

Understanding Switch Mode Power Supplies

Switch mode power supplies (SMPS) have been used for many years in industrial and aerospace applications where good efficiency, light weight and small size were of prime concern. Today SMPS (often called “choppers” or “switchers” are used extensively in AC powered electronic devices such as computers, monitors, television receivers, and VCRs.

This Tech Tip explains the basic operation of the typical switch mode power supplies used in consumer electronic equipment. We will cover both the Pulse Width (PWM) and Pulse Rate (PRM) types. Refer to Tech Tip #204 for information on identifying SMPS problems, and to Tech Tip #205 for information on troubleshooting PWM type SMPS.

SMPS Benefits

A SMPS offers three main advantages over a conventional linear power supply:

- 1) high efficiency & less heat generation
- 2) tighter regulation, and
- 3) smaller size and weight.

Of these, greater efficiency is the biggest advantage.

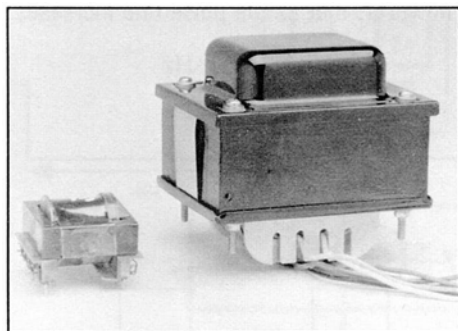


Fig. 1: The SMPS transformer (left) and the AC power transformer both provide isolation and various output voltages, but the SMPS transformer is smaller, lighter weight, and more efficient.

Conventional “linear” power supplies are inefficient because they regulate by dumping the excess power in to heat. The AC power transformer, operating at 60 Hz, also contributes to the inefficiency of some power supplies. When all the inefficiencies are added, conventional, linear power supplies are typically 40-50% efficient, while switchers have efficiencies from 60 to 90%. This is very important when the designer wants to reduce generated heat, reduce power costs, or increase battery life.

Another key benefit of a SMPS is their ability to closely regulate the output voltage. Switchers adjust for changes in input voltage or load current, with little change in efficiency. Switch mode supplies regulate continuously, and follow load changes almost immediately. In addition, switchers have the unique ability to maintain the correct output under low input voltage conditions. In fact switchers can actually produce an output voltage that is higher than the DC voltage applied to the input.

A final advantage of switchers is their relatively small size and weight. Because switchers operate at high frequencies, the parts are physically smaller than those needed for a conventional, 60 Hz power supply of the same power rating. The transformers, capacitors and coils are both physically smaller and lighter. This makes them ideal for use in portable equipment.

Switchers Aren't New

You may think that switch mode supplies are relatively “new” technology. But quite the opposite is true. One of the first switch mode power supplies was the mechanical vibrator circuit used in early

automobiles. The vibrator “chopped” the 6 volt battery voltage into an AC signal that could be stepped up and down to deliver the plate and bias voltages needed to power the tube radio.

A more modern SMPS that you may be familiar with is the horizontal output stage of a television receiver or computer monitor that develops the high voltage. Although this “flyback” circuit is not commonly called a switch mode supply, it is a type of switcher.

Today's more sophisticated SMPS still employ the same basic concept used in the early vibrator supply: a DC voltage is converted to an AC signal, the AC signal is stepped up by a transformer; and the stepped-up AC is converted back to a DC voltage. Today's supplies use feedback and variable switching to provide regulation, and incorporate a solid state switch. Figure 2 illustrates the basic functions of a SMPS.

Basic Switcher Operation

Let's take a closer look at the basic switcher block diagram shown in Figure 2. The heart of all switch mode supplies is the switching transistor and switching transformer. Raw (unregulated) B+ is supplied to the switching transistor through the primary winding of the transformer. The switching transistor (SOT) is a switch. When the switch is closed (the transistor is turned on) it provides a path for current to flow through the transformer primary to ground. As we'll see a bit later, changing how fast or how long the switch remains closed regulates the output voltages.

The current flow in the primary winding of the transformer produces an expanding

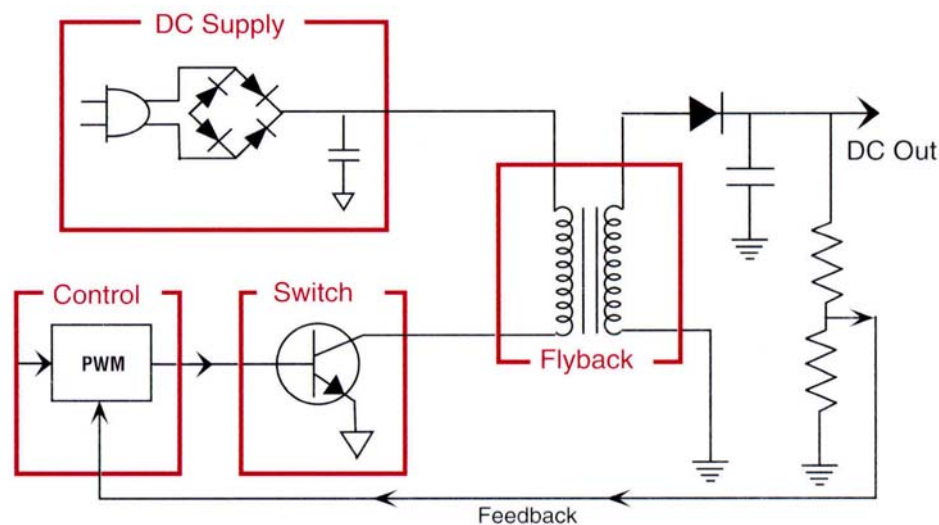


Fig. 2: A basic SMPS consists of a DC voltage source, a switching device, a step up/down transformer, (flyback) and a switching control stage.

magnetic field which couples to the secondary windings through the core. As the transistor is switched on and off the magnetic field alternately expands and collapses in all of the transformer windings. By designing the transformer with different secondary turns ratios, various amplitude pulses are produced at the output of each secondary winding. The output of each winding is applied to high speed switching diodes and filters which produce the DC output voltages of the SMPS.

It is important to remember that all of the windings are mutually coupled by the magnetic field. If more power is applied to the primary winding, more power is delivered to the secondary windings; if the voltage at one secondary winding increases (or decreases) the voltages at the other windings change by an amount equal to the turns ratio.

Achieving Efficient Regulation

Regulation is important in most power supplies. Good regulation is needed to maintain a constant output voltage for changes in load current and changes in

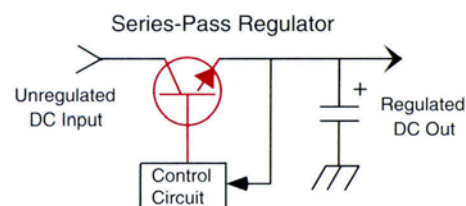


Fig. 3: A conventional, series-pass regulator dissipates the unused power as heat.

the input voltage. Switch mode power supplies provide fast, efficient regulation. To better understand why, let's review conventional power supply regulation.

Conventional power supplies regulate by using a series-pass regulator operating in its linear mode, as shown in Figure 3. The series pass regulator maintains a fairly constant output voltage with changes in input voltage and load current. But, in order to maintain regulation for all load conditions, more power is applied to regulator than is needed by the load. This unused power is dissipated as heat.

The key to making the regulator more efficient is to produce only as much power as the load consumes. Then there will be no extra power to dissipate. This would be easy if the load current never increased or decreased, or if the source voltage remained constant. Of course this never happens.

Switchers are very efficient regulators because they only produce as much power as is needed by the load. Voltage regulation is achieved by sampling the DC output voltage and comparing it to a reference. (If the SMPS has several outputs the main supply is sampled). The resulting correction voltage is used to control the frequency or "on" time of the switching transistor, which in turn delivers more or less power to the load.

The regulators used in consumer equipment fall into two types; 1) pulse width modulated (PWM), and 2) pulse

rate modulated (PRM). Television receivers and computer monitors may use either type, while VCR commonly use PRM supplies.

Pulse Width Modulated Regulation

PWM regulators vary the "on" or conduction time of the switching transistor. Figure 4 shows an example of pulse rate modulation. Note that the frequency of the signal remains constant and only the duty cycle varies.

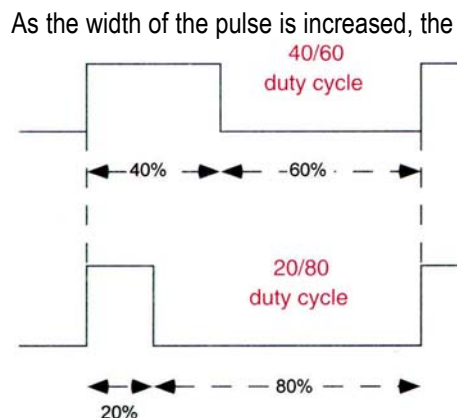


Fig. 4: The PWM regulates by varying the "on" time of the switching transistor

switching transistor stays on longer, and more energy is applied to the switching transformer. This produces an increase in the DC output voltage (Unless the load is shorted, or draws excessive current). Likewise, as the pulse width is made narrower, the transistor is on for a shorter amount of time, and less energy is applied to the transformer.

Pulse Rate Modulated Regulation

Figure 5 shows an example of pulse rate modulation. The PRM regulator varies the rate (frequency) at which the switching transistor is turned off and on. Notice, however, that as the pulse rate increases,

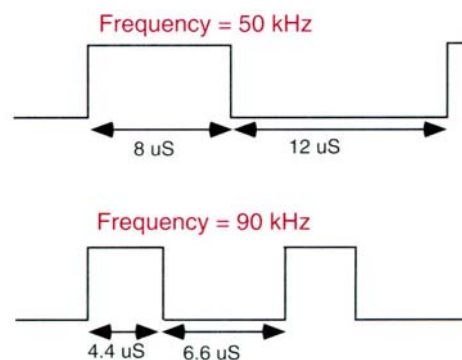


Fig. 5: The PRM regulates by varying the frequency of the pulses, which varies the switching transistor's conduction time.

the “on time” decreases. Thus, if the output voltage is too high, the switching transistor is turned on and off at a faster rate. This results in less energy being applied to the switching transformer. A typical PRM supply may operate at frequencies as high as 90 kHz under a “no load” condition, but slow to 40 kHz under full load.

Putting It All Together

Figure 6 shows a block diagram of a typical SMPS. While specific switchers may vary somewhat from this diagram, all SMPS have these basic functional blocks. Some switchers, for example, may connect the System Control line to a different point in the control loop.

The blocks can be grouped in to four sections or “most important circuits” (MICS): 1) Unregulated Bt, 2) Startup & Drive, 3) Secondary circuits, and 4) Feedback & Control.

MIC 1 - Unregulated B+

The SMPS needs a source of power. The gray shaded blocks in Figure 6 provide the unregulated B+ to power the switcher. In an AC operated device the AC line voltage is rectified by a conventional full wave power supply. (This is why everything on the primary side of the switching transformer is at “Hot ground” potential). Often an RF filter network is used to prevent the high frequencies produced by the switcher from getting on the AC power line.

Most microprocessor controlled chassis include a standby power supply to keep the micro running when the main power to the unit is turned off. This allows the micro to respond to the “on” command from the remote control, or front panel switch. The standby supply may be a small, conventional supply, or it may be a small SMPS.

The primary of the switching transformer and the switching transistor are also part of the unregulated B+ stages. A field effect

transistor (FET) is usually used for the switch. FETs offer several advantages over bipolar transistors for SMPS applications. (A horizontal output transistor is a bipolar transistor). First, FETs are voltage operated and can be driven directly without a driver stage. Secondly, FETs are bi-directional (conduct with voltage of either polarity applied to the source and drain) which eliminates the need for a damper diode. Thirdly, FETs operate efficiently at high switching frequencies.

Lastly, FETs have a low “on” resistance which contributes to the efficiency of the SMPS, and reduces heat build up. (The reason that FETs aren’t used as horizontal output transistors is that they can not handle the large reverse voltage spikes, 900-1100 VPP, produced in horizontal output stages).

MIC 2 - Startup & Drive

The pink shaded blocks in Figure 6 are responsible for the signal that drives the switching transistor. The driver block is

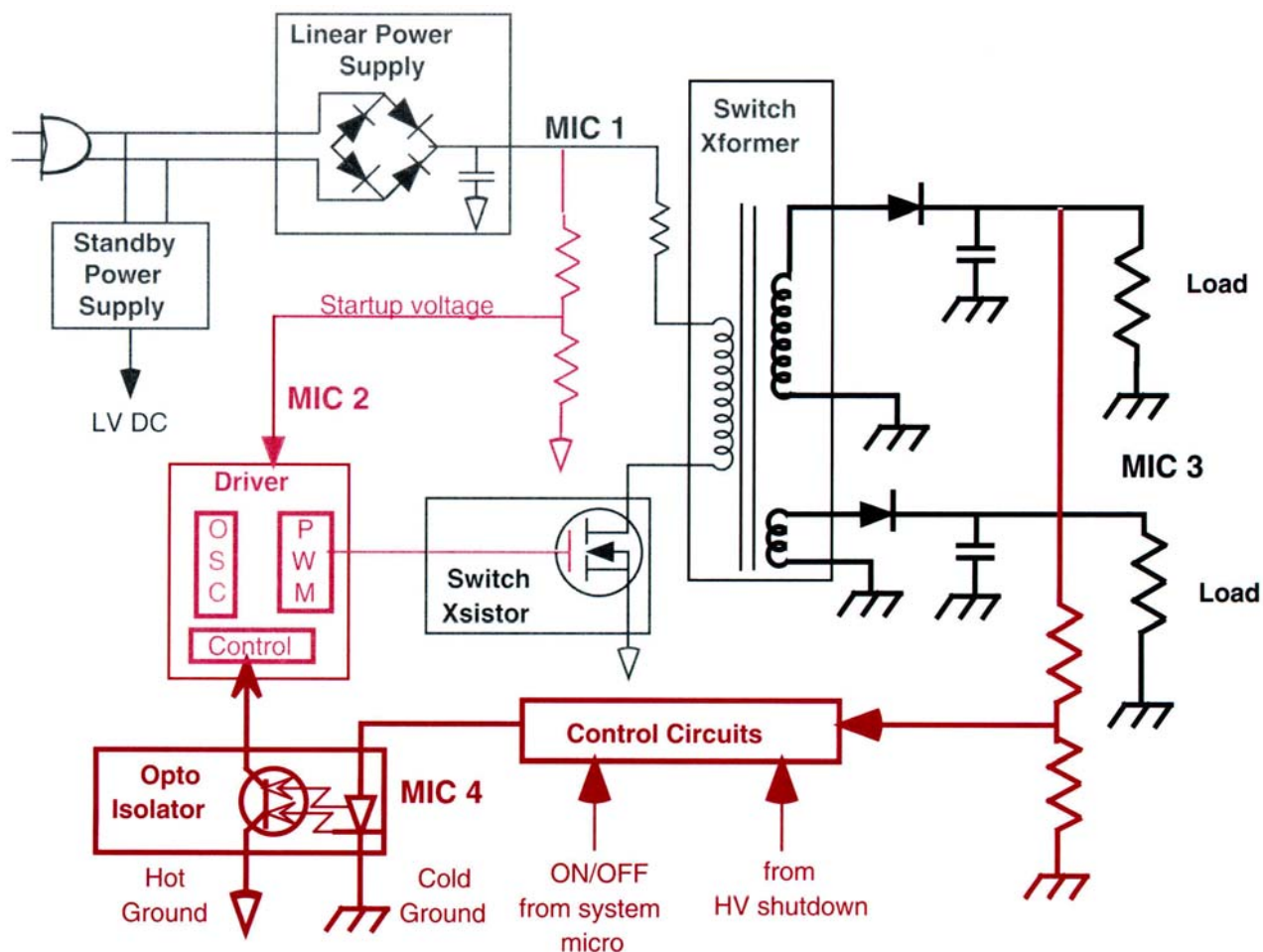


Fig. 6: The four most important circuits in a switch mode power supply are: Unregulated B+(MIC1),Startup and Drive (MIC2). Secondary Loads (MIC3),and Feedback and control (MIC4).

either a PWM or PRM, and the necessary oscillator and control. This block may be a single IC, or may include discrete components.

This stage receives its initial DC voltage from a resistor divider on the B+ supply. After the SMPS is running, the "run voltage" for the driver stage may come from one of the secondary windings on the switching transformer.

One important signal that is applied to the driver comes from the output of the opto isolator. This feedback signal is a sample of the output voltage of the SMPS. It is compared to a reference level in the driver control block. (The reference may be a discrete zener diode, or may be internal to the driver IC). A correction or error voltage is produced which changes the pulse width or pulse rate to regulate the SMPS.

Several other control signals may be associated with the driver, depending on the specific SMPS: over current shutdown, over voltage shutdown, and/or under voltage (low B+) shutdown. These control signals may be applied to the driver block via separate opto isolators; they may be combined in to a common control line and then applied via an opto isolator; they may be applied to the Feedback & Control blocks; or they may not be used at all.

MIC 3 - Secondary circuits

The secondary circuits are indicated by the black blocks in Figure 6. A SMPS may

have five or more DC outputs, depending on its application. There are several things you need to keep in mind about the secondary circuits.

First, a problem in one of the secondary loads (such as the horizontal output stage) may cause what appears to be a SMPS problem. Before you troubleshoot a "dead" SMPS symptom, be sure to determine if the problem is the load or the SMPS.

Secondly, most SMPS will not run properly without the main load connected. The main load is the output that is monitored by the Feedback & Control circuit for voltage regulation control. Usually this is the highest voltage output, or the output that has the most current drain. (In television receiver and computer monitors the main load powers the horizontal output stage). Refer to Tech Tip #204, "Identifying SMPS Problems" for more information on isolating a SMPS problem from a load problem.

Lastly, keep in mind that SMPS typically operate at frequencies from 40 to 150 kHz. This means that you can not replace the rectifier diodes with conventional, AC power supply diodes. The diodes used in the outputs of a SMPS are special high frequency, quick recovery types. The electrolytic capacitors should have low equivalent series resistance (ESR) and leakage.

MIC 4 - Feedback & Control

The Feedback & Control blocks shown in

Figure 6 (red) couple a sample of the output voltage back to the driver stage. Two major parts of this functional area are the feedback divider network and the opto isolator.

The feedback divider network usually consists of two precision resistors which divide the output voltage. The divided down voltage is coupled to the Driver block through an opto isolator. The Driver uses this feedback voltage to regulate the switching transistor. Some SMPS may use a separate winding of the switching transformer to produce the feedback voltage.

An opto isolator is needed to maintain isolation between the cold ground (secondary side of the switching transformer, and the hot ground (primary side), while coupling the DC feedback voltage. An opto isolator consists of a photo transistor and an LED. As the feedback voltage changes the brightness of the LED changes. The changes in light cause the conduction of the photo transistor to change. (The voltage at TP10 is supplied by the Driver, and is pulled to ground by the conduction of the opto isolator).

Refer to the Tech Tip #204 for information on identifying SMPS problems, Tech Tip #205 for information on troubleshooting PWM type SMPS, or Tech Tip #206 for information on troubleshooting PRM type SMPS.

**For more information,
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