during the conducting period of the diode and delivers this energy to the load during the non-conducting period. In this way the time during which current passes though the load is extended and the ripple considerably reduced. The capacitor commences discharging into the load, and the voltage falls at a rate determined by the load resistance and the size of the capacitor ($t = RC$).

A general waveform is as follows[3]:



Word Count: 481

[3] Pasahow, Edward. Electronics Ready Reference Manual. McGraw, 1985.

Aim:

A special charger is needed for Ni-Cad cells because they have a very low internal resistance, but must be charged at a fairly low current in order to avoid damage. In practice this means that they must be charged from a constant voltage source. The principal aim of this experiment is to create a circuit suitable for use in a battery charger. As explained, I must transform an AC current to DC.

The following introductory experiments will be made to achieve my aim:

1) Use half wave rectification to remove the negative voltage from the circuit and investigate the effects of a capacitor in this circuit.
2) Repeat the first experiment using full wave rectification.
3) Obtain a desired DC voltage and current with the most effective rectification method.

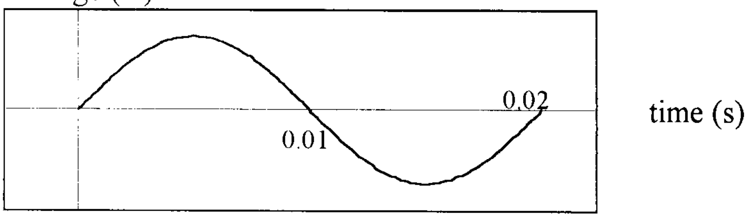
The final experiment will consist of all relevant knowledge obtained during the introductory experiments 1-3 to obtain 7.2 volts DC and 30 mA for use in a battery charger similar to the specifications of a Sanyo.

Introductory Experiments 1-3:

The following three experiments gave me an introduction into electronic circuits before the final experiment.

Experiment 1:

The wave form of a normal AC voltage is:



The specifications of Sanyo battery charger are 7.2 V and 30 mA DC. I desire to transform a normal AC voltage to suit these requirements for use in the battery charger.

To do this, I first constructed a half wave rectifier using a diode, an AC power pack, a cathode ray oscilloscope (CRO), and a resistor.

The input AC power pack (0 - 12 V). This units settings did nor correspond with the AC voltmeter. Occasionally the input voltage was less than the output voltage. This is not possible. The power pack was replaced, and the new one was tested. It worked satisfactorily.

To determine the approximate resistance needed:

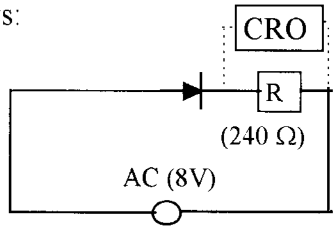
$V = IR$

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

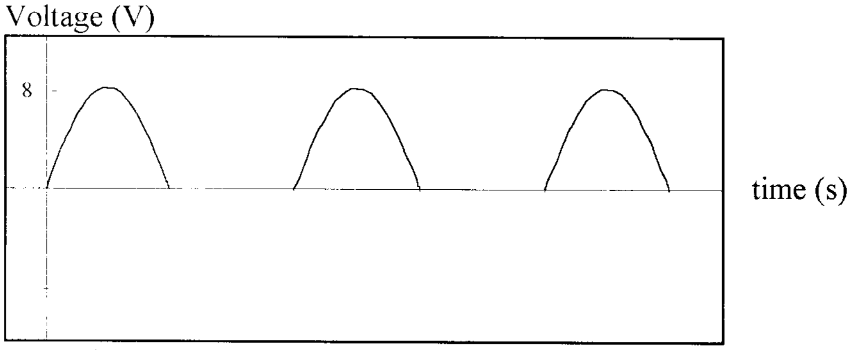
$$= \frac{7.2}{30 \times 10^{-3}}$$

$$= 240\Omega$$

The circuit looks as follows:



The CRO gave the following waveform for the half rectified (DC) voltage:



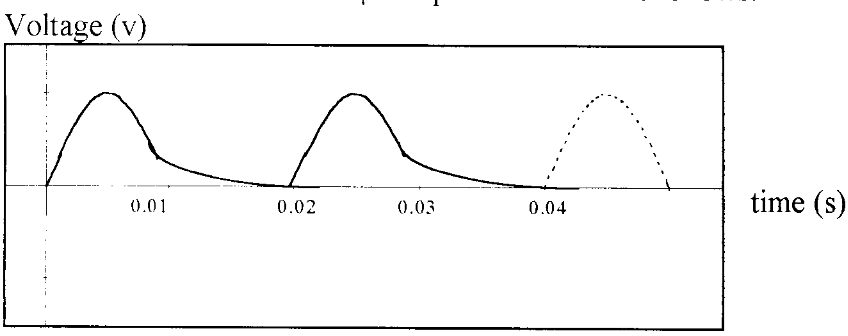
From the CRO, I saw that only the positive AC voltage of the cycle was shown on the screen, hence, the voltage-time graph (above) has no negative voltage.
The now half wave rectified circuit is very unsmooth and gives an inadequate voltage output because it was much less than the desired 7.2 V output., therefore, an insufficient power output. (Power = Voltage × Current).

To modify this experiment I used the theory that the amount of smoothing = Resistance × Capacitance or that time constant (t) = RC.

Because the resistance affects the output voltage and current, I will not change the resistor to improve the smoothing. This will be done by only changing the size of capacitor.
I observed the effect the capacitor had on the waveform viewed on the CRO.

With a 240Ω resistor, the three capacitors I used as a comparison were 3.3 μF (micro Farad), 10 μF and 100 μF capacitors.
The results are as follows:
3.3 μF ⟶ minimal smoothing occurred.
10 μF ⟶ more smoothing occurred than the 3.3 μF capacitor.
100 μF ⟶ more smoothing occurred than the 3.3 μF and 10 μF capacitors.

The waveform with the 100 μF capacitor looked as follows:



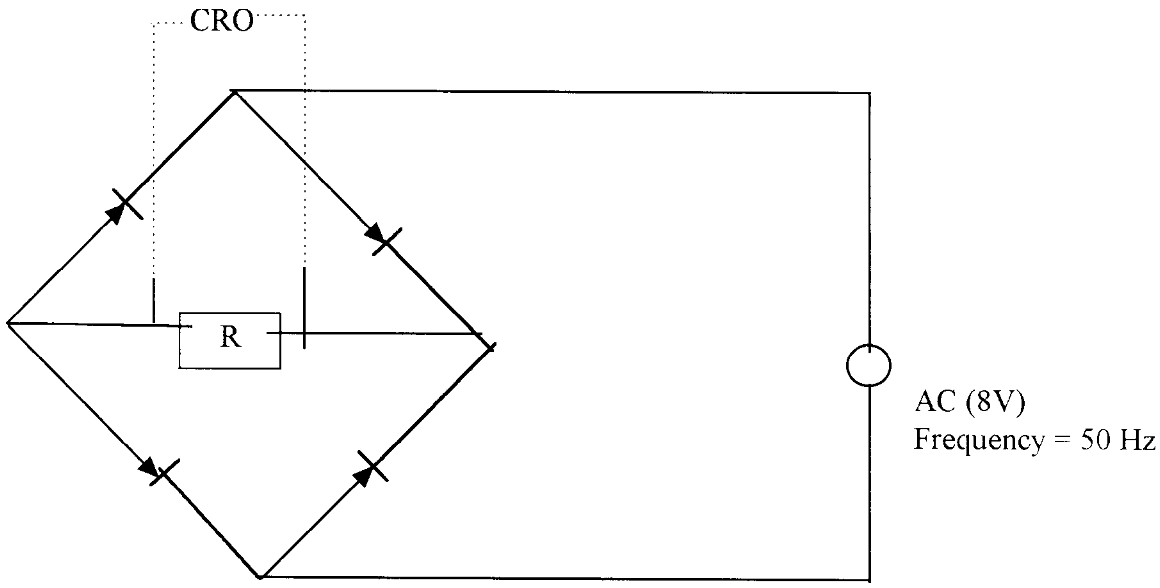
The capacitor placed across the rectified voltage will charge up to the peak voltage and, as the voltage drops will discharge.
The voltage across the output will be higher than otherwise. The lumpy voltage time graph will be smoothed.

In theory, a full wave rectification circuit would give double the average voltage than a half wave rectification circuit (because it has twice as many cycles in a given time). This will be investigated in my next experiment.

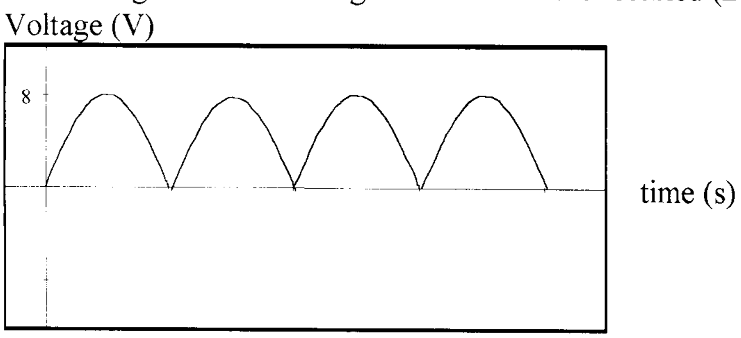
Experiment 2:

I constructed a full wave rectifier using four diodes, a resistor of 240 Ω, an AC power pack and a CRO.

The circuit looks as follows:

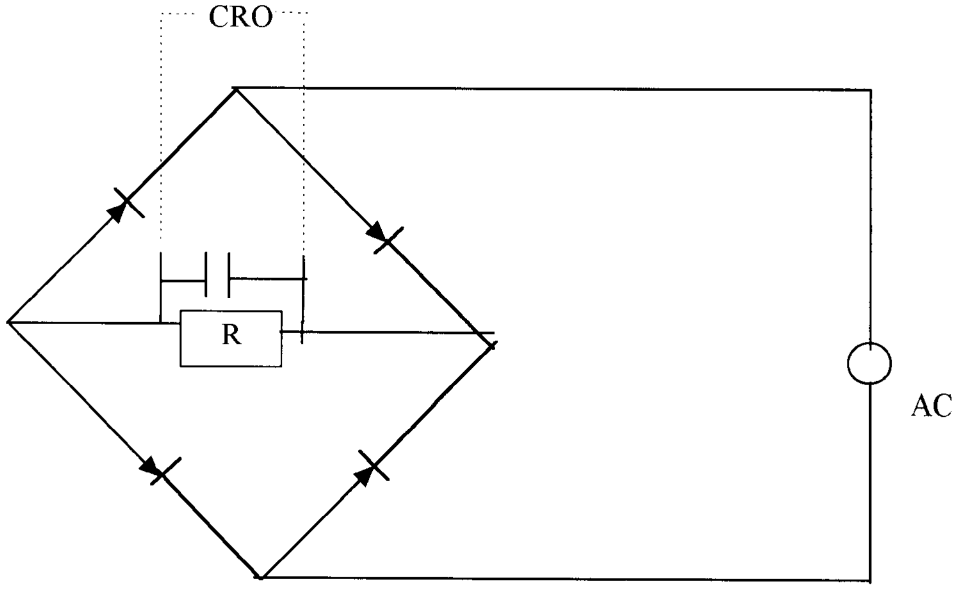


The CRO gave the following waveform for the rectified (DC) voltage:



From the CRO, I saw that not only was the positive AC voltage of the cycle shown on the screen but the original negative voltage was now positive, hence, again the voltage-time graph (above) has no negative voltage, but has twice the average voltage than the half rectified wave form, therefore, double the power. Because t = RC, by keeping the resistance a constant at 240 Ω, I added a capacitor. I observed the effect the capacitor had on the waveform viewed on the CRO.

The circuit looked as follows:



The three capacitors I used as a comparison were 3.3 μF, 10 μF and 100 μF capacitors.
The results are as follows:

3.3 μF ⟶ minimal smoothing occurred. $t = RC = 240 \times 2.2 \times 10^{-6}$
$\mathbf{= 5.28 \times 10^{-4}\ s}$

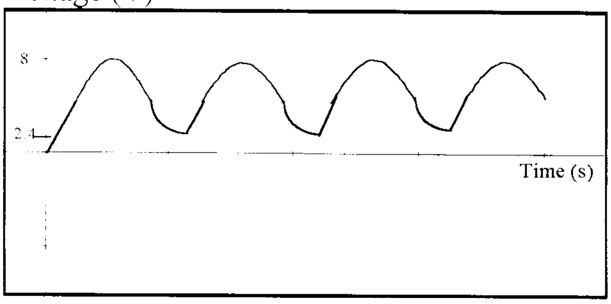
10 μF ⟶ more smoothing occurred than the 3.3 μF capacitor. $t = RC = 240 \times 10 \times 10^{-6}$
$\mathbf{= 2.4 \times 10^{-3}\ s}$

100 μF ⟶ more smoothing occurred than the 3.3 μF and 10 μF capacitors. $t = RC = 240 \times 100 \times 10^{-6}$
$\mathbf{= 0.024\ s}$

Since the "normal" waveform has a time constant of 0.02 seconds, the now fully rectified waveform with a higher time constant of 0.024 seconds is now smoother than the original AC waveform.

The CRO gave the following waveform for the full rectified (DC) voltage with a 100 μF capacitor:

Voltage (V)

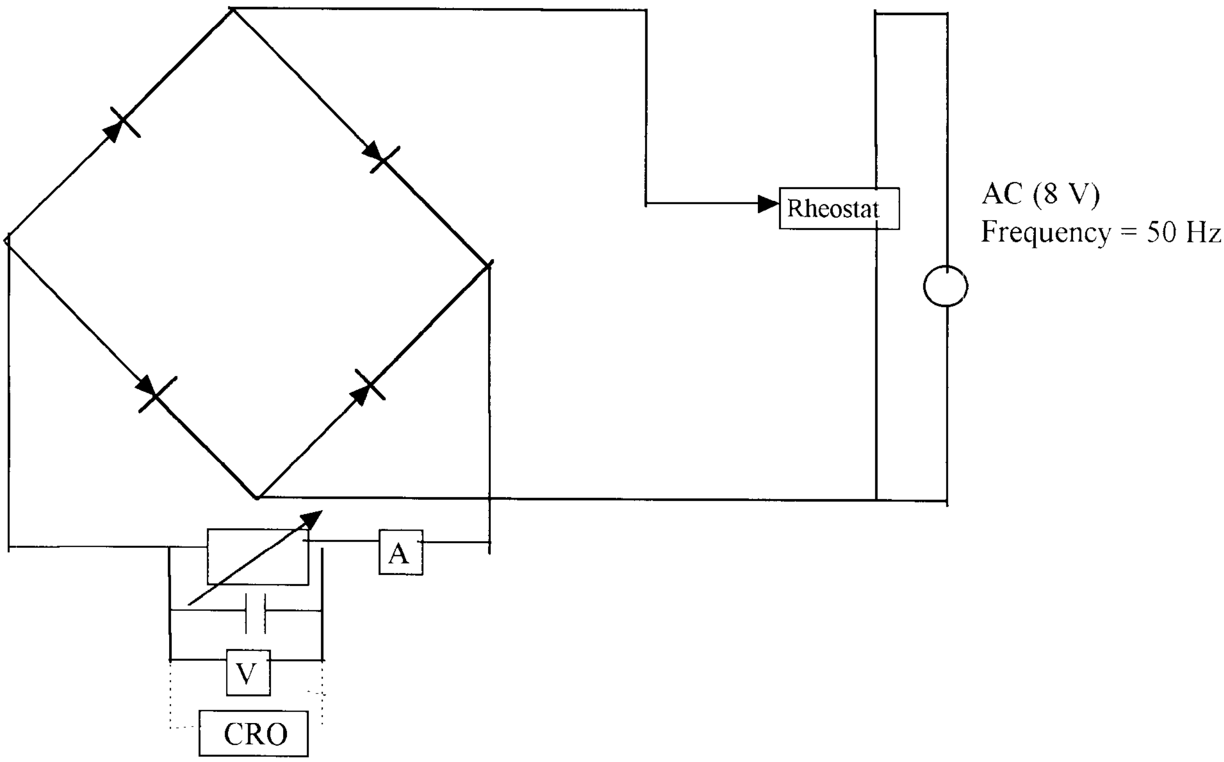


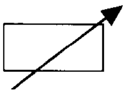
The waveform using full wave rectification is much smoother than the waveform of half wave rectification.

Experiment 3:

After constructing the bridge type apparatus for full wave rectification, I included milliampere and voltage meters to measure the output voltage and current. I also introduced a rheostat to keep the input voltage a constant.

The circuit looks as follows:



Where  is a decade box. This allows me to change the resistance, with a range of 0 Ω to 9999Ω. A rheostat, on the other hand, will be used to keep the input voltage constant.

Now I can determine the effect changing the resistance has on the waveform. This is done systematically by decreasing the resistance by one kilo-ohm and then adjusting the input voltage back to 8 V after each time this is done.

An AC voltmeter was connected to the input voltage to check it.

The table below shows the output voltage and current when using a capacitor of 100 μF:

Resistance (kΩ)	**measured Resistance (kΩ)**	**output Voltage (V)**	**Current (mA)**	**T = RC**	**Waveform**
10	9.73	4.6	0.8	0.001	Some ripple
9	8.82	4.6	0.89	0.0009	More ripple (less smooth)
8	7.86	4.6	0.96	0.0008	More ripple (less smooth)
7	6.89	4.6	1.0	0.0007	More ripple (less smooth)
6	5.93	4.6	1.1	0.0006	More ripple (less smooth)
5	4.97	4.6	1.22	0.0005	More ripple (less smooth)
4	3.98	4.5	1.4	0.0004	More ripple (less smooth)
3	3.03	4.48	1.8	0.0003	More ripple (less smooth)
2	2.03	4.45	2.36	0.0002	More ripple (less smooth)
1	1.02	3.73	4.05	0.0001	More ripple (less smooth)

The voltage range was (4.6-3.73) = 0.87 V. The current range was (4.05-0.8) = 3.25 mA.

The first voltmeter and ammeter had bent needles making it difficult to read the result. These were replaced and the new meters were zeroed.

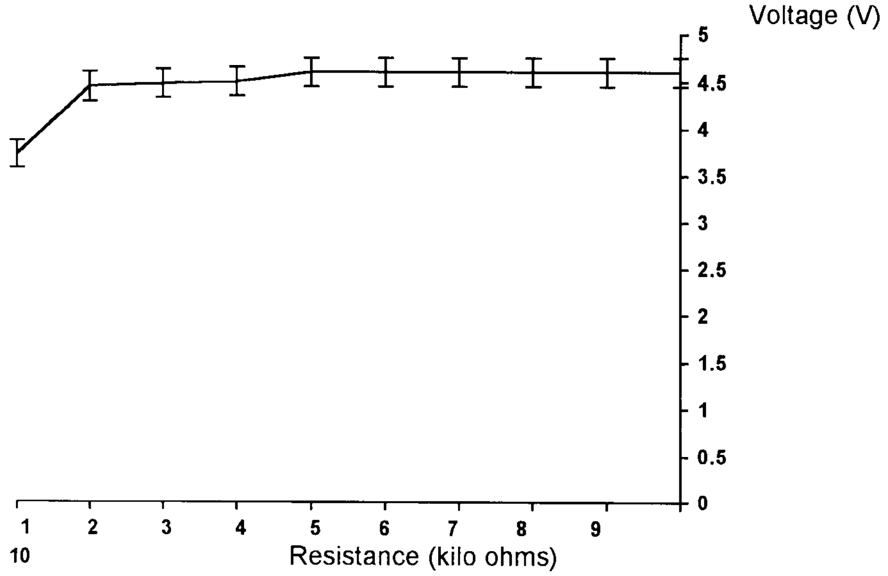
I now must modify this circuit to obtain 7.2 V DC output and 30 mA. This is attempted by introducing a rheostat to vary the input (AC), using a variable load resistor to vary load current and use an appropriate capacitor to smooth the output voltage to give 7.2 V at 30 mA for a particular load resistor.

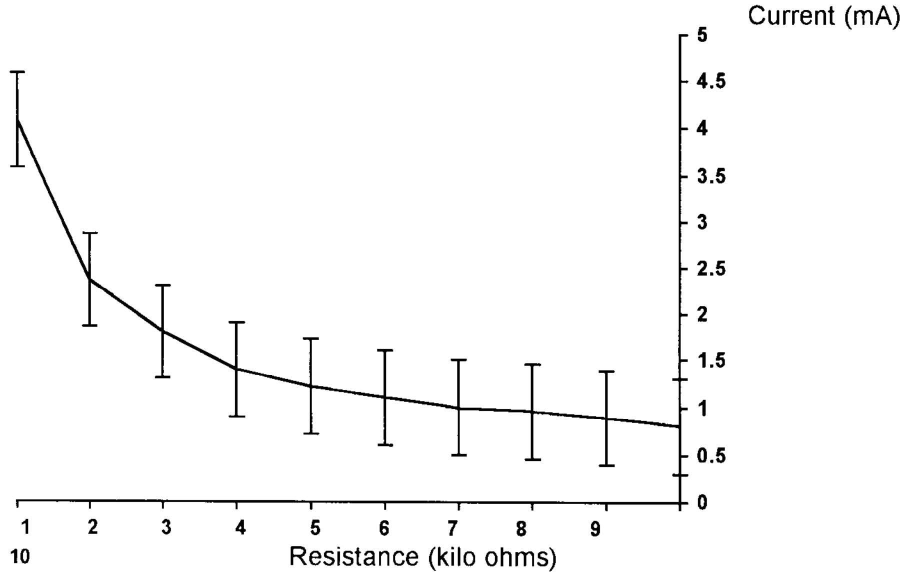
The values for the resistance are accurate to within 1 % because the digital ohm meter was of this accuracy. The current and voltage are accurate to within 1 % of full scale deflection of the meter.

0 - 15 scale voltmeter has an accuracy of ± 0.15 V.

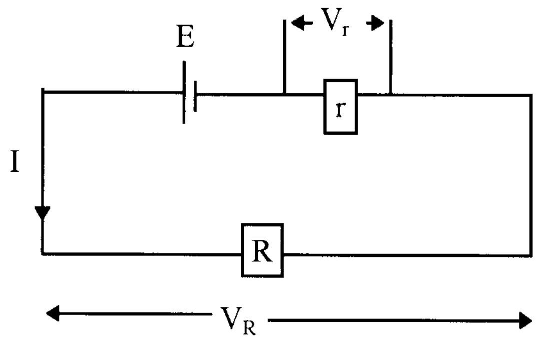
0 - 50 scale milliampere meter has an accuracy of ± 0.5 mA.

The graphs below summarises this table with a fixed input voltage:





As seen in the graphs above, as the resistance decreases, the voltage decreases and the current increases. The power supply generates voltage E (electro-motive force) that has internal resistance r (constant). When a load resistance is connected to the external circuit, there is a potential voltage V_R across the resistance R and a voltage drop V_r across the internal resistance of the power supply.



$E = V_r + V_R$.
$V_R = E - Vr = E - Ir$.
From the last equation we can see that when the current increases in the circuit, the voltage drop on the internal resistance will decrease and the voltage across the external R will decrease.

When the load resistance R increases, the current decreases ($I= \frac{V}{R}$). As a result, the voltage drop across the internal resistance is decreased. The total voltages on each of the components of the circuit always equal to E volts, therefore, the voltage across the resistance R is: E - Ir

I have already proved that the smoothing depends on the capacitance. I have now proven that the output current and voltage depends on the resistance.

Analysis Of Introductory Experiments:

From these experiments I see that I will require a resistance of less than 1 kΩ to obtain a current of 30 mA. As seen in experiment 1, the resistance needed was 240 Ω.
If this is done, the output voltage will drop considerably below the desired 7.2 volts. The only way to over come this problem is to increase the input voltage.

If smoothing depends on resistance and capacitance, and I use a low resistance for a higher current, I will require a larger capacitor of 660 μF (two 330 μF capacitors) to increase the smoothing once again.

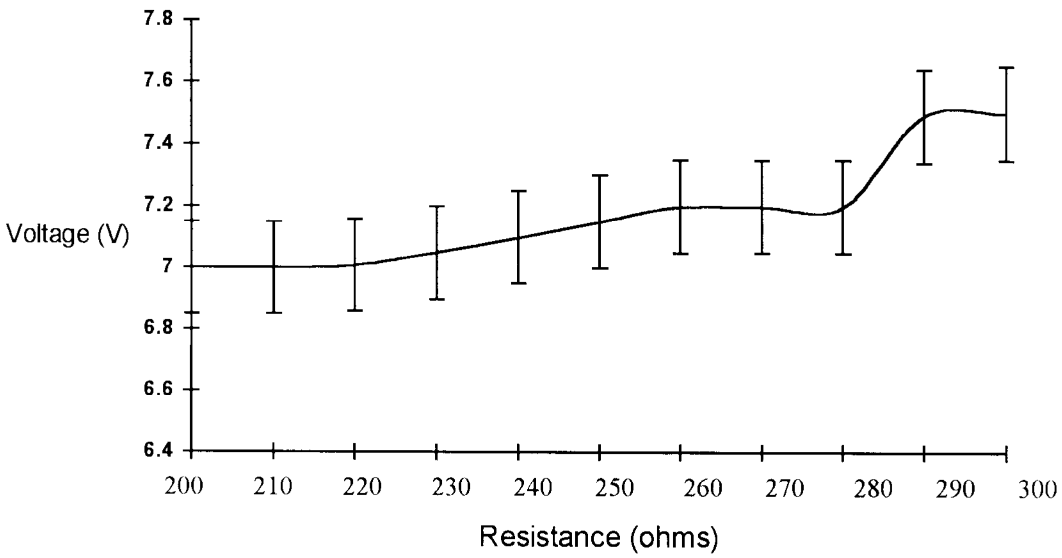
Final Experiment:

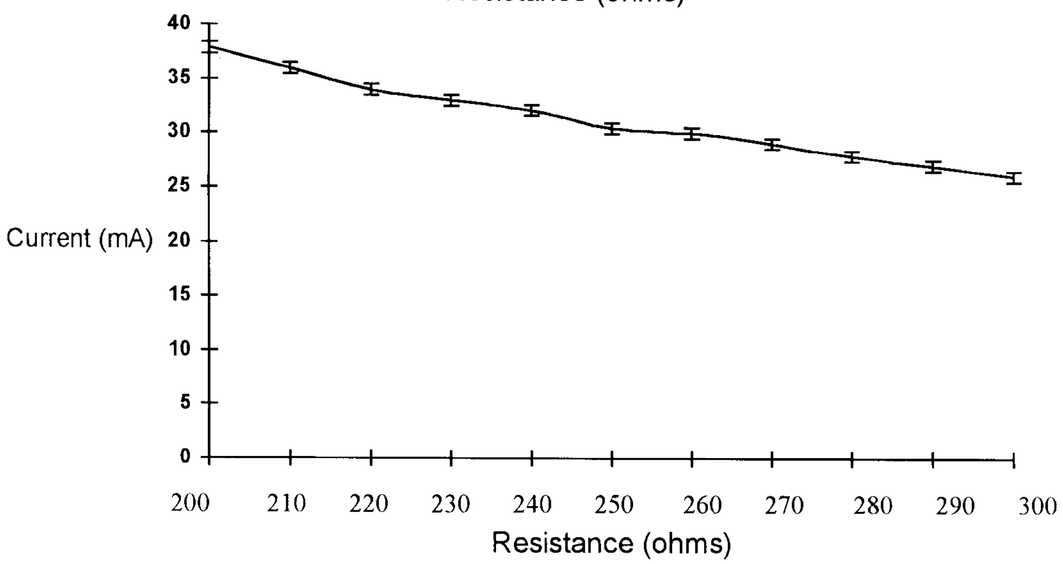
The method of this experiment is similar to that of introductory experiment 3, but I needed to find the exact resistance required. This will be approximately 240 Ω. It will not be exactly 240 Ω because the input voltage and current will be altered by a rheostat.
I was not sure of what resistance to use (between 10Ω and 1000 Ω) so I took a wide range of resistances, cutting it down to between 200 Ω and 300Ω.

The table below summarises this (with nominal resistances):

Resistance (Ω)	**Current (mA)**	**output Voltage (V)**
200	37.9	7.00
210	36	7.00
220	34	7.01
230	33	7.05
240	32.1	7.1
250	30.4	7.15
260	30	7.2
270	29	7.2
280	27.9	7.2
290	27	7.49
300	26	7.5

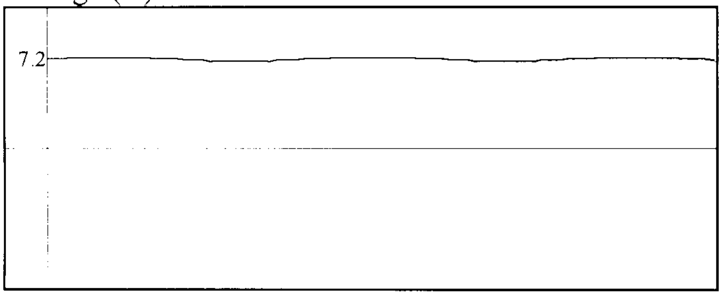
Graphically these look as follows:





As seen in the table, I have reached 7.2 V DC and 30 mA.

Now that this is achieve, the smoothing of the waveform can now be improved using a 660 μF.
The waveform looks as follows:



Discussion:

Difficulties And Equipment:

The equipment gave me quite a lot of trouble while performing these experiments. These are as follows:
A few wires did not give a good contact, these were replaced.
The diodes will have a minimal voltage loss across them (0.7 % maximum), however, this is uncontrollable.
The capacitor will have an uncertainty of ± 5 % (shown with error bars on appropriate graphs). I will have to assume that the voltmeter, ammeter and the rheostat have negligible uncertainties.
Another uncertainty is reading off the meters. This is done by eye and can cause uncertainties of 1 % of the scale. I was very careful not to cause a parallax error.

Summary Of Findings And Conclusion:

To produce 7.2 V and 30 mA DC from AC, I first converted the AC to DC using half wave rectification. This did not produce enough voltage or current, hence, I used full wave rectification.
The waveform after full wave rectification was too unsmooth for use in the battery charger, therefore, I added a capacitor. This smoothed the waveform somewhat but the current and voltage was too low. Reducing the resistance to 260 Ω gave the desired voltage and current but the time constant (R × C) was reduced, therefore I replaced the 100 μF capacitor with two 330 μF capacitors for a total of 660 μF.
The time constant of the waveform is:

$$t = RC$$
$$= 260 \times 660 \times 10^{-6}$$
$$= 0.1716 \text{ sec}$$

This is quite a large time constant considering that the time constant of the original AC wave was 0.02.
This is excellent smoothing and the waveform has a negligible AC component.
This power supply is now suitable for use in a battery charger.

After completing this experiment, I looked at the voltage waveform of the battery charger by wiring the CRO to the battery terminals on the charger. This showed an extremely unsmooth wave, and hence, I can deduce that the charger does not require a very smooth waveform to operate.
After completing the experiment I placed the charger terminals across the CRO and saw an extreemely unsmooth wave, this means that the charger does not require a smooth wave to operate.

Word Count: 1754