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ABSTRACT

The final module emphasizes utilizing the information learned in modules 1-14 to analyze and evaluate the power supply constructed in Module 0. The module contains the following narrative--power supply evaluation; experiment 1--resistance analysis of the half-wave and semiconductor power supply; experiment 2--voltage analysis of the half-wave and semiconductor power supply; experiment 3--current analysis of the half-wave and semiconductor power supply; and experiment 4--waveform analysis of the half-wave and semiconductor power supply. Each lesson consists of an overview, a list of study resources, lesson narratives, programed instructional materials, and lesson summaries. (Author/BP)

NAVPERS 94558-15a

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE FIFTEEN
SPECIAL TOPICS

Study Booklet

BUREAU OF NAVAL PERSONNEL

January 1972

OVERVIEW

MODULE FIFTEEN

Special Topics

In this module you will utilize the information you learned in Modules 1 through 14 to analyze and evaluate the Power Supply you constructed in Module 0.

For you to more easily complete the above, this module contains the following:

Narrative	Power Supply Evaluation
Experiment 1	Resistance Analysis of the Half-wave Semiconductor Power Supply
Experiment 2	Voltage Analysis of the Half-wave Semiconductor Power Supply
Experiment 3	Current Analysis of the Half-wave Semiconductor Power Supply
Experiment 4	Waveform Analysis of the Half-wave Semiconductor Power Supply

TURN TO THE FOLLOWING PAGE AND BEGIN.

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BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

M O D U L E F I F T E E N

<u>Power Supply Evaluation</u>

Study Booklet

Bureau of Naval Personnel

January 1972

LIST OF STUDY RESOURCES

Power Supply Evaluation

To learn the material in this lesson you will require the following:

STUDY BOOKLET:

Lesson Narrative

ENRICHMENT MATERIAL:

NAVPERS 93400A-2 "Power Supplies and Amplifiers." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C. U.S. Government Printing Office, 1965.

EXPERIMENT MATERIALS:

Power Supply

Multimeter

Oscilloscope

Test Leads

PROCEDE TO THE FOLLOWING PAGE AND CONTINUE WITH THE NARRATIVE.

NARRATIVE

Power Supply Evaluation

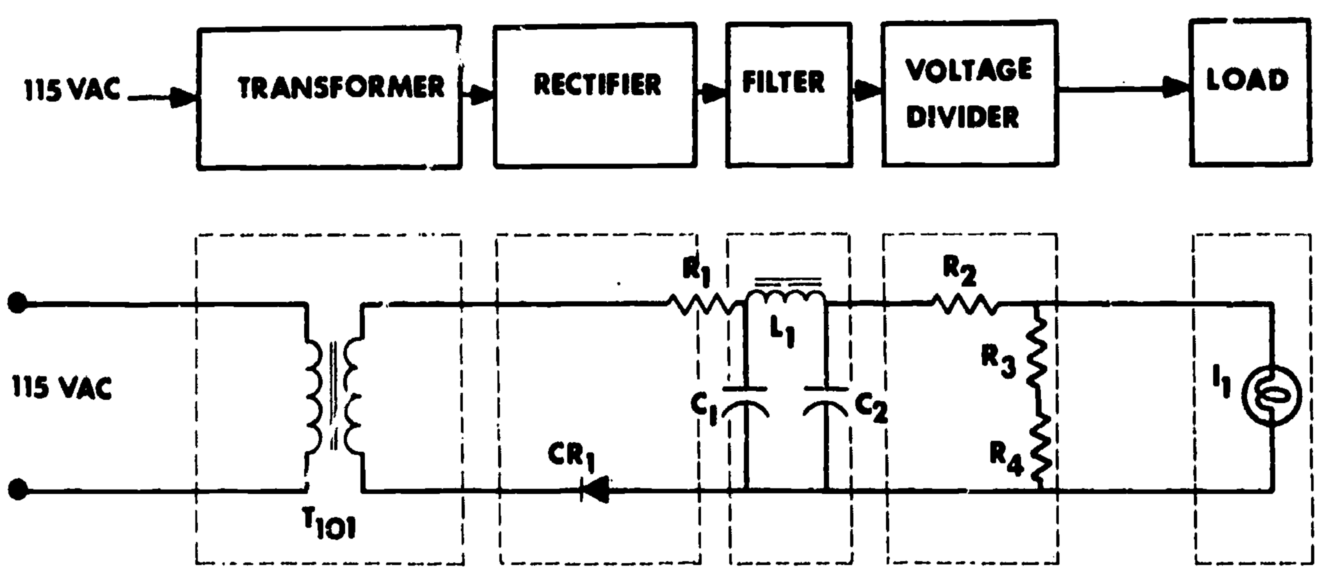
When you completed construction of your power supply in Module-0, you were asked:

> "...what is the purpose of all those components, how do they work, what is their function, what are they called and are they really necessary? In short, what do you know about what you have just completed building?"

At that time you weren't expected to be able to answer all those questions, but now that you have completed the instructional portion of the course you possess the necessary knowledge to explain the operation of your power supply and how it converts the 115VAC from the wall outlet to DC voltage to light the lamp.

Later in this module, utilizing the oscilloscope and multimeter, we will proceed through the power supply and determine the function and operation of the various components. However, before we start the experiment let's first analyze a basic power supply in terms of a block diagram, its five basic parts, and the operation of each part.

BLOCK DIAGRAM:



RECTIFICATION

The transmission of electrical energy over great distances was made economical through the use of alternating current. Alternating current can be transmitted over great distances with a minimum of power dissipation within the transmission line.

Most electron tubes and many other electrical devices require a steady source of dc voltage. This voltage may be provided by a dc generator or by changing ac to dc. The process of changing ac to dc is called RECTIFICATION. The devices used to accomplish rectification are called RECTIFIERS.

The Process of Rectification

Since a semiconductor diode will pass current in only one direction, it is ideally suited for converting alternating current to direct current. When a sine wave is applied across a diode the polarity across the diode during one alternation will be such that the anode is positive in respect to the cathode and the diode will conduct. However, during the next alternation, the anode will become negative in respect to the cathode and no circuit current will flow. Therefore you can see that a diode will conduct only during one alternation for each cycle of input voltage.

Figure #1 shows a diode connected across the 120 volt ac line. During the positive alternation of source voltage, the sine wave applied to the diode makes the anode positive with respect to the cathode. Since this polarity of anode voltage causes the diode to conduct, a current will flow in the circuit. Current will flow from the negative supply lead, through the ammeter and diode to the positive supply lead. This current will exist during the entire period of time that the anode is positive with respect to the cathode, or for the first 180° of the input sine wave.

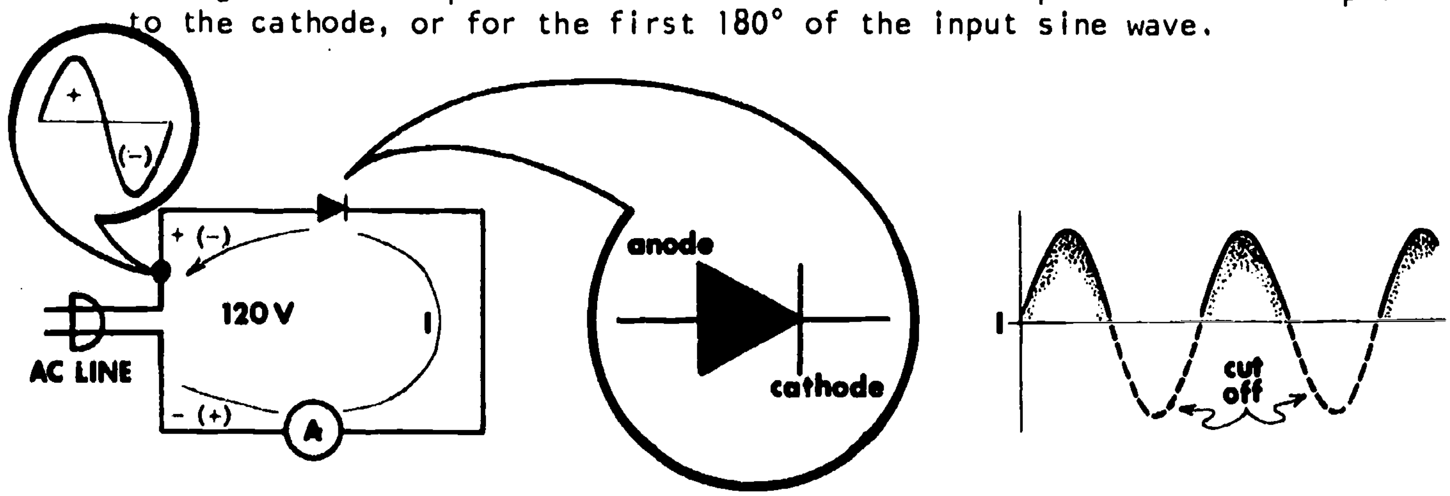


Figure #1 - Simple Diode Rectifier

During the negative alternation of anode voltage the anode is driven negative in respect to the cathode and the diode cannot conduct. When conditions are such that the diode cannot conduct, the diode is said to be CUT-OFF. The diode will be cut-off and no current will flow in the circuit during the entire negative alternation.

For each cycle of input voltage the diode will conduct for 180° and will be cut-off for the remaining 180°. The circuit current will therefore have the appearance of a series of positive half cycles (shown shaded). Notice that although the current is in the form of pulses, the current always flows through the circuit IN THE SAME DIRECTION. Current which flows in pulses but is always in the same direction is called PULSATING DC. The diode has thus RECTIFIED the input voltage.

A Practical Half-Wave Rectifier

To utilize the diode as a rectifier, it is connected in series with the load device through which the direct current is to flow. Since in many cases it is necessary to have a rectified voltage which is greater (or smaller) than the source voltage, the rectifier circuit is often supplied power from a step-up (or step-down) transformer. A schematic diagram of a complete half-wave rectifier circuit is shown in Figure #2.

The transformer secondary windings supply voltage to the anode and cathode of the diode. Notice that the cathode of the diode is connected to the secondary winding through the load resistor (R_L). Any current flowing through the diode will also flow through the load resistor causing a voltage to be developed across it. The magnitude of the voltage dropped across the load resistor is directly proportional to the current flowing through it.

The operation of the half-wave rectifier is as follows: When switch S_1 is closed, the primary of the transformer is energized, and a voltage will be induced into the secondary windings. The voltage induced into the secondary windings will alternate, causing the anode of the diode

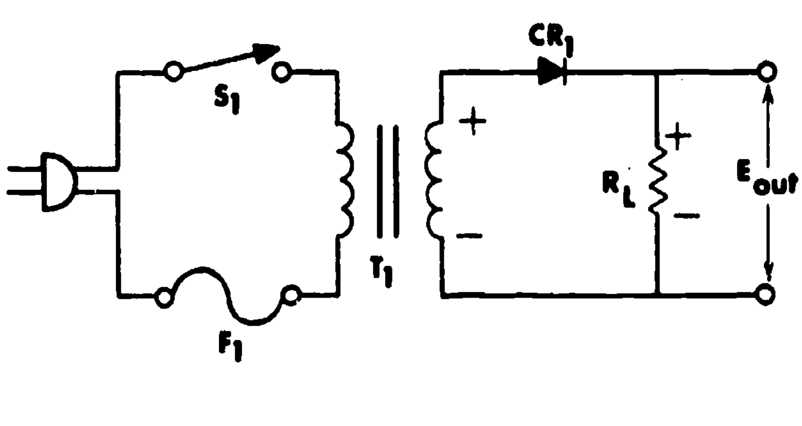


Figure #2 - Half-wave Rectifier Circuit

to be positive with respect to the cathode on one alternation, and then negative with respect to the cathode during the other alternation.

The operation of a half-wave rectifier circuit will be analyzed using the simplified circuit shown in Figure #3. In this figure the circuit has been redrawn to emphasize the fact that the rectifier diode and the load resistor form a simple series circuit connected across the transformer secondary.

When the secondary voltage waveform (e_{sec}) is as 0° the voltage is 0 and therefore no circuit current will flow. An instant later the top end of the secondary winding becomes slightly positive and current begins to flow in the circuit. Since the diode and load resistor form a series circuit, the same current flows through both the diode and resistor.

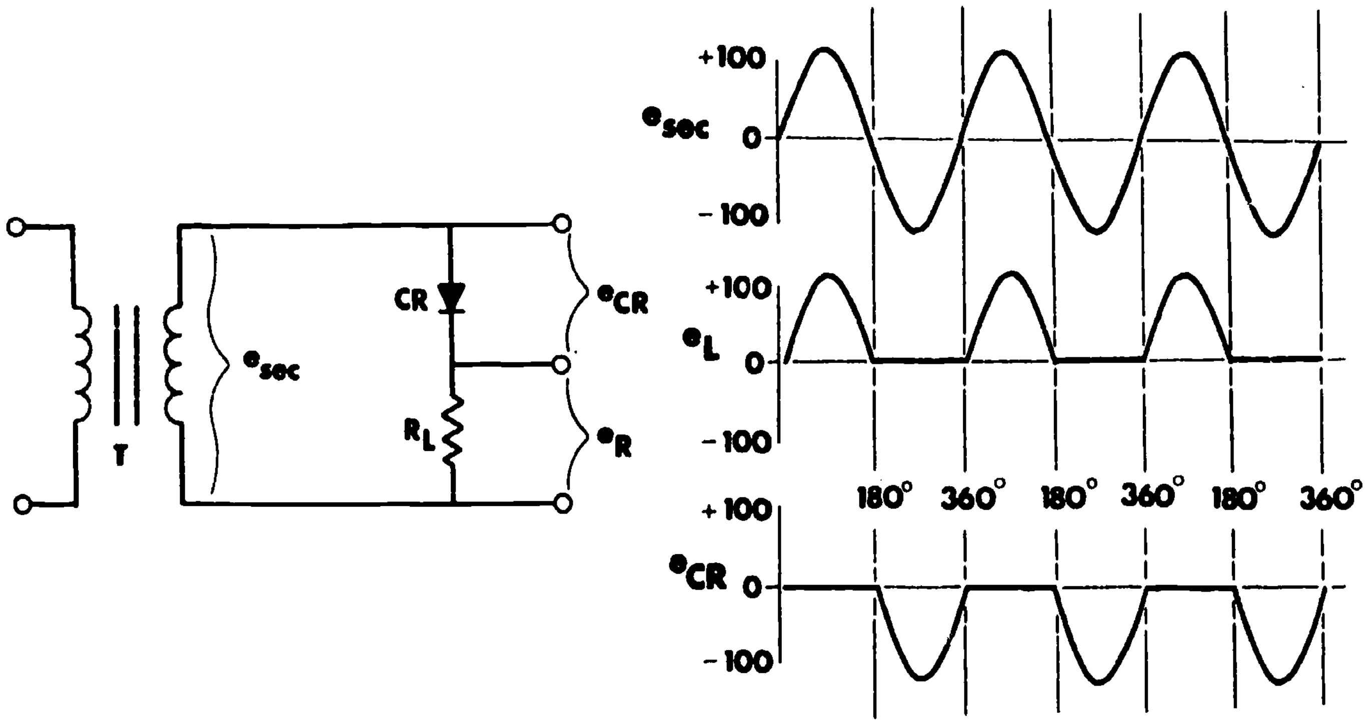


Figure #3 - Rectifier Circuit and Voltage Waveforms

This current will produce voltage drops across the load resistor and diode which have the polarities shown in figure #3. Since the conducting resistance of the diode is approximately 0 ohms, all of the applied voltage will be dropped across the load resistor and no voltage will be dropped across the diode.

As the positive alternation of applied voltage progresses, the voltage applied to the diode and resistor increases steadily. At 30° the applied sine wave attains one-half the peak value or 50 volts which is dropped across R_L.

At 90° the applied sine wave reaches its peak value and the voltage applied to the circuit is 100 volts. From 90° to 180° the voltage applied to the circuit decreases from 100 volts to zero volts, causing the load voltage to drop to zero.

During the negative alternation of applied voltage the diode cannot conduct and no current flows in the circuit. Since there is no current flow through R_L, the load voltage remains at zero volts throughout the negative alternation. During this time the entire negative alternation is dropped across the diode (e_{CR}). This is in accordance with Kirchhoff's Law ($e_{sec} = e_R + e_{CR}$).

The voltage waveforms for the diode e_b and load resistor e_R are shown in Figure #3. Notice that for practical purposes all the positive alternations appear across the load resistor while all the negative alternations are dropped across the rectifier diode.

Waveform Analysis

The overall objective of any rectifier circuit is to convert ac to the proper type of dc required by the load. Although the simple half-wave rectifier provides a uni-directional load current, this current occurs in the form of pulses.

Since a half-wave rectifier diode conducts once during each full cycle of input voltage, the frequency of the pulses is the same as the frequency of the input sinewave. The output pulse frequency is called the RIPPLE FREQUENCY. If the rectifier circuit is supplied power from the 60 cycle per second ac line voltage, 60 pulses of load current will occur each second. Therefore, THE RIPPLE FREQUENCY OF A HALF-WAVE RECTIFIER IS THE SAME AS THE LINE FREQUENCY.

If a series of current pulses like those obtained from a half-wave rectifier are applied to a load resistance, some average amount of power will be dissipated over a given period of time. This average dc power is determined by the amplitude of the pulses and the time between pulses. The higher the peak amplitude of the pulses or the less time between pulses, the greater will be the average dc power supplied to the load. To determine the average dc power, it is first necessary to obtain the average values of current and voltage in the input pulses.

Since the current and voltage waveforms in a half-wave rectifier circuit are essentially half sine waves, a conversion factor can be developed on this basis. The electrical average value of a complete sine wave of voltage or current was found to be equal to 0.637 times its peak or maximum value. Since the load voltage consists of a series of half sine waves of voltage, the average value of load voltage can be computed by multiplying the maximum value of the voltage pulse by one-half of 0.637. Stated mathematically:

$$E_{avg} = 0.318\ E_{max}$$

where:

E_{avg} = the average load voltage

E_{max} = the peak value of the load voltage pulse

In most applications, the voltage drop across the rectifier diode is small compared to the load voltage, and E_{max} in this equation can be assumed to be equal to the peak value of the applied sine wave.

Since the load current has the same wave shape as load voltage, the equation can be modified to apply to load current. Thus,

$$I_{avg} = 0.318\ I_{max}$$

where:

I_{avg} = the average load current

I_{max} = the peak load current

Figure #4 shows the relationship between the maximum (peak) and average values of current and voltage for a half-wave rectifier circuit. If a line is drawn through the rectified waveform at a point 0.318 of the distance from zero to maximum, the waveform will be divided such that area A is equal to area B. Thus, the pulses of current or voltage have the same

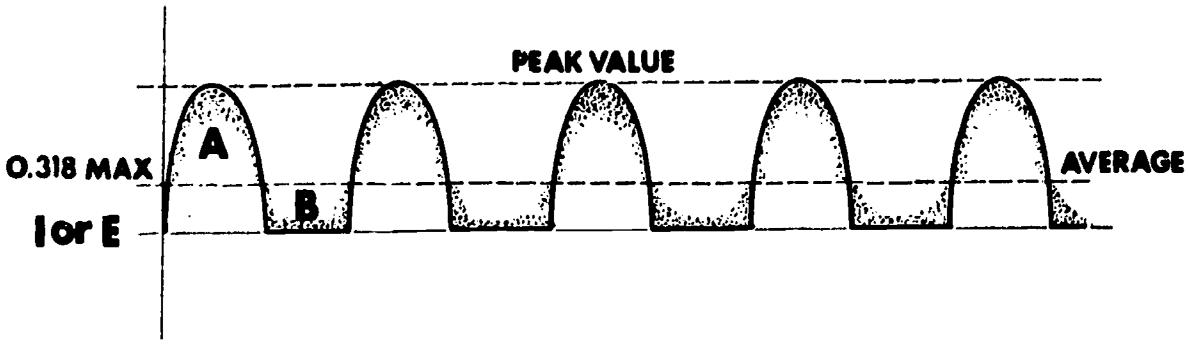


Figure #4 - Peak and Average Values For A Half-wave Rectifier

effect on the load as a steady current or voltage having a value equal to 0.318 of the peak values of the pulses.

The half-wave rectifier utilizes the transformer during only one-half of the cycle, therefore for a given size transformer, less power will be developed than if the transformer were utilized on both halves of the cycle. In other words, if a considerable amount of power is to be developed in the load, the half-wave transformer must be relatively large compared with what it would be if both halves of the cycle were utilized. This disadvantage limits the use of the half-wave rectifier to applications that require a very small current drain. The half-wave rectifier is widely used for commercial ac-dc radio receivers and for other low power devices.

FILTER CIRCUITS

All electronic equipment consists of a combination of individual circuits, each of which is dependent upon particular values of voltage and current for their proper operation. To ensure such a condition, it is often necessary to separate direct currents from alternating currents or alternating currents of a specific range of frequencies from alternating currents outside the desired frequency band. A device capable of performing this function of frequency discrimination is known as a FILTER.

For the proper operation of amplifiers, oscillators, modulators and other electronic devices, it is necessary to provide a smooth dc voltage. A pure dc voltage, such as supplied by a battery is very desirable. However, the dc voltage required in many electronic applications are much higher than a practical battery can supply. Therefore a combination of a rectifier circuit and a filter circuit is necessary to produce a dc voltage that is reasonably smooth. If the pulsating dc voltage that is present at the output of a rectifier was directly applied to a load, the pulsations may cause improper operation of that load. To suppress the magnitude of the variations in voltage, the rectifier output voltage is first applied to a filter circuit where various combinations of inductors, capacitors, and sometimes resistors produce the desired degree of ripple suppression. In the following discussion ripple voltage and the action of various types of filter circuits will be discussed.

RIPPLE VOLTAGE

The polarity of a rectifier's output voltage does not reverse, but its magnitude varies above and below an average value as the successive pulses of energy are delivered to the load. In figure #5, the average voltage is shown as the line that divides the wave-form so that area A equals area B. The variation of voltage about this average value is called RIPPLE.

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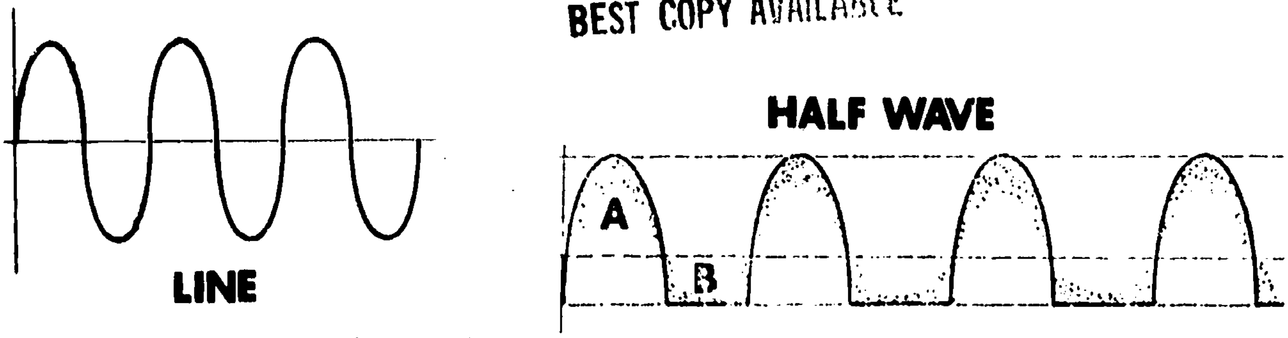


Figure #5 - Unfiltered Rectifier Outputs.

Ripple Frequency

The number of variations above and below the average voltage each second is known as the ripple frequency. The ripple frequency of a rectifier's output voltage is determined by the rectifier configuration and the frequency of the line voltage. In half-wave rectifiers, the ripple frequency equals the line frequency as shown in Figure #5. Ripple frequency plays a major role in determining the size of filter components, as you will learn later.

Ripple Amplitude

The output voltage of any rectifier is composed of a series of dc pulses. For most applications the ripple voltage must be reduced to a very low amplitude. The amount of ripple that can be tolerated varies with the purpose and type of load.

TYPES OF FILTERS

Capacitance Filter

A ripple voltage exists in the output of a rectifier because the rectifier supplies pulses of energy to the load. A capacitor connected in parallel with the load resistance will reduce variations in the output by storing energy during the conduction time of the rectifier and releasing energy to the load during the cut-off time of the rectifier.

The action of a capacitance filter is illustrated in Figure #6, where a

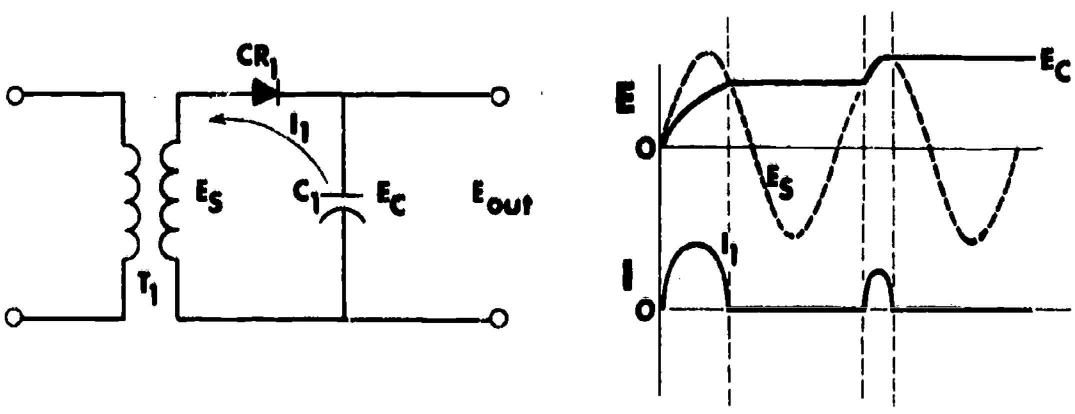


Figure #6 - Half-wave Rectifier (no load)

half-wave rectifier with its output applied to a capacitor is shown. The peak ac input is 100 volts. As the first positive half cycle is applied to the anode of CR_1, the diode conducts and capacitor C_1 begins to charge. The rate of charging C_1 is limited only by the reactance of the transformer secondary winding and the resistance of the rectifier. Therefore, the capacitor voltage rises nearly as fast as the input pulse. When the input voltage starts to decrease, the voltage of the capacitor does not follow. Instead, the voltage remains constant since the capacitor does not have a discharge path.

Assume that C_1 charges to 80 volts during the first half of the input cycle. Since C_1 has no discharge path, the cathode of CR_1 will remain at a positive 80 volt potential. The anode-to-ground voltage must therefore exceed +80 volts before CR_1 will again conduct. During the positive half of the second input cycle, when the anode-to-ground voltage reaches a value greater than +80 volts, CR_1 goes into conduction and allows further charging of C_1. Assuming that the capacitor C_1 now charges to 100 volts, CR_1 can no longer conduct since the anode can no longer become positive with respect to the cathode. The output across the capacitor is now pure dc equal to the peak value of the input voltage.

If the action of the anode current is analyzed, it will be noted that at the beginning of the charge time of C_1, anode current (I_1) is impeded only by the reactance of the transformer winding, and the resistance of the rectifier. Therefore, I_1 is initially at a relatively high value. As the capacitor continues to charge, I_1 decreases in value, since the voltage across the capacitor approaches the anode-to-ground voltage. During the positive half of the second input voltage cycle, anode current does not flow until the anode voltage is above E_C. Since C_1 is already partially charged, anode-to-cathode potential is smaller and the resultant anode current is lower.

If a load resistance is connected in parallel with the capacitor, as indicated in Figure #7, a change will be noted on the voltage appearing

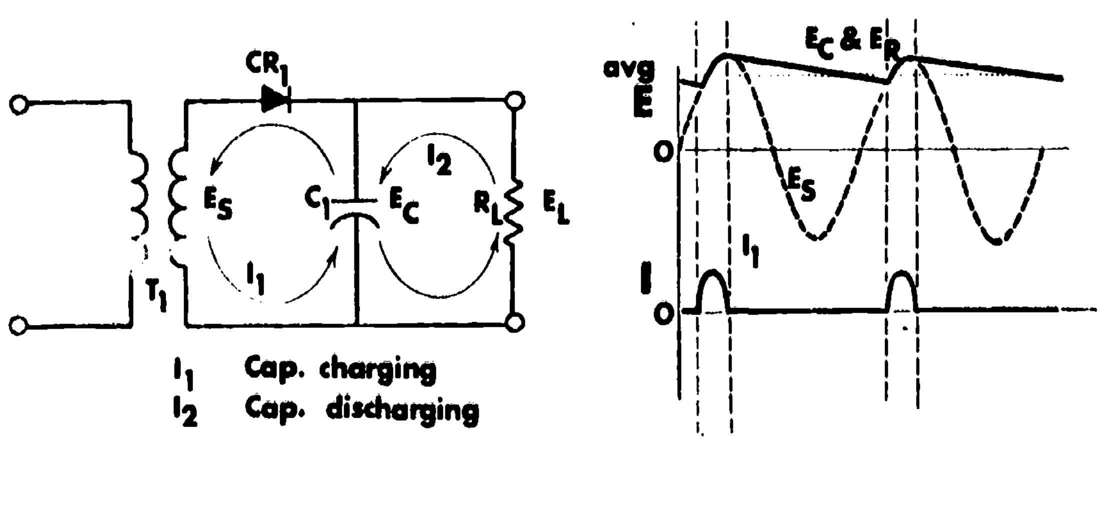


Figure #7 - Half Wave Rectifier -- Resistive Load

across the capacitor. Since C_1 and R_L are in parallel, E_c is equal to E_{RL} and any variations in E_C will also appear across R_L.

Assume that C_1 has been charged to the peak input voltage. During the time CR_1 is cut-off, C_1 can discharge through R_L. Since the values of C_1 and R_L are large, the time constant is long and E_c will decrease slowly. When the next positive pulse appears on the anode of CR_1, and anode-to-ground voltage is greater than E_c, CR_1 will again conduct, allowing C_1 to again charge to peak input voltage. The entire process continues producing the wave shape shown in Figure #7. The average dc output is less than the peak input voltage, but is greater than that which would exist without the addition of the capacitance filter. The unfiltered half-wave rectifier would have an average voltage equal to .318 E max. With C_1 in the circuit, the ripple component has been reduced considerably. Therefore, the filtered average dc voltage output would be larger, its exact value is dependent upon the value of the capacitor and the resistance of the load. As the value of the filter capacitor or the load resistance is increased, the average dc output voltage is increased.

Any filter configuration which uses a capacitor directly in parallel with the load is termed a capacitive input filter. All capacitive input filters have the following characteristics.

1. High voltage output - since the input capacitor can charge to almost peak input voltage, a properly designed capacitive input filter will provide a high output voltage in comparison to other types of filters.

2. Low current output - capacitive input filters are primarily used in low current applications. This is because peak I_L increases as R_L decreases. Peak I_L must be lower than the peak current rating of the rectifier.

3. Poor regulation - in comparison to other types of filters, capacitive input filters will have a greater change in output voltage from no load to full load conditions. Regulation is discussed in another part of this chapter.

Inductance Filter

An inductor may also be used as a filter component because of its ability to store energy in the form of a magnetic field. Because an inductor resists changes in the magnitude of current flow, it will be placed in series with the rectifier and the load rather than in parallel. Since the inductor used in rectifier filter circuits "chokes" or stops the passage of ripple into the load it is called a FILTER CHOKE.

Consider the action of a large inductance in series with the output of a half-wave rectifier. Any change in the current through the coil, either

an increase or decrease, is opposed by the inductor thus affecting the voltage output as shown in Figure #8. The ripple has been reduced but the output is not good enough for most practical applications.

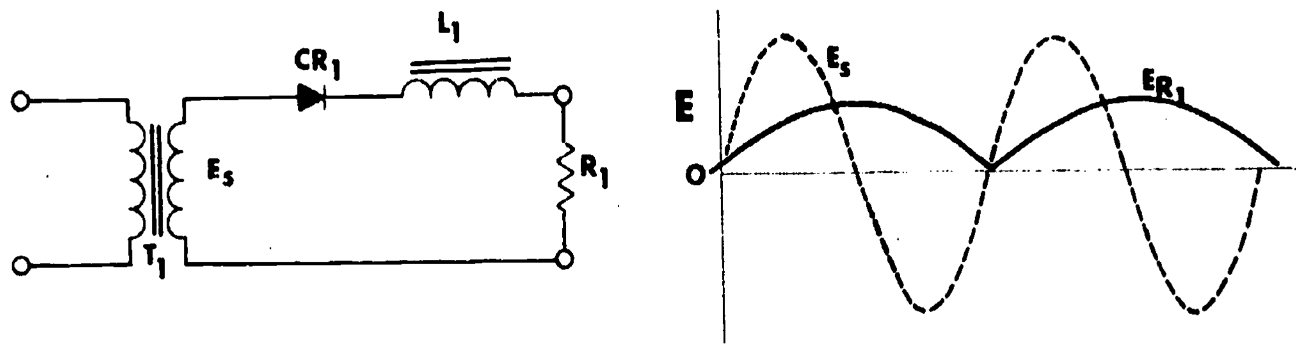


Figure #8 - Half Wave Rectifier, Inductance Filter

The amplitude of the ripple voltage is determined by the ratio of X_L to R, since the inductor and the load resistor in series form a voltage divider. By using an inductor that has a very high inductance, a large percentage of the ripple in a rectifier's output will appear across the inductor and the ripple voltage at the output will be reduced.

The inductance prevents the current from reaching the peak value that is reached without the inductance. Consequently the output voltage never reaches the peak value of the applied sine wave. Thus, a rectifier whose output is filtered by an inductor cannot produce as high a voltage output for a given input as can one whose output is filtered by a capacitor. However, this disadvantage is partly compensated for by the fact that the inductance filter permits a larger current drain without a serious change in output voltage.

Any filter configuration which uses an inductor directly in series with the rectifier is termed a choke input filter. Compared to capacitive input filters, inductive input filters will have the following characteristics:

1. Lower output voltage - in a half-wave circuit the dc output cannot exceed the average value of the input.

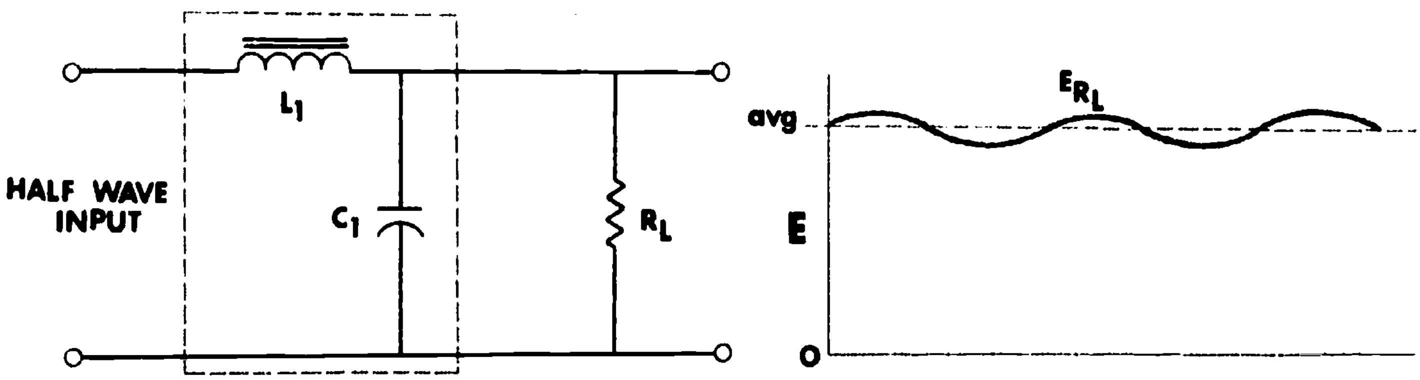
2. Higher current output - this is due to the lower peak current and higher average current of the rectifier.

3. Better regulation - less change between no-load and full-load voltages.

L Type Filter

The ripple voltage present in a rectifier output cannot be adequately reduced in many cases by either the simple capacitance or inductance filter. Much more effective filtration results if both capacitors and inductors are used. The L type filter, so named because of its resemblance to an inverted L, is a filter that combines the action of a capacitor and of an inductor to produce a voltage with a nearly constant magnitude.

Figure #9 illustrates the L type filter. The inductor, L_1, is directly in series with the rectifier. Therefore, the filter is classified as a choke input filter. Since the inductor is in series with the rectifier and the transformer winding, the reactance of the coil affects the charge time of the capacitor. The charge time of C_1 is longer than it would be if the same capacitor were used in a circuit without an inductor (simple capacitance filter). The action of the input choke allows a continuous flow of current from the rectifier. Because of the uniform flow of current the L type has applications where high currents are required.



Pi-Type Filter

A pi-type filter is basically a capacitive input filter and an L type filter connected in parallel. Its name is derived from its resemblance to the Greek letter Pi. The circuit shown in Figure #10 is a pi-type filter.

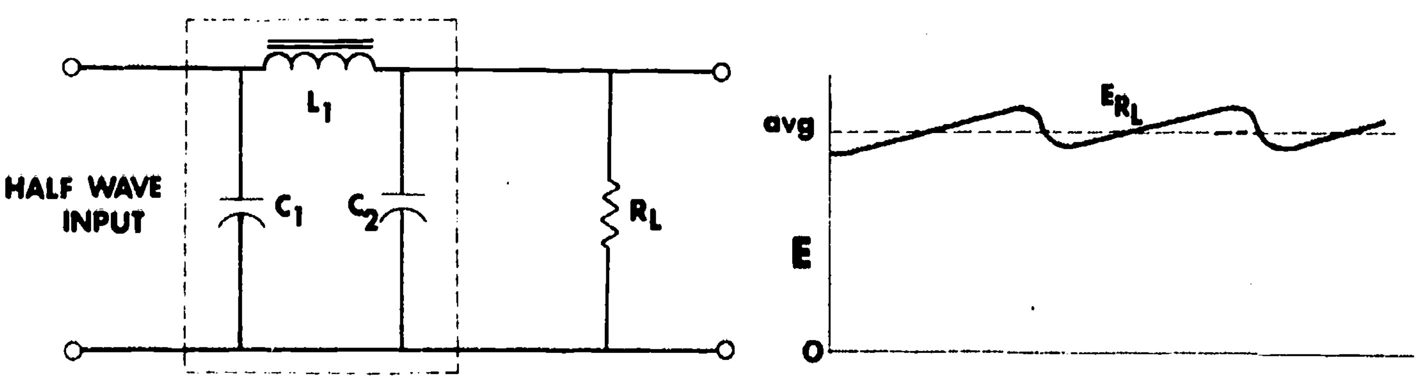


Figure #10 - Pi-type Filter

With this type filter the output waveform closely approximates a pure dc.

REGULATION

Percentage of Regulation

When a load is placed on a power supply, the terminal voltage generally decreases. The comparison of this fall of voltage to the full-load voltage, expressed in percent, is called percent of regulation. A circuit has poor regulation if a large drop occurs in the terminal voltage when full load is applied.

The difference between the no-load voltage and the full-load voltage is caused by the flow of load current through the internal resistance of the power supply. The IR drop caused by the load current within the supply circuit is subtracted from the voltage available for the load resistance at the output terminals. A perfect power supply would have zero internal resistance and the percentage of regulation would be zero. Such a supply would provide the same voltage under full-load that it develops with no-load current flowing. In general, the lower the percentage of regulation, the better the power supply in furnishing dc voltage and current for electronic equipment.

The first (input) capacitor C_1 represents a low-impedance path through which most of the ripple current flows. Since the X_C of C_1 is low, very little ripple current may now flow through two possible paths, C_2 and L_1 accomplished by this first component. The remaining ripple voltage may be considered as appearing across L_1 and C_2 which are in series. The remaining ripple current may now flow through two possible paths, C_2 and L_1 or R_L and L_1. Since the value of R_L is quite large when compared with the X_C of C_2, almost all of the current will flow through the C_2 - L_1 path. Because the X_L of L_1 is so much larger than the X_C of C_2, almost all of the remaining ripple voltage appears across L_1 and consequently does not appear in the output.

Since the large ripple current flowing through C_1 causes a fairly large voltage drop across the rectifier, the current flow through the rectifier is a series of sharp-peaked pulses. If these pulses exceed the peak current rating of the rectifier, damage may result. Because of this, the pi-type filter is used only in low-current applications such as radio receivers.

In many cases where cost and size are a factor the inductor may be replaced with a resistor. The value of resistance used, however, will be a compromise between good filtering and high dc output. The reactance of L is high while the dc resistance is low. This means the ripple voltage drop across L_1 will be large while the dc voltage drop will be low. If the value of R was equal to the X_L of L_1, percentage of ripple would remain low but the dc output would be reduced due to the large IR drop across the resistor. If the value of R was equal to the dc resistance of L, the dc output would remain high, but the percentage of ripple would increase due to the change in R/X_C ratio (formerly the X_L/X_C ratio).

Regulation of a Capacitor-Input Filter

A capacitor-input filter with no load produces a terminal voltage which is nearly equal to the peak value of the applied pulsating voltage. As the load is increased, the terminal voltage falls, because the current drawn by the load prevents the capacitor from retaining its charge. The capacitor-input filter is undesirable for applications which require a large current, because the peak current that must flow in the rectifier to charge the input capacitor may damage the rectifier. Since the output voltage falls considerable as the load current is increased, this type of filter is said to have relative poor regulation (see Figure #11). It may be used, however, where the load current is light or nearly constant.

Regulation of Choke Input Filter

The regulation of choke input filters will be discussed by considering a specific type of filter, the L type. At no load the output voltage of the choke input filter is nearly equal to the peak voltage of the sine wave applied. This high voltage can be obtained because with no load current being drawn the capacitor can be charged to the peak voltage. However, if only a small load current is drawn, the output voltage falls sharply to some lower value. (See Figure #11). As the load current increases beyond a value indicated by point A in the illustration, there is very little change in output voltage except that which takes place due to the dc resistance of the choke coil.

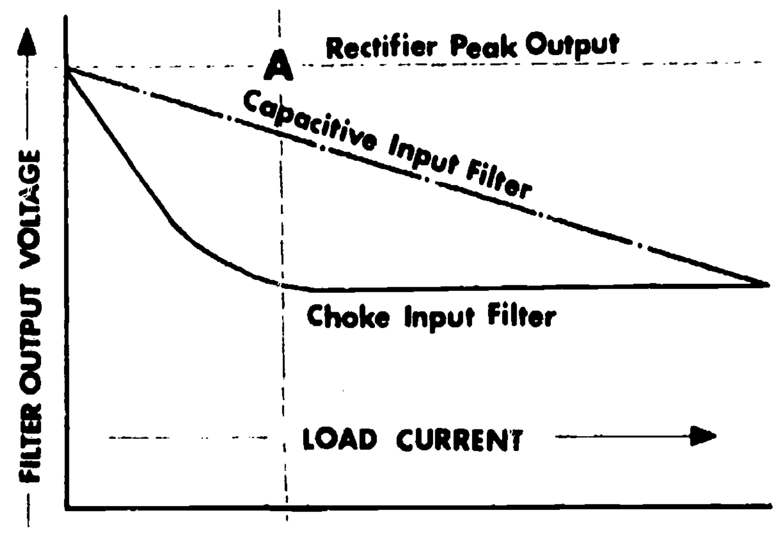


Figure #11 - The effect of increasing load current on the terminal voltage of capacitor and choke input filters

Since the voltage at the output of a choke input filter changes very little over a wide range of load, a choke filter has good regulation. In practice, a fixed minimum load which will draw a current equal to the magnitude of point A, usually is put across the terminals of the filter to prevent the large change of voltage which takes place between no load and the load at point A.

Voltage Dividers

In many cases a resistor is placed across the output terminals of a rectifier power supply. The name applied to such a resistor depends on its principal use. If it serves the purpose of bleeding off the charge on the filter capacitors when the rectifier is turned off, the resistor is called a BLEEDER RESISTOR. If it serves the purpose of applying a fixed minimum load to a filter circuit to improve the voltage regulation of the power supply, it is called a minimum LOAD RESISTOR. If loads are connected to the resistor at various points to provide a variety of voltages which are less than the terminal voltage, the resistor is called a VOLTAGE DIVIDER.

In general a resistor placed across the output terminals of a rectifier power supply may fulfill all of these functions. However, if the resistor is to be a bleeder resistor only, it can have a very high resistance so that it will draw a negligible current from the rectifier. If the resistor is to serve as a minimum load resistor, it should be of such a value that it will draw approximately 10 percent of the full load current. It must be of sufficient wattage rating to dissipate the heat produced by the current flowing through it while the circuit is energized.

Circuits

A resistor which is used as a minimum load resistor also may be used as a voltage divider because the current flowing through the resistor produces a voltage drop across it equal to the applied voltage. In Figure #12, three equal resistors are connected in series.

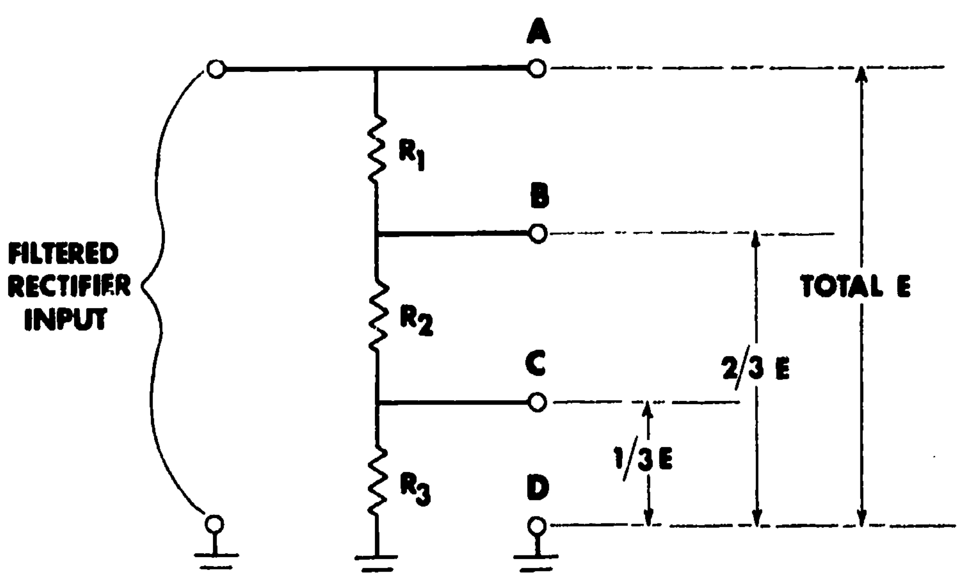


Figure #12 - Simple Voltage Divider

As long as no current is drawn from any terminal except the top or line terminal, the voltage across the resistors will divide proportionally to the resistance of each as shown.

It is common practice to ground one side of most circuits. Therefore ground potential is normally used as a reference for measurement of voltages as at point D of Figure #13-1. If a rectifier and its filter are connected so that no parts of the power supply are grounded, it is possible to ground the circuit at any point without affecting the operation of the rectifier, providing the insulation of all parts is sufficient to withstand the voltage involved. Thus in Figure #13-2, point C is grounded and point D becomes negative with respect to ground. Such a circuit is frequently used to furnish both positive and negative voltages from the same power supply. In Figure #13-3, point A is grounded and all voltages along the divider are negative with respect to ground. An important point to note, however, is that point A will always be MORE POSITIVE than point B so long as the power supply polarity is maintained as shown in Figure #13-3.

It has been assumed in Figure #12 and #13 that no load was attached to the divider except across the line terminals A and D and that voltages could be

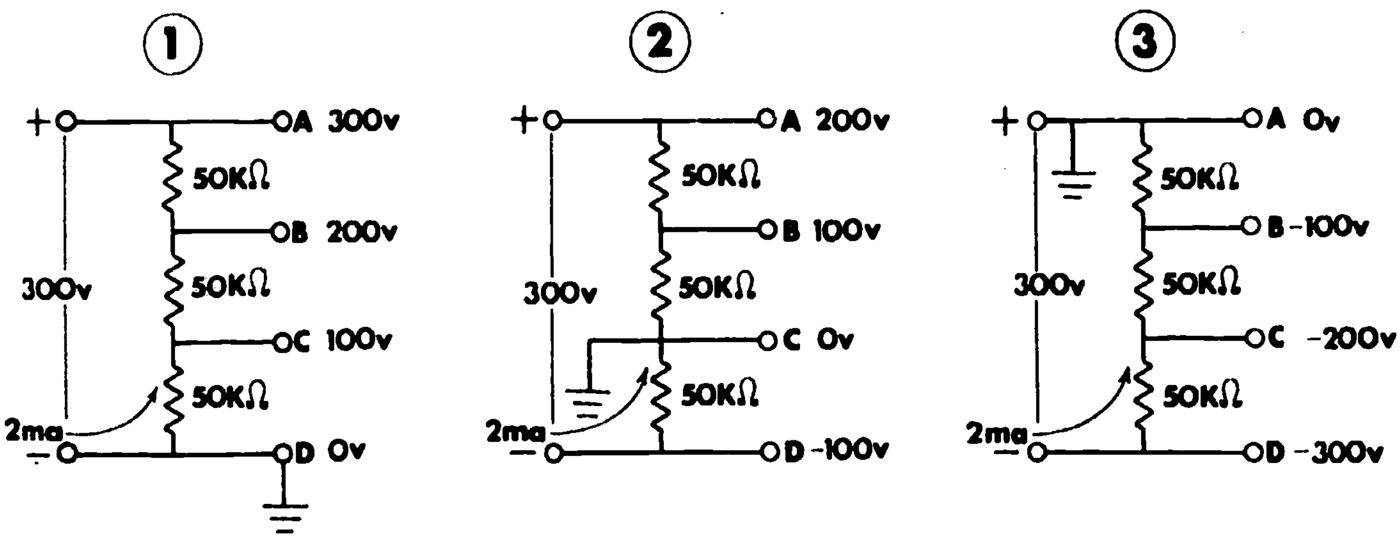
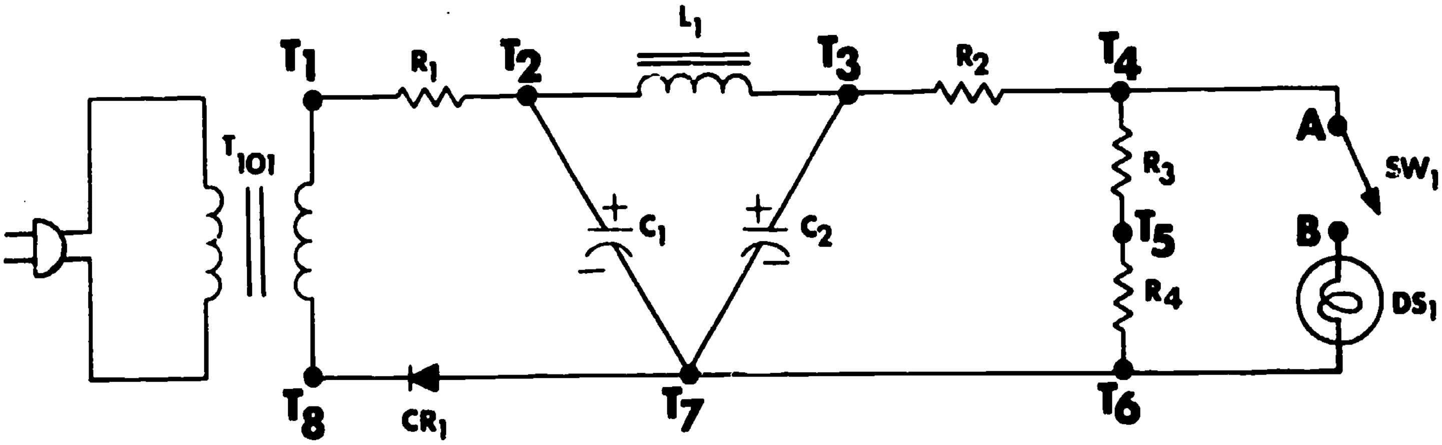


Figure #13 - Effect of Moving Ground Point
On A Voltage Divider

measured without drawing appreciable current. As soon as a load is attached to the divider at any intermediate terminals, the voltage division shown no longer is correct. This is because the resistance of the attached load forms a parallel circuit with the part of the divider across which it is placed, and therefore changes the total resistance between the terminals concerned. Thus, it can be seen that the voltage appearing across the intermediate terminals of a voltage divider will divide proportionately to the values of the divider resistors only as long as no

appreciable current is drawn from these terminals. Under load conditions the voltages at these terminals will have various values, depending upon the resistance of the loads. A voltage divider must therefore be designed for the particular load conditions under which it is to operate.

Now that we have seen how a basic power supply functions, and some of the different configurations, let's now take a look at the power supply you constructed and analyze its function and operation. For ease of understanding and explanation, take a look at the schematic of your power supply (as you view the schematic notice that the components are numbered, also compare the physical layout to the schematic).



Now proceed to the experiments.

NOTE: Due to the manufacturing differences in the production of the chokes and power transformers used in your power supplies and the tolerances of the resistors, all values for current and voltage are approximate. Therefore, if your answers do not agree exactly with those given in the book it is probably due to the difference in the manufacturing of the components used.

EXPERIMENT: Resistance Analysis of the Half-Wave Semiconductor Power Supply

You are now going to measure and record the resistance of the half-wave rectifier.

CAUTION: Be SURE the line cord is NOT plugged in DURING THIS EXPERIMENT.

For this experiment you will need a multimeter and your completed half-wave power supply.

1. Disconnect the transformer secondary lead from terminal T8 and open S_1.

2. With your multimeter, determine the DC ohmic value of the following: (Ensure the multimeter is zeroed if the range switch is changed.)

   Primary T101 = ____________
   Secondary T101 = ____________
   R_1 = ____________
   L_1 = ____________
   R_2 = ____________
   R_3 = ____________
   R_4 = ____________
   I_1 = ____________
   CR_1 = ____________

   Reverse leads - CR_1 = ________

   Terminal T1 to T7
   With switch open = ________

   Terminal T1 to T7
   With switch closed = ________

- -

ANSWERS ARE ON NEXT PAGE

Answers:

Primary T101	= 29 Ω
Secondary T101	= 2.1 Ω
R_1	= 4.7 Ω
L_1	= 25 Ω or 40 Ω (Depending on type choke used)
R_2	= 4.7 Ω
R_3	= 1 K
R_4	= 1 K
I_1	= 7 Ω
CR_1	= 12Ω or ∞
Reverse Leads	
CR_1	= ∞ or 12 Ω

T_1 to T_7 Swith Open = 2K Ω

T_1 to T_7 Switch closed = 34 Ω 55 Ω (Depending on type choke used)

- -

Now that you have completed the resistance experiment, answer the following questions:

(1) Why was it necessary to lift the secondary transformer lead from T8?

____

(2) With the DC resistance readings you observed at the primary and secondary of the transformer, would you believe the transformer to be a step-up or step-down transformer?

____

(3) Why were the resistance readings you received across CR_1 different when you reversed the test leads?

____

(4) Why were the resistance readings you received across T_1 to T_7 different when the switch was open and when it was closed?

____

ANSWERS ON NEXT PAGE.

ANSWERS:

(1) To eliminate a parallel current path through the secondary of the transformer, which would give confusing readings.

(2) Step-down. The resistance of the secondary is much less than that of the primary. This would indicate that more wire was used in the primary. If both the primary and secondary used the same size and type of wire, a reasonably accurate turns ratio could be determined from the resistance readings.

Mathematically: $P_{in} = P_{out}$

Substitute: $\dfrac{E_p^{\,2}}{R_p} = \dfrac{E_s^{\,2}}{R_s}$

Transpose: $\dfrac{E_p^{\,2}}{E_s^{\,2}} = \dfrac{R_p}{R_s}$

Take the Square Root: $\dfrac{E_p}{E_s} = \sqrt{\dfrac{R_p}{R_s}}$

And because: $\dfrac{N_p}{N_s} = \dfrac{E_p}{E_s}$ Then $\dfrac{N_p}{N_s}$ must $= \sqrt{\dfrac{R_p}{R_s}}$

Substitute values: $\dfrac{N_p}{N_s} = \sqrt{\dfrac{29\Omega}{2.1\Omega}} = \sqrt{13.8} = 3.71$ to 1

This ratio is approximate due to errors in resistance measurement, and the fact that the transformer windings may not use the same size of wire.

This transformer is a voltage step-down device, and therefore a current step-up device. In order to keep power in the primary equal to power in the secondary when voltage is stepped down, current <u>must</u> be stepped up. P = IE

Therefore, the wire used in the secondary windings may be larger than the wire in the primary in order to accomodate the increased current. This will cause the turns ratio calculated from resistance values to be in error. However, we can still determine from our readings that it is a step down transformer.

(3) A semiconductor diode has the physical properties of offering a very high resistance to current flow in one direction and a very small opposition to current in the other direction. When the meter leads were reversed the internal battery was applied to the diode in the opposite direction, therefore, the change in the resistance reading.

(4) When the switch is closed a very small resistance, the lamp, is added in parallel which causes a decrease in total resistance.

If you were able to answer these questions correctly, reconnect the secondary transformer lead to T8 and proceed to the next experiment. If you had difficulty, return to the beginning of the Resistance Experiment.

EXPERIMENT: Voltage Analysis of the Half-Wave Semiconductor Diode Power Supply.

For this experiment you will need a multimeter and your completed half-wave power supply.

NOTE: DO NOT ATTEMPT TO READ THE INPUT VOLTAGE!

1. Ensure the secondary transformer lead that was disconnected in the previous experiment is re-connected to T8.

2. Connect the line cord to a 115 VAC outlet and measure the ac output voltage from the secondary of the transformer T101 (T_1 to T_8) with the switch open __________, with the switch closed __________.

   Answers: Switch open = 30 vac
   Switch closed = 29 vac

3. Measure the DCV between T4 and T7 with the switch open __________, switch closed __________.

   Answers: Switch open = 38 vdc
   Switch closed = 7.4 vdc or 3.6 vdc

4. Measure the DCV across R2 with the switch open __________, switch closed __________.

   Answers: Switch open = .1 vdc
   Switch closed = 1.35 vdc

Now that you have completed the voltage experiment, answer the following questions:

(1) Is T101 a step-up or step-down transformer? What is the turns ratio?

____

(2) Why the difference in the ac voltage readings at the secondary of T101 when the switch is opened and closed?

____

(3) How is it possible that the voltage measurement in Step 3 (switch open) is greater than the output of the transformer?

____

(4) Why the difference in the voltage measurements in Step 3 when the switch is opened and closed?

____

(5) Why the difference in the voltage measurements in Step 4 when the switch is opened and closed?

____

ANSWERS ON THE FOLLOWING PAGE.

ANSWERS:

(1) Step-down. $\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{115v}{30v} = \frac{3.83}{1} = 3.83:1$

(2) When the switch is closed, it causes an increase in I_t. When I_t increases, the voltage drop across the internal resistance of the transformer increases, giving a decreased output at the terminals of the transformer.

(3) The ac voltage measurement is an EFFECTIVE voltage (.707 of Peak), however, the capacitors are charging to the Peak voltage which is 1.414 E_{eff}. Therefore, if you measured 30v at the output of the transformer, the capacitors are trying to charge to a peak value of 42.42v (less voltage drops across R1, L1 and R2).

(4) When the switch is closed, R_t decreases, I_t increases, and the voltage drops across R1, L1 and R2 increase, causing less voltage available at the load.

(5) When the switch closes, the current through R2 increases, causing an increased voltage drop.

If you were able to answer these questions correctly proceed to the next experiment, if not return to the beginning of the Voltage Experiment.

EXPERIMENT: Current Analysis of the Half-Wave Semiconductor Diode Power Supply

For this experiment you will need a multimeter and your completed half-wave power supply.

CAUTION! EACH TIME THE AMMETER IS PLACED INTO THE CIRCUIT ENSURE THE POWER SUPPLY IS UNPLUGGED.

1. Measure the current through R2 with the switch open ____________, switch closed ____________.

   Switch open = 17 ma
   Switch closed = 280 ma or 185 ma (Depending on the type choke used)

2. Measure the current through R3 with the switch open ____________, switch closed ____________.

   Switch open = 18.5 ma
   Switch closed = 3.8 ma

3. Measure the current through the light I_L? ________

   Current I_L = 275 ma or 185 ma (Depending on type choke used)

Now that you have completed the current experiment, answer the following questions:

(1) Why the difference in the current measurement through R2 when the switch is opened and closed?

____

(2) Determine the current through R4 with the switch open ____________, with the switch closed ____________.

(3) When the switch is closed, I_t increases by how much? ____________

(4) What happens to the current through R1 and L1 when the switch is closed? ____________________________
Why? ____________________________

ANSWERS ON FOLLOWING PAGE.

ANSWERS:

(1) When the lamp is placed in the circuit it causes a parallel path for current, which increases I_t flowing through R_2.

(2) The current will be the same through R4 as through R3, because they are in series. Switch open 17 ma, Switch closed 1 ma.

(3) I_t will increase by 244 ma. (I_t flows through R2 and this value was determined by subtracting the switch open value from the switch closed value.)

(4) The current through R1 and L1 will increase due to the decrease of resistance caused by the paralleling of I1 with R3 and R4.

$$\uparrow I_t = \frac{E}{R\downarrow}$$

If you answered these questions correctly proceed to the next experiment. If you had difficulty return to the beginning of the current measurement experiment.

EXPERIMENT: Waveform Analysis of the Half-wave Semiconductor Diode Power Supply

Introduction

The oscilloscope is a test instrument which displays voltage variations with respect to time. It traces a graph of instantaneous voltages such as the waveforms you have seen produced by alternators and generators. Used properly, a good oscilloscope can measure the frequency, phase difference, amplitude, and shape of any periodic waveform. (A periodic waveform is one which has the same shape and size through each cycle.) An oscilloscope is one of the most versatile test instruments available to you.

Because it uses extremely high voltages in some of its circuits, do not attempt to remove it from its case. Handle the oscilloscope with care, for it is delicate, and the cathode ray tube can implode, throwing pieces of glass around with great force.

Get an oscilloscope from the materials center now.

You are now ready to check some of the waveforms in your power supply. IN THE FOLLOWING STEPS, ALWAYS REMEMBER TO DISCONNECT THE POWER SUPPLY BEFORE YOU TOUCH ANY OF ITS LEADS, AND PLUG IT in again AFTER all connections are made. Leave the light switch closed all the time to insure that all capacitors are discharged before you touch the circuit.

To see what the voltage waveform from the transformer secondary looks like:

Step 1. Turn on the oscilloscope and place the H/SWEEP SEL switch is in the 15 position. Adjust the INTENSITY and FOCUS controls for a single thin sweep on the face of the scope. It may be necessary to adjust the V POS and H POS controls to center the sweep on the face of the oscilloscope. Adjust the H GAIN control so that both the start and end of the sweep are visible on the CRT.

Step 2. Connect the common (black) lead on the scope to T8 and the vertical (yellow) input lead to T1. Now plug in your power supply. Make certain the switch is closed and the light bulb glows.

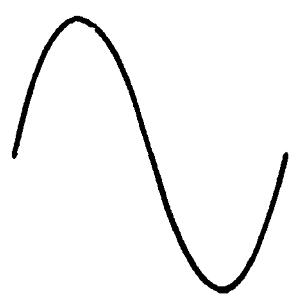
Step 3. Set the V RANGE switch to the 6 v scale and adjust the V CAL control to bring the signal amplitude just within the vertical limits of the CRT.

Step 4. Set the INT/EXT SYNC switch to the INT position. Adjust the SWEEP VERNIER control slowly and see how it affects the display. Set it to show one steady cycle of a sine wave. If the signal later starts to jump or drift, readjust this control.

Step 5. Vary the SYNC/PHASE control slowly and observe its effect on the signal. Set this control so that the signal starts on the positive alternation about half way between the positive and negative peaks. Readjust the SWEEP VERNIER knob, if necessary.

Step 6. Draw the signal you see on your oscilloscope. This is the output of the transformer secondary.

The waveform should look about like this:



Now let's check on the rectification at the diode.

Step 7. Unplug the power supply and move the vertical input lead from T1 to T7. Plug in the power supply. Adjust the SYNC/PHASE control if the waveform is not stable.

Step 8. Draw the signal now showing on the scope.

You should see a sine wave with one alternation clipped off by the action of the rectifier.

The output of the rectifier is pulsating DC, and must be smoothed out to a (nearly) pure DC. This is done by the filtering action of capacitors and inductors. Since pulsating DC has changes in voltage, the capacitors C1 and C2 will oppose the changes by charging and discharging.

Let's see how this affects the waveform.

Step 9. Unplug the power supply again, move the vertical input lead to T2 and the black lead to T7.

Step 10. Plug in the power supply.

Step 11. Turn the SWEEP VERNIER counterclockwise until you see a stable pattern with two negative peaks.

Step 12. Draw this pattern.

Your pattern should look like this:

In this waveform, C1 reduces the negative peak amplitude, for some current flow charges the capacitor. The capacitor's discharge fills in part of the zero voltage spaces between the negative peaks when C1 acts as a voltage source. The result is a sawtooth waveform of lower amplitude than the diode output.

The inductor, by opposing the changes in current flow through it, will smooth out the signal even more, and, in conjunction with C2, will provide a nearly pure DC voltage. Look at this waveform with your oscilloscope.

Step 13. Unplug the power supply. Connect the vertical input lead to T3.

Step 14. Plug in the power supply, and check the signal on your oscilloscope. It should be very nearly a straight line -- DC with only a small amount of ripple:

The last oscilloscope reading we take will be the output of the power supply taken from across the load.

Waveform Across The Load

Step 15. Connect the common test lead to T4 and the vertical input lead to T6 to read the waveform across the lamp.

Step 16. Observe that the waveform of the output of your power supply is almost pure DC with only a slight ripple.

From this experiment using the oscilloscope, you have had visual proof that your power supply converts AC to DC.