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Understanding Switched Mode Power Supplies (SMPS)

Switched-mode power supplies (often called "switchers" or "choppers") have been around for many years. Early applications were found in the military and aerospace industries because of the need for lightweight, compact power supplies. Next, the switcher became popular in the computer industry. Today, they are also used in televisions, VCRs, cameras and other consumer electronic products.

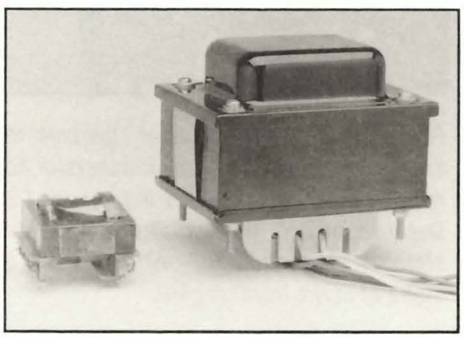

Fig. 1: The switched mode power supply (SMPS) transformer (left) serves the same purpose as the AC power transformer. Both provide isolation and various voltage outputs. In addition to its smaller size, the SMPS wastes much less power as heat.

Switched Mode Power Supplies (SMPS) are now found in most television sets and VCRs. Some names might have a familiar ring, such as, the "PWM" Pulse Width Modulated (NAP, RCA, Zenith), "Chopper" Power Supply (RCA), "VIPUR" Variable Interval Pulse Regulator (PRM type, RCA), plus variations of these.

This Tech Tip explains how switching supplies used in TV receivers work. It will concentrate on the switchers used in TV receivers, since those found in VCRs and some other applications are low-cost, replaceable modules, while those in televisions are repairable. Tech Tip #158 explains how to troubleshoot bad switching supplies.

The Benefits of Switchers

Switchers offer three main advantages over conventional "linear" power supplies: high efficiency, tight regulation, and small size. Of these, efficiency is usually the most important.

The typical efficiency of a conventional "linear" regulated power supply (with a series solid-state regulator working in the linear region) is only 40% to 50%. The other half of the power is wasted as heat in the regulator device. Switchers, by comparison, offer efficiencies of 60% to 90%. This is very important when the designer wants to reduce generated heat, reduce power costs, or increase battery life.

Most switchers provide better regulation than linear supplies. They adjust for changes in input voltage or load current, with little change in efficiency. The regulation is usually faster than a linear supply, offering even more advantages in critical circuits or in devices facing widely changing voltage input or load current conditions.

Because the switcher operates at high frequencies, the parts used in a switcher are physically smaller than those needed for a 60 Hz supply of the same power rating. The transformers, capacitors, and other filtering components are smaller. This is especially important for portable equipment such as computers, VCRs, and camcorders.

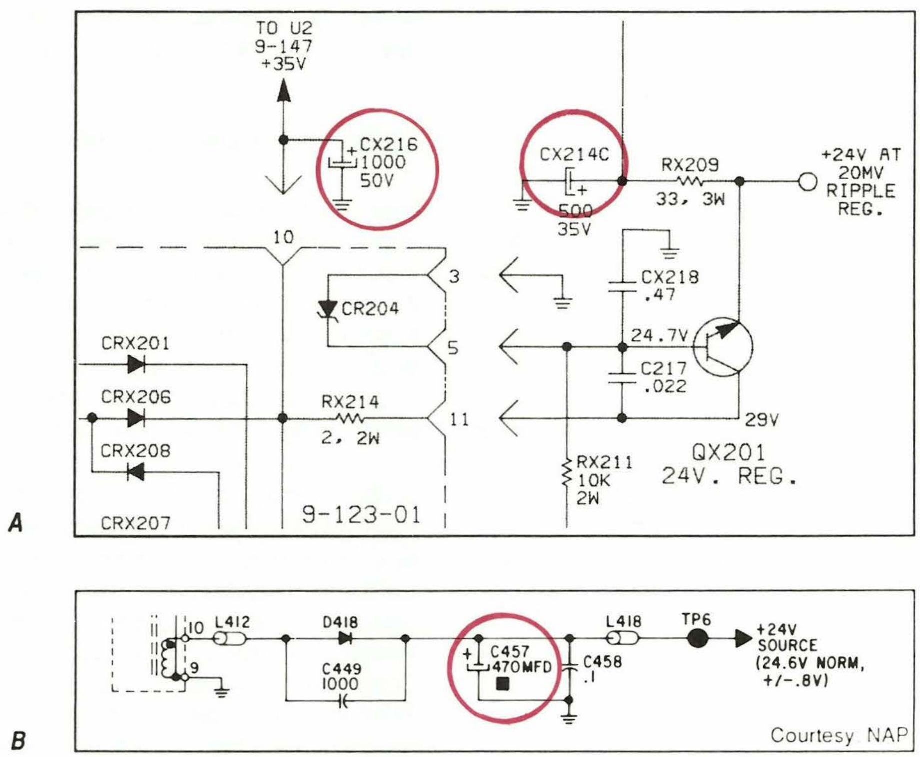

Fig. 2: Because the SMPS (B) operates at such high frequencies, smaller values of capacitance are needed for filtering compared to the 60 Hz output of a conventional supply (A).

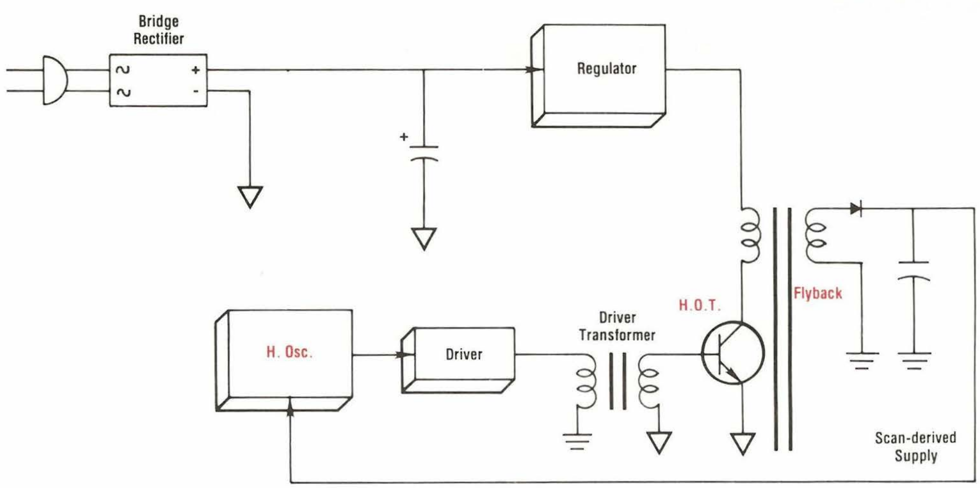

Fig. 3: The horizontal output stage of a TV receiver is really a form of an SMPS. The main pieces are: 1. The oscillator, 2. The power switch (output transistor) and 3. The flyback transformer.

They're Not New

Switchers are often considered a "space-age" invention. In reality, switched mode power supplies have been used since the first car radios. A mechanical "vibrator" allowed the 6 volt automotive current to develop the power needed to bias vacuum tubes. Furthermore, every television high voltage section is a switcher. As you learn more about switchers, you'll see that many of the troubleshooting processes are the same, whether you are servicing a switcher or a conventional high voltage section.

The block diagram in Fig. 3 shows that the switcher and the conventional horizontal output stage have three main sections: an oscillator, a solid-state power switch (bipolar transistor, MOSFET, SCR, etc.), and a flyback transformer. Some switchers also have a damper diode, to prevent ringing. This is not always needed, however, since some ringing in the signal is acceptable. In other cases, the function of the damper diode is part of the power transistor.

Let's start by examining the similarities between the switcher and the horizontal output stage.

- Both are driven by an oscillator
- Both use a flyback transformer
- Both operate at a relatively high frequency
- Both use a power device to switch power to the transformer
- Both receive raw B+ voltage from a simple linear power supply powered from the AC line.

Later, we will learn about the differences between the scan derived supplies used in televisions and the switched mode power supplies. They are:

- The switched mode power supply usually operates at a frequency higher than the 15,734 Hz horizontal sync frequency
- The signal at the switcher's output transistor may change in frequency, pulse width, or both
- Since the switcher is the regulator, additional regulation is not needed between the raw B+ supply and the flyback transformer.

Before we look at the circuit configuration, we need to understand the principle the switcher uses to regulate its output. Switchers use pulse modulation to obtain the high efficiency.

Linear Versus Switching Regulation

In order to compensate for changing conditions, regulated power supplies must have more power available at the regulator input than required by the load. The difference in the amount of available power versus the power needed by the load determines how well the supply compensates for changes in load current or incoming AC line voltage changes, such as brown outs.

Linear power supplies maintain a constant output voltage by converting the excess power to heat. The regulator's power transistor, in series with the load, operates in its linear ("half-on") region. When the load needs more current, the effective resistance of the transistor reduces, causing it to convert less power to heat. When the load current decreases, the regulator increases its electrical resistance, converting more incoming power to heat.

Instead of operating in the linear region, the switcher's regulator transistor operates as a switch; either fully on (saturated) or fully off (cutoff). The amount of power delivered to the load depends on how long the switching transistor is on versus how long it's off (duty cycle). Since the transistor doesn't operate in its "half-on/half-off" region, it produces much less heat. The result is high efficiency, since almost all of the power is delivered to the load.

There are two basic types of regulators: the pulse width modulated regulator and the pulse rate modulated regulator. Switched mode power supplies used in televisions use either type. The pulse rate modulated regulator is often used in VCRs, but this is by no means universal.

Fig. 4: This SMPS regulator operates the entire TV receiver. The power transistor and heat-sink are much smaller than needed for linear regulation, because the SMPS's transistor only operates "full-on" or "full-off" instead of in the linear region.

The Pulse Width Modulator

A "pulse width modulated" regulator switches the regulator transistor on and off at a constant rate (frequency). The PWM signal comes from an oscillator, which varies the on-time and off-time of the switching transistor. As the switching transistor stays on longer, more energy is applied to the switching transformer, resulting in a higher DC output power. Likewise, a narrower pulse turns the switching transistor on for a shorter time, resulting in less energy being applied to the transformer.

Voltage regulation is achieved by comparing the DC output to a reference voltage. This comparison is then used to adjust the amount of time the switching transistor is turned on, ultimately regulating the output voltage.

The biggest difference between the PWM and the PRM (described next) is that the time for one complete cycle of a PWM regulator remains

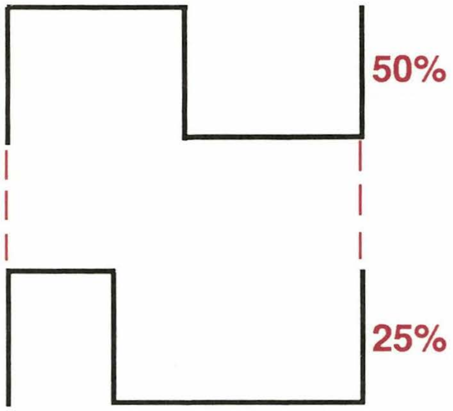

Fig. 5: The total period of a Pulse Width Modulator (PWM) stays the same, but the ratio between the "on" and "off" time changes. A 50% duty cycle (top) supplies twice as much power to the circuit as a 25% duty cycle, if all other parameters stay the same.

constant. Any change in the drive signal causes both the on-time and off-time to change in order to keep the frequency of the signal constant.

The Pulse Rate Modulator

A variation of the switched mode power supply uses pulse rate modulated (PRM). When all is said and done, both regulators operate in a similar manner; changing the amount of time the switch is turned on.

Unlike the PWM, the PRM does not operate at a constant frequency. The switching frequency increases when less current is needed. This might seem backwards, since a higher repetition rate seems to apply more power to the switching transformer. This would be true if the switching transistor produced a constant duty cycle (ratio between on and off time) for all applied frequencies. It doesn't.

The easiest way to understand the PRM is to imagine that the "off time" stays constant, while the "on time" varies. Just like the fixed-frequency PWM, the amount of power delivered to the switching transformer depends on how long the switching transistor is left on. Fig. 6 shows what happens as the signal changes.

When the power supply needs a 50% duty cycle (equal on and off times) the switching transistor produces a repetition rate of 100 kHz. As Fig. 6 shows, this is a 5 microsecond on-time and a 5 microsecond off-time. Reducing the on-time to 1 microsecond, while leaving the off-time at 5 microseconds change the period to 6 microseconds, which translates to a frequency of 167 kHz. The frequency has increased, but the amount of power delivered to the switching transformer has decreased by 80%.

The advantage of the PRM over the PWM is a simpler oscillator circuit. In fact, the output transistor often doubles as the oscillator, with the addition of an inverting winding on the flyback transformer. The disadvantage is that the output signal varies in frequency, which complicates RF shielding and filtering of the output.

In testing a switcher that uses pulse rate modulation, the waveshape and frequency both give troubleshooting information. Testing the frequency is a good first-step, since many schematics show the operating frequency for different load conditions. If the frequency is close to normal, examine the waveshape to see if the duty cycle is normal. Beyond that, the PWM and PRM supplies use similar troubleshooting procedures.

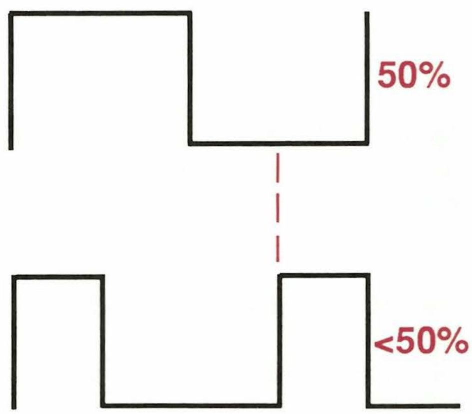

Fig. 6: The difference in the Pulse Rate Modulator (PRM) is that the output changes frequency as the "on" time changes. The PRM costs less to build, but has less reliable filtering and regulation.

The Complete Switcher

The switched mode power supply needs a source of power. As Fig. 7 shows, unregulated B+ feeds from the AC line through a conventional full-wave bridge power supply to the primary of the flyback transformer. Notice that the primary of the switcher is "hot" and requires the use of an isolation transformer for safety for yourself and for the circuits.

The bottom side of the flyback's primary winding then feeds to ground through the switching transistor, which can be either a bipolar transistor or a power MOSFET. The switching transistor alternately connects and disconnects the bottom side of the transformer to ground. Magnetic flux builds when the transistor conducts, and collapses (flies back) when the transistor is off. This changing magnetic field causes the transformer action.

Fig. 7 also shows that there are several secondary windings, with different turns ratios in order to produce different output voltages. The flyback transformer isolates these windings from the primary, allowing a hot ground on the primary

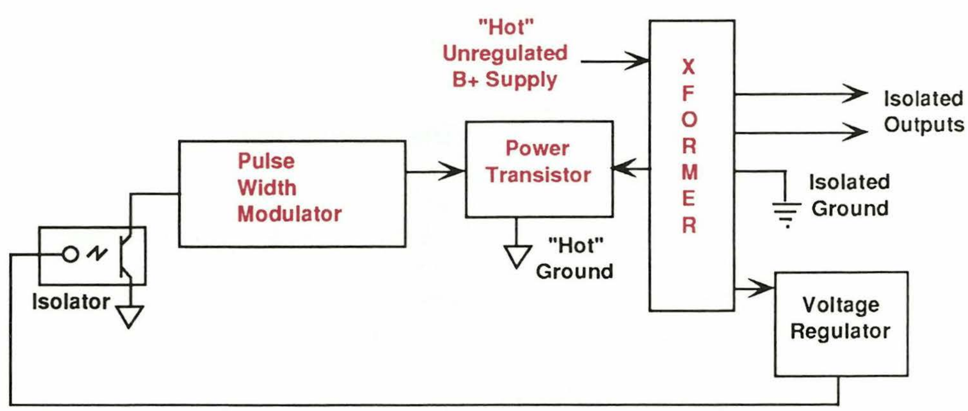

Fig. 7: A typical SMPS consists of the unregulated B+ source, the switching transformer, the switching transistor, and the oscillator. Regulation is provided via feedback from one of the secondary windings. Opto-isolators are used if isolation is needed between input and output; otherwise a direct connection may be used.

side and isolated power feeding the loads. The filtering on these outputs is relatively simple, because the high frequencies at which the switcher operates are easier to filter than a 60 Hz AC line signal.

One of the secondary windings also feeds the regulator. The output is compared to a reference, such as a zener diode, which creates the correction signal which controls the switcher's oscillator. Since the switcher transformer usually provides isolation from the AC line, the regulator feedback normally passes through an isolation component. Opto-isolators are often used to couple the signal back to the oscillator.

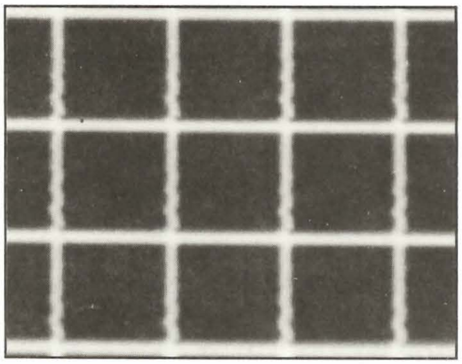

Fig. 8: A linear regulator usually responds slowly to changes in beam current, which causes the vertical lines to bend when a crosshatch test pattern is on the screen at a high brightness level.

Why They Regulate Better

In addition to higher efficiency and smaller size, the high operating frequency of the switcher provides better regulation, because it can correct for changes in line or load conditions in a few cycles of the switching signal. A linear regulator, or a regulator synchronized to the horizontal oscillator may require up to 6 horizontal lines of time to correct for changes in picture brightness. The switcher can be 10 to 100 times faster in responding, for better picture quality.

This, by the way, is the reason that the boxes of a crosshatch video pattern are often bent at high brightness levels. The power supply needs several horizontal lines to return to normal after each horizontal white line. The lines immediately after the white line bend because the horizontal output stage finds itself with too much current. Reducing the brightness or contrast reduces the bending, but may not eliminate it completely on some receivers.

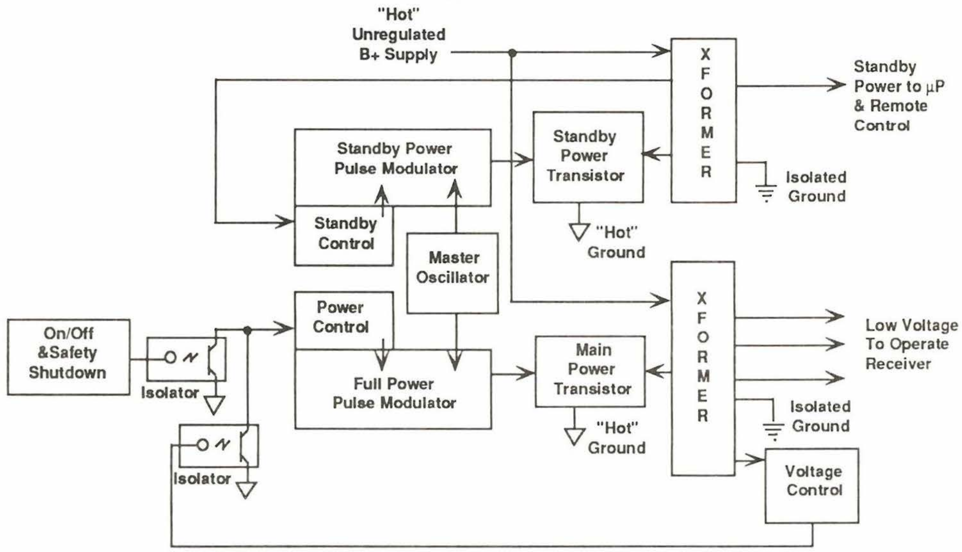

Fig. 9: Many TV receivers use two SMPS. One runs constantly to power the remote control receiver and microprocessor memory. A larger supply powers the rest of the receiver, when activated by the remote control circuits.

The Safety Shutdown Circuits

TV receivers almost always have safety circuits which cause the receiver to shut down when a problem causes the possibility of excessive high voltage. Before switchers were used to power the horizontal output stage, these safety circuits usually interrupted the signal in the horizontal stages; the oscillator or driver stages were normally controlled. Receivers using switchers usually feed the shutdown control signal directly to the power supply, removing power from the output stage to accomplish shutdown.

Troubleshoot shutdown problems using the same methods as a conventional receiver. The only difference is the destination of the shutdown signal path. See Tech Tip #131 for details.

The Standby Supply

Some TV receivers have two switcher supplies. The "standby" power supply runs all the time the receiver is plugged into AC power. It usually operates the remote control circuits, and may also keep data stored in digital memory while the receiver is turned off.

A second, larger switcher runs the rest of the receiver when power is applied. This second supply generally has a much larger switching transistor and flyback transformer, since it is responsible for operating the horizontal output stage and most of the other circuits in the receiver.

When troubleshooting a double supply receiver, first confirm the standby supply operates correctly. If it has problems, the larger supply cannot start. If the small supply is okay, proceed to troubleshoot the main supply using the processes covered in Tech Tip #158.

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