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Switchmode Power Supplies

Disclaimer

Careless troubleshooting of a line-powered switchmode power supply can result in severe electrical shock or electrocution. This is potentially more lethal than the high-voltage section of a TV or monitor due to the availability of high current. Even the charge on the main filter capacitors with the unit unplugged can kill. This warning includes those innocent-looking laptop and Zip-drive power packs as well.

Neither the author or publisher will be responsible for damage to equipment, your ego, countywide power outages, spontaneously generated mini (or larger) black holes, planetary disruptions, or personal injury or worse that may result from the use of this material.

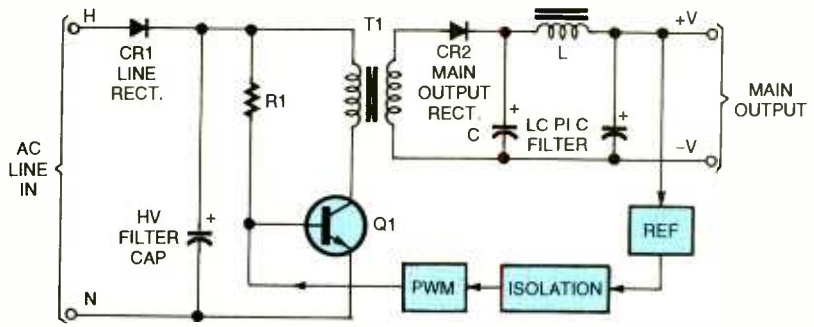

Fig. 1. The flyback circuit shown above is a very common topology for small switchers.

This month and next, we will deal with the types of power supplies found in PCs, laptops, and other computers and peripherals; TVs and monitors; printers and fax machines; as well as on the ends of the power cords of some PDAs, cellphone chargers, computer-backup drives, and other small devices.

Introduction

Until the 1970s or so, most consumer electronic equipment used a basic power transformer/rectifier/filter capacitor type of power supply for converting the AC line into the various voltages needed by internal circuitry. Even regulation was present only where absolutely needed—the high voltage supplies of color TV sets, for example. Remember those old TVs with boat-anchor-type power transformers? (Of course, if you recall those, you also fondly recall the days of vacuum-tube sets and the corner drugstore with a public tube tester!)

Switchmode power supplies (SMPSs) had been commonplace in military and avionic equipment long before they found their way into consumer electronics. I have some DC-DC and DC-AC converter modules from a Minuteman I missile from around 1962—examples of such military use. I suppose that the cost of the switching transistors wasn't as big a deal with a $100 million missile as a $300 TV (even in 1960s dollars).

Nowadays, all TVs, monitors, PCs and VCRs; most laptop and camcorder power packs; many printers and fax machines; and even certain audio equipment like portable CD players use this technology to reduce cost, weight, and size.

What Is A Switchmode Power Supply?

Also called switching power supplies and sometimes chopper-controlled power supplies, SMPSs use high-frequency (relative to 50/60 Hz) switching devices such as *B*ipolar *J*unction *T*ransistors (BJTs), MOSFETs, *I*nsulated *G*ate *B*ipolar *T*ransistors (IGBTs), or Thyristors (SCRs or triacs) to take directly rectified line voltage and convert it to a pulsed waveform.

Most small SMPSs use BJTs or MOSFETs. IGBTs may be found in large systems, and thyristors are used where their advantages (latching in the ON state and high-power capability) outweigh the increased complexity of the circuitry to assure that they turn off properly. (Except for special *G*ate *T*urn *O*ff or GTO thyristors, the gate input is pretty much ignored once the device is triggered; and the current must go to zero to reset it to the OFF state.)

The input to the switches is usually either 150–160 V_{DC} after rectification of 115 V_{AC}, or it is 300–320 V_{DC} after doubling of 115 V_{AC} or rectification of 220–240 V_{AC}. Up to this point, there is no line isolation as there is no line-connected (large, bulky, heavy) power transformer.

A relatively small high-frequency transformer converts the pulsed waveform into one or more output voltages that are then rectified and filtered using electrolytic capacitors and small inductors in a "pi" configuration (C-L-C); or for outputs that are less critical, just a capacitor is used.

This high-frequency transformer provides the isolation barrier and the conversion to generate the multiple voltages often provided by an SMPS.

Feedback is accomplished across the isolation barrier by either a small pulse transformer or opto-isolator. The feedback controls the pulse width or pulse frequency of the switching devices to maintain the output constant. Since the feedback is usually only from the "primary" output, regulation of the other outputs, if any, is usually worse than for the primary output.

Also, because of the nature of the switching designs, the regulation even of the primary output is usually not nearly as good both statically and dynamically

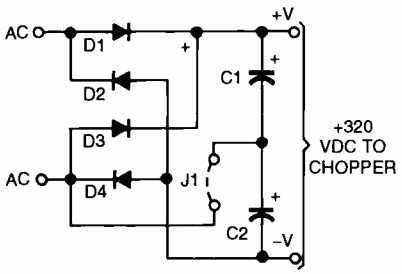

Fig. 2. This common circuit uses a bridge rectifier as a doubler or normal bridge by changing one jumper.

as a decent linear supply.

DC-DC converters are switchmode power supplies without the line-input rectification and filtering. They are commonly found in battery-operated equipment like CD players and laptop computers. They have similar advantages to SMPSs—compact, lightweight, and highly efficient.

Description Of Typical Flyback-Type SMPSs

Probably the most common topology for small switchers is the flyback circuit shown in Fig. 1. The input to the supply is the AC line, which may have RFI and surge protection (not shown). There may be several inductors, coupled inductors, and capacitors to filter line noise and spikes as well as to minimize the transmission of switching-generated radio-frequency interference back into the power line.

There may be MOV-type of surge suppressors across the three input leads (H, N, G). A line fuse is usually present as well to prevent a meltdown in case of a catastrophic failure. It rarely can prevent damage to the supply in the event of an overload, however.

Line rectification is usually via a voltage doubler or diode bridge. One common circuit (see Fig. 2) uses a bridge rectifier as a doubler or normal bridge by changing one jumper. The voltage across the switching transistor is usually around 160–320 volts. Some universal supplies are designed to accept a wide range of input voltages—90–240 V_{AC} (possibly up to 400 Hz or more) as well as DC—and will automatically work just about anywhere in the world as long as a suitable plug adapter can be found.

When Q1 turns on, current increases linearly in T1, based on the voltage applied and the leakage inductance of T1's primary winding. Little power is transferred to the secondary during this phase of the cycle. When Q1 turns off, the field collapses; and this sequence transfers power to the output. The longer Q1 is on, the more energy is stored (until saturation, at which point it blows up). Thus, controlling the pulse width of the Q1 "on-time" determines the amount of power available from the output.

The output rectifier, CR2, must be a high-efficiency, high-frequency unit—a 1N400X will not work. The pi filter on the output smooths the pulses provided by CR2. Sometimes, a full-wave configuration is used with a center-tapped transformer secondary.

Note that the transformer, T1, is a special type that includes an air gap in its core (among other things) to provide the inductive characteristics needed for operation in flyback mode.

Multiple output windings on T1 provide for up to a half dozen or more separate (and possibly isolated as well) positive or negative voltages, but, as noted, only one of these is usually used for regulation.

A reference circuit monitors the main output and controls the duty cycle of the switching pulses to maintain a constant output voltage.

The start-up resistor, R1, (some start-up circuits are more sophisticated than this one) provides the initial current to the switchmode transistor base. In the old days, SMPS controllers were designed with discrete components. Assuring stable operation is a challenge with any SMPS, but particularly with the flyback topology where leaving the drive on for too long will result in transformer core saturation and instant smoke. Nowadays, an IC PWM controller chip is almost always used. The block diagram of one very popular PWM controller IC is shown in Fig. 3.

Many small SMPSs use opto-isolators for the feedback. An opto-isolator is simply an LED and a photodiode in a single package. As its name implies, an opto-isolator provides the isolation barrier (between the low-voltage secondary outputs and the line-connected primary) for the feedback circuit.

Typically, a reference circuit on the output side senses the primary output voltage and turns on the LED of the opto-isolator when the output voltage exceeds the desired value. The photodiode detects the light from the LED and causes the pulse width of the switching waveform to be reduced enough to provide just the right amount of output power to maintain the output voltage constant. This circuit may be as simple as putting the photodiode across the base drive to the BJT switch, thus cutting it off when the output voltage exceeds the desired value. The reference is often a TL431 or similar shunt regulator chip monitoring a voltage-divided version of the primary output. When the shunt-regulator kicks in, the opto-isolator LED turns on, reducing the switchmode transistor drive. There may be an adjustment for the output voltage.

Other designs use small pulse transformers to provide isolated feedback. Where additional regulation is needed, small linear regulators may be included following the output(s).

There are many other topologies for switching power supplies. However, the

Advantages Of SMPSs Compared To *Linear-Power* Supplies (LPSs)

The benefits of implementing switch-mode operation are related to size, weight, and efficiency.

- Size and weight—Since the transformer and final filter(s) run at a high frequency (we are talking about 10 kHz to 1 MHz or more), they can be much smaller and lighter than the big bulky components needed for 50/60-Hz operation. Power density for SMPSs compared to LPSs may easily exceed 20:1.

- Efficiency—There is relatively little power lost since the switching devices are (ideally) fully on or fully off. The efficiency can be much higher for SMPSs than for LPSs, especially near full load. Efficiencies can exceed 85% (compared to 50–60% for typical LPSs), with improvements being made continuously in this technology.

With the advent of the laptop computer, cellular phone, and other portable devices, the importance of optimizing power usage has increased dramatically. There are now many ICs for controlling and implementing SMPSs with relatively few external components. Maxim, Linear Technology, and Unitrode (now part of Texas Instruments) are just a few of the major manufacturers of controller ICs.

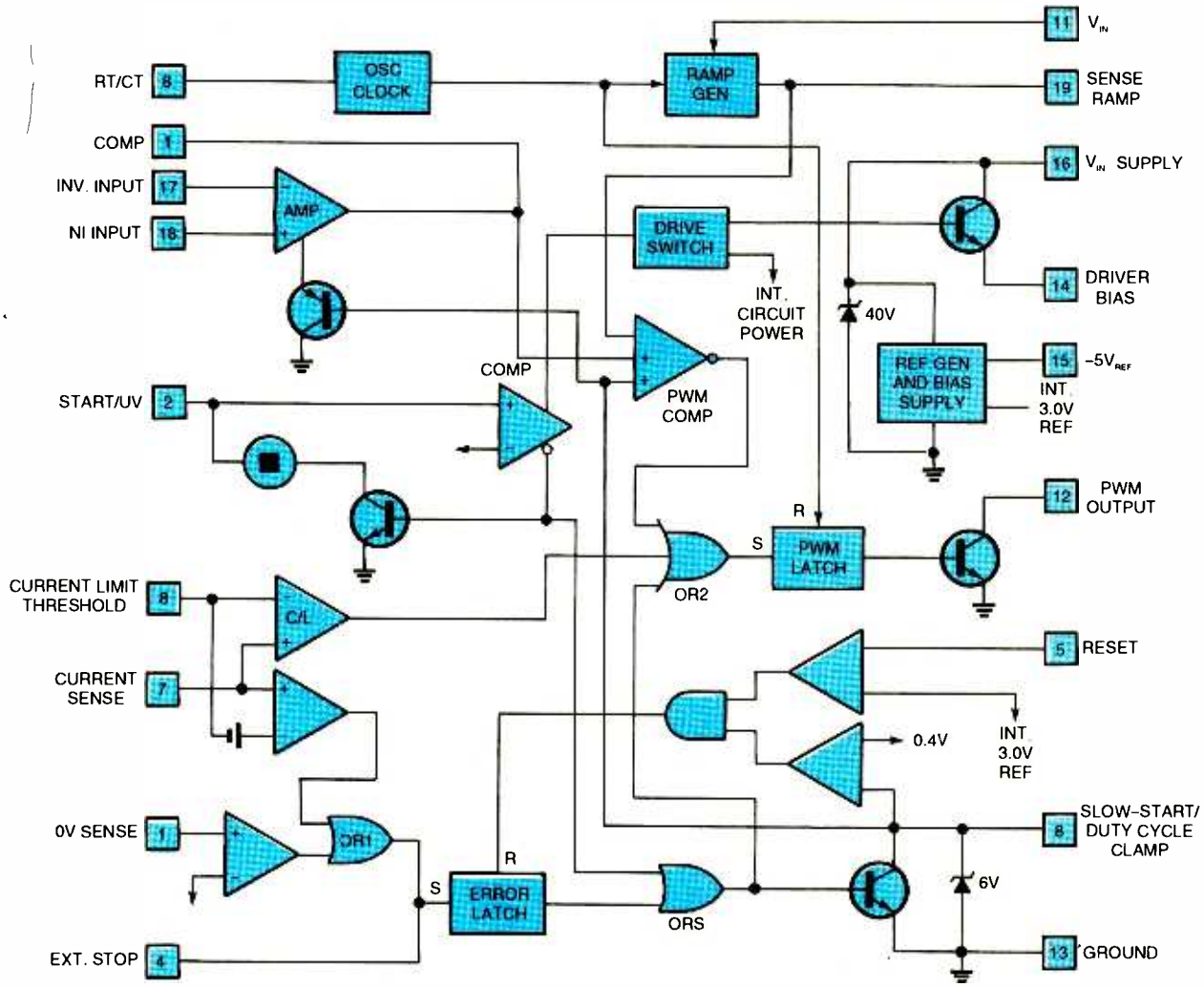

Fig. 3. This is a block diagram for a popular TI PWM controller. On-chip PWMs have been decreasing in cost and, as a result, increasing in popularity among inventors.

basic principles are similar but the details differ, depending on application. The flyback topology described above is one of the most common for small multi-output supplies. However, you may find other types of circuits in TVs and monitors. Some are downright strange (to be polite). I sometimes wonder if engineers are given bonuses based on the uniqueness and difficulty level of their designs!

Switchmode Power Supply Repair

Unlike PC system boards where any disasters are likely to only affect your pocketbook, power supplies, especially line-connected switchmode power supplies, can be dangerous.

Having said that, I suggest that repairing a power supply on your own may in fact be the only economical option. It is very common for service centers to simply replace the entire power supply board or module even if the problem is a 25-cent capacitor. It may simply not pay for them to take the bench time to diagnose down to the component level. Many problems with switchmode power supplies are easy to find and also easy and inexpensive to fix—not all, but surprisingly many.

Most Common Problems

The following probably account for 95% or more of the common SMPS ailments:

- Supply dead, fuse blown—shorted switchmode power transistor and other semiconductors, open fusible resistors, or other bad parts. Note: Actual cause of failure may be power surge/brownout/lightning strikes, random failure, or primary side electrolytic capacitor(s) with greatly reduced capacity or entirely open—test them before powering up the repaired unit.

- Supply dead, fuse not blown—bad start-up circuit (open start-up resistors), open fusible resistors (due to shorted semiconductors), or bad controller components.

- One or more outputs out-of-tolerance or with excessive ripple at the line frequency (50/60 Hz) or twice the line frequency (100/120 Hz)—dried-up main filter capacitor(s) on rectified AC input.

- One or more outputs out of tolerance or with excessive ripple at the switching frequency (10s of kHz typical)—dried-up or leaky filter capacitors on affected outputs.

- Audible whine with low voltage on one or more outputs—shorted semiconductors, faulty regulator circuitry resulting in overvoltage crowbar kicking in, faulty overvoltage-sensing circuit or SCR, or faulty controller.

- Periodic power cycling, tweet-tweet, flub-flub, or blinking power light—shorted semiconductors, faulty over-voltage or over-current sensing components, or bad controller.

In all cases, bad solder connections are possibilities as well, since there are usually large components in these supplies; and soldering to their pins may not always be perfect. An excessive load can also result in most of these symptoms or may be the original cause of the failure.

Repair Or Replace

Some manufacturers have inexpensive flat-rate service policies for power supplies. If you are not inclined to or not interested in doing the diagnosis and repair yourself, it may be worthwhile to look into these. In some cases, $25 will get you a replacement supply regardless of original condition.

However, this is probably the exception, and replacements could run more than the total original cost of the equipment—especially in the case of most TVs and many computer monitors, where the power supply is built onto the main circuit board.

Nothing really degrades in a switch-mode power supply except possibly the electrolytic capacitors (unless a catastrophic failure resulted in a total meltdown), and these can usually be replaced for a total cost of a few dollars. Therefore, it usually makes sense to repair a faulty supply assuming it can be done reasonably quickly (depending on how much you value your time and the down time of the equipment) and, of course, assuming that the equipment it powers is worth the effort. Most replacement parts are readily available and kits containing common service components are also available for many popular power supplies (such as those found in some terminals, MacIntosh and other Apple computers, various brands of video monitors, and some TVs and VCRs).

Where an exact replacement power supply is no longer available or excessively expensive, it may be possible to simply replace the guts if space allows and the mounting arrangement is compatible. For example, for an older full-size PC tower, the original power supply may be in a non-standard box but the circuit board itself may use a standard hole configuration such that an inexpensive replacement may be installed in its place.

Alternatively, many surplus electronics distributors have a wide selection of power supplies of all shapes, sizes, output voltages, and current capacities. One of these may make a suitable replacement for your custom supply with a lot less hassle than attempting to repair your undocumented original. It will likely be much newer as well, with no end-of-life issues like dried-up electrolytic capacitors to worry about. Of course, you must know the voltage and current maximum current requirements of each of the outputs in order to make a selection.

Power-Supply Fundamentals

A typical line-connected power supply must perform the following functions:

- Voltage conversion—changing the 115/230 V_{AC} line voltage into one or more other voltages as determined by application.
- Rectification—turning the AC into DC.
- Filtering—smoothing the ripple of the rectified voltage(s).
- Regulation—making the output voltage(s) independent of line and load variations.
- Isolation—separating the supply outputs from any direct connection to the AC line.

Wrap-up

Between now and next time, round up all the dead SMPSs you have buried under other junk, but don't try to repair them just yet. However, if they have been unplugged for awhile, it's safe to open the case(s) to identify the major components and any that are obviously fried. As always, e-mail is welcome (no snail mail please!) at sam@repairfaq.org. Much more information is available on my Web site: *www.repairfaq.org*. P