TAB BOOKS/No.806 $9.95

THE POWER SUPPLY HANDBOOK

A broad and varied collection of ready-to-build power sources for electronics hobbyists and engineers.

BY THE EDITORS OF 73 MAGAZINE

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TAB BOOKS Inc.
BLUE RIDGE SUMMIT, PA. 17214

FIRST EDITION

FIRST PRINTING—JANUARY 1979
SECOND PRINTING—APRIL 1980

Printed in the United States of America

Library of Congress Cataloging in Publication Data

Main entry under title:

The Power supply handbook.

Includes index.
1. Electronic apparatus and appliances—Power supply. I. 73 magazine for radio amateurs.
TK7868.P6P68 621.381'04'4 78-31272
ISBN 0-8306-9806-X
ISBN 0-8306-8806-4 pbk.

Foreword

All too often the power supply takes a backseat to other electronic circuits. It is a simple matter to say "...and build a power supply to furnish the required voltage and current." But when it comes down to actually building the power supply, it isn't as easy as you might imagine without some sort of guidance, unless you're an electronic engineer with a warehouse of parts at your disposal.

Well, the guidance is here in these 420 pages of *The Handbook of Power Supplies*. This is a collection of every conceivable type of power supply for the electronic hobbyist, ham, experimenter, engineer, technician, CBer, and do-it-yourselfer. Be it a lab supply, inverter, or special purpose type, you can build it, or even possibly design it from scratch, with the information compiled here.

With the onset of home computers in kit form and the like, this book takes on even more significance. These mini-brains require power supplies of special caliber to protect the microprocessors and other logic circuits from damage. Many of these aspects of power supply selection are covered in Chapter 1.

Regulated low-voltage power supplies are by far the most often used in today's solid-state circuitry. Chapter 2 covers a multitude of this type of supply. You'll find regulated supplies with rated outputs from 0.35V on up to 50V in this chapter.

There's going to be a case when you find a power supply that fits your requirements in every way except one minor detail, and that is the purpose of Chapter 3. This chapter is a collection of mostly add-on gadgets that can be attached to an existing power supply, a voltage splitter for example.

Although it seems as though vacuum tubes have almost disappeared, there's still a lot of equipment floating around that rely on them. And these pieces of equipment also require power supplies, but they need higher voltages than our common regulated low-voltage supplies of Chapter 2 deliver. Chapter 4 covers a few of these high-voltage supplies chiefly for transmitters and the like. One of these babies delivers 3000V!

Chapters 5, 6, and 7 cover inverters, AC-to-DC converters, and DC-to-DC converters, respectively. Battery chargers, another type of power supply, are the subject of Chapter 8, including special types for silver-zinc and gelled cells. Sensing circuits, both voltage and current, are covered in Chapter 9. Mobile power and accessories are handled in Chapter 10.

A final chapter deals with special purpose AC supplies. Whatever the application, you will have no trouble finding or designing a power supply with the wealth of knowhow contained on the following pages.

Mike Fair
TAB Editorial Staff

Contents

Chapter 1
Power Supply Facts

This chapter contains all of the raw data that you need to engineer your own power supply. You'll probably discover that in many cases some of the power supplies illustrated in later chapters will come very close to what you require for a particular circuit; however, there are those slight variations that you need to know how to handle. This is the purpose of the information included here—to smooth out those ripples.

You'll also read about a lot of hard-core theory in this chapter. There are several sections that deal with actual power supply design from scratch. Then there are sections that deal with power transformer ratings, how to build transformerless supplies, how to make the most of triacs, and even how to test a supply for home computer applications.

DESIGNING A REGULATED SUPPLY

Regulated power supplies are a mystery. Almost every IC construction project includes a regulated supply and most solid-state equipment built for 117V also has a regulated supply or supplies to power the low-voltage solid-state devices. But the mystery is that while most hobbyists have a good idea of how to use transistors and integrated circuits in simple applications, few have the remotest idea of how the regulated

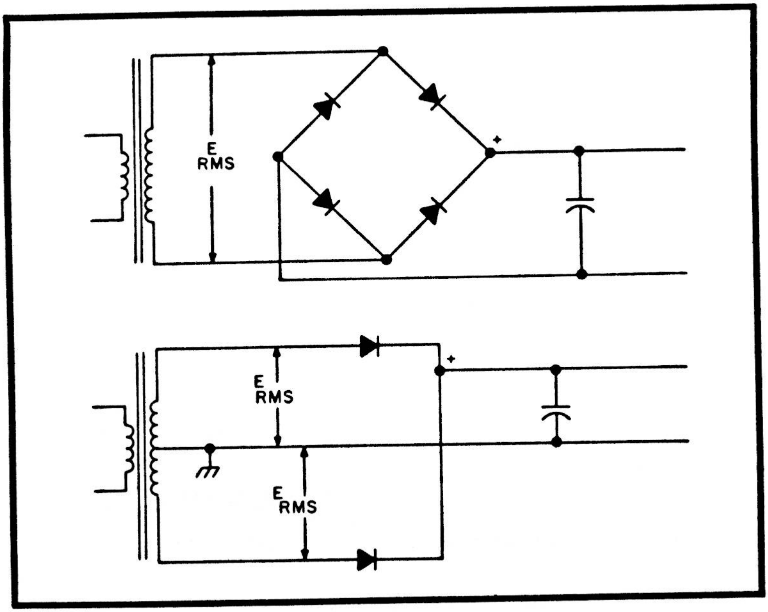

Fig. 1-1. Schematic of full-wave rectifier circuits. (A) Bridge. (B) Center-tapped transformer.

supply works and fewer still could design one from scratch if required to.

This portion of the chapter deals with the operation of regulated power supplies for low-voltage applications and gives all the necessary information needed to design a regulated supply from scratch. Information is given so that the designer may select the proper components such as the transformer, diodes, capacitor, regulator, pass transistors and heat sinks. Sources for all parts are given so that the designer won't be stuck for some hard to find parts.

The regulated power supply consists of an unregulated DC power supply feeding a regulating circuit. The unregulated DC supply may consist of a full-wave rectifier feeding a filter capacitor as shown in Fig. 1-1 or it may be a battery used in a mobile or portable installation. The regulating circuit may be a circuit made up of discrete components or it may be a regulating IC, such as the NE550. Components and design options are chosen according to the voltage and current requirements of the project needing the regulated supply.

Integrated circuit voltage regulators are commonly used today, rather than discrete components, because of their low cost and ease of use. The basic design comes from the Signetics *Digital, Linear, Mos* manual and is based on the Signetics NE550 regulator IC. This basic design is simple and permits numerous output voltages and limiting currents by merely selecting readily available resistor combinations.

The DC Power Supply

The DC power supply used for most low-voltage power supplies is a capacitive load circuit as shown in Fig. 1-1. Inductive filters are occasionally used instead of capacitors, but high-value, high-current inductors are more difficult to locate and more expensive than low-voltage high-value capacitors. Either a full-wave (Fig 1-1) or half-wave (Fig. 1-2) circuit may be used to supply the DC; however, a full-wave circuit is preferred because it provides better basic regulation. The full-wave circuit is used in this design.

In order to determine the voltage and current ratings of the components to be used in the unregulated DC power supply, it is first necessary to determine the voltage and current requirements of the equipment or device to be powered. When determining these power requirements it is best to allow reasonable safety factors in order to prevent overheating and to insure that the equipment will operate correctly. Normally a current safety factor of 10% is allowed in cases

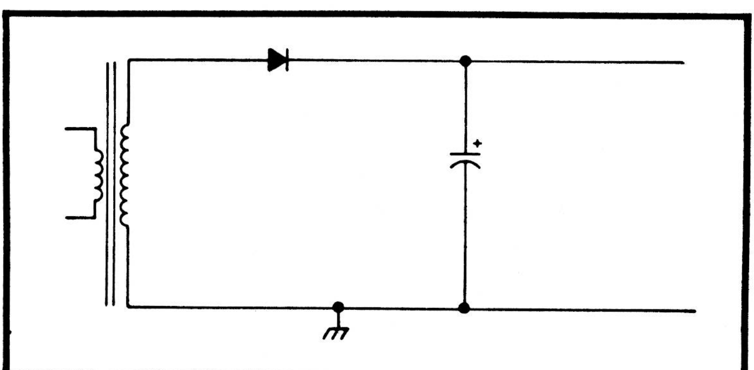

Fig. 1-2. Schematic of half-wave rectifier circuit.

where peak current is being drawn 50% of the time or less. In all other cases allow a safety factor of one-third.

To determine the required current rating for the transformer use the formula $I = 1.3 \times I_p$, where I_p is the anticipated peak current requirements of the equipment.

The designer may design the basic unregulated DC power supply so that the DC output voltage is anywhere from 30% to 98% of the peak AC voltage of the transformer. If a large value filter capacitor is used, the 98% value may be achieved and little ripple will appear on the output of the basic supply. Unfortunately, very high-capacitance capacitors are expensive and in some cases may be hard to find. Smaller value capacitors are less expensive and easy to locate but will give lower DC outputs and will produce appreciable ripple on the output. For given DC output voltage (under load), the AC output of the transformer will have to be higher for small filter capacitors as compared to large value filter capacitors. Note that in general it is less expensive to use a transformer of higher voltage with a low-capacitance capacitor for a given DC output than it is to use a large capacitor and a lower voltage transformer to produce the same DC voltage. This is logical since the cost of a transformer does not increase appreciably as the voltage goes up, while the cost of a capacitor increases significantly as the value of capacitance goes up. In order to minimize the cost of the supply, one of the design factors is to keep the filter capacitor to moderate size and low cost.

Keep in mind that with no load on the output, the DC output from a simple capacitive filter supply will be virtually ripple free. When a load is placed across the supply, ripple will be evident. Further, the amount of AC ripple on the DC output will increase as the size of the filter capacitor decreases (everybody knows that), but this AC ripple can be significant and not affect the operation of the regulator.

Determining the DC output voltage for a given transformer voltage can be difficult task if exact values are required. For practical purposes, however, only minimum values, not exact values are needed. For example, if our computations show us that we will get 18V DC output from a DC supply, but we really get more than 18V, then this is of no consequence. We only want to assure ourselves that we will get at least the minimum required under load. With this in mind, the following formulas can be used to determine the AC (RMS) value of the transformer required:

$$E_{PEAK} = 1.4 \times E_{MS}$$
$$E_{OUT} = .71 \times E_{PEAK}$$

thus,

$$E_{OUT} = 0.71 \times 1.4 \times E_{RMS}$$

where E_{OUT} is the minimum DC output voltage from the unregulated DC power supply, and E_{RMS} is the secondary voltage of the transformer. In summary, the anticipated DC output voltage under load from a simple unregulated supply as shown in Fig 1-1 will be equal to or greater than the AC voltage from the secondary of the transformer. This will only hold true if the current ratings of the transformer are not exceeded. The above formula takes into consideration that a moderate size capacitor will be used and is based on the assumption that ripple on the DC output voltage can be 10% or less. The NE550 regulator IC, which is used for the design presented here, can tolerate 10% ripple provided that the lowest DC input voltage (low part of the ripple) is at least 3V higher than the desired DC regulated voltage. Thus, we will have to consider the DC input voltage to be the bottom of the ripple as shown in Fig. 1-3. Note that the peak voltage cannot be higher than the maximum ratings of the NE550. As defined, $E_{DC\ INPUT} = E_{REG} + 3$, where E_{REG} is the desired regulated voltage.

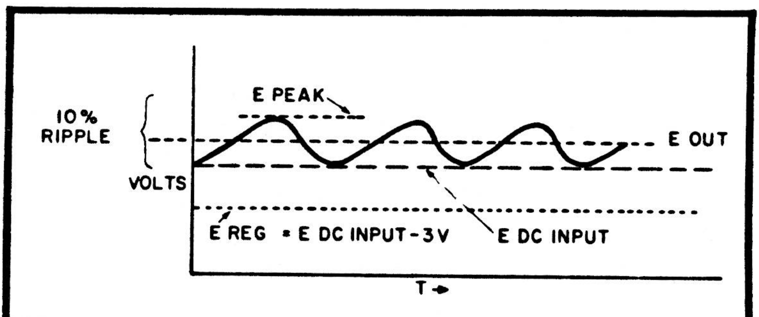

Fig. 1-3. Allowable ripple.

Current	Voltage	Distributor	Part #	Approx. Cost
3 A	12.6 V	Radio Shack	273-1511	$4.29
2 A	25.2 V	Radio Shack	273-1512	4.29
6.6 A	6.3 V	Verada		3.75 ea., 3/$10
2.5 A	30 V	M. Weinshenker		4.85
12 A	18 V	VHF Engineering		

Fig. 1-4. Listing of possible transformers to use in designing a regulated power supply.

The DC input voltage is also 95% of E_{OUT} (E_{DC} input is 5% lower then E_{OUT} because of ripple); thus $E_{DC\ INPUT} = 0.95\ E_{OUT} = 0.95\ E_{RMS}$. Solving the two equations gives $E_{RMS} = (E_{REG} + 3)/0.95$. We now have a very simple formula to use to determine the secondary (E_{RMS}) value of the transformer given only what we want for a regulated voltage and assuming that we will not exceed the manufacturer's current rating for the transformer chosen.

These formulas given for I and E_{RMS} will hold true for virtually all low-voltage, high-current supplies provided that good quality properly designed transformers are selected. The transformers recommended mentioned later fall into that class. If low-grade transformers with high internal resistance are used, then E_{RMS} may approach a value of $(E_{REG} + 3)/0.5$.

As an example, assume that we want a power supply to deliver 5A at 12V regulated. The minimum ratings of the transformer would be determined as follows:

$$I = 1.3 \times I_p = 1.3 \times 5 = 6.5\text{A}$$

$E_{RMS} = (12 + 3)/0.95 = 16\text{V}$. Looking through the various catalogs you probably won't find a transformer that has a secondary exactly matching our requirements, but you would find one that exceeds the requirements. Looking at Fig. 1-4 we find that Verada in Lowell, Massachusetts, is offering $3.75 each or 3 for $10. Three of these transformers with their secondaries in series, primaries in parallel, (Fig. 1-5) will give an output of 18.9V at 6.6A at a cost of $10.00. This is well less than the equivalent single transformer would cost if purchased from an electronic supply house. Thus three Verada transformers are used in this design with an RMS secondary voltage of 18.9V.

It is a good idea to check the peak DC output voltage obtainable under any circumstances to see that this voltage does not exceed the voltage ratings of the NE550 regulator. The maximum voltage is given by $E_{MA} = 1.4 \times E_{RMS}$. Thus in our case $E_{MAX} = 1.4 \times 18.9 = 26.5V$. The maximum voltage rating of the NE550 is 40V. We are within the limits in this case. In a case where E_{REG} is 37V, the maximum allowable for the NE550, or any case where E_{MAX} exceeds 40V, then the circuit in Fig. 1-6 must be used to provide the DC input voltage to the regulator.

Selection of diodes can be made in a fashion similar to the transformer. Diodes in a full-wave configuration pass only one-half the total current, thus $I_D = 0.5I$, where I_D represents the current requirements of the diodes. In our example, the maximum current is 6.5A, so the diodes would have to handle 3.25A each. Since this an oddball value, the next higher current rating would be used such as diodes with a 6A rating. To be conservative for low-voltage supplies, the voltage ratings of the diodes should be greater than the maximum peak voltage that can be encountered. For a bridge rectifier config-

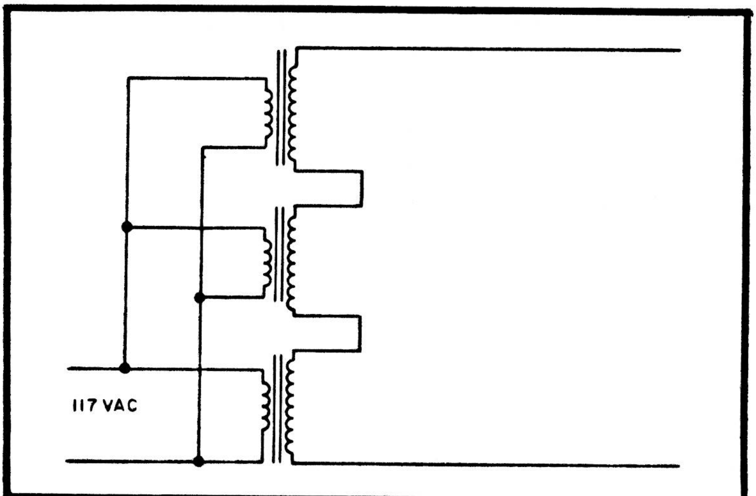

Fig. 1-5. Schematic of three transformers with their secondaries wired in series and primaries in parallel.

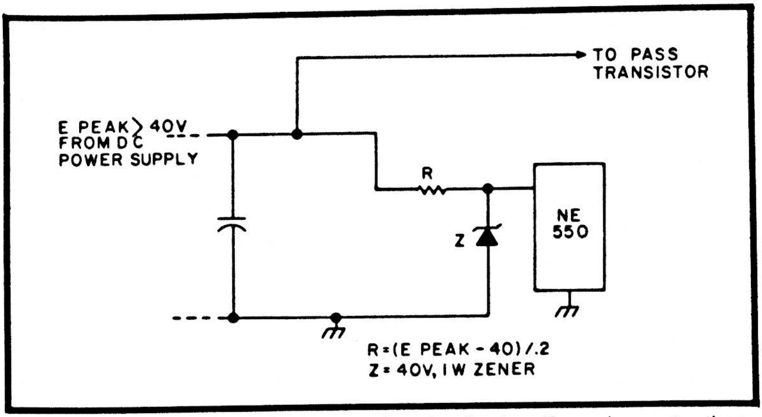

Fig. 1-6. Schematic of regulator protective circuit when E_{PEAK} is greater than 40V.

uration, each diode should have a PIV (peak inverse voltage) rating of four times the E_{RMS} value of the transformer secondary, while for a center-tapped rectifier configuration the PIV should be six times the E_{RMS} value of the transformer secondary. In our example, diodes in a bridge would have to have a minimum PIV rating of 75.6V, while diodes in the half-wave configurations should have a rating of 113V. These are oddball values, so we would use diodes of the next higher rating. A bridge with 100 PIV rating could be used (Poly Paks 10A, 100V bridge) or two diodes in center-tapped configuration with a rating of 150V would do. Note that the current rating for a complete diode bridge (as compared to individual diodes in a bridge) is not divided in half. In this example 6.5A is the requirement, so a 10A bridge would be required. Diode bridges are preferred since they are usually epoxy encapsulated and may be mounted directly to a heat sink without having to worry about mica insulators and special means to provide insulation.

The Filter Capacitor

The filter capacitor smooths the pulsating DC and gives steady state DC with some percentage of ripple on top. One of design criteria is that we can tolerate 10% ripple. If the wrong capacitor is chosen, the ripple may exceed 10% (if the capacitor is too small) and the output voltage may be too low,