# The PowerLight 9.0^PFC^

## High-Power Innovations in Audio Amplifier Technology

Sometimes the magnitude of a task requires tossing aside conventional technologies used for smaller, easier undertakings, and instead developing and adapting new ones to suit. QSC's engineers faced such a situation developing the Power-Light 9.0^PFC^, the first high-power professional audio amplifier to feature power factor correction, a very prominent feature among other "firsts" and "mosts."

Responding to the growing demand in the sound reinforcement industry for more powerful and reliable amplification in smaller and lighter packaging, our PowerLight 9.0^PFC^ design team took on no small challenge: to develop an amplifier that delivers at least twice the power of one of the world's most powerful amplifiers—the PowerLight 4.0—without sacrificing the rack size and ratio of watts per pound. And of course, the team couldn't compromise audio performance in any way.

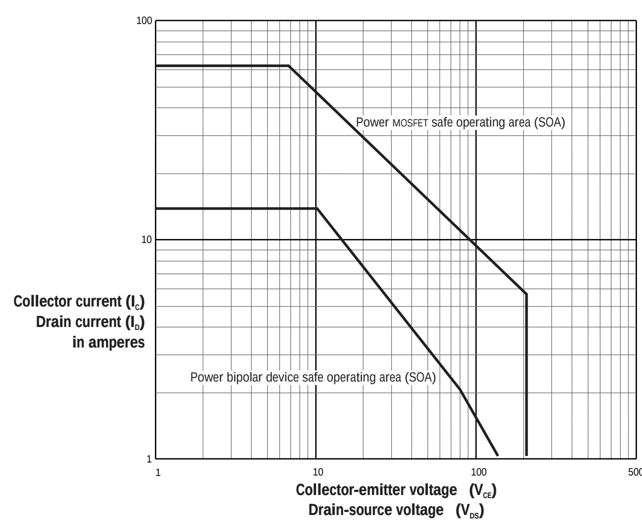
The design team's job was to develop a new class of amplifier whose power is measured in thousands of watts, rather than hundreds. The result is the most innovative and advanced amplifier on the planet, delivering up to 9000 watts of undistorted power. The objective of this paper is to take the reader behind the curtains and explain the basic technology and its benefits to the pro audio user.

## The amplifier: new devices, new techniques

Seeking to double the 4.0's power output in the same size package, we quickly saw that we could not simply scale up the familiar bipolar transistor designs that have served us well at lower powers. It would simply take too many devices and too much heat sink area to do the job. No, this required a new class of device.

The most rapidly advancing class of power devices today is the N-channel power metal oxide semiconductor field-effect transistor (MOSFET), currently used primarily for high-power switching supplies; this application requires devices with very high speed, capable of handling high currents and high voltages, and having low on-resistance. Coincidentally, these properties also make them suitable for high-performance audio amplification. The power MOSFET supplies an unmatched combination of very high peak voltage *and* current capability, together with uniform gain. Among the broad choice of device ratings are large-die transistors that individually can replace several bipolar devices. Furthermore, the power MOSFET has no "second breakdown" region, which has historically limited the maximum power potential of bipolar devices. The power handling capacity of the MOSFET is limited strictly by the thermal capacity of the device package and the heat sink structure it is attached to, which can be made as heavy as required. For the PowerLight 9.0^PFC^, we determined that eight latest-generation, large-die MOSFETs can replace a bank of 56 bipolar devices, with equal or better energy handling ability.

Don't confuse the N-channel MOSFET with the lateral type that has been used for years in many traditional linear audio amplifiers. The lateral devices, although available in both polarities, have inherently lower current and efficiency limits. Although simple moderate-power-level designs utilizing lateral MOSFETs have been successful, their per-device power capacity is no better than traditional bipolar devices, and




***SOA comparison of power devices***

their efficiency is somewhat lower. The switching-type, N-channel MOSFET employed in the PowerLight 9.0PFC, on the other hand, has far lower on-losses and far greater current capacity.

There are two main obstacles to using N-channel MOSFETS effectively: their turn-on thresholds vary widely from one device to another; and they can only be produced effectively in N-channel polarity. The threshold variations would tend to result in uncontrollable idle current and possible crossover distortion, and the single polarity requires a new circuit concept to produce a fully complementary, matched positive and negative output signal. To solve the problems we developed a fundamentally superior amplifier architecture that we call Full-Bridge Current Cell topology.

## The current cell concept

Current cell topology solves both problems by enclosing each FET within closed-loop active circuitry to create a predictable relationship between input signal and output current. This support circuitry converts the real-world device, despite its variables, into an ideal circuit element with zero turn-on threshold and better than 1% linearity. In effect, it creates the ideal device that every audio engineer has dreamed of. Cell elements are matched to within 1%, making low-distortion arrays easy to configure.

Deploying these cells in a conventional half bridge would require dual matching positive and negative power supplies in order to produce a symmetrical output signal. Because of the high power requirements, though, the PowerLight 9.0PFC uses four dual current cells on each channel in an internally grounded, full-bridge configuration, which also simplifies the power supply structure, as we'll discuss later.

The full-bridge topology has a balanced, fully symmetrical power flow, and it delivers positive and negative output voltages from a common power supply reservoir. Furthermore, it balances out certain residual distortion mechanisms from the audio signal. When combined with the four-step Class H rail control scheme described below, the result is a very high power linear output stage with an efficiency approaching that of a Class D (pulse-width modulation) amplifier.

## Class B signal conversion

Getting good results even with ideal current cells required another innovation: a perfect Class A-to-B converter. Audio from the input stage is in the form of a Class A signal, a continuous voltage which varies symmetrically between positive and negative limits. For optimum efficiency, we need to split this single continuous signal into perfectly matched positive and negative halves, so the resulting Class B signals can be routed to their respective current cells.

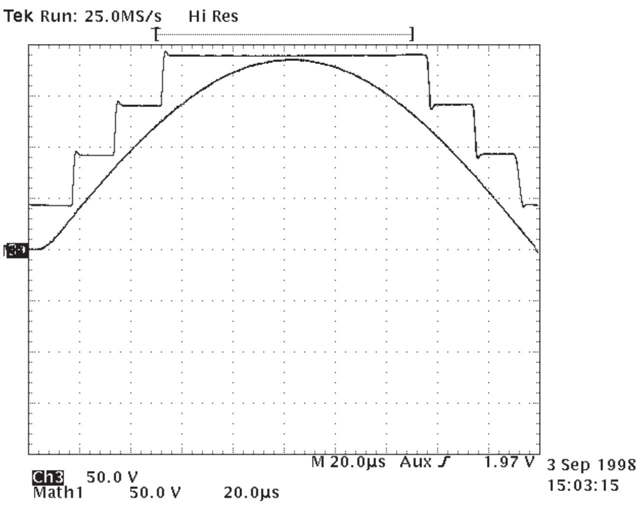
In a conventional amplifier, this polarity split is done with moderate accuracy using complementary positive- and negative-polarity transistors, carefully biased so they "just meet" at zero. The positive transistor handles the positive half of the waveform and ignores the negative half, and the negative transistor does the opposite. In most cases, it works acceptably well, although the center matching is somewhat imprecise and thermally variable, requiring carefully designed thermal compensation circuits to maintain a good trade-off between acceptably low crossover distortion (zero-crossing errors) and excessive idle current. Also, because the bipolar scheme uses two separate amplifying transistors, the cumulative component tolerances can cause a mismatch between the positive and negative halves. There are also breakdown situations in which both devices might amplify at the same time, leading to a catastrophic overload of both output polarities. And in a design involving many thousands of watts, the stakes in eliminating these problems are very high.

The PowerLight 9.0PFC uses an innovative "current steering" scheme, which first converts the audio signal to a current using conventional conversion techniques. The current then enters a special cell carefully designed around the exact exponential characteristics of transistor junctions and separates the original current into positive and negative halves. Additional cells then route the signal current to the four quadrants of the full-bridge output circuit, where the actual power amplification takes place. Processing a signal as current instead of voltage delivers exceptional high frequency bandwidth. Thus, current steering makes it possible for the PowerLight 9.0PFC to have both very high power and excellent performance over the full audio band and complete stability at high frequencies.

Current steering is inherently linear because the total current remains constant, preventing unpredictable conditions that trigger destructive increases in idle current. Even a component failure cannot result in simultaneous positive and negative conduction; at worst, only the point at which the positive and negative polarities split would be affected, and even then regular DC fault shutdown protection would guard against such a severe fault. As a result, the massive power of the output stage is smoothly and predictably controlled. Also, the circuit transfer function is uniform—open- and closed-loop gains remain constant even through the crossover transition. Moreover, the crossover operating point is completely free of thermal transient modulation because it is maintained instantly and electronically; therefore, crossover distortion never creeps in even during the most severe musical dynamics. These are some reasons why the PowerLight 9.0PFC offers superb signal integrity similar to Class A designs, but without the characteristic high losses.

## Multi-tier energy reservoir

Several PowerLight models use multi-tier power supply rails to improve efficiency. For example, the PowerLight 4.0 has a bipolar, 3-tier design.




***4-tier Class H rail switching in the PowerLight 9.0$^{PFC}$***

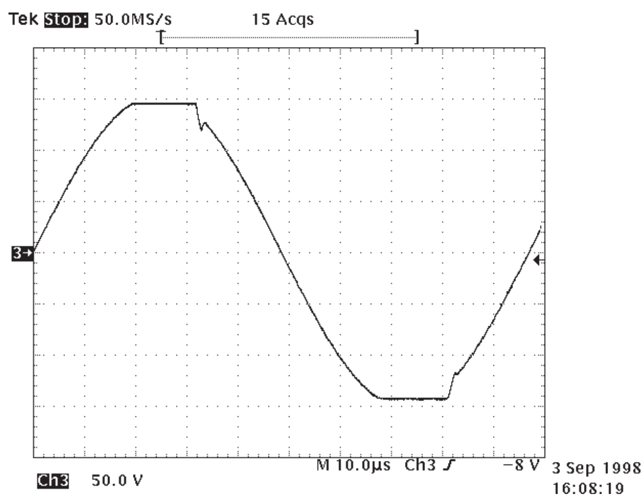
The PowerLight 9.0$^{PFC}$ ups this to a four-tier design, which would normally require eight distinct rail voltages (four positive and four negative). However, the full-bridge output stage allows us to do the same thing with a single, much less complex four-tier supply that serves both polarities of the output signal.

But even multiple-rail designs will operate at less than optimal efficiency if the rail switching is slow or imprecise. In the PowerLight 9.0$^{PFC}$, a predictive switching scheme guarantees that each supply voltage will be switched on just before the signal needs it, and switched off as soon as possible after the signal falls, in order to squeeze maximum efficiency from the four-tier supply.

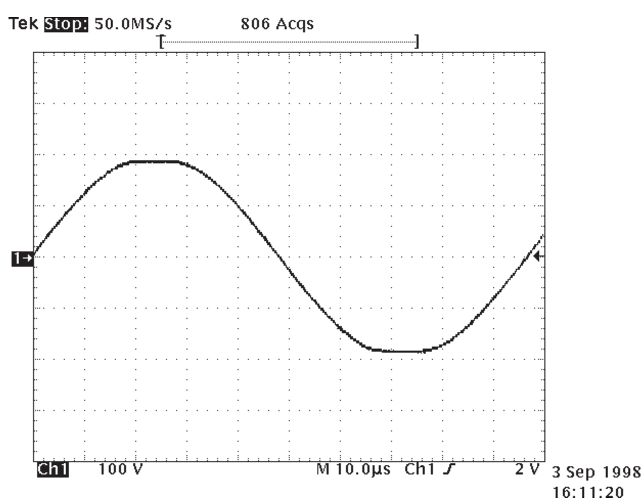
The full-bridge topology also eliminates a subtle large-signal low frequency loading problem inherent in half-bridge designs. The extended period of a low frequency signal pulls current for a long time from first one supply polarity and then the other. As a result, the positive and negative supplies don't share the load as equally as with higher frequency signals. The effect is of power supply reservoir that shrinks as the frequency decreases, reducing low frequency power bandwidth. The full bridge uses the same supply reservoir for both output polarities, so it loads the supply equally regardless of frequency to ensure a uniform low-frequency power bandwidth.

## "Perfect" clipping behavior

Another notable feature is the "non-clipping feedback loop." When ordinary amplifiers reach their voltage limits, the output devices become fully turned on, the feedback signal no longer tracks the input signal, and all internal circuitry slams to its positive or negative limit. When the signal comes back into scale there is a small delay before the internal circuitry recovers, so the amplifier remains in clipping slightly longer than necessary, followed by an abrupt recovery to linear operation. This is often termed *clip sticking.* The PowerLight 9.0$^{PFC}$ is immune to this problem because the signal clips *outside* of the feedback loop. A precision signal processing circuit tracks the available headroom and drives the amplifier with a signal that will clip just within the maximum possible linear amplitude. Therefore, the output cells themselves never actually clip, the feedback signal and internal circuitry remain within scale, and clip recovery is instant, clean, and perfectly controlled. A further benefit: the amplifier maintains constant damping during clipping and never loses control of the load, no matter what the input signal does. Users say this results in cleaner, tighter subwoofer performance.




***"Clip sticking" in a conventional amplifier***




***"Smooth" clipping in the PowerLight 9.0$^{PFC}$***

A 50 kHz Bessel filter and other signal processing circuitry completely prevent slew rate distortion by carefully tailoring rise time to just a little less than the PowerLight 9.0PFC's excellent 40 v/µs slew rate, resulting in the most distortion-free high power high frequency performance available.

These new approaches to audio power circuitry ensure that unlike with some other high power amplifiers, the 9.0's sound remains tight and controlled even if the audio signal tries to exceed its awesome power limits. The amp drives the most reactive loads with ease, and at least for now, the amplifier no longer needs to be a limiting element in system performance.

### Esoteric design for the real world

Much of the value in QSC amplifiers comes from our time-tested solutions to the many mundane problems that exist in all high-power amplifiers. For instance, as in other QSC designs, the output power devices mount directly to their metal heat sinks to ensure the tightest possible coupling between the power chip and the cooling structure.

Instead of lighter, high-density finned structures, QSC amps use aluminum extrusions for cooling, providing extra thermal mass to absorb musical peaks without short-term temperature rise. With four variable-speed fans providing cooling air flow, the PowerLight 9.0PFC boasts a higher thermal capacity than any other high-power amplifier.

We also use the latest generation of components and production processes: 1% resistors are standard, with 0.1% resistors in critical areas. Surface mount technology (SMT) increases component density of small parts by 300%, with more reliable solder connections.

### So how does it sound?

User response to actual production units has been outstanding. We naturally assumed that such a large and expensive amplifier would only be considered for limited applications such as subwoofers, but users have reported that all types of speakers gain new life and authority with the added headroom and control of the PowerLight 9.0PFC. The PowerLight 9.0PFC has been described as a "musical" amplifier, an evaluation that greatly pleases us. Much of this success is due to the audio design, but the power supply also plays a key role in the amplifier's performance.

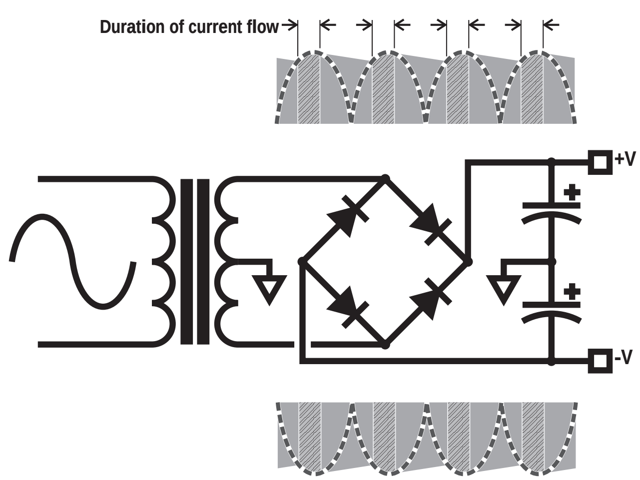
## The power supply story

An amplifier's output section is the pump that supplies power to the speakers, but it can only work if its reservoir is full. This is the job of an amplifier's power supply—to maintain a controlled reservoir of energy at the right value to support the output stage. The problem, of course, is that commercial energy is supplied in the form of AC power at a somewhat constant voltage, which must be converted to a steady reservoir of DC that the output section can draw on.

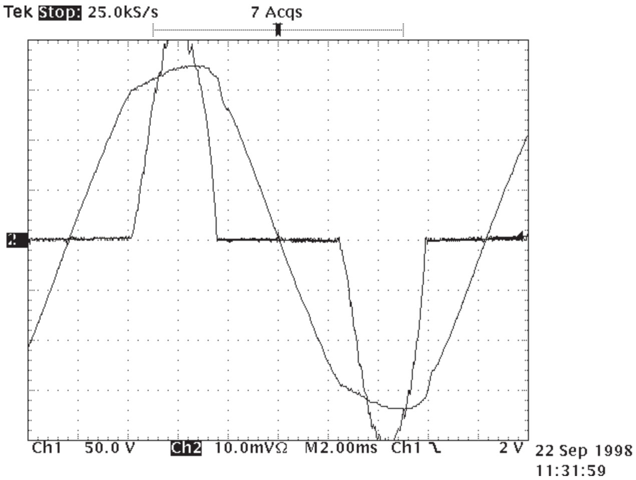
Conventional designs have performed this function acceptably but with noticeable limitations. The most common form of AC-to-DC converter is a peak rectifier followed by capacitive filters; it uses simple, rugged, and low-cost components. It is normally coupled to the AC service with an isolating transformer, which converts the AC voltage to the exact requirements of the output stage and isolates the audio circuitry from shock hazard. However, because of the low operating frequency (50 or 60 Hz) of the transformer, it needs large amounts of iron in its core and many turns of copper in its windings. This is the familiar AC power transformer supply that makes conventional amplifiers large and heavy.

In recent years, QSC has pioneered replacing the heavy low-frequency power transformer with a much lighter but much more efficient high-frequency transformer as part of a direct offline switching power supply. A full-wave AC-to-DC converter, without isolation, provides the high-voltage DC reservoir that the high-frequency switching devices convert to high-frequency AC.

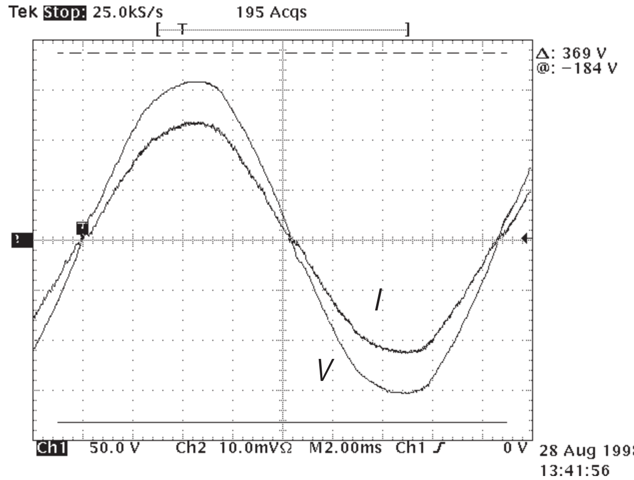
Both types of supply bear a common flaw that is fairly negligible at lower amplifier power points but becomes ever more important as power increases. The peak rectification circuit in either type inherently causes AC current to flow only for relatively short bursts at the peaks of the AC voltage waveform. The entire current demand of the supply is concentrated into these short pulses, resulting in very high peak currents. Under heavy demand, this non-linearity can severely distort the voltage waveform, which can in turn affect other equipment.




***A basic bipolar power supply with an isolation transformer and peak rectification***




***AC voltage and current relationships in a high-power peak-rectified supply, showing short current flow pulses and voltage waveform distortion***




***AC voltage and current relationships in a power-factor-corrected power supply; the current (I) remains directly proportional to the voltage (V) throughout the waveform***

The high peak currents cause added loading on the AC wiring and circuit breakers, reducing the effective maximum power of the supply. This power factor in this situation would be described as poor—i.e., the supply draws more current than it ought to for its power rating. The power factors of conventional AC transformer and offline switching supplies range from 0.6 to 0.75, which means they only deliver 60 to 75% of the power you would expect for a given current. Since the available current is limited by wiring and circuit breakers, this reduces the maximum rating of the amplifier by the same amount.

To correct for this and allow use of the full power of the AC service, we need a power supply that draws current over the entire AC cycle. Therefore, we abandon the simple peak rectifier and use a *power factor corrected* (PFC) supply instead. To accomplish this, we change the energy transfer from the usual voltage mode to current mode. The circuitry is more complex but is the only way to use the full energy of the AC service. And as a major bonus, this type of supply is also capable of correcting for changes in AC voltage, producing a more uniform and stable energy reservoir for the output section. This accomplishment is the other half of the story behind the PowerLight 9.0$^{PFC}$.

First, the incoming AC is rectified, but it does not directly charge a large capacitive energy reservoir as in a peak rectifier. Instead, the voltage is coupled “as is” to a high-frequency inductor, which is capable of storing high currents for a brief period. The output of this inductor is controlled by a bank of high voltage switching MOSFET devices, similar in size to those used in the audio amplifier but with a much higher voltage rating. These are turned on briefly to add energy to the inductor, and then turned off very quickly so this energy is discharged into the energy reservoir. A control circuit adjusts the *duty cycle,* or on-off ratio, to manage the current build-up in the inductor and thus the energy transferred to the load.

The PFC control system for these switches is very complex, as it must simultaneously perform two missions. First, the current drawn from the AC line must be made to match the voltage waveform. This is the essential requirement for a good power factor. The PowerLight 9.0$^{PFC}$ supply typically achieves a 0.99 power factor, meaning it synchronizes AC current and voltage almost perfectly. Second, the *average* current must be made to match the average demand of the audio section, in order to maintain the proper voltage level in the audio energy reservoir. Since typical audio power demand bounces up and down rapidly, balancing these two somewhat conflicting requirements is one of the keys to successfully adapting PFC supplies to audio amplifiers.

As with the power amplifier circuitry, the power supply of the PowerLight 9.0$^{PFC}$ features true state-of-the-art performance in several areas. The switching MOSFETs are true industrial-type devices, the highest-current film capacitors available are used in the PFC circuit, and the high-frequency isolation transformer achieves an unprecedented coupling factor that is even an order of magnitude better than good conventional design parameters.

The resulting performance of the PowerLight 9.0$^{PFC}$ sets world standards for the audio industry:

- Sustained power handling exceeds 7500 watts per channel.
- Power factor reaches 0.99.
- Thermal efficiency exceeds 90% at typical powers.
- Line regulation compensates for normal voltage variations.
- Specific “road tuning” of the control circuitry in real-world venues strikes the optimum balance between maintaining a stiff DC supply and a smooth AC current draw.

When combined with the outstanding efficiency of the output stage, the result is approximately *twice as much power* for average program material on a given amount of AC service.

## The PowerLight story

So far, this paper has focused on the unique technology embodied in the PowerLight 9.0PFC. However, as a member of the PowerLight family, this amplifier also embodies the other attributes of QSC's most advanced amplifier series, which covers a vast range of power points and includes several special purpose models. In the PowerLight series, QSC is dedicated to building the lightest possible amplifiers with fully professional performance.

All PowerLight amplifiers share these features:

- Advanced, low-noise balanced inputs have 20 dB more common mode rejection.
- Detented gain controls facilitate easy gain matching.
- Road-tuned clip limiting provides a transparent backstop to outboard program limiters, allowing the operator to concentrate on the program dynamics and average power levels rather than exact peak limiting.
- Balanced differential feedback from both output terminals ensures higher damping factor and greater control at all frequencies.
- "One knob" bridge mono control maintains perfect balance and full protection with reduced risk of operator error.
- Remote AC standby allows amplifiers to be switched on remotely without inrush surges.
- Full-flow thermal design exhausts at the front, drawing cool air into the rack instead of waste heat.

And all PowerLight amps feature the QSC DataPort, a high-resolution multi-pin signal path that conveys precision signals to QSControl system controllers such as the CM16, which provides remote control and monitoring of up to eight two-channel amplifiers.

QSC continues to push key elements of PowerLight technology into lower-price markets. For instance, the PLX series uses tightly focused production technology to deliver *voltage mode* switching supply and bipolar output technology to the retail market, which does not require the DataPort and other advanced system links. The PowerLight 9.0PFC sits at the other end of the scale—the most advanced, innovative and powerful amplifier available on Earth; an amplifier that can be used with the confidence that its energy conversion efficiency and audio quality will never be significantly exceeded.



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