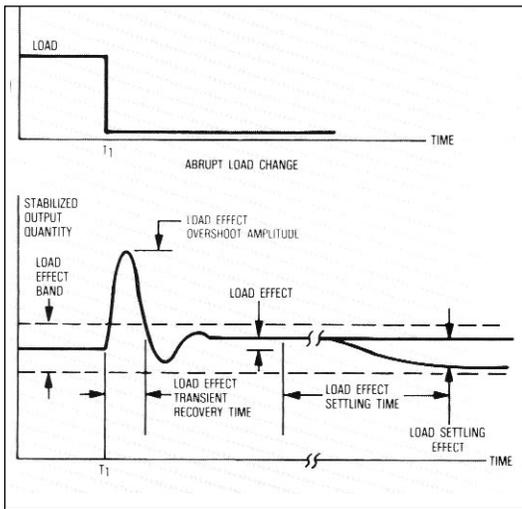


Agilent AN 372-1

Power Supply Testing

Application Note



An electronic load offers a broad range of operating modes, providing versatile loading configurations needed for characterizing and verifying DC power supply design specifications.



Agilent Technologies
Innovating the HP Way

Introduction

As regulated-power supply technology evolves, testing methods for design verification and product function require more sophisticated electronic equipment. The different power supply architectures and output combinations also dictate the need for versatile test instruments that can accommodate a broad range of specifications. As a result, one testing requirement that has been growing in importance is the method of loading the power supply under test. The need for a higher degree of load control due to test sophistication, such as the need for computer programmability, has increased the demand for electronic load instruments. The following examination of the most common power supply architectures or topologies clearly illustrates the growing need for higher performance and versatility in electronic loads and power supply test equipment.

An Overview of Power Supply Topologies

Of all the possible power supply topologies, linear and switching regulation techniques are the most common design implementations. Linear power supplies are typically used in R&D environments and in production test systems because they provide high performance, low PARD (ripple and noise), excellent line and load regulation, and superior transient recovery time specifications. However,

they are relatively inefficient when compared to switching power supplies, and tend to be large and heavy due to the heat sinks required to continuously dissipate power from the series transistors and due to the magnetics used in this design. Typically, linear power supplies provide a most effective solution in lower power applications, and are often used as subassemblies in various products.

Switching power supplies address the disadvantages of linear power supplies (namely the low efficiency and relatively large size and weight), and are therefore a more effective and less costly solution for high power applications. The relative disadvantages occur in three areas when compared to linear power supplies: slower transient recovery time, higher PARD, and lower reliability. Switching power supplies are used in a wide variety of industries and environments, and are commonly found as subassemblies in products such as computers, computer peripherals, and copiers. Recent power supply designs combine the best features of switching and linear topologies. Below, Table 1 compares the typical specifications for linear and switching topologies.

Table 1

Regulation Technique	Load Regulation	Line Regulation	Transient Response	PARD	Efficiency
Switching	0.05 – 0.5%	0.05 – 0.5%	1 – 20 ms	5 – 20 mVrms 20 – 150 mVp-p	65 – 85%
Linear (Series Pass)	0.005 – 0.1%	0.005 – 0.1%	20 – 200 μ s	0.25 – 5 mVrms 1.0 – 15 mVp-p	30 – 50%

An Overview of Power Supply Testing Needs

Power supplies are used in a wide variety of products and test systems. As a result, the tests performed to determine operating specifications can differ from manufacturer to manufacturer, or from end user to end user. For instance, the tests performed in an R&D environment are primarily for power supply design verification. These tests require high performance test equipment and a high degree of manual control for bench use. In contrast, power supply testing in production environments primarily focus on overall function based on the specifications determined during the products design phase. Automation is often essential due to large volume testing, which requires high test throughput and test repeatability. Power supply test instruments must then be computer programmable. For both test environments, measurement synchronization is necessary to perform some tests properly and to obtain valid data. In addition, considerations such as test set reliability, protection of the power supply under test, rack space, and total cost of ownership may be of equal importance to the power supply test set designer. Proper selection of testing instrumentation will provide the best combination of measurement sophistication and test set complexity.

Power Supply Testing Instrumentation

The power supply testing methods and configurations discussed in this application note are certainly not the only means of obtaining the desired measurements. However, certain instruments are essential to all tests, regardless of the implementation. Some commercially available turnkey power supply test systems incorporate custom board level instrumentation and hand wiring. However, power supply test systems based on standard products afford greater benefits. These systems are more reliable and provide repeatable, high performance measurements because of their low noise environment. A system which utilizes standard instrumentation is modular, allows configuration flexibility based on performance needs, and is easier to upgrade. In addition, the service, replacement, or calibration of separate instruments in the system can be performed with minimal system down-time.

The tests covered in the following section are configured with standard instrumentation: electronic loads, digital oscilloscopes, digital multimeters, true rms voltmeters, wattmeters, and AC power sources.

Electronic loads can facilitate power supply testing in several ways. They are typically programmable, although most require external DAC programmers.

This capability enables finer control over loading values during testing, and can provide the test set operator with valuable status information. These loads are often designed with FETs, which provide increased reliability over less sophisticated solutions consisting of relays and resistors. Also, these products offer a selection of operating modes: constant current (CC), constant voltage (CV), and constant resistance (CR). The more sophisticated electronic loads provide all three modes in one product for optimum testing flexibility. They provide a versatile solution for testing both DC voltage and current sources. A final advantage is provided by loads with readback over the bus. This can eliminate the need for digital multimeters for voltage and current measurements in some tests. As mentioned, there are varying degrees of electronic load sophistication. The Agilent Electronic Load family provides all of the most sophisticated features and high level performance in one box.

Several other instruments are required for power supply testing. The performance criteria (accuracy, resolution, stability, bandwidth, etc.) vary for each test. In general, the measurement capability of the instruments should ensure an error no greater than 10% of the measured specification. Table 2 on the next page provides a guideline for instrument performance levels for each test discussed in this application note.

Power Supply Tests

Table 2

	Load Transient Recovery Time	Load Effect	Current Limit Characterization	PARD	Efficiency and Power Factor	Start-Up
Electronic Load	$t_{rise} \leq 15 \mu s$ Trigger output to the oscilloscope	1% programming accuracy CC or CR mode	1% programming accuracy CR or CC mode	1% programming accuracy CC or CR mode Low PARD	1% programming accuracy CC or CV mode	1% programming accuracy CR mode
Digital Oscilloscope	$t_{sample} \leq 100 ns$	N/A	N/A	$t_{sample} \leq 25 ns$ DC to 20 MHz minimum bandwidth Record length $\geq 2 K$ samples 100 μ /Div (linears) 1 mV/Div (switchers)	N/A	$t_{sample} \leq 1 \mu s$ Record length 1 K samples minimum
Digital Multimeter	N/A	5½ Digits $\pm 0.005\%$ accuracy	5½ Digits $\pm 0.005\%$ accuracy	N/A	N/A	N/A
Wattmeter	N/A	N/A	N/A	N/A	1% accuracy with crest factors to 10:1 in current waveforms	N/A
Regulated AC Source	>1% regulation Adjustable peak and frequency	>1% regulation Adjustable peak and frequency	N/A	>1% regulation Adjustable peak and frequency	>1% regulation Adjustable peak and frequency Power factor measurement capability	>1% regulation Adjustable peak and frequency Phase control
RF rms Voltmeter	N/A	N/A	N/A	100 μ V Full scale DC to 20 MHz minimum bandwidth	N/A	N/A

Load Transient Recovery Time

A constant voltage DC power supply is designed with a feedback loop which continuously acts to maintain the output voltage at a steady-state level. The feedback loop has a finite bandwidth, which limits the ability of the power supply to respond to a change in the load current. If the time delay between the power supply feedback loop input and output approaches a critical value at its unity gain crossover, the power supply will become unstable and oscillate. Typically, this time delay is measured as an angular difference and is expressed as a degree of phase shift. The critical value is 180 degrees of phase shift between the loop input and output.

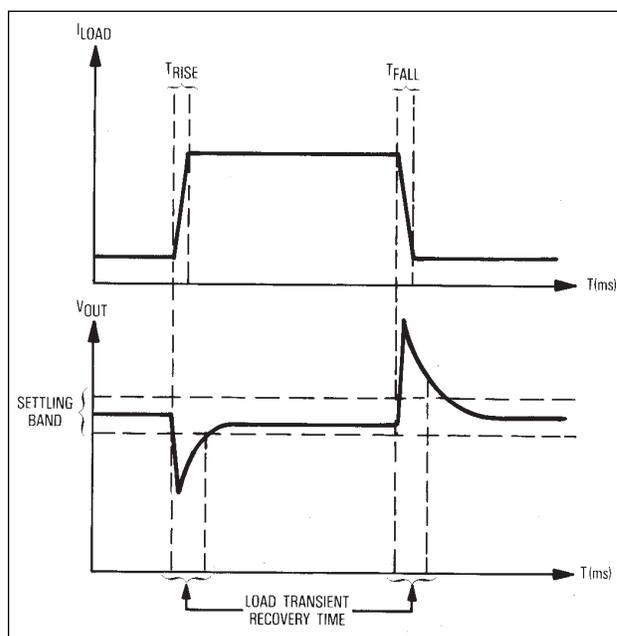


Figure 1. Load Transient Recovery Time

Load transient recovery time measurements require an electronic load with a risetime and falltime at least five times faster than the power supply under test.

For a step change in load current, a marginally stable CV power supply will have a ringing voltage output. This defeats the purpose of the power supply's regulation circuitry and can be damaging to voltage-sensitive loads. An example of a voltage-sensitive load is the logic circuitry in a computer. In this case, a computer manufacturer that purchases power supplies from an external source may consider verifying the load transient recovery specification of the power supply subassembly. This test can also reveal critical manufacturing flaws that can cause instability, such as a defective output filter capacitor or loose capacitor connections.

Test Overview/Procedures

CV Load Transient Recovery Time is a dynamic measurement of the time required for the output voltage of a CV power supply to settle within a predefined settling band following a load current induced transient (see Figure 1). The response is typically measured in microseconds or milliseconds, and varies in value depending on the topology of the power supply under test. The electronic load

used in this test should have a risetime at least five times faster than the power supply under test, and should be able to operate in CC mode (or CR mode) up to the maximum current rating of the power supply. Measuring the load transient recovery time requires the load to have the capability to pulse between two different values in CC or CR mode. For continuous load transient testing, the repetition rate of the pulses should be slow enough so that the power supply feedback loop can recover and stabilize after each applied transient.

Figure 2 shows a typical test system for making load transient recovery time measurements. Measurement of V_{out} of the power supply can be made with a digitizing oscilloscope as the load input pulses are applied. Synchronization of the measurement is crucial in obtaining proper measurements. Therefore, a common trigger should start the electronic load and oscilloscope measurements.

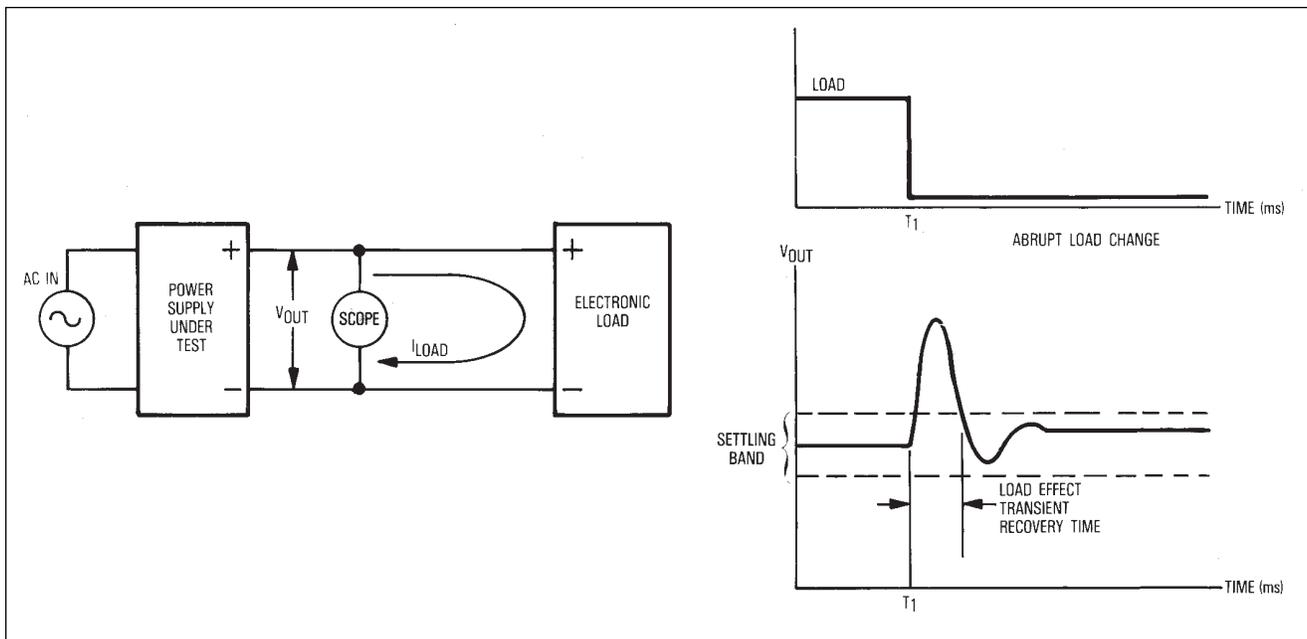


Figure 2. Load Transient Recovery Test Configuration and V_{out} Measurement Results for a CV Power Supply

Load Effect (Load Regulation)

Load Effect or Load Regulation is a static performance measurement which defines the ability of a power supply under test to remain within specified output limits for a predetermined load change (see Figure 3). In a CV power supply, the influenced quantity of interest is the steady-state output current. In a CC power supply, the influenced quantity is the steady-state output voltage. For single output CV power supplies, voltage load effect is given for a load current change equal to the current rating of the supply. A typical specification would be stated in millivolts, or as a % of the rated output voltage.

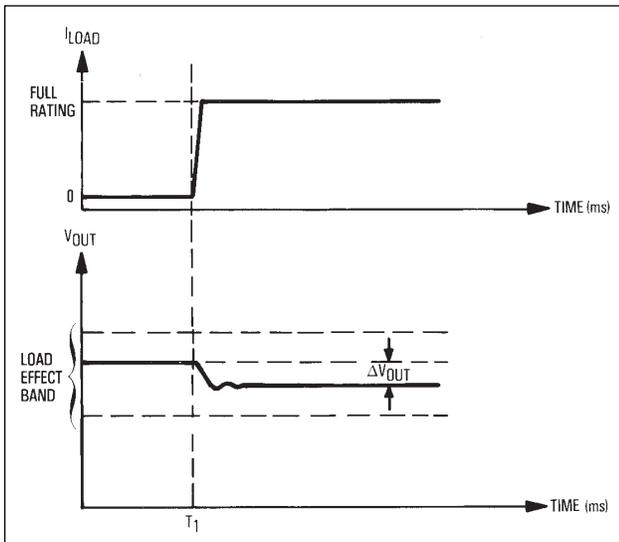


Figure 3. Load Effect

For a load current change equal to the full current rating of a CV power supply, the resulting change in V_{OUT} should not exceed the predetermined load effect band. Typical specifications for load effect range from 0.005 to 0.5% of the maximum output voltage.

For multiple output CV power supplies, cross load effect is determined. This is an extension of the load effect test for a single output power supply, and determines the ability of all outputs of a CV power supply to remain within their specified voltage rating for a load current change on one output. Conversely, the ability of one output to withstand the effects of changes on all other outputs can be specified.

Test Overview/ Procedures

For a CV power supply, measurement of the output voltage and input voltage should be made after the load is varied from the minimum to the full current rating of the power supply under test (Figure 4). Measurement of the AC input voltage is necessary to ensure that the output voltage change is a result of only the load change, and not from a change in the AC input. To decrease the test time when test throughput is a concern, a regulated AC source providing a predetermined AC input level and frequency can be utilized. This will eliminate the need for the AC input voltage measurement.

The output voltage should be allowed the specified settling time before measurements are taken. An electronic load selected for this test must be capable of operating in CC or CR mode, and must have input ratings (voltage, current, and power) sufficient to accommodate the maximum ratings of the power supply under test.

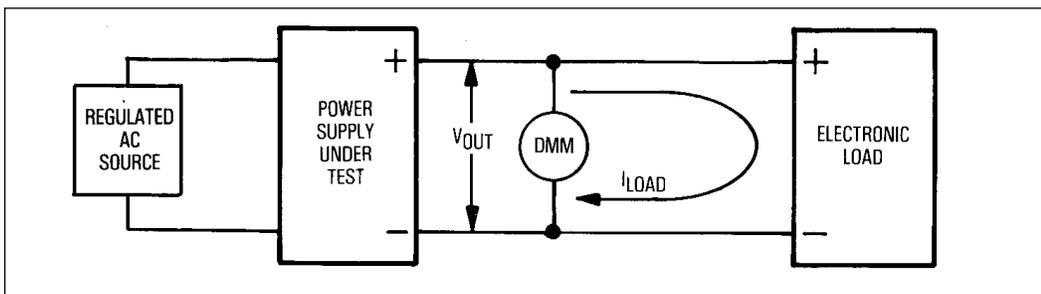


Figure 4. Load Effect Testing Configuration

A regulated AC source is used in this load effect testing configuration to maintain the AC input at a predetermined value. This will ensure that the test results reflect changes in V_{OUT} only with respect to load current changes.

Current Limit Characterization

Current limit measurements demonstrate the degree to which a constant voltage power supply limits its maximum output current to a preset value. This preset value can be fixed or variable throughout a specified range. There are basically three types of current limiting design implementations:

1. Conventional current limiting power supplies
2. CV/CC mode power supplies
3. Foldback current limiting power supplies

Conventional current limiting power supplies and CV/CC mode power supplies are very similar in function. These implementations generally vary only in the degree of regulation in the constant current operating region (see Figure 5) and in the ability of the user to adjust the CC operating point (CV/CC power supplies). A rounded crossover knee and sloping current limit characteristic denotes less precise current regulation. In comparison, a sharp knee and vertical current limit characteristic denote a higher degree of current regulation. The foldback current limiting power supply employs a technique that enables both the output voltage and current to decrease simultaneously for load resistances below the crossover value. The purpose of current limiting is to provide protection for the power supply and the device being powered (assuming the current limit value is below the maximum current rating of the device).

Test Overview/ Procedures

A measurement of the output voltage and current of the power supply under test is required while decrementing the electronic load resistance (or current in CC mode) by steps from an initial value that produces the power supply's full rated voltage output (see Figure 6). The voltage will remain constant until the compliance current (output current of the power supply) increases to the preset current limit value. The crossover region or current limit has been reached when the rated output voltage of the power supply changes by a degree greater than the load regulation specification. At the current limit knee, the compliance current and output voltage behavior is determined by the type of current limiting circuit implemented in the power supply design (see Table 3).

Table 3. Typical Test Results of Standard Current Limiting Implementations

Current Limiting Method	I Compliance (or I_{out}) at Minimum Load Resistance
CV/CC	Remain constant (CC mode)
Conventional Current Limiting	Typically $\leq (105\%) I_{max}$
Current Foldback	Typically foldback is $\leq (50\%) I_{max}$

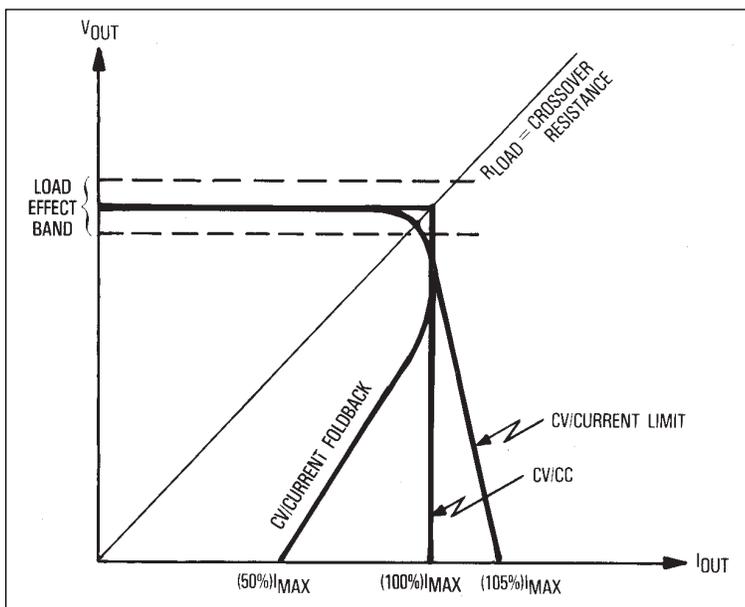


Figure 5. Typical Operating Characteristics of Three Types of Current Limiting Power Supplies

PARD (Periodic and Random Deviation)

PARD (formerly known as ripple and noise) is the periodic and random deviation of the DC output voltage from its average value, over a specified bandwidth, and with all other parameters constant. It is representative of all undesirable AC and noise components that remain in the DC output voltage after the regulation and filtering circuitry (see Figure 7).

PARD is measured in rms or peak-to-peak values, and is typically specified over a bandwidth range of 20 Hz to 20 MHz. Any deviation below 20 Hz is included in a specification called output drift. In

some applications, a low output ripple specification is critical. An example would be where the power supply is providing power to a high gain amplifier with inadequate ripple rejection for the application. In this case, a portion of the power supply PARD would be amplified along with the desired signal. It is extremely important that the PARD value be specified as a peak-to-peak value as well as an rms value in this application. The peak-to-peak value would provide information on high magnitude, short duration noise spikes while the rms value would be beneficial for determination of the expected signal-to-noise ratio.

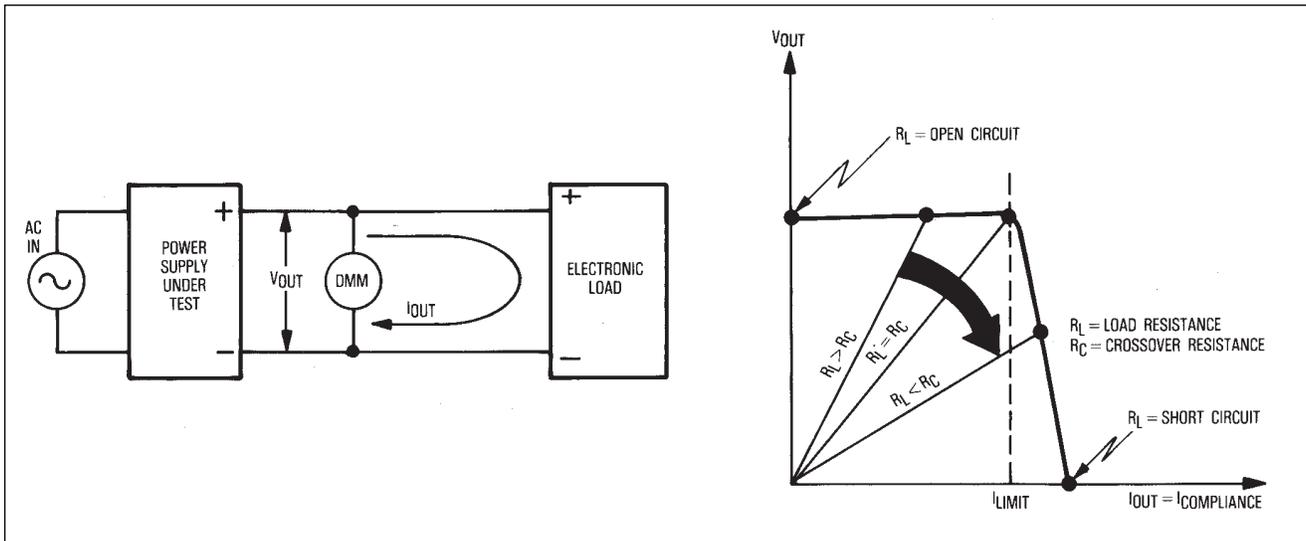


Figure 6. Test Configuration and Results for Current Limit Characterization

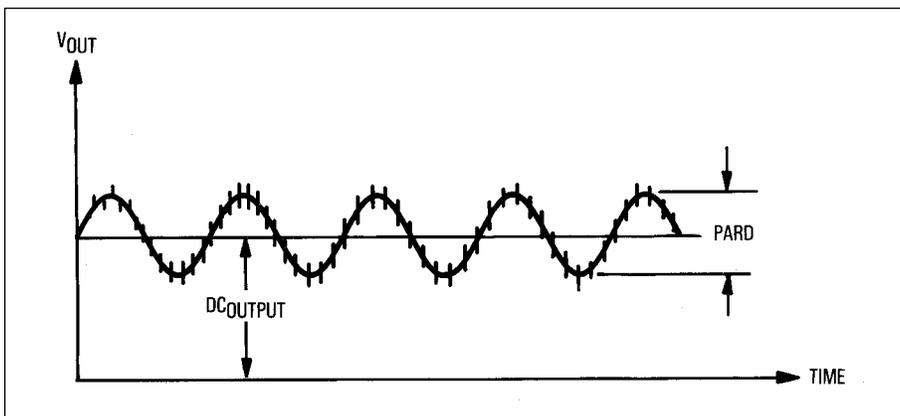


Figure 7. PARD Consists of Undesirable Signals Superimposed on the DC Output of a Power Supply

Test Overview/Procedures

To make PARD measurements, the electronic load used should operate in CR mode for constant voltage and constant current power supplies. The load should also have lower PARD than the power supply being tested. This is especially important when measuring the PARD of linear power supplies, since they typically have excellent PARD specifications. A regulated AC source should be applied to the input of the power supply under test. PARD measurements are made at the lowest and highest specified values of AC input to the power supply, and at the lowest and highest specified source frequencies.

Proper connections between the instruments and power supply under test are essential when making these measurements. Since PARD consists of low level, broadband signals, major test set concerns are ground loops, proper shielding, and impedance matching. A digitizing oscilloscope can be used for peak-to-peak measurements (see Figure 8). High frequency noise spikes need to be measured, and therefore the digitizing rate of the oscilloscope must be at least five times the maximum PARD frequency for proper sampling. To eliminate cable ringing and standing waves, the typical configuration includes coaxial cabling with 50 Ohm terminations at both ends. Capacitors should be connected in series with the signal path to block the DC current.

A true rms RF voltmeter should be used to measure the rms specification. Precautions similar to those for the peak-to-peak measurements should be considered. For both measurements, care should be taken to prevent ground loops. Since most oscilloscopes and true rms voltmeters have ground referenced inputs, testing a power supply with grounded outputs may create such a ground loop. In this case, it may be necessary to use instruments with floating (differential amplifier) inputs to eliminate this problem.

The first set of PARD measurements should be made with the AC source voltage and frequency set at the lowest specified values, and with the power supply under test at its minimum and then maximum rated load value. A second set of measurements should be made with the AC source set at the highest specified values of amplitude and frequency, and with the power supply minimally loaded and then maximally loaded. To test multiple output power supplies, PARD measurements for each output should be made with all other outputs set initially to minimum load, and then to maximum load.

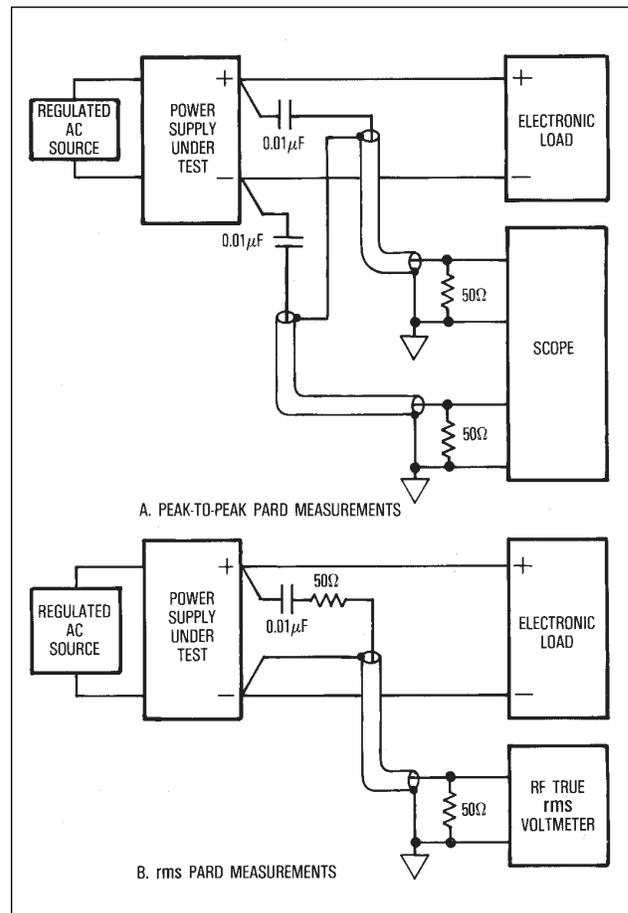


Figure 8. PARD Testing Configuration

Efficiency

The efficiency of a power supply is simply the ratio of its total output power to its total input power. To obtain the true input power (rms voltage x in-phase rms current) of a typical AC-to-DC converting power supply, commercially available wattmeters or AC sources can be used to measure the necessary parameters. The instrument used to measure the input current and voltage must be capable of sampling the input signals at a rate fast enough to produce accurate measurements.

This test serves as a good indication of the overall correct operation of the power supply under test. If the measured efficiency is outside the specified range for the topology of the power supply, it is probable that a design flaw or a manufacturing problem exists that should be addressed.

Test Overview/Procedures

The efficiency and power factor of the power supply under test should be measured under steady-state operation after the unit has been allowed to warm up. The electronic load can be operated in CC mode (for CV power supplies) and CV mode for (CC power supplies). At least two load settings should be used, one of them being the maximum rated load for the power supply under test (see Figure 9 for test configuration). Some power supplies vary substantially in efficiency and power factor as a function of loading. In this case, the load should be varied through enough settings so that curves can be plotted from the data to provide the best representation of the test results.

Start-Up

The start-up delay of a power supply is the amount of time between the application of AC input and the time at which the outputs are within their regulation specification. For switching power supplies or power supplies with current limiting, this time period is essential for proper sequencing of the output voltage at turn-on. In switching power supply designs, undesirable events can occur at turn-on, causing current spikes which can destroy the switching transistors. The problem occurs when the feedback loop tries to compensate for the low output voltage that it sees when the AC input is initially applied to the power supply. This problem is usually solved by adding “soft-start” circuitry to limit the time the switching transistors are turned on during the start-up sequence. This will limit the current flow through them until the power supply has reached stable operation.

Another undesirable condition that can occur during power supply start-up is voltage latch-up. In this case, the output voltage of a CV power supply with current foldback fails to reach its full value at turn-on because the output current attempts to immediately go to a high value. The protective response of the current foldback circuitry of the power supply can cause the output voltage to “latch-up” at a point where the current that must be dissipated can cause damage to the power supply (see Figure 10). It is, therefore, beneficial to measure the start-up delay time and fully characterize it to ensure safe operation at turn-on.

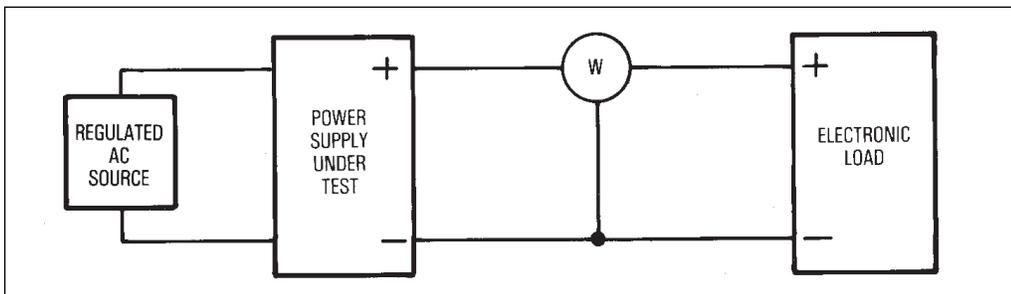


Figure 9. Configuration for Testing Efficiency and Power Factor

In this test configuration for measuring power supply efficiency and power factor, the variable AC source provides measurements for input power and power factor.

To fully characterize the start-up sequence of the power supply under test, measurements must be made of the output voltage response to the instantaneous application of the AC input (see Figure 11). A digital oscilloscope should be used so that storage of the output values can be accomplished for the measured start-up time period. To accurately

control the AC input frequency and amplitude to the power supply under test, a regulated AC source should be used. Turn-on of the AC source at selected 60 Hz (50 Hz) phases (zero-crossing and positive or negative peak voltage, for example) is important for thorough characterization of start-up. The electronic load used in this test should operate in CR mode.

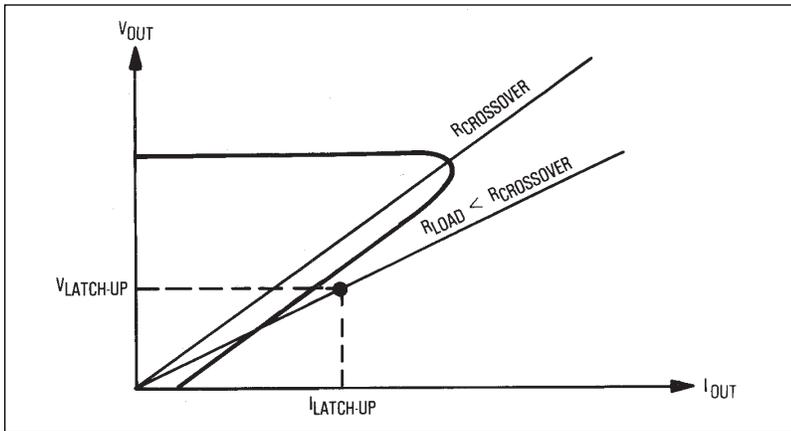


Figure 10. Voltage Latch-Up

Undesirable voltage latch-up and turn-on can cause the power supply to operate at current levels that may be damaging to internal circuitry.

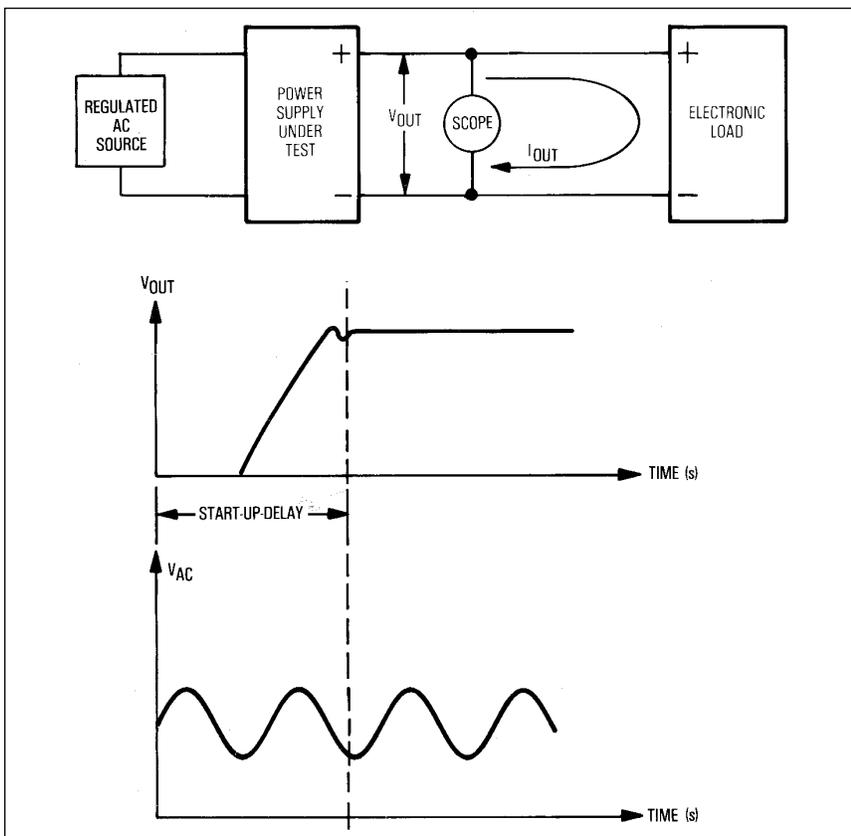


Figure 11. Start-Up Delay Test Configurations and Results

Other Power Supply Tests

An observation of any DC power supply data sheet from a power supply manufacturer reveals a number of design specifications that must be verified and tested. These tests often differ in technique and in the test equipment that is used to measure the various parameters. The common aspect of all of these tests is that a method of controlled loading of the power supply outputs is required, which is most easily done with an electronic load. The list below contains a brief description of some of these tests.

Drift

This test involves the measurement of the periodic and random deviation of a power supply's output current or voltage (typically over 8 hours), typically covering a bandwidth from DC to 20 Hz. The electronic load used for this test should be able to operate in CC or CV mode.

Test Equipment:

- Computer (for long-term testing)
- Electronic Load
- True rms Voltmeter

Source Effect (Line Regulation)

A measurement of the change in the output voltage or current due to a change in the source voltage magnitude. The output of interest is measured after it settles within the regulation specifications. The electronic load used for this test should be able to operate in CC or CV mode.

Test Equipment:

- Electronic Load
- Regulated AC Source
- Digital Multimeter
- Precision Current Shunt

Short Circuit Output Current

This test measures the steady-state current of the power supply under test after the output terminals have been shorted. The short circuit can be provided by an electronic load operating in CR mode.

Test Equipment:

- Electronic Load
- Digital Multimeter
- Precision Current Shunt

Overvoltage Shutdown

Typically, a power supply is expected to shut down if its output voltage exceeds the maximum input voltage of its intended load, the maximum operating voltage of the power supply, or a variably set voltage limit. The overvoltage protection test demonstrates the ability of the power supply under test to correctly respond to any of those conditions. An electronic load in CC mode can be used to test the output voltage response.

Test Equipment:

- Electronic Load
- Digital Multimeter

Programming Response Time

This test measures the maximum time required for the programmed output voltage or current of a power supply to change from a specified initial value to a value within a specified tolerance band of a newly programmed value, following the onset of a step change in an analog programming signal, or the gating of a digital signal. An electronic load in CC, CR, or CV could be used in this test.

Test Equipment:

- Computer
- Electronic Load
- Digital Multimeter
- Precision Current Shunt

Power Supply Testing with Agilent Electronic Loads

The Agilent Electronic Load Family offers the power supply tester the solution for many of the tests that must be performed. For bench or system applications in large or small scale testing environments, Agilent Electronic Loads provide high quality and reliability with superior performance, features, and documentation. This will make power supply test system configuration easier, measurement procedures repeatable, and operating environments safer.

The Agilent 6060A 300 Watt and 6063A 240 V Single Input DC Electronic Load provide many features that are fully programmable in CC, CV, or CR mode. For measurements that require step load changes, the 6060A and 6063A contain a transient generator that has a minimum risetime of 12 microseconds. This allows for load transient response testing of high performance linear (series regulated) power supplies as well as switching power supplies. In addition, the duty cycle and frequency of the transient generator can be fully controlled using the front panel, or via programming through the built-in GPIB.

Synchronizing the measuring instruments in a power supply test system is essential to retrieve valid test data. The 6060A and 6063A can generate triggers that can externally trigger a DMM, digital oscilloscope, or wattmeter to take a measurement as the load changes according to the testing goals. The 6060A and 6063A can also change in response to external triggers from other test equipment.

For testing multiple output power supplies, Agilent offers the 6050A 1800 Watt Load Mainframe. This product provides an economical alternative to the 6060A and 6063A for large scale testing environments. It has six slots which can be user-configured up to 1800 Watts with the Agilent Electronic Load Modules—the 60501A 150 Watt Module, the 60502A 300 Watt Module, the 60503A 240 Volt Module, and the 60504A 600 Watt Module. The 6050A provides all of the features of the 6060A and 6063A.

The Electronic Load Family provides “One Box” solutions for system applications. These loads contain a DMM and precision current shunt for voltage, current, and power readback via the built-in GPIB. In addition, Agilent Electronic Loads contain a transient generator, provide status readback, and have voltage and current programmers that reside in the box. This eliminates the need for external DMMs in many power supply test applications, and therefore saves rack space and additional test system costs.

For reliable and safe operation, Agilent Electronic Loads offer full protection against overvoltage, overcurrent, overpower, overtemperature, and reverse polarity conditions. The reliability of Agilent Electronic Loads are backed by a standard three year warranty. The reliability, performance, and features of the 6060A, 6050A, 60501A, 60502A, 60503A, and 60504A, combined with competitive prices, make these products an optimum solution for power supply testing applications.

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Printed in U.S.A. 10/00

5952-4190



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