QSC Flexible Amplifier Summing Technology™

Optimizing amplifier power through high performance
bridge-parallel configurations

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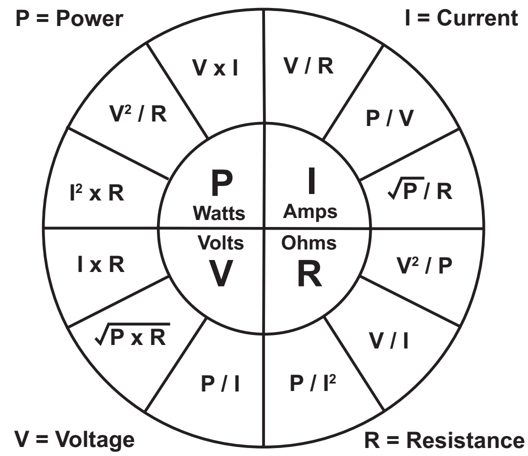
Flexible Amplifier Summing Technology™

QSC has long history of methodical product development and design. While not always the first to market, delivering rugged and robust designs has long been one of the company's hallmarks. The wildly successful K Series loudspeaker line is but one recent example and the PLD and CXD amplifiers are no exception to the rule.

Numerous professional audio manufacturers have rushed into the class D and DSP enabled amplifier market, however many of these product offerings have left-end users with a less than satisfactory experience in both the audio and user interface domains. The QSC PLD and CXD amplifier lines strive to address perceived shortcomings in elegant and transparent ways while offering ground breaking technologies for improved performance. Perhaps the most innovative and practical QSC achievement is the patent-pending feature set called Flexible Amplifier Summing Technology™ (FAST) In order to fully explain FAST an understanding of the limitations that all power amplifiers face needs to be explored.

All amplifiers have blocks of circuitry that are used to provide voltage and current gain to an input signal. Vacuum tubes, bipolar transistors, switching MOSFETs devices have physical limits to the amount of voltage that can be put across them, the amount of current that can be run through them, and the amount of power that they can dissipate as waste heat. Engineers select devices that balance the cost of the product with the amount of output power needed to drive a given load. Broadly speaking, designing an amplifier that only needs to drive 100W at 8Ω, does not require components that handle hundreds of amperes of current. So what are the design parameters or equations that govern these choices?

Ohm's and Joule's Laws



The amount of power that is delivered to a load is governed by two laws – Ohm's law and Joule's law. Ohm's law states that in order to drive a specific current through a specific resistance or load requires a specific voltage.

Mathematically, the formula is stated as:

$$V = I \times R$$

V = volts, I = current in amps, and R = resistance in ohms.

Joule's law explains power and states that the amount of power delivered by an electrical circuit is equal to the product of the amount of voltage across the element multiplied by the amount of current through the element.

Mathematically, this looks like:

$$P = I \times V$$

P = power in Watts, V = voltage, and I = current in amps.

These two simple equations are the foundation for every power amplifier design and can be substituted and blended together to understand the different relationships.

For example, Joule's law can be stated as $V = P / I$ with Joule and Ohm as equal to each other – (V is the same for both); $P / I = I \times R$. One more wave of the hand and $P = I^2 \times R$. To determine how much current an amplifier is going to need to drive 100W at 8Ω, simply substitute figures and calculate. For the equation $P = I^2 \times R$, both P and R are known and a simple calculation indicates that the amount of current the amplifier will have to deliver is 3.53 amps.

At the same time, the voltage that the amp needs to produce 100W can also be calculated. By reformulating the equations, power can also be stated as being equal to the square of the voltage divided by the resistance of the load or $P = V^2 / R$. A quick calculation shows that the 100W load will need at least 28.28V coming from the amp to make it work.

Understanding the use of these formulas is vital to the successful development of any power amplifier. An amplifier that can output 100W into 8 ohms using power components designed to handle 3.53 amps and produce 28.28V reacts very differently when a 4Ω load is placed on the amplifier. A 4Ω load is going to try to draw even more current out of the amp and by using Ohms law; a designer can calculate that the same 28.28V with 4Ω will try to pull a whopping 7 amps of current. Since the original design only required the outputs to handle 3.5A, placing a 4Ω load on the power amplifier will cause the amp to fail.

All high quality amplifiers have some form of protection built into them to prevent them from failing when connected to loads that would otherwise damage them. Most frequently, this protection comes in the form of what is called current limiting. In the case of the 100W amplifier above, a limiter could be placed on the amount of current coming out of the amp – similar to how a rev limiter on a car keeps the RPM in check. With a limiter that only allows 3.53 amps out of the amplifier, connecting a 4Ω load which will want to draw 7A is still limited to 3.53A. This means that the amplifier can now deliver 100W at 8Ω and 50W at 4Ω without failing. In reality, amplifier engineers will design an amplifier so that it has enough voltage to drive the highest desired load resistance to the rated power, and enough current so that it can drive the rated power at the lowest desired load resistance. So, at the low resistance range, usually 2Ω or 4Ω, the amplifier' s power will be limited by the available output current, and at the higher resistance range, the amplifier's power will be limited by the available output voltage.

Now, in most cases, the issue would be settled – but not in professional audio. Audio engineers and integrators continually look for ways to get more power out of their amps. The more power they can get from a single amplifier, the fewer the amplifiers are required for a sound system be it portable or installed. Given the voltage and current limitations previously mentioned, with a single amplifier channel nothing can be done. However, if two or more amplifier channels can be combined it is possible to work around some of these issues.

Bridge and Parallel Configurations

The professional audio industry has long supported and made heavy use of bridge mode on audio amplifiers. Bridge mode is simply driving one amplifier channel out of phase with respect to a second channel then taking the output from the positive terminals of both channels. While one the signal from one channel goes in a positive direction, the other channel moves in the negative direction. Effectively, the load sees twice the output voltage that it would normally see. In the case of a little 100W into 8Ω amplifier, bridging the amplifier delivers 56.56V into the load. Theoretically speaking, the amplifier could now deliver a whopping 400W into an 8Ω load.

Another method of channel combining exists, but it is seldom used in professional audio. The method of putting two output channels in parallel would provide the user double the available current, much akin to the way bridging doubles the available voltage. This would mean a 100W amp with a 3.53A limitation would now be able to deliver the 7A needed to drive that 4Ω load. This begs the question, why are power amplifiers with the ability to parallel outputs not in broad use today? The simple answer is that paralleling amplifier channels is more difficult than it appears – much more difficult than bridging a pair of channels. Unless very careful measures are followed, each amplifier channel will not share current equally – and thus there is no real benefit.

QSC has pioneered a method of combining output channels that allows for standard bridging with the benefit of the doubling of output voltage and allows paralleling with near perfect current sharing with no loss of fidelity. Instead of being limited to a pair of amplifier channels the paradigm has been extended to include multi-channel amplifiers. This means that not only can two channels be placed in parallel; three or even four channels can also be placed in parallel. In these heavily parallel modes, the full available output power of the amplifier can be delivered to a single low impedance load – even down to 1Ω. Moreover, the high impedance performance has been extended by offering a bridge/parallel combination. With a four channel amplifier, two pairs of channels can be independently paralleled and then the parallel combination is bridged providing double the voltage and double the current. The result is full amplifier power that can be delivered into 8Ω load. QSC calls this Flexible Amplifier Summing Technology (FAST).

Developing FAST Technology

In order to create FAST QSC engineers had to overcome several technical hurdles. It required a very well behaved output stage, a method to force each channel to share current in parallel mode, a method to make sure that no matter the output configuration, the amplifier met exceptional audio specifications.

QSC Proprietary MOSFET Circuits

The first of the three major hurdles was to create a repeatable and well behaved output stage. With low powered amplifiers, it is fairly easy to do this, as components required for the 150W range are widely available. However, to get great performance at higher voltage and current levels, available options currently do not meet QSC design specifications. To overcome this challenge, QSC engineers worked directly with semiconductor fabs to create a custom power MOSFET that could handle the voltage and current needed, along with specific qualities that make the device more suitable for audio. This custom MOSFET was then matched with a pair of high speed, low loss current steering diodes and bonded together on a common substrate. Finally, that assembly of diodes and MOSFETS is paired with a duplicate set and mounted into a high temperature package, creating a QSC “power module” that can handle delivering 1250W of power to a loudspeaker load.

The second challenge to overcome was finding a way to ensure that paralleled channels would share the output current equally. There has been recent work in this area however, the solution is expensive, complicated, and requires numerous components. By avoiding the use of active circuitry to control the current directly, the QSC approach is much simpler. The first step in getting channels to share current was to make sure that each power stage received the exact same drive signal. The classic topology for a class D amplifier involves an input stage followed by a modulator to turn an analog signal into a pulse width modulated signal, which is in turn followed by the output devices, which are finally followed by a low pass filter. By using a single modulator and taking the pulse width modulated output and distributed it to each of the power modules, this ensures that each channel gets the exact same drive signal. This drive linking provides the majority of the way to share current. As mentioned earlier, the final section of a typical class D output section is the output filter. This output filter averages the pulse width modulated wave form and re-creates the audio input signal and provides a blocking path for high frequency currents.

If one output section tries to switch before another output section, the output filter will prevent any current flow between the output sections, so long as the amount of time that the output sections differ remains very short compared to the time constant of the filter. By controlling the drive linking signal to ensure that each of the power modules turns on or off within about 60ns of each other, the output filters will block any errant current that would have otherwise flowed. By carefully regulating the timing of these signals, this ensures that all of the power modules are switching at exactly the same time – and since each power module is effectively identical, this ensures that the same amount of current is delivered to the load by each channel.

The final hurdle to overcome directly affects the quality of the audio being amplified. In most situations, each audio amplifier has its own negative feedback path that effectively forces the output to be a larger, distortion free version of its input. Correctly designed, this feedback path will compensate for variations in output device topology, output filter tolerances, power supply ripple, load changes, and all other error sources. When combing two or more channels in parallel, the question of which feedback loop controls the output must be answered. Due to component tolerance issues, a situation can arise where multiple feedback loops "fight" each other, resulting in at best, poor audio quality and current sharing and at worst, outright amplifier instability and failure.

Once again QSC engineers turned to the power module. Since the each power module is effectively identical to its neighbor modules, it can be assumed that error sources in each module will likely be common. Because of this commonality, the corrective action that any particular feedback loop would make due to power stage errors would be the same irrespective of the actual power module in use. Taking advantage of this arrangement, QSC engineers use one global feedback network to control all of the channels that are placed in parallel mode. By eliminating the unnecessary feedback paths and carefully controlling the pertinent error sources, excellent audio performance maintained no matter the channel combination.

Results That Matter

In the end, none of the technological breakthroughs or nuances of implementation mean anything unless they provide real and tangible benefit to the end customer. While making custom integrated circuits is fun, real value needs to be provided to the end customer and in the case of the PLD and CXD line of amplifiers, the value comes in the form of real, usable power. As previously mentioned, all amplifiers have voltage and current limits and these limits describe how much power the amplifier can deliver to a given load. The graph (Figure A) demonstrates how a "normal" amplifier behaves. PLD and CXD amplifiers have the ability to deliver 100Vrms to the load, and can also deliver 17.7Arms to the load.

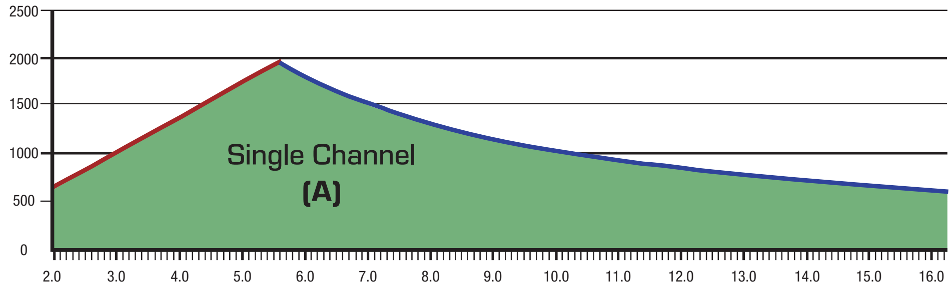


Figure A

Figure A shows the limit of an amplifier's current drive capability along with the voltage drive. The current drive is the red line, the voltage is the blue. In this graph, amplifier can only produce about 600W at 16Ω because it is limited by voltage. Similarly, the amp can only do 600W at 2Ω because of the current limitations of the amp. Essentially, the power delivery region is the region below the two curves.

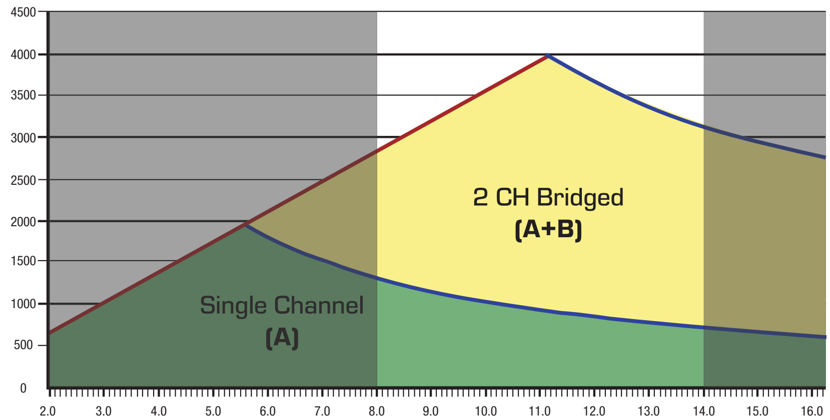


Figure B

If the available voltage is doubled by bridging two channels, the blue line moves up and to the right as shown in the graph (Figure B). This means more power is available at higher impedances, but there is no power increase in the lower impedance range.

When two channels are put in parallel this essentially doubles the current capability. This is illustrated by following the 100Vrms (blue) curve. In this case the red current line moves up and is steeper, offering much more power at low impedances (Figure C).

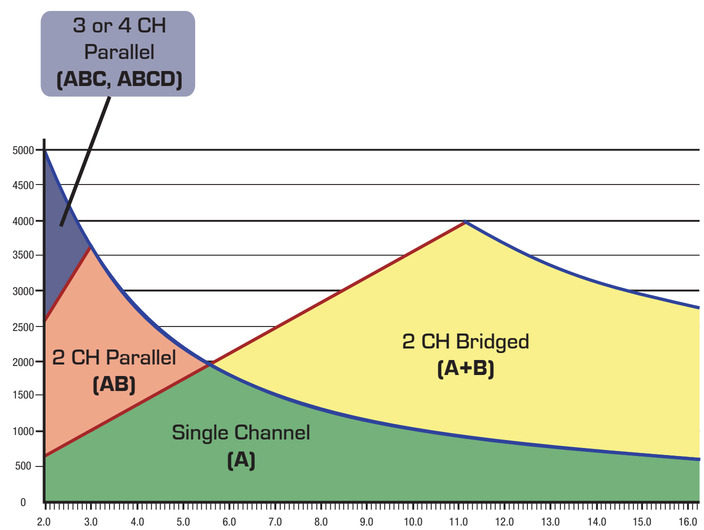


Figure C

In this case, the available power went from 600W at 2Ω to almost 2500W. Moving to three channels and four channels in parallel offers similar benefits. In fact when four channels are combined in parallel, the amplifier can theoretically and safely deliver the full power of the amp into 1 ohm loads.

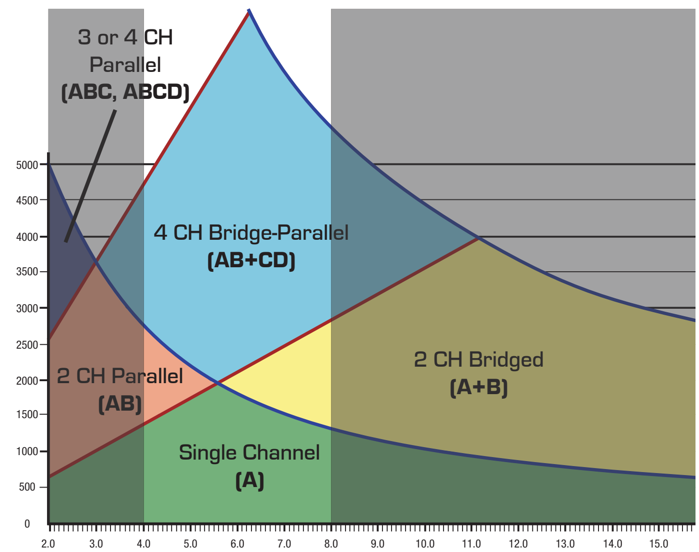


Figure D

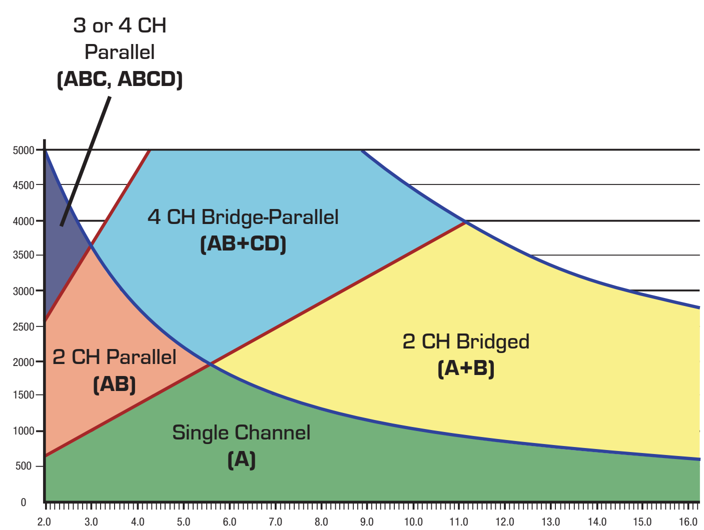


Figure E

Figure D represents what can happen if both the current and voltage is doubled and made available to the load by placing the amplifier into bridge parallel mode. This mode opens up the full available power of the amplifier in the 4Ω to 8Ω region. This means that the amplifier can deliver the full power available from the supply to the load at 8Ω, 4Ω, and 2Ω by simply configuring the output mode. Finally Figure E shows that the power supply of the PLD and CXD amplifiers is capable of delivering 5000W of power.

Conclusion

In summary, Flexible Amplifier Summing Technology (FAST) is a combination of technological breakthroughs consisting of custom designed, well behaved power modules, single modulator control, single loop system feedback, and precision timing. These individual breakthroughs allow a single amplifier to be combined in a variety of ways that allow the full output of the power supply to be delivered to 8Ω, 4Ω, 2Ω, and even 1Ω loads. PLD and CXD amplifiers are the first QSC amplifier solutions to take advantage of this technology.

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