Testing a power supply (Part 1)

Robert Hanrahan - April 02, 2013

Read Part 2 of this series which covers noise, and Part 3 on stability.

This three-part series describes how to properly test a DC/DC power supply, and ensure that it works reliably over various operating conditions. This series is intended to provide the designer with a sufficient understanding about some, but not necessarily all, of the testing needed to verify a reliable power supply design. Be sure to check out the two videos embedded in this article for even more detail.

Introduction

In my 20 years of being a field application engineer, I have seen a fair share of power supply designs. In many cases these designs work without any issues. Occasionally I found problems that could have been avoided with a little extra engineering effort before releasing a product to production. All too often system designers employ a power circuit without thoroughly ensuring its proper operation throughout operating extremes. Situations exist where prototypes work fine, so further power supply testing gets overlooked, or is the last item to be checked for proper operation. Sometimes issues don’t arise until the product is in production, resulting in field failures.

These power supply problems vary greatly, from system noise that didn’t show problems with a prototype, but later caused system performance issues, to power supply stability problems, which resulted in intermittent system shutdown. The focus of this article is on the different tests associated with DC-to-DC power supplies.

Why test?

The power supply is the foundation for any electronic product, so verifying its performance and design margins is necessary to ensure a high quality and reliable product. Not verifying a power supply leaves a designer vulnerable to a potentially unpleasant situation, if problems arise after products are in the field. Power supplies may operate fine under typical conditions, but may be at the edge of normal operation. When a power supply is heated or cooled, or when components age, its characteristics change to a point where a marginal design might fail.

No matter how basic a power supply may be, it should be tested by a qualified individual to ensure it meets system requirements. Although software might need to be written or FPGAs fully debugged, it is critical that the power supply be verified it is working properly and operating with sufficient design margins.

Power supply testing is not complex. One only needs a good understanding of which tests are
needed, and how to properly perform them. A designer should establish a test specification and a test plan for the power supply. The test specification should include all acceptable operating limits and the various operating conditions (temperature, line conditions, and so forth), under which the system must operate. A test plan describes the process on how to ensure the design meets the test specification.

System conditions (line, loads, etc.) and the environment vary greatly from application to application. Therefore, specific test specifications and plans vary from one system to another. This article does not discuss philosophy regarding design margins for quality products, but assumes the design test specifications are well understood. We focus on sound methods to test and verify that a design meets or exceeds predetermined specifications.

Simulation

Component modeling and simulations have made significant advancements, giving designers great design tools for expediting power supply designs. In some cases it is difficult to accurately model a system power load, especially complex systems, so simulations must rely on some level of assumptions.

Large systems, which include a wide range of impedances on the power rails, can cause unexpected power supply performance characteristics - which only accurate testing can uncover. Power supply simulation tools such as TI's WEBENCH™ help expedite a sound design providing the engineer with an excellent starting point for hardware creation. However, only system bench testing can accurately provide actual circuit characteristics over operating extremes.

Test equipment

The test equipment needed for proper power supply testing varies with the type of power system being tested, as well as the financial budget for the equipment. Here is an example list of equipment, which will be referenced later.

- DC power supply capable of developing voltage and current for the specific design. A programmable version is preferred.

- Electronic or dynamic load capable of handling your system requirements: voltage and current. A programmable version with load-step capability is preferred.

- Two volt meters, accurate to the desired specifications.

- Two current meters, or low Ohm power resistors with additional voltmeters. A current meter within an electronic load may be sufficient for one meter.

- Oscilloscope 500 MHz BW or greater with probe for noise measurements.

- Frequency response analyzer or network analyzer designed for power supply stability measurements.

To learn more about simplifying power designs, register for this free webinar, "Simplify Power Designs with Micromodule Products" sponsored by Analog Devices.
Preparing for tests

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After a power supply is designed and built with the components planned for production, situate it to allow access to the power supply input and output. If possible, disconnect the system load from the power supply for initial testing. With the system load disconnected you can test both minimum and maximum loads while protecting the system from any possible power supply fault condition.

After verifying proper operation you may want to run some tests with the system load in place, and possibly in parallel with an electronic load to simulate a worst case scenario. As an example, stability and noise measurements may be effected by the reactive load of your system, as compared to a more resistive load used for testing.

To prepare for testing, add wires to the power supply’s input and output for easy access and connections. Make these wires short and thick to ensure minimum IR loss across the wires. The specific gauge of wire depends on the current being delivered. Generally, thicker is better. The output connections should be from points at or very close to both sides of the last output capacitor. Connect the input wires close to the input capacitor. Mark the wires clearly so as not to mix up the polarity.

Most power circuits have a feedback control loop from the output voltage to a feedback input on the regulator IC. For stability measurements add a component to allow a signal injection point from a frequency response network analyzer (explained later). A small resistor in the range of 10 to 50 Ohms can be added to the feedback biasing network without causing significant output voltage error. Add this resistor between the output voltage and the top of the feedback network (Figure 1).

The added resistor should be very close to the existing top feedback resistor with short wires (less than two inches), extending from the added resistor to allow probe connections from a network analyzer. Some designers are adding this feedback resistor with test pads to their printed circuit board (PCB). This extra resistor with test points makes system testing much easier and can be removed and shorted on the final production PCB.
Figure 1. Adding an additional feedback resistor to a power supply provides injection and measurement points for stability measurements

Testing

The diagram in Figure 2 represents a typical test setup that can be used for the following tests.

Figure 2. A DC-to-DC test setup for noise and efficiency measurements.

Output voltage accuracy and tolerance

As voltage levels within a system decrease, the output accuracy requirements become more demanding. Circuits often require very tight tolerance, which entails a combination of the initial accuracy as well as other contributions to the overall accuracy budget. We’ll cover various contributions to the overall voltage limit below, and further in Part 2 of this series.

Output accuracy is easy to measure, but does not indicate what the worst case accuracy will be over production variations in component values. This is one design limit that is best determined by simulation, or good old hand calculations. Output variation from ripple and noise (discussed in Part 2) can be measured and used along with worst case initial accuracy from simulation/calculation to determine total worst case output voltage (minimum and maximum).
When testing the output voltage accuracy, set the input voltage to two or three levels. The following test procedure should be run at the minimum and maximum expected input voltage, and optionally at the nominal level.

1. Connect dynamic load to output wires described earlier.
2. Connect voltmeter to output close to the output capacitor. Do not use the voltmeter in a load box.
3. Connect a voltmeter to the input close to the input capacitors. The voltmeter in the DC power supply cannot be used to accurately set the input voltage.
4. Before connecting the DC power supply to your power circuit, set the proper input voltage and verify correct polarity.
5. Connect the power supply to input, apply power and adjust again as needed for proper voltage at the input terminals.
6. Vary load from minimum to maximum, logging results at regular load steps.
7. Adjust the input voltage to another level and rerun the procedure.
8. Graph the results.

**Start-up time and overshoot**

The time it takes for a power supply to start providing a clean output voltage can vary greatly. In many cases the time delay does not affect the system operation, so this test may be insignificant. In some cases the power supply may be designed to start after the input rises above a specific voltage level, often called the under voltage lockout level and explained in specific IC datasheets. Following is a basic method of measuring the time it takes for a power supply to start up after input voltage is applied, and how to measure start-up overshoot on the output.

On a related note, the faster the start-up of a power circuit, the higher the inrush current. High inrush current may result in a droop in the system voltage, especially in situations where overall system power is limited. Input voltage droop can result in problems elsewhere in a system. If applicable, the designer may limit the start-up time by utilizing a soft-start circuit. Details about soft-start can be found in many available power IC datasheets.

When power is applied to a power supply circuit, it is not uncommon for the output voltage to rise above the nominal value before settling. This often is called overshoot and can cause a problem when load circuitry is not able to tolerate the higher voltage. Adding or increasing a soft-start circuit often reduces unwanted start-up overshoot.

1. Before connecting the DC power supply to your power circuit, set the proper input voltage and verify correct polarity.
2. Connect the power supply to input, apply power and adjust again as needed for nominal voltage at the input terminals (do not use the voltmeter on the power supply).
3. Connect the dynamic load to the output and set for the typical load current expected.
4. Using short ground wires place an oscilloscope probe directly across the input connections and another scope probe across the output connections.
5. Set the oscilloscope to trigger from the probe across the input and set it to normal trigger mode and positive slope. Set the trigger level at a predetermined input voltage level to be used for the start of timing point for the following step (depends on the overall input/output voltage levels and input noise).
6. While turning off and on the DC power supply, measure and log the time it takes for the output to rise above 80 percent of VOUT (or other predetermined level).
7. Turn off and on the power supply and measure the time it takes for the output voltage to climb from 20 to 80 percent (or other specified levels). Observe and capture the output signal as it rises.
to ensure it looks clean and does not reverse phase at any point. A non-monotonic power rail may cause system problems with some loads.

8. To ensure the start-up overshoot is tolerable, measure it by applying input power while observing and triggering on the positive edge of the output voltage. Capture and note the peak output voltage.

**Current limit**

Most power supply designs employ a method of limiting current in case of a fault or extreme conditions. The design’s current limit is obtained by simply increasing the load until the output voltage drops by a specific amount. The voltage drop value used for this test may vary, depending on the intention of the current limit. Some current limits are used for safety and/or component protection during fault conditions where others are used to limit current during normal transient conditions. Current limit circuits may drop abruptly and stay off (often called a crow bar), or it may retry after some period of time (hiccup protection).

Other current limit circuits may simply maintain a fixed current set-point as the load is increased (cycle-by-cycle). This scheme might be used to avoid component overstress during transient conditions, providing the ability to reduce the size of various circuit components. In any case, a predetermined output voltage drop should be used for this measurement, 30 percent as an example.

1. Before connecting the DC power supply to your power circuit, set the proper input voltage and verify correct polarity.
2. Connect the power supply to input.
3. Connect the dynamic load to the output and set for the typical load current expected.
4. Turn on the DC power supply and adjust again as needed for nominal voltage at the input terminals.
5. Slowly increase the load until the output voltage starts to drop below a predetermined level, 10 percent as an example.
6. Log the output current where the output voltage starts to drop.

**Efficiency**

Efficiency of a power supply is the measurement of the amount of energy that goes out from the circuit, divided by the amount of energy going into the circuit (*100 for a percentage). Accurate measurement of efficiency is not difficult, yet small measurement errors can result in significant inaccuracies. Efficiency errors most often occur from one of the following:

**Measuring current**

Using a digital voltmeter (DVM) to measure current may not provide accurate results. A specific DVM may be very accurate at measuring voltage, yet not accurate at measuring current, so check the manufacturer’s specifications. A low-value precision power resistor in series with the input and output cable along with a good voltmeter provides an accurate way to measure current. As an example, an appropriately sized 0.1 percent 0.1 Ohm resistor works well for accurate current measurements from mA to many amps (I = V/R). A high-quality dynamic load may also provide accurate current measurement. Yet, you need to verify accuracy specifications for the particular instrument.

**Measuring input and output voltage at the wrong location**
One of the most common errors in efficiency measurements is improper placement of the measurement probes. People often forget that wires have resistance and associated losses. When measuring voltage into or out of a power supply, it is critical to make the measurements right at the input and output of the circuits. If the voltage is measured at the source voltage, the losses across the input cable result in a lower efficiency than reality. The output voltage also must be measured at the direct output from the circuit, preferably across the output capacitors. If the output voltage is measured after the wires to the load, or if you use a voltmeter in a load box, your calculated efficiency again will be lower than reality.

**Efficiency measurement procedure**

Following is a procedure to accurately measure power supply efficiency. Other methods exist, but this procedure is accurate and easy to follow. It is valuable to run three sets of measurements resulting in three efficiency curves, all overlaid on the same graph. Run through the procedure with the input voltage set at the typical input voltage, at a maximum input voltage, and again for the minimum input voltage.

The efficiency curves generated by these tests describe much about the power supply design. Steep rise-to-peak efficiency at low-load current followed by a long linear line to low efficiency indicates high DC losses, (conduction losses) where a long rise to peak efficiency with minimal drop at higher current indicate low DC losses, but high AC losses. Typically we want to see a profile that peaks its efficiency around 50 percent of $I_{OUT}$, indicating a good balance of AC and DC losses. But much depends on the specific system requirements (Figure 3).

**Figure 3. An efficiency graph describes how well a power supply performs over operating conditions and can help identify design problems**

Here is a simple procedure for accurately measuring efficiency:

1. Before connecting the DC power supply to your power circuit, set the proper input voltage and verify correct polarity.
2. Connect a voltmeter to the input and output of the power supply close to the input and output connectors.
3. Connect a current meter to the input and output, see earlier comments.
4. Connect the electronic load to the output and set it to the lowest value of interest.
5. Turn on the input voltage and set it to provide exactly the nominal input voltage across the power supply input. Important: Input voltage accuracy may need to be within a few millivolts to ensure overall accuracy and needs to be adjusted after each time the load is changed.
6. Record the input and output current along with the output voltage. The input voltage is fixed by step 5.
7. Increase the load at regular intervals up to a load at or above 100 percent. Testing up to 110 percent of maximum load or greater is valuable to help understand operating margins.
8. Plot curves of the output power over the input power (*100) to show the peak efficiency and efficiency at different loads (Figure 3)

**Ground loops**

Another common error when making power supply measurements is where people connect an oscilloscope ground to a potential above or below ground, resulting in current flowing to/from the scope itself. These ground loops not only cause significant measurement errors but can cause damage to the test equipment. Be careful when connecting your oscilloscope grounds to power supplies.

In Part 2, we will cover good probing techniques for measuring: noise, load and line transient, output switching ripple noise, switching transient noise, and switching node waveform.

Join the conversation about testing power supplies on TI’s E2E™ Community: [www.ti.com/engineer56-ca](http://www.ti.com/engineer56-ca).

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**References**

For more information, visit: [www.ti.com/power-ca](http://www.ti.com/power-ca), [www.ti.com/webenchcenter-ca](http://www.ti.com/webenchcenter-ca).

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**About the author**

Robert M. Hanrahan currently is Member of Technical Staff at TI where he is involved with analog field applications. He has more than 20 years of experience in digital and analog design, applications engineering, and management. Robert has published numerous application notes and articles in electronics and aviation trade magazines and has a patent in his name. His degrees include a BS from The University of the State of New York, and he holds a commercial pilot and flight instructor certificate, as well as a ham radio license. Robert can be reached at [ti_rhanrahan@list.ti.com](mailto:ti_rhanrahan@list.ti.com).

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