Introduction

These course notes are to be read in association with the PI University video course, *Techniques for Measuring Efficiency*. This course will demonstrate two different techniques for measuring the conversion efficiency of a switching power supply. The first technique uses a wattmeter and two multimeters. The second, less accurate technique shows how to perform this measurement when no wattmeter is available.

Note that the techniques shown are for quick internal evaluation only and do not follow all of the specified steps required for energy standards compliance.

Equipment Required

The following equipment is needed for completion of this course:

1. A programmable AC source or a Variac
2. An electronic load
3. Either a wattmeter and two digital multimeters (preferably one with high resolution for current measurements), **OR** four digital multimeters (one with both true RMS and high current resolution to measure input current, and one with high current resolution to measure output current)

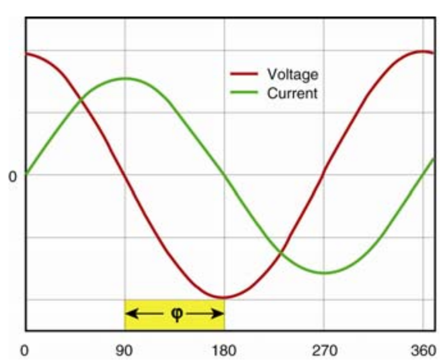
Note: When using multimeters, it is very important to set the meter at an appropriate range for the voltages and currents you are measuring.

Efficiency and the Impact of Power Factor

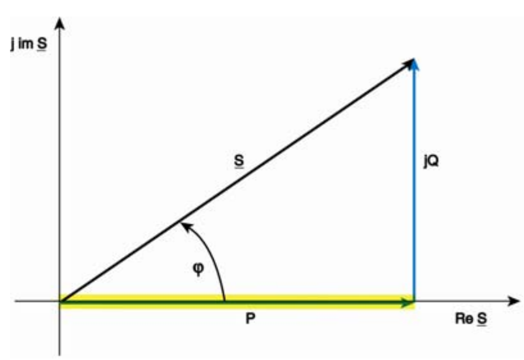
$$\text{Power supply efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

The DC output power is simply equal to Volts Amps and can be measured with two multimeters. A high-resolution multimeter is used to measure the current delivered to the load and a standard multimeter is used to measure the output voltage of the power supply.

The AC input power cannot simply be calculated as RMS Input Voltage RMS Input Current because of the phase angle between the voltage and current. Only the real power consumed by the supply (P) must be considered. The reactive power Q, which is returned to the source, should not be included.



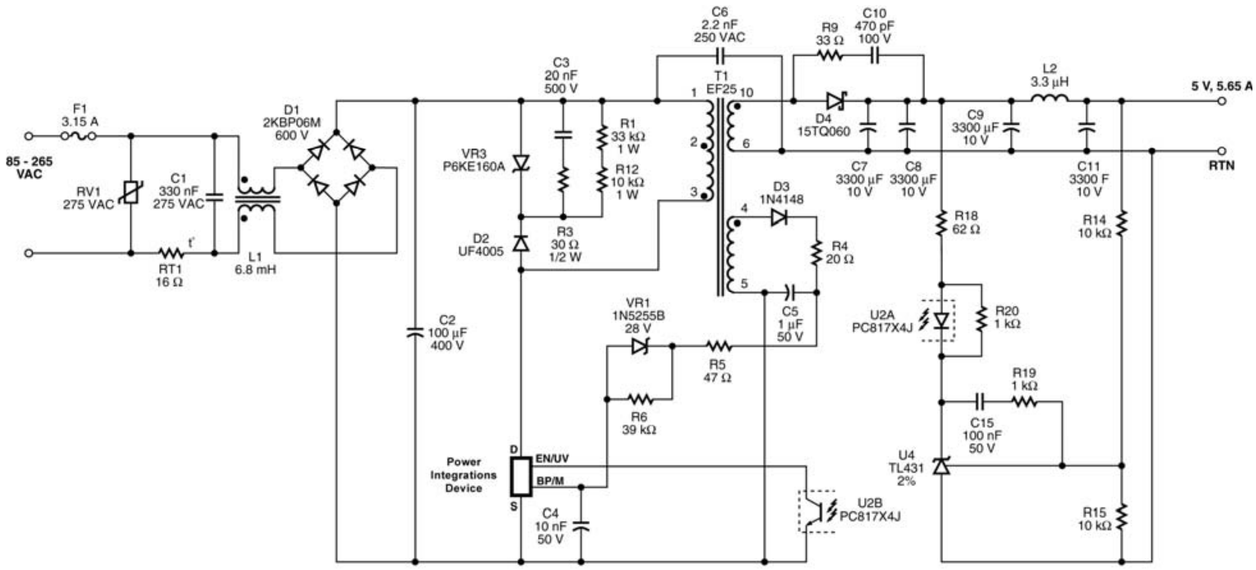
Phase angle between input voltage and current



Power consumed by supply = S x sin φ

The advantage of a wattmeter is that it can accurately measure true input power because it automatically corrects for power factor. If a wattmeter is not available, two multimeters can be used to measure the input voltages and currents. This alternative method is less accurate than using a wattmeter and does involve breaking into the circuit of the power supply under test.

As a demonstration, a power supply will be used based on the schematic shown below.



Flyback power supply

Connecting Output Multimeters

Place the voltage meter directly across the board output terminals and connect the electronic load. Measuring voltage at the output terminals negates any voltage drop in the cables connecting the load. For some applications, such as cell phone chargers or laptop adapters, the loss in the cables must be included, in which case the output voltage is measured at the load. Then connect a high resolution current meter in series with the load to measure output current.

AC Turn-On Considerations

When using a device with an on/off control scheme, the worst-case efficiency measurements can be achieved when the power supply is snapped on at the test input voltage with full load applied to the output. However, snapping on the power supply will cause a very large inrush current as the bulk capacitor charges, and this may blow the fuse in your input current meter when it is set to a low range.

Control Scheme	AC Turn On	Multimeter Current Range
On/Off	Snap On	High (~ 10 A)
Others (PWM)	Ramp	Pout < 300 W: Low (~ 300 mA)
		Pout > 300 W: High (~ 10 A)

Recommended AC turn-on procedures for different SMPS control schemes

If using the four multimeter method, first measure the inrush current of your power supply when it is snapped on at low line and maximum load and then check the datasheet for your meter to verify it can carry that amount of peak current at high line voltage.

Note: This is not a concern when using a wattmeter.

For all other control schemes, the turn-on method will not affect efficiency measurements, and it is recommended that the AC voltage be slowly increased to limit inrush current.

Wattmeter Method

Connect the wattmeter to the input of the power supply and set the display to averaging mode for more stable readings. Turn on the AC input voltage and slowly increase it to the desired test voltage. Increase the load on the supply to full load. Turn off the supply and snap it back on to complete the measurements.

In the demonstration, the meters on the power supply's output indicate 4.97 volts and 4.005 amps. The voltage reading on the electronic load indicates 4.48 volts. This is due to a drop of 490 mV in the output cables and voltage sense element of the multimeter, highlighting the importance of measuring the output voltage at the power supply terminals.

Thus, output power = 4.97 V 4.005 A = 19.90 watts. The input power read from the wattmeter display = 25.76 watts. Therefore, power supply efficiency = 19.90 watts/25.76 watts = 77.3%.

Multimeter Method

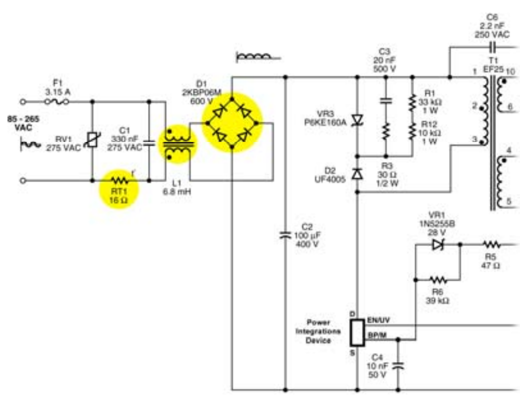
With the multimeter method, the effect of power factor is circumvented by taking the input power measurement after the diode rectifier stage has converted the AC input to DC. To improve the measurement accuracy, the losses in components prior to the DC bus stage must be taken into account.

The diode rectifier bridge is typically the most lossy component in the input stage, with the drop in each diode being as much as 0.9 V in the worst case. Losses can also be calculated in other elements with significant and measureable resistance or voltage drops.

Connecting the Multimeters

Break the DC bus between the bridge rectifier and the bulk capacitor C2. Breaking the DC bus after the bulk capacitor would require the meter to measure the high frequency switching currents of the power supply, which the meter cannot do accurately.

Next, solder in two leads which can be used to connect the multimeters to the circuit. Connect a high resolution true RMS multimeter set to measure current across the break. Take a second multimeter set to measure voltage and connect it from the DC positive to the negative of the bulk capacitor.



AC input losses

Test procedure

Turn on the AC source and slowly bring up the voltage to the desired test voltage. Increase the load on the power supply to full load. Set the input current meter to the highest current range. Turn off the AC input voltage and snap it back on.

In the demonstration, the power supply still provides 4.97 volts and 4.008 amps, and output power of 19.92 watts. On the input, the DC bus voltage is 151.6 volts and the input current is 0.166 amps. The input power is calculated as:

$$V_{IN} \quad I_{IN} = 151.6 \quad 0.166 = 25.1656 \text{ W}$$

Now the power lost in the rectifier bridge must be added:

Power loss estimate = combined worst-case diode drops   input current

= 1.8 V   0.166 A

= 0.299 W

So, total input power = 25.1656 W + 0.299 W

= 25.46 W

Using this technique, the efficiency of the power supply is calculated as:

$$\frac{19.92 \text{ W}}{25.46 \text{ W}}$$

= 78.2%

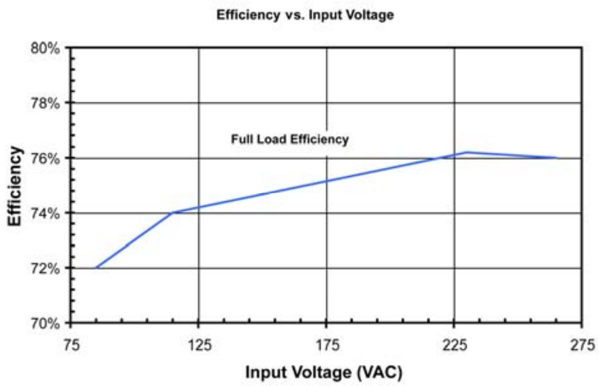
Comparing this with the 77.3% calculated when measuring the input power with a wattmeter, we see that the four-multimeter method is 0.9 percent less accurate.

Improving accuracy

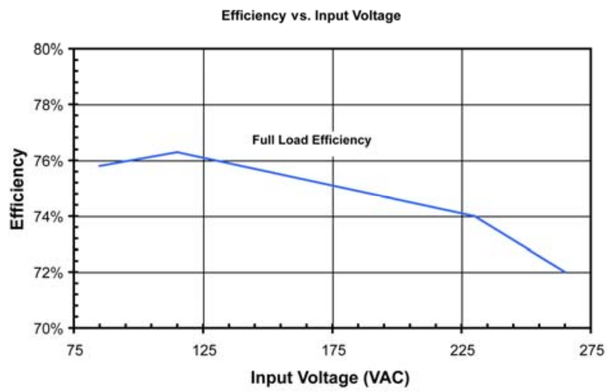
The accuracy of this method can be improved by adjusting the input power to include the losses in other input stage components besides the diode bridge, such as inrush limiters, common-mode chokes, and the current sense element of the digital multimeter. To account for these losses, measure the voltage drop across each component during normal operation and multiply this number by the input current measured. Including these losses will increase the total input power and lower the calculated efficiency. However, this method will never be as accurate as using a wattmeter to measure input power.

Measure over a range of input and output values to identify the cause of losses

The efficiency of your supply will vary with input voltage and output load. When evaluating a power supply, it is common to measure the efficiency at several different input line levels to gain a better understanding of where the losses are in the circuit. Plot the results on a graph showing efficiency vs. line voltage for full load.

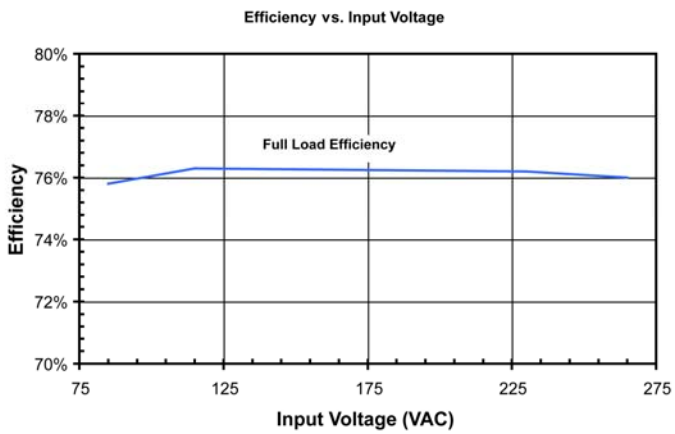


The effect of conduction losses on efficiency



The effect of switching losses on efficiency

A drop in efficiency at low line voltages is typically due to conduction losses caused by resistive elements in the circuit. These losses increase at low line voltages because higher current is necessary to supply the same output power. A drop in efficiency at high input line voltages is typically due to switching losses. These losses are due to parasitic capacitances. The losses increase at high line voltages as parasitics are charged to and discharged from higher voltages. When the causes of losses are identified and corrected, the characteristic shown below should be obtained.



Efficiency vs. input voltage for a well-designed power supply

For More Information

If you have any questions or comments about the information presented in this course, please email PIUniversity@powerint.com.