Part Two

Test Saturation Voltage to Achieve High Efficiency

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Build a low-cost saturation tester to measure the saturation voltage of switching transistors accurately in the presence of high switching voltages or noise.

In switch-mode power supplies, saturation losses represent the main source of inefficiency in the power transistor. Because those losses are a function of a transistor's saturation voltage, it's important that power-supply designers be able to accurately measure saturation voltage when evaluating particular devices as power switches for their designs.

In the March issue, part one of this two-part article series discussed the contribution of saturation losses to power-supply inefficiency, the relationship between saturation voltage and saturation losses, and a novel approach to accurately measuring saturation voltage even when high voltages or noise are present.

That measurement technique can be applied by building the low-cost tester described here in part two of the article. A detailed description is given of the circuitry and components required to construct the saturation voltage tester or probe. In addition, a procedure for calibrating the probe is given along with some tips on how to use the probe effectively.

Building a Saturation Tester

Fig. 1 shows the circuit for a saturation-voltage probe. In looking at the figure, the input from the switching transistor is on the left and the output to the oscilloscope, or differential probe, is on the right. The circuit, powered by two 9-V alkaline batteries, consumes approximately 14.7 mA and 12.4 mA for the 9-V and –9-V supplies, respectively. Both batteries are monitored for end of battery life through resistor R6, diodes D8 to D10 and transistor Q7. Power indicator D8 will go out if the voltage of either battery drops below 6.2 V. Power indicator diodes D8 and D6 are used to start the voltage reference. The voltage reference self-biases and will not start on its own.

Parameter	Value
Positive power-supply voltage	9 V at 14.7 mA
Negative power-supply voltage	–9 V at 12.4 mA
Rise time	12 ns
Fall time	30 ns
Input-voltage range	–9 V to 1 kV

Table 1. *Specifications for a saturation-voltage test probe to measure SMPS losses.*

The voltage reference consists of red LED D7 plus the current source R9 and transistor Q6 (2 mA), the current mirror transistor Q3, resistor R3, and the current source transistor Q2 and resistor R2 (1 mA). While this may seem odd in that the voltage reference is used to produce a precision current that is then used to bias itself, overall it produces a highly stable supply that is largely independent of battery voltage and fairly stable with temperature, while being low in cost and not using any special devices. The current source plus current mirror is also used to bias the current source transistor Q4 and resistor R4 (10 mA), which in turn is used to bias the output transistor Q1.

The temperature stability of the current sources and voltage reference can be improved by replacing transistors Q2, Q3, Q4, Q5 and Q6 with npn transistor array CA3096. However, this is a more expensive solution, and the CA3096 is out of production and no longer readily available. For most applications, the 2N3904 and 2N3606 transistors work well and are inexpensive.

Working from the input of the saturation probe and moving right, the signal first reaches a 0.5-A fast fuse. The fuse protects against excess reverse voltage (more than –9 V). From the fuse, we contact diode D3 (reverse protection) and diode D4. D4 is used with zener-diode D5 to limit the maximum positive input swing. This limits the maximum output voltage and produces a consistent positive output swing throughout the battery's life. Switch S1 and diode D4 allow the output to be zeroed when setting up the oscilloscope's baseline, which is very handy.

Continuing to move to the right, resistor R1 is used to provide an additional voltage drop to balance the voltage dropped by diode D1 with the voltage drop of transistor Q1. It is also used with capacitor C1 to adjust the transient response time. The voltage drop of diode D1 is only about 0.55 V due to the small 2-mA bias current, while the voltage drop on output transistor Q1 is about 0.7 V at 10 mA. Finally, moving to the right through resistors R1 and R5, the signal reaches the base of the output transistor Q1. This output goes through resistor R11 to the output connector.

Figs. 2 and **3** show the completed saturation probe, which was built in an off-the-shelf plastic box. The probe's specifications are shown in **Table 1**, while the parts are listed in **Table 2**.

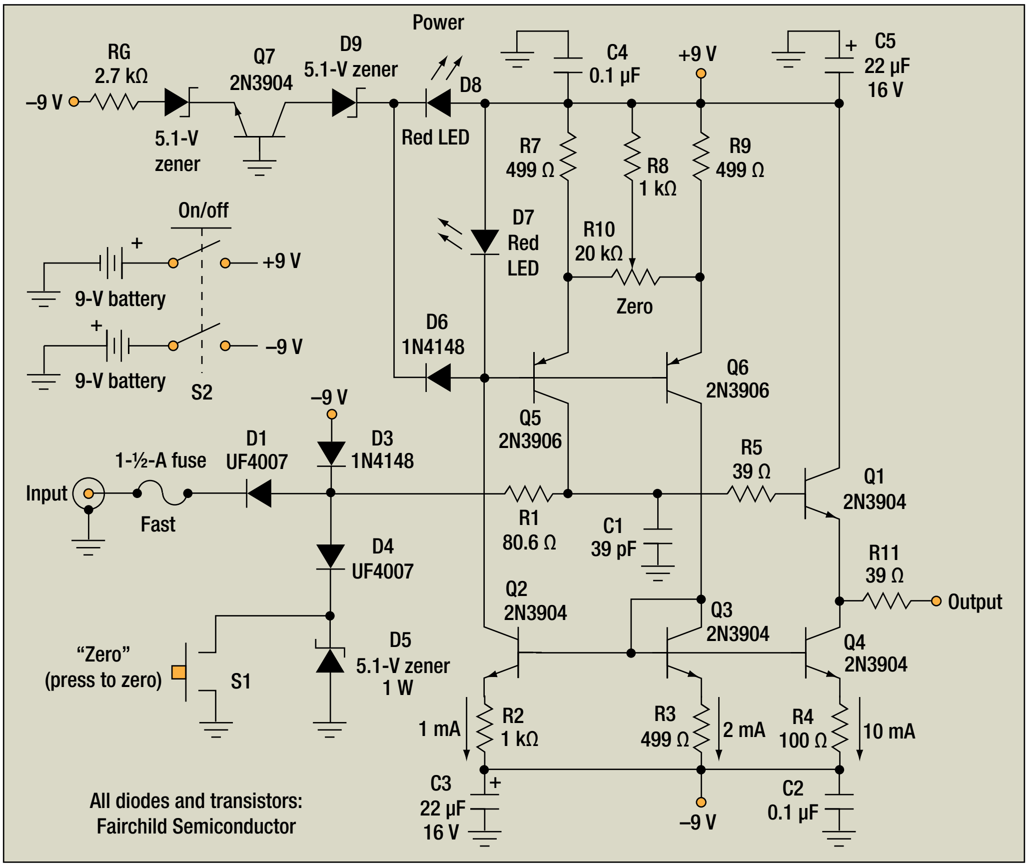

Fig. 1. *Build this circuit of a saturation voltage probe for accurate measurements in switching power supplies.*

Calibration

Once the circuit is built, it should operate readily. Put the batteries in and turn it on. The front-panel LED should be lit; if not, check the wiring. The voltage drop across resistors R2, R3, R4, R7 and R9 should be around 1 V. The LED reference voltage should be approximately 1.65 V. Remember, the reference will not start if the power light is not lit. Short the input and measure the output voltage. Adjust the "zero" trimmer to set the output voltage to 0.000 V, or as close to that as possible. Connect the input to a known positive voltage from 0 V to 5 V. The output should be within a few tens of millivolts of this voltage. Reverse the input leads. The voltage should be very close to the same magnitude but simply reversed in polarity.

Next, connect a pulse generator to the input and set it to 2 V, a 2-µs pulse width and a frequency of 100 kHz. The output should reproduce the input within the rise-time and fall-time specifications. If better rise times and fall times are required, simply turn up the current in the circuit. Caution: The saturation probe is polarity sensitive, so be sure to connect the probe correctly to the circuit.

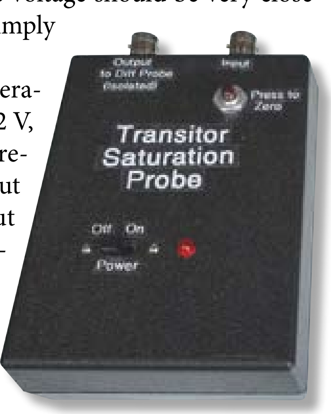

Fig. 2. *A small box houses the finished low-cost saturation voltage tester.*

Recommendations

The saturation probe provides a low-cost solution to the need to measure saturation voltage plus other voltages that are required to evaluate the design of a switching circuit in a high-efficiency power supply. Without proper switch transistor operation, the power supply could fail to achieve optimum efficiency and reliability.

The present design of the saturation probe is simple and cost effective, can be easily built and offers good performance, but it does require the use of a differential probe

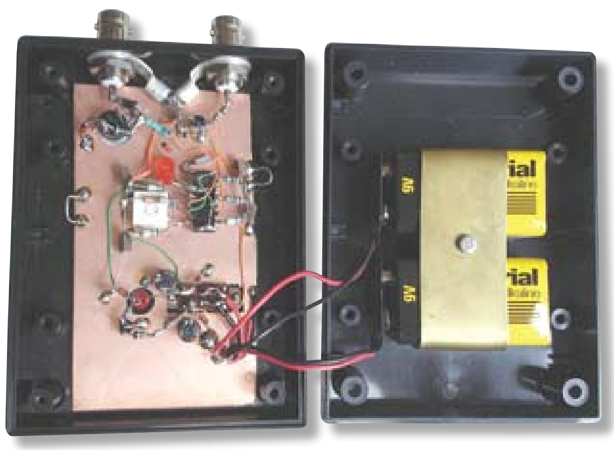

Fig. 3. *An inside look of the test box shown in Fig. 2 with the cover removed.*

Resistors	Capacitors	Semiconductors	Connectors	Switches	Miscellaneous
R1 = 80.6 Ω	C1 = 39 pF chip-on-glass ceramic	Q1-Q4, Q7 = 2N3904 Fairchild Semiconductor	2 BNCs for input and output	S1 = momentary SPST, input zero	Plastic enclosure
R2, R8 = R2 = 1 kΩ	C2, C4 = 0.1 µF ceramic	Q5, Q6 = 2N3906 Fairchild Semiconductor	2 9-V battery connectors	S2 = DPDT slide switch, power	2 9-V batteries
R3, R7, R9 = 499 Ω	C3, C5 = 22 µF 16-V aluminum	D1, D4 = UF4007 Fairchild Semiconductor			
R4 = 100 Ω		D3, D6 = 1N4148 Fairchild Semiconductor			
R5, R11 = 39 Ω		D5 = 5.1-V 1-W zener diode Fairchild Semiconductor			
R6 = 2.7 kΩ		D9, D10 = 5.1-V 0.5-W zener diode Fairchild Semiconductor			
R10 = 20-kΩ 1-turn potentiometer		D7, D8 = Red LED			

Table 2. *Components list for building a saturation-voltage test probe.*

for floating measurements. One possible improvement to the probe would be to incorporate the functionality of the differential probe into the saturation probe to produce a stand-alone solution to both floating and ground-referenced measurements.

One final note: This article focused on saturation-voltage measurement in high-efficiency power supplies. However, there are many other applications where the same basic measurements would be of value, as for example in motor drivers or dc power switches. **PETech**