John Linsley Hood 1985 Headphone Amplifier
XEN Audio
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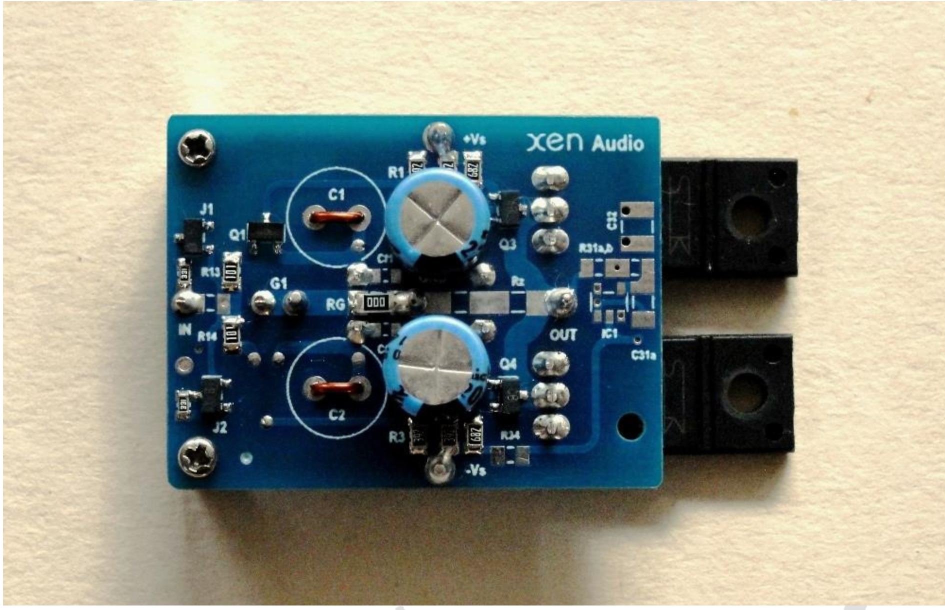


Earlier, we published an article (in the now deleted Schitt Magni thread) on a low-component-count headphone amplifier design using 8 BJTs and 16 resistors. This is of course by no means the simplest possible topology. The F5-HA, for example, can offer excellent performance with only 4 FETs and 6 resistors. But to get the most of such simple circuits, device matching is unavoidable.

So can we still find a solution similar to the F5-HA, but using BJTs instead ? Yes, certainly.
One needs to look no further than what John Linsley Hood has already published decades ago.

Background

When people talk about the JLH Headphone amplifier, they usually refer to a scaled down version of the famous JLH 10W Single-Ended Class A 1969. This has become particularly popular because of low-cost kits or PCBs offered on the internet. But in actual fact, there are a couple of circuits published by Linsley Hood which are specific for headphone amplification. One of these in particular, published around 1985, has been listed in at least two websites [1, 2].

This is interesting in the sense that it is essentially the same CFA topology as the F5-HA, but using BJTs throughout. This makes life easier for not-so-experienced builders, both because of availability of devices, as well as the more complementary nature of N- & P-BJT's, in comparison to FETs.

Some Circuit Modifications

Instead of copy & paste the original circuit blindly, there are a few areas where we would like to apply some modifications.

As published, the circuit has decent performance when driving headphones with impedance above 100 ohm, but performance suffers when demanded to drive low impedances phones at high current. One of the obvious improvements is to increase the hfe of the output devices, e.g. with Darlington's or CFP's (as in the Hiraga Le Monstre), thus reducing significantly the burden of the input devices to drive the output base currents. Since there are no ready-made Darlington's with good hfe linearity, we resorted to the well-proven 2SC3324 / 4883 and 2SA1312 / 1859 solution that was also used in the Pioneer Super Linear HPA Project. Of course one can also use ready-made Darlingtons such as TTB1020 / TTD1415, or MJF6338 / MJF6668.

Darlington's are inherently less prompt to oscillations than CFP's, and the extra bias voltage (across R1, 2) can be used advantageously to increase open loop gain. With the now much reduced base current (from ~1mA originally to <5μA), there is no longer a need for high bias current at the input stage. We can thus choose to use the same low noise 2SC3324 / 2SA1312, and bias them near their optimal working point at around 1.5mA.

The other modification is centred around the feedback loop. In the original JLH circuit, two electrolytic capacitors have to be included in the feedback network, as the emitter voltages of the input pair are not the same and differs by 2x Vbe. In order that the LF cut-off is low enough not to sacrifice bass response, relatively large-value bipolar electrolytic capacitors have to be used. These, however, have relatively high dissipation factor and will introduce additional distortion in the feedback loop. Even if one were to put additional film capacitors in parallel, these only become effective at higher frequencies (> 1kHz). These are good reasons to want to get rid of them altogether.

The simplest way is to remove these capacitors, split the shunt resistor of the feedback loop into two separate resistors (R7, R8), and increase the current through R2, R4 so as to create a DC voltage across R7, R8 to make up the required Vbe drop. However, in doing so, one has essentially separated the N and the P halves of the push-pull circuit into two, each with its own independent feedback network, very much like the F5 power amplifier. When the N & P devices are not truly complementary, there will be a very slight increase in distortion.

The PCB design will accommodate both solutions, and it is easy enough to do A-B tests to find out which is subjectively better. We prefer no caps ourselves.

Linsley Hood also include a sort of current limiter around the emitter resistors of the output stage. This is different from those in the F5 Power Amp from Nelson Pass. In the latter, this is used only to limit maximum current, and thus is normally "inactive". In the JLH solution however, this is active even under normal DC bias. But here it is combined with a low pass filter with a time constant of ~ 1s, so that it is effectively an active DC bias control circuit, as similar to the self-biasing current source in the Borbely EB602/200.

From our previous experience with the F5X Power Amp and F5 Headamp, we are not a fan of either of the above, and rather rely on proper thermal design to ensure bias stability. Thus, this self-biasing circuit has been removed altogether.

At least in one of the published schematics, a bandwidth limiting capacitor is included in the feedback network, because the amplifier is only marginally stable at HF, with an overshoot of about 3dB at 3MHz. We found the value of 2.2nF used in the publication to be too heavy handed. Spice simulations show that a capacitor of 47pF should be sufficient. One can also choose to add a Zobel network at the output to add load at HF additionally. The PCB has been designed to accommodate both.

We are not a fan of DC Servos, and the amount of negative feedback also help to suppress any DC drifts. The DC offset is best trimmed via R2, R4, as these have the least impact on AC performance.

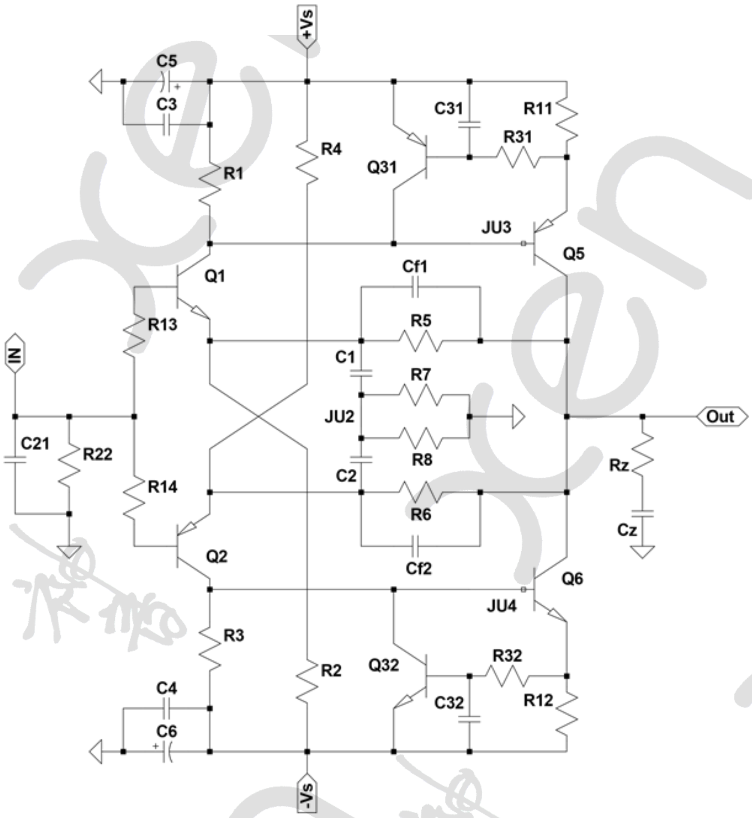


Fig. 1 John Linsley Hood Headphone Amplifier 1985 Original Version

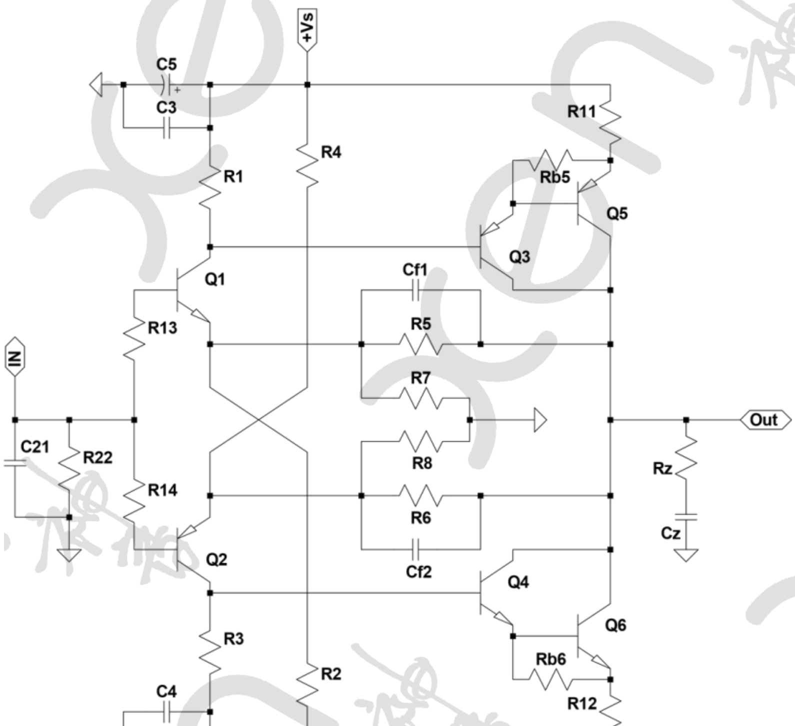
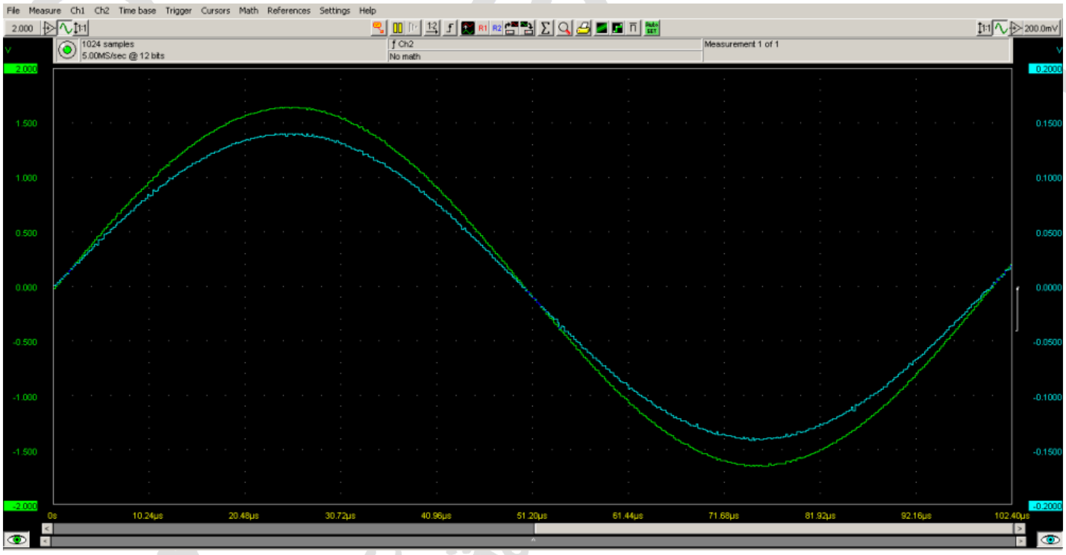


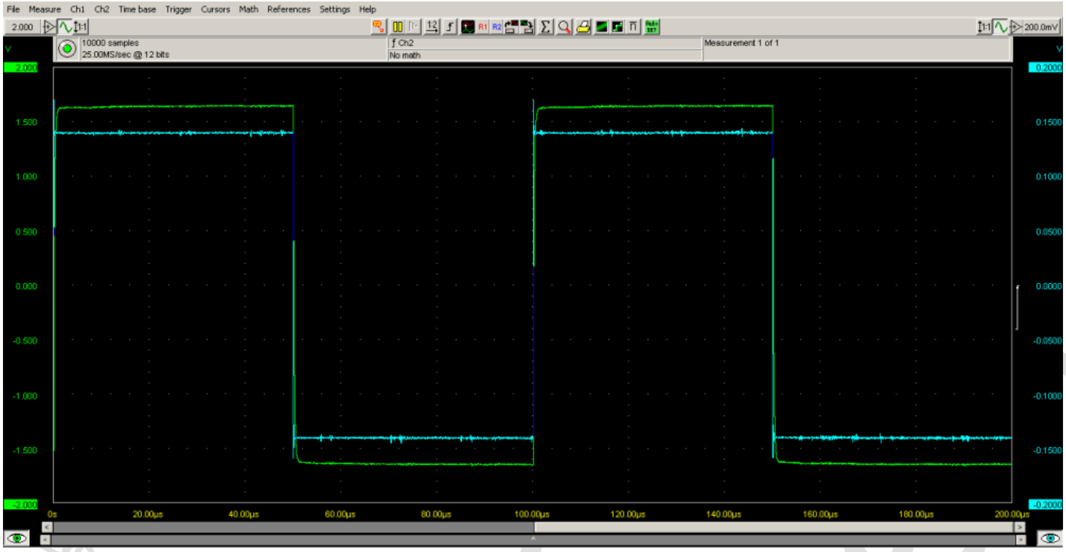
Fig. 2 John Linsley Hood Headphone Amplifier 1985 XEN Version

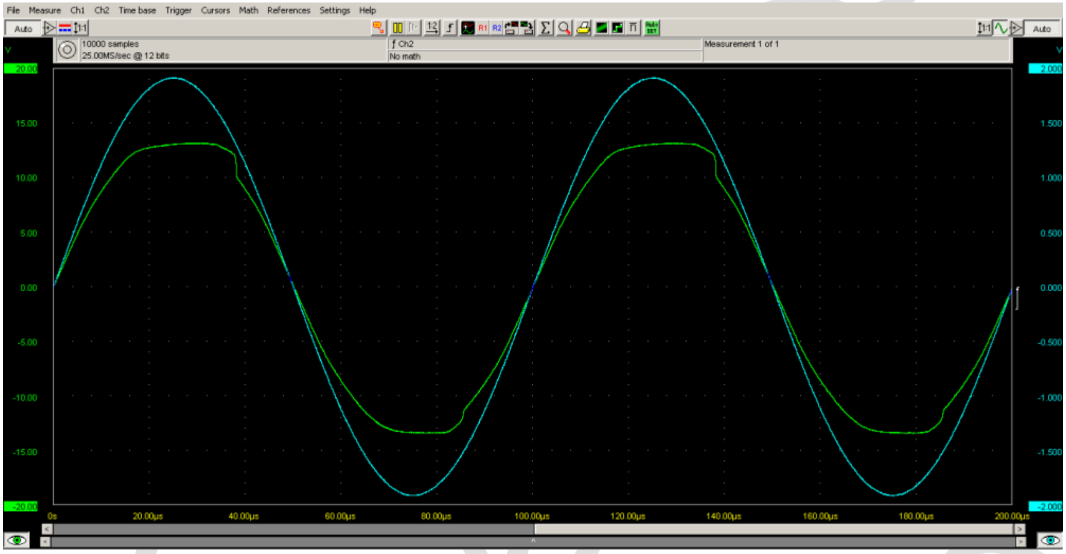
Prototype Measurements

We only built the XEN version, and it worked first time with no trimming. Bias was stable at 140mA after 5 minutes warm up, and DC drift was below +/-10mV over an hour. Just as in the Pioneer Super Linear Headphone Amp, the bias of the input stage is via R2 and R4, and is therefore sensitive to rail DC voltage. If the rail voltages are slightly different, you can trim the output DC offset by trimming R2, R4. A 1M 0805 in parallel with R2 should increase DC by about 20mV.

Frequency response is 1MHz at -3dB with no load at the output. Increasing Cf1,2 will decrease that to give you even more stability margin. 10kHz sine and square waves are clean. Clipping occurs at about +/-10V with 30R load.







Comparison to the F5.HA

From the topology's point of view, one can consider the JLH to be essentially the BJT version of the F5-HA, especially when you consider the discrete Darlington as a single active device. Though they are both based on the same CFA topology, there are quite some differences in detail though.

Look at the open loop gain of the JLH, you will find that it is quite low with 30R load. The front end has about a gain of 4, and the second stage has about a gain of 10. So with a closed loop gain of 10, it only has about 10dB NFB. This is reflected also in the relatively high output impedance of about 8R. Not much damping factor for a 30R load. Of course, when you have a 65R load, thing improves by 6dB. Even better when you have 300R load.

The fact that it still has such low distortion at 30R is due to the very heavy degeneration. Essentially the open-loop distortion of the active devices is swamped by the emitter resistors for both stages.

For example, at the front end, the equivalent emitter resistance is about 25R, compared to the emitter resistor of 460R (510R//5.1k). For the output stage, the Darlington has an equivalent emitter resistance of 0.17R, but is degenerated by 6.8R.

Like in the original Pioneer Super Linear, the JLH also uses a single resistor to bias the front end. This means that it not only has poor PSRR, but also rail voltage differences will result in output DC offsets. One can split R2,4 into two equal halves and add a 200µF cap in between to Gnd. This improves PSRR at HF, but not at DC. The other alternative is to change to CCS bias, as in the SL. We did not want to change the original JLH beyond recognition and ruin its simplicity. So one just need to use a very low noise PSU and trim the DC in circuit. In that sense, the self-biasing frontend of the F5-HA is more advantageous.

Since the amount of NFB is totally dependent on load impedance, one can take advantage of that and device two versions – one with high gain, low bias for loads > 100R. The other with low gain high bias for loads < 100R. You do not see much improvements in THD, for the reasons mentioned above. But you can see reduction in output impedance and hence damping factor. For phones with flat impedances over frequency, that of course does not matter at all.

Adding small resistors Rb5,6 between base and emitter of Q5,6 will reduce distortion a bit more, as it not only increases the bias of Q3,4, but also improves off-switching speed of the Darlington. But we found these to make the amplifier more prone to oscillations. So we left them out in the end.

Also worth mentioning is the somewhat higher thermal drift of output devices. As the base bias of the Darlington comes from the front end collector resistor, the negative Vbe tempco of the output devices will result in rise in bias current. It is advisable to apply generous heat sinking and readjust the bias after half an hour's warm up. The self-biasing circuit of the original JLH circuit would of course take care of that automatically. But we already discussed earlier why we do not use them ourselves.

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References

1. http://www.startfetch.com/jlh/jlh-1985-headphone.pdf

2. http://www.angelfire.com/sd/paulkemble/sound3.html

Appendix 1 **Bill of Materials – Original Version, not tested**
Per Channel (+/-15V rails)

Quantity	Designation	Description	
1	Q1	KSC1845E	
1	Q2	KSA992E, matched hfe to Q1	
0	Q3	Not used, jumper E-B with 0805 0R	
0	Q4	Not used, jumper E-B with 0805 0R	
1	Q5	2SA1859	
1	Q6	2SC4883, matched hfe to Q5	
1	Q31	2SA1312BL	
1	Q32	2SC3324BL	
6	R1, 3	3x // Susumu 0805 3.6k 0.5%	
8	R2, 4	4x // Susumu 0805 16k 0.5%	
2	R5, 6	Vishay Dale RN55 2.2k 1%	
2	R7, 8	Beyschlag MMA0204 300R 1%	
4	R11, 12	2x Beyschlag MMA0204 3.3R 1%	
2	R13, 14	Susumu 0805 100R 0.5%	
1	R22	Susumu 0805 100k 0.5%	
2	R31,32	Susumu 0805 10k 0.5%	
2	C1, 2	Nichicon ES 47µ 16V // Panasonic 0805 ECPU 16V 100n	
2	C3, 4	Panasonic 0805 ECPU 16V 100n	
2	C5, 6	Nichicon KA 220µ 16V	
1	C21	0805 Murata C0G 100p	Optional
2	C31, 32	1206 Murata X5R 100µ 6.3V	or Nichicon 100µ 16V
2	Cf1, 2	Murata 0603 C0G 1000p	

Jumper Settings

	JU2	Closed

Appendix 2 Bill of Materials – XEN Version

Per Channel (+/-15V rails)

Quantity	Designation	Description	Alternatives
1	Q1	2SC3324BL	BC807-40
1	Q2	2SA1312BL, matched hfe to Q1	BC817-40
1	Q3	2SA1312BL	BC817-40
1	Q4	2SC3324BL, matched hfe to Q3	BC807-40
1	Q5	2SA1859	D44H11
1	Q6	2SC4883, matched hfe to Q5	D45H11
2+2	R1, 3	Susumu 0805 3.3k // 3.6k 0.5%	
4	R2, 4	2x // Susumu 0805 20k 0.5%	
2		// Susumu 0805 18k 0.5%	Trim DC & Bias
2	R5, 6	Vishay Dale RN55 5.1k 1%	
2	R7, 8	Beyschlag MMA0204 510R 1%	
4	R11, 12	2x Beyschlag MMA0204 3.3R 1%	
2	R13, 14	Susumu 0805 100R 0.5%	
1	R22	Susumu 0805 100k 0.5%	
1	Rz	Beyschlag MMA0204 24R 1%	
2	Rb5, 6	Not used	
2	C1, 2	Replace by Jumper	
2	C3, 4	Panasonic 0805 ECPU 16V 100n	
2	C5, 6	Nichicon KA 220µ 16V	
1	C21	0805 C0G 100p	Optional
2	Cf1, 2	Murata 0603 C0G 47p	
1	Cz	Panasonic 1206 ECHU 10n 50V 5%	

Jumper Settings

	JU2	Open