

Building the LVPS—Low Voltage Power Supply

Introduction

Low voltage is one of those relative terms—up to 25 volts [V] dc is low, and most people would call 1000V high. Power supplies provide energy from many different kinds of sources and at widely varying rates: gigawatts (10^9W) from nuclear plants to microwatts ($10^{-6}W$) from watch batteries. Sources of energy for power supplies include nuclear fission, burning of coal, oil, gas or wood, chemicals reacting, and sunlight, wind and tides. Power is delivered in electrical form as alternating or direct current (ac or dc) and in many combinations of current and voltage. Electrical power supplies in a narrow sense are really converters from one voltage/current combination to another—with, one hopes, only small power losses.

Project LVPS

In this project, you'll build a power supply that takes power at 120V, 60 hertz [Hz] ac from a wall outlet and converts it to dc. The power supply is adjustable between 2V to 12V and can supply currents up to 1 ampere (A).

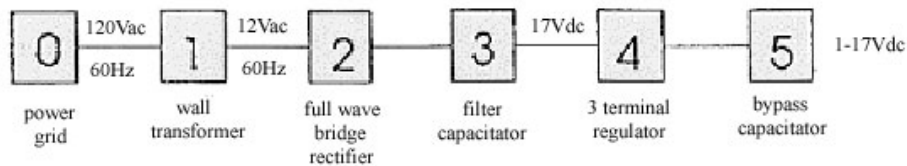


Figure 1: Block diagram of LVPS

Background

The circuit diagram for the LVPS looks like

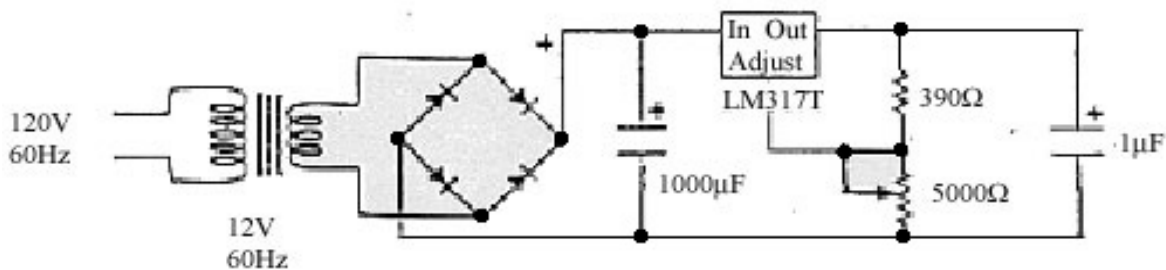


Figure 2: Circuit diagram for LVPS

Wall Transformer

The LVPS starts with your wall transformer, which reduces the 120V ac from the line to a safe and convenient nominal 12V ac sine wave voltage with only moderate loss of power (heating the transformer). A sine wave voltage varies in time and can be described mathematically by the function

$$V(t) = V_0 \sin(2\pi t/T + \phi) = V_0 \sin(2\pi f t + \phi)$$

where V_0 is called the *amplitude* (maximum value). The voltage varies between $V_0 = 17V$ and $-V_0 = -17V$ since a sine function varies between +1 and -1.



Figure 3: Wall transformer

The 12V ac refers to the root mean square (rms) amplitude defined by $V_{rms} = V_0/\sqrt{2}$. The sine function is periodic in time. This means that the value of the voltage at time t will be exactly the same at a later time $t' = t + T$ where T is the *period*. The *frequency* f is defined to be $f = 1/T$. The units of frequency are inverse seconds [sec^{-1}] which are called hertz [Hz]. A graph of the sine wave voltage vs. time looks like

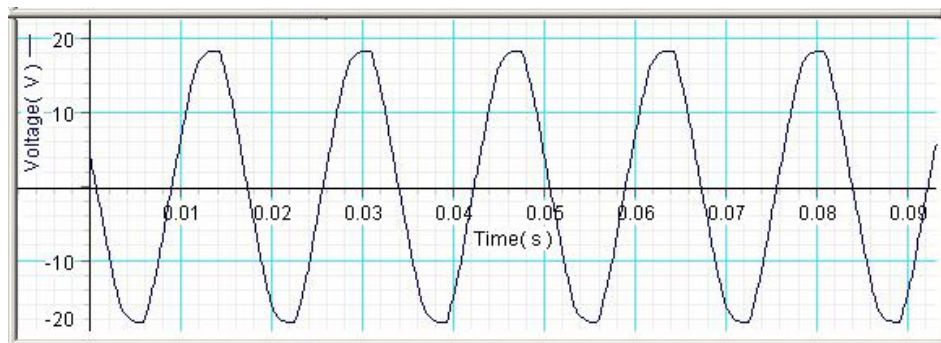


Figure 4: Wall transformer output voltage

Bridge Rectifier

Next comes a full-wave bridge rectifier consisting of four half-wave rectifiers that act as diodes. A half-wave rectifier allows current to flow through it in only one direction, as shown by the arrow in the symbol for it.



Figure 5: Half-wave rectifier

If an alternating sine-wave voltage is applied to a rectifier, it transmits only the positive half-waves as shown in the sketch below.

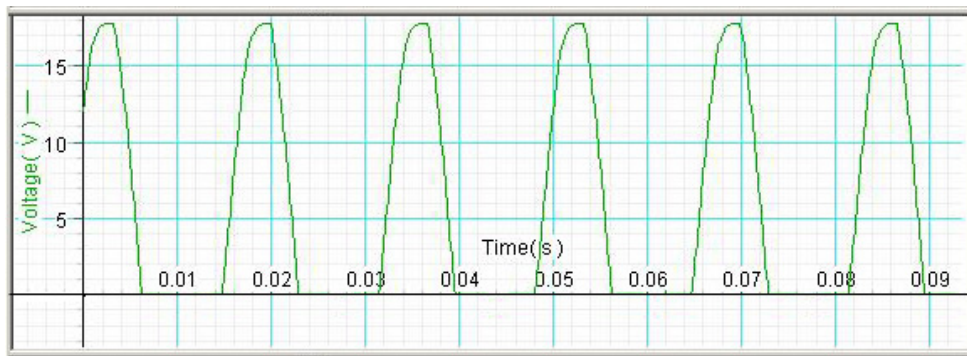


Figure 6: Rectifier sine wave after passing through half-wave rectifier

Four half-wave rectifiers connected as shown in Figure 7 form a bridge rectifier.

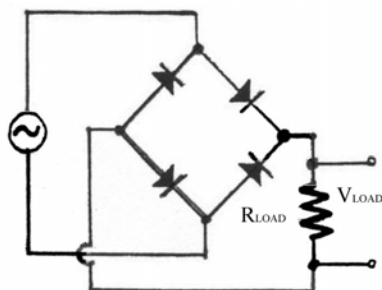


Figure 7: Bridge rectifier

In the next two sketches below, the four half-wave rectifiers act as switches that connect the upper or lower lead on the left, when either is positive, to the right-hand output lead, and to the left-hand output lead when either is negative (convince yourself of this).

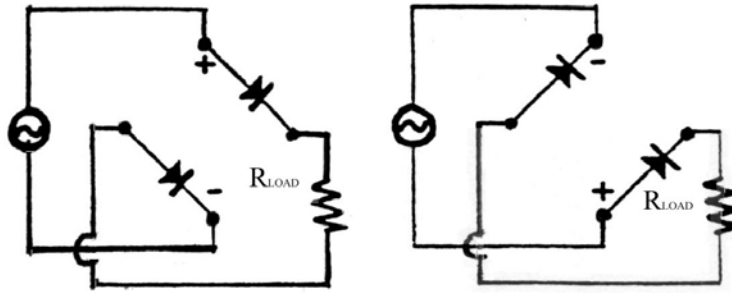


Figure 8: Bridge rectifier in action

In this way the wiggly ac is made to flow in only one direction—i.e., it is straightened out or rectified. This is shown in the next sketch.

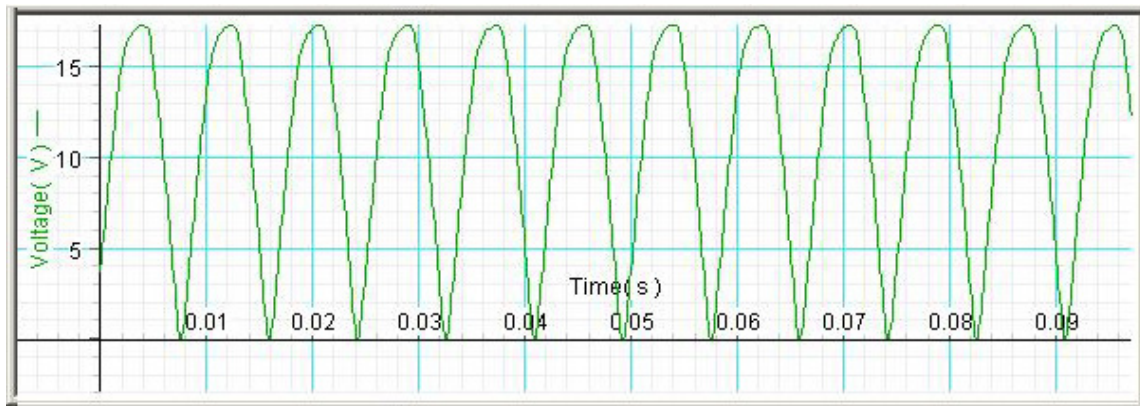


Figure 9: Voltage output from the bridge rectifier

Capacitors

Capacitors are circuit elements that store electric charge Q according to

$$Q = CV$$

where V is the voltage across the capacitor and C is the constant of proportionality called the capacitance. The unit of capacitance is the farad [F] and is defined by $[1F] = [1C]/[1V]$.

Capacitors come in many shapes and sizes but the basic idea is two conductors separated by a spacing which may be filled with an insulating material (dielectric). One conductor has charge $+Q$ and the other conductor has charge $-Q$. The conductor with positive charge is at a higher voltage V than the conductor with negative charge. Most capacitors are in the picofarad [pF] to millifarad range, $1000\mu F$.

Capacitors can do many things in both ac circuits and dc circuits.

- Capacitors store energy
- Capacitors when coupled with resistors can delay voltage changes
- Capacitors can be used to filter unwanted frequency signals
- Capacitors are needed to make resonant circuits
- Capacitors and resistors can be combined to make frequency dependent and independent voltage dividers

We denote capacitors in circuits by the symbol



Figure 10: Capacitor symbol

Smoothing Out the Rectifier Output

A $1000\ \mu F$ capacitor then smoothes out the rectifier output.

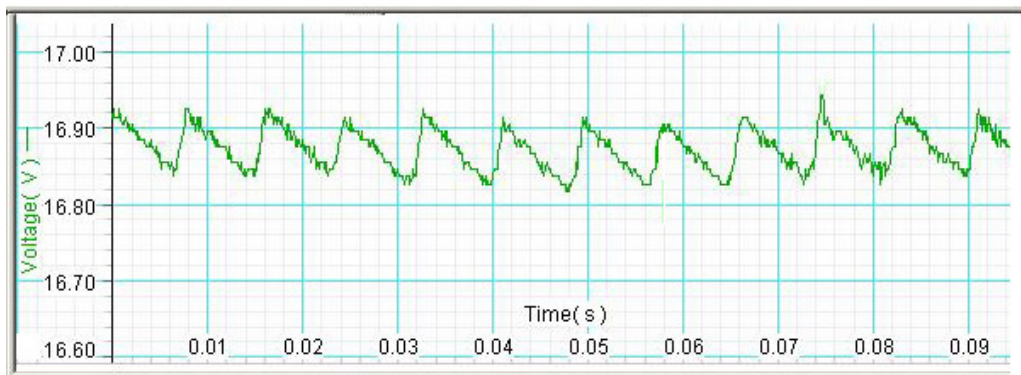


Figure 11: Smoothed out voltage due to $1000\ \mu F$

Voltage Regulator

Next comes the LM317T three-terminal integrated circuit (IC), containing 26 transistors and various resistors and capacitors. It keeps the output voltage constant with respect to an internal reference voltage, using feedback—i.e., it is a ‘voltage regulator’. It also protects itself against overload (too much current) and is compensated for changes in temperature.



Figure 12: Heat sink, LM317T voltage regulator, and socket

Potentiometer

A resistor network—one variable resistor (a 5000Ω potentiometer, or "5k pot") and one fixed resistor (390Ω , $1/2W$) serves to adjust the output voltage. Notice that the pot, here used as a variable resistance, has the slider and one end connected. This guarantees that some part of the pot resistance will be in the circuit, even if there is an uncertain contact inside the pot.

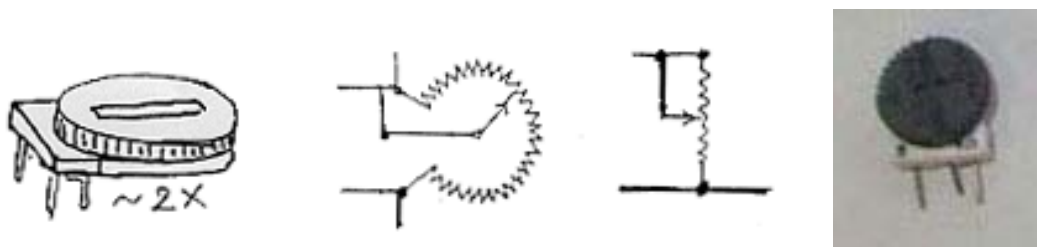


Figure 13: potentiometer and 'pot' circuit diagram

High Frequency Filter

Finally, a $1\mu F$ capacitor across the output bypasses high-frequency disturbances from either direction—from the ac supply line or from the load.

Building the Low Voltage Power Supply

The circuit diagram for the LVPS tells us how the various parts are connected but we will place the parts on the perboard in order to minimize the number of wires and solders. So in the following instructions try to understand the layout in terms of the circuit diagram. This will help you find any missed or incorrect connections.

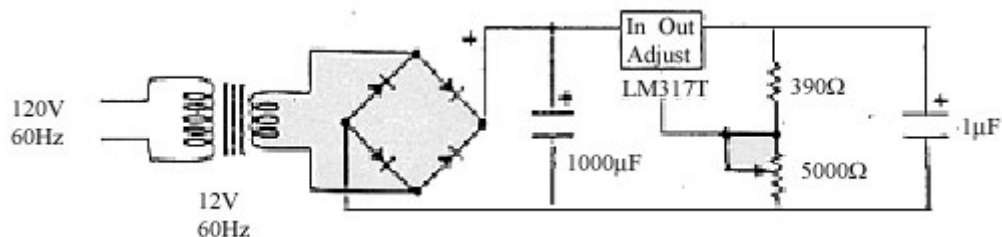


Figure 14: Circuit diagram for LVPS

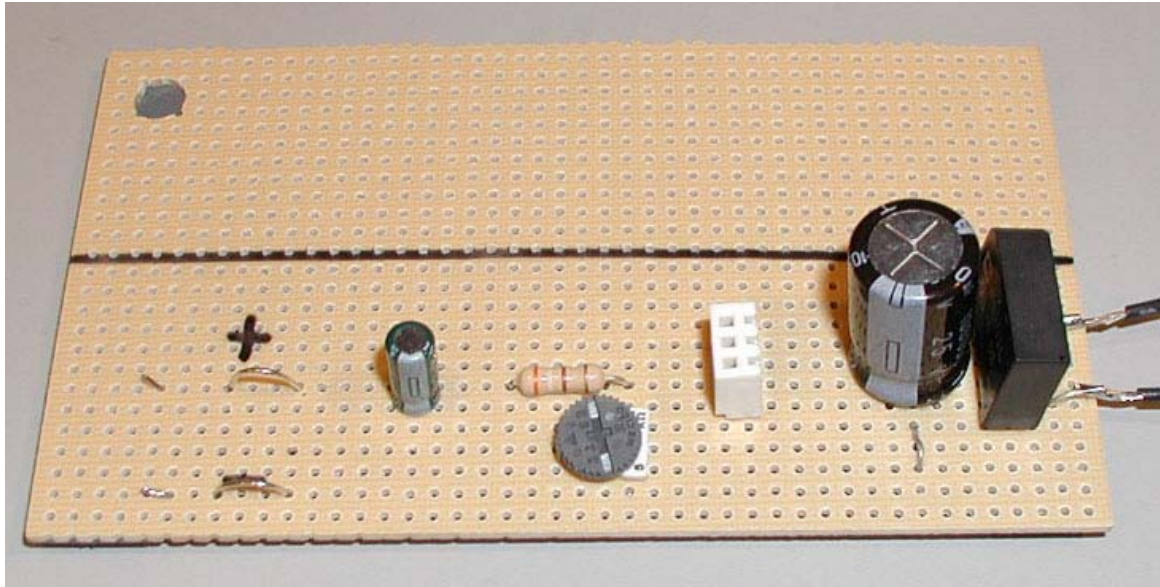


Figure 15: Top view of LVPS (transformer leads on right)

There are many ways to assemble the LVPS, but we will give you detailed step-by-step instructions to guarantee success. It takes up less than half the space on the perfboard, **leaving room to build other things later**. The top view of the LVPS will help in placing the parts.

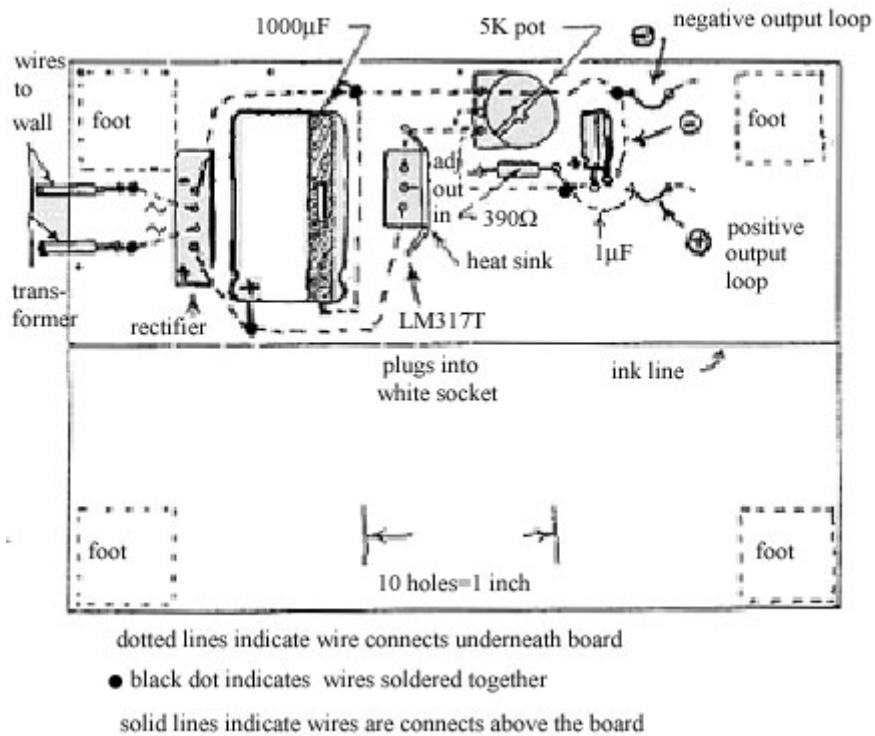


Figure 16 Top view of layout of LVPS (transformer leads on left)

Here is a template (top view) to help place the parts on the perfboard.

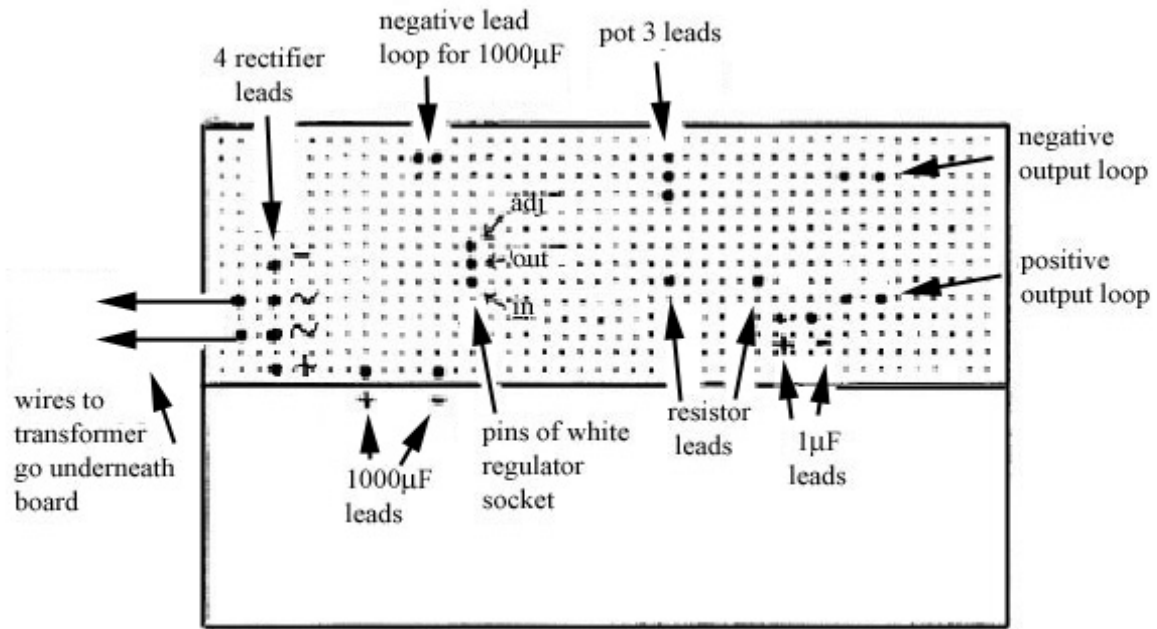


Figure 17 Template LVPS (top view)

The bottom view of the LVPS shows the wiring.

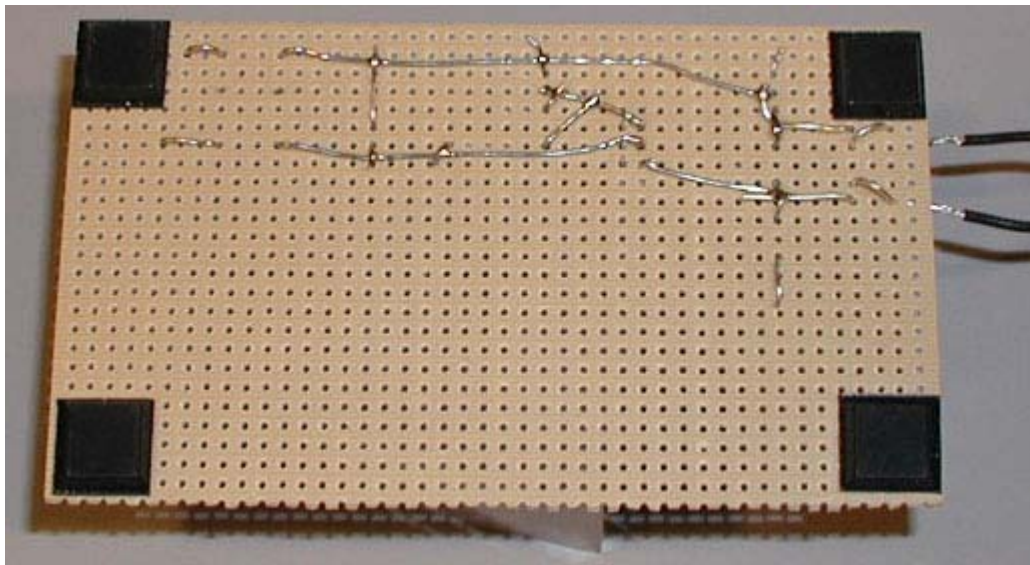


Figure 18: Bottom view of LVPS

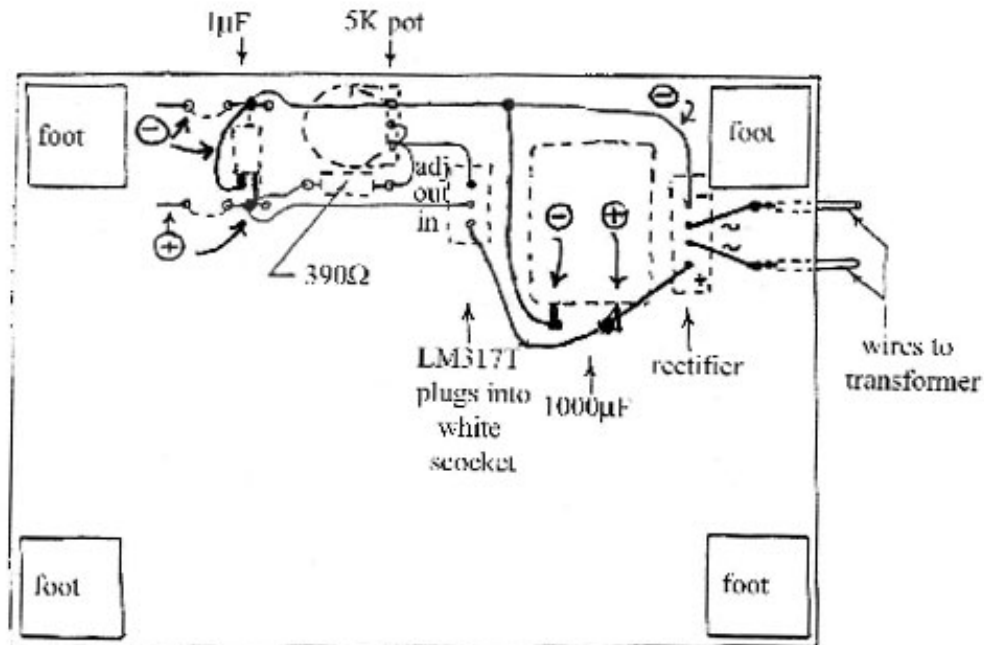


Figure 19: Wiring on bottom side of LVPS

Construction Steps

1. Find and identify parts in the plastic bag.
2. Draw a line with a pen lengthwise along the center of the perfboard.
3. Stick 4 feet on the corners of the bottom side as close to the edge as possible.
4. Place the parts according to the top view of perfboard. Bend the white socket's short leads carefully while installing. (The black regulator's three leads will fit into the socket. You will only solder the socket's leads so that the regulator can be easily removed). Identify on your perfboard which socket leads will correspond to the ADJ, OUT, and IN leads of the regulator.
5. Bend the leads of the rectifier, capacitors, and resistors as shown on the bottom view of perfboard.
6. Measure, cut, and solder a piece of the bare #22 wire to the minus lead (-) of the rectifier. Extend this wire across the board, and then form a loop on the top side. This will be the minus (-) output loop.
7. Loop the end of the minus lead (-) of the large capacitor (the band points to the minus lead) through the perfboard at the bare wire from step 6. (This will help hold the capacitor to the perfboard). Solder the minus lead (-) of the large capacitor to the bare wire from step 6.

8. Solder the pot lead nearest the edge of the perfboard to the bare wire of step 6. Be sure the pot is oriented as shown in the top view.
9. Solder the minus lead (-) of the small capacitor (the band points to the minus lead) the bare wire of step 6.
10. Solder the plus lead (+) of the rectifier to the plus lead (+) of the large capacitor.
11. Solder the plus lead (+) of the large capacitor to the IN lead of the socket. (See step 4).
12. Measure, cut, and solder another piece of the bare #22 wire to the OUT lead of the socket. Extend this wire across the perfboard, and then form a loop on the top side. This will be the plus (+) output loop.
13. Solder the plus lead (+) of the small capacitor to the bare wire of the previous step 12.
14. Solder one lead of the resistor to the bare wire of step 12.
15. Solder the other lead of the resistor to the two other leads of the pot, thus connecting those two leads of the pot together.
16. Measure, cut, and solder another piece of the bare #22 wire to the ADJ lead of the socket to either of the connected pot leads of the previous step 15.
17. Remove about 6 mm of the insulation from two different lengths, 50 mm and 100 mm (2 in and 4 in) of black stranded wire. Tin all four ends and solder one length to each of the ac leads of the rectifier.

Trying out Your LVPS

Do not plug in the LM317T regulator. You should have already soldered alligator clips to your transformer leads, multimeter leads, and made clip leads. Clip one of the wall transformer leads to one of the LVPS leads of step 17.

Set the MMM to the 25DCV range. Connect the voltmeter across the 1000 μF capacitor, red to the plus side and black to the minus side. Plug in the wall transformer. Now touch the second transformer lead to the other ac lead of the LVPS. There should be little or no spark and the meter should read about 17V – 18V. Transfer the voltmeter leads to the output loops. Place the regulator in the heat sink with its metal back covered by the heat sink. **Now plug in the regulator into the socket with the number LM317T facing the large capacitor.** Turn the pot and the output should vary from about 1.2V to 15V or more.

To make sure that your LVPS is working as it should, use the 1157 lamp (used as a rear brake light in a car) from the plastic bag labeled LVPST (*LVPS Test Kit*) as a load on the LVPS. This lamp has two filaments (tail and stop light) with nominal ratings of 8 watts and 27 watts respectively at an applied voltage of 12.6V.

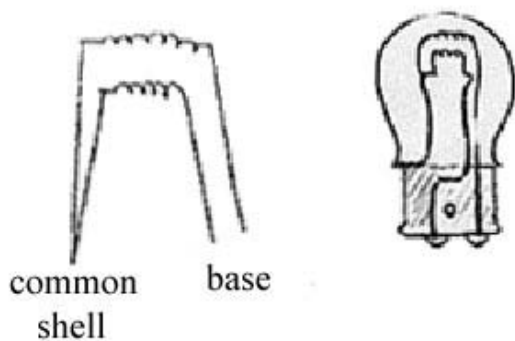


Figure 20: Lamp and socket

One lead to each filament is connected to the brass shell and the other lead is connected to one of the two terminals (soldered bumps) on the base of the lamp.

Plug the lamp into the socket provided in your Red Box. There are two black leads from the socket. In order to connect one of the filaments to the LVPS, use your clip lead to connect one of the black wires from the socket to one output of the LVPS. Use a second clip lead to connect the other output of the LVPS to anywhere on the socket. (This connects the LVPS to the brass shell of the lamp.) Identify the 8W filament (cold resistance about 2Ω), either with your MMM on the RX1 range or by lighting it with the LVPS---it's the upper filament in the lamp.

Parts List for LVPS

LVPS

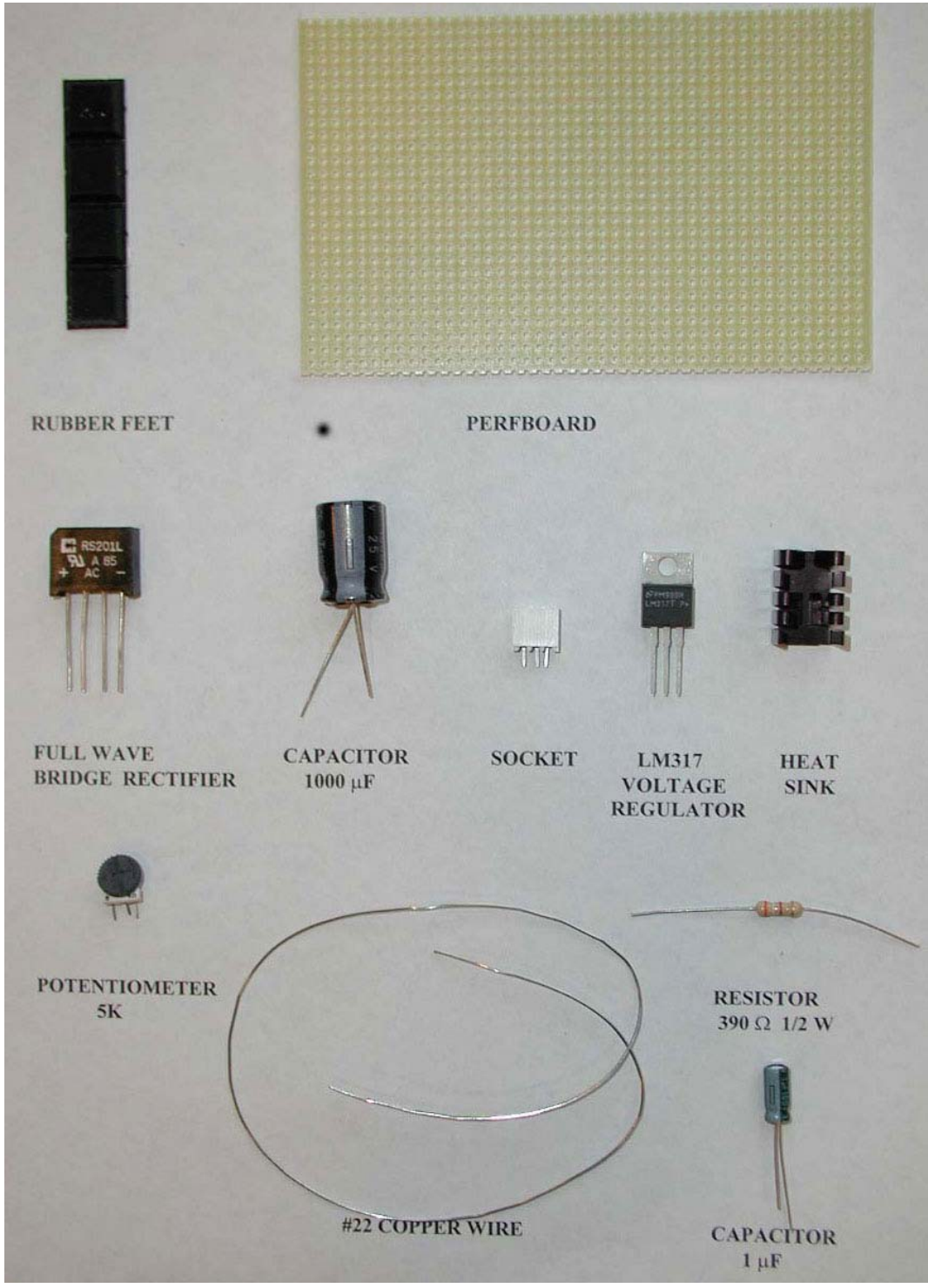
- 1 perfboard
- 4 rubber feet
- 1 full wave bridge rectifier
- 1 electrolytic capacitor, $1000\mu F$
- 1 socket for LM317T regulator
- 1 potentiometer, $5k\Omega$
- 1 electrolytic capacitor, $1\mu F$
- 1 resistor, 390Ω $1/2W$
- 1 ft wire, #22 bare solid
- 1 voltage regulator LM317T
- 1 heat sink for LM317 regulator

LVPST

- 1 resistor, 2.4Ω $2W$
- 1 lamp #1157 automotive

RED BOX

- 1 socket for 1157 lamp



Testing the LVPS

Each of you has built a power supply that converts ac (alternating current) power at 120V (volt), at a frequency of 60 Hz (hertz = cycles/sec) from the wall outlet into dc (direct current) power with a voltage range from 1.2V to about 17V. When the output voltage without load (lamp) is set between 1.2V and about 12V, the output voltage will not change appreciably if a load is then placed across it. You will find that range when you place the 8W (watt) filament of an 1157 lamp across the output of the LVPS. **See Building the LVPS: Trying out your LVPS.**

Measurements and Data

You can set your pot at ten different settings from lowest to highest output by turning the top of the pot either clockwise or counterclockwise (depending on how you wired the legs). Set the pot so the no load output voltage is minimum, 2V, 4V, 6V, 8V, 10V, 12V, 14V, 16V, and maximum. Use the accompanying table to record the results of your measurements. For each setting you will:

1. Measure the output voltage (no-load voltage) of the LVPS when the lamp is not connected;
2. Measure the output voltage (load voltage) of the LVPS when the lamp is connected across the output of the LVPS.
3. Then connect the lamp and measure the load voltage across the terminals of the LVPS.

Questions

1. What range of no-load output voltages remains unchanged after the lamp is connected across the LVPS output terminals?
2. Briefly describe how you distinguished between the 8W filament and the 27W filament?
3. What happens when you connect the outputs of the LVPS to the two black wires in the socket? Can you figure out the wiring diagram for the lamp?

Graph

Plot the output voltage of the LVPS without the lamp connected along the horizontal axis and the output voltage of the LVPS with the lamp connected along the vertical axis.

Data Table for LVPS

Pot Setting	V_{LVPS} (no load) [volts]	V_{LVPS} (load) [volts]
minimum		
	2	
	4	
	6	
	8	
	10	
	12	
	14	
	16	
maximum		