Agilent E3631A

Programmable
Power Supply

TUTORIAL

pages from User's Guide

Tutorial

Tutorial

The Agilent E3631A is a high performance instrument capable of delivering clean dc power. But to take full advantage of the performance characteristics designed into the power supply, certain basic precautions must be observed when connecting it for use on the lab bench or as a controlled power supply. This chapter describes basic operation of linear power supplies and gives specific details on the operation and use of the Agilent E3631A DC power supply:

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Overview of Agilent E3631A Operation

Series regulated power supplies were introduced many years ago and are still used extensively today. The basic design technique, which has not changed over the years, consists of placing a control element in series with the rectifier and load device. Figure 7-1 shows a simplified schematic of a series regulated supply with the series element depicted as a variable resistor. Feedback control circuits continuously monitor the output and adjust the series resistance to maintain a constant output voltage. Because the variable resistance of Figure 7-1 is actually one or more power transistor operating in the linear (class A) mode, supplies with this type of regulator are often called *linear* power supplies. Linear power supplies have many advantages and usually provide the simplest most effective means of satisfying high performance and low power requirements.

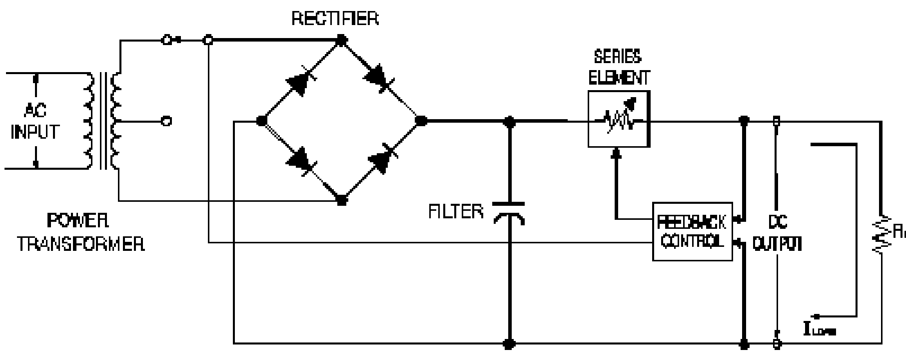

Figure 7-1. Diagram of Simple Series Power Supply with Tap Selection

To keep the voltage across the series resistance low, some supplies use preregulation before the rectifier bridge. Figure 7-1 shows a controlled transformer tap as used in the Agilent E3631A. This is one of several techniques using semiconductors for preregulation to reduce the power dissipated across the series element.

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In terms of performance, linear regulated supplies have a very precise regulating properties and respond quickly to variations of the line and load. Hence, their line and load regulation and transient recovery time are superior to supplies using other regulation techniques. These supplies also exhibit low ripple and noise, are tolerant of ambient temperature changes, and with their circuit simplicity, have a high reliability.

The Agilent E3631A contains three linear regulated power supplies. Each is controlled by a control circuit that provides voltages to program the outputs. Each supply sends back to the control circuit voltages representing outputs at the terminals. The control circuits receive information from the front panel and send information to the display. Similarly the control circuits “talk” to the remote interface for input and output with the GPIB and RS-232 interfaces.

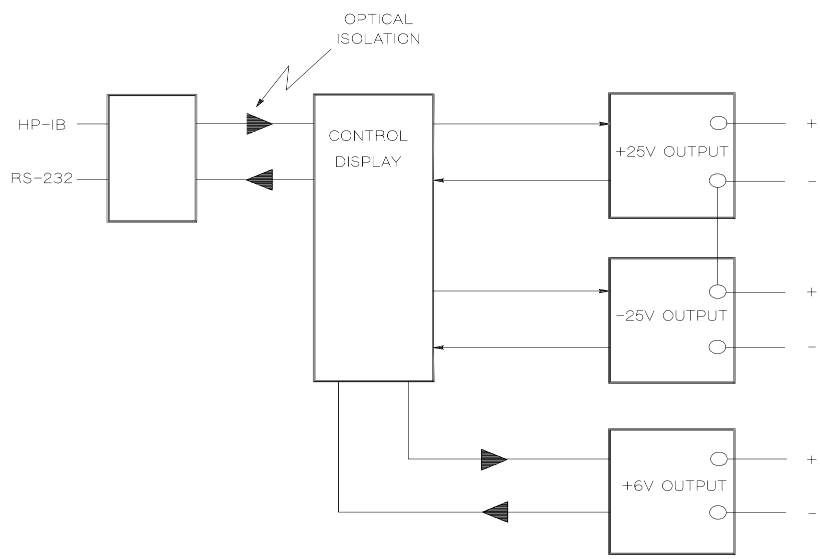

Figure 7-2. Block Diagram of the Three Supplies Showing The Optical Isolation

The control circuit and display circuit share the same common ground as the ±25V supplies. The remote interface is at earth ground and optically isolated from the control circuit and the ±25V supplies. The +6V supply is also optically isolated from the remote interface and the ±25V supplies.

Output Characteristics

An ideal constant-voltage power supply would have a zero output impedance at all frequencies. Thus, as shown in Figure 7-3, the voltage would remain perfectly constant in spite of any changes in output current demanded by the load.

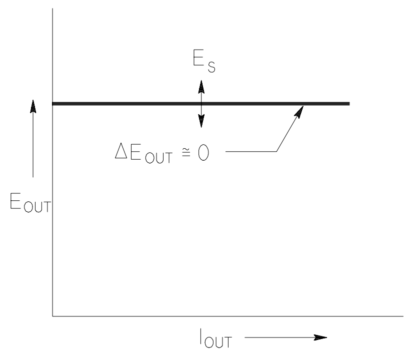

Figure 7-3. Ideal Constant Voltage Power Supply

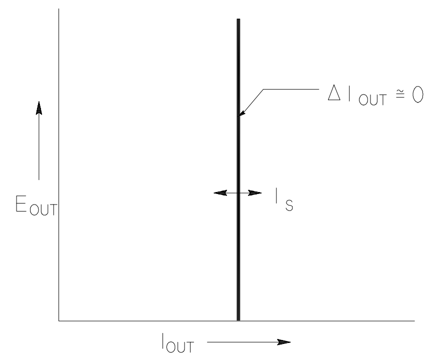

Figure 7-4. Ideal Constant Current Power Supply

The ideal constant-current power supply exhibits an infinite output impedance at all frequencies. Thus as Figure 7-4 indicates, the ideal constant-current power supply would accommodate a load resistance change by altering its output voltage by just the amount necessary to maintain its output current at a constant value.

Each of the three Agilent E3631A power supply outputs can operate in either constant-voltage (CV) mode or constant-current (CC) mode. Under certain fault conditions, the power supply can not operate in either CV or CC mode and becomes unregulated.

Figure 7-5 shows the operating modes of the three outputs of the Agilent E3631A power supply. The operating point of one supply will be either above or below the line $R_L = R_C$. This line represents a load where the output voltage and the output current are equal to the voltage and current setting. When the load R_L is greater than R_C, the output voltage will dominate since the current will be less then the current setting. The power supply is said to be in constant-voltage mode. The load at point 1 has a relatively high resistance value (compared to R_C), the output voltage is at the voltage setting, and the output current is less than the current setting. In this case the power supply is in the constant-voltage mode and the current setting acts as a current limit.

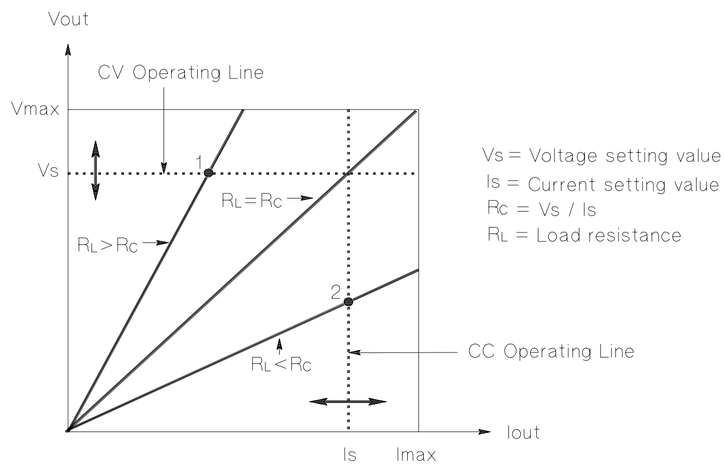

Figure 7-5. Output Characteristics

When the load R_L is less than R_C, the output current will dominate since the voltage will be less than the set voltage. The power supply is said to be in constant-current mode. The load at point 2 has a relatively low resistance, the output voltage is less than the voltage setting, the output current is at the current setting. The supply is in constant-current mode and the voltage setting acts as a voltage limit.

Unregulated State

If the power supply should go into a mode of operation that is neither CV or CC, the power supply is *unregulated*. In this mode the output is not predictable. The unregulated condition may be the result of the ac line voltage below the specifications. The unregulated condition may occur momentarily. For example when the output is programmed for a large voltage step; the output capacitor or a large capacitive load will charge up at the current limit setting. During the ramp up of the output voltage the power supply will be in the unregulated mode. During the transition from CV to CC as when the output is shorted, the unregulated state may occur briefly during the transition.

Unwanted Signals

An ideal power supply has a perfect dc output with no signals across the terminals or from the terminals to earth ground. The actual power supply has finite noise across the output terminals, and a finite current will flow through any impedance connected from either terminal to earth ground. The first is called *normal mode voltage noise* and the second *common mode current noise*.

Normal mode voltage noise is in the form of ripple related to the line frequency plus some random noise. Both of these are of very low value in the Agilent E3631A. Careful lead layout and keeping the power supply circuitry away from power devices and other noise sources will keep these values low.

Common mode noise can be a problem for very sensitive circuitry that is referenced to earth ground. When a circuit is referenced to earth ground, a low level line--related ac current will flow from the output terminals to earth ground. Any impedance to earth ground will create a voltage drop equal to the current flow multiplied by the impedance. To minimize this effect, the output terminal can be grounded at the output terminal. Alternately, any impedances to earth ground should have a complementary impedance to earth ground to cancel any generated voltages. If the circuit is not referenced to earth ground, common mode power line noise is typically not a problem.

The output will also change due to changes in the load. As the load increases the output current will cause a small drop in the output voltage of the power supply due to the output impedance R. Any resistance in the connecting wire will add to this resistance and increase the voltage drop. Using the largest possible hook up wire will minimize the voltage drop.

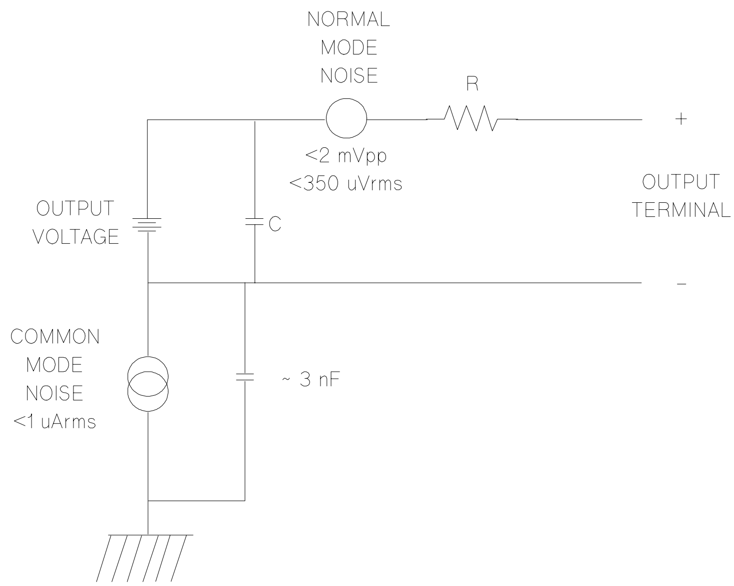

Figure 7-6. Simplified Diagram of Common Mode and Normal Mode Sources of Noise

When the load changes very rapidly, as when a relay contact is closed, the inductance in the hook up wire and in the power supply output will cause a spike to appear at the load. The spike is a function of the rate of change of the load current. When very rapid changes in load are expected, a capacitor with a low series resistance, in parallel with the power supply, and close to the load is the best way to minimize these voltage spikes.

Connecting the Load

Output Isolation

The outputs of all three power supplies are isolated from earth ground. Any output terminal may be grounded, or an external voltage source may be connected between any terminal output and ground. However, output terminals must be kept within ±240 Vdc of ground. The ± 25V supplies are tied together at one common terminal. Any one of the three terminals can be tied to ground as needed. An earth ground terminal is provided on the front panel for convenience.

Multiple Loads

When connecting multiple loads to the power supply, each load should be connected to the output terminals using separate connecting wires. This minimizes mutual coupling effects between loads and takes full advantage of the low output impedance of the power supply. Each pair of wires should be as short as possible and twisted or shielded to reduce lead inductance and noise pick-up. If a shield is used, connect one end to the power supply ground terminal and leave the other end disconnected.

If cabling considerations require the use of distribution terminals that are located remotely from the power supply, connect output terminals to the distribution terminals by a pair of twisted or shielded wires. Connect each load to the distribution terminals separately.

Table 7-1. Wire Rating

AWG	10	12	14	16	18	20	22	24	26	28
Suggested maximum Current(amps)*	40	25	20	13	10	7	5	3.5	2.5	1.7
mΩ/ft	1.00	1.59	2.53	4.02	6.39	10.2	16.1	25.7	40.8	64.9
mΩ/m	3.3	5.2	8.3	13.2	21.0	33.5	52.8	84.3	133.9	212.9
*Single conductor in free air at 30 °C with insulation										

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Warning *To satisfy safety requirements, load wires must be heavy enough not to overheat while carrying the short-circuit output current of the power supply.*

Load Consideration

Capacitive Loading

In most cases, the power supply will be stable for almost any size load capacitance. Large load capacitors may cause ringing in the power supply's transient response. It is possible that certain combinations of load capacitance, equivalent series resistance, and load lead inductance will result in instability. If this occurs, the problem may often be solved by either increasing or decreasing the total load capacitance.

A large load capacitor may cause the power supply to cross into CC or unregulated mode momentarily when the output voltage is reprogrammed. The slew rate of the output voltage will be limited to the current setting divided by the total load capacitance (internal and external).

Table 7-2. Slew Rate

AWG	Internal Capacitance	Internal Bleed Resistor	Slew Rate at No Load and Full Scale Current Setting
+6V Output	1000 µF	390 Ω	8 V/msec
+25V Output	470 µF	5 kΩ	1.5 V/msec
-25V Output	470 µF	5 KΩ	1.5 V/msec

Inductive loading

Inductive loads present no loop stability problems in constant voltage mode. In constant current mode, inductive loads form a parallel resonance with the power supply’s output capacitor. Generally this will not affect the stability of the power supply, but it may cause ringing of the current in the load.

Pulse Loading

In some applications the load current varies periodically from a minimum to a maximum value. The constant current circuit limits the output current. Some peak loading exceeding the current limit can be obtained due to the output capacitor. To stay within the specifications for the output, the current limit should be set greater than the peak current expected or the supply may go into CC mode or unregulated mode for brief periods.

Reverse Current Loading

An active load connected to the supply may actually deliver a reverse current to the supply during a portion of its operating cycle. An external source can not be allowed to pump current into the supply without risking loss of regulation and possible damage. These effects can be avoided by preloading the output with a dummy load resistor. The dummy load resistor should draw at least the same amount of current from the supply as the active load may deliver to the supply. The value of the current for the dummy load plus the value of the current the load draws from the supply must be less than the maximum current of the supply.

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Extending the Voltage

The power supply may be able to provide voltages greater than its rated maximum outputs if the power-line voltage is at or above its nominal value. Operation can be extended up to 3% over the rated output without damage to the power supply, but performance can not be guaranteed to meet specifications in this region. If the power-line voltage is maintained in the upper end of the input voltage range, the power supply will probably operate within its specifications. The power supply is more likely to stay within specifications if only one of the voltage or current outputs is exceeded.

Series Connections

Series operation of two or more power supplies can be accomplished up to the output isolation rating (240 Vdc) of any one supply to obtain a higher voltage than that available from a single supply. Series connected power supplies can be operated with one load across both power supplies or with a separate load for each power supply. The power supply has a reverse polarity diode connected across the output terminals so that if operated in series with other power supplies, damage will not occur if the load is short-circuited or if one power supply is turned on separately from its series partners.

When series connection is used, the output voltage is the sum of the voltages of the individual power supplies. The current is the current of any one power supply. Each of the individual power supplies must be adjusted in order to obtain the total output voltage.

In the Agilent E3631A the two 25V supplies can be operated in series to obtain one 0 - 50V supply. The power supply can be put in “Track” mode and then the output will be twice that shown on the front panel. The current will be that of either the + 25V supply or the -25V supply.

Remote Programming

During remote programming a constant-voltage regulated power supply is called upon to change its output voltage rapidly. The most important factor limiting the speed of output voltage change is the output capacitor and load resistor.

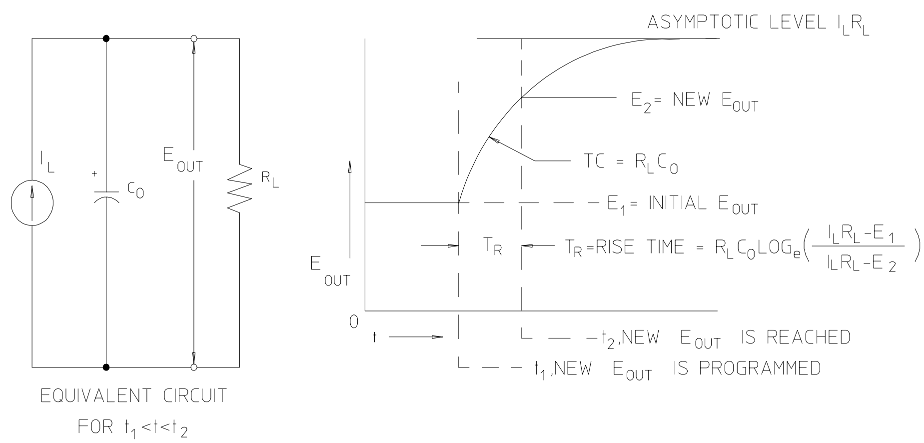

Figure 7-7. Speed of Response - Programming Up (Full Load)

The equivalent circuit and the nature of the output voltage waveform when the supply is being programmed upward are shown in Figure 7-7. When the new output is programmed, the power supply regulator circuit senses that the output is less than desired and turns on the series regulator to its maximum value I_L, the current limit or constant current setting.

This constant current I_L charges the output capacitor C_O and load resistor R_L parallel. The output therefore rises exponentially with a time constant $R_L C_L$ towards voltage level $I_L R_L$, a value higher than the new output voltage being programmed.

When this exponential rise reaches the newly programmed voltage level, the constant voltage amplifier resumes its normal regulating action and holds the output constant. Thus, the rise time can be determined approximately using the formula shown in Figure 7-7.

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If no load resistor is attached to the power supply output terminal, then the output voltage will rise linearly at a rate of C_O/I_L when programmed upward, and $T_R = C_O(E_2-E_1)/I_L$, the shortest possible up-programming time.

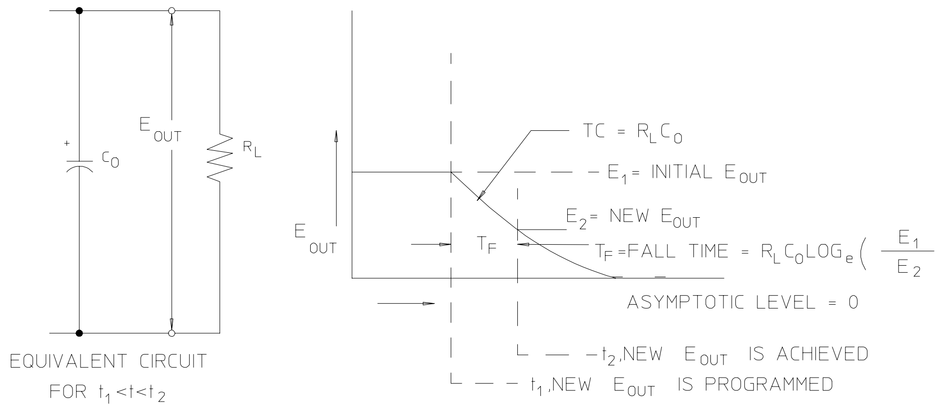

Figure 7-8. Speed of Response -Programming Down

Figure 7-8 shows that when the power supply is programmed down, the regulator senses that the output voltage is higher than desired and turns off the series transistors entirely. Since the control circuit can in no way cause the series regulator transistors to conduct backwards, the output capacitor can only be discharged through the load resistor and internal current source (I_S).

The output voltage decays linearly with slope of I_S/C_O with no load and stops falling when it reaches the new output voltage which has been demanded. If full load is connected, the output voltage will fall exponentially faster.

Since up-programming speed is aided by the conduction of the series regulating transistor, while down programming normally has no active element aiding in the discharge of the output capacitor, laboratory power supplies normally program upward more rapidly than downward.

Reliability

Reliability of electronic semiconductor equipment depends heavily on the temperature of the components. The lower the temperature of the components, the better the reliability. The Agilent E3631A incorporates circuitry to reduce the internal power dissipation of the power supply and therefore reduce the internal heat of the power supply. Maximum internal power dissipation occurs at maximum current. The internal power dissipation further increases as the output voltage is lowered. A fan internal to the Agilent E3631A is essential to keep internal temperatures low. To assist in cooling the Agilent E3631A the sides and rear of the Agilent E3631A should be kept clear.