

BK PRECISION®

POWER SUPPLY GUIDE



Table of Contents

Introduction	3
Variable AC Power Supply	4
Types of DC Power Supplies	5
Battery Eliminator	5
Constant Voltage Supply	5
Constant Voltage/Constant Current Supply	6
Multiple Output Supply	7
Programmable Supply	7
Multi-range Supply	9
Power Supply Specifications	10
Constant Current and Constant Voltage Mode	10
Output	11
Regulation	12
Ripple and noise	12
Temperature	14
AC input	14
Tracking accuracy	14
DC Isolation	14
Theory of Operation	16
Linear Regulation	16
Switching Mode	16
Application	18
Using a power supply to generate a DC offset with a function generator	18
Power Supply Questions and Tips	19
How do I measure power supply efficiency?	19
Why is there such a large variation in prices between power supplies?	19
Which is best: switching mode or linear?	20
What is a crowbar?	20
What's the best way to test a power supply under load?	20
How do I measure ripple and noise?	20
Wire and contact resistance	21
Can I connect in parallel?	21
References	22
Appendix 1: Glossary	23

Introduction

Power supplies are amongst the most popular pieces of electronic test equipment. This isn't surprising, as controlled electrical energy is used in a tremendous number of ways. In this guide, we'll look at a variety of different types of power supplies, their controls, how they operate, and some examples of their application.

A power supply could broadly be defined to be anything that supplies power, such as a hydroelectric dam, an internal combustion engine, or a hydraulic pump. However, we'll limit our discussion to the types of electrical power supplies that are predominantly used for test and measurement, maintenance, and product development activities.

This document is intended for users or potential users of power supplies. Its aim is to define the terms used, introduce the different types of power supplies and the technology behind them, explain the controls of typical power supplies, and survey some examples of their use.

Here's a table of some of the different types of power supplies. We'll focus on the types that are highlighted.

	Output = DC	Output = AC
Input = AC	<ul style="list-style-type: none">• "Wall wart"• Bench power supplies• Battery charger	<ul style="list-style-type: none">• Isolation transformer• Variable AC supply• Frequency changer
Input = DC	<ul style="list-style-type: none">• DC-DC converter	<ul style="list-style-type: none">• Inverter• Generator

The term "bench power supply" here is used somewhat lightly, as some of the power supplies we're discussing could be too heavy to put on a bench. Still, the nomenclature is useful, as even the heavy, high-output power supplies have lots in common with their smaller cousins. But the term "bench" is descriptive to many folks, as it conjures up a mental image of a DC power supply used on an engineer's or technician's bench for a myriad of power tasks.

The remainder of this document will look at the bench type of power supply in more detail after a quick look at AC power supplies.

Variable AC Power Supply

When testing electrical equipment that is powered from the AC line, it is often important to evaluate the equipment when it is exposed to over- or under-voltage conditions. Normal AC line voltage variations are on the order of $\pm 10\%$, but can be more when many heavy loads are utilizing the line at the same time. A designer may also want to test beyond the normal AC line voltage variations for stress testing purposes (to find out where the design weaknesses are). A variable AC supply is needed for this type of testing. A variable AC supply can also be handy during a "brownout" (low line voltage conditions) to boost the line voltage back to normal levels. Another use is to boost the voltage when a load is connected through a long extension cord and the voltage drop of the cord is significant.

The different AC voltages are generated using a transformer (or an autotransformer). The transformer may have multiple windings or taps, in which case the instrument uses switches to select the different voltages. Alternatively, a variable transformer (adjustable autotransformer) can be used to (almost) continuously vary the voltage¹. Some variable AC supplies include meters to monitor the voltage, current, and/or power.

Some products, such as the B&K Precision model 1655A Variable Isolated AC Power Supply shown below, combine both an isolation transformer and a variable transformer. This product also includes the ability to perform AC leakage testing and has a convenient adjustable power supply for soldering irons. This is a practical and useful tool for the troubleshooting bench.



¹ These variable transformers are often called "Variacs", which originally was a trademark of General Radio Corporation, but the word has become generic and entered the general lexicon.

Types of DC Power Supplies

Battery Eliminator

These types of supplies tend to be the least expensive. The name describes their main purpose, which is to act in place of a battery. These units are inexpensive and handy when one needs to work on battery-operated equipment, as they allow one to work on the equipment without having to find the necessary batteries.

One popular type puts out 13.8 volts DC and is intended to provide DC power to devices normally powered from an automobile battery. Typical uses is servicing CB radios and automotive stereo equipment. Their line regulation specification is usually wider than lab supplies, but this is fine, as voltages in automobiles vary substantially.

Another popular type (shown at the right) replaces various arrangements of 1.5 volt batteries and 9 and 12 volt batteries. The only controls are an on-off switch and a rotary switch to allow you to choose the desired output voltage.

Because they are true power supplies, they are designed to operate safely into a dead short continuously.



Illustration 1: [B&K Precision model 1502](#)

Look for the banana jacks to be spaced at 0.75 inches (19 mm) so that the dual banana plug adapters used with coaxial cables can be used.

Constant Voltage Supply

A slightly more complex power supply than the battery eliminator supplies a constant, adjustable voltage. Because they are adjustable, they usually are supplied with a meter to show you the voltage the supply is set to. Some also have meters to let you monitor the current. A typical model is [B&K 1686A](#) shown on the right.

The basic behavior of the supply is to maintain the voltage you have set regardless of the load's resistance.

These models have a knob to adjust the output voltage. Some models may not be adjustable all the way down to zero volts and their maximum output current may be proportional to the output voltage, rather than supplying the rated current at any output voltage.



In the model at the right, "tie" points are provided to allow monitoring output voltage with a more

accurate digital meter or to allow connections to other circuits (note the tie points have a 2 A limit).

These types of supplies work well as battery eliminators and will also show you the current that the load is drawing.

Constant Voltage/Constant Current Supply

Probably the most popular type of lab power supply is a constant voltage/constant current supply. In addition to supplying constant voltage, these supplies can also supply constant current. When in constant current mode, the power supply will maintain the set current regardless of changes in the load's resistance. A typical example of this type of power supply is [B&K 1621A](#) shown:



This power supply outputs one adjustable voltage, which is indicated by the one set of banana jack terminals. The above arrangement of output terminals with the ground terminal between the + and - terminals is the most common and makes connecting either terminal to ground using a metal shorting bar very convenient. This is useful when you want one of the terminals to be referenced to ground. Of course, the same thing can be done with a piece of wire or a jumper wire with stackable banana plugs.

The above power supply has coarse and fine controls for both current and voltage. Some power supplies instead use 10-turn pots for adjustment. Others use thumbwheel switches or pushbutton switches. Thumbwheel and pushbutton switches are useful (if their settings are accurate) because they can eliminate the need for a meter.

These types of power supplies often have other useful features:

- ◆ Remote sensing: a high-impedance input that lets you measure the voltage at the load. The power supply then corrects for the voltage drop in the leads connecting the supply to the load.
- ◆ Master/slave connections: various methods exist to allow you to connect power supplies from the same family in parallel or series to get higher voltages or higher currents.
- ◆ Remote programming terminal: some power supplies have input terminals for a voltage or resistance that can be used to control the voltage or current output. Note: this is called analog programming, not digital programming using a computer.

Multiple Output Supply

Multiple output power supplies have more than one DC output, often two or three. These are useful and cost-effective for systems that require multiple voltages. An often-used power supply for circuit development is a triple output supply. One output supplies 0 to 6 volts, intended for digital logic. The other two supply (typically) 0 to 20 volts, which can be used with bipolar analog circuitry. Sometimes a tracking adjustment is supplied for the two 20 volt supplies so that the + and - 20 volt supplies can be adjusted together by turning one knob.

A popular model is the [B&K 9130](#):



The three outputs can be set independently either by the knob or the keypad. The channel 1 and channel 2 outputs are 31 volts at 3.1 amps and the third channel will output 6 volts at 3.1 amps. The supply is thus capable of putting out over 200 watts continuously. The outputs can be turned on and off independently or all at once (useful for powering up a whole printed circuit board).

The supply has a number of useful features. The outputs can be set to timed operation: after a time interval has passed, the output turns itself off. Voltage limits are settable for all channels, so your prototype electrical design can be protected from an accidental over-voltage setting. The two 30 volt channels can be connected in series or parallel for higher voltage or current, respectively. There are also storage registers for saving up to 50 instrument states for easy recall later (useful for repetitive testing).

A nice feature for unattended operation is that the power supply can be set to have its output on at the last power-on settings. Thus, if it is operating a circuit and the AC power fails, the power supply will again start supplying power when the AC power comes back on.

This particular supply is also programmable via a computer, which leads us to the next type of supply.

Programmable Supply

Programmable power supplies are sometimes called "system" power supplies, as they are often used as part of a computer-operated system for testing or production. We'll exclude from this discussion "programming" via external voltages or resistances, which was used primarily before

digital control became popular.

There have been numerous types of computer interfaces over the years with instrumentation. Two of the most popular have been IEEE-488, also known as GPIB (general purpose interface bus), and RS-232 serial communications. Network interfaces (e.g., Ethernet) and USB interfaces have also been used. We won't discuss the merits of the different types of interfaces here, as they are beyond the scope of this document.

At a slightly higher level than the type of interface is the command language for the power supply. This means the set of instructions sent to the instrument over the digital interface and the information received by the computer from the instrument. Three categories you will see are:

- Proprietary Proprietary command languages are typically specific to one manufacturer and sometimes even specific to a specific set of instruments. A disadvantage of proprietary command languages is that the user needs to write software specific to that instrument. Changing to a different power supply from another vendor means rewriting the software.
- SCPI Stands for "Standard Commands for Programmable Instruments", often pronounced "skippy" or "skuppy". Because having to rewrite software upon a change of vendor is painful, the test/measurement industry developed SCPI to standardize the commands for instrumentation to make it easier to change instrument vendors without having to rewrite a lot of software.
- SCPI-like SCPI has helped greatly, but isn't a complete solution, because new features get added that require new commands. In spite of this, many vendors try to make their instrument command languages SCPI-like, meaning they use as much of the standard as they can. The syntax also looks familiar to software developers, so development times are faster.

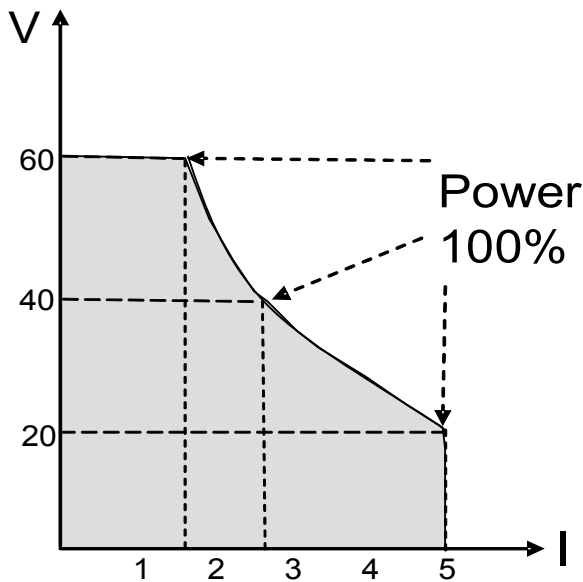
Here lists some typical set of SCPI commands common for power supplies:

```
[SOURce:]
  MODE {<FIXed|LIST|DRM>}
  MODE?
  VOLTage
    [:LEVel] {<n>}
    [:LEVel]?
    :PROTection
      :STATe {<bool>}
      :STATe?
      [:LEVel] {<n>}
      [:LEVel]?
  CURRent
    [:LEVel] {<n>}
    [:LEVel]?
```

By sending any of the above list of commands through the interface the instrument supports, the supply can be controlled with a computer rather than pushing front panel keys. This is very useful especially when doing more complex setups like generating dynamic voltage steps using list mode.

Multi-range Supply

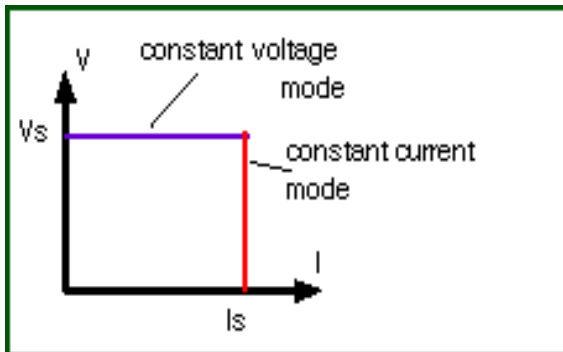
Most conventional power supplies operate with fixed voltage and current ratings, e.g. 30V / 3A. In this example, the maximum output power of 90 W can only be realized when the supply operates at 30 V / 3 A. For all other voltage/current combinations, the output power will be less. Multi range supplies are different in that they recalculate voltage/current limits for each setting, forming a constant power hyperbolic shaped boundary as illustrated in the diagram below. The B&K model [9110](#), rated 100W / 60V / 5A is an example of that type of supply. Any voltage/current combinations that lie on the hyperbolic curve are possible, e.g. 20V/5A or 60V/1,66A, and in each case the supply operates at maximum power. The benefits of this architecture are clear: A multi range supply offers greater flexibility in output ratings and allows users to substitute several fixed rating with a single multi range supply, thus saving cost and bench space.



Power Supply Specifications

Constant Current and Constant Voltage Mode

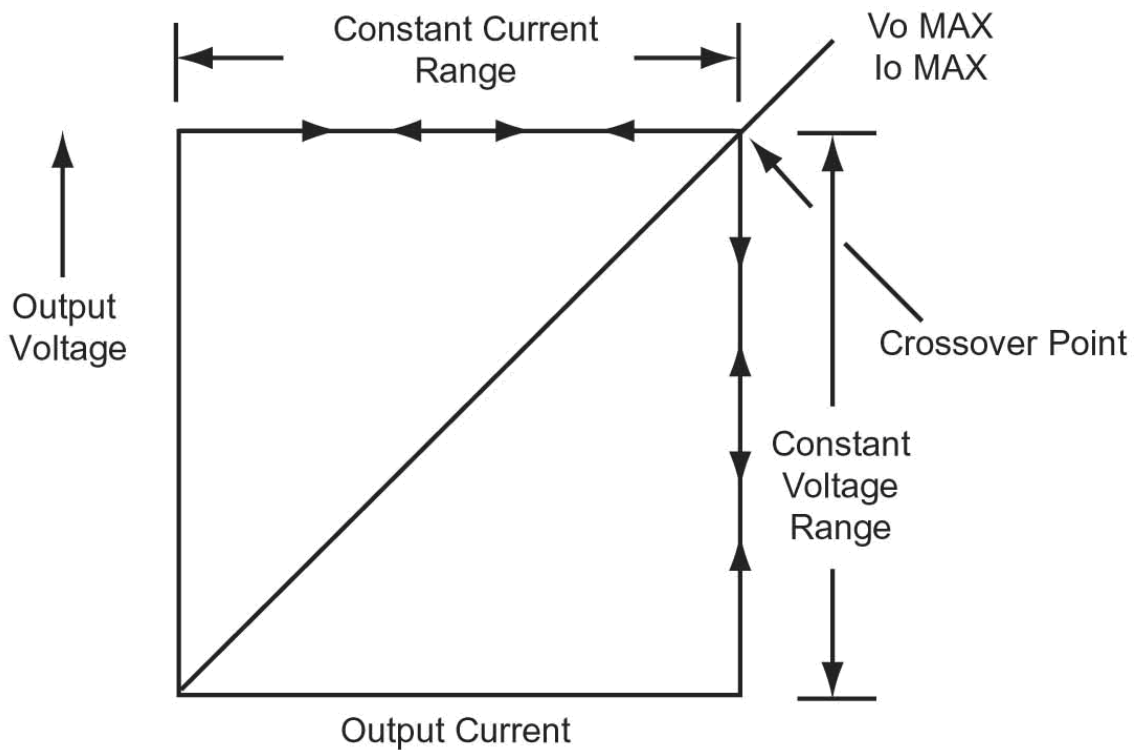
The category of DC power supplies discussed in this section changes AC line voltage into DC voltages. The most common and versatile regulated DC power supply is the constant current (CC) or constant voltage (CV) type which as the name implies can provide either a constant current or constant voltage within a certain range, see image below.



The working characteristic of this power supply is called a constant voltage/constant current automatic crossover type. This permits continuous transition from constant current to constant voltage modes in response to the load change. The intersection of constant voltage and constant current modes is called the crossover point. The figure below shows the relationship between this crossover point and the load.

For example, if the load is such that the power supply connected to it is operating in the constant voltage mode, a regulated output voltage is provided. The output voltage remains constant as the load increases, up until the point where the preset current limit is reached. At that point, the output current becomes constant and the output voltage drops in proportion to further increase in load. On some power supply models, the crossover point is indicated by a front panel LED indicators. The crossover point is reached when the CV indicator goes off and the CC indicator comes on.

Similarly, crossover from the constant current to the constant voltage mode automatically occurs from a decrease in load. A good example of this would be seen when charging a 12-volt battery. Initially, the open circuit voltage of the power supply may be preset for 13.8 volts. A low battery will place a heavy load on the supply and it will operate in the constant current mode, which may be adjusted for a 1 amp charging rate. As the battery becomes charged, and its voltage approaches 13.8 volts, its load decreases to the point where it no longer demands the full 1 amp charging rate. This is the crossover point where the power supply goes into the constant voltage mode.



In the following list of specifications, we'll list tips and questions you might want to consider when looking at power supply specifications. Read the specifications carefully and always look at the fine print.

Output

The output voltage and current (or voltages and currents for multiple outputs) are of course of fundamental importance. If you are searching for a power supply for a specific application, consider being conservative and buying more capability than you need -- projects often have new functionality added late in the design cycle.

Tips and questions to ask:

- ◆ Ensure the output is specified over the allowed input line voltage range (example: some switching power supplies have to be derated e.g. at 90 VAC).
- ◆ Some supplies (commonly switching power supplies) are not rated down to 0 volts output.
- ◆ How much can the supply be floated above or below ground?
- ◆ How much does the output drift over time? A typical value might be 5 to 10 mV over 10 hours under constant load and input voltage.
- ◆ If the output is at a fixed voltage, can it be adjusted slightly to a desired value?
- ◆ Check to see if the supply has remote sensing. Remote sensing uses two high impedance input terminals to sense the output voltage of the supply. When connected at the load, this feature can correct for voltage drops in the supply-to-load connection wires.
- ◆ Some power supplies have output protection. This is sometimes called a "crowbar", "over-voltage protection", or "limit voltage protection". The feature either limits the output voltage to a value set by the user or shuts the output off if the output voltage reaches the set limit. The intent is to provide circuit protection for voltage-sensitive circuits. Example: you're powering a

5 volt logic circuit with a power supply capable of supplying 40 volts of output. You set the power supply's over-voltage protection to 5.5 volts. Then the output will never exceed 5.5 volts regardless of how much you turn the voltage adjust knob. Note: a "crowbar" denotes a device (usually an SCR) that shorts the output when the the set voltage limit is exceeded. The behavior of a crowbar might not be desirable -- while powering off the circuit will protect it, it might also cause a problem by not having the circuit powered!

Regulation

Load regulation is how much the output voltage changes when the load changes, usually from 0 to 100% of rating. This can conveniently and easily be measured by modern DC loads. Typical specifications are from 0.1% to 0.01%. When you think about it, this is excellent behavior -- a change of up to 1 part in 10,000 (it's done with negative feedback control circuits).

Line regulation is how much the output changes for a change in the input AC voltage. It is usually specified as mV per a given change of the input or as a percentage change over the whole allowed input range. Typical values are again in the range of 0.1% to 0.01%.

For very finicky designs, one might want to know how the output changes when the three major factors change: input voltage, load, and temperature. This is rarely specified and would probably have to be measured.

The above regulation specifications are steady state behavior. Transient behavior is important for some applications. Transient response time can be specified and is related to how long it takes the power supply to recover to a specified value after a sudden change in load or output. This may be an important specification when the power supply is used with digital circuitry that consumes energy in bursts. For example, a radio transmitter will go from no power to full power quickly, leading to step changes in the demand on the power supply. A supply with poor transient response (or an unstable response that causes oscillation) will be detrimental to the application, both because it might not be able to supply enough power and its output transients could be coupled into the circuitry it is supplying power, leading to anomalous behavior.

Ripple and noise

There is no universally-accepted method of measuring ripple and noise. Some vendors include external circuitry in making the measurements, so to duplicate their results, you will need to contact them how they make their measurements. The easiest measurement is to connect an AC-coupled oscilloscope to the output of the power supply. The measurement can be made of common-mode noise (noise on both + and - outputs of the power supply with respect to the AC power ground) or normal-mode (also called differential-mode) noise, which is the noise seen between the + and - terminals of the power supply. Note: since the outside of the BNC connector on many scopes is connected to the power ground, you'll have to use an isolation transformer to power the scope or use a differential amplifier to measure the normal-mode noise.

Ripple for linear power supplies is usually measured at twice line frequency. For switching power supplies, you'll want to examine higher frequencies and may see voltage spikes. Ripple can be defined as the portion of unfiltered AC voltage and noise present at the output of a filtered power supply when operated at full load and is typically specified in volts RMS. Noise on the other hand is typically specified as peak-to-peak AC voltage and can be defined as the portion of unfiltered and unshielded EMI noise present at the output of a filtered power supply when operated at full load.

It can be important to know what bandwidth the noise is specified over. Often it is 20 MHz, as an oscilloscope is used to measure it. Note: sometimes ripple and noise is specified as PARD, which

is an acronym for "periodic and random deviations".

Most linear power supplies should have less than 3 mV RMS ripple and less than 50 mV peak for switching supplies

★Practical Example: Here are some example ripple and noise measurements. The output of a B&K Precision 9130 power supply set to 9 volts was connected through a 50 ohm coaxial cable (using a dual banana plug adapter) to a B&K Precision 2534 digital storage oscilloscope (60 MHz bandwidth). The scope's input was AC coupled (the channel was checked to ensure that the AC coupling made no measurable affect on the amplitude of an input signal down to 30 Hz). The scope was powered using a medical-grade isolation transformer, so the noise measurement is differential, not common-mode. There was no measurable power line ripple and the noise was mostly wideband with some spikes with a fundamental frequency of 40 MHz. These spikes are not from this power supply because i) they were present with the power supply turned off and ii) they were present on other instruments on the author's bench, also turned off. It is probably digital interference from the author's computer being conducted through the power line. The 9130 is specified to have less than 3 mV RMS of noise; this particular supply met the specification. Note these are example measurements and are not intended to construe anything particular about the characteristics of the 9130 power supplies in general. However, it hopefully shows that something as "simple" as connecting a single cable to a power supply and making a measurement involves a number of things to think about. Had the author used a 20 MHz low-pass filter on the input, he wouldn't have spent time tracking down this spurious noise.

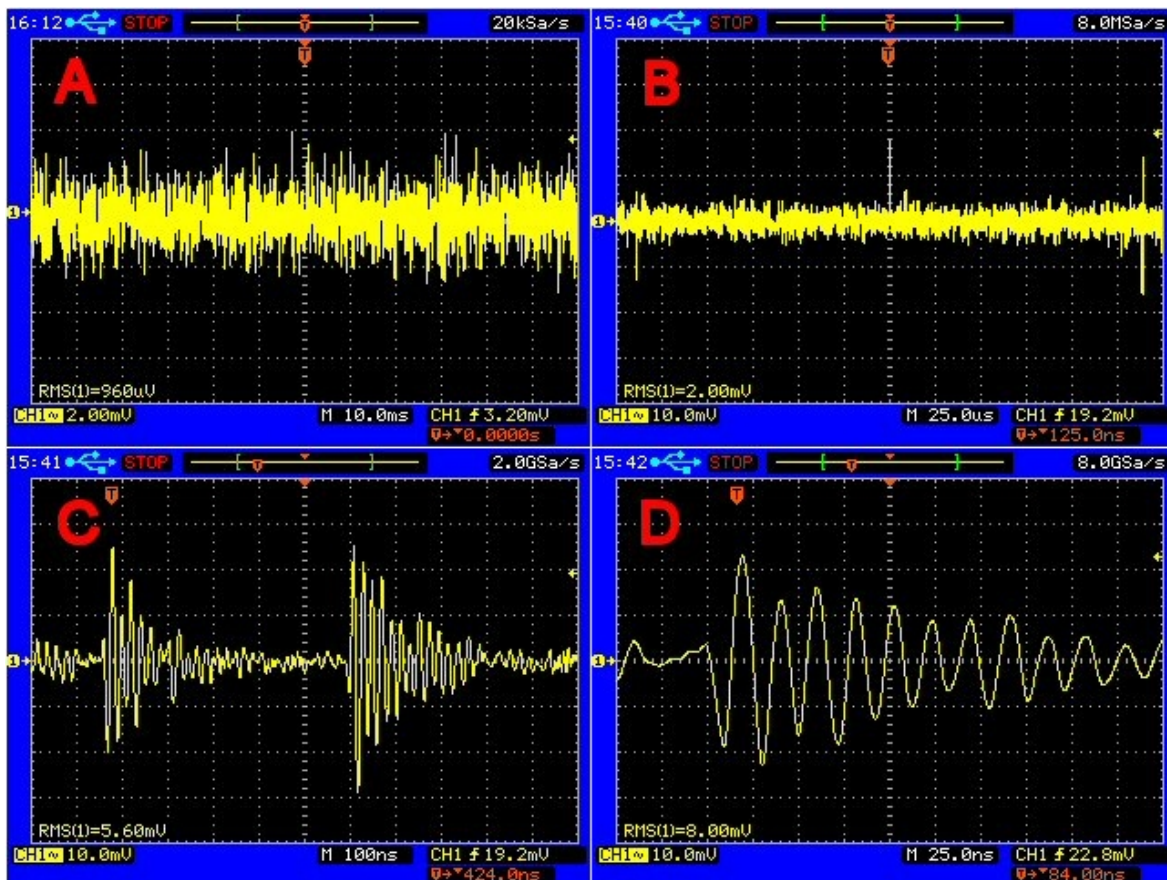


Illustration 2: (A) Typical thermal noise (B) Slower capture of (A) showing spike (~15 mV) (C&D) Details of spike

Temperature

As the components that make up power supplies are temperature sensitive, it should be no surprise that power supplies as a whole can also be temperature sensitive. This is true even when designers try to minimize the effects of temperature. Modern lab-quality power supplies should have temperature coefficients of under 0.05% per °C. This is usually specified over the operating temperature range, which often is 0 to 40 °C. It is usually implied or assumed that the power supply is tested at a constant load with no AC line variation.

AC input

Larger power supplies may use three phase power. These can be more economical and a bit more efficient than single phase supplies, although the ripple frequencies will be higher.

Isolation: specified as the DC or AC voltage that can be applied between input and output without the supply failing. Typical numbers are 500 to 1500 V. The power supply's isolation between input and output or chassis comes from the isolation provided by the supply's transformer.

Some power supplies contain large filtering capacitors which essentially present a short to the rectifier when the supply is first powered on. Some power supplies have circuits to minimize the inrush current or spread it out over time (a "soft start").

The hold-over specification defines how long the AC input can go away and the power supply will still stay in regulation. The charge stored on the filter capacitors is used to supply the power while the AC input is off.

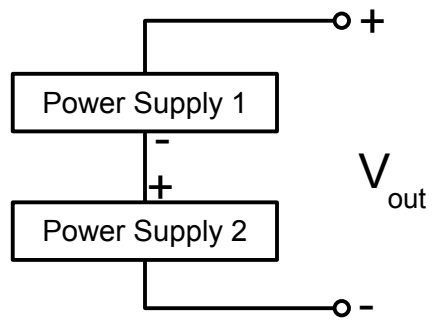
As the cost of energy increases, power supply efficiency becomes more important. Efficiency is the output power divided by the input power and of course will always be less than 100% (it's usually converted to a percent). The best supplies can be 90% efficient or better. Linear power supplies are typically much less efficient than switching mode power supplies.

Tracking accuracy

Some power supplies with two or more outputs may have a tracking feature. This is where one output will track the output voltage of another output. This is useful when supplying power to circuits that need a positive and negative rail. The tracking accuracy specification defines how closely the second output tracks the output of the first output.

DC Isolation

Isolation refers to how much the + or - terminals can be "floated" above or below power line ground. This specification often includes the output voltage of the power supply. It's important not to exceed the specification, as you might cause dielectric breakdown of an internal component and/or exposure to hazardous voltages. It is fairly common to put two power supplies in series to get a higher voltage than either can supply. For example, consider the following circuit:



V_{out} will be the sum of the voltages set on power supply 1 and power supply 2. Note that this series operation must be such that the current doesn't exceed that of the power supply with the minimum current rating.

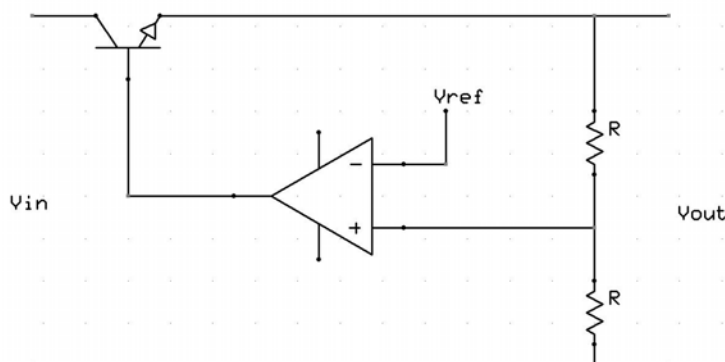
To be sure you stay within the DC isolation specifications of the manufacturer, ensure that none of the voltages on any of the external wires *with respect to ground* exceeds the DC isolation specification.

Theory of Operation

There are two primary ways that power supplies operate: linear regulation and switching mode.

Linear Regulation

The principle of operation of a linear regulation type power supply is shown in the following diagram:



The input voltage typically comes from a transformer, full-wave rectifier, and filter capacitor stage. The output voltage is compared to a reference voltage (derived, for example, from the front-panel settings of the power supply) and the difference is fed to the transistor to allow more or less current through it. The transistor is usually a bipolar or MOSFET type (sometimes as part of a control IC for smaller supplies) and is operated in its linear region (hence the name, "linear" regulation). The linear regulation strategy has advantages of simplicity, low noise, fast response time, and excellent regulation. A disadvantage is that they are inefficient, as they are always dissipating power. In the above design, you can see that the transistor has $V_{in} - V_{out}$ across it. Multiply this difference by the current to get the power being dissipated. For a large voltage difference (i.e., low power supply output voltage) and large current, the overall efficiency can drop down to nearly 10%. The maximum efficiency for a linear supply is generally around 60%. Typical average efficiencies are in the 30-40% range.

Switching Mode

Note: In this section, we will abbreviate a switching mode power supply as SMPS.

A problem of the typical linear power supply is the size and weight of the transformer. The size is needed because of the low frequency (50 to 60 Hz). For the same power output, the transformer size goes down (a lot) as the frequency goes up (up to a point). The SMPS takes advantage of this by chopping the AC line's waveform into lots of little pieces and changing them to a desired voltage level with a much smaller transformer. A key fact is that the switching element (a transistor) is either off or fully on (saturated). The voltage drop across the transistor is small (for either a bipolar transistor or a MOSFET), meaning little power is being wasted in it. When it's off, no power is being dissipated. This is one of the efficiency wins of a SMPS.

The filter capacitors can also be smaller at these higher frequencies and chokes are more effective. A lower frequency limit is 25 kHz (to stay above the human hearing range) and the state-of-the-art upper limit is currently around 3 MHz. Most switching supplies use frequencies in the range of about 50 kHz to 1 MHz.

Parasitic behaviors and the skin effect in conduction become important at the higher switching frequencies, especially because the waveforms are square waves and rich in harmonics. In passive elements like capacitors and inductors, ESR (equivalent series resistance) becomes important and leads to inefficiencies. Resistors need to be non-inductive. Careful, optimized switching mode designs can realize efficiencies of 95%, but the typical SMPS is around 75% efficient, still much better than the typical linear supply. This is one reason they are universally seen in personal computers.

Another advantage with SMPS is that the switching can be modulated in various ways, depending on the load conditions. The power supply output is regulated with a feedback circuit which adjusts the timing (duty cycle) with which the MOSFETS are switched on or off.

The benefits of switching mode power supplies don't come with some costs. The higher frequencies and switching mean higher levels of electromagnetic interference (EMI), both radiated and conducted. This can put switching noise back into the power line. The control electronics also become more complicated (even more so recently because of the desire to have higher power factors).

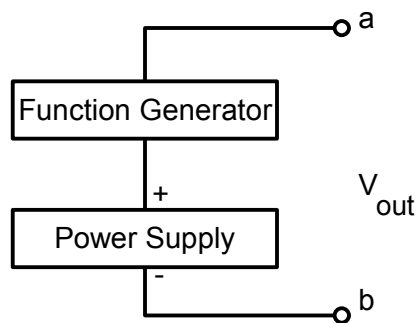
Switching mode power supplies may struggle to produce low voltages. This is because the transistor has to switch current -- i.e., the SMPS can't operate unless enough current is flowing. Because of this, switching mode power supplies often have a minimum output voltage specification.

Application

<http://www.amtex.com.au/ApplicationNotesPower.htm>

Using a power supply to generate a DC offset with a function generator

If a signal source such as a function generator does not have a DC offset capability, you can effectively add this feature using a DC power supply. As in the specification for the DC isolation of a DC power supply, it is important that this mode of operation of the signal source be allowed by the manufacturer and that you don't exceed the specifications. You'll also need a signal source whose output terminals (usually a BNC connector) are isolated from ground. If the connector is not isolated from ground, the instrument can be isolated from power line ground using an isolation transformer. However, the metal chassis of the instrument may then be above or below ground potential when DC biased, so take suitable precautions against electrical shock. The connection method is shown in the following diagram.

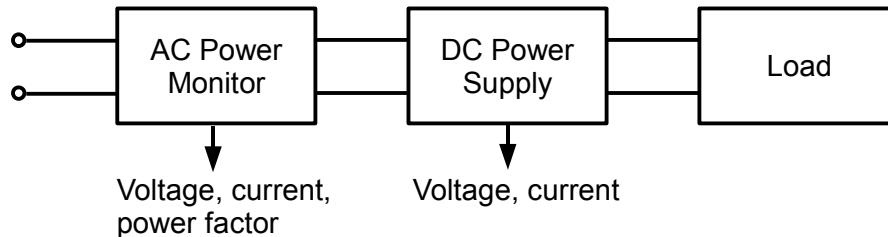


The reason this can be a useful thing to do is because the function generator's signal can then be inserted into a circuit that is biased above or below ground (or the DC power supply can supply the bias, such as for a transistor). You must be careful not to exceed the function generator's current capabilities.

Power Supply Questions and Tips

How do I measure power supply efficiency?

If efficiency is important to you, you'll want to measure it carefully. For a typical DC power supply operated from the AC line, you'll need to measure the input AC power and the DC power being output by the supply as in the following diagram:



Probably the best tool for measuring the AC power used by the DC power supply is an oscilloscope. You'll need to measure the AC voltage and AC current going into the power supply. The best approach is probably to use a non-inductive current shunt for the current measurement and two independent differential amplifiers to measure the AC input voltage to the power supply and the AC voltage across the shunt. The power waveform can be gotten by multiplying the current and voltage waveform using the oscilloscope. With suitable bandwidth in the scope and amplifiers, this will be an accurate measurement, show you the power factor, and tell you about any power line harmonics/transients associated with the DC power supply's operation. If your scope can't do the multiplication, you can still measure the RMS values of voltage and current, measure the power factor, and multiply the three together.

For measuring the power consumed by the load, you can use the voltage and current meters of the DC power supply as long as you know they're accurate. For confirmation, you can use a DC load instead, set to the same load characteristics.

The measured efficiency in percent will then be

$$100 \frac{P_{\text{out}}}{P_{\text{in}}}$$

where P_{in} is the measured AC power in and P_{out} is the measured DC power out, both in the same power units.

Why is there such a large variation in prices between power supplies?

A similar question can be asked about automobiles. Both questions share the same answer: there are a lot of factors at play and a simple answer is probably not possible. Some of the factors are

- ◆ Vendor's name and reputation
- ◆ How conservative the design is
- ◆ Number and type of competing units
- ◆ Certifications (e.g., safety, EMI, etc.)
- ◆ Reliability of the design (and effort expended to test the design)

- ◆ Quality of components and construction used
- ◆ The number of features

One thing to think about when evaluating a power supply (or any piece of equipment) is the total cost of ownership. Include the cost of yearly calibrations and any estimated losses due to unavailability or having to repair or replace the unit if it fails. Over a decade or more, these costs can easily exceed the original cost of the power supply.

Which is best: switching mode or linear?

It depends on what you mean by "best". You may get some guidance from the following table:

Type	Strengths	Weaknesses
Linear	<ul style="list-style-type: none"> ◆ Low noise and EMC disturbances ◆ Good line and load regulation ◆ Fast transient response ◆ Can produce very low current output 	<ul style="list-style-type: none"> ◆ Low efficiency (30-40% average) ◆ Weight (transformer) ◆ Larger heat sinks ◆ More expensive for higher power
Switching mode	<ul style="list-style-type: none"> ◆ High efficiency (75% average with some around 95%) ◆ More affordable for higher power ◆ Lighter weight 	<ul style="list-style-type: none"> ◆ Can't supply low voltages and needs to supply a minimum current ◆ More noise (including impulse noise and EMC disturbances) ◆ Much slower transient response compare to linear

Please consult the Theory of Operation section for more comments on the two types.

Increasingly, hybrid technologies using both linear and switching type circuits, are gaining in popularity. The aim of this approach is to create power supplies whose characteristics combine the strength of both linear and switching mode technologies.

What is a crowbar?

It's a protective device used on the output of power supplies (usually an SCR) to short the output if the output voltage goes above a set level. See the Output section under Power Supply Specifications.

What's the best way to test a power supply under load?

Certainly, an excellent way is to test it with the actual load it is intended to supply, if that's possible. However, that may not stress the supply enough to tell you much about its suitability and robustness for your application. An excellent tool for testing power supplies is a DC load. They can be programmed to apply a wide variety of varying loads to a power supply and can do it relentlessly. Once a particular supply is qualified, they make good tools for ongoing or incoming inspection.

How do I measure ripple and noise?

This can be done with an oscilloscope or a wideband AC RMS voltmeter. But there are nuances to be aware of -- see the Ripple and Noise section under Power Supply Specifications.

Wire and contact resistance

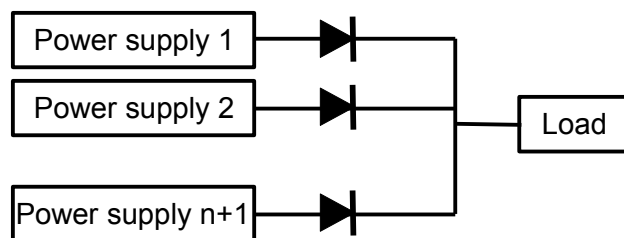
Contact resistance in bad joints or poorly made up mechanical connections can add significant loads, especially in high-current applications. A bad or corroded crimped joint can have a resistance of hundreds of milliohms or even above an ohm. These reduce efficiency and create hot spots. If you've ever had to clean the battery terminals on your car to get it to start, you've seen the problem.

A 10 gauge copper wire has a resistance of a little over 3 Ω /m. For a circuit with 10 m of wire, this is 30 m Ω . A 100 m Ω connection would thus supply 75% of the wiring resistance (as well as waste 75% of the power lost in the wiring).

Bad joints are relatively easy to find if you can access the wire under load. A digital multimeter can be used to measure the voltage drop across the joints (be careful when significant voltages are being carried by the wire). Knowing the current (measure it with a clamp-on DC ammeter if the power supply's meter isn't handy), you can calculate the joint's resistance. If the wire is insulated, special insulation piercing probes are available, such as [CalTest Electronics CT3044](#), or the [Pomona 5913](#). If you use piercing probes, consider turning the power supply off first -- an accidental arc can ruin the sharp tips (aside from being a potential safety hazard).

Can I connect in parallel?

The load needs n power supplies for operation, so n+1 supplies are used, allowing for one to fail. The diodes are to isolate the supplies from each other (they may or may not be needed; again, ask your vendor). The supplies may need to have control lines connected together so that they can intelligently share the load. The requirement is to have each supply output the same voltage so they share the load equally. The wiring should be short and each leg equal for each supply.



References

M. Schwartz, *Information Transmission, Modulation, and Noise*, 2nd ed., McGraw-Hill, 1970, ISBN 07-055761-6.

Appendix 1: Glossary

<http://www.abbotelectronics.com/engineer/glossary.htm>

<http://www.currentsolutions.com/knowledge/glossary.htm>

Line regulation	How much the load voltage or current changes when the power supply is operated at varying line voltages throughout a given range. Typically stated as a percentage of the total voltage or current available from the supply. A rating of "0%" would mean perfect regulation.
Load regulation	How much the load voltage or current changes between operating the power supply at no-load and full-load conditions. Typically stated as a percentage of the total voltage or current available from the supply. A rating of "0%" would mean perfect regulation.
Efficiency	Measured in percentage, it indicates the amount of power being output over the amount of power consumed in a system.
EMI	Electromagnetic Interference
Inrush current	An initial amount of current drawn by a power supply at startup. It is sometimes referred to as startup current and it's generally several magnitudes greater than the steady-state value of the supply.
Inverter	A electrical device used to convert DC to AC power.
Remote sensing	Provided in some instruments that can be used to sense a DUT's voltage at its terminal in order to provide accurate readings to compensate for voltage drops across leads connected to the instrument and the DUT.
Constant voltage	A regulated power supply that delivers a constant voltage to a load even when the load resistance changes to a value that will not exceed the power supplies current limit.
Constant current	A regulated power supply that delivers a constant current to a load, even when the load resistance changes. Note that the power supply must follow Ohm's Law.
Current limit	A value set as a limit on the current a power supply can output. When current reaches the limit, a typical CV/CC power supply will switch from CV to CC mode. This is also known as the crossover point.
Overload protection	A protection feature in most DC power supplies to prevent any device from drawing more power than the supplies are intended to produce.
Overvoltage protection	Protection found in many power supplies that limits the amount of voltage that can be output.
Parallel operation	Found in many dual and triple output power supplies, this mode of operation allows two or more independent outputs to connect together in parallel to increase the current output.
Series operation	A mode of operation in many dual and triple output power supplies in which connect two or more independent outputs in series to increase the voltage output.
PARD	Periodic (ripple) and random (noise) deviations of an output voltage from the desired value.
PWM	Pulse Width Modulation
Resolution	The smallest change in voltage or current that can be made by an adjustment of the controls.
Thermal protection	Protection against damage to the supply due to excessive temperature
Transient recovery time	The amount of time it takes for a power supply to recover its output after a step change.

AC	Alternating current. Describes voltage and current that varies in amplitude, usually in a sinusoidal waveform with respect to time. AC power is almost universally used for distributing electrical power.
Blackout	Loss of AC electrical power.
Brownout	A planned AC voltage reduction by the power company to counter excessive demand.
Capacitive coupling	Two separated conductors always form a capacitor. The closer they are, the more it's possible for voltage variations on one conductor to be electrostatically induced on the other conductor (contrast to inductive coupling).
Inductive coupling	When a changing current is flowing in one wire, a voltage is induced in a nearby wire because of the magnetic field caused by the current (contrast to capacitive coupling).
Crest factor	In an AC waveform, crest factor is the ratio of the peak value to the RMS value.
DC	Direct current. Used to describe an unchanging voltage, current, or electrical power.
Drift	The change in time of an output voltage or current.
Electronic load	A type of instrument that serves as a load, usually dynamic, and can be used for testing power supplies and sources.
ESR	Equivalent series resistance. The simple "series" model of a capacitor or an inductor places the pure reactance in series with a pure resistor, whose value is usually called the ESR. Often measured on larger electrolytic capacitors and a high value of ESR generally indicates a bad capacitor.
Ground	Electrical ground in an AC power system is a wire that is connected to the earth, hence the name "ground". The reason for such connection stems from the need to protect users of electrical equipment from shock hazards. Power is delivered to the utilization site using a pole mounted or other type of transformer. The output of such a transformer consists essentially of two lead wires, with the utilization voltage available between the leads. For a variety of complicated reasons involving safety, one of these transformer lead wires is connected to the earth using a copper bar driven into the ground.
Minimum load	If specified for a power supply, it is the minimum load current that must be drawn from the power supply so that it meets its performance specifications.
Surge	A momentary increase in the AC power line voltage.
Output impedance	The ratio of a change in output voltage to a change in load current.
Power factor	The ratio between real and apparent power. This determines how much current is required to produce a certain amount of power. It is always desirable to have the ratio be as close as 1. A lower power factor system would mean greater loss in power to produce the same amount of work as compared to with a higher power factor system.
Ripple Voltage	The portion of unfiltered AC voltage and noise present at the output of a filtered power supply, operated at full load. Typically stated in rms AC voltages (with zero ripple voltage representing a perfectly filtered power supply).
Ripple Current	The portion of unfiltered AC current at the output of a filtered power supply.
RMS	Root Mean Square. For any waveform, the RMS is square root of the average of the sum of the squares of the sampled values. For a continuous function, an analogous integral formula applies.

Safety ground	A circuit designed to conduct away dangerous voltages (due to a defect or accident), thus protecting people from accidental shocks. The metal covers of instruments and appliances are connected to ground (and hence called a safety ground). Thus, if an electrically "hot" wire inside the device accidentally touches the metal case, the connection to safety ground means the metal will stay near ground potential. The usual outcome of such a condition is that the circuit breaker will trip.
Temperature range	The range the power supply is specified to operate over. It can also designate a temperature range the supply can be stored in.
True power	Also referred to as real power, are usually measured in watts.
Apparent power	The product of RMS current and RMS voltage, usually measured in the units of VA (volt-amps)



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