APPLICATION NOTE

Optimizing Processes to Speed Design Validation Power Tests

KEYSIGHT

Introduction

Testing speed is critical to design validation engineers. They must perform various tests quickly to thoroughly evaluate today's complex systems and test new designs under various operating and environmental conditions to determine their limits.

Quickly setting up and altering a test configuration is important for validation tests. However, reducing test duration is also important, particularly for long and elaborate tests. Those who have spent long periods with their hands in an environmental chamber set to extremes waiting for a test to finish can appreciate the importance of reducing the test time.

To design validation engineers, tests per unit time is a more critical aspect of throughput than devices per unit time. The reverse is true for manufacturing test engineers. But both benefit from all means of reducing testing time. The only difference is which ones to emphasize.

The power instruments selected for a test and how they are set up and used can significantly affect test throughput. Modern power instruments (such as system power supplies and electronic loads) include features that can improve test throughput. Knowing these features and methods for effectively using power products is essential for efficient testing.

This application note is for engineers who need to conduct complex or time-consuming tests using power products. It presents methods and techniques to decrease setup and test time. It is also valuable for manufacturing engineers, as these methods benefit manufacturing tests.

Minimize Setup Time

Reducing the time required to set up equipment for a design validation test enables engineers to run more tests. Accelerating testing reduces the time required to perform test iterations with varying design parameters and operating conditions. Manufacturing engineers must also monitor setup time, particularly for test procedures requiring changing or complicated test configurations.

One-box solutions simplify setup

One of the easiest ways to reduce setup time is to use one-box power products. These instruments substantially reduce the time required to assemble the power subsystem for a test. Many of today's system power supplies, AC sources, and electronic loads feature built-in voltage and current measurements, built-in voltage and current programmers, status readback, and service request interrupts in a single solution (Figure 1). Using integrated solutions eliminates the need to assemble a power subsystem from individual pieces, which takes longer and can result in a system with limited flexibility and uncertain performance.

One-box solutions offer many features that reduce complexity and uncertainty, including the following:

- Fully specified performance. One set of specifications covers the entire instrument, from GPIB input to output.
- Ease of use. Front-panel controls or easy-to-use graphical user interfaces speed up system development. You can program outputs in volts, amps, and similar self-documenting programming commands. System features like status readback and electronic calibration also speed development and reduce required maintenance time.
- Reduced system complexity. With everything in one box, there is no long list of extra equipment to obtain and stuff into a crowded rack. A one-box system also eliminates external cabling and interconnections between units, significantly increasing reliability and simplifying integration.

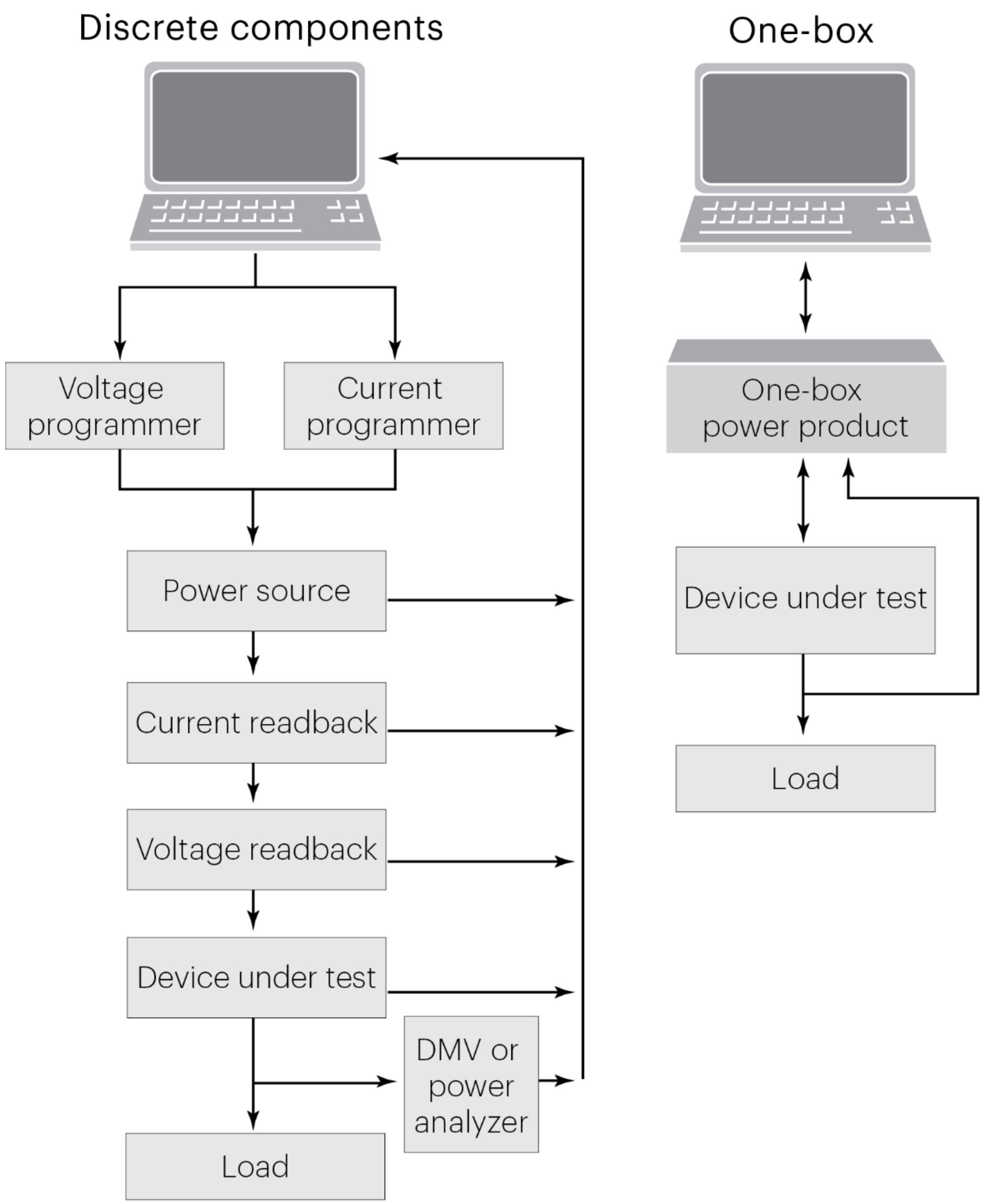

Figure 1. The one-box approach to power products eliminates or reduces the need to assemble a power subsystem from many separate components

Scope substitution

A number of power products also incorporate built-in measurement functions. This further reduces the need for additional equipment and cabling, making test setup even faster and easier.

One-box solutions have many applications that reduce setup time. For example, the peak and DC-average current draws need evaluation to adequately specify the power source for products that exhibit pulsed and dynamic current loading (such as digital cellular phones and hard drives).

For this evaluation, you could use an oscilloscope to monitor a shunt or current probe. However, this approach can create problems with voltage drops, ground loops, common-mode noise, space, and calibration. A simpler and less expensive alternative is to use a power supply with built-in dynamic measurement capabilities. A capable DC source can acquire pre- and post-trigger buffer data when a user-set threshold is crossed. Figure 2 shows data measured by a DC source.

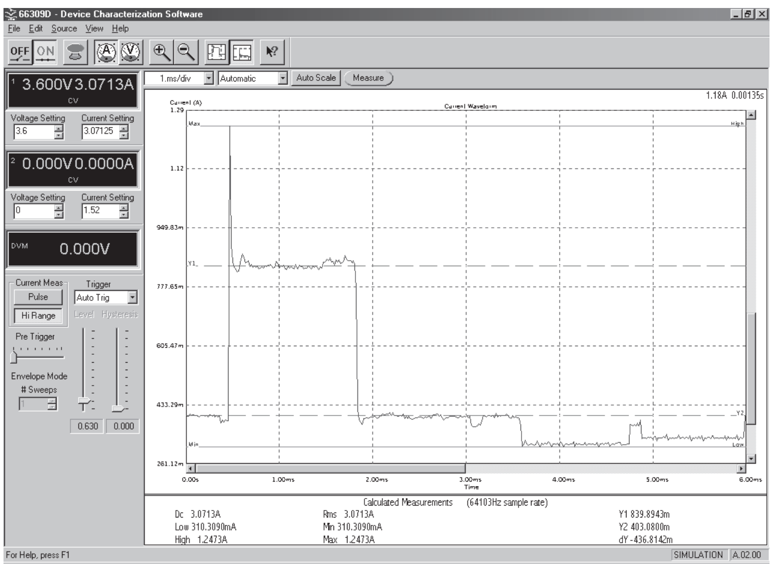

Figure 2. Characterization of pulse current loading of a digital cellular phone, captured by a DC source with built-in measurement capabilities

You can use an electronic load with built-in waveform digitization instead of an oscilloscope for certain measurements, such as observing power supply transient behavior and noise. Using a scope is time-consuming in many systems because operating parameters require specification during setup. For test programs that allow the execution of tests in random order, you would need to program a complete setup for each test segment, a lengthy process.

Oscilloscopes must also acquire large amounts of data before they can provide measurement results. Switching an oscilloscope between power supply outputs increases the time it takes for data to be available. System throughput improves each time you use the digitization capabilities of a load in place of the more complex functions of an oscilloscope.

More measurement capabilities

Another example of using built-in measurement functions is accurately measuring device-under-test (DUT) supply currents above 10 A, which is beyond the range of the typical digital multimeter (DMM) in ammeter mode. You could use an external shunt and a DMM's voltage mode for this measurement. However, a power source with a built-in shunt has the one-box advantages of fewer components to connect, less wiring complexity, more straightforward control, and documented error and performance characteristics. Table 1 shows the level of accuracy you can expect with a good-quality supply.

Table 1. Current measurement accuracy of a typical power supply with built-in measurement capabilities at various output current levels

Output level	Typical accuracy
Full	0.1% to 0.5%
10% of full output	0.5% to 1%
1% of full output	Near 10%

While the advantages of using the power source to measure high currents are clear, the benefits of using it to measure low currents are less noticeable. A good system DMM can measure current down to the picoamp level, but DUT supply currents rarely need measurements this low. Generally, the most challenging measurement will involve current draw by a battery-powered device in sleep mode, where measuring microamps with reasonable accuracy is usually adequate.

A system DMM's stated accuracy (0.01% to 0.1%) does not include other possible error sources affecting the measurement, such as cabling. However, the power supply accuracy figures in Table 1 incorporate all relevant factors because cabling and other error sources are not necessary with the built-in measurement capability.

Yet another example of reducing setup time and complexity with one-box power products is characterizing AC inrush current versus the turn-on phase. This measurement provides essential design insights but can be challenging to achieve. The current digitization and peak-current measurement must be in sync with the startup phase of the voltage.

A traditional test setup includes an AC source with programmable phase capability, an output trigger port, a digital oscilloscope, and a current probe. However, some advanced AC sources can provide built-in voltage generation, current waveform digitization, peak-current measurement, and synchronization. This setup enables AC inrush current characterization without cabling and synchronizing separate instruments (Figure 3).

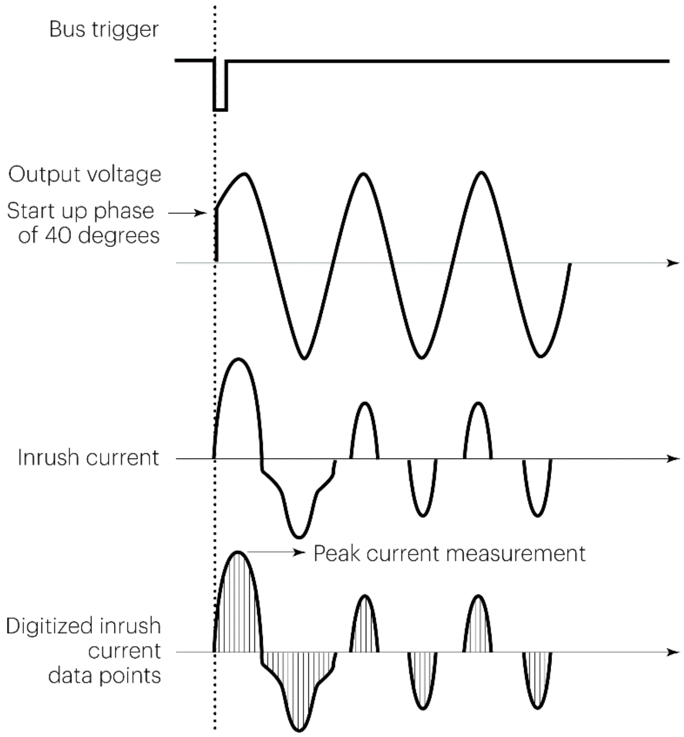

Figure 3. An AC inrush current measurement at 40 degrees using the Keysight 6800 Series AC power source / analyzer

Manage hazardous conditions more effectively

Modern power products may include safety features that make handling and reporting dangerous conditions easier. Having these features built-in reduces the time required to plan for unexpected hazardous situations. Overcurrent and overvoltage protection can shut down the output and send interrupt requests when dangerous conditions occur. In addition, external control ports on many newer instruments make it easy to incorporate emergency system shutdowns in response to external events.

Remote disable offers a simple way to shut down a power supply in response to a hazardous operating condition or to protect system operators. Remote inhibit (RI) is an input to a power supply that turns off the output when the RI terminal pulls low. Shorting the ordinarily open switch turns off the supply's output (Figure 4). Also shown is the discrete fault indicator (DFI), which can send a signal to an operator or other system components whenever the power supply detects a user-defined fault.

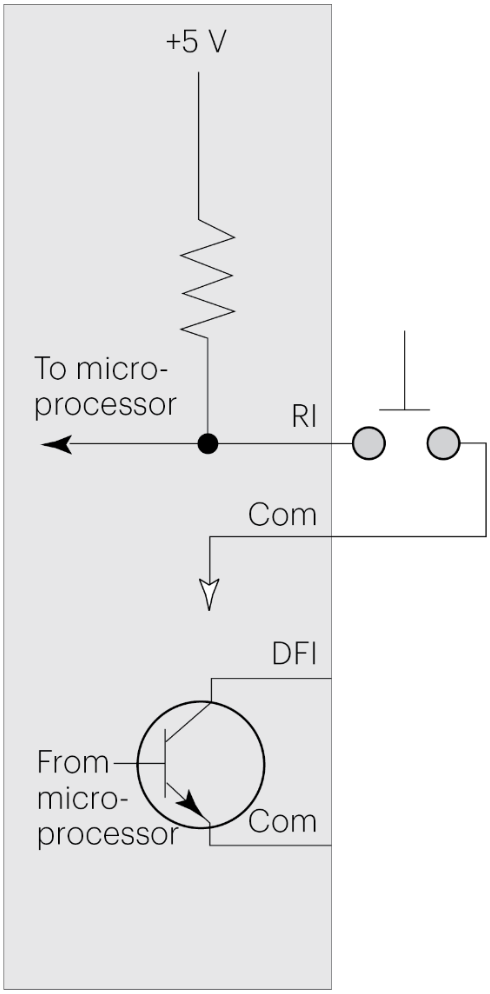

Figure 4. Schematic of RI and DFI functions

You can use a DFI signal to report almost any operating condition. For example, to generate a DFI signal from a power supply when the DUT draws excessive current, you would program the current slightly higher than the maximum expected current of the DUT, enabling overcurrent protection mode. Then you would program the power supply to generate a DFI signal when it enters constant-current (CC) mode. If the DUT current reaches the current-limit setting, the DFI output goes low, disables the power supply, and informs the operator of the overcurrent condition.

You can daisy-chain the DFI and RI signals, disabling all supplies in the system if one supply detects a fault. These features simplify management of the inevitable problem conditions that arise during design validation testing.

Another factor in reducing test setup time is the command language of the test equipment. If the equipment uses a command language that is easy to program and modify, you can set up each test much faster. Furthermore, the fewer languages you need to learn, the faster and easier the test configuring will go. Suppose all the test instruments have a common command language. In this case, you will not spend so much time paging through reference manuals learning different command sets, reducing the time required to program and debug the test setup.

Reduce Test Runtime

Although the time required to run tests may not be as significant to design validation engineers as setup time, it is still worth reducing, especially for long or complicated tests. For manufacturing test engineers, who must design tests that repeatedly run, shrinking the test duration is essential for improving throughput. Test runtime reductions can occur in all phases of the testing process: the time required to send and execute commands to control the power subsystem, the time needed for the power subsystem to perform its operations, and the time required for measuring and monitoring during test operation.

Reduce command and control time

Reducing the time required for the power subsystem components to receive commands from the test system computer and interpret and execute them is essential to lowering test runtime.

List mode

Power products with a feature known as list mode can store entire instrument setup states. You can recall these setups with a single command, reducing the time required to send a long series of individual configuration steps. The longer and more complicated the test sequence, the more time list mode saves. List mode also benefits applications that require a variety of voltage levels simultaneously.

You can pace the execution of a list by triggers or automatically. After a list is stored in memory, a trigger begins its execution. A trigger can continue to execute each step in the list, or you can specify the amount of time the power instrument remains at each step as part of the list. Storing lists in one of the nonvolatile memory locations to stay resident in the power instrument, even after it is off, reduces setup time for the next test.

In a modular power system, list mode enables you to download a command sequence to each power system module during system setup. The module interprets the commands and then stores them internally, ready to execute. The command sequence may be accessed with a single trigger command from the test system computer and accessed repeatedly during testing. The module runs at maximum speed when the sequence begins because this process eliminates the GPIB bus transfer and load command processing steps.

A modular power system also enables triggering via the backplane in conjunction with list mode to add even more capability and flexibility. Various modules can be preconfigured with a command list to output particular voltage levels. With a single trigger command to launch a programming sequence, module-to-module backplane triggering can initiate list-mode setups in subsequent modules. Figure 5a shows a block diagram of such a setup, and Figure 5b shows the resulting power-output curves.

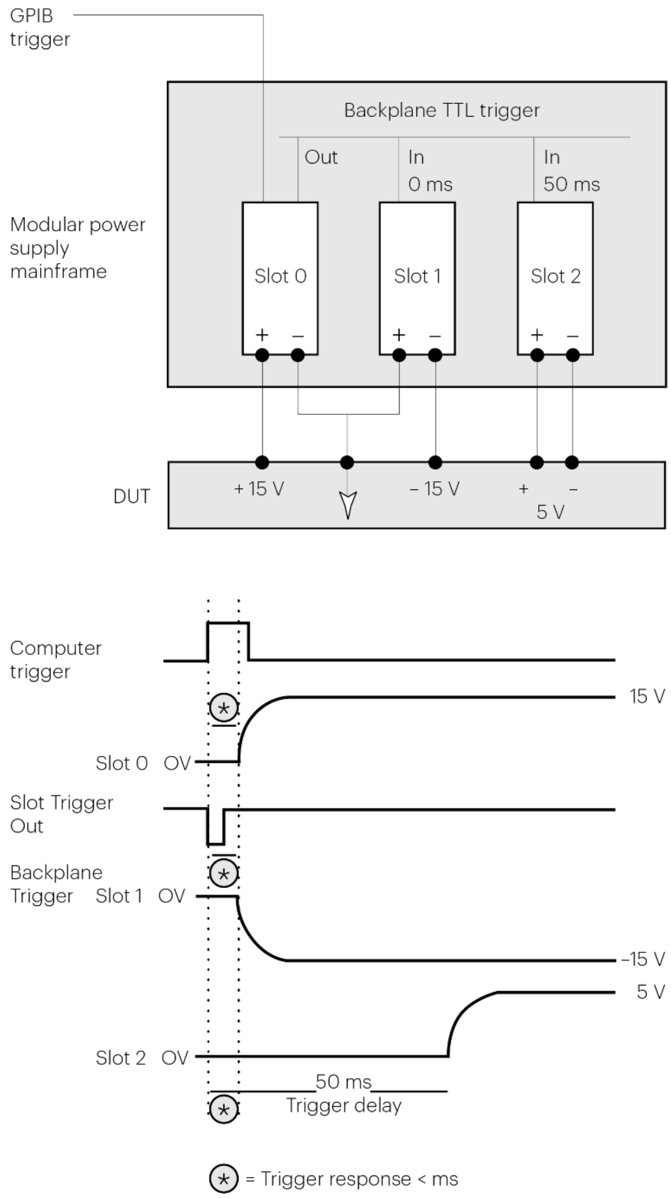

Figure 5. Use backplane triggering in conjunction with list mode to launch outputs at different times. (a) A three-module setup in which slots 0 and 1 provide power simultaneously and slot 2 is set to start 50 ms later. (b) The set of power curves generated by this setup shows the delayed output of slot 2.

Using lists and triggers saves time in several ways:

- The computer sends the list sequence only once.
- The module interprets the commands only once.
- The module can automatically step through the list without computer intervention.

Use the GPIB interface more efficiently

Another way to save on the time required to transfer commands from the test system computer to the power subsystem is to use multiple single-output power supplies rather than one multiple-output supply. Doing so allows overlap of GPIB operations to the multiple supplies and avoids the delays resulting from sequential command processing in a multiple-output supply.

A multiple-output supply processes commands controlling the various outputs sequentially, one output at a time. With a multiple-supply setup, however, one supply can process a command while the next receives one, and so on.

This technique is most beneficial when making queries from the supplies. With a multiple-output supply, the measure command must be sent and the response retrieved from a particular output before querying the next output. A query can take two measurement cycles because the measurements must be consecutive.

With multiple instruments, however, a command can be sent to each of the supplies to start the measurement and then retrieve the responses. Because the measurements overlap, only one measurement cycle is necessary. Although the time savings for an individual setup or query operation can be modest, for complex repetitive tests, the cumulative time savings can dramatically impact overall system throughput.

Use the available features

Judicious use of the available commands and power-instrument features is also essential for reducing test time. The operation-complete command can save significant test time, especially for tests where certain operations take a highly variable amount of time to complete. The traditional way to handle this type of condition is to determine the worst-case execution time for an operation and establish that as the wait time for that step for all test runs. Of course, this would waste significant time during runs when the operation in question completes quickly.

With the operation-complete command, the test control software finds out after the variable-length operation is complete, allowing the test to proceed immediately rather than waiting for each operation's worst-case execution time.

Another feature that can reduce test time is binary transfer mode. Transferring large data arrays such as measurement waveforms is faster in binary than in ASCII format for instruments that support it. Binary transmission requires fewer bytes, reducing transfer time by a factor of two or more.

Optimize the execution sequence

A final method of saving time in controlling the power subsystem is to order the execution sequence to minimize runtime. The first step in optimizing the execution sequence is to order the test steps such that at the end of one step, the DUT is in the desired state to begin the next step. For example, if the DUT needs to be off for the start of a test step, the preceding step should leave it off. If a particular step requires the DUT to be in a warmed-up state, place this step later in the sequence, perhaps with a system timer to guarantee that it has been on long enough. This technique is not always feasible but can yield significant improvements.

Another method of optimizing the execution sequence to speed test runtime involves overlapping wait periods. A typical test sequence before optimization might be as follows:

1. Apply a load to the DUT or set up its programmed state.
2. Wait for the DUT output to settle.
3. Connect relays to engage measurement equipment.
4. Wait for relays to close.
5. Set up measurement instruments.
6. Wait for the setup to complete.
7. Initiate measurement.
8. Wait for the measurement to complete.
9. Disconnect relays.
10. Turn off the power source.
11. Wait for the DUT output to settle.

Most of these steps involve a wait while the action completes. In addition, most DUTs need time to stabilize after power is applied or a load condition has changed. By separating the programming and wait states, you can rearrange the test so that one instrument is programming while another is completing its step. You could rearrange the above test sequence as follows:

1. Apply load to the DUT.
2. Connect relays to engage measurement equipment.
3. Set up measurement instruments.
4. Wait for the relays to close, the measurement instrument to settle, and the DUT output to settle.
5. Initiate measurement.
6. Wait for the measurement to complete.
7. Disconnect relays.
8. Turn off the power source.
9. Wait for the DUT output to settle.

Overlapping the wait periods minimizes overall delays. While the DUT is settling, the test program is busy programming the relays and setting up the measurement instruments. You can use a common or global timer to implement an overlapped wait. Each programming routine that sets up an instrument or DUT can tell a global timer how long each action will take; this identifies which action requires the longest wait. Then, when a measurement or other test requires that the previous commands be completed, a call to a single wait function will wait until the global timer expires before continuing, as follows:

1. Apply load to the DUT.
2. Connect relays to engage measurement equipment.
3. Set up measurement instruments.
4. Wait for the global timer.
5. Initiate measurement.
6. Wait for the global timer.
7. Disconnect relays.
8. Turn off the power source.
9. Wait for the DUT output to settle.

With this approach, the test does not have to wait any longer than is necessary for instrument setup, and the programming is more straightforward.

A one-box solution simplifies many of these steps without requiring execution sequence optimization. Also, for design validation testing, you should weigh the time saved during the test against the time needed to determine the optimal sequence. However, this technique can yield throughput benefits for tests with long wait periods and manufacturing tests.

Reduce operation and output time

Many power products have features that can help reduce the time required to operate. Some of these features function automatically, and some need activation by appropriate programming or special commands.

Change output voltage quickly

A power supply with a down-programming feature can significantly reduce test time, particularly when you need multiple voltage-level settings. Without down-programming, the capacitor in the supply's output filter (or any load capacitance) can take seconds or even minutes to discharge when the output voltage level drops. The lighter the load, the longer it takes.

Down-programming uses an active circuit to force the output down to the new level, usually within milliseconds. This circuit functions automatically whenever the set voltage is below the present output level. The execution sequence is important with power supplies that have the down-programming feature. Because programming up is generally faster than programming down, you should sequence multiple tests such that each consecutive test is at the same or higher voltage level than the previous test.

Another technique for reducing test time is to program the output voltage up or down rather than using the output-on or output-off commands. Setting the output voltage to 0 volts takes less time than the output-off command, and simply setting the voltage back up to the desired voltage takes less time than the longer output-on command.

When programming voltage up, the output needs to remain in constant-voltage (CV) mode for the duration of the test by staying below the user-established current limit. The output will enter CC mode if it reaches the current limit. Then output voltage will not rise as quickly and will take longer to reach the desired value, slowing down the entire test. During transition of the output voltage from a lower value to a higher value, you must ensure that the current-limit setting (also known as the CC setting) is high enough to provide charging current to the DUT, the output capacitor inside the power supply, and any external capacitor.

Change loads quickly

When simulating real-life loading conditions, controlling the slew rate of an electronic load may be necessary. For example, a controlled slew rate might be necessary to simulate inrush current, or a slow slew rate might be necessary to keep a power supply stable and reduce ringing. Using different slew rates for transient tests can also help identify the loading rate that causes instability. A programmable slew rate enables you to change the slew rate of an electronic load to accommodate such requirements. However, you should use a slower slew rate only when necessary, as it will decrease throughput.

Controlling the slew rate of an electronic load separately for rising and falling transitions enables you to slow down only the transition necessary for a particular test while keeping the other transition at maximum speed. Independently controllable slew rates for CC, CV, and constant-resistance modes enable even more flexibility.

Fast response prevents shutdowns

A power supply with fast response combined with remote voltage sensing is essential for increasing the throughput of certain tests, particularly those of wireless communications devices, which characteristically have a transmit burst current drain. The combination of this pulsed current drain and wiring impedance to the test fixture makes it challenging to maintain a stable DC voltage at the DUT when testing these devices. A significant transient voltage drop can easily activate the DUT’s low-voltage shutdown circuit and disrupt the test, impairing throughput.

The transient voltage response specification on typical power supplies is inadequate to ensure proper performance in this application. It specifies the performance directly at the power supply output terminals operating in local voltage sense mode. It does not consider the wiring voltage drop the power supply attempts to compensate for when operating in remote voltage sense mode. Moreover, most power supplies do not have sufficient speed to match the DUT transmit burst current’s fast rise and fall times. As a result, the actual transient voltage drop may be significant at the DUT even when the power supply is operating in remote voltage sense mode.

A suitably fast-responding power supply can provide an order-of-magnitude reduction in the transient voltage drop. Figure 6 shows the difference in transient voltage drop between a standard DC source and a fast-responding DC source.

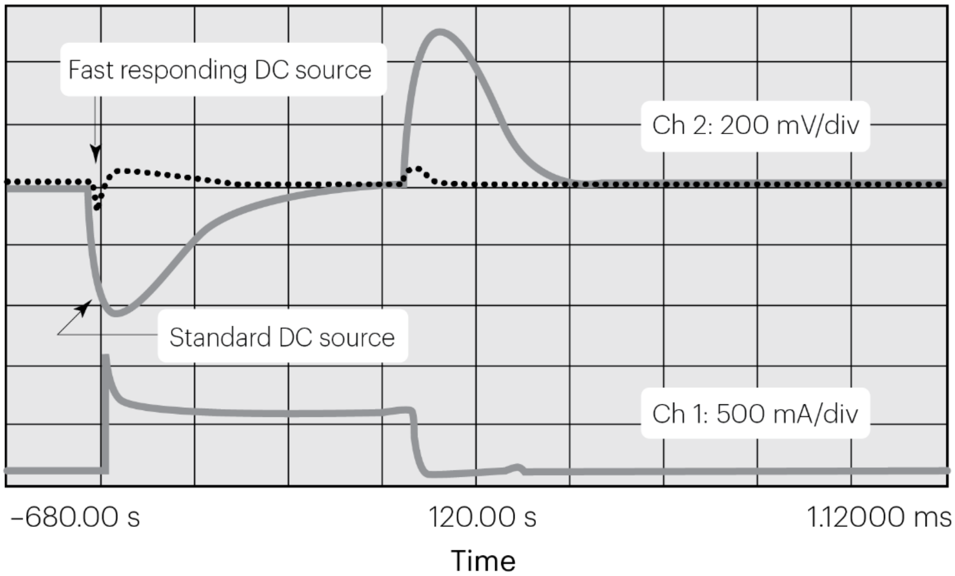

Figure 6. The difference in transient voltage drop between a standard DC source and a fast-responding DC source

Charge batteries faster

If charging batteries is part of a test, you can save considerable time using pulse charging rather than CC. Using a power supply in CC mode is a simple way to recharge batteries and achieve 100% charge levels. However, this method is slow because the charging current is only a fraction of the battery's amp-hour rating.

Pulse charging, also called transient mode, reduces the charging time yet still charges the battery to greater than 90% capacity. Figure 7 shows the setup for this method. The electronic load acts as a switch, providing the current pulses.

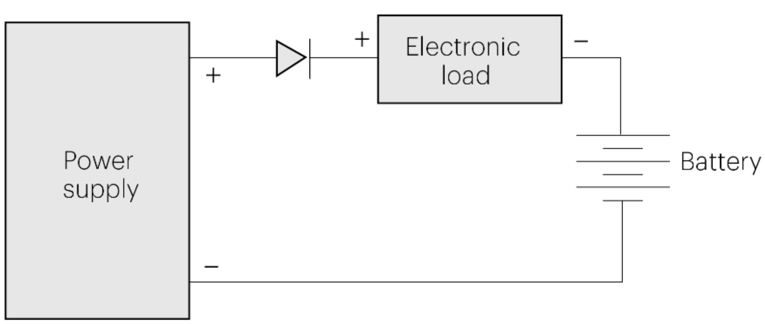

Figure 7. The setup for pulse charging using an electronic load as a switch

Reduce measurement and monitoring time

Another area for improving runtime throughput is measuring and monitoring the operation of the DUT and power instruments. Measurement capabilities built into many power supplies and loads can help reduce time and complexity in automated testing. Built-in measurement features enable you to measure a supply's output voltage and current and a load's input voltage and current.

A good example is testing a DC-to-DC converter with four outputs. To test the device thoroughly, you must measure the input voltage to the converter and the four output voltages. If you use a single DMM to measure the voltages, you need a multiplexer to sequence through the measurements, as shown in Figure 8a. This arrangement is time-consuming to set up and slow to run, as the test program must wait for the multiplexer's switches to move and settle for each measurement. The DMM's measurement time for each output would be even greater than required for the multiplexer, adding to the total measurement time.

The DC source and loads needed to test the converter can perform all measurements in parallel, as shown in Figure 8b. Remote sensing used in this configuration provides regulation and measurement at the DUT rather than at the loads or the DC source. This approach also works if you require current measurements, eliminating the need for shunts.

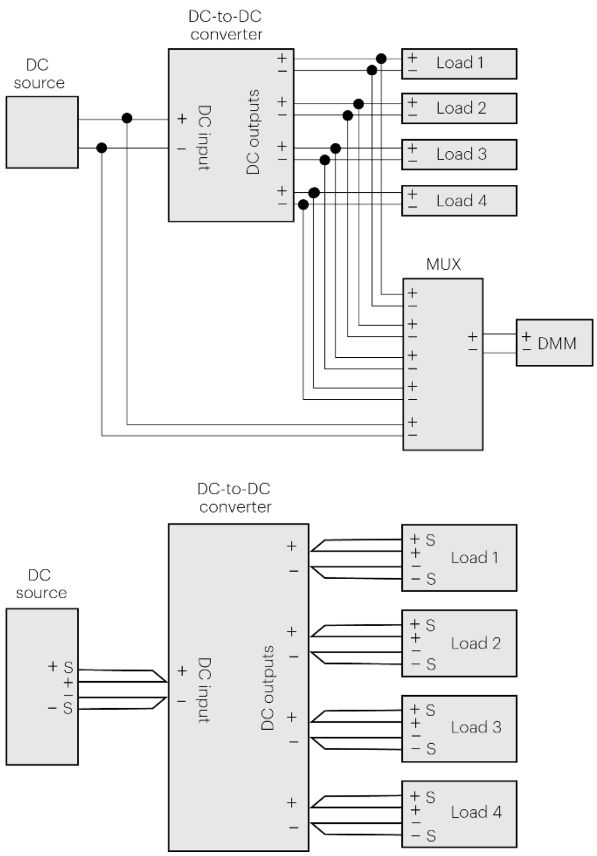

Figure 8. Testing a DC-to-DC converter with four outputs: (a) Using a single DMM requires a complex multiplexing scheme that can result in significant delays. (b) Using a DC power source and electronic loads with built-in measurement capabilities eliminates the need for a DMM and multiplexer and can significantly increase test speed.

This built-in measurement system eliminates (or significantly reduces) the need for the multiplexer, voltmeter, associated cabling, and current shunts. Eliminating these hardware items saves runtime as well as setup time by doing away with the following:

- Program lines associated with the multiplexer.
- GPIB bus transactions to control the multiplexer.
- The time for the multiplexer to decode the commands.
- The time for the multiplexer's switches to settle on each new setting.

For tests that require voltage and current measurements, some power products allow these measurements to be made simultaneously with multiple internal A / D converters. Using the correct commands to save time with this capability is vital. A measure command initiates both measurements simultaneously, but only one parameter is immediately read back. The other should use a special retrieval command that does not initiate another measurement (A / D conversion process) that would take longer.

You can reduce test time by using available measurement buffers to store multiple measurements. Samples for multiple measurements can be concatenated in the buffer and transferred to the test system computer as an array in a single operation, saving interface time. The computer's program can then extract the various measurements from the array.

Control integration time to improve speed and accuracy

Being able to precisely set the integration time when measuring the DC values of pulsed current drains optimizes test throughput and accuracy. Figure 9 is an example of a pulsed current drain. When the measurement integration time is precisely set to an integral multiple of the pulse period, the measurement accuracy is predominantly the specified DC accuracy of the test equipment. However, significant error becomes apparent when there is even a slight mismatch between the pulse period and integration time. This mismatch causes either a part of a pulse to be missed or an additional part of another pulse to be captured in the integration.

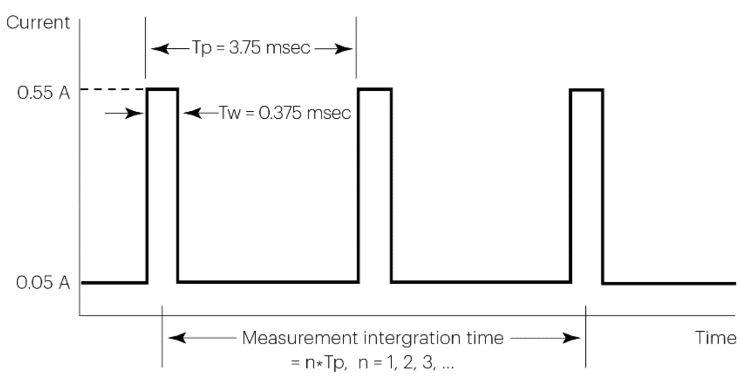

Figure 9. Setting measurement integration time for a pulsed signal

For example, using an integration time 10% too long (4.13 ms instead of 3.75 ms) on the signal in Figure 9 will produce about 45% error when capturing a second pulse.

The error decreases with a longer integration time and the number of pulses averaged. A tenfold longer integration time will have one-tenth the error. Integration time must increase to reduce this mismatch error. In other words, the accuracy improves at the expense of reduced test system throughput.

Using specialized test equipment with a highly accurate integration time setting for these measurements can significantly shorten the integration time without sacrificing accuracy.

Status monitoring

Because modern system power supplies and loads have complex capabilities above their traditional functions, it is essential to know the internal status of a power instrument during test operation and what actions it has taken in response to changing input signals and other factors.

For example, a common monitoring task is checking for when a supply has entered CC mode, in which the supply will adjust its voltage to maintain a specified current level as load conditions change. This can happen when a logic device fails, for instance, resulting in sharply higher current draws by the DUT. Failing to respond to the situation could cause extensive damage to the load or other unsafe conditions.

Continually reading the supply's status via GPIB and checking for a change in the CC bit is one way to monitor the situation. However, this is slow and time-consuming for the computer. A faster way is to set up the supply so that a bit gets set in its serial poll register when entering CC mode. Performing a serial poll is a much faster GPIB operation, so the process wastes less time with each check. Suppose the programming environment supports interrupts via GPIB service requests (SRQs). In that case, you can eliminate the polling process by setting up the source to generate an SRQ whenever it enters CC mode.

Status-register setups vary from instrument to instrument and have evolved to offer robust monitoring and response capabilities. Many supplies offer registers that show operating modes and conditions as standard events (normal operating conditions) and questionable events. Questionable events include overvoltage, overcurrent, and overtemperature conditions and transitions into unregulated states, such as when the supply is in neither CC nor CV mode. These conditions set bits in the status register and can generate SRQs.

A final technique for minimizing measurement time is to customize the number of samples to take the minimum number needed for the test application. Taking a lot of samples increases accuracy and noise rejection, but the tradeoff is increased measurement time. With a power instrument that can specify the number of samples, measurement speed can be optimized relative to the application's required performance.

The Basics Are Still Important

Even with all the specialized features available on modern power instruments, some basic principles still apply. For one thing, processing speed remains important: A power instrument that processes commands faster will have greater throughput than a slower one.

Having accurate power instruments improves throughput as well as precision and resolution. Suppose a power source is not accurate or stable enough. In that case, a DMM must constantly verify its output levels, possibly with a program loop, to keep the voltages at or near expected values. Temperature drift, sudden load changes, and insufficient resolution are some factors that can cause issues. A more accurate supply can avoid the extra time, complexity, and expense required for frequent verification.

Finally, having reliable instruments is critical to maintaining throughput for design validation engineers as well as for a manufacturing facility. A test system experiencing downtime has zero throughput. Instruments that produce or dissipate large amounts of power are especially susceptible to problems, so reliability in power products is critical.

One-box power subsystem solutions have reliability and speed advantages. Without the extra shunts, multiplexers, DMMs, and other elements, there are fewer discrete elements, reducing the chance of errors and instability. Moving parts such as relays tend to be the most unreliable. Also, simpler test systems have fewer problems because of their low complexity. The simpler a system is, the quicker it is to troubleshoot problems when they occur.

Summary

Power instruments now incorporate many features that can improve test throughput. Features that reduce test setup time are essential in the design validation process, as they can increase the number of tests power equipment can complete in a given period. One-box power products with built-in measurement capabilities and multiple channels are examples.

Features that reduce test runtime are particularly important for manufacturing testing, as they increase the number of devices that can run through a test configuration in a given period. These include capabilities such as down-programming and list mode.

Reducing setup and runtime benefits both design validation and manufacturing test environments. Selecting capable power instruments and using them effectively is essential for improving test throughput.

Resources

Learn more about Keysight ATE power supplies.