Back

The PLH Amplifier

By Nelson Pass

This solid-state magician demonstrates his latest design.

In 1969 John Linsley Hood wrote in *Wireless World*:

> *During the past few years a number of excellent designs have been published for domestic audio amplifiers. However, some of these designs are now rendered obsolescent by changes in the availability of components, and others are intended to provide levels of power output which are in excess of the requirements of a normal living room. Also, most designs have tended to be rather complex.*
>
> *In the circumstances it seemed worthwhile to consider just how simple a design could be made which would give adequate output power together with a standard of performance which was beyond reproach, and this study has resulted in the present design.*

He then described a Class A power amplifier using three gain stages of bipolar transistors in a topology which continues to be admired for its elegant simplicity and sound quality.

The centerpiece of this design is the middle stage, an NPN transistor used as a phase splitter, simultaneously driving the positive half of the output stage and the negative half with symmetric signals of opposite phase.

Figure 1 shows a simplified version of the JLH topology. Signal input appears at the base of Q1, and is amplified and inverted to drive the base of Q2. Q2 acts as a gain device and also a signal splitter, driving both Q3 and Q4 simultaneously, but out of phase with each other. Q3 and Q4 form the output transistors, Q3 operating as a common emitter gain device, contributing current and voltage gain, and Q4 operating as a common collector device contributing only current gain. The resistors provide bias for the system, and R1 and R2 feed the output of the amplifier in a loop back to the emitter of Q1.

Q2 is the heart of the design, and in my opinion, it is the elegant economy with which it performs the complementary gain to drive the output devices that gives the circuit its classic beauty.

The JLH was designed at a time when "the tube era was in decline" and the new generation of designers was pulling out all the stops to produce big science amplifiers—pure voltage sources with high power and infinitesimal distortion—complex circuits with lots of feedback.

Thirty-six years and a little progress later, we can perhaps appreciate the simple charm of the JLH topology as an exercise in minimalism, but if you haven't listened to one, you might be very surprised by the quality of sound, which is extraordinarily good within its power limitations. If you have efficient speakers and you like to listen to two-channel sound at reasonable levels, the JLH is still in the top rank.

The amplifier has reasonable specifications; nothing special that isn't wildly exceeded by a $3 chip, but it produces real music. Its flaws are not irritating and it does a wonderful job wringing more music out of modern recordings and even MP3s. I can't think of another transistor design from that era that works as well.

Figure 2 shows the circuit rendered more completely, but for more extensive documentation on the versions of the JLH amplifier, I recommend The Class A Amplifier site **www.tcaas.btinternet.co.uk.**

In **Fig. 2** additional details of setting up the DC bias for each device are shown, where capacitors are used to separate DC values from AC values. C1 separates feedback from bias current. C2 separates input signal from input DC bias voltage, and C3 blocks the output DC of the amplifier from the load. C4 removes supply noise from the voltage powering the front end of the amplifier, and C5 forms a "bootstrap" circuit, making resistors R5 and R6 behave more like a constant-current source at audio frequencies.

FIGURE 1: Simplified JLH amp.

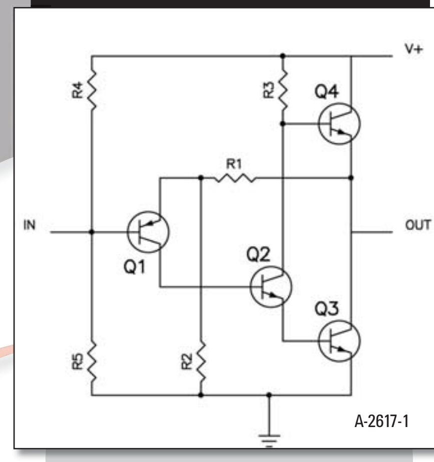
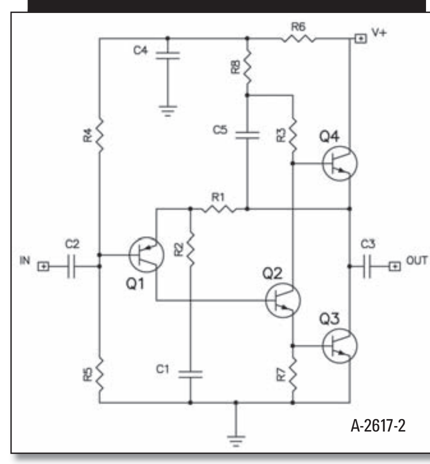


FIGURE 2: JLH amplifier 1969.



The original JLH amplifier has approximately 55dB of open loop gain divided into 22dB of amplifier gain and about 33dB of feedback. As detailed in the original article, it delivered 10W at approximately 0.1% harmonic distortion or less.

The amplifier's popular longevity speaks volumes about the quality of its sound, and this is understandable given its simplicity coupled with excellent measured performance. It has a particularly tube-like quality compared to the more complex solid-state designs of the era and since.

FIGURE 3: JLH amplifier 1996 (simplified).

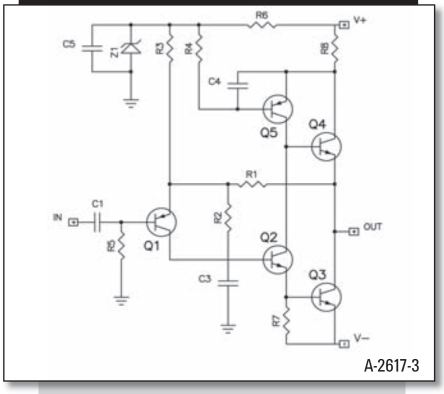
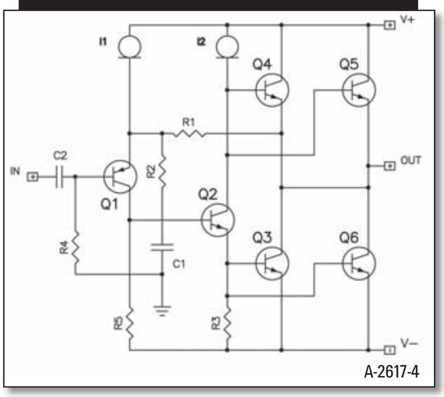


FIGURE 4: JLH variant 2000.



The distortion is largely 2nd harmonic, and is closely proportional to the output voltage. This means that .01% distortion at 0.1W becomes 1% at 10W, and you can draw a pretty straight line between the two points on a logarithmic graph. Such a curve is characteristic of a single-ended output topology, and there have been arguments regarding whether or not the output stage is single-ended Class A, push-pull Class A, or a mixture of both. We will be having some fun with that later.

One flaw in the original JLH design was that its bias current, that idling current which flows through the parts of the circuit, had some dependency on the power supply voltage, resulting in altered performance for different AC line voltages. Power supply regulation solves this problem neatly, but there were other ways this was addressed in later versions of the circuit.

NEWER JLH CIRCUITS

John Linsley Hood published an update to the amplifier in 1996 that addressed bias stability issues, parts substitutions, and provided a version that had a direct-coupled output, eliminating the output capacitor. At the same time, it was in many ways the same amplifier, the measured performance being very similar.

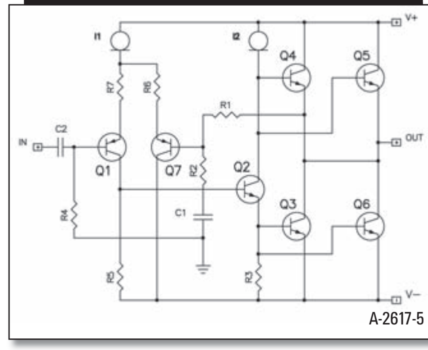
The JLH circuit continues to be interesting to the audiophile community and has been the subject of several updates. **Figures 3** and **4** show simplified schematics of later generations of JLH amplifiers.

Figure 3 shows a simplified schematic of the 1996 version published by John Linsley Hood that fixes the bias stability issue with the addition of Z1 and the Q5 portion of the circuit. This version also direct-coupled the output of the amplifier, using dual supply rails.

In 2000 someone else produced the circuit seen in **Fig. 4**, in which constant-current sources are used to bias the first two gain stages, giving good power supply rejection to the circuit. This version also doubled up on the number of output devices. You will notice that **Figs. 1-4** have their feedback loop addressing the emitter of the feedback transistor. Nowadays they have gotten fancy and call it "current feedback."

Just for your entertainment, I cobbled together the circuit of **Fig. 5** as an example with a differential input. An obvious variation, but I haven't seen it used. You can drive this input stage with a balanced signal by lifting C1 from ground and driving it as a negative input. At 100Ω each, R6 and R7 will give this input about the same open loop gain as the original input transistor with the 220Ω degeneration of the original feedback impedance.

FIGURE 5: Differential input.



By June Linsley Hood

John Linsley Hood was born in 1925, and educated at Reading School (UK). He became a student assistant at GEC Research Laboratories, London, before joining the RAF, where he worked on radar, first at Telecommunications Research Establishment at Malvern, then at an experimental TRE unit at Malabar Hill, Bombay.

After a course at Reading University, he got a job in the electronics laboratory at Windscale in Cumbria, in the Department of Atomic Energy. Next he went to British Cellophane, in Bridgewater, Somerset, as head of the electronics research laboratory. He stayed there nearly 25 years working on varied instrumentation projects.

His interest in radio and audio began at the age of eight when his grandfather gave him an old crystal set to play with, and was boosted further when he made friends with a railway signalman who gave him useful information. While at Windscale he began his quest to design amplifiers which would have greater power and less background noise and distortion, which resulted in his Class A amplifier which was described and published in *Wireless World* in 1969.

He wrote many articles for *Wireless World* (later *Electronics World*), also for *Hi-Fi News*, *Electronics Today*, *Short Wave Magazine,* and *The Gramophone*.

He was asked to contribute chapters to Ian Sinclair's *Audio + Hi-Fi Handbook*, which encouraged him to write a book on his own, and in the late 1970s he joyfully took voluntary redundancy from British Cellophane in order to concentrate on writing and consultancy work.

He was also a keen photographer, an ARPS with a reputation for high quality monochrome landscape work. He was interested in photographic chemistry and in testing and comparing developers, lenses, and printing papers.

Mr. Linsley Hood died March 11, 2004.-Ed.

I recently measured the performance of a working copy of the circuit of **Fig. 4**. It had 17.5V supply rails and was biased at about 2A per channel. The open loop gain is also about 55dB into 8Ω, and its measured performance is comparable to the original circuit.

Figure 6 shows the distortion versus output power. The bandwidth of the amplifier is –3dB at 100kHz, the damping factor is about 35, and the distortion versus frequency is fairly flat, rising slightly at 20kHz.

THE PLH AMPLIFIER

One of the issues that arises from adding gain stages to amplifiers is that while they increase the open loop gain and allow more feedback correction, they themselves are the source of additional distortion. While the extra feedback can lower the distortion numbers, usually the additional circuitry is reflected in a more complex distortion character having higher order harmonics and inter-modulation components. These are generally agreed to be less musical sounding.

Michael Cunningham wrote "Novelists must usually decide what degree of slavish accuracy would make their stories more alive, and what degree would make them less." The amplifier designer has a similar problem to solve. It's not hard to make an amplifier that measures well—it's comparatively hard to please audiophiles.

My own approach is to make the signal path as simple as possible, work to lower the distortion of that basic circuit before feedback is applied, and then apply minimal (or no) feedback, largely in agreement with the comments in Linsley Hood's original article. The result is not always the best objective measurements, but the sound is often interesting.

The three-stage topology of the JLH amplifier routinely uses simple Class A operation and about 33dB negative feedback to achieve this performance, and this lured me to consider what kind of amplifier I could achieve with an even simpler circuit and less feedback. The output stage and the intermediate phase splitter cannot be dispensed with and still resemble a JLH, but you can certainly remove the input transistor.

By thumbnail calculation, the input transistor of the JLH contributes about 27dB of voltage gain. Remove it and the open loop gain of the amplifier drops into the region of about 28dB. If you scale back the gain of the amplifier from 22dB to 18dB, you end up with about 10dB of feedback—a very minimal amount.

Unfortunately, only 10dB of feedback means that the original amplifier will likely deliver something more like 1.5% distortion at 10W. Since such a figure is better than that seen on many single-ended Class A tube amplifiers (SET), this might be an acceptable amplifier. Actual-

FIGURE 6: THD vs. output at 1kHz at 8Ω.

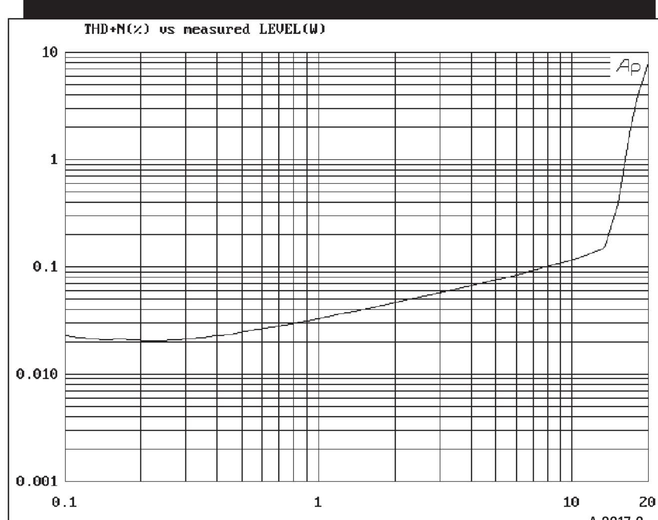
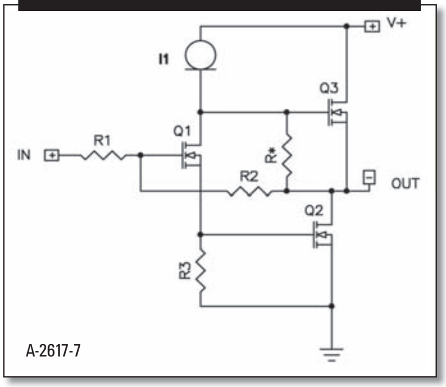


FIGURE 7: Simplified PLH amplifier.



ly, since the input transistor is no longer contributing to the distortion figure, you would expect the performance to be better than that, and maybe that's the point.

With that in mind, I stripped down the JLH to the simpler MOSFET topology shown in **Fig. 7**, and (ahem) added my initial to the name.

I chose MOSFETs for their high input impedance and because they really deliver their most linear operation in Class A mode. Since the JLH performs two phase inversions in the signal path, removing the input leaves the amplifier phase inverting, so you can label the output node as "minus" and the output ground as "plus."

The feedback path of R1 and R2 now addresses a "virtual ground" at the gate of Q1. Q1 is biased by a current source I1, and drives the gates of Q2 and Q3 simultaneously with voltage of opposite phase.

As a concept, you can get about 35dB open loop gain from this circuit with the intended MOSFETs. You would only see it at lower frequencies, however; because the gate capacitance of the MOSFETs will come into play at the higher audio frequencies.

To give a more uniform open loop gain to this circuit across the audio band, and a more interesting comparison to the original circuit, choose values similar to the original JLH without the input transistor, which means that for the circuit of **Fig. 7**, you would be adding 0.47Ω source resistors to Q2 and Q3, and this will give you about 26dB open loop gain.

Like the original JLH, this circuit operates between a positive voltage and ground, so you will need input and output coupling capacitors. There is no reason that it can't be made direct-coupled using dual supplies, but I will save that for another time.

Figure 8 shows the actual circuit. As with the simplified circuit, Q1 is the input transistor and the feedback is accomplished through R1 and R2. The source of Q1 follows the gate input signal and drives the transistor Q2 in common source mode (voltage and current gain). The drain of Q1 delivers an inverted and amplified version of the input signal to drive transistor Q3 in common drain mode (current gain).

The idealized current source I1 and R* of the simplified circuit is replaced by the network of P2, R4, and C2. C2 produces a "bootstrap" connection to the output that makes P2 look like a constant-current source in parallel with R*, approximately the resistance between the wiper and the counter-clockwise connection of P2. P1, R6, and C5 form a filter to take out power supply noise, and adjusting P1 will set the bias current of the amplifier.

P2 will be used to set the relative gain contribution of the upper transistor Q3 versus the lower transistor Q2, but does not affect the bias current or output DC value.

FIGURE 8: PLH power amplifier.

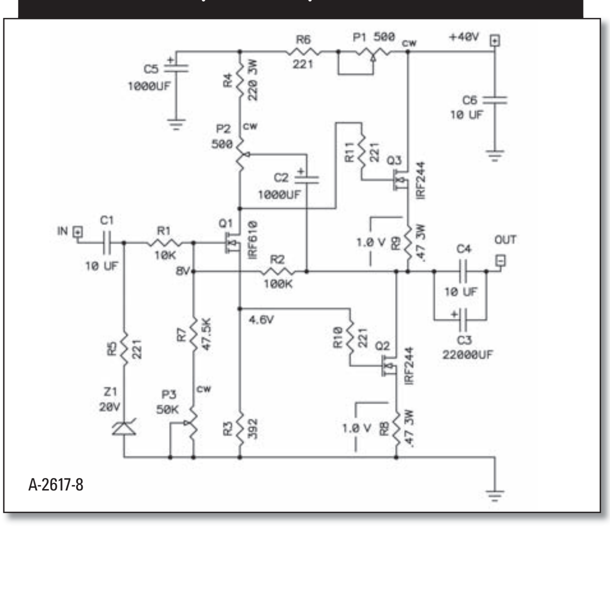
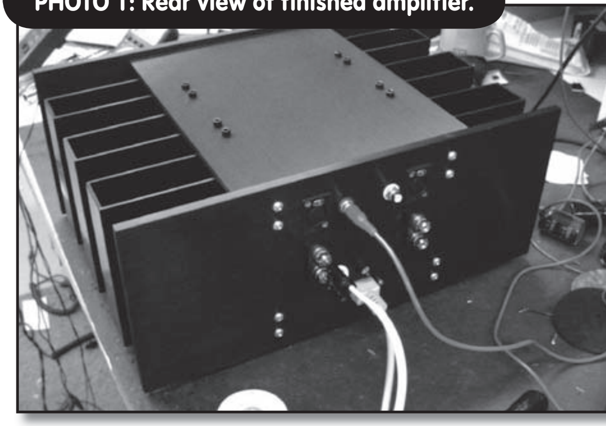


PHOTO 1: Rear view of finished amplifier.



Most of the resistors are ¼W types, but I recommend a 3W value for R4, R8, and R9. The capacitors are all rated at 50V. None of the values needs tight tolerance. P2 is best chosen as higher wattage type. You can get by with 2W, but 5W is preferred.

I have shown nominal voltages on the schematic as guides. The circuit will work with supply voltages from 35 to 45V without modification using P1 and P3 potentiometers to adjust the bias current and output DC. This particular amplifier is biased at 2A, and the output voltage is set at 20V, or one-half of the 40V supply value.

The MOSFETs used are fairly arbitrary, and in general you can substitute similar types. Since virtually all the power MOSFETs are rated at least 40V, you are left a wide latitude of choices of vertical types. Lateral MOSFETs would also work with adjusted resistor values.

Remember that all MOSFETs are static sensitive. It is not necessary to match the Q2 and Q3.

You will need a power supply that happily sources 35 to 45V at 2A per channel. A regulated supply is most ideal, as the bias will vary in rough proportionality to supply voltage, although we built four units without a regulated supply and they work fine. The heatsinks should be able to dissipate about 70-90W per channel with a rise of about 25° C. You can find examples sprinkled about at **www.passdiy.com** and elsewhere.

This summer, Chris and Matt Williams ("The Kleinhorn, Pt. 1, 1/05, p. 24) helped me to build the amplifiers which worked more or less the same. Lucky boys, they got away with two of them. These were made from machined plates of aluminum, bolted together, with heatsinks

FIGURE 9: Distortion vs. output, one pair output device.

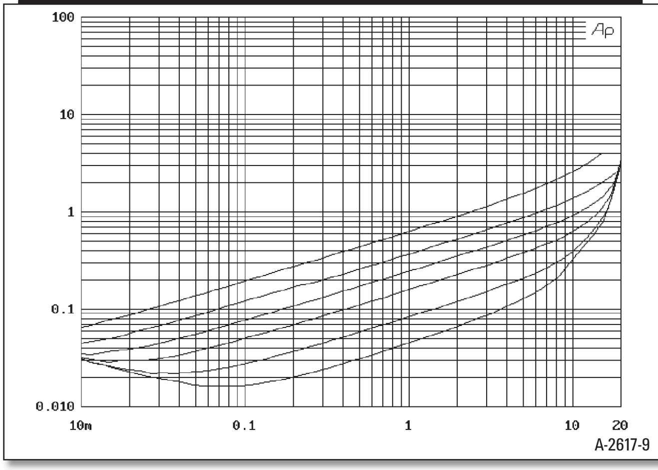
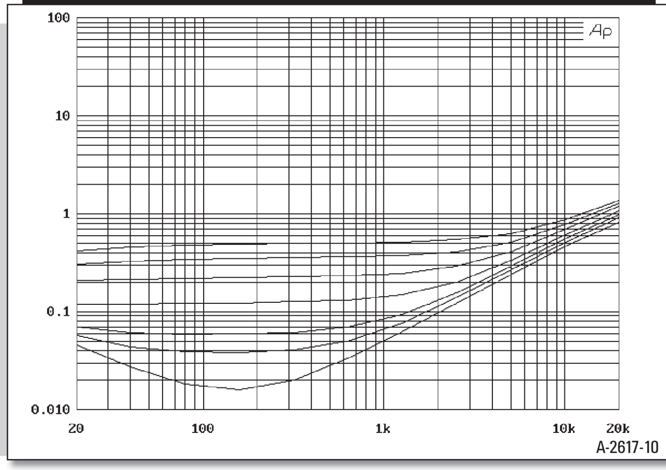


FIGURE 10: Distortion vs. frequency, one pair output device.



made from square aluminum tubing and all of it anodized black. The wiring was all point-to-point on an output stage PC board (**Photo 1**).

We used a transformer with a 35V secondary rectified into a 30,000µF capacitor. We filtered that supply voltage through a 0.5Ω at 25W resistor to another 30,000µF capacitor, which reduced the ripple noise by about 20dB. This powered both channels.

Remember to use good grounding—a star ground at the (-) terminal of the second capacitor is a good idea, and keep the input and grounding leads away from the power supply components, or you will pick up noise. The chassis should always be earth-grounded to the AC power plug, and the circuit ground was connected to the chassis through a 5A power thermistor.

ADJUSTMENT

At a minimum, adjustment of the amplifier requires a DC voltmeter. I recommend the use of a Variac® to slowly turn on the AC power for your initial check-out. Before you apply power to the amplifier, set the value of P1 to its maximum resistance, which should set the bias at a minimum current. Set P2 and P3 at their midpoints.

I recommend firing up (unfortunate phrase, that) one channel at a time, with the other channel disconnected from the supply rail. It's a good idea to put a 3A fast blow fuse in series with the positive rail of each channel, and to keep some spare fuses handy.

When power is applied, the output of the amplifier, the voltage across the source resistors R8 and R9, should be less than 1V. The output DC voltage, as seen on the drain of Q2, should be somewhere around 20V.

If you can bring the supply rail up to 40V without having the bias go above 1V, then adjust P3 to put the output voltage at about one-half the supply voltage (20V with a 40V rail). Now slowly decrease the value of P1 until the source resistor voltage approaches 1V.

As the channel warms up, adjust P1 and P3 in small steps so that the output is at 20V and the voltage on one of the source resistors is 1V. Watch the output voltage and current draw for a half hour or so, readjusting as needed as the circuit warms up. The bias will tend to drift up, but the DC output value will tend to be more constant. At the end of this procedure you should have a stable channel.

If you share two channels off a common supply, you will be taking another look at these settings later because the supply voltage will drop a volt or more when both channels are connected.

PERFORMANCE

The final adjusted circuit has an open loop gain of about 26dB, a closed loop gain of 16dB, and uses about 10dB of neg-

FIGURE 11: PLH with parallel outputs times 2.

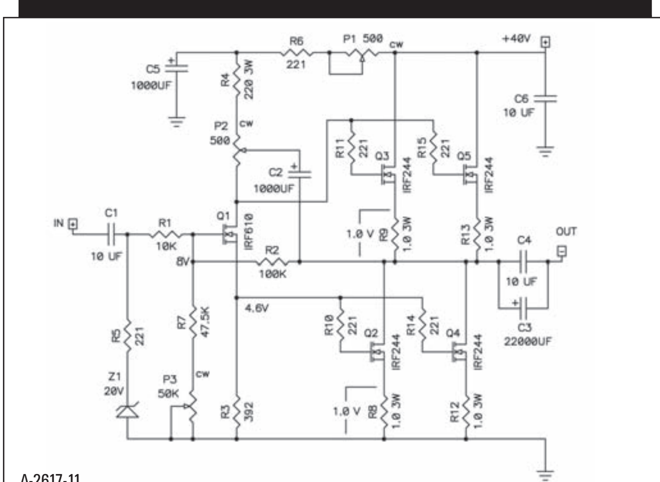
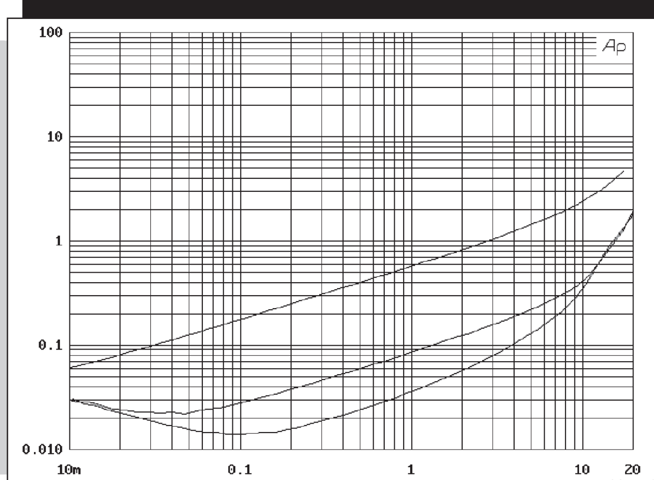


FIGURE 12: Distortion vs. output, two parallel outputs.



ative feedback. The bandwidth is –3dB at about 1Hz and 100kHz. The (unweighted) noise is about 80μV. The input impedance is about 14kΩ, and the output impedance is about 3Ω (a damping factor of 2.5).

The upper and lower output devices share the same value of DC current, but as mentioned before, this circuit can be adjusted to vary the AC current contributions from each. When the values are set equal, then the classic push-pull balance is achieved. By adjusting P2, you can shift this balance so that one device takes a larger share of the output.

As you turn P2 clockwise (note the "cw" on the schematic), a greater percentage of current comes from the upper device Q3, and as you turn it counterclockwise, a greater percentage comes from the lower device Q2. Fully counterclockwise results in the upper transistor bank functioning as a constant-current source, with all the gain in the lower bank, operating as a purely single-ended Class A circuit. An 80% clockwise rotation of P2 gives about a 1:1 ratio between the devices (as the pot rotates through about 10 hours of a clock, with full clockwise as 11 PM, you would set the pot to 9 PM).

Linsley Hood spent some time experimenting with his circuit using mismatched output devices and noted that if you don't have equal gain, it is better to place the devices with greater gain on the bottom of the circuit. I confirmed that this was the case by adjusting the balance between the positive and negative halves of the output stage, measuring and listening to various settings.

I spent a great deal of time playing with this balance, trying to reconcile the best curves to the best sound. At low and mid-band frequencies, setting P2 to a value that gave equal contribution to the output current resulted in the lowest distortion versus output power. By comparison, setting the value so that the lower half delivered two-thirds of the output current gave about twice the distortion, but it remained more constant over the audio band.

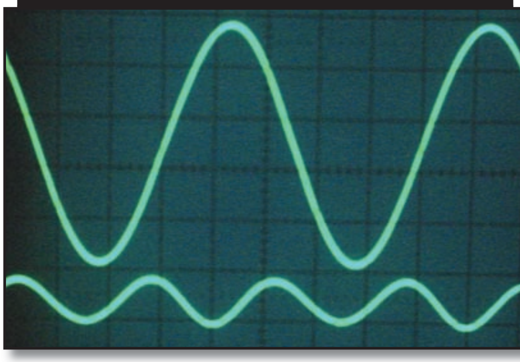
This more "single-ended" output stage showed a more pure second harmonic type distortion than the more "push-pull" output stage, which contained more third and higher harmonics. This was not a completely apples-to-apples comparison, though, as increasing R5 also had the effect of slightly increasing the open loop gain, and thus the amount of negative feedback.

I encourage you to try varying P2. Remember that you can confirm the ratio of upper versus lower output current by measuring the AC voltage across the source resistors R8 and R9, while running a low-frequency sine-wave into a resistive load at about 5W or so.

Figure 9 shows the distortion versus power into 8Ω at 1kHz, with the lowest curve showing the 1/1 ratio (push-pull operation) and the highest curve showing a 0/1 ratio (P2 fully counterclockwise), where Q3 operates as a constant-current source and the circuit is operated as single-ended Class A.

Figure 10 shows the distortion versus frequency at 1W, and you see that the differences between the two settings tend to go away at the highest frequencies, where the variations in capacitance of the devices do not tend to cancel. Also, there are some harmonic content differences over the range of settings. The lowest distortion curves have greater content of higher order harmonics, which tend to go

PHOTO 2: Distortion waveform at 1W at 1kHz.



away as you move toward single-ended operation.

Photo 2 shows an example of the harmonic content with the ratio of top/bottom gain of 2/3, which was one of my favorite settings.

I suggest that you mount P2 on the front panel of the amplifier, and listen to it at the various values. Over most of the range, the open loop gain of the amplifier does not alter significantly until you get close to the counterclockwise position (0/1), where it drops off about 5dB, resulting in about 5dB of negative feedback. At the 1/1 position, the open loop gain is about 26dB, giving about 10dB of feedback. Note that the differences you will hear are not strictly feedback related, but are also a function of push-pull cancellation of distortion.

When the amount of power and heat starts getting big, we often parallel output devices in a circuit in order to share the dissipation. In this case the dissipation is about 40W per device, and it is tempting to use another pair of devices in parallel with the originals to take that value down to a more reliable 20W per device. **Figure 11** shows the circuit that does this. Note that I have increased the values of the source resistors to 1.0Ω.

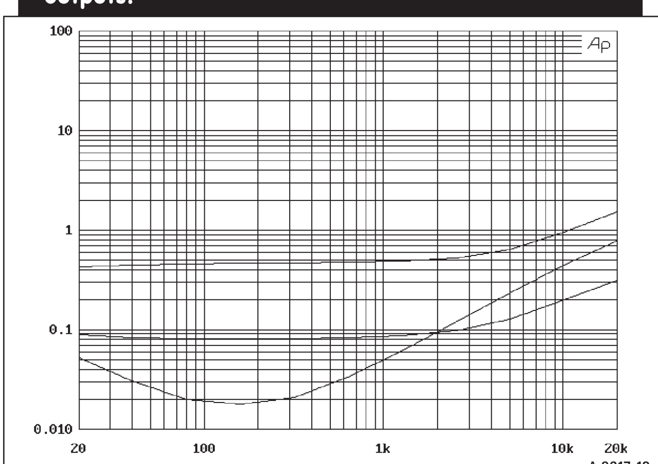
Figure 12 shows the performance of this circuit with the 1/1 setting being the lowest curve, the 0/1 setting the highest, and a 2/3 ratio shown in the middle. There is somewhat less distortion than the curves of **Fig. 9**.

Figure 13 has a little bit different story to tell. At 1W over the audio band, the 1/1 ratio might not be considered the best choice, as the 2/3 value has a more uniform performance.

The question often comes up, "How many output devices in parallel is optimal?" The best answer often lies in trial and error. I built a version with four parallel devices and 2.0Ω source resistors. After measurement and listening, I decided that four pairs were too many.

It's interesting to look at a casual comparison of the results with the original JLH, PLH, and two of the Zen amplifiers in the context of simplicity, gain, and feedback applied. All of the amplifiers make it up to 10W before the distortion becomes too complex, and they all decline at lower wattages with the second harmonic characteristic described earlier. It's reasonable to pick 1W and 10W into 8Ω as benchmarks. For the PLH example, I used the circuit of **Fig. 11** with the 1/1 setting.

FIGURE 13: Distortion vs. frequency, two parallel outputs.



The greater amount of feedback on some amplifiers helps them to measure better, so you can assume that an otherwise equal amplifier would have some proportionality between measurement and feedback. I was curious about this—if it were true, then how would these amplifiers measure if they all had the same amount of feedback?

I normalized the output impedance and distortion figures to what we would expect if all the amplifiers had 20dB of feedback and assumed that the difference would be due to feedback (**Table 1**). Here you can see some interesting things. First, for unknown reasons, the normalized output impedances of the JLH and PLH are about twice that of the Zen amps.

Second, you see that the original Zen amp stands out as having the highest distortion. This is partially explainable by the fact that the other three designs all have some mechanism to cancel some distortion without negative feedback. In the JLH and PLH, the output stages are driven out of phase by a phase splitter, and in the ZV4 (Zen Variations #4), the P channel input buffer and Aleph current source offer some cancellation.

While the distortion numbers for the JLH are better than the PLH, it operates at about 23dB more negative feedback. Normalizing these numbers to a 20dB feedback figure, the PLH appears at least four times more linear. Of the potential explanations, the first is the possibility that the more heavily biased MOSFETs are more linear than the bipolar devices.

Another possibility is that the input device of the JLH, used to produce much of the feedback, is contributing significantly to the distortion. It could be that the data is in error (like *that's* never happened), or perhaps the calculation assumption that the distortion would be inversely proportional to the negative feedback is flawed. Maybe it's all these things.

AND NOW FOR SOMETHING COMPLETELY DIFFERENT

Somewhere in the last 26 articles, I grew tired of telling the readers how wonderful it sounds. So I decided not to do that anymore. If you want to know, go build it.

Comments and questions are best directed to the Pass Labs forum on **www.diyaudio.com** *aX*

TABLE 1

	Gain (dB)	Open Loop (dB)	Feedback (dB)	Zout ohms	Normalized Ohms	THD % @ 1 Watt	Normalized @ 1 Watt	THD % @ 10 Watt	Normalized @ 10 Watt
JLH	22	55	33	0.23	1.03	0.03	0.13	0.12	0.54
ZEN	9	23	15	1.00	0.53	0.60	0.32	2.50	1.33
ZV4	13	33	20	0.60	0.60	0.06	0.06	0.20	0.20
PLH	17	27	10	3.00	0.95	0.04	0.01	0.35	0.11