The Evolution of Power Supplies

Part 2: Switching techniques.

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Part 1 of this pair of articles covered the development of dynamotor and vibrator power supplies as they applied to automobile radios. Hams took advantage of power supplies available from both military and commercial sources and used them for powering their equipment in mobile applications. During the development period for the dynamotor and vibrator supply, conventional AC wall-powered power supply design remained fairly constant, except for the changes required in the transition from vacuum tubes to semiconductors, with voltage regulation becoming the most obvious advancement.

Here in Part 2 we will cover later power supply designs utilizing switching techniques that enabled the use of simple and reasonably efficient power conversion equipment in many applications, including spacecraft. Power supplies used in the home PC are of a switching type that exhibits both reasonably high reliability and high efficiency. When they fail, a ham is usually available to catch the pieces, but what does he do with them?

Some failed switching supplies are repairable if sufficient information is available for use as a troubleshooting guide. Hopefully the following discussion will help you learn more about switching supplies, and perhaps even enable the repair of a few, too.

DC-DC converter

A DC-DC converter is designed along the lines of a vibrator power supply, and in fact is really just a solid state version of it. The primary differences between the vibrator and DC-DC converter are the operating frequency, efficiency, and performance reliability. DC-DC converters can be operated at almost any switching frequency of interest, with many operating in the 30 kHz region. At that frequency, the amount of iron required in the transformer core is reduced considerably, allowing the power transformer to be miniaturized without a loss in output power availability. The power conversion efficiency of DC-DC converters has approached 90%.

For a period of time, DC-AC inverters (switchers) were developed to produce 120 VAC from a 12 VDC power source. Many inverter kits were made available to the ham so that low-power 120 V vacuum tube equipment could be powered in automobile applications. Because of this application, inverters were designed to output 120 VAC at 60 hertz, but, unfortunately, early inverter designs were load-dependent, causing them to shift frequency with load variances. In addition, the output waveform was anything but a sine wave, so that switcher noise was evident in receivers operating in the vicinity of an inverter. Although most inverters were well filtered, it was never really enough.

In operation, one or two transistors may be used to provide the switching, as shown in **Figs. 1** and **2**. **Fig. 1** uses a single transistor and a transformer operating in an Armstrong oscillator configuration which is suitable for producing a voltage at almost any magnitude but low power. Excessive loading on the single-ended oscillator can cause it to stall. **Fig. 2** shows two transistors operating in a push-pull Armstrong oscillator, making it capable of producing a reasonably high power output. Output is taken from the emitters through winding "P" (primary) and the feedback to drive the bases is obtained from winding "T" (tickler).

Two switching techniques have been used in DC switchers: transistor saturation and core saturation. It doesn't matter which switching technique is

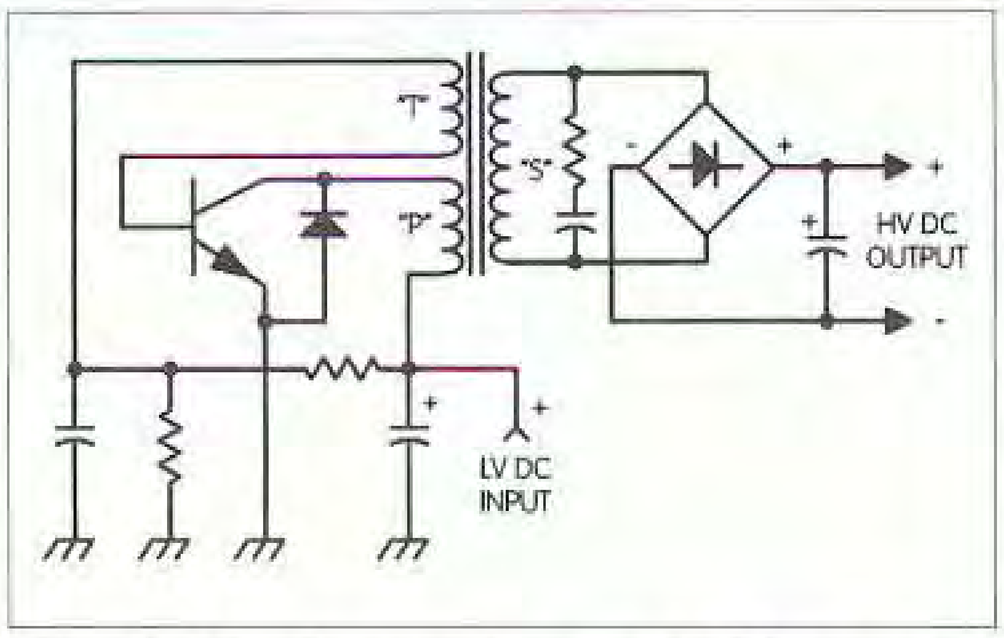

Fig. 1. Single transistor switching power supply.

used, but it is essential that current must increase rapidly through the primary winding to a point where saturation occurs, and that's the switch point for starting the next cycle. For the circuit shown in **Fig. 2** to operate properly, the transistors must saturate in order to obtain a low series emitter-collector resistance value. The low saturation resistance reduces the transistor heat dissipation, particularly in high power supplies.

Upon reaching the next switch point, the second transistor begins to conduct, driving the alternate transistor into cutoff until the following switch point is achieved. The circuit operates just like an electronic teeter-totter that has a hard stop at the end of each travel.

When first developed, DC-DC converters (switchers) were used to power vacuum tube circuits in which a high voltage was required for tube operation. Hams used switching supplies for mobile applications until solid state radios became available. However, DC-DC converters continue to fly in many of the older spacecraft and are used for power conversion in some solid state equipment today to power gas panel displays and particularly where a negative voltage must be developed.

Even the high power audio amplifiers (boomers) used in automobiles require supply voltages well above 12 volts and that voltage is provided by a DC-DC converter. The reliability of a solid state converter parallels that of the old dynamotor in many respects, but with an efficiency exceeding that of a vibrator supply.

Power switchers

With the advent of home computers, power supplies evolved even further. If you can remember when huge power transformers were used in electronic equipment, you'll recall that the weight became almost unbearable when the equipment needed to be moved. Of course, the evolution in TV set power supplies eliminated the power transformer, with technology advancements influencing the switcher design as used in modern home computers.

Computer power supplies still use a power transformer, but it is small in comparison to the huge 60 Hz power transformer size that would be required to handle an equivalent amount of power, which is typically in the region of 230 watts.

Switching power supplies for computers were developed around several techniques, but the typical design uses an IC oscillator with pulsewidth modulation for voltage regulation and load control. With the low cost of switcher supplies, it really isn't cost effective to repair them, but it is fun to try. Therefore, here are a few highlights about how a switching supply operates. Hopefully, the insight might enable you to try to repair a failed supply or two.

The first step in examining a switcher supply is to look at two of the common methods for driving the output power transformer. **Fig. 3** shows two transistors, *not* complementary, but of the same type, driving the transformer primary through a capacitor. Separate out-of-phase square wave signals drive the transistor bases, causing a square wave current flow through the primary winding of the transformer. The high voltage provided to the circuit is in the range of plus and minus 120 VDC at about one ampere of current in order to achieve 230 watts of output power. **Fig. 4** utilizes a slightly different design approach using complementary transistors, but the power transfer is the same as in **Fig 3.**

A block diagram of a typical switching power supply is shown in **Fig. 5**, where the major circuit components are identified. The circuit designs of other available switching supplies vary considerably, but the concept of operation is similar and **Fig. 5** will aid in understanding and repairing them.

Because switching supplies are pulse (square wave) operated, they must be loaded at all times to prevent high voltage transients from breaking down components. The +5 V output is the recommended circuit to be loaded prior to the application of 120 VAC to the input. Most switching supplies will fail to start if the load is missing or is too light. Load sensing in **Fig. 5** is sampled at both the -5 and -12 volt outputs, while other supply designs may choose to sample elsewhere. Any output can be used for no-load sensing, because voltage spikes due to a no-load condition will appear equally in the other outputs from the transformer.

Switching power supplies operate in a closed loop, which requires that every circuit must respond as designed or

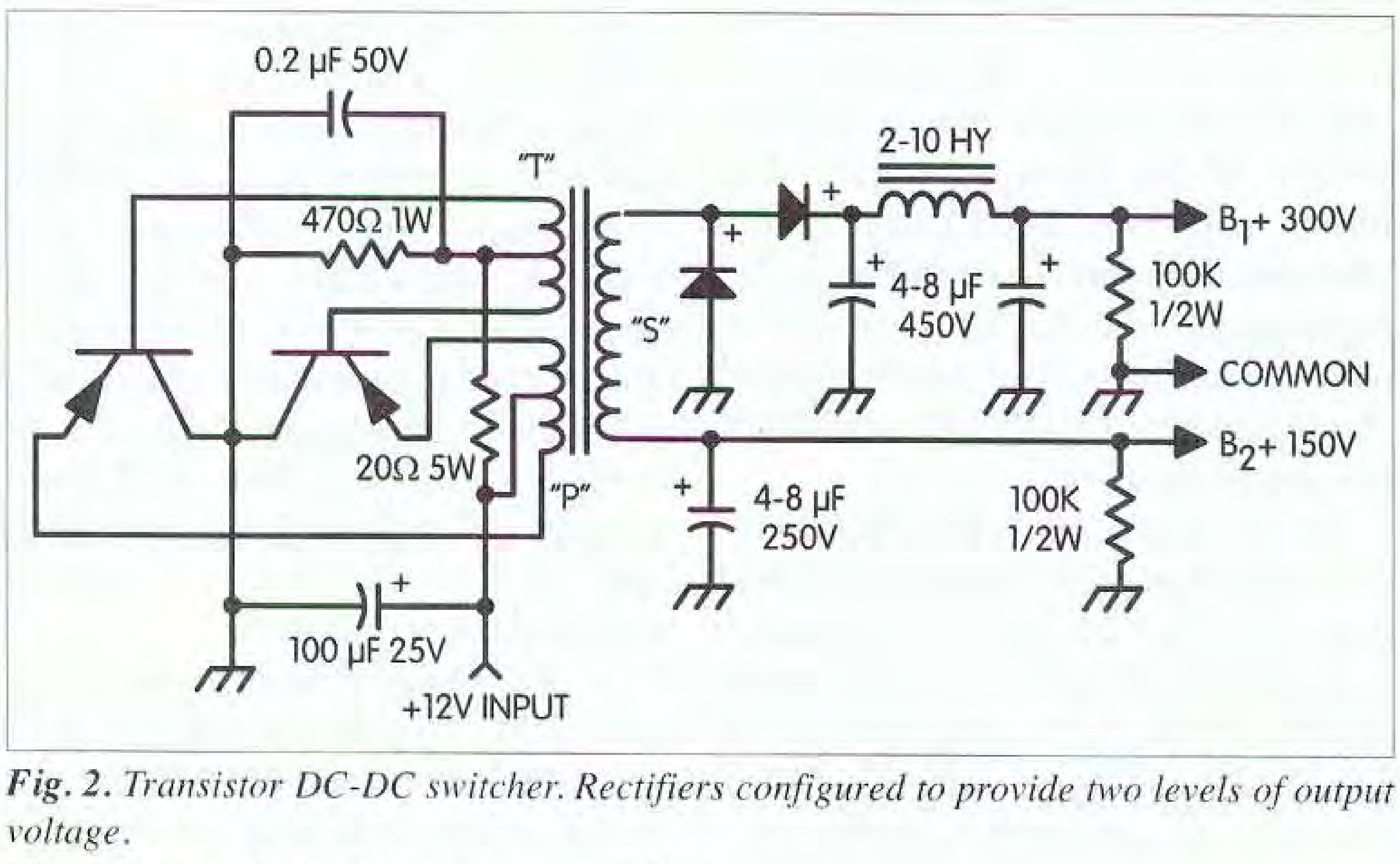

Fig. 2. Transistor DC-DC switcher. Rectifiers configured to provide two levels of output voltage.

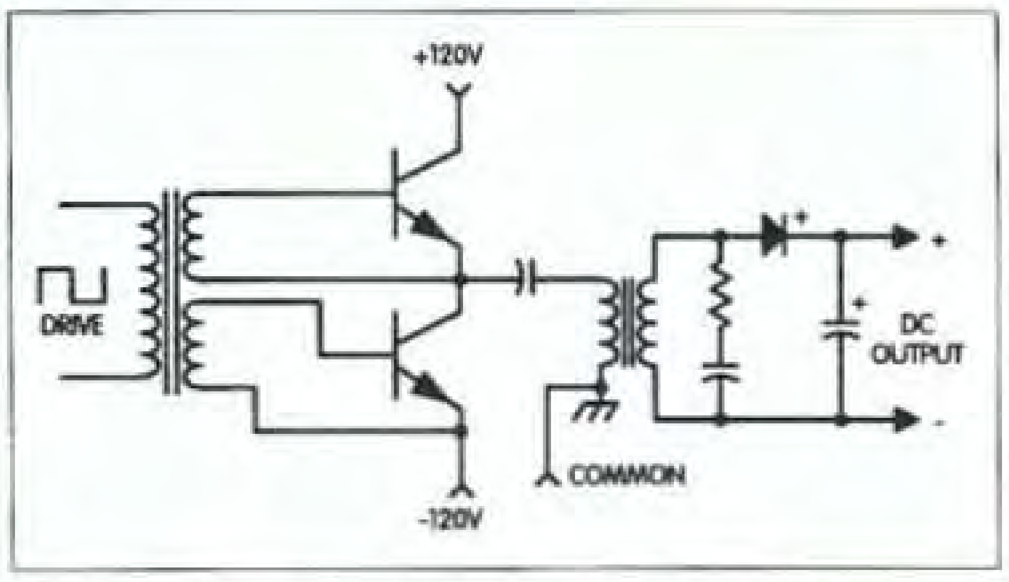

Fig. 3. Same type transistor switch driver.

the oscillator/PWM (pulsewidth modulator) will not allow the switching action to begin. Troubleshooting a failed switching supply becomes difficult because of the closed loop design concept. Using the teeter-totter again, the board must be whole, or it will fail to rock back and forth.

Circuit operation begins with power applied to the output driver circuit. *No DC voltage is applied directly* to the supply's output circuit or PWM. However, the initial application of AC power causes the output of T1 to pulse which is sufficient for the PWM to "start." Starting is done by IC1, which must oscillate to provide a square wave drive signal for transistors Q3-4, which are the excitation drivers that provide the drive to transformer T2. The output of T2 provides the drive signal to output transistors Q1-2. Once transistor Q1 and Q2 begin driving T1, power becomes available at each of the DC output terminals. A failure in any one of the loop elements will cause the power supply to malfunction.

Once the power supply is up and operating, voltage regulation is controlled by IC1 by changing the pulsewidth of the drive signal to transistors Q3 and Q4. The width of the supplied pulse is relative to the amount of required load power measured as terminal voltage at the -5 and -12 V outputs.

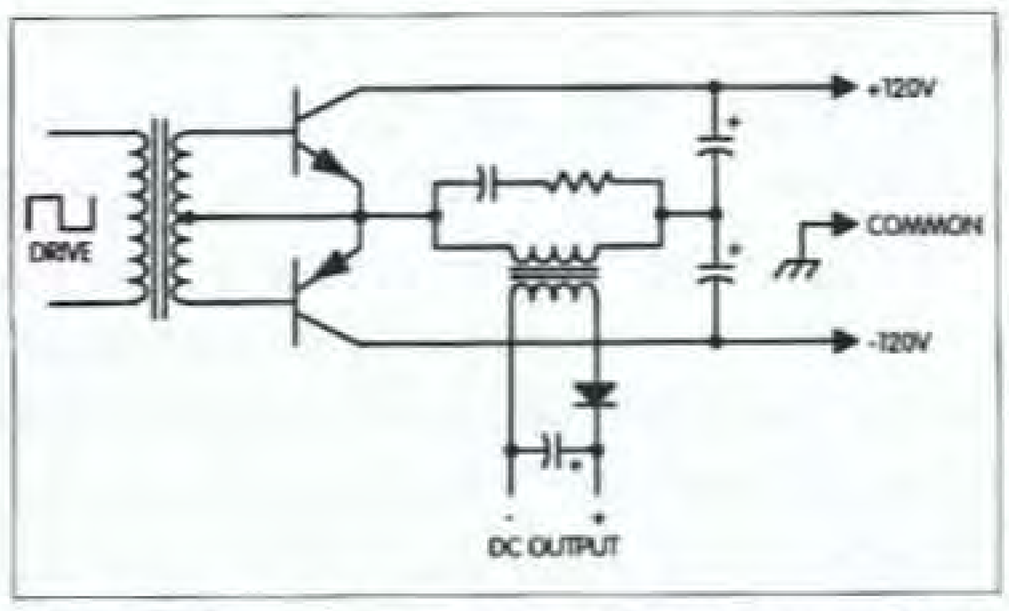

Fig. 4. Complementary transistor switch driver.

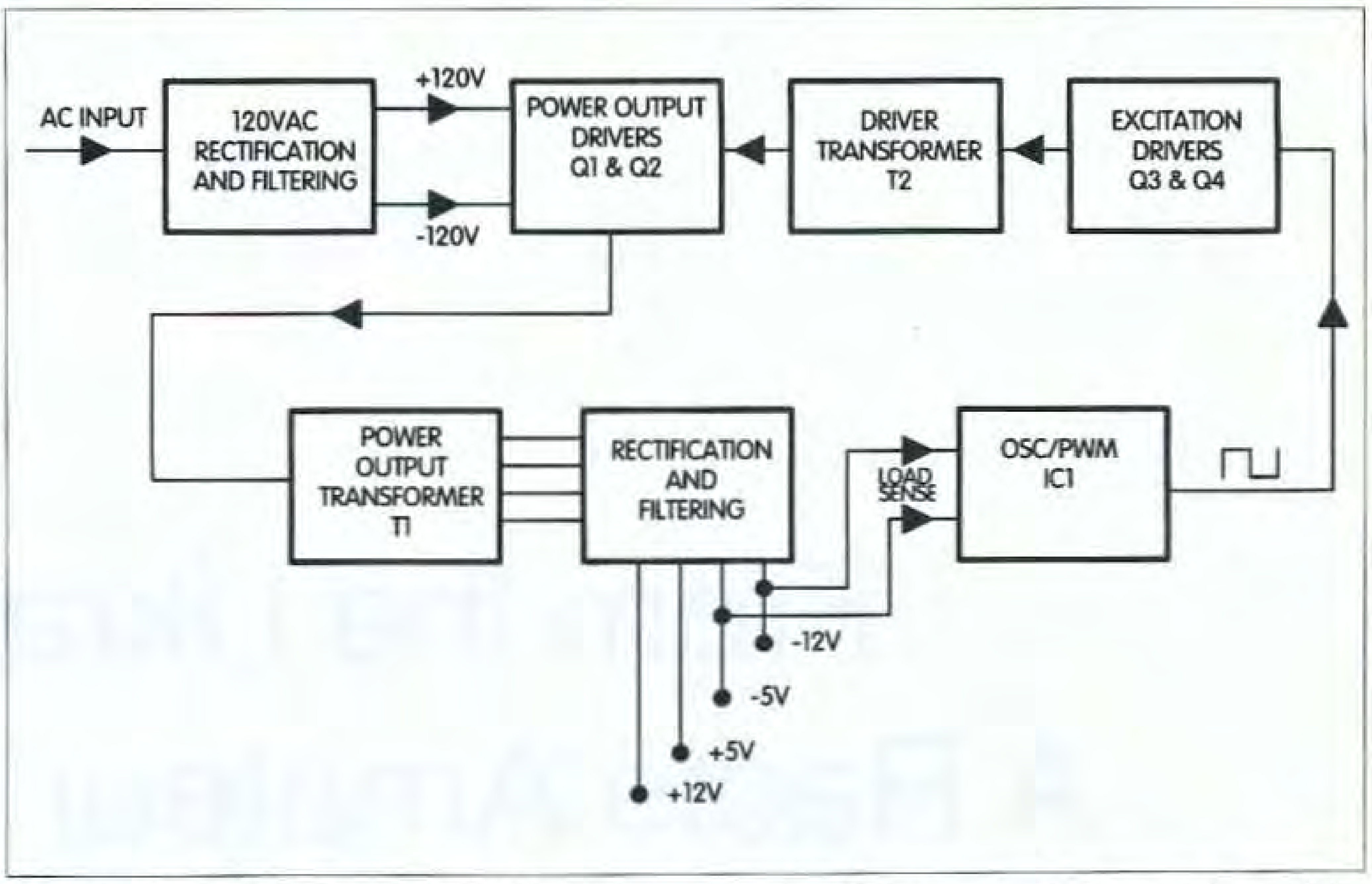

Fig. 5. Typical 230-watt switching power supply. Voltage regulation performed by pulsewidth modulation.

Because switching power supplies designed for computer applications require a fixed load, they are unsuitable for use with ham radio equipment where the load can vary. Of course, there are exceptions to every rule and hams will find the exception. For hams, the caution is that a suitable load (perhaps on the order of 50% of the rated amount) must remain on the supply at all times, and due to the switching nature of the circuit, an abundance of RF noise is generated and can cause RFI problems in receivers.

Conclusions

Power supplies powered from the AC mains and from automobile batteries have evolved over the years. Yet simple 120 VAC transformer-operated supplies are still very common, with their changes being primarily in the regulator circuitry. But the older automobile power supplies have evolved considerably from the dynamotor and vibrator configurations to DC-DC switching converters in applications in which a voltage is required that is greater than the battery voltage or of an opposite polarity.

The transition from vacuum tube technology to solid state technology was the primary driver for the elimination of power supplies in automotive applications. Perhaps the greatest changes in AC power supplies have been those associated with use in TV sets and computers, where the large, bulky power transformers have essentially been eliminated. Switching supplies have provided a high reliability and have retained a fairly high efficiency in the power conversion process.