



# Choosing the Right Power Supply for Accurate Power Delivery

## How to Interpret Linear Power Supply Specifications

### Application Note

#### Introduction to Power Supply Specifications

At first glance, a variable DC power supply appears to be a fairly simple device. However, it is a sophisticated, accurate, electrically-rugged workhorse. It has to reliably deliver stable, precise, clean voltage and current, no matter its load --

resistive, inductive, capacitive, low-impedance, high-impedance, steady-state or variable. How well the power supply fulfills this mission and where it hits its limits are defined in its specifications. Choosing the right power supply for your application requires a good understanding of how they are specified.

## Ensuring Your Power Supply Meets Its Specifications

Before analyzing what the specifications mean, the potential user must begin with the question, "Do I believe the specifications?" Look for a clear explanation from the manufacturer of how it supports the published specifications. For example, does its manufacturing line use test stations that have standards to a nationally-recognized primary standards laboratory such as NIST (National Institute of Standards and Technology)? Look for a safety certification by one of the internationally recognized agencies, such as CSA, UL or VDE. This says that the power supply manufacturer has invested time and resources in having independent confirmation of compliance to international safety standards.

Regular performance verification is important to insure that your power supply is operating within the manufacturer's specifications. For Tektronix power supplies, the recommended calibration cycle is 1 year. Detailed descriptions of performance specifications and the procedures for verifying performance of Tektronix power supplies can be found in the Technical Reference Manual for each instrument. Even if you don't plan on performing your own calibration, the Technical Reference Manual can be helpful in understanding the meaning of the specifications and expected tolerances.

Many of these specifications are tested as part of the manufacturing process of the power supplies and as part of the performance verification that is conducted during routine maintenance. Tektronix verifies every power supply using traceable standards, and offers test data from manufacturing quality testing as an option.

## Two Types of Power Supplies

There are two basic types of power supplies in common use: linear and switch-mode, or "switching." Both are available for use as bench DC power and system power supplies for design, production and repair. Linear power supplies operate by rectifying AC line power to create DC, and then filtering and regulating it to produce user-selectable voltage or current levels. Linear supplies are heavier because the 50 Hz or 60 Hz transformer and associated filters are physically larger. Switch-mode power supplies start out the same way, rectifying and filtering AC line input voltage, however they chop (or "switch") the DC into high-frequency AC. Switch-mode power supplies are significantly smaller, lighter and more efficient than linear power supplies, so they have replaced linear supplies in many applications.

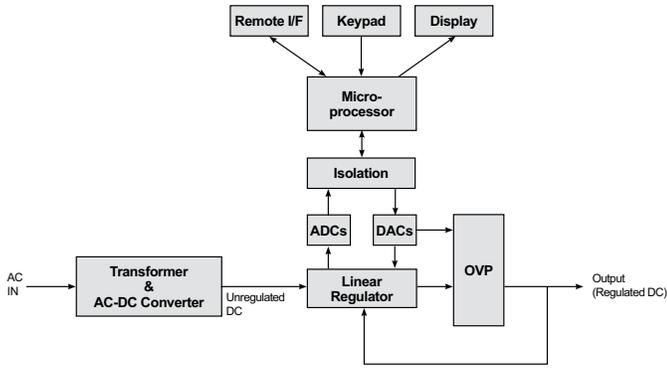


Figure 1. Simplified Block Diagram of a Programmable Linear Power Supply.

However, linear supplies continue to be a popular choice for test equipment. They are generally durable, accurate and deliver power with little noise. Their simple, direct feedback mechanisms deliver excellent load regulation and overall stability. Figure 1 shows a simplified block diagram of a linear bench power supply. Applications that may be sensitive to small power variations are good candidates for linear power supplies. For example, linear power supplies are a good choice for powering sensitive RF amplifier blocks within a prototype circuit board, documenting the input power level at which a circuit starts to fail, or checking the characteristics of individual components. It's one thing to claim that a linear power supply has excellent stability and low noise, but it takes a good understanding of linear power supply specifications to be able to quantify these qualities and others.

## Linear Power Supply Specifications

It may seem like there are a multitude of specifications for linear power supplies, but they may be grouped into three logical categories: accuracy and resolution, stability, and AC characteristics. We will describe the key specifications that fall into each of these groups.

Most DC bench power supplies have two modes of operation. In constant voltage (CV) mode, the power supply regulates the output voltage based on the user settings. In constant current (CC) mode, the power supply regulates the current. Whether the supply is in CV or CC mode depends not only on the user settings, but also on the resistance of the load. A power supply will have different specifications that apply when it is in CV mode and when it is in CC mode.

## Accuracy and Resolution

At any given time, either voltage or current is being regulated by the power supply and matches the setting within the instrument's accuracy.

- In constant voltage mode, the output voltage will match the voltage setting within the accuracy specifications of the instrument. The current will be determined by the impedance of the load.
- In constant current mode, the output current will be very close to the setting. The voltage will be determined by the impedance of the load.

Historically, the DC power supply user turned potentiometers to set output voltage or current. Today, microprocessors receive input from the user interface or remote interface. A digital-to-analog converter (DAC) takes the digital setting and translates this into an analog value which is used as reference for the analog regulator. Setting resolution and accuracy are determined by the quality of this conversion and regulation process.

Voltage and current settings (sometimes called limits or programmed values) each have resolution and accuracy specifications associated with them. The resolution of these settings determines the minimum increment in which the output may be adjusted, and the accuracy describes the extent to which the value of the output matches international standards.

In order to show the values of the unregulated parameter most DC power supplies provide built-in meters for measuring both voltage and current. The meters measure the voltage and current being delivered by the power supply output. Since the meters read the voltage and current back into the power supply, the measurements produced by the meters are often called “readback” values. Most professional bench power supplies incorporate digital meters that use analog to digital converters and for these instruments the specifications are similar to those of a digital multimeter. The power supply displays meter values on its display and can also transmit them over its remote interface if it is equipped with one.

Setting and readback specifications should be considered separately. Good performance on readback accuracy does not necessarily mean good performance in setting accuracy.

**Setting Accuracy** determines how close the regulated parameter is to its theoretical value as defined by an international standard. Output uncertainty in a power supply is largely due to error terms in the DAC, including quantization error. Setting accuracy is tested by measuring the regulated variable with a traceable, precision measurement system connected to the output of the power supply.

Setting accuracy is given as:

$$\pm(\% \text{ of setting} + \text{offset})$$

For example, the Tektronix PWS4323 power supply has a voltage setting accuracy specification of  $\pm(0.03\% + 3 \text{ mV})$ . So when it is set to deliver 5 volts, the uncertainty in the output value will be  $(5\text{V})(0.03\%) + 3 \text{ mV}$ , or 4.5 mV. Current setting accuracy is specified and calculated similarly.

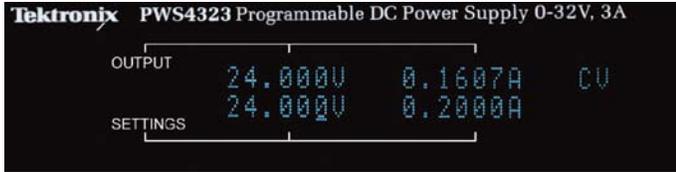
**Setting Resolution** is the smallest change in voltage or current settings that can be selected on the power supply. This parameter is sometimes called programming resolution. The resolution specification limits the number of discrete levels that can be set. Often, this is defined by a combination of user interface digits available, and the number of bits available in the DAC. A DAC with more bits will have finer control of its output and be able to deliver more distinct values for the control loop to use as a reference. However, with corrections for offset and gain errors, there will be less resolution than the number of bits in the DAC would suggest.

Changing a setting in a single step of resolution may not always cause a corresponding change in the output. However, the setting accuracy specification governs the relationship between settings and output, and a calibrated instrument should perform within this tolerance.

Setting resolution may be expressed as an absolute unit value or as a percentage of full scale. For example, the voltage setting resolution on the Tektronix PWS4323 is 1 mV and the current setting resolution is 0.1 mA.

**Readback Accuracy** is sometimes called meter accuracy. It determines how close the internally measured values are to the theoretical value of the output voltage (after setting accuracy is applied). Like a digital multimeter, this is tested using a traceable reference standard. Read-back accuracy is expressed as:

$$\pm(\% \text{ of measured value} + \text{offset})$$



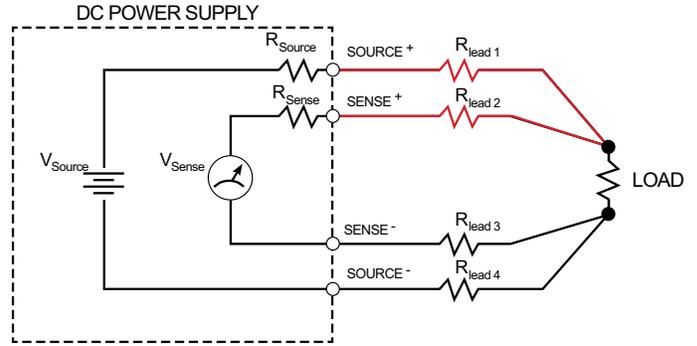
**Figure 2.** The least significant digits on the upper display correspond to the 1 mV and 0.1 mA readback resolution of the Tektronix PWS4000 series instruments. The least significant digits on the lower display correspond to the setting resolution.

**Readback Resolution** is the smallest change in internally-measured output voltage or current that the instrument can discern. It is usually expressed as an absolute value, but may also be given as a percentage of full scale.

The voltage readback resolution on the Tektronix PWS4323 is 1 mV and the current setting resolution is 0.1 mA.

### Using Remote Sense for Better Voltage Accuracy

Voltage drop in the cables that carry current between the power supply and device under test (DUT) mean the voltage at the DUT is less than at the output terminals of the power supply. Simply using heavier-gauge wire will reduce the voltage drop in the test leads on any power supply. Keeping cables as short as possible also helps. But if a power supply is equipped with remote sense capability, using a four-wire connection can help make sure the voltage you set on the supply is the voltage you get at the DUT.



**Figure 3.** Remote sense eliminates the effect of lead resistance by separating the source current from the sense circuit. The source adjusts to maintain the specified voltage across the load.

With a four-wire connection from the power supply to the DUT, one set of leads carries the output current, while the other set of leads is used by the power supply to measure voltage directly at the DUT terminals, as illustrated in the Figure 3. The sense leads are connected inside the power supply to a high-impedance voltmeter circuit, meaning close to zero current is flowing in the sense leads, virtually eliminating voltage drop in those leads. The power supply maintains the desired output voltage at the sense leads by increasing the voltage at the output to compensate for voltage drops in the source leads that deliver the current to the DUT.

## Stability Specifications

Stability specifications describe how the instrument responds to changes. Over the long term, performance of the instrument will inevitably change due to aging. Long term stability issues are handled by requiring regular verification and calibration of the instruments. Tektronix power supplies have a 1-year calibration cycle. Several linear power supply specifications deal with the instrument's ability to deliver stable output over the short term. This section discusses specifications that describe output stability under conditions of changing load, AC line voltage, and temperature.

### Temperature Stability

The accuracies discussed above are usually specified as being valid over a particular range around 25°C. A typical range is between 20°C and 30°C (68°F to 86°F). If you are using the power supply in a lab environment, with stable ambient temperature, then the effect of temperature on the output should be small. If, on the other hand, you are working in an industrial setting or field installation that may experience temperatures significantly different from room temperature, it is important to consider this in determining accuracy. The uncertainty in the output will increase as ambient temperature deviates from room temperature.

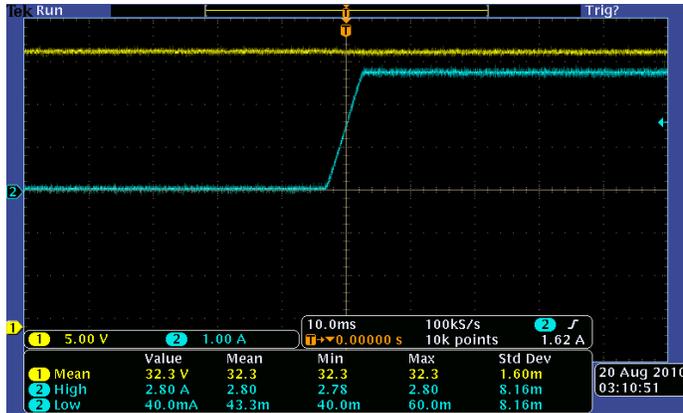
## Load Regulation (Voltage and Current)

Load regulation is a measure of the ability of an output channel to remain constant during changes in the load. As the impedance of the device under test changes, the regulated parameter should not change significantly. Of course if the load changes too much, the regulated parameter may change between voltage and current, depending on the limit setting for the unregulated parameter. But assuming the power supply does not reach this crossover point, it will maintain a low output impedance when operating as a voltage source and a high output impedance when operating as a current source. In other words, the bench power supply is designed to mimic an ideal power supply.

Load regulation may be specified in several ways. For example, voltage regulation may be expressed as voltage change per ampere drawn. However, most power supply manufacturers including Tektronix express load regulation as an output accuracy during a significant change in the unregulated parameter. This familiar format is easy to understand and easy to verify through testing:

$$\pm(\% \text{ of setting} + \text{offset})$$

Tektronix load regulation specifications are verified with the regulated variable set to full scale output. The unregulated variable is varied from 0 to 98% and the output is checked against the relevant specification.



**Figure 4.** This oscilloscope screen capture shows the regulation of output voltage on a Tektronix PWS4323 when the load transitions from drawing 0 A to drawing 2.8 A. The voltage remains stable throughout the transition.

Using the Tektronix PWS4323 power supply as an example, the load regulation specification for output voltage is plus or minus 0.01% of the selected output voltage + 2 mV, so at its full rated output of 32V the output will remain within  $\pm 5.2$  mV even as the load changes from drawing no current to just below 3 amps which is the instrument's maximum rated current.

Load regulation for constant current mode is defined similarly to line regulation for constant voltage mode. Current load regulation describes how the power supply output current varies in response to a step change in load impedance.

## Line Regulation (Voltage and Current)

Line regulation is a measure of the ability of the power supply to maintain its output voltage or output current while its AC line input voltage and frequency vary over the full allowable range. Line voltage and frequency greatly affect the available power to feed the output, especially when maximum current is being drawn from the supply.

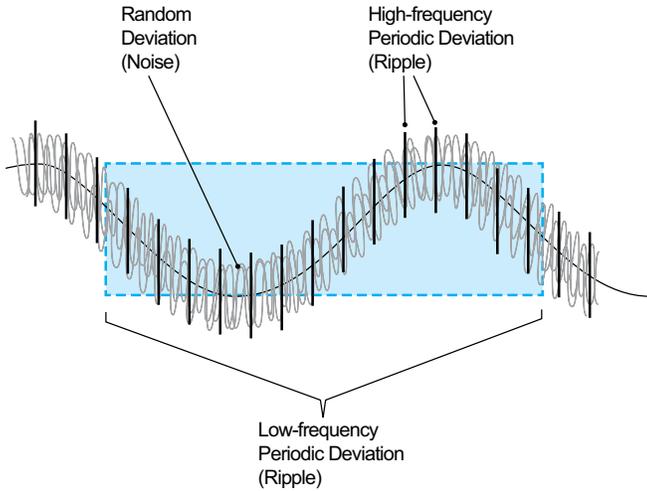
In a lab with stable AC line voltage, and testing for short periods, line regulation may be ignored. However, if you are working an area prone to sags and swells in AC line voltage, or testing over extended periods, line regulation is an important consideration.

Voltage line regulation can be specified as a ratio of DC output voltage change to change in AC line (RMS) voltage and frequency. However, to be consistent with most test equipment specifications, manufacturers usually express line regulation as an uncertainty in the output over the full range of acceptable AC line parameters. This gives a “worst case” picture and is given as:

$$\pm(\% \text{ of setting} + \text{offset})$$

For example, the Tektronix PWS4323 has a voltage line regulation specification of  $\pm(0.01\% + 1 \text{ mV})$ . So when it is set to deliver 32 VDC, the output will remain within  $(32\text{V})(0.01\%) + 1 \text{ mV} = 4.2 \text{ mV}$  even as the AC source voltage varies over the full allowable range.

Current load regulation is a comparable specification. Instead of stating the allowable voltage variation in the output as the AC source varies, it states the amount of allowable current variation as the AC source varies. Once again this specification is typically valid over the entire range of the AC source voltage and frequency.



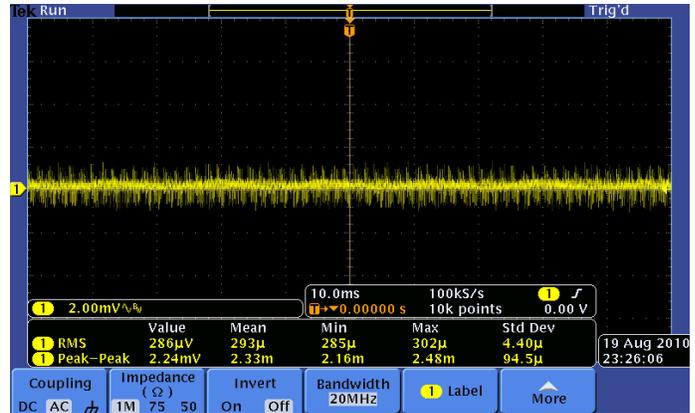
**Figure 5.** This simplified drawing shows the concepts of periodic (ripple) and random (noise) distortion.

## AC Characteristics

Although we are discussing DC power supplies, the output of these power supplies is not perfect DC. Some AC is to be expected on the output. For some applications excessive AC on the output can produce unexpected circuit behavior, so it helps to know the amplitude of the residual AC. Especially for automated testing, it may be useful to know the response of the instrument to changes in load and settings.

### Ripple and Noise Specifications

Spurious AC components on the output of a DC supply are called ripple and noise, or periodic and random deviation (PARD). These terms are often used interchangeably.



**Figure 6.** A noise measurement on a Tektronix PWS4323. This measurement is taken with a 1X probe, with bandwidth of approximately 7 MHz while the power supply is delivering full rated current.

The term “ripple” refers to periodic AC on the output. When viewed in the frequency domain, ripple shows up as spurious responses. Unlike ripple, which is periodic, noise is random. Noise covers a broad spectrum and when it is viewed in the frequency domain, it manifests itself as an increase in the baseline. Since ripple and noise are usually lumped together and cannot be easily separated from each other, in this application note we will use the single abbreviation PARD to refer to the combined effects.

PARD figures must be specified with a bandwidth and they should be specified for both current and voltage.

Because the shape of PARD is indeterminate, voltage PARD is usually expressed both as a root mean square voltage which can provide a sense of the noise power, and as a peak-to-peak voltage which may be relevant when driving high impedance loads.

Because of the bandwidth consideration, PARD specifications are heavily dependent upon the measurement technique used to test them. You can usually find the procedure for checking PARD in the manufacturer's performance verification procedure. It is important to consider the whole signal path to verify ripple and noise specifications. For example, using a high bandwidth oscilloscope with a low bandwidth probe can make the specs appear better than they are.

The Tektronix PWS4323 has a voltage PARD specification of  $1\text{ mV}_{\text{RMS}}$  and  $4\text{ mV}_{\text{p-p}}$ , for example, specified over a bandwidth of 20 Hz to 7 MHz. A wider bandwidth specification is also given, for frequencies from 20 Hz to 20 MHz. This specifications is  $3\text{ mV}_{\text{RMS}}$  and  $20\text{ mV}_{\text{p-p}}$ .

Current PARD is relevant when using a power supply in constant current mode. In contrast to voltage PARD it is common to see current PARD given as an rms value only.

### Transient Response

Another set of AC characteristics describe how quickly a power supply can respond to changes. Transient response specifications indicate how quickly the output settles to a stable DC value after a change in load or settings. Most power supplies have a significant capacitance in parallel with their outputs to help deliver clean, steady DC. When this capacitance is placed in parallel with the load resistance, a time constant results and the size of the time constant varies with the load impedance.

	Time to stabilize to within 75 mV of terminal Value
Load change from 0.1 A to 1 A	< 400 $\mu\text{s}$
Setting change from 1 V to 11 V into a $10\Omega$ load	< 35 ms
Setting change from 11 V to 1 V into a $10\Omega$ load	< 35 ms

**Table 1.** Voltage transient response specifications for a Tektronix PWS4323 power supply.

Because of this heavy dependence on the resistance of the load, response to setting changes must be specified for a specific load. It is common to see specifications for open circuits, short circuits or specific resistance values.

Transient response is tested by applying significant step changes to load impedance and settings, and measuring the time to settle to a final value.

The voltage transient response for all of the Tektronix PWS4000 Series supplies is given for three conditions: increasing load, increasing setting and decreasing setting.

## Accurate Results Require an Accurate Power Supply

To ensure confidence in your test results and repeatability of those results, you must have a power supply with the performance to accurately deliver the power you need to your device. If your power supply does not have high enough accuracy or stability, your measurement results will be affected by not only your device's performance, but the performance of your power supply. Temperature drift, sudden load changes, and fluctuating AC line voltage are just some of the factors that can cause trouble. With a more accurate supply that is designed to handle these variations, and to consistently and accurately provide the voltage or current you specify, you can be confident in your test results.

## PWS4000 Series Power Supplies Deliver Accurate Power for Measurement Confidence

Owners of the Tektronix PWS4000 Series Programmable DC Power Supply are assured of excellent performance and quality. With wide current and voltage ranges, plus 0.1 mA and 1 mV resolution on most models, PWS4000 Series power supplies can generate the power you need to satisfy a variety of applications. Because the PWS4000 delivers below 5 mV<sub>p-p</sub> noise and ripple, 0.03% basic voltage accuracy, and 0.05% current accuracy, you can be confident that the true output accurately matches your settings and won't introduce bothersome signals into whatever you test.

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