Principles of switching power supplies

By The ES&T Staff

This article is partly based on the service manual for the RCA CTC176 color television set by Thomson Consumer Electronics. The schematic diagram for the power supply of this set is reproduced within this article as Figure 3. However, for a broader view, refer to the Profax schematic diagram in this issue, which is the schematic diagram for this set.

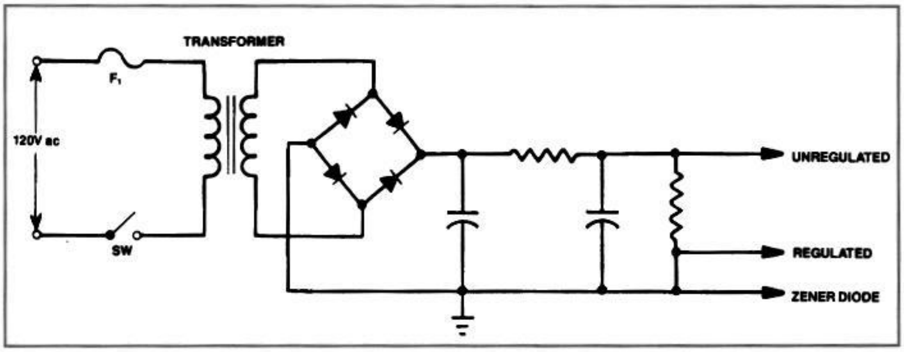

Figure 1. A linear power supply consists of a transformer to step the voltage down to the desired value, a rectifier to convert the ac to dc, and a series pass element to regulate the voltage.

The function of a power supply

The purpose of a power supply is to convert the input power line voltage, in the United States 120V at 60Hz, into one or more dc voltages that are required to operate the various circuits in an electronics product.

Historically, power supplies have been linear. That is, they consist of a transformer to step the voltage down to the desired value, a rectifier to convert the ac to dc, and a series pass element to regulate the voltage so that it remains near the desired value in spite of fluctuations in the input voltage, or changes in the load (Figure 1).

Such power supplies worked fine for many years, but they had disadvantages. For one thing, they required large, heavy transformers to handle the currents at 60Hz. That means large costs for transformers and added weight of the product.

Furthermore, the regulation components consumed power (losses) which resulted in waste.

The switching power supply

For many years, given the state of electronics technology and the cost of components, series pass voltage regulation was the most practical and efficient method of achieving voltage regulation.

With the advent of high-speed switching semiconductor components, engineers began to investigate the possibility of regulating the voltage output of power supplies in a new way. Instead of regulating voltage by dropping some of it across a pass transistor, or other component, which dissipates power as it regulates, it might be possible to switch the supply power in and out of the circuit, and regulate the voltage in that manner.

When the load is low and the line voltage is within specs, the power into the supply is switched in by the switching element only for brief periods of time. When the load on the supply is high, or the line voltage is low, or both, the switch remains closed longer so that more energy can flow in during a given interval.

Thus, in most switching power supplies, the switching frequency is higher at light loads and lower at heavier loads. The switching frequency is lower at heavier loads because the switch must remain closed for longer periods of time in order to allow more energy to flow into the power supply.

A simple switcher

In one of the most basic examples of a switching power supply (Figure 2), a transistor switch applies the unregulated voltage across an inductor for brief periods of

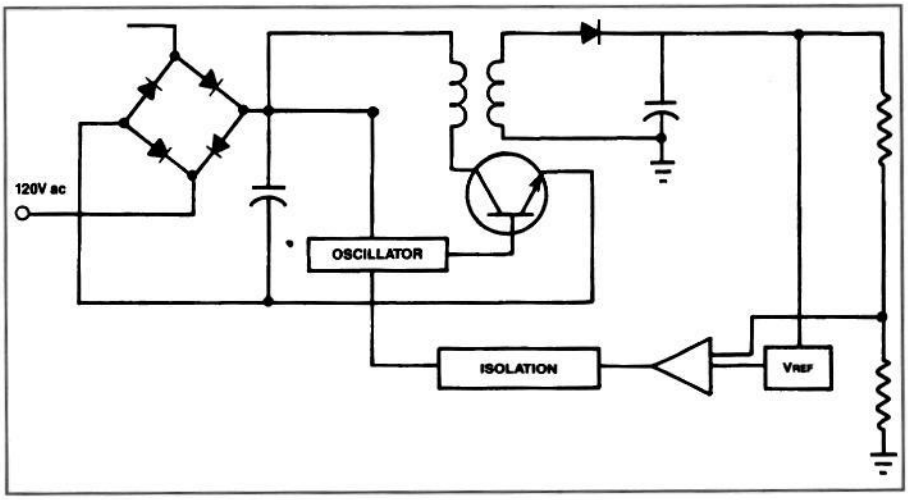

Figure 2. In this switching power supply, a transistor applies the unregulated voltage across an inductor intermittently. The current in the inductor increases when the transistor is on. The energy represented by this increase in current is stored in a magnetic field. This energy is then transferred to a filter capacitor in the output circuit.

time. The current in the inductor increases during each period when the transistor is on. The energy represented by this increase in current is stored in the inductor's magnetic field.

The energy thus stored in the inductor's magnetic field is then transferred to a filter capacitor, which is in the output circuit.

The capacitor serves as the component that outputs the power supply's voltage to the load circuit. It is also a filter which smooths the dc output.

Gaining an understanding of switchers

A lot of technicians have difficulty understanding switchers, and troubleshooting them. Much of this problem stems from the fact that there is not a single switching power supply circuit, but an almost infinite variety of such circuits, depending on the manufacturer, the nature of the product that the supply is used in, and the state of advancement of electronic circuit/component technology when the supply was designed and built.

The key to understanding switchers, then, is to recognize the general principle of the units, as stated earlier, and to read the manufacturer's literature, if available, to see how the supply in a particular product applies this principle.

Of course, troubleshooting a switching power supply that's not functioning presents problems of a complexity that you just don't encounter in linear supplies. But an understanding of the nature of these circuits will make troubleshooting considerably easier.

A real world switcher

The power supply in the RCA CTC176 color television (Figure 3) uses a variable frequency, variable pulse width (switching) regulator. U4101, the hybrid IC, contains most of the regulator circuit components, including the power switching FET.

When power is first applied to the set, approximately 150Vdc is developed by the bridge rectifier diodes and filter capacitor. This voltage is applied through the primary winding of T4101 pins 1 and 3 into U4101 pins 11 and 12.

Pins 11 and 12 are the drain of the power FET. This FET is internal to U4101. The source of the FET is connected to pins 8 and 9 of the IC. R4124 is connected between the junction of pins 8 and 9 and

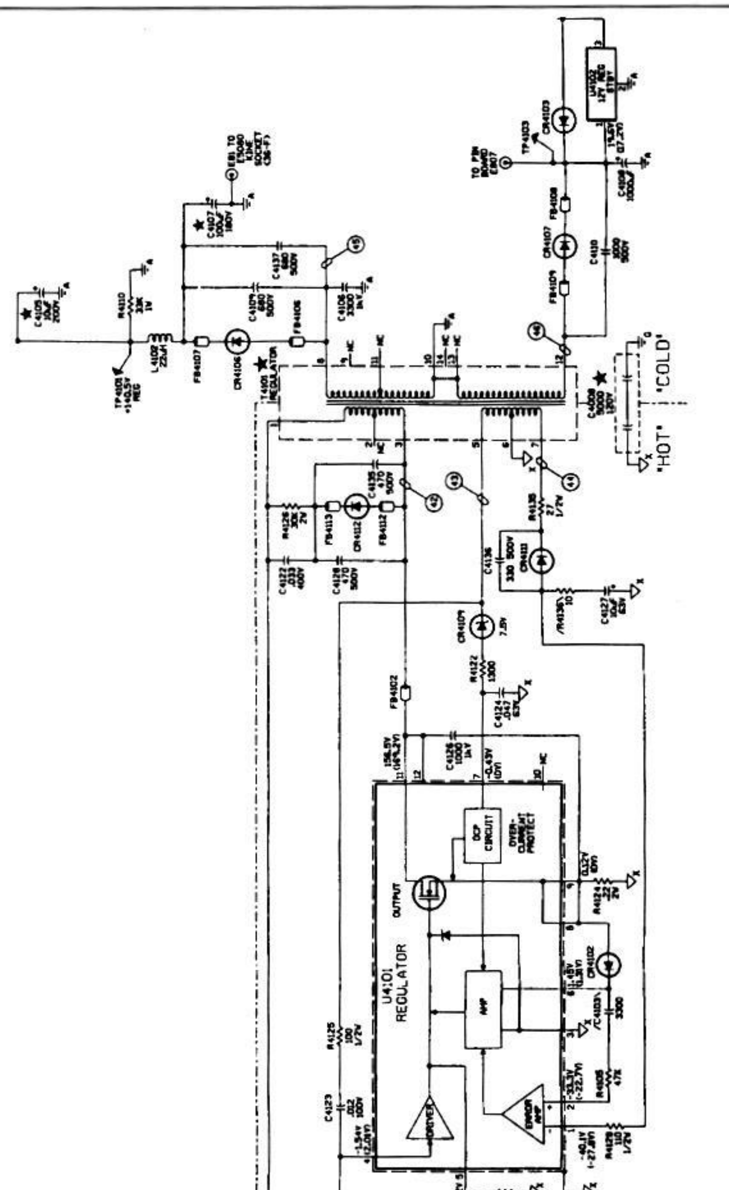

Figure 3. The power supply in the RCA CTC176 color television uses a variable frequency, variable pulse width (switching) regulator. U4101, the hybrid IC, contains most of the regulator circuit components, including the power switching FET.

ground. R4104, the start-up resistor, provides bias to the gate of the FET through pin 4 of U4101 to turn the FET on.

When the FET is turned on, the drain current flows through the primary winding of transformer T4101 through the FET to ground. Current flowing in the primary induces a voltage on the winding between pins 5 and 6 on the transformer. This voltage is coupled from pin 5 through R4125 and C4123 into pin 4 of U4101.

Pin 4 of U4101 is connected internally to the gate of the FET. The polarity of the voltage is such that it turns the FET on harder. As more current flows, a larger voltage is built up on R4124, the FET source resistor.

The overcurrent protection circuit

Eventually, the voltage will be large enough to turn on the overcurrent protection circuit (OCP) internal to U4101. This will cause the FET to turn off.

When the FET turns off, current in the primary windings of T4101 ceases, and the collapsing magnetic field induces current in the secondary windings, charging filter capacitors C4107 and C4108.

Once the voltage sensed by the OCP circuit has dropped sufficiently, the FET will again begin to conduct.

This sequence repeats for several cycles until stable oscillation begins. The frequency of oscillation will vary with load from approximately 100KHz at standby to 38KHz at full load.

Regulating the voltage

The feedback winding between pins 5 and 7 on T4101 is tightly coupled to the secondary windings. The voltage on the feedback winding tends to follow the voltage changes on the secondary windings.

The voltage developed on pin 7 of T4101 is rectified by CR4111 and filtered by C4127. This negative voltage is applied to pin 1 of U4101.

Internal to U4101 is a precision voltage reference, trimmed to –40.5V ± 0.5V. The error amp acts to make the voltage on pin 1 of U4101 equal to the reference voltage.

If the load on the secondaries increases and the voltage drops, the voltage developed at pin 7 of T4101 would decrease. When the pin 7 voltage decreases, the error amp output signal causes the FET to stay on longer thus increasing the output voltage. In this way, the IC is able to hold the output of the supply constant with varying line voltages and loads.

Overcurrent protection

If an excessive load is placed on the power supply outputs, the on time of the FET will increase. This will result in m ore current through the FET and source resistor R4124. A voltage drop will be developed proportional to the current and this voltage will be applied to the overcurrent protection circuit internal to U4101.

This circuit is also connected to pin 7. A capacitor, C4124, is connected to pin 7. As the current increases, it will charge C4124 and turn on the overcurrent protection circuit. This will turn off the FET. Increasing the value of C4124 would increase the overcurrent protection trip point.

Other parts of the power supply

The network composed of C4122, C4128, R4126 and CR4112 is a snubber network used to reduce the high voltage spike developed when the FET turns off.

C4103 and R4105 are part of a compensation network which tends to stabilize the supply from parasitic oscillations.

R4129 is an ESD protection resistor for the gate of the FET.

R4122 and CR4109 help stabilize the overcurrent protection with line voltage variations.

All of the ferrite beads are for RFI emission reduction.

C4107, L4102 and C4105 form a filter network to reduce the ripple in the REG B+ and to reduce high frequency switching noise.

The secondary windings of T4101 provide standby voltages of +12V and +5V plus a regulated +140.5V supply used to power the horizontal deflection circuit.

Troubleshooting

Finding problems with this power supply circuit is a fairly straightforward task. The most important voltage to measure is the one found on pin 1 of U4101. It should be -40.5V ± 0.5V. If this voltage is correct, it is very probable that the IC is working correctly and any incorrect output voltages are caused by abnormal loads.

As the output loads increase, the output voltages drop and the frequency of oscillation will decrease. With high enough loads, the frequency will be in the audible range. If the outputs are shorted, the supply will shut down until the problem causing the short is corrected.

Under no-load conditions, the REG B+ voltage will rise and the supply will go into a "burst" mode where there is a series of drive pulses at an audible rate. Note: it is not recommended that the supply be run without loads as the REG B+ output capacitors may be stressed by over-voltage.

If pin 1 of U4101 is shorted, the REG B+ output voltage will be low (approximately 30V). If pin 1 is open, the REG B+ voltage will rise to over 200V.

In all cases, the voltage on pin 1 of U4101 should be checked for -40.5V ± 0.5V. This is the best indication that U4101 is operating correctly. It is normal for the REG B+ voltage to rise 4 or 5 volts when the supply is in the standby mode.

Consult the literature

Unfortunately, it's a fact of life that switching power supplies are more varied in design and more complex than are linear power supplies. The fact that frequently switching power supplies are largely contained in an IC package for which only a block diagram is given adds to the difficulty of understanding and troubleshooting them.

The mode of operation of linear power supplies was usually fairly straightforward, and a study of the circuit itself and its schematic diagram would lead to an understanding of the circuit operation. With a given switcher, the operating principles may not be obvious, and it may be necessary to obtain a detailed explanation from the manufacturer's literature.

As with any other complex, sophisticated electronics circuitry, the more you study switching power supplies, and the more variations you see, the clearer the operation of the circuits will become. ■