Module

1

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Power Supplies

1.0 Power Supply Basics

Parts of a Power Supply

A DC Power Supply Unit (commonly called a PSU) deriving power from the AC mains (line) supply performs a number of tasks:

- 1. It changes (in most cases reduces) the level of supply to a value suitable for driving the load circuit.
- 2. It produces a DC supply from a pure AC wave.
- 3. It prevents any AC from appearing at the supply output.
- 4. It will ensure that the output voltage is kept at a constant level, independent of changes in:
- a. The AC supply voltage at the supply input.
- b. The Load current drawn from the supply output.
- c. Temperature.

To do these things the basic PSU has four main stages, illustrated in Fig. 1.0.1

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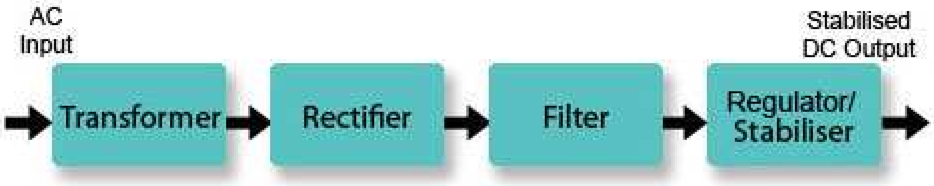

Fig. 1.0.1 Power Supply Block Diagram

Power supplies in recent times have greatly improved in reliability but, because they have to handle considerably higher voltages and currents than any or most of the circuitry they supply, they are often the most susceptible to failure of any part of an electronic system.

Modern power supplies have also increased greatly in their complexity, and can supply very stable output voltages controlled by feedback systems. Many power supply circuits also contain automatic safety circuits to prevent dangerous over voltage or over current situations.

The power modules on Learnabout-electronics therefore introduce many of the techniques used in modern power supplies, the study of which is essential to an understanding of electronic systems.

Warning

Safety Information

If you are considering building or repairing a power supply, especially one that is powered from mains (line) voltages the power supply modules on this site will help you understand how many commonly encountered circuits work. However you must realise that the voltages and currents present in many power supplies are, at best dangerous, and can be present even when the power supply is switched off! At worst, the high voltages present in power supplies can, and from time to time do KILL.

The information provided on this site will not alone, qualify you to work safely on power supplies. You must also have the skills and equipment to work safely, and be fully aware of locally relevant health and safety issues.

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1.1 Transformers and Rectifiers

After studying this section, you should be able to:

Describe the principles of transformers used in basic power supplies.

- Primary and secondary voltages.
- Isolation.

Describe the principles of rectification used in basic power supplies.

- Half Wave.
- Full Wave.
- Bridge.

The Transformer

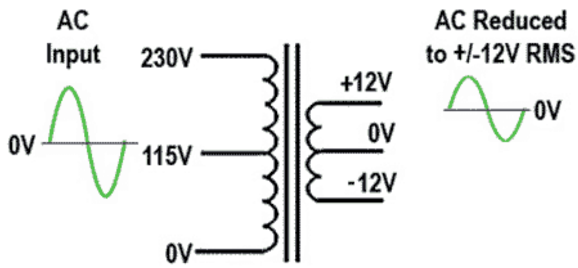

Fig. 1.1.1 Typical Input Transformer

In a basic power supply the input power transformer has its primary winding connected to the mains (line) supply. A secondary winding, electro-magnetically coupled but electrically isolated from the primary is used to obtain an AC voltage of suitable amplitude, and after further processing by the PSU, to drive the electronics circuit it is to supply.

The transformer stage must be able to supply the current needed. If too small a transformer is used, it is likely that the power supply's ability to maintain full output voltage at full output current will be impaired. With too small a transformer, the losses will increase dramatically as full load is placed on the transformer.

As the transformer is likely to be the most costly item in the power supply unit, careful consideration must be given to balancing cost with likely current requirement. There may also be a need for safety devices such as thermal fuses to disconnect the transformer if overheating occurs, and electrical isolation between primary and secondary windings, for electrical safety.

The Rectifier Stage

Three types of silicon diode rectifier circuit may be used, each having a different action in the way that the AC input is converted to DC. These differences are illustrated in Figs. 1.1.2 to 1.1.6

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Half Wave Rectification

A single silicon diode may be used to obtain a DC voltage from the AC input as shown in Fig 1.1.2. This system is cheap but is only suitable for fairly non-demanding uses. The DC voltage produced by the single diode is less than with the other systems, limiting the efficiency of the power supply, and the amount of AC ripple left on the DC supply is generally greater.

The half wave rectifier conducts on only half of each cycle of the AC input wave, effectively blocking the other half cycle, leaving the output wave shown in Fig. 1.1.2. As the average DC value of one half cycle of a sine wave is 0.637 of the peak value, the average DC value of the whole cycle after half wave rectification will be 0.637 divided by 2, because the average value of every alternate half cycle where the diode does not conduct, will of course be zero. This gives an output of:

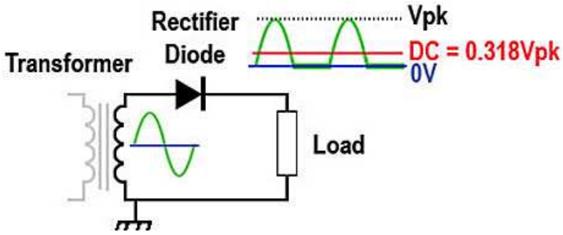

Fig. 1.1.2 Half Wave Rectification

Vpk x 0.318

This figure is approximate, as the amplitude of the half cycles for which the diode conducts will also be reduced by about 0.6V due to the forward voltage drop (the depletion layer p.d.) of the silicon rectifier diode. This additional voltage drop may be insignificant when large voltages are rectified, but in low voltage power supplies where the AC from the secondary winding of the mains transformer may be only a few volts, this 0.6V drop across the diode junction may have to be compensated for, by having a slightly higher transformer secondary voltage.

Half wave rectification is not very efficient at producing DC from a 50Hz or 60Hz AC input. In addition the gaps between the 50 or 60Hz diode output pulses make it more difficult to remove the AC ripple remaining after rectification.

Full Wave Rectification

If a transformer with a centre tapped secondary winding is used, more efficient full wave rectification can be used. The centre-tapped secondary produces two anti-phase outputs, as shown in Fig 1.1.3.

If each of these outputs is ‘half wave rectified’ by one of the two diodes, with each diode conducting on alternate half cycles, two pulses of current occur at every cycle, instead of once per cycle in half wave rectification. The output frequency of the full wave rectifier is therefore twice the input frequency. This effectively provides twice the output voltage of the half wave circuit, Vpk x 0.637 instead of Vpk x 0.318 as the ‘missing’ half cycle is now rectified, reducing the power wasted in the half wave circuit. The higher output frequency also makes the smoothing of any remaining AC ripple easier.

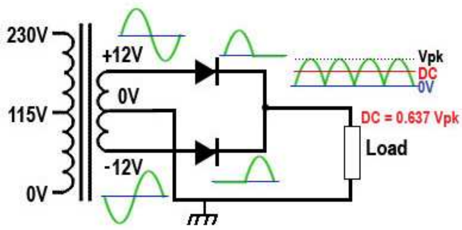

Fig. 1.1.3 Full Wave Rectification

Although this full wave design is more efficient than the half wave, it requires a centre tapped (and therefore more expensive) transformer.

The Bridge Rectifier

The full wave bridge rectifier uses four diodes arranged in a bridge circuit as shown in Fig. 1.1.4 to give full wave rectification without the need for a centre-tapped transformer. An additional advantage is that, as two diodes (effectively in series) are conducting at any one time, the diodes need only half the reverse breakdown voltage capability of diodes used for half and conventional full wave rectification. The bridge rectifier can be built from separate diodes or a combined bridge rectifier can be used.

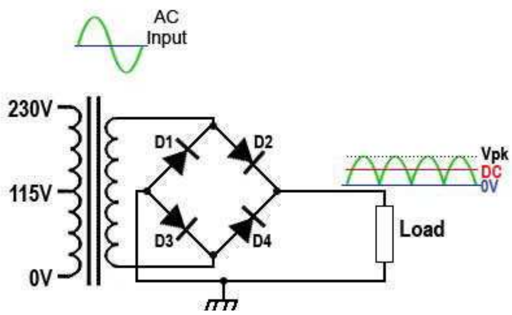

Fig. 1.1.4 The Bridge Rectifier

The current paths on positive and negative half cycles of the input wave are shown in Fig. 1.1.5 and Fig. 1.1.6. It can be seen that on each half cycle, opposite pairs of diodes conduct, but the current through the load remains in the same polarity for both half cycles.

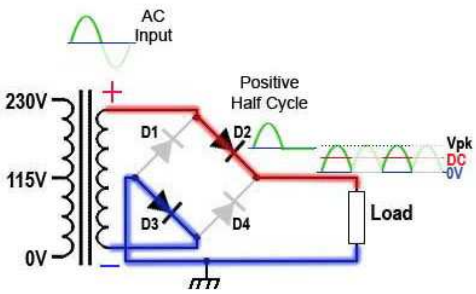

Fig. 1.1.5 Current Flow on the Positive Half Cycle

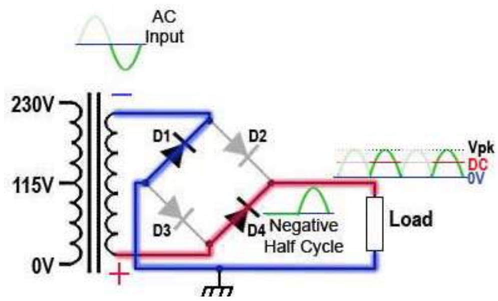

Fig. 1.1.6 Current Flow on the Negative Half Cycle

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1.2 Filter Circuits

What you'll learn in Module 1.2

After studying this section, you should be able to:

Describe the principles of a reservoir capacitor in basic power supplies.

- Reservoir capacitor action.
- The effect of a reservoir capacitor on the DC component.
- The effect of a reservoir capacitor on the diode current.

Describe the principles of a low pass filter used in basic power supplies.

- LC filters.
- RC filters.

Filter Components

A typical power supply filter circuit can be best understood by dividing the circuit into two parts, the reservoir capacitor and the low pass filter. Each of these parts contributes to removing the remaining AC pulses, but in different ways.

The Reservoir Capacitor

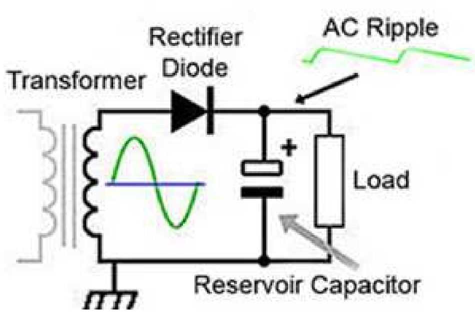

Fig. 1.2.1 The Reservoir Capacitor

Fig. 1.2.1 shows an electrolytic capacitor used as a reservoir capacitor, so called because it acts as a temporary storage for the power supply output current. The rectifier diode supplies current to charge a reservoir capacitor on each cycle of the input wave. The reservoir capacitor is a large electrolytic, usually of several hundred or even a thousand or more microfarads, especially in mains frequency PSUs. This very large value of capacitance is required because the reservoir capacitor, when charged, must provide enough DC to maintain a steady PSU output in the absence of an input current; i.e. during the gaps between the positive half cycles when the rectifier is not conducting.

The action of the reservoir capacitor on a half wave rectified sine wave is shown in Fig. 1.2.2. During each cycle, the rectifier anode AC voltage increases towards Vpk. At some point close to Vpk the anode voltage exceeds the cathode voltage, the rectifier conducts and a pulse of current flows, charging the reservoir capacitor to the value of Vpk.

Once the input wave passes Vpk the rectifier anode falls below the capacitor voltage, the rectifier becomes reverse biased and conduction stops. The load circuit is now supplied by the reservoir capacitor alone (hence the need for a large capacitor).

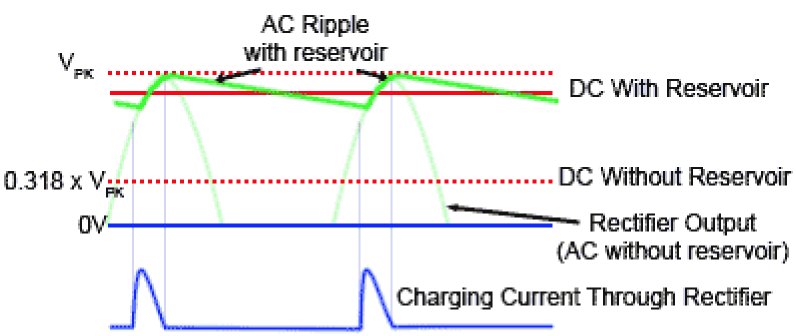

Fig. 1.2.2 Reservoir Capacitor Action

Of course, even though the reservoir capacitor has large value, it discharges as it supplies the load, and its voltage falls, but not by very much. At some point during the next cycle of the mains input,

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the rectifier input voltage rises above the vo1tage on the partly discharged capacitor and the reservoir is re-charged to the peak value Vpk again.

AC Ripple

The amount by which the reservoir capacitor discharges on each half cycle is determined by the current drawn by the load. The higher the load current, the more the discharge, but provided that the current drawn is not excessive, the amount of the AC present in the output is much reduced. Typically the peak-to-peak amplitude of the remaining AC (called ripple as the AC waves are now much reduced) would be no more than 10% of the DC output voltage.

The DC output of the rectifier, without the reservoir capacitor, is either 0.637 Vpk for full wave rectifiers, or 0.317 Vpk for half wave. Adding the capacitor increases the DC level of the output wave to nearly the peak value of the input wave, as can be seen from Fig. 1.1.9.

To obtain the least AC ripple and the highest DC level it would seem sensible to use the largest reservoir capacitor possible. There is a snag however. The capacitor supplies the load current for most of the time (when the diode is not conducting). This current partly discharges the capacitor, so all of the energy used by the load during most of the cycle must be made up in the very short remaining time during which the diode conducts in each cycle.

The formula relating charge, time and current states that:

$$Q = It$$

The charge (Q) on a capacitor depends on the amount of current (I) flowing for a time (t).

Therefore the shorter the charging time, the larger current the diode must supply to charge it. If the capacitor is very large, its voltage will hardly fall at all between charging pulses; this will produce a very small amount of ripple, but require very short pulses of much higher current to charge the reservoir capacitor. Both the input transformer and the rectifier diodes must be capable of supplying this current. This means using a higher current rating for the diodes and the transformer than would be necessary with a smaller reservoir capacitor.

There is an advantage therefore in reducing the value of the reservoir capacitor, thereby allowing an increase in the ripple present, but this can be effectively removed by using a low pass filter and regulator stages between the reservoir capacitor and the load.

This effect of increasing reservoir size on diode and transformer current should be born in mind during any servicing operations; replacing the reservoir capacitor with a larger value than in the original design "to reduce mains hum" may seem like a good idea, but could risk damaging the rectifier diode and/or the transformer.

With full wave rectification the performance of the reservoir capacitor in removing AC ripple is significantly better than with half wave, for the same size of reservoir capacitor, the ripple is about half the amplitude of that in half wave supplies, because in full wave circuits, discharge periods are shorter with the reservoir capacitor being recharged at twice the frequency of the half wave design.

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Low Pass Filters

Although a useable power supply can be made using only a reservoir capacitor to remove AC ripple, it is usually necessary to also include a low pass filter and/or a regulator stage after the reservoir capacitor to remove any remaining AC ripple and improve the stabilisation of the DC output voltage under variable load conditions.

Either LC or RC low pass filters can be used to remove the ripple remaining after the reservoir capacitor. The LC filter shown in Fig. 1.2.3 is more efficient and gives better results than the RC filter shown in Fig. 1.2.4 but for basic power supplies, LC designs are less popular than RC, as the inductors needed for the filter to work efficiently at 50 to 120Hz need to be large and expensive laminated or toroidal core types. However modern designs using switch mode supplies, where any AC ripple is at much higher frequencies, much smaller ferrite core inductors can be used.

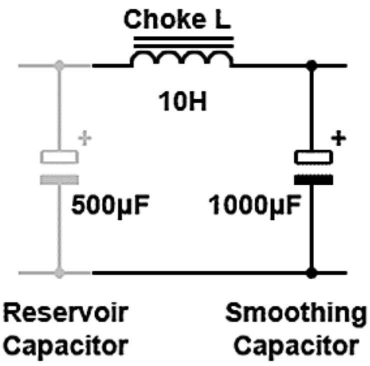

Fig. 1.2.3 LC Filter

The low pass filter passes low frequency, in this case DC (0Hz) and blocks higher frequencies, whether 50Hz or 120Hz in basic circuits or tens of kHz in switch mode designs.

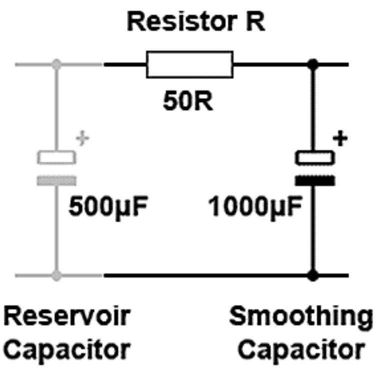

Fig. 1.2.4 RC Filter

The reactance (X_C) of the capacitor in the either of the filters is very low compared with the resistance of resistor R or the reactance of the choke X_L at the ripple frequency. In RC designs the resistance of R must be a fairly low value as the entire load current, maybe several amperes, must pass through it, generating a considerable amount of heat. A typical value would therefore be 50 ohms or less, and even at this value, a large wire wound resistor would normally need to be used. This limits the efficiency of the filter as the ratio between the resistance of R and the capacitor reactance will not be greater than about 25:1. This then would be the typical reduction ratio of the ripple amplitude. By including the low pass filter some voltage is lost across the resistor, but this disadvantage is offset by the better ripple performance than by using the reservoir capacitor alone.

The LC filter performs much better than the RC filter because it is possible to make the ratio between X_C and X_L much bigger than the ratio between X_C and R. Typically the ratio in a LC filter could be 1:4000 giving much better ripple rejection than the RC filter. Also, since the DC resistance of the inductor in the LC filter is much less than the resistance of R in the RC filter, the problem of heat being generated by the large DC current is very much reduced in LC filters.

With a combined reservoir capacitor and low pass filter it is possible to remove 95% or more of the AC ripple and obtain an output voltage of about the peak voltage of the input wave. A simple power supply consisting of only transformer, rectifier, reservoir and low pass filter however, does have some drawbacks.

The output voltage of the PSU tends to fall as more current is drawn from the output. This is due to:

a. The reservoir capacitor being discharged more on each cycle.

b. Greater voltage drop across the resistor or choke in the low pass filter as current increases.

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These problems can be largely overcome by including a regulator stage at the power supply output as described in Power Supplies Module 2.

The basic power supply circuits described here in Module 1 however, are commonly used in the common ‘wall wart’ type DC adaptors supplied with many electronics products. The most common versions comprise a transformer, bridge rectifier and sometimes a reservoir capacitor. Additional filtering and regulation/stabilisation being usually performed in the circuit supplied by the adaptor.

Fig. 1.2.5 DC Adaptor

How the output of a basic power supply may be improved by Regulation Circuits is explained in Power Supplies Module 2

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1.3 Power Supply Basics Quiz

Try our quiz, based on the information you can find here in Power Supplies Module 1. Check your answers at http://www.learnabout-electronics.org/PSU/psu13.php and see how many you get right. If you get any answers wrong. Just follow the hints to find the right answer and learn about Power Supplies as you go.

1.

Refer to Fig 1.3.1. What is the function of block B?

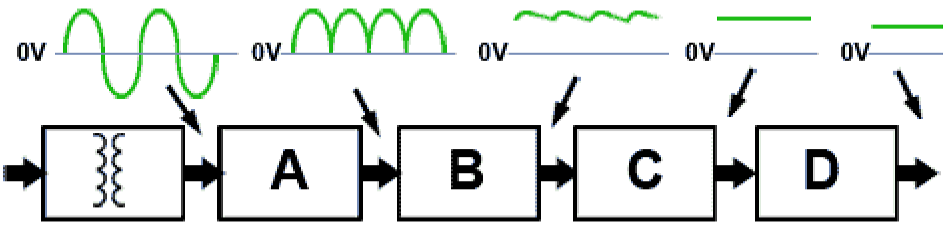

Fig 1.3.1

a) Rectifier.

b) Reservoir capacitor.

c) Low pass filter.

d) Regulator.

2.

Refer to Fig 1.3.1. What is the function of block A?

a) Transformer.

b) Full wave rectifier.

c) Bridge rectifier.

d) Reservoir capacitor.

3.

Refer to Fig 1.3.1. What will be the approximate value of the DC component of the waveform at the output of block A?

a) V_{PK} x 0.318

b) V_{PK} x 0.5

c) V_{PK} x 0.637

d) V_{PK} x 0.707

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4.

Refer to Fig 1.3.2. If input B is more positive than input A, which diodes will be conducting?

a) D1 and D2.

b) D2 and D3

c) D1 and D4

d) D3 and D4

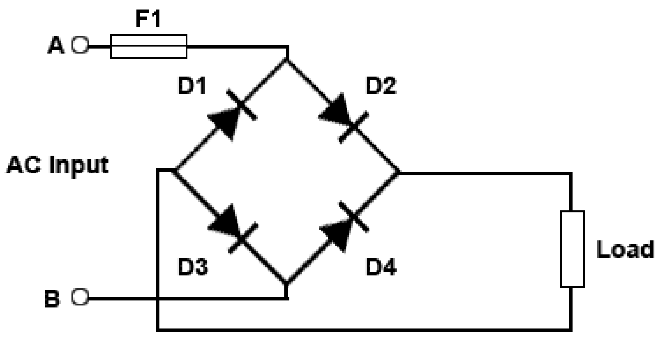

Fig. 1.3.2

5.

Refer to Fig 1.3.2. If D4 were to go short circuit, what would be the effect on the operation of the circuit?

a) A decrease in the current through D1.

b) Fuse F1 would blow.

c) A higher voltage across the load.

d) A larger peak current through D2 and D3.

6.

What is the action of the reservoir capacitor in a basic power supply circuit?

a) To de-couple the DC component of the rectifier AC output.

b) To Increase the DC component and reduce the AC component of the AC wave.

c) To remove the DC component of the AC wave.

d) To regulate the AC wave.

7.

Which of the following is an advantage of using a LC low pass filter rather than a RC low pass filter in a power supply?

a) The reactance of L will be much lower than the resistance of R at mains frequency

b) The reactance of L will be much higher than the resistance of R at mains frequency.

c) An inductor can dissipate more power than a resistor.

d) LC filters are less expensive than RC filters.

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8.

Refer to Fig 1.3.3. What is the power dissipated in R1?

a) 5W

b) 2W

c) 500mW

d) 50mW

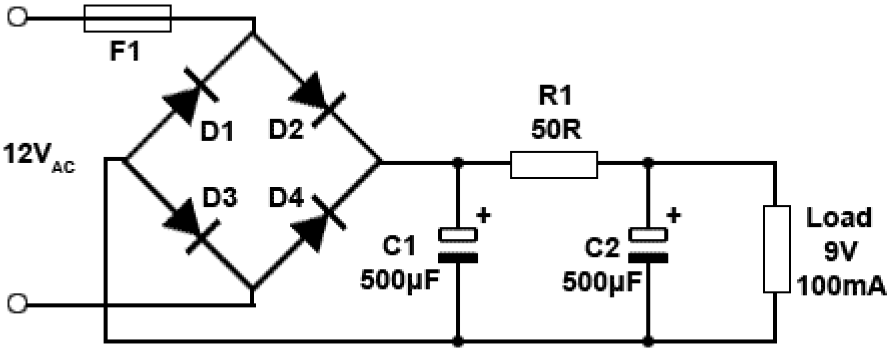

Fig. 1.3.3

9.

Refer to Fig 1.3.3. What will be the approximate value of DC across C1?

a) 3.8V

b) 7.6V

c) 10.8V

d) 14.5V

10.

Refer to Fig 1.3.3. What is the reactance of C2 at the ripple frequency?

a) 6.4Ω

b) 0.3Ω

c) 5.1Ω

d) 3.2Ω

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