Increasing dc Power Supply Test System Throughput with Agilent Technologies N3300A dc Electronic Loads

Product Note

Introduction

Increasing system throughput is critical for today's dc power supply manufacturing environment. Reducing test time allows the dc power supply manufacturer to decrease the cost of testing, which allows the delivery of competitively priced products in a timely way. The new Agilent Technologies N3300A family of electronic loads is optimized to be the core of a fast, flexible and reliable dc power supply test system.

This product note describes some of the ways this new family of electronic loads can be used to achieve maximum throughput for your dc power supply test system.

How to use the examples in this Product Note:
The following examples are programming language independent. They are composed only of the character strings being sent to the Agilent N3300A dc Electronic Load Mainframe. The intention is to illustrate

general ideas and methods, not to provide full test programs. Where other programming instructions are needed they are described in italics. Also, note that there are short forms of almost all of the commands that can be found in the N3300A Programming Guide (included with each mainframe). These have not been used in the examples because the full command description provides a more clear illustration of its purpose. For the fastest test routines it is recommended that you use the short forms.

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1) Increase the Speed of Load Program Execution Using List Mode

By using the new Agilent N3300A Series dc electronic load, the test system throughput will improve because all operations execute faster. Command processing speed can be increased further by using a powerful new feature called List mode. This mode allows the downloading of a command sequence to each load module during system set-up. Each List can have up to 50 commands that control the load input settings. The load module interprets the commands then stores them internally — ready to execute. The command sequence may then be accessed repetitively during testing. When the sequence is accessed and executed the module runs at maximum speed because the GPIB bus transfer and load command processing steps are eliminated. Lists may be stored in one of the non-volatile memory locations to be still resident in the load memory even after the load is turned off. Four non-volatile memory locations exist in each load module and each is capable of storing one List of up to 50 steps.

Execution of a List can occur in one of two ways: paced by triggers or paced automatically. After a List is stored in the memory of an electronic load module, a trigger is used to begin the execution of the List. On the occurrence of a trigger all modules begin executing their List steps simultaneously. Triggers can continue to be used to begin each step in the List. Or, use the Dwell Time to determine the amount of time the load remains at each List step. Using this method the sequence will then continue automatically as each preset Dwell Time elapses.

Using Lists and triggers saves time in several ways:
- The computer sends the List sequence only once.
- The load interprets the commands only once.
- The load can automatically step through the List without computer intervention.

List Creation and Control
To create a List use the List mode commands. For example:

```
LIST:CURRENT 2.5,2.7,2.9
```

This command would be part of a three-step List. It changes the programmed input current level from 2.5 amps to 2.7 amps and then to 2.9 amps. This general structure of the List commands allows all changes of a particular parameter to be sent in one command. Changes to each parameter are sent in separate commands with the same number of steps for each. This is a channel specific command, meaning that it applies only to the previously addressed module. A set of List commands must be sent to each module that will be included in the procedure. Not all modules in the mainframe, however, need to be included in each List. Only those modules which have been programmed to List mode will respond to the `INITIATE LIST`. Otherwise, they will remain in the immediate (or fixed) mode.

All of the commands available in the CV, CC, and CR modes are accessible in List mode by using the corresponding List commands. The commands associated with the transient generator are also included. The transient generator is used to create either a one-time pulse or a continuous pulse stream. Please reference the N3300A Programming Guide for the complete set of List commands.

In addition to the input control commands the following List execution commands are provided:

LIST:STEP ONCE
    causes the List to advance one step after each trigger

LIST:STEP AUTO
    causes the entire List to be executed sequentially after the starting trigger, paced by the dwell delays. As each dwell time elapses the next step is begun.

LIST:COUNT <n>
    specifies the number of times (n) the List is cycled

LIST:DWELL <n>, …
    specifies the total time period of each step

Measurement commands are not included in the List but can be initiated using the same trigger. The internal timer, which can be used to generate triggers at a specified rate, is a convenient feature to use when combining Lists with measurements.

Below is an example of the List command strings that would be needed to program two load modules to step through three input settings. Similar sequences are being sent to the two modules (channel 1 and channel 2). Note that if a setting is identical for every step, then it need only be given once. This has been done for `LIST:CURRENT:RANGE` and `LIST:CURRENT:TLEVEL`. If all steps are not identical then all steps must be included or you will generate an error. Also, note that all of the following parameters must be specified, whether or not you wish to change them: `CURRENT:TLEVEL, CURRENT:RANGE, CURRENT:SLEW, CURRENT:DWELL,` and `CURRENT`. In the other modes (voltage, resistance, transient) there are corresponding required commands.

This example shows a self-pacing List which requires only one trigger and continues independently from there:

There will be more examples illustrating how to use Lists in combination with other features.

This minor example, executed only once, would not decrease test time. Efficiency gains occur when a test is used repeatedly — exactly what's needed in a manufacturing setting. To repeat a routine later in a test program, only these two commands are needed:
```
INITIATE LIST
TRIGGER
```

Command	Comment
`LIST:STEP AUTO`	// The list will continue to execute // after 1 trigger
`CHANNEL 1`	// All commands following will go to // channel 1
`CURRENT:MODE LIST`	// Command specifies whether the // current setting will be controlled by // values in a List or the CURRENT // command setting.
`LIST:CURRENT:TLEVEL 5`	// If the transient generator is enabled, // the transient level will be 5 volts // (not used in this example)
`LIST:CURRENT:RANGE MIN`	// Set the minimum current // programming range.
`LIST:CURRENT:SLEW MAX, MAX, 5E6`	// Steps 1&2 slew at max rate, step 3 at // 5E6A/s.
`LIST:DWELL 0.5,0.5,0.25`	// Steps 1&2 take 0.5 sec, and step 3 // takes 0.25 sec.
`LIST:CURRENT 1.0,1.1,5.0`	// Programmed current steps through // 1.0 , 1.1, and 5.0 amps.
`CHANNEL 2`	// All commands following will go to // channel 2
`CURRENT:MODE LIST`	// same as above
`LIST:CURRENT:TLEVEL 5`	// same as above
`LIST:CURRENT:RANGE MIN`	// same as above
`LIST:CURRENT:SLEW 6E6, 7E6, 5E6`	// Each step has a different current // slew rate.
`LIST:DWELL 0.5,0.5,0.25`	// same as above
`LIST:CURRENT 0.5,0.55,1.0`	// The programmed current steps // through 0.5, 0.55 and 1.0 amps
	// The following commands apply to // all channels.
`INITIATE LIST`	// Prepares the List to start on the next // trigger.
`TRIGGER`	// The List (in both modules) begins

2) Minimize Measurement Time

Built into each electronic load module are an ammeter, voltmeter, power meter and digitizer. These tools can make many of the needed measurements at the dc power supply outputs during testing. While the increased measurement speed greatly enhances system throughput, Agilent's innovative electronic loads enable even faster measurement operations using simple techniques.

Shorten Measurement Time by Reducing the Number of Samples in a Measurement
Unless otherwise programmed, upon receipt of a voltage measurement command, the electronic load will acquire 1000 voltage samples for averaging. Overall, it can average up to 4096 voltage samples. By taking large numbers of samples, accuracy and noise rejection can be increased. The trade-off for higher accuracy and noise rejection is increased measurement time. The time difference might be 2 or 3 times faster depending upon the specific tests. The N3300A family provides flexibility to optimize measurement speed relative to the measurement performance required by the application.

Current measurements are executed in the same way as voltage measurements with the same size buffer and the same flexibility in choice of number of samples. Voltage and current samples are acquired simultaneously and power is calculated from the voltage and current for each sample.

To define the number of samples in a voltage or current measurement, use:

`SENSE:SWEEP:POINTS <n>`

For example, to define a measurement to have 100 points use the command:

`SENSE:SWEEP:POINTS 100`

This command applies to both voltage and current measurements. Voltage and current measurements cannot be configured separately. It also indirectly applies to power measurements which are calculated from voltage and current.

Quick Waveform Digitization
Oscilloscopes are often used for measurements to observe power supply transient behavior and noise. Oscilloscopes are very powerful

measurement tools, but in many systems using them is time consuming because many operating parameters must be specified. This is particularly true if your test program allows execution of tests in any order, then the current state of all test instruments is not always known. So a full set-up for each test segment would need to be programmed — a time-consuming process. Oscilloscopes also usually need to acquire large amounts of data before providing any measurement results. If an oscilloscope has to be switched between power supply outputs then even more time is needed before data is available.

Each module includes a 4096 sample digitizer so no switching is needed to move the oscilloscope between outputs. The sampling rate is programmable. Transient response is an example of a power supply test for which the measurement system of the N3300A Electronic Load is well suited.

Overall, the N3300A Series Electronic Load greatly reduces the need for oscilloscope use. System throughput is enhanced each time the digitization capabilities of the load are used in place of the more complex functions of an oscilloscope. Throughput is also enhanced by avoiding switching an oscilloscope between power supply outputs.

Using the Electronic Load as a digitizer
When using the N3300A dc Electronic Load measurement system as a digitizer all samples should not be averaged together automatically. The actual sample values should be retrieved as an array of length 4096 points. To do this, use the command string:

MEASURE:ARRAY:VOLTAGE?

or

MEASURE:ARRAY:CURRENT?

Then read the 4096 length array to the computer. To obtain the data in array format after a triggered measurement has occurred, use the commands:

FETCH:ARRAY:VOLTAGE?

or

FETCH:ARRAY:CURRENT?

The FETCH command will not initiate a new measurement, it simply returns all samples present in the buffer as an array. FETCH should only be used after the actual measurement is completed. An example is provided later in this section.

By using the built-in measurement capabilities of the loads, it is easy to synchronize the load transitions and measurements relative to each other. The same trigger can be used to begin both operations. Additional commands are available to offset a measurement relative to a trigger.

Following is an example of the command strings used by the electronic load for a typical transient response test. In this test the load current is raised from 5 amps to 10 amps and the power supply output voltage is measured:

```
CHANNEL 1                          // This test will involve the module at
                                   // channel 1

MODE CURRENT                       // Set for operation in the CC mode
CURRENT 5                          // Set a steady state of 5 amps
INITIATE ACQUIRE                   // Initiate the measurement trigger
                                   // system.

SENSE:SWEEP:POINTS 4096            // Take a full buffer of readings
                                   // (4096 readings) in each measurement.

SENSE:SWEEP:TINTERVAL 10E-6        // Take readings at an interval of
                                   // 10 microseconds.

CURRENT:TRIGGERED 10               // When trigger id received, the load
                                   // module will be set for 10 amps.

TRIGGER                            // This trigger will start both the
                                   // increase in load current and the
                                   // voltage measurement.

// (wait for test to complete)
FETCH:ARRAY:VOLTAGE?               // Prepares to return the previously
                                   // obtained data.
// (read back the 4096 length array to your computer)
```

Most measurement commands, such as the INITIATE ACQUIRE and SENSE commands shown above, refer to both current and voltage. Each time a measurement is made new data will be acquired simultaneously for current and voltage. Voltage and current measurements cannot be controlled separately.

Because of this dual operation, if this command was sent:

MEASURE:ARRAY:VOLTAGE?

Both voltage and current would be measured. But only the voltage measurement data array would be available to be read back to the computer. After this array is read back, the current measurement data can be retrieved with the command:

FETCH:ARRAY:CURRENT?

This feature allows simultaneous acquisition of voltage and current measurements.

3) Change Loading Conditions Quickly

There are many reasons why system designers might want to control the slew rate of the load. Examples: simulation of real life loading conditions; or keeping the power supply under test stable. Performing transient response tests at different slew rates could be used to find the loading rate that would cause instability.

An example of a real-life loading condition simulated with slew rate control is inrush current. In this case, the load demands a large amount of current quickly ramped, and then loads the power supply further at a slower rate.

The slew rate of the N3300A Agilent dc Electronic Load is not only programmable but can also be set separately for rising and falling transitions. This allows the user to slow down only the transition that is necessary for that test, while keeping the other transition at maximum speed.

Constant current, constant voltage, and constant resistance modes each have independently controllable slew rates. These commands are available in both the immediately executed operating mode and the List mode.

In the following example, the test requires that current out of the power supply under test is increased gradually. But at the end of the test the current is reduced to zero as quickly as the load can program it down. This technique might be used in a case where the power supply under test exhibits instability or "ringing" upon instantaneous loading.

```
MODE CURRENT                    // Operation will be in the CC mode.

CURRENT:SLEW:POSITIVE 3E4       // Set the rising slew rate to 30,000
                                // amps/sec.

CURRENT:SLEW:NEGATIVE   MAX     // Set the falling slew rate to maximum.

CURRENT:RANGE MAX               // Highest constant current range.

CURRENT 40                      // 40 amps are drawn from the power
                                // supply under test and it will be
                                // ramped up at a rate of 30,000 amps
                                // per second

// test program here

CURRENT 0                       // Zero amps are drawn from the power
                                // supply under test and the current will
                                // be ramped down at maximum rate
```

If different rising and falling slew rates are not required, then they can be specified at the same using the command:

```
CURRENT:SLEW <n>
```

This command programs the rising and the falling rates to be the same.
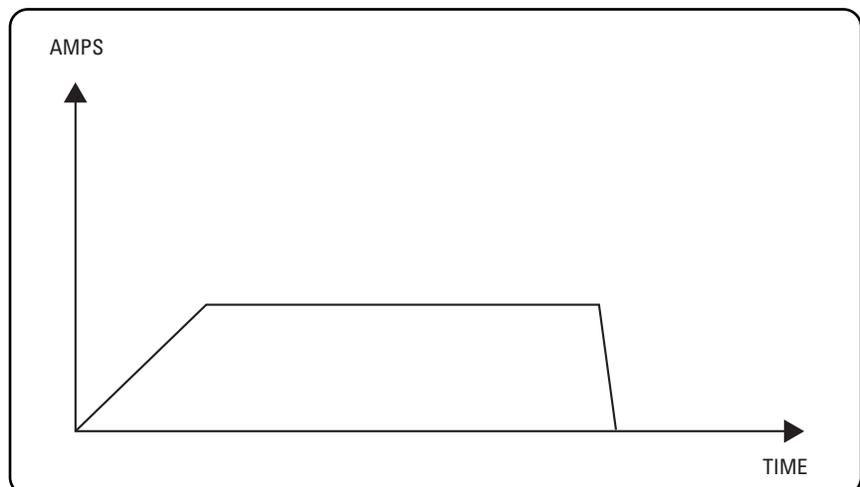
4) Increase Throughput When Testing Multiple Power Supplies Simultaneously, or Multiple Outputs of One Power Supply

Reduce test time by simultaneously testing multiple power supplies or multiple power supply outputs. The N3300A has been optimized for multiple channel operation. The flexible trigger system makes simultaneous triggering possible and also allows for programmable time offsets. User-friendly features allow setting load input values and making measurements easy to implement when testing multiple output power supplies.

Saving Time When Measuring at the Load Inputs

Measurements of voltage and current on the outputs of a multiple output power supply are usually taken with a multiplexer to connect each output sequentially to a voltmeter or an oscilloscope. The power supply outputs are measured one at a time with pauses between measurements when the multiplexer switches the voltmeter over to the next output. If the test involves observing the effect of one output on all others — such as cross-regulation — then the same sequence must be repeated to take measurements on each output.

The built-in measurement capability saves time and simplifies procedures. Each electronic load module has its own voltmeter, ammeter and digitizer. Power measurements can also be read back from the load. Current and voltage measurements are taken with dual simultaneous analog-to-digital converters, so there is no time offset between the voltage and current measurements. For this reason power calculations are extremely accurate. By using this built-in measurement system the multiplexer, voltmeter, associated cabling and current shunts can be eliminated or greatly reduced. Eliminating these hardware items saves time in numerous ways:

- program lines associated with the multiplexer are eliminated
- GPIB bus transactions to control the multiplexer are eliminated
- the time for the multiplexer to decode commands is eliminated
- the time for the multiplexer's switches to settle on the new setting is eliminated

An additional benefit: system simplification significantly enhances system reliability. Moving parts, such as relays, tend to be among the most unreliable. Reduction of wiring and connections also increases reliability and enhances serviceability.

Making measurements through many connections can decrease accuracy. Current measurements require an even more complex set-up with more wiring that could pick up stray noise. Using the internal measurement system in the electronic load enhances the quality and consistency of measurements while greatly improving system throughput.

Using the Measurement Buffers to Store Multiple Measurements

As long as the total number of measurement samples does not exceed 4096, samples for more than one measurement can be concatenated in the buffer. The buffer is then read back to the computer in the form of a 4096 long array and separated into the various measurements within the system's computer program.

The most important application of this feature is to interweave multiple measurements into a List. The same trigger that starts a List step can also be used to trigger an initiated measurement. But an automatically sequenced List cannot be interrupted to read the measurement data to the computer. If each measurement replaced the previous one in the buffer then only one measurement could be made during the execution of each List.

If this command is used:

```
TRIGGER:ACQUIRE:COUNT <n>
```

it allows the programmer to define the number of measurements for which the one INITIATE command remains active. In addition, it will concatenate that number of measurements together in the 4096 long buffer. Define the number of samples to be taken on each measurement using

```
SENSE:SWEEP:POINTS <n>
```

as previously described. All samples must total no more than 4096. For example, no more than four measurements could each contain 1000 samples.

Example of multiple output power supply cross-regulation:

This example uses the electronic load's capabilities to simultaneously trigger multiple modules and to interweave measurements with a List. The example represents a segment of a test of a triple output power supply, so three load modules are used. The goal of the test is to determine the effect of a load change of one power supply output on the regulation in the other two.

Five amps are drawn from all outputs. One at a time, the outputs are raised to 10 amps then returned to 5 amps. At each transition all three power supply outputs are measured with a series of 580 readings spaced by an interval of 200 microseconds. There are 7 List steps in this test, including those that return the exercised channel to the original 5 amps. So this creates 7 times 580, or 4060 readings. The buffer can store 4096 readings so there are 36 unused locations. (See Figure 1.) Note: Details of this test are power supply specific. The numbers are used only to illustrate the method.

580	580	580	580	580	580	580	36

0   4096

Figure 1. Usage of 4096 long buffer, using 7 measurements, each 580 samples long

This example assumes that the Agilent N3300A dc Electronic Load is already in the CC mode. If the mode is previously defined outside the List then it does not have to be stated in the List.

Both the List and the measurements are triggered off the internal timer which is set for one second. The List progression in this example is defined by triggers not dwell time. The dwell time is set shorter (0.1 seconds) to make sure that it will not interfere. The measurement start is delayed 0.3 seconds after the trigger so that the power supply outputs can stabilize before measurement begins.
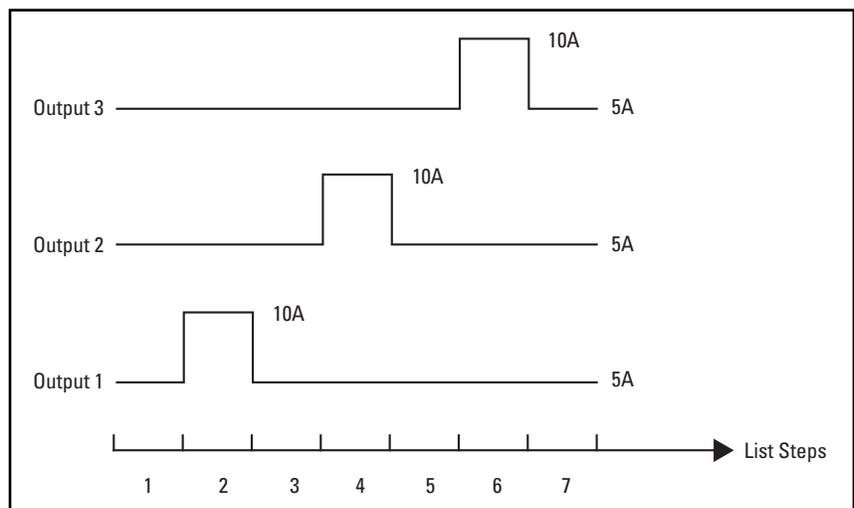

Figure 2. Changing power supply currents sequentially to observe cross regulation.

Character strings sent to the N3300A load:

```
                                    // Prepare the measurement system.
SENSE:SWEEP:POINTS 580              // Set the number of samples in each reading to 580.
SENSE:SWEEP:TINTERVAL 200 E-6       // Set the interval of one sample to 0.2ms.
SENSE:SWEEP:OFFSET 0.3              // Begin measurement 0.3 seconds after the trigger.
TRIGGER:ACQUIRE:COUNT 7             // Set the number of triggers that the measurement
                                    // system will react to and prepare to concatenate all
                                    // seven measurements into one array.
                                    //
```

// Dimension 3 arrays (one for each of the 3 channels)   to be prepared to transfer the three 4096
// wide voltage buffers.

```
                                    // Prepare the List system.
                                    //
LIST: STEP ONCE                     // The List will execute one step on each trigger.
LIST:DWELL 0.1                      // Minimum time on each step is 100ms. (The next step will
                                    // not begin until a trigger occurs)
                                    //
                                    // Send channel specific commands.
                                    //
CHANNEL 1                           // Following commands apply to only channel 1.
CURRENT:MODE LIST                   // The current will be set by a List.
LIST:CURRENT:SLEW MAX               // all steps will change with max slew rate
LIST:CURRENT:RANGE MAX              // High range.
LIST:CURRENT:TLEVELEL MIN           // Not used but must be included to operate in List mode.
LIST:CURRENT 5,10,5,5,5,5,5         // Current setting for all List steps.
                                    //
CHANNEL 2                           // The following commands apply to only channel 2.

CURRENT:MODE LIST
LIST:CURRENT:SLEW MAX
LIST:CURRENT:RANGE MAX
LIST:CURRENT:TLEVEL MIN
LIST:CURRENT 5,5,5,10,5,5,5
                                    //
CHANNEL 3                           // The following commands apply to only channel 3.

CURRENT:MODE LIST
LIST:CURRENT: SLEW MAX
LIST:CURRENT:RANGE MAX
LIST:CURRENT:TLEVEL MIN
LIST:CURRENT 5,5,5,5,5,10,5
                                    //
INITIATE:CONTINUOUS:LIST            // List system initiated.
INITIATE:ACQUIRE                    // This command initializes the measurement system.
                                    //
TRIGGER:TIMER 1.0                   // The internal timer is set to 1 second.
TRIGGER:SOURCE TIMER                // The trigger source is the internal timer and triggers begin
                                    // now.
```

// wait for the Lists and measurements to complete

```
TRIGGER:SOURCE HOLD              // The timer based triggers are stopped.
                                 //
CHANNEL 1
FETCH:ARRAY:VOLTAGE?             // Prepare to transfer the voltage
                                 // buffer of channel 1 to the computer.
                                 //
```
// read channel 1's array back to the computer, and examine its data
```
                                 //
CHANNEL 2
FETCH:ARRAY:VOLTAGE?             // Prepare to transfer the voltage buffer
                                 // of channel 2 to the computer.
                                 //
```
// read channel 2's array back to the computer, and examine its data
```
                                 //

CHANNEL 3
FETCH:ARRAY:VOLTAGE?             // Prepare to transfer the voltage buffer
                                 // of channel 3 to the computer.
                                 //
```
// read channel 3's array back to the computer, and examine its data
```
                                 //
```

After the arrays are read back to the computer, the data is separated into the seven 580-sample groups. Then each set of 580 samples is averaged.

Note: LIST:CURRENT:TLEVEL is not needed for the described functions but is one of the commands that must be included in each list.

Variations of the above example:
If the number of measurement samples in this example is not adequate for testing the cross-regulation of the particular multiple output dc power supply being tested, don't use the List feature. Then the 4096 sample points will be available for each measurement. This still saves a great deal of test time, especially when compared with using one oscilloscope switched between the three outputs.

A benefit of having samples from only one measurement in the buffer is that the load's internal averaging, Minimum and Maximum features can be used. Using MIN and MAX allows easy determination of the band of voltage fluctuation.

5) Reduce Overall System Throughput by Minimizing Downtime

Test system downtime is unacceptable in the modern high-volume manufacturing facility. The benefits of increased system throughput can be lost instantly due to test system failures. Over a period of time, system reliability has a definite influence on overall production throughput in a manufacturing facility.

Choosing the most reliable test instruments is the critical first step of building a reliable test system. When compared to other products, the initial cost of the Agilent N3300A may be more. However, the high quality and reliability of Agilent electronic loads must be considered. When compared to the costs of production downtime, the extra initial cost is easily justified.

Instruments that produce or dissipate large amounts of power are especially susceptible to problems. Electronic components have limits to the current and voltage they can handle before beginning to degrade. Also, the heat generated by dissipating power can degrade electronic components. An electronic load that will perform trouble-free for years must be designed to withstand full-rated current and voltage continuously. Designing highly reliable electronic loads requires years of experience to understand how to design power circuits which will not be stressed under extreme operating conditions. Agilent Technologies (formerly Hewlett-Packard) has a proven record of providing highly-reliable electronic loads. The average MTBF (mean time between failure) of Agilent Technologies dc electronic loads is more than 300,000 hours.

Simpler test systems have fewer problems due to lower complexity. Also, the simpler a system is, the quicker it is to troubleshoot problems. The advanced measurement capabilities of the Agilent N3300A Electronic Loads eliminates many complications. A typical power supply test system tests either multiple output power supplies or multiple single output dc sources. Often one voltmeter is used to monitor many power supply outputs, along with a multiplexer with relays to switch it between the power supply outputs. If current is also monitored shunt resistors also must be added. This approach involves many wires and many connections, in addition to the voltmeter, multiplexer and shunts. Moving parts, such as relays, tend to be among the most unreliable in an electronic test system. Eliminating any of those types of components will lead to increased test reliability and significantly less downtime. The last diagram (next page) demonstrates clearly the more simple method of monitoring power supplies under test using the Agilent N3300A dc Electronic Loads

The Agilent N3300A Series Electronic Loads have exceptional measurement capabilities which will allow most system designers to reduce the need for voltmeters, multiplexers, shunts and cabling. Test of dynamic operating conditions, such as transient response testing, usually requires an oscilloscope. Using the digitization capabilities of the N3300A Series of dc Electronic Loads may result in fewer tests needing to use oscilloscopes and that allows further system simplification.

Using the N3300A Series of Electronic Loads as the core of the Power Supply Test System, provides a simpler, more reliable design and minimizes system downtime.
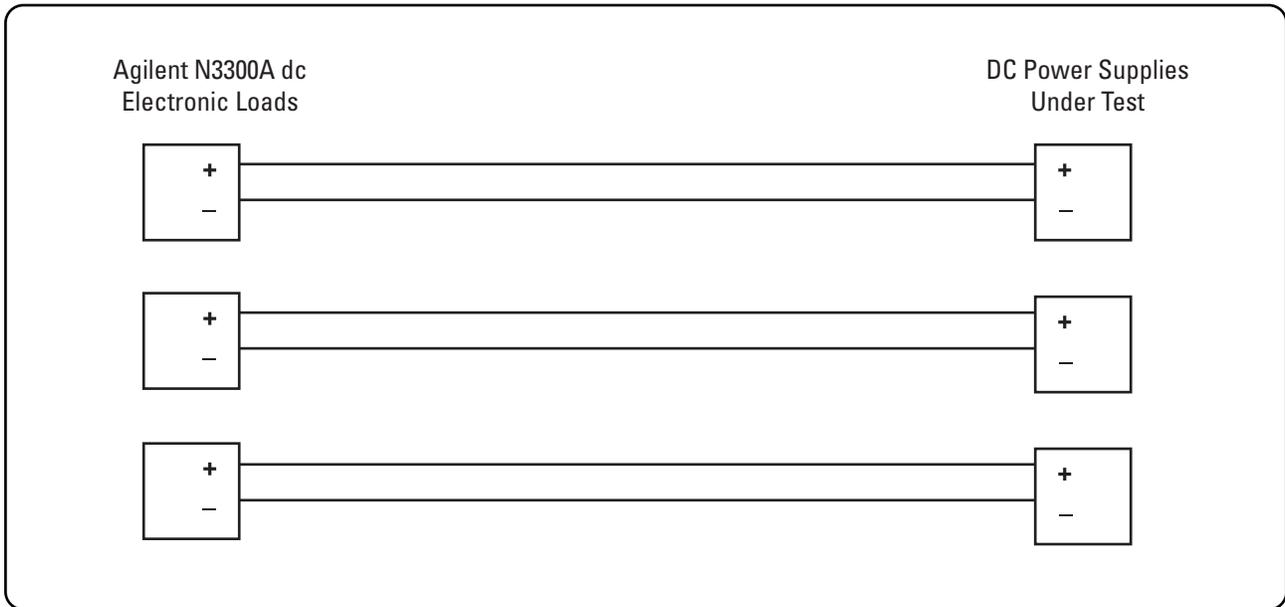
Monitoring power supplies under test with Agilent N3300A Series electronic loads
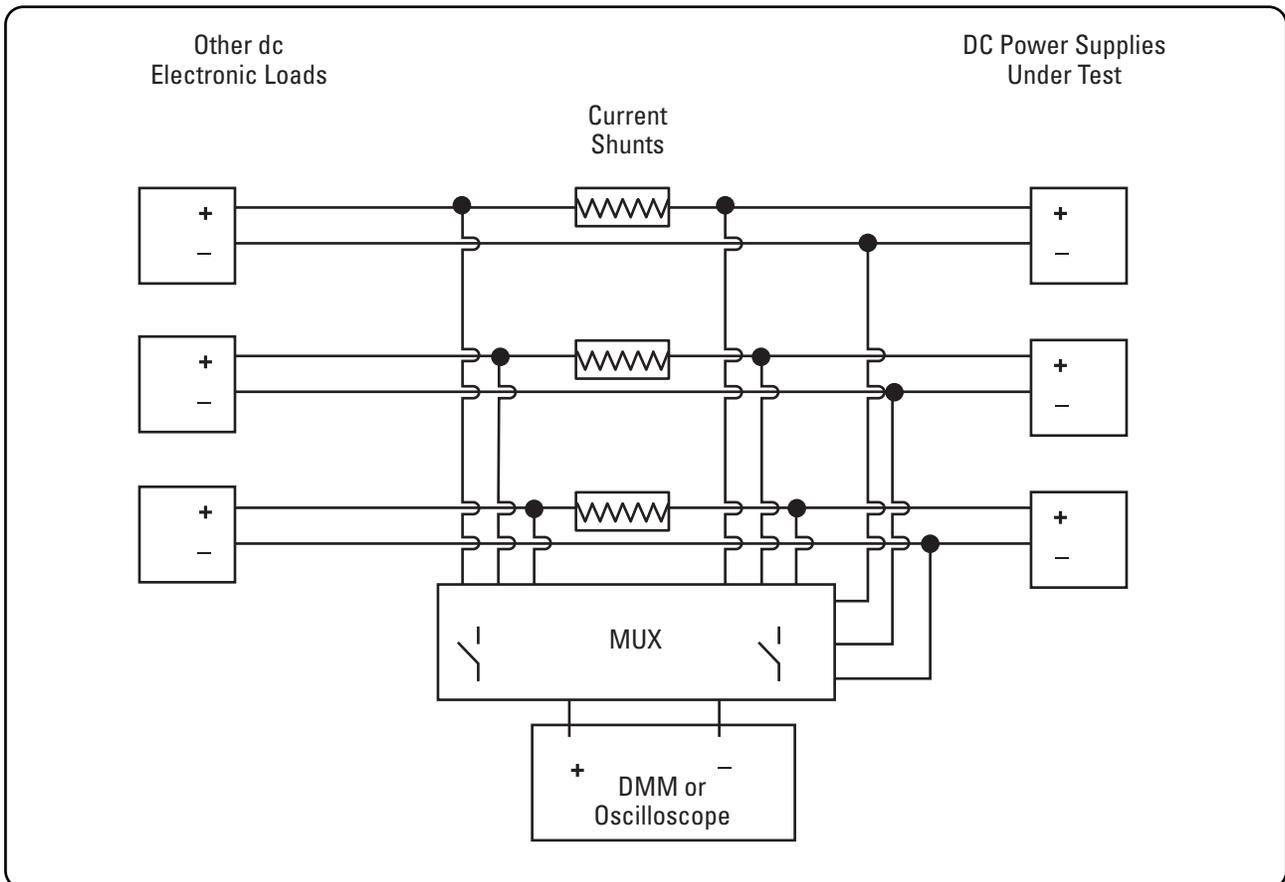
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