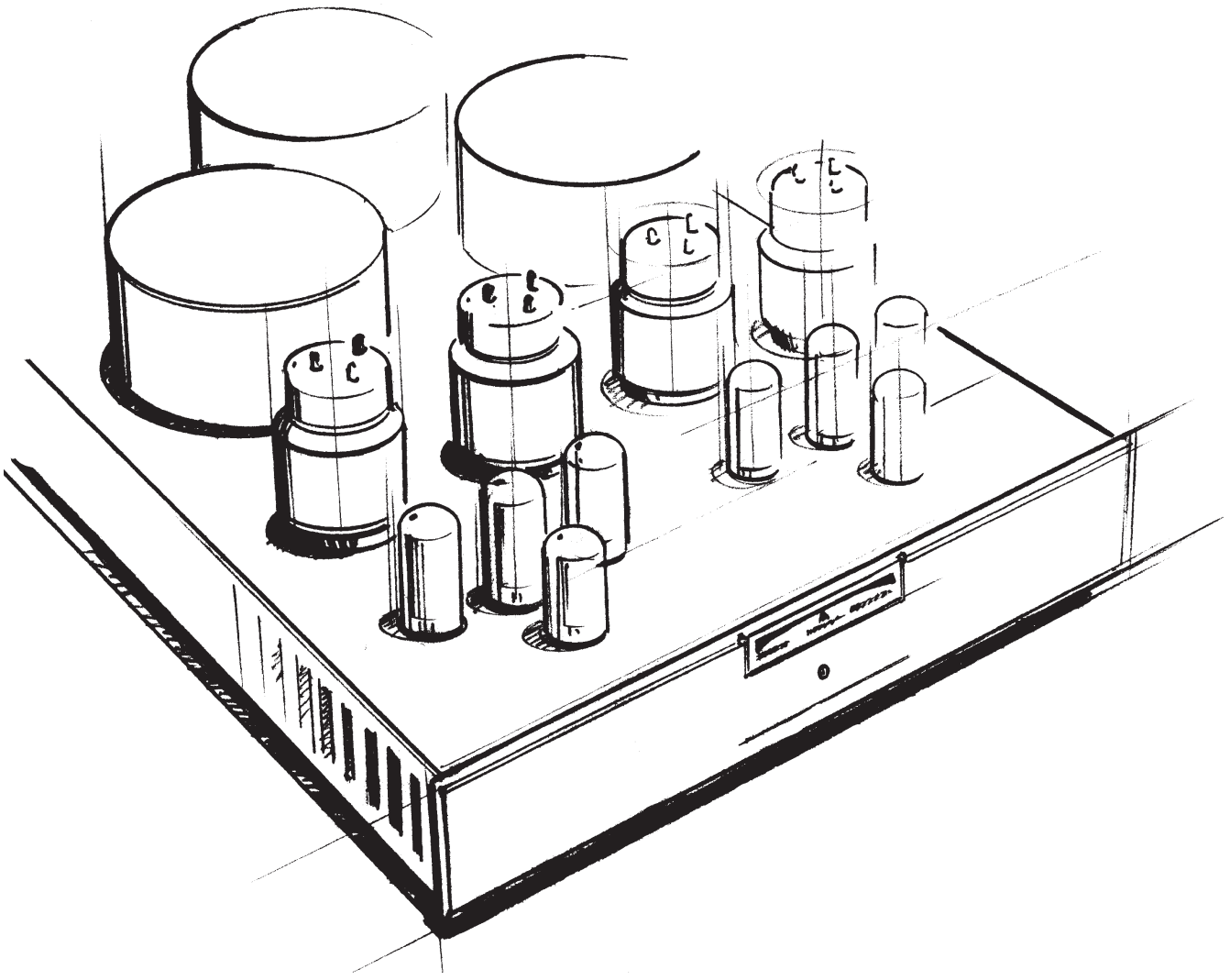
Balanced Audio Technology

VK·60

White Paper



Introduction

The VK-60 is another example of Balanced Audio Technology's relentless pursuit of the "purist" ideal. Modern circuit design principles have been employed to achieve some of the most desirable attributes of the ideal power amplifier. The result is a unique combination of true all-triode zero feedback topology, the ability to drive difficult loads, automatic individual biasing of output tubes and fully balanced design. The VK-60's short signal path is effectively made broad by incorporating high current differential gain stages. Only plate-loaded triode circuits are employed throughout, together with custom oil-filled signal capacitors. Broadband toroidal output transformers serve as the final link between this high fidelity active circuit and your loudspeakers.

Many of the design ideas employed in the VK-60 power amplifier are consistent with those outlined in our VK-5 preamplifier White Paper. These products are the result of the same philosophical approach, and when used together, synergistically create a whole that is truly greater than the sum of its parts. We recommend, therefore, that you consider the VK-5 and VK-60 White Papers together to complete your understanding of Balanced Audio Technology's unique design approach. This paper focuses primarily on those aspects of design that are pertinent to the VK-60 power amplifier.

Overall Topology

The best way to start discussing the VK-60 is by looking at its most important attributes:

- 60 Watts per channel in stereo configuration
- 120 Watts per channel available in monoblock form
- Easily configurable as either a stereo or monoblock unit
- Automatic individual biasing of output tubes
- Fully differential topology from input to output for optimal balanced operation
- No solid state devices in the signal path
- High current low-restriction signal path
- Single-ended bridge output stage, combining the best features of both push-pull and single-ended circuits
- Full compatibility with single-ended preamplifiers
- Zero feedback design
- Plate-loaded triode circuit implementation used throughout
- Custom oil-filled signal capacitors
- Dual mono construction
- 800 VA potted toroidal power transformer
- Low transformation ratio toroidal output transformers with ultra-broadband characteristics
- 500 Joules of power supply energy storage

In the creation of the VK-60, these features were not assembled in an ad hoc fashion. Rather, a logical step-by-step approach was taken, resulting in a product that is more than simply the sum of its parts. The ambitious goal for the VK-60 was to provide a reference standard tube power amplifier with exceptional ease of use. We wanted to design an amplifier that requires little more than turning it on to achieve world class performance. This outstanding ease of use begins with a sophisticated automatic bias circuit.

Automatic Bias

The advanced design of the VK-60 eliminates the traditional headache associated with most tube power amplifiers: the constant need to set and readjust the proper bias of the output tubes. A typical power amplifier will demonstrate its best performance only when the output tubes are biased optimally. Any deviation from this ideal point will result in some performance degradation, including loss of output power, increased signal distortion and reduced tube life. A small loss of power may be tolerable, but the reduced service life of an amplifier's output devices is unacceptable. It is extremely desirable, therefore, to have a power amplifier automatically adjust its output tube bias invisibly to the user, compensating for such conditions as partial mismatching or aging of tubes, as well as fluctuations in line voltage.

Unfortunately, this highly desirable feature is not found in typical commercial products. The reason for this lies in the tremendous challenge that such circuits present to their designers. Creating an automatic bias circuit that reliably and predictably controls the operating conditions of output tubes without affecting the sound in some negative way is a very serious design task. These conflicting requirements qualify the development of a sonically transparent yet robust autobias topology as possibly the most difficult area of power amplifier design.

The VK-60 autobias circuit is active in nature and should not be confused with popular (and often crude) passive self-biasing schemes that can never achieve a comparable level of performance. The "soft" low-feedback character of the VK-60 autobias circuit provides the best possible combination of sonic characteristics, measured performance, and usability.

An important attribute of the Balanced Audio Technology automatic bias circuit is that it ensures that the VK-60 sounds wonderful within the first few minutes of listening. There is a straightforward explanation for this. Most manual bias or passive self-bias circuits are adjusted for their proper bias setpoint with the tubes fully warmed up. As the tubes warm up, their emissions increase and the bias rises to its final value after the tubes reach their full operating temperature. During the warm-up cycle, however, the bias in traditional designs will be set too low and only gradually move upward to its appropriate setpoint. Depending upon tube type, this stabilization may take up to 45 minutes or even longer.

During this period of lower tube emission, the improperly biased unit will sound clinical or even unlistenable. Not so with the VK-60. Its automatic bias circuit compensates for lower tube emissions during the warm-up cycle. The VK-60 always stays within a narrow window of its optimal bias setpoint due to the sophisticated tracking inherent in its automatic bias design.

Maintaining the proper bias also contributes to prolonging the useful service life of the output tubes. The circuit ensures that plate power dissipation of the output tubes always stays at a conservative level.

In addition, automatic biasing makes changing output tubes in the VK-60 a straightforward task. A customer simply installs a new set of tubes and turns the unit ON. The circuit automatically sets the conditions for the best operation. Individual LED indicators show the status of each output tube. Failure of any LED to turn ON indicates a problem with the corresponding tube, which may then be easily replaced. For optimal performance, replacement tubes provided by Balanced Audio Technology should be used.

The Low Restriction Signal Path

The circuit topology of the VK-60 is consistent with our philosophy of utmost simplicity in implementing a clean, unobstructed signal path. However, the unique design of the VK-60 goes significantly beyond simply reducing the number of gain stages.

Every gain stage introduced into a circuit should perform a useful function. Unfortunately, every gain stage (be it active or passive) will also restrict the signal flow to some degree. The more restriction it imposes, the stronger the negative effects such as loss of detail, anemic bass and lackluster dynamics. Balanced Audio Technology has developed an approach that allows the designer to evaluate this aspect of a proposed circuit's configuration in a meaningful and consistent fashion, even before a prototype is built. This shortens the overall product cycle and improves the quality of every new design.

Just as with the electrical resistance of a conductor, the *restriction* to the signal flow that is introduced by a gain stage is a function of two variables: the signal path's length as well as its *width*. Restriction caused by length is typically controlled by reducing the number of gain stages. Restriction caused by width, however, is typically ignored.

We introduce here the concept of *signal path width* as a predictive tool for analyzing the *relative* sonic merits of a particular implementation. Let us postulate that other things being equal, the signal path's *restriction* can be approximated by the equation:

$$Rs = a \star Ls/Ps$$

The terms in the above equation are defined as follows:

Rs = signal path restriction
a = scale constant
Ls = signal path's length (number of stages)
Ps = signal stage's quiescent power (a measure of the stage's width)

Once introduced, this representation strikes many people as intuitive. It also provides a unique insight into why some units with a single stage topology or "short signal path" still sound compromised. Since a short signal path can also be very narrow, the result may be a high-restriction stage with anemic sound.

Further, it is not simply the power that a stage can supply to its load that is important, but its quiescent power. One can configure a very powerful Class-B stage which will fail our test due to its low quiescent current. Most people would agree that such a stage would sound restricted in its overall representation of musical detail due to its inadequate performance around the zero crossover point.

Signal stage power has been confirmed as a predictor of sonic goodness by a significant amount of experimentation performed by Balanced Audio Technology. This experimentation has provided a firm foundation for our innovative decisions, as applied to both preamplifier and power amplifier design. The first product of this philosophy was the VK-5 line stage preamplifier, which employed a gain stage with an exceptionally *wide* signal path. These high-power gain stages operate with uncommonly low *restriction*, to achieve an unprecedented level of sonic transparency. The design of the VK-60 also follows this unique philosophy. Its high-power circuit allows us to avoid the use of popular cathode followers that are responsible for the sonic deficiency of many designs.

Zero Feedback Topology

This powerful comparison tool can be developed further by incorporating additional factors that typically have known sonic effects. One such factor is the amount of global negative feedback that is present in the circuit, denoted here by Kfb. With the introduction of this new term, the equation takes the following form:

$$Rs = a \star (1+Kfb) \star Ls/Ps$$

Put simply, high feedback circuits are restrictive circuits according to this equation. Empirical evidence confirms this to be the case.

In zero-feedback configuration the user listens to the unique voices of each individual component. These voices come through totally free and uncorrected, like solo dancers in a ballet theater. As with solo dancers, these components also must meet the most demanding performance requirements. The proper choice and application of each component are now of paramount importance. The individual parts selected for the VK-60, from the signal capacitors to the power tubes and the output transformers are well qualified for such a mission. Their characteristics are linear and well controlled. The 6C33 tubes are ideal for audio power application due to their low plate impedance and high current capability. The linear operating

range for the VK-60 oversized output transformers extends far beyond their specified 60 Watt output power rating.

In order to evaluate the effects of negative feedback on sound characteristics, an early VK-60 prototype was equipped with feedback controls that provided an adjustment range from 3 dB to 10 dB. We soon discovered that as little as 3 dB of negative feedback was detrimental to the sound. The insertion of negative feedback generally reduces the sound stage as well as lessening the air around the reproduction of the human voice. The sound becomes restricted, no longer breathing like the live event. Thus, notwithstanding the improvements that negative feedback brings to an amplifier's measured performance, every listener preferred the zero feedback position. So uniform was the response, that we decided to eliminate these controls entirely.

We did this without degrading the test bench behavior of the VK-60, while maintaining its low output impedance. The VK-60 is capable of driving demanding speaker loads with a poise uncommon among its true-zero-feedback brethren.

Single-Ended vs. Push-Pull - Is There a Better Alternative?

Single-ended amplifiers have recently become quite popular in high end audio. They can present a wonderfully lucid portrayal of the musical event in the critical middle frequencies, albeit at the cost of low power capability and limitations in the lower bass and higher treble frequency extremes. One of the factors contributing to their stellar midrange performance is the single-ended amplifier's Class-A operation. According to our formulae, this creates a low restriction signal stage. Unfortunately, Class-A single-ended amplifiers are very inefficient. Consequently, their low output power and drive capability present the buyer with a limited choice of speakers for acceptable system matching. Moreover, even when the speaker-amplifier interface is optimized for single-ended amplifiers, the lack of dynamics and slam (that come from having a full bandwidth design) has left many audiophiles wanting for more.

The push-pull amplifier on the other hand can provide higher power output due to the inherent efficiency of this topology. The output devices are often pentodes, beam tetrodes, or these devices configured as triodes. The push-pull amplifier is generally characterized by higher power output, lower output impedance, wider bandwidth, and good dynamics and slam. Unfortunately, it can also be characterized as somewhat opaque or veiled in its presentation of the critical middle frequencies.

One of the reasons for this is that most push-pull amplifiers are biased relatively low, creating, in essence, another restrictive stage. Moderate bias is dictated by allowable output tube power dissipation. Since these circuits typically have a high plate-to-plate impedance, they must operate from a high voltage supply in order to achieve the required output power levels. High plate voltage limits the amount of bias current that can be tolerated without overstressing the tube.

The ideal amplifier would offer the midrange lucidity of the single-ended amplifier while maintaining the power, dynamics and universality of the best push-pull designs. The ideal amplifier would offer a single-ended bridge between these two worlds.

The Single-Ended Bridge Output Stage

Let's take a closer look at these two popular design alternatives: push-pull and single-ended. While either of these terms could be broadly interpreted, some typical properties of each topology are identifiable. The typical push-pull design will have an output transformer with a center tap, carrying equal direct currents through each half. For a number of reasons it is imperative to maintain a high degree of symmetry between the two halves of the primary winding. In the practical single-ended implementation, the full DC bias required for Class-A operation flows through the transformer primary winding.

Either of these traditional implementations challenges the output transformer designer. The transformer easily becomes *the* limiting factor in the circuit. The push-pull stage requires a high degree of transformer winding symmetry and complicated winding techniques in order to achieve acceptable bandwidth. The single-ended implementation calls for an output transformer of large size or one with an air gap to stop the DC magnetization. In both cases, the primary winding of the output transformer is connected to the high voltage source, thus requiring a high degree of electrical isolation from the secondary coil which is at ground potential. None of these requirements, however, is present in the Balanced Audio Technology VK-60 output transformer.

The implementation chosen for the VK-60 output stage incorporates the best attributes of both traditional configurations, without being burdened by their drawbacks. Among the unique characteristics of this output stage are:

- Plate-loaded triode topology
- High bias current operation for low signal restriction
- No DC flowing through the output transformer
- No requirement for a high degree of winding symmetry
- Very low transformation ratio - 2.89 for the 8 Ohm tap
- DC isolation not required between primary and secondary
- Linear characteristics for low distortion levels

With a very low transformation ratio and no DC requirement, we were able to develop custom potted toroidal output transformers with a wide bandwidth and extremely high quality factor. Thus, we obtain a level of dynamics and clarity of expression beyond that of the traditional push-pull design. But since the VK-60 is not a push-pull design, we also capture the midrange clarity of the finest single-ended amplifiers. The single-ended bridge implementation from Balanced Audio Technology provides you with the best of both worlds.

The OTL Trap

Another popular configuration that enjoys a strong following is the Output Transformer-Less or OTL amplifier. Since the 6C33 power tube almost seems designed specifically for this application, a common question is: why isn't the VK-60 an OTL design? An OTL seems to offer great potential for sonic improvement through the elimination of what is perceived as a weak link - the output transformer. It is hard to argue with the general notion that fewer components are better, but let's not forget that "everything should be made as simple as possible, but not any simpler". If in the process of reducing the number of stages or components, we cross the line and start affecting fundamental equipment functionality, then we have deviated from the purist ideal. In the case of an OTL, this lost functionality is its ability to drive a load.

Our position comes from theoretical knowledge combined with practical experience. For a number of years we extensively studied the available OTL implementations and later designed our own model, aimed at achieving the best possible performance from this topology. We succeeded at this. However, while the positive aspects of the overall package were undeniable, so were its shortcomings – indistinct bass and an inability to drive difficult loads. Killing the critical link between the active stage and the speaker turns out to be a bad idea after all. It leaves a wide gap unbridged. We decided, instead, to concentrate on making this link as good as theoretically possible.

First, we carefully analyzed the reasons for the sonic deficiencies of traditional output transformers and discovered ways of eliminating many of them. Then we identified ways of successfully using a superior toroidal configuration. The common apprehension about output toroids stems not from their "fundamental faults", but from improper application. Simply putting a new and better saddle on an old horse is not going to make it run faster. A different circuit topology is required to truly unleash the ultimate potential of the toroidal output transformer. When handled properly, these transformers display sonic qualities that are well beyond those achievable by E-I designs. Their measured performance characteristics are an order of magnitude better than what is traditionally available in E-I products. This reflects a fundamental belief at Balanced Audio Technology: make substantial improvements to critical areas of design without sacrificing important functionality.

The Balanced Audio Technology OTL power amplifier is still running well in one of our reference systems. It has provided us with valuable insight into what an OTL can and cannot do. With the right speaker, the OTL can sound wonderful, although still somewhat deficient in the bass. Even with the speaker optimized for an OTL, however, the VK-60 easily eclipses the OTL's performance. On more difficult loads, there is no comparison.

People who love OTL's in their systems will be pleasantly surprised by the VK-60 sound. They will be able to hear all the best things they traditionally associate with an OTL. But they will also discover that they can finally drive a majority of loudspeakers without experiencing compression on moderately loud passages. They will be impressed with the tight bass control and the fact that a short in one of the output tubes is not going to burn out their expensive speakers. They will discover the new freedom of the VK-60: a step beyond the OTL.

Output Transformers with Multiple Taps

In order to discuss the proper connection of a loudspeaker to a tube power amplifier, we must understand the very reason for the existence of the output transformer and multiple taps.

Every piece of equipment, including an automobile, a computer or an audio power amplifier has limited resources. If someone could build a car with unlimited engine power, this car would need no gear shifter. A computer with unlimited speed and storage space would need no video data compression or smart memory management. Likewise, the tube power amplifier with unlimited power and drive capability would need no output transformer with different taps.

Any system with limited resources will have its performance peak at some point (for example, maximum engine power achieved at a specific rpm's). As we move away from this optimum point, some aspects of performance will decrease. Here we arrive at the following conclusion:

To keep a specific performance characteristic at its peak, a system must be maintained at a particular fixed set of conditions.

Unfortunately, different performance characteristics may peak at different operating points. In an automobile engine, the rpm's for maximum torque are usually different from those for maximum power. What do you do in this situation? You switch gears.

Similarly, various speakers present different impedance characteristics to the amplifier output. What do you do in this situation? You switch output taps. Or if you have an OTL...

you switch speakers. Indeed, many owners of OTL's have found themselves metaphorically driving a car with a great engine but no transmission to apply that power. Great performance is locked inside, but always frustratingly out of reach. The issue is one of load drive and power transfer.

Power Transfer

"The maximum power transfer from the generator to the load will occur when the load impedance is equal to the source impedance." Wrong. At least in the real world. Let's examine the reason for this confusion.

Consider a signal generator of which a power amplifier is a good example. It is characterized by its output voltage and the source impedance, commonly referred to as an output impedance. Connect the load to the amplifier output. Start plotting the power that is produced into the load versus the changing load impedance. If you do this on paper, using an imaginary amplifier, you will create a familiar bell curve. It starts at zero power into a zero impedance load, goes up, peaks at the point of Zload = Zout and then begins to drop smoothly. As load impedance heads towards infinity, the power transferred to the load asymptotically approaches zero once again. The power curve has two slopes: positive from 0 Ohm to Zload = Zout, then negative from this point on. Being on the positive slope means that you develop more power into a higher impedance load. Record this fact in your memory for later.

Applying the above logic to a real world power amplifier produces an interesting observation. Most of the time, the elusive "maximum power transfer" is not achieved. Take a typical solid state monster amplifier. It has an output impedance of .02 Ohm. Rated power is 200 Watts into 8 Ohms and 400 Watts into 4 Ohms. It is obvious that we are on the negative slope of the power curve. Decreasing the load impedance means more power—to a point. There is no way the power curve will keep rising all the way to the Zout = Zload point, for it would mean many Kilowatts produced into the .02 Ohm load. The power amplifier will run into current limiting long before the magic maximum power point is reached.

This is reality. In most amplifiers the maximum power derived from looking at the Zout number will never materialize. Either current or voltage at the amplifier output will be limited before this maximum is reached. This raises another conflict between conventional engineering wisdom and reality. In the ideal amplifier the output impedance is constant and works as a great predictor of the maximum load power. Most amplifiers do not follow the ideal model.

Consider a typical OTL design. It specs an output impedance of 5 Ohms. Then it is stated to provide 70 Watts into a 4 Ohm load and 100 Watts into 8 Ohms. These power numbers indicate that we are still on a *positive* slope of the power curve, where higher load impedance means more power. Stated differently, the effective *true* output impedance of this amplifier must be higher than 8 Ohms. The specified 5 Ohm output impedance does not correspond to the maximum power point. So much for the ideal model.

To summarize:

Small-signal output impedance of the power amplifier is not very useful at predicting its load drive behavior

Many amplifiers' real world *effective* output impedance are substantially higher than their specified small-signal numbers

Optimal power transfer from amplifier to the load does not happen in most cases

Through careful optimization, however, the VK-60 comes closer than many competing models to achieving maximum power transfer while still maintaining strong load drive capability.

Real World Taps for Real World Speakers

The VK-60 is equipped with several sets of output taps for optimal speaker connection. These taps are optimized to drive real world speakers and not the resistive loads commonly used during laboratory testing. The "standard" 8 and 4 Ohm loads provide a very poor representation of most loudspeakers' real behavior. It is a fact that most so-called 8 Ohm speakers have impedances that should be more appropriately defined as 6 or even 5 Ohms. A typical 4 Ohm speaker is in reality closer to 3 or even 2 Ohms. It seems unreasonable, therefore, to waste the limited resources of a typical tube power amplifier by optimizing its performance for 8 and 4 Ohm loads. Therefore, while the VK-60 will provide its rated power output into these "standard" measurement loads, the peak power will occur into a 3 Ohm load (in the case of 4 Ohm taps) and into 6 to 7 Ohm load (in the case of 8 Ohm taps). Such optimization provides for the best possible performance when working with real loudspeakers, offering the combination of *maximum power delivery* and *load drive capability*.

These two parameters unfortunately don't peak at the same time. Optimizing the circuit for maximum power delivery into an 8 Ohm load will usually increase the output impedance of the amplifier. Balancing these two conflicting requirements calls for a good deal of insight into the ways that audio components interact in the real world.

When moving a speaker cable from one transformer tap to another, the user changes both of the above parameters

simultaneously. He can, therefore, optimize his system for either more power or better speaker control (or something in between). Due to the wide range of loudspeakers available, it is advisable not to follow the somewhat simplistic model of just connecting an 8 Ohm speaker to the 8 Ohm taps. While in some cases such a connection will prove to be optimal, other 8 Ohm loudspeakers, especially high-efficiency models, will produce their best sound when connected to the 6 or 4 Ohm outputs. Similarly, we have found some nominally rated 4 Ohm speakers to sound best on the 8 Ohm taps. Therefore, experimentation with different speaker connections should be performed in order to attain the maximum performance available from each system. A loudspeaker's sensitivity, the shape of its impedance curve, room acoustics, as well as a particular listeners' tastes will all affect the choice of the "right" set of output taps in any particular configuration.

Components and Construction

As in the development of the VK-5 preamplifier, the outstanding design potential of the VK-60 power amplifier would not be fully realized without a matching level of excellence in component selection and construction quality. Indeed, certain attributes of the VK-60 implementation, such as its zero feedback design, would be impossible to achieve without the quality of parts that Balanced Audio Technology has selected to complement its design.

The most prominent visual aspect of the VK-60 is its bank of Russian 6C33 output tubes. A version of these rugged power triodes has faithfully served in MIG-25 fighter aircraft for decades. The driver tubes are 6SN7's, renowned for their linearity and reliability. These comprise the high-power, low restriction driver/output tube circuitry for the VK-60. The complete circuit for each channel is mounted on separate 3-oz copper printed circuit board. The only element that the two channels share is a toroidal power transformer of substantial size and superior reserve capability. But even here, the left and right channels enjoy totally separate secondary windings.

The VK-60 incorporates a power-on time delay circuit to improve the reliability of its vacuum tubes. Ample ventilation is provided for all high-power components. Generous design margins are applied to all components with stresses typically not exceeding 50% of maximum ratings.

Only one custom oil-filled capacitor is used per signal phase in the audio chain. The output transformers are toroidal units with wide signal bandwidth. Loudspeaker connections are made via a row of externally mounted high quality gold-plated binding posts instead of sound-degrading terminal blocks. This arrangement is also more convenient than internal output jumpers, sometimes found in competing designs. The binding posts offer a substantial hex head design that allows tight speaker cable connections through the use of a 7/16" hex wrench. Gold-plated Neutrik XLR connectors are used for inputs.

These quality components are presented on an elegant open chassis with a custom grab bar that both accentuates the masculine look as well as providing a convenient handle for carrying the not insubstantial weight of the VK-60. The chassis is constructed of high tensile strength steel for greater rigidity and can be used with standard 1/4" threaded cone feet.

Taken together, the components, construction, and design of the VK-60 allow this power amplifier to be extremely reliable, aesthetically graceful, and musically without peer.

Conclusion

The Balanced Audio Technology VK-60 represents a refreshing and unconventional approach to designing and building a top-performing power amplifier. Its true all-triode, zero-feedback, fully balanced design combined with automatic individual biasing of output tubes and the ability to drive difficult loads is unique in the industry. The VK-60 brings the best of single-ended and push-pull designs together in an exceptionally user friendly power amplifier. To protect your investment, a single VK-60 can be easily reconfigured into a 120 Watt monoblock if you later decide that you need more power. Through careful execution, we have made the VK-60 easy to use, simple to upgrade and a joy for both the eyes and ears to behold.

You owe it to yourself to experience the Balanced Audio Technology VK-60.

Balanced Audio Technology
26 Beethoven Drive Wilmington DE 19807 Phone 302.999.8855 Fax 302.999.8818