# Selecting a Linear or PWM Power Source

*by Mitchel Orr, Pacific Power Source*

Understanding the capabilities and differences of linear and pulse-width modulated (PWM) AC power sources is especially helpful when determining which models meet your requirements. And, the selection of an AC power source should be based on more than just three catalog specifications of rated voltage, frequency, and power.

Critical operational capabilities include bandwidth, current, and regulation. Other application-specific requirements are size, weight, operating temperature, and cost.

For many midrange applications, either linear or PWM switchmode technology will provide equally satisfactory performance. In other more stringent applications, only one of the two technologies will best meet an operator's particular needs.

Within the United States, commercial supplied AC power is convenient, reliable, and usually stable. By intent, supplied AC is inflexible. Commercial AC is neither flexible enough nor noise-free enough to allow precision measurements. However, many tests require a wide range of controlled voltages and frequencies. Other tests must support startup surges and the measurement of harmonic currents.

Unpredictable variations make repeatable controlled tests impossible. As a result, a precision AC power source becomes an obvious solution.

A well-instrumented AC power source can deliver precisely managed power to fully characterize a UUT. It may be used to present a range of voltages and currents to determine steady-state power needs. In addition, transients, harmonic waveforms, and other voltage perturbations may be added.

These features support limit testing and verification of operational extremes for a UUT. Using the AC power source's built-in measurement features, the loading characteristics of the UUT can be analyzed.

## Load and Performance Testing Requirements

A rugged power source is essential for use in the production environment. A production source must be convenient to use and deliver the prescribed wave shapes, frequencies, and power to the UUTs.

For general-purpose testing, ease of reconfiguration is important. Reconfiguration capabilities include voltage range, frequency range, number of output phases, and execution of preestablished voltage limit tests.

Many loads are not resistive. As a result, an applied voltage and load current may not be in phase. Out-of-phase operation is identified here as low power factor. By definition, power factor is the ratio of real to apparent power but most often observed as the phase angle difference between voltage and current waveforms.

Additionally, a load may demand peak current many times greater than that predicted by average power con-

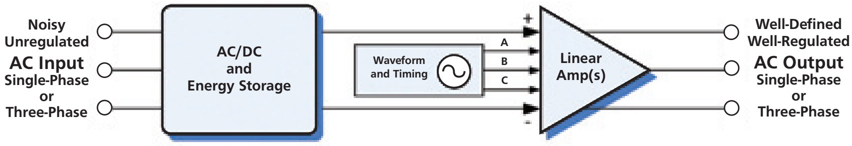



Figure 1. AC to AC Linear Amplification Power Conversion

sumption. A high peak current condition is identified by the crest factor, which is the ratio of peak current to an AC waveform's rms current.

Finally, in many applications, the selected AC power source must provide a reservoir of energy. Reserve energy is necessary to meet startup surge current requirements without distorting the voltage waveform.

## Overview of Power Conversion

Electrical power converters transform electrical energy in one form into electrical energy in another form. An AC power converter can be thought of as a unit with only input and output terminals. From this simplistic perspective, the input-to-output process appears to be simply AC to AC power conversion.

However, from the implementation perspective, internal power management involves AC to DC conversion at the input. The output requires DC to AC conversion. Any wide-range AC to AC power source includes intermediate processes of AC to DC and DC to AC conversion. These are not academic considerations. The efficiency of each conversion process has implications for weight, size, temperature rise, and cost.

More efficient conversion processes including amplification facilitate smaller, lighter weight, and cooler running units. Less efficient conversion processes result in larger, heavier, and hotter running units. It follows that the efficiency of each type of amplifier is a significant factor in determining size, weight, and temperature rise.

AC to AC power conversion provides a reliable source of operator-controlled AC power. The AC mains provide basic power. The converter delivers a tightly controlled synthesized waveform at the prescribed voltage, frequency, and power level.

## Basic AC to AC Conversion

The reason for using either linear or switching technology depends on the specific application. For example, consider a nonsinusoidal unity power factor load with a high crest factor. This load requirement is best satisfied by a linear amplifier. High-power linear amplifiers can deliver peak currents with undistorted voltage waveforms.

For another example, consider a load with a very low power factor. Low power-factor requirements are more easily satisfied by PWM switchmode amplifiers. Switchmode amplifiers can deliver full current in all four quadrants.

## Technological Considerations

Consider the individual testing requirements to determine whether linear amplification or PWM switchmode operation provides superior performance. In addition, careful evaluation of requirements will determine which of the two technologies provides the more cost-effective solution. Operational requirements include the following:

- Fast transient response
- High crest factor
- Low output impedance
- Low power factor loads, both nonlinear and reactive
- Startup surge current
- Size and weight

## Linear AC Power Source

Linear AC power sources produce low-distortion output waveforms. Linear amplification is achieved by using nonsaturating methods. The advantage of linear amplification is faithful reproduction of the oscillator waveforms.

However, linear amplifiers have the disadvantage of being very inefficient. The types of linear amplification include Class A, B, and AB. The letters refer to the signal conduction angle. Class A linear amplifiers typically operate at less than 50% efficiency. Class B or AB can achieve peak efficiencies greater than 50%.

As a consequence of low operating efficiency, size and weight can become major issues for linear power sources. Keep in mind that linear AC power sources feature full power wide bandwidth, excellent transient response, and the lowest possible output impedance.

The characteristics of linear-amplifier technology include the following:

- Very low output distortion
- Wide output bandwidth
- High crest factor handling for a wide range of loads without waveform distortion
- Wide range of active output impedance control (optional)
- Higher temperature operation due to Class A, B, and AB amplifier inefficiencies
- Larger size due to increased component count
- Higher weight due to increased component count

**Figure 1** illustrates the operation of an AC to AC linear power source. At the input, single-phase or three-phase AC is converted to DC. Following rectification, filtering removes AC ripple, broadband noise, and intermittent transients.

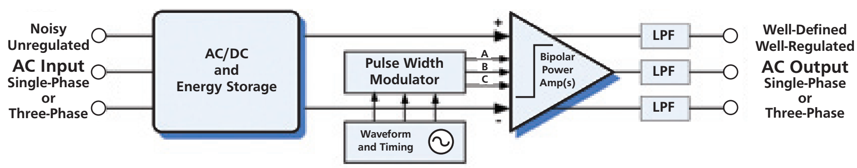



Figure 2. AC to AC Switchmode Power Conversion

Energy storage overcomes the effects of dropouts and line sags. The stored energy is subsequently used for powering the output amplifier.

| Application | Linear | Switchmode |
|---|---|---|
| DC Supply ATE Tests | Best | |
| 400 Hz, Synchronous ATE System | Best | |
| R&D Power Line Disturbance Tests | Best | |
| Watt-Hour Meter Testing | Best | |
| Power Line Disturbance Tests | Best | |
| Production Life Tests (frequency conversion) | | Best |
| Circuit Breaker Tests | | Best |
| Safety Compliance Tests | | Best |
| Commercial Appliance Test and Burn-In | | Best |
| Motor Performance and Safety Tests | | Best |

**Table 1. Typical AC to AC Power Source Applications**
*In a particular situation, either amplifier type may be more appropriate.*

| Feature/Capability | Linear | Switchmode |
|---|---|---|
| Highest Amplifier Efficiency | | Best |
| Lowest Operating Temperature | | Best |
| Lowest Weight | | Best |
| Smallest Size | | Best |
| Lowest Cost | | Best |
| Low-Power Factor Handling | | Best |
| Lowest Harmonic Distortion | Best | |
| Highest Small-Signal Bandwidth | Best | |
| Highest Large-Signal Bandwidth | Best | |

**Table 2. Feature/Capability of Each Technology**

Simultaneously, a low-level controlled waveform is generated by an oscillator in the power source.

As a practical matter, typical waveforms are stored as digital samples. Consequently, synthesized wave shapes are identical regardless of output frequency. Finally, the waveform is amplified to the required level of voltage and power. When required to manage complex loads, the linear amplifier's output impedance can be fixed or managed through controlled feedback. The linear amplifier's wide bandwidth is ideally suited to faithfully delivering complex waveforms.

## Switchmode AC Power Source

Switchmode AC power sources use a combination of linear and nonlinear methods to achieve waveform amplification, including PWM, nonlinear amplification, and low-pass filtering. Switchmode amplifiers are highly efficient because they are either fully on or fully off. Consequently, less power is dissipated in the amplifier than for linear amplifiers with full-range conduction cycles.

Switchmode amplification is called Class D. Class D amplifiers provide an output with high harmonic content. An output-stage low-pass filter removes high-frequency distortion. The output of the low-pass filter is an amplified version of the input signal.

**Figure 2** illustrates the operation of an AC to AC switchmode power source. Input power processing and oscillator signal generation are identical to those of the linear AC power source. However, for switchmode conversion, the low-level analog signal is not sent directly to a linear amplifier. Rather, it is sent to the input of a pulse-width modulator, which operates at a free-running frequency many times greater than the highest frequency in the input waveform.

With zero analog signal amplitude input, the output of the modulator is a rectangular wave with equal positive and negative periods. Consequently, for zero input, the output of the low-pass output filter is exactly zero volts.

As the width of the modulated pulses follows the polarity and amplitude of the input signal, the filter's output becomes an amplified version of the oscillator input signal. Because the output is derived from pulse-width samples, there is a larger fractional percentage distortion than with a linear Class A, B, or AB amplifier. But, the output stage efficiency is much greater than for linear amplifiers, typically 80% or more. Lower power loss in the output stage results in cooler operation and smaller size components.

The characteristics of switchmode technology include the following:

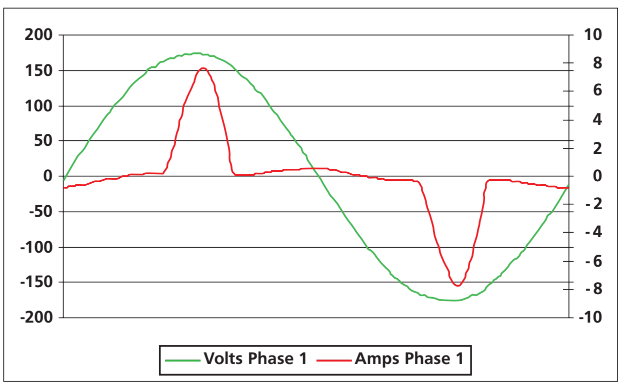
- Moderately low output distortion
- Capability to provide full current into very low power factor reactive loads
- Capability to provide full current over full voltage range without derating
- Moderately wide output bandwidth
- Moderate range for active output impedance control
- Lower weight due to higher amplification efficiencies
- Smaller size due to smaller/fewer components
- Lower temperature operation due to higher amplifier efficiencies
- Limited ability to reproduce complex transient waveforms

## Comparison of Features and Capabilities

**Table 1** lists typical applications for AC to AC power sources. Linear technologies provide superior performance for some testing applications; PWM switchmode technology excels for other applications.

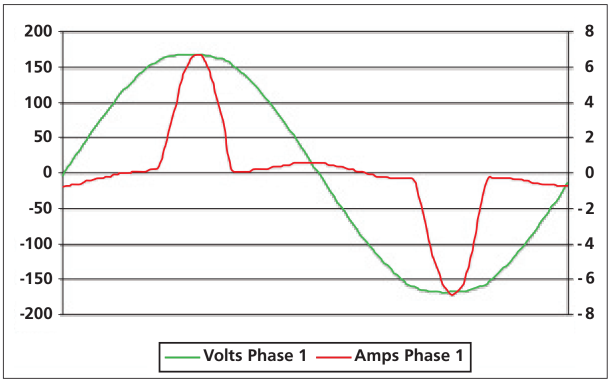
**Table 2** lists generic benefits of each of the two technologies. No single technology performs well in all areas. And remember that over-specifying may lead to avoidable cost, weight, and environmental concerns.

**Figure 3** demonstrates the peak current capability of a typical linear amplifier driving a nonlinear load. It depicts




| Nonlinear Load Driven With Linear Amplifier | |
|---|---|
| Vrms | 124.20 |
| Irms | 2.77 |
| Ipeak | **7.71** |
| Icrest | 2.78 |
| kW | 0.23 |
| kVA | 0.34 |
| PF | 0.66 |

**Figure 3. Peak Current Capability of Linear Power Source**




| Nonlinear Load Driven With Switchmode Amplifier | |
|---|---|
| Vrms | 122.46 |
| Irms | 2.58 |
| Ipeak | **6.70** |
| Icrest | 2.59 |
| kW | 0.21 |
| kVA | 0.31 |
| PF | 0.68 |

Figure 4. Peak Current Capability of Switchmode Power Source

the output voltage and current waveforms of a typical nonlinear load.

Of particular note is the peak current demand of 7.71 A pk creating a 2.78:1 crest factor even though the rms current measures at less than 3 A rms. By driving this particular load with a linear amplifier, the output voltage waveform remains undistorted, allowing unrestricted evaluation of the UUT.

In **Figure 4**, the same load was connected to a switchmode AC power source. Here we see clipping on the peak of the voltage waveform as the current demanded by the load exceeds the crest factor capability of the amplifier. This clipping is a direct result of the increased output impedance of the power source.

The increased impedance served to reduce both the peak current and the current crest factor. Had this power amplifier been used to evaluate the UUT, the rms and peak current demand would be underreported and the load-induced voltage distortion overstated.

## Conclusion

Under conditions of midrange performance, switchmode sources are more cost-effective. For the absolute highest midrange performance, linear amplifiers are more capable. There is no single-parameter, right or wrong solution when it comes to selecting a linear or a switchmode AC power source. The appropriate solution depends on the full set of requirements including:

- Output voltage range
- Output current, including inrush and overload
- High peak current for nonlinear (high crest factor) loads
- Phase angle of output current (power factor)
- Accurate replication of custom or high harmonic waveforms or both
- Fast transient capability
- Amplifier output voltage distortion
- Amplifier output impedance and control
- Size, weight, and efficiency limits
- Environmental needs and limits
- Performance vs. price considerations

Given a set of realistic requirements, you can make an objective decision about which technology provides the appropriate solution. When the exact requirements are not obvious, knowledgeable vendor application support often is the best path to success.

## About the Author

*Mitchel Orr is the sales manager for Pacific Power Source. Mr. Orr, a U.S. Navy veteran, began his career at the company in 1986 and since then has worked as a test technician, an in-house and field service technician, an applications engineer, and product marketing manager. He earned a business degree from National University. Pacific Power Source, 17692 Fitch, Irvine, CA 92614, 949-251-1800, e-mail: Mitchel.orr@pacificpower.com*

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