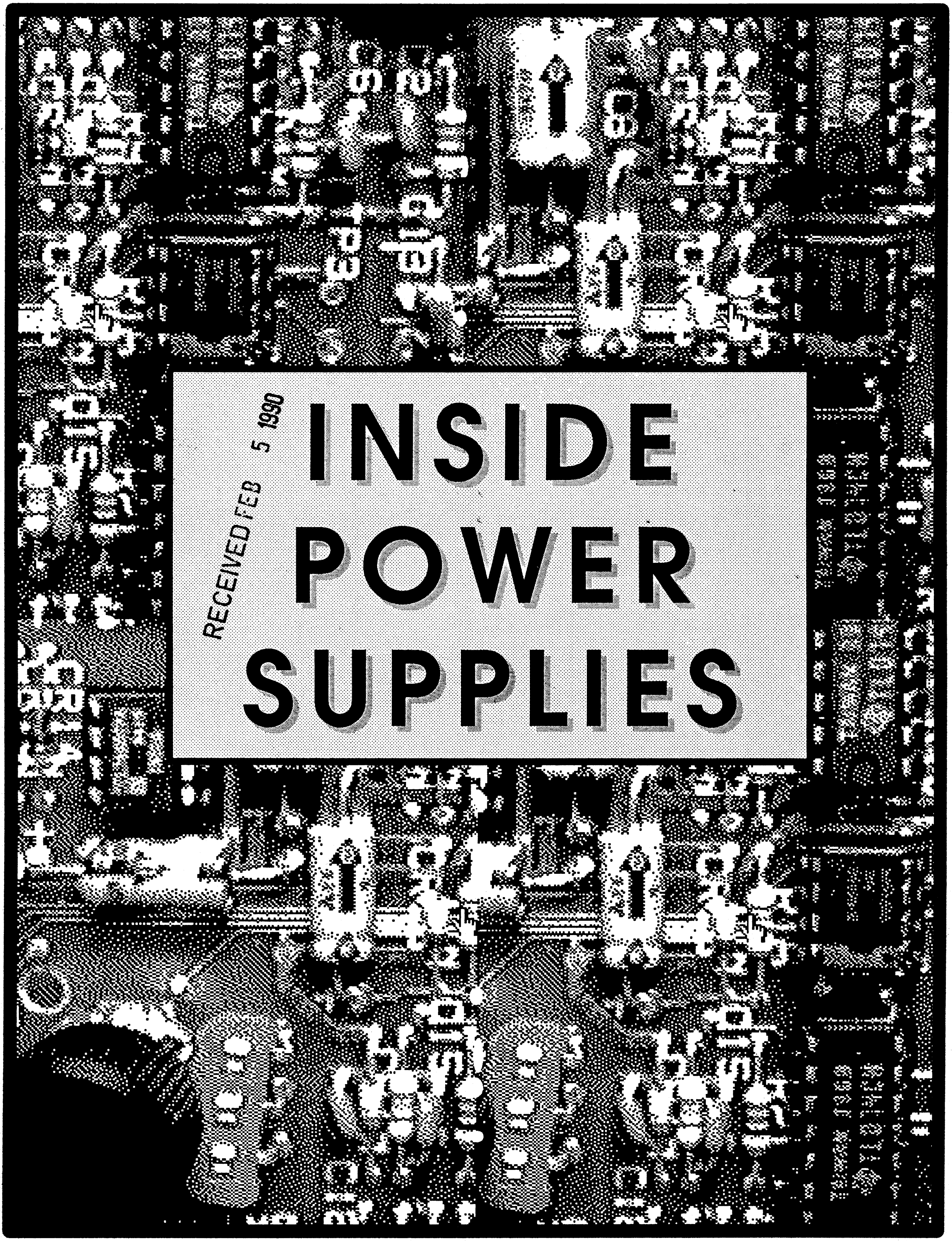


INSIDE POWER SUPPLIES

INSIDE POWER SUPPLIES

CONTENTS

INTRODUCTION

The purpose of this manual is to give you a basic overview of what a power supply is, what the basic components in one are, how a power supply accomplishes its job, and what to do when it does not function properly.

Due to the nature of the systems used in the Coin-Op Industry, I will concentrate on power supplies that are running logic boards and associated systems.

Extensive theory of operation and semiconductor theory will be avoided. This gives us the ability to get down to "brass tacks" and do some "real world" troubleshooting.

The beginning of this manual covers most of the theory and basic electronics that will be covered. If you already have a working knowledge of this, you may wish only to skim through those sections. However, the more in depth information, in the back, is well worth concentrated reading. There you will find actual circuits and trouble shooting tips.

I hope you find this manual informative, and ultimately, I hope it helps you with the troubleshooting and repair of the power supplies you will run into every day, as a Coin-Op technician.

POWER SUPPLIES AND THEIR LIMITATIONS

Power supplies come in many shapes, sizes and forms. The simplest power supply is the common battery we run into every day, and supplies range in complexity all the way up to the DC to DC converter; otherwise known as the switch mode power supply. They all have one goal in common, to supply the proper power to the load applied.

Unfortunately, they also have another thing in common, operating limitations. The "ideal" power supply could be considered to be a battery that is capable of supplying an infinite amount of current, never degrades with use, and has no internal resistance. Needless to say, such supplies do not exist, although design engineers go to great lengths to come as close as possible.

We are all familiar with current limitations, but the idea of internal resistance may need a little clarification. All "real world" power supplies have the equivalent of a resistor in series with its output. Figure 1-1 shows the comparison of an ideal power supply and a "real world" power supply. This internal resistance becomes an important factor when powering a load that has a varying current demand, like a logic board. Figure 1-2 numerically demonstrates this effect.

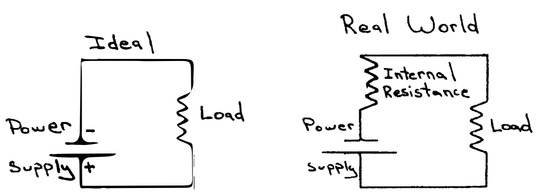


Figure 1-1

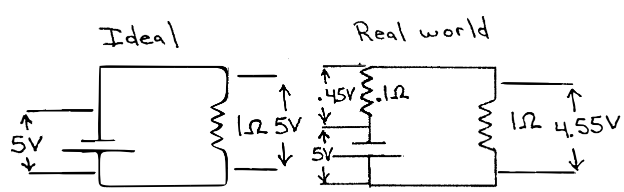


Figure 1-2

As you can see, the internal resistance of the supply doesn't cause much of an effect at low current demands, but as the current demand becomes greater the internal resistance of the supply drops more and more voltage, decreasing the amount of voltage reaching the load. A logic board, that may have literally millions of transistors switching "on" and "off" at a high rate of speed, demand the use of a power supply with an extremely low internal resistance.

Otherwise, the fast paced changes in current demand, caused by the switching of logic transistors, would cause fluctuations in the voltage, known as noise. Later in this manual you will see how failed components, and your selection of replacement components, can cause increases in this internal resistance leading to unreliable board operation or possible damage to the logic boards.

Basic Components Of Power Supplies

Transformers

In power supplies, transformers perform two major functions: One is voltage conversion, the other is isolation.

Voltage conversion is the most obvious function. The 120Vac that is supplied by the national power grid is, in general, much too high to be easily regulated down to lower voltages without being extremely inefficient and dissipating a *lot* of heat. Not only that, if there were a regulator failure and the unregulated voltage were applied directly to the board the result would be disastrous.

Isolation is another important function. A transformer creates an almost complete isolation of its output with respect to the wall power that is driving it. This is a good idea for safety's sake. If there were no isolation from the main power grid it could be possible for someone to be electrocuted by touching one of the supposed low voltage outputs and even the low voltage ground wouldn't be at 0 volts with respect to earth ground. Transformers that are used to power monitors don't even perform any voltage conversion, they are just used solely for isolation purposes.

A transformer is only capable of passing a fluctuating signal. DC will not cause an output to be produced. If DC were applied the output would pulse briefly while the magnetic field expands, but it would quickly drop off. Figure 2-1 shows the input and output relationship of a transformer being driven by different wave forms.

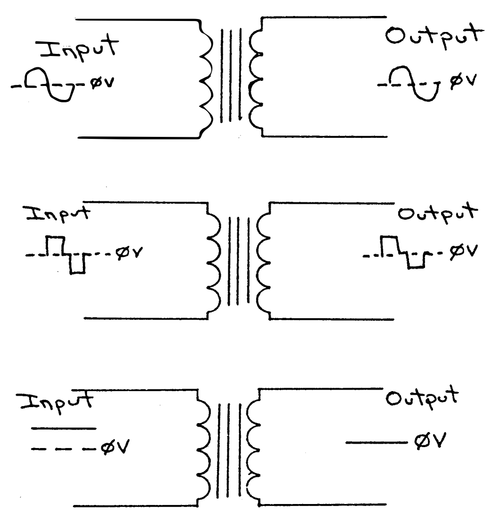


Figure 2-1

The two main classes of transformers that will be encountered when servicing power supplies are: Wall voltage driven and Pulse transformers.

Wall voltage transformers are designed to function at the low frequencies that are provided from the AC power grid, and tend to be much larger than their equivalent pulse transformer counterparts. Figure 2-2 shows the relative sizes of a 60Hz power transformer and the equivalent pulse transformer.

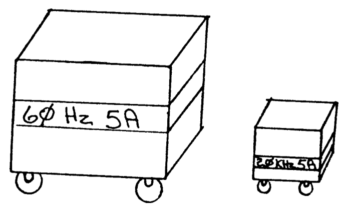


Figure 2-2

Pulse transformers are used in switch mode regulators. They are designed to operate at much higher frequencies than the standard 60Hz available at a wall outlet. Their power output to volume ratio is very high, this is why switch mode power supplies can deliver such high output currents and yet be so small.

Resistors

Resistors have got to be the most common passive component used in electronics today. Figure 2-3 shows the schematic symbol of a resistor. The name resistor is very descriptive of what it does. Resistors resist the flow of current that passes through them.

Figure 2-3

Resistors are rated in how much they resist current flow, expressed in ohms, and how much power they can dissipate, expressed in watts. For example 330 ohms, 1/4 watt.

When replacing defective resistors in power supplies, both values must be taken into consideration. You usually can use a resistor that has a higher power dissipation, but the ohm value shouldn't be bumped more than about 5% in either direction to ensure proper operation.

Resistors also come in different classes. The two types that will be encountered most in power supplies are carbon composition and wire-wound. The main difference is that wire-wound types can be operated much closer to their maximum power dissipation without adversely affecting the life span of the device. You might think this sounds great and why aren't wire-wound types used in all applications. The most obvious reason is cost.

Wire-wound resistors tend to be much more expensive than carbon types, and since they are literally a spool of resistive wire wound on a core, they tend to act like an AC choke when a signal that has an AC component is passed through them. Sometimes this choke effect is desirable, but in amplifiers it usually is not. A wire-wound type will usually be identified on the schematic, but if it is not, you can usually see the actual spool of wire showing through the coating that has been applied over it.

As a rule of thumb: Replace resistors with as close to an exact replacement as possible to avoid undesirable side effects.

Capacitors

Capacitors are the main energy storage and filtering device used in power supplies. They are also one of the components that determine the internal resistance of the supply. Figure 2-4 shows the schematic symbol of a capacitor and figure 2-5 shows the "real world" model.

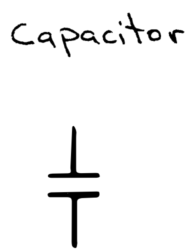


Figure 2-4

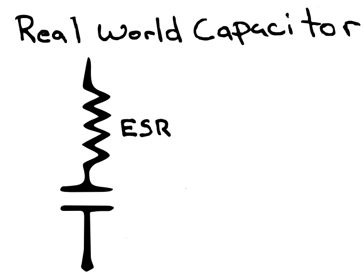


Figure 2-5

Capacitors in power supplies are current storage devices used to maintain a constant DC output even though the input signal may drop to 0 volts for certain periods of time. They can be thought of as extremely fast recovering batteries that can dump all of their current almost instantly.

The capacitance needed to maintain a constant DC output drops as the input frequency to the filter increases. That's why 60Hz transformer powered supplies have large filter caps. Another factor is the amount of current drawn from the supply. The more current delivered to the load, the bigger the capacitor reserve must be to ensure a steady output when the input signal drops to 0 volts.

All capacitors have an ESR, or Equivalent Series Resistance (shown in Figure 2-5). This resistance causes a decrease in filtering capability at high frequencies, this is why in some switch mode supplies the designers parallel several small caps instead of using one large capacitor. Paralleling the caps is in essence paralleling the internal resistors also, reducing the overall effect. In other words three 1K Mfd capacitors are a better filter than one 3K Mfd.

With resistance also comes another problem, heat. Anytime current is passed through a resistor -heat is produced. In a capacitor that is working properly, the ESR is so low that the heat produced is negligible and there is no problem dissipating it. As an electrolytic capacitor ages, and dries out a little, the resistance goes up, that causes more heat. The heat dries out the capacitor more, the resistance goes even higher and so on until total failure results. A capacitor should *always* run cool, any one that gets warm or hot should be replaced.

Capacitors all have a basic construction. Two conductive plates separated by an insulator. The plates hold the charge while the insulator keeps the plates from shorting or loosing their charge. The thinner the insulator the more capacitance per volume of space, but also a limitation, voltage breakdown. The amount of voltage a capacitor can block until the insulator breaks down is determined by the insulator, and is usually marked on the capacitor. Never, never, operate a capacitor at a higher voltage than its rating. It may short or or even blow-up!

The materials used to make a capacitor determine its operating characteristics and physical size. Electrolytic capacitors, the workhorse of the cap world, are made of aluminum plates separated by a "wax paper" insulator and an electrolyte paste. They offer high capacitance in a small package, but they tend to act like a choke at high frequencies. They are also polarity sensitive, that is they have a positive and a negative lead.

Tantalum capacitors are made from just that, tantalum. They offer high capacitance per volume and good high frequency response, but they are much more expensive than electrolytics, so they are only used where their particular characteristics are needed. They are also polarity sensitive. Mylar, ceramic disc, and polyester caps offer different combinations of characteristics, but can usually be interchanged in power supply circuits. They are not polarity sensitive.

One quick note: Electrolytics are available in low ESR types for use in switch mode supplies and other high frequency applications.

Chokes

Chokes are another filter/energy storage device that is primarily used in switch mode power supplies. Figure 2-6 shows the schematic symbol of a choke. Chokes are like a mirror image of a capacitor. Capacitors block DC and let AC pass, chokes block AC and let DC pass. In linear regulators, chokes usually consist of a little ferrite bead over a small jumper wire. This type of choke is used to keep the supply from oscillating. In switch mode supplies chokes are usually coils of wire wound onto ferrite cores. There they are used to block the high frequency AC signal that comes from the pulse transformer, and the magnetic field is stored energy that is released when the field collapses. Since power supply chokes are wound from heavy wire they very rarely open up or short and never should need replacing.

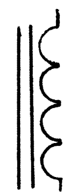


Figure 2-6

Rectifiers

In electronics, rectifier usually means, diode. Figure 2-7 is the schematic symbol of a diode. In power supplies, the rectifier section can be a single diode, or a full wave bridge made of 4 diodes. Figure 2-8 shows the schematic symbol of a full wave bridge. As you can see, it is just 4 diodes put together. Sometimes all of the diodes will be encased in a common 4 lead package, at other times it will consist of the actual 4 diodes mounted to a PC board.

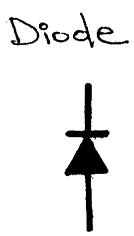


Figure 2-7

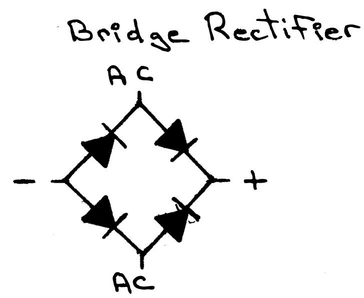
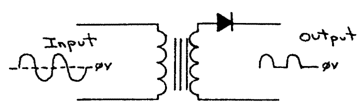
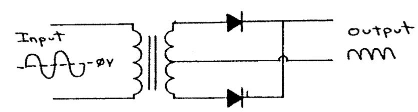


Figure 2-8

A rectifier diode serves the function of allowing current flow in only one direction. The easiest way to remember which way is easy, if not a little strange, the electrons flow in the *opposite* direction of the arrow in the schematic symbol, or from the cathode to the anode. On diodes, the cathode is marked by a band on the package and it corresponds to the bar at the end of the arrow in the symbol. This one-way valve effect is what converts AC to pulsating DC.

Figure 2-9 shows the wave form of a half wave rectified AC. A bridge rectifier is a full wave device that rectifies both sides of the wave form. Figure 2-10 shows the output of a bridge circuit. Since the voltage out of a bridge spends less time at 0 volts, it is easier to filter, and it is the arrangement usually used. Figure 2-11 shows an alternate way to get full wave rectification from a center-tapped transformer and 2 diodes.





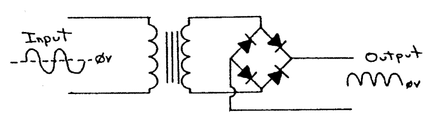


Figure 2-9 *Figure 2-10* *Figure 2-11*

Diodes are rated in PIV (Peak Inverse Voltage), current, and sometimes, the speed in which they recover (how fast they can switch states). The PIV rating is the maximum amount of voltage the diode or bridge can block in the "off" state before it breaks down. The current rating is the maximum amount of current the diode or bridge can handle in the "on" state. The recovery speed is only important when the frequencies involved are high, like in switch mode regulators. Ordinary silicon diodes work fine at 60Hz, but they tend to turn "off" and "on" too slowly for switch mode applications. Fast Recovery diode types are readily available, and should be used in "switcher" supply output sections.

The rectifier diodes are also another factor that determines the internal resistance of the supply. Rectifiers have an internal bulk resistance that varies with the current through them. The more the current flows, the more the bulk resistance. Modern fabrication techniques have all but eliminated the need to worry about a rectifier's bulk resistance. If you purchase decent quality parts and make sure you don't operate the diode beyond its limits, you won't have any problems.

You can always replace a diode with one that will handle more voltage, current, or is faster, but don't go the other way. You will just end up with another shorted diode, and another service call.

Zener Diodes

Zener diodes are another type of special diode that is used in power supplies. Figure 2-12 is the symbol for a zener diode. When a normal diode is conducting, it is called "forward biased", when it is blocking current, it is called "reversed biased". When a rectifier diode is reversed biased with enough voltage to surpass it's rating, it breaks down or suffers avalanche. This is always destructive to a rectifier diode.

Figure 2-12

Zener diodes, on the other hand, are intended to be operated in the reverse biased mode, and they are designed to break down at very specific voltages. Unlike rectifiers, zeners can recover from this avalanche or "zener effect". This means the voltage across the diode remains constant. A little mini-regulator with only 2 legs! Unfortunately they tend to be low current devices, so their output has to be amplified to be useful.

Zener diodes are rated in voltage and power dissipation. The voltage is the reverse biased breakdown voltage or the zener voltage. The power rating determines how much current the diode can shunt without getting cooked. Figure 2-13 shows a simple zener diode regulator. (Notice the resistor used for current limiting.) As long as the input voltage remains higher than the zener voltage, the output will remain constant.

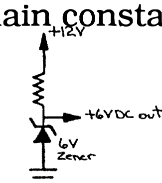


Figure 2-13

Zeners tend to run warm since they are usually passing current. They do open or short rather frequently when they are operated near their current limit, but it is rather difficult to test if they are actually breaking down at the right voltage without applying at least that voltage to them. If you suspect a zener, first check its current limiting resistor or resistors and if they are OK, swap out the diode. It is very easy to load down the output of a zener circuit, so it is also best to check any components that are connected to it also, or at least temporarily cut them loose.

When replacing zener diodes, always use one with the same voltage rating and meet or exceed the power dissipation factor.

Transistors

Transistors are the basis of all electronics as we know it today. They can act as switches to turn something on and off at a high rate, hence the name TTL or transistor transistor logic. They can also act as amplifiers, replacing the much bulkier and inefficient vacuum tubes that were the main stay before them.

Figure 2-14 shows the schematic symbols for the two types of transistors you will encounter everyday. NPN and PNP transistors operate exactly alike but the polarities are reversed. Figure 2-15 shows the current flow through both types of transistors. As with the diode, the electrons flow in the opposite direction of the arrow in the symbol. The transistor you will encounter the most is the NPN so we will use that one in all of the following examples. Just remember that PNP's act the same way with the voltages being the opposite.

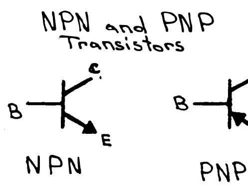


Figure 2-14

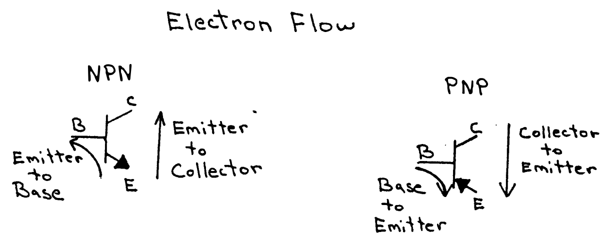


Figure 2-15

The way the transistors are operated in a power supply is how that type of supply gets its name. In a switch mode regulator the main power transistor, or transistors, are turned "on" hard to quickly switch the power on and off through the transformer. Hence the name switch mode regulator, or switcher. In series-pass or dissipative regulators, the main transistor is operated as an amplifier in its linear region. Hence the name linear regulator.

Although most of your trouble shooting will be done using voltage measurements, transistors are actually current activated devices. The gain, or hFE, is actually a current gain. For example, if a transistor has a gain of 100 and you apply a base current of 10mA the transistor can amplify that to 1 amp of output. This current amplification indirectly causes the voltage to change also.

The base of a transistor is the control input, it is here that the signal to be amplified is applied as the switch activator. There is one parameter that must be met before a transistor can be turned "on", That is, the base must have at least 0.7V greater potential than the emitter. This also means that when the transistor is turned "on" the emitter will always have about 0.7V less than the applied base voltage (remember that the voltages are reversed for PNP). When operated as a switch, the emitter is usually tied directly to

ground. This means that the emitter can never have any positive potential on it. That causes the transistor to turn "on" very *hard* for voltages above 0.7V, and it acts like a switch.

The emitter being 0.7V less than the base is what is exploited in linear regulators. Figure 2-16 shows the effect of a constant voltage applied to the base of a transistor connected to a load and a voltage supply. As you can see, this is in effect, a regulator, not a real stable one, but a regulator none-the-less. The constant voltage source could be a zener diode system, and the transistor is the amplifier. We will cover more on this in a later section.

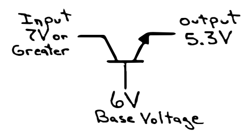


Figure 2-16

Transistors have parameters that also must be taken into account. The best way to check to see what the particular parameters of a transistor are, is to look it up in a cross-reference book. The voltages and gain factors are so varied in range that there is not enough room here to cover them all, but let's skim over a few of the most important ones. Vce is the maximum voltage difference that is allowed between the collector and the emitter. Vbe is the maximum between the base and the emitter. Power dissipation or Pd is the maximum amount of power the package can handle before it over heats, and gain is the amount of current gain the transistor has.

Testing a transistor is just like testing two diodes. The base-emitter junction should test like a diode and the base-collector junction should test like another one. One type of transistor that may test a little funny is the darlington type. Figure 2-17 shows a darlington NPN transistor. It is just two NPN transistors tied together. It has a very high gain and the outside connections are such that when testing the base-emitter junction you are actually testing two junctions inside the package. Just keep that in mind and look at the schematic.

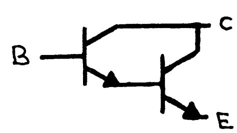


Figure 2-17

When replacing defective transistors try to meet or exceed all of the operating parameters. One parameter that is not met could cause problems. Get a good cross-reference guide and use it to look up the type of transistor you are replacing, if you don't have an exact replacement, use the parameters to see if you have a suitable replacement.

Integrated Circuits

Integrated circuits have been incorporated into every facet of the electronics world, and power supplies are no exception. Unfortunately, the number of different power supply related IC's is much too large to cover fully here, so I will give a quick run down of the most common features and how they are used.

First of all, IC's need a power source to operate. Power supplies will have some method of powering any IC's that are used on it, and that circuit may fail. Some, like the 3-terminal devices we will cover in the next section, obtain their power from the unregulated voltage they use for the output. If a supply has an apparent IC problem make sure it is not the power system used to run that IC.

They also must have an internal, regulated, voltage source to use as a reference. This is usually accomplished with a zener diode that is part of the actual IC. This reference is what the IC compares the output to, and makes any needed changes to the output, to ensure a constant and stable supply.

Last, they all have an output driver to apply their signal to the outside world. In the case of the fixed voltage 3-terminal regulator, the output driver is capable of delivering 1 amp, and usually used to directly power a load. In high current linear regulators, the IC drives current amplifiers to boost their limited outputs (usually 150 mA or less) to a level that will power the load. Switch mode power supply IC's pulse the main drive transistors "on" and "off".

Some IC's incorporate other functions such as over current and over voltage protection, but not all. Refer to a data book or cross-reference guide for information about a specific IC. Just looking at a good schematic will give you an idea of the functions involved.

IC's are used extensively in high current supplies and are very reliable. Their failure rates are very low, especially when compared to the heavy current semiconductors that are also used.

Linear Power Supplies

Introduction To Linear Power Supplies

Linear power supplies, driven by a transformer connected to the AC wall current, are slowly giving way to the more efficient switch mode supply, but there are still literally thousands of them in use today. Even switch mode regulators incorporate linear outputs for some voltages.

The term "Linear" Power Supply is derived from the fact that the transistor or transistors in the current amplifier are operated in their linear region between cutoff and saturation. In contrast, switch mode supplies operate their drive transistors only in the cutoff or saturation modes. Linear regulators are also sometimes called dissipative regulators because the excess power is dissipated as heat during the regulation process.

Linear Power Supply Operation

Let's put together a linear regulator and see how it works, and what happens when particular parts fail.

Figure 3-1 is the first stage of a typical linear regulator. T1 is a 60Hz step down transformer that provides 14Vac (RMS) to BR1, the bridge rectifier. C1 is the main filter capacitor. Even though the output of the transformer is 14Vac the DC voltage across C1 will be almost 20Vdc. That is because transformer outputs are rated in RMS volts not the peak output. C1 is charged to the peak output which is obtained by dividing the RMS value by 0.707.

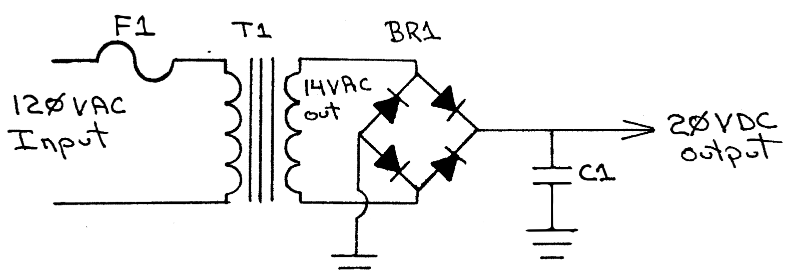


Figure 3-1

If one of the diodes in BR1 were to short it would cause F1 to blow. If one were to open up, the bridge would only provide 1 /2 wave rectified rectification and excessive AC ripple across C 1 would occur, causing the output to ripple also. If C 1 opened up, or became resistive, its filtering capacity would be zip or drastically reduced and once again, excessive ripple would occur.

If no more current than 1 amp were needed, a fixed regulator could be added and the power supply would be complete. Figure 3-2 shows the pin-outs of the common positive and negative fixed regulators available today. They are available in all of the popular voltages (+5, +12, -5, -12, etc.) and are a quick and easy way to get an amp of fairly regulated voltage. The marking on the packages denote the output voltage of the fixed regulator. 78xx are the positive regulators and 79xx are the negative, where xx is the voltage output. For example: 7805 is a positive 5 volt regulator and 7912 is a negative 12 volt regulator.

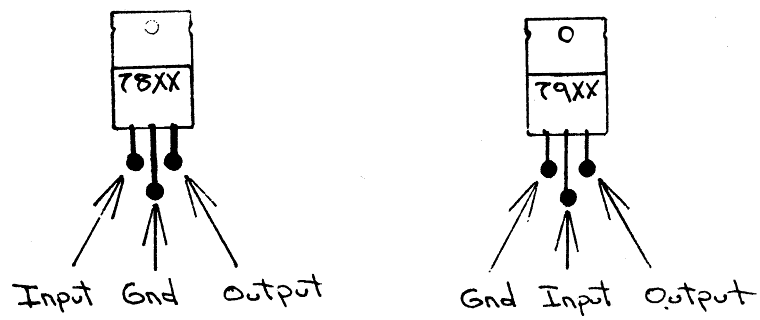


Figure 3-2

Fixed regulators are used quite often and are one of the linear components used in switched mode supplies for secondary output voltages. They have built in thermal and over-current shut down circuits and are fairly reliable.

Figure 3-3 is our basic bridge and filter capacitor arrangement along with a typical high current +5 volt regulator and a 7812 fixed regulator to provide a +12 output. Let's break up the supply and see what the separate functions are.

We have already examined the operation of T1, BR1, and C1. They supply the unregulated voltage to the rest of the power supply.

IC2 is a 7812 fixed regulator to provide a non-adjustable 12V output to power an audio amp or some other circuit. C6, C7, and C8 are used to improve the transient response of the 12V system. Transient response is the ability to track a quickly changing load without adversely affecting the voltage output. If IC2 were to fail one of three scenarios would occur. If IC2 were to open up, there wouldn't be any +12V output and the audio amp or other load wouldn't function. If IC2's input and output shorted together, the load would get the unregulated voltage and draw an larger than normal current. Hopefully, the fuse F2 would blow before permanent damage occurred. IC2 could also short to ground, once again blowing F2.

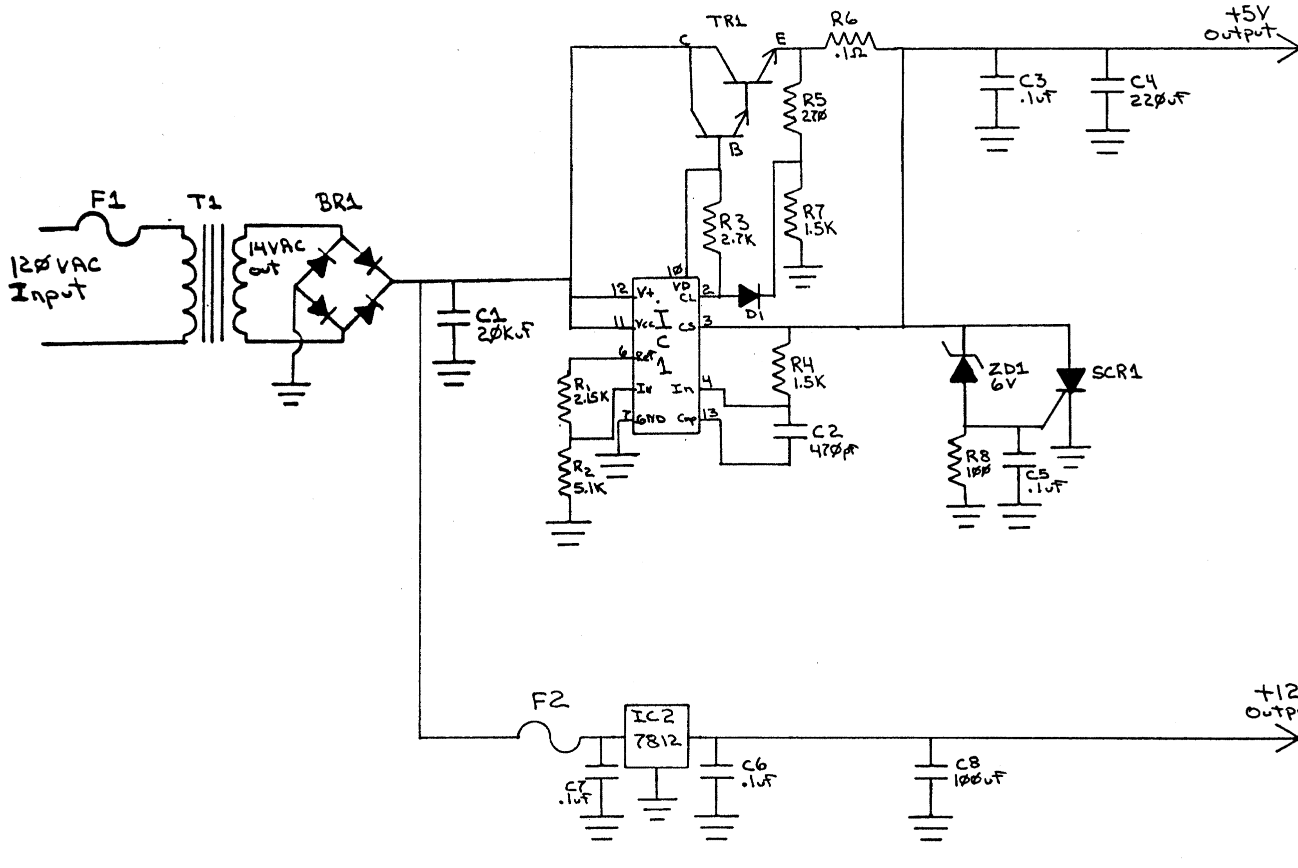

TR1
R6
.1Ω
+5V
Output
C
E
B
C3
.1uF
C4
220uF
R5
270
R7
1.5K
R3
2.7K
F1
T1
BR1
120VAC
Input
14VAC
out
C1
20KuF
D1
IC1
R4
1.5K
C2
470pF
ZD1
6V
SCR1
R1
2.15K
R2
5.1K
R8
100
C5
.1uF
F2
IC2
7812
+12V
Output
C7
.1uF
C6
.1uF
C8
100uF

Figure 3-3

Onto the high current +5 supply. IC1 is a LM723 voltage regulator. It is capable of supplying 150 mA of tightly regulated voltage. It is powered directly from the unregulated input voltage on pins 11 and 12, and it contains a precision voltage reference. R1 and R2 form a voltage divider that sets the output voltage. High precision resistors would be used here to ensure a minimum of variation from unit to unit. Pins 2 and 3 along with R3, R5, R6, and D1 form a feedback system to sample the output, and a current sense circuit that shuts down the supply in the event of a short on the output.

The 150 mA of power the LM723 can provide is not nearly enough to power a set of logic boards, but it is more than enough to drive a current amplifier or series-pass transistor. TR1 is the series-pass transistor, or current amplifier. In the our power supply, a NPN Darlington transistor is used because of its high current gain. This allows the LM723 to drive it directly without any intermediate amplifiers. A darlington transistor, in this arrangement, has the characteristic of having 1.4V less voltage on the emitter than is applied to the base.

The LM723 is configured to maintain approximately 6.5Vdc on the base of TR1, that gives a regulated output of 5.1Vdc. (6.5V-1.4V). A standard NPN transistor's emitter is 0.7Vdc less than the applied base voltage, but much more base current is required to drive it, causing the LM723 to work harder and possibly shortening its life span. Always replace a darlington transistor with another darlington.

C3 and C4 are used to improve the transient response of the +5 output just like C6, C7, and C8 do for the +12 system.

ZD1, R8, C5, and SCR1 form an overvoltage crowbar circuit that protects the load in the event of regulator failure. If the output voltage goes above 6Vdc, ZD1 breaks down and causes a voltage drop to occur across R8. That voltage causes SCR1 to fire, shorting the output to ground, saving the logic boards from getting crispy crittered! C5 is used to keep brief spikes from triggering the circuit.

Troubleshooting Linear Power Supplies

Failure Modes Of The Linear Power Supply

The failure modes of the +5 regulator are very straight forward. LM723's are very reliable, the most common failure is in its output section. The internal output drive transistor tends to open up, causing the drive to TR1 to stop. That means no +5Vdc output. A meter on the base of TR1 can check for drive.

TR1 can open up or short. An open TR1 would cause the output to drop out. An emitter-collector short would cause the output to jump up to the unregulated input voltage, triggering the crowbar circuit and blowing F1. An emitter-base or base-collector short would most likely damage IC1, causing the output to drop to 0 volts or jump up to the unregulated input voltage.

If C3 or C4 were to open up, the +5Vdc output would get noisy, or oscillate, causing erratic logic operation. If either of them shorted, the output would be shorted to ground. That would mean no output and the over-current system would shut down the regulator.

If ZD1 or SCR1 were to open up, the over-voltage protection circuit would be disabled. If either one shorted, the output would, once again, be shorted to ground.

Linear Regulator Type II

There is another type of linear regulator that is used for less demanding needs like audio amplifier applications, or high voltage supplies. Figure 3-4 is the schematic of one. The input section comprised of T1, BR1, and C1 are the basic unregulated supply we have already covered. In this case, the regulator is made up from R1, C2, and ZD1. They are in the same configuration as the basic zener regulator we covered in the section on components. C2 has been added to stabilize the output during quick load changes.

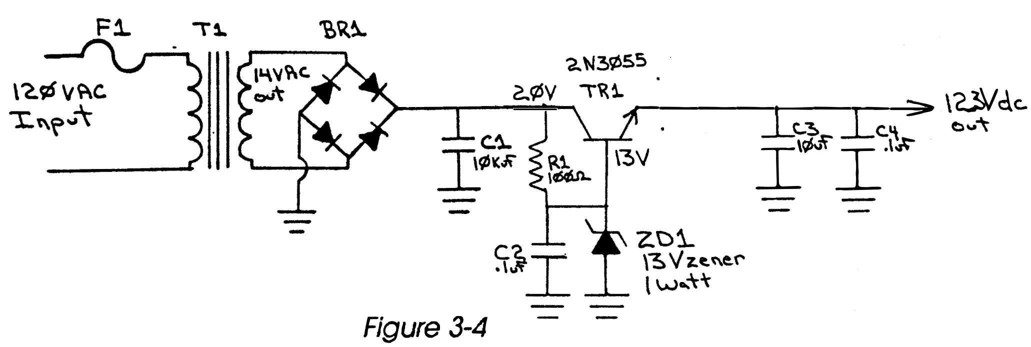


Figure 3-4

The zener diode keeps a constant 14 volts applied to the base of TR1. That means the emitter is going to have a regulated 12.6 volts on it, and again C3 and C4 are used for transient response. This type of regulator is not very stable over wide load fluctuations, so it is not often used for powering logic boards. It is, however, easy to implement and is a reliable way to get a fairly stable voltage for some applications, like audio amplifiers or plasma display systems.

Failure Modes Of The Linear Regulator Type II

Failures of the zener diode, in this type of supply, is the most common problem. If ZD1 shorts, the base of the transistor will be grounded effectively cutting it off, killing the output. If it opens up, the output will go high, but R1 will limit that to some degree. If C2 opened up, the output may oscillate, and if it shorted, it would have the same effect as a shorted ZD1. If C3 or C4 opened up, the output would fluctuate with load changes. Problems with BR1 and C1 would cause the same problems as those discussed in the previous example.

Notes On Linear Power Supplies

Linear supplies are not going away anytime soon, and linear components will always be with us. With a little patience and a multimeter, they shouldn't be too difficult to troubleshoot and repair.

Switch Mode Power Supplies

Introduction To Switch Mode Power Supplies

Switch mode regulators or "switchers" are a child of the satellite business and offer distinct advantages over linear regulators. Engineers needed a reliable and efficient means of getting a stable voltage from the solar panels used to power the satellites. They also needed a regulator that didn't waste or dissipate the precious energy they had available. The switcher was the result.

They offer efficiencies in the order of 85% or more. That means that 85% of the power being put into the regulator is actually being delivered to the load. Compare that to the 35% to 50% efficiencies of linear regulators. Another advantage is size. The high frequencies employed by the switch mode supply allow the use of much smaller transformers than had been previously used. A transformer designed to deliver 10Vac at 60Hz would be very large and weigh at least several pounds, the equivalent 200KHz pulse transformer would only weigh a few ounces and have a much smaller volume to power ratio. Switchers can also be operated from a much wider input voltage range than linear types.

The "off the shelf" switching regulator you can purchase from your local distributor would have no problem operating from an AC input of 90Vac or all the way up to 130Vac. A linear regulator would probably suffer from a low output voltage if it were operated at 90Vac and it would begin to over heat with 130Vac.

The switch mode regulator is superior, in many aspects, to the linear regulator and can be considered a "black box" for replacement purposes. Although a switch mode design is harder to implement compared to an equivalent linear design.

Switch Mode Supply Operation

Switch mode regulators come in two basic types: Saturation and, Pulse Width Modulated.

Saturation types use the magnetic saturation of a transformer to accomplish the on/off switching action, and a feedback system is applied to the windings of the transformer to perform the regulating action. This type of switcher is not very efficient (or stable) because a lot of energy is wasted on saturating the transformer. In fact, they are not much better than linear regulators and aren't used very often anymore.

Pulse Width Modulated (PWM) types are the most efficient and are the type you will run into most often. We will use this type in the examples that follow. Pulse Width Modulation, or PWM as it will be referred to, only uses power as it is needed to maintain the output.

Let's go over the basic flow of a switch mode regulator. Figure 4-1 shows the block diagram of a typical switcher. First the wall voltage is applied to the main power handling circuit where it is rectified an filtered to DC. That voltage is pulsed on and off through the pulse transformer by the control logic. The pulse transformer drops the voltage and boosts the current which is then rectified and filtered by the output section back to DC. A sample of the output is fed back to the control logic which makes any corrections needed to maintain a constant output. Quite a bit of action for such a little box!

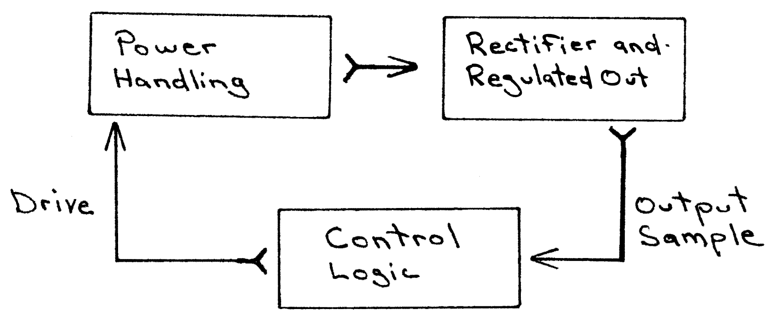


Figure 4-1

Switch Mode Power Supply Circuits

Main Power Handling Circuit

Figure 4-2 is the main power handling circuit of our switcher. I omitted a fuse, but let's assume there is an external fuse protecting the supply.

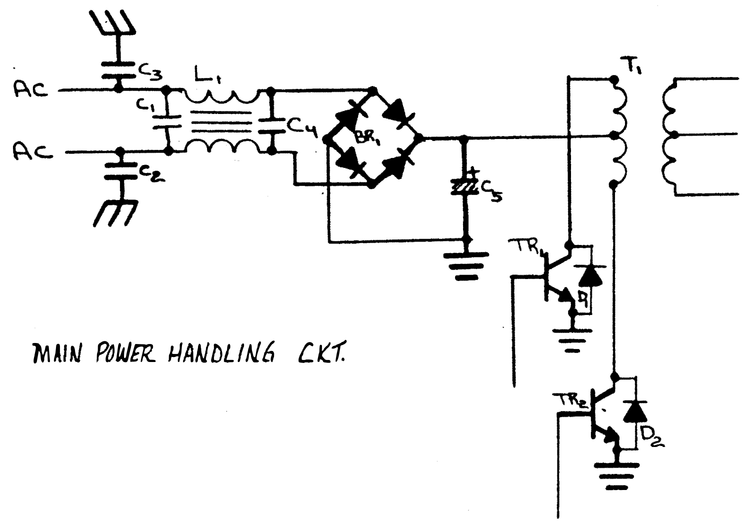


Figure 4-2

The two AC terminals are where the wall voltage is applied. C1, C2, C3, C4, and L1 form a noise filter. It keeps any noise on the AC line from getting into the supply, and most important, it keeps any noise in the supply from getting out onto the AC bus.

BR1 and C5 make up an unregulated DC supply. BR1 full wave rectifies the 115Vac RMS wall voltage and C5 filters it to its peak value of 163Vdc.

TR1 and TR2 are the switching transistors that the control logic uses to pulse the DC through T1. D1 and D2 are de-spiking diodes to protect TR1 and TR2 from spikes that occur in T1 when the magnetic field collapses.

T1 is a pulse transformer that converts the high frequency, high voltage pulses, induced in its primary to a low voltage, high amperage source that can be filtered into a useable output, in our case +5Vdc. It also provides isolation between the wall voltage and the output.

Failure Modes Of The Main Power Handling Circuit

Now that we know what the parts are suppose to do when they are functioning properly, let's examine what happens when they fail.

If C1 or C4 were to short, which happens often, it would cause a direct short between the two AC lines, blowing the fuse. If C2 or C3 were to short, it would apply that line to the case, which should be connected to earth ground. That would also blow the fuse. Although a neutral to ground short may not.

The shorting of C2 or C3 could also cause another problem. If the case were not grounded, and one of those capacitors failed, the case could have an AC potential on it, creating a shock hazard to anyone who touched it. Probably you when you go to adjust the output voltage. If any of these capacitors opened, it would diminish the ability of the filter and it could cause glitches to be produced on the output when line noise is present.

If BR1 were to short, once again the fuse would blow. On the other hand if it were to open, there would be no output.

If C5 shorted, the fuse would also blow, assuming the unit had not been over-fused. In that case, BR1 might fail under the excessive load. If C5 open up or becomes "leaky", the AC ripple in the unregulated DC supply would increase. This would reduce the effective DC value of the supply, resulting int the control logic trying to compensate for it. This compensation would cause TR1 and TR2 to have to work harder, possibly resulting in their failure. If the ripple becomes too excessive, it will be induced in the output, causing it to become noisy. Erratic logic board operation would result.

TR1 and TR2 are the real work horses of the power handling circuit. They fail most often. If either one shorts out, it would cause the fuse to blow. If either one opened up, the control logic would, once again, try to compensate for the drop in the output by putting the surviving transistor into extra work taking up the slack. Failure of the surviving transistor wouldn't take too long under the increased load.

A short in D1 or D2 would have the same effect as a shorted TR1 or TR2. An open diode would cause premature failure of the transistor it was protecting. When replacing switching transistors, always test the protection diodes to make sure one of them isn't open. If you don't you might be replacing the transistors again!

T1, our pulse transformer, rarely fails, but an open transformer would mean no output. A short in T1 could cause either the fuse to blow if it were just in the primary or secondary windings only. If the short were between the primary and secondary it could do anything from blow the fuse to fry the boards, but like I said they rarely, if ever, fail.

Transistor Drive And Output Rectifier Circuits

Figure 4-3 is the main power handling circuit attached to the output rectifier section and the transistor drive transformers.

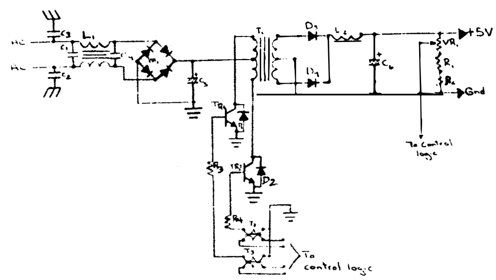


Figure 4-3

D3, D4, L2, and C6 form a very average rectifier circuit, very similar to those found in linear supplies. D3 and D4 are high speed diodes used to rectify the output voltage from T1 to pulsating DC. L2 is used as a choke to block high frequencies and pass DC; it is also used as energy storage in the form of a magnetic field. C6 is a low ESR electrolytic capacitor used as a filter and energy storage device. VR1, R1, and R2 are arranged as a voltage divider that supplies the feedback voltage to the control logic. T2 and T3 are used to apply the drive pulses from the control logic to TR1 and TR2. They also maintain the isolation from the wall voltage. R3 and R4 are used to limit the amount of base current to TR1 and TR2.

Failure Modes Of The Drive And Rectifier Circuits

Failures in this section are similar to failures of the equivalent parts in linear supplies. A shorted D3 or D4 would cause excessive current drain through T1. That could cause the fuse to blow, switching transistor failure (which would cause the fuse to blow) or cause the supply to just shut down.

L1 is made from heavy gauge wire, so failures are almost impossible, but cold solder joints on the lugs do occur.

C6 is the filter capacitor for the +5 volts. If it shorted, it would cause the same effect as a shorted D3 or D4; it may also cause D3 or D4 to fail. If C6 opened up or became "leaky", a noisy output would result, causing erratic board operation. A quick service note: A leaky +5 filter cap can also cause the supply to emit an audible "squeal" during operation.

VR1, R1, and R2 have so little current through them that failure is not likely. If one were to open up, it would cause the supply to shut down. The most common problem in this area is a VR1 that gets broken when the supply is being adjusted.

T2, T3, R3, R4 are also parts with an *extremely* low failure rate. If one should fail, improper drive to the switching transistors would occur causing possible failure. If you suspect a problem in this area, look for broken solder connections.

Control Logic

In the past the control logic of a switch mode regulator was implemented using separate components, like op-amps, zener diodes, and transistors. Thanks to advances in the IC field, there are single chips that incorporate most of the functions needed. We will be looking at the TL494, a very common IC used today. To better understand the inner workings of the chip, we'll examine its inner workings.

The heart of a switcher is a pulse width modulator. Figure 4-4 shows the basic arrangement of a pulse width modulator. The whole thing is made from two op-amps. One is an error amplifier. Used to apply a sample of the voltage to be regulated to the actual modulator. The "+" terminal goes to a reference voltage. This is a "rock steady" voltage source used to compare the sample to. It is this comparing to a known standard that causes regulation to occur. Inside the TL494, a precision zener diode provides the reference voltage. The two resistors connected to the error amp sets the gain, or how drastically the output changes in relationship to the change on the input.

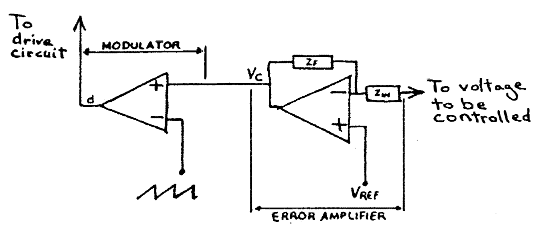


Figure 4-4

The error amp, in our example, is arranged as an inverting amplifier, that is, the voltage that causes the output to change is connected to the "-" terminal. That means as the sample of +5V goes *up* in value, the output of the error amp goes *down*.

The output of the error amp is then applied to the actual modulator. This op-amp is configured as a comparitor. It compares the voltages on its inputs and swings its output to the positive supply rail when the voltage on the (+) terminal is greater than the voltage on the (-) terminal. Likewise, it swings its output to the negative supply rail when the voltage on the (-) terminal is greater than that on the (+) terminal.

The modulator compares the voltage from the error amp to an applied sawtooth wave. Figure 4-5 shows the result. That is exactly what pulse width modulation is. The duty cycle of the output is controlled by the amplitude of the input.

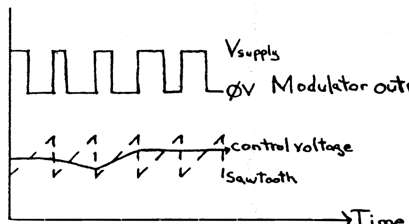


Figure 4-5

The actual flow of the circuit is as follows: A sample of the voltage to be regulated is applied to the error amp. It then compares that to a known standard. It then outputs a proportional control voltage, which is then applied to the modulator. The modulator compares the control voltage to a sawtooth wave. When the control voltage is greater than the sawtooth wave, the modulator quickly pulls its output low, and when the control voltage is lower than the amplitude of the sawtooth wave, the modulator pulls its output high.

The modulator can then drive other circuitry and eventually the main switching transistors.

That's great, but to get an actual supply up and running we need more than just a pulse width modulator. We need the reference voltage, sawtooth generator, a circuit to convert the modulator output to two complimentary outputs, and current amplifiers to drive a load. This is where the IC steps in.

Figure 4-6 shows the pin-out of the TL494 switch mode supply IC. It contains all of the needed hardware and then some. It contains two error amps, and a reference regulator. Pins 5 and 6 are terminals to attach a resistor and capacitor that are used to set the frequency of the internal sawtooth generator. The "Dead Time Control" pin is used to set the minimum off time of the outputs. That is so it can be assured that one of the main switching transistors is not still turned "on" when the other begins to conduct.

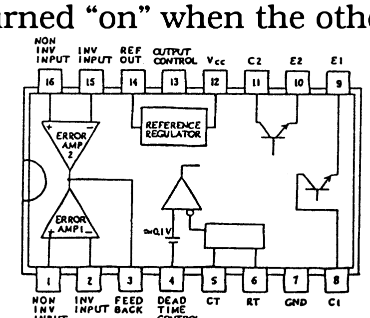


Figure 4-6

Pins 7 and 12 are the power input connections. Pins 8, 9, 10, and 11 are the connections to the chip's output driver transistors. These outputs will be used to drive the main switching transistors. Pin 13 is an output control pin. When it is pulled low, it disables the outputs. Very useful for over-voltage and current protection.

Figure 4-7 shows the control logic for the supply we are examining. T4, D5, D6, and C10 have been added as a low voltage unregulated supply for the IC. Compare this figure to the pin-out of the IC in 4-6 and much of the circuit is self explanatory. Pin 1 is where the +5 sample is applied to the error amp. The reference output on pin 14 is applied to two voltage dividers -made from R5, R6 and R7, R8. The voltage from the dividers is also applied to the error amp as the reference voltage.

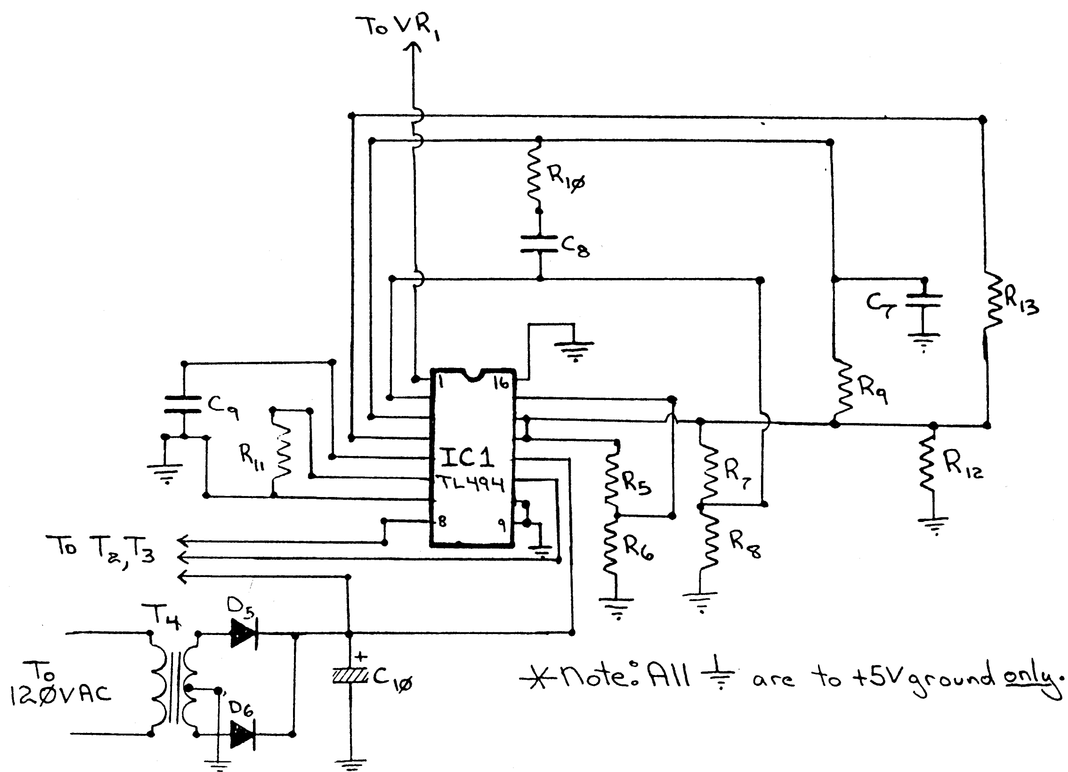


Figure 4-7

R9, R10, R13, C7, C8, and R12 are used to set the gain of the error amp and to provide dead time control. C9 and R11 set the frequency of the sawtooth generator. The emitters of the drive transistors are grounded and the collectors, along with a positive voltage from the supply, are used to pulse the drive transformers. Also, note that pin 13 is pulled "high". There is no over-voltage or current sensing being used.

Unfortunately, not every switcher uses the same control IC or even the same parts arrangements when similar IC's are used. The main thing to remember is that they all perform the same tasks in the same basic manner.

Failure Modes Of The Control Logic

Fortunately for us technicians, problems with the control logic don't usually occur. In fact, I have never had a failure occur in a control IC. That is not to say it doesn't happen, it is just very rare. If it appears that there is a problem with the control logic, check its power supply or look for a resistor that is way out of tolerance. You will probably find the problem there.

Notes On Switch Mode Power Supplies

Switch mode power supplies are being incorporated into just about all games being manufactured today. When troubleshooting them, break the supply up into functional areas and check *everything* that may have caused the failure, before powering it back up. This is especially true with switchers that have multiple output voltages. These other outputs are rectified and filtered in the same manner as the +5 output, but there is no feedback to the control logic. A failure in one of those outputs would cause the same symptoms as similar failures in the +5 circuit.

Switchers aren't all that difficult to repair, but due to their recent drop in price, you may want to weigh the time and overall cost of a particular repair before you start replacing parts.

Conclusion

Well, that appears to be "the whole ball of wax." I'm sure by now that you have already had to repair, or attempt to repair, at least a few power supplies and I'm also sure, that you have noticed the diversity in the designs. The examples used in this manual, while they won't match every power supply you will work on, show the basic functions and fundamentals used in all power supplies.

Like any other skill, the repairing of power supplies will get easier the more you practice it, and in this business, you will get plenty of practice! In no time at all, you will be able to recognize and repair the common problems, and have the ability to ferret out the solutions to the difficult fixes.

I hope this manual has given you a good head start.