A Headphone Buffer/Amplifier and Auto-EQ for Headphones

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Before the iPOD and similar portable music products (MP3), even pre-Internet, we could listen with headphones through equipment, such as receivers and tape decks and there would be plenty of drive for any impedance headphone. The new portable products are very limited in output current capability and cannot drive many of the available headphones with low distortion. The iPOD-like products typically have a maximum output of little more than a 1 volt rms into high Z ear/head phones. A quick survey via the Internet shows that about ½ of all headphone models has an impedance of less than 100-200 Ohms. This is too low for most portable products to drive cleanly at adequate volume. Thus, an add-on buffer or high current driver for use with all headphones is needed.

Pre Internet era:

A stroll down memory lane – My history in DIY audio circuit development -

One of the most popular buffer circuits today is called the "diamond" buffer. The name comes from the bridge-like configuration of four transistors that when drawn looks like the playing card diamond. This circuit configuration was first described in the literature by R. Baker from MIT Lincoln Laboratory in a 1963 IEEE International Solid State paper (**Fig 3**). In 1975, I created a similar idea for my line level amplifier using a four transistor bridge circuit reconfigured for gain by swapping the emitters and collectors. Without knowing it then, my idea was somewhat similar to the arrangement like the earlier Sziklai compound transistor (1953; **Fig 1**). My idea was derived from the compound-complimentary circuit of **Fig.2**. This audio circuit was popular for many years. It was a natural take from tube designs and adapted for transistors. Making that circuit into a push-pull or diamond configuration was the idea I created for my own DIY preamp. It was later part of an article using a *passive* RIAA jFET phono stage and line driver I published in The Audio Amateur [5].

One of the advantages of the 'diamond' buffer configuration is that *if* all transistors have the *same* characteristics, the distortion is nulled or can-

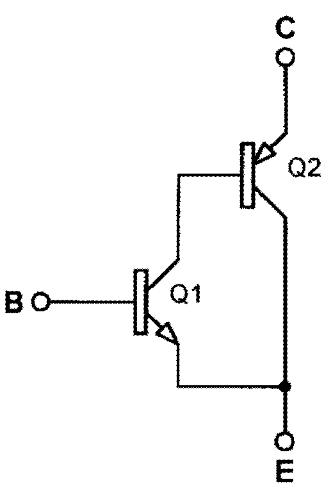

Figure 1: Sziklai compound Transistor (1953).

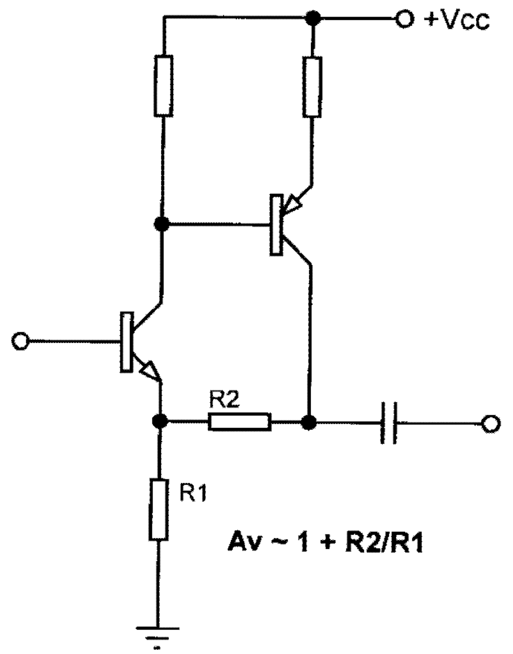

Figure 2: Compound-Complimentary with gain.

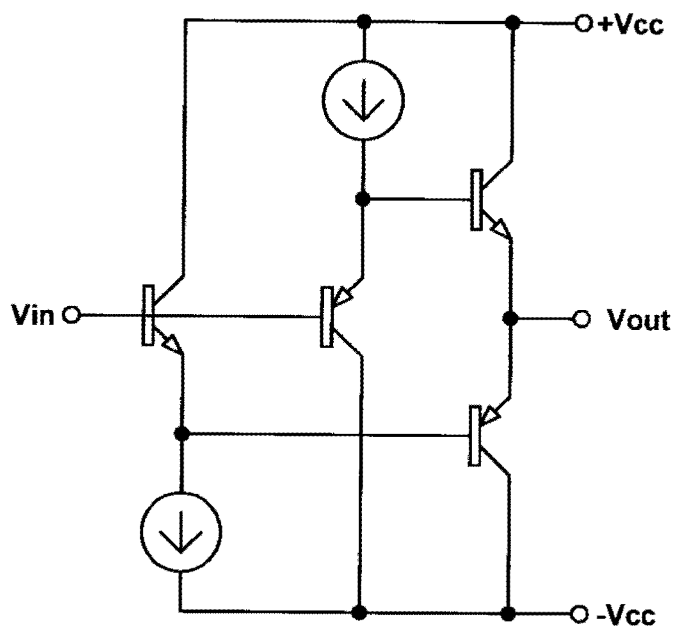

Figure 3:"Diamond" buffer (1963).

celled. After all, it is a bridge circuit topology. Configured as a line driver with a gain of ten, my minimalist 4 transistor topology with careful device matching was able to get below .005% THD but the output level had to be raised to 22 volts p-p output. At 1-2 volts rms output the THD was below my residual test limit of .0018% (calculated to be .0007% at 1 volt) using only 20db of negative feedback. You just have to use well matched compliments. I used a Tektronix transistor characteristic curve tracer for matching complimentary transistors. From that article, I got a call from several well known audio designers including an IC designer who asked about why I changed to this push-pull topology instead of the more conventional differential input – as I had used on the jFET phonograph stage. Primarily, I made that change because the line stage needed to handle larger signal levels with high linearity and because I only thought of it after I developed the phono stage. He asked if I had to do it over again, which circuit would I use in the phono stage. The bridge or diamond circuit, I said. Actually, I called it a compound-complementary push-pull circuit for lack of a better name. It could also be called a "diamond amplifier" circuit. The parallel input pair would be lower in noise potential than a differential pair circuit. I also preferred the arrangement because the input and feedback occurred in the same transistor – making the most direct correction. I discussed other benefits – low z circuit parts values I used meant the parasitic capacitances of the circuit layout and transistors would have very short time constants – this allows the circuit to have very wide bandwidth. My personal test equipment of that time could only measure a clean circuit rise time of 50ns. That was the same rise time as my generators' square wave rise time being used to drive the circuit! It was a very wideband circuit suitable for HF/RF. Later, I designed a cascoded and current sourced version to improve CMR and PSR. I didn't publish that circuit but offered it to anyone who contacted me. That design showed up later as a construction article in TAA [11] by one of those who had contacted me for the schematic.

With a circuit part substitution and implemented with a diamond buffer on input and output, a new circuit and patent was produced in hybrid form by Comlinear Corp in 1982 and the first IC version in 1987 by Comlinear and Elantec. It was called a current-mode feedback circuit and the rest is history. Many IC and discrete variations exist now. **Fig 4** is the original published topology which I used in my TAA [5] article. **Fig 5** is the basic changed new circuit for the Comlinear patent. In some ways, it is another derivative of that original basic "minimalist" 4 transistor diamond circuit with a high current linear output follower.

Let's get back to the new buffer being described here. Why a new buffer? I had hope that the IC buffer versions would be useful for ultra-linear audio applications. In 1979 I had tried the IC current buffer LH0002 in a line stage – a diamond or bridge configuration - and now tried a newer high current diamond buffer, the LME49600. They were very well matched for low *dc* offset but not as well matched for *ac* characteristics. The distortion from the LME49600 is very high when used *open*-loop. The printed specs for the very low THD being touted says it is used in the negative feedback loop of an Op-amp to get the distortion down. So, this device *must* be used inside the feedback loop of an (IC) Op-amp and that raises the cost and complexity of the project as really great audiophile IC Op-amps are expensive.

The buffer circuit here does not require high amounts of overall negative feedback to get THD below -100db (< .001%) Although I have nothing against high negative feedback per se, the extra complexity just isn't always needed. This simple circuitry has, as main features, a minimal number of transistors, low cost and high power output. All we need is a balanced/symmetrical circuit and matched compliments to get very low distortion. The work-around to matching transistors has always been to use more NFB as a more practical method for high volume

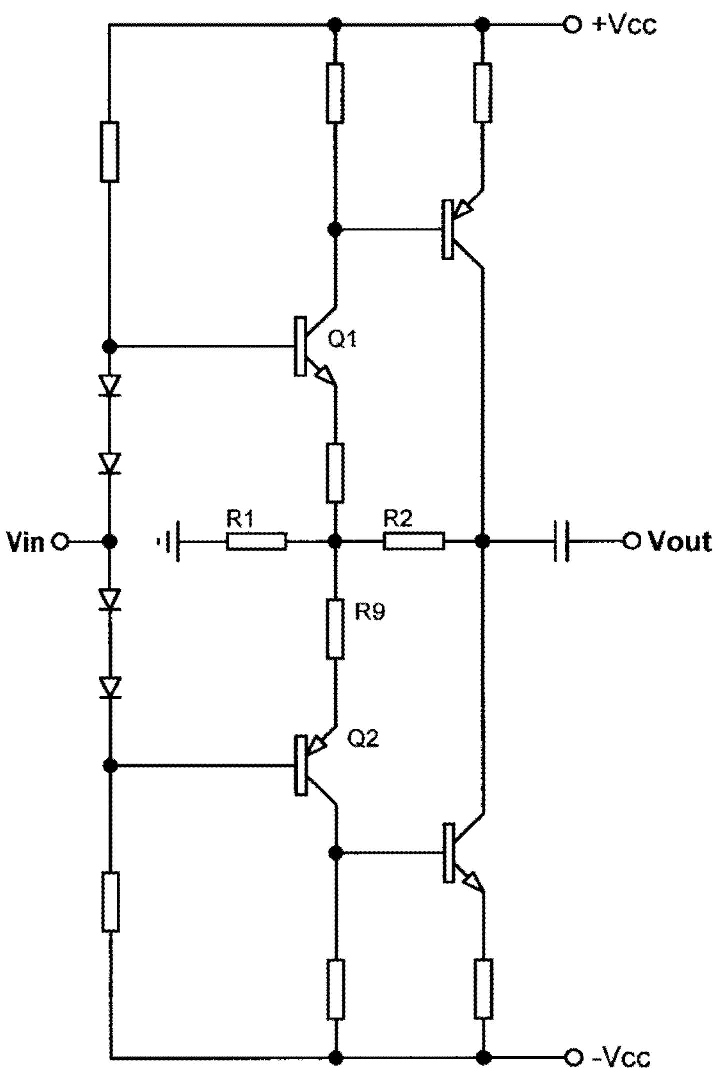

Figure 4: My C-C Push-Pull (1980) aka "Diamond" amplifier.

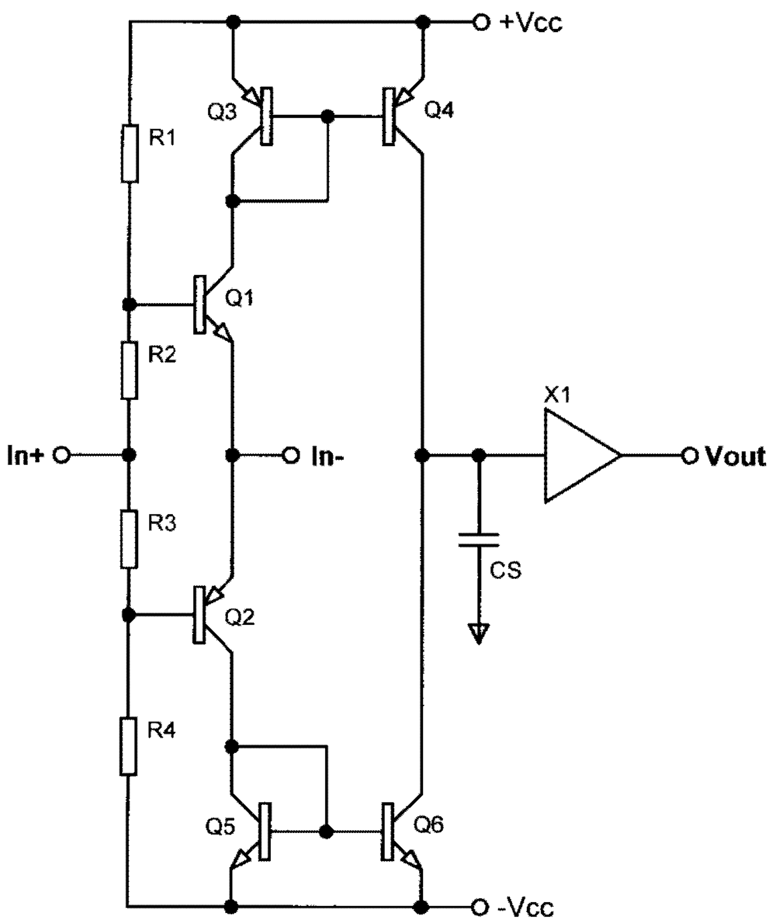

Figure 5: Comlinear current feedback (1982).

production.

If you remove the gain setting resistor (R1) from Fig 4 and reduce R2 to zero ohms you have the new buffer. As this turns out, during research for this headphone buffer/driver design, it is also a complimentary push-pull version of what is known as a Sziklai transistor pair. This pair of NPN and PNP was first described in 1953 and patented by G.C.Sziklai and is sometimes known as a "compound transistor" or "compound Darlington." Current gain is similar to that of a Darlington pair, which is the product of the gains of the two transistors. Some advantages are: The combination is more immune to thermal runaway. And, a Sziklai derived complimentary push-pull arrangement would be more immune to NPN and PNP mismatches. As an interesting aside, the Sziklai pair most resembles the IGBT equivalent circuit.

Fig 6 shows the new jFET/BJT complementary push-pull buffer. By using a jFET instead of BJT at the input stage, we can have a stable, low distortion source of bias voltage for the high current output stage. At this point it would be easy to add two complimentary transistors as followers to drive low z loads as well. However, with such follower circuits, as the current draw increases so does the distortion. It didn't measure much but we can improve on the situation a little more. We can use another Sziklai transistor pair as output followers/drivers to reduce distortion at low load Z and we are done (**Fig 7**).

In all the intervening years, I haven't found any reason to change topology so when I needed a headphone amplifier, I started where I had left off – the diamond or bridge or complementary push-pull circuit topology. Push-pull complementary topologies in a wide range of variations have become well established. The gain shown in **Fig 8** is set at 12db for iPOD and MP3 players. Using it from the direct output of a SACD-CD/DVD player or from a computer audio line out seems Ok at this gain level, too. Notice no servo on the direct-coupled output. You might wonder how I get away with direct-coupling from input to output. Years ago, when I was explaining to Walt Jung [4] about capac-

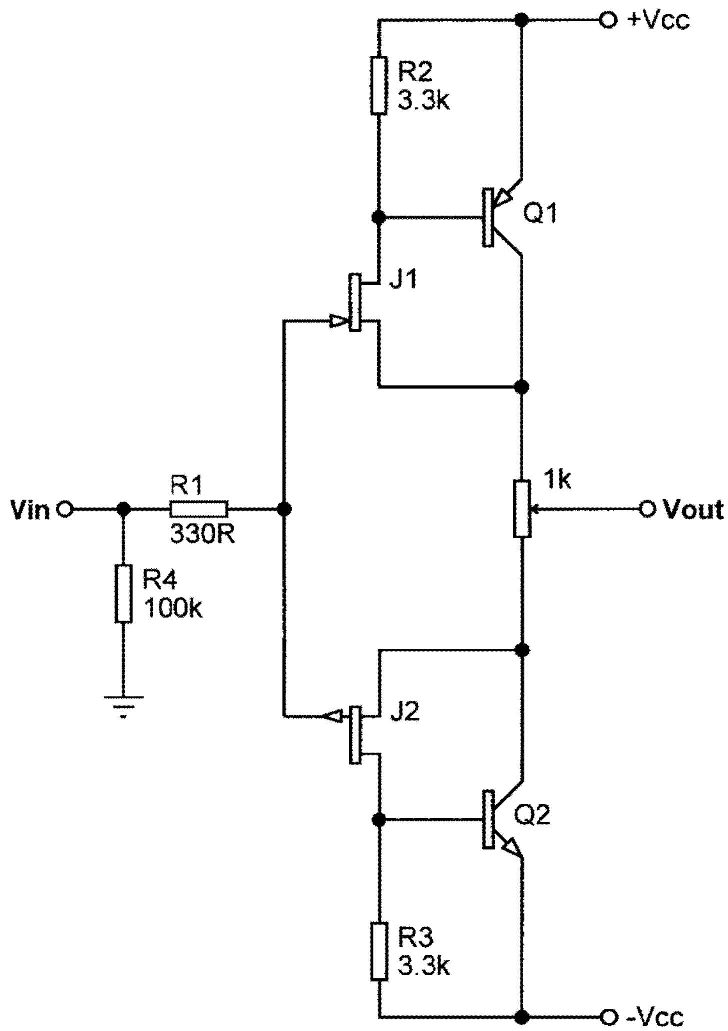

Figure 6: jFET-BJT complimentary push-pull buffer, suitable for driving into high Z loads such as an amplifier input, with extremely low THD.

itor design and I found that audible distortion was due to dielectric absorption, I told him that the best capacitor was no capacitor at all. But, he asked, what about dc offset and drift in the output? I said use a *servo* circuit to keep the dc nulled at the output. He applied my idea/concept of a servo to his own preamp design and that helped establish the "dc servo" as a standard feature when eliminating coupling capacitors in audio circuits.

This circuit, however, is very dc stable with time and temperature. Most of the discrete complimentary circuits and their derivatives in use today have multiple constant-current sources for biasing – one for each complimentary device. Consequently, these current sources and the complimentary transistors do not temperature track with one another very well. So, we still need a dc servo to keep dc from the output. I have had this prototype powered 24/7 for a month and I never see more than a couple millivolts drift away from zero; not even when I touch the transistors or from room temp changes etc. It helps to run the transistors warmer than room temp to minimize ambient temperature variations on the transistors. And, no more dc offset than 20mV from cold start to temperature stable operation (a few minutes) has been observed.

We can calculate the closed-loop Harmonic Distortion as follows. We have 62-12 = 52dB of feedback. Add -52 dB to the measured open-loop HD and we get a closed-loop HD of -52 plus -55 = -107dB for second harmonic and -117dB for the 3rd harmonic. Lighter loads (>30 Ohms) will give lower THD as would closer matching. The THD does not increase with increased source resistance.

Some might think that circuits with exceptionally low THD (more than -100 dB) are over-kill and not needed. After all, it is said, we can't hear it. I did some experiments years ago using electrostatic headphones and electrostatic loudspeakers which had very low distortion to determine what level of THD I could hear. I found with midrange frequencies at 90dB SPL I could not hear harmonics below 0.1%

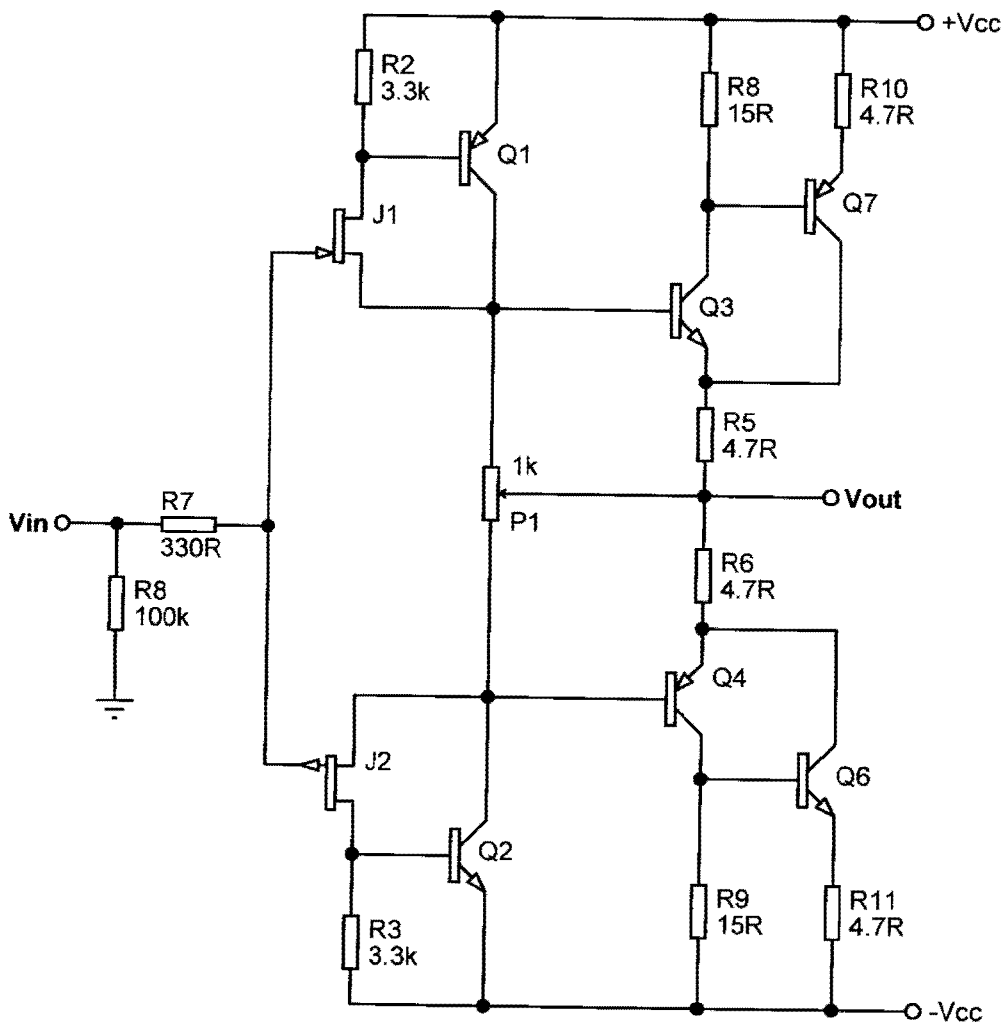

Figure 7: The completed Buffer

Open-loop gain	+62dB
Open-loop bandwidth (-3dB)	25kHz
Open-loop Harmonic Distortion at 1.0v rms, 1 kHz	
2nd harmonic	-55dB
3rd harmonic	-65dB
Open-loop noise (30 KHz BW and no weighting)	-85dbv
[Closed-loop gain]	+12dB
[Closed-loop s/n with input shorted]	-135dB

Table 1: Prototype amp data using a worst-case 30 Ohm load.